PERFORMANCE OF REHABILITATED ASPHALT CONCRETE PAVEMENTS IN THE LTPP EXPERIMENTS - DATA COLLECTED THROUGH FEBRUARY 1997

Submitted To:
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Department of Transportation
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FOREWORD

This report documents performance trends and observations drawn from analysis of the rehabilitated asphalt pavements monitored as a part of the Long Term Pavement Performance Program. This information may be used to guide highway agency strategy selection decisions. However, because most of the rehabilitation treatments are still relatively recent, the findings reported must be regarded as preliminary. That is, the relative performance of the different treatments over the long term may differ from that observed at this time.

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Director, Office of Infrastructure
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NOTICE

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This report is a project deliverable under the LTPP Data Analysis Technical Support study. ERES Consultants is the prime contractor and Brent Rauhut Engineering is a subcontractor. BRE staff who provided significant contributions to this study included Amy Simpson and Jerry Daleiden. The technical review of report was provided by the TRB Expert Task Group on LTPP Data Analyses. Contracting Officer's Technical Representative (COTR): Cheryl Allen Richter, HNR-30

16. Abstract

Two experiments are included within the Long Term Pavement Performance (LTPP) program to provide data on the performance of rehabilitated asphalt concrete(AC) pavements. These two experiments include the Specific Pavement Studies Number 5 (SPS-5) and the General Pavement Studies Number 6 (GPS-6). The SPS-5 experiment was developed to study the performance of AC overlays of existing AC pavements and includes nine test sections per project. The GPS experiment was designed to monitor test sections selected from existing pavements that were nominated by State Highway Agencies (SHAs).

This report summarizes the performance trends and initial observations of the 17 SPS-5 projects and the 125 GPS-6 test sections. It provides results that can be used in making rehabilitation decisions. The primary approach adopted was the development of graphs of performance indicators (or distress types) versus time. These performance indicators included fatigue cracking, longitudinal cracking within the wheel path and outside the wheel path, transverse cracking, rutting, and roughness. The analyses were made to evaluate the effects of the different experimental factors included within the SPS-5 and GPS-6 experiments on performance. These analyses and summaries were related to the effect of overlay thickness, the effects of milling, and the effects of mixture type on performance. The following provides an overall summary of the findings related to the three primary factors included in the experiment.

- The nominal 127-mm overlays have generally performed better than the nominal 51-mm overlays, as expected. The thicker overlays generally exhibited less cracking distress than the thinner ones, but had little effect on the occurrence of rutting and no apparent effect on roughness.
- The test sections that had been milled prior to placement of the overlays generally have performed better than those test sections that were not milled. Although there are exceptions to these findings, less fatigue cracking, longitudinal cracking within the wheel paths, and transverse cracking were observed on the sections that had been milled. No substantial difference was noted between longitudinal cracking outside the wheel paths, rutting, and roughness between the test sections with and without milling.
- The different type of mixtures (virgin or recycled asphalt concrete mixtures) appeared to have the least effect on performance of any of the factors included in this experiment. However, for those sites where there was a difference, the virgin mixtures generally performed slightly better than the recycled concrete mixtures.
- More importantly, the results and findings from this initial evaluation suggest that there will be sufficient data in time to support development of the expected products from these experiments, and development and calibration of the AASHTO 2002 Mechanistic-Empirical design guide as well as other rehabilitation design procedures.

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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 yards	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	cubit meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 | 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)		
˚F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	˚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 F

Symbol	When You Know	Multiply By	To F
		LENGTH	
mm	millimeters	0.039	inche
m	meters	3.28	feet
m	meters	1.09	yard
km	kilometers	0.621	miles
		AREA	
mm^2	square millimeters	0.0016	squa
m^2	square meters	10.764	squa
m^2	square meters	1.195	squa
ha	hectares	2.47	acre
km^2	square kilometers	0.386	squa
		VOLUME	
mL	milliliters	0.034	fluid
L	liters	0.264	gallo
m^3	cubic meters	35.71	cubic
m^3	cubic meters	1.307	cubic
		MASS	
g	grams	0.035	ounc
kg	kilograms	2.202	pour
Mg (or 't')	megagrams (or 'metric ton')	1.103	shor
		TEMPERATURE (exact)	
˚C	Celsius temperature	1.8C+32 1.8C+32	Fahr temp
		ILLUMINATION	
lx	lux	0.0929	foot-
cd/m^2	candela/m^2	0.2919	foot-
		FORCE and PRESSURE or STRE	
N	newtons	0.225	pour
kPa	kilopascals	0.145	pour squa

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

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

One of the primary objectives of the Long Term Pavement Performance (LTPP) Studies was to "develop improved design methodologies and strategies for the rehabilitation of existing pavements." The study approach for rehabilitated asphalt concrete (AC) pavements involves construction of AC overlays over existing pavements to provide test sections with varying characteristics and observation of these test sections to advance industry's knowledge of how they perform and how this performance is affected by various parameters. Those parameters include preparation of the existing pavement surface before overlay, pavement structure, traffic, materials, and environmental factors.

Two experiments were planned to provide definitive data on the performance of various rehabilitation techniques of AC pavements. These two experiments are defined as the Specific Pavement Studies No. 5 (SPS-5) and the General Pavement Studies No. 6 (GPS-6). The SPS-5 experiment, "Study of Rehabilitation of Asphalt Concrete Pavements," was designed to have 16 projects, each containing 9 test sections treated specifically so that performance comparisons could be made in their performance with the environment, traffic, existing pavement, and subgrade as constants. The GPS-6 experiment, "AC Overlay of AC Pavements," involved single test sections where an AC overlay is placed on an existing AC pavement. In the latter case, there was an experiment design for which test sections were sought from the State Highway Agencies (SHAs) to fill out the experimental factorial. Both of these experiments are discussed in this report.

This report summarizes the performance trends and initial observations of the 17 SPS-5 experimental projects and the 125 GPS-6 test sections. The LTPP data public release dated July 1996 is the source of data for the GPS-6 test sections, and the February 1997 release was used for the SPS-5 projects. The purpose of the report is to provide results that can be used in making rehabilitation decisions. Although performance observations are scheduled to continue for some 10 more years, the insights available at this time offer opportunity for improvements in rehabilitation practices.

1.2 SPS-5 STANDARD EXPERIMENT

The standard SPS-5 experiment design was developed to study the performance of AC overlays of existing AC pavements and includes nine test sections per project, as shown in table 1. Each column in table 1 represents a specific project and each cell represents a specific test section. Abbreviations of state names appear in table 1 to both indicate the states participating and what part of the experimental factorial their projects represent.

The test sections in the standard SPS-5 experiment include:

- Four 152-m-long AC pavement rehabilitation test sections with milling prior to overlay, four without milling, and one control section that is neither milled nor overlaid.

- Two of the milled test sections are overlaid with recycled AC mix and two are overlaid with virgin AC mix. Similarly, two of the unmilled test sections are overlaid with recycled AC mix and two are overlaid with virgin AC mix.

- For each set of two overlays (as described above), one is placed with a thickness of 51 mm and the other is placed with a thickness of 127 mm. In the experiment, these are referred to as thin and thick overlays.

Each test section has an identifying number that is common for all SPS-5 projects, which indicates its characteristics as follows:

Number	Description
501	Control (no treatment)
502	Thin (51 mm) overlay, recycled mix
503	Thick (127 mm) overlay, recycled mix
504	Thick (127 mm) overlay, virgin mix
505	Thin (51 mm) overlay, virgin mix
506	Thin (51 mm) overlay, virgin mix, with milling
507	Thick (127 mm) overlay, virgin mix, with milling
508	Thick (127 mm) overlay, recycled mix, with milling
509	Thin (51 mm) overlay, recycled mix, with milling

Twelve states also built “supplemental test sections” to allow observation of other rehabilitation treatments that were of interest. Observations from the supplemental test sections, however, are not addressed in this report.

As summarized in table 1, replicates were sought for the eight sets of parameters. However, acceptable projects were not nominated for two of the data sets (see blank columns), and three

Table 1. SPS-5 project, study of rehabilitation of asphalt concrete pavements.

Rehabilitation Procedures			Factors for Moisture, Temperature, and Pavement Condition														
			Wet										Dry				
Surface Prep	Overlay Material	Overlay Thickness	Freeze					No Freeze					Freeze				
			Fair			Poor		Fair		Poor			Fair			Poor	
Routine Maint. (Control)		0	MD	MN	NJ	ME		TX	GA	MS	FL				MT	MAN	
MINIMUM	Recycled AC	Thin	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	
		Thick	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	
	Virgin AC	Thin	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	
		Thick	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	
INTENSE	Recycled AC	Thin	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	
		Thick	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	
	Virgin AC	Thin	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	
		Thick	MD	MN	NJ	ME		TX	GA	MS	FL	AL	CO	AB	MT	MAN	

1 in = 25.4 mm
Subgrade soil supposed to be fine-grained, but several have coarse-grained subgrade.
Traffic requirement is greater than 85,000 ESALs/year.
Blank cells were not constructed.

projects were nominated and accepted for each of the following factor combinations: 1) wet-freeze fair condition, 2) wet-no freeze poor condition and 3) dry-freeze fair condition.

In table 1, "intensive surface preparation" denotes those test sections where 51mm of the surface was milled off and patching was done where needed to rectify localized failures. "Minimum surface preparation" indicates that only patching was done. As part of the experiment, it was specified that the recycled mixtures contain 30 percent recycled asphalt pavement (RAP) and that the RAP was to be the material milled from the intensive surface preparation test sections. As part of the experiment design, a control section to which no treatments were to be applied was also included in each project to provide for comparisons to the rehabilitated test sections.

In general, the experiment is intended to evaluate some of the more common rehabilitation techniques currently used by SHAs. The experimental factors include the condition of the pavement before overlay (both structurally and functionally), the loading conditions the test section is exposed to (including both environment and traffic), and the various treatment applications. Specifically, the five products expected from the SPS-5 experiment are:[(1)]

1. Comparisons and development of empirical prediction models for performance of AC pavements with different intensities of surface preparation, with thin and thick AC overlays, and with virgin and recycled AC overlay mixtures.

2. Evaluation and field verification of the *American Association of State Highway and Transportation Officials (AASHTO) Guide* design procedures for rehabilitation of existing AC pavements with AC overlays and other analytical overlay design procedures for AC pavements.[(2)]

3. Determination of <u>appropriate timing</u> to rehabilitate AC pavements in relation to existing condition and type of rehabilitation procedures.

4. Development of procedures to verify and update the pavement management and life-cycle cost concepts in the *AASHTO Guide* using the performance prediction models developed for rehabilitated AC pavements.

5. Development of a comprehensive database on the performance of rehabilitated AC pavements for use by state and provincial engineers and other researchers.

1.3 GPS-6 EXPERIMENT

The GPS-6 experiment was designed to monitor test sections selected from existing pavements nominated by the SHAs. The experimental plan for GPS-6 initially involved selection of AC pavements that were already overlaid with AC, as shown in figure 1.

In 1988, soon after the LTPP project was funded, a decision was made to seek another class of GPS-6 test sections for which the condition of the existing pavement prior to overlay could be rigorously established. This decision was made because condition prior to overlay was believed to be an important factor affecting the performance of an overlay. The original GPS-6 test sections were then designated as GPS-6A test sections and recruitment was initiated for test sections yet to be overlaid, which were designated as GPS-6B test sections.

It can be seen from figure 1 that the experiment design established 128 cells to be recruited from the SHAs.(3) The numbers in the cells indicate the numbers of test sections actually nominated and selected for each individual cell and the tables below the experiment factorial indicate the number of cells with 1, 2, 3, or 4 test sections and the distributions of sections and cells within the four environmental zones. Although there were only 49 cells represented by 60 test sections, it can be seen that these 49 cells are reasonably well distributed throughout the experimental plan.

The experimental plan has two levels per factor, so the factor midpoints (or boundaries between the levels) are identified at the bottom of the figure. As stated above, figure 1 relates to the GPS-6A test sections and includes those test sections that were overlaid prior to their selection into the LTPP program and initiation of performance monitoring.

Figure 2 provides the same information as figure 1, except that it represents the GPS-6B test sections. This part of the GPS-6 experiment includes those test sections that were overlaid after their selection into the LTPP program and initiation of performance monitoring. In summary, there are 62 GPS-6B test sections in 48 cells. There is again a reasonable distribution of test sections throughout the experimental plan, except that there are three columns of cells that have no test sections.

Table 2 lists the numbers of GPS-6A and GPS-6B test sections in each state. As summarized, there are 60 GPS-6A test sections distributed through 28 states, which are shown in figure 1. However, the number of GPS-6B test sections listed in table 2 (65 distributed through 28 states) is different from the number shown in figure 2. Figure 2 shows only 62 test sections. The additional three test sections (test sections 124135, 231026, and 371040) have resulted from recent overlays of GPS-1 or GPS-2 test sections since the data assessment was completed by Rauhut et al. in 1996, but were not added to figure 2 due to lack of data on the pavement surface condition prior to overlay.(3)

The overlay ages for the GPS-6A test sections range from 8 to 29 years, with a mean of 15 years. For the GPS-6B test sections, ages range from 1 to 9 years, with a mean of 6 years. Data from GPS-6A represent the long term performance of the overlays, whereas none of the GPS-6B overlays have been in place more than 9 years. Conversely, the GPS-6B data include more rigorous information on condition prior to overlay, the construction of the overlay, and traffic (where the traffic has been monitored according to guidelines since construction). Together, data from the two experiments should eventually provide a reasonably complete picture of overlay performance.

GENERAL PAVEMENT STUDIES

AC OVERLAY of AC

MOISTURE
TEMPERATURE
SUBGRADE TYPE
TRAFFIC RATE
ORIG. PVT. COND.
ORIG. PVT. SN.
OL THICKNESS

			WET								DRY							
			FREEZE				NO FREEZE				FREEZE				NO FREEZE			
			F		C		F		C		F		C		F		C	
			L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
L	L	P	1										1	1	1			1
		G	2	1			1		1		1	3		1		1		
	H	P									2	2		1	1			1
		G		1	1		1	1			2		4	1			1	
H	L	P		1					1			1		1		1	1	
		G		1	1			1		1	2		1					1
	H	P	1					1	1	1				1			2	1
		G	1			1						1						

No. of Sections/Cell	No. of Cells	No. of Secs.
1	41	41
2	6	12
3	1	3
4	1	4
All	49	60

Environ. Region	No. of Sections	No. of Cells
W - F	12	11
W - NF	10	10
D - F	26	17
D - NF	12	11
All	60	49

	Factor Midpoints:	
Traffic Rate	130	KESAL/Yr
Original Pavement Structural No.	3.6	
Overlay Thickness	2.5	inches

Figure 1. Number of GPS-6A test sections in each cell of the experimental plan, AC overlay of AC pavements.

GENERAL PAVEMENT STUDIES

AC OVERLAY of AC

OL THICKNESS	ORIG. PVT. SN.	ORIG. PVT. COND.	WET								DRY							
		MOISTURE → TEMPERATURE	FREEZE				NO FREEZE				FREEZE				NO FREEZE			
		SUBGRADE TYPE	F		C		F		C		F		C		F		C	
		TRAFFIC RATE	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
L	L	P	1			1	3	1		1	1	2	1		1			
		G	1				1		1	1	1		1					
	H	P	4		2		2	1	1		1			2	1	1		1
		G	2					1	2	1		1						1
H	L	P					2			1	1	2	1					
		G	1					1		1					1			
	H	P			2	1						1				1		
		G						1		1		1				1		

No. of Sections/Cell	No. of Cells	No. of Secs.
1	37	37
2	9	18
3	1	3
4	1	4
All	48	62

Environ. Region	No. of Sections	No. of Cells
W - F	15	9
W - NF	23	18
D - F	16	13
D - NF	8	8
All	62	48

Factor Midpoints:

Traffic Rate	130	KESAL/Yr
Original Pavement Structural No.	3.6	
Overlay Thickness	2.5	inches

Figure 2. Number of GPS-6B test sections in each cell of the experimental plan, AC overlay of AC pavements.

Table 2. Distribution of GPS-6 projects by state or province.

State	GPS-6A Sections	GPS-6B Sections		State	GPS-6A Sections	GPS-6B Sections
Alabama	2	3		New Mexico	5	
Alaska	2	2		New York		2
Arizona	4			N. Carolina		2
California	1	2		Oklahoma	1	2
Colorado	3	1		Oregon	2	
Dist. Of Col.		1		Pennsylvania	1	1
Florida		5		S. Carolina		1
Georgia		1		S. Dakota		2
Idaho	1			Tennessee	2	7
Illinois	1			Texas	5	6
Indiana	1	1		Utah	4	
Iowa	1			Vermont		1
Kansas	2			Virginia		3
Kentucky	2			Washington	5	2
Maine		3		Wyoming	3	
Michigan	1			Alberta		1
Minnesota	1			Br. Columbia	2	
Mississippi		4		Manitoba		2
Missouri	1	2		New Brunswick	1	
Montana	2	3		Nova Scotia	1	
Nebraska		1		Quebec		1
Nevada		1		Saskatchewan	2	2
New Jersey	1			**TOTALS**	**60**	**65**

1.4 PERFORMANCE TRENDS

The performance characteristics evaluated and included in this study were pavement cracking, rutting, and roughness. Performances of the test sections are compared to establish relative effectiveness of the different rehabilitation techniques within the SPS-5 project, and the performances of the GPS-6 test sections are examined to further augment the basis for establishing performance trends.

Graphs of performance characteristics and tabulated performance data versus time of measurement were used for the comparisons and appear throughout this report. Other parameters considered to affect the performance of rehabilitated pavements included layer thicknesses, condition before overlay, recycled versus virgin AC mixes, milling versus no milling, etc. There are so many of these parameters that detailed evaluation of their effects will ultimately require statistical procedures when more data become available. Equivalent single axle loads (ESALs) were also considered, but these data were not available or complete enough in the LTPP data public release of February 1997 for successful analytical applications.

Pavement surface cracking, for the purposes of discussion here, has been divided into four general categories: fatigue cracking, longitudinal cracking within and outside the wheel path, and transverse cracking. Although other forms or types of pavement cracking may exist, the four types noted are the only ones used in these early analyses and observations.

The presence of each type of cracking can be interpreted as a potential indicator of various pavement deterioration mechanisms. For example, fatigue cracking is commonly considered an indicator of inadequate structural capacity for the traffic levels exhibited. Longitudinal cracking has been subdivided to reflect whether it might be primarily load-related (in the wheel path) or non-load-related (not in the wheel path). However, transverse cracking is usually a function of the environmental conditions relative to the stiffness and strength of the AC layer and of the underlying base.

As fatigue cracking generally develops from longitudinal cracking in the wheel path, these two distress types are related and are discussed together in chapter 3. To some extent, transverse cracking and longitudinal cracking not in the wheel path are related as their occurrence depends on many of the same characteristics. However, these will be discussed separately in chapters 4 and 5, respectively.

1.5 ORGANIZATION OF THE REPORT

The primary approach to observing the trends was the development of graphs of performance indicators versus time (observation dates) or ESALs when available (for GPS-6 test sections). These graphs appear in alphabetical order in the appendices as follows:

Appendix D - Fatigue Cracking
Appendix E - Longitudinal Cracking in the Wheel Path
Appendix F - Transverse Cracking
Appendix G - Longitudinal Cracking Not in the Wheel Path
Appendix H - Rutting
Appendix I - Roughness

For those SPS projects for which substantial distress had occurred, two graphs per project are furnished for a particular performance indicator. One shows the performance of the control section and those test sections with overlays of recycled AC mixtures and the other of the control section and test sections with overlays of virgin AC mixtures. Figure 3 illustrates the graphical presentation approach. This figure may also be found as figure D.1 in appendix D. Subsequent appendices are organized similarly, but each for its own performance indicator (e.g., transverse cracking, rutting, etc.). Tabulations of amounts of cracking distresses are also included in chapters where the distresses are discussed.

Graphs for the GPS-6 test sections having sufficient data to offer value to these evaluations are also included in the appropriate appendices by specific performance indicator as for the SPS-5 projects. These will appear behind the SPS-5 graphs, one graph per state in alphabetical order.

Chapter 2 will identify materials and layer thicknesses for all SPS-5 projects and GPS-6 test sections for which data are available. Although overlay thicknesses were designated for the SPS-5 overlays, level surveys were conducted before milling and at various stages during construction, so actual low, high, and mean thicknesses of the various layer types appear in the database for each test section, as well as standard deviations of the thicknesses. This includes rut level-up, milling replacement, binder course, surface course, and surface friction course. Average milling depths are also provided so these can be considered in establishing actual overlay depths.

Tables providing detailed pavement thickness data by test section are available for each SPS-5 project in appendix A. These data include thicknesses of all layers for each test section, as well as the actual average overlay thicknesses (average finished surface elevations less the average original surface elevations) and the deviations between the specified overlay thicknesses and the actual mean overlay thicknesses. The database also includes average, low, and high values for each of the construction layers (e.g., binder course, surface course, milling replacement, etc.), as well as the standard deviations for each.

While such detailed data are not available for the GPS-6 test sections, average layer thicknesses measured from the AC cores recovered at each end of a particular test section are provided in appendix B. Also included are original construction and overlay dates, identification of subgrade, subbase and base materials, and reported conditions of original pavements prior to overlay. Available cracking distress data of all four types of cracking for the individual GPS-6 test sections appear in tabular form in appendix C.

Each of the seven “performance indicators,” listed above with their appendices, will be discussed within its own chapter, so the reader may refer to the appropriate appendix for the graphs while reading the results from the evaluations for specific performance indicators (e.g., appendix D provides graphs for chapter 3, which concerns fatigue cracking). The results for the six performance indicators appear in chapters 3 through 7.

Chapter 8 provides a summary of the findings from the observations and evaluation of the performance results.

1.6 DATA AVAILABLE FOR EVALUATION

There are three SPS-5 projects and numerous GPS-6 test sections that have been essentially omitted from this study because of data limitations. Two of the SPS-5 projects are those in New Mexico and Oklahoma. Construction was completed in 1997 and there has not been sufficient time for data to be of value to this study. Also, thickness data were not available in the National Information Management System (NIMS) when the data were downloaded. The third SPS-5 project omitted for cracking studies was the one in Florida, because it was completed in April 1995 and there is only one data point after overlay for each distress type. However, rutting, roughness, and pavement thickness data are included for the Florida project.

As would be expected, not all SPS-5 projects have exhibited all four types of cracking considered. Graphs are provided for only those SPS-5 projects having cracking data for at least two measurements after overlay for at least one test section other than the control. In addition, graphs for projects having small amounts of distress also were omitted. Small amounts of distress were arbitrarily established as 10 m^2 or less for fatigue cracking, 10 cracks or less for transverse cracking, and 50 m or less for both types of longitudinal cracking. While arbitrary, these definitions appear to be reasonable for this purpose.

Similarly, nominal levels for rutting and roughness were established as an average value of 6 mm and 1.6 m/km or less, respectively. The single values of rut depths for each test section referred to in this report are average rut depths for a test section from 11 transverse profile measurements. Rut depths are calculations to approximate measurements in each wheel path using a 1.8-m straight edge that were obtained by processing the transverse profile data with the RUT5 program.[(4)] The single values of IRI for each test section are averages from five longitudinal profile measurements for each wheel path.

Table 3 indicates which SPS-5 projects satisfied the criteria discussed above for a particular distress. Graphs were prepared only for the state and distress combinations where an "X" appears in table 3. For example, a graph will appear in appendix D for fatigue cracking on the Alabama project, but no graphs were prepared for Alabama in appendices E, F, or G (the three other types of cracking).   Cells that are blank in table 3 indicate those SPS-5 projects that exhibit no cracking distress. Cells with individual test section numbers indicate those projects and test sections with nominal cracking. As an example, table 3 indicates that California test sections 505, 506, 507, and 509 had exhibited a nominal amount of longitudinal cracking in the wheel paths, but that the control section (which was also overlaid), as well as test sections 502, 503, 504, and 508 were free of this cracking distress. No fatigue cracking had been noted on any of the test sections.

It should be noted that the cracking distresses refer only to data resulting from "manual distress surveys", which means a trained distress surveyor has visited the test section and collected the data from visual observation. Results from initial observations of photographic film were found to omit a lot of the low severity cracking.[(5)] Although the equipment used for extracting the distress data from the film has been improved, the resulting data were unavailable in the LTPP data public release used for this study.

Graphs are provided in this report only for those GPS-6 test sections that have more than one manual distress survey (one data point) after overlay because the value of the graphs with only one point would be limited (refer to table 4). Each of these graphs includes all test sections in a state for which data are available. The X's in table 4 indicate those state and distress combinations for which at least two sets of performance measurement data are available after overlay and for which graphs are included in the respective appendix.

No performance data were available in the NIMS in early 1997 for the GPS-6 test sections in Idaho, Michigan, Nebraska, Nevada, New Jersey, New York, Nova Scotia, South Dakota, Vermont, Virginia, or Washington, D.C. Thus, performance trends or observations for these GPS-6 test sections could not be included in these studies. Distress data for individual test sections were sometimes missing for other states also.

Table 3. Performance data available for SPS-5 projects.

State	Fatigue Cracking	Long. Cracking in Wheel Path	Transverse Cracking	Long. Cracking Not in Wheel Path	Rutting	Roughness (IRI)
Alabama	X	508			X	X
Alberta	X	X	502-506	X	X	X
Arizona	X	502	X	502	X	X
California		505, 506, 507, 509	501, 504, 509	501, 505, 506, 509	X	X
Colorado	X	X	X	X	X	X
Georgia					X	X
Maine			X	X	X	X
Manitoba		X	501	X	X	X
Maryland		501, 505	X	X	X	X
Minnesota			X	X	X	X
Mississippi		X	X		X	X
Montana					X	X
New Jersey				X	X	X
Texas		501	X	X	X	X
New Mexico	Not included - Less than one year old					
Oklahoma	Not included - Less than one year old					
Florida	Not included - Only one performance measurement since overlaid in April 1995.					

Table 4. States/provinces for which useful GPS-6 test section data were available for graphing.

State/ Province	Fatigue Cracking	Long. Cracking in the Wheel Path	Transverse Cracking	Long. Cracking Not in the Wheel Path
Alabama	X	X	X	
Alaska		X	X	
Colorado	X	X	X	X
Missouri			X	X
Illinois			X	
New Mexico	X	X	X	
Oklahoma			X	X
Texas	X	X	X	X
Utah	X		X	

CHAPTER 2. DATA CONSIDERATIONS

This report is a continuation and update of the work for the SPS-5 experiment originally reported by Daleiden et al. except with the addition of the GPS-6 performance data and some materials, traffic, and distress monitoring data for certain projects.(6) As such, one purpose of this chapter is to discuss briefly the data that were used from the LTPP data public release dated October 1996 and February 1997. Another is to offer important data on layer thicknesses not previously available in usable form. This chapter primarily focuses on original pavement and overlay thicknesses, as the variations in layer thicknesses are especially important to the occurrence of distresses in the pavements and the data are relatively complete.

2.1 DATA USED FOR STUDY OF SPS-5 PROJECTS

At the time the working database was assembled for this study, there was some level of materials data in the NIMS for 6 of the 17 SPS-5 projects, some historical traffic data were available for 5 of the 17 SPS-5 projects, and some monitored traffic data were available for 4 of the 17 SPS-5 (not all the same as those for which historical traffic data were available). Table 5 provides general data on rehabilitation dates, layer thicknesses, subgrade types, conditions prior to overlay, and what are believed to be nine of the most important environmental variables.

The NIMS includes seven modules for SPS-5, with layer thickness data available in four of the modules. Table 6 identifies the data modules, indicates those having layer thickness data, and shows the modules currently represented in the working database. As summarized, there are four modules containing both layer thickness and materials data. The inventory data provide the general layer thickness data for a pavement prior to its overlay that are available from provincial or SHA records. The materials data, when it is all available for a project, will give more detailed data in terms of layer thicknesses of the original pavement near the ends of each of the test sections, rather than general data for an entire construction project.

It should be noted that the working database developed for the SPS-5 study does not include all of the data stored in the NIMS. The data elements in each data module were studied to eliminate data elements that did not appear to have any reasonable probability of affecting the overlay's performance. A typical example of data elements eliminated are sample numbers and material testing details. However, the results of the laboratory testing, when available, were retained and included in the data used for this study.

Table 5. General data for SPS-5 projects.[6]

State/ State Numerical Code		Rehab Date	Original Layer Thicknesses, mm				Subgrade Type	Condition Prior to Overlay	Environmental Data Annu					
			TS	GB	TB	SURF			Rain	0	32	Wet	High	FR
Alabama	1	Dec. 1991	0	272	0	94	Clayey Sand	Poor	1372	31	66	139	34	3
Arizona	4	May 1990	0	361	0	127	Silty Gravel	Poor	178	6	182	42	3	1
California	6	May 1992	Not Available				Sand	Poor	330	18	58	32	7	2
Colorado	8	Oct. 1991	0	0	91	170	Clayey Silt	Fair	406	168	29	92	7	15
Florida	12	Apr. 1995	0	683	0	81	Clayey Silt	Poor	1422	1	50	190	32	
Georgia	13	June 1993	0	737	0	467	Silt	Fair	1270	66	34	141	33	6
Maine	23	June 1995	0	1168	124	231	Silty Clay	Poor	1118	170	2	172	25	10
Maryland	24	June 1992	152	147	107	112	Silty Clay	Fair	965	89	31	122	23	8
Minnesota	27	Oct. 1990	0	457	0	90	Clayey	Fair	660	184	4	113	15	9
Mississippi	28	Sep. 1990	150	0	0	320	Gravel	Poor	1372	56	68	110	35	5
Montana	30	Sep. 1991	0	457	0	130	Clayey Sand	Fair	381	148	28	82	6	12
N. Jersey	34	Aug. 1992	0	254	0	241	Silty Sand	Fair	1194	103	12	143	30	9
N. Mexico	35	Sep. 1996	0	305	0	241	Clayey Silt	Fair	432	108	36	78	6	11
Oklahoma	40	July 1997	0	0	203	114	Fat Clay	Fair	1092	64	71	106	26	6
Texas	48	Sep. 1991	203	0	376	234	Clayey	Fair	940	39	92	106	24	4
Alberta	81	Oct. 1990	0	295	74	165	Gravel	Fair	483	200	0	130	7	11
Manitoba	83	Sep.1989	0	257	0	137	Silty Clay	Poor	508	192	5	113	9	7

TS - Treated Subgrade
GB - Granular Base
TB - Treated Base
SURF - Surface

1 in. - 25.4 mm
Rain - Annual Rainfall (mm)
0 - Number of Days Below 0°C
32 - Number of Days Above 32°C
WET - Number of Days With Precip.
HIGH - Number of Days With Heavy Precip.

°C = (°F - 32)/1.8
FRZT - Number of Freeze/Thaw Cy
FIND - Freeze Index
MAX - Average Monthly Max. Tem
MIN - Average Monthly Min. Temp

Table 6. Details on data organization for the SPS-5 experiment.

Data Modules in the NIMS	Modules Containing		Modules Included in Working Database
	Layer Thickness Data	Materials Data	
Inventory	X	X	X
Monitoring			
Construction	X	X	X
Rehabilitation	X	X	X
Materials	X	X	X
Traffic			
Environmental			

2.1.1 Thickness Data for the SPS-5 Experiment

The layer thicknesses used in previous reports were based solely on results from coring at locations off the ends of the test sections, so actual mean thicknesses or variation in thicknesses within the test sections were not known. The best layer data for the overlay thicknesses within each test section can be found in the construction module, because it is based on actual elevation surveys during construction of the rehabilitation treatments. These elevation measurements are made at 55 locations in a grid arrangement over each test section. Test section 501 was not included in the level survey program, because it is meant to be a control section without any overlay and/or milling.

The elevation surveys were conducted on the original pavement prior to any milling or overlays. Milled depths were measured periodically along each edge of the lane and elevations were established on the milled pavement. Elevations were measured again after the AC mixture was laid to replace the milled material. The mill replacement thickness was then calculated as the difference between the elevation after milling replacement and the elevation after milling. If a rut level-up mixture was placed (no milling), elevations were taken on it to allow calculation of the thicknesses at the 55 points. Similarly, elevation measurements were made on top of the binder and surface courses, as well as on top of the surface friction course, if there was one. The data presently available do not indicate that any surface friction courses were placed.

Tables 91 through 105 in appendix A were developed from the database and provide detailed pavement thickness data for each test section in each SPS-5 project, except for California, New Mexico, and Oklahoma, for which the necessary data were not yet available in the NIMS. As shown in appendix A, sufficient data to calculate overlay thicknesses are not yet available for 8 of the 17 projects, including New Mexico and Oklahoma. The other five SPS-5 projects (Alberta, Arizona, Manitoba, Minnesota, and Mississippi) were rehabilitated prior to issuance of the requirements for level surveys. In the absence of level surveys, determining variability in overlay thicknesses for test sections in these five projects will require the use of cores, ground penetrating radar measurements, or other means.

There are two important data elements in these tables that were not available in the database and had to be calculated. These are the overlay thicknesses and the deviation in the overlay thicknesses. The data available directly from the construction module that must be used to calculate the overlay thicknesses were:

- Average depths of milling
- Average thicknesses of material to replace the milled materials
- Average rut level-up thicknesses
- Average thicknesses of binder courses
- Average thicknesses of surface courses
- Average thicknesses of surface friction courses

The most direct method of arriving at overlay thicknesses would have been to calculate at each of the 55 points in a test section the differences between elevations from the final level survey and the elevations from the survey conducted prior to any milling. These calculations could still be accomplished using the level survey data. However, these data are not currently in the NIMS database, so another approach had to be followed.

As there are substantial differences between the average depths of milling and the average thicknesses of the milling replacement, it is necessary to add up the average thicknesses of all materials placed after milling and then subtract the average milling depths. Assuming that all the values are correct, this should result in the average thickness of the materials placed above the original pavement surface elevation (before the construction was initiated). This was the method used to calculate the average overlay thicknesses appearing in the tables, except for Florida and Georgia, which are discussed below:

- *Florida.* The level surveys for Florida to represent the original surface appear to have been made after milling. Therefore, the overlay thicknesses calculated for test sections 502-505 were correct, but those for test sections 506-509 had "lost" the materials that were milled in addition to the porous friction course. This was approximately corrected by adding back the depths of milling and subtracting estimated thicknesses for the porous friction course. Test sections 506-509 are all located between test sections 503 and 504, so the porous friction course thickness for each was interpolated linearly according to location. This resulted in addition of 21, 16, 29 and 24 mm, respectively, to the overlay thicknesses calculated for test sections 506-509, as described previously.

- *Georgia.* The initial level surveys for Georgia were conducted while a porous friction course was still in place, but the subsequent level surveys were conducted after the milling, which removed the porous friction course from test sections 503, 504, and 505 and the porous friction course plus other materials from test sections 506-509. It can be seen that the approximate thicknesses of the porous friction course were 18 mm for test section 503, 28 mm for test section 504, and 30 mm for test section 505. These values were added back to get the calculated overlay thicknesses in order to delete the porous friction course thickness from the original pavement for these comparative studies. As test section 506 is located next to test section 505, 30 mm was added to delete the porous friction course. Similarly, test section 507 is adjacent to test section 504, so 28 mm was added. Test sections 508 and 509 are between test sections 502 and 503, so the porous friction course thicknesses were interpolated linearly, leading to addition of 12 mm for test section 508 and 6 mm for test section 509.

Once the average overlay thicknesses were calculated, the average deviation in overlay thicknesses (or differences from the specified thicknesses) were calculated. Tables 7 and 8 offer consolidated data on overlay thicknesses and deviations in overlay thicknesses. Only those SPS-5 projects with data supporting overlay thickness calculations are included in these two tables.

Table 7 shows overlay thickness data separately for those specified to be 51 mm in thickness and those specified to be 127 mm in thickness. It can be seen that the actual overlay thicknesses were often much less than the specified thickness, and sometimes were thicker than specified. This is especially true for those test sections where 51-mm overlays were specified, as the deviations often represent a large fraction of the specified thickness. However, there are still substantial differences in overlay thicknesses between the "thick and thin" overlays, so effects of thickness on performance should be apparent within the same project. Tables 91-105 may be used to consider the possible effects of thickness deviations on performance.

Table 8 offers information on deviations from the specified overlay thicknesses for the SPS-5 projects. Many of these deviations are quite large in comparison with the overlay thicknesses listed in table 7. These deviations sometimes result from substantial milling and little or no milling replacement. Apparent discrepancies that were noted from a review of the thickness data were filed with the Federal Highway Adminstration (FHWA) through the use of the LTPP Data Feedback Reports. A summary of the discrepancies found are listed below:

- *Arizona*. Test sections 502, 503, and 505 for the Arizona project were milled, although they were not supposed to be milled sections. However, the construction report explained that a thin porous friction course was milled off.

- *California.* A 51-mm RAP overlay was placed on the control section 501 of the California project, although it was not to have been overlaid. This does not appear in the database, but does appear in the construction report.

- *Colorado.* A 33-mm rut level-up course was placed on the control section 501 of the Colorado project, although it was not to have been overlaid. This does not appear in the database, but does appear in the construction report.

- *Colorado.* Substantial milling (53 to 56 mm) is reported for the milled test sections 506-509 in Colorado, but no milling replacement is reported. As the overlay thicknesses for these test sections are much lower than intended, it appears possible that milling replacement values may have just been omitted.

- *Florida.* Test sections 502, 504, and 505 for the Florida project were milled, although they were not supposed to be milled sections. However, review of the elevation data suggests that these test sections were milled to remove a porous friction course.

- *Georgia.* Test sections 503, 504, and 505 for the Georgia project were milled, although they were not supposed to be milled sections. However, review of the elevation data suggests that these test sections were milled to remove a porous friction course.

- *Maine.* All average depths of milling for the Maine project are reported as 38 mm. This uniformity appears unlikely and raises the question whether these were measured or estimated.

- *Manitoba.* The Manitoba data suggest that test sections 506-509 were not milled, although they were supposed to be milled sections.

- *Montana.* It can be seen from table 7 that the calculated overlay thicknesses are much smaller for the Montana project than intended. It appears probable that some error may exist in the elevation data. Also, milling depths for test sections 502-509 are reported uniformly as 25 mm, which seems unlikely and may mean that they were estimated. More importantly, no milling replacement is reported for this project. It appears appropriate to review the elevation data files and check all the calculations. If it were found that test sections 502-505 were actually not milled, the calculated overlay thicknesses for these test sections would each be increased by 25 mm.

- *New Jersey*. Test section 503 for the New Jersey project is reported to have 66 mm of milling replacement, although it was not milled. In addition, all milling depths are reported to be 25 mm and raises the question of whether they were measured or estimated.

Table 7. Calculated overlay thicknesses for those SPS-5 projects with sufficient elevation data.

