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Evaluating the Need to Seal Thermal Cracks in Alaska's Asphalt Concrete Pavements

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13. ABSTRACT (Maximum 200 words)

The AKDOT&PF has promoted routine sealing of all cracks in asphalt concrete (AC) pavements for many years. In doing so, AKDOT&PF follows the generally accepted "best practice" of sealing pavement cracks to the extent that time and money allows. This study of 91 sites on 20+ year old AC pavements in AKDOT&PF's Central and Interior Regions identified two distinct types of thermal cracks. Both types are known to be ubiquitous on AC pavements throughout all but the most southern parts of the State. Based on the field observations during 2012, researchers conclude that significant maintenance funds can be saved or redirected by not sealing or reduced sealing of thermal cracks in AC pavements. Furthermore, the authors suggest that thermal crack maintenance be significantly reduced without negatively influencing general long-term pavement performance.

The report addresses, separately, each of the two recognized forms of thermal cracking. It recommends that "lessor thermal cracking" receive little or no maintenance. The report recommends that maintenance treatment of even the relatively large "major transverse thermal cracks" can be greatly reduced based on inexpensive, long-term assessments following new pavement construction.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

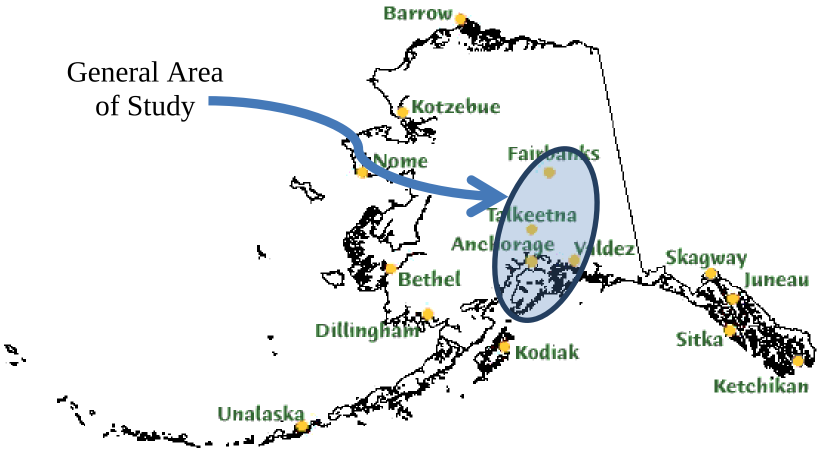
INTRODUCTION

The Alaska Department of Transportation and Public Facilities (ADOT&PF) has promoted routine sealing (or in severe cases, patching) of all cracks in asphalt concrete (AC) pavements for many years. Crack sealing is a common maintenance practice for all pavement types in most areas of the United States. In fact, a diligent effort at crack sealing has long been considered one of the chief hallmarks of good pavement maintenance throughout the world. The ADOT&PF has followed the generally accepted "best practice" of sealing pavement cracks to the extent that time and money have allowed, hoping that new technology might someday eliminate pavement cracking, or at least eliminate or minimize certain types of cracking. To date, no paving material or construction innovations used in Alaska have been *confirmed* as improving the long-term outlook for eliminating cracking. Therefore, it is assumed that considerable funds will continue to go toward crack sealing in Alaska.

Accepted "best practice" may not necessarily be *the* best practice after all. This study, which documents careful examination of a selected sampling of Alaska's AC pavements, concentrated on the colder, dryer interior area of Alaska's contiguous highway system, where a very high incidence of thermal cracking occurs. A conclusion drawn from this study is that significant maintenance funds can be saved or redirected by *not sealing certain types of cracks*. The process used for selecting study sections is fully explained in the main body of this report.

Based on many field observations made by ADOT&PF research engineers over the preceding 30 years, a conjecture had developed that certain crack types may sometimes be ignored, that is, left completely unsealed for the life of the pavement with no negative effects. The research reported herein represents the first attempt in Alaska to verify or reject this conjecture through a systematic field study of a significant portion of Alaska's paved highway system.

Only certain crack types are the subject of speculation regarding required sealing. These include the two most common types of thermal cracks found on nearly every paved road in colder parts of the state nominally bound by Tok, Fairbanks, Anchorage, Homer, and Valdez. The shaded area on the following map indicates the general area of Alaska included in the study.

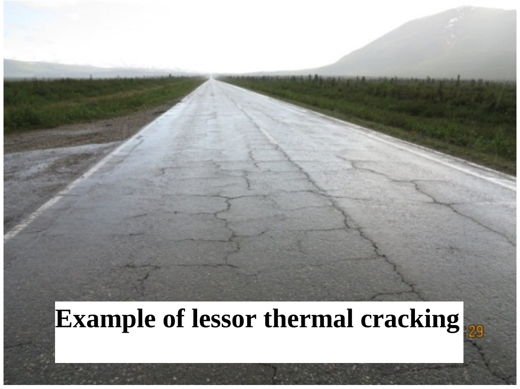


Source of Alaska Map: Larry Pearson, Alaska Scenes

A map in Chapter IV of this report shows locations of highway sections that were studied. The following two photos show types of cracks. The left photo shows an example of a sealed *major transverse thermal crack*. This thermal crack, commonly known as a “thumper,” usually extends across the entire width of the pavement surface, or nearly so, and tends to be oriented perpendicular to the roadway centerline. The driver feels a definite thump caused by major transverse cracks when passing over them. By definition, major thermal cracks are thermally induced. The photo on the right shows an example of a grid-like pattern of thermal cracking, categorized in this study as *lessor thermal cracking*, to differentiate this form of thermal cracking from that commonly identified in other literature as block, map, or grid cracking. Unlike these common terms, lessor thermal cracking not only applies to cracks with a characteristic appearance, but also defines the cracks as being a product of thermal stresses. By definition, lessor thermal cracking is thermally induced.

The field study was limited to one year, and Alaska is a very big state. Therefore, researchers decided to concentrate on the interconnected highway system extending through the state’s mid-section, namely the Alaska, Tok Cutoff, Parks, Richardson, Glenn, Elliott, Steese, and Sterling Highways. These highways allowed for sampling of easily accessible pavements from north of Fairbanks to Homer. Taken as a whole, these highways represent an area of Alaska where thermal cracking is perhaps the most consistently present and visually obvious pavement damage feature.


Example of major transverse thermal crack


Example of lessor thermal cracking

Recommendations are provided that aim at saving or optimally adjusting expenditure of a significant portion of ADOT&PF Maintenance & Operations (M&O) funds now spent on crack sealing. The study provides ADOT&PF with research findings that can be directly incorporated in its departmental guidelines for pavement preservation treatments in Alaska.

Use of the terms *crack sealant, crack sealing,* and *crack sealing material* generically refer to any materials placed in cracks for the purpose of preventing water intrusion. The term *crack filling* is used in the Literature Review only to relate the content of other publications.

OBJECTIVES

The major objectives of the project were met:

1. Studying current crack sealing practices (a literature search) coupled with field examination of various maintenance methods, concentrating effort on the colder, dryer areas of the state, that is, those easily accessible areas of the interconnected paved road system with extensive thermal cracking,
2. Defining areas of Alaska where sealing is best done or avoided,
3. Collecting photo and word descriptions that will provide permanent, positive identification of various crack types—pertinent to implementing the project’s findings, and
4. Providing sealing recommendations, specific to thermal crack type, aimed at economically optimizing the way M&O funds are spent on crack sealing.

RESEARCH APPROACH

Information contained in this report resulted from the following activities:

- Review of literature

- Selection of field sites and data collection
- Presentation of data in spreadsheet and photo formats
- Analysis of data collected from field sites
- Discussion and integration of findings
- Development of conclusions and implementation guidelines

FIELDWORK

Selecting Field Sites

The main objective of the project was to examine thermal cracking on a reasonably large sampling of older Alaska asphalt concrete pavement sections in a first attempt to evaluate the efficacy of sealing.

ADOT&PF Pavement Management System (PMS) records indicated the existence of 52 sections of asphalt concrete pavement 20 or more years old that are spread reasonably throughout the contiguous suburban road system of the department’s Northern and Central Regions. The minimum 20-year pavement surfacing age was selected because such pavements could be considered “old,” since they had reached or exceeded a normal pavement design life. Additionally, the total number (52) of pavement sections 20+ years old would provide more than enough individual sampling locations for examination during a single field season.

From the 52 old road sections, 91 field evaluation sites were eventually selected. That sampling is large enough to reasonably represent the performance of older asphalt concrete pavements throughout the area of Alaska’s highway system being studied. All field evaluation sites were 0.1 mile in length.

It is important for the reader to realize why it was necessary for this study to view pavement performance (regarding thermal cracking) as a snapshot in time based only on the study of older pavements. To date ADOT&PF does not record pavement-cracking development or the locations of specific repairs on Alaska highways. Therefore, it was necessary for researchers to interpret thermal cracking/pavement performance relationships based solely on the surface condition of old pavements.

Data Collection

Each sample location was evaluated using three methods:

- **STCE** (**S**pecial **T**hermal **C**rack **E**valuation) was developed for this research project to serve a specific purpose. This method shares almost nothing in terms of data format or purpose with the following methods and defines only thermal cracking aspects of a pavement.
- **LTPP** (used in **L**ong **T**erm **P**avement **P**erformance program) is the standard FHWA method for generally defining the surface condition of a pavement.
- **PASER** (**PA**vement **S**urface **E**valuation and **R**ating) is the University of Wisconsin's simplified method for generally defining the surface condition of a pavement.

The STCE method provided data specifically used for evaluating thermal cracking damage. The LTPP and PASER methods provided a suite of standard data indicating the general condition of each field evaluation site.

A single MS Excel spreadsheet (containing several workbooks) was used as a database and for analysis.

IMPLEMENTATION RECOMMENDATIONS

Detailed discussions and findings leading to the recommendations listed next are presented in Chapter V and in the Conclusions subsection (first part) of Chapter VI. The reader is strongly encouraged to read those chapters to gain an understanding of the reasoning that led to (and justified) the following recommendations.

1. **Recognition:**
   Learn to recognize thermal cracks in the field.
   a. Learn to recognize the difference between thermal cracks and other types of cracks.
   b. Learn to recognize the difference between major transverse thermal cracks and lessor thermal cracks.

2. **Lessor Thermal Cracks:**
   Do not apply sealing materials to lessor thermal cracks.

3. **Major Transverse Cracks, Old Pavements (approximately ≥ 5 years old):**
   Decide which major transverse cracks require sealant and which do not.
   a. Do not seal previously unsealed major transverse cracks on older pavements if those cracks show no severe degradation.

   b. Do not reapply sealant to previously sealed major transverse cracks until/unless further degradation is seen.

4. **Major Transverse Cracks, New Pavements (approximately < 5 years old):**

   Decide which major transverse cracks require sealant and which do not. An empirical approach is recommended.

   After major transverse thermal cracks begin to appear, apply sealant to, for example, every other transverse crack. Then monitor the results for several years to determine if the sealant has provided any obvious advantage. Begin applying sealant to all cracks if deemed necessary.

5. **Major Transverse Cracks, Areas of Severe Bumps:**

   In areas where severe bumps are produced because the transverse crack zones are deeply depressed, apply a banded patch/seal of the type commonly used in ADOT&PF's Northern Region. Further discussion concerning application methods and materials regarding this technique is beyond the scope of this report. Contact ADOT&PF Northern Region Maintenance and Operations for further information.

6. **Major Transverse Cracks, Trying New Sealing Methods:**

   Accompany every trial of new crack sealing materials or methods with a plan to monitor and document its long-term performance. A study period of 5 to 8 years should be sufficient to get a clear idea of benefit versus cost. Keep in mind that the objective is not just to get a longer-lasting seal. The objective should be to provide a seal that improves overall pavement performance more than previously used sealing techniques and certainly more than no seal at all. To convincingly address the last point, it will be necessary to include in each trial a sampling of cracks that receive no sealant at all.

   Evaluation metrics should include *ride quality*. This ensures that pavement performance from the user's perspective is considered in the evaluation.

7. **In Areas of Delaminating Pavement:**

   In areas where the pavement is delaminating, apply sealant as necessary to all cracks to limit potholing and raveling of the general pavement surface, and severe spalling along major transverse cracks. Pavement delamination results from a poor bond between AC pavement layers, and usually is recognized only after associated pavement damage becomes apparent. Severe cracking, raveling, and potholes appear when upper pavement layers break away from lower layers. These pavements tend to self-destruct, and any sources of water entry accelerate the process.

8. **Sealing Requirements for Poor Drainage Areas (based on engineering judgment and not directly supported by research conducted during this study):**
    a. Seal all cracks in areas of otherwise good drainage, where the pavement surface is subjected to routine or semi-continuous water flow (but is not routinely submerged).
    b. Do not seal cracks in areas where the pavement is routinely submerged and must handle traffic during submersion (e.g., intersections and urban areas where drainage is poor or often blocked during thaw periods). Under these conditions, open cracks may actually offer a "relief valve" to aid in reducing pore pressures of saturated materials beneath the pavement layer.

USEFUL RULES OF THUMB

- If the pavement surface appears damaged to the extent that patching seems appropriate → then apply patching material according to standard practice.
- If the pavement surface appears damaged only to the extent that sealing seems appropriate → then re-read the implementation recommendations of this report, decide if sealing is actually necessary, and proceed accordingly.

I. INTRODUCTION

The Alaska Department of Transportation and Public Facilities (ADOT&PF) has promoted routine sealing of cracks in asphalt concrete (AC) pavements for many years. Crack sealing is a common maintenance practice for all pavement types in most areas of the United States. In fact, a diligent effort at crack sealing is considered one of the standard hallmarks of good pavement-maintenance practice throughout the world. The ADOT&PF has followed the generally accepted "best practice" of sealing pavement cracks to the extent that time and money have allowed, hoping that new technology might someday eliminate pavement cracking, or at least eliminate or minimize certain types of cracking. To date, no paving material or construction innovations used in Alaska have been *confirmed* as improving the long-term prognosis for cracking; thus, it can be assumed that considerable funds will continue to be spent on crack sealing in Alaska.

This study examines, and calls into question, the basis of the accepted best practice. The report documents a careful examination of Alaska's AC pavements, and concludes that significant maintenance funds can be saved or optimally redirected by *not sealing certain types of cracks*.

Based on many field observations made by ADOT&PF research engineers over the preceding 30 years, a conjecture has developed that certain crack types may sometimes be ignored, that is, left completely unsealed for the life of the pavement with no negative effects. The research reported herein represents the first attempt in Alaska to verify or reject this conjecture through a systematic field study of a significant portion of Alaska's contiguous paved highway system.

Only certain crack types are the subject of speculation here regarding required sealing. These include the two most common types of thermal cracks found on nearly every paved road in colder areas of Alaska. Figure I.1 shows an example of the grid-like pattern of thermal cracking categorized in this study as *lessor thermal cracking*, a term we have used to differentiate this form of thermal cracking from cracking identified in other literature, such as block, map, or grid types of cracking. These terms are used in other systems of pavement damage identification without the implicit (and essential) requirement that the cracks be the consequence of thermally induced stresses. By definition, lessor thermal cracking is thermally induced. Figure I.2 shows an example of a sealed *major transverse thermal crack*. This type of thermal crack, commonly known as a "thumper," usually extends across the entire width of the pavement surface, or nearly so, and tends to be oriented perpendicular to the roadway centerline. The driver can feel a definite thump caused by major transverse cracks when driving over them. By definition, major thermal cracks are thermally induced.


06/06/2012 17:29

Figure I.1 Example of lessor thermal cracking


08/14/2012 12:14

Figure I.2 Example of Major transverse thermal crack

The field study was limited to one year, and Alaska is a very big state. Therefore, researchers decided to concentrate on the interconnected highway system extending through the state's mid-section, namely the Alaska, Tok Cutoff, Parks, Richardson, Glenn, Elliott, Steese, and Sterling Highways. These highways allowed for sampling of easily accessible pavements from north of Fairbanks to Homer. Taken as a whole, these highways represent an area of Alaska where thermal cracking is perhaps the most consistently present and visually obvious pavement damage feature.

Recommendations are provided that aim at saving and/or optimally adjusting expenditure of ADOT&PF's Maintenance & Operations (M&O) funds now spent on crack sealing. The study provides ADOT&PF with research findings that can be directly incorporated in its departmental guidelines for pavement preservation treatments in Alaska.

PROBLEM STATEMENT

Funds are spent in two ways with respect to cracking of AC pavements in Alaska. Premium hot mix asphalt materials and special construction procedures are aimed at minimizing cracking or hopefully eliminating it in the future. On the other hand, when cracking does occur it is routinely repaired by sealing or patching at significant expense. The proposed work focuses on crack repairs, and more specifically, crack sealing. The ADOT&PF has promoted and conducted routine sealing of cracks in AC pavements for many years.

Only a small amount of specific annual pavement-sealing cost data was obtained during the course of this study, but it obviously suggests that statewide costs are substantial. A maintenance superintendent for ADOT&PF's Northern Region stated that the region presently spends about $460,000 annually for sealing 360 lane-miles of the northern half of the Parks Highway. Since most of Alaska's non-urban paved highways are two-lane, the $460,000 figure suggests nearly $2,600 annually per centerline-mile as a reasonable figure for older paved roads (with mature thermal crack development) throughout much of ADOT&PF's Northern and Central Regions. Given the nearly 5,000 paved miles of roadway in Alaska, it follows that a total expenditure of several million dollars statewide is not an unreasonable figure. Southern areas of Alaska are not considered in this dollar estimate because those roads were not examined as part of this research. Also, the warmer, rainy climate of southern Alaska is more akin to the maritime western coast of Washington State and British Colombia and therefore less likely to produce the severe thermal cracking seen in Central and Interior Alaska.

Many years of careful observation suggest that lessor thermal cracks, such as those shown in Figure I.1, might be successfully ignored, and simply left completely unsealed for the life of the pavement with no negative effects on other aspects of pavement performance. Many example areas of such cracking, observed to have never been sealed, were casually noted and discussed, but a formal study to verify such observations has never been done. Such observations seemed to hold particularly true within the more northern area of Alaska's main highway system, where the climate is classified as semiarid. The study considered the possibility of delineating areas of the state where sealing of lessor thermal cracks was (or was not) necessary.

Less is known about major transverse cracking in Alaska. Prior to this study there had been no reported research addressing major transverse cracking on a large sampling of ADOT&PF pavements, although there is another current research effort looking at thermal cracking of Alaska's pavements(Burritt, personal communication, 2012). Maintenance of major transverse cracks has relied on speculation about how the cracks "operate" and on many different M&O opinions as to which maintenance practices are best suited to one area of Alaska or another. The approach used in this study was to examine a large number of major transverse cracks in a large number of areas and attempt to determine the efficacy of various maintenance practices. During this process it was possible to gain economically valuable insight into a question seldom asked—the controversial question of whether sealing of major transverse cracks is, in fact, always necessary.

Research conducted for this report was narrowly focused on repair practices (mainly sealing and minor patching) used for Alaska's thermal cracks, that is, only those crack types caused by seasonal and daily thermal stresses. Other crack types were intentionally omitted from consideration, including (1) major longitudinal cracks, (2) alligator cracking, and (3) any of the myriad of large "earth" cracks commonly seen in Alaska; that is, those caused by embankment and/or foundation failures. In general, the study did not include cracks caused by failure of the pavement structure (alligator cracking) or mass failure of the embankment itself (most other large cracks). Such cracks are not amenable to common sealing or minor patching. Repair methods for these crack types are usually addressed temporarily by major patching efforts. The cracks are often permanently repaired only by major embankment/foundation work.

Subsequent uses of the terms *crack sealant, crack sealing,* and *crack sealing material* generically refer to any materials placed into cracks for the purpose of preventing water intrusion. The term *crack filling* is used only in the Literature Review to relate the content of other publications.

OBJECTIVES

The major objectives of the project were met:

1. Studying current crack sealing practices (a literature search) coupled with field examination of various maintenance methods, concentrating the effort in the colder areas of the state,
2. Defining areas of Alaska where sealing is best done or avoided,
3. Collecting photo and word descriptions that will provide permanent, positive identification of various crack types—pertinent to implementing the project's findings, and
4. Providing sealing recommendations, specific to thermal crack type, aimed at economically optimizing the expenditure of M&O funds on crack sealing.

RESEARCH APPROACH

Information contained in this report resulted from the following activities:

- Review of literature
- Selection of field sites and data collection
- Presentation of data in spreadsheet and photo formats
- Analysis of data collected from field sites
- Discussion and integration of findings
- Development of conclusions and implementation guidelines

Review of Literature: Chapter II, *Literature Review*, summarizes selected items of the engineering literature, namely an introduction to the general subject of thermal cracking and a discussion of present-day understanding concerning thermal crack maintenance.

Many references describe studies performed on the susceptibility of materials to thermal cracking, as well as methods used for sealing. Studies pertaining to crack susceptibility of materials and sealing of thermal cracks considered climate, traffic levels, material types, and sealant application methods. Most of these methods involved selection of paving materials to minimize thermal cracking and/or providing an effective seal at a given location. A significant portion of the crack sealing literature recognized magnitude of annual thermal crack movement as a factor in considering sealing methods/materials.

Apparently, only a relatively small number (perhaps less than 20%) of the literature sources addressed specific pavement performance advantages of sealing thermal cracks. Fewer than half of those sources attempted to answer the question of whether or not crack sealing is an economic necessity in a given area.

Selection of Field Sites and Data Collection: This information is covered in Chapter IV, titled *Fieldwork*. Details of the three methods used to evaluate pavement sections in the field are contained in Appendix C, titled *Descriptions of Pavement Survey Methods***.**

Time and funding constraints required limiting the study to 91 sections of standard "hot mix"-type AC pavements. All of the sections are located in non-urban areas on the interconnected network of roads comprising Alaska's main highway system.

The intention was to examine thermal cracking on a reasonably large sampling of *older* AC pavement sections in Alaska. A minimum pavement surfacing age of 20 years was selected because such pavements are considered to have reached or exceeded a normal pavement design life. Another advantage to examining older pavements is that thermal cracking has matured to its most severe form. At this time, the ADOT&PF does not normally collect data about the history of cracking severity or sealing effectiveness on highway pavements.

Each of the 91 sample locations were evaluated using three methods:

- LTPP (evaluation method used in the **L**ong **T**erm **P**avement **P**erformance program)
- PASER (**PA**vement **S**urface **E**valuation and **R**ating)
- STCE (**S**pecial **T**hermal **C**rack **E**valuation) – developed specifically for this research project

In addition, each location was photographed and subjectively described to document the long-term effects of the various crack maintenance practices.

Presentation of Data in Spreadsheet and Photo Formats: This information is covered in Appendix D, titled *Description of Data Storage and Analysis Spreadsheet.* Except for photos, all field data were entered into a Microsoft Excel workbook (spreadsheet). Four worksheets were used to input various items of field data. Four additional worksheets were used for data analysis and collecting weather data.

Details of thermal cracking at each of the field sites are shown in 1,766 photos (8.25 GB) that were collected. The photos are stored, in “.jpg” format, with a separate folder for each site.

Analysis of Data Collected from Field Sites: This subject is partially covered in Appendix D. Several of the spreadsheet’s worksheets were used to analyze raw field data from other worksheets. Additional analytical work is presented in Chapter V, titled *Interpretation of Field Data*.

Several forms of “Exploratory” spreadsheet analyses were the first steps toward converting the raw field data into a useful form, one in which relationships or trends could be seen. Tables of simple descriptive statistics effectively transformed the large amount of field data into summarized forms where the interpretation process could begin. Additional analyses were necessary to support interpretation of the field data in a way that directly addressed the research objectives. Analyses used to illustrate specific points of interpretation are included with applicable text in Chapter V.

Photos were used to aid subjective analysis of each site and to confirm thermal crack descriptions used for spreadsheet input.

Discussion and Integration of Findings: This material is covered in Chapter V, titled *Interpretation of Field Data*. The chapter describes the process of digesting and integrating research findings, which led to useful conclusions that satisfy the research objectives. This process collectively considered all pertinent information obtained from the literature review and the field sites (including data analyses, photos, and subjective descriptions). Conclusions resulting from this process had to address the research objectives.

The large collection of photos obtained from the field sites provides permanent confirmation of the real-world nature of this research effort. Photos were used throughout the study to confirm that the data analyses were producing practical conclusions.

Development of Conclusions and Implementation Guidelines: This information is covered in Chapter VI, titled *Conclusions and Implementation Recommendations*. This activity distills *useful* and *economically practical* results from the research effort. The chapter presents conclusions that support a prudent implementation strategy and then provides specific implementation guidelines according to that strategy.

It is important for the reader to realize why it was necessary for this research to view pavement performance (regarding thermal cracking) as a snapshot in time based only on the study of older pavements. To date, ADOT&PF does not routinely record pavement-cracking development or the locations of specific repairs on Alaska highways. This is not a criticism, merely a fact. Therefore, it was necessary for researchers to interpret thermal cracking/pavement performance relationships solely based on the surface condition of old pavements.

II. LITERATURE REVIEW

This chapter provides readers with a general background in the subject area of thermal cracking. The two subjects most thoroughly covered are the engineering “science” of thermal cracks (causes, characteristics, etc.) and the maintenance of thermal cracking in road pavements. Unfortunately, very little of the engineering literature on thermal cracking in pavements considers the basic question of whether or not maintenance of the various thermal cracking types is actually necessary (and the important economic implications of that question). Nor does the literature seem to differentiate between the two types of thermal cracking evaluated during this research.

INTRODUCTION TO THERMAL CRACKING

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 researchers theorize that openings in the base and or subgrade layers could be the cause (Dore and Zubeck 2009). The effect of this type of crack 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 cracking 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 categorized thermal cracking into low-temperature thermal cracking and thermal fatigue cracking. The authors defined low-temperature cracking as that which occurs when there is a rapid temperature drop. Thermal fatigue cracking occurs where diurnal temperature cycling takes place, but the absolute temperature never reaches the temperatures mentioned for low-temperature thermal cracking.

Thermal Crack Mechanisms

There seems to be two major approaches to explaining thermal cracking: macro and micro approaches. The macro approach equates major stresses and strengths. The micro approach is a finite discussion of discontinuities and stress risers through the application of fracture mechanics. According to Dore and Zubeck (2009), low-temperature cracking occurs when temperatures drop rapidly below -16°C to -35°C. The thermal contraction stress then exceeds the tensile strength of the asphalt, and a crack forms. Thermal fatigue cracking occurs in regions that are not as cold, and forms because of diurnal temperature cycling. The authors also report that two conditions must be met to have a thermal crack: low temperature and constraint. Thermal cracking needs to have enough of a drop in temperature (in both magnitude and rate) to activate or, later, reactivate the cracking process. The aspect of the granular base interaction and its effect on thermal cracking is stated and used by Zubeck and Vinson (2007) in a Mohr-Coulomb equation to calculate the constraining force, and this involves obtaining cohesion and the friction angle of the granular base layer.

