SCHOOL OF CIVIL ENGINEERING OKLAHOMA STATE UNIVERSITY

DEPRESSED TRANSVERSE CRACKS
IN ASPHALT PAVEMENTS
IN OKLAHOMA

By

Donald R. Snethen
and
Samir Ahmed

FINAL
REPORT

Report No. FHWA/OK 92(01)

July, 1991

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. FHWA/OK 92(01)	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE DEPRESSED TRANSVERSE CRACKS IN ASPHALT PAVEMENTS IN OKLAHOMA		5. REPORT DATE July, 1991
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Donald R. Snethen and Samir Ahmed		8. PERFORMING ORGANIZATION REPORT
		10. WORK UNIT NO.
9. PERFORMING ORGANIZATION AND ADDRESS School of Civil Engineering, ES 207 Oklahoma State University Stillwater, OK 74078-0327		11. CONTRACT OR GRANT NO. Agreement No. 2166
		13. TYPE OF REPORT AND PERIOD COVERED Final Report—Feb.-Sept. 1988 Sept. 1988 to July 1991
12. SPONSORING AGENCY NAME AND ADDRESS Research and Development Division Oklahoma Department of Transportation 200 NE 21st Street Oklahoma City, OK 73105-3204		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. ABSTRACT

Transverse cracking of asphalt pavements is a costly pavement distress occurring in states that experience cold/freezing temperatures during the winter months. The cracks are caused by low temperature-induced tensile stresses that exceed the tensile strength of the pavement material. The majority of these cracks occur in the transverse direction relative to the pavement and with regular frequency along the roadway. The major objectives of this research included:

1. Determine the nature and extent of transverse cracking in asphalt pavements in Oklahoma.
2. Conduct a field and laboratory investigation of pavement materials and highway features to determine and evaluate the various factors that influence transverse cracking.
3. Review ODOT practices for dealing with transverse cracking of asphalt pavements.

The results of the research project confirm that the transverse cracking of pavements is a thermally-induced problem. Based on evaluation of collected data, the number of cracks increased and the average spacing decreased as the average low monthly temperature decreased. Depressions associated with transverse cracks were influenced by subgrade moisture conditions; specifically, as the average subgrade moisture content increased, the occurrence and severity of the depressions increased. Transverse cracking and particularly depressed transverse cracks appear to be more of a problem on fine-grained soil subgrades. Transverse cracking of asphalt pavements is a problem across the state of Oklahoma with severity of the problem varying from division to division based on such factors as pavement age, pavement cross section, traffic, asphalt properties, and maintenance procedures. Although maintenance and remedial procedures vary across the state, ODOT's procedures are consistent with those reported by surrounding states.

17. KEY WORDS Asphalt Concrete, Asphalt Pavement, Thermal Cracking, Transverse Cracking, Pavement Thickness, Depressed Transverse Cracks		18. DISTRIBUTION STATEMENT No Restrictions	
19. SECURITY CLASSIF. (OF THIS REPORT) None	20. SECURITY CLASSIF. (OF THIS PAGE) None	21. NO. OF PAGES 60	22. PRICE

DEPRESSED TRANSVERSE CRACKS IN

ASPHALT PAVEMENTS IN OKLAHOMA

FINAL REPORT

By

Donald R. Snethen, Ph.D., P.E.
and
Samir Ahmed, Ph.D., P.E.

School of Civil Engineering
Oklahoma State University
Stillwater, Oklahoma
July, 1991

Prepared for

OKLAHOMA DEPARTMENT OF TRANSPORTATION
Research and Development Division

In Cooperation With the

FEDERAL HIGHWAY ADMINISTRATION

EXECUTIVE SUMMARY

Transverse cracking of asphalt pavements is a costly pavement distress occurring in states that experience cold/freezing temperatures during the winter months. The cracks are caused by low temperature-induced tensile stresses that exceed the tensile strength of the pavement materiale The majority of these cracks occur in the transverse direction relative to the pavement and with regular frequency along the roadway. The major objectives of this research included:

1. determine the nature and extent of transverse cracking in asphalt pavements in Oklahoma;
2. conduct a field and laboratory investigation of pavement materials and highway features to determine and evaluate the various factors that influence transverse cracking; and
3. review ODOT practices for dealing with the problem of transverse cracking of asphalt pavements.

The results of the research project confirm that transverse cracking of pavements is a thermally-induced problem. Based on evaluation of collected data, the number of cracks increased and the average spacing decreased as the average low monthly temperature decreased. Depressions associated with transverse cracks were influenced by subgrade moisture conditions; specifically, as the average subgrade moisture content increased, the occurrence and severity of the depressions increased. Transverse cracking and particularly depressed transverse cracks appear to be more of a problem on fine-grained soil subgrades. Transverse cracking of asphalt pavements is a problem across the state of Oklahoma with severity of the problem varying from division to division based on such factors as pavement age, pavement cross section, traffic, asphalt properties, and maintenance procedures. Although maintenance and remedial procedures vary across the state, ODOT's procedures are consistent with those reported by surrounding states.

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

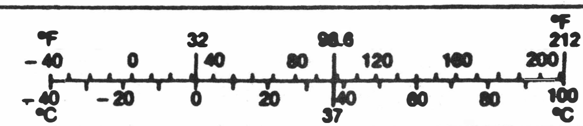
NOTE: Volumes greater than 1000 L shall be shown in m^3.

	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Background

The performance of flexible pavements depends on a variety of design, construction, materials, traffic, maintenance, and climatic factors. Because of its diverse climatic conditions, Oklahoma flexible pavements are exposed to temperature-induced stress extremes which can result in transverse cracking of the pavement structure.

Transverse cracking of flexible pavements is an extensive and costly type of pavement distress in all states that experience relatively cold temperatures during the winter months. These cracks are caused by low temperature-induced tensile stresses that exceed the tensile strength of the pavement materials and result in cracks or fractures. Due to the geometric configuration of the pavement, the principal axis of thermal contraction is in the longitudinal direction and a major portion of these thermal or low-temperature cracks occur transversely, typically with regular frequency along the roadway.

These transverse pavement cracks are usually spaced at regular intervals that range from a few feet to several hundred feet, depending primarily on the age of the pavement and the rheological properties of the asphalt mixtures. In some cases, these cracks are limited in depth, but others may penetrate through the total pavement structure. Cyclic temperature changes over a period of several years result in a gradual increase in both width and depth of the crack.

Initially, these cracks are not particularly harmful to the pavement, but poor riding quality can result as these cracks become progressively wider and deeper. Open cracks permit the ingress of substantial quantities of surface water as well as other detritus. Water, of course, can cause stripping in the asphalt-bound materials as well as softening of the base and/or subgrade. In extreme cases, depressions occur at these cracks due to subgrade softening, the application of heavy axle loads, and possibly pumping of fine subgrade materials. Secondary cracks, more or less parallel and on both sides of the primary transverse crack, may also occur.

Objectives of the Research

It is obvious that this type of progressive pavement distress can drastically reduce the serviceability of a highway and soon become a serious safety hazard for users. Solutions to the problem are undoubtedly related to characteristics of the subgrade soil and the paving materials employed, the design of the flexible pavement structure, and the maintenance practices used. By developing a better understanding of these relationships, it should be possible to suggest remedial measures to eliminate or at least mitigate the problems associated with depressed transverse cracks. The major objectives of this research program are to:

1. Determine the nature and extent or severity of depressed transverse cracking of flexible pavements throughout the Oklahoma highway system;
2. Conduct both field and laboratory investigations of paving materials and subgrade soils to characterize depression cracks at selected sites and ascertain unique and/or common elements that contribute to the occurrence and distribution of this type of distress;
3. Review Oklahoma Department of Transportation (ODOT) practices and procedures pertaining to structural pavement design, design of surface paving mixtures, construction, and roadway maintenance to establish

any correlations with the development of depression cracking in flexible pavements;

4. Based on the results of this study and evaluation, implement recommendations, where warranted, regarding

   a. revisions in paving materials and construction specifications

   b. structural and mix design procedures

   c. maintenance practices for routine crack sealing

   d. remedial measures used on depression cracks prior to overlaying operations.

CHAPTER II

THERMAL CRACKING OF ASPHALT PAVEMENTS: LITERATURE REVIEW

Mechanisms and Manifestations

Low temperature shrinkage cracking of asphalt pavements has been recognized as a problem since the mid-1930s. However, because of the low paved mileage with smaller traffic volumes and lighter loads, the problem was not acute prior to World War II. As performance requirements for pavement increased, the problem of low-temperature cracking started to become more serious. In the late 1950s and the early 1960s, a number of highway engineers became concerned. Several Canadian researchers conducted crack surveys to determine the extent of the problem. Concurrently, field and laboratory research investigations were initiated by several state highway departments to find and eliminate the cause of the cracking. In 1965, the Canadian Good Roads Association [1] recognized the severity of low-temperature cracking and gave it top priority for highway research needs.

Kher [2] found that during the first winter transverse cracking begins as hairline cracks which slowly widen with time. Because pavements cannot contract in the longitudinal direction, these low-temperature cracks form in the transverse direction. Hairline cracks begin as partial transverse cracks and extend completely across the roadway after subsequent winters. Hairline cracks progressively widen and eventually become 10 to 20 mm wide.

Haas and Topper [3] confirm that low-temperature cracks may actually occur as very fine or micro-cracks during cold weather and then open up, becoming visually apparent as warming occurs. However, they advance the hypothesis that thermally-induced cracking occurs in two main phases: limited depth crack initiation and subsequent full-depth propagation which occurs when air temperatures rise. These primary distress modes generally manifest many types of secondary distress. Kher [2] describes two of these secondary distresses:

1. Water and deicing salts infiltrate through the cracks and soften the base material underneath, resulting in partial loss of support. Furthermore, pumping or hydraulic pressure dislodges and expels aggregate and fine material from the cracks and subgrade, causing a void which results in the depressions associated with transverse cracking.
2. Water entering the cracks may freeze and form an ice lense below the crack, thus elevating crack edges, lipping, or tenting.

The primary distress that leads to transverse cracking has little effect on riding quality of the pavement. The secondary distresses described, however, can be highly detrimental to the performance and the useful life of the structure.

Haas and Hopper [3] discussed four reactions that cause transverse cracking:

1. Simple thermal contraction of the surface.
2. Base course restraint to contraction of the surface.
3. Sudden warming and subsequent weakening of a highly stressed surface.
4. Shrinkage cracking of the subgrade and subsequent reflection through to the surface layer.

Anderson and Haas [4] elaborated on the fourth factor and determined that freezing causes shrinkage and cracking of the base or subbase, which is propagated through the bituminous surface. Their study provides a compilation of the factors of possible significance in low-temperature cracking (see Figure

1). It begins by dividing the pavement into components in which the cracking may begin: surface, base, subbase, and subgrade. The possible results, external factors, and component factors that influence the extent of thermal cracking are listed for each component.

Studies which support the hypothesis that the major cause of transverse cracking of asphalt pavement is the buildup of tensile forces during the winter when the temperature drops to low levels include: Hills and Brien [5], Shields and Anderson [6], and Monosmith et al. [7]. Studies that explored the significance of variables in relation to low temperature include Kari and Santucci [8] and Busby and Rader [9].

Kari and Santucci [8] have shown that the phenomenon of transverse cracking exists on the basis of viscosity measurements. Their work is primarily related to air void variations with depth on relatively new pavements. Busby and Rader's [9] surveys in Alberta, Canada, attempted to make correlations between transverse cracking and age, thickness, and foundation of the pavement. Increased cracking frequency, caused either by increased stiffness of the asphalt mix or by increased exposure to extreme low temperatures, were shown to increase with pavement age. They affirm that cracking occurred because of lessened elasticity caused primarily by hardening of the asphalt with aging and the increased susceptibility of the pavement to low-temperature stress and cracking.

Bituminous paving mixtures exhibit both plastic and elastic properties, depending on the temperature to which the mixtures are subjected and to the viscosity of the asphalt in the mixture. Busby and Rader [9] determined that an increase in the thickness of the asphalt concrete layer resulted in a decrease of the low-temperature cracking frequency when all other variables

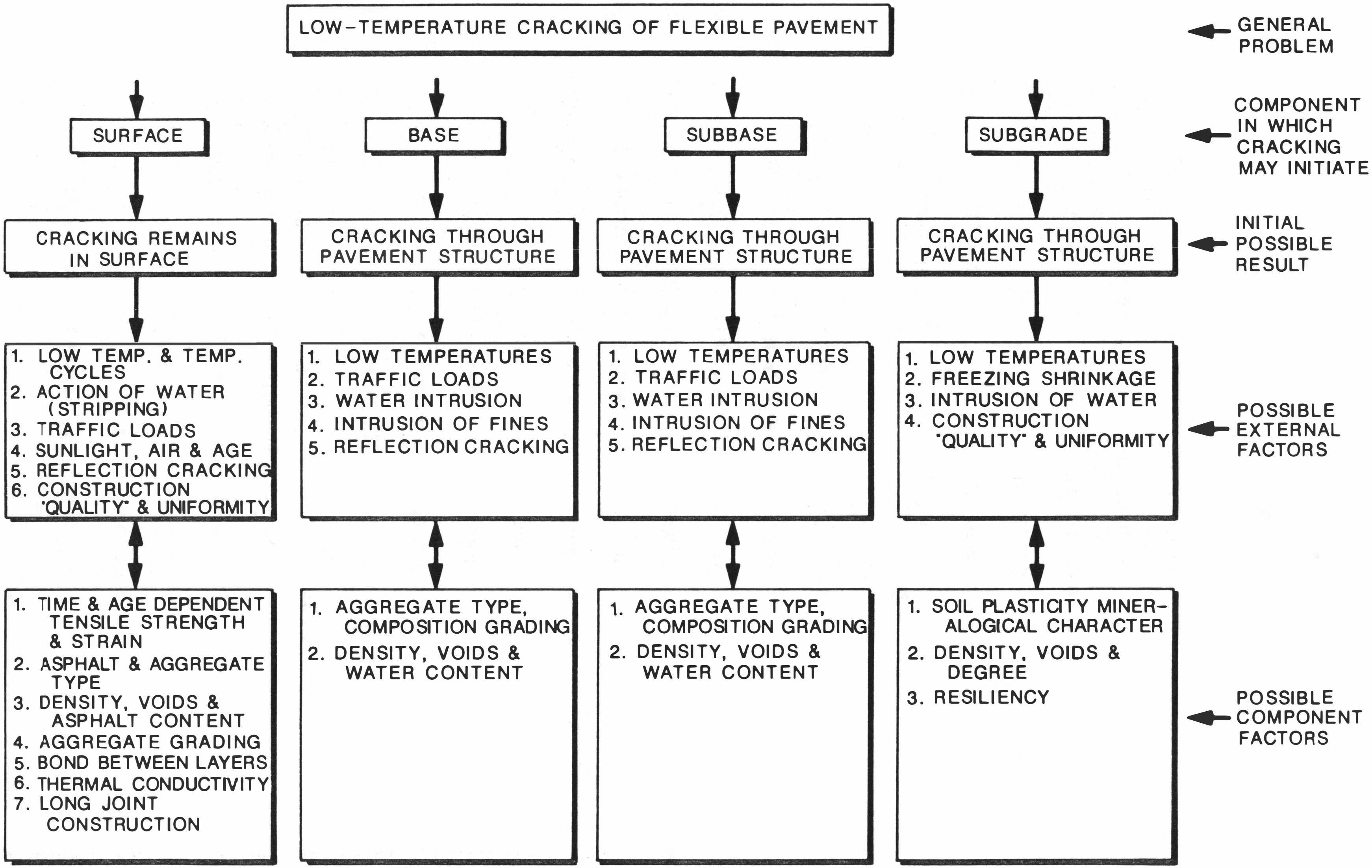


Figure 1. Factors of Possible Significance in Low-Temperature Cracking of Flexible Pavements

were the same. The cracking frequency also increased when the pavements were placed over clay subgrades.