State	Thicknesses in mm for Specified Overlay Thicknesses					
	51-mm Overlays			127-mm Overlays		
	Low	High	Average	Low	High	Average
Alabama	33	48	38	102	124	114
Colorado	13	89	47	76	155	116
Florida	25	57	42	109	136	132
Georgia	23	71	50	116	158	132
Maine	58	91	71	135	152	143
Maryland	15	51	40	99	124	113
Montana*	3	10	5	63	76	69
New Jersey	43	79	63	86	155	119
Texas	56	69	60	122	132	127

*Possible error in the elevation data, refer to discussion in the text.

Table 8. Overlay thickness deviations from specified overlay thicknesses.

State	Deviations From Specified Overlay Thicknesses in mm		
	Low	High	Average
Alabama	3	25	13
Colorado	8	51	32
Florida	3	26	12
Georgia	2	31	15
Maine	7	40	18
Maryland	3	28	12
Montana	41	64	52
New Jersey	2	41	19
Texas	3	18	7

2.1.2 Performance Data for SPS-5 Studies

The SPS-5 project data used in this study were from the LTPP data public release dated February 1997. Graphical summaries of the distress data with time (included in appendices D through I) provide the primary documentation of performance. Tables reflecting the distress and/or performance data also appear in the separate chapters that address the performance indicators individually.

2.2 DATA USED FOR STUDY OF GPS-6 PERFORMANCE

The GPS-6 test section data used for this study were extracted from the LTPP data public release dated October 1996. Table 4 identified those states for which sufficient GPS-6 data are available to develop useful performance graphs for the four types of pavement cracking. These graphs will appear in the appendices individually by distress type, as stated in chapter 1. Tabular data are also included separately for each state for which distress data are available for at least one GPS-6 project. These tables are included in appendix B and they include:

- SHRP ID and experiment (GPS-6A or GPS-6B)
- Original construction date
- Subgrade type
- Thicknesses and material types for subbases and bases
- AC thickness
- Condition prior to overlay
- Month of overlay
- Overlay thickness

The layer thicknesses in the tables are based on laboratory measurements. These are the best data on layer thicknesses available for the GPS-6 pavements. Where laboratory data were not available for the AC overlay thicknesses, they were not entered.

All of the available cracking distress data for GPS-6 test sections appear in appendix C. However, separate tables in chapters 3 through 5 provide the last measurement of the distress of interest for each test section in a specific chapter.

It should be noted that the condition of the existing pavement prior to overlay placement (defined as either "good" or "poor") has been used throughout this report. This condition represents a subjective rating of the original pavement, prior to overlay, that was provided by the SHAs for each of the GPS test sections. In addition, "age of overlay" is used throughout this report and always means the age at the last time monitoring data were collected.

CHAPTER 3. FATIGUE CRACKING AND LONGITUDINAL CRACKING IN THE WHEEL PATH

Fatigue cracking and longitudinal cracking in the wheel path (LCWP) area are described in the *Distress Identification Manual*, with three levels of severity identified for both.[7] For the purposes of this report, cracking at all severity levels has been combined.

LCWP is defined as "cracks predominantly parallel to the pavement centerline" located in the wheel paths and is measured in meters at each severity level. Fatigue cracking is defined as a series of interconnected cracks (characteristically with a "chicken wire/alligator" pattern) and is measured in square meters at each severity level. Fatigue cracking usually develops as multiple longitudinal cracks in the wheel path become connected laterally. Thus, increases in fatigue cracking over time (or with cumulative traffic) can be accompanied by decreases in longitudinal cracking in the wheel path. This relationship needs to be kept in mind while reading chapter 3.

As these are studies of overlaid pavements, much of the load-related cracking in the overlays is believed to have reflected from cracks in the original AC pavement. However, LCWP can be initiated at the surface or bottom of the AC overlay. The cause of this type of cracking, and the direction of crack propagation, can only be determined through trenching studies or taking cores through cracked areas, which was beyond the scope of this study.

3.1 FATIGUE CRACKING

3.1.1 Fatigue Cracking on SPS-5 Test Sections

The graphs of fatigue cracking with time appear in appendix D, and table 9 provides the amounts of fatigue cracking noted by project and test section. The five SPS-5 projects not listed on table 9 (Florida, Montana, New Jersey, New Mexico, and Oklahoma) did not have post-overlay fatigue cracking data available in the NIMS. Table 9 also provides information about fatigue cracking present in the existing pavements prior to the overlays. It should be noted that columns designated as "age of overlay" throughout this report always mean age at the last time monitoring data were collected.

<u>General Overview of Observations from Data</u>

Excluding the control sections and those test sections without pre-overlay fatigue cracking data, 47 of 90 test sections (52 percent) exhibited fatigue cracking prior to overlay placement (table 9b). Of these 47 test sections, 7 have exhibited fatigue cracking after overlay placement. More importantly, 3 to 6 years after overlay placement, 14 of 96 test sections (15 percent) have exhibited fatigue cracking (i.e., 7 sections that had no fatigue cracking prior to overlay have exhibited fatigue cracking after overlay placement). Of the control sections, 5 out of 11 (excluding California), or 45 percent, have exhibited fatigue cracking (table 9a).

Table 9a. Fatigue cracking noted in SPS-5 test sections at time of last manual distress surv

State	Age of Overlays (Years)	Fatigue Cracking by Section, m²						
		501	502	503	504	505	506	507
Alabama	3.6	271	0	0	0	0	0	0
Alberta	4.9	1	32.5	4.4	0	0	0	0
Arizona	4.4	243	0.4	0	0	17	0	0
California	2.8	0	0	0	0	0	0	0
Colorado	3.0	0.9	0	0	0	3.5	18.3	7.8
Georgia	2.8	0	0	0	0	0	0	0
Maine	.4	0	0	0	0	0	0	0
Manitoba	6.1	17	2	3	0	4	0	0
Maryland	3.4	0	0	0	0	0	0	0
Minnesota	4.8	0	0	0	0	0	0	0
Mississippi	3.2	0	0	0	0	0	0	0
Texas	4.0	0	0	0	0	0	0	0

Note that the “age of overlays” column provides the years between overlay and last manual distress survey.

Table 9b. Area of fatigue cracking prior to overlay, m².

State	Fatigue Cracking by Section, m²						
	501	502	503	504	505	506	507
Alabama	68	31	31	2	31	13	30
Alberta	NA	NA	NA	NA	0	11	0
Arizona	31	36	NA	31	56	162	170
California	34	15	NA	37	38	39	43
Colorado	1	0	3	1	15	44	28
Georgia	NA	15	0	1	2	0	1
Maine	0	0	0	0	0	0	0
Manitoba	0	0	1	7	0	0	9
Maryland	2	0	59	88	103	47	56
Minnesota	0	0	0	0	0	0	0
Mississippi	0	5	6	0	0	0	0
Texas	0	0	0	0	0	0	0

NA = Fatigue cracking data not available.

More importantly, two of the SPS-5 projects (Alberta and Colorado) have a few test sections where the fatigue cracking is greater than the amount measured on the control section (501). A rut level-up course was placed on the control section of the Colorado project, which could explain this difference. However, only routine maintenance was applied to the Alberta control section.

Some general observations from these data are listed below and are based on only the 12 projects with a complete set of post-overlay fatigue cracking data (table 9a).

- *Thin Versus Thick Overlays***.** Out of 48 possible test sections, 9 of the test sections with a thin AC overlay (19 percent) have exhibited fatigue cracking, whereas only 4 of the test sections with a thick overlay (8 percent) have exhibited fatigue cracking. The average area of fatigue cracking that has occurred on those test sections with a thin overlay is 10.2 m^2 and only 4.1 m^2 for those with a thick overlay.

  It is generally believed that thicker AC overlays should have longer service lives in terms of fatigue cracking compared with life expectancy of thinner overlays. The initial performance trends from the SPS-5 projects support this hypothesis. Continued monitoring and future analysis should be able to determine the overall benefit of increased AC overlay thickness relative to extending the pavement's life in terms of fatigue cracking.

- *Virgin Versus Recycled Mixtures.* Out of 48 possible test sections, 8 of the test sections (17 percent) with recycled mixtures (AC overlay mixtures with RAP) exhibited fatigue cracking, whereas 5 of the test sections (10 percent) with virgin mixtures (AC overlay mixtures without RAP) exhibited fatigue cracking. The average area of fatigue cracking that has occurred on those test sections with recycled mixtures that have cracked is 7.2 m^2, and 10.1 m^2 for those with virgin mixtures. In other words, the recycled mixtures have a higher percentage of sections with fatigue cracking compared with the virgin mixtures, but exhibit on the average smaller areas of cracking.

  Although debatable, it is generally believed that mixtures with RAP are stiffer (higher moduli), but are no more or less susceptible to repeated load fracture than those mixtures without RAP. The initial performance trends from the SPS-5 projects are more in line with this hypothesis. Continued monitoring and review of the laboratory resilient modulus data, when available, should be able to confirm or reject this hypothesis.

- *Milled Versus Non-Milled Surfaces.* Out of 48 possible test sections, 8 of the test sections (17 percent) with milling exhibited fatigue cracking, whereas 5 of the test sections (10 percent) without milling exhibited fatigue cracking. The average area of fatigue cracking that has occurred on those test sections with milling prior to overlay is 8.3 m^2 and 8.4 m^2 for those without milling.

In general, it is believed that the use of milling and replacing the milled thickness with a new AC mixture prior to overlay should result in a stronger pavement that is less susceptible to repeated load fracture, compared with the condition where milling is not used prior to overlay. The initial performance trends from the SPS-5 projects appear to contradict this hypothesis. Review of the air voids and densities measured on the different AC mixtures, when available, should determine whether the milling resulted in different or lower compactive efforts of the AC mixtures placed over the original pavement that had not been milled. Continued monitoring and review of the indirect tensile strengths and mixture volumetric properties, when available, should be able to confirm or reject the above hypothesis and to determine the overall effect of milling, if any, on the occurrence of fatigue cracks.

- None of the "504" test sections (thick overlay without milling and virgin mixtures, without RAP) have exhibited fatigue cracking after overlay placement.

Detailed Assessment of Fatigue Cracking

As shown in table 9, only three projects exhibited fatigue cracking (greater than the nominal amount previously defined) at the times of the surveys for which data were available in the NIMS. These projects (Alberta, Arizona, and Colorado) are discussed in greater detail in the following paragraphs. Table 10 summarizes the number of test sections (excluding the Maine project and all of the control sections) with different areas of fatigue cracking.

Table 10. Summary of SPS-5 test sections with fatigue cracking.

Total SPS-5 Sections		Area of Fatigue Cracking, m²			
		0	**1-10 (Nominal)**	**10-60**	**> 60**
Number of Test Sections	88	75	9	4	0
Percentage in Each Group	100.0	85.2	10.2	4.6	0.0

Extent or Area of Fatigue Cracks in Comparison Prior to Overlay	Number of Test Sections	Percentage in Each Group
Area Fatigue Cracks Less than Prior to Overlay	46	56.1
Area Fatigue Cracks Equal to Prior to Overlay	32	39.0
Area Fatigue Cracks Greater than Prior to Overlay	4	4.9
Total	82	100.0

More importantly, table 10 also summarizes the number of test sections (excluding the Maine project) with fatigue cracking in comparison to the area of fatigue cracks measured in each section prior to overlay. These summaries show that only a few of the test sections have exhibited fatigue cracks and only four overlaid test sections have more fatigue cracks than were measured prior to overlay.

Alberta Project. The fatigue cracking prior to overlay for the Alberta project varied from none to 11 m^2, with a mean value of approximately 3 m^2. While the control section still displayed a very small, but measurable amount of fatigue cracking (original AC thickness was 234 mm, highest for any of the test sections), test sections 502, 503, 508, and 509, all of which have recycled mixes, are beginning to exhibit varying amounts of fatigue cracking. Although overlay thicknesses are not presently available, it can be seen from table 104 that the original AC thicknesses for test sections 502 and 508 are only 137 mm and 140 mm, respectively, which is much less than for any other test section. However, it is difficult to extract clear conclusions why one test section is doing better than another. The following observations are intended to shed some light on this:

- The only test sections exhibiting fatigue cracking are those test sections with recycled overlay mixtures. However, three of the four test sections have thinner original AC layers than any of the others (137, 140 and 168 mm compared with an average of 210 mm for the other six test sections). This substantial difference in overall pavement thickness may have contributed to the greater amount of fatigue cracking.

- While the thinner original AC thickness may help explain why test section 508 is cracking, this does not apply for test section 503. Although very nominal fatigue cracking was observed prior to overlay, fatigue cracking was present 4.9 years after overlay placement.

Arizona Project. The fatigue cracking on the Arizona project was more advanced when overlaid. All of the test sections had some cracking and the mean amount was 74 m^2. Three test sections have exhibited fatigue cracking after 4.4 years. Of these three, control section 501 with 243 m^2 has an order of magnitude more than test section 505 with 17 m^2 (second largest amount). However, the impact of this is confounded by the fact that the original AC thickness for 501 was around 81 mm, as compared with an average of 138 mm for the other eight.

Colorado Project. The fatigue cracking for the Colorado project was under way, but on average, was relatively limited at the time of overlay. While the cracking for the control section was still only 0.9 m^2, three of the overlaid test sections have exhibited some fatigue cracking. All three of these test sections had virgin overlay mixes, unlike the three in Alberta that all had recycled overlay mixes.

It can be seen that test section 506 had 44 m^2 of fatigue cracking prior to overlay, which was the most of any of these test sections. It had 18.3 m^2 when surveyed after overlay, which is still the most of any of the test sections. This appears to support the common expectation that, with all other things being equal, more fatigue cracking may be expected where more existed prior to overlay.

Alabama Project. It can be seen from both figure 13 and table 9 that fatigue cracking (greater than the nominal amount) occurred on the Alabama project prior to the overlay. After 3.6 years, the fatigue cracking on the Alabama control section 501 had increased greatly, while no fatigue cracking was observed in the overlaid test sections.

Summary

The following provides an overall summary of the observations made from the SPS-5 fatigue cracking data.

- Considering all available data, 55 (or 70 percent) of the 79 test sections that had fatigue cracking in the original pavements have not exhibited any fatigue cracks as of the last distress survey used for this study.

- Three of the 16 test sections with the thicker overlays exhibited fatigue cracking, with the highest amount being 7.8 m^2.

- Six of the 16 test sections with thin overlays had fatigue cracking and the amounts were generally greater than for the thicker overlays.

- Another important observation is that 4 of the 17 projects exhibited fatigue cracking 2.5 to 6 years after overlay placement.

- The greatest amount of cracking observed was 32.5 m^2 for a test section having only 72 percent of the original AC thickness as the average of the other 9 sections.

3.1.2 Fatigue Cracking on GPS-6 Test Sections

Table 11 provides the primary data, selected or calculated from that available in appendices B and C, that were used for the studies leading to results discussed below. It identifies the state, SHRP identification number, experiment (GPS-6A or 6B), age before overlay, AC thickness before overlay, condition before overlay (good or poor), overlay thickness, age of overlay, and amount of fatigue cracking noted at the time of the last distress survey for which data are available. Tables 12, 13 and 14 were prepared from the data in table 11. Graphs of the performance of selected test sections appear in appendix E. The results in these tables are discussed below. Figure 4 graphically shows the probability of occurrence of fatigue cracks with overlay age for the GPS-6 data. It should be remembered that the original pavement condition prior to overlay is a subjective rating provided by the individual SHAs on the existing pavement prior to overlay (refer to section 2.2 in this report).

<u>AC Layer Thickness</u>

Table 12 provides AC layer thickness data and ages of overlays at the time of last survey. It can be readily seen that broad ranges of original, overlay, and total AC thicknesses appear in the database. It is not surprising that the average original AC thickness for those sections in the "good condition prior to overlay" category was larger than the average for those in the "poor condition" category (i.e., the thicker the AC layer, the better the performance). Similarly, the average overlay thickness for the test sections in poor condition was somewhat larger than that for test sections in good condition prior to overlay, although the ranges of overlay thicknesses are very similar. As a result, the average total thicknesses after overlay (original AC plus overlay thicknesses) were almost identical for those in the poor and good condition prior to overlay. Similarly, the average ages of overlay were almost identical.

The data summarized in table 12 and graphically presented in the appendices were also reviewed to evaluate the effect of overlay thickness on the overlay performance, relative to fatigue cracking. The number of test sections, thickness range, average thickness, and standard deviation for each group are summarized in table 15.

Table 11. Fatigue cracking in GPS-6 test sections at last survey.

State	Section	Exp.	Original Pavement			Overlay Thick-ness (mm)	Age* of Overlay (years)	Fatigue Cracking (sq m)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Alabama	16012	6A	11.6	94	Good	33	11.6	105
Alabama	16019	6A	14.8	163	Poor	89	12.0	0
Alabama	14127	6B	14.7	211	Poor	43	4.0	0
Alabama	14129	6B	13.4	76	Good	38	3.8	29
Alaska	21008	6A	10.3	33	--	--	6.5	0
Alaska	26010	6A	13.2	53	Poor	43	12.5	0
Alaska	21004	6B	13.8	91	Poor	46	4.0	0
Alaska	29035	6B	18.8	53	Good	97	3.2	0
Alberta	811804	6B	10.8	89	Poor	99	0.2	0
Arizona	46053	6A	20.5	81	Poor	120	6.5	0
Arizona	46054	6A	3.8	178	Good	53	5.8	6
Arizona	46060	6A	21.5	99	Poor	102	6.4	0
British Columbia	826006	6A	17.5	81	Poor	53	15.7	36
British Columbia	826007	6A	2.7	64	Poor	132	12.6	0
California	68534	6B	22.5	119	Poor	89	1.2	0
Colorado	86002	6A	(0.8)	147	Poor	71	26.4	350
Colorado	86013	6A	(0.3)	69	Poor	38	10.4	0
Colorado	87783	6A	3.7	127	Good	91	9.4	14
Colorado	87781	6B	9.3	86	Poor	56	10.1	0
Florida	124101	6B	24.2	33	Good	114	1.7	0
Florida	124135	6B	21.2	36	--	--	0.9	0
Florida	124136	6B	21.2	36	Poor	--	0.9	0
Florida	124137	6B	21.5	71	Good	--	0.9	0
Georgia	134420	6B	8.4	125	Poor	--	2.1	0
Illinois	176050	6A	18.5	61	Poor	117	15.2	0
Indiana	181037	6B	11.7	71	Poor	25	0.1	0
Iowa	196049	6A	13.4	137	Good	71	12.6	0
Kansas	206026	6A	14.0	25	Good	147	12.6	0
Kentucky	216040	6A	14.9	155	Good	41	7.0	0
Kentucky	216043	6A	7.9	140	Good	51	16.0	0
Maine	231028	6B	21.8	163	--	--	0.1	0
Manitoba	836450	6B	18.0	112	Poor	150	3.8	0
Manitoba	836451	6B	18.0	104	Poor	66	3.8	0
Minnesota	276064	6A	12.0	193	Poor	142	8.7	116
Mississippi	282807	6B	10.7	269	Poor	--	2.3	0
Mississippi	283091	6B	16.3	89	Good	--	0.3	0
Mississippi	283093	6B	7.5	104	Good	76	1.8	0
Mississippi	283094	6B	7.5	231	Good	76	3.6	0

Table 11. Fatigue cracking in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement: Age Before Overlay (years)	Original Pavement: AC Thick-ness (mm)	Original Pavement: Condition Before Overlay	Overlay Thick-ness (mm)	Age* of Overlay (years)	Fatigue Cracking (sq m)
Missouri	296067	6A	15.9	180	Poor	25	13.8	0
Missouri	295403	6B	24.0	102	Good	56	5.0	0
Missouri	295413	6B	24.0	97	Poor	79	5.0	0
Montana	306004	6A	17.8	89	Good	180	11.4	0
Montana	307075	6A	17.3	86	Good	94	12.6	0
Montana	307076	6B	5.8	132	Good	61	0.4	0
Montana	307088	6B	10.1	124	Poor	43	0.3	0
New Brunswick	846804	6A	(0.5)	99	Good	56	16.6	0
New Mexico	351002	6A	26.5	109	Poor	99	9.2	0
New Mexico	356033	6A	22.5	107	Poor	64	13.2	76
New Mexico	356035	6A	19.5	91	Good	112	9.2	58
New Mexico	356401	6A	13.5	102	Poor	109	10.2	7
North Carolina	371040	6B	16.7	135	--	--	0.5	0
North Carolina	371803	6B	12.7	132	Poor	76	5.7	5
Oklahoma	406010	6A	14.5	114	Good	51	9.9	0
Oklahoma	404086	6B	19.3	109	Poor	33	5.3	0
Oklahoma	404164	6B	16.3	117	Poor	--	0.3	0
Oregon	416011	6A	25.1	155	Poor	173	5.3	0
Pennsylvania	421608	6A	0.0	61	Good	66	6.1	0
Quebec	891021	6B	14.2	132	--	--	0.2	0
Quebec	891127	6B	15.7	124	--	--	0.2	0
Saskatchewan	906400	6A	9.7	196	Poor	61	13.6	0
Saskatchewan	906801	6A	8.7	--	Poor	102	13.6	0
Saskatchewan	906410	6B	21.3	117	Poor	94	4.9	0
Saskatchewan	906412	6B	21.3	112	Poor	140	4.9	0
South Dakota	469197	6B	25.7	89	Poor	94	4.1	0
Tennessee	476015	6A	10.6	224	Good	140	8.6	0
Tennessee	476022	6A	8.6	119	Good	51	12.6	--
Tennessee	473108	6B	17.6	140	Good	--	3.5	0
Tennessee	473109	6B	10.6	132	Poor	--	4.2	0
Tennessee	473110	6B	8.1	130	Poor	140	3.9	0
Tennessee	479024	6B	18.0	145	Good	--	(0.1)	0
Texas	481046	6A	15.3	274	Poor	53	24.6	48
Texas	486079	6A	12.4	175	Good	66	10.6	5
Texas	486086	6A	13.6	221	Good	38	10.2	0
Texas	486160	6A	18.3	61	Poor	41	12.5	12
Texas	486179	6A	9.6	41	Poor	112	20.6	0
Texas	481093	6B	8.4	74	Good	64	6.6	36
Texas	481113	6B	6.4	38	Poor	94	3.1	0
Texas	481116	6B	3.3	38	Good	84	0.7	83

Table 11. Fatigue cracking in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement: Age Before Overlay (years)	Original Pavement: AC Thick-ness (mm)	Original Pavement: Condition Before Overlay	Overlay Thick-ness (mm)	Age* of Overlay (years)	Fatigue Cracking (sq m)
Texas	481119	6B	14.3	135	Poor	41	6.0	0
Texas	481130	6B	21.0	69	Poor	25	2.5	0
Texas	483875	6B	7.0	41	Good	25	4.2	5
Utah	491004	6A	6.3	81	Good	117	17.8	305
Utah	491005	6A	13.5	150	Good	97	7.7	5
Utah	491006	6A	16.2	234	Good	64	7.8	0
Utah	491007	6A	8.3	239	Good	51	3.7	0
Washington	536049	6A	16.2	236	Good	33	6.1	0
Washington	531005	6B	16.0	267	Poor	58	5.2	1
Wyoming	566031	6A	5.3	64	Poor	64	10.6	0
Wyoming	566032	6A	12.6	76	Good	58	10.7	0

*Age of Overlay is the age at the time the last distress survey (available at the time the data were extracted) was conducted.

Table 12. Average thickness data and age of overlay at time of last survey.

Original Condition Before Overlay	Original AC Thickness (mm)		Overlay Thickness (mm)		Total Thickness (mm)		Age of Overlay (Years)	
	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.
Poor	36-274	117	25-173	87	94-328	198	0.1-26.4	7.9
Good	25-239	141	25-180	77	66-364	199	0.1-17.8	7.4

As shown, the most important observation is the discrepancy between the total number of test sections between the two fatigue cracking groups of data. In summary, additional monitoring will be required to determine the effect of overlay thickness on the occurrence and growth of fatigue cracks.

Overlay Age

Table 13 lists the number of test sections exhibiting various levels of fatigue cracking distress and table 14 summarizes the cumulative number of test sections in each time or age category. Of the 82 GPS-6 test sections, 46 were originally in poor condition before overlay and 36 were in good condition. Some additional comments on these results follow:

- Of the 82 GPS-6 test sections, 62 (or 76 percent) had no fatigue distress, 7 more exhibited less than 10 m^2 and 13 exhibited more than 10 m^2. For the 69 test sections having 10 m^2 or less of fatigue cracking (table 13), 30 (or 43 percent) were less than 5 years old, 18 (or 26 percent) had been overlaid 5 to 9.9 years, 17 (or 25 percent) had been overlaid 10 to 14.9 years, 3 (or 4 percent) had been overlaid 15 to 20 years, and only 1 test section had been overlaid more than 20 years. Obviously, time and/or cumulative traffic are important factors that affect the occurrence of fatigue cracks.

- Six of the 46 test sections that were originally in poor condition had exhibited more than 10 m^2 of fatigue cracking since overlay (table 13). The amounts of fatigue cracking for these 6 ranged from 12 to 350 m^2, with an average of 106 m^2.

- Similarly, only 7 of the 36 test sections that were originally in good condition had exhibited more than 10 m^2 of fatigue cracking (table 13). The amounts of fatigue cracking varied from 14 to 305 m^2, with an average of 90 m^2.

While very few of the test sections have amounts of fatigue cracking that exceed the nominal amount (10 m^2), it must be remembered that many of these overlays are relatively new (GPS-6B test sections) and that an unknown number of the original pavements had not exhibited fatigue cracking prior to overlay. Separate consideration of the GPS-6A test sections should offer some indication of the long-term performance of the overlays, which will not be possible for some years for the SPS-5 and GPS-6B test sections.

Table 13. Numbers of GPS-6 test sections with various extents of fatigue cracking distress.

Original Condition Before Overlay	Fatigue Cracking Extent					
	Total* Test Sites	0	1 to 10 m^2 (Nominal)	11 to 30 m^2	31 to 60 m^2	> 60 m^2
Poor	46	37	3	1	2	3
Good	36	25	4	2	2	3
Total	82	62	7	3	4	6

*Number of test sections for which fatigue data are available.

Table 14. Ages of GPS-6 test section overlays with 10 m^2 of fatigue cracking or less.

Original Condition Before Overlay	Total* Test Sections	Total Number 0 to 10 m^2	Number <5 Years	Number $\geq$ 5 Years	Number $\geq$ 10 Years	Number $\geq$ 15 Years	Number $\geq$ 20 Years
Poor	46	40	19	21	12	2	1
Good	36	29	11	18	9	2	0
Total	82	69	30	39	21	4	1

*Number of test sections for which fatigue data are available and prior condition was provided.

Table 15. Hot mix asphalt (HMA) thicknesses of the GPS-6 test sections for each original condition before overlay group.

Original Condition Before Overlay	Fatigue Cracking Category							
	None				Greater Than Nominal			
	No. Of Sections	Thickness Range, mm	Mean, mm	Standard Deviation, mm	No. of Sections	Thickness Range, mm	Mean, mm	Standard Deviation, mm
Poor	32	25-173	84	40.6	6	41-142	71	36.4
Good	21	33-180	77	38.8	7	33-117	77	33.4

Table 16 provides the same data as table 14, except that it is restricted to GPS-6A test sections. As shown and expected, the greatest difference between the two tables is that there are very few GPS-6A test sections with the age of the overlay less than 5 years. However, figure 4 shows that once fatigue cracks develop or are observed at the surface, the area of fatigue cracks grows fairly rapidly.

Table 16. Ages of GPS-6A overlays with 10 m^2 of fatigue cracking or less.

Original Condition Before Overlay	Total Test Sections	Total Number 0 to 10 m^2	Number <5 Years	Number $\geq$ 5 Years	Number $\geq$ 10 Years	Number $\geq$ 15 Years	Number $\geq$ 20 Years
Poor	21	15	0	15	11	2	1
Good	22	18	1	17	9	2	0
Total	43	33	1	32	20	4	1

Note: One GPS-6A test section overlay in the good group was less than 5 years old when the last manual distress survey was conducted.

Original Pavement Condition

The effects of original pavement condition prior to overlay placement on the fatigue cracking performance of the GPS-6A test sections can be summarized by considering the number of test sections at three levels of fatigue cracking. Table 17 summarizes the number of GPS-6A test sections with different extents of fatigue cracking for the different pavement groups and these results are comparable to table 13.

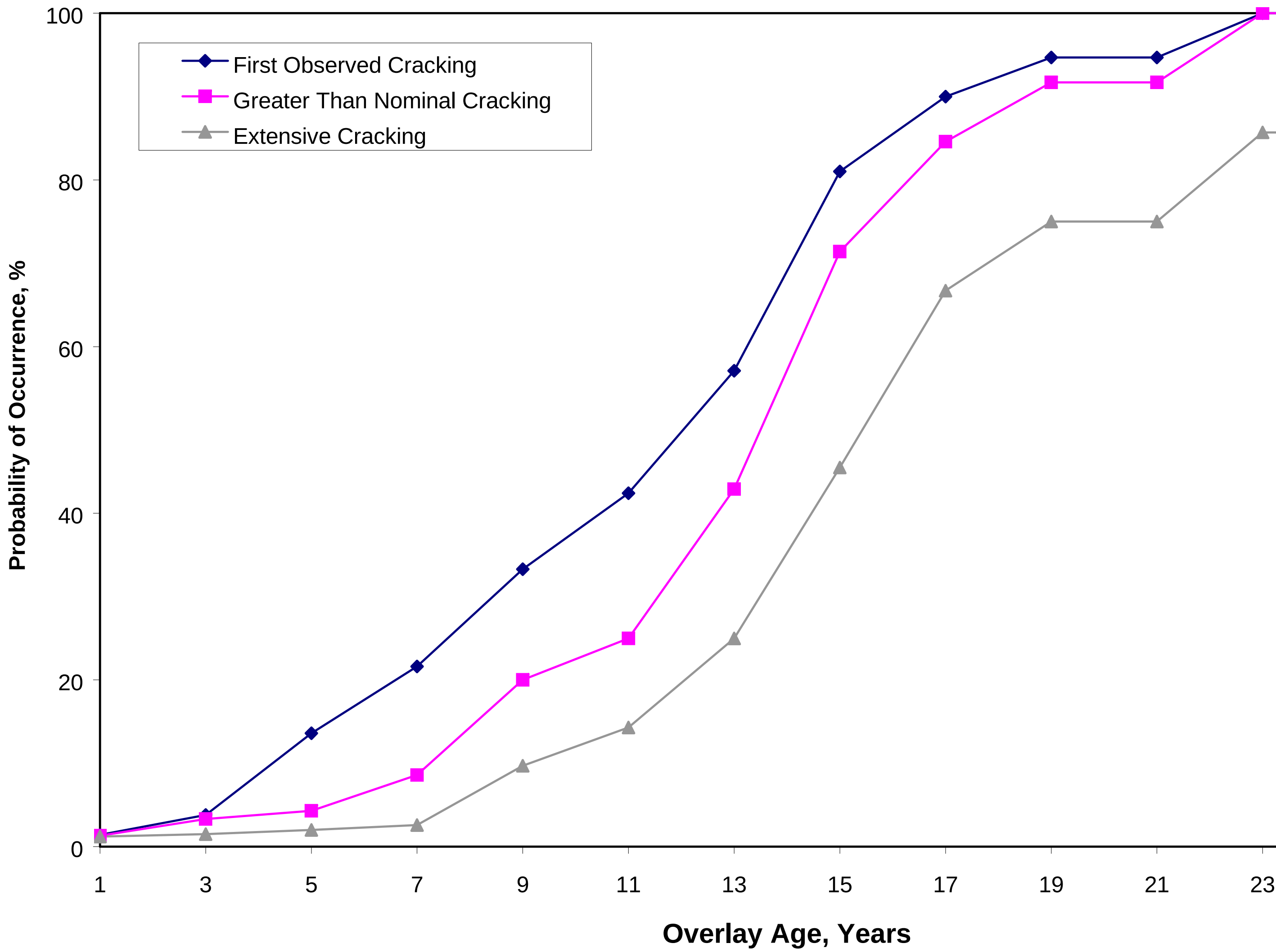

Figure 4. Probability of occurrence for different levels of fatigue cracking on the GPS-6 test

Table 17. Number of GPS-6A test sections with fatigue cracking.

Original Condition Before Overlay	Number of GPS-6A Test Sites	Fatigue Cracking Extent		
		None	1 to 10 m2 (Nominal)	11 or More m2
Poor	21	14	1	6
Good	22	15	3	4
Total	43	29	4	10

It does not appear from these limited data that the original condition of pavement to be overlaid has a major impact on the incidence of fatigue cracking in an overlay. However, the overlays with original pavements in poor condition did exhibit more fatigue cracking than the overlays over pavements in good condition. It is encouraging to note that 68 percent of those in the good group and 67 percent of those in the poor group have exhibited no fatigue cracking.

The message from the GPS-6A data appears to be that overlays typical of the population of 43 test sections for which data were available have exhibited little to no fatigue cracking for 5 to 15 years, and some even longer. However, data are not available as to the existence, amount, or severities of fatigue cracking prior to these overlays so more detailed information with relation to fatigue cracking prior to overlay must likely await aging of GPS-6B and SPS-5 test sections for which distress surveys were generally conducted prior to the overlays.

3.2 LONGITUDINAL CRACKING IN WHEEL PATHS

3.2.1 Longitudinal Cracking in Wheel Paths for SPS-5 Test Sections

The amounts of LCWP appear in table 18 for each test section in each SPS-5 project with the exception of those projects that do not have any post-overlay LCWP data recorded in the NIMS. Those projects include Florida, Montana, New Jersey, New Mexico, and Oklahoma. Table 18 also provides information about LCWP present in the existing pavements prior to the overlays. The graphs for four of the nine projects exhibiting greater than nominal longitudinal cracking in the wheel path (Alberta, Colorado, Manitoba, and Mississippi) appear in appendix E. As stated previously, a review of the LCWP is complicated by the fact that the length of these cracks can decrease with time as they transform into fatigue cracks.

General Overview of Observations from Data

Excluding the control sections and those test sections without pre-overlay LCWP data, only 19 of 90 test sections (18 percent) exhibited more than nominal LCWP (50 m) prior to overlay placement. All of those test sections were from the Arizona, California, Maryland, and Mississippi SPS-5 projects (table 18b). Of those 19 test sections, 6 have exhibited LCWP after

Table 18a. Longitudinal cracking in the wheel path noted on SPS-5 test sections at time of last manua

State	Age of Overlays (Years)	Longitudinal Cracking in Wheel Path by Test Section, m.						
		501	502	503	504	505	506	507
Alabama	3.6	0	0	0	0	0	0	0
Alberta	4.9	26	12.6	60.4	25.2	36.5	13.9	7.5
Arizona	4.4	0	41.5	0	0	0	0	0
California	2.4	0	2.5	1.6	0.9	17	4.4	10.3
Colorado	3.0	3.3	63	4.2	13.9	27	31.7	61.2
Georgia	2.8	0	0	0	0	0	0	0
Maine	0.4	0	0	0	0	0	0	0
Manitoba	6.0	6	282	305	80	224	294	158
Maryland	3.3	7.2	0	0	0	4.9	0	0
Minnesota	4.8	0	0	0	0	0	0	0
Mississippi	3.2	66.5	175	0	0	0	6	0
Texas	3.8	10	0	0	0	0	0	0

Table 18b. Length of longitudinal cracking in the wheel paths prior to overlay.

State	Longitudinal Cracking in Wheel Path by Test Section, m.						
	501	502	503	504	505	506	507
Alabama	3	0	0	0	0	0	0
Alberta	NA	NA	NA	NA	2	0	2
Arizona	252	281	NA	172	80	63	103
California	109	43	NA	23	35	94	139
Colorado	24	0	6	6	15	19	10
Georgia	NA	2	0	0	0	0	0
Maine	0	0	0	0	0	0	0
Manitoba	0	0	0	0	0	0	0
Maryland	7	62	3	3	0	6	21
Minnesota	0	0	0	0	0	0	0
Mississippi	27	93	120	96	37	33	50
Texas	0	0	0	0	0	0	0

NA= LCWP data not available.

overlay placement. More importantly, 3 to 6 years after overlay placement, 14 of 96 test sections (15 percent) have exhibited more than nominal LCWP after overlay and 8 of those were from the Manitoba project (table 18a). The following summarizes the number of test sections with LCWP for the 11 SPS-5 projects identified in table 18 that are greater than 2 years in age.

Length of LCWP, m	Number of Test Sections
0	51 (or 58 percent)
1-10	11 (or 12.5 percent)
10-50	13 (or 14.8 percent)
50-160	7 (or 8 percent)
>160	6 (or 6.8 percent)

More importantly, table 19 summarizes the number of test sections with different levels of LCWP for those factors considered in the SPS-5 experimental plan.

Table 19. Summary of SPS-5 test sections with different lengths of LCWP.

Length of LCWP, m	Overlay Thickness		Overlay Mixture		Surface Preparation	
	Thin	Thick	Without RAP	With RAP	Without Milling	With Milling
0	27	32	30	29	29	30
1-10	5	5	5	5	5	5
>10	16	11	13	14	14	13

The above suggests that there is no distinction between the different types of mixtures and types of surface preparation used on the SPS-5 projects in terms of LCWP, but that a lesser number of the test sections with the thick overlays have exhibited LCWP, compared with those with thin overlays. However, considering only those SPS-5 test sections with LCWP, the following summarizes and compares the average length of LCWP for each factor included in the experimental design.

Overlay Thickness	Overlay Mix Type	Surface Preparation
Thin - 70.8 m	With RAP - 80.3 m	Without Milling - 72.5 m
Thick - 66.0 m	Without RAP - 56.5 m	With Milling - 64.7 m

Note: All of the above have coefficients of variation in excess of 100 percent, which would indicate that there is no significant difference between the means.

As shown, there does not appear to be a significant difference between the thin and thick overlays and milled and non-milled surfaces for those test sections with LCWP. However, the overlay mixtures with RAP that are cracked consistently have greater lengths of LCWP, on the average, than those with virgin mixtures.

More importantly, this type of cracking appears to be more project specific and was found to be highly variable on some of the SPS-5 projects, suggesting that it may also be test-section specific (for example, the Colorado and Mississippi projects). Combining the results (initial observations) from the fatigue cracking and LCWP review suggests that some of the LCWP may have initiated at the surface of the overlays because the crack lengths do not appear to be dependent on overlay thickness, but appear to be more dependent on the type of overlay mixture placed. As a result, climatic, traffic, and laboratory materials data must be reviewed to understand why selected test sections have exhibited LCWP. Thus, continued monitoring and more detailed analyses are required before any definitive conclusions can be reached.