Ponniah et al. (1996) used a fracture mechanics approach to investigate the mechanism of thermal cracking. They stated that asphalt binders are the controlling factor in thermal cracking. Asphalt pavement layers have built-in flaws that act as stress concentrators. Micro cracks then develop at the asphalt/aggregate interface due to differential thermal contraction. Being very different materials, asphalt cement and aggregates will contract differently in response to a given amount of temperature change. The differential thermal micro cracks create localized areas of stress concentration and occur at or near areas of discontinuity. The resulting stress causes premature failure in the asphalt binder. Based on the fracture mechanics theory, it is the rate of energy dissipation (fracture energy) that controls the failure mode from crack initiation to crack propagation.

Thermal Crack Influencing Factors

The three primary factors that influence thermal cracking are temperature, coefficient of thermal expansion and contraction, and the rate of temperature drop (Dore and Zubeck 2009, Marasteanu et al. 2004). Other important factors that influence thermal cracking are (1) geometry of structure (i.e., pavement thickness, shape of laboratory sample, etc.), (2) specific field conditions; and (3) material preparation factors such as compaction of asphalt, densities, and air voids. Different thicknesses of the same material will have different cooling and heating rates, which will create a slab with differential cooling/heating and, therefore, prone to development of thermally induced stresses and strains. Zubeck and Vinson (2007) stated that aging of asphalt concrete negatively affects fracture temperature and fracture strength. This finding reinforces the much repeated observation that old pavements become stiff and brittle, and increasingly susceptible to both fatigue and thermal cracking. Marasteanu et al. (2007) identified two distinct aging periods for pavements. The first is short-term aging and occurs during the time of asphalt mixture production and the pavement construction process. The second is long-term aging that occurs over the years following pavement construction. McHattie et al. (1980) and Osterkamp (1986) also mentioned the influence of base, sub-base, and subgrade layers on thermal cracking, expected because of variations in thermal expansion coefficients (and other thermal properties) of the different materials types.

From a fracture mechanics point of view, the main parameters influencing thermal cracks are temperature, stiffness, fracture toughness, and fracture energy (Li and Marasteanu 2004). Stiffness is obtained from a load and displacement plot and is defined as the slope of the developed or measured curve in the linear or near-linear portion. Fracture toughness, $K_{IC,}$ characterizes the critical stress at the crack tip; it is a function of the load and geometry of the specimen and crack length. The stress intensity factor (K_I) is part of determining fracture toughness, which quantifies the stress concentration around micro cracks and increases with increasing load until an unstable fracture occurs at what is called *the critical value* (Ponniah et al. 1996). Once the stiffness modulus and fracture toughness are determined, fracture energy can be obtained. Fracture energy is a fundamental property of materials, and fracture energy tests and analysis can be used to evaluate asphalt and asphalt binders at low temperature (Ponniah et al. 1996). Rosales et al. (2011) stated that fracture energy is unique to a particular material and indicates the resistance to crack propagation in asphalt binders at low temperatures. Wagoner et al. (2005) showed that fracture energy is a better method for determining asphalt resistance to fracture than other test measures such as tensile strength. Tensile strength tests have been shown to underestimate the tensile strength of more ductile materials.

Material ingredients in AC such as polymer modified asphalt and reclaimed asphalt pavement (RAP) also have an influence on thermal cracking (Dore and Zubeck 2009, Rosales et al. 2011).

Thermal Crack Tests

Thermal crack tests can be divided into those that pertain to binders and those that pertain to AC mixtures.

The Bending Beam Rheometer (BBR) Test (AASHTO T313-05) is used to determine a binder's creep stiffness as a function of time. The Direct Tension Test (DTT) (AASHTO T314-02) also tests the stiffness of asphalt binder material. The DTT is conducted at the anticipated lowest field temperature and one other temperature. Instead of being a beam bending action, it is performed as a tension stress/strain test. The two failure stresses at their corresponding temperatures are plotted on the same graph as the BBR Test. Where the two curves intersect is the lower temperature of the performance grade for that particular asphalt binder. Another method used to investigate the low-temperature characteristics of an asphalt binder is the Double Edge Notch Test (DENT) (Marasteanu et al. 2007). Determination of fracture energy is the final result of this test.

Several tests to evaluate low-temperature performance of asphalt mixtures have been employed by researchers. These tests include the Indirect Tensile Test (IDT) for Creep Stiffness and Strength (AASHTO T322), Thermal Stress Restrained Specimen Test (TSRST), Modified IDT for Fracture Energy, Disc-Shaped Compact Tension Test (DCT), Semi Circular Bending Test (SCB), and Single Edged Notched Beam Test (SENB).

As stated previously, one of the most important parameters in low-temperature cracking is the coefficient of thermal contraction and thermal expansion. This coefficient goes through a transition when asphalt reaches a temperature low enough that it transitions from a quasi-elastic/brittle state to a brittle state; this is called the glass transition temperature. Dilatometric testing is necessary to determine accurate coefficients of thermal contraction/expansion (Marasteanu et al. 2007). Since 2007, a new test—the Asphalt Binder Cracking Device (ABCD) Test (Kim 2007)—has been gaining acceptance as a way of rapidly evaluating multiple samples of asphalt binders in the laboratory.

Thermal Crack Modeling

Marasteanu et al. (2007) stated that low-temperature crack modeling can be categorized as either empirical or mechanistic-based. Empirical models use equations created from regression analysis performed on inputs important to the situation being studied. Mechanistic models rely on mechanics of materials theory to create the modeling equations used for predictions of failure.

There are also probabilistic analyses that assign parameter variances for inputs to the analysis being performed. Most of the models focus on the wear layer only, for example, the AC pavement, and not the entire pavement structure, which may extend several feet beneath the pavement. All models need valid parameters obtained from the field and laboratory testing, as mentioned above.

The two empirical models mentioned are those created by Fromm and Phang (1972) and Haas et al. (1987). Fromm and Phang (1972) performed research for the Ontario Department of Transportation by studying the extent of cracking on 33 pavement sections in Ontario, Canada. They developed three equations to predict the cracking index by performing multiple regression analysis using 11 parameters. The three prediction equations consist of (1) a general crack index equation, (2) an equation for the northern area of Ontario, and (3) an equation for the southern area of Ontario. Haas et al. (1987) gathered data from 26 airports in Canada to develop a statistically derived predictive equation for thermal crack spacing. Asphalt cores were obtained along with evaluations of field conditions.

The mechanistic models are based on mechanics of materials and some include the Mohr-Coulomb friction-cohesion principle between the surface asphalt layer and the granular base. Starting with an earlier method, Hills and Brien (1966) compared asphalt tensile strength to the thermal stress applied to it. The procedure was created to predict the temperature at which a thermally induced fracture will happen. A master curve is created for tensile strength versus temperature through laboratory methods. Then a stress curve is created and plotted concurrently with the tensile strength curve. Where the two curves intersect gives the predicted fracture temperature. Their primary governing principle is that an asphalt mix is elastic and isotropic. The authors used Hooke’s law equations for a beam and slab and a linear coefficient of thermal contraction for the temperature-induced strain.

The Hills and Brien method was implemented into a computer program named COLD by Finn et al. (1977). COLD provides predicted temperatures at which certain asphalt mixes will fracture due to thermal stresses. A thermal gradient is first derived and is then used to calculate thermal stresses, as done with Hills and Brien (1966). A primary input is the tensile strength versus temperature. As described with Hills and Brien (1966), fracture occurs where the stress curve crosses the tensile strength versus temperature relationship. COLD accounts for the variability of strength versus temperature.

The Strategic Highway Research Program (SHRP) funded the development of a thermal cracking model to predict the amount of thermal cracking with time (project SHRP A-005 Thermal Cracking Model – Hiltunen and Roque 1994). The authors described the existence of a thermal gradient, assumed that micro cracks exist, and contended that thermal stresses (due to the thermal gradient) will cause micro cracks to enlarge and propagate through the asphalt layer. The variation of material properties influences the extent and location of these cracks. This model is incorporated into the AASHTO Mechanistic Design Guide as a way of assessing thermal cracking potential. The Thermal Crack Model has three components: calculation of thermal stress with time assuming asphalt has viscoelastic properties, calculation of crack fracture depth based on linear elastic fracture mechanics, and the amount of cracking using a probability-based model.

The Fictitious Crack Model offers a numerical simulation for estimating the distribution of thermal cracks in AC pavements with frictional restraint between layers (Shen and Kirkner 1999). The method, first proposed by Hillerborg et al. (1976), assumes cracking and damage on a mesoscale, which redistributes the stress on a macroscale. The assumed damage or fictitious cracks represent the heterogeneity of asphalt material. It is the friction of the underlying layer that allows for redistribution of the stress and cracking. A nonlinear stability analysis is used to formulate a stepwise formation of the open cracks, which increases stability.

Zubeck and Vinson (2007) created a deterministic as well as a probabilistic model that incorporates the estimated variances for the inputs. These models predict low-temperature crack spacing as a function of time, pavement thickness and bulk density, pavement restraint conditions calculated from the friction angle and cohesion of the granular base layer, air temperature, and results from the TSRST. They also incorporated aging by predicting field aging using the long-term oven-aging process on sample material in the laboratory.

The latest model for thermal cracking prediction is an improved version of the TCMODEL (Dave et al. 2011), developed at the University of Illinois Urbana-Champaign and called ILLI-TC (Marasteanu et al. 2012). Fracture is now determined with a 2D viscoelastic cohesive zone model instead of a 1D Paris Law-based model. Marasteanu described the Paris Law approach as being an empirical approach, whereas the cohesive zone model uses fundamental fracture mechanics. Also mentioned are the sometimes unusual combinations of strength and fracture energy for asphalt mixes. Some can have high strength and low fracture energy such as for some recycled mixes, and some have both high strength and high fracture energy as with some mixes with polymer additives. The ILLI-TC model applies this concept directly as opposed to indirectly as with the previous TCMODEL. A graphic user interface (GUI) called Visual-LTC provides a user-friendly means to input parameters and data from which the analysis is performed.

Thermal Cracks in Alaska

There have been a few studies related to low-temperature cracking that have been relevant to AC pavements in Alaska. McHattie et al. (1980) performed field evaluations and measurements of fatigue cracks and thermal cracks, for 120 road sections over a three-year period. This same work included repeated measurements across a sampling of major transverse thermal cracks—measurements that clearly demonstrated significant crack-width variations through the year. Relationships were evaluated between fines content, pavement thickness, pavement age, traffic loading, and climate. A correlation was found between low temperature and thermal cracking. Osterkamp et al. (1986) also discussed thermal cracking across Alaska. The primary failure mode for thermal cracking was not known at the time, but the authors noted a possible correlation between the temperature in the wear surface and the temperature 2 meters below. There was a lag between the air temperature and crack movement of about a day. Thermal cracks were observed to extend several feet beneath the pavement. It was suggested that zones of weakness could be introduced into pavements to control where thermal cracks form. Raad et al. (1995) performed a study of thermal cracks in pavements, where crumb rubber was introduced into the asphalt concrete mix. The TSRST test was used as well as field observations to confirm that rubber modifications to the hot mix asphalt (HMA) improved low-temperature cracking and tensile strength. Mixes from Fairbanks displayed more improvement than those from Anchorage, AC 2.5 versus AC 5. Zubeck et al. (1999) performed a study of the effects of polymer additives in asphalt mixes in Alaska. The TSRST test was used to compare these additives to conventional mixes. Although improvements to low-temperature stress were observed, issues arose related to storage stability, compatibility with oils used in mixes, constructability, and certain additives producing unacceptable smoking when heated.

CRACK SEALING/FILLING

Crack sealing and filling are basic crack treatments and constitute the most extensive pavement maintenance or preservation treatments performed in Alaska and other cold regions, as found in a survey conducted by Hicks et al. (2012) and in the Guidelines for the Preservation of High-Traffic-Volume Roadways (Peshkin et al. 2011).

In this section, the terms *crack sealing* and *crack filling* refer to conceptually similar methods that attempt to prevent water entry into open cracks. Both methods require placing a liquid or semi-liquid material into the crack, which subsequently cools, dries, and/or cures to seal the crack. Differences between the methods involve use of different materials and installation methods. Sealing is generally considered the more expensive and longer lasting of the two. Sealing and filling are discussed below under subject headings using the term *sealing*.

Crack Sealing Criteria

Shober (1996) asks questions related to criteria. Does the joint sealing enhance pavement performance? If joint sealing does enhance pavement performance, then is it cost-effective? If it is cost-effective, then it is appropriate to determine the best sealant system to use. Economics, that is, cost-effectiveness is being considered by Shober. In effect, he appeared to be asking whether an economically justifiable reason for crack sealing truly exists for a particular pavement in a particular area.

In a survey conducted by Fang et al. (2000), more than 50% of the states responding claimed that cracks are sealed because this procedure is a long-standing policy, unsure, or did not respond. Only 17% stated that the decision to seal was based on research. This response included both supporters and non-supporters of crack sealing.

The reason for crack sealing, as commonly stated, is to prevent water intrusion, thus preventing further deterioration or secondary spalling of the crack edges. Hicks et al. (2000) provided a decision tree for pavement-cracking treatments. The first criterion is to determine whether a crack is load-associated or not. If it is load-associated and is further determined to be fatigue-cracking, no preventative treatment is recommended. If the crack is longitudinal or is thought to be a non-load-associated type, such as a transverse crack, and has average daily traffic (ADT) less than 1000, then crack sealing or chip sealing is appropriate. If the ADT is between 1000 and 5000, then crack sealing or a more general chip seal is also appropriate. If the ADT is over 5000 then crack sealing or a thin HMA overlay is recommended.

Peshkin et al. (2011) provided a table with recommendations for crack filling and crack sealing, with a trigger based on the pavement condition index (PCI). When a certain road section has a PCI in the range of 75–90, it is considered timely to perform crack filling. The authors indicated that the need to fill cracks will probably happen within 3–6 years of the last treatment. When a road section has a PCI of 80–95, it is considered time to perform crack sealing with an accompanying statement that the "life span" of the installed crack sealant is in the range of 2–5 years.

Caltrans (2009) recommended that cracks should be greater than 1/4 inch in width before applying a treatment such as a seal or fill. The FHWA (1999) recommended that crack widths of 0.2 inch or greater should be sealed or filled. Eaton and Ashcroft (1992) created a report for the Cold Regions Research and Engineering Laboratory that cracks with widths greater than 1/8 inch should be treated.

Crack Sealing Methods

Crack treatments are most often consist of two methodologies: one method for crack *sealing* and the other for crack *filling*. The perceived need for one or the other depends on whether the cracks are "working" or "non-working." The FHWA (1999) defined working versus non-working based on whether or not a crack (or most of the cracks in an area) displays horizontal movement, that is, variation in width as temperatures vary throughout the year. Cracks with movement (working cracks) are sealed, and cracks with no movement are filled with the appropriate material for the climatic conditions and traffic levels. The minimum amount of movement that distinguishes between the two types is 3 mm or approximately 1/8 inch. All thermal cracks are considered working cracks; therefore, it is recommended they be appropriately sealed and not filled. The FWHA (1999) manual on crack sealing stated that most diagonal and longitudinal cracks are non-working.

The FHWA (1999) defined crack sealing as the placement of specialized treatment materials above or into working cracks, using unique configurations to prevent the intrusion of water or incompressibles into the crack. Crack filling is defined as the placement of ordinary treatment materials into non-working cracks to substantially reduce the infiltration of water and to reinforce the adjacent pavement. If both working and non-working cracks exist, then treat for the more demanding type of crack, that is, the working crack.

The FHWA (1999) recommended a general stepwise approach to any crack treatment as follows: review records, perform crack survey, determine appropriate maintenance procedure based on crack density, choose whether to seal or fill, select the most appropriate material for climate and traffic, acquire the most appropriate and cost effective materials and equipment, conduct treatment application inspection, and then evaluate post application performance. A suggestion for the actual treatment procedure is the following: crack routing or sawing (may be omitted), crack cleaning and drying, material preparation and application per manufacturer's specifications, material shaping and finishing (may be omitted), and blotting (may be omitted). It is stated that cleaning and drying cracks are the most important steps for successful crack treatments. Failure often occurs from lack of adhesion, which is caused by dirt or moisture.

Crack Sealing Materials

There are three families of crack sealing materials: cold applied thermoplastic bituminous materials, hot applied thermoplastic bituminous materials, and chemically cured thermosetting materials (FHWA 1999). Cold applied thermoplastic bituminous materials consist of liquid asphalt (emulsion) and polymer-modified liquid asphalt. Hot applied thermoplastic bituminous materials consist of asphalt cement, fiberized asphalt, asphalt rubber, rubberized asphalt, and low-modulus rubberized asphalt. Chemically cured thermosetting materials are self-leveling silicone. In general, these materials have been listed from the least to the most expensive in terms of cost, meaning that self-leveling silicone materials are the most costly.

When considering which crack sealing material to use, the following guidelines have been offered by FHWA (1999): 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. Table II.1 contains appropriate specifications for the crack treatment materials previously mentioned.

Table II.1 Crack sealing materials and their corresponding specifications

Material Type	Specification	Application
Asphalt Emulsion	ASTM D 977, AASHTO M 140, ASTM D 2397, AASHTO M 208	Filling
Asphalt Cement	ASTM D 3381, AASHTO M 20, AASHTO M 226	Filling
Fiberized Asphalt	Manufacturer-recommended specs.	Filling
Polymer-Modified Emulsion	ASTM D 977, AASHTO M 140, ASTM D 2397, AASHTO M 208	Filling, possible sealing
Asphalt Rubber	State specs., ASTM D 5078	Sealing, possible filling
Rubberized Asphalt	ASTM D 1190, AASHTO M 173, Fed SS-S-164	Sealing
	ASTM D 3405, AASHTO M 301, Fed SS-S-1401	Sealing
Low-Modulus Rubberized Asphalt	State-modified ASTM D 3405 specs	Sealing
Self-Leveling Silicone	ASTM D 5893	Sealing

No matter which material is chosen, the best possibility for success *absolutely requires* proper installation.

Crack Sealing Performance

The inspection procedure for quality, both during and after the treatment has been applied, should be agreed upon ahead of time. The FHWA (1999) recommended that a post-procedure crack survey of 150-meter sections should take place annually. Items to evaluate and record are full-depth adhesion loss, full-depth cohesion loss, complete pull-out of material, spalls or secondary cracks extending below treatment material, and potholes. The inspection should be documented in terms of percent failure, that is, length of failure divided by total length of treated crack times 100. Effectiveness is defined as 100 minus percent failure (100 - % failure).

There were several reports by state DOTs indicating policies that required the sealing of cracks to minimize water infiltration and prevent entry of incompressibles such as sand and gravel. Johnson et al. (2000) performed a study in Montana on crack sealing methods and materials. Four sites were selected using nine crack sealing materials and six different sealing techniques. The stated goal was to determine what role crack sealing plays in Montana’s pavement management system (PMS). ASTM D5329 was the primary testing specification. All nine materials displayed a cone penetration value of greater than 90, with no substantial differences between materials. Routing of the transverse cracks showed greater success than methods where the cracks were simply capped with sealant. Routing was determined unnecessary for longitudinal cracks. Operators preferred to produce shallow reservoirs versus square reservoirs. Many sealants displayed failure during the coldest months, but would heal during the summer months.

Crack Sealing Effectiveness

Shober (1996) stated that crack sealing must somehow enhance pavement performance either by enhancing quality of ride and/or by extending pavement longevity. The sealing should be cost-effective, meaning the benefits should outweigh the costs and costs should also include user delays and safety issues when traffic patterns are changed to perform sealing operations. He also thought that road authority agencies should be customer driven and holistic. Customers might not have an opinion on water infiltration or incompressible material in a crack unless it affects the quality of their ride or the cost-effective life of the pavement. Whether crack sealing does or does not provide long-term benefits to the driving public and total roadway costs should be determined with a life cycle cost analysis. If crack sealing is determined to be cost-effective, then the most effective material and procedure should be determined for the climate and traffic at hand. According to Shober's study (1996), too many agencies start and end the crack sealing thought process by just considering appropriate materials and application procedures, entirely skipping the arduous task of life cycle cost analysis to determine whether crack sealing is in fact an economic necessity. He described a situation in Wisconsin where two adjoining counties had jointed plain concrete pavement. One county routinely sealed joints, while the adjoining county did not. After 11 years, it was determined that the county that did not seal actually had better performing pavement in terms of faulting, cracking, spalling, and patching. However, Shober stated elsewhere in the report that such does not hold true everywhere. He advised making a prudent decision to not seal the cracks in some sections of the road when sealing is conducted, and then performing long-term comparative monitoring.

The Wisconsin DOT uses a Pavement Distress Index (PDI) to measure the amount of distress in that state's pavements. The PDI measures the extent and severity of several distress types and compiles them into one figure ranging from 0 to 100, with 100 being the most severe. Shober (1996) used the PDI to evaluate and perform a statistical analysis at the 95% confidence interval level. There were differences depending on spacing of openings sealed. There were no statistical differences between sealed and unsealed openings using PDI as the measurement. The

Wisconsin DOT made it a policy not to seal joints in Portland cement concrete (PCC), claiming to save $6,000,000 annually (Shober 1996).

The FHWA (1999) provided a method for determining material quantity, an important step in calculating the cost of a crack treatment program (see Table II.2). Table II.3 is a crack treatment project cost-estimating method. The FHWA (1999) indicated that, with this information, a life cycle cost can be estimated.

Table II.2 Material cost estimation

Step	Description	Units
A	Length of section to be treated.	m
B	Length of sample segment inspected.	m
C	Amount (length) of targeted crack in sample segment inspected.	lin m
D	Amount (length) of targeted crack in section. D = C x (A/B)	lin m
E	Average estimated width of targeted crack.	mm
F	Type of material configuration planned.	
G	Cross-sectional area of planned configuration.	mm^2
H	Total volume in m^3 of targeted crack to be treated. $H = (G/10^6) \times D$	m^3
I	Total volume in L of targeted crack to be treated. $I = H \times 1000\ L/m^3$	L
J	Unit weight of planned treatment material in kg/L.	Kg/L
K	Theoretical amount of material needed in Kg. K = J x I	Kg
L	Total material amount recommended with ___ % wastage. L = 1.___ x K	Kg

Table II.3 Crack treatment project cost estimation

Step	Description	Units
A	Cost of purchasing and shipping material in $/Kg	$ /Kg
B	Application rate in Kg/lin m (including wastage).	Kg/lin m
C	Placement cost (labor & equipment) in $/day.	$ /day
D	Production rate in lin m of crack per day.	Lin m/day
E	User delay cost in $/day.	$ /day
F	Total installation cost in $/lin m. F = (A x B) + (C/D) + (E/D)	$ /lin m
G	Interest rate.	Percent
H	Estimated service life of treatments in years. (Time to 50% failure.)	Years
I	Average annual cost in $/lin m. $I = [F \times G \times (1+G)^H] / [(1+G)^H - 1]$	$ /lin m

LITERATURE REVIEW SUMMARY

Thermal cracking has been defined in some literature sources as a type of pavement surface distress that occurs in cold regions and displays itself as an opening in the pavement perpendicular to the flow of traffic. Thermal cracks occur every 30 meters to 40 meters; as the pavement age-hardens, the spacing between the cracks becomes less. When the length of a thermal crack approaches the width of the road, the thermal cracking interconnects with longitudinal lesser cracks. This is different from longitudinal cracks caused by other issues such as differential heaving.

Although most researchers describe thermal cracking as occurring in the wear layer, some have observed that, in more extreme cold regions such as the interior of Alaska, thermal cracks 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 type is major transverse thermal cracking and the other is a lesser form of map, block or grid cracking.

Thermal cracking has also been described as low-temperature cracking, which occurs in the more extreme low-temperature areas where rapid cooling causes a crack, as opposed to diurnal daily temperature cycling that acts as 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 for either 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, that is, 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: empirical and mechanistic. Empirical modeling has been pronounced effective for the range of data used to create predictive equations. Mechanics-based methods are considered more generally applicable (provided correct input values are used). The latest approach that accounts 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, and parameters determined in a fracture energy-based test supplies some of the material properties. Thermal crack spacing is predicted.

Treatments for cracks involve either sealing or filling, depending on whether cracks are the working or non-working type. These terms are defined by the amount of horizontal movement an opening undergoes annually. All thermal cracks are considered 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. The Wisconsin DOT does not seal cracks in PCC sections, stating that it is saving $6,000,000 annually. If crack sealing is determined to be 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 are 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, including 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 Norway, Finland, China, and Japan, Canadian Provinces, and some states in the U.S. bordering Canada showed that crack sealing is presently the pavement preservation treatment used most.

III. THERMAL CRACKS CHARACTERISTICS, APPEARANCE, AND VARIATIONS

Thermal cracking is an interesting form of pavement damage that has received little field study in Alaska. Much more is unknown than known about it. When does it form—early, mid, or late winter? How does it form—slowly or quickly like breaking glass? How deep does it extend below the pavement surface? What factors control the exact location of individual cracks? Are underlying soil properties a key factor in some kinds of pavement thermal cracking? Do thermal cracks influence other forms of pavement damage?

Thankfully, although the mechanics of in situ thermal cracking in Alaska may be a puzzle the thermal cracks themselves are very easy to recognize and describe.

This study recognized two distinct types of thermal cracks:

- Major Transverse Thermal Cracks
- Lessor Thermal Cracks

Major Transverse Thermal Cracks are oriented perpendicular or nearly perpendicular to the road's centerline; that is, they are transverse to the roadway. The normal gamut of their appearance runs from hairline, extending nearly straight across the road (almost invisible to casual observation), to spalled, ragged zones, several inches to, in rare cases, several feet wide that may extend crookedly across the road. Many of these cracks bifurcate between the two pavement edges and form two or more branches. The cracks are usually identified easily, even from vehicles at a speed of 60 mph. A zone of pavement along the crack is nearly always at least slightly depressed, and this produces the somewhat rhythmic bump felt by all vehicle occupants on all roads in colder areas of Alaska. These depressed zones can become quite deep and extremely annoying to those inside the vehicles, possibly to the point of influencing user costs through accumulated vehicle damage. It is common knowledge among ADOT&PF engineers that these cracks extend below the bottom of the pavement to variable depths (as much as several feet below the pavement). Additional research is needed to fully define the physical aspects of major transverse thermal cracks.