Thermal Properties of Asphalt Pavements

Recent literature emphasizes the importance of considering the thermal properties of asphalt when studying pavement deterioration. Whiffen and Lister [10] reported that bituminous roads deteriorated markedly with the rise of temperature due to the reduction in viscosity of the bitumens and tars which in turn caused a reduction of the dynamic elastic moduli of the layer forming the road. These experiments emphasized the necessity of recording temperature when measuring dynamic stresses of deflections of loads under traffic. Kallas [11] reported that the use of thicker asphalt courses in many heavy-duty highways has resulted in the need for more information on temperature variations in pavement structures. Temperature data are necessary in studies on pavement deflections, stresses, and strains under moving wheel loads. Pavement temperature data are of interest in any study or test involving temperature-dependent mechanical properties of paving mixtures or paving asphalts.

Cold temperatures increase the stiffness of the asphalt concrete. This allows the pavement to offer greater resistance to loads. However, a pavement will not deflect as much when cold and heavy loading may cause cracking in the asphalt. Conversely, high temperatures decrease the stiffness of the asphalt concrete, which increases the possibility of densification and rutting of the pavement under heavy loads.

Several studies suggest that thicker asphalt-treated sections are less effected by temperature than thinner sections. Dorman [12], Whiffen and Lister [10], and Jimeniz and Gallaway [13] indicated that the flexibility of thin asphaltic concrete slabs is greater than that of thicker ones at higher temperatures. In cold temperatures the flexibility of both thick and thin slabs is reduced. Although thick slabs retain their ability to resist cracking, stiffness in thin slabs leads to cracking.

Previous Field and Laboratory Studies

The problems of transverse cracking have been recognized since the late 1950s and several provinces in Canada have conducted experimental tests to determine the causes of and find practical solutions to the problem. One of the earliest experiments was conducted at Arkona in south Ontario [1]. In 1960, pavements were laid to test the behavior of three different asphalts. The initial purpose of the test was not primarily to study transverse cracking, but to show the major differences between asphalts; however, a relationship between asphalt and cracking was found.

Another important early investigation was a transverse crack study conducted on pavements on three Ontario test roads in their eighth, ninth, and tenth years [15]. The survey demonstrated a substantial increase in the number of transverse pavement cracks each year. The investigation found that low temperatures were the primary cause of transverse pavement cracking.

In Saskatchewan, three test sections were conducted in 1963 on a roadway that was constructed in 1960 [1]. The major variables were asphalt source, asphalt grade, and thickness of the prime coat. Crack patterns were recorded, as well as considerable initial and periodic materials data. The principle finding was that the asphalt source was related to the degree of cracking. Figure 2 shows that the degree of cracking was significantly reduced with softer asphalts. In summary, all test sections indicated that asphalt source and grade were two of the most significant variables.

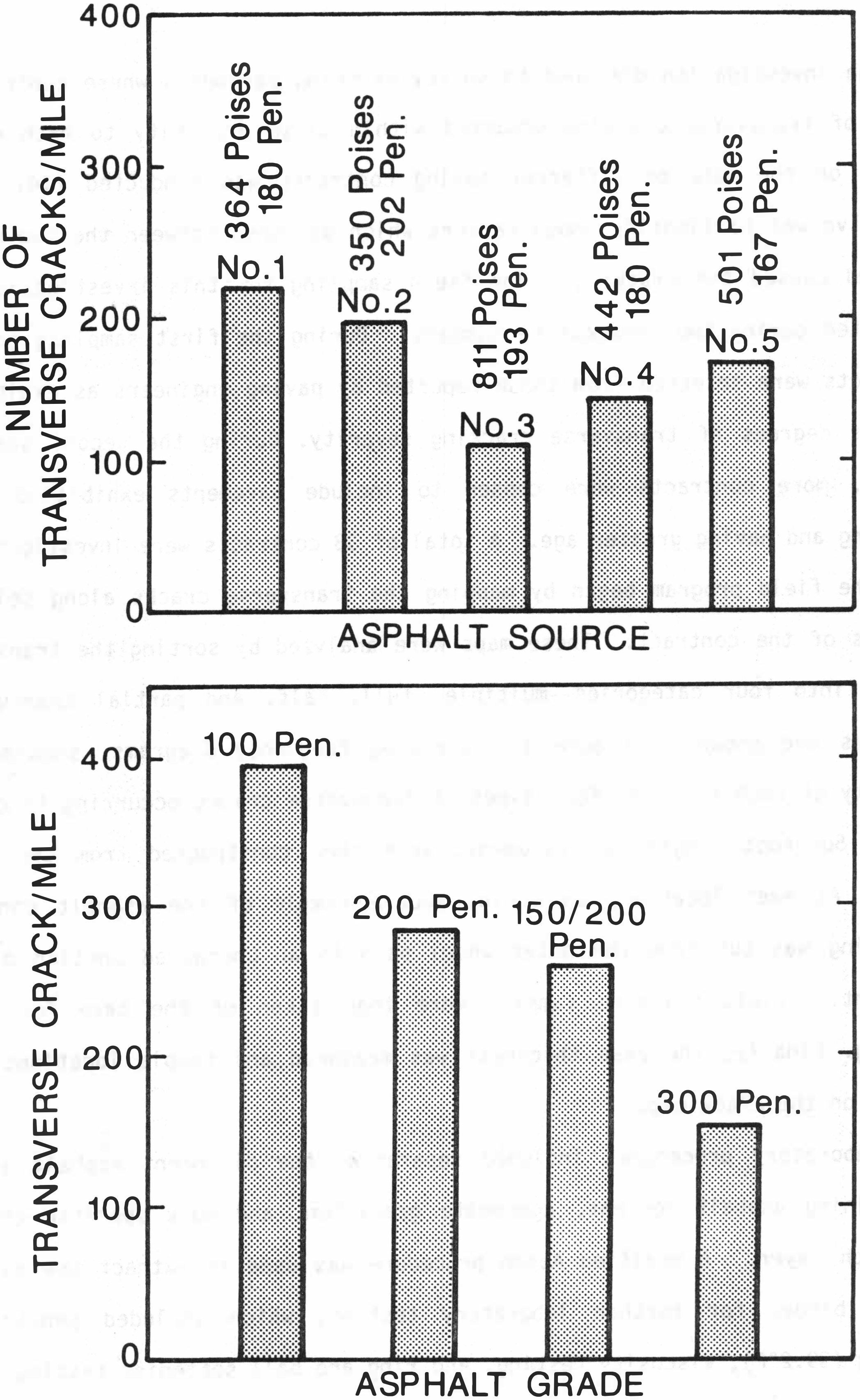


Figure 2. Summary of Cracking Vs Asphalt Source and Grade [1]

An investigation designed to survey existing pavements where contrasting types of transverse cracking occurred within close proximity to each other, either on the same or different paving contracts was conducted [14]. The objective was to identify those factors which differed between the two paving job and caused the cracking. The field sampling for this investigation was conducted during two consecutive summers. During the first sampling period, contracts were selected from those reported by paving engineers as exhibiting various degrees of transverse cracking severity. During the second sampling period, more contracts were chosen to include pavements exhibiting light cracking and having greater age. A total of 33 contracts were investigated.

The field program began by mapping the transverse cracks along selected lengths of the contract. These maps were analyzed by sorting the transverse cracks into four categories--multiple, full, half, and partial transverse. Examples are shown in Figure 3. Cracking frequency diagrams, showing the quantity of each of these four types of transverse cracks occurring in consecutive 500-foot lengths of pavement, were then constructed from the crack maps. At each location, an 18-in. square sample of the asphalt concrete surfacing was cut from the outer wheel path in an uncracked portion of the pavement. Field moisture samples were then taken of the base for later testing. Finally, the base thickness was measured and sample locations were marked on the crack map.

Laboratory procedures included separating the different asphalt layers determining asphalt content, aggregate gradation, and bulk specific gravity for each layer. A modified Abson procedure was used to extract the asphalt cement binder for further laboratory testing, which included penetration testing (39.2°F), viscosity testing, and ring and ball softening testing.

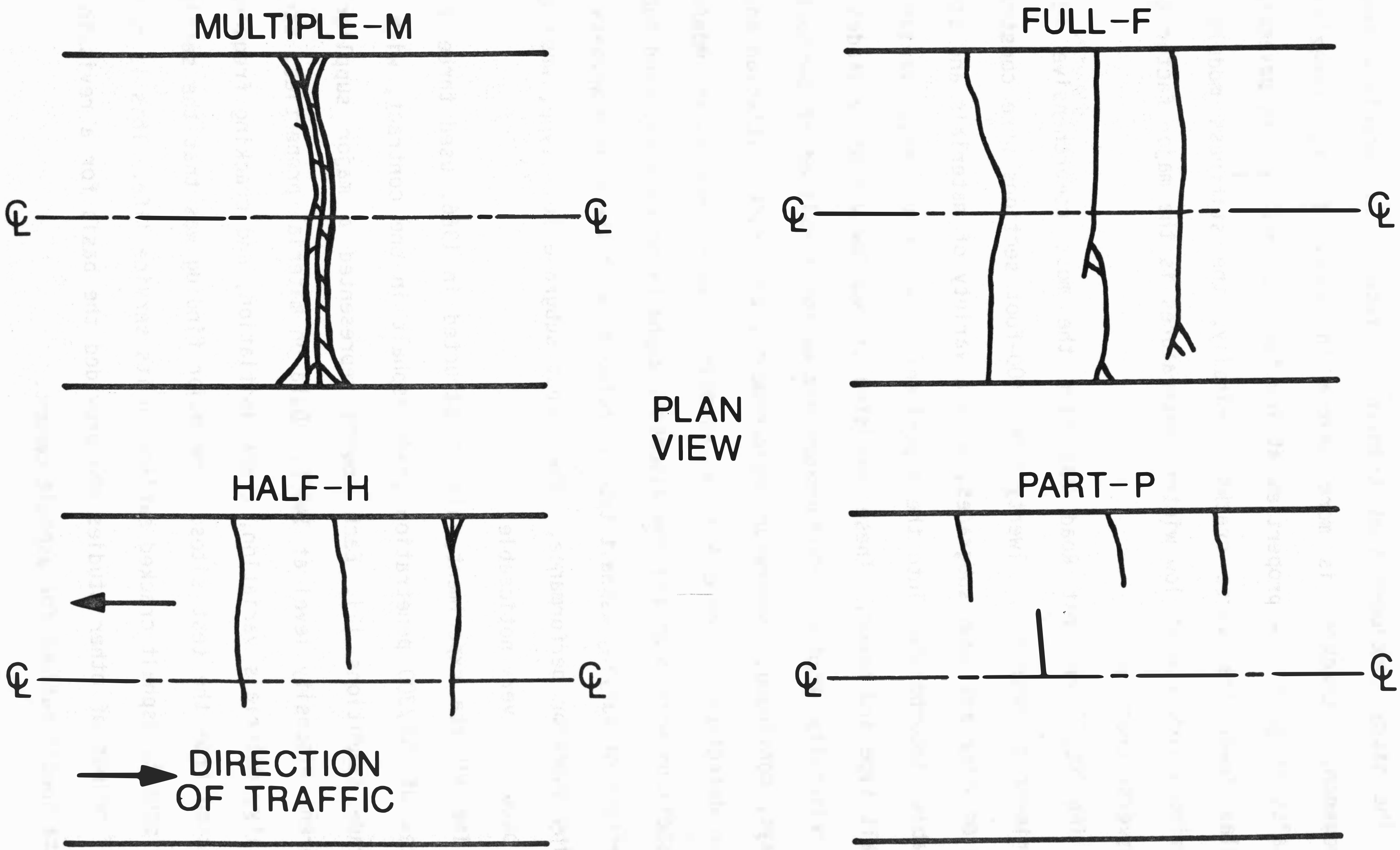


Figure 3. Different Types of Transverse Cracks [14]

The study concluded that transverse cracking is largely a temperature phenomenon. Cracking is more severe in areas of high freezing index. Asphalts of good flow properties at low temperatures lead to pavements which display fewer transverse cracks. Finally, the stiffness modulus of the bituminous concrete at low winter temperatures is the major factor governing transverse cracking.

The St. Anne Test Road has been the most comprehensive full-scale experiment to date [1]. Twenty-nine, 400-foot sections were constructed in 1966 on clay and sand subgrades, with a variety of materials and structural variables incorporated into the experiment. Two of the major variables were asphalt type and grade. These consisted of two low viscosity grades and two high viscosity grades. Performance evaluation consisted of periodic crack surveys, continuous temperature measurements, and crack initiation and propagation detection. Figure 4 is an example of some crack survey measurements for sections with high and low viscosity asphalts on clay and sand subgrades. The effect of varying asphalt type is notable, with the high viscosity asphalt showing superior performance. The effect subgrade soil type, when cracking does occur, is very noticeable.

The Alberta experiment, also constructed in 1966, used three different sources of 200/300 penetration grade asphalt in one contract, with uniform subgrade conditions [1]. Each source represented a major supplier and a different viscosity level at 140°F. Data on material properties, structural capacity, materials variation, crack initiation, and cracking frequency were collected from the test sites. One major finding was that the section with low-viscosity asphalt cracked earlier in its service life. This is consistent with findings of other studies and provided the basis for a revision to the Alberta specifications for asphalt cement.