Detailed Assessment of LCWP

The following discusses some of the observations for the individual projects.

Alabama Project. It can be seen from table 18 that the Alabama project had virtually no LCWP, and the only LCWP observed after 3 years was 10 m in test section 508. The only LCWP noted prior to overlay was 2.7 m in the control section 501, which was apparently not visible when surveyed after the overlays of the other test sections had been placed.

Alberta Project. The pavement test sections in the Alberta project had very little fatigue cracking or LCWP prior to their overlays, but all test sections now have LCWP in the overlays and three have exhibited fatigue cracking. Test sections 503 and 505, however, are the only ones with LCWP greater than that observed on the control section. Both of these were not milled prior to overlay.

Arizona Project. The Arizona pavement test sections had exhibited substantial fatigue cracking (average of 74 m^2) and LCWP (average of 142 m) prior to the overlays. After overlay, the only section exhibiting LCWP is test section 502, with 41.5 m versus 281 m prior to its overlay. Extensive LCWP (252 m) was recorded on the control section prior to routine maintenance, but no LCWP was observed 4 years after rehabilitation. As stated in the previous section, however, extensive fatigue cracking was observed in the control section. It is possible that the LCWP propagated into full-scale fatigue cracks on the control section.

California Project. The California test sections also had exhibited substantial LCWP prior to the overlays. In only 2.4 years after overlay placement, LCWP had occurred on all test sections (with the exception of test section 508) and indicates structural deterioration. The LCWP measured for test sections 502 through 509 varied from 0 m to 17 m, with a mean of 6.3 m. The control section 501 was also overlaid, so it is unknown how much LCWP might have occurred under the "do-nothing" strategy. It and test section 508 with a thick overlay were the only test sections exhibiting no LCWP.

Colorado Project. The Colorado test sections had 0 to 24 m (mean of 9 m) of LCWP and 0 to 44 m^2 of fatigue cracking (mean of 12 m^2) prior to overlay. After 3 years, every test section had exhibited LCWP ranging from 3 to 63 m, with an average of 30.7 m. As can be seen, the average is over three times that for the existing pavements prior to overlay. The control section 501 had 24 m of LCWP prior to overlay, but it is not indicative of the "do-nothing" strategy because a rut leveling course of around 33 mm was placed.

It may also be seen in table 94 that Colorado test section 502 averaged 89 mm in thickness rather than the 51 mm specified and had no LCWP when overlaid. However, it had exhibited much more LCWP than the others, except for test section 507, which had an average overlay thickness of 97 mm instead of 127 mm as intended. The Colorado overlays do not appear to be performing very well in terms of LCWP. Prior to overlay, the average LCWP was 9 m and 3 years after the overlays were placed, 30.7 m of LCWP was present. Only 3 of the test sections had exhibited fatigue cracking at 3 years after overlay.

Although both the thin and thick overlays had one test section with substantial LCWP, the average length of LCWP for the thicker overlays was 20.6 m versus 31.2 m for the thin test sections. It is interesting to note that test section 509 had as little LCWP as any other test section, although its overlay thickness was apparently (based on data available and calculations as described in chapter 2) only 13 mm. There are no discernable trends between virgin or recycled mixes or between milling or not milling.

Manitoba Project. The pavements in the Manitoba project had very little LCWP prior to the overlays, but all of the overlays have major amounts. Test sections 502 and 508 had LCWP throughout both wheel paths. Control section 501 is the only test section that still is displaying little cracking (only 6 m). It is not possible to explain definitely why the overlay has so much LCWP while the existing pavements have very little, without in-depth analyses that are beyond the scope of this study. As can be seen from table 105, there is almost no thickness data to draw on for additional insight.

Mississippi Project. The pavements in the Mississippi project had substantial LCWP prior to overlay. The control section 501 had 27 m, which had increased to 66.5 m in the 3.2 years since the other test sections were overlaid. No LCWP was noted for the four test sections with the thicker overlays or for test section 505 with the thinner overlay. The three other test sections with thin overlays had from 6 to 175 m of LCWP, with a mean of 87 m. Thus, the thicker overlays have performed much better than the thin ones.

Summary

Eight of the 14 projects (for which data are available) had LCWP in the overlays. Of those eight, LCWP had been quite nominal (less than 50 m) for four (Alabama, Arizona, Maryland, and Mississippi). Of the 32 overlaid test sections in these four projects, five had any LCWP. Of these four the two with the thinnest overlays in Mississippi had more than nominal LCWP.

Even for the four other projects (Alberta, California, Colorado, and Manitoba), only Manitoba had extensive LCWP in all test sections. The average amounts of LCWP for the overlays in these four projects were 23.9 m for Alberta (4.9 years old), 6.3 m for California (2.4 years old), 25.9 m for Colorado (3.0 years old), and 222 m for Manitoba (6.0 years old). As noted, climate and age may have some effect on the occurrence of these cracks. As the average LCWP for the 32 sections with the thinner overlays was 41.1 m versus 29.3 m for the 32 sections with thicker overlays, the thicker overlays have shorter lengths of LCWP on the average, as expected.

The milled test sections for six of the eight projects exhibited less LCWP. For the other two, the differences were quite small. Milling does appear to help reduce LCWP, but the advantage may not be cost-effective.

3.2.2 Longitudinal Cracking in Wheel Paths in GPS-6 Test Sections

Table 20 provides the primary data, selected or calculated from that available in appendices B and C, that were used for the studies leading to results discussed below. Graphs of the performance of selected test sections appear in appendix E. Tables 21 and 22 were prepared from the data in table 20. Figure 5 graphically shows the probability of occurrence of LCWP with overlay age for the GPS-6 data. As shown, LCWP occurred on some test sections shortly after the overlay was placed. This suggests that these early cracks probably initiated at the surface of the overlay. The other important observation is that it takes a relatively long period of time for the LCWP to exceed 100 m. One possible explanation for this observation is that some of the LCWP are developing into fatigue cracks.

Table 21 indicates that both LCWP and prior pavement condition data (categories of "poor" and "good" only) are available for 83 GPS-6 test sections. Of these, 46 were originally in poor condition and 37 were in good condition. More importantly, 51 (or 61 percent) of the 83 test sections had exhibited no LCWP and 25 others had exhibited 50 m or less. Table 23 summarizes the number of GPS-6 test sections with various lengths of LCWP.

<u>AC Overlay Thickness</u>

The data summarized in table 20 were also reviewed to evaluate the effect of overlay thickness on performance relative to LCWP. The number of sections, thickness range, average thickness, and standard deviation for each major LCWP group is summarized in table 24.

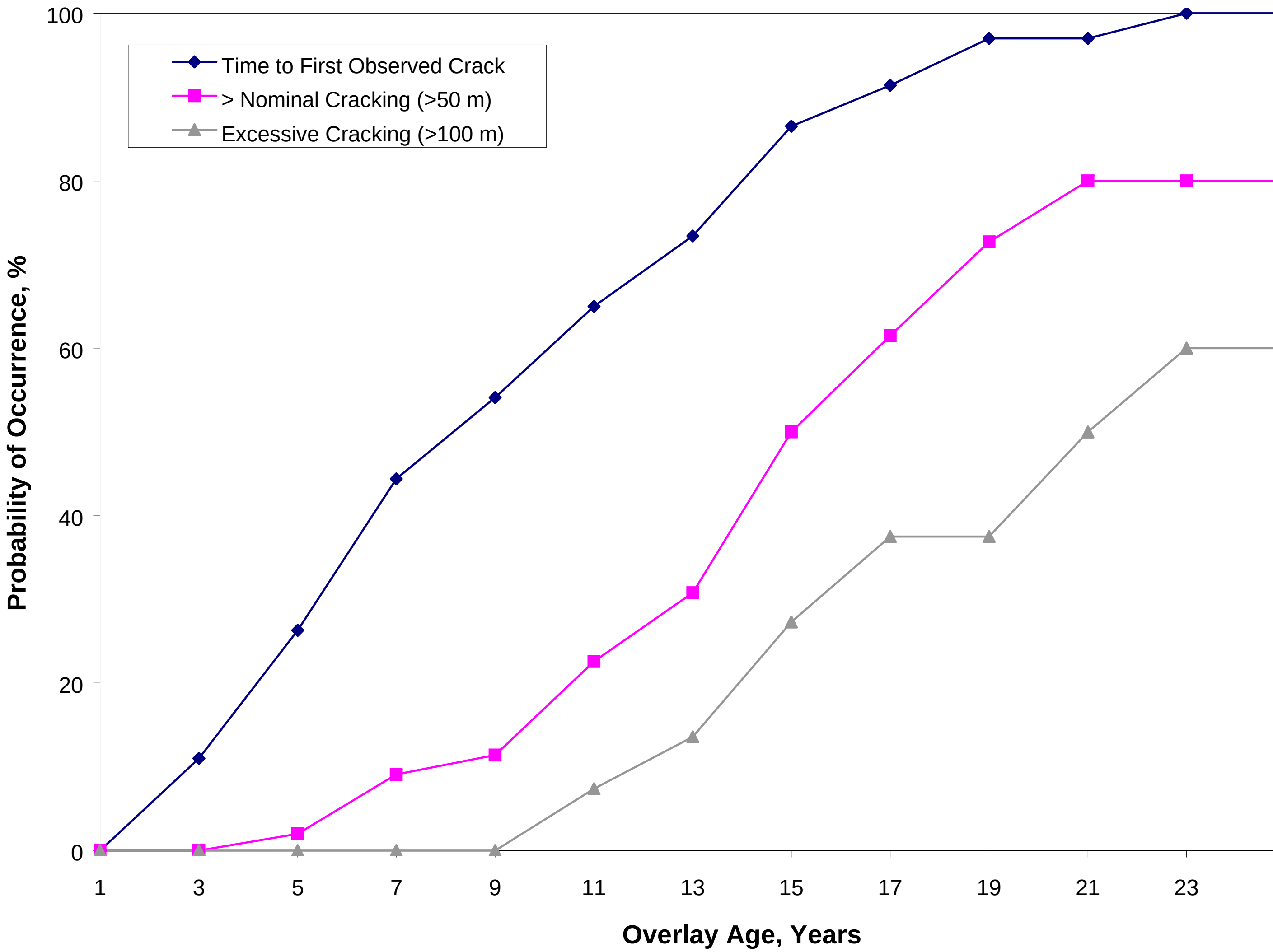

Figure 5. Probability of occurrence for different levels of LCWP on the GPS-6 test secti

Table 20. Longitudinal cracking in wheel path in GPS-6 sections at last survey.

State	Section	Exp.	Original Pavement			Overlay Thick-ness (mm)	Age of Overlay (years)	Longitudinal Cracking - Wheelpath (m)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Alabama	16012	6A	11.6	94	Good	33	9.2	26
Alabama	16019	6A	14.8	163	Poor	89	12.0	37
Alabama	14127	6B	14.7	211	Poor	43	4.0	0
Alabama	14129	6B	13.4	76	Good	38	3.8	2
Alaska	21008	6A	10.3	33	--	--	6.5	62
Alaska	26010	6A	13.2	53	Poor	43	12.5	0
Alaska	21004	6B	13.8	91	Poor	46	4.0	6
Alaska	29035	6B	18.8	53	Good	97	3.2	0
Alberta	811804	6B	10.8	89	Poor	99	0.2	0
Arizona	46053	6A	20.5	81	Poor	120	6.5	0
Arizona	46054	6A	3.8	178	Good	53	5.8	61
Arizona	46060	6A	21.5	99	Poor	102	6.4	60
British Columbia	826006	6A	17.5	81	Poor	53	15.7	16
British Columbia	826007	6A	2.7	64	Poor	132	12.6	0
California	68534	6B	22.5	119	Poor	89	1.2	0
Colorado	86002	6A	(0.8)	147	Poor*	71	26.4	4
Colorado	86013	6A	(0.3)	69	Poor*	38	10.4	15
Colorado	87783	6A	3.7	127	Good*	91	9.4	1
Colorado	87781	6B	9.3	86	Poor	56	10.1	0
Florida	124101	6B	24.2	33	Good	114	1.7	0
Florida	124135	6B	21.2	36	--	--	0.9	0
Florida	124136	6B	21.2	36	Poor	--	0.9	0
Florida	124137	6B	21.5	71	Good	--	0.9	0
Georgia	134420	6B	8.4	125	Poor	--	2.1	2
Illinois	176050	6A	18.5	61	Poor	117	15.2	0
Indiana	181037	6B	11.7	71	Poor	25	0.1	0
Iowa	196049	6A	13.4	137	Good	71	12.6	0
Kansas	206026	6A	14.0	25	Good	147	12.6	0
Kentucky	216040	6A	14.9	155	Good	41	7.0	0
Kentucky	216043	6A	7.9	140	Good	51	16.0	0
Maine	231028	6B	21.8	163	--	--	0.1	0
Manitoba	836450	6B	18.0	112	Poor	150	3.8	0
Manitoba	836451	6B	18.0	104	Poor	66	3.8	0
Minnesota	276064	6A	12.0	193	Poor	142	8.7	0
Mississippi	282807	6B	10.7	269	Poor	--	2.3	1
Mississippi	283091	6B	16.3	89	Good	--	0.3	0
Mississippi	283093	6B	7.5	104	Good	76	1.8	0
Mississippi	283094	6B	7.5	231	Good	76	3.6	0

Table 20. Longitudinal cracking in wheel path in GPS-6 sections at last survey (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (mm)	Age of Overlay (years)	Longitudinal Cracking - Wheelpath (m)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Missouri	296067	6A	15.9	180	Poor	25	13.8	99
Missouri	295403	6B	24.0	102	Good	56	5.0	0
Missouri	295413	6B	24.0	97	Poor	79	5.0	0
Montana	306004	6A	17.8	89	Good	180	11.4	139
Montana	307075	6A	17.3	86	Good	94	12.6	0
Montana	307076	6B	5.8	132	Good	61	0.4	0
Montana	307088	6B	10.1	124	Poor	43	0.3	0
New Brunswick	846804	6A	(0.5)	99	Good	56	16.6	0
New Mexico	351002	6A	26.5	109	Poor	99	9.2	0
New Mexico	356033	6A	22.5	107	Poor	64	13.2	6
New Mexico	356035	6A	19.5	91	Good	112	9.2	31
New Mexico	356401	6A	13.5	102	Poor	109	10.2	120
North Carolina	371040	6B	16.7	135	--	--	0.5	0
North Carolina	371803	6B	12.7	132	Poor	76	5.7	21
Oklahoma	406010	6A	14.5	114	Good	51	9.9	12
Oklahoma	404086	6B	19.3	109	Poor	33	5.3	7
Oklahoma	404164	6B	16.3	117	Poor	--	0.3	0
Oregon	416011	6A	25.1	155	Poor	173	5.3	0
Pennsylvania	421608	6A	0.0	61	Good	66	6.1	0
Quebec	891021	6B	14.2	132	--	--	0.2	0
Quebec	891127	6B	15.7	124	--	--	0.2	0
Saskatchewan	906400	6A	9.7	196	Poor	61	13.6	46
Saskatchewan	906801	6A	8.7	--	Poor	102	13.6	15
Saskatchewan	906410	6B	21.3	117	Poor	94	4.9	0
Saskatchewan	906412	6B	21.3	112	Poor	140	4.9	0
South Dakota	469197	6B	25.7	89	Poor	94	4.1	0
Tennessee	476015	6A	10.6	224	Good	140	8.6	0
Tennessee	476022	6A	8.6	119	Good	51	12.6	0
Tennessee	473108	6B	17.6	140	Good	--	3.5	0
Tennessee	473109	6B	10.6	132	Poor	--	4.2	0
Tennessee	473110	6B	8.1	130	Poor	140	3.9	0
Tennessee	479024	6B	18.0	145	Good	--	(0.1)	0
Texas	481046	6A	15.3	274	Poor *	53	24.6	7
Texas	486079	6A	12.4	175	Good*	66	10.6	83
Texas	486086	6A	13.6	221	Good*	38	10.2	1
Texas	486160	6A	18.3	61	Poor*	41	12.5	32
Texas	486179	6A	9.6	41	Poor*	112	20.6	0
Texas	481093	6B	8.4	74	Good	64	6.6	15
Texas	481113	6B	6.4	38	Poor	94	3.1	0
Texas	481116	6B	3.3	38	Good	84	0.7	0

Table 20. Longitudinal cracking in wheel path in GPS-6 sections at last survey (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (mm)	Age of Overlay (years)	Longitudinal Cracking - Wheelpath (m)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Texas	481119	6B	14.3	135	Poor	41	6.0	3
Texas	481130	6B	21.0	69	Poor	25	2.5	0
Texas	483875	6B	7.0	41	Good	25	4.2	11
Utah	491004	6A	6.3	81	Good	117	17.8	0
Utah	491005	6A	13.5	150	Good	97	7.7	53
Utah	491006	6A	16.2	234	Good	64	7.8	1
Utah	491007	6A	8.3	239	Good	51	3.7	11
Washington	536049	6A	16.2	236	Good	33	6.1	40
Washington	531005	6B	16.0	267	Poor	58	5.2	0
Wyoming	566031	6A	5.3	64	Poor	64	10.6	0
Wyoming	566032	6A	12.6	76	Good	58	10.7	0

Table 21. Ages of GPS-6 overlays with 50 m of longitudinal cracking in the wheel paths or less.

Original Condition Before Overlay	Total* Test Sections	Total Number 0 to 50 m	Number < 5 Years	Number ≥ 5 Years	Number ≥ 10 Years	Number ≥ 15 Years	Number ≥ 20 Years
Poor	46	43	19	24	15	5	3
Good	37	33	13	20	9	3	0
Total	83	76	32	44	24	8	3

*Number of test sections for which data for prior condition and longitudinal cracking in the wheel base were provided.

Table 22. Ages of GPS-6A overlays with 50 m of longitudinal cracking in the wheel paths or less.

Original Condition Before Overlay	Total* Test Sections	Total Number 0 to 50 m	Number < 5 Years	Number ≥ 5 Years	Number ≥ 10 Years	Number ≥ 15 Years	Number ≥ 20 Years
Poor	21	18	0	18	14	5	3
Good	23	18	1	17	9	2	0
Total	44	36	1	35	23	7	3

*Number of test sections for which data for prior condition and longitudinal cracking in the wheel base were provided.

Table 23. Number of GPS-6 test sections with different lengths of LCWP.

Original Condition Before Overlay	Number of Test Sections	Length of LCWP				
		0	1-10 m	11-20 m	21-50 m	>50 m
Poor	46	28	8	3	4	3
Good	37	23	4	3	3	4
Total	83	51	12	6	7	7

Table 24. HMA thicknesses of the GPS-6 test sections with different lengths of LCWP and different original pavement prior to overlay conditions.

Original Pavement Condition	LCWP - None				LCWP - 1 to 50 m (Nominal)				LCWP> 50 m			
	No. of Sections	Range in Thickness, mm	Mean, mm	Standard Deviation, mm	No. of Sections	Thickness Range, mm	Mean, mm	Standard Deviation, mm	No. of Sections	Thickness Range, mm	Mean, mm	Standard Deviation, mm
Poor	25	25-173	91.9	41.2	13	33-102	59.1	20.9	3	25-109	78.7	46.6
Good	18	41-147	80.8	31.3	11	25-112	54.5	26.8	4	53-180	99.0	57.1

Although the number of sections within each category or group of LCWP varies, there is no consistent trend in the amount of cracking and overlay thickness.

AC Overlay Age

Table 21 listed the number of GPS-6 test sections with nominal LCWP (50 m or less) or less by overlay age category. Of these 76 test sections, 32 were less than 5 years in age and 44 were greater than 5 years. Table 25 summarizes the average overlay age in the different LCWP categories for those sections with complete data sets.

Table 25. Average overlay age for those GPS-6 test sections with different lengths of LCWP.

Original Condition Before Overlay	Length of LCWP								
	0 m			1-50 m (Nominal)			>50 m		
	No. of Sections	Average Overlay Age Years	Standard Deviation Years	No. of Sections	Average Overlay Age Years	Standard Deviation Years	No. of Sections	Average Overlay Age Years	Standard Deviation Years
Poor	25	6.3	5.03	13	12.5	6.89	3	10.1	3.7
Good	18	8.3	2.88	11	7.3	2.57	4	8.9	2.59

As summarized, there is no consistent trend regarding the effect of the time (overlay age) on LCWP. However, 32 of the 76 overlays that exhibited 50 m or less in the LCWP were less than 5 years old (figure 5). This could bias the data from table 21, so it will not be useful to discuss it further. Table 22 provides the same data as table 21, except that only GPS-6A data are included. This should relate to more long-term performance.

Ignoring the one test section with an overlay less than 5 years old, 8 (or 35 percent) of the overlays in the good group (original pavement condition before overlay - refer to section 2.2 in this report) were performing well (50 m or less of LCWP) after 5 to 9.9 years, 7 (or 30 percent) were after 10 to 14.9 years, and 2 (or 9 percent) had served for more than 15 years. Eleven of the 18 test sections had exhibited no LCWP, 6 of which were 10 to 14.9 years old and 2 were more than 15 years old. Only 4 (or 17 percent) had exhibited more than 50 m of LCWP.

For the poor group (original pavement condition before overlay), 4 (or 19 percent) of the overlays were performing well (50 m or less of LCWP) after 5 to 9.9 years, 6 (or 29 percent) after 10 to 14.9 years, 5 (or 24 percent) after 15 to 19.9 years, and 3 (or 14 percent) for more than 20 years. Ten of the 18 test sections performing well had exhibited no LCWP, 3 of which were 10 to 14.9 years old, one 15.2 years old, and 1 more than 20 years old. Only 3 (or 14 percent) had exhibited more than 50 m of LCWP. As for fatigue cracking, it appears that good performance (less than 50 m of LCWP) may result for 5 to 15 years, but lack of knowledge of LCWP prior to overlay limits the utility of this broad observation.

<u>Original Pavement Condition</u>

The effects of original pavement condition on the LCWP performance can be summarized by considering the number of GPS-6 test sections at three levels of LCWP. Table 26 summarizes the number of GPS-6 test sections with different lengths of LCWP within each original pavement condition prior to overlay group.

Table 26. Number of GPS-6 test sections with different lengths of LCWP for different original pavement conditions prior to overlay.

Original Condition Before Overlay	Number of Test Sections	Longitudinal Cracking in Wheel Path		
		None	1 - 50 m (Nominal)	51 m or Greater
Poor	37	22	11	4
Good	46	28	15	3
Total	83	50	26	7

As the overlays placed over pavements in the poor condition before overlay category appear to have performed slightly better than those over pavements in good condition (a greater number without cracking) before overlay, the condition of the original pavement does not appear to have had much impact on the incidence of LCWP.

Detailed Assessment of Cumulative Traffic, Layer Thickness, and Age

Tables 27 and 28 were prepared to take another approach to seeking explanation of the performance of these overlays. Table 27 provides selected data for those GPS-6A overlays that have been in service longer than 15 years, to seek a common factor that might indicate why they have performed well for a substantial period of time. Table 28 provides selected data for the GPS-6A test sections that have exhibited more than nominal fatigue cracking (10 m^2) or LCWP (50 m), again seeking a common factor that might indicate why they exhibited the cracking.

Those data elements included in tables 27 and 28 were selected because they are believed to be very significant to the occurrence of load-induced cracking in the wheel paths. The objective of this review is to see if the performance of the overlays can be “explained” by any of the selected data elements included in tables 27 and 28. The tabulation of fatigue cracking next to LCWP provides some insight as to the relationship between these two types of cracking distress as previously discussed.

Table 27. Selected data for GPS-6A overlays 15 or more years old.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	LCWP (m)	Fatigue Cracking (m^2)
British Columbia	826006	15.7	81	53	134	149	16	36
Colorado	086002	26.4	147	71	218	247	4	350
Illinois	176050	15.2	61	117	178	10	0	0
Kentucky	216043	16.0	140	51	191	633	0	0
New Brunswick	846804	16.6	99	56	146	591	0	0
Texas	481046	24.6	274	53	327	295	7	48
Texas	486179	20.6	41	112	153	74	0	0
Utah	491004	17.8	81	117	198	45	0	305

It can be seen in table 27 that four of these eight test sections had exhibited no fatigue cracking or LCWP. This might be explained by limited traffic, thick AC layers or “strong” base/subgrade soils. As an example, the longevity for Texas section 486179 may likely be explained by the low annual traffic level of 74 KESALs/year. However, the longevity of Texas section 481046 (24.6 years) appears to be explainable by its very stiff structure. It was originally 274 mm of AC over 213 mm of crushed stone gravel. The overlay of 153 mm resulted in a total AC thickness of 295 mm. Table C.1 in appendix C indicates that there was 23 m^2 of fatigue cracking and no LCWP in June of 1991. It took 4 years for this to advance to 48 m^2 of fatigue cracking and 7 m of LCWP.

Illinois section 176050 had functioned for more than 15 years with a 117-mm overlay over an original pavement with 61 mm of AC. If the annual ESALs of 10,000 is correct, this could explain its longevity.

Kentucky section 216043 had a substantial original AC thickness and a thin overlay, but has the highest annual ESALs of the eight. There is likely some other reason for its good performance (i.e., no fatigue cracking and no LCWP) for 16 years. Other factors affecting its performance could include superior materials and/or construction, drainage, etc.

Table 28. Selected data for GPS-6A overlays that had exhibited more than nominal LCWP or fatigue cracking.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	LCWP (m)	Fatigue Cracking (m^2)
Alabama	016012	9.2	94	33	127	827	26	105
Arizona	046054	5.8	178	53	231	---	61	6
Arizona	046060	6.4	99	102	201	889	60	0
British Columbia	826006	15.7	81	53	134	149	16	36
Colorado	086002	26.4	147	71	218	247	4	350
Colorado	087783	9.4	127	91	218	151	1	14
Minnesota	276064	8.7	193	142	335	---	0	116
Missouri	296067	13.8	180	25	205	114	99	0
Montana	306004	11.4	89	180	269	---	139	0
New Mexico	356033	13.2	107	64	171	96	6	76
New Mexico	356035	9.2	91	112	203	342	31	58
New Mexico	356401	10.2	102	109	211	330	120	7
Texas	481046	24.6	274	53	327	295	7	48
Texas	486079	10.6	175	66	241	394	83	5
Texas	486160	12.5	61	41	102	144	32	12
Utah	491004	17.8	81	117	198	45	0	305
Utah	491005	7.7	7.7	97	247	96	53	5

Similarly, New Brunswick section 846804 has a relatively light original AC pavement and overlay and very substantial traffic, but has served for more than 16 years with no LCWP or fatigue cracking. As for the Kentucky test section, the explanation appears to lie with characteristics other than AC thickness and traffic level.

Both Colorado section 086002 and Utah section 491004 have extensive fatigue cracking (350 and 305 m^2) after 26.4 and 19.7 years, respectively. Test section 086002 had a substantial original AC thickness and moderate traffic, so this may account for its service of 26.4 years. However, the data indicate that it was in the poor condition category prior to its overlay over 26 years prior to inspection. The majority of both wheel paths was apparently covered with fatigue cracking in June 1995. In June 1994, there was 11 m^2 of moderate and 113 m^2 of high severity fatigue cracking. Less than a year later, 350 m^2 of high severity cracking was noted. No low severity cracking was noted in June 1994. It appears that some other distresses caused the poor rating and that the combination of a substantial AC thickness of 218 mm and a moderate level of traffic allowed good performance for more than 20 years, with the fatigue cracking beginning late in the service life of the overlay and accelerating rapidly.

Similarly, Utah section 491004 is reported to have had no fatigue cracking and only 55 m of LCWP in July 1991. Four years later, it had no LCWP and 350 m^2 of fatigue cracking. The overlay apparently performed well for 14 years and then deteriorated rapidly. These data support the belief that once fatigue cracks develop they can increase in area at an accelerated rate (see figure 4).

The cracking distress in Alabama section 016012 might be expected as the overlay was very thin and the traffic level is quite high. There was 39 m^2 of fatigue cracking and 14 m of LCWP in July 1992. Eight months later, this cracking had advanced to 105 m^2 of fatigue cracking and 26 m of LCWP. The August 1995 results in table 134 were ignored because they showed no fatigue cracking and 103 m of LCWP. While healing may have occurred during the hot Alabama summer, this appeared questionable enough to be disregarded.

The only other test section having a high traffic level was Arizona section 046060, with 889 annual KESALs. After 6.4 years, the overlay had begun to exhibit LCWP, which had not yet advanced to fatigue cracking.

The overlays for sections 826006, 086002, and 481046 are more than 15 years old and were discussed above. One other test section might be considered to have a light AC thickness. Texas section 486160 had an original surface of 61 mm and an overlay of 41 mm, for a total AC thickness of 102 mm, which is roughly one-half of the average thicknesses indicated in table 14. However, after 12.5 years the fatigue cracking was just beginning to exceed the nominal level of 10 m^2 established for this study. This is probably because of a relatively low traffic level and other characteristics as well.

Similarly, Missouri section 296067 was beginning to have substantial LCWP after 13.8 years, but as yet had not exhibited fatigue cracking. Montana section 306004 was also exhibiting substantial LCWP, but no fatigue cracking, after 11.4 years.

The overlay for New Mexico section 356033 had exhibited 157 m of LCWP in March 1991, but no fatigue cracking after about 9 years. By February 1994, the LCWP had advanced into 76 m^2 of fatigue cracking, with 6 m of LCWP still existing. This test section had an original AC thickness of 107 mm, reported to be in poor condition prior to overlay (what specific distresses existed are not specified).

The other two New Mexico test sections had substantial AC thicknesses and moderate traffic levels. Fatigue cracking was well advanced in section 356033 after 9.2 years, while it was just getting under way for section 356401 after 10.2 years.

Fatigue cracking had just passed the nominal stage (10 m^2) for Colorado section 087783 after 9.4 years. It was still nominal for Utah section 491005 after 7.7 years, but the LCWP had advanced past the nominal stage (50 m).

Summary

In summary, it appears that the long service of four of the eight overlays in table 27 (15 or more years old) can be roughly explained by thick AC and/or low or moderate traffic levels, which are believed to significantly affect fatigue and LCWP performance. The reported traffic level appears questionable for the Illinois test section and the performance of the other three (Kentucky, New Brunswick, and British Columbia) appears to at least partially result from other factors.

Based on the data in table 28 for 14 test sections with traffic data that had exhibited more than nominal LCWP (50 m) or fatigue cracking (10 m^2), it is believed that 11 had provided reasonable performance (considering overlay age, traffic levels, AC thickness, and levels of distress) and three had not. One appeared to have too light a structure (in terms of AC thickness) for the heavy traffic it had carried, and the reasons for the performance of the other two are not clear.

3.3 SUMMARY OF FINDINGS FOR FATIGUE CRACKING AND LONGITUDINAL CRACKING IN WHEEL PATHS

The study of the early performance of the SPS-5 projects for which distress data are available is encouraging. Many of the SPS-5 projects have little to no load-related cracking at this point in time. One exception is the Alberta project, which was exhibiting more fatigue cracking and LCWP 4.9 years after the overlays than it was prior to the overlays. In addition, some of the SPS-5 projects do have larger amounts of LCWP for some of the thicker overlays. Some of these LCWP are believed to be test-section specific and could have initiated at or near the pavement's surface. Thus, it is recommended that trenching or coring studies be implemented to determine the direction of crack propagation and the location of where the cracks initiated.

More importantly, the substantial variations in overlay thicknesses from those specified and the variations in original pavement structure (described in chapter 2) complicate the assessment of the effects on performance of the several factors in the SPS-5 experiment design. As expected, however, the thicker overlays consistently have less load-related cracking than the thin overlays. Based on the SPS-5 data, it appears that the virgin mixes have lesser amounts of LCWP than the recycled mixes, but the only conclusion that can be drawn with respect to milling versus non-milling is that milling apparently had little effect in the short term and may or may not be significant in the long term. Continued monitoring is needed to reach definitive conclusions regarding these parameters.

While the conclusions from the GPS-6 data must be tempered by the lack of specific data on cracking prior to overlay, the study appears to corroborate the favorable short-term performance indicated by the SPS-5 projects. The separate study of GPS-6A data appears to indicate that overlay designs that provide pavement structure consistent with traffic expectations may be expected to perform well for 10 years or more.

CHAPTER 4. TRANSVERSE CRACKING

Transverse cracking is described in the *Distress Identification Manual* with three levels of severity identified.[7] For the purposes of this report, cracking at all severity levels has been combined.

Transverse cracks are defined as cracks that are predominantly perpendicular to the pavement center line that are not located over portland cement concrete joints. As there are no portland cement concrete layers included in the SPS-5 or GPS-6 experiments, all transverse cracks were counted for this study. Transverse cracking is reported as the number of cracks within the test section and as the total length of transverse cracks, because all cracks do not extend completely across the lane. The study only includes number of cracks, which was established as nominal if 10 or less transverse cracks are present.

4.1 TRANSVERSE CRACKING IN SPS-5 TEST SECTIONS

The graphs of transverse cracking appear in appendix F, and table 29 provides the amounts of transverse cracking noted by project and test section.   Table 29 also provides information about transverse cracking present in the existing pavements prior to the overlays.

4.1.1 General Overview of Observations from Data

Overall, 61 percent of the test sections have no transverse cracks, 28 percent have less than a nominal number of cracks (10 cracks) and 11 percent have more than a nominal number. Table 30 summarizes the number of test sections within each extent of transverse cracking.

Eight of the 12 projects for which distress data are available had exhibited transverse cracking on 2 or more test sections at the times of the surveys. For those projects which have more than one test section with transverse cracks (excluding the control section), table 31 summarizes the average number of cracks per test section.

Some general observations from these data are listed below.

- ***Thin versus Thick Overlay.*** The thicker AC overlays on the average have a fewer number of transverse cracks than the thin overlays, as expected.

  Specifically, 8 of 48 test sections (17 percent) with thin overlays have exhibited more than nominal transverse cracking (10 cracks), whereas 2 of the thick overlays (4 percent) have more than nominal cracking. It is generally believed that the occurrence of transverse cracks is only slightly dependent on the AC overlay thickness, as related to other mixture properties. However, the frequency of cracks is believed to be more heavily influenced by layer thickness. The average number of cracks occurring on those test sections with a thin overlay is 7.0 and 2.2 for those with thick overlays. Although continued monitoring and a review of the materials data are needed to confirm or reject this hypothesis, the available data seem to support the hypothesis.

Table 29a. Number of transverse cracks noted on SPS-5 test sections at time of last manual distress surveys.

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State	Age of Overlays (Years)	Number of Transverse Cracks By Section						
		501	502	503	504	505	506	507
Alabama	3.6	8	0	0	0	0	0	0
Alberta	4.9	2	7	1	1	1	1	0
Arizona	4.4	0	41	0	0	2	0	0
California	2.4	6	0	0	4	0	0	0
Colorado	3.0	9	1	0	1	1	15	1
Georgia	2.8	0	0	0	0	0	0	0
Maine	0.3	23	0	0	0	0	0	0
Manitoba	6.0	4	4	1	3	4	0	4
Maryland	3.3	26	4	0	4	13	7	0
Minnesota	4.8	22	21	NA	16	24	25	13
Mississippi	3.2	28	0	0	0	0	0	0
Texas	3.8	161	1	0	0	25	0	0

Table 29b. Number of transverse cracks prior to overlay.

State	Number of Transverse Cracks By Section						
	501	502	503	504	505	506	507
Alabama	0	0	0	0	0	0	0
Alberta	NA	NA	NA	NA	0	3	0
Arizona	196	202	NA	81	71	88	137
California	162	42	NA	32	27	56	94
Colorado	10	4	7	22	24	21	30
Georgia	NA	4	0	1	2	0	0
Maine	23	35	62	42	1	14	0
Manitoba	3	1	3	2	0	0	1
Maryland	14	17	11	9	12	10	14
Minnesota	22	NA	NA	NA	NA	NA	NA
Mississippi	14	46	74	24	9	9	26
Texas	95	NA	NA	NA	NA	NA	NA

*NA=Data not available.

Table 30. Summary of SPS-5 test sections with various amounts of transverse cracking.

Number of Transverse Cracks	**Number of Test Sections in Each Group**					
	Overlay Thickness		**Overlay Mix**		**Surface Preparation**	
	Thin	**Thick**	**Without RAP**	**With RAP**	**Without Milling**	**With Milling**
0	26	32	28	30	25	33
1-10	14	13	13	14	16	11
>10	8	2	7	3	6	4

		Number of Transverse Cracks			
		0	**1-10 (Nominal)**	**11-50**	**>50**
Number of Test Sections	87	50	27	10	0
Percentage in Each Group	100.0	57.5	31.0	11.5	0.0

- ***Virgin versus Recycled Mixtures.*** Out of 48 test sections, 7 of the sections (15 percent) with virgin mixtures exhibited more than nominal transverse cracking (10 cracks), whereas only 3 (6 percent) with recycled mixtures exceed the nominal amount. In addition, the average number of cracks for the virgin mixtures with transverse cracking is 5.5 and 4.6 for the recycled mixtures. In general, it is believed that mixtures with RAP are stiffer (or more brittle) and more susceptible to thermal fracture. The initial performance observations seem to contradict the debatable hypothesis. Continued monitoring, review of the laboratory resilient modulus and indirect tensile strength (when available), climatic data, and the use of statistical analysis techniques should be able to confirm or reject this hypothesis.

- ***Milled versus Non-Milled Surfaces.*** It is generally believed that transverse cracks initiate at the surface (low temperature cracking) and bottom (reflection cracks) of the AC overlay. Assuming an adequate bond between the overlay and original surface, no difference to fewer cracks should be expected on those sections with overlays placed on milled surfaces. Out of 48 test sections, 6 (13 percent) without milling and 4 (8 percent) with milling have exhibited more than nominal transverse cracks (10 cracks). The average number of cracks for sections with overlays placed on milled surfaces is 3.3 and 6.3 for those without milling. The data seem to support this hypothesis, however, continued monitoring and detailed statistical analyses are needed to support or reject the hypothesis.

Table 31. Average transverse cracking for thick vs. thin overlays, recycled vs. virgin AC r and milled vs. unmilled test sections

State	Average Number of Transverse Cracks (%)*									
	Thin Overlays		Thick Overlays		Virgin		Recycled		Unmilled	
Alberta	2.25	(142%)	0.50	(115%)	0.75	(67%)	2.0	(168%)	2.5	(120%)
Arizona	12.25	(158%)	0	(---)	0.5	(200%)	11.75	(168%)	10.75	(187%)
California	0.25	(200%)	1.0	(200%)	1.0	(200%)	0.25	(200%)	1.0	(200%)
Colorado	4.25	(167%)	0.5	(115%)	4.5	(156%)	0.25	(200%)	0.75	(67%)
Manitoba	2.5	(77%)	2.25	(67%)	2.75	(69%)	2.0	(71%)	3.0	(47%)
Maryland	6.0	(91%)	1.0	(200%)	6.0	(91%)	1.0	(200%)	5.25	(105%)
Minnesota	22.5	(11%)	12.3	(33%)	19.5	(30%)	16.3	(44%)	20.3	(20%)
Texas	6.5	(190%)	0	(---)	6.25	(200%)	0.25	(200%)	6.5	(190%)
Averages	**7.1**	**(102%)**	**2.2**	**(188%)**	**5.2**	**(120%)**	**4.2**	**(148%)**	**6.3**	**(104%)**

*The numbers in parentheses ( ) are the coefficient of variations.