Lessor Thermal Cracks are so named simply because they constitute all other thermally induced cracks that are not major transverse cracks. Their appearance ranges from short segments of hairline cracking to a very distinctive grid-like pattern. In newer pavements, short segments of this crack type are usually more or less perpendicular to the centerline, or more or less parallel to the centerline. In older pavements, the maturing pattern often becomes grid-like, as the individual segments lengthen and intersect. These cracks are referred to as lessor thermal cracks (1) because their width is nearly always less than 1/4 inch, that is, smaller in size compared with major transverse cracks, and (2) to limit confusion, because more descriptive terms such as block cracking or grid cracking are already used in established pavement condition rating systems. These cracks are *believed* to not extend below the bottom of the pavement. Additional research is needed to confirm this belief and fully define other physical aspects of lessor thermal cracking.

Thermal cracks are much easier to recognize visually than from word descriptions. Both types of thermal cracks are easily recognized and differentiated by their appearance in the field or in good photographs. Typical examples of these thermal crack types are presented in the following series of photos.

PHOTOS AND FEATURES OF MAJOR TRANSVERSE CRACKS

Major transverse thermal cracks (Figures III.1 to III.5) are very simple to identify; they run from one side of the road to the other and are more or less perpendicular to the roadway centerline. These thermal cracks are described in terms of general shape as well as the type and width of pavement deterioration along the crack. Other interesting features found in or near these cracks have been noted as well, such as the presence or absence of sealant and sealant condition.

Figure III.1 Regular appearance of major transverse thermal cracks

Figure III.2 Major transverse thermal cracks with new sealant (left) and old sealant (right)

Figure III.3 Examples of crooked major transverse thermal cracks

Figure III.4 Examples of bifurcated major transverse thermal cracks


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Figure III.5 Examples of spalled zones along major transverse thermal cracks

PHOTOS AND FEATURES OF LESSOR THERMAL CRACKS

Lessor thermal cracking is classified as none, slight, moderate, and severe.

- **Slight** (Figures III.6 and III.7): Individual cracks are far apart, with little or no connectivity.
- **Moderate** (Figure III.8): An interconnected grid-type pattern has developed.
- **Severe** (Figure III.9): An interconnected grid-type pattern has developed with parallel grid elements usually closer than 10 feet. Cracks are also described as having an opening width of 1/8 inch or less, or more than 1/8 inch.

Other interesting features found in or near these cracks have been noted as well, such as presence or absence of sealant and sealant condition.


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Figure III.6 Lessor thermal cracking—slight (note sealing in left photo)

Figure III.7 Lessor thermal cracking—slight w/ cracks wider than 1/8 inch

Figure III.8 Lessor thermal cracks—moderate (note some very old sealant in left photo)

Figure III.9 Lessor thermal cracks—severe (no sealant)

IV. FIELDWORK

SELECTING FIELD SITES

The objective of this project was to examine thermal cracking on a reasonably large sampling of older Alaska asphalt concrete (AC) pavement sections in a first attempt to evaluate the efficacy of sealing.

There are some limitations/constraints used in selecting pavement areas for study:

- Only standard “hot mix”-type asphalt concrete pavements were intended for study.
- Maximum sample size was limited due to time limitations of a single field season.
- Pavements were examined only during a single summer season.
- Urban areas were not studied mostly for safety reasons.
- Sample locations recognized as being paved with an asphalt surface treatment pavement (e.g., double-shot chip job or high-float pavement) were deleted from the study.
- Sample locations recognized as including an asphalt surface treatment overlay (e.g., a “chip job” seal coat) were deleted from the study.
- Sample locations heavily damaged due to poor foundation conditions, for example, permafrost, were deleted from the study.

The Pavement Management System (PMS) records* of ADOT&PF indicated the existence of 52 sections of AC pavement that were 20 or more years old and spread reasonably throughout the contiguous non-urban road system of the department’s Northern and Central Regions. The minimum 20-year pavement surfacing age was selected because such pavements could be classified as truly old by normal standards. These pavements had reached or exceeded a normal pavement design life, and therefore would be expected to exhibit well-developed evidence of the relationship between thermal cracking and any other aspects of long-term pavement performance. Additionally, the total number (52) of 20+ year old pavement sections would provide more than enough individual sampling locations for examination during a single field season. *(* archived records of* actual *pavement surface data—available only by special request through ADOT&PF’s PMS Engineer*)

Researchers decided on a sampling size of 120 locations to be apportioned throughout the 52 old pavement sections. This practical sample size was selected based on workload considerations. Locations were selected *randomly,* with the longer of the 52 old pavement sections being allotted a proportionally higher number of the 120 total. The randomness of a selected sample location was modified only when deemed necessary to improve the quality of the sampling process, due to safety concerns, or because of uncertainty about pavement age evidenced in the field. It was eventually necessary to remove about 20% of the originally selected 120 locations from the sampling, as explained later in the report.

The total number of evaluated sections was pared down to 91 after several weeks of fieldwork, mostly due to encountering unexpected or problematic pavement types (newer than expected, recent maintenance overlay, very poor foundation conditions, surface treatment pavement type, etc.). A few sections were removed because of safety concerns, for example, to improve traffic visibility or because of unsafe parking conditions. Questions about the true age of the pavement surfacing layer at some locations remained throughout the project. For various reasons, including recognition of undocumented maintenance work, it was significantly more difficult to establish pavement age than had been originally assumed. Pavement ages were identified using the best available data. Sections were removed wherever age was obviously questionable. Although assigned ages may not be 100% accurate, the total sampling is considered large enough to compensate for the inclusion of a few new pavements.

Sample locations, including highway name and milepost, are provided in Appendix A. All sample locations were 0.1 mile in length, and centered approximately at the milepost locations indicated in the list. The research team believes that the 91 sample locations eventually chosen during the course of the fieldwork are sufficient to meet the research objectives defined for the project. The final sampling size is considered large enough to reasonably represent the performance of older AC pavements throughout the area of Alaska’s highway system being studied.

Urban pavement sections were not selected because of the inherent dangers of conducting fieldwork in urban areas, and because the non-urban sampling was considered sufficiently large to provide a basis for valid conclusions.

Figure IV.1 is a map of Alaska showing the general area of the state that was sampled. Locations of the 91 sample sites are indicated by the yellow pins. Sections shown on the map are located on the following highways (listed generally from north to south):

- Elliott Highway—within about 50 miles of Fairbanks
- Steese Highway—within about 40 miles of Fairbanks
- Richardson Highway—between Delta and Valdez

- Parks Highway—between Healy and Willow
- Alaska Highway—between Tok and Delta
- Tok Cutoff—Tok to about 30 miles south of Tok
- Glenn Highway—Little Nelchina River to about 15 miles west of Glennallen
- Sterling Highway—except for about 30 miles at north end

The exact location of each of the 91 sample sites is accurately identified by latitude and longitude coordinates (WGS 84) contained in Appendix A.

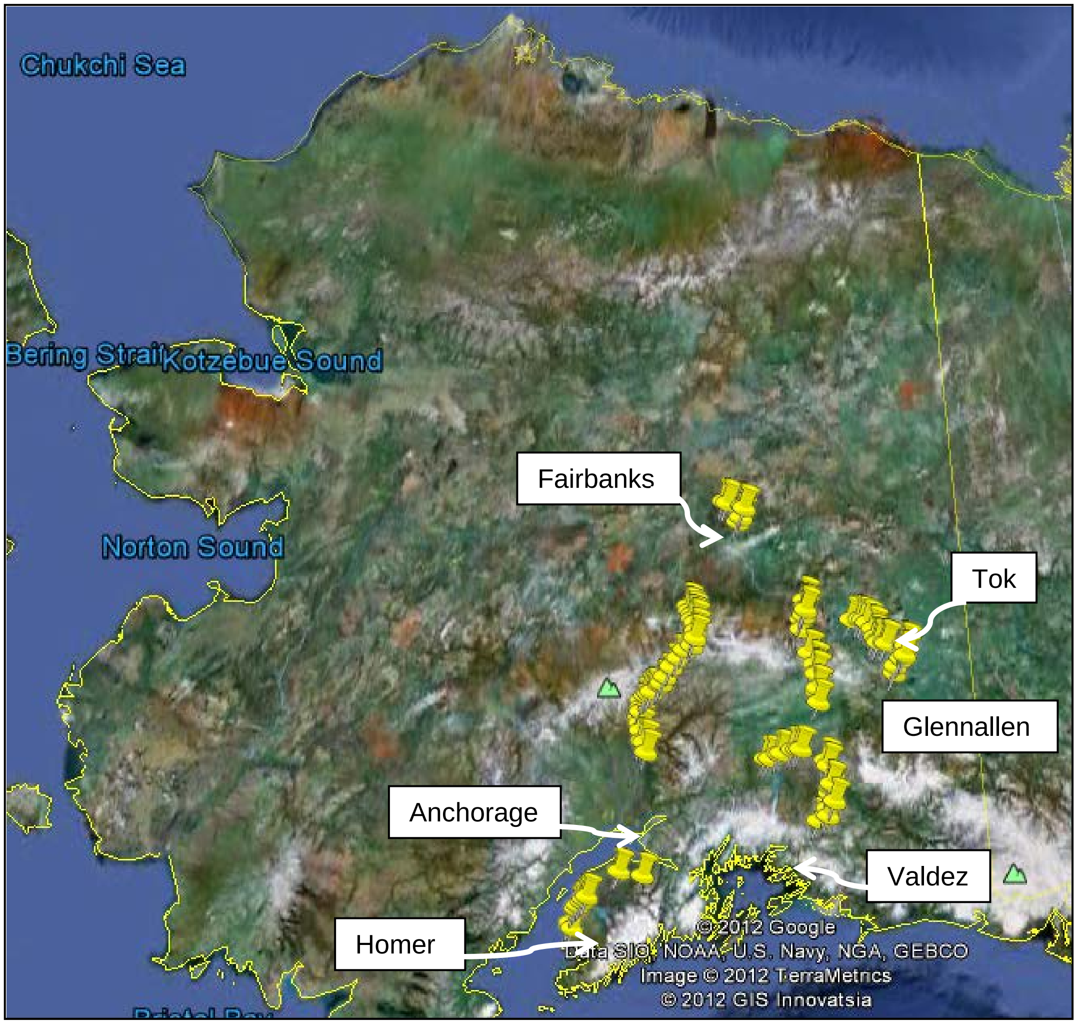


Figure IV.1 Google Maps® representation showing 91 sample sites

DATA COLLECTION

Each sample location was evaluated using three methods:

- **STCE** (**S**pecial **T**hermal **C**rack **E**valuation) was developed for this research project to serve a specific purpose—it shares almost nothing in terms of data format or purpose with the following methods and defines only thermal cracking aspects of a pavement.
- **LTPP** (evaluation method used in **L**ong **T**erm **P**avement **P**erformance program) is the standard FHWA method for generally defining the surface condition of a pavement. Download a pdf copy of FHWA/LTPP Distress Identification Manual from http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/03031/03031.pdf
- **PASER** (**PA**vement **S**urface **E**valuation and **R**ating) is the University of Wisconsin's simplified method for generally defining the surface condition of a pavement. Download a pdf copy of the PASER Asphalt Road Manual from http://epdfiles.engr.wisc.edu/pdf_web_files/tic/manuals/Asphalt-PASER_02.pdf

The STCE method provided data specifically used for evaluating thermal cracking damage. The LTPP and PASER methods are standard and comprehensive ways of documenting the general condition of the paved surface—to provide an overall pavement condition "snapshot" at a single point in time.

Brief Description of STCE Method

The Special Thermal Crack Evaluation (STCE) does not share data format or purpose with the LTPP and PASER methods described in the next subsection. The STCE method was developed to serve a specific purpose and (as opposed to the LTTP and PASER methods) does not provide a snapshot of general pavement condition.

Because STCE was critical to the objectives of this research, it is discussed in more detail in this report than the LTPP and PASER methods. Details of all three methods are presented in Appendix C.

The STCE method collects data to help answer three basic questions that are important to Alaska's pavement maintenance. To what degree does vehicle traffic affect thermal cracking? Is the interaction between thermal cracking and traffic a significant contributing factor in producing additional forms of damage in AC pavements? Does the maintenance practice of sealing thermal cracks significantly improve general pavement performance? These questions are expanded with brief commentary:

- Does the condition of the thermal cracks themselves tend to deteriorate with time?
    - Theory says they should be affected by repeated vehicle loading.
    - This question is addressed by comparing the condition of thermal cracks in wheel path versus non-wheel path areas on old pavements.
- Do thermal cracks negatively influence other aspects of pavement performance?
    - This is the assumed case in all pavement preservation literature.
    - The question is addressed by examining the pavement for signs of fatigue cracking, potholing, excess rutting, or other signs of structural softening near thermal cracking on old pavements.
- Is sealing of thermal cracks necessary?
    - Standard practice indicates that it is.
    - This question is addressed by comparing the condition of sealed cracks versus non-sealed cracks on old pavements.

Note the emphasis for examining *old* pavements. It is common sense that careful examination of thermal cracking and sealing on old pavements in a given area is the most reliable basis for proposing good maintenance strategies for that same area in the future. With this empirical approach in mind, only pavements thought to be 20 years old or older were evaluated.

The STCE method requires field personnel with experience recognizing/describing all aspects of pavement surface damage and maintenance techniques, that is, the same skill set required for performing the LTPP and PASER methods.

Data collection at each of the 91 field sites consisted of providing responses to the following:

1. What is the difference in the wheel path versus the non-wheel path condition of major transverse thermal cracks with the section?
2. What is the difference in the wheel path versus non-wheel path condition of lessor thermal cracks?
3. What is the maximum total width of the widest of major transverse cracks observed at the site (total width includes the damaged zone extending perpendicular to the edge of the crack)?

4. What is the maximum total width of the widest of lessor thermal cracks observed at the site (total width includes the damaged zone extending perpendicular to the edge of the crack)?
5. What is the extent of noticeable pavement deterioration due to major transverse thermal cracking?
6. What is the extent of noticeable pavement deterioration due to lessor thermal cracking?
7. Which thermal cracks received sealant?
8. What is the present condition of the existing sealant?

The field data sheets (two sheets) used for collecting STCE field data were developed for this research, and examples are contained in Appendix B. The data sheets are not further discussed here because they are cumbersome, and if needed again, would be redesigned. A single field data sheet would be devised for future studies of this type based on field experience.

Each field site was photographed and visually examined to obtain a general impression of the long-term value of crack sealant practices (sealed versus non-sealed) at that location. Photo references and miscellaneous notes were added to the field data sheets to document the observations.

Brief Description of Modified LTPP Method

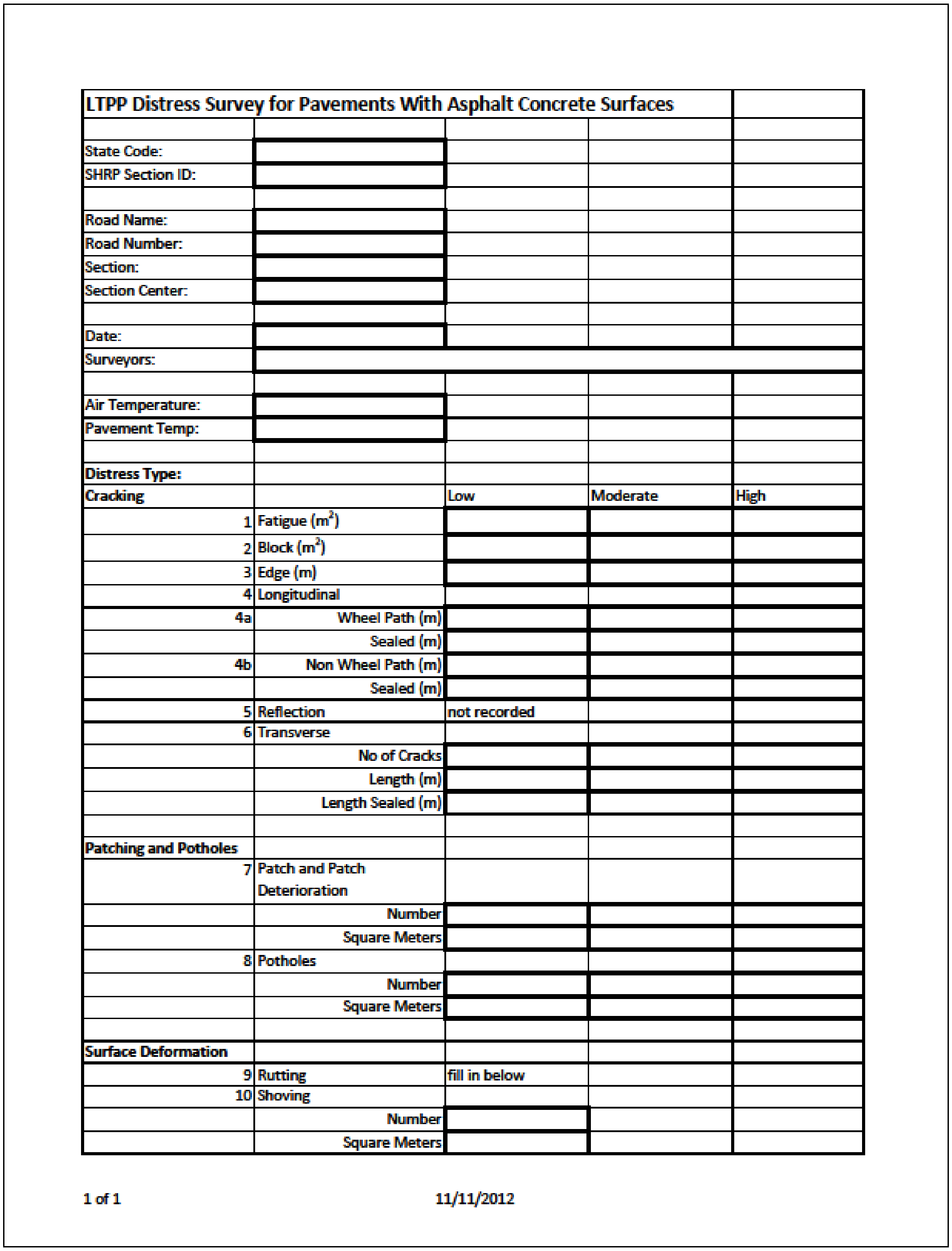
The Long Term Pavement Performance Program (LTPP), which started in 1987, was conducted under the Strategic Highway Research Program (SHRP) (Miller and Bellinger 2003). Though the SHRP ended in 1992 as planned, the LTPP continues under the FHWA. To date 2,500 pavement sections have been evaluated for all of the United States, Puerto Rico, and 10 Canadian Provinces (FHWA 2010). The data consisted of surface condition, climate, and traffic volumes and loads. The data were intended for use in providing information for designing longer lasting, improved roads.

Normally under a LTPP program, 500 feet are surveyed, and the data are kept in two forms: mapping distresses in 50-foot increments and quantitative measured values. The LTPP manual states that photographs depicting certain distress or showing levels of severity are also acceptable. For this particular study, it was decided by the team that 1/10 of a mile, that is, approximately 530 feet, would be the length for each evaluation. The milepost locations designated as the location of each of the 91 project field sites are used to define the center point for each 530-foot LTPP survey. This length was measured with a typical pavement measuring wheel; paint marks displayed the center point and both ends. It was decided that photographs showing either typical distresses for the section or some unique severe distress would be one form of documentation. Filling out the typical quantitative measurements would be the other form of documentation. The blank forms for quantitative measurements shown in the LTPP manual are shown in Figures IV.2 and IV.3.

The FHWA manual “Distress Identification Manual for the Long Term Pavement Performance Program” describes how to identify surface distresses in AC pavements in five parts, A through E.

A. Cracking
B. Patching and Potholes
C. Surface Deformation
D. Surface Defects
E. Miscellaneous Defects

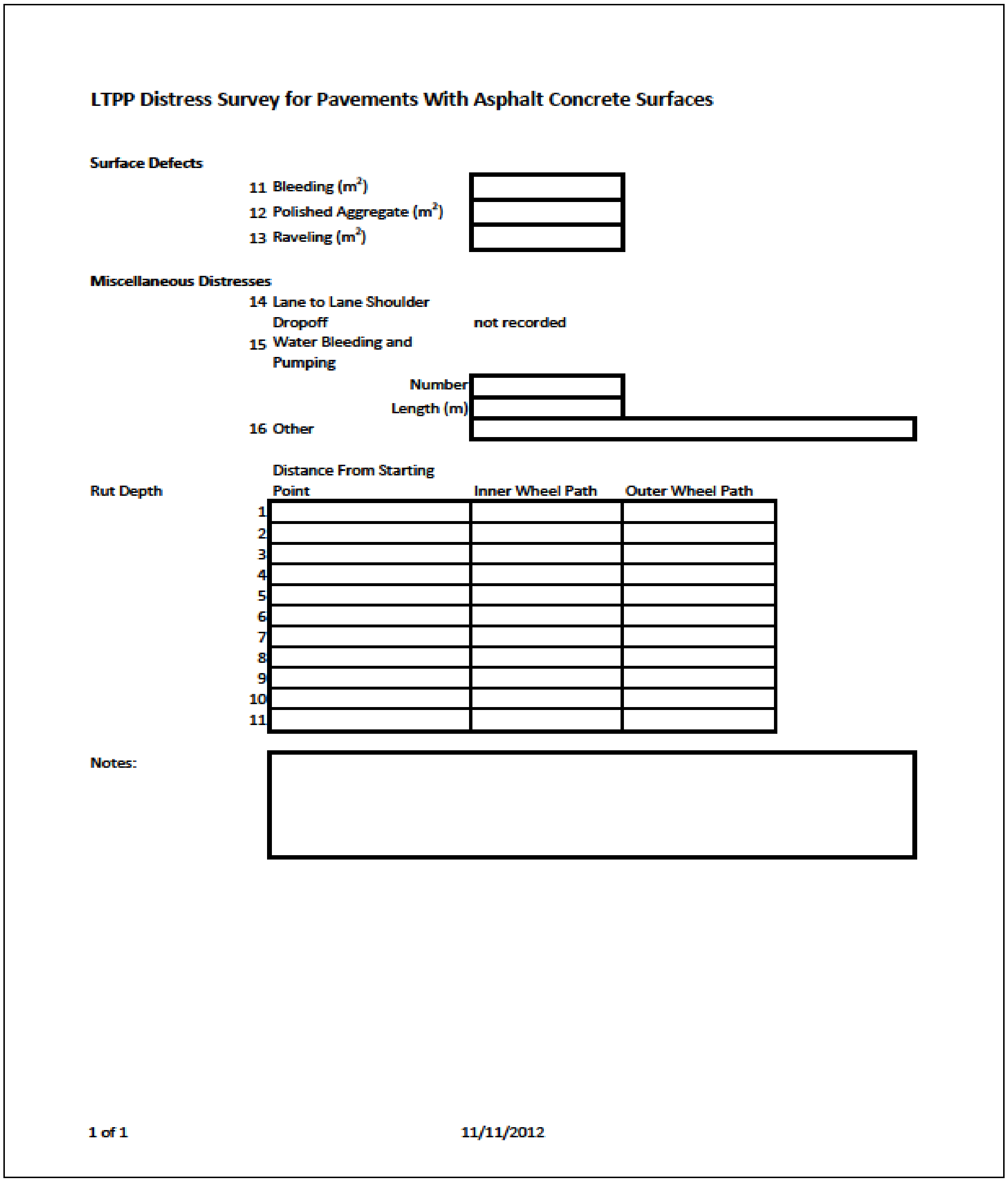
More detail about the LTPP method can be found in Appendix C.



LTPP Distress Survey for Pavements With Asphalt Concrete Surfaces				
State Code:				
SHRP Section ID:				
Road Name:				
Road Number:				
Section:				
Section Center:				
Date:				
Surveyors:				
Air Temperature:				
Pavement Temp:				
Distress Type:				
Cracking		Low	Moderate	High
1	Fatigue (m^2)			
2	Block (m^2)			
3	Edge (m)			
4	Longitudinal			
4a	Wheel Path (m)			
	Sealed (m)			
4b	Non Wheel Path (m)			
	Sealed (m)			
5	Reflection	not recorded		
6	Transverse			
	No of Cracks			
	Length (m)			
	Length Sealed (m)			
Patching and Potholes				
7	Patch and Patch Deterioration			
	Number			
	Square Meters			
8	Potholes			
	Number			
	Square Meters			
Surface Deformation				
9	Rutting	fill in below		
10	Shoving			
	Number			
	Square Meters			

1 of 1 11/11/2012

Figure IV.2 Printout of LTPP survey sheet page 1 used in this study



LTPP Distress Survey for Pavements With Asphalt Concrete Surfaces

Surface Defects

11 Bleeding (m^2) ☐

12 Polished Aggregate (m^2) ☐

13 Raveling (m^2) ☐

Miscellaneous Distresses

14 Lane to Lane Shoulder Dropoff — not recorded

15 Water Bleeding and Pumping

Number ☐

Length (m) ☐

16 Other ☐

Rut Depth

	Distance From Starting Point	Inner Wheel Path	Outer Wheel Path
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

Notes: ☐

1 of 1 11/11/2012

Figure IV.3 Printout of LTPP survey sheet page 2 used in this study

Brief Description of PASER Method

PASER for Asphalt Roads (Walker 2002) is a road surface condition rating system produced by the Wisconsin Transportation Information Center, a department at the University of Wisconsin-Extension program, which also maintains the rating system. Various road surface distresses are discussed in this publication, along with possible treatments that could revitalize the condition providing improved serviceability that will extend the life of the treated road.