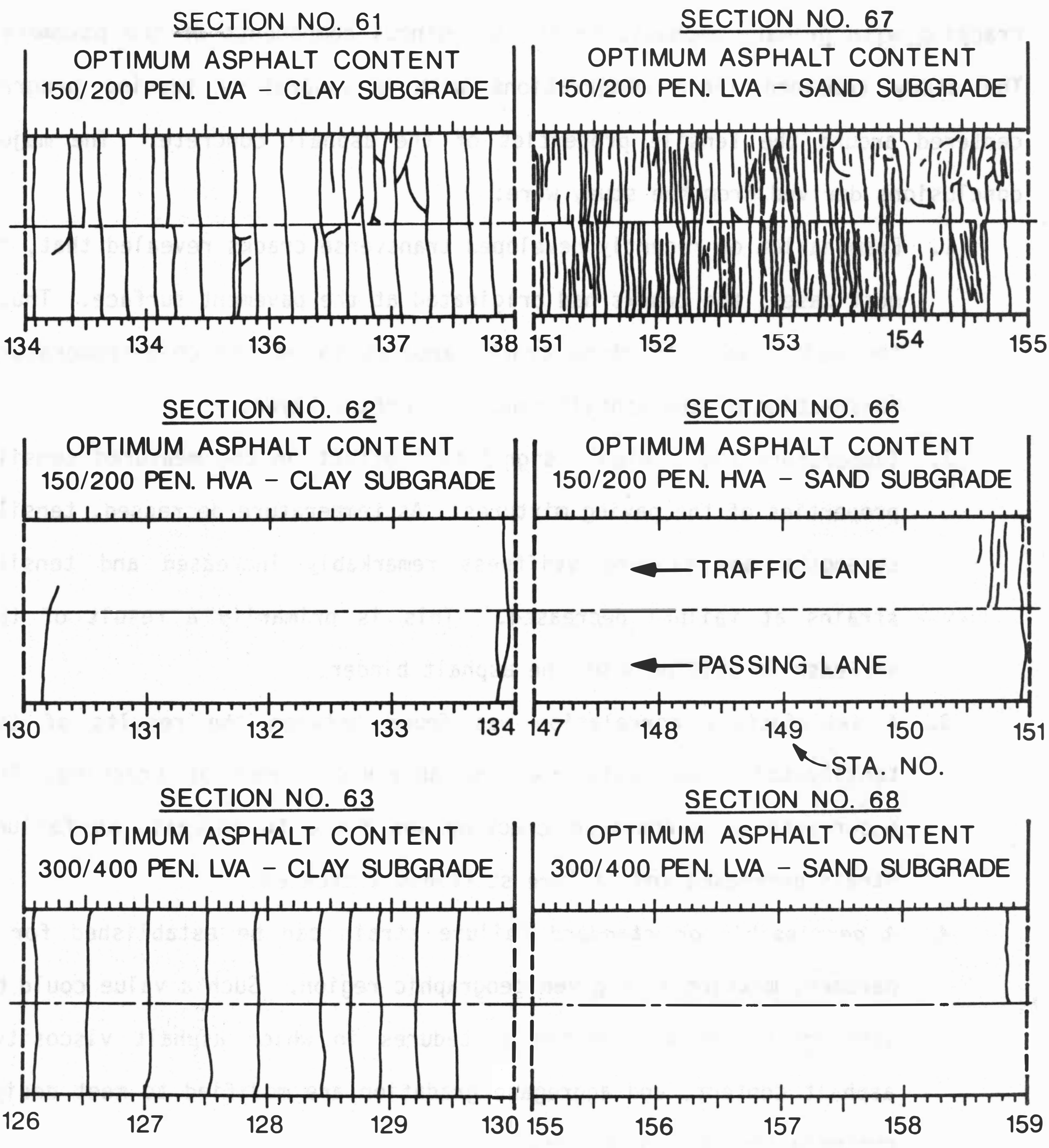


Figure 4. Example of Crack Survey Measurements at St. Anne Test Road [1]

In a detailed study of transverse cracking in Oklahoma asphalt pavement, Noureldin and Manke [16, 17] investigated the nature and extent of transverse cracking with primary emphasis on the bituminous components of the pavement. The study combined field observations with a laboratory testing program centered around the tensile properties of the asphalt concrete. The major conclusions derived from the study were:

1. Examination of recently developed transverse cracks revealed that, in most cases, the cracks had originated at the pavement surface. Thus, the major cause of these cracks appears to be the cold-temperature contraction of the asphalt concrete surface layer.
2. Temperature had a highly significant effect on the measured tensile properties of the paving mixtures. As temperature decreased, tensile strengths and failure stiffness remarkably increased and tensile strains at failure decreased. This is primarily a result of the increase in stiffness of the asphalt binder.
3. A satisfactory correlation was found between the results of the tensile-splitting tests and the observed degree of cracking. The occurrence of transverse cracking was found to increase as failure strain decreased and failure stiffness increased.
4. A permissible or standard failure strain can be established for a pavement mixture in a given geographic region. Such a value could be used in future mix design procedures in which asphalt viscosity, asphalt content, and aggregate gradation are modified to meet design criteria for failure strain.
5. The stiffness moduli of recovered asphalts, determined at the expected minimum temperature in central Oklahoma, were significantly correlated with Cracking Indexes of the pavement test sites. The

stiffer or harder the asphalt cement in a pavement was, the greater was the degree of transverse cracking.

Design Procedures to Minimize Thermal Cracking

The need for low-temperature modifications to pavement designs in some regions was recognized over 30 years ago. Since that time, various agencies and individuals have devoted considerable research effort to solutions for the problem. These investigations, both field- and laboratory-oriented, led to establishing design concepts for controlling or eliminating low-temperature cracking. Hajek and Haas [18] include such concepts as setting limiting penetration and viscosity requirements on the asphalt cements, limiting the strain or stiffness of the asphalt concrete, and calculating the fracture temperature. Most agree that asphalt source and grade are two important variables. Furthermore, cracking could be eliminated or significantly reduced by altering levels of these variables.

Haas et al. [1] describe a design and treatment approach that uses index properties of the asphalt and/or the asphalt mix that have been subjectively correlated to minimize field cracking frequency. The design approach, see Figure 5, begins by setting the viscosity and penetration specifications so that certain asphalts are eliminated, particularly hard grade asphalts. Next, a limiting stiffness or strain is set for the particular design application and the asphalt is compared to these limits. Finally, a probable fracture temperature is calculated for the mix under consideration and compared with the expected low temperature.

Using this design approach, the cracking frequency and density are shown to increase with decreasing failure strain and increasing failure stress and stiffness. Finally, low viscosity asphalt cement exhibits the greatest change

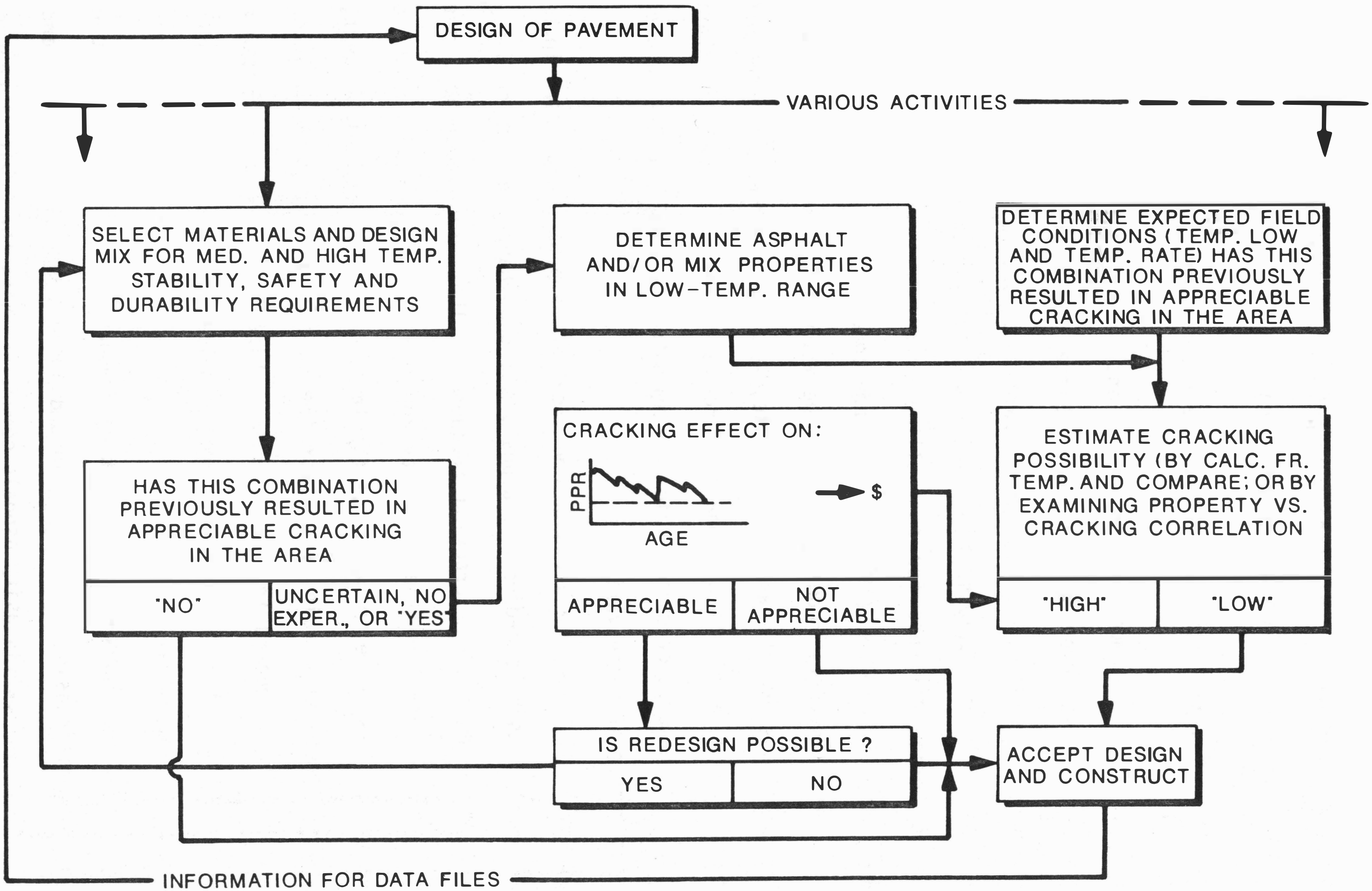


Figure 5. General Design Approach for Low-Temperature Cracking Problem [1]

in mix density, failure stress and strain, stiffness, and cracking frequency. These findings can enable a design prediction to determine if a mix will crack by comparing strains, stresses, and stiffnesses from uncracked and cracked sections. The greater the stiffness modulus, the greater the thermal stress developed in the pavement by temperature. Therefore, the mixture should be designed and asphalt grade selected to have a high modulus of rupture to ensure adequate tensile strength, but a low stiffness modulus so that the mixture will be flexible rather than stiff or brittle.

Present methods of designing asphalt paving mixtures require minimum stability at an elevated temperature, flow between certain limits, specified ranges of air voids, and voids in mineral aggregate. In addition, the aggregate must meet certain grading requirements and tests for wear and soundness. Busby and Rader [9] contend that the asphalt cement with the lowest viscosity meeting high temperature stability requirements should be used. Figure 6 shows minimum temperatures for each grade of asphalt. If high temperature stability requirements cannot be met, a less desirable asphalt will have to be selected and some cracking should be expected.

Thickness of the asphalt concrete also appears to have some effect on low-temperature transverse cracking. Burgess, Kopvillem, and Young [19] concluded that increasing the asphalt thickness appears to reduce the cracking frequency. However, they point out that if a mix is susceptible to cracking, the pavement will crack regardless of thickness.

Maintenance Measures to Minimize Effects of Thermal Cracking

Once thermal cracking has occurred, it becomes necessary to minimize the adverse effects of the crack propagation or in cases where the cracking has

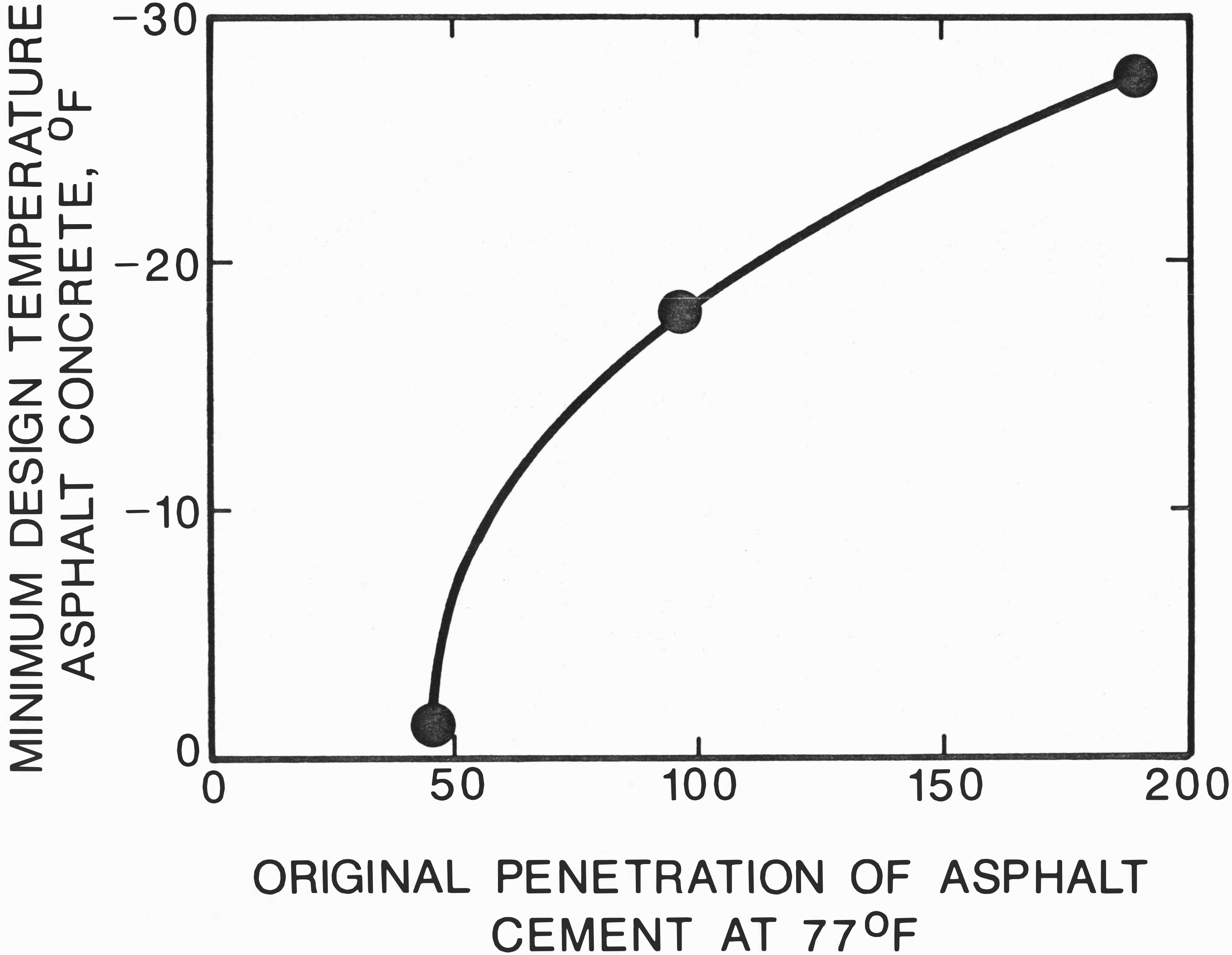


Figure 6. Minimum Design Temperatures for Various Asphalt Grades [9]

become severe, restore the ride quality of the damaged pavement. Essentially the options available for preventive maintenance/surface restoration include:

1. Fog sealing
2. Crack filling
3. Crack repair, including routing and milling
4. Patching, including milling and use of paving fabrics
5. Overlays, including use of paving fabrics.

All of these options tend to be site-specific and labor-intensive, therefore expensive. The degree of success for use of these options has been somewhat variable and limited effort has been expended to thoroughly evaluate the reasons for the variability.

A cooperative analysis by teams of engineers from Iowa, Kansas, Nebraska, North Dakota, and Oklahoma [20] suggested that simple maintenance may be the key to reducing the severity of transverse cracks. Several methods were discussed. The first of these was fog sealing the pavement. All teams concluded that using this as a part of their routine maintenance procedure retarded the development of cracks and was cost effective. They recommended that larger transverse cracks be filled with some type of bituminous crack filler. Crack filling materials included cut backs, emulsions, emulsion slurry, asphalt cements, and rubberized asphalts. It was also reported that sealing cracks with rubberized asphalt blended in the field provided excellent results. It was agreed that asphalt cements, cut backs, and emulsions do not seal the wider cracks but do provide a filler, thus reducing the amount of water that can infiltrate the base and weaken the road structure. The procedure for restoring the riding quality of the road with depressed transverse cracks was the same in most of the states. Narrow cracks were filled with a slurry or bituminous mix after which the depression is leveled using a cold mix or slurry.

Many conclusions may be made about remedial treatments of asphalt pavements with transverse cracking. Although there are no treatments currently available which will completely eliminate transverse crack reflection--particularly if the crack is temperature-related--there are some treatments that effectively hinder their development.