It is also obvious that the number of transverse cracks occurring along these projects are test-section specific. Some of the projects have extensive variations in the number of cracks exhibited within each test section (e.g., the Arizona and Texas projects). Thus both climatic and laboratory materials test data, when available, need to be included in a detailed analysis of the test sections before any definitive conclusions can be reached.

4.1.2 Detailed Assessment of Transverse Cracking

Table 32 indicates the level of transverse cracking for each project's control section and the numbers of test sections with zero, nominal (10 cracks), or greater than nominal transverse cracking. Table 30 summarized the number of test sections (excluding the Maine project and all of the control sections) with different numbers of transverse cracks.

It can be readily seen that more than half of the 71 test sections (no data for Minnesota 503) had no transverse cracking, 27 had nominal transverse cracking, and 10 had more transverse cracks than the nominal level established. Of these 10, 6 were in the Minnesota project and there was 1 each in the Arizona, Colorado, Maryland and Texas projects.

Table 29b indicates that Arizona test section 502 had 202 cracks, which relates to an average crack spacing of only 0.75 m. This was the highest number of transverse cracks for any test section in any of the nine projects that exhibited any transverse cracking after overlay. The distress survey for the Maine project was conducted only 4 months after the overlay, so it lends little to the analysis at this time.

Table 92 in appendix A indicates that there are no data available for calculating the average overlay thicknesses for the Arizona project in an attempt to explain the 41 cracks in test section 502, as compared with the other test sections. In addition, there are no data available for calculation of overlay thicknesses for the Minnesota project, so little explanation is available why the cracking for this project greatly exceeds that exhibited by any of the other projects. Table 94 shows that the overlay thickness for Colorado test section 506 was only 13 mm, instead of 51 mm as planned. This test section has 15 transverse cracks. However, the calculations indicate that test section 509 was also only 13 mm, but it had no transverse cracks 3 years after the overlay.

Table 98 indicates that the overlay from Maryland test section 505 is very close to the 51 mm specified, but it has 13 cracks while test section 506 had 7 although the overlay thickness was calculated as only 15 mm. It is likely that these differences are related to differences in materials or construction. It does not seem likely that it is related to test section 506 having been milled prior to overlay. As another possibility, it can be seen from table 98 that 41 mm of material was milled for test section 506 but no milling replacement was reported. If this was an error and the overlay placed on test section 506 was actually around the 51 mm specified, then the resulting cracking would appear much more reasonable.

Table 33 summarizes the number of test sections (excluding the Maine, California, Colorado, and New Jersey projects) with transverse cracking in comparison with the number of transverse cracks on the control section. Table 33 also summarizes the number of test sections (excluding the Maine project) with transverse cracks in comparison with the number of transverse cracks counted in each section prior to overlay.

Table 32. Numbers of SPS-5 test sections by project at various levels of transverse cracking.

State	Control Section 501 Numbers of Cracks			Numbers of Sections (502-509) With Levels of Transverse Cracks		
	0	1-10	>10	0	1-10	>10
Alberta		X		3	5	---
Arizona	X			5	2	1
California*		X		6	2	---
Colorado*		X		3	4	1
Maine			X	8	---	---
Manitoba		X		1	7	---
Maryland			X	4	3	1
Minnesota**			X	1	1	6
Texas			X	6	1	1
TOTALS	1	4	4	37	25	10

*Although the control section 501 was to have no overlay, California's has a 51-mm RAP overlay and Colorado's has a rut level-up course an average of 31 mm in thickness, so the amounts of transverse cracking in these test sections are not indicative of a "do nothing" strategy.
**There were no transverse crack data for Minnesota test section 503.

Table 33. Summary of transverse cracking data for the SPS-5 test sections in comparison with the control section and prior to overlay.

Transverse Cracks Compared with Control Section	Number of Test Sections	Percentage in Each Group
Less than Control Section	49	69.0
Equal to Control Section	16	22.5
Greater than Control Section	6	8.5
Total	**71**	**100.0**
Transverse Cracks Compared Prior to Overlay	**Number of Test Sections**	**Percentage in Each Group**
Less than Prior to Overlay	44	54.3
Equal to Prior to Overlay	20	24.7
Greater than Prior to Overlay	17	21.0
Total	**81**	**100.0**

Forty-two test sections (for which data prior to overlays were available) had transverse cracking prior to the overlays. Of these, transverse cracking has occurred in the overlays of 23 test sections. Two test sections in Alberta have transverse cracking in overlaid test sections that had no transverse cracking prior to overlay. The Minnesota and Texas projects were omitted because they were not surveyed prior to overlay placement.

4.1.3 Summary

It appears clear that the overlays, both the thin and the thick, are doing quite well relative to the amount of transverse cracking that existed prior to the overlays. It can be seen, however, that those single test sections in Arizona, Colorado, Maryland, and Texas that had exhibited more than nominal transverse cracking (10 cracks) were all thin overlay test sections. The thick overlays that exhibit more than nominal overlay cracking were two in Minnesota, where six of the eight overlaid test sections had exhibited more than nominal cracking.

It can be seen that on average the thick overlays performed better than the thin ones. The only exception was for the California project, for which one thick overlay had exhibited four cracks when the rest had exhibited none or one crack.

There appears to be no consistent difference between the type of overlay mixture (virgin versus recycled) in relation to transverse cracking. Although the virgin mixes performed better for two of the four-paired projects, these results do not appear to be strong enough to conclude that either type of mix performs better than the other for transverse cracking.

The milled sections for all projects, with the exception of Colorado, have a fewer number of cracks, on the average, than those that had not been milled. However, this evidence does not necessarily represent a statistical difference to justify a conclusion that milling tends to reduce transverse cracking.

4.2 TRANSVERSE CRACKING IN GPS-6 TEST SECTIONS

Table 34 provides the primary data, selected or calculated from that available in appendices B and C, that were used for the studies leading to results discussed below. Graphs of transverse cracking appear in appendix F. Figure 6 graphically shows the probability of occurrence of transverse cracks with overlay age for the GPS-6 data. As shown, transverse cracks have occurred shortly after overlay placement on more than a few of the test sections.

As noted in chapter 3, the overlays for the GPS-6B test sections are relatively young, with the ages at the time of the last survey ranging from 0.1 to 6.6 years and an average age of less than 3 years. Both GPS-6A and GPS-6B data are included in table 35, while tables 36, 37, 38, 39, and 40 include only GPS-6A overlays to provide insight concerning the long-term performance in transverse cracking.

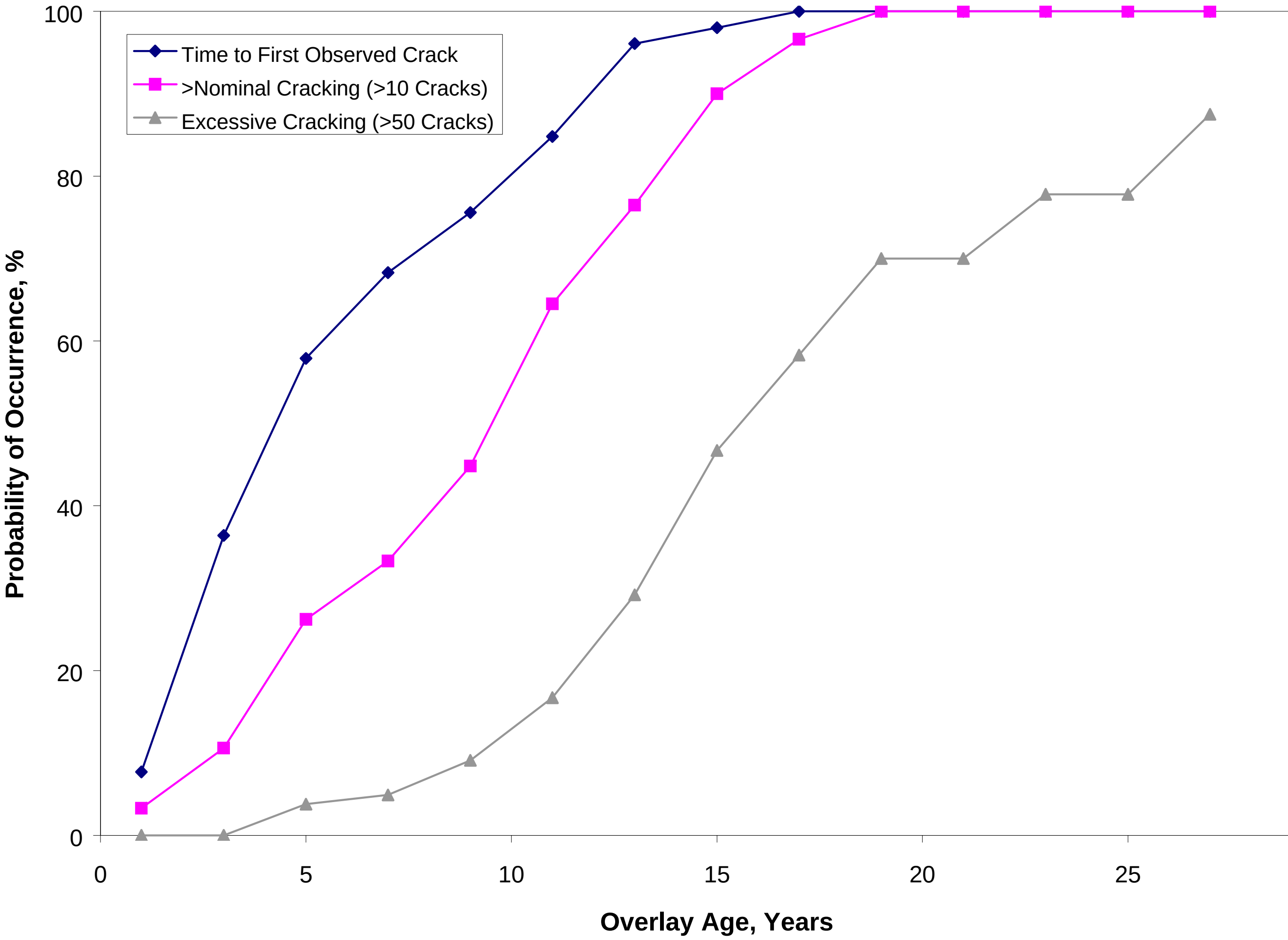


Figure 6. Probability of occurrence of different levels of transverse cracks on the GPS-6 test

Table 34. Number of transverse cracks in GPS-6 test sections at last survey.

State	Section	Exp.	Original Pavement				Age of Overlay (years)	Transverse Cracking - Number
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay	Overlay Thick-ness (mm)		
Alabama	16012	6A	11.6	94	Good	33	11.6	60
Alabama	16019	6A	14.8	163	Poor	89	12.0	0
Alabama	14127	6B	14.7	211	Poor	43	4.0	2
Alabama	14129	6B	13.4	76	Good	38	3.8	7
Alaska	21008	6A	10.3	33	--	--	6.5	13
Alaska	26010	6A	13.2	53	Poor	43	12.5	14
Alaska	21004	6B	13.8	91	Poor	46	4.0	30
Alaska	29035	6B	18.8	53	Good	97	3.2	9
Alberta	811804	6B	10.8	89	Poor	99	0.2	0
Arizona	46053	6A	20.5	81	Poor	120	6.5	1
Arizona	46054	6A	3.8	178	Good	53	5.8	65
Arizona	46060	6A	21.5	99	Poor	102	6.4	9
British Columbia	826006	6A	17.5	81	Poor	53	15.7	3
British Columbia	826007	6A	2.7	64	Poor	132	12.6	0
California	68534	6B	22.5	119	Poor	89	1.2	0
Colorado	86002	6A	(0.8)	147	Poor	71	26.4	40
Colorado	86013	6A	(0.3)	69	Poor	38	10.4	57
Colorado	87783	6A	3.7	127	Good	91	9.4	0
Colorado	87781	6B	9.3	86	Poor	56	10.1	19
Florida	124101	6B	24.2	33	Good	114	1.7	0
Florida	124135	6B	21.2	36	--	--	0.9	0
Florida	124136	6B	21.2	36	Poor	--	0.9	0
Florida	124137	6B	21.5	71	Good	--	0.9	0
Georgia	134420	6B	8.4	125	Poor	--	2.1	2
Illinois	176050	6A	18.5	61	Poor	117	15.2	17
Indiana	181037	6B	11.7	71	Poor	25	0.1	0
Iowa	196049	6A	13.4	137	Good	71	12.6	11
Kansas	206026	6A	14.0	25	Good	147	12.6	0
Kentucky	216040	6A	14.9	155	Good	41	7.0	0
Kentucky	216043	6A	7.9	140	Good	51	16.0	0
Maine	231028	6B	21.8	163	--	--	0.1	0
Manitoba	836450	6B	18.0	112	Poor	150	3.8	1
Manitoba	836451	6B	18.0	104	Poor	66	3.8	1
Minnesota	276064	6A	12.0	193	Poor	142	8.7	6
Mississippi	282807	6B	10.7	269	Poor	--	2.3	41
Mississippi	283091	6B	16.3	89	Good	--	0.3	12
Mississippi	283093	6B	7.5	104	Good	76	1.8	0
Mississippi	283094	6B	7.5	231	Good	76	3.6	0

Table 34. Number of transverse cracks in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (mm)	Age of Overlay (years)	Transverse Cracking - Number
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Missouri	296067	6A	15.9	180	Poor	25	13.8	121
Missouri	295403	6B	24.0	102	Good	56	5.0	26
Missouri	295413	6B	24.0	97	Poor	79	5.0	0
Montana	306004	6A	17.8	89	Good	180	11.4	10
Montana	307075	6A	17.3	86	Good	94	12.6	6
Montana	307076	6B	5.8	132	Good	61	0.4	0
Montana	307088	6B	10.1	124	Poor	43	0.3	0
New Brunswick	846804	6A	(0.5)	99	Good	56	16.6	0
New Mexico	351002	6A	26.5	109	Poor	99	9.2	0
New Mexico	356033	6A	22.5	107	Poor	64	13.2	35
New Mexico	356035	6A	19.5	91	Good	112	9.2	2
New Mexico	356401	6A	13.5	102	Poor	109	10.2	18
North Carolina	371040	6B	16.7	135	--	--	0.5	0
North Carolina	371803	6B	12.7	132	Poor	76	5.7	47
Oklahoma	406010	6A	14.5	114	Good	51	9.9	51
Oklahoma	404086	6B	19.3	109	Poor	33	5.3	14
Oklahoma	404164	6B	16.3	117	Poor	--	0.3	24
Oregon	416011	6A	25.1	155	Poor	173	5.3	0
Pennsylvania	421608	6A	0.0	61	Good	66	6.1	1
Quebec	891021	6B	14.2	132	--	--	0.2	0
Quebec	891127	6B	15.7	124	--	--	0.2	0
Saskatchewan	906400	6A	9.7	196	Poor	61	13.6	9
Saskatchewan	906801	6A	8.7	--	Poor	102	13.6	13
Saskatchewan	906410	6B	21.3	117	Poor	94	4.9	9
Saskatchewan	906412	6B	21.3	112	Poor	140	4.9	7
South Dakota	469197	6B	25.7	89	Poor	94	4.1	52
Tennessee	476015	6A	10.6	224	Good	140	8.6	0
Tennessee	476022	6A	8.6	119	Good	51	12.6	0
Tennessee	473108	6B	17.6	140	Good	--	3.5	0
Tennessee	473109	6B	10.6	132	Poor	--	4.2	0
Tennessee	473110	6B	8.1	130	Poor	140	3.9	0
Tennessee	479024	6B	18.0	145	Good	--	(0.1)	3
Texas	481046	6A	15.3	274	Poor	53	24.6	39
Texas	486079	6A	12.4	175	Good	66	10.6	48
Texas	486086	6A	13.6	221	Good	38	10.2	0
Texas	486160	6A	18.3	61	Poor	41	12.5	91
Texas	486179	6A	9.6	41	Poor	112	20.6	11
Texas	481093	6B	8.4	74	Good	64	6.6	3
Texas	481113	6B	6.4	38	Poor	94	3.1	0
Texas	481116	6B	3.3	38	Good	84	0.7	0

Table 34. Number of transverse cracks in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement					
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay	Overlay Thick-ness (mm)	Age of Overlay (years)	Transverse Cracking - Number
Texas	481119	6B	14.3	135	Poor	41	6.0	1
Texas	481130	6B	21.0	69	Poor	25	2.5	0
Texas	483875	6B	7.0	41	Good	25	4.2	1
Utah	491004	6A	6.3	81	Good	117	17.8	34
Utah	491005	6A	13.5	150	Good	97	7.7	0
Utah	491006	6A	16.2	234	Good	64	7.8	0
Utah	491007	6A	8.3	239	Good	51	3.7	11
Washington	536049	6A	16.2	236	Good	33	6.1	2
Washington	531005	6B	16.0	267	Poor	58	5.2	15
Wyoming	566031	6A	5.3	64	Poor	64	10.6	19
Wyoming	566032	6A	12.6	76	Good	58	10.7	11

Table 35. Ages of GPS-6 overlays with 10 transverse cracks or less.

Original Condition Before Overlay	Total* Test Sections	Total Number 0 to 10 Cracks	Number $\geq$ 5 Years	Number $\geq$ 10 Years	Number $\geq$ 15 Years	Number $\geq$ 20 Years
Poor	46	26	11	4	1	0
Good	37	27	16	7	2	0
Total	83	53	27	11	3	0

*Number of test sections for which transverse cracking data are available and prior condition data were provided.

Table 36. Ages of GPS-6A overlays with 10 transverse cracks or less.

Original Condition Before Overlay	Total Test Sections	Total Number 0 to 10 Cracks	Number $\geq$ 5 Years	Number $\geq$ 10 Years	Number $\geq$ 15 Years	Number $\geq$ 20 Years
Poor	21	9	9	4	1	0
Good	23	16	15	7	2	0
Total	44	25	24	11	3	0

Note: One GPS-6A test section overlay in the good group was less than 5 years old when the last manual distress survey was conducted.

4.2.1 Original Pavement Condition

As discussed for fatigue cracking, table 35 indicates that both transverse cracking and prior condition data (poor or good only) are available for 83 GPS-6 test sections. Of these, 46 were originally in the poor condition before overlay category and 36 were in the good condition category. Of the 83 test sections, 31 (or 37 percent) had exhibited no transverse cracking, 22 (or 27 percent) more had exhibited 10 or less cracks, and 30 (36 percent) had exhibited more than 10 transverse cracks. It can be seen that transverse cracking is much more prevalent than fatigue cracking and LCWP.

For the 53 test sections having 10 transverse cracks or less, 26 (or 49 percent) had been overlaid less than 5 years, 16 (or 30 percent) had been overlaid 5 to 9.9 years, 8 (or 15 percent) had been overlaid 10 to 14.9 years, and 3 (6 percent) had been overlaid more than 15 years.

Table 36 provides the same information as table 35, except that it is restricted to GPS-6A test sections. The results from table 36 can be further summarized by considering the number of overlays at three levels of cracking. Table 41 tabulates the number of GPS-6A test sections with different amounts of transverse cracking.

Ignoring the 1 test section with an overlay less than 5 years old, 15 (or 68 percent) of the remaining 22 overlays in the good condition prior to overlay group had 10 or less transverse cracks. Eight (or 36 percent) of the overlays had less than 10 transverse cracks after 5 to 9.9 years, while 5 (or 23 percent) had less than 10 cracks after 10 to 14.9 years, and 2 had served more than 15 years with very few cracks. Ten of the 15 test sections had exhibited no transverse cracking. Of these, 3 were 10 to 14.9 years old and 2 were more than 15 years old. Seven (or 32 percent) of the 22 overlays in the good group condition prior to overlay more than 5 years of age had exhibited more than 10 transverse cracks.

For the group in poor condition prior to overlay, 9 overlays (or 43 percent) had 10 or less transverse cracks, while 12 (or 57 percent) had more than 10 transverse cracks. Of the 9 overlays with few cracks, 5 (or 24 percent) were 5 to 9.9 years of age, 3 (or 14 percent) were 10 to 14.9 years old, and 1 had served more than 15 years. Four of the 9 test sections had exhibited no transverse cracking. Also, all 12 of the test sections that had exhibited more than 10 transverse cracks were more than 10 years old, with one more than 15 years and 3 more than 20 years.

These results suggest, as would be expected, that overlays may be expected to exhibit less transverse cracking (or reflection of transverse cracking through the overlay) when the original pavements are in good condition prior to overlay than if they were in poor condition. However, as discussed in chapter 3, the lack of specific knowledge as to prior transverse cracking limits the utility of this broad observation.

4.2.2 AC Overlay Age

Table 37 provides selected data for those GPS-6A overlays that have been in service longer than 15 years, to seek a common factor that might explain why some sections have few transverse cracks over a substantial period of time. Review of table 37 indicates that the two overlays (Kentucky and New Brunswick) that had no transverse cracks were those that have exhibited the highest traffic. It should be noted that these two test sections had overlays in the 51 to 56 mm range, while the British Columbia test section with three transverse cracks also had a thin overlay over a relatively thin original AC pavement.

Table 37. Selected data for GPS-6A overlays 15 or more years old.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	Number of Transverse Cracks
British Columbia	826006	15.7	81	53	134	149	3
Colorado	086002	26.4	147	71	218	247	40
Illinois	176050	15.2	61	117	178	(10)?	17
Kentucky	216043	16.0	140	51	191	633	0
New Brunswick	846804	16.6	99	56	146	591	0
Texas	481046	24.6	274	53	327	295	39
Texas	486179	20.6	41	112	153	74	11
Utah	491004	17.8	81	117	198	45	34

It may also be noted that two of the three test sections with limited transverse cracks are located in Canada, which could imply that more attention is given to mixes to resist transverse cracking than in warmer climates. It appears that these data do not offer an explanation of why these 3 test sections have performed with limited transverse cracking for more than 15 years.

Table 38 provides selected data for the GPS-6A test sections that have exhibited more than nominal transverse cracking (10 cracks), seeking a common factor that might indicate why they exhibited the cracking. One interesting fact is that the test sections in Alaska and Saskatchewan both exhibited just slightly more than a nominal number of transverse cracks, although these are the coldest climates of the 22 test sections included in table 38.

Table 39 uses data from table 38 but the data are rearranged so that the test sections are ranked in order according to numbers of cracks, the largest amount of transverse cracks represented by the number "1," with the last column recording the relative rank of each according to age of overlay. Figure 7 graphically shows the comparison between AC overlay age and number of transverse cracks for a range of overlay thicknesses. As shown, the LTPP GPS-6 data indicate a significant increase in the number of transverse cracks with age for overlays less than 60 mm in thickness. For the thicker overlays, there does not appear to be a clear effect or trend.

Table 38. Selected data for GPS-6A overlays that had exhibited more than nominal transverse cracking.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness, mm	Annual KESALs	Number of Transverse Cracks
Alabama	016012	9.2	94	33	127	827	60
Alaska	021008	5.5	33	---	---	---	13
Alaska	026010	12.5	53	43	96	126	14
Arizona	046054	5.8	178	53	231	---	65
Colorado	086002	26.4	147	71	218	247	40
Colorado	086013	10.4	69	38	107	55	57
Illinois	176050	15.2	61	117	178	(10)?	17
Iowa	196049	12.6	137	71	208	863	11
Missouri	296067	13.8	180	25	205	114	121
New Mexico	356033	13.2	107	64	171	96	35
New Mexico	356401	10.2	102	109	211	330	18
Oklahoma	406010	9.9	114	51	165	---	51
Saskatchewan	906801	13.6	---	102	---	121	13
Texas	481046	24.6	274	53	327	295	39
Texas	486079	10.6	175	66	241	394	48
Texas	486160	12.5	61	41	102	144	91
Texas	486179	10.6	41	112	153	74	11
Utah	491004	17.8	81	117	198	45	34
Utah	491007	3.7	239	51	290	90	11
Washington	531005	5.2	267	58	325	326	15
Wyoming	566031	10.6	64	64	128	31	19
Wyoming	566032	10.7	76	58	134	59	11

Table 39. Ranking in amounts of transverse cracking and age of overlay for GPS-6 test sec

Ranking By Amount of Transverse Cracking	State	SHRP ID	Number of Transverse Cracks	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness (mm)	Annual KESALs	Overlay A (Years)
1	Missouri	296067	121	180	25	205	114	13.8
2	Texas	486160	91	61	41	102	144	12.5
3	Arizona	046054	65	178	53	231	---	5.8
4	Alabama	016012	60	94	33	127	827	11.6
5	Colorado	086013	57	69	38	107	55	10.4
6	Oklahoma	406010	51	114	51	165	---	9.9
7	Texas	406079	48	175	66	241	394	10.6
8	Colorado	086002	40	147	71	218	247	26.4
9	Texas	481046	39	274	53	327	295	24.6
10	New Mexico	356033	35	107	64	171	96	13.2
11	Utah	491004	34	81	117	198	45	17.8
12	Wyoming	566031	19	64	64	128	31	10.6
13	New Mexico	356401	18	102	109	211	330	10.2
14	Illinois	176050	17	61	117	178	---	15.2
15	Washington	531005	15	267	58	325	326	5.2
16	Alaska	026010	14	53	43	96	126	12.5
17	Saskatchewan	906801	13	---	102	---	121	13.6
17	Alaska	021008	13	33	---	---	---	5.5
18	Iowa	196049	11	137	71	208	863	12.6
18	Wyoming	566032	11	76	58	134	59	10.7
18	Texas	486179	11	41	112	153	74	10.6
18	Utah	491007	11	239	51	290	90	3.7

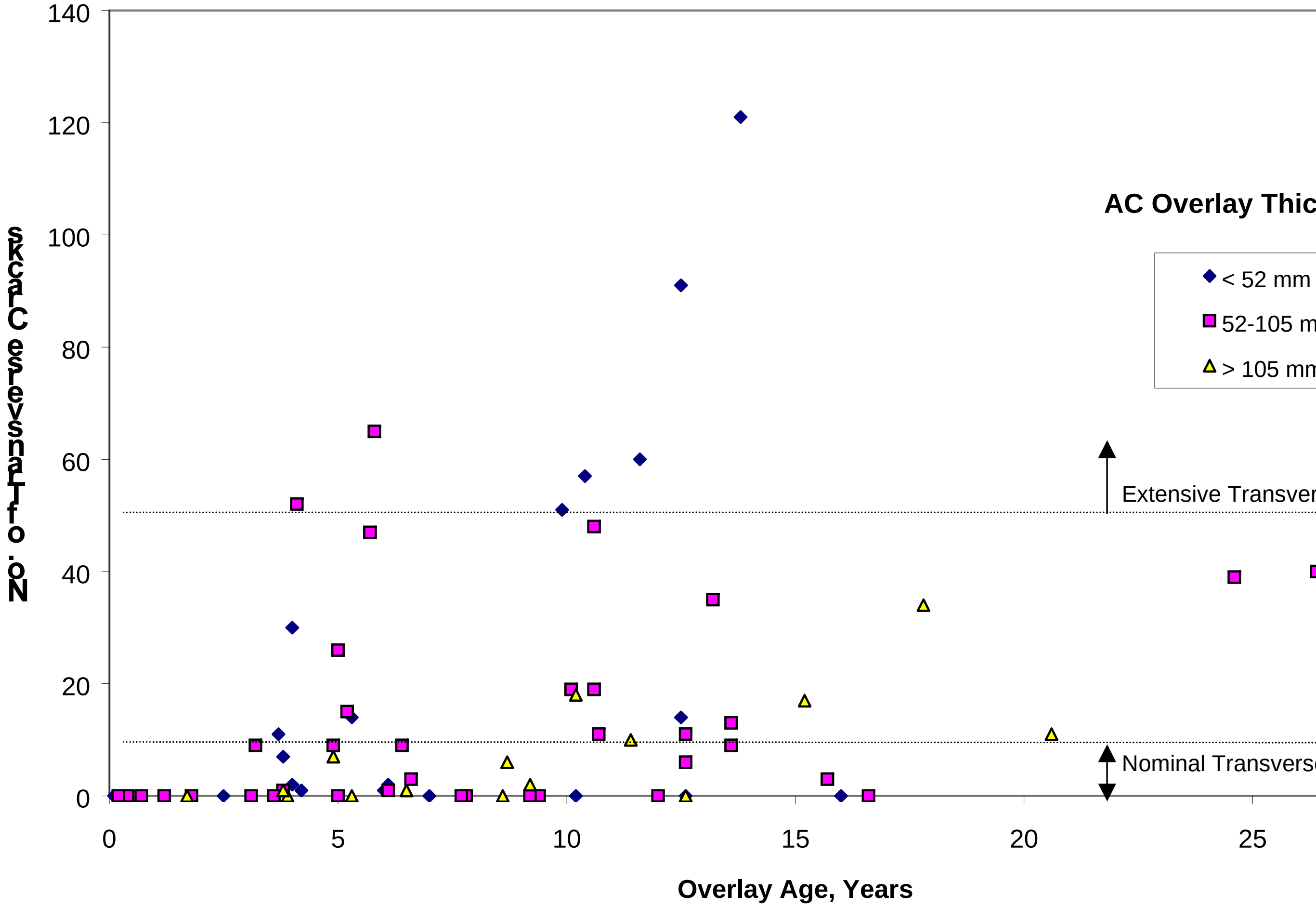


Figure 7. Graphical relationship between overlay age and the number of transverse cra observed on the GPS-6 test sections for different ranges of overlay thicknesses.

4.2.3 AC Thicknesses

A trend appears to present itself, when studying the overlay thicknesses (figure 7). The average overlay thickness for the 10 test sections with the greatest amounts of transverse cracking is 50 mm. The average overlay thickness for the 22 test sections appearing in table 38 is 67 mm. The average overlay thickness for the 24 test sections in table 34 that have exhibited 10 or less transverse cracks is 93 mm. More importantly, table 42 summarizes the incidence or number of GPS-6 test sections with different amounts of transverse cracks for the different ranges in overlay thicknesses for the AC overlays that are greater than 3 years in age (see figure 7).

This appears to indicate that, in general, increasing the thickness of an overlay can be expected to reduce the incidence of transverse cracking. However, it can be seen from table 30 that there are exceptions.

Table 40 lists 9 of the 24 GPS-6A test sections appearing in table 34 that exhibited 10 or less cracks and that have overlay thicknesses that could be considered relatively thin. Some are in the ranges of those in table 39 that had exhibited substantial transverse cracking. The bottom line appears to be that increased overlay thicknesses tend to decrease transverse cracking, but thin overlays may perform well if other conditions are favorable. It can also be seen from table 40 that three of the test sections with thin overlays that have functioned well for a number of years are in Canada, so it appears that transverse cracking in overlays can be reasonably controlled in areas experiencing very low temperatures.

Looking now at total AC thickness in table 39, it can be seen that there is substantial variation, from 96 to 327 mm, that does not appear to be related to the number of cracks, so this does not appear to be a strong factor concerning the formation of transverse cracks.

4.3 SUMMARY OF FINDINGS FOR TRANSVERSE CRACKING

While it is a widely accepted belief that transverse cracking (whether low temperature cracks or reflection cracks) is to some degree a result of low temperatures, the moderate incidence of transverse cracking on Canadian test sections indicates that the transverse cracking has been limited in those areas where low temperatures are a fact of life. Similarly, transverse cracking increases with age, but some overlays have survived with limited or no transverse cracking for long periods of time. Obviously, there are other factors contributing to good or poor performance.

It is hypothesized that the binder and mixture properties will be found to have significant effects on transverse cracking when more detailed analyses are conducted in the future. For example, Lytton et al. found that the occurrence of transverse cracks was heavily dependent on the binder (or asphalt) and mixture properties, climate, age, and AC layer thickness, but was found to be relatively insensitive to traffic and properties of the subsurface layers, including the subgrade.[8] The following lists a summary of the overall findings or observations that are related to the occurrence of transverse cracking.

Table 40. GPS-6A test sections with thin overlays that exhibited 10 or less transverse cracks.

State	SHRP ID	Overlay Thickness (mm)	Number of Transverse Cracks	Overlay Age (Years)
British Columbia	826006	53	3	15.7
Kentucky	216040	41	0	7.0
Kentucky	216043	51	0	16.0
New Brunswick	846804	56	0	16.6
Saskatchewan	906400	61	9	13.6
Tennessee	476022	51	0	12.6
Texas	486086	38	0	10.2
Utah	491006	64	0	7.8
Washington	536049	33	2	6.1

Table 41. Number of GPS-6A test sections with different number of transverse cracks.

Original Condition Before Overlay	Total Test Sections GPS-6A	No Transverse Cracking	1 to 10 Cracks	11 or More Cracks
Good	23	10	6	7
Poor	21	4	5	12
Total	44	14	11	19

Table 42. Number of GPS-6 test sections with different amounts of transverse cracking for different HMA overlay thicknesses.

Number of Transverse Cracks	Overlay Thickness, mm (%)*					
	25-59		60-105		>105	
0	5	(19%)	8	(33%)	5	(33%)
1-10 (Nominal)	7	(27%)	8	(33%)	6	(40%)
11-50	8	(31%)	7	(29%)	4	(27%)
>50	6	(23%)	1	(4%)	0	(0%)
Total Test Sections (> 3 years in Age)	**26**		**24**		**15**	

*Numbers in parentheses are the percentage of test sections in that group of AC overlay thicknesses.

- Both the SPS-5 and GPS-6 data indicate that thicker overlays will have a fewer number of transverse cracks than thin overlays (60 mm or less).

- AC overlay age was found to have an effect on the occurrence of transverse cracks for thin overlays (less than 60 mm), but no measurable effect on the thicker overlays. Lytton et al. also found that the potential of transverse cracking of thin AC layers was less dependent on the binder and mixture properties.[8] As the thickness of the AC layer increases, the binder and mixture properties become much more important and the thickness and age of the AC layer less important. Although the LTPP data do not conclusively support those findings, they at least do not contradict them.

- With the exception of the Colorado project, the data from table 31 show consistently fewer transverse cracks on milled surfaces, compared with unmilled surfaces prior to overlay placement. This appears logical, as removal of the top material from the original AC layer should reduce the effects of the cracks in the original pavement on the overlay and replacement of the milled material in effect increases the thickness of the uncracked new material over the original pavement. However, this does not represent a significant difference.

- There is no benefit or advantage derived from using one mix type over the other (virgin versus recycled mixes) in reducing the number of transverse cracks.

- While stress is introduced by wheel loads and may be expected to interact with shrinkage stresses caused by low temperatures, the data appear to indicate that traffic levels are not particularly important to the occurrence of transverse cracks. This preliminary observation is similar to the findings by Lytton et al.[8]

It is clear that the occurrence of transverse cracking, like the occurrence of fatigue or longitudinal cracking in the wheel path, is affected by interactions between the variables considered and other variables that could not be included in this limited study. The significance of these other variables and the interactions between variables may be analyzed in the future using statistical techniques.

CHAPTER 5. LONGITUDINAL CRACKING NOT IN THE WHEEL PATHS

Longitudinal cracking not in the wheel paths (LCNWP) is described in the *Distress Identification Manual* with three levels of severity identified.[7] For the purposes of this report, cracking at all severity levels has been combined.

LCNWP is described as cracks that are predominantly parallel to the pavement center line but not in the wheel paths. It needs to be noted that there can be three cracks not in the wheel paths: one near the outside edge of the lane, one between the wheel path, and one near the inside edge of the lane. However, two parallel cracks in either of these three locations are considered together and are not measured individually and the lengths added, so the maximum amount of LCNWP would be 457 m.

5.1 LONGITUDINAL CRACKING NOT IN WHEEL PATHS IN SPS-5 TEST SECTIONS

The graphs of LCNWP appear in appendix G, and table 43a provides the amounts of LCNWP noted by project and test section. Table 43b also provides information about LCNWP present in the existing pavements prior to the overlays. Ten of the 14 projects for which distress data are available had exhibited LCNWP at the time of the surveys.

5.1.1 General Overview of Observations from Data

Table 44 indicates the level of LCNWP for each project's control section and the numbers of test sections with none, nominal (50 m or less), or greater than nominal LCNWP. It can be readily seen that nearly half of the 71 test sections had exhibited no LCNWP, 16 had exhibited nominal LCNWP, and 21 had exhibited more LCNWP than the 50 m established as nominal. Seventeen of these overlaid test sections with more than 50 m were in 3 of the 9 projects, while 4 projects had no LCNWP greater than 50 m. The totals in table 44 indicate that 50 (70 percent) of the overlaid test sections had either none or nominal amounts of LCNWP at these early stages of their service lives.

Table 45 transforms the data in table 43 in the form of average lengths of LCNWP for a set of four test sections for each project. The pooled averages at the bottom of the table represent all projects combined. Of the three states omitted from this table, none of the overlaid test sections in Maine exhibited any LCNWP 4 months after the overlay, and the Arizona and California projects exhibited no LCNWP on most overlaid test sections and only very nominal amounts on the others.

- ***Thin versus Thick Overlay.*** It can be seen that, on average, the thick overlays have slightly less LCNWP than the thin ones. However, this smaller length of LCNWP does not represent a significant difference. The only exception was for the Alberta project, for which the thick overlays had exhibited much more

Table 43a. Longitudinal cracking not in the wheel path noted in SPS-5 test sections at tin last manual distress surveys.

State	Age of Overlays (Years)	LCNWP By Section, Meters						
		501	**502**	**503**	**504**	**505**	**506**	**507**
Alabama	3.6	0	0	0	0	0	0	0
Alberta	4.9	0.5	25	191	191	8.6	17.2	158
Arizona	4.4	0	3.6	0	0	0	0	0
California	2.4	2.6	0	0	0	4.4	6.4	0
Colorado	3.0	9.7	4.2	5.5	13.2	73	92	52
Georgia	2.8	0	0	0	0	0	0	0
Maine	0.3	266	0	NA	0	0	0	0
Manitoba	6.0	144	140	0	152	176	16	90
Maryland	3.3	238	0.2	0	0	61	11.2	0
Minnesota	4.8	35	92	0	137	241	230	184
Mississippi	3.2	0	0	0	0	0	0	0
New Jersey	2.2	NA	NA	240	NA	NA	NA	27
Texas	3.8	366	0	0	0	149	0	0

Table 43b. Length of longitudinal cracks outside the wheel paths prior to overlay, m.