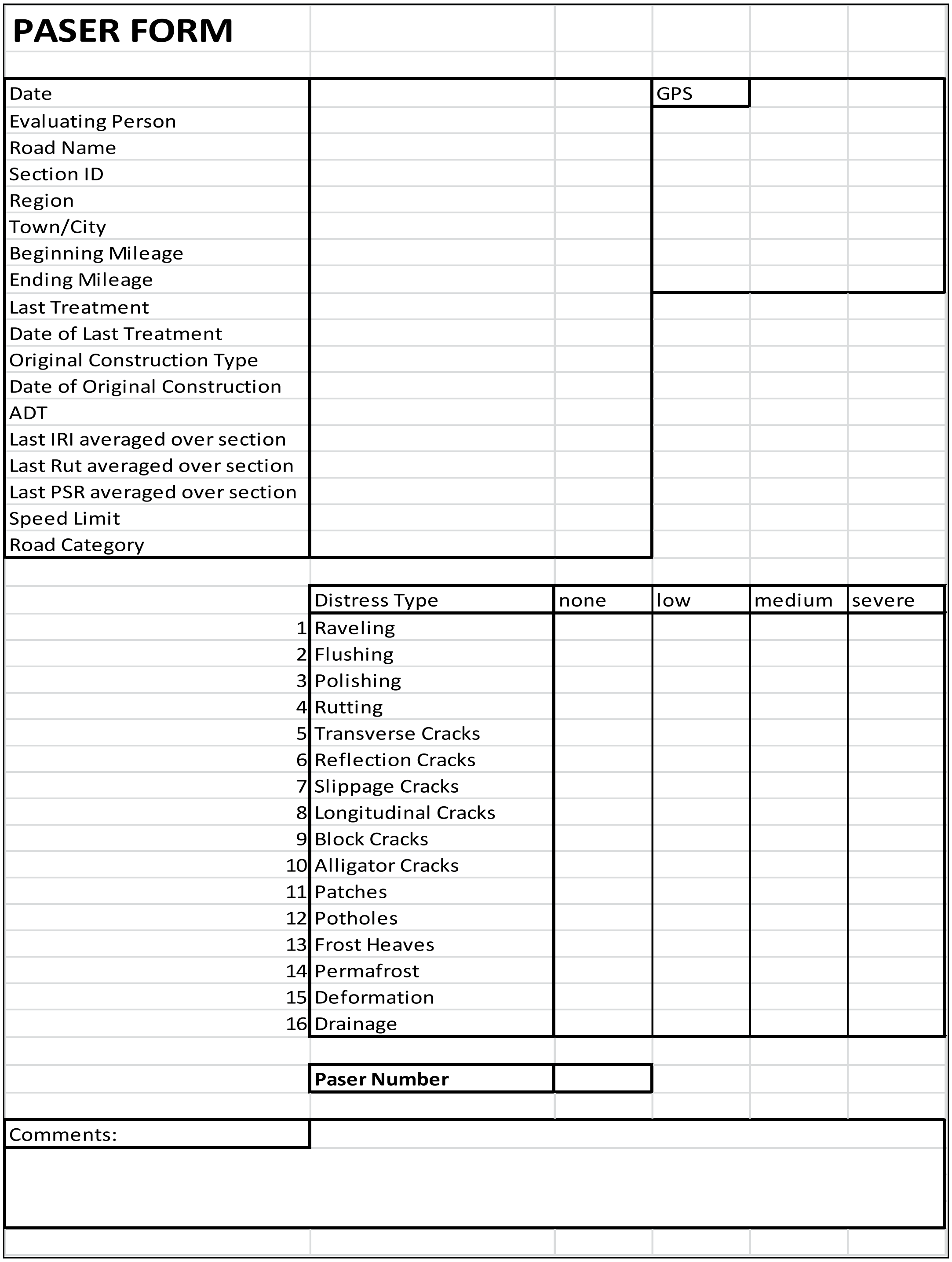
Currently the rating system provides data that are used in a computerized pavement management system called PASERWARE at the Wisconsin Department of Transportation.

The PASER rating is a methodology whereby the observer takes into account the severity level of various road surface conditions and combines them into a single number as a result. The result ranges from 10 to 1, with 10 being a newly constructed roadway and 1 being a totally failed roadway. This system differs from the LTPP road condition survey, a rating system better recognized nationally. The LTPP survey has the observer quantifying conditions more objectively. For instance, various types of cracks are either measured in length or given as a percentage of the surface area of the section being evaluated. The same measurements are recorded for raveling, bleeding, and polishing. The depth of ruts are measured and recorded over multiple equal lengths. Even the severity of conditions should be measured before they are recorded as low, medium, or severe. PASER is quick to perform with less quantification, as compared with the LTPP survey.

Surface defects, surface deformations, cracks, and patches and potholes comprise the four major categories of distresses. Raveling, flushing, and polishing are surface defects. Rutting, rippling and shoveling, settling, and frost heaves make up surface deformations. Transverse, longitudinal, block, alligator, reflection, and slippage are the various names for crack types. PASER is intended as a quick overall survey of any road section, where the categories of severity described for each distress type are as follows: n – none, l – low, m – medium, and s – severe. Categories are meant to be assigned by quick visual assessment (a “windshield” survey).

Figure IV.4 (the PASER field data form) depicts the adaptation of the PASER rating system to an electronic spreadsheet with a few added parameters important to Alaska and other cold regions. The spreadsheet is constructed with check-off columns so that the observer can quickly rate distresses. The other added distresses are frost heave, permafrost, deformation, and drainage. These distress types are of great importance in a cold-region environment.

More details about the PASER method can be found in Appendix C.



PASER FORM

Date		GPS
Evaluating Person		
Road Name		
Section ID		
Region		
Town/City		
Beginning Mileage		
Ending Mileage		
Last Treatment		
Date of Last Treatment		
Original Construction Type		
Date of Original Construction		
ADT		
Last IRI averaged over section		
Last Rut averaged over section		
Last PSR averaged over section		
Speed Limit		
Road Category		

	Distress Type	none	low	medium	severe
1	Raveling				
2	Flushing				
3	Polishing				
4	Rutting				
5	Transverse Cracks				
6	Reflection Cracks				
7	Slippage Cracks				
8	Longitudinal Cracks				
9	Block Cracks				
10	Alligator Cracks				
11	Patches				
12	Potholes				
13	Frost Heaves				
14	Permafrost				
15	Deformation				
16	Drainage				

Paser Number

Comments:

Figure IV.4 PASER form used in this study

V. INTERPRETATION OF FIELD DATA

IMPORTANCE OF AGE AND TEMPERATURE DATA

The subject of this report is thermal cracking, so the importance of pavement age and temperature must be emphasized. A synergy of asphalt cement weathering and low temperatures has produced thermal cracking in almost every old AC pavement in colder areas of Alaska. These data are illustrated in the figures that follow to provide a detailed picture of the range of pavement age and temperature environment that helped produce the large amount of thermal cracking seen on Alaska roads.

Is temperature regime and pavement age significant in this age of new paving materials, for example, polymer-rich asphalt cements? The ADOT&PF now uses performance graded (PG) asphalt cements for all AC paving in Alaska. This new material is supposed to modify the long-term temperature susceptibility of AC pavements and may someday prove to minimize or even eliminate thermal cracking. Such benefits have not been field-verified in Alaska. Until then, this study of old pavements provides the only real insight into thermal cracking versus other pavement performance issues in Alaska. And yes, lacking evidence to the contrary, temperature environment and pavement age are still considered important variables.

Figure V.1 shows the minimum, maximum, and average age for the road sections evaluated on each of the indicated highways.

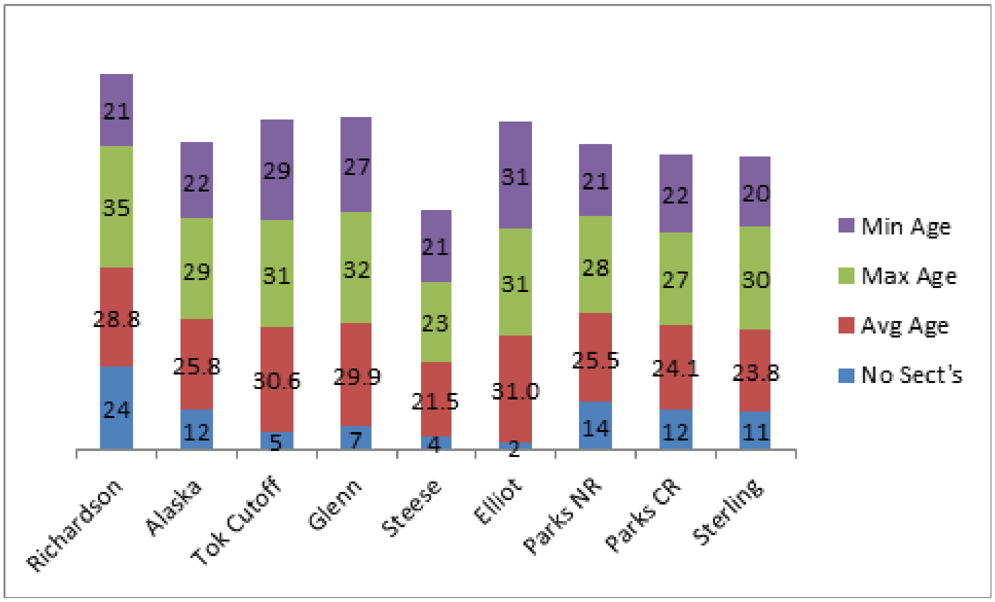


Figure V.1 Number of sections, average age, maximum age, minimum age

Figure V.2 shows the extreme temperatures for minimum and maximum *air temperatures* as per ADOT&PF'S Road Weather Information System (RWIS) website data. Data were extracted from the temperature data probe information that can be found at http://www.dot.state.ak.us/iways/roadweather/forms/AreaSelectForm.html. At this URL, temperature probe data are obtained via the "RWIS – Camera – TDP Area & Corridor Maps" tab.

Figure V.2 Minimum and maximum air temperature for RWIS sites on the various roads in proximity to the sites evaluated (approximately past 5–6 years)

Note the largest extreme minimum/maximum air temperature range of 127°F for the Northern Region end of the Parks Highway. The smallest extreme minimum/maximum air temperature range shown is 114°F for the Steese Highway.

The minimum air temperature recorded was -40°F for five different sites: one on the Richardson, one on the Alaska, one on the Tok Cutoff, one on the Glenn, and one on the Parks Northern Region (NR). The lowest pavement surface temperature was -39°F, which occurred on the Alaska Highway. The maximum air temperature was 90°F, which occurred on the Parks Central Region (CR), and the maximum pavement surface temperature was 129°F, which occurred on the Richardson Highway.

Figure V.3 shows the extreme temperatures for minimum and maximum pavement surface temperatures according to RWIS data. The largest minimum/maximum pavement surface-temperature range is 161°F for the Richardson Highway. The smallest maximum/minimum pavement surface-temperature range is 146°F indicated on both the Steese and Sterling Highways.

Figure V.3 Minimum and maximum pavement surface temperature for RWIS sites on the various roads in proximity to the sites evaluated (approximately past 5–6 years)

A couple of interesting details are clearly shown in Figures V.2 and V.3:

- The pavement surface is subjected to temperature cycling much larger than would be indicated by air temperatures.
- Summertime temperatures of the pavement surface may run as much as 30 to 40°F above the air temperature.

Maximum temperature differences between air and pavement surface would be expected on cloudless, dry, summer days with no wind. Minimum air/surface temperature differences would be expected (1) on rainy, windy summer days, (2) during spring/fall nights with cloud cover, and (3) during the darker winter months.

Historical precipitation data were not as readily available as temperature data. However, an isopleth data "map" of precipitation from the *Environmental Atlas of Alaska* (Hartman and Johnson 1978) indicates that mean annual precipitation for most of the evaluated sites has been between about 15 and 40 inches. Most sections appear to fall at the lower end of these precipitation averages. Recent climate changes would not have significantly influenced these averages.

INTERPRETATION OF PASER AND LTPP DATA

The full spectrum of PASER and LTPP pavement condition data was collected from each of the 91 evaluated sites during the course of fieldwork for this research. It was the wish of sponsoring agencies that standard road condition assessments be included in the total field data collection. This task would add a general pavement condition context to the otherwise specialized thermal crack data. These data in addition to photos and miscellaneous comments form a comprehensive record of surface condition at each field site, and will provide interested readers and researchers the opportunity to review and further study all performance aspects of each of the sections, even those aspects apparently unrelated to thermal cracking.

Presentation of the large PASER or LTPP data set, even in summary form, within chapters of this report is impractical. It is available free of charge on CD in Excel spreadsheet format as an attachment to hard copies of this report or it can be downloaded from ADOT&PF's Research, Development and Technology Transfer library site at http://www.dot.alaska.gov/stwddes/research/search_lib.shtml

PASER

Interpretation of PASER data in this subsection focuses only on PASER's transverse crack measurements. These data support other ways of characterizing thermal cracking used in this study. Histograms included in Figure V.4 depict levels of severity for transverse cracking using the PASER method. All sections on a given highway are represented on one histogram. Each histogram contains four bars. Each bar indicates the number of sites on the highway that exhibit a specific transverse crack severity level, as described in Chapter IV:

n = none
l = low
m = medium
s = severe

The number at the top of each bar indicates the number of sites rated at that severity level.

Significant Points:

- Only 1 out of 91 sites exhibited no transverse cracking. This site was on the Richardson Highway.
- Only 6 out of 91 sites exhibited severe transverse cracking (crack width more than 1/2 inch to 3/4 inch depending on the amount of spalling along the crack edge)
- All other sites have either low or moderate transverse cracking—about evenly split (all crack widths less than about 3/4 inch).

These data simply indicate that almost all old AC pavement sections studied in ADOT&PF's Central and Northern Regions contain major transverse thermal cracks that are no more than moderately severe.

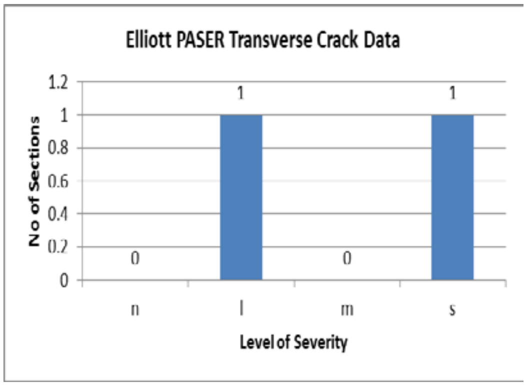


Figure V.4 PASER method for the number of sections on the different highways at each level of severity

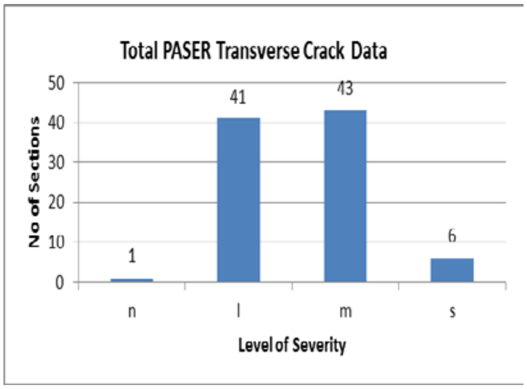


Figure V.4 (Continued) PASER method for the number of sections on the different highways at each level of severity

LTPP

As with PASER, the interpretation of LTPP data focuses only on transverse crack measurements, that is, LTPP's specific recognition of thermal cracking. The histograms included in Figure V.5 depict information about LTPP's three levels of transverse crack severity as well as the apparent effectiveness of sealants used on those cracks. All sections on a given highway are represented by one histogram. Each histogram contains a maximum of 9 bars. From left to right, the bars represent:

Low*	Total linear feet of low-severity transverse cracking
Low-S	Total linear feet of effectively sealed transverse cracks of low severity
Low-A**	Average linear feet of low-severity transverse cracking
Med*	Total linear feet of medium-severity transverse cracking
Med-S	Total linear feet of effectively sealed transverse cracks of medium severity
Med-A**	Average linear feet of medium-severity transverse cracking
High*	Total linear feet of high-severity transverse cracking

High-S	Total linear feet of effectively sealed transverse cracks of high severity
High-A**	Average linear feet of high-severity transverse cracking

(LTPP transverse crack severity level as described in Appendix C)*
*(** average for all sites on a given highway)*

The number at the top of each bar indicates the linear feet of transverse crack represented by that bar.

Significant points:

- There is very little high-severity transverse cracking (> 3/4 inch width) on these old pavements even though essentially all contain transverse cracks.
- Less than 1/3 of the total lengths of low-severity and medium-severity transverse cracking appeared to be effectively sealed.
- Less than 1/4 of the total length of high-severity transverse cracking appeared to be effectively sealed.

The effectiveness of transverse crack sealants has apparently played no major role in determining the present condition of old pavements. On this basis alone, one might question any presumed need for sealing transverse cracks within the large area of Alaska examined during this research.

An interesting observation based on Figure V.5 is that transverse cracking (according to the LTPP category) is *not* obviously more severe on the more northern sites.

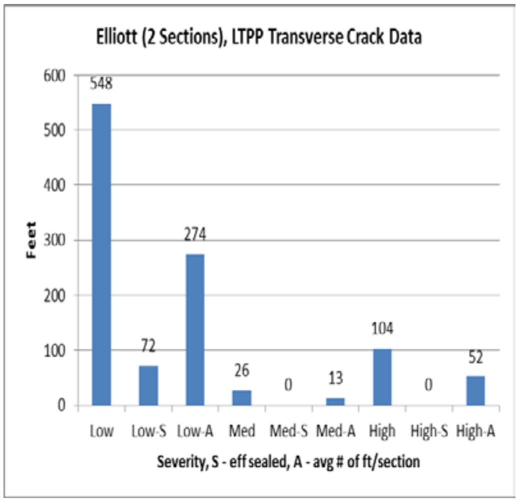


Figure V.5 Length of transverse cracks at the different severity levels per LTPP method

Figure V.5 (Continued) Length of transverse cracks at the different severity levels per LTPP method

INTERPRETATION OF STCE DATA

A number of interesting histograms were created from the spreadsheet's STCE data. These histograms summarize aspects of thermal cracking that are important to the objectives of this research. Each histogram is described and its significance explained.

At the top of the frequency bar for each histogram, a number is shown. These numbers are a count of the individual cases represented by that particular bar. The numbers do not represent percentages; percentages are read from a histogram's vertical axis. Note that these numbers in each histogram do not add up to 91, that is, the total number of field sites, because not all sites contained both major transverse and lessor thermal cracking.

Figure V.6 shows whether portions of major transverse cracks within wheel paths are performing worse than portions outside the wheel paths. Consistent, large differences in performance between the two locations would indicate that traffic loading plays an important part in degrading pavement near the cracks themselves. Theory indicates that the difference between wheel path and non-wheel path damage should be rather substantial. Such a difference should occur if the combination of wheel loads plus the softening influence of water intruding beneath the AC pavement combines to amplify damage in the wheel paths. Assuming that the wheel loading/water theory is correct, one could assume that fairly large areas of the pavement are affected within the wheel path—not just the pavement immediately adjacent to the edge of the crack.

What Figure V.6 reveals, however, is that differences were observed only 35% of the time, and large differences, only 11% of the time. This finding suggests that there is often no marked softening of the pavement structure in the wheel path.

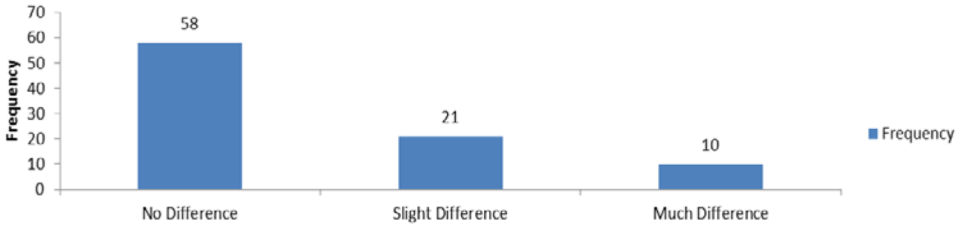


Figure V.6 Condition of major transverse cracks (wp Vs non-wp*)
(wheel path versus non-wheel path)*

Figure V.7 shows whether portions of lessor thermal cracks within wheel paths show more damage than outside the wheel paths. Again, differences in performance between the two locations would indicate that traffic loading plus water was working in combination to more heavily damage pavement near the cracks. Theory certainly suggests that a noticeable difference should exist.

Figure V.7 indicates that, for lessor thermal cracks, there is almost no difference between wheel paths (wp) and non-wheel path (non-wp) areas. Only at 1 site out of 84 total was a difference seen, or just over 1%. Figure V.7 shows that in one case the difference was slight. Therefore, based on the project data, lessor thermal cracking seems unaffected by softening of the pavement structure.

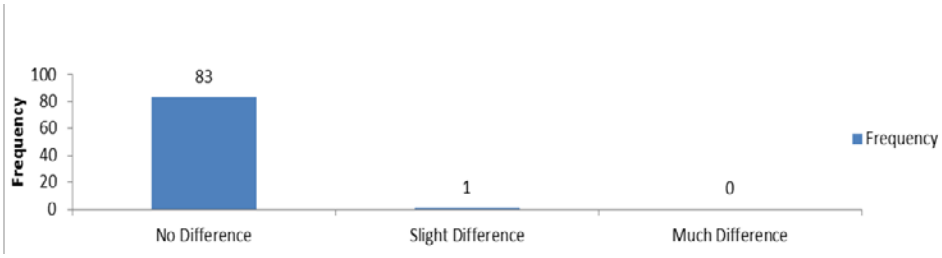


Figure V.7 Condition of lessor thermal cracks (wp Vs non-wp)

Figure V.8 supports Figure V.6 for transverse cracks by adding more to the story. Not only is there usually little damage difference between wheel path and non-wheel path locations (Figure V.6), but also usually no marked softening much beyond the edges of the cracks themselves.

The crack zone width indicated in Figure V.8 includes the combined total width including both sides of the crack.

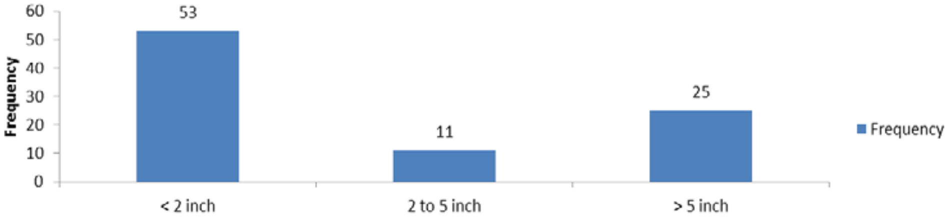


Figure V.8 Maximum observed width of major transverse crack zone

The histogram in Figure V.9 simply indicates that most lessor thermal cracks are no wider than 1/8 inch (94%). Perhaps most important in this finding is that vehicle action, water, and time (20 years or more) did not combine to widen lessor thermal cracks or noticeably degrade/damage pavement adjacent to those cracks.

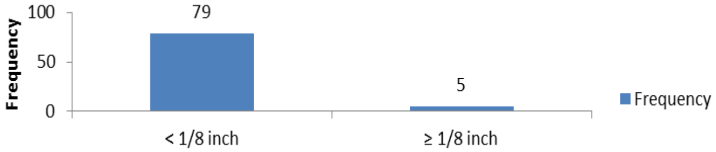


Figure V.9 Maximum observed width of lessor thermal crack zone

Figure V.10 shows that only about 8% of the examined pavements showed any signs of major transverse cracks affecting pavement performance anywhere but very near the crack. In fact, as shown in Figure V.10, it was only at two field sites that the relationship between transverse cracks and more general pavement performance were truly obvious. It is important to note that all of the 8% indicated here were in areas where multiple layers of pavement were present—and in the process of delaminating.

Field data collected to produce Figure V.10 required careful assessment of the road surface as a whole. At each field site, the evaluator had to address the question of whether there were obvious signs that rutting, alligator cracking, raveling, or potholes were associated more with the near vicinity of major transverse thermal cracks than all other areas of the road.

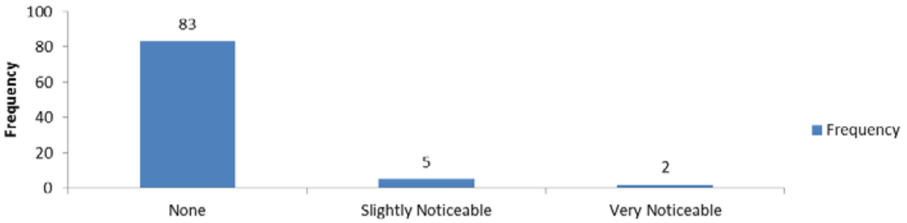


Figure V.10 General pavement deterioration due to major transverse cracking

Figure V.11 indicates that no sites could be found where lessor thermal cracks appeared to be influencing other aspects of pavement performance. Very few exceptions were found where minor potholing occurred at intersections of lessor crack segments. This observation also holds true for most of the delaminating pavements viewed during the study.

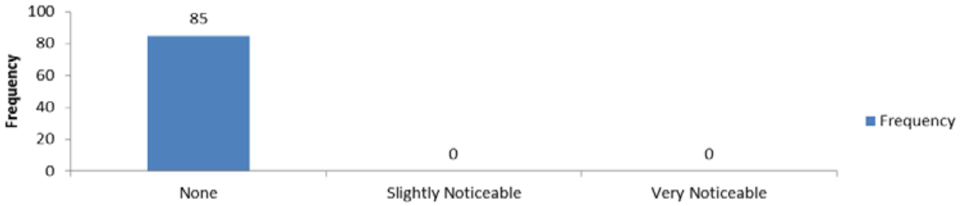


Figure V.11 General pavement deterioration due to lessor thermal cracking

Before beginning fieldwork for this project, the research team hoped that many of the old rural pavement sites selected for study would have received little or no sealing. The fact that many of the sites had received sealant and patching maintenance obscured interpretation of the pavement aging process with respect to all crack types. The bright side (from the team's perspective) was that much of the old sealing had cracked. Even many of the newer seals had cracked. In the end, it was found that many of the older pavements were imperfectly sealed and appeared to have been so for a long time. The team decided that the original assumption that old, cracked pavements were good candidates for study remained valid.

Figure V.12 indicated that more than half the sites contained major transverse cracks that had been sealed at some time (at 48 sites). There had been an attempt to seal *all* thermal cracks at only 28 sites. At 14 additional sites the sealant was so old that it appeared similar to an old strip of black paint, and was sealing nothing at present.

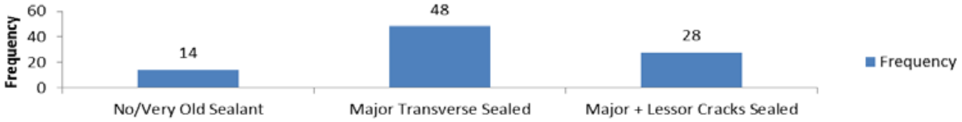


Figure V.12 Presence of crack sealant

Figure V.13 reveals more about crack sealant. Of the 83 sites where sealants were recognized (some old sealants were very difficult to recognize), only about 13% of those sites still exhibited effective sealants. Even sites that generally contained effectively sealed thermal cracks offered plenty of the unsealed variety for study.