CHAPTER III

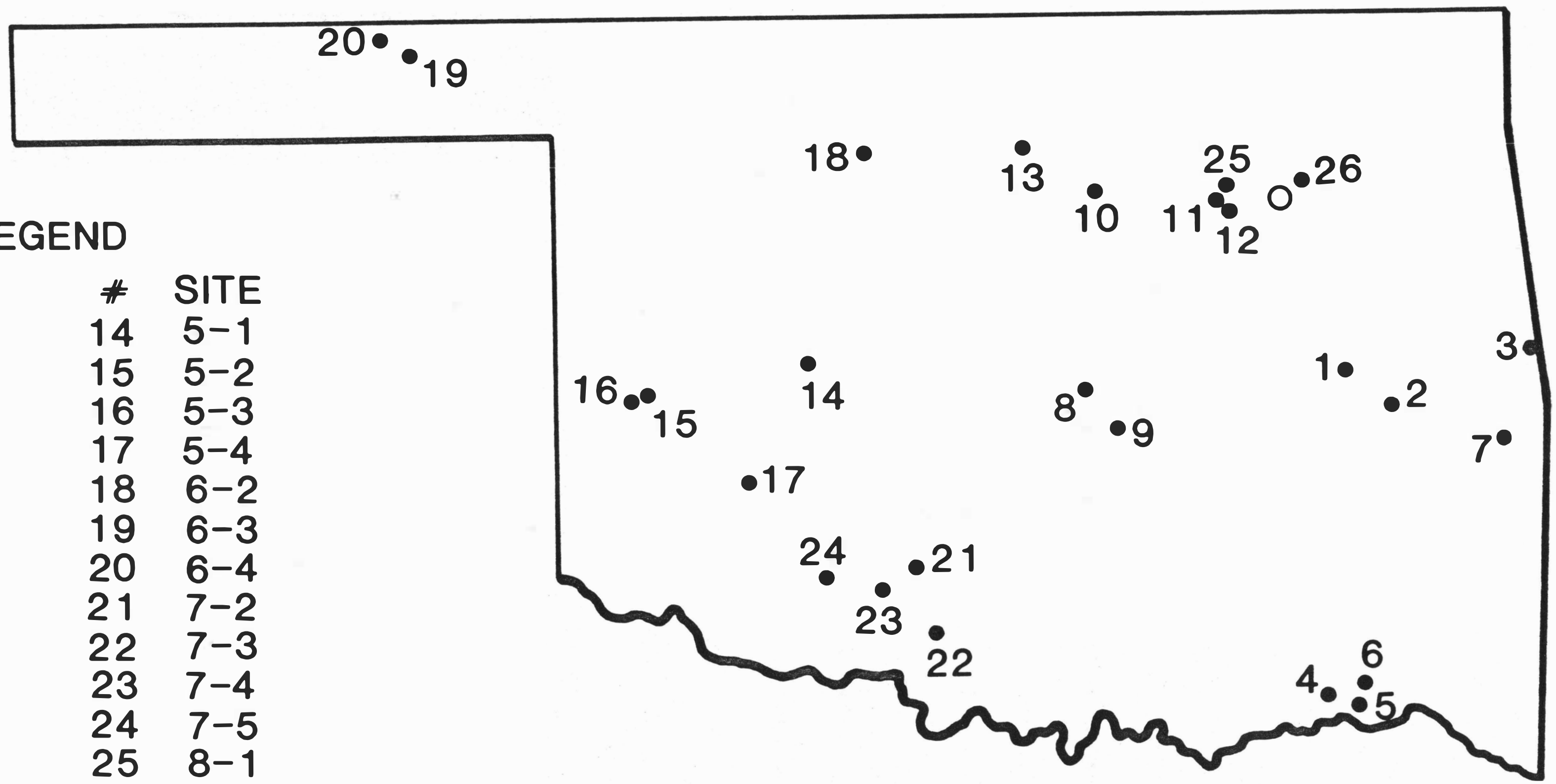
FIELD AND LABORATORY INVESTIGATION

Field Investigation

The field investigation was divided into three phases--Phases I, II, and III--corresponding to three site visits. Study sites were selected from locations recommended by Oklahoma Department of Transportation (ODOT) Division Maintenance personnel. During Phase I, several miles of roadway were inventoried with regard to number of cracks, location of cracks, and whether the cracks were depressed or nondepressed. Phase II efforts involved collection of various crack dimension and pavement cross section feature data. During Phase III, pavement core samples and subgrade soil samples were collected for later testing. The locations of the 26 sites used in the study are shown in Figure 7.

Phase I Site Visit

The initial site visit consisted of choosing a two-mile section of pavement which represented typical transverse cracking of the pavement. A reference point such as a mile marker or intersection was established, and a crack survey was made of a two-mile section. The survey included location of each crack using a surveying wheel and assessment of the type of crack, i.e., depressed or nondepressed. The data collected from the initial site visit were used to locate the transverse cracks on a plan and profile sheet of the test section. A 1000-ft section was then selected according to the frequency and distribution of cracks and the profile of the highway section.



LEGEND

#	SITE	#	SITE
1	1-1	14	5-1
2	1-2	15	5-2
3	1-3	16	5-3
4	2-1	17	5-4
5	2-2	18	6-2
6	2-3	19	6-3
7	2-5	20	6-4
8	3-1	21	7-2
9	3-3	22	7-3
10	4-1	23	7-4
11	4-2	24	7-5
12	4-3	25	8-1
13	4-4	26	8-2

Figure 7. Location of Field Study Sites for Depressed Transverse Crack Project

Phase II Site Visit

Typical depressed and nondepressed cracks were plotted for the 1000-ft section located in Phase I of the project, as shown in Figure 8. The transverse highway profile at two typical cracks was surveyed (see Figure 9). At the two selected typical cracks, detailed surveys of the cracks and depressions were made. The standard for location of the transverse survey points is shown in Figure 10. The crack depth, crack width, depression width, and depression depth were measured for the depressed crack at each section. Crack width and depth were measured for the nondepressed crack. This was done by using a flat metal straight edge placed on the pavement surface perpendicular to the crack. Typical results of the detailed crack survey are shown in Figure 11. Photographs were taken to show the severity and extent of the cracking.

Phase III Site Visit

Pavement cores and soil samples were taken using an ODOT Research Division drilling rig. A 6.0-in. diameter core barrel was used to obtain samples from the center of the travel lane and wheel path at the typical depressed and nondepressed cracks selected in Phase II of the field work. After coring, each specimen was immediately wrapped in an appropriately marked plastic bag for transport to the laboratory. Soil samples were then taken at depths of 0.5 to 1.0, 1.5 to 2.0, 2.5 to 3.0, 3.5 to 4.0, and 4.5 to 5.0 ft. in one hole. Shelby tube samples were attempted in the other hole at sites with more cohesive soils but with limited success. At sites which could not be Shelby tube sampled, a soil sample was augered from a depth of 0.5 to 3.5 ft in the hole.

ODOT - Depressed Transverse Cracking in Asphalt Pavements Project
Crack Survey
Site 1, SH 51 West of Stillwater

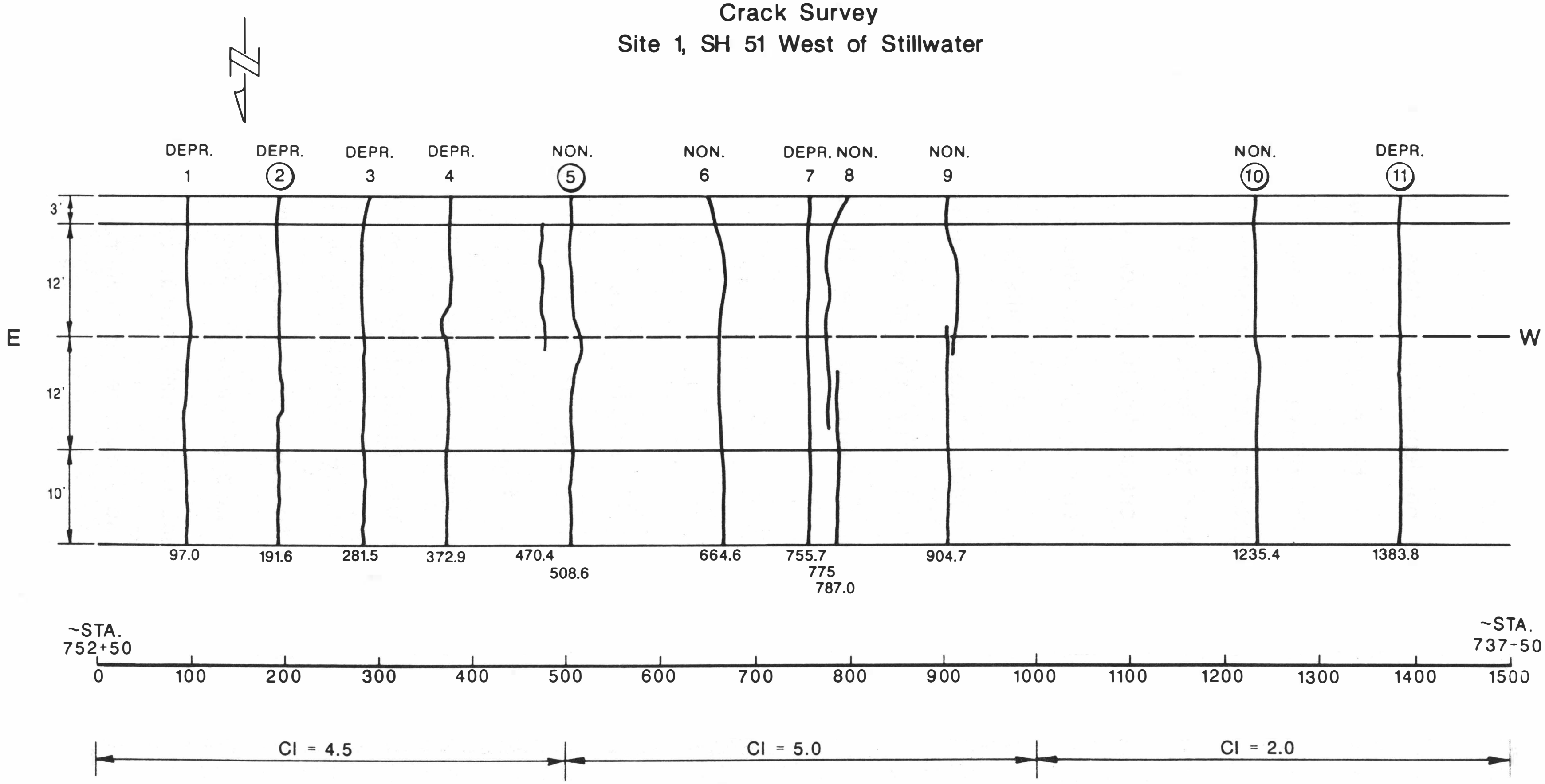


Figure 8. Typical Crack Survey Results for 1000-Ft Field Study Section

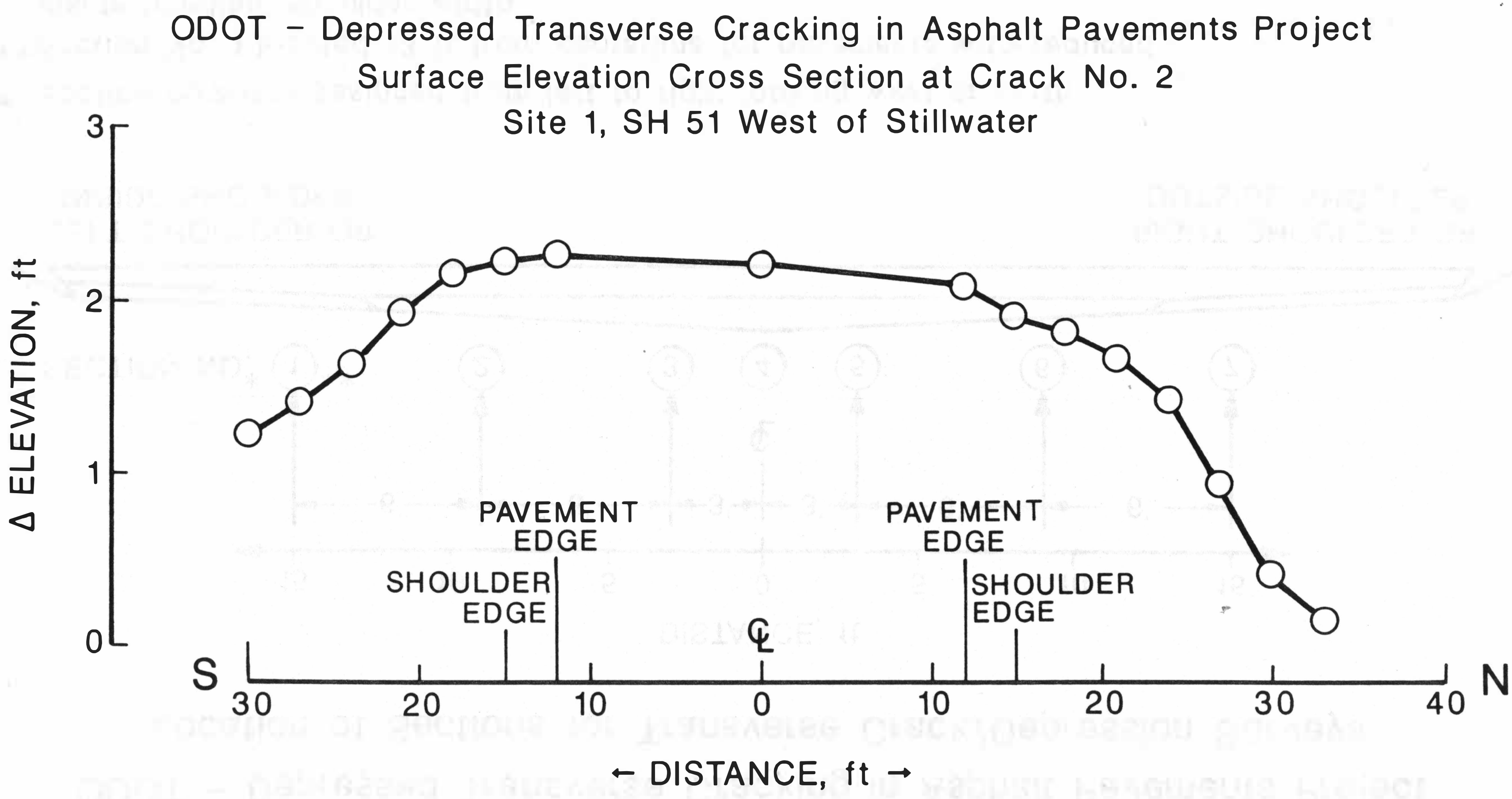
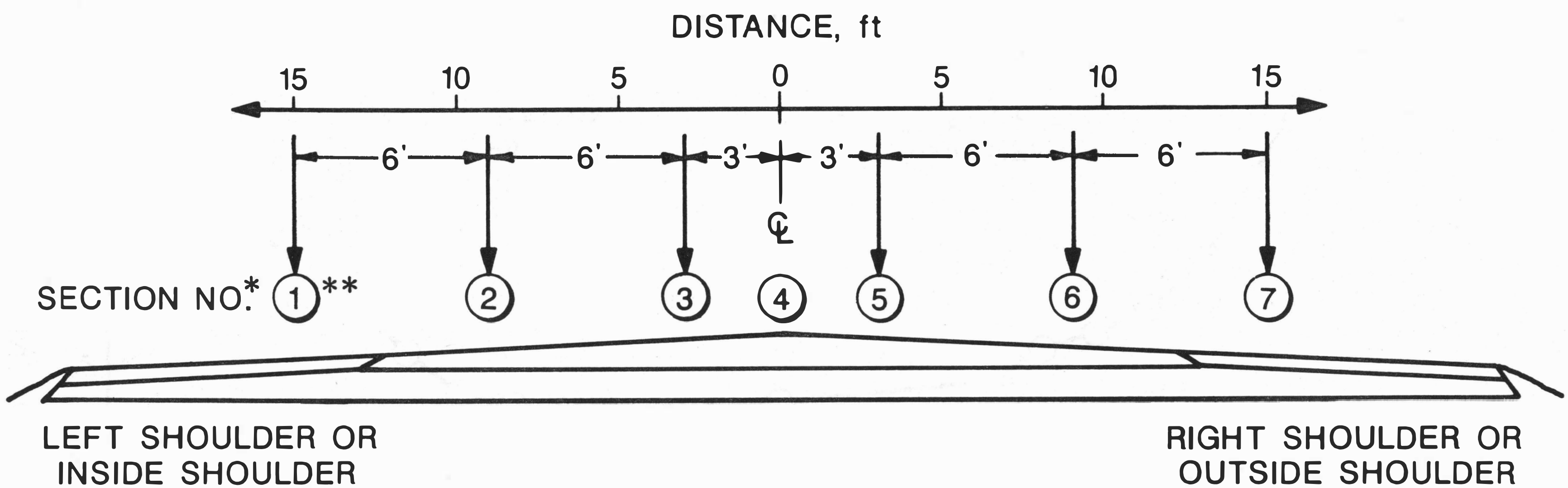