State	Test Section						
	501	**502**	**503**	**504**	**505**	**506**	**507**
Alabama	0	0	0	0	0	0	0
Alberta	NA	NA	NA	NA	0	0	0
Arizona	0	0	NA	0	0	0	0
California	0	0	0	0	0	0	0
Colorado	123	122	153	136	148	144	116
Georgia	NA	2	0	0	0	0	0
Maine	266	296	245	280	283	198	305
Manitoba	0	8	53	0	19	6	14
Maryland	0	7	0	0	0	12	85
Minnesota	211	0	0	0	0	0	0
Mississippi	0	0	0	0	0	0	0
Texas	0	0	0	0	0	0	0

NA=Data not available.

Table 44. Number of SPS-5 test sections by projects at various levels of longitudinal cracking not in wheel paths.

State	Control Section 501 Number of Cracks			Numbers of Sections (502-509) by Levels of LCNWP		
	0	**1-50m**	**> 50m**	**0**	**1-50m**	**> 50m**
Alberta	X				3	5
Arizona	X			7	1	
California		X		5	3	
Colorado		X		1	4	3
Maine			X	7		
Manitoba			X	1	1	6
Maryland			X	5	3	
Minnesota		X		1	1	6
Texas			X	7		1
TOTALS	**2**	**3**	**4**	**34**	**16**	**21**

Note: New Jersey's project was omitted as data were only available for test sections 503, 507, and 508. Data for test section 503 were also missing for the Maine project.

Table 45. Average LCNWP for thick vs. thin overlays, recycled vs. virgin AC mixes, and milled vs. unmilled test sections.

State	Average LCNWP in Meters (%)*											
	Thin Overlays		**Thick Overlays**		**Virgin**		**Recycled**		**Unmilled**		**Milled**	
Alberta	50	(132%)	174	(11%)	94	(101%)	130	(56%)	104	(97%)	120	(57%)
Colorado	44	(102%)	18	(133%)	58	(59%)	4	(75%)	24	(137%)	38	(113%)
Manitoba	114	(60%)	78	(81%)	109	(66%)	83	(77%)	117	(68%)	75	(61%)
Maryland	18	(160%)	7	(205%)	18	(162%)	7	(195%)	15	(199%)	10	(130%)
Minnesota	166	(48%)	94	(87%)	198	(24%)	62	(74%)	118	(85%)	143	(55%)
Texas	37	(201%)	0	(0%)	37	(201%)	0	(0%)	37	(201%)	0	(0%)
Averages	**72**		**62**		**86**		**35**		**69**		**64**	

*The numbers in parentheses are the coefficient of variations.

LCNWP than the thin ones. The reason for this occurrence is not directly obvious from the available data for this initial study of performance trends.

- ***Virgin versus Recycled Mixtures.*** It can also be seen that the recycled mixtures generally exhibited much less LCNWP than the virgin mixes. However, the virgin mix performed better (smaller length of LCNWP) for the Alberta project.

- ***Milled versus Unmilled Surfaces***. The milled test sections performed better than the unmilled test sections for three of the projects, and three of the unmilled test sections also performed better than milled sections. As the overall averages differed very little, it appears that, in general, milling offers no advantage for resisting LCNWP.

5.1.2 Detailed Assessment of Longitudinal Cracking Not in Wheel Path

It can be seen from table 43 that the only survey data for the Maine project was conducted only about 4 months after the overlay was placed. At that time, the control section had 266 m of LCNWP, but the overlays were too new for it to have reflected up at that time. Table 46 summarizes the number of test sections (excluding the Maine project and all of the control sections) with different lengths of LCNWP.

Table 46. Number of LTPP test sections with various lengths of LCNWP.

SPS-5 Projects	SPS-5 Total Sections	LCNWP, m			
		0	1 - 50 (Nominal)	51 - 160	> 160
Number of Test Sections	90	49	17	16	8
Percentage in Each Group	100	54.4	18.9	17.8	8.9
GPS-6 Projects Original Condition Before Overlay	**Number of GPS-6 Test Sections**	**LCNWP, m**			
		0	**1 - 50 (Nominal)**	**51 - 160**	**> 160**
Poor	46	22	15	7	2
Good	37	21	7	7	2
Total	83	43	22	14	4

As shown, an appreciable number of test sections have extensive LCNWP (27 percent). At the time of the last manual distress surveys, three of the projects had major amounts of LCNWP in their control sections. Because the control sections for California and Colorado were covered during construction, the amounts appearing in table 43 have little or no meaning in relation to what would have occurred with the "do nothing strategy." Table 47 summarizes the number of test sections (excluding the Maine, California, Colorado, and New Jersey projects) with LCNWP in comparison with the length of LCNWP on the control section and in comparison with the lengths prior to overlay.

Table 47. Summary of LCNWP data for the SPS-5 test sections in comparison with the control section and prior to overlay.

LCNWP in Comparison to Control Section	Number of Test Sections	Percentage in Each Group
Less than Control Section	23	31.9
Equal to Control Section	31	43.1
Greater than Control Section	18	25.0
Total	72	100
LCNWP in Comparison Prior to Overlay	**Number of Test Sections**	**Percentage in Each Group**
Less than Prior to Overlay	13	15.3
Equal to Prior to Overlay	45	53.0
Greater than Prior to Overlay	27	31.7
Total	85	100

As shown, 25 percent of the test sections have greater lengths of LCNWP than that which was measured in the control or "do nothing" section.

It is interesting to note, however, that the Alberta, Arizona, and California projects had exhibited no LCNWP prior to the overlays, but the Alberta overlays have all since exhibited substantial LCNWP. The Arizona project had exhibited a nominal amount (less than 50 m) on one thin overlay and the California project had nominal amounts on three thin overlays. Table 47 also summarizes the number of test sections (excluding the Maine project) with LCNWP in comparison with the length of LCNWP measured in each section prior to overlay. As shown, more than 30 percent of the test sections have greater lengths of LCNWP after overlay than that which was measured prior to overlay. All eight of the Colorado and Maine test sections had LCNWP prior to the overlays. The Alabama, Georgia, and Mississippi projects did not have LCNWP prior to or since the overlays.

5.1.3 Summary

In summary, the overlays of 13 (65 percent) of the 20 test sections (known to have exhibited LCNWP in the original pavements prior to overlay) have resisted reflection of the LCNWP through to the overlay surfaces. More importantly, 25 percent of the overlaid test sections have lengths of LCNWP that are greater than the control or "do nothing" section. More than 30 percent of the overlaid test sections have lengths of LCNWP that are greater than that which was measured prior to overlay placement. These percentages are significantly greater than those determined for fatigue and transverse cracks and suggest that the LCNWP may be more dependent on other parameters that were not included in this study.

5.2 LONGITUDINAL CRACKING NOT IN WHEEL PATHS IN GPS-6 TEST SECTIONS

Table 48 provides the primary data, selected or calculated from that available in appendices B and C, that were used for the studies leading to results discussed below. Graphs of LCNWP appear in appendix G. Figure 8 graphically shows the probability of occurrence of LCNWP with overlay age for the GPS-6 data. As shown, LCNWP occurred on more than just a few test sections shortly after the overlay was placed, but it has taken a relatively long period of time for the LCNWP to exceed 150 m.

As noted in chapter 3, the overlays from the GPS-6B test sections are relatively young. The ages at the time of the last survey range from 0.1 to 6.6 years, with an average age of less than 3 years. Both GPS-6A and GPS-6B data are included in table 49, while tables 50, 51, 52, 53, and 54 include only GPS-6A overlays to provide insight concerning the long-term performance in LCNWP.

5.2.1 Original Pavement Condition

Table 49 indicates that both LCNWP and prior condition data (poor or good only) are available for 83 GPS-6 test sections. Of these, 46 were originally in the poor condition before overlay category and 37 were in the good condition category (table 49). Table 46 summarizes the number of GPS-6 test sections with various levels of LCNWP within each original condition before overlay group. The condition of the existing pavement prior to overlay appears to have no effect on the occurrence and length of LCNWP.

Of the 83 test sections, 43 (52 percent) had exhibited no LCNWP, 22 (27 percent) more had exhibited 50 m or less of LCNWP, and 18 (21 percent) had exhibited more than 50 m of LCNWP.

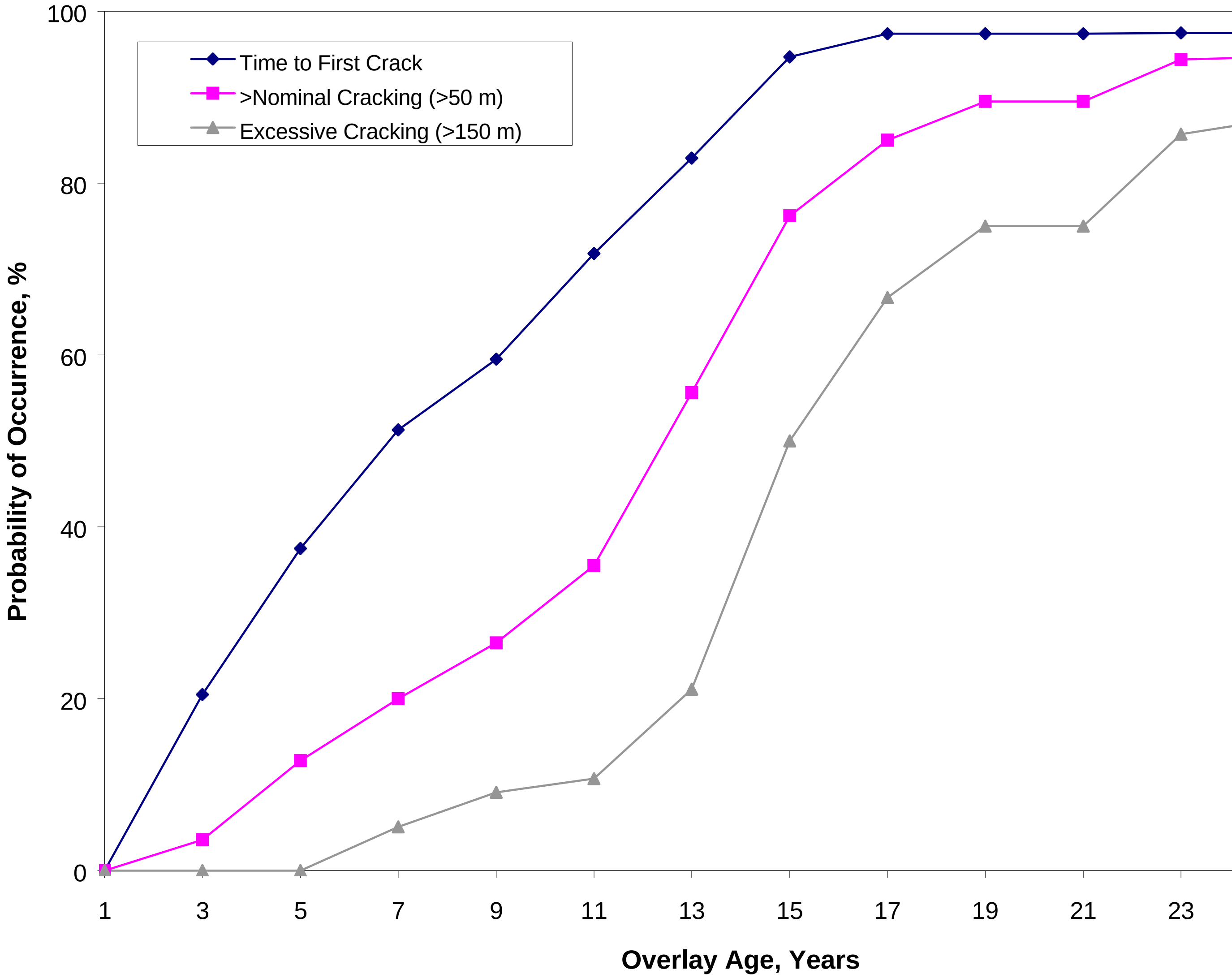


Figure 8. Probability of occurrence of different levels of LCNWP on the GPS-6 test secti

Table 48. Longitudinal cracking not in wheel paths in GPS-6 test sections at last survey.

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	Longitudinal Cracking -Non-Wheelpath (m)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Alabama	16012	6A	11.6	94	Good	33	11.6	38
Alabama	16019	6A	14.8	163	Poor	89	12.0	0
Alabama	14127	6B	14.7	211	Poor	43	4.0	0
Alabama	14129	6B	13.4	76	Good	38	3.8	2
Alaska	21008	6A	10.3	33	--	--	6.5	0
Alaska	26010	6A	13.2	53	Poor	43	12.5	9
Alaska	21004	6B	13.8	91	Poor	46	4.0	13
Alaska	29035	6B	18.8	53	Good	97	3.2	7
Alberta	811804	6B	10.8	89	Poor	99	0.2	0
Arizona	46053	6A	20.5	81	Poor	120	6.5	2
Arizona	46054	6A	3.8	178	Good	53	5.8	104
Arizona	46060	6A	21.5	99	Poor	102	6.4	8
British Columbia	826006	6A	17.5	81	Poor	53	15.7	15
British Columbia	826007	6A	2.7	64	Poor	132	12.6	0
California	68534	6B	22.5	119	Poor	89	1.2	0
Colorado	86002	6A	(0.8)	147	Poor	71	26.4	0
Colorado	86013	6A	(0.3)	69	Poor	38	10.4	40
Colorado	87783	6A	3.7	127	Good	91	9.4	17
Colorado	87781	6B	9.3	86	Poor	56	10.1	0
Florida	124101	6B	24.2	33	Good	114	1.7	0
Florida	124135	6B	21.2	36	--	--	0.9	0
Florida	124136	6B	21.2	36	Poor	--	0.9	0
Florida	124137	6B	21.5	71	Good	--	0.9	0
Georgia	134420	6B	8.4	125	Poor	--	2.1	4
Illinois	176050	6A	18.5	61	Poor	117	15.2	153
Indiana	181037	6B	11.7	71	Poor	25	0.1	0
Iowa	196049	6A	13.4	137	Good	71	12.6	0
Kansas	206026	6A	14.0	25	Good	147	12.6	0
Kentucky	216040	6A	14.9	155	Good	41	7.0	0
Kentucky	216043	6A	7.9	140	Good	51	16.0	0
Maine	231028	6B	21.8	163	--	--	0.1	0
Manitoba	836450	6B	18.0	112	Poor	150	3.8	36
Manitoba	836451	6B	18.0	104	Poor	66	3.8	101
Minnesota	276064	6A	12.0	193	Poor	142	8.7	0
Mississippi	282807	6B	10.7	269	Poor	--	2.3	18
Mississippi	283091	6B	16.3	89	Good	--	0.3	0
Mississippi	283093	6B	7.5	104	Good	76	1.8	0
Mississippi	283094	6B	7.5	231	Good	76	3.6	0

Table 48. Longitudinal cracking not in wheel paths in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	Longitudinal Cracking -Non-Wheelpath (m)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Missouri	296067	6A	15.9	180	Poor	25	13.8	288
Missouri	295403	6B	24.0	102	Good	56	5.0	88
Missouri	295413	6B	24.0	97	Poor	79	5.0	0
Montana	306004	6A	17.8	89	Good	180	11.4	0
Montana	307075	6A	17.3	86	Good	94	12.6	0
Montana	307076	6B	5.8	132	Good	61	0.4	0
Montana	307088	6B	10.1	124	Poor	43	0.3	0
New Brunswick	846804	6A	(0.5)	99	Good	56	16.6	2
New Mexico	351002	6A	26.5	109	Poor	99	9.2	0
New Mexico	356033	6A	22.5	107	Poor	64	13.2	3
New Mexico	356035	6A	19.5	91	Good	112	9.2	0
New Mexico	356401	6A	13.5	102	Poor	109	10.2	0
North Carolina	371040	6B	16.7	135	--	--	0.5	0
North Carolina	371803	6B	12.7	132	Poor	76	5.7	9
Oklahoma	406010	6A	14.5	114	Good	51	9.9	242
Oklahoma	404086	6B	19.3	109	Poor	33	5.3	3
Oklahoma	404164	6B	16.3	117	Poor	--	0.3	0
Oregon	416011	6A	25.1	155	Poor	173	5.3	0
Pennsylvania	421608	6A	0.0	61	Good	66	6.1	0
Quebec	891021	6B	14.2	132	--	--	0.2	0
Quebec	891127	6B	15.7	124	--	--	0.2	0
Saskatchewan	906400	6A	9.7	196	Poor	61	13.6	120
Saskatchewan	906801	6A	8.7	--	Poor	102	13.6	117
Saskatchewan	906410	6B	21.3	117	Poor	94	4.9	17
Saskatchewan	906412	6B	21.3	112	Poor	140	4.9	0
South Dakota	469197	6B	25.7	89	Poor	94	4.1	147
Tennessee	476015	6A	10.6	224	Good	140	8.6	0
Tennessee	476022	6A	8.6	119	Good	51	12.6	0
Tennessee	473108	6B	17.6	140	Good	--	3.5	0
Tennessee	473109	6B	10.6	132	Poor	--	4.2	0
Tennessee	473110	6B	8.1	130	Poor	140	3.9	0
Tennessee	479024	6B	18.0	145	Good	--	(0.1)	0
Texas	481046	6A	15.3	274	Poor	53	24.6	170
Texas	486079	6A	12.4	175	Good	66	10.6	141
Texas	486086	6A	13.6	221	Good	38	10.2	2
Texas	486160	6A	18.3	61	Poor	41	12.5	82
Texas	486179	6A	9.6	41	Poor	112	20.6	36
Texas	481093	6B	8.4	74	Good	64	6.6	28
Texas	481113	6B	6.4	38	Poor	94	3.1	0
Texas	481116	6B	3.3	38	Good	84	0.7	0

Table 48. Longitudinal cracking not in wheel paths in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	Longitudinal Cracking -Non-Wheelpath (m)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Texas	481119	6B	14.3	135	Poor	41	6.0	0
Texas	481130	6B	21.0	69	Poor	25	2.5	0
Texas	483875	6B	7.0	41	Good	25	4.2	0
Utah	491004	6A	6.3	81	Good	117	17.8	151
Utah	491005	6A	13.5	150	Good	97	7.7	161
Utah	491006	6A	16.2	234	Good	64	7.8	153
Utah	491007	6A	8.3	239	Good	51	3.7	124
Washington	536049	6A	16.2	236	Good	33	6.1	0
Washington	531005	6B	16.0	267	Poor	58	5.2	89
Wyoming	566031	6A	5.3	64	Poor	64	10.6	39
Wyoming	566032	6A	12.6	76	Good	58	10.7	146

Table 49. Ages of GPS-6 overlays with 50 m or less of longitudinal cracking not in wheel paths.

Original Condition Before Overlay	Total* Test Sections	Total Number 50 m or Less of LCNWP	Number ≥ 5 Years	Number ≥ 10 Years	Number ≥ 15 Years	Number ≥ 20 Years
Poor	46	37	20	11	3	2
Good	37	28	16	9	2	0
Total	83	65	36	20	5	2

*Number of test sections for which LCNWP data are available and prior condition data were provided.

Table 50. Ages of GPS-6A overlays with 50 m or less of longitudinal cracking not in wheel paths.

Original Condition Before Overlay	Total Test Sections	Total Number 0 to 50 m	Number ≥ 5 Years	Number ≥ 10 Years	Number ≥ 15 Years	Number ≥ 20 Years
Poor	21	15	15	10	3	2
Good	23	15	15	9	2	0
Total	44	30	30	19	5	2

Note: One GPS-6A test section overlay in the good group was less than 5 years old when the last manual distress survey was conducted.

5.2.2 AC Overlay Age

For the 65 test sections having 50 m or less of LCNWP (table 35), 29 (45 percent) had been overlaid less than 5 years, 16 (25 percent) had been overlaid 5 to 9.9 years, 15 (23 percent) had been overlaid 10 to14.9 years, 3 had been overlaid 15 to 19.9 years, and 2 had been overlaid more than 20 years.

Table 50 provides the same information as table 49, except that it is restricted to GPS-6A test sections. Ignoring the 1 test section with an overlay less than 5 years old, 15 (68 percent) of the remaining 22 overlays in good condition prior to overlay category had LCNWP of 50 m or less. Eight (36 percent) of the overlays had 50 m or less after 5 to 9.9 years, 5 (23 percent) after 10 to 14.9 years, and 2 had served for more than 15 years. Eleven of the 15 test sections had exhibited no LCNWP, 5 of which were 10 to 14.9 years old, and 1 was well over 15 years old. Seven (32 percent) of the 22 overlays in the good condition prior to overlay category and more than 5 years of age had exhibited more than 50 m of LCNWP.

For the group in the poor condition prior to overlay category, 15 overlays (71 percent) had 50 m or less of LCNWP, while 6 (29 percent) had more than 50 m of LCNWP. Of the 15 overlays with less than 50 m of LCNWP, 5 (24 percent) were 5 to 9.9 years of age, 7 (33 percent) were 10 to 14.9 years old, 1 had served more than 15 years, and 2 had served more than 20 years. Also, all 6 of the test sections that had exhibited more than 50 m of LCNWP were more than 10 years old, with 1 more than 15 years and 2 more than 20 years.

Table 51 provides selected data for those 8 GPS-6A overlays that have been in service longer than 15 years. It can be seen that 2 of these 8 test sections had no LCNWP and that one other had only 2 m. One is the Colorado test section 086002, whose overlay was 26.4 years of age at the time of the last survey. It should also be noted that Texas 486179 only has 36 m after 20.6 years.

It may be noted that three of the five overlays with less than 50 m of LCNWP also had little transverse cracking, while a fourth (Texas 486179) had one more transverse crack than the 10 established as the nominal level. It should also be noted that these overlays ranged from Texas into Canada. It is interesting to note that only 3 of the 8 overlays had more than 50 m of LCNWP and that the average age for those 3 overlays was 19.2 years. The data available do not appear to explain why these 8 overlays have functioned reasonably well over 15 years.

Table 52 provides selected data for the GPS-6A test sections that have exhibited more than nominal (50 m) LCNWP, seeking a common factor that might indicate why they exhibit more extensive cracking. It may be noted that these 14 overlays range from 3.7 to 24.6 years of age, averaging 12.7 years. The 30 overlays exhibiting only nominal LCNWP averaged 11.4 years of age. It appears that the incidence of LCNWP is not very dependent on the age of the overlay, so it is apparent that there are other factors that strongly affect the occurrence of LCNWP.

Table 51. Selected data for GPS-6A overlays 15 or more years old.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	Meters of LCNWP
British Columbia	826006	15.7	81	53	134	149	15
Colorado	086002	26.4	147	71	218	247	0
Illinois	176050	15.2	61	117	178	(10)?	153
Kentucky	216043	16.0	140	51	191	633	0
New Brunswick	846804	16.6	99	56	146	591	2
Texas	481046	24.6	274	53	327	295	170
Texas	486179	20.6	41	112	153	74	36
Utah	491004	17.8	81	117	198	45	151

Table 52. Selected data for GPS-6A overlays that had exhibited more than 50 m of longitudinal cracking not in wheel paths.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness, mm	Annual KESALs	Meters of LCNWP
Arizona	046054	5.8	178	53	231	---	104
Illinois	176050	15.2	61	117	178	(10)?	153
Missouri	296067	13.8	180	25	205	114	288
Oklahoma	406010	9.9	114	51	165	---	242
Saskatchewan	906400	9.7	196	61	257	121	120
Saskatchewan	906801	13.6	---	102	---	121	117
Texas	481046	24.6	274	53	327	295	170
Texas	486079	10.6	175	66	241	394	141
Texas	486160	12.5	61	41	102	144	82
Utah	491004	17.8	81	117	198	45	151
Utah	491005	13.5	150	97	247	96	161
Utah	491006	16.2	234	64	298	139	153
Utah	491007	3.7	239	51	290	90	124
Wyoming	566032	10.7	76	58	134	59	146

5.2.3 AC Overlay Thickness

Table 53 uses data from table 52, but the data are rearranged such that the test sections are ordered according to the amount of LCNWP, with the one with the most LCNWP having a ranking of 1.

It can be seen that the original AC thickness varied from 61 to 274 mm, and that the amounts of LCNWP do not appear to be correlated to the original AC thickness. However, it can be seen that 13 of the 18 overlays are relatively thin, averaging from 25 to 66 mm. The overlay thicknesses for the other 5 only varied from 94 to 117 mm, while the average for all 11 test sections is 68 mm. The average overlay thickness for the 30 GPS-6A test sections that have exhibited 50 m or less of LCNWP is 85 mm.

More importantly, table 55 summarizes the incidence or number of GPS-6 test sections with different amounts of LCNWP for the different ranges in overlay thicknesses for the AC overlays that are greater than 3 years in age. This appears to indicate that, in general, increasing the thickness of an overlay can be expected to reduce the incidence of LCNWP, but it can be seen from table 53 that there are many exceptions.

Table 54 lists 11 of the 30 GPS-6A test sections appearing in table 48 that had exhibited 50 m or less of LCNWP that could be considered relatively thin. Some are in the ranges of those in table 53 that had exhibited substantial LCNWP. The bottom line appears to be that increased overlay thicknesses tend to decrease LCNWP, but thin overlays have performed with less than 50 m of LCNWP if other conditions are favorable.

It can be seen from comparison of the rankings by age of overlay versus the rankings for the amount of LCNWP that they are not correlated. Except for the Oklahoma test section, the five overlays having the highest amounts of LCNWP are also the oldest. This appears to indicate, as expected, that the occurrence of LCNWP does increase with age. However, a comparison of the average ages for the 30 overlays listed in table 48 that had exhibited 50 m or less of LCNWP and the average ages for the 11 in table 53 that had exhibited the most LCNWP indicated that they are not statistically different at 11.1 and 12.3 years, respectively. This appears to indicate that other factors, such as subsurface properties and construction, are stronger parameters affecting the incidence of LCNWP.

Table 53. Ranking in amounts of longitudinal cracking not in the wheel paths and age overlay for GPS-6 test sections.

Ranking By Amount of LCNWP	State	SHRP ID	Meters of LCNWP	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness (mm)	Annual KESALs	Overlay Age (Yea
1	Missouri	296067	288	180	25	205	114	13.8
2	Oklahoma	406010	242	114	51	165	---	9.9
3	Texas	481046	170	274	53	327	295	24.6
4	Utah	491005	161	150	97	247	96	13.5
5	Utah	491006	153	234	64	298	139	16.2
5	Illinois	176050	153	61	117	178	10(?)	15.2
6	Utah	491004	151	81	117	198	45	6.3
7	South Dakota	469197	147	89	94	183	3(?)	4.1
8	Wyoming	566032	146	76	58	134	59	12.6
9	Texas	406079	141	175	66	241	394	10.6
10	Utah	491007	124	239	51	290	90	8.3
11	Saskatchewan	906400	120	196	61	257		13.6
12	Saskatchewan	906801	117	---	102	---		13.6
13	Arizona	046054	104	178	53	231		5.8
14	Manitoba	836451	101	104	66	170		3.8
15	Washington	531005	89	267	58	325		5.2
16	Missouri	295403	88	102	56	158		5.0
17	Texas	486160	82	61	41	102		12.5

Table 54. GPS-6A test sections with thin overlays that exhibited 50 m or less of longitudinal cracking not in the wheel paths.

State	SHRP ID	Overlay Thickness (mm)	Meters of LCNWP	Overlay Age (Years)
Alabama	016012	33	38	11.6
Alaska	026010	43	9	12.5
British Columbia	826006	15	53	15.7
Colorado	086013	38	40	10.4
Kentucky	216040	41	0	7.0
Kentucky	216043	51	0	16.0
New Mexico	356033	64	3	13.2
Pennsylvania	421608	66	0	6.1
Tennessee	476022	51	0	12.6
Texas	486086	38	2	10.2
Washington	536049	33	0	6.1

Table 55. Number of GPS-6 test sections with different lengths of LCNWP for different HMA overlay thicknesses.

Length of LCNWP, m	Overlay Thickness, mm ( )*					
	25 - 59		60 - 105		> 105	
0	8	(30.8)	9	(37.5)	10	(66.7)
1 - 50 (Nominal)	9	(34.6)	8	(33.3)	3	(20.0)
51 - 160	6	(23.1)	6	(25.0)	2	(13.3)
> 160	3	(11.5)	1	(4.2)	0	(0.0)
Total Test Sections (> 3 Years/Age)	26		24		15	

*Numbers in parentheses are the percentage of test sections in that group of AC overlay thickness.

5.3 SUMMARY OF FINDINGS FOR LONGITUDINAL CRACKING NOT IN WHEEL PATHS

The following lists a summary of the overall observations that are related to the occurrence of LCNWP.

- Both the SPS-5 and GPS-6 data indicate that thicker overlays consistently have less LCNWP as well as a lower incidence of cracking.

- The data from table 45 appear to indicate that milling offers no consistent advantage for resisting LCNWP during the early life of an overlay. For three of the six projects, the milled test sections performed better than the unmilled test sections, while the reverse was true for the other three projects (the unmilled test sections performed better than the milled test sections).

- The recycled AC mixes resisted LCNWP substantially better than the virgin mixes for five of the six projects, with the overall average LCNWP amount exhibited being only 40 percent of that for the virgin mixes.

- Overlay age and condition of the pavement prior to the overlay appear to have little to no impact on the performance of the overlay in resisting LCNWP. However, 45 percent of the overlays over pavements known to have exhibited LCNWP prior to overlays have successfully resisted reflection of these cracks through to the overlay surfaces during their early years.

It is apparent that the occurrence of LCNWP, like the occurrence of the other types of cracking, is affected by interactions between the variables considered and other variables that could not be included in this limited study. The significance of these other variables and the interactions between variables may be analyzed in the future using statistical techniques.

CHAPTER 6. RUTTING

Rutting is described in the *Distress Identification Manual* as "a longitudinal surface depression in the wheel path.[7] It may have associated transverse displacement." There are no severity levels established. To follow the format for the other distresses, 6 mm or less (relative to1.8-m straight edge) has been established as the nominal case and the categories for comparison are 6 mm or less, 6.1 to 20 mm and greater than 20 mm of rut depth. Twenty mm was selected because that approximates a level of rutting at which many agencies would be considering rehabilitation. Actually, none of the SPS-5 projects have exhibited more than 20 mm of average rut depth at the times of measurement.

The rut depths used and reported in this study represent averages of the two wheel paths for 11 cross profiles per test section. The characterization is based on a 1.8-m straight edge, which is that used by SHRP previously for LTPP studies.[4] This was adopted because it appeared to best represent the potential for hydroplaning and appeared to be a more logical characterization than the lane-width stringline offered by PASCO (a company located in Harrisburg, Pennsylvania).

6.1 RUTTING IN SPS-5 TEST SECTIONS

The graphs of rut depths appear in appendix H for the 14 projects for which the data were available when the graphs were created. Since that time, data for the Florida project have been received and are included in table 56, which provides the rut depths by project and test section. Unlike the cracking distresses discussed in previous chapters, every test section will have some rutting, even if it is minor (such as 1 or 2 mm).

It can be seen at a glance from table 56 that the great majority of the test sections have exhibited only nominal rut depths (less than 6 mm) at the time of measurement. Only the Maryland and Mississippi projects had exhibited substantial rutting in some of the overlays.

6.1.1 Detailed Assessment of Rutting

It is interesting to note that, in less than a year, the Florida and Maine projects had exhibited up to 4 mm of rutting. This is quite similar to the magnitudes that had been exhibited by the older projects. Figure 9 provides a general explanation for this. Permanent deformation in the wheel paths occurs at a somewhat high rate early in the life of the pavement, but the rate generally decreases dramatically after the initial traffic densification is completed. Rutting will continue at this slower rate for some time, or until plastic flow begins to occur.

It should also be noted that the average rut depths in the control section 501 were still not especially serious at the time of the measurements. The control sections in the California, Colorado, or Montana projects are not indicative of a "do nothing strategy," as intended, because they were overlaid for the California and Montana projects and the ruts were filled for the Colorado project.

Table 56. Average rut depths calculated for SPS-5 test sections from most recent digitized transv

State	Age of Overlays (Years)	Rut Depths By Section, mm						
		501	502	503	504	505	506	507
Alabama	4.1	---	3	3	4	3	3	3
Alberta	4.7	9	5	7	6	4	6	5
Arizona	4.8	7	4	6	3	5	4	5
California	2.9	4	4	3	4	4	4	4
Colorado	4.6	10	3	4	3	3	4	5
Florida	0.8	---	3	4	3	3	3	4
Georgia	2.6	6	4	3	4	3	3	4
Maine	0.4	11	3	3	3	2	4	3
Manitoba	6.4	*	3	3	2	2	2	3
Maryland	3.4	10	13	18	8	5	4	6
Minnesota	3.0	7	2	2	2	2	2	2
Mississippi	5.3	13	10	11	15	8	9	16
Montana	4.8	---	6	5	5	4	8	6
New Jersey	3.3	9	4	4	3	3	4	4
New Mexico	No Data as Yet							
Oklahoma	No Data as Yet							
Texas	3.5	---	5	5	4	5	4	6

*Not available - 9 mm June 1993

In some in-service pavements, the rutting rate increases drastically, generally exacerbated by the occurrence of other distresses in the wheel paths that allow water to soak into underlying layers or a loss of shear strength in the AC mixture. Some type of rehabilitation or reconstruction is almost always applied to avoid the rapid deterioration shown in figure 9 toward the end of the pavement's service life.

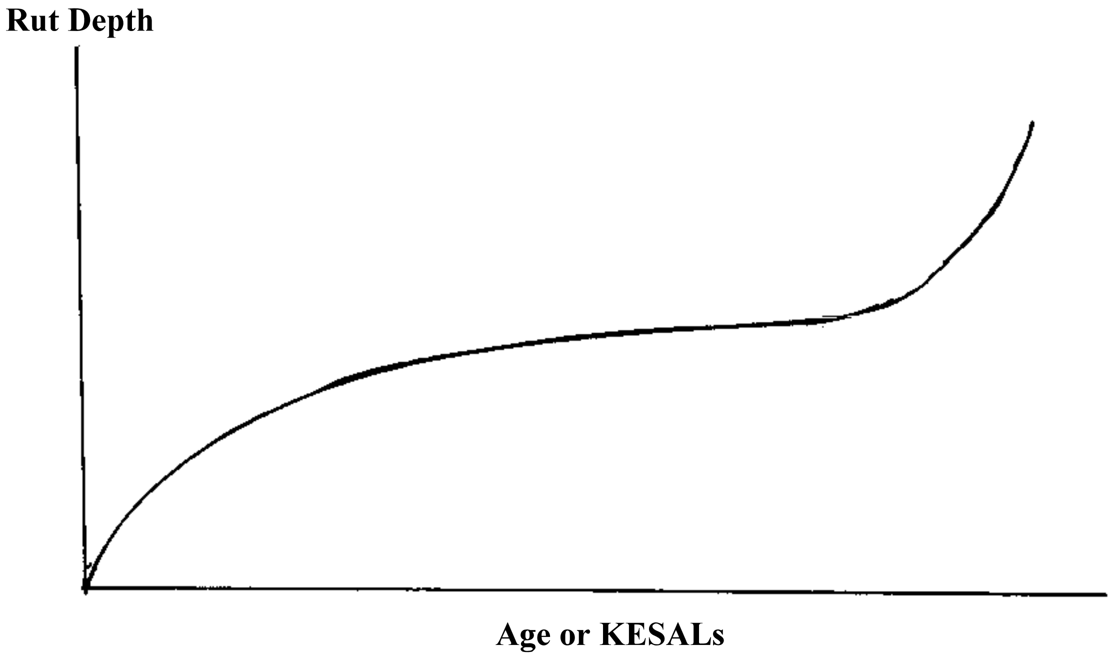


Figure 9. General form for rutting.

Table 57 summarizes the number of test sections with different amounts of rutting for those overlays greater than 2 years in age (excludes the Florida and Maine projects, as well as all of the control sections).

Table 57. Number of SPS-5 test sections with various rut depths.

	Total Sections	**Rut Depths, mm**			
		< 7 (Nominal)	**7 - 12**	**13 - 20**	**> 20**
Number of Test Sections	104	88	10	6	0
Percentage in Each Group	100.0	84.6	9.6	5.8	0.0

Table 58 provides information on the rut depths prior to the overlays. It can be seen that the projects in Colorado, Maine, and Mississippi had substantial rutting prior to the overlays, while the rest of the test sections for which these data are available varied from the established nominal level of 6 mm or less up to 12 mm, on average.

Table 59 compares, for the 10 test sections for which all the data are available, the average original rut depths in the test sections to be overlaid with the average rut depths in the overlays at the time the measurements were made. It also includes a ratio of the rut depths in the overlays to those in the original pavements. These averages are again averaged for the 10 projects. It can be seen that the average rut depths for the overlays in the Maryland project were slightly greater than the averages before the overlays after 3.4 years. The rut depths in the overlays for the other nine projects were generally less than for the original pavements. Based on the data in tables 59 and 60, it appears that the SPS-5 overlays have essentially no rutting (less than nominal or 7 mm) during the early part of their service lives. It is unfortunate that traffic and materials data are not yet available for the SPS-5 test sections, as this information might help explain the higher rut depths for some of the test sections.

It can be seen that the average rut depths in the overlays for the 10 projects was 5.8 mm, as compared with 10.3 mm for the original pavements. On average, the rut depths for the overlays are 61 percent of those of the original pavements. Considering that these overlays are relatively new, it appears probable that many of the test sections may exhibit as much rutting as existed in the original pavements at some point within their service lives. However, it should be remembered that most of the original pavements had not exhibited rut depths that would normally trigger an overlay.

Table 60 indicates the rut depths for each project's control section and the number of test sections that have exhibited different levels of rut depths since they were overlaid. As would be expected, the control sections for 13 of the 14 projects listed had exhibited more than the nominal range of rutting, while the one in Alabama had exhibited 6 mm on average. None of the test sections had exhibited more than 20 mm, except for test section 507 in Colorado, which had exhibited 23 mm.

6.1.2 General Overview of Observations from Rutting Data

Thin versus Thick Overlay. Table 61 provides a basis for comparing the various treatments as in chapters 4 and 5. It can be seen that the thick overlays exhibited more rutting for eight of the projects than the thin overlays, but the thin overlays exhibited more rutting for three of the projects. The rut depths were approximately even between the thin and thick overlays for four of the projects. The overall averages at the bottom of table 45 also indicate that the thick overlays exhibit more rutting than the thin ones, but the difference is less than 1 mm and does not represent a significant difference.