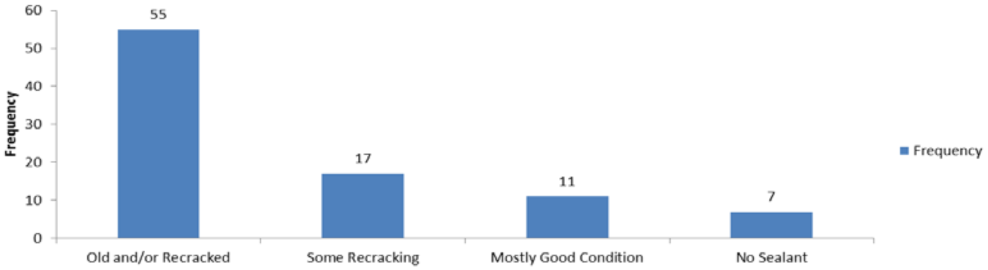


Figure V.13 Present condition of sealant

INTERPRETATION BASED ON PHOTOS AND MISCELLANEOUS COMMENTS

This subsection summarizes and interprets thermal crack characteristics and aspects of crack sealing performance based on photos and miscellaneous comments accumulated during project fieldwork and not presented elsewhere in this report. Interpretation of observations presented as statements in the project’s Excel workbook comments section are included.

Major Transverse Thermal Cracks

These cracks often do not extend straight across the road in a simple, straight line. General characteristics based on all observations are as follows:

- General shape of crack in plan view
    - Simple (fairly straight with < 1/2 inch width) — 50%.
    - Crooked or very crooked — 50%.
    - Bifurcated (transverse cracks that exhibit several distinct branches) — relatively infrequent.
- Early versus mature appearance*
    - Individual major transverse thermal cracks are usually first seen as a narrow crack extending completely across the paved surface or nearly so. There is some speculation that individual transverse thermal cracks form very quickly.

      (Description of early appearance is based on the research team's experience observing the performance of recently constructed asphalt concrete pavements in Alaska. Description of mature appearance is based on observations and photos collected during this study.)*
- Crack widths between pavement shoulders (as seen mid-summer 2012)

  Most were not more than about 1 inch, and of those:
    - 1/4 inch to 1/2 inch — 95%.
    - 1/2 inch to 1 inch — 5%.
- Appearance along the crack
    - Very little depression (most major transverse crack zones are depressed at least a small amount below the normal pavement surface) — 75%.
    - Deeply depressed (> 1/4 inch) — 5%.
    - Moderate to heavy spalling along the crack zone — 15%.
    - Faulting where one side of the crack is found to be noticeably higher than the opposite side — infrequent.
    - Wide cracks with heavily spalled zones — often appear to be associated with delamination of multiple pavement layers.
- Depth of cracking
    - These cracks always extend completely through the AC pavement and well into the underlying aggregate materials. Neither the crack depths themselves nor the specific factors controlling those depths have been studied in Alaska until recently. A recent, as yet unpublished research effort (Burritt 2012) is directed at thermal crack depth on Alaska's pavements.

Miscellaneous observations and photos suggest that relatively little of the major transverse thermal cracking seen on old pavements appears to be in immediate need of, or would greatly benefit from, sealing at the present time.

Lesser Thermal Cracks

Unlike major transverse cracks, lessor thermal cracks have a much less consistent general appearance.

- Early versus mature appearance
    - Lessor thermal cracks usually first appear as individual hairline crack segments perpendicular to the centerline. As lessor thermal cracking matures, crack segments often intersect and interconnect to form net-like (irregular) or orthogonal grid-like patterns where crack segments are nearly perpendicular.

      (Description of early appearance is based on the research team's experience observing the performance of recently constructed asphalt concrete pavements in Alaska. Description of mature appearance is based on observations and photos collected during this study.)
- Crack widths (as seen mid-summer 2012)
    - Usually hairline to 1/4 inch.
    - > 1/4 inch — infrequent.
- Appearance along the crack
    - Almost never depressed or spalled zones along these cracks.
    - Rare examples of spalling or small potholes at crack segment intersections were invariably associated with delamination of multiple pavement layers.
- Depth of cracking
    - These cracks are *thought* to extend only through the AC pavement. This type of cracking has not been studied in Alaska.

Nearly all observations and photos suggest that *none* of the lessor thermal cracking seen on old pavements requires sealant. Once formed, this crack type almost never deteriorates to the point that general pavement performance is affected.

Wheel Path Versus Non-Wheel Path Conditions

For major transverse thermal cracks, visual observations backed by photographic evidence identified few sites where examples could be found of wheel path damage being noticeably worse than non-wheel path damage.

For lessor thermal cracking, visual observations identified *very few* instances where the condition of lesser thermal cracking was worse in wheel path areas than non-wheel path areas. The few examples where lesser thermal cracking showed more damage in the wheel paths were in areas where pavement delamination was occurring. These observations are well supported by substantial photographic evidence as in the following examples. Figure V.14 shows the typical appearance of nearly all lessor thermal cracks seen during fieldwork for this research. Note that there is essentially no difference in performance between wheel path and non-wheel path locations. Neither does pavement condition vary as a function of distance perpendicular to the edge of any individual crack.

Figure V.14 Lessor thermal cracks showing same performance in wheel path and non-wheel path locations (extremely common appearance)

Relatively few observations support the theory that open pavement cracks always allow enough surface water infiltration to facilitate load-related pavement damage. The negative influence of water would have been evident if the most heavily trafficked areas of the pavement exhibited significantly more damage than the least trafficked areas.

Influence of Cracking on Adjacent Pavement Areas

These observations compared the condition of the pavement near cracks versus the condition of the pavement further away. As explained above, pavement condition should be expected to vary as a function of distance from a crack; the worse condition would be generally expected near the crack because of the interaction of water and traffic loadings. At most sites, there was no obvious correlation between pavement condition and distance from the edge of a crack except for the usual influence zone (usually less than 2 inches wide) adjacent to major transverse thermal cracks.

Much attention was given to the often-depressed and sometimes spalled zones adjacent to transverse cracks. In most cases, the damage did not appear to be the result of softening. Instead, damage appeared to result from the simple downward bending of the pavement along the crack (cantilever-like), as if some of the underlying support had been removed. The true nature of this support "removal" has not been determined. The loss of underlying fines to the surface is not a common, obvious occurrence. Furthermore, and more intriguing perhaps, are the writers' repeated observations made during many winters at times of very low temperature and with the aid of a metal bar. Tapping the road surface along the edge of transverse thermal cracks often produces a hollow sound indicating the presence of a space between the underside of the pavement layer and the top of the base course. The writers conjecture that low-temperature contraction* of the sub-pavement soils produces cantilevering of the AC pavement near the crack, which leads to subsequent cracking of the AC material. This effect could produce spalling as seen along the edges of transverse cracks, that is, pavement breakage without obvious signs that the pavement support materials have softened. Figure V.15 shows examples of the typical case, where pavement damage does not extend far beyond the crack edge—even for severe transverse cracks.

(assuming differential contraction between base course and AC pavement materials)*

Figure V.15 Severe major transverse cracks with little influence on pavement performance beyond crack edges (very common)

Here again, it must be emphasized that most observations certainly did not support the assumption that thermal cracks allow enough water past the AC pavement layer to soften the pavement structure.

Effect of Chip Seals

Where chip seals had been placed on some of the older pavements, thermal cracking was often quite difficult to see. Some of the originally selected sites were in fact removed from study because chip seals made it impossible to rate the underlying condition of the old road surface. It was noted that chip seals are an effective and, apparently, a fairly permanent way of hiding accumulated thermal cracking. Chip seals usually do a good job of covering major transverse thermal cracks as well. The downside of chip seals is that, in exchange for improving surface friction and hiding thermal cracks, the road surface often ends up with an unattractive mottled appearance.

Close inspection indicated that old thermal cracks were indeed present and open. The bottom line though is that chip seals seem to provide an effective form of permanent visual "camouflage" for thermal cracks. However, on close inspection, the seal coats examined during this research did not appear to have permanently sealed anything but the smallest thermal cracks.

Effect of Maintenance "Banding"

A wide form (several feet wide) of patch/seal was examined in a number of areas in ADOT&PF's Northern Region. This type of maintenance treatment is applied to major transverse thermal cracks, apparently with the intention of simultaneously accomplishing sealing, patching, and re-leveling.

Except for the newest of these treatments, nearly every band had re-cracked to reveal the old thermal crack. Failure of the sealing function appeared to cause no problem however. These bands appeared to be performing a valuable function. Most of the banded transverse cracks, even those with old bands, still provided a permanent re-leveling of the area adjacent to the crack, and certainly less of a bump for the driving public than if there were no band. Figure V.16 shows two examples of maintenance banding in ADOT&PF's Northern Region.

Figure V.16 Examples of patch/seal band maintenance of major transverse thermal cracks

Observations concerning the effectiveness of the bands provide more evidence that thermal cracks can be allowed to remain open without necessarily causing further pavement damage.

Effect of Pavement Delamination

The problem of pavement delamination was observed at some of the research field sites. This problem was easy to identify where (1) much potholing and raveling were present, and (2) where another pavement layer could be found at the bottom of the potholes and heavily raveled areas. Figure V.17 shows typical negative results of a combination of pavement cracks and delaminating pavement.

Figure V.17 Examples of pavement delamination damage accentuated at crack locations

It was obvious that the delamination process greatly amplified the importance of all cracks in terms of other forms of surface damage. In fact, the delamination process seemed to be aggravated by *any* openings in the pavement surface that facilitated water getting to the interface between delaminating layers. Only in areas of delaminating pavement was pothole formation seen to be obviously associated with both types of thermal cracking. Delamination tended to increase the severity of spalling along major transverse cracks as well. It is fortunate that relatively few miles of Alaska's paved roads exhibit delamination.

VI. CONCLUSIONS AND IMPLEMENTATION RECOMMENDATIONS

There is a wise saying of unknown source: *In theory, theory is reality. In reality, it is not.* Standard wisdom regarding the theory of pavement-damage mechanisms has held that all cracks in a roadway pavement surface must be sealed to prevent inevitable damage due to water intrusion. Conclusions here do not support the accepted "seal every crack" standard practice without reservation, nor do they unreservedly support a standard strategy, because field observations on a large portion of Alaska's paved road system simply do not justify that support.

There is an important caveat associated with the attitude expressed in the above paragraph. Readers from outside of Alaska must understand that many of the sites evaluated during this research receive little annual precipitation. For example, much of Alaska's interior area is classified as semi-arid. Researchers involved in this study were well aware that the unusually good performance of pavements with respect to extreme levels of thermal cracking is likely due to a fortunate combination of compensating climate factors. Thus, although most roads in Alaska certainly experience temperatures low enough to cause thermal cracking, precipitation levels might be low enough (especially for most Northern Region pavements) to retard deterioration. Or other influencing factors may be present.

There is a pavement condition—delamination—that demands constant attention to sealing to avoid serious raveling and potholing. Areas of roadway where multiple pavement layers are delaminating *do* require careful and constant attention to the sealing of all cracks. This condition is discussed further in the last conclusion statement.

The following conclusion statements are derived from observations of predominantly older pavements. Keep in mind that the age of pavements examined during this research was vitally important to producing valid conclusions and implementation recommendations. Older pavements have had sufficient time to accumulate mature patterns of thermal crack damage. Those older pavements have also had sufficient time to develop any characteristics that would evidence relationships between thermal cracking and other aspects of pavement damage.

CONCLUSIONS—LESSOR THERMAL CRACKS

The linear feet of lessor thermal cracking on a road surface appears to be greater in colder areas and (for a given climate area) greater on older pavements (general observation).

The characteristics of lessor thermal cracks appear to be the same within and outside of wheel paths at any given location (only 1 case was slightly different).

Lessor thermal cracks do not appear to deteriorate after formation; that is, they do not become wider or spall with time (only 5 cracks were wider that 1/8 inch).

Zones of pavement adjacent to lessor thermal cracks show no more deterioration than the pavement surface in general; that is, there is no evidence of pavement softening associated with lessor thermal cracks (no exceptions noted).

The condition of lessor thermal cracks and areas of pavement adjacent to those cracks appear to be similar regardless of whether or not the lessor thermal cracks were sealed (general observation without apparent exceptions). In other words, general pavement performance appears the same regardless of whether or not lessor thermal cracks are sealed.

Sealant placed on lessor thermal cracks could be felt as bumps while driving, and is quite unattractive visually.

CONCLUSIONS—MAJOR TRANSVERSE CRACKS

The spacing between major transverse cracks is less for road surfaces in colder areas and (for a given climate area) less on older pavements (general observation).

The condition of a major transverse crack within the wheel path versus outside the wheel path is the same or only slightly different (about 89% of the sections where major transverse cracking was present)

Major transverse cracks almost always exhibit a zone of influence (a depressed and/or spalled zone) that extends parallel to and along each crack. Only about 28% of those cracks have influence zones more than 5 inches in total width.

Major transverse cracks were not associated with noticeable pavement problems in about 92% of the sections where that crack type was present. Major transverse cracks were associated with very noticeable pavement problems in about 2% of sections where that crack type was present. Damage usually does not extend beyond the immediate crack zone.

There appears to be no obvious, consistent long-term performance differences associated with sealed versus non-sealed major transverse cracks in any general area of the Alaska highway system examined during this study. This finding appears true in terms of the long-term condition of the cracks themselves as well as the long-term condition of the general pavement surface.

Sealant placed on major transverse thermal cracks produces a negative visual impression, but does not seem to influence ride quality—most cracks of this type are accompanied by a depressed zone that produces the familiar vehicle tire thump whether sealed or not. However, wide bands of sealing/patching applied to major transverse cracks appear to lessen tire thump, and the effect often seems to be somewhat permanent. Except for very recent applications, all observed seal/patches of this type had re-cracked; that is, they provide no seal. These wide seal/patches do, however, seem to lessen the bump.

Observations were documented regarding major transverse thermal cracks treated through the process of routing followed by sealant. No general pavement performance benefits were noted compared with regular sealing—or in most cases, compared to no sealing at all. This method of sealing cracks is fairly new, so long-term monitoring may produce different conclusions. Additional field monitoring of this expensive sealing method will determine if pavement performance benefits are worth the additional expense of using it. Additional field study must recognize and discriminate between the long-term performance of the sealant itself (does the sealant stay in place?) and the degree to which it improves performance of the general pavement surface.

Observations were documented regarding the use of wide bands of fine patching material for re-leveling and (presumably) sealing major transverse cracks. This maintenance approach is often unsightly, and nearly all of these patch/seal bands re-crack and therefore do not provide a long-term seal. However, the method often permanently re-levels the pavement surface, and the lack of long-term sealing usually causes no problems at all. Because this method often succeeds in permanently reducing the bump associated with major transverse cracking, the research team tentatively considers this maintenance technique to be a success. Additional field study is needed to learn more details about the long-term performance of these maintenance bands.

CONCLUSIONS—DELAMINATING PAVEMENTS

A number of pavement sections evaluated during this research were found to be generally damaged by the process of pavement delamination. Delamination tended to be accentuated wherever cracks in the pavement surface allowed water to access the interface between delaminating pavement layers. Based on these observations, paving methods that might lead to delamination should be avoided if possible, and any observed breaks in the pavement surface should be sealed if possible.

Design: Obvious pavement design approaches to minimizing the chance of pavement delamination would include the following:

- Construct new pavements as a single layer if possible.
- Construct multiple-layer new pavements and pavement overlays in such a way as to achieve a good, continuously sealing bond between layers. An obvious example of violating this principle would be placing an overlying pavement layer during even a light rainstorm.
- Do not place pavement overlays on top of obviously delaminating pavements.

- Leave the delaminating pavement layers in place prior to placing new pavement, and then the delaminating pavement layers into small pieces using a milling machine, reclaimer, or similar equipment.

Maintenance: One course of action might be to seal every new crack on every new multi-layer pavement as the crack appears, assuming the possibility that that particular pavement type might be susceptible to delamination. On the other hand, economic considerations suggest that evidence of delamination should be *seen* before any extraordinary effort to seal most or all thermal cracks is begun. The strategy for maintaining a badly delaminating pavement must depend on where that section of pavement sits in the queue for replacement—and it should be in the queue for replacement. It is practical to assume that delaminating pavements are not permanently repairable, and to think of the careful maintenance of these pavements (keeping the water out) as simply a holding action against unacceptably rapid failure.

IMPLEMENTATION RECOMMENDATIONS

1. **Recognition:**
   Learn to recognize thermal cracks in the field.
   a. Learn to recognize the difference between thermal cracks and other types of cracks.
   b. Learn to recognize the difference between major transverse thermal cracks and lessor thermal cracks.

2. **Lessor Thermal Cracks:**
   Do not apply sealing materials to lessor thermal cracks.

3. **Major Transverse Cracks, Old Pavements (approximately ≥ 5 years old):**
   Decide which major transverse cracks require sealant and which do not.
   a. Do not seal previously unsealed major transverse cracks on older pavements if those cracks show no severe degradation.
   b. Do not reapply sealant to previously sealed major transverse cracks until/unless further degradation is seen.

4. **Major Transverse Cracks, New Pavements (approximately < 5 years old):**

   Decide which major transverse cracks require sealant and which do not. An empirical approach is recommended.

   After major transverse thermal cracks begin to appear, apply sealant to, for example, every other transverse crack. Then monitor the results for several years to determine if the sealant has provided any obvious advantage. Begin applying sealant to all cracks if deemed necessary.

5. **Major Transverse Cracks, Areas of Severe Bumps:**

   In areas where severe bumps are produced because the transverse crack zones are deeply depressed, apply a banded patch/seal of the type commonly used in ADOT&PF's Northern Region. Further discussion concerning application methods and materials regarding this technique is beyond the scope of this report. Contact ADOT&PF Northern Region Maintenance & Operations for further information.

6. **Major Transverse Cracks, Trying New Sealing Methods:**

   Accompany every trial of new crack sealing materials or methods with a plan to monitor and document its long-term performance. A study period of 5 to 8 years should be sufficient to get a clear idea of benefit versus cost. Keep in mind that the objective is not just to get a longer lasting seal. The objective should be to provide a seal that improves overall pavement performance more than previously used sealing techniques and certainly more than no seal at all. To convincingly address the last point, it will be necessary to include in each trial a sampling of cracks that receive no sealant at all.

   Evaluation metrics should include *ride quality*. This ensures that pavement performance from the user's perspective is considered in the evaluation.

7. **In Areas of Delaminating Pavement:**

   Apply sealant as necessary in areas where the pavement is delaminating, to all cracks to limit potholing and raveling of the general pavement surface, and severe spalling along major transverse cracks. These pavements tend to self-destruct, and any sources of water entry accelerate the process.

8. **Sealing Requirements for Poor Drainage Areas (based on engineering judgment and not directly supported by research conducted during this study):**
    a. Seal all cracks in areas of otherwise good drainage where the pavement surface is subjected to routine or semi-continuous water flow (but is not routinely submerged).
    b. Do not seal cracks in areas where the pavement is routinely submerged and must routinely handle traffic during submersion (e.g., some intersections and urban areas with poor drainage or drainage routinely blocked during thaw periods). Under these conditions, open cracks may actually offer a "relief valve" to aid in reducing pore pressures of saturated materials beneath the pavement layer.

A POSSIBLE NEW DIRECTION?

Building a better mousetrap is said to be a sure road to economic success, but what about building a better thermal crack?

The ADOT&PF has conducted and is presently conducting field experiments addressing thermal crack "improvement." In the late 1970s and early 1980s, ADOT&PF researchers measured spacing between major transverse cracks at many locations and measured annual variations in crack width. In the mid-1980s, those researchers experimented with precutting transverse cracks at 50-foot intervals on a section of road with new embankment and pavement (west end of Phillips Field Road, Fairbanks). This experiment was successful, but essentially forgotten. Recent FHWA emphasis and support in the area of pavement preservation has fostered renewed interest in construction/maintenance issues related to thermal cracking. With this impetus, ADOT&PF and AUTC researchers are again studying thermal crack precutting. This time the experiment (Richardson Highway near Fairbanks) involves a combination of old embankment and a newly replaced AC pavement surface.

Figure VI.1 compares a precut Phillips Field Road crack with a natural major transverse thermal crack on another local Fairbanks road. Both pavements are more than 25 years old. Neither crack has ever been sealed. The precut crack provides a much better appearance. The natural crack looks much worse, exhibiting both spalling and bifurcation. However, one must admit that pavement performance near the natural crack is—as was commonly found during this research—acceptable. Lessor thermal cracks abound between the transverse cracks on both of these old roads, but they have caused no maintenance problems to date.

Figure VI.1 25+ year old major transverse thermal cracks, precut (left) natural (right)

It can be strongly argued that the better appearance of precut transverse cracks, especially in urban areas, provides the impression that the pavement has been more “professionally finished.” Regardless of other benefits, the driving public would obviously perceive a successfully precut pavement as being less in need of maintenance than its naturally cracked counterpart is.

There are other benefits to precutting in addition to improved aesthetics. Based on observations on a single (aforementioned) section of Alaska road that was precut, it appears that vehicle ride smoothness is significantly improved. Also, unless the driver is paying close attention to details of the pavement surface, there is something of an impression (coupled with the benefit of a smoother ride) that transverse cracks hardly exist at all. The synergistic combination of a positive visual perception plus actual smoother ride suggests that there may be real economic value associated with precutting.

RECOMMENDATIONS FOR CONTINUING RESEARCH

Limited research efforts in Alaska since the mid-1980s (including this research) have strongly suggested that a much more economical and sustainable engineering approach to the thermal cracking problem is possible. Field experiments in Fairbanks, Alaska, found that joints, presawn at the time of 1984 construction, control the location and character of transverse thermal cracks to this day. Furthermore, decades of casual field observations, capped by this research project, indicate that much sealing of natural thermal cracking may be omitted without detrimentally effecting long-term pavement performance. Observations and past research point at two directions of continuing research that promise improved economics and lower environmental impact compared with the old “see a crack—seal a crack” approach.

Research Direction 1 is in the area of presawn thermal cracks (joints). Presawn joints appeared to control transverse thermal cracking in the above-cited case involving new pavement and embankment. Further research would look at the possibility of dealing with overlays on existing pavement structures, as well as optimizing the depth and spacing of the presawn joints. In terms of potential theoretical and laboratory studies, the detailed nature of thermal cracking and pavement deterioration (or lack of deterioration) in *real* multi-layered pavement structures is still largely unknown. Research Direction 1 aims at swapping a bit more cost and effort during construction for reduced maintenance, better surface appearance (aesthetics), and a smoother ride.

Research Direction 2 continues assessing the need to seal thermal cracks. Additional research would further confirm that sealing of certain thermal crack types is unnecessary. Research is needed to develop an understanding of why, contrary to accepted engineering belief, heavily trafficked pavements can survive quite well for decades with many thermal cracks and little or no sealing. Research Direction 2 simply aims at greatly reducing the use of crack sealing materials without negatively affecting pavement performance. Reduced use of petroleum products for maintaining the pavement surface, over a 20 to 25 year pavement life, obviously promotes wiser use of maintenance funds, not to mention better environmental stewardship.

The strategy behind proceeding simultaneously with both directions of research is that the two are complementary. We expect that the results from both areas of research will combine to sustainably minimize maintenance efforts and the use of materials. We also expect that this can be done without sacrificing practical aspects of pavement performance—with the bonus of providing better pavement surface aesthetics.

FUTURE RESEARCH—GENERAL SUMMARY

- Monitor the performance of field trials of new AC pavements with presawn major transverse cracks.
    - Help design field tests that include both sealed thermal cracks and non-sealed thermal cracks (control cracks)
    - Determine if pre-sawing of transverse joints can be successful in cases where the pavement, and perhaps base course, is new but the existing embankment already contains earth (thermal) cracks

  - Determine if special methods can be employed to prevent reflection of pre-existing earth cracks at non-presawn locations (using special compaction methods and/or bonding/cementitious materials to fill existing earth cracks)
- Record thermal crack development on new pavements
  - Record actual cracking events if possible
  - Determine the maximum depth and rate of penetration of transverse cracks into materials below the base of the AC pavement
- Determine amount of water actually entering cracks in the roadway and its effect on base and sub-base moisture contents.
  - Flat versus sloped centerline
  - Moisture content versus stiffness versus distance from crack edge
  - Test locations should include transverse thermal cracks as well as the lessor (grid-type) thermal cracks
- Strengthen verification of field observations/evidence that indicates thermal damage is not related to other forms of damage either by origin or through the nature of ongoing mechanical processes.
- Correlate climate factors, for example, rainfall, degree-days freezing with thermal cracking characteristics such as spacing, amount of spalling or crack width.
- Conduct laboratory studies of moisture content versus surface stiffness for laboratory-scale pavement sections
  - Controlled water inflow at crack opening
  - Controlled pavement centerline grade and crown
- Determine the optimal spacing and depth for presawn transverse joints in AC pavements.
- Address the following questions: What is an acceptable road in Alaska? Are standard ride roughness-acceptability levels reasonable for locations with extensive thermal cracking? A reasonable, that is, practical reduction of these requirements would save considerable funds and materials.