Figure 9. Typical Highway Surface Elevation Cross Section at a Depressed Transverse Crack

ODOT - Depressed Transverse Cracking in Asphalt Pavements Project

Location of Sections for Transverse Crack/Depression Surveys



* Section numbers assigned from left to right looking west or north

**Section No. 1 located 13 ft from centerline for pavements with reduced inside (median) shoulder width

Figure 10. Standard for Location of Crack Survey Sections for Transverse Cracks

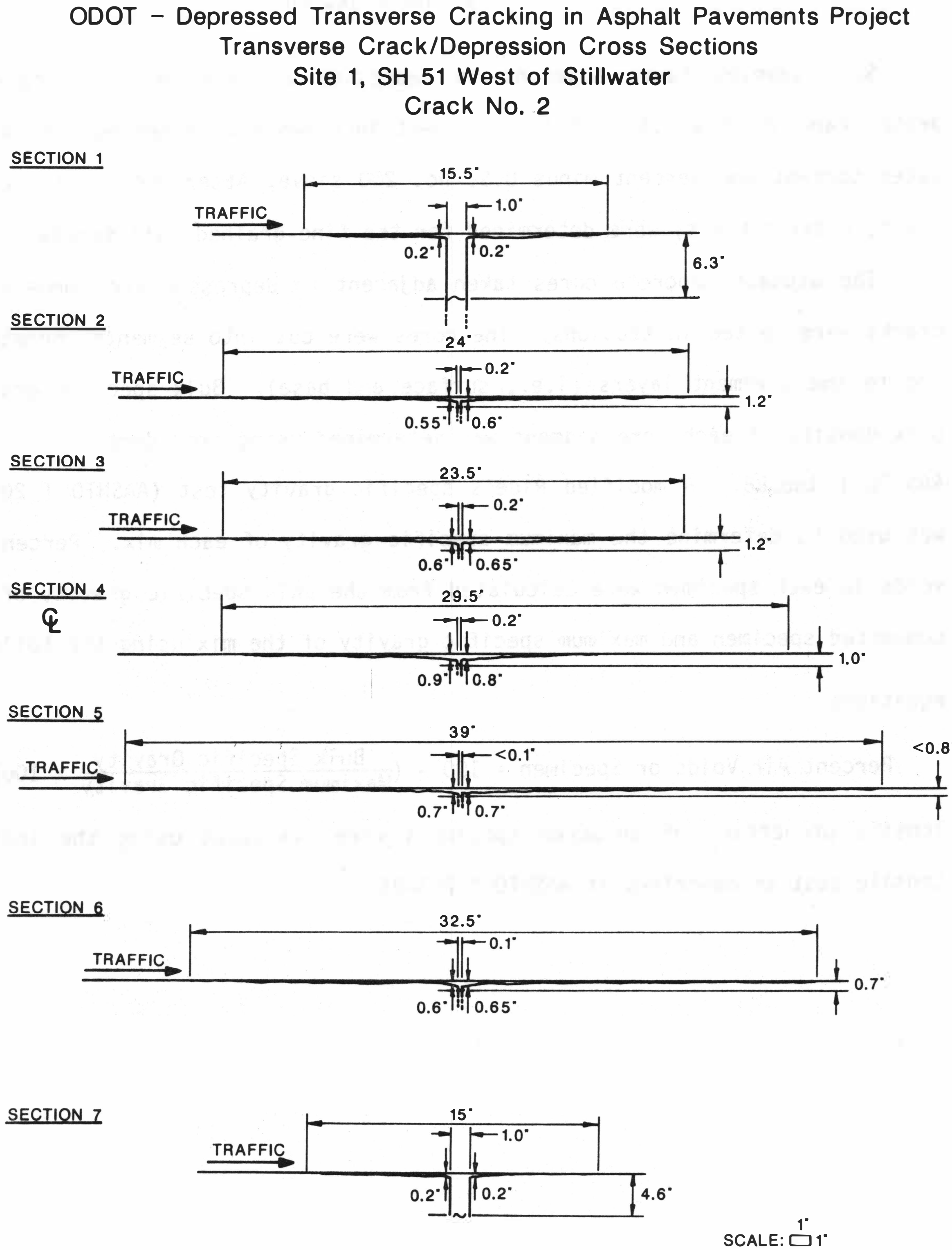


Figure 11. Typical Transverse Crack/Depression Cross Sections for a Selected Transverse Crack

Laboratory Investigation

Soil samples taken adjacent to depressed and nondepressed cracks at depths ranging from 0.5 to 5 ft in 0.5-ft increments were tested for natural water content and percent minus U.S. No. 200 sieve. Atterberg Limits (Liquid Limit, Plastic Limit) were determined for the fine-grained soil samples.

The asphalt concrete cores taken adjacent to depressed and nondepressed cracks were tested in sections. The cores were cut into segments corresponding to the pavement layers (i.e., surface and base). Bulk specific gravity/bulk density of each core segment was determined using procedures outlined in AASHTO T 166-88. A modified Rice's specific gravity test (AASHTO T 209-82) was used to determine the maximum specific gravity of each mix. Percent air voids in each specimen were calculated from the bulk specific gravity of each compacted specimen and maximum specific gravity of the mix using the following equation:

$$\text{Percent Air Voids or Specimen} = 100 - \left(\frac{\text{Bulk Specific Gravity}}{\text{Maximum Specific Gravity}} \times 100\right)$$

Tensile properties of selected specimens were evaluated using the indirect tensile test as described in AASHTO T 283-85.

CHAPTER IV

RESULTS

Introduction

The results of field and laboratory investigations were compiled and evaluated using the statistical analysis program, SYSTAT. The computer program was used to determine if any two variables were linearly related, rather than developing linear regression equations to predict responses. The correlation coefficient "r" was used as a measure of the strength of the linear relationship between pairs of variables. The value of "r" may fall anywhere between -1 and +1. The coefficient "r" is equal to 1 if all (X_i, Y_{ie}) pairs lie on a straight line with a positive slope; and r is equal to -1 if all (X_i, Y_{ie}) pairs lie on a straight line with negative slope. According to this property, the largest positive and largest nega-tive correlations are achieved only when all points lie on a straight line. Any other configuration of points will yield an "r" value less than 1 in absolute magnitude. Thus, "r" measures the degree of linearity of the relationship between variables. Figure 12 illustrates several configurations of points associated with different values of "r" [21].

Results of Field and Laboratory Investigations

All data collected during the field investigation site visits were either plotted on plan and profile sheets or on typical data presentations, as shown in Figure 8, 9, and 11. Because of the large number of figures resulting from 26 field study sites, it was decided to combine and present the data in tabu-lar form. General site and climate data, including average daily traffic, pavement age, pavement thickness, and annual and monthly temperature and

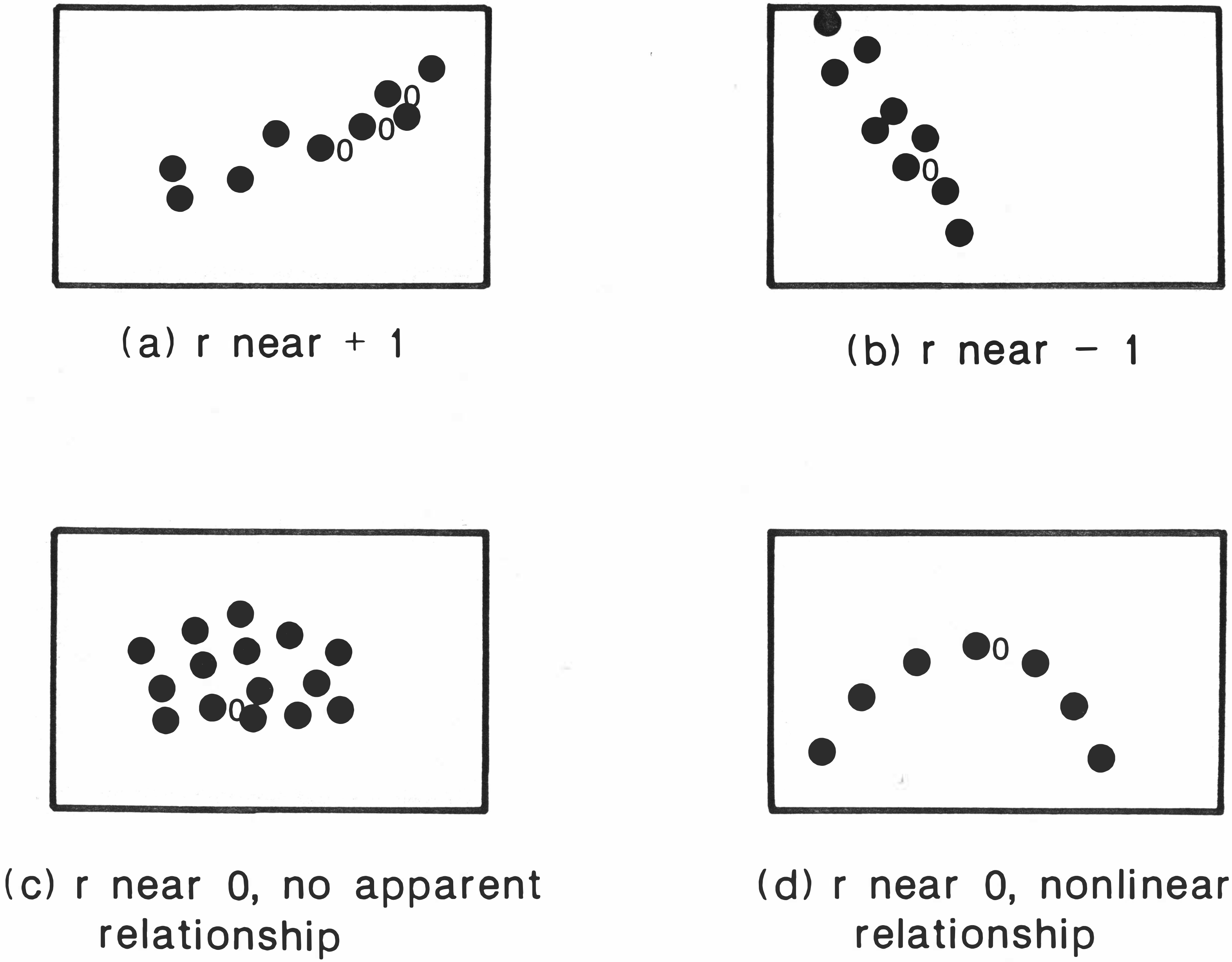


Figure 12. Typical Data Plots Showing Different Values of "r"

rainfall values are presented in Table 1. The total number of cracks, number of depressed and nondepressed cracks, and the average spacing for each group is shown in Table 2. Further categorization of the number and average spacing of total, depressed, and nondepressed cracks was done on the basis of cut, fill, and at-grade portions of the 1000-ft long field study sites; results are presented in Table 3. Average end (cross section) areas at transverse sections and average crack volume were calculated for depressed and nondepressed cracks, and are presented in Tables 4 and 5, respectively. The results of laboratory tests on asphalt concrete cores and subgrade soil samples are presented in Tables 6 and 7, respectively.

Statistical Comparisons

To evaluate the factors that influence the occurrence and distribution of transverse cracks in asphalt pavements using statistical methods, it is necessary to establish some parameter(s) as dependent variables and compare them to the remaining parameters (i.e., independent variables). Crack Indexes were selected as dependent variables, and the field and laboratory data summarized in Tables 1 through 7 were selected as independent variables. Conventional Crack Indexes, such as number of transverse cracks per 1000 ft, were used as well as some variations to try to represent both the number of cracks and the severity of the crack. For example, the number of transverse cracks times the cross sectional (average end) area at the pavement centerline of the typical crack at each field site was one variation used in the correlation study. The following is a list of the dependent variables which were used in this study:

1. Number of full transverse cracks per 1000 ft,
2. Average transverse crack spacing in a 1000-ft section,

TABLE 1

GENERAL SITE AND CLIMATE DATA

Site No.	Average Daily Traffic (1987)	Pave-ment Age (Years)	Original Pavement Thickness (In.)		Average Annual Temp. (1986-89)	Average High Monthly Temp. (1986-89)	Average Low Monthly Temp. (1986-89)	Average Annual Rainfall (1986-89)	Average Monthly Rainfall (1986-89)
			Surface	Base					
1-1	8500	16	2.0	6	60.9	83.7	37.9	40.8	8.2
1-2	4700	19	3.5	16	62.9	84.4	39.0	42.0	8.2
1-3	1300	14	4.0	8	60.9	82.5	36.7	45.2	8.3
2-1	2900	16	4.0	8	63.8	84.8	41.0	43.2	7.3
2-2	4400	16	4.0	8	63.8	84.8	41.0	43.2	7.3
2-3	900	11	6.0	6	63.8	84.8	41.0	43.2	7.3
2-5	4400	20	4.5	7	62.4	81.5	37.9	38.8	7.2
3-1	14000	27	4.5	8	59.2	81.6	35.9	42.6	7.8
3-3	2700	16	4.0	8	62.7	84.9	37.9	45.7	8.1
4-1	15500	15	4.5	8	57.2	82.2	33.4	36.4	7.2
4-2	3900	15	4.5	8	61.1	83.3	35.9	37.6	8.2
4-3	1350	21	2.0	10	61.0	82.5	35.1	43.1	6.9
4-4	3100	19	4.5	8	60.8	83.1	32.8	40.8	9.2
5-1	2600	37	0.5	8	60.4	82.8	34.6	29.4	7.1
5-2	10000	20	4.5	9	60.3	81.1	34.6	32.8	8.5
5-3	9500	15	4.5	8	60.3	81.1	34.6	29.8	8.2
5-4	2200	11	5.0	7	61.3	83.5	35.9	28.7	7.9
6-2	2400	38	--[a]	--[a]	61.2	83.8	33.5	34.1	7.8
6-3	1800	53	1.5	6	59.2	80.3	34.2	16.1	4.9
6-4	4300	46	1.5	8	58.9	80.1	32.0	14.3	3.9
7-2	3800	23	4.5	8	61.9	83.9	37.5	44.7	10.4
7-3	2900	56	1.5	5	61.7	84.2	37.0	41.2	11.3
7-4	6400	23	4.5	8	61.7	84.2	36.4	28.7	8.1
7-5	4500	20	4.5	8	61.6	84.8	37.1	28.7	8.1
8-1	100	12	3.0	6	61.5	81.9	38.9	31.4	7.2
8-3	4800	18	4.5	8	61.2	84.3	35.7	41.9	7.6

[a]Data not available.