Table 58. Average rut depths calculated from the digitized transverse profiles prior to overl

State	Test Section						
	501	502	503	504	505	506	507
Alabama	6	NA	NA	NA	NA	NA	NA
Alberta	8	5	5	7	7	8	6
Arizona	11	14	12	11	12	14	11
California	16	13	5	8	5	6	7
Colorado	17	6	7	6	7	21	20
Georgia	11	NA	NA	NA	NA	NA	NA
Maine	13	13	13	14	13	15	13
Manitoba	NA	NA	NA	NA	NA	NA	NA
Maryland	8	7	8	8	7	8	7
Minnesota	8	8	7	8	7	6	6
Mississippi	13	19	17	15	15	17	14
Montana	NA	11	9	9	11	10	8
New Jersey	7	9	6	3	5	8	7
Texas	8	12	11	11	9	9	10

*NA=Data not available.

Table 59. Relationship between rutting in original pavements and in overlays.

State	Average Rut Depths, mm (%)*				
	Original Pavement		Overlay		Overlay RD/Original RD
Alberta	7	(18.%)	5	(17.0%)	0.7
Arizona	12	(14.1%)	5	(19.9%)	0.4
California	7	(36.3%)	4	(12.3%)	0.6
Colorado	13	(55.0%)	4	(20.7%)	0.3
Maine	14	(6.4%)	3	(17.8%)	0.2
Maryland	8	(7.1%)	10	(50.5%)	1.3
Mississippi	17	(13.0%)	12	(29.0%)	0.7
Montana	9	(15.0%)	6	(29.2%)	0.7
New Jersey	6	(29.3%)	4	(12.3%)	0.7
Texas	10	(13.1%)	5	(16.2%)	0.5
AVERAGES	**10.3**	**(34.9%)**	**5.8**	**(50.0%)**	**0.6 (49.8%)**

*Numbers in the parentheses represent the coefficient of variations throughout the SPS-5 project.

Virgin versus Recycled Mixtures. Six of the virgin mixes exhibited more rutting than the recycled mixes, while five of the recycled mixes exhibited more rutting than the virgin mixes. The rutting for four of the projects was essentially the same for the virgin and recycled mixtures. The differences were in general fairly minor, except for the Maryland project where the recycled mixes all exhibited substantial rutting after 3.4 years. Assuming that there was some type of problem with the recycled mix for the Maryland project and excluding its values, the difference between the recycled and virgin mixes is quite small, leading to the conclusion that there is no important difference in the resistance of rutting between virgin and recycled mixes.

Milled versus Unmilled Surfaces. Four of the unmilled test sections exhibited more rutting than the milled test sections, while seven of the milled test sections exhibited more rutting than the unmilled test sections. However, the differences between milled and unmilled test sections and the overall average difference are almost negligible, so it is concluded, for the LTPP SPS-5 test sections, that milling has offered no advantage through 1997, as far as the occurrence of rutting is concerned.

This conclusion, in some cases however, contradicts the experience of the authors. On surfaces with large transverse profile differences, milling or reshaping the AC surface can reduce the variability of the in place air voids and densities of the overlay mixture, resulting in lower rut depths. On the other hand, these results or initial observations help support the hypothesis that the rutting of an AC overlay is more highly dependent on the stiffness and other mixture properties of the overlay itself.

Table 60. Number of SPS-5 test sections by projects at various levels of rut depths.

State	Control Section 501 Rut Depths in mm			Numbers of Sections (502-509) by Levels of Rut Depths		
	≤ 6	7-20m	> 20m	≤ 6	7-20m	> 20m
Alabama	X			8		
Alberta		X		7	1	
Arizona		X		8		
California		X		8		
Colorado		X		8		
Florida				8		
Georgia		X		8		
Maine		X		8		
Manitoba		X		8		
Maryland		X		3	5	
Minnesota		X		8		
Mississippi		X		2	6	
Montana		X		7	1	
New Jersey		X		8		
New Mexico	No Data as Yet					
Oklahoma	No Data as Yet					
Texas		X		8		
TOTALS	**1**	**13**	**0**	**99**	**13**	**0**

Table 61. Average rut depths for thick vs. thin overlays, recycled vs. virgin AC mixes, and milled vs. un

State	**Average Rut Depths in mm (%)***									
	Thin Overlays		**Thick Overlays**		**Virgin**		**Recycled**		**Unmilled**	
Alabama	3	(0%)	3.5	(16%)	3.3	(15%)	3.3	(15%)	3.3	(15%)
Alberta	5	(16%)	5.8	(17%)	5.3	(18%)	5.5	(18%)	5.5	(23%)
Arizona	4.5	(13%)	4.8	(26%)	4.3	(22%)	5.0	(16%)	4.5	(29%)
California	3.8	(13%)	3.8	(13%)	4.0	(0%)	3.5	(16%)	3.8	(13%)
Colorado	3.3	(15%)	4.0	(20%)	3.8	(25%)	3.5	(16%)	3.3	(15%)
Florida	3.0	(0%)	3.5	(16%)	3.3	(15%)	3.3	(15%)	3.3	(15%)
Georgia	3.5	(16%)	3.5	(16%)	3.5	(16%)	3.5	(16%)	3.5	(16%)
Maine	3.0	(27%)	3.0	(0%)	3.0	(27%)	3.0	(0%)	2.8	(18%)
Manitoba	2.5	(23%)	3.3	(38%)	2.3	(22%)	3.5	(29%)	2.5	(23%)
Maryland	8.5	(55%)	11.8	(48%)	5.8	(29%)	14.5	(18%)	11.0	(52%)
Minnesota	2.0	(0%)	1.8	(28%)	2.0	(0%)	1.8	(28%)	2.0	(0%)
Mississippi	8.8	(11%)	14.3	(16%)	12.0	(34%)	11.0	(27%)	11.0	(27%)
Montana	6.3	(27%)	4.8	(26%)	5.8	(29%)	5.3	(32%)	5.0	(16%)
New Jersey	3.8	(13%)	3.8	(13%)	3.5	(16%)	4.0	(0%)	3.5	(16%)
New Mexico	No Data as Yet									
Oklahoma	No Data as Yet									
Texas	4.5	(13%)	4.8	(20%)	4.8	(20%)	4.5	(13%)	4.8	(10%)
AVERAGES	**4.4**	**(46%)**	**5.1**	**(67%)**	**4.4**	**(54%)**	**5.0**	**(67%)**	**4.7**	**(58%)**

*The numbers in parentheses are the coefficient of variations.

6.2 RUTTING IN GPS-6 TEST SECTIONS

Table 62 provides the primary data, selected or calculated from appendix B, that were used for the studies leading to the results discussed below. Graphs of rut depths appear in appendix H. Figure 10 graphically shows the probability of occurrence of rutting with overlay age for the GPS-6 data. Both GPS-6A and GPS-6B data are included in table 63, while tables 64, 65, 66, 67, 68, and 69 include only GPS-6A overlays to provide insight concerning the long-term performance in rutting.

6.2.1 Original Pavement Condition

Table 63 indicates that both rut depth data and existing pavement condition prior to overlay data (poor or good categories) are available for 109 GPS-6 test sections. Of these, 58 were originally in poor condition before overlay and 51 were in the good condition category.

Of the 108 test sections, 81 (75 percent) had average rut depths of 6 mm or less and 25 (23 percent) had more than 6 mm of rutting. For the 81 test sections having 6 mm or less rutting, 29 (36 percent) had been overlaid less than 5 years, 25 (31 percent) had been overlaid 5 to 9.9 years, 20 (24 percent) had been overlaid 10 to 14.9 years, 6 had been overlaid 15 to 19.9 years, and 1 had been overlaid more than 20 years.

Table 64 provides the same information as table 63, except that it is restricted to GPS-6A test sections. Ignoring the 2 test sections with overlays less than 5 years old, 19 of the remaining 28 overlays in good condition prior to overlay had 6 mm or less of rutting. Five (18 percent) of the 28 overlays had 6 mm or less of rutting after 5 to 9.9 years, 9 (32 percent) after 10 to 14.9 years, and 5 after more than 15 years. Nine (32 percent) of the 28 overlays in the good group more than 5 years of age had more than 6 mm of rutting. Also, 9 of 10 test sections that had more than 6 mm of rutting were more than 10 years old, with 3 of them more than 15 years old.

For the group in poor condition prior to overlay, 14 overlays (56 percent) had 6 mm or less of rutting, while 11 (44 percent) had more than 6 mm. Of the 14 overlays with 6 mm or less of rutting, 5 (20 percent) were 5 to 9.9 years of age, 7 (28 percent) were 10 to 14.9 years old, 1 had served more than 15 years, and 1 had served more than 20 years. Also, 9 of the 11 test sections that had more than 6 mm of rutting were more than 10 years old, one was more than 15 years old, and another more than 20 years old.

Table 62. Average rut depths in GPS-6 test sections at last survey.

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	Rut Depths (mm)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Alabama	011001	6B	11.6	84	Good	---	12.7	3
Alabama	016012	6A	11.6	94	Good	33	10.2	8
Alabama	016019	6A	14.8	163	Poor	89	14.8	3
Alabama	014127	6B	14.7	211	Poor	43	6.7	6
Alabama	014129	6B	13.4	76	Good	38	6.7	5
Alaska	021008	6A	10.3	33	--	--	6.6	3
Alaska	026010	6A	13.2	53	Poor	43	12.6	20
Alaska	021004	6B	13.8	91	Poor	46	4.0	7
Alaska	029035	6B	18.8	53	Good	97	5.0	4
Alberta	811804	6B	10.8	89	Poor	99	0.2	1
Arizona	046005	6A	10.3	46	Poor	61	9.9	5
Arizona	046053	6A	20.5	81	Poor	120	6.5	13
Arizona	046054	6A	3.8	178	Good	53	5.8	6
Arizona	046060	6A	21.5	99	Poor	102	6.4	4
British Columbia	826006	6A	17.5	81	Poor	53	18.4	10
British Columbia	826007	6A	2.7	64	Poor	132	13.3	5
California	068534	6B	22.5	119	Poor	89	3.8	2
California	066044	6A	33.3	81	Poor	122	15.7	4
California	068535	6B	23.8	188	Good	76	0.3	3
Colorado	086002	6A	(0.8)	147	Poor	71	26.3	10
Colorado	086013	6A	(0.3)	69	Poor	38	11.3	7
Colorado	087783	6A	3.7	127	Good	91	11.3	6
Colorado	087781	6B	9.3	86	Poor	56	14.6	5
Florida	123997	6B	20.7	79	Poor	---	0.7	2
Florida	124101	6B	24.2	33	Good	114	4.5	3
Florida	124135	6B	21.2	36	--	--	3.8	4
Florida	124136	6B	21.2	36	Poor	--	3.8	5
Florida	124137	6B	21.5	71	Good	--	3.8	4
Georgia	134420	6B	8.4	125	Poor	--	3.2	4
Idaho	166027	6A	19.2	91	Good	51	16.6	3
Illinois	176050	6A	18.5	61	Poor	117	13.3	7
Indiana	181037	6B	11.7	71	Poor	25	---	---
Iowa	196049	6A	13.4	137	Good	71	18.6	6
Kansas	206026	6A	14.0	25	Good	147	14.9	5
Kentucky	216040	6A	14.9	155	Good	41	9.4	11
Kentucky	216043	6A	7.9	140	Good	51	12.4	15
Maine	231009	6B	23.0	145	---	---	2.2	2
Maine	231028	6B	21.8	163	--	--	1.1	3

Table 62. Average rut depths in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	Rut Depths (mm)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Manitoba	836450	6B	18.0	112	Poor	150	3.7	3
Manitoba	836451	6B	18.0	104	Poor	66	3.7	2
Minnesota	276064	6A	12.0	193	Poor	142	10.3	9
Mississippi	282807	6B	10.7	269	Poor	--	2.3	5
Mississippi	283091	6B	16.3	89	Good	--	0.4	4
Mississippi	283093	6B	7.5	104	Good	76	6.6	4
Mississippi	283094	6B	7.5	231	Good	76	6.6	5
Missouri	296067	6A	15.9	180	Poor	25	13.7	6
Missouri	295403	6B	24.0	102	Good	56	4.9	2
Missouri	295413	6B	24.0	97	Poor	79	1.4	3
Montana	306004	6A	17.8	89	Good	180	13.4	6
Montana	307066	6B	10.3	137	Good	43	4.8	7
Montana	307075	6A	17.3	86	Good	94	14.4	12
Montana	307076	6B	5.8	132	Good	61	5.0	12
Montana	307088	6B	10.1	124	Poor	43	4.9	7
Nebraska	316700	6B	12.8	137	Poor	99	0.6	2
Nevada	321030	6B	19.1	193	Poor	69	3.6	3
New Brunswick	846804	6A	(0.5)	99	Good	56	16.7	8
New Jersey	346057	6A	8.6	155	Good	46	15.5	9
New Mexico	351002	6A	26.5	109	Poor	99	10.2	9
New Mexico	352007	6A	3.4	67	Good	69	4.3	5
New Mexico	356033	6A	22.5	107	Poor	64	14.2	6
New Mexico	356035	6A	19.5	91	Good	112	10.2	10
New Mexico	356401	6A	13.5	102	Poor	109	11.2	9
New York	361008	6B	0.2	28	Good	33	6.2	4
New York	361011	6B	9.3	249	Poor	---	2.1	4
North Carolina	371040	6B	16.7	135	--	--	0.5	1
North Carolina	371803	6B	12.7	132	Poor	76	5.7	3
Nova Scotia	866802	6A	3.5	66	Good	89	19.9	9
Oklahoma	406010	6A	14.5	114	Good	51	11.3	4
Oklahoma	404086	6B	19.3	109	Poor	33	5.5	4
Oklahoma	404164	6B	16.3	117	Poor	--	1.7	4
Oregon	416011	6A	25.1	155	Poor	173	6.8	3
Pennsylvania	421608	6A	0.0	61	Good	66	8.0	3
Pennsylvania	421618	6B	---	51	Good	150	7.0	3
Quebec	891021	6B	14.2	132	--	--	0.2	1
Quebec	891127	6B	15.7	124	--	--	1.2	5
Saskatchewan	906400	6A	9.7	196	Poor	61	9.3	5
Saskatchewan	906801	6A	8.7	--	Poor	102	9.3	9
Saskatchewan	906410	6B	21.3	117	Poor	94	0.6	6
Saskatchewan	906412	6B	21.3	112	Poor	140	0.6	4
South Carolina	451025	6B	13.6	28	Poor	---	2.3	2

Table 62. Average rut depths in GPS-6 test sections at last survey (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	Rut Depths (mm)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
South Dakota	469106	6B	33.6	89	Poor	94	---	---
South Dakota	469197	6B	25.7	89	Poor	94	1.2	3
Tennessee	476015	6A	10.6	224	Good	140	10.9	6
Tennessee	476022	6A	8.6	119	Good	51	13.7	6
Tennessee	473108	6B	17.6	140	Good	--	0.4	5
Tennessee	473109	6B	10.6	132	Poor	--	5.7	5
Tennessee	473110	6B	8.1	130	Poor	140	6.5	4
Tennessee	479024	6B	18.0	145	Good	--	3.2	5
Texas	481046	6A	15.3	274	Poor	53	24.2	6
Texas	486079	6A	12.4	175	Good	66	10.2	6
Texas	486086	6A	13.6	221	Good	38	10.1	7
Texas	486160	6A	18.3	61	Poor	41	12.0	4
Texas	486179	6A	9.6	41	Poor	112	20.2	10
Texas	481093	6B	8.4	74	Good	64	6.4	9
Texas	481113	6B	6.4	38	Poor	94	2.7	5
Texas	481116	6B	3.3	38	Good	84	4.4	8
Texas	481119	6B	14.3	135	Poor	41	5.6	7
Texas	481130	6B	21.0	69	Poor	25	2.3	6
Texas	483875	6B	7.0	412	Good	25	3.7	7
Utah	491004	6A	6.3	81	Good	117	18.4	3
Utah	491005	6A	13.5	150	Good	97	12.4	2
Utah	491006	6A	16.2	234	Good	61	8.4	4
Utah	491007	6A	8.3	239	Good	51	8.4	3
Vermont	501683	6B	28.0	66	Poor	---	4.1	5
Virginia	511417	6B	9.6	183	Poor	38	5.2	6
Virginia	511419	6B	10.1	155	Good	86	6.2	5
Virginia	511423	6B	11.9	30	Poor	48	6.1	5
Washington	536049	6A	16.2	236	Good	33	1.0	12
Washington	531005	6B	16.0	267	Poor	58	5.8	5
Washington	531007	6B	7.8	61	Good	102	3.9	4
Washington	536020	6A	---	69	Good	66	16.8	4
Washington	536048	6A	---	160	Good	66	17.6	5
Washington	536056	6A	---	97	Poor	64	8.8	5
Washington	537322	6A	---	188	Good	56	5.7	5
Wyoming	566029	6A	---	53	Poor	46	11.3	4
Wyoming	566031	6A	5.3	64	Poor	64	12.4	3
Wyoming	566032	6A	12.6	76	Good	58	12.6	2

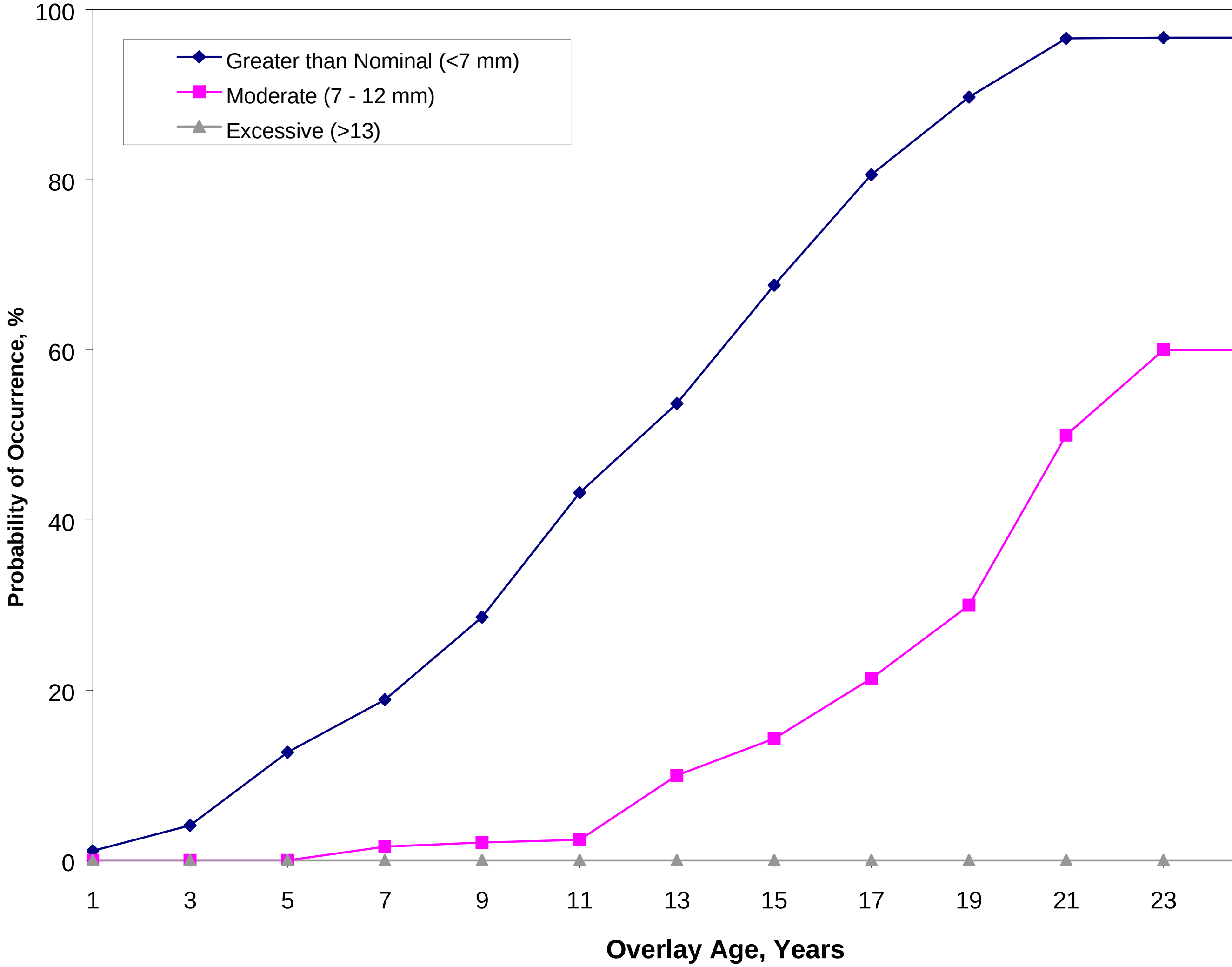


Figure 10. Probability of occurrence of different levels of rutting on the GPS-6 test secti

Table 63. Ages of GPS-6 overlays with rut depths of 6 mm or less.

Original Condition Before Overlay	Total* Test Sections	Total Number 1 to 6 mm	Number ≥ 5 Years	Number ≥ 10 Years	Number ≥ 15 Years	Number ≥ 20 Years
Poor	57	44	24	11	2	1
Good	51	37	28	16	5	---

*Number of test sections for which rutting data are available and prior condition data were provided.

Table 64. Ages of GPS-6A overlays with rut depths of 6 mm or less.

Original Condition Before Overlay	Total Test Sections	Total Number 1 to 6 mm	Number ≥ 5 Years	Number ≥ 10 Years	Number ≥ 15 Years	Number ≥ 20 Years
Poor	25	14	14	9	2	1
Good	30	20	19	14	5	---

Note: One GPS-6A test section overlay in the good group was less than 5 years old when the last manual distress survey was conducted.

Original condition of the existing pavement prior to overlay does not appear to affect future rutting in the overlay.

6.2.2 AC Overlay Age

Table 65 provides insight as to amounts of rutting at different age levels for the GPS-6A test sections. After 10 years, 24 (or 62 percent) of the 39 overlays 10 years or older still had 6 mm or less of average rut depth, while another 13 (or 33 percent) had 7 to 13 mm. Only 2 (or 5 percent) had more than 13 mm. Stated differently, 95 of the overlays did not exhibit enough rutting in their first 10 years to cause serious concern.

After 15 years, 7 of the 12 overlays of that age or older still had nominal levels of rutting and the other 5 still had rut depths of no more than 13 mm. Only 3 of the 55 GPS-6A overlays were more than 20 years old. All had 10 mm or less of rutting when last monitored.

Table 65. Numbers of GPS-6A test sections with various levels of average rut depth and various ages of overlays.

Age Groups (Years)	Levels of Average Rut Depth		
	1 - 6 mm	**7 - 13 mm**	**14 - 20 mm**
5 to 9.9	10	3	0
10 to 14.9	17	8	2
15 to 20	6	3	0
> 20	1	2	0
All	34	16	2

Table 66 provides selected data for those GPS-6A overlays that have been in service longer than 15 years. It can be seen that only 1 of these 12 relatively old test sections has more than 10 mm of rutting on average and that it had the thinnest overlay and the highest annual traffic of this group. Also, the overlay in New Brunswick has only 8 mm of rutting, although its relatively thin overlay had been subjected to substantial traffic for 16.6 years.

The performance of these relatively old overlays clearly indicates that long-term resistance to rutting under heavy traffic is quite possible and appears to imply that the occurrence of early rutting serious enough to warrant concern may primarily result from problems in mix design or in construction that are not typical of the data in the LTPP database (figure 10).

Table 67 provides selected data for the 20 GPS-6A test sections that have more than 6 mm of rutting, seeking a common factor that might indicate why they exhibited more than nominal rutting (greater than 6 mm). It may be noted that these overlays range from 1.0 to 26.3 years of age, averaging 12.5 years. The 35 overlays having 6 mm or less of rutting averaged 12.0 years of age. It appears that the incidence of rutting is not entirely dependent on the age of the overlay.

Table 68 uses data from table 67, but the data are rearranged so that the test sections are ranked according to the average rut depths, with the section with the deepest average rut depth having a ranking of 1.

6.2.3 AC Overlay Thickness

It can be seen from table 68 that the original AC thickness varied from 41 to 236 mm and that the average rut depths do not appear to be correlated to the original AC thickness. However, it can be seen that 10 of the 20 overlays are relatively thin, ranging from 33 to 56 mm. The overlay thicknesses for the other 10 varied from 71 to 142 mm, while the average for all 20 test sections is 76 mm. The average overlay thickness for the 34 GPS-6A test sections (for which overlay thicknesses are available with average rut depths of 6 mm or less) is 80 mm. Figure 11 graphically compares the average rut depths as a function of overlay age for different ranges in overlay thickness. As shown, the thinner overlays have the higher rut depths, but this comparison does not represent a statistical difference between the groups of thicknesses.

Table 66. Selected data for GPS-6A overlays 15 or more years old.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	Rut Depth (mm)
British Columbia	826006	15.7	81	53	134	149	10
California	066044	15.7	81	122	203	166	4
Colorado	086002	26.4	147	71	218	247	10
Idaho	166027	16.6	91	51	142	128	3
Illinois	176050	15.2	61	117	178	(10)?	7
Kentucky	216043	16.0	140	51	191	633	15
New Brunswick	846804	16.6	99	56	146	591	8
New Jersey	346057	15.5	155	46	201	231	9
Nova Scotia	866802	19.9	66	89	155	434	9
Texas	481046	24.6	274	53	327	295	6
Texas	486179	20.6	41	112	153	74	10
Utah	491004	17.8	81	117	198	45	3

Table 67. Selected data for GPS-6A overlays that exhibited average rut depths of more than 6 mm.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	Rut Depths (mm)
Alabama	16012	10.2	94	33	127	828	8
Alaska	26010	12.6	53	43	96	126	20
Arizona	46053	6.5	81	120	201	1,877	13
British Columbia	826006	18.4	81	53	134	149	10
Colorado	86002	26.3	147	71	218	247	10
Colorado	86013	11.3	69	38	207	55	7
Illinois	176050	13.3	61	117	178	10(?)	7
Kentucky	216040	9.4	155	41	196	294	11
Kentucky	216043	12.4	140	51	191	633	15
Minnesota	276064	10.3	193	142	235	---	9
Montana	307075	14.4	86	94	180	281	12
New Brunswick	846804	16.7	99	56	155	591	8
New Jersey	346057	15.5	155	46	201	231	9
New Mexico	351002	10.2	109	99	208	27	9
New Mexico	356035	10.2	91	112	203	342	10
New Mexico	356401	11.2	102	109	211	330	9
Saskatchewan	906801	9.3	---	102	---	121	9
Texas	486086	10.1	221	38	259	228	7
Texas	486179	20.2	41	112	153	74	10
Washington	536049	1.0	236	33	269	596	12

Table 68. Ranking in rut depth and age of overlay for GPS-6 test sections.

Ranking By Rut Depth	State	SHRP ID	Rut Depth (mm)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness (mm)	Annual KESALs	Overlay Age (Yea
1	Alaska	26010	20	53	43	96	126	12.6
2	Kentucky	216043	15	140	51	191	633	12.4
3	Arizona	046053	13	81	120	201	1,877	6.5
4	Montana	307075	12	86	94	180	281	14.4
4	Washington	536049	12	236	33	269	596	1.0
5	Kentucky	216040	11	155	41	96	294	9.4
6	British Columbia	826006	10	81	53	134	149	18.4
6	Colorado	86002	10	147	71	218	247	26.3
6	New Mexico	356035	10	91	112	203	342	10.2
6	Texas	486179	10	41	112	153	74	20.2
7	Minnesota	276064	9	193	142	235	---	10.3
7	New Jersey	346057	9	155	46	201	231	15.5
7	New Mexico	351002	9	109	99	208	27	10.2
7	New Mexico	356401	9	102	109	211	330	11.2
7	Saskatchewan	906801	9	---	102	---	121	9.3
8	Alabama	016012	8	94	33	127	828	10.2
8	New Brunswick	846804	8	99	56	155	591	16.7
9	Colorado	086013	7	69	38	207	55	11.3
9	Illinois	176050	7	61	117	178	10(?)	13.3
9	Texas	486086	7	221	38	259	228	10.1

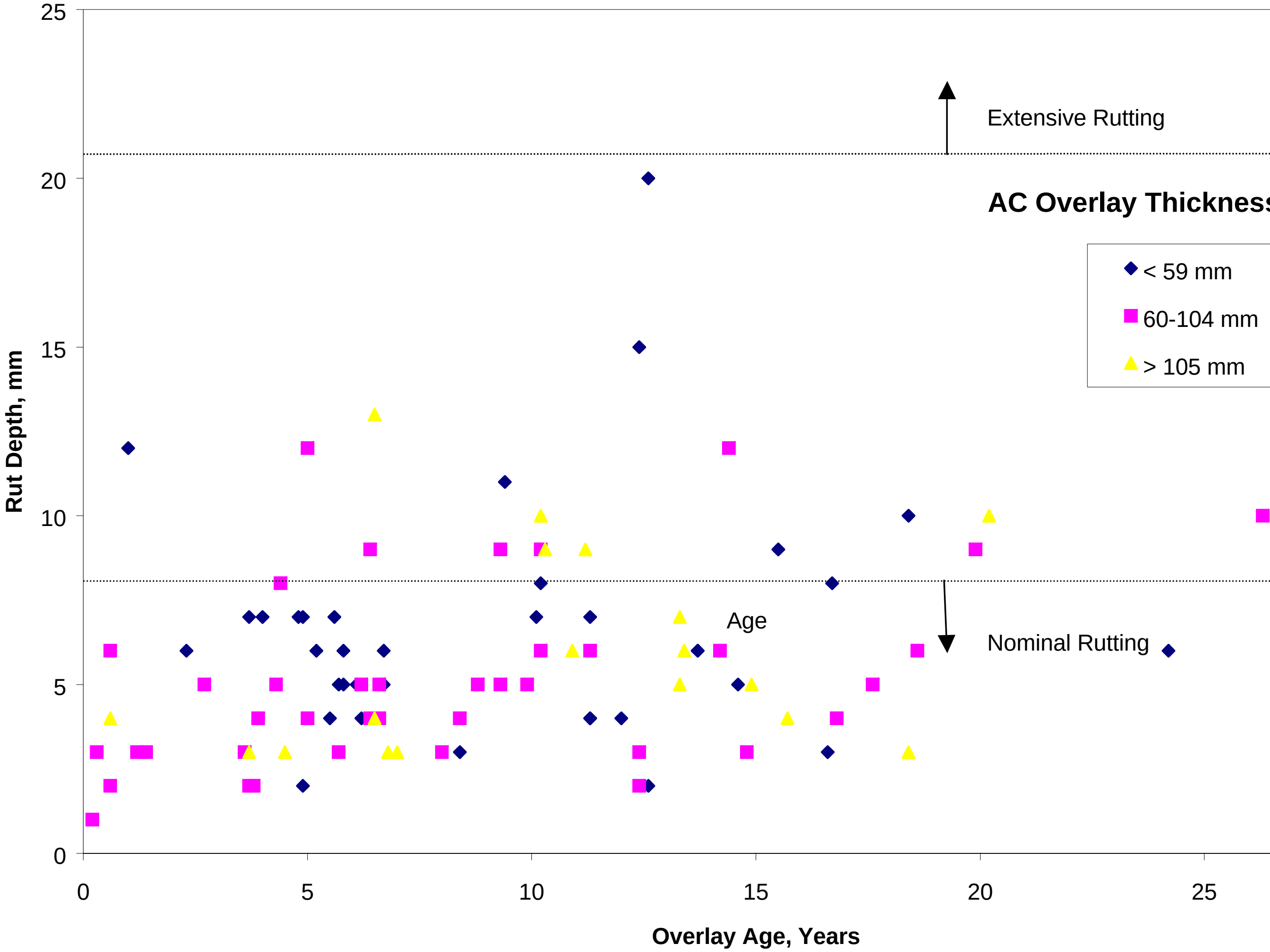


Figure 11. Graphical comparison of rut depth versus overlay age for a range of overla thi cknesses for the GPS-6 test sections.

Table 69. Average KESALs for different levels of rutting.

From Table Number	Number of Sections	Average Rut Depth Level (mm)	Cumulative KESALs		
			From	To	Average
51	6	11 or More	596	12,201	4,841
51	13	10 or Less	275	9,870	3,309
51	8	9 or Less	275	9,870	3,740
51	4	7 or 8	622	9,870	5,310
51	2	7	622	2,303	2,925
49	4	6 or Less	801	7,257	3,197

More importantly, table 70 summarizes the incidence or number of GPS-6 test sections with different levels of rutting for the different ranges in overlay thicknesses for the AC overlays that are greater than 2 years in age.

Table 70. Number of GPS-6 test sections with different levels of rutting for different HMA overlay thicknesses.

Rut Depth, mm	AC Overlay Thickness, mm (%)*					
	25 - 59		60 - 105		> 105	
< 7	22	(61.1%)	25	(75.8%)	11	(64.7%)
7 - 12	12	(33.3%)	8	(24.2%)	5	(29.4%)
13 - 20	2	(5.6%)	0	(0%)	1	(5.9%)
> 20	0	(0%)	0	(0%)	0	(0%)
Total Test Section (>2 Years/Age)	36		33		17	

*Numbers in parentheses represent the percentage of test sections in that group of AC overlay thickness.

As noted above, AC overlay thickness does not appear to have an important effect on rutting. In addition, very few of the test sections have what would be considered excessive rutting.

Because rutting is believed to be dependent on cumulative traffic, rough approximations of cumulative KESALs were considered, using data from tables 65 and 66. The results from these comparisons appear in table 69. While the results in table 69 are based on limited data, the six test sections with the most rutting did generally have the most or higher levels of traffic. The exception was the four test sections with 7- or 8-mm rut depths, which for this sample happened to have carried more KESALs. It can be seen that the magnitude of rutting appears to decrease with decreasing cumulative KESALs (as expected), but the results for the four test sections with 7- or 8-mm of rutting do indicate again that very adequate resistance to rutting may be obtained where heavy traffic occurs. It appears that both thin and thicker overlays can offer adequate resistance to rutting for substantial traffic.

6.3 SUMMARY OF FINDINGS FOR RUTTING

The SPS-5 data appear, at least in an overlay's early life, to indicate the following:

- Thick overlays are not superior to thin overlays (±50 mm) in resisting rutting.
- Virgin and recycled mixtures appear to offer similar resistance to rutting.
- The unmilled test sections rutted about the same as the milled test sections.

The GPS-6A data offer insight concerning long-term performance of overlays in rutting. In general, the data appear to indicate:

- The great majority of overlays may be expected to successfully resist more than nominal rutting for 10 years or more.
- The majority of overlays should serve 15 or more years before rutting itself becomes sufficient to require rehabilitation.
- Traffic levels are important in predicting rutting, but other factors (such as materials properties and construction techniques/quality control) are likely more important.
- As long as the overlay thickness is reasonable (perhaps ±50 mm), overlay thickness does not appear to have a major impact on the occurrence of rutting (assuming adequate mix design and placement).

In summary, it appears that the AC overlays of the LTPP test sections have been resistant to rutting. In fact, excessive rut depths have been measured on a limited number of the LTPP test sections through 1997. Based on the number of reports, technical papers, and other documents reporting excessive rutting of flexible pavements, the LTPP data may not be truly representative of the cross-section of rutting behavior of HMA mixtures across the United States and Canada.

CHAPTER 7. ROUGHNESS

Roughness has been defined "as distortion of the pavement surface that contributes to an undesirable or uncomfortable ride." [9] The characterization of pavement roughness used for this study is International Roughness Index (IRI), which is becoming a standard for pavement roughness used by numerous agencies and has been the primary measurement of roughness used in previous LTPP studies.[10] IRI is derived from the simulation of a "quarter-car" traveling along the longitudinal profile of the road and is calculated from the longitudinal profiles in each wheel path for LTPP. Profiles for the LTPP test sections are averages of multiple runs of a GM Profilometer.

A value of zero for IRI implies absolute smoothness, which is impossible to attain in construction. Unlike the other distresses discussed previously, a certain level of roughness exists before a pavement is opened to traffic. Initial values of IRI for pavements with AC surfaces usually run between 0.60 and 0.95 m/km, but can be lower or higher. To follow the format for the other distresses, 1.6 m/km or less has been established as the nominal case and the categories for comparison are 1.6 m/km or less, 1.6 to 2.4 m/km, and greater than 2.4 m/km. 2.4 m/km was selected because that approximates a level of roughness at which many agencies would be considering rehabilitation.

7.1 ROUGHNESS IN SPS-5 TEST SECTIONS

The graphs of IRI appear in appendix I for the 14 projects for which the data were available when the graphs were created. Table 71 provides values of IRI by project and test section. As discussed previously, all test sections are built with some roughness, which generally increases over time and with traffic. It can be seen from table 71 that the great majority of the test sections had only nominal roughness (1.6 m/km or less) at the time of measurement. Only the Manitoba and Mississippi projects had exhibited more than 1.6 m/km in some of the overlays, whereas the Georgia and New Jersey projects exhibited less than 0.8 m/km.

Table 72 summarizes the number of test sections with different levels of roughness for those overlays greater than 2 years in age (excluding the Florida and Maine projects, as well as all of the control sections). As shown, very few of the SPS-5 test sections have roughness values exceeding the nominal IRI (1.6 m/km).

Table 73 provides information on the roughness prior to the overlays. It can be seen that the project in Minnesota had substantial roughness prior to the overlay and that six other projects had at least one test section with an IRI greater than 2.4 m/km.

**Table 71. Average values of International Roughness Index (IRI) calculated for SPS-5 test sect
most recent Profilometer data.**

State	Age of Overlays (Years)	IRI By Section (m/km)						
		501	502	503	504	505	506	507
Alabama	4.4	1.08	0.82	0.86	0.93	0.91	0.79	0.93
Alberta	4.7	1.85	1.16	1.18	1.53	1.24	1.08	1.47
Arizona	2.8	1.34	1.43	0.96	1.24	1.30	1.05	1.36
California	2.9	1.24	1.00	1.10	1.03	0.96	0.93	0.97
Colorado	4.1	0.93	0.94	0.78	0.85	0.75	1.17	0.86
Florida	0.6	--	0.68	0.74	0.64	0.49	0.50	0.55
Georgia	2.9	1.87	0.52	0.54	0.49	0.56	0.47	0.47
Maine	0.2	--	0.77	0.94	0.86	0.70	0.76	0.85
Manitoba	5.7	1.55	1.73	1.43	1.26	1.53	1.73	1.10
Maryland	4.2	1.48	1.50	1.19	1.08	1.22	0.85	0.98
Minnesota	3.8	2.45	1.13	0.99	1.25	1.31	1.21	0.91
Mississippi	4.9	1.54	1.65	1.99	1.56	1.82	1.84	1.55
Montana	5.0	--	1.50	1.09	0.79	1.12	0.88	1.14
New Jersey	4.1	1.99	1.02	0.70	0.73	0.89	0.76	0.80
New Mexico	--	No data as yet						
Oklahoma	--	No data as yet						
Texas	2.8	2.00	1.27	1.18	1.53	1.46	1.50	1.46

Table 72. Number of SPS-5 test sections with various IRI values.