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APPENDIX A: SECTION AND SUBSECTION LOCATIONS FOR FIELD INVENTORY

Inventory Location by Section and Subsection

R.L. McHattie, Updated 08/06/2012 (final) Note: MP references highway historic mileposting

Section	Subsection	Start MP	End MP	Center of Detailed Thermal Crack Evaluation Location MP	Start of Section (MP)	End of Section (MP)	Age of Section (years)	Latitude (North)			Longitude (West)		
								degrees	minutes	seconds	degrees	minutes	seconds
Richardson Highway, NR, 190000													
1	a	33	34	33.7	26.5	34	26	61	11	40.0	145	34	18.0
2	a	34	35	34.2	34	40	28	61	11	46.0	145	33	34.0
3	a	44	45	45.1	40	46	30	61	15	13.0	145	17	13.0
4	a	51	52	51.7	46	52	34	61	20	26.0	145	18	36.0
5	a	52	53	52.5	52	65	30	61	20	59.0	145	18	12.5
5	b	61	62	61.6				61	26	21.0	145	6	49.0
6	a	70	71	70.2	65	78	35	61	32	11.0	145	14	14.0
6	b	75	76	75.6				61	36	56.5	145	12	37.5
7	a	78.5	79.5	78	78	100	21	61	38	45.0	145	11	28.0
7	b	79	80	78.8				61	39	27.5	145	11	6.0
7	d	95	96	95.9				61	53	3.0	145	15	48.0
8	a	100	101	100.7	100	106	24	61	57	7.0	145	19	10.0
9	a	159	160	159.7	158	184.1	28	62	40	55.5	145	27	8.0
9	b	168.5	169.5	169.4				62	48	31.5	145	29	52.5
9	c	172	173	172.9				62	51	21.5	145	28	23.0
10	a	185.4	186	185.7	185.4	186	28	63	2	1.0	145	29	41.5
11	a	186	187	186.9	186	191	30	63	3	4.0	145	29	51.5
12	a	195	196	195.3	191	203	28	63	9	13.5	145	31	57.0
14	c	231	232	231.6	216.5	264	31	63	35	26.0	145	52	16.5
14	d	241	242	241.2				63	43	9.5	145	51	50.5
14	e	244.5	245.5	245.6				63	45	46.0	145	47	15.0
14	f	250	251	251				63	50	4.0	145	44	26.0
14	g	252.5	253.5	252.7				63	51	32.0	145	44	30.0
14	h	259	260	259.9				63	57	21.0	145	45	52.5
Alaska Highway, NR, 180000													
19	a	1314.5	1315.5	1315.1	1314	1333	29	63	20	17.5	143	1	7.0
19	b	1316	1317	1316.5				63	20	29.5	143	3	54.0
19	d	1331	1332	1331.6				63	22	18.0	143	32	13.0
20	a	1333	1334	1333.2	1333	1362	26	63	22	47.0	143	35	6.5
20	b	1337	1338	1338.8				63	23	15.5	143	45	25.5
20	c	1340	1341	1340.4				63	24	3.0	143	47	43.5
20	d	1344	1345	1344.3				63	27	12.5	143	50	23.5
20	e	1350	1351	1352.2				63	33	26.5	143	53	3.5
20	f	1359	1360	1359.5				63	38	25.5	144	1	50.5
21	a	1363	1364	1363.8	1363	1378	22	63	40	29.5	144	7	59.5
21	b	1366.5	1367.5	1367.1				63	41	17.0	144	13	59.0
21	c	1374.7	1375.7	1374.7				63	41	17.5	144	28	34.5

Inventory Location by Section and Subsection

R.L. McHattie, Updated 08/06/2012 (final)   Note: MP references highway historic mileposting

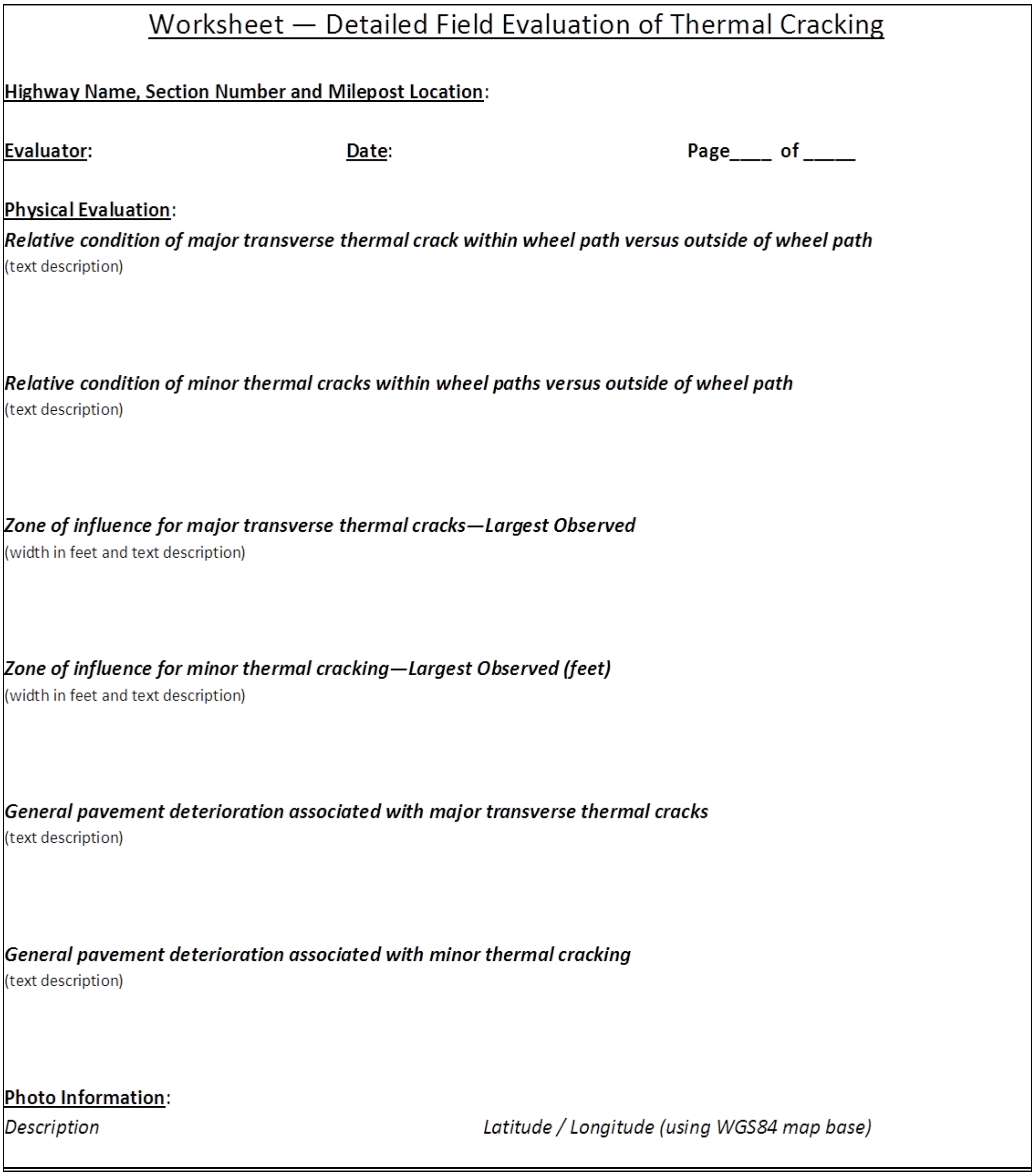
Section	Subsection	Start MP	End MP		Center of Detailed Thermal Crack Evaluation Location MP	Start of Section (MP)	End of Section (MP)	Age of Section (years)		Latitude (North)				Longitude (West)		
										degrees	minutes	seconds		degrees	minutes	seconds
Tok Cutoff, NR, 230000																
22	a	94	95		93.9	92	96.8	31		62	59	51.5		143	21	50.0
23	a	101	102		101.5	99	112	31		63	5	4.0		143	19	33.5
23	b	110.5	111.5		110.9					63	10	17.0		143	9	16.0
24	a	115	116		115.6	113	122	31		63	12	47.0		143	2	16.0
25	a	123	124		123.5	122	124.6	29		63	19	18.0		142	59	48.0
Glenn Highway, NR, 135000																
26	a	138.5	139.5		138.9	136	154	27		61	59	16.5		146	54	17.0
26	b	143	144		143.3					61	59	25.5		146	46	51.5
26	c	152	153		152.5					62	2	54.0		146	32	59.5
27	a	155	156		155.5	154	174	32		62	3	31.5		146	28	8.0
27	b	165	166		165.5					62	5	50.0		146	10	33.5
27	c	170	171		170.4					62	5	58.0		146	2	41.0
27	d	173	174		173.3					62	6	21.0		145	57	38.0
Steese Highway, NR, 152000																
29	a	8	9		8.5	Chena Hot Sp. Road	Fox Weigh Sta.	23		64	55	49.5		147	38	2.0
30	a	14	15		14.5	Fox Weigh Sta.	Cleary Parking Lot	21		64	59	16.5		147	32	7.5
31	a	26.5	27.5		27	Cleary Parking Lot	End of Pvmt.	21?		65	6	12.0		147	27	15.0
31	b	29	30		29.3					65	7	24.0		147	30	7.0
Elliott Highway, NR, 153000																
32	a	21	22		21.7	Chatanika River	17	31		65	9	48.5		147	56	46.5
33	a	26	27		26.9	20	27	31		65	10	50.0		148	3	11.5
Parks Highway , NR, 170000 (Parks--Northern Region)																
34	b	163	164		163.7	157	165	25		62	53	32.5		149	44	56.5
35	a	165	166		165.6	165	185	27		62	54	47.5		149	42	46.5
35	b	172	173		172.7					62	59	53.5		149	36	45.5
35	c	183	184		183.2					63	7	30.0		149	27	22.5
36	a	193	194		193.1	192	205	26		63	14	3.0		149	15	57.0
36	b	202	203		202.5					63	20	18.5		149	6	11.0
37	a	210	211		210.3	210	215	26		63	23	40.5		148	53	43.5
38	a	218	219		218.9	215	229	21		63	29	25.5		148	49	16.5
38	b	224	225		224.5					63	34	20.0		148	48	44.0
39	a	232	233		233.1	229	234	25		63	40	47.0		148	49	45.5
40	a	236	237		236.8	236	240	25		63	43	20.5		148	53	40.0
41	a	240	241		240.8	240	241.2	25		63	46	32.5		148	54	37.0
42	a	243	244		245.0	241.2	258	28		63	49	11.5		148	59	1.5
42	b	249	250		249.6					63	52	52.0		149	1	36.5

Inventory Location by Section and Subsection

R.L. McHattie, Updated 08/06/2012 (final)   Note: MP references highway historic mileposting

Section	Subsection	Start MP	End MP		Center of Detailed Thermal Crack Evaluation Location MP	Start of Section (MP)	End of Section (MP)	Age of Section (years)		Latitude (North)				Longitude (West)		
										degrees	minutes	seconds		degrees	minutes	seconds
Parks Highway , CR, 170000 (Parks--Central Region)																
44	a	84	85		89.5	83	104	27		62	2	43.0		150	3	38.0
44	d	102	103		102.2					62	10	2.5		150	6	57.5
45	a	104	105		104.7	104	132	22		62	10	51.0		150	11	25.0
45	b	114	115		114.6					62	18	49.0		150	13	57.5
45	c	121	122		121.2					62	24	25.5		150	15	28.5
45	d	126	128		126.2					62	28	43.5		150	16	26.0
45	e	131	132		131.5					62	32	59.5		150	14	21.5
46	a	135	136		135.2	132	157	25		62	36	0.5		150	14	11.0
46	b	141	142		141.8					62	41	17.0		150	14	32.0
46	c	147	148		147.4					62	44	55.5		150	7	32.5
46	d	150	151		150.8					62	46	35.0		150	2	26.0
46	e	153	154		153.7					62	48	14.5		149	58	17.0
Sterling Highway, CR, 110000																
47	a	56	57		56.4	56	58	28		60	29	9.0		150	2	57.0
48	a	77	78		78.0	74	79	30		60	31	34.5		150	38	48.5
49	a	79	80		79.3	79	82	20		60	31	37.5		150	40	55.5
50	a	122	123		122.1	117	123	23		60	10	39.0		151	26	18.5
51	a	125	126		125.8	124	127	23		60	8	30.0		151	30	24.5
52	a	129	130		129.1	128	161	23		60	6	27.5		151	33	48.5
52	b	134	135		134.3					60	3	16.0		151	39	4.5
52	c	138	139		138.7					60	0	29.5		151	42	46.5
52	d	152	153		152.9					59	49	37.0		151	49	6.0
52	e	154	155		154.7					59	48	19.0		151	50	11.0
52	f	160	161		160.2					59	45	10.0		151	46	11.5

APPENDIX B: FIELD SHEETS FOR EVALUATING THERMAL CRACKING



Worksheet — Detailed Field Evaluation of Thermal Cracking

Highway Name, Section Number and Milepost Location:

Evaluator: **Date**: **Page____ of _____**

Physical Evaluation:

Relative condition of major transverse thermal crack within wheel path versus outside of wheel path

(text description)

Relative condition of minor thermal cracks within wheel paths versus outside of wheel path

(text description)

Zone of influence for major transverse thermal cracks—Largest Observed

(width in feet and text description)

Zone of influence for minor thermal cracking—Largest Observed (feet)

(width in feet and text description)

General pavement deterioration associated with major transverse thermal cracks

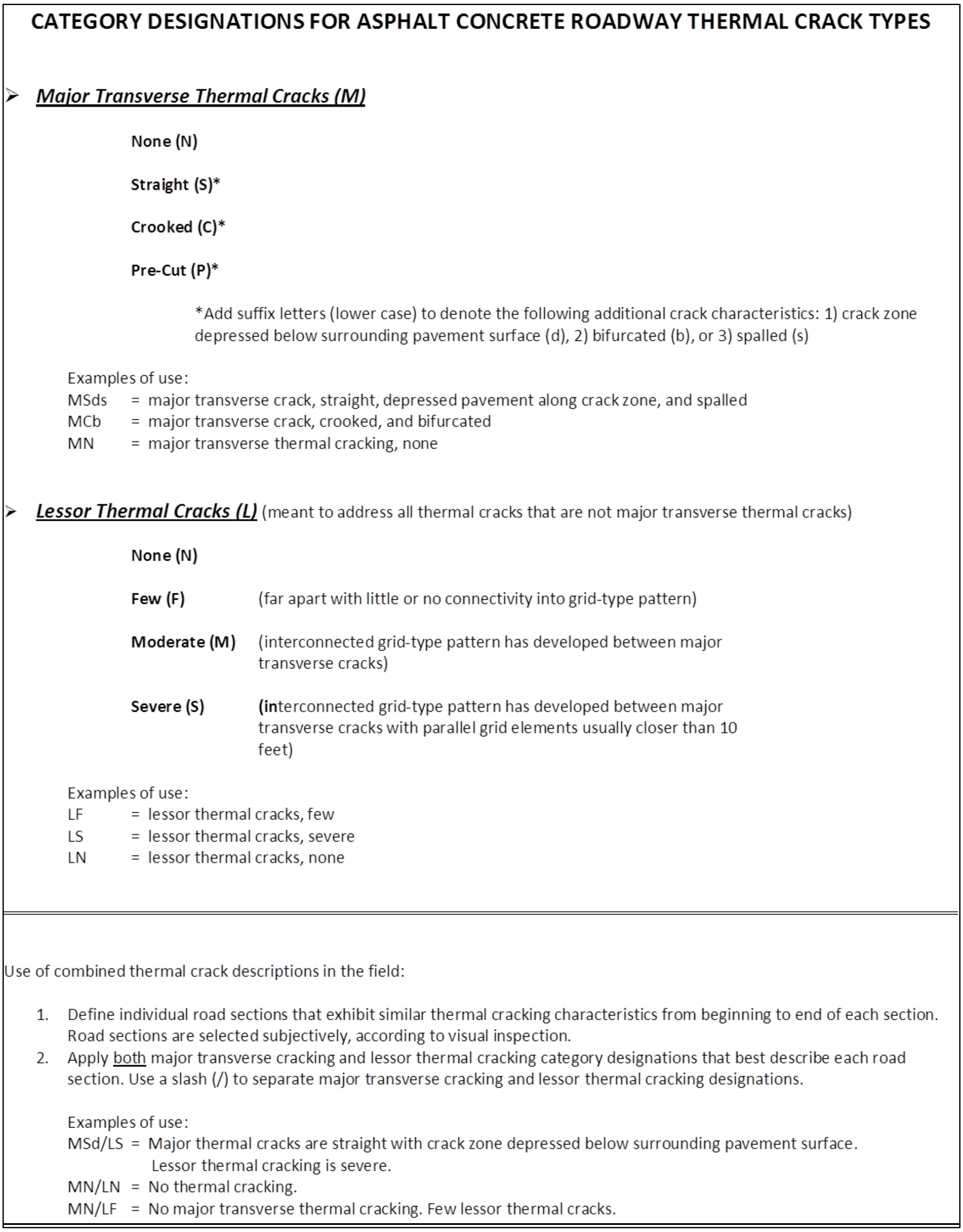
(text description)

General pavement deterioration associated with minor thermal cracking

(text description)

Photo Information:

Description *Latitude / Longitude (using WGS84 map base)*



CATEGORY DESIGNATIONS FOR ASPHALT CONCRETE ROADWAY THERMAL CRACK TYPES

- ***Major Transverse Thermal Cracks (M)***

None (N)

Straight (S)*

Crooked (C)*

Pre-Cut (P)*

*Add suffix letters (lower case) to denote the following additional crack characteristics: 1) crack zone depressed below surrounding pavement surface (d), 2) bifurcated (b), or 3) spalled (s)

Examples of use:
MSds = major transverse crack, straight, depressed pavement along crack zone, and spalled
MCb = major transverse crack, crooked, and bifurcated
MN = major transverse thermal cracking, none

- ***Lessor Thermal Cracks (L)*** (meant to address all thermal cracks that are not major transverse thermal cracks)

None (N)

Few (F) (far apart with little or no connectivity into grid-type pattern)

Moderate (M) (interconnected grid-type pattern has developed between major transverse cracks)

Severe (S) (**in**terconnected grid-type pattern has developed between major transverse cracks with parallel grid elements usually closer than 10 feet)

Examples of use:
LF = lessor thermal cracks, few
LS = lessor thermal cracks, severe
LN = lessor thermal cracks, none

Use of combined thermal crack descriptions in the field:

1. Define individual road sections that exhibit similar thermal cracking characteristics from beginning to end of each section. Road sections are selected subjectively, according to visual inspection.
2. Apply both major transverse cracking and lessor thermal cracking category designations that best describe each road section. Use a slash (/) to separate major transverse cracking and lessor thermal cracking designations.

Examples of use:
MSd/LS = Major thermal cracks are straight with crack zone depressed below surrounding pavement surface. Lessor thermal cracking is severe.
MN/LN = No thermal cracking.
MN/LF = No major transverse thermal cracking. Few lessor thermal cracks.

APPENDIX C: DESCRIPTIONS OF PAVEMENT SURVEY METHODS

Description of STCE Condition Inventory Method

The Special Thermal Crack Evaluation (STCE) does not share data format or purpose with the LTPP and PASER methods described below. LTPP and PASER methods are a comprehensive way of documenting the general condition of the paved surface—to provide sort of an overall pavement condition "snapshot" at a single point in time. The STCE method was developed to serve a specific purpose, and provides no similar snapshot of general pavement condition.

The STCE method collects data to help answer three very basic questions that are important to Alaska's pavement maintenance. To what degree does vehicle traffic affect thermal cracking? Is the interaction between thermal cracking and traffic a significant contributing factor in producing additional forms of damage in asphalt concrete (AC) pavements? Does the maintenance practice of sealing thermal cracks significantly improve general pavement performance? These questions are expanded with brief commentary:

- Does the condition of the thermal cracks themselves tend to deteriorate with time?
    - Theory says they should be affected by repeated vehicle loadings.
    - This question is addressed by comparing the condition of thermal cracks in wheel path versus non-wheel path areas on old pavements.
- Do thermal cracks negatively influence other aspects of pavement performance?
    - This case is assumed in all pavement preservation literature.
    - The question is addressed by examining the pavement for signs of fatigue cracking, potholing, excess rutting, or other signs of structural softening near thermal cracking on old pavements.
- Is sealing of thermal cracks necessary?
    - Standard practice says it is.
    - This question is addressed by comparing the condition of sealed cracks versus non-sealed cracks on old pavements.

Note the emphasis for examining old pavements. It is common sense that careful examination of thermal cracking and sealing on old pavements in a given area is the most reliable basis for proposing good maintenance strategies for that same area in the future. With this empirical approach in mind, only pavements thought to be 20 years old or older were evaluated.

The STCE method requires field personnel with experience recognizing/describing all aspects of pavement surface damage and maintenance techniques, that is, the same skill set required for performing LTPP and PASER evaluations. This will become clear as the method is further explained.

Data collection at each of the 91 field sites consisted of providing responses to the following:

1. What is the difference in the wheel path versus the non-wheel path condition of major transverse thermal cracks with the section?
    - No difference
    - Slightly different
    - Much different

2. What is the difference in the wheel path versus non-wheel path condition of lessor thermal cracks?
    - No difference
    - Slightly different
    - Much different

3. What is the maximum total width of the widest of major transverse cracks observed at the site (total width includes the damaged zone extending perpendicular to the edge of the crack)?
    - Less than 2 inches
    - 2 to 5 inches
    - More than 5 inches

4. What is the maximum total width of the widest of lessor thermal cracks observed at the site (total width includes the damaged zone extending perpendicular to the edge of the crack)?
    - Less than 1/8 inch
    - More than 1/8 inch

5. What is the extent of noticeable pavement deterioration due to major transverse thermal cracking?
    - None
    - Slightly noticeable
    - Very noticeable

6. What is the extent of noticeable pavement deterioration due to lessor thermal cracking?
   - None
   - Slightly noticeable
   - Very noticeable

7. Which thermal cracks received sealant?
   - No thermal cracks sealed (or sealant so old as to appear absent)
   - Major transverse thermal cracks sealed
   - Both types of thermal cracks sealed

8. What is the present condition of the existing sealant?
   - No sealant (or sealant so old as to appear absent)
   - Sealant failed and most or all sealed thermal cracks have opened (re-cracked)
   - Some sealant failure (some re-cracking)
   - Most sealant in good condition (limited or no re-cracking)

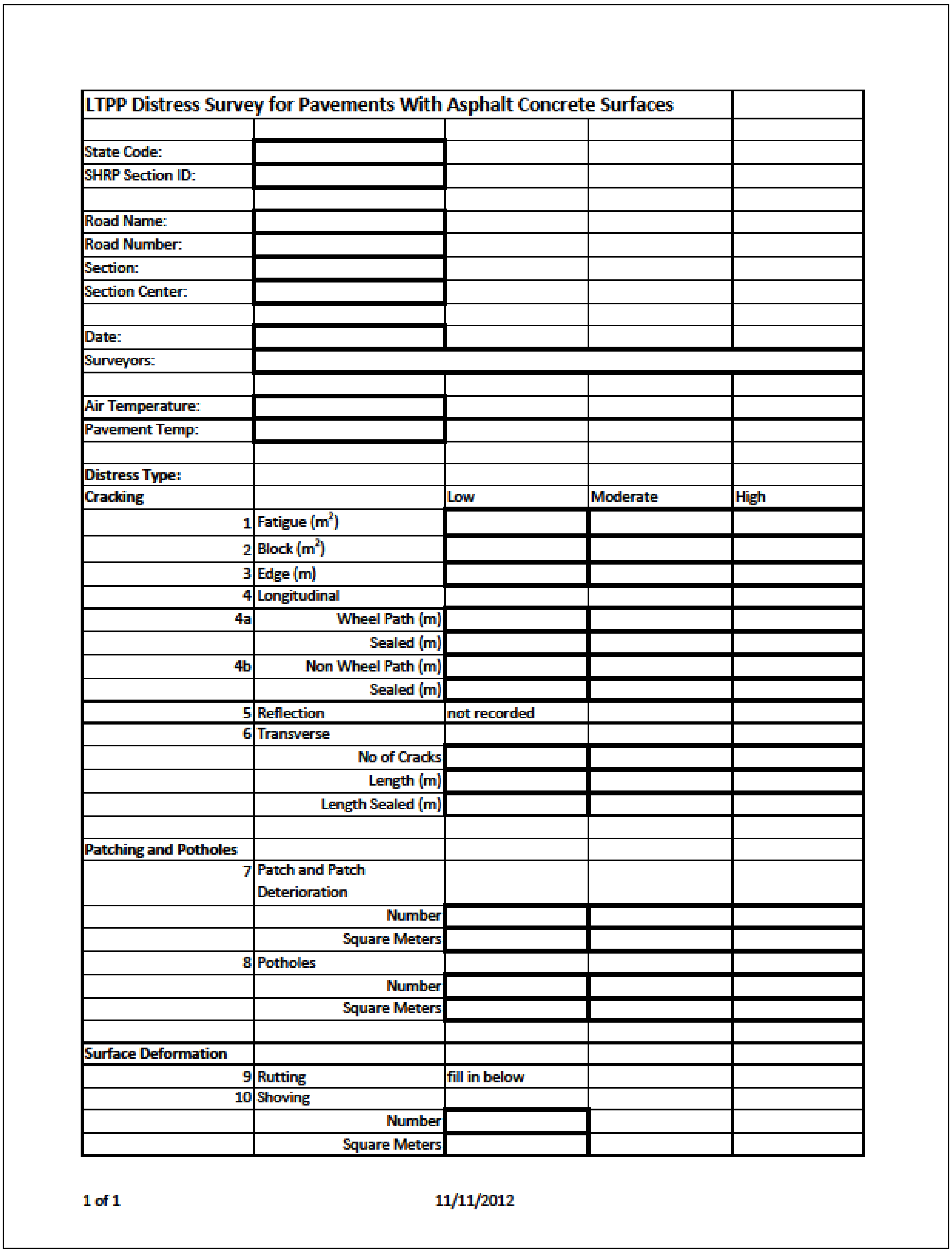
The field data sheets (two sheets) used for collecting STCE field data were specifically developed for this research, and examples are contained in Appendix B. The data sheets will not be further discussed here because, although useful, they were cumbersome. A single field data sheet would be devised for future studies of this type. It could be much improved based on this study’s field experience.

Each field site was photographed and visually examined to obtain a general impression of the long-term value of crack sealant practices at that location. Photo references and miscellaneous notes were added to the field data sheets to document this work.

Description of Modified LTPP Condition Inventory Method

The Long Term Pavement Performance Program (LTPP), which started in 1987, was conducted under the Strategic Highway Research Program (SHRP) (Miller and Bellinger 2003). Though the SHRP ended in 1992 as planned, the LTPP continues under the FHWA. To date 2,500 pavement sections have been evaluated for all of the United States as well as Puerto Rico and 10 Canadian Provinces (FHWA 2010). The data consisted of surface condition, climate, and traffic volumes and loads. The data were intended for use in providing information for designing longer lasting, improved roads.

Normally under a LTPP survey program, 500 feet are surveyed, and the data are kept in two forms. Mapping distresses in 50-foot increments is one form of the data and quantitative measured values is the other form. The LTPP manual also states that photographs depicting certain distress or showing levels of severity are also acceptable. For this particular study, it was decided by the team that 1/10 of a mile, that is, approximately 530 feet, would be the length for each evaluation. The milepost locations designated as the location of each of the 91 project field sites are used to define the center point for each 530-foot LTPP survey. This length was measured with a typical pavement measuring wheel, where paint marks displayed the center point and both ends. It was decided that photographs showing either typical distresses for the section or some unique severe distress would be one form of documentation. Filling out the typical quantitative measurements would be the other form of documentation. The blank forms for quantitative measurements shown in Appendix A of the LTPP manual were converted to an Excel spreadsheet version, as shown in Figure C.1 and Figure C.2. Evaluation of the distresses was conducted according to the LTPP manual and a brief synopsis is provided as follows.