TABLE 2

CRACK TYPE, NUMBER OF CRACKS, AND AVERAGE CRACK SPACING AT FIELD STUDY SITES

Site No.	Depressed Cracks		Nondepressed Cracks		Total Cracks	
	Number	Average Spacing (ft)	Number	Average Spacing (ft)	Number	Average Spacing (ft)
1-1	6	149.7	--[b]	--[b]	6	149.7
1-2	10	94.4	27	36.2	37	27.4
1-3	4	291.3	5	130.6	9	97.1
2-1	4	236.7	20	43.9	24	40.6
2-2	5	189.8	10	88.9	15	61.1
2-3	--[a]	--[a]	32	31.7	32	31.7
2-5	3	142.5	19	52.6	22	46.2
3-1	14	65.5	12	84.1	26	37.0
3-3	13	69.0	17	63.5	30	31.7
4-1	5	164.5	4	132.0	9	128.6
4-2	9	110.0	4	274.5	13	79.8
4-3	8	103.3	3	387.5	11	93.9
4-4	10	84.2	5	90.2	15	72.0
5-1	6	133.8	12	84.4e	18	54.6
5-2	1	--[c]	5	208.2	6	166.6
5-3	6	184.2	5	155.5	11	92.1
5-4	1	--[c]	16	46.1	17	46.1
6-2	9	120.1	12	79.6	21	47.9
6-3	23	39.7	7	58.7	30	25.7
6-4	27	35.2	4	144.0	31	33.0
7-2	1	--[c]	2	222.0	3	111.0
7-3	4	238.3	10	74.5	14	73.8
7-4	1	--[c]	6	135.8	7	140.5
7-5	2	423.0	13	75.3	15	70.1
8-1	5	207.2	15	65.3	20	50.6
8-3	2	469.0	6	137.8	8	126.8

[a]No depressed cracks at site.

[b]No nondepressed cracks at site.

[c]Insufficient number of cracks to calculate.

TABLE 3

NUMBER AND AVERAGE SPACING OF DEPRESSED AND NONDEPRESSED CRACKS
IN CUT, FILL, AND AT-GRADE PORTIONS OF FIELD SITE

		Cracks in Cut Portion							Cracks in F		
		Depressed		Nondepressed		Total			Depressed		Nondep
Site No.	Length of Cut (ft)	Number	Average Spacing (ft)	Number	Average Spacing (ft)	Number	Average Spacing (ft)	Length of Fill (ft)	Number	Average Spacing (ft)	Number
1-1	1000	6	149.7	0	--	6	149.7	0	0	--	0
1-2	0	0	--	0	--	0	--	710	7	62.5	20
1-3	0	0	--	0	--	0	--	1000	4	291.3	5
2-1	200	0	--	0	--	0	--	760	3	236.7	20
2-2	0	0	--	0	--	0	--	1000	5	189.8	10
2-3	190	0	--	6	40.3	6	40.3	610	0	--	19
2-5	0	0	--	0	--	0	--	1000	3	142.5	19
3-1	735	11	53.6	11	80.1	22	32.9	265	3	63.0	1
3-3	330	3	79.7	6	42.3	9	33.9	670	10	61.4	11
4-1	800	5	130.5	2	156.0	7	109.7	200	0	--	2
4-2	510	3	96.7	3	465.0	6	123.2	490	6	99.8	1
4-3	570	6	64.2	1	--	7	89.5	430	2	98.0	2
4-4	450	7	68.5	0	--	7	68.5	550	3	138.5	5
5-1	455	1	--	8	50.7	9	42.0	545	5	95.0	4
5-2	150	0	--	1	--	1	--	850	1	--	4
5-3	0	0	--	0	--	0	--	1000	6	184.2	5
5-4	380	0	--	8	49.6	8	49.6	620	1	--	8
6-2	500	6	98.2	10	49.2	16	29.6	500	3	217.0	2
6-3	0	0	--	0	--	0	--	750	20	38.0	12
6-4	1000	27	35.3	4	144.0	31	33.0	0	0	--	0
7-2	320	0	--	0	--	0	--	680	1	--	2
7-3	210	1	--	1	--	2	70.0	790	3	57.0	9
7-4	0	0	--	0	--	0	--	1000	1	--	6
7-5	1000	2	423.0	13	75.3	15	70.1	0	0	--	0
8-1	470	2	133.0	5	67.8	7	53.2	530	3	181.0	10
8-3	330	0	--	3	91.5	3	91.5	610	2	469.0	3

ill Portion				Cracks on At-Grade Portion					
ressed	Total		Length of At-Grade (ft)	Depressed		Nondepressed		Total	
Average Spacing (ft)	Number	Average Spacing (ft)		Number	Average Spacing (ft)	Number	Average Spacing (ft)	Number	Average Spacing (ft)
--	0	--	0	0	--	0	--	0	--
37.6	27	26.1	290	3	56.7	7	38.8	10	22.1
130.6	9	97.1	0	0	--	0	--	0	--
43.3	23	44.6	40	1	--	9	--	0	--
88.9	15	61.1	0	0	--	0	--	0	--
31.5	19	31.5	200	0	--	7	25.4	7	25.4
52.7	22	46.2	0	0	--	0	--	0	--
--	4	57.7	0	0	--	0	--	0	--
31.7	21	29.6	0	0	--	0	--	0	--
117.0	2	117.0	0	0	--	0	--	0	--
--	7	79.8	0	0	--	0	--	0	--
42.0	4	68.7	0	0	--	0	--	0	--
90.3	8	63.4	0	0	--	0	--	0	--
143.3	9	65.4	0	0	--	0	--	0	--
194.3	5	145.8	0	0	--	0	--	0	--
155.5	11	92.1	0	0	--	0	--	0	--
37.6	9	37.6	0	0	--	0	--	0	--
329.0	5	108.5	0	0	--	0	--	0	--
53.5	32	22.6	250	3	28.5	0	--	3	28.5
--	0	--	0	0	--	0	--	0	--
222.0	3	111.0	0	0	--	0	--	0	--
65.9	12	58.4	0	0	--	0	--	0	--
135.8	7	140.5	0	0	--	0	--	0	--
--	0	--	0	0	--	0	--	0	--
51.2	13	40.4	0	0	--	0	--	0	--
200.5	5	150.0	60	0	--	0	--	0	--

TABLE 4

AVERAGE END AREA AT TRANSVERSE SECTIONS AND AVERAGE CRACK VOLUME FOR TYPICAL DEPRESSED CRACK (INCLUDES CRACK AND DEPRESSION)

Site No.	Average Cross-Sectional Area of Crack at Section ($in.^2$)							Average Volume of Crack ($In.^3$)
	1	2	3	4	5	6	7	
1-1	3.4	6.2	5.4	8.4	7.1	6.3	5.5	182.6
1-2	---[a]	0.0	2.2	0.1	0.0	0.9	0.3	16.2
1-3	8.0	10.2	6.4	9.5	19.3	3.3	3.3	259.7
2-1	1.4	7.3	5.8	3.3	3.8	4.7	0.2	130.2
2-2	0.6	4.7	2.4	1.1	3.2	2.1	0.6	72.6
2-3	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]
2-5	0.1	0.1	0.1	0.1	0.1	0.1	0.6	2.9
3-1	---[a]	4.1	1.6	2.5	3.0	8.1	1.3	93.3
3-3	0.7	4.1	2.1	0.6	2.9	4.2	0.6	77.5
4-1	7.8	7.0	7.4	12.5	13.6	10.1	6.9	278.5
4-2	1.6	10.7	5.9	5.5	8.0	9.4	3.0	213.6
4-3	1.4	7.8	9.2	13.7	10.4	8.5	13.0	270.0
4-4	0.0	11.0	7.5	3.8	6.2	6.9	6.9	201.4
5-1	0.1	2.2	3.4	2.1	6.2	11.4	---[a]	97.4
5-2	0.2	1.9	1.2	0.4	0.7	0.0	0.4	21.9
5-3	0.0	2.0	2.2	0.0	8.3	6.1	0.2	96.8
5-4	---[a]	1.6	1.1	0.2	0.1	0.1	---[a]	11.2
6-2	---[a]	0.8	1.0	0.0	0.5	0.9	---[a]	11.6
6-3	---[a]	4.1	1.5	0.1	1.3	0.0	---[a]	25.5
6-4	---[a]	---[b]	0.1	3.3	4.8	5.6	0.0	65.6
7-2	11.2	9.9	9.9	13.9	8.6	8.2	12.6	304.9
7-3	8.9	---[b]	---[b]	6.6	6.1	7.2	3.4	144.7
7-4	---[a]	0.0	0.0	0.8	0.8	1.3	---[a]	10.1
7-5	2.2	1.2	0.0	1.3	2.7	3.5	0.7	53.5
8-1	0.0	3.1	7.5	6.2	5.0	4.9	0.8	125.8
8-3	2.2	3.3	1.2	4.6	6.2	3.3	0.8	95.7

[a]Section 1 not within roadway because of narrow or nonexistent shoulder.
[b]Insufficient data.

TABLE 5

AVERAGE END AREA AT TRANSVERSE SECTIONS
AND AVERAGE CRACK VOLUME FOR
TYPICAL NONDEPRESSED CRACK

Site No.	Average Cross-Sectional Area of Crack at Section ($In.^2$) 1	2	3	4	5	6	7	Average Volume of Crack ($In.^3$)
1-1	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]
1-2	0.2	0.0	0.2	0.1	---[b]	0.1	0.4	3.5
1-3	2.1	4.8	0.8	0.8	4.6	3.9	3.9	96.7
2-1	0.8	0.1	0.1	0.1	0.2	0.2	0.4	7.0
2-2	---[a]	0.5	0.4	0.8	0.1	0.2	0.5	12.1
2-3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.5
2-5	0.2	0.3	0.0	0.2	0.0	0.0	0.3	4.2
3-1	0.3	0.0	0.0	0.0	0.3	0.5	0.0	5.6
3-3	0.3	0.0	0.1	1.0	0.9	3.7	0.9	33.3
4-1	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]
4-2	6.0	0.3	0.3	1.4	0.1	0.1	2.8	35.5
4-3	3.3	0.3	0.2	0.7	0.1	0.1	0.7	18.2
4-4	0.5	0.0	0.7	2.4	0.3	3.8	2.0	42.7
5-1	0.7	0.0	0.0	0.4	0.1	0.0	0.4	5.9
5-2	0.1	0.2	0.0	0.0	0.1	0.1	0.1	3.2
5-3	0.1	0.0	0.1	0.0	0.0	0.0	0.2	2.4
5-4	---[a]	0.4	0.2	0.2	0.1	0.2	---[a]	7.4
6-2	---[a]	0.0	0.0	0.0	0.0	0.0	---[a]	0.3
6-3	---[a]	0.0	0.0	0.0	0.1	0.0	---[a]	0.5
6-4	---[a]	0.1	---[b]	0.0	--[b]	0.1	0.2	1.5
7-2	0.1	0.0	0.0	0.1	0.1	0.0	0.3	2.4
7-3	2.5	0.0	0.0	2.5	0.0	0.2	0.4	17.7
7-4	---[a]	0.2	0.0	0.1	0.0	0.0	---[a]	2.8
7-5	2.0	0.0	0.0	0.1	0.1	0.0	0.6	9.2
8-1	0.0	0.4	3.5	2.1	0.3	1.5	2.4	43.1
8-3	0.6	0.1	0.0	0.0	0.0	0.0	0.0	2.9

[a]Section 1 not within roadway because of narrow or nonexistent shoulder.
[b]Insufficient data.

TABLE 6

RESULTS OF LABORATORY TESTS ON ASPHALT CONCRETE CORES

Site No.	Type of Crack	Bulk Specific Gravity		Maximum Specific Gravity		Percent Voids		Split Tensile Strength (psi)	
		Surface	Base	Surface	Base	Surface	Base	Surface	Base
1-1	D	2.26	2.22	2.41	2.47	6.2	10.1	185.1	76.5
1-2	D	2.24	2.26	2.43	2.53	7.8	10.7	212.9	120.0
1-2	ND	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	146.9	--[a]
1-3	D	2.22	2.04	2.46	2.44	9.8	16.4	157.5	--[b]
1-3	ND	2.18	2.07	2.46	2.44	11.4	15.2	201.5	115.7
2-1	D	2.26	1.97	2.44	2.45	7.4	9.8	175.0	73.6
2-1	ND	2.30	1.97	2.59	2.42	11.2	18.6	129.0	58.5
2-2	D	2.29	1.97	2.43	2.43	5.8	18.9	146.5	59.9
2-2	ND	2.11	1.93	2.45	2.44	13.9	20.9	162.5	102.5
2-3	D	2.21	1.91	2.02	2.46	--[b]	22.4	--[b]	--[b]
2-5	D	2.25	2.21	2.43	2.45	7.4	9.8	170.0	74.0
2-5	ND	2.35	2.25	2.44	2.46	3.7	8.5	147.5	47.2
3-1	D	2.28	1.79	2.42	2.43	5.8	26.3	108.4	90.2
3-1	ND	2.26	--[c]	2.45	--[c]	7.8	--[c]	149.9	269.5
3-3	D	2.31	1.87	2.53	2.47	8.7	24.3	179.1	28.5
3-3	ND	2.13	1.86	2.50	2.44	14.8	23.8	142.3	52.3
4-1	D	1.86	1.91	2.46	2.51	24.4	23.9	100.0	52.1
4-1	ND	2.27	1.94	2.47	2.43	8.1	20.2	100.7	55.3
4-2	D	2.43	2.02	2.59	2.48	6.2	18.5	143.7	78.8
4-2	ND	2.42	2.04	2.58	2.45	6.2	16.7	164.9	86.4
4-3	D	2.36	1.98	2.54	2.45	7.1	19.2	125.2	79.4
4-3	ND	2.43	1.99	2.55	2.47	4.7	19.4	122.6	101.7
4-4	D	2.23	--[b]	2.46	2.44	9.3	--[b]	76.5	92.4
4-4	ND	2.23	--[b]	2.45	2.43	9.0	--[b]	97.9	53.6
5-1	D	2.37	--[c]	2.51	--[c]	5.6	--[c]	104.9	84.3
5-1	ND	2.37	--[c]	2.49	--[c]	4.8	--[c]	85.9	--[c]
5-2	D	2.36	2.24	2.51	2.48	6.6	9.8	105.0	91.0
5-2	ND	2.34	--[c]	2.50	--[c]	6.4	--[c]	91.1	79.5
5-3	D	2.35	--[c]	2.50	--[c]	6.0	--[c]	90.7	170.5
5-3	ND	2.37	--[c]	2.50	--[c]	5.2	--[c]	99.3	152.6
5-4	D	2.36	--[b]	2.51	2.43	6.0	--[b]	127.4	--[b]
5-4	ND	2.35	--[b]	2.48	2.43	5.2	--[b]	129.3	71.1
6-2	D	2.19	1.98	2.46	2.36	11.0	16.1	62.3	46.0
6-2	ND	2.23	--[c]	2.45	--[c]	9.0	--[c]	58.5	59.6
6-3	D	2.19	2.03	2.43	2.36	9.9	14.0	109.3	85.4
6-3	ND	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	108.0	46.3
6-4	D	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	111.9	44.6
6-4	ND	2.33	--[b]	2.50	2.40	6.8	--[b]	113.5	46.0
7-2	D	2.30	1.94	2.46	2.44	6.5	20.5	120.7	66.3
7-2	ND	2.39	1.97	2.45	2.43	2.4	18.9	147.5	54.8
7-3	D	2.35	1.87	2.48	2.45	5.2	23.7	147.9	92.5
7-3	ND	2.32	1.91	2.48	2.44	6.5	21.7	124.4	84.6
7-4	D	2.34	2.14	2.46	2.46	4.9	13.0	151.2	134.2
7-4	ND	2.34	2.14	2.47	2.46	5.3	13.0	153.6	135.8
7-5	D	2.30	2.33	2.46	2.56	6.5	9.0	165.7	--[b]
7-5	ND	2.27	1.86	2.48	2.44	8.5	23.8	194.8	25.8
8-1	D	2.31	--[c]	2.48	--[c]	6.9	--[c]	182.1	167.5
8-1	ND	2.38	2.21	2.48	2.48	4.0	10.9	169.1	167.2
8-3	D	2.42	1.90	2.56	2.43	5.5	21.8	189.3	71.7
8-3	ND	2.37	1.90	2.56	2.44	7.4	22.1	140.1	68.7

[a]Good quality cores not available.