	Total Sections	IRI, m/km			
		≤ 0.8	.81 - 1.6 (Nominal)	1.61 - 2.4	> 2.4
Number of Test Sections	104	19	78	7	0
Percentage in Each Group	100.0	18.3	75.0	6.7	0.0

Table 74 was prepared to offer insight as to the reductions in IRI to be gained by overlays, as a function of IRI for the pavement before overlay. The IRI values before overlay came from table 73, but the values after overlay were those calculated from the first profile measurements made after the overlays were placed. The "original low values" and the "original high values" are for the test sections identified in table 73. As four of the original low values were for the control sections that did not receive overlays, data for these test sections were ignored for calculating the averages at the bottom of the table. These were included to indicate the changes in IRI that had occurred between the measurement before and after overlays, which varied from -4 percent to 14 percent.

Table 75 compares the average original roughness in the test sections to be overlaid with the average roughnesses in the overlays at the time the measurements were made. It also includes a ratio of the roughness of the overlay to that of the original pavement. These averages were computed for the 14 projects for which the required data are available. It can be seen that roughness has been substantially reduced for most of the projects. The primary differences between results shown in table 74 and table 75 is that table 75 deals in averages for entire projects rather than for the test sections in each project with the lowest and highest roughness. It can be seen that the average IRIs in the overlays for the 14 projects was 1.05 m/km, as compared with 1.69 m/km for the original pavements. On average, the IRI values for the overlays are 65 percent of those of the original pavements at this early point in their service lives.

Table 76 indicates the IRI for each project's control section and the number of test sections that have exhibited different levels of roughness since they were overlaid. It is interesting to note that the control sections for 7 of the 11 projects for which data were available had relatively nominal roughness (less than 1.6 m/km). Only one of the test sections had more than 2.4 m/km. Review of table 73 indicates that average values for the original pavements were not especially high, except for the Minnesota project, but at least one test section was quite rough for six of the projects.

Table 73. Average IRI values prior to overlay, m/km.

State	Test Section						
	501	**502**	**503**	**504**	**505**	**506**	**507**
Alabama	0.96	1.04	1.00	1.00	1.15	1.06	1.25
Alberta	1.67	2.10	2.13	2.51	1.40	1.53	1.62
Arizona	1.19	2.00	1.71	1.57	2.60	1.77	1.84
California	3.95	3.16	1.79	1.94	1.58	1.86	2.37
Colorado	0.92	0.94	0.79	0.85	0.73	1.23	0.85
Georgia	NA	1.08	0.97	1.12	1.22	1.07	0.89
Maine	1.22	1.03	1.22	1.38	1.28	1.17	1.44
Manitoba	NA	NA	NA	NA	NA	NA	NA
Maryland	1.38	1.71	2.08	2.05	1.81	1.44	1.41
Minnesota	2.27	2.82	2.76	3.21	2.67	2.08	2.64
Mississippi	1.04	2.60	2.72	2.44	1.76	2.07	2.09
Montana	NA	1.75	1.85	1.36	1.08	2.01	1.07
New Jersey	1.74	2.05	2.01	1.61	1.77	2.03	2.05
Texas	1.86	1.36	1.49	1.39	1.55	1.23	1.47

Table 74. Comparison of IRI values before and after overlays for test sections with lowest and highest original IRI values.

State	Original Low Value of IRI				Original High Values of		
	Section Number	IRI Before Overlay (m/km)	IRI After Overlay (m/km)	$\left[\frac{\text{IRI After}}{\text{IRI Before}}\right]$	Section Number	IRI Before Overlay (m/km)	IRI A Over (m/k
Alabama	*501	0.95	1.08	1.14	509	1.72	0.8
Alberta	505	1.40	1.16	0.83	504	2.51	1.3
Arizona	*501	1.19	1.26	1.06	505	2.60	1.2
California	504	1.30	1.03	0.79	#501	3.75	1.1
Colorado	505	1.38	0.71	0.51	507	2.99	0.7
Florida	506	0.98	0.50	0.51	505	1.46	0.4
Georgia	507	0.89	0.47	0.51	505	1.22	0.5
Maine	502	1.03	0.78	0.76	504	1.38	0.8
Maryland	*501	1.38	1.32	0.96	503	2.08	1.0
Minnesota	506	2.08	1.09	0.52	504	3.21	1.1
Mississippi	*501	1.04	1.08	1.04	509	2.77	1.7
Montana	509	0.99	0.73	0.73	506	2.00	0.7
New Jersey	508	1.54	0.75	0.49	509	2.19	0.7
Texas	506	1.53	1.19	0.78	509	1.96	1.2
AVERAGES		**1.31**	**0.84**	**0.64**		**2.27**	**0.9**

*Control section - Ignored in computation of averages.
#Control section for California was overlaid.

Table 75. Relationship between IRI in original pavements and in overlays.

State	Average Roughness (IRI), m/km (%)*					
	Original Pavement		Overlay		Overlay IRI/Original IRI	
Alabama	1.16	(20.7%)	0.89	(7.8%)	0.77	
Alberta	1.89	(19.4%)	1.26	(12.5%)	0.67	
Arizona	1.93	(19.7%)	1.17	(15.9%)	0.61	
California	2.12	(22.9%)	0.99	(10.0%)	0.47	
Colorado	0.89	(17.1%)	0.89	(14.9%)	1.00	
Florida	1.22		0.61	(15.7%)	0.50	
Georgia	1.04	(10.6%)	0.53	(11.7%)	0.51	
Maine	1.23	(10.9%)	0.84	(12.9%)	0.68	
Manitoba	---		1.42	(16.7%)	---	
Maryland	1.68	(16.6%)	1.09	(19.9%)	0.65	
Minnesota	2.70	(11.9%)	1.11	(12.7%)	0.41	
Mississippi	2.35	(15.1%)	1.73	(10.2%)	0.74	
Montana	1.41	(28.75)	1.06	(22.3%)	0.75	
New Jersey	1.91	(12.4%)	0.80	(13.1%)	0.42	
New Mexico	2.38		---		---	
Oklahoma	---		---		---	
Texas	1.46	(15.0%)	1.35	(11.40%)	0.92	
AVERAGES	**1.69**	**(32.3%)**	**1.05**	**(29.9%)**	**0.65**	**(27.5%)**

*Numbers in the parentheses are the coefficient of variations.

It can also be seen that the IRI values since overlay for 113 of the 120 test sections were 1.6 m/km or less, while only 7 were more than 1.6m/km. The IRI values of two test sections in Manitoba exceeded the 1.6 m/km level (1.73 m/km), while IRI values for five of the test sections in the Mississippi project exceeded 1.6 m/km (1.65, 1.82, 1.84, 1.91, and 1.99 m/km).

Table 77 provides a basis for comparing the various treatments, as in previous chapters. It can be seen that the thick overlays were rougher in 4 of the projects than the thin overlays, but the thin overlays were rougher in 11 of the projects. The overall averages at the bottom of table 77 indicate that the thick overlays exhibit slightly less roughness than the thin ones, but this does not represent a significant difference.

Table 76. Number of SPS-5 test sections by projects at various levels of roughness (IRI).

State	Control Section 501 IRI in m/km			Numbers of Sections (502-509) by Levels of IRI (m/km)		
	1.60 ≤	1.61 to 2.40	> 2.40	1.60 ≤	1.61 to 2.40	> 2.40
Alabama	X			8		
Alberta		X		8		
Arizona	X			8		
California	X			8		
Colorado	X			8		
Florida		Unknown		8		
Georgia		X		8		
Maine		Unknown		8		
Manitoba	X			6	2	
Maryland	X			8	0	
Minnesota			X	8	0	
Mississippi	X			3	5	
Montana		Unknown		8	0	
New Jersey		X		8	0	
New Mexico	No Data as Yet					
Oklahoma	No Data as Yet					
Texas		X		8	0	
TOTALS	**7**	**4**	**1**	**113**	**7**	**0**

Ten of the virgin mixes were less rough than the recycled mixes, while five of the recycled mixes were less rough than the virgin mixes. The roughness for four of the projects, however, was essentially the same for the virgin and recycled mixtures. The overall averages for all 15 projects were essentially identical, leading to the conclusion that there is no difference in roughness between virgin and recycled mixes.

Seven of the unmilled test sections were rougher than the milled test sections, while four of the milled test sections were rougher than the unmilled test sections. The average IRI values for four of the projects were essentially the same for milled and unmilled test sections. Although the overall averages indicate that the IRI values for the unmilled test sections were slightly higher than for the milled test sections, the difference is not significant.

Table 77. Roughness (IRI) for thick vs. thin overlays, recycled vs. virgin AC mixes, and milled vs. unmilled test sections.

State	Average IRI in m/km (%)*									
	Thin Overlays		Thick Overlays		Virgin		Recycled		Unmilled	
Alabama	0.85	(7%)	0.93	(7%)	0.89	(8%)	0.90	(9%)	0.88	(6%)
Alberta	1.17	(6%)	1.34	(14%)	1.33	(16%)	1.18	(1%)	1.28	(13%)
Arizona	1.21	(15%)	1.13	(18%)	1.24	(11%)	1.10	(20%)	1.23	(16%)
California	1.00	(8%)	0.98	(13%)	0.97	(4%)	1.01	(14%)	1.02	(6%)
Colorado	0.95	(18%)	0.83	(4%)	0.91	(20%)	0.87	(10%)	0.83	(10%)
Florida	0.56	(16%)	0.66	(13%)	0.55	(12%)	0.68	(11%)	0.64	(17%)
Georgia	0.52	(7%)	0.54	(16%)	0.50	(9%)	0.56	(12%)	0.53	(6%)
Maine	0.82	(18%)	0.87	(6%)	0.79	(10%)	0.89	(12%)	0.82	(13%)
Manitoba	1.60	(10%)	1.24	(11%)	1.40	(20%)	1.43	(16%)	1.49	(13%)
Maryland	1.17	(23%)	1.02	(15%)	1.03	(15%)	1.16	(24%)	1.25	(14%)
Minnesota	1.17	(11%)	1.05	(14%)	1.17	(15%)	1.05	(6%)	1.17	(12%)
Mississippi	1.81	(6%)	1.66	(13%)	1.69	(9%)	1.78	(12%)	1.76	(11%)
Montana	1.16	(22%)	0.95	(20%)	0.98	(18%)	1.13	(26%)	1.13	(26%)
New Jersey	0.86	(14%)	0.74	(6%)	0.80	(9%)	0.81	(18%)	0.84	(18%)
New Mexico	No Data as Yet									
Oklahoma	No Data as Yet									
Texas	1.37	(9%)	1.33	(15%)	1.49	(2%)	1.21	(5%)	1.36	(12%)
AVERAGES	**1.08**	**(32%)**	**1.02**	**(28%)**	**1.05**	**(32%)**	**1.05**	**(29%)**	**1.08**	**(31%)**

*The numbers in parentheses are the coefficient of variations.

Review of figures 93 through 99 in appendix I indicates that the increase in roughness after overlay is quite nominal, at least for the early years depicted by these graphs. This was true for the Manitoba project for about 6 years, but the graphs show that, although the roughness is not yet serious, the growth rate has increased dramatically.

7.2 ROUGHNESS IN GPS-6 TEST SECTIONS

Table 78 provides the primary data, selected or calculated from appendix B and the IRI database, that were used for the studies leading to the results discussed below. Graphs of IRI appear in appendix I. Figure 12 graphically shows the probability of occurrence of different levels of roughness with overlay age for the GPS-6 data. Both GPS-6A and GPS-6B data are included in table 79, while tables 80, 81, 82, and 83 include only GPS-6A overlays to provide insight concerning the long-term performance in roughness.

Table 79 indicates that both IRI data and existing pavement condition data prior to overlay (poor or good categories) are available for 99 GPS-6 test sections. Of these, 56 were originally in the poor condition before overlay category and 43 were in good condition category.

7.2.1 Original Pavement Condition

Of the 99 test sections, 81 (or 82 percent) had average IRI values of 1.6 m/km or less and 18 (or 18 percent) more had values greater than 1.6 m/km. For the 81 test sections having IRI values of 1.6 m/km or less, 39 (or 48 percent) had been overlaid less than 5 years, 20 (or 25 percent) had been overlaid 5 to 9.9 years, 14 (or 17 percent) had been overlaid 10 to 14.9 years, 7 had been overlaid 15 to 19.9 years, and 1 had been overlaid more than 20 years.

Table 80 provides the same information as table 79, except that it is restricted to GPS-6A test sections. Ignoring the 1 test section with an overlay less than 5 years old, 14 of the remaining 21 overlays in good condition prior to overlay had IRI values of 1.6 m/km or less. Five (or 24 percent) of the 21 overlays had 1.6 m/km or less after 5 to 9.9 years, 6 (or 29 percent) had after 10 to 14.9 years, and 3 had after more than 15 years. Seven (or 33 percent) of the 21 overlays in the good group more than 5 years of age had an IRI value of more than 1.6 m/km. Also, 5 of 7 test sections that had an IRI value of more than 1.6 m/km were more than 10 years old, with 1 more than 15 years old.

For the poor condition prior to overlay group, 16 overlays (or 76 percent) had an IRI value of 1.6 m/km or less, while 5 (or 24 percent) had more than 1.6 m/km. Of the 16 overlays with IRI values of 1.6 m/km or less, 4 (or 25 percent) were less than 5 years of age when the last available profile was measured. Of the remaining 12 overlays, one was 5 to 9.9 years of age, 6 were 10 to 14.9 years old, four had served more than 15 years, and another had served more than 20 years. Also, 4 of the 5 test sections that had IRI values more than 1.6 m/km were more than 10 years old.

Table 78. Average IRI values for GPS-6 test sections calculated from last profile measurements.

State	Section	Exp.	Original Pavement: Age Before Overlay (years)	Original Pavement: AC Thickness (mm)	Original Pavement: Condition Before Overlay	Overlay Thickness (mm)	Age of Overlay (years)	International Roughness Index (m/km)
Alabama	11001	6B	12.7	84	Good	--	0.7	0.63
Alabama	14127	6B	14.7	211	Poor	43	4.8	0.88
Alabama	14129	6B	13.4	76	Good	38	4.7	1.07
Alabama	16012	6A	11.6	94	Good	33	11.6	2.42
Alabama	16019	6A	14.8	163	Poor	89	11.0	0.78
Alaska	21004	6B	13.8	91	Poor	46	0.2	1.7
Alaska	21008	6A	10.3	33	--	--	2.7	0.94
Alaska	26010	6A	13.2	53	Poor	43	7.5	1.08
Alaska	29035	6B	18.8	53	Good	97	1.2	1.01
Alberta	811804	6B	10.8	89	Poor	99	1.2	0.75
Arizona	46053	6A	20.5	81	Poor	120	4.6	1.39
Arizona	46054	6A	3.8	178	Good	53	5.8	0.99
Arizona	46055	6B	10.2	46	Poor	61	7.9	0.71
Arizona	46060	6A	21.5	99	Poor	102	3.5	0.67
British Columbia	826006	6A	17.5	81	Poor	53	16.4	1.3
British Columbia	826007	6A	2.7	64	Poor	132	11.3	0.73
California	66044	6B	33.3	81	Poor	122	13.7	0.91
California	68534	6B	22.5	119	Poor	89	1.7	0.78
California	68535	6B	23.8	188	Good	76	1.7	0.77
Colorado	86002	6A	--	147	Poor	71	--	3.01
Colorado	86013	6A	--	69	Poor	38	8.8	2.19
Colorado	87781	6B	9.3	86	Poor	56	12.2	1.32
Colorado	87783	6A	3.7	127	Good	91	9.0	1.19
Florida	124101	6B	24.2	33	Good	114	2.9	0.55
Florida	124135	6B	21.2	36	--	--	2.4	0.5
Florida	124136	6B	21.2	36	Poor	--	2.4	0.57
Florida	124137	6B	21.5	71	Good	--	2.4	0.43
Georgia	134420	6B	8.4	125	Poor	--	1.6	0.81
Idaho	166027	6A	19.2	91	Good	51	14.8	1.32
Illinois	176050	6A	18.5	61	Poor	117	17.2	0.84
Indiana	181037	6B	11.7	71	Poor	25	--	--
Iowa	196049	6A	13.4	137	Good	71	18.7	1.7
Kansas	206026	6A	14.0	25	Poor	147	15.3	1.02
Kentucky	216040	6A	14.9	155	Good	41	11.2	1.67
Kentucky	216043	6A	7.9	140	Good	51	16.5	1.09

Table 78. Average IRI values for GPS-6 test sections calculated from last profile measurements (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	International Roughness Index (m/km)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Maine	231009	6B	23.0	145	Poor	--	2.1	0.76
Maine	231028	6B	21.8	163	--	--	0.9	1.1
Manitoba	836450	6B	18.0	112	Poor	150	5.7	0.87
Manitoba	836451	6B	18.0	104	Poor	66	5.7	1.32
Minnesota	276064	6A	12.0	193	Poor	142	10.5	1.08
Mississippi	282807	6B	10.7	269	Poor	--	2.0	1.19
Mississippi	283093	6B	7.5	104	Good	76	6.0	1.03
Mississippi	283094	6B	7.5	231	Good	76	6.0	0.94
Missouri	295403	6B	24.0	102	Good	56	3.4	1.22
Missouri	295413	6B	24.0	97	Poor	79	3.4	1.15
Missouri	296067	6A	15.9	180	Poor	25	12.2	1.49
Montana	306004	6A	17.8	89	Good	180	11.6	1.9
Montana	307066	6B	10.3	137	Good	43	2.9	0.88
Montana	307075	6A	17.3	86	Good	94	12.6	1.01
Montana	307076	6B	5.8	132	Good	61	3.1	0.93
Montana	307088	6B	10.1	124	Poor	43	3.1	0.7
Nebraska	316700	6B	12.8	137	Poor	99	7.1	2.09
Nevada	321030	6B	19.1	193	Poor	69	0.1	1.05
New Brunswick	846804	6A	--	99	Good	56	--	0
New Jersey	346057	6A	8.5	155	Good	46	15.1	1.54
New Mexico	351002	6A	26.5	109	Poor	99	10.4	0.98
New Mexico	352007	6A	3.4	67	Good	69	--	--
New Mexico	356033	6A	22.5	107	Poor	64	14.4	1.64
New Mexico	356035	6A	19.5	91	Good	112	10.4	1.5
New Mexico	356401	6A	13.5	102	Poor	109	11.4	1.38
New York	361008	6B	0.2	28	Good	33	5.9	1.02
New York	361011	6B	9.3	249	Poor	--	1.8	0.83
North Carolina	371040	6B	16.7	135	--	--	--	--
North Carolina	371803	6B	12.7	132	Poor	76	4.3	0.81
Oklahoma	404086	6B	19.3	109	Poor	33	5.7	1.35
Oklahoma	404164	6B	16.3	117	Poor	--	0.7	0.8
Oklahoma	406010	6A	14.5	114	Good	51	10.2	1.64
Oregon	416011	6A	25.1	155	Poor	173	4.7	1.18
Oregon	416012	6A	35.1	185	Poor	112	2.9	0.91
Pennsylvania	421608	6A	0.0	61	Good	66	7.2	1.68

Table 78. Average IRI values for GPS-6 test sections calculated from last profile measurements (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	International Roughness Index (m/km)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Pennsylvania	421618	6B	--	51	Good	150	6.2	1.68
Quebec	891021	6B	14.2	132	--	--	0.2	0.96
Quebec	891127	6B	15.7	124	--	--	1.0	1.06
Saskatchewan	906400	6A	9.7	196	Poor	61	14.5	1.97
Saskatchewan	906410	6B	21.3	117	Poor	94	5.7	1.22
Saskatchewan	906412	6B	21.3	112	Poor	140	5.7	0.92
Saskatchewan	906801	6A	8.7	--	Poor	102	14.5	2.26
South Carolina	451025	6B	13.6	28	Poor	--	0.6	1.24
South Dakota	469106	6B	33.6	147	Good	61	0.9	0.93
South Dakota	469197	6B	25.7	89	Poor	94	4.1	1.04
Tennessee	473108	6B	17.6	140	Good	--	4.3	0.58
Tennessee	473109	6B	10.6	132	Poor	--	4.7	1.16
Tennessee	473110	6B	8.1	130	Poor	140	4.6	0.71
Tennessee	476015	6A	10.6	224	Good	51	9.3	0.85
Tennessee	476022	6A	8.6	119	Good	--	15.2	0.6
Tennessee	479024	6B	18.0	145	Good	--	--	--
Texas	481046	6A	15.3	274	Poor	53	23.9	1.49
Texas	481093	6B	8.4	74	Good	64	6.6	0.79
Texas	481113	6B	6.4	38	Poor	94	2.7	0.69
Texas	481116	6B	3.3	38	Good	84	1.3	1.59
Texas	481119	6B	14.3	135	Poor	41	5.2	1.01
Texas	481130	6B	21.0	69	Poor	25	2.3	1.06
Texas	483875	6B	7.0	41	Good	25	1.9	1.13
Texas	486079	6A	12.4	175	Good	66	9.9	2.9
Texas	486086	6A	13.6	221	Good	38	10.3	0.8
Texas	486160	6A	18.3	61	Poor	41	12.4	2.15
Texas	486179	6A	9.6	41	Poor	112	19.9	1.42
Utah	491004	6A	6.3	81	Good	117	17.9	2.88
Utah	491005	6A	13.5	150	Good	97	10.8	0.88
Utah	491006	6A	16.2	234	Good	64	7.7	0.73
Utah	491007	6A	8.3	239	Good	51	6.0	1.17
Vermont	501683	6B	28.0	66	Poor	--	3.9	0.95
Virginia	511417	6B	9.6	183	Poor	38	5.3	1.26
Virginia	511419	6B	10.1	155	Good	86	6.2	1.4
Virginia	511423	6B	10.9	30	Poor	48	5.1	2.07

Table 78. Average IRI values for GPS-6 test sections calculated from last profile measurements (continued).

State	Section	Exp.	Original Pavement			Overlay Thick-ness (m)	Age of Overlay (years)	International Roughness Index (m/km)
			Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay			
Washington	531005	6B	16.0	267	Poor	64	3.9	0.76
Washington	531007	6A	7.8	61	Good	102	3.3	1.52
Washington	536020	6A	--	69	Good	66	--	0.65
Washington	536048	6B	--	160	Good	66	--	0.98
Washington	5836049	6A	16.2	236	Good	33	6.1	1.34
Washington	536056	6A	--	97	Poor	64	--	1.06
Washington	537322	6A	--	188	Good	56	--	0.81
Wyoming	566029	6A	--	53	Poor	46	--	1.23
Wyoming	566031	6A	5.3	64	Poor	64	10.6	2
Wyoming	566032	6A	12.6	76	Good	58	10.7	1.36

Table 79. Ages of GPS-6 overlays with IRI values of 1.6 m/km or less.

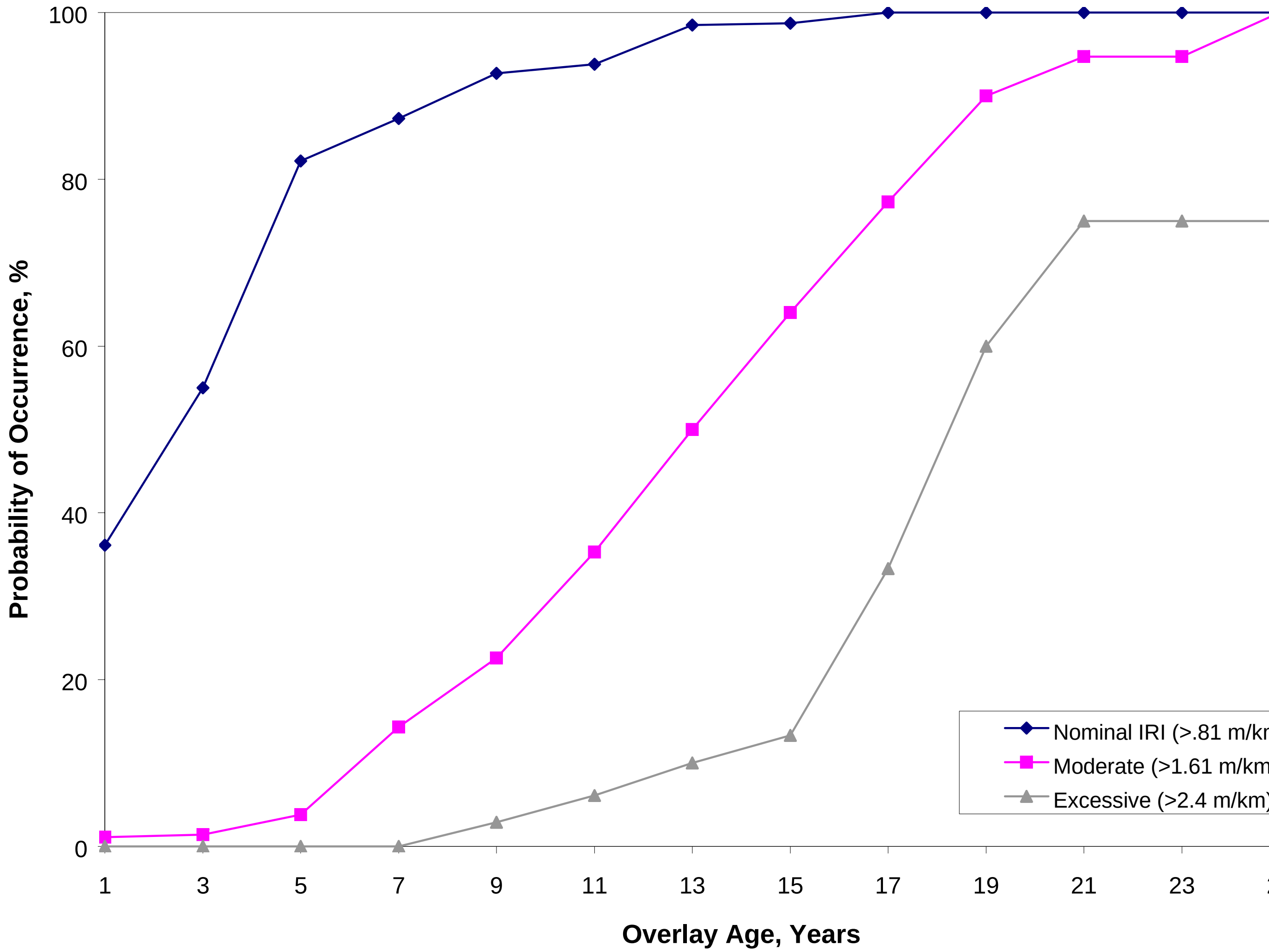
Original Condition Before Overlay	Total* Test Sections	Total Number $\leq$ 1.6	Number $\geq$ 5 Years	Number $\geq$ 10 Years	Number $\geq$ 15 Years	Number $\geq$ 20 Years
Poor	56	47	22	13	5	1
Good	43	34	20	9	3	--

*Number of test sections for which rutting data are available and prior condition data were provided.

Table 80. Ages of GPS-6A overlays with IRI values of 1.6 m/km or less.

Original Condition Before Overlay	Total Test Sections	Total Number $\leq$ 1.6	Number $\geq$ 5 Years	Number $\geq$ 10 Years	Number $\geq$ 15 Years	Number $\geq$ 20 Years
Poor	21	16	12	11	5	1
Good	22	15	14	9	3	--

Note: One GPS-6A test section overlay in the good group was less than 5 years old when the last manual distress survey was conducted.



Probability of Occurrence, %
100
80
60
40
20
0
1
3
5
7
9
11
13
15
17
19
21
23
Overlay Age, Years
Nominal IRI (>.81 m/k
Moderate (>1.61 m/km
Excessive (>2.4 m/km)

Figure 12. Probability of occurrence of different levels of roughness on the GPS-6 test sec

For this limited sample, there were 9 percent more overlays that were rougher over the pavements in a good condition than those over pavements in a poor condition. It appears that the condition of the original pavement does not have an effect on the future roughness of an overlay for those test sections included in the LTPP database.

7.2.2 AC Overlay Age

Table 81 provides insight as to amounts of roughness exhibited at different age levels for the GPS-6A test sections. After 10 years, 20 (or 69 percent) of the 29 overlays 10 years or older still had IRI values of 1.6 m/km, while another 8 (or 28 percent) had values of 1.61 to 2.4 m/km. Only one had more than 2.4 m/km. Stated differently, 97 percent of the overlays are not rough enough in their first 10 years to cause serious concern.

Table 81. Numbers of GPS-6A test sections with various levels of average IRI values and various ages of overlays.

Age Groups (Years)	Levels of Average IRI		
	≤ 1.6 m/km	1.61 to 2.4 m/km	> 2.4 m/km
5 to 9.9	6	2	1
10 to 14.9	12	7	1
15 to 20	7	1	0
> 20	1	0	0
All	26	10	2

After 15 years, 8 of the 9 overlays of that age or older were still experiencing nominal roughness and the other one still had an IRI value of less than 2.4 m/km. Only one of the 38 GPS-6A overlays appearing in table 63 was more than 20 years old and this one still had nominal roughness (less than 1.6 m/km).

Table 82 provides selected data for those GPS-6A overlays that have been in service longer than 15 years. It can be seen that only 2 of these 10 relatively old test sections has more than 2.4 m/km of roughness. The overlay for the Colorado test section had 3.01 m/km after 24.9 years of service. The one in Utah had 2.88 m/km after 17.9 years. The Kentucky test section had exhibited only 1.09 m/km of roughness after 16.5 years with 633 KESALs per year (based on monitored traffic data).

Table 82. Selected data for GPS-6A overlays 15 or more years old.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	IRI (m/km)
British Columbia	826006	15.7	81	53	134	149	1.30
Colorado	086002	24.9	147	71	218	247	3.01
Illinois	176050	17.2	61	117	178	(10?)	0.84
Kansas	206026	15.3	25	147	172	58	1.02
Kentucky	216043	16.5	140	51	1912	633	1.09
New Jersey	346057	15.1	155	46	201	231	1.54
Tennessee	476022	15.2	119	---	---	---	0.6
Texas	481046	23.9	274	53	327	295	1.49
Texas	486179	19.9	41	112	153	74	1.42
Utah	491004	17.9	81	117	198	45	2.88

Table 83 provides selected data for the 12 GPS-6A test sections that have more than 1.6 m/km of roughness, seeking a common factor that might indicate why they exhibited more than nominal roughness. It may be noted that these overlays range from 5.1 to 17.9 years of age, averaging 11.5 years. The 31 overlays with 1.6 m/km or less of roughness also averaged 11.5 years of age. It appears that the incidence of roughness, on average, is not dependent on the age of the overlay. The graphs for individual overlays in appendix I generally indicate that roughness in overlaid pavements increases with age at a very slow rate. In addition, the overlays listed in table 78 that have substantial roughness can be seen to have IRI values increasing at a higher rate than the majority.

Table 84 uses data from table 83, but the data are rearranged such that the test sections are ordered according to the average roughness, with the one with the most roughness having a ranking of 1. Observation of table 84 and the graphs in appendix I lead to a tentative conclusion that the rate of growth in roughness and the occurrence of high levels of roughness for overlays are primarily dependent on factors other than age that are essentially established when the overlay is placed.

Table 83. Selected data for GPS-6A overlays that exhibited average IRI values of more than 1.6 m/km.

State	SHRP ID	Overlay Age (Years)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness mm	Annual KESALs	IRI (m/km)
Alabama	16012	10.2	94	33	127	828	2.42
Alaska	26010	12.6	53	43	96	126	1.70
Colorado	86013	11.3	69	38	207	55	2.19
Kentucky	216040	9.4	155	41	196	294	1.67
New Mexico	356033	14.4	107	64	171	96	1.64
Saskatchewan	906400	9.7	196	64	257	121	2.26
Saskatchewan	906801	14.5	---	102	---	121	1.97
Texas	486079	9.9	175	66	241	394	2.90
Texas	486160	12.4	61	112	173	144	2.15
Utah	491004	17.9	81	117	198	45	2.88
Virginia	511423	5.1	30	48	78	159	2.07
Wyoming	566031	10.6	64	64	128	31	2.00

Table 84. Ranking in roughness and age of overlay for GPS-6 test sections.

Ranking by IRI	State	SHRP ID	IRI (m/km)	Original AC Thickness (mm)	Overlay Thickness (mm)	Total AC Thickness (mm)	Annual KESALs	Overlay Age (Years)	Ranking by Age of Overlay
1	Texas	486079	2.90	175	66	241	394	9.9	7
2	Utah	491004	2.88	81	117	198	45	17.9	1
3	Alabama	016012	2.42	94	33	127	828	11.6	5
4	Saskatchewan	906400	2.26	196	64	261	121	9.7	8
5	Colorado	086013	2.19	69	38	207	55	8.8	10
6	Texas	486160	2.15	61	112	173	144	12.4	4
7	Virginia	511423	2.07	30	48	78	159	5.1	11
8	Wyoming	566031	2.00	64	64	128	31	10.6	6
9	Saskatchewan	906801	1.97	---	102	---	121	9.3	9
10	Alaska	26010	1.70	53	43	96	126	13.2	3
11	Kentucky	216040	1.67	155	41	96	294	14.9	2
12	New Mexico	256033	1.64	107	64	171	96	11.6	5

7.2.3 AC Overlay Thickness

It can be seen from table 84 that the original AC thickness varied from 30 to 196 mm and that the average IRI values do not appear to be correlated to the original AC thickness. However, it can be seen that 9 of the 12 overlays are relatively thin, ranging from 33 to 66 mm. The overlay thicknesses for the other 5 varied from 102 to 117 mm, while the average for all 12 test sections is 66 mm. The average overlay thickness for the 31 GPS-6A test sections (for which overlay thicknesses are available and that have average IRI values of 1.6 m/km or less) is 74 mm, so the overlays for those test sections with more than nominal roughness appear to be somewhat thinner than those for smoother test sections.

More importantly, table 85 summarizes the incidence or number of GPS-6 test sections with different levels of roughness for the different ranges in overlay thickness for the AC overlays that are greater than 2 years in age.

Table 85. Number of GPS-6 test sections with different IRI values for different HMA overlay thicknesses.

Roughness - IRI Value, m/km	Overlay Thickness, mm (%)*					
	25 - 59		60 - 105		> 105	
≤ 0.8	2	(6.7%)	7	(25.0%)	3	(16.7%)
0.81 - 1.60 (Nominal)	22	(73.3 %)	14	(50.0%)	12	(66.7%)
1.61 - 2.40	5	(16.7%)	6	(21.4%)	2	(11.1%)
> 2.40	1	(3.3%)	1	(3.6%)	1	(5.6%)
Total Test Section (> 2 Year/Age)	30		28		18	

*Numbers in the parentheses represent the percentage of test sections in that group of AC overlay thickness.

As shown, the predominance of roughness data are less than 1.6 m/km, and AC overlay thickness does not have a consistent effect on roughness.

Review of figures 101 through 139 in appendix I indicates clearly that the great majority of the GPS-6 overlays have very low roughness deterioration rates. A few (about 9 percent) are experiencing some increase in roughness to indicate that unacceptable roughness will eventually result.

7.3 SUMMARY OF FINDINGS FOR ROUGHNESS

The SPS-5 data appear, at least in the overlay's early life, to indicate the following:

- Substantial reductions in pavement roughness can be obtained by an overlay, even for pavements that were not especially rough.

- Major reductions in pavement roughness can be obtained by an overlay for pavements that are relatively rough, as the roughness built into an overlay does not appear to be affected substantially by the roughness in the original pavement.

- The growth in roughness is generally quite nominal for some years after an overlay is placed.

- There do not appear to be any important differences between the virgin or recycled mixes, thin versus thick overlays, and milled versus unmilled surfaces related to roughness.

The GPS-6A data offer insight concerning the long-term performance of overlays in relation to roughness.

- The condition of the original pavement (only available in terms of "good or poor") appears to have little to do with the roughness of the overlay that can be placed on it or in the long-term growth of roughness in the overlay.

- The thin overlays were found to be as smooth or as rough as the thick overlays. In other words, the IRIs measured on thin overlays were about the same as those measured on the thick overlays.

- The amount of traffic (or ESALs) on an overlay clearly affects the growth of roughness, but it is quite possible to construct overlays for heavy traffic that will remain smooth for 15 to 20 or more years.

In summary, it appears that most overlays built in the United States and Canada offer adequate resistance to growth of roughness and that the occurrence of unacceptable roughness is likely to be caused by materials or placement inadequacies.

CHAPTER 8. SUMMARY OF ANALYTICAL RESULTS

The studies reported in the preceding chapters can be viewed separately as results applicable to the early performance (primarily from SPS-5) and long-term performance (primarily from GPS-6A) of an AC overlay of an AC pavement. These results will be summarized below in a format intended to offer highway professionals specific information that they may use in design decisions.

8.1 OVERLAY THICKNESSES AND OTHER DATA ISSUES

Chapter 2 provides specific information on layer thicknesses for SPS-5 projects, indicating what is missing, what was actually built versus what was specified, and identifying probable errors that need to be sorted out from the raw survey data. These discrepancies and missing data were formally submitted to FHWA through the use of the LTPP Feedback Forms. All of these discrepancies will be resolved and the "cleaned" data included in a future release of the LTPP data.

8.2 EARLY PERFORMANCE BASED ON SPS-5 DATA

Table 86 indicates the percentages of SPS-5 test sections having nominal (as established in chapter 1) and greater than nominal levels of distress. As shown or summarized, longitudinal cracking not in the wheel paths (LCNWP) was the most prevalent of the four types of cracking distresses. Five of the 14 projects exhibited no LCNWP in overlaid test sections and 2 others had no more than 50 m in any test section. However, the other seven projects had at least one test section with more than 50 m of LCNWP. Minnesota had seven test sections with greater than nominal LCNWP, Manitoba had six, and Alberta had five. Even though LCNWP was more prevalent, 54 percent of the test sections had none and 16 percent more had less than 50 m.

Conversely, very little fatigue cracking was evident at the time of the last manual distress surveys. Only eight test sections exhibited any fatigue cracking; five of these had less than 10 m^2 and the highest amount in the other three was 32.5 m^2.

There were more test sections with longitudinal cracking in the wheel paths (LCWP), most of which can be expected to become fatigue cracks at some point in the future. Even so, 58 percent did not have any LCWP and 27 percent had only 50 m or less. All of the LCWP greater than the 50 m established as nominal were in three projects (Alberta, Manitoba, and Mississippi). The Minnesota test sections had no LCWP and the Arizona project had none except for 41.5 m in one thin overlay. Fifty-eight percent of the test sections had no transverse cracking and 30 percent had 10 or less cracks.

Table 86. Percentages of SPS-5 test sections with none, nominal, or greater than nominal distress for AC overlay greater than 2 years in age.