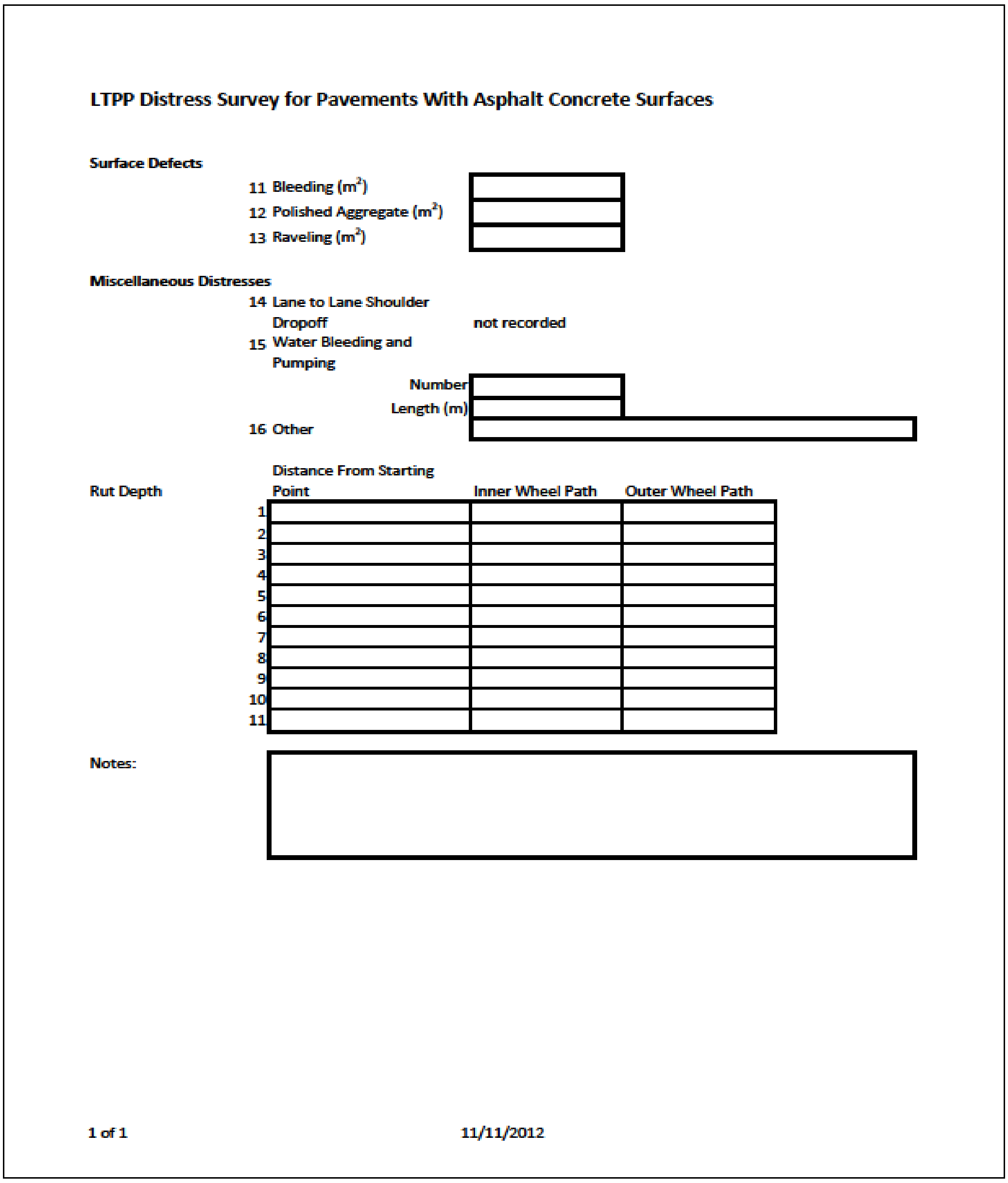


LTPP Distress Survey for Pavements With Asphalt Concrete Surfaces				
State Code:				
SHRP Section ID:				
Road Name:				
Road Number:				
Section:				
Section Center:				
Date:				
Surveyors:				
Air Temperature:				
Pavement Temp:				
Distress Type:				
Cracking		Low	Moderate	High
1	Fatigue (m^2)			
2	Block (m^2)			
3	Edge (m)			
4	Longitudinal			
4a	Wheel Path (m)			
	Sealed (m)			
4b	Non Wheel Path (m)			
	Sealed (m)			
5	Reflection	not recorded		
6	Transverse			
	No of Cracks			
	Length (m)			
	Length Sealed (m)			
Patching and Potholes				
7	Patch and Patch Deterioration			
	Number			
	Square Meters			
8	Potholes			
	Number			
	Square Meters			
Surface Deformation				
9	Rutting	fill in below		
10	Shoving			
	Number			
	Square Meters			

1 of 1

11/11/2012

Figure C.1 Printout of LTPP survey sheet page 1 used in this study



LTPP Distress Survey for Pavements With Asphalt Concrete Surfaces

Surface Defects

11 Bleeding (m^2)

12 Polished Aggregate (m^2)

13 Raveling (m^2)

Miscellaneous Distresses

14 Lane to Lane Shoulder Dropoff — not recorded

15 Water Bleeding and Pumping

Number

Length (m)

16 Other

Rut Depth

	Distance From Starting Point	Inner Wheel Path	Outer Wheel Path
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

Notes:

1 of 1 11/11/2012

Figure C.2 Printout of LTPP survey sheet page 2 used in this study

The FHWA manual “Distress Identification Manual for the Long Term Pavement Performance Program” describes how to identify surface distresses in AC pavements in five parts, A through E.

A. Cracking
B. Patching and Potholes
C. Surface Deformation
D. Surface Defects
E. Miscellaneous Defects

A. Cracking

Cracks types that are to be evaluated and recorded for a section are included in the following list.

1. Fatigue
2. Block
3. Edge
4. Longitudinal
    a. Wheel Path
    b. Non-wheel path
5. Reflection
6. Transverse

1. Fatigue Cracking

Fatigue cracking occurs where there is repeated traffic loading. It can be described as many interconnected cracks that can resemble and is sometimes referred to as chicken wire or alligator cracking with individual crack lengths less than a foot. When evaluating fatigue cracks, the width or opening of the crack and associated severity along with amount in terms of square footage or square meters are quantifying measurements. The amount of affected area is recorded as low, medium, and/or high. The same section of evaluated roadway can have more than one level of severity.

- Low severity means the cracks are tight with no pumping or secondary deterioration or spalling and little interconnection.
- Medium severity shows signs of crack deterioration or spalling at the initial stages. Cracks are becoming more interconnected.
- High severity is when spalling is strongly evident and loose pieces are removed as traffic passes over the area. Pumping is obvious.

2. Block Cracking

Block cracking is described as cracking that divides the pavement into blocks from approximately a half a foot per side to 30 feet per side. The divisions are much greater than those for fatigue cracking.

- Low severity is large area of contiguous blocks with tight cracks and no secondary deterioration.

- Medium severity displays as blocks of closer spacing or smaller area than low severity and shows signs of spalling.
- High severity describes blocks that do not reach the size of fatigue cracking but have advanced to the point of many divisions in a defined area and spalling is very evident.

3. Edge Cracking

Edge cracking occurs on roads without paved shoulders. This cracking occurs within 1.5 feet from the edge of the pavement. It often displays as crescent shapes but includes longitudinal cracks as well.

  - Low severity cracks are tight with no loss or breakup of asphalt material.
  - Moderate severity cracks show up to 10% loss of material and/or spalling along the total length of the edge crack.
  - High severity cracks display more than 10% of the length of the edge crack with loss of material and/or spalling.

4. Longitudinal Cracks

Longitudinal cracks run in a direction parallel to the direction of travel. Under a LTPP type of evaluation, they are denoted as being either wheel path or non-wheel path types. The lengths of cracks that remain successfully sealed are recorded on a separate line as well as the total length of longitudinal cracks.

- Low severity cracks are tight, 1/4 inch or less, with no spalling or crack edge deterioration. Cracking can also be described as a sealed crack where the opening cannot be determined.
- Medium severity cracks are open from 1/4 inch to 3/4 inch with little signs of secondary deterioration and little adjacent cracking.
- High severity cracks are open more than 3/4 inch with spalling along the crack edges and much adjacent cracking as well.

5. Reflection Cracking

There is very little Portland cement concrete pavement used in Alaska and therefore even less area where concrete pavement sections have been overlaid with AC in Alaska. Exceptions could be at some bridges. There were no such sections for this study.

6. Transverse Cracking

Transverse cracks run in a general perpendicular direction to that of traffic flow. The quantity of transverse cracks is recorded as well as the total length in a given section at a certain level of severity. More than one severity level can exist in a given section, but it is common to average the severity levels unless there is a clear distinction between cracks of different severities. The total length of cracks that remain successfully sealed are recorded on a separate line as well as the total length of transverse cracks.

- Low severity cracks are tight, 1/4 inch or less, with no spalling or deterioration along the crack edge. Cracking can also be described as a sealed crack where the opening cannot be determined.
- Medium severity cracks are open from 1/4 inch to 3/4 inch with little signs of secondary deterioration and little adjacent cracking.
- High severity cracks are open more than 3/4 inch with spalling along the crack edge and much adjacent cracking as well.

B. Patching and Potholes

Patches

The LTPP manual (Miller and Bellinger 1999) defines patching as a portion of pavement surface that has been removed and replaced or has had additional material applied to the pavement after original construction. There are basically two ways of documenting pavement patches. One is the number of patches within an evaluated section at a certain level of severity. The other is the amount of surface area of patch at a particular level of severity. There can be more than one level of severity in a given section.

Roads maintained by ADOT&PF often exhibit patches several hundred feet long.

- Low severity is displayed as with a new patch; that is, no secondary distress such as rutting, raveling, cracking, pumping has occurred.
- Medium severity shows moderate signs of secondary deterioration such as rutting, raveling, cracking, and pumping.
- High severity contains rutting, raveling, cracking, spalling of the edges, or any combination of these that can be described as severe for any one of the distress types.

Potholes

Potholes are defined as bowl-shaped holes in the pavement surface of various depths.

- Low severity for potholes is less than 1 inch deep.
- Medium severity has a depth between 1inch and 2 inches.
- High severity is a depth greater than 2 inches.

C. Surface Deformations – Rutting and Shoving

Rutting

A rut is defined as a wheel path longitudinal depression in an asphalt pavement surface. The LTPP manual does not define severity levels for rutting. Direct measurement is required and is read at maximum rut depth in a 50-foot-long section using a straight edge one yard in length. For this study, more of an average rut depth was recorded. This reading was also checked with data obtained from ADOT&PF's Office of Pavement Management and Preservation.

Shoving

Shoving is defined as a longitudinal displacement of a localized area of pavement surface. Shoving is sometimes recognized as semi-circular small wave or bump-like surfaces that appear to have had plastic deformation or occurred when the pavement surface was at an elevated temperature. No examples of shoving were seen in any of the 91 sections surveyed.

D. Surface Defects – Bleeding, Polished Aggregate, Raveling

Bleeding

Bleeding is defined as excess bituminous binder occurring on the pavement surface, and usually found in the wheel path. LTPP does not require bleeding to be documented in terms of severity, but for the purpose of this study, it was. The LTPP manual does describe severity levels of a sort, because it states that bleeding can be as light as a just-noticeable discoloration, to presence of enough excess binder to cause loss of aggregate surface texture, to an extreme level of excess binder that produces a shiny glass-like surface that is tacky (on a warm day) to touch. Bleeding is recorded as the amount of surface area affected.

- For this study, low severity is a discoloration.
- Medium severity is loss of surface texture from excess binder.
- High severity is a level of excess binder so that it appears as a shiny glass-like surface that is tacky to the touch.

Polished Aggregate

Polished aggregate is defined as surface binder worn away to expose coarse aggregate more than when originally placed. LTPP does not specify severity levels of polished aggregate. For this study, it was occasionally found that different areas of a section being evaluated showed different degrees of polished aggregate. Sometimes wheel paths on a bend might show more polishing than other areas. Polished aggregate is recorded in terms of surface area affected.

- For this study, low severity is when coarse aggregate can be seen in an area more so than an adjacent area but does not appear to affect friction.
- Medium severity displays more coarse-aggregate surface than at low severity.
- High severity is when much binder has been worn away and coarse aggregate shows much surface in a manner where the surface exposed is smooth in appearance.

Raveling

Raveling is defined as the wearing away of the pavement surface form the loss of fine and/or coarse aggregate as well as binder. It results in a rough surface or more rough than when originally placed. The LTPP manual does not define severity levels in terms of low, medium, or high, but does describe that raveling can be loss of fines, to loss of fines and some coarse aggregate, and finally loss of fine and coarse aggregate.

- For this study, low severity is loss of fine aggregate.
- Medium severity is loss of fine and some coarse aggregate.
- High severity is loss of fine and coarse aggregate.

There was at least some raveling on most road sections evaluated for this study.

E. Miscellaneous Defects – Lane to Shoulder Drop-off, Water Bleeding and Pumping

Lane to Shoulder Drop-off

Shoulder drop-off is defined as the difference in elevation between the traveled surface and the outside shoulder. It is also stated that it typically occurs from a difference in asphalt layering from the traveled surface to the shoulder. LTPP does not require that different severity levels be discriminated. Direct measurements should be made and recorded.

For this particular study, shoulder drop-off was not recorded. Shoulders on ADOT&PF maintained highways vary greatly, sometimes almost constantly, as the roads cross a wide variety of terrain. Shoulder conditions in areas of poor foundation very often exhibit the accumulated effects of many, many cycles of construction, reconstruction, and maintenance. Some shoulders are up to 6ft wide, are paved, and are in great condition. Some shoulders are gravel, of little width, and drop off steeply due to narrowing geographical features such as rock outcroppings or shoulder/side-slope failures caused by foundation instabilities. Many sections evaluated experience low ADTs, such as 500 or less. Shoulder drop-offs were not recorded, although other distress types that occurred on shoulders were recorded such as cracking, raveling, etc.

Water Pumping and Bleeding

Water pumping and bleeding is defined as seeping or ejection of water from beneath the pavement surface through cracks. Besides direct observation of water exiting cracks due to recent rains or springtime thaw, evidence of this distress is the fine material left on the roadway surface. Fines can migrate to the pavement surface with the upward flow of water and can be deposited along cracks as the water evaporates. LTPP does not require that severity levels be recorded. The number of occurrences and the length of area affected are both recorded.

For this study, at the time of evaluation it was either sunny and dry or raining at a constant rate. No water pumping or bleeding was witnessed for any of the sections observed.

Description of PASER Condition Inventory Method

PASER for Asphalt Roads (Walker 2002) is a road surface condition rating system that was produced and is maintained by the Wisconsin Transportation Information Center, which is a department at the University of Wisconsin-Extension program. Various road surface distresses are discussed along with possible treatments that could revitalize the condition providing improved serviceability, which will extend the life of the treated road. Currently the rating system provides data used in a computerized pavement management system called PASERWARE at the Wisconsin Department of Transportation.

The PASER rating is a methodology whereby the observer takes into account the severity level of various road conditions and combines them into a single number as a result. The result ranges from 10 to 1, with 10 being a newly constructed roadway and 1 being a totally failed roadway. This differs from a more nationally recognized rating system such as the LTPP road condition survey. The LTPP survey has the observer quantifying conditions more objectively. For instance, various types of cracks are either measured in length or given as a percentage of the surface area of the section being evaluated. The same measurements are recorded for raveling, bleeding, and polishing. The depth of ruts are measured and recorded over multiple equal lengths. Even the severity of conditions should be measured before they are recorded as low, medium, or severe. PASER is quick to perform with less quantification as compared with the LTPP survey.

In order to evaluate and document the various road sections for pavement preservation treatments in Alaska, an Excel spreadsheet was created and modeled after the PASER manual for asphalt roads (Walker 2002). The PASER rating system provides a quick, visual method for rating road surface condition. It is a simplified method to inventory roads and streets, and periodically evaluate roads and streets, which then can be used to set priorities in a pavement management system for Alaska.

Surface defects, surface deformations, cracks, and patches and potholes comprise the four major categories of distresses. Raveling, flushing, and polishing are surface defects. Rutting, rippling and shoveling, settling, and frost heaves make up surface deformations. Transverse, longitudinal, block, alligator, reflection, and slippage name the various types of cracks. Environment, aging, traffic loading, and quality of construction methods and materials cause deterioration of roads. Understanding these causes lead to pragmatic and cost-effective solutions.

The PASER manual suggests that when evaluating a road section, first look at the general condition of the road surface. Next, think about what treatments would correct the distresses or bring it back to an acceptable level of serviceability. Finally, compare what is being looked at to what pictures and descriptions are in the PASER asphalt manual. The PASER rating system is described in Table C.1. The manual also notes that not all distresses described for a particular rating need to actually exist on the pavement section being evaluated in order to have a particular rating.

PASER is intended as a quick overall survey of any road section where the categories of severity described for each distress type are: n – none, l – low, m – medium, and s – severe. Categories are meant to be assigned by quick visual assessment (a “windshield” survey). The following definitions were used as a rough guide to assist with assigning a severity category to cracking during this study:
n – none = no cracking,
l – low = 1/4 inch or less,
m – medium = 1/4 inch to 1/2 inch and possibly up to 3/4 inch if the edges are in good condition
s – severe = more than 1/2 if there is much edge deterioration and secondary cracking, or more than 3/4 inch if the edges are in good condition

Crack widths were not meant to be measured directly; this served as a guide for estimating severity category when more definition is needed to make a decision about an overall rating.

Table C.1 PASER rating system for asphalt concrete roads (Walker 2002)

Surface Rating	Visible Distress	General Condition/ Treatment Measure
10	None	New condition.
9	None	Recent overlay, like new.
8	No longitudinal cracks except reflection of paving joints. Occasional widely spaced transverse cracks, 40 ft. All cracks sealed or tight, opening 1/4″ or less.	Recent sealcoat or new cold mix. Little or no maintenance required.

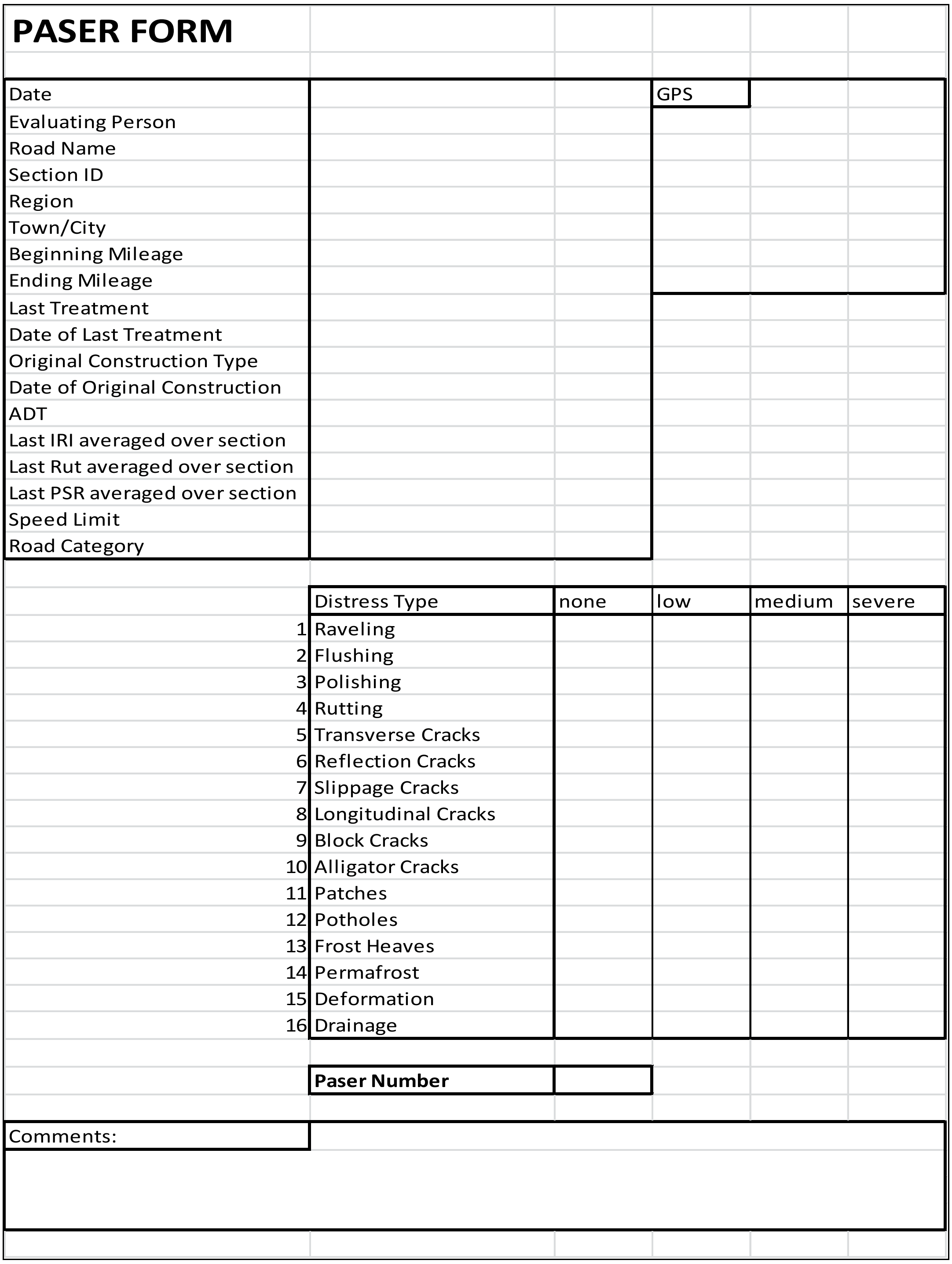
Surface Rating	Visible Distress	General Condition/ Treatment Measure
7	Very slight or no raveling showing some traffic wear. Tight longitudinal cracks due to reflection of paving joints. Tight transverse cracks spaced 10 ft with slight crack spalling. None to a few patches in excellent condition.	First signs of aging. Maintain with routine crack filling.
6	Slight raveling and traffic wear. Longitudinal cracks opened 1/4″ – 1/2″ with some spaced less than 10 ft. First sign of block cracking. Slight to Moderate flushing and polishing. Occasional patching in good condition.	Shows signs of aging. Sound structural condition. Could extend life with a sealcoat.
5	Moderate to severe raveling, loss of fine and course aggregate. Longitudinal and transverse cracks opened to 1/2″ with slight crack spalling and secondary cracks. First sign of longitudinal cracks near pavement edge. Block cracking on 50% of the surface. Extensive to severe flushing or polishing. Some patching or edge wedging in good condition.	Surface aging. Sound structural condition. Needs sealcoat or thin non-structural overlay of 2″ or less.
4	Severe surface raveling. Multiple longitudinal and Transverse cracking with slight raveling. Longitudinal cracking in wheel path. Block cracking over 50% of the surface. Patching in fair condition. Slight rutting or distortions, 1/2″ deep or less.	Significant aging and first signs of need for strengthening. Would benefit from an overlay of 2″ or more.
3	Closely spaced longitudinal and transverse cracking with spalling and crack erosion. Severe block cracking. Some alligator cracking, 25% of surface or less. Patches in fair to poor condition. Moderate rutting or distortion at 1″ to 2″ deep. Occasional potholes.	Needs patching and repair prior to major overlay. Milling and removal of deterioration extends the life of the overlay.

Surface Rating	Visible Distress	General Condition/ Treatment Measure
2	Alligator cracking over 25% of the surface. Severe rutting and distortions over 2″ deep. Extensive patching in poor condition. Potholes.	Severe deterioration. Needs reconstruction with extensive base repair. Pulverization of old pavement is effective.
1	Severe distress with extensive loss of surface integrity.	Failed and needs total reconstruction.

Figure C.3 (the PASER field data form) depicts the adaptation of the PASER rating system into an electronic spreadsheet with a few added parameters important to Alaska and other cold regions. The spreadsheet is constructed with check-off columns so that the observer can quickly rate distresses. The other added distresses are frost heave, permafrost, deformation, and drainage. These distress types are of great importance in a cold-region environment.

Figure C.3 requires other identification and “housekeeping” data. These include date, person performing the survey, ADOT&PF region – Northern, Central, or Southeast – road name, town/city, beginning mile, end mile, last treatment, date of last treatment, original construction type, date of original construction, ADT, last IRI averaged over section, last rut averaged over section, last PSR averaged over section, speed limit, and road category. If these data are recorded onto the sheets before going to the site, it will give the observer an idea of the conditions to be expected. There is a placeholder for GPS data points. Most of this data are obtainable through the PMS or at the site.

A space was provided at the bottom of the sheet to add comments, with the intention that some particularly row ratings might need further explanation or a potential treatment could be recommended. These comments will also help to explain the rating given.



PASER FORM

Date		GPS
Evaluating Person		
Road Name		
Section ID		
Region		
Town/City		
Beginning Mileage		
Ending Mileage		
Last Treatment		
Date of Last Treatment		
Original Construction Type		
Date of Original Construction		
ADT		
Last IRI averaged over section		
Last Rut averaged over section		
Last PSR averaged over section		
Speed Limit		
Road Category		

	Distress Type	none	low	medium	severe
1	Raveling				
2	Flushing				
3	Polishing				
4	Rutting				
5	Transverse Cracks				
6	Reflection Cracks				
7	Slippage Cracks				
8	Longitudinal Cracks				
9	Block Cracks				
10	Alligator Cracks				
11	Patches				
12	Potholes				
13	Frost Heaves				
14	Permafrost				
15	Deformation				
16	Drainage				

Paser Number

Comments:

Figure C.3 PASER form used in this study

APPENDIX D: DESCRIPTION OF DATA STORAGE AND ANALYSIS SPREADSHEET

SPREADSHEET — USED FOR DATA PRESENTATION AND ANALYSIS

Except for photographs, all data obtained from evaluations based on the standard PASER and LTPP pavement condition rating systems as well as data from the special STCE method developed for this study are documented in a single MS Excel file. In addition to field data, the Excel file contains supporting information pertaining to the field sites and the informative results from rudimentary analyses of the field data. Each person conducting standard field evaluations recorded data using both PASER and LTPP forms. The special thermal cracking evaluation was done using STCE forms developed for this study. Field personnel collected photos as a way of supplementing data entered on the forms. As a special supplement to the STCE data collection, many photos (1,766) were collected to verify thermal cracking conditions at the time of the survey.

The Excel workbook consists of eight worksheets:

- Master
- PASER
- LTPP
- Section ID & Location
- Totals
- Age Statistics
- Transverse Crack Component
- Weather Statistics

Pertinent data from the LTPP, PASER, and STCE ratings are presented in a single worksheet labeled “Master.” PASER and LTPP data are actually copied to the Main worksheet from individual PASER and LTPP worksheets, which contain additional subsidiary but useful information. These individual worksheets helped simplify the PASER and LTPP data input processes. The more simple STCE data were entered directly onto the Master worksheet. Information identification and location of all field sites is contained in Section ID & Location worksheet. Age data were obtained prior to actual field site evaluations from ADOT&PF. Weather data were obtained from a page on ADOT&PF’s website where extreme air and pavement temperatures can be found.