[b]Sample not intact.

[c]Base material not sampled.

TABLE 7

RESULTS OF LABORATORY TESTS ON SUBGRADE SOIL SAMPLES

Site No.	Type of Crack	Natural Water Content (%)	Percent Minus No. 200	Liquid Limit (%)	Plastic Limit (%)	Plastic Index	AASHTO Soil Class.
1-1	D	16.5	85.9	0	0	NP	A3
1-1	D	10.7	40.0	0	0	NP	A2
1-2	ND	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]
1-3	D	18.1	76.7	0	0	NP	A3
1-3	ND	11.2	23.4	0	0	NP	A1
2-1	D	14.1	31.7	0	0	NP	A2
2-1	ND	15.9	37.9	0	0	NP	A2
2-2	D	17.0	42.2	30.6	17.6	13.0	A6
2-2	ND	14.7	36.5	25.2	20.0	5.2	A4
2-3	ND	7.8	29.4	0	0	NP	A2
2-5	D	14.0	74.8	29.1	17.2	11.9	A4
2-5	ND	14.0	75.1	28.0	17.4	10.6	A6
3-1	D	14.5	75.2	32.6	16.5	16.1	A6
3-1	ND	13.1	80.1	31.4	17.0	14.4	A6
3-3	D	13.8	41.1	25.0	15.5	9.5	A6
3-3	ND	11.9	50.4	22.0	16.5	5.5	A6
4-1	D	13.1	34.9	20.7	17.3	3.4	A2
4-1	ND	12.1	45.2	21.7	16.0	5.7	A6
4-2	D	10.4	39.1	0	0	NP	A2
4-2	ND	12.8	41.5	24.0	16.7	7.3	A6
4-3	D	15.0	65.3	22.2	15.1	7.1	A4
4-3	ND	15.7	65.3	23.3	16.7	6.6	A4
4-4	D	15.3	66.3	0	0	NP	A2
4-4	ND	12.0	69.4	31.4	20.9	10.5	A4
5-1	D	13.2	63.7	22.8	16.0	6.8	A6
5-1	ND	18.8	59.7	0	0	NP	A3
5-2	D	16.3	79.7	32.9	15.7	17.2	A6
5-2	ND	16.9	80.5	33.8	20.4	13.4	A6
5-3	D	12.2	45.5	31.7	14.5	17.4	A6
5-3	ND	14.3	64.8	37.4	17.8	19.6	A6
5-4	D	8.3	25.9	0	0	NP	A2
5-4	ND	6.9	21.5	0	0	NP	A1
6-2	D	5.5	33.1	0	0	NP	A2
6-2	ND	6.5	26.0	0	0	NP	A2
6-3	D	8.5	58.0	24.5	12.6	11.9	A6
6-3	ND	8.3	54.4	23.2	13.3	9.9	A6
6-4	D	14.8	57.7	22.2	11.4	10.8	A6
6-4	ND	13.6	57.8	23.1	12.0	11.1	A6
7-2	D	10.4	21.9	0	0	NP	A1
7-2	ND	7.2	20.5	0	0	NP	A1
7-3	D	17.7	65.4	34.0	18.5	15.5	A6
7-3	ND	14.8	68.2	41.0	23.5	17.5	A7
7-4	D	15.3	46.2	27.5	15.9	11.6	A6
7-4	ND	11.2	64.6	27.1	15.1	12.0	A6
7-5	D	19.6	79.8	33.5	19.5	14.0	A6
7-5	ND	22.9	77.1	0	0	NP	A3
8-1	D	19.2	84.3	35.1	21.5	13.6	A6
8-1	ND	22.0	90.1	38.9	26.0	12.9	A6
8-3	D	15.0	65.1	0	0	NP	A3
8-3	ND	15.6	62.2	0	0	NP	A3

[a]Soil samples not taken0

3. Number of full transverse cracks times the average end area at pavement centerline of typical cracks, and

4. Average transverse crack spacing times the average end area (in.^{2}) at pavement centerline of typical cracks.

Other dependent variables were tried, but they gave no measurable correlation with the field and laboratory data. Results of the statistical comparisons that yielded reasonable correlations (i.e., $r > 0.4$) are discussed in the following sections.

Number of Cracks Per 1000 Feet

Correlation coefficients on the range 0.4 to 0.7 were found between the number of cracks per 1000 ft and climatic factors such as average high monthly temperature (AHMT), average low monthly temperature (ALMT), and average monthly rainfall. The correlation with ALMT was obviously not unexpected, since transverse cracking of asphalt pavements is a thermal problem, the fact that as the ALMT decreased the number of cracks increased was not suprising. In other words, the colder the temperature the more the asphalt pavement cracks. The correlation with AHMT indicated that as the AHMT increased, the number of cracks per 1000 ft increased. This most likely reflects the fatigue effect of the expansion/contraction cycles induced by temperature extremes. In other words, the greater the temperature range from low to high, the greater the expansion/contraction deformation cycle (i.e., more deformation) the greater the cracking.

The correlation with average monthly rainfall (AMR) indicated that as rainfall increased, the number of cracks increased. This most likely reflects the moisture degradation influence on the asphalt concrete and the worsening of the cracking as water enters the transverse crack and strips the asphalt adjacent to the crack and softens the subgrade soil.

Average Crack Spacing

The statistical evaluation indicated that the average crack spacing correlated ($0.4 < r < 0.5$) with the average natural water content of the upper 2 ft of the subgrade. However, this was contrary to what was indicated or expected in the literature. For example, the average crack spacing increased (i.e., fewer cracks in 1000-ft section) as the average natural water content increased. It is generally accepted that the wetting of the subgrade from water moving through the transverse crack results in the notable depression which is characteristic of the "mature" transverse crack. Based on this fact, it is also a generally accepted fact that softer subgrades will result in more cracking rather than less.

Number of Cracks Per 1000 Feet Times Average End Area at Pavement Centerline

The statistical evaluation indicated that the number of cracks times average end area correlated ($0.42 < r < 0.53$) with the average plastic limit of the upper portion of the subgrade. The correlation with one of the measures of plasticity of soils confirms the accepted trend that transverse cracking, particularly depressed transverse cracking and severity of damage, is more significant in pavements founded on cohesive subgrades. This is due to the "softening" of cohesive subgrades as water moves through the cracks into the subgrade.

Results of Division Office Visits

The final portion of the evaluation of depressed transverse cracks in Oklahoma asphalt pavements involved a review of ODOT procedures for construction and maintenance of asphalt pavements. To complete this review, visits were scheduled with construction and maintenance personnel in all eight division offices. One member of the OSU research project staff and at least one representative from the ODOT Research Division traveled to each division office. Specific topics of discussion included:

1. Occurrence/extent of depressed (or nondepressed) transverse cracking problem within the division.
2. Extent that ODOT material or construction specifications and/or construction procedures influence the depressed/nondepressed transverse cracking problem.
3. Local experience or practice with regard to early detection of transverse cracking problem and maintenance and remedial procedures for dealing with depressed/nondepressed transverse cracks.

The discussions were limited to small groups and the exchange of information was very good. Summaries of the discussions with each division office are presented in the Appendix to this report. The following sections present the major findings from the visits according to the discussion topics listed.

Occurrence/Extent of Transverse Cracking Problem

The extent of the transverse cracking problem varies from division to division with the lowest occurrence of transverse cracks in Division 1 (i.e. moderate problem). Serious transverse cracking problems were noted in Divisions 3, 5, 6, and 7. In other words, transverse cracking is a problem that exists statewide with varying degrees of seriousness. Depressed transverse cracking is a problem that also varies across the state. Essentially all divisions reported some depressions or faulting associated with the transverse cracking. The extent of the occurrence of depressions appears to be related to how active and effective maintenance programs are in reducing the ingression of water into the subgrade.

Other factors which influence the occurrence/extent of transverse cracking include pavement age, pavement cross section, subgrade type, and traffic. Asphalt pavements between 15 and 20 years old seem to exhibit a greater amount of transverse cracking. This is the result of the change in asphalt properties that occurred in the early to mid-1970s because of the energy crisis. Refining processes changed so that more petroleum products could be obtained, at the cost of the properties of the asphalt being produced.

Base course materials consisting of soil asphalt and to a degree hot sand asphalt generally result in more transverse cracks. Both materials have essentially been eliminated from routine use. Although several divisions reflected an influence of subgrade soil type on transverse cracking, the results were inconclusive. For example, one division believed that fine-grained soils posed more of a problem while another blamed sandy subgrades. The actual occurrence of transverse cracks is surely related to the subgrade, but more than likely the subgrade influence is reflected in the condition of the subgrade rather than the soil type. For example, the rigidity of the subgrade soil as reflected in the density of the soil is probably a greater influence than soil type.

The occurrence of depressions or faulting is more related to soil type since fine-grained soils are more likely to soften than coarse-grained soils. The obvious influence of traffic is supported by the division office discussions; that is, the more traffic and the heavier the traffic, the more transverse cracking and more depressions or faulting.

Specifications/Materials Influence

The major conclusion from this discussion topic was that asphalt properties changed in the early to mid-1970s. The asphalt was more brittle, less "sticky," and appeared to be more temperature-dependent. Recently, different additives (i.e., polymers) have been mixed with asphalts to reduce the effects brought on by the refining process. Coarse graded asphalt mixes designed to reduce the rutting problem pose more of a transverse cracking problem and reduced "waterproofing" effect, both of which result in faster pavement degradation. Omitting soil asphalt bases and use of greater thickness of full-depth asphalt have both helped reduce the transverse cracking problem.

Maintenance/Remedial Procedures

The general philosophy of ODOT division offices with regard to maintenance procedures and policies, with a few exceptions, is to react to problems as they occur rather than try to prevent the problem. This philosophy works well within the manpower, money, and time constraints placed on division maintenance personnel; however, it allows some problems to develop to detrimental extents before action is taken. In cases where preventive maintenance procedures are used, the extent of the transverse cracking problem is greatly reduced. For example, Divisions 1, 2, and 5 routinely use fog sealing as a way to seal surface cracking and waterproof the surface, thus reducing the harmful effects of moisture on the asphalt mix.

Divisions 1 and 2 both report minimal transverse cracking problems while Division 5 reports serious problems. (Note: Division 5 does not routinely use fog sealing over the roadway; rather it uses it more frequently on the shoulders.) Preventive maintenance in the form of crack sealing early in the development of the transverse crack is reported by all divisions. Early detection of transverse cracks is difficult and there is no uniform procedure in which some form of roadway condition review is made. Most of the early detection is done by alert maintenance personnel with experience in recognizing the problem.

Successful remedial maintenance procedures for restoring ride quality generally fall into one of the following categories:

1. Crack filling/sealing with asphalt (liquid, emulsion, cutback, rubber, polymer-heated) and sand, screenings, or chips. The cracks are generally always cleaned, using air pressure, but the use of routing or milling varies from division to division.
2. Seal coat or chip or armor coat following crack filling/ sealing. This is done with or without paving fabrics.
3. Overlay following leveling course and/or crack filling/sealing. This is generally done using paving fabric over the old pavement surface. A variation of this procedure is microsurfacing, using a polymer-treated asphalt and screenings slurry to fill depressions and provide a new wearing surface.

A variety of crack filling product and crack restoration methods have been tried but with limited success. For example, some of the various crack filling products include cement/sand grout, fly ash slurry, hot mix, fiber reinforced asphalt, none of which performed well. Milling and replacement of the asphalt concrete in trenches as wide as 28 inches did not prove to be successful.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The major conclusions that can be drawn from the study may be sum-marized as follows:

1. Examination of the literature and evaluation of transverse cracks at the 26 field test sites confirm that, in most cases, transverse cracks originate at the pavement surface and extend down into and/or through the pavement. The primary cause of transverse cracking is thermal-induced stress causing contraction of the asphalt concrete surface layer. Average low temperature was found to have a signifi-cant effect on transverse cracking. The number of cracks increased and average spacing between the cracks decreased with decreasing average low temperature.
2. Transverse crack depressions or faults are caused by an the ingres-sion of water through the cracks in the pavement to the subgrade soils. This causes softening of the subgrade soil and subsequent depression or faulting adjacent to the crack. Additionally, pumping of fines from the base and subgrade through the cracks contributes to the loss of support.
3. The plastic limit of the fine-grained soils correlated with crack indexes such as number of cracks per 1000 ft. This indicates that pavements overlying fine-grained soils pose a greater risk of trans-verse cracking.
4. Transverse cracking, whether depressed or nondepressed, is a state-wide problem with the extent of the problem varying with such factors

as pavement age, pavement cross section, traffic, and asphalt properties.

5. There is a general consensus that asphalt properties changed for the worse in the early 1970s. Specifically, the asphalt was more brittle and less "sticky." The change in properties generally resulted in asphalt concrete pavements that were more susceptible to thermal-induced property changes.
6. Although detailed field evaluations were not conducted for most of the field trials of the various preventative maintenance or remedial repair procedures used by the Division offices, the observations made and experience gained indicated that some procedures performed better than others. For example, fog sealing used as a preventative maintenance procedure reduced and/or delayed the extent and severity of transverse cracking. In the three Divisions where fog sealing was routinely used (i.e., annually or semi-annually) on pavements starting 3 to 4 years after construction, the reported incidence of transverse cracking was significantly less. The key to a successful fog sealing program is to start as soon as hairline cracks appear in the roadway surface and to continue the process periodically as long as the transverse cracks are no more than 1/4 to 1/2 in. wide. Once the cracks reach 1/4 to 1/2 in. wide or more, crack sealing should be started and continued on an as-needed basis. Successful crack sealing depends on how thoroughly the cracks are cleaned and the type of material used for sealing the cracks (i.e., CRS-2 or rubber asphalt).
7. Similar observational methods used for remedial repair procedures indicated that some procedures performed better than others; specifically, crack filling/leveling, microsurfacing, and overlaying using

geotextiles (i.e., paving fabrics). Crack filling/leveling goes beyond crack sealing because it incorporates sand, screenings, or chips into the crack sealing material to provide some "stiffness" to the filler, so that it not only seals the crack but levels the surface and restores some of the lost ride quality. Routing the cracks sometimes helps but is not a necessity. Microsurfacing has performed well in restoring ride quality in many applications, especially where the transverse cracks and depressions are individually filled and leveled prior to placing the surface treatment. Overlaying with paving fabrics, although costly, provides the most improved riding surface of all the remedial repair procedure. The performance of an overlay on a pavement with transverse cracks depends on how effectively cracks and depressions are fitted and leveled prior to overlaying. For extensively cracked and depressed pavements, milling the surface helps with the leveling of the pavement prior to overlaying.

8. Some remedial repair methods that have not worked well include: crack filling/leveling with stiff materials like cement and fly ash grout, sawing out cracks with rock saws and backfilling with hot mix-cold lay, and milling transverse slots in the pavement over cracks and backfilling with hot mix.

Recommendations

The following recommendations are considered pertinent to the results of this research investigation:

1. Further comprehensive testing of cracked and uncracked pavement sections should be undertaken to develop a better understanding of actual thermal effects on stress, strain, and stiffness values.

Asphalt chemistry and aggregate properties should also be considered in the evaluation.