In all, 91 sections were evaluated for the Richardson, Alaska, Tok Cutoff, Glenn, Steese, Elliott, Parks Northern Region, Parks Central Region, and Sterling Highways. Totals were tabulated for the distresses mentioned in the PASER and LTPP descriptions. The number of sections evaluated for each highway is shown in Table D.1.

Table D.1 ADOT&PF highways and number of sections evaluated for each highway

No	Highway	No of Sections
1	Richardson	24
2	Alaska	12
3	Tok Cutoff	5
4	Glenn	7
5	Steese	4
6	Elliott	2
7	Parks NR	14
8	Parks CR	12
9	Sterling	11
	Total	91

It was intended that field evaluations be performed only on older sections of roads. According to the best available records, ages of the sections varied from 20 years old for a section on the Sterling to 35 years old for two sections on the Richardson. The average age from each highway ranges from 21.5 on the Steese to 30.6 on the Tok Cutoff. During the evaluation, some sections appeared to be newer than their recorded age.

Before getting into details of the worksheet data contained in the spreadsheet, it is worthwhile to point out that only one rating feature is obviously shared between the three methods of pavement evaluation (LTPP, PASER, and STCE) and pertinent to this research. Although two types of thermal cracking are recognized and studied during this project, only transverse cracks, that is, major transverse thermal cracks, are explicitly recognized as a product of thermal damage by all three methods.

The 8 sheets of the Excel workbook are explained in detail in the following subsection.

MASTER WORKSHEET

The Master sheet in the Excel workbook lists the majority of data from the PASER evaluation, the LTPP evaluation, and a non-parametric rank of 8 categories related to thermal cracking observed using the STCE method. Data are included for all 91 sections with each section depicting a row in the sheet. There are no totals or any sort of descriptive statistics. Information from the PASER and LTPP sheets is automatically loaded into the Master sheet. Only the information related to actual rating of distresses is what is loaded from the PASER sheet. The same goes for the LTPP information. A sample of data in the Master sheet is shown in Figure D.1.

Section ID		**PASER**
		Transverse
1	a	m
2	a	m
3	a	m
4	a	m
5	a	l
5	b	m

LTPP		
Transverse Qty.		
Low	**Moderate**	**High**
100	16	0
87	8	0
0	6	0
0	15	0
29	6	0
0	6	0

STCE
Present Condition of Sealant **1 = old and/or re-cracked, 2 = some re-cracking, 3 = mostly good condition, 4 = no sealant**
3
3
1
2
1
1

Figure D.1 PASER, LTPP, and STCE data sample from the Master sheet

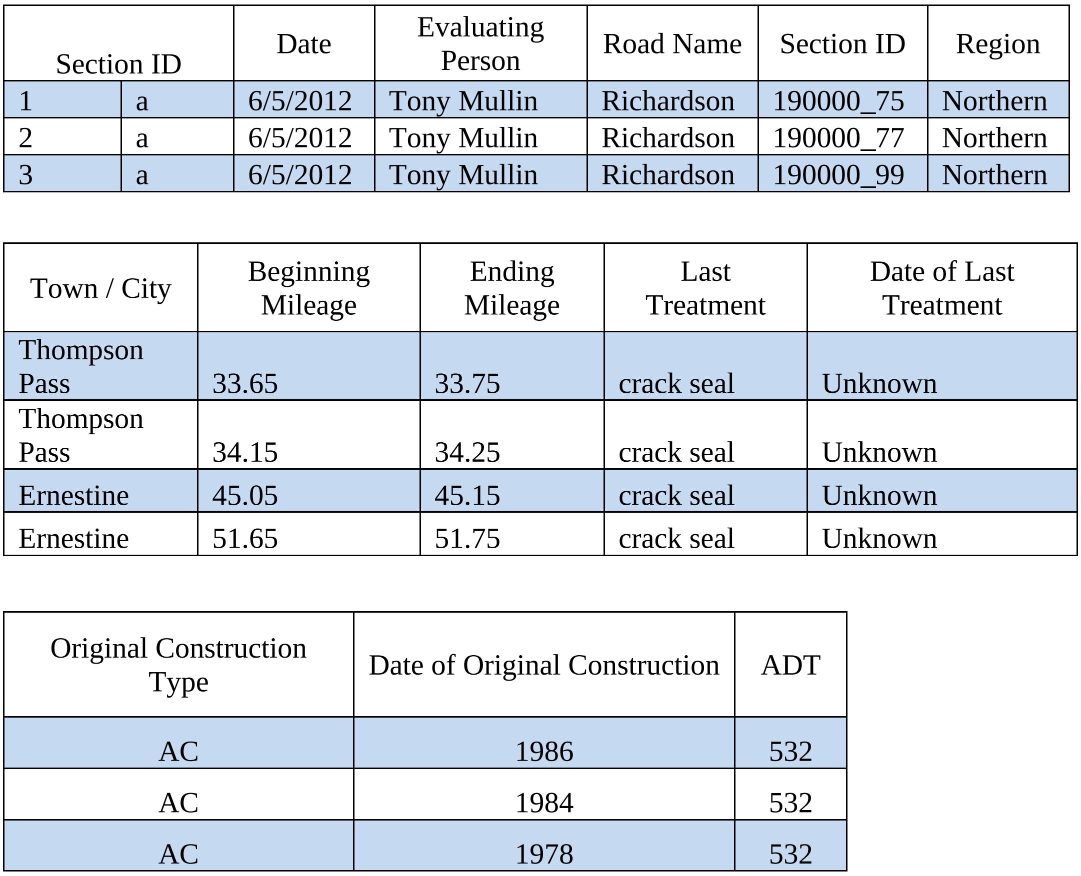
Note that each row of data shown in Figure D.1 represents a single one of the 91 field sites, and each row contains all data pertaining to that single site. Only small portions of six rows (representing 6 sites) can be shown in this figure. These rows would extend far across the spreadsheet.

PASER WORKSHEET

The PASER worksheet contains all field data originally recorded on a PASER form for each field site. Every row of the worksheet contains data for a single field site. The first 14 fields (left-most) of each worksheet row contain general information about site data. While these first fields do not contain distress data per se, the last 5 of the 14 listed items would certainly represent variables that could influence type and degree of distress. The first 14 fields in the first section are listed in Table D.2, and an example of actual data for these fields is shown in Figure D.2.

Table D.2 Non-distress descriptor fields for the PASER evaluation

No.	Description
1	Project Section ID
2	Date of Evaluation
3	Evaluating Person
4	Road Name
5	ADOT&PF Section ID
6	Region
7	Town / City
8	Beginning Mileage
9	End Mileage
10	Last Treatment
11	Date of Last Treatment
12	Original Construction Type
13	Date of Original Construction
14	ADT



Section ID		Date	Evaluating Person	Road Name	Section ID	Region
1	a	6/5/2012	Tony Mullin	Richardson	190000_75	Northern
2	a	6/5/2012	Tony Mullin	Richardson	190000_77	Northern
3	a	6/5/2012	Tony Mullin	Richardson	190000_99	Northern

Town / City	Beginning Mileage	Ending Mileage	Last Treatment	Date of Last Treatment
Thompson Pass	33.65	33.75	crack seal	Unknown
Thompson Pass	34.15	34.25	crack seal	Unknown
Ernestine	45.05	45.15	crack seal	Unknown
Ernestine	51.65	51.75	crack seal	Unknown

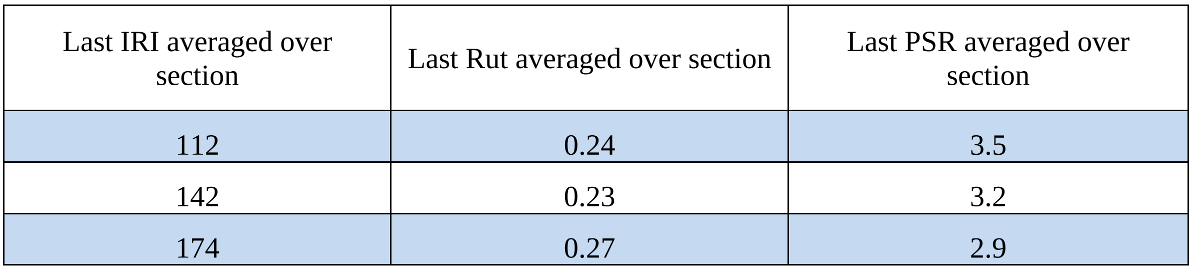
Original Construction Type	Date of Original Construction	ADT
AC	1986	532
AC	1984	532
AC	1978	532

Figure D.2 Actual entries in the PASER Excel spreadsheet's first 14 fields

The next three fields come from ADOT&PF Pavement Management System data that are related to road distress. It is automatically collected from a properly equipped vehicle that records laser readings, which are then translated into International Roughness Index (IRI) ratings and rut measurements. From this, a Present Serviceability Rating (PSR) is calculated. The IRI, rut, and PSR are charted so that a trend can be assessed, shown in Table D.3 and Figure D.3.

Table D.3 ADOT&PF automatically collected / calculated data

No	Description
15	IRI – automatically collected through Dynatest
16	Rut – automatically collected through Dynatest
17	PSR – calculated form IRI and rut



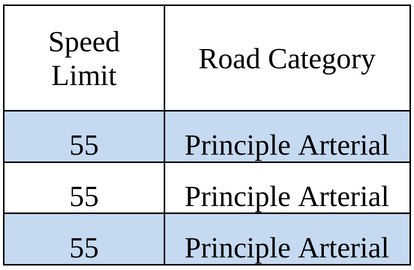
Last IRI averaged over section	Last Rut averaged over section	Last PSR averaged over section
112	0.24	3.5
142	0.23	3.2
174	0.27	2.9

Figure D.3 ADOT&PF distress data collected and calculated by Dynatest Engineering Consultants

The next two fields are the speed limit and road category, shown in Table D.4 and Figure D.4.

Table D.4 Fields 18 and 19, speed limit and road category

No	Description
18	Speed Limit
19	Road Category



Speed Limit	Road Category
55	Principle Arterial
55	Principle Arterial
55	Principle Arterial

Figure D.4 PASER fields 18 and 19

The next 13 fields, that is, 20–32, are ratings for various pavement surface distresses. The ratings are n – none, l – low, m – medium, and s – severe. A description for the meaning of each level for each distress can be found in Appendix C in a subsection describing the PASER method. Table D.5 and Figure D.5 list samples of these entries.

Table D.5 Pavement distress fields

No	Description
20	Rutting
21	Transverse Cracks
22	Reflection Cracks
23	Slippage Cracks
24	Longitudinal Cracks
25	Block Cracks
26	Alligator Cracks
27	Patches
28	Potholes
29	Frost Heaves
30	Permafrost
31	Deformation
32	Drainage

Rutting	Transverse Cracks	Reflection Cracks	Slippage Cracks	Longitudinal Cracks
l	m	n	n	m
l	m	n	n	m
n	m	n	n	m
n	m	n	n	m

Block Cracks	Alligator Cracks	Patches	Potholes
l	m	l	l
n	l	n	n
s	n	n	n

Frost Heaves	Permafrost	Deformation	Drainage
n	n	n	n
n	n	n	n
n	n	n	n

Figure D.5 Field ratings for pavement surface distresses with ratings of n—none, 1—low, m—medium, and s--severe

The last field of the PASER rating (field 33) contains a number from 1 to 10, with 10 being a newly constructed road and 1 being in need of total reconstruction. A more detailed description is found in Appendix C in a subsection describing the PASER method. Figure D.6 shows sample entries for three field sites. The fields between 1 and 33 were omitted to show only the field site numbers and PASER's general condition number.

Section ID		Rating
1	a	6
2	a	7
3	a	6

Figure D.6 Overall PASER ratings for the first three field sites

LTPP WORKSHEET

The LTPP worksheet contains all field data originally recorded on a LTPP form for each field site. Every row of the worksheet contains data for a single field site. Certain fields of data are automatically transferred from the LTPP worksheet to the Main worksheet that contains data from all three evaluation methods, so that analysis, such as descriptive statistics, can more easily be performed. The LTPP worksheet contains two data fields that are not transferred to the Main worksheet.

The first three fields are the project section ID, date of evaluation, and evaluator's name, shown in Figure D.7.

Section ID		Date	Surveyor
1	a	6/5/2012	Tony Mullin
2	a	6/5/2012	Tony Mullin
3	a	6/5/2012	Tony Mullin

Figure D.7 First three fields of the LTPP worksheet

The next three categories are for Fatigue, Block, and Edge cracking. All three are measured in terms of square footage of the surface area affected in the section of pavement being evaluated. As shown in Figure D.8, these three distress types are further delineated in terms of low, medium, and high levels of severity, as described in an Appendix C subsection describing the LTPP method.

Fatigue (ft sq)			Block (ft sq)			Edge (ft)		
Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
0	6400	0	0	0	0	514	0	0
70	0	0	0	0	0	239	0	0
0	0	0	0	0	0	0	0	0

Figure D.8 Fatigue, Block, and Edge cracking as entered in the LTPP worksheet

The next two fields are for Longitudinal Wheel Path crack data: one for the length of crack whether it is sealed or not, the other for just sealed cracks of this category. Both are divided into low, medium, and high severity as well, and are shown in Figure D.9. Severity levels are described in Appendix C for the LTPP method.

Longitudinal Wheel Path (ft)			Longitudinal Wheel Path Sealed (ft)		
Low	Moderate	High	Low	Moderate	High
795	0	0	174	0	0
533	0	0	251	0	0
1590	0	0	1000	0	0

Figure D.9 Excel LTPP worksheet fields for Longitudinal Wheel Path cracking

The next two categories are for Longitudinal Non-Wheel Path Cracks: one for the length of crack whether it is sealed or not, and the other for just sealed cracks of this category. Both are divided into low, medium, and high severity as well, shown in Figure D.10. The severity levels are described in Appendix C for the LTPP method.

Longitudinal Non-Wheel Path (ft)			Longitudinal Non-Wheel Path Sealed (ft)		
Low	Moderate	High	Low	Moderate	High
530	0	0	530	0	0
530	0	0	260	0	0
530	0	0	380	0	0

Figure D.10 Excel LTPP worksheet fields for Non-Wheel Path Longitudinal cracking

The next three fields contain transverse crack data. The first of these fields is for the quantity (number count) of transverse cracks at low, medium, and high levels of severity. The second is for the total length (approximate linear measure) of transverse cracks, that is, whether sealed or not at low, medium, and high severity levels. The third is for the length of sealed transverse cracks at low, medium, and high levels of severity. These fields are shown in Figure D.11. The levels of severity for the transverse crack categories are explained in Appendix C for the LTPP method.

Transverse Quantity			Transverse (ft)			Transverse Sealed (ft)		
Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
100	16	0	60	384	0	6	38	0
87	8	0	522	192	0	261	96	0
0	6	0	0	216	0	0	0	0

Figure D.11 Excel LTPP worksheet fields for Transverse crack data

The next two categories are for Patches. In a similar manner as for transverse cracking, the first of these fields is for the quantities (number count) of patches at low, medium, and high levels of severity. The second category for patches is the square footage of patches at low, medium, and high levels of severity. These fields are shown in Figure D.12. An explanation for LTPP evaluation of patches is in Appendix C for the LTPP method.

Patch/ Patch Deterioration Quantity			Patch/ Patch Deterioration (sq ft)		
Low	Moderate	High	Low	Moderate	High
5	0	0	3	0	0
1	0	0	6,360	0	0
0	0	0	0	0	0

Figure D.12 Excel LTPP worksheet fields for Patch data

The next two fields, for Pothole data, are similar to the fields for Transverse cracks and Patches. The first of these fields is for the quantity (count) of potholes at low, medium, and high levels of severity. The second category for potholes is the square footage of patches at low, medium, and high levels of severity, shown in Figure D.13. An explanation for LTPP evaluation of potholes is in Appendix C for the LTPP method.

Potholes Quantity			Potholes (sq ft)		
Low	Moderate	High	Low	Moderate	High
3	0	0	1	0	0
3	0	0	1	0	0
0	0	0	0	0	0

Figure D.13 Excel LTPP worksheet fields for Pothole data

Data for the next four damage categories were recorded in separate LTPP worksheet fields in a manner similar to that immediately above. These categories include Shoving, Bleeding, Polished Aggregate, and Raveling, and are shown in Figure D.14. These features are measured in terms of square footage of distress and the level of the severity, that is, n-none, l-low, m-medium, and h-high.

Shoving (sq ft)		Bleeding (sq ft)		Polished Aggregate (sq ft)		Raveling (sq ft)	
Qty.	Level	Qty.	Level	Qty.	Level	Qty.	Level
0	n	0	n	0	n	10,176	L
0	n	0	n	0	n	6,360	L
0	n	0	n	0	n	12720	L

Figure D.14 Excel LTPP worksheet fields for Shoving, Bleeding, and Polished Aggregate

The last two damage categories are Water Bleeding and Pumping, and Rutting. Water Bleeding and Pumping are measured in length of feet, and the severity level is also recorded. Rutting was measured in overall average depth in inches, shown in Figure D.15.

Water Bleeding and Pumping (ft)		Rutting
Qty.	Level	in
0	n	0.25
0	n	0.25
0	n	0

Figure D.15 Excel LTPP worksheet fields for Water Bleeding / Pumping and Rutting

SECTION ID AND LOCATION WORKSHEET

The next worksheet contains the project-section ID and location data. Fifty-two major highway sections were listed. Each of these road sections was identified as being at least 20 years old according to ADOT&PF pavement management data. Each section is the product of a single construction project. Some of the sections were quite long, some more than 20 miles in total length. Long sections were sampled within two or more designated subsections. Subsections are identified by section number (1 through 52), and by a lowercase letter. A short section, such as section 8 on the Richardson Highway, was assigned only a single subsection designated 8a. Section 14 on the Richardson Highway is very long and therefore contains six subsections designated 14a through 14h. As previously indicated, the total of all subsections on all roadways is 91. The ends of each subsection are defined using milepost location. A 1/10 mile (528 ft) portion of each subsection was chosen for sampling using the LTPP, PASER, and STCE methods. The *center* of that field site location was defined with reasonable accuracy using both approximate historic milepost location and latitude/longitude coordinates. Appendix A provides a copy of the Section ID and Location worksheet.

The first field in this worksheet contains the subsection identity. The next two fields contain the start and end milepost locations for the subsections. Milepost locations were estimated using measured distances from physical milepost signs located along all Alaska highways.

The next field contains the estimated milepost location of the center of the field site to the nearest 1/10 of a mile. The next three fields contain the milepost start, milepost end, and age of the section. The last six fields contain latitude and longitude designating the *center* of the field site. These are listed as degree, minute, and second as obtained by GPS (WGS 84 map basis). A sample of these entries is shown in Figure D.16.

Section	Subsection	Start MP	End MP	Center of Detailed Thermal crack Evaluation Location MP
Richardson Highway, NR, 190000				
1	a	33	34	33.7
2	a	34	35	34.2
3	a	44	45	45.1

Start of Section (MP)	End of Section (MP)	Age of Section (years)
26.5	34	26
34	40	28
40	46	30

Latitude (North)			Longitude (West)		
degrees	minutes	seconds	degrees	minutes	seconds
61	11	40.0	145	34	18.0
61	11	46.0	145	33	34.0
61	15	13.0	145	17	13.0

Figure D.16 Excel Worksheet fields for Section ID and Location data

TOTALS WORKSHEET

This Excel spreadsheet displays count totals for PASER distresses with categories of none, low, medium, and severe categories (n. l. m, and s) for each highway. An example is shown in Figure D.17. Grand totals for those PASER categories are shown in Figure D.18. The number of sections indicated at the bottom in both these figures is simply a check sum to verify that all sections are accounted for.

Richardson Highway	PASER PASER PASER			
	Alligator	Block	Longitudinal	Transverse
total n's	12	4	5	1
total l's	8	10	13	7
total m's	4	7	5	14
total s's	0	3	1	2
No. of Sections	24			

Figure D.17 Example of totals for PASER distress categories on the Richardson Highway

All Sections		PASER PASER PASER			
		Alligator	Block	Longitudinal	Transverse
Grand	total n's	59	16	7	1
Grand	total l's	22	53	59	41
Grand	total m's	7	18	17	43
Grand	total s's	3	4	8	6
sum	check	91	91	91	91

Figure D.18 Example of grand totals (all sections) for PASER distress categories

Next, a set of descriptive statistics for LTPP damage categories is provided. Statistics include totals, averages, standard deviations, maximums, and minimums. These are compiled for each highway as well as grand totals for all sections. Examples of these tables are shown in Figure D.19 and Figure D.20. Standard deviations were omitted from tables of grand totals.

Richardson Highway	Transverse (ft)		
	Low	Moderate	High
Totals	10138	7080	312
No of Sections	24	24	24
Avg per section	422	295	13
Std Deviation	504	490	30
max	1740	2160	96
min	0	0	0

Figure D.19 Example descriptive statistics for LTPP data, Transverse cracking lengths, Richardson Highway

All Sections	Transverse (ft)		
	Low	Moderate	High
Grand Totals	27452	15671	886
No of Sections	91	91	91
Avg per section	302	172	10
max	1740	2160	208
min	0	0	0

Figure D.20 Example descriptive statistics for LTPP data, Transverse Cracking lengths, all sections

Totals were compiled for the STCE thermal crack categories. As above, this compilation was done for each highway and as a grand total for all highways taken together. Explanations for all STCE categories are presented in the STCE subsection of Appendix C. Examples of these totals are shown in Figure D.21 and Figure D.22. In these figures, "WP" designates areas of the pavement that are generally within the wheel path. "Non-WP" designates all areas of the pavement, within the driven way, that are outside the wheel path.

Section ID	Condition of Major Transverse Cracks (WP Vs Non-WP) 1 = no difference, 2 = slight difference, 3 = much difference
Richardson Highway	
No. of Sections	24
Total 1's	18
Total 2's	6
Total 3's	0

Figure D.21 Totals Major Transverse Crack condition, Richardson Highway

Grand Totals	Condition of Major Transverse Cracks (WP Vs Non-WP) 1 = no difference, 2 = slight difference, 3 = much difference
Section Total	90
Grand Total 1's	59
Grand Total 2's	21
Grand Total 3's	10

Figure D.22 Grand totals for Major Transverse Crack condition, all sections

The next sheet is for descriptive statistics for the ages of the highways evaluated. A sample (Richardson Hwy.) is shown in Figure D.23, as well as an overall comparison table, shown in Figure D.24.

No of Sections	24
Avg Age	28.8
Max Age	35
Min Age	21
Std Dev	3.9

Figure D.23 Age statistics for the Richardson Hwy. sections

Road	**No Sect's**	**Avg Age**	**Max Age**	**Min Age**	**Std Dev**
Richardson	24	28.8	35	21	3.9
Alaska	12	25.8	29	22	2.5
Tok Cutoff	5	30.6	31	29	0.8
Glenn	7	29.9	32	27	2.5
Steese	4	21.5	23	21	0.9
Elliott	2	31.0	31	31	0.0
Parks NR	14	25.5	28	21	2.1
Parks CR	12	24.1	27	22	1.9
Sterling	11	23.8	30	20	2.6

Figure D.24 Comparative table for all highways evaluated

TRANSVERSE CRACK COMPARISON WORKSHEET

The next Excel spreadsheet compares the levels of n-none, l-low, m-medium, and s-severe from the PASER evaluations for transverse cracking among the various highways studied, as shown in Figure D.25.

Road	No Sect's	No of n's	% n's	No of l's	% l's	No of m's	% m's	No of s's	% s's
Richardson	24	1	4%	7	29%	14	58%	2	8%
Alaska	12	0	0%	12	100%	0	0%	0	0%
Tok Cutoff	5	0	0%	4	80%	1	20%	0	0%
Glenn	7	0	0%	0	0%	7	100%	0	0%
Steese	4	0	0%	3	75%	1	25%	0	0%
Elliot	2	0	0%	1	50%	0	0%	1	50%
Parks NR	14	0	0%	11	79%	3	21%	0	0%
Parks CR	12	0	0%	2	17%	10	83%	0	0%
Sterling	11	0	0%	1	9%	7	64%	3	27%

Figure D.25 PASER evaluations for transverse cracking

ADOT&PF ROAD WEATHER INFORMATION WORKSHEET

ADOT&PF maintains weather related information, Road Weather Information System (RWIS), for specific points on many roads within their jurisdiction. The public has access to this system of temperature measurements and cameras.

The last Excel worksheet in the workbook is a listing of RWIS temperature data from highways evaluated for this study. The sections evaluated do not coincide exactly with the RWIS sites, but information was recorded in the Excel workbook for those RWIS sites relatively nearby. Information includes the extreme temperature values, dates, and times for minimum air temperature, minimum pavement surface temperature, maximum air temperature, and maximum pavement surface temperature, as shown in Figure D.26. The GPS latitude/longitude coordinates and the elevations are given for each station listed. In all, extreme data for 18 RWIS sites were recorded.

Road	AKDOT&PF Maintenance Station	MP	Elevation (m)
Richardson	Thompson Pass	25.7	884
Richardson	Stuart Creek	45.7	411
Richardson	Edgerton Highway	83	447
Richardson	Trims DOT MS	218.2	755
Richardson	Tenderfoot	292.6	416

Air Min T (°F)	Date	Time (24)	Pave Min T (°F)	Date	Time (24)
-25	1/7/2009	2:43	-24	1/7/2009	3:43
-30	1/19/2012	8:16	-24	1/19/2012	9:56
-38	1/7/2009	17:50	-27	1/7/2009	17:50
-37	2/10/2008	3:34	-31	2/10/2008	5:04
-40	1/6/2009	5:13	-32	2/7/2008	9:12

Air Max T (°F)	Date	Time (24)	Pave Max T (°F)	Date	Time (24)
74	7/6/2009	16:44	120	7/4/2009	14:44
81	6/20/2007	16:31	128	6/27/2007	15:01
88	6/26/2004	18:42	129	6/25/2004	16:07
81	7/8/2009	16:35	118	6/14/2005	15:30
89	7/8/2009	19:13	120	7/8/2009	15:43

Latitude	Longitude
61.12986	145.73386
61.26084	145.28378
61.81911	145.21614
63.41605	145.74929
64.28361	146.28153

Figure D.26 ADOT&PF RWIS extreme temperature data for the Richardson Hwy.

A CD containing the Excel spreadsheet is included with hard copies of this report. A complete set of project photos (or an additional copy of the Excel spreadsheet) can be obtained by contacting the ADOT&PF Research Development and Technology Transfer Section, Fairbanks, Alaska.

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