2. Current asphalt specifications are primarily concerned with rheological properties at high and moderate temperatures (penetration at 77°F, viscosity at 140°F and 275°F, and softening point). Some consistency measurement, such as viscosity, at lower temperatures should be considered in future specifications.
3. ODOT should continue with its plans to use resilient properties (i.e., Resilient Modulus) to design asphalt pavements since it provides a method to accommodate the change in stiffness from layer to layer, which has an influence on occurrence of transverse cracking.
4. A comprehensive evaluation of preventive and remedial maintenance procedures should be conducted to establish the conditions under which the various procedures perform best.

REFERENCES

[1] Haas, R. C. G. et al. "Low Temperature Pavement Cracking in Canada: The Problem and Its Treatment." *Proceedings of the Canadian Good Roads Association*, 1970, pp. 69-96.

[2] Kher, Ramesh. *Road Test to Determine Implications of Preventing Thermal Reflection Cracking in Asphalt Overlays*. Ontario: Research and Development Division, Ministry of Transportation and Communications, 1977.

[3] Haas, R. C. G., and T. H. Hopper. "Thermal Fracture Phenomena in Bituminous Surfaces." *Highway Research Board, Special Report 101* (1969), pp. 136-153.

[4] Anderson, K. O., and R. C. G. Haas. "A Design Subsystem for the Response of Flexible Pavements at Low Temperature." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 38 (1969), pp. 179-223.

[5] Hills, J. F., and D. Brien. "The Fracture of Bitumens and Asphalt Mines by Temperature-Induced Stresses." *Proceedings of the AAPT*, Vol. 35 (1966), p. 292.

[6] Shields, B. P., and K. D. Anderson. "Some Aspects of Transverse Cracking in Bituminous Pavements." *Proceedings, Canadian Technical Asphalt Association*, Vol. 9 (1964), p. 209.

[7] Monosmith, C. L. et al. "Temperature-Induced Stresses and Deformation in Asphaltic Concrete." *Proceedings of the AAPT*, Vol. 34 (1965), p. 248.

[8] Karis, W. J., and L. E. Santucci. "Control of Asphalt Concrete Construction by the Air Permeability Test." *Proceedings of the AAPT*, Vol. 32 (1963), pp. 124-189.

[9] Busby, E. O., and L. F. Rader. "Flexural Stiffness Properties of Asphalt Concrete at Low Temperatures." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 41 (1972), pp. 163-187.

[10] Whiffin, A. G., and N. W. Lister. "The Application of Elastic Theory to Flexible Pavements." *Proc., Intl. Conf. on Structural Design of Asphalt Pavement*, Univ. of Michigan, 1963.

[11] Kallas, Benard. "Low Temperature Mechanical Properties of Asphalt Concrete." *The Asphalt Institute Research Report 82-3* (Sept., 1982), pp. 1-11.

[12] Dorman, G. M. "The Extension of Practice of a Fundamental Procedure for the Design of Flexible Pavements." *Proc., Intl. Conf. on Structural Design of Asphalt*. Univ. of Michigan, 1963.

[13] Jimenez, R. A., and B. M. Gallaway. "Behavior of Asphaltic Concrete Diaphragms to Repetitive Loadings." Proceedings, Intl. Conf. on Structural Design of Asphalt Pavement, University of Michigan, 1963.

[14] Fromm, H. J., and W. A. Phang. "A Study of Transverse Cracking of Bituminous Pavements." Proceedings of the Association of Asphalt Paving Technologists, Vol. 41 (1972), pp. 424-493.

[15] McLeod, N. W. "A Four-Year Survey of Low Temperature Transverse Pavement Cracking on Three Ontario Test Roads." Proceedings of the Association of Asphalt Paving Technologists, Vol. 41 (1972), pp. 424-493.

[16] Manke, P. G., and M. S. Noureldin. A Study of Transverse Cracking in Oklahoma Flexible Highway Pavements. Research Project No. 72-03-3, Interim Report 5. School of Civil Engineering, Oklahoma State University, 1977.

[17] Noureldin, M. S., and P. G. Manke. "Study of Transverse Cracking in Flexible Highway Pavements in Oklahoma." Transportation Research Record 695. Transportation Research Board, Washington, DC, 1978, pp. 28-33.

[18] Hajek, J. J., and R. C. G. Haas. "Predicting Low-Temperature Cracking Frequency of Asphalt Concrete Pavements." Highway Research Board, Research Record No. 407 (1972), pp. 39-54.

[19] Burgess, R. A., O. Kopvillem, and F. D. Young. "Ste. Anne Test Road--Relationship Between Predicted Fracture Temperatures and Low-Temperature Field Performance." Proceedings, Association of Asphalt Paving Technologists, Vol. 40 (1971), pp. 148-226.

[20] Transverse Cracking of Asphalt Pavements. Summary report of a cooperative analysis by teams from Iowa, Kansas, Nebraska, North Dakota, and Oklahoma. U.S. Department of Transportation, Nov., 1981.

[21] Devore, J. L. Probability and Statistics for Engineering and the Sciences. 2nd Ed. New York: Brooks/Cole Publishing Co., 1977.

APPENDIX

SUMMARY OF DISCUSSIONS FROM DIVISION OFFICE VISITS

ODOT--Depressed Transverse Cracks in Asphalt Pavements

ODOT Practices

Division 1

Occurrence/Extent

- Transverse cracking is not a serious problem (probably 4% or less of asphalt pavements exhibit transverse cracking).

- Depressed transverse cracks are a minimal problem (probably 2% or less of asphalt pavements exhibit depressed transverse cracking).

- Transverse cracking problem evolved in mid-1970s on 1- to 2-year-old roadways.

Specifications/Materials

- Thicker pavements pose less of a problem.
- Construction trends are moving to larger aggregate mixes with fewer fines.

- Properties of asphalt changed ≈ 1972.

Maintenance/Remedial Procedures

- Fog sealing (with asphalt emulsion or cutback) is used on all asphalt pavements 3 to 4 years old.

- Crack sealing (with CRS-2) for early detected cracks (<3/4 in.), then CRS-2 with screening/chips as cracks open wider.

- Other crack sealing/crack filling options tried:

1. Cement/silt grout
2. Removing crack and adjacent asphalt concrete and replacing with hot mix/cold lay
3. Geotextiles--beneath chip seal or overlay
4. Microsurfacing--lateral crack filling, then longitudinal application, then overlay.

Division 2

Occurrence/Extent

- Transverse cracking is a moderate problem with approximately 15 to 20% of asphalt pavements exhibiting the problem. Tends to occur over certain stretches of roadway and appears to be prevalent in east-west roadways.

- Depressed transverse cracks are not a serious problem.

Specifications/Materials

- Major problems with asphalt pavements involve aggregate stripping and changes in properties of asphalt.

- Construction trends are moving toward coarse aggregate mixes to reduce rutting but at a loss of "waterproofing" and flexibility.

- Full-depth asphalt pavements over aggregate base and a properly prepared subgrade perform welle

- Typical problem leading to cracking is the use by contractors of the minimum (or lower) asphalt percentage which results in a stiffer, more brittle mix which is more susceptible to transverse cracking.

Maintenance/Remedial Procedures

- Maintenance approach is more reactive than preventive. In other words, maintenance activities respond to first observation of transverse cracking.

- Fog sealing (with asphalt emulsion at 0.15 gal/yd^2) is used at least once a year on all asphalt pavements. Fog sealing has been very successful in reducing transverse cracking because it tends to "rejuvenate" the surface and fills and/or seals small cracks.

- Small cracks can be identified after a light rain; the pavement surface adjacent to the crack will appear drier than the surrounding area because of surface tension effects along the crack.

- Seal coat and chips, with or without paving fabric, is an alternative preventive measure used.

- As cracking progresses, crack sealing (with CRS2) with sand, screenings, or chips is used depending on size of crack.

- Polymer-treated asphalts are used for chip seal and crack sealing.

- No experience with rubber asphalt; considered a viable alternative.

- Limited use of microsurfacing, primarily as a leveling course for ruts. Limited success.

Division 3

Occurrence/Extent

- Transverse cracking in asphalt pavements is a serious problem involving 50 to 60% of the pavements.

- Depressed transverse cracks occur in approximately 20% of the asphalt pavements.

- General problem is in northwest portion of division where full-depth asphalt is used more often and traffic is greater.

- Full-depth asphalt pavements appear to pose a greater problem, especially when hot sand asphalt and soil asphalt are used as bases. Cracking or depressions do not seem as severe when stabilized aggregate base courses are used.

Specifications/Materials

- Aggregate source appears to have same effect on cracking behavior. Local "bromide" aggregate exhibits microcracking problem because of oxidation.

- Characteristics of asphalt changed in early to mid-1970s. Transverse cracking of asphalt pavements appears to be greater in asphalts with "changed" characteristics (i.e., not as sticky or flexible).

- Construction procedure is using a lower percent fines; therefore, the tendency to take on water is greater.

Maintenance/Remedial Procedures

- Detection of transverse cracks is based on observation; then preventive maintenance actions are taken.

- Preventive maintenance approaches include: fog sealing (used primarily on older roads with open graded mixes, seal coats with chips [using CRS-2S]), and crack seal (using AC 2A or rubber asphalt in routed cracks).

- Remedial maintenance activities (i.e., restoring ride quality) include crack sealing with rubber asphalt and overlaying using paving fabric.

- Plan to try infra-red heater to soften asphalt concrete, mix in fine aggregate, reheat, and compact.

- No experience with microsurfacing but consider it to be a viable alternative.

Division 4

Occurrence/Extent

- Asphalt pavements constructed in early to mid-1970s appear to pose more problems with transverse cracking.
- Asphalt pavements constructed on stabilized aggregate base courses do not show signs of transverse cracking.
- Transverse cracking problem appears to occur more when pavements are constructed on fine-grained soil subgrades.

Specifications/Materials

- Asphalt characteristics changed in early 1970s, i.e., asphalt was more brittle, less sticky. Asphalt properties vary greatly, i.e.e penetration and viscosity may be within acceptable limits, but chemical composition and therefore engineering properties vary.
- Low percent fines in mixes is conducive to transverse cracking problem.
- In late 1970s, ODOT opted for "softer" asphalts; the result was more rutting.

Maintenance/Remedial Procedures

- Early detection of transverse cracking is difficult.
- Basic maintenance philosophy is reactive, i.e., responds to problems as they come up. Most maintenance dollars go to safety and ride quality rather than preventive maintenance.
- Maintenance procedures for transverse cracks include crack filling/sealing (with liquid asphalts and screenings or chips) and microsurfacing.
- Microsurfacing using level course for depressions followed by total surface application has performed very well.
- Some remedial procedures that were tried and did not perform well included:

  Sawing transverse crack with rock saw and backfilling with type C mix.
  Fly ash-cement grout filler.

- Paving fabrics are not used, either with seal coats or overlays, on roadway with wide transverse cracks.
- Need a comprehensive demonstration project to evaluate both preventive and remedial maintenance procedures.

Division 5

Occurrence/Extent

- Transverse cracking of asphalt pavements is a serious problem in the Division.
- Depressed transverse cracks appear more common by job., i.e., interstate highways show more depressed cracks because of greater traffic volumes.
- Transverse cracks appear to occur more in pavements on sandy subgrades.

Specifications/Materials

"No specific comments."

Maintenance/Remedial Procedures

- Fog sealing is used extensively for protecting the pavement surface, i.e., helps remediate hairline cracks. Used extensively on shoulders of interstate highways as well as roadway surfaces. Typically applied twice a year.
- Crack filling/sealing has generally not been successful.
- Common approach is seal coat (SSI or CRS2S) and chips (3/8 in. or screenings) to maintain ride quality. If cracks become depressed, strip sealing may be used.
- Microsurfacing has worked successfully for maintaining ride quality, but it is expensive.
- Several remedial procedures that have been tried with minimal success include:

    Crack filling with fast setting cement grout, fly ash slurry, liquid asphalt and chips, hot mix.
    Cleaning crack, filling with hot mix and overlaying with paving fabric.
    Milling 28-inch wide by 6-inch deep trenches across the pavement, placing paving fabric and hot mix in the trench, and overlaying.

- Most maintenance procedures do not "stop" the cracking; they only delay the reappearance of the crack.

Division 6

Occurrence/Extent

- Nearly all asphalt pavements exhibit some transverse cracking.
- Recurring maintenance problems occur in approximately 50% of the roadways.
- Most problems occur in roadways with soil asphalt bases, i.e., sand and asphalt mixed in-place.

Specifications/Materials

- Most roads in the Division are 30 to 40 years old and were constructed when stiffer asphalts were used to reduce rutting.
- Asphalt properties changed in early to mid-1970s, but few roads were constructed during this period.
- No problems have been noted with coarse aggregate mixes.
- Full-depth asphalt pavements have not been a problem with respect to transverse cracking.

Maintenance/Remedial Procedures

- Common maintenance approach to transverse cracking is crack sealing or crack leveling.
- Crack sealing using CRS-2S without filler is the routine maintenance approach. It is generally done in the fall and spring, and prior to any chip seal or overlay.
- Problems with paving fabrics beneath seal coats or overlays have occurred when the cracks were not sealed or leveled.
- Fog sealing is occasionally used to help raveling problem. It is not used for transverse cracking problem because of skid resistance problems and cost.
- Microsurfacing has not been used extensively because of cost.
- Paving fabrics are used extensively between leveling course and overlay.
- Thin overlays are often used to maintain ride quality.

Division 7

Occurrence/Extent

- Transverse cracking of asphalt pavements is a serious problem.
- Transverse cracking is more prevalent in pavements constructed in early 1970s. Pavements constructed earlier do not seem to crack extensively.
- Transverse cracking occurs in pavements placed on sandy or clayey subgrades, i.e., subgrade has no effect.

Specifications/Materials

- Asphalt characteristics changed for the worse in early 1970s.
- Pavement design changed, i.e., changed from hot sand asphalt base to stabilized aggregate base to reduce rutting problem.
- Aggregate performance has an influence on cracking behavior.

Maintenance/Remedial Procedures

- Preventive maintenance procedures basically involve crack filling/sealing and seal coat and chips.
- Cracking filling/sealing uses CRS-2S and either sand or chips placed in layers in the cracks.
- Cracking filling/sealing used routinely before seal coat and chips or overlay.
- Paving fabrics are often used before overlaying.
- Microsurfacing has been used with some success to fill/level transverse cracks before general longitudinal application.
- Fog sealing with CRS-2S has been used to seal surface cracks when they are very small. Generally not effective as cracks widen in preventing moisture ingression.

Division 8

Occurrence/Extent

- Transverse cracking of asphalt pavements is a moderately serious problem affecting approximately 25% of the asphalt pavements.
- Pavements between 15 to 20 years old show significant cracking.
- No apparent significant influence of pavement cross section or subgrade soil.

Specifications/Materials

- Asphalt properties changed in early 1970s. Material became more brittle and less "sticky."
- Division is using polymer modified asphalt to try to address problems with poor quality asphalts.
- Omitting soil asphalt bases has helped reduce transverse cracking problem. Many problems still occur with full-depth asphalt.

Maintenance/Remedial Procedures

- Preventive maintenance procedures include cracking sealing with CRS-2S and blot with sand, and fog sealing of roads showing hairline cracking. Fog sealing is generally used with open-graded materials.
- Remedial maintenance procedures include crack filling with CRS-2S and chips placed in alternating layers, paving fabrics with overlays, and geotextile strips saturated with asphalt followed by cold mix/cold lay.
- Routing or milling has not been used, but plans are to try it in conjunction with crack filling.
- Microsurfacing has been used on only one job. No record available on success.
- Crack filling using cement/sand slurry was moderately successful.
- Expanded clay aggregate and asphalt has been used as a crack filler with some success.