Distress Type	Levels of Distress			
	None	Nominal	Greater Than Nominal	
			Moderate	Excessive
Fatigue Cracking	85	10	5	0
Longitudinal Cracking in Wheel Paths	58	27	8	7
Transverse Cracking	58	30	12	0
Longitudinal Cracking Not in Wheel Paths	54	19	18	9
Rutting	---	84	16	0
Roughness	---	93	7	0

"None" does not apply for either rutting or roughness, but it can be seen that the average rut depths and IRI values for only 16 and 7 percent of the overlaid test sections, respectively, had exceeded the nominal levels. In fact, 13 out of 15 of those with rut depths exceeding 6 mm are in 2 projects. In general, the overlays have little permanent deformation in the wheel paths in their early years. Review of the graphs in appendix H indicate that long-term rates of rutting are generally quite small.

As for rutting, all seven overlaid test sections with IRI values of greater than 1.6 m/km are in two projects, with the highest IRI a value of 1.91. Review of the graphs in appendix I indicate that the rate of growth in IRI is generally small, so it is likely that most of these overlays will serve for many years before roughness will necessitate rehabilitation. However, it can be seen from figures 96 and 98 that the rate of growth in IRI is increasing for certain test sections in the Manitoba and Mississippi projects, which are the ones with IRI values exceeding 1.6 m/km.

Another observation is the number of overlaid test sections that exceed the distress value measured prior to overlay. The percentage of test sections for each distress type is summarized below.

Distress Type	Percentage of Test Sections With Distress Value Exceeding The Value Prior to Overlay
Fatigue Cracking	5
Longitudinal Cracking in Wheel Path	27
Transverse Cracking	21
Longitudinal Cracking Not in Wheel Path	32
Rutting	8
Roughness	7

As shown, there are a substantial number of test sections for which both longitudinal cracking and transverse cracks have exceeded the amount of cracking prior to overlay. Based on the data collected and reviewed, these cracking distresses appear to be related to the reflection of the existing cracks prior to overlay, to climate parameters, and to AC mixture properties.

Table 87 provides the results from comparison of the performance of overlaid test sections with thin and thick overlays, virgin or recycled overlay mixes, and milled and unmilled test sections. These results were tabulated from study of comparisons for each distress type in previous chapters. However, these results or observations should be considered preliminary. In most cases, there are insufficient data at this time to provide conclusive statements on the factors included in the experiment design. Continued monitoring and materials data are needed and will be extremely valuable in achieving the objectives of the experiment. Each treatment is discussed separately below.

- **Effects of Overlay Thickness.** The nominal 127-mm overlays have less fatigue and transverse cracking than the nominal 51-mm ones, although there were exceptions. This is logical because tensile stress and strain levels would be reduced in thicker pavements, and the distance for the crack to propagate is increased. However, overlay thickness did not appear to have a strong effect on the occurrence of both types of longitudinal cracking or rutting and had no apparent effect on roughness based on early performance trends.

- **Effects of Milling**. The test sections that were milled prior to the overlays generally performed better than the unmilled test sections for transverse cracking, but they seemed to have little or no advantage in resisting both types of longitudinal cracking, fatigue cracking, rutting, or roughness.

- **Effects of Mix Type.** The effect of mix type (virgin versus recycled) for the overlays seemed to be important only for the two types of longitudinal cracking (LCWP and LCNWP). However, the results contradict each other as shown in table 87. The test sections with recycled mixes had more LCWP than the test sections with virgin mixes, while the test sections with virgin mixes had more LCNWP than the sections with recycled mixes.

Table 87. Analytical results from SPS-5 data.

Distress Type	Factor		
	Overlay Thickness Increasing	**Milling Surface**	**Recycled Mix**
Fatigue Cracking	Less	Less	No Advantage Over Virgin
Longitudinal Cracking in Wheel Paths	No Advantage	No Advantage	More
Transverse Cracking	Less	Less	No Advantage Over Virgin
Longitudinal Cracking Not in Wheel Paths	No Advantage	No Advantage	Less
Rutting	No Advantage	No Advantage	No Advantage Over Virgin
Roughness	No Advantage	No Advantage	No Advantage Over Virgin

8.3 LONG TERM PERFORMANCE BASED ON GPS-6A DATA

Tables 88 and 89 provide the same information about the GPS-6 and GPS-6A test sections, respectively, as provided by table 67 for SPS-5 test sections. Table 90 summarizes the average overlay age of the GPS-6 test sections when there is a 50 percent probability of occurrence for different levels of each distress studied.

- **Fatigue Cracking and Longitudinal Cracking in Wheel Paths**. Sixty-eight percent of the 43 GPS-6A overlays had no fatigue cracking and another 9 percent had no more than 10 m^2. The 23 percent that had more than nominal fatigue cracking were on average substantially older than those overlays with less.

  Tables 14 and 16 in chapter 3 indicate that most of the test sections performed well past 10 years of age, some even longer, and that condition before overlay had little to do with the incidence of fatigue cracking. However, the condition data available only indicate “poor” or “good,” so it is not known what distress or distresses may have caused a rating to be poor.

  As discussed in chapter 3, longitudinal cracking in the wheel paths (LCWP) and fatigue cracking are correlated, as fatigue cracking usually develops after multiple longitudinal cracks appear in a wheel path. Fewer of the overlays were free of LCWP than were free of fatigue cracking, but fewer had exceeded nominal levels also. (The definition of nominal distress levels for this report are arbitrary, so the numbers exceeding nominal levels depend on the definitions and may or may not be acceptable to individual professionals reading the report.)

Table 88. Percentages of GPS-6 test sections with none, nominal, or greater than nominal distress.

Distress Type	Levels of Distress			
	None	Nominal	Greater Than Nominal	
			Moderate	Excessive
Fatigue Cracking	76	9	8	7
Longitudinal Cracking in Wheel Paths	61	30	10	0
Transverse Cracking	40	25	27	8
Longitudinal Cracking Not in Wheel Paths	52	27	17	4
Rutting	---	67	33	0
Roughness	---	79	17	4

Table 89. Percentages of GPS-6A test sections with none, nominal, or greater than nominal distress.

Distress Type	Levels of Distress			
	None	Nominal	Greater Than Nominal	
			Moderate	Excessive
Fatigue Cracking	68	9	9	14
Longitudinal Cracking in Wheel Paths	44	38	18	0
Transverse Cracking	32	22	33	13
Longitudinal Cracking Not in Wheel Paths	42	27	22	9
Rutting	---	62	38	0
Roughness	---	71	21	8

Table 90. Overlay ages in years of the GPS-6 test sections when each distress exceeds at 50 percent probability of occurrence for different levels of the distress (to the nearest ½ year).

Distress Type	Levels of Distress	
	Nominal	Excessive
Fatigue Cracking (figure 4)	14.0	15.5
Longitudinal Cracking in Wheel Paths (figure 5)	15.0	21.0
Transverse Cracking (figure 6)	9.5	16.0
Longitudinal Cracking Not in Wheel Paths (figure 8)	12.5	15.0
Rutting (figure 9)	12.5	21.0
Roughness (figure 11)	3.0	18.5

- **Transverse Cracking.** It can be seen from tables 36 (chapter 4), 88, 89, and 90 that most of the overlays had some transverse cracking and that 43 percent had exceeded the 10 or less cracks established as nominal for this report. It can also be seen that the average age of the overlays with more than 10 transverse cracks was substantially greater than the average age for those that had none or 10 or less.

  The data for transverse cracking indicate that the amount of cracking is somewhat dependent on condition of the original pavement prior to overlay. As for the SPS-5 data, these data also indicate that increasing overlay thickness will decrease the occurrence of transverse cracks. However, there were examples of thin overlays that performed well for long periods of time.

  In addition, the overlays in Canada exhibited only moderate transverse cracking, which suggests that transverse cracking can be controlled or minimized in very cold climates.

- **Longitudinal Cracking Not in Wheel Paths**. There are a higher percentage of LTPP test sections where the lengths of longitudinal cracking not in wheel paths (LCNWP) are greater than the nominal level than for LCWP. However, this observation may be a result of the nominal levels selected for this report. As for the other types of cracking, thicker overlays appear to resist cracking better than thin ones.

  The condition of the original pavement prior to overlay does not appear to have much effect on the occurrence of LCNWP, nor does the age of the overlay. It appears that the primary factors influencing LCNWP may include the asphalt concrete material properties, construction techniques, and environmental variables to a greater extent than the limited set of variables considered in this study.

- **Rutting.** For the LTPP SPS-5 and GPS-6 test sections, rutting is not affected by or related to the condition of the original pavement or age of the overlay. Thicker overlays were observed to resist rutting slightly better than thin ones. However, it appears that the AC mix properties and placement/compaction techniques are the most significant factors to limit rutting.

  The limited study of the effects of traffic volume (ESALs) in chapter 6 suggests, as expected, that rut depths increase with increasing traffic levels. The very small rates of rutting after the first few years (indicated by the graphs in appendix H) however, appear to indicate that most of the rutting occurs early in an overlay's life.

  It appears that the majority of overlays may be expected to serve for 15 years or more before rutting becomes sufficient to require rehabilitation, and there are a number of examples of overlays successfully resisting rutting for more than 20 years.

- **Roughness.** The great majority of overlays may be expected to offer a long service life before roughness becomes severe enough to require rehabilitation. It is clearly possible to attain long-term control of roughness with thin or thick overlays, although the thicker overlays were found to offer a slight advantage.

  The condition of the original pavement prior to overlay appears to have little effect on the occurrence of or increase in roughness. The amount of traffic (or ESALs) does affect the growth of roughness, but it is quite possible to construct overlays of moderate thickness that will carry heavy traffic for 15 to 20 years or more with acceptable or tolerable levels of roughness.

  As the increase in roughness is generally quite small, the attention to detail in constructing a relatively smooth pavement to minimize initial roughness appears to be very important.

8.4 GENERAL SUMMARY

It should be noted that this study was conducted using a limited set of variables. The approach was to view the data in various ways to develop insight of value to practicing highway personnel. While this is believed to have been reasonably successful, there are a number of other variables that may be at least as significant as those few reported herein. Consequently, it will be necessary to conduct detailed sensitivity analyses to meet the objectives of the LTPP program. This will become possible after ongoing studies are completed and current deficiencies in the database are resolved.

More importantly, many of the GPS-6 test sections and SPS-5 projects were found to have limited distress (none to nominal values). Additional monitoring on these sites, especially the SPS-5 projects, will be extremely valuable as the materials, traffic, and climatic data become available. Future monitoring and data analysis studies will be needed to make conclusive statements regarding the effectiveness and differences between the rehabilitation techniques included in these studies.

The mechanics of cracking in pavements are diverse in terms of types of cracking distress and complex in terms of propagation of cracks and how this is affected by numerous mix design and construction variables. Much of the data needed will not be available, such as incidence of micro cracking as the overlay is compacted and cools. It is hoped that interaction with the Superpave studies and future analyses of LTPP data will be able to explain many of the uncertainties identified in this study.

It appears from these and other studies of rutting and roughness that they are somewhat easier than cracking to deal with, but still complex. The data appear to indicate that the long-term control of rutting and roughness is gained or lost during construction. If the AC mix will resist rutting adequately and is placed at reasonable density, the early permanent deformation will be limited and the future rutting rate nominal.

Similarly, if the overlay material is not subject to excessive permanent deformation and is placed relatively smooth (say around an IRI of 0.8 m/km), it very likely will not become very rough over its service life).

This report has purposely included a wealth of data tables and graphs, so that the work necessary to this study may not have to be duplicated by future analysts. Also, it is hoped that the study of SPS-5 overlay thicknesses and identification of problems needing resolution will be valuable in improving the database.

Appendix A
Pavement Thickness Data for SPS-5 Projects

Table 91. Pavement thickness data (mm) for the Alabama SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	**502**	**503**	**504**	**505**	**506**	**507**	**508**	**509**	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		55	55	55	55	55	55	55	55	
Average Overlay Thickness		33	102	109	36	36	124	122	48	
Precision of Overlay										
Bias in Overlay Thickness		18	25	18	15	15	3	5	3	13
Average Depth of Milling	0	0	0	0	0	43	33	23	25	31
Average Thickness of Milling Replacement		0	0	0	0	25	18	30	28	25
Original AC Thickness	94	84	84	89	91	91	81	64	84	84
Granular Base Thickness	264	381	381	381	381	381	381	381	381	381
Treated Base Thickness		33	102	112	36	76	142	145	81	91
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 92. Pavement thickness data (mm) for the Arizona SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		18	18	18	18	18	18	18	18	
Average Overlay Thickness										
Precision of Overlay										
Bias in Overlay Thickness										
Average Depth of Milling	0	28	10	28	18	74	69	69	64	45
Average Thickness of Milling Replacement		0	0	0	0	0	0	0	0	0
Original AC Thickness	81	135	117	135	122	150	130	137	130	132
Granular Base Thickness	353	373	422	447	325	325	526	381	376	397
Treated Base Thickness		69	119	122	71	104	170	165	99	115
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 93. Pavement thickness data (mm) for the California SPS-5 project

and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	**502**	**503**	**504**	**505**	**506**	**507**	**508**	**509**	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements										
Average Overlay Thickness										
Precision of Overlay										
Bias in Overlay Thickness										
Average Depth of Milling	0	0	0	0	0	0	0	0	0	0
Average Thickness of Milling Replacement										
Original AC Thickness										
Granular Base Thickness										
Treated Base Thickness										
Treated Subgrade Thickness										

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 94. Pavement thickness data (mm) for the Colorado SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		55	55	55	55	55	55	55	55	
Average Overlay Thickness		89	135	155	74	13	97	76	13	
Precision of Overlay										
Bias in Overlay Thickness		-38	-8	-28	-23	38	30	51	38	32
Average Depth of Milling	0	0	0	0	0	53	53	56	53	54
Average Thickness of Milling Replacement		0	0	0	0	0	0	0	0	0
Original AC Thickness	269	201	216	203	244	259	239	185	198	218
Granular Base Thickness	0	0	0	0	0	0	0	0	0	0
Treated Base Thickness	33	97	145	147	81	94	175	201	109	131
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 95. Pavement thickness data (mm) for the Florida SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	**502**	**503**	**504**	**505**	**506**	**507**	**508**	**509**	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		50	55	55	55	55	55	55	55	
Average Overlay Thickness		30	135	109	25	54	120	136	57	
Precision of Overlay										
Bias in Overlay Thickness		21	-8	18	26	-3	7	-9	-6	12
Average Depth of Milling		23	32	13	25	69	64	71	74	46
Average Thickness of Milling Replacement		0	0	0	0	36	56	66	43	50
Original AC Thickness		84	73	86	99	76	81	89	84	84
Granular Base Thickness		683	683	683	683	683	683	683	683	683
Treated Base Thickness		53	135	122	48	102	168	180	107	114
Treated Subgrade Thickness		0	0	0	0	0	0	0	0	0

Notes:
1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.
4. Level surveys were conducted after the porous friction course was milled off, so calculations for sections 502-505 were correct. However, estimated thicknesses of porous friction course had to be added for sections 506-509 to eliminate the original porous friction course from the comparative studies.

Table 96. Pavement thickness data (mm) for the Georgia SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		24	23	22	24	24	24	18	24	
Average Overlay Thickness		23	125	130	40	71	158	116	64	
Precision of Overlay										
Bias in Overlay Thickness		28	2	-3	11	-20	-31	11	-13	15
Average Depth of Milling	0	0	18	28	30	61	38	66	41	35
Average Thickness of Milling Replacement		0	0	0	0	53	48	48	56	51
Original AC Thickness	378	381	373	384	376	376	376	356	353	372
Granular Base Thickness	279	279	279	279	279	279	279	279	279	279
Treated Base Thickness		46	155	152	66	122	191	201	124	132
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes:
1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.
4. Original level surveys were conducted before the porous friction course was milled off, so approximate increases to the overlay thicknesses were made to eliminate the original porous friction course from the comparative studies.

Table 97. Pavement thickness data (mm) for the Maine SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		55	55	55	55	55	55	55	55	
Average Overlay Thickness		91	140	145	69	66	152	135	58	
Precision of Overlay										
Bias in Overlay Thickness		-40	-13	-18	-18	-15	-25	-8	-7	18
Average Depth of Milling	0	0	0	0	0	38	38	38	38	38
Average Thickness of Milling Replacement		0	0	0	0	51	58	51	43	51
Original AC Thickness	249	249	249	249	249	249	249	249	249	249
Granular Base Thickness	1168	1168	1168	1168	1168	1168	1168	1168	1168	1168
Treated Base Thickness		86	142	142	61	102	191	170	94	124
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes: 1. All measurements are in mm.
2 Mean values are of absolute values of the data elements.
3 Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 98. Pavement thickness data (mm) for the Maryland SPS-5 project

and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		55	55	55	55	55	55	55	55	
Average Overlay Thickness		46	124	117	48	15	112	99	51	
Precision of Overlay										
Bias in Overlay Thickness		5	3	10	3	36	15	28	0	12
Average Depth of Milling	0	0	0	0	0	41	41	41	38	40
Average Thickness of Milling Replacement		0	0	0	0	0	46	0	43	22
Original AC Thickness	112	117	112	119	112	119	119	112	132	118
Granular Base Thickness	142	135	135	130	135	165	130	127	165	140
Treated Base Thickness		53	124	114	51	91	188	140	89	106
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes:
1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 99. Pavement thickness data (mm) for the Minnesota SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements										
Average Overlay Thickness										
Precision of Overlay										
Bias in Overlay Thickness										
Average Depth of Milling	0	0	0	0	0	0	0	0	0	0
Average Thickness of Milling Replacement										
Original AC Thickness										
Granular Base Thickness										
Treated Base Thickness										
Treated Subgrade Thickness										

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 100. Pavement thickness data (mm) for the Mississippi SPS-5 project

and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements										
Average Overlay Thickness										
Precision of Overlay										
Bias in Overlay Thickness										
Average Depth of Milling	0	0	0	0	0	38	38	38	38	38
Average Thickness of Milling Replacement										
Original AC Thickness	318	318	318	318	318	318	318	318	318	318
Granular Base Thickness	0	0	0	0	0	0	0	0	0	0
Treated Base Thickness		51	127	127	51	89	165	165	89	108
Treated Subgrade Thickness	152	152	152	152	152	152	152	0	152	133

Notes:
1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 101. Pavement thickness data (mm) for the Montana SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		55	55	55	55	55	55	55	55	
Average Overlay Thickness		3	76	66	10	3	71	63	3	
Precision of Overlay										
Bias in Overlay Thickness		48	51	61	41	48	56	64	48	52
Average Depth of Milling	0	25	25	25	25	25	25	25	25	25
Average Thickness of Milling Replacement		0	0	0	0	0	0	0	0	0
Original AC Thickness	137	135	132	140	147	91	84	81	94	113
Granular Base Thickness	480	437	475	462	460	460	462	472	472	463
Treated Base Thickness	43	66	117	142	51	107	191	180	114	121
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 102. Pavement thickness data (mm) for the New Jersey SPS-5 project

and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	**502**	**503**	**504**	**505**	**506**	**507**	**508**	**509**	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		55	55	55	55	55	55	55	55	
Average Overlay Thickness		43	114	119	53	76	86	155	79	
Precision of Overlay										
Bias in Overlay Thickness		8	13	8	-2	-25	41	-28	-28	19
Average Depth of Milling	0	0	0	0	0	25	25	25	25	25
Average Thickness of Milling Replacement		0	66	0	0	53	56	56	64	57
Original AC Thickness	234	224	229	216	229	216	188	206	216	215
Granular Base Thickness	1930	1295	813	805	762	254	1626	813	813	898
Treated Base Thickness		51	127	127	51	102	178	178	102	114
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 103. Pavement thickness data (mm) for the Texas SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements		55	55	55	55	55	55	55	55	
Average Overlay Thickness		58	122	122	58	69	130	132	56	
Precision of Overlay										
Bias in Overlay Thickness		-7	5	5	-7	-18	-3	-5	-5	7
Average Depth of Milling	0	0	0	0	0	46	46	38	43	43
Average Thickness of Milling Replacement		0	0	0	0	56	56	53	46	53
Original AC Thickness	241	241	241	241	241	236	236	229	234	237
Granular Base Thickness	0	0	0	0	0	0	0	0	0	0
Treated Base Thickness		376	269	269	224	224	224	356	376	290
Treated Subgrade Thickness	165	254	254	254	254	254	254	254	254	254

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 104. Pavement thickness data (mm) for the Alberta SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements										
Average Overlay Thickness										
Precision of Overlay										
Bias in Overlay Thickness										
Average Depth of Milling	0	0	0	0	0	56	53	48	51	52
Average Thickness of Milling Replacement										
Original AC Thickness	234	137	198	201	218	213	191	140	168	183
Granular Base Thickness	295	343	328	279	295	330	330	373	343	328
Treated Base Thickness		53	127	122	53	94	160	178	84	109
Treated Subgrade Thickness	0	0	0	0	0	0	0	0	0	0

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

Table 105. Pavement thickness data (mm) for the Manitoba SPS-5 project and test sections

Data Element	SPS-5 Test Section Identification									Mean
	501	502	503	504	505	506	507	508	509	
Specified Overlay Thickness		51	127	127	51	51	127	127	51	
Number of Measurements										
Average Overlay Thickness										
Precision of Overlay										
Bias in Overlay Thickness										
Average Depth of Milling	0	0	0	0	0	0	0	0	0	0
Average Thickness of Milling Replacement										
Original AC Thickness	102	102	102							102
Granular Base Thickness	330	330	330							330
Treated Base Thickness		64	140							102
Treated Subgrade Thickness	0	0	0							0

Notes: 1. All measurements are in mm.
2. Mean values are of absolute values of the data elements.
3. Mean values for milling depths or thickness of milling replacement include only sections where milling occurred.

APPENDIX B

Descriptions of GPS-6 Test Sections

Table 106. Description of GPS-6 test sections in Alabama.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Da Ov
016012	6A	June 1972	Silty Sand	158 mm of Soil Aggregate Mixture Predominantly Coarse	137 mm of Asphalt Treated Mixture	94	Good	Jan
016019	6A	June 1966	Poorly Graded Sand	122 mm of Soil Aggregate Mixture Predominantly Fine	48 mm of Hot-Mix Asphalt Concrete	163	Poor	Apr
011001	6B	Oct. 1980	Clayey Sand with Gravel	485 mm of Crushed Gravel	157 mm of Crushed Gravel	84	Good	June
014127	6B	Aug. 1974	Clayey Sand with Gravel	None	188 mm of Soil Aggregate Mixture Predominantly Coarse	211	Poor	Apri
014129	6B	Jan. 1976	Silty Sand with Gravel	38 mm Soil Aggregate Mixture Predominantly Coarse	320 mm of Soil Aggregate Mixture Predominantly Coarse	76	Good	June

Table 107. Description of GPS-6 test sections in Alaska.

SHRP ID	Experiment	Original Pavement						Date Over
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	
021004	6B	July 1977	Poorly Graded Gravel with Silt and Sand	330 mm of Soil Aggregate Mixture Predominantly Coarse	356 mm of Soil Aggregate Mixture Predominantly Coarse	91	Poor	June 1
021008	6A	Sept. 1978	Poorly Graded Gravel with Silt and Sand	190 mm of Crushed Gravel	114 mm of Crushed Gravel	33	--	Dec. 1
026010	6A	Oct. 1969	Well Graded Gravel with Silt and Sand	178 mm of Soil Aggregate Mixture Predominantly Coarse	127 mm of Crushed Gravel	53	Poor	Dec. 1
029035	6B	Aug. 1971	Poorly Graded Gravel with Silt and Sand	152 mm of Soil Aggregate Mixture Predominantly Coarse	152 mm of Crushed Gravel	53	Good	July 1

-- = Not Available

Table 108. Description of GPS-6 test sections in Alberta.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over	
811804	6B	July 1982	Lean Clay	246 mm Soil Aggregate Mixture Predominantly Coarse	328 mm Soil Aggregate Mixture Predominantly Coarse	89	Poor	June	

Table 109. Description of GPS-6 Test Sections in Arizona.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
046053	6A	1/1/68	Silty Sand with Gravel	None	290 mm of Soil Aggregate Mixture Predominantly Coarse	81	Poor	10/1/
046054	6A	---	Silty Sand with Gravel	None	798 mm of Soil Aggregate Mixture Predominantly Coarse	178	Good	5/1/8
046055	6A	1/1/75	Clayey Gravel with Sand	None	300 mm of Crushed Gravel	46	Poor	4/1/8
046060	6A	1/1/67	Clayey Gravel with Sand	None	254 mm of Soil Aggregate Mixture Predominantly Coarse	99	Poor	10/1/

-- = Not Available

Table 110. Description of GPS-6 test sections in British Columbia.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
826006	6A	June 1959	Silty Sand	605 mm of Sand	208 mm of Crushed Gravel	81	Poor	Dec. 1
826007	6A	May 1976	Poorly Graded Gravel with Silt and Sand	None	315 mm of Soil Aggregate Mixture Predominantly Coarse	64	Poor	Dec. 1

-- = Not Available

Table 111. Description of GPS-6 test sections in California.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
066044	6A	6/1/47	Sandy Silt	244 mm of Soil Aggregate Mix Predominantly Coarse	84 mm of Crushed Stone	81	Poor	9/9/8
068534	6B	1/1/69	Clayey Sand	820 mm of Soil Aggregate Mixture Predominantly Fine	160 mm of Soil Aggregate Mixture Predominantly Coarse	120	Poor	7/8/9
068535	6B	9/1/67	Silty Clay with Sand	500 mm of Soil Aggregate Mixture Predominantly Fine	150 mm of Soil Aggregate Mixture Predominantly Coarse	188	Good	7/29/9

Table 112. Description of GPS-6 test sections in Colorado.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
086002	6A	---	Clay	None	246 mm of Soil Aggregate Mixture Predominantly Coarse	147	Poor*	Dec. 1
086013	6A	---	Silty Sand	495 mm of Soil Aggregate Mixture Predominantly Coarse	117 mm of Asphalt Treated Base	69	Poor*	Dec. 1
087783	6A	---	Clayey Sand	414 mm of Uncrushed Gravel	150 mm of Crushed Gravel	127	Good*	Dec. 1
087781	6B	May 1972	Sandy Lean Clay	None	180 mm of Asphalt Treated Base	86	Poor	Sept. 1

* From state test sections nomination forms.

Table 113. Description of GPS-6 test sections in Florida.

SHRP ID	Experiment	Original Pavement						Date Over
		Construction Date	Subgrade	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	
123997	6B	5/31/74	Poorly Graded Sand with Silt	381 mm Fine-Grained Soil Aggregate Mixture	295 mm Coarse-Grained Soil Aggregate Mixture	79	Poor	2/7/9
124101	6B	4/30/67	Poorly Graded Sand with Silt	335 mm Fine-Grained Soil Aggregate Mixture	246 mm Fine-Grained Soil Aggregate Mixture	33	Good	7/31/
124135	6B	1/31/71	Poorly Graded Sand	305 mm Fine-Grained Soil Aggregate Mixture	84 mm Fine-Grained Soil Aggregate Mixture	36	--	4/1/9
124136	6B	1/31/71	Poorly Graded Sand with Silt	300 mm Fine-Grained Soil Aggregate Mixture	206 mm Caliche	36	Poor	4/1/9
124137	6B	11/30/70	Poorly Graded Sand	442 mm Fine-Grained Soil Aggregate Mixture	254 mm Fine-Grained Soil Aggregate Mixture	71	Good	4/1/9

-- = Not Available

Table 114. Description of GPS-6 test sections in Georgia, Idaho, Illinois, Indiana, and Io

SHRP ID	Experiment	Original Pavement						
		Construction Date	**Subgrade**	**Subbase Thickness and Type**	**Base Thickness and Type**	**AC Thickness (mm)**	**Condition Prior to Overlay**	**Dat Ove**
Georgia 134420	6B	May 1984	Silty Sand	--	200 mm of Soil Cement	125	Poor	Oct.
Idaho 166027	6A	Sep. 1960	Silty Gravel with Sand	396 mm Soil Aggregate Mixture Predominatly Coarse	290 mm Crushed Gravel	91	Good	Dec.
Illinois 176050	6A	July 1959	Lean Clay	152 mm of Crushed Stone	203 mm of Crushed Stone	61	Poor	Dec.
Indiana 181037	6B	Jan. 1983	Sandy Silty Clay	0	295 mm HMAC	71	Poor	Sep.
Indiana 186012	6A	---	---	---	---	---	Good	Dec.
Iowa 196049	6A	Aug. 1962	Sandy Lean Clay	0	381 mm HMAC	137	Good	Jan.

-- = Not Available

Table 115. Description of GPS-6 test sections in Kansas.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
201006	6A	---	---	---	---	---	Good	Dec. 1
206026	6A	Jan. 1962	Sandy Lean Clay	0	208 mm HMAC	25	Good	Jan 19

-- = Not Available

Table 116. Description of GPS-6 test sections in Kentucky.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
216040	6A	Jan. 1967	Lean Clay with Sand	None	356 mm of Crushed Stone	155	Good	Dec. 1
216043	6A	Jan. 1971	Silty Gravel with Sand	None	330 mm of Crushed Stone	140	Good	Dec. 1

-- = Not Available

Table 117. Description of GPS-6 test sections in Maine.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
231009	6B	8/31/70	Poorly Graded Sand with Silt and Gravel	655 mm Soil Aggregate Mixture Coarse-Grained	123 mm Crushed Gravel	145	Poor	8/23/
231026	6B	6/30/73	Silty Sand with Gravel	--	447 mm Gravel	163	--	9/27/
231028	6B	10/31/72	Poorly Graded Sand with Gravel	--	498 mm Coarse-Grained Soil Aggregate Mixture	163	--	9/7/9

-- = Not Available

Table 118. Description of GPS-6 test sections in Manitoba.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
836450	6B	8/31/71	Silty Sand	107 mm Gravel	114 mm Crushed Gravel	112	Poor	9/13/
836451	6B	8/31/71	Poorly Graded Sand with Silt	94 mm Gravel	183 mm Crushed Gravel	104	Poor	9/13/

Table 119. Description of GPS-6 test sections in Minnesota.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
276064	6A	1968	Well Graded Sand with Silt and Gravel	None	137 mm of ATB	193	Poor	197

Table 120. Description of GPS-6 test sections in Mississippi and Missouri.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date of Overlay
Mississippi 282807	6B	Dec. 1982	Sandy Lean Clay	None	168 mm of Soil Cement	269	Poor	Aug. 199
Mississipi 283091	6B	Apr. 1979	Silty Sand	None	203 mm of Hot-Mix Asphalt Concrete	89	Good	Aug. 199
Mississippi 283093	6B	Dec. 1981	Silty Sand	175 mm of Lime Treated Subgrade Soil	160 mm of Hot-Mix Asphalt Concrete	104	Good	June 198
Mississippi 283094	6B	Dec. 1981	Silty Sand	135 mm of Lime Treated Subgrade Soil	140 mm of Soil Cement	231	Good	June 198
Missouri 295403	6B	Sept. 1965	Silty Sand	None	158 mm of Soil Cement	102	Good	Sept. 198
Missouri 295413	6B	Sept. 1965	Sandy Silt	None	127 mm of Soil Cement	97	Poor	Sept. 198
Missouri 296067	6A	Jan. 1965	Clayey Sand with Gravel	None	102 mm of Crushed Stone	180	Poor	Dec. 198

-- = Not Available

Table 121. Description of GPS-6 test sections in Montana.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
306004	6A	4/1/65	Sandy Lean Clay	244 mm Coarse-Grained Soil Aggregate Mixture	290 mm Crushed Gravel	89	Good	12/31
307066	6B	5/31/81	Sandy Clay with Gravel	404 mm Coarse-Grained Soil Aggregate Mixture	76 mm Crushed Gravel	137	Good	9/12/
307075	6A	10/1/64	Clayey Gravel	528 mm Coarse-Grained Soil Aggregate Mixture	285 mm Crushed Gravel	86	Good	12/31
307076	6B	7/31/85	Silty Sand	691 mm Coarse-Grained Soil Aggregate Mixture	239 mm Asphalt Treated Mixture	132	Good	6/1/9
307088	6B	5/31/81	Clayey Sand with Gravel	401 mm Coarse-Grained Soil Aggregate Mixture	23 mm Crushed Gravel	124	Poor	7/9/9

Table 122. Description of GPS-6 test sections in Nebraska, Nevada, New Brunswick, and Nev

SHRP ID	Experi ment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
Nebraska 316700	6B	Jan. 1976	Silt	0	0	137	Poor	Oct. 1
Nevada 321030	6B	Dec. 1973	Clayey Gravel with Sand	71 mm Soil Aggregate Mixture Predominantly Fine	46 mm Asphalt-Treated Mixture	193	Poor	Jan. 1
New Brunswick 846804	6A	Jan. 1966	Poorly Graded Gravel with Silt and Sand	937 mm Gravel	81 mm Asphalt-Treated Mixture	99	Good	July 1
New Jersey 346057	6A	Dec. 1971	Well-Graded Gravel with Silt and Sand	0	190 mm Crushed Gravel	155	Good	June

-- = Not Available

Table 123. Description of GPS-6 test sections in New Mexico.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Dat Ove
351002	6A	June 1958	Silty Gravel with Sand	--	166 mm of Soil Aggregate Mixture Predominantly Coarse	109	Poor	Dec.
352007	6A	July 1977	Silty Sand	Fine Soil Aggregate Mixture Predominantly Fine	97 mm of Sand Asphalt	67	Good	Dec.
356033	6A	June 1958	Silty Sand with Gravel	--	297 mm of Crushed Slag	107	Poor	Dec.
356035	6A	June 1965	Silty Sand	234 mm or Cement Aggregate Mixture	152 mm of Soil Aggregate Mixture Predominantly Coarse	91	Good	Dec.
356401	6A	June 1970	Silty Sand	152 mm of Cement Aggregate Mixture	152 mm of Soil Aggregate Mixture Predominantly Coarse	102	Poor	Dec.

-- = Not Available

Table 124. Description of GPS-6 test sections in New York, North Carolina, and Nova Sc

SHRP ID	Experi ment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Dat Over
New York 361008	6B	June 1989	Silt with Sand	305 mm Soil Aggregate Mixture Predominantly Coarse	246 mm HMAC	28	Good	Aug.1
New York 361011	6B	May 1984	Silty Gravel with Sand	0	384 mm Crushed Gravel	249	Poor	Sep. 1
North Carolina 371040	6B	Sep. 1978	Silt with Gravel	0	366 mm Soil Aggregate Mixture Predominantly Coarse	135	---	June
North Carolina 371803	6B	Nov. 1977	Gravelly Silt	0	320 mm Soil Aggregate Mixture Predominantly Fine	132	Poor	Aug.
Nova Scotia 866802	6A	June 1972	Poorly Graded Gravel with Silt	269 mm Crushed Gravel	94 mm Crushed Gravel	66	Good	Dec.

-- = Not Available

Table 125. Description of GPS-6 test sections in Oklahoma and Oregon.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date o Overla
Oklahoma 404086	6B	May 1970	Silt	--	200 mm of Sand Asphalt	109	Poor	Aug. 19
Oklahoma 404164	6B	Apr. 1978	Silty Sand	--	193 mm of Sand Asphalt	117	Poor	Aug. 19
Oklahoma 406010	6A	June 1970	Clayey Sand with Gravel	--	180 mm of Hot-Mix Asphalt Concrete	114	Good	Dec. 19
Oregon 416011	6A	June 1963	Gravelly Fat Clay	457 mm Soil Aggregate Mixture Predomina ntly Coarse	89 mm Soil Aggregate Mixture Predominant ly Coarse	155	Poor	July 19
Oregon 416012	6A	June 1953	Poorly-Graded Sand	356 mm Crushed Stone	89 mm Crushed Gravel	185	Poor	July 19

-- = Not Available

Table 126. Description of GPS-6 test sections in Pennsylvania and Quebec.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date of Overlay
Pennsylvania 421608	6A	---	Clayey Sand with Gravel	0	267 mm Crushed Slag	61	Good	Aug. 198
Pennsylvania 421618	6B	---	Sandy Lean Clay with Gravel	0	244 mm Crushed Gravel	51	Good	Aug. 198
Quebec 891021	6B	June 1981	Silty Sand with Gravel	594 mm Sand	417 mm Crushed Gravel	124	Poor	Aug. 199
Quebec 891127	6B	Oct. 1978	Silty Sand with Gravel	594 mm Sand	417 mm Crushed Gravel	132	Poor	Aug. 199

-- = Not Available

Table 127. Description of GPS-6 test sections in Saskatchewan, South Carolina, and South

SHRP ID	Exper iment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
Saskatchewan 906400	6A	May 1972	Silty Sand	0	0	196	Poor	Jan. 19
Saskathewan 906410	6B	June 1968	Sandy Silt	107 mm Sand	132 mm Crushed Gravel	117	Poor	Oct. 19
Saskatchewan 906412	6B	June 1968	Silty Sand	122 mm Gravel	127 mm Gravel	112	Poor	Oct. 19
Saskatchewan 906801	6A	May 1972	Sandy Lean Clay	0	0	---	Poor	Jan. 19
South Carolina 451025	6B	Feb. 1980	Silty Sand	0	211 mm Crushed Stone	28	Poor	Sep. 19
South Dakota 469106	6B	Jan. 1959	Sandy Lean Clay	0	165 mm Gravel	147	Good	Aug. 1
South Dakota 469197	6B	Jan. 1964	Lean Clay with Sand	254 mm Gravel	127 mm Gravel	89	Poor	Sep. 19

-- = Not Available

Table 128. Description of GPS-6 test sections in Tennessee.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
471023	6B	June 1972	Sandy Lean Clay with Gravel	152 mm Crushed Stone	155 mm Asphalt-Treated Mixture	137	Poor	Aug. 1
473101	6B	Dec. 1979	Fat Clay with Sand	140 mm Crushed Stone	84 mm HMAC	157	Poor	June 1
476015	6A	June 1974	Sandy Silt	0	185 mm Soil Aggregate Mixture Predominantly Coarse	224	Good	Jan. 19
476022	6A	June 1970	Sandy Lean Clay	175 mm Crushed Stone	157 mm Asphalt Concrete Dense-Graded, Cold Laid Mixed-In-Place	119mm	Good	Jan. 19
473108	6B	July 1972	Sandy Lean Clay	155 mm Crushed Stone	170 mm HMAC	140	Good	Feb. 19
473109	6B	Nov. 1978	Sandy Lean Clay	114 mm Crushed Stone	109 mm Open-Graded Hot Laid Central Plant Mix Asphalt Concrete	132	Poor	June 19

Table 128. Description of GPS-6 test sections in Tennessee (continued).

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
473110	6B	Aug. 1981	Sandy Lean Clay	Soil Aggregate Mixture Predominantly Coarse	104 mm HMAC	130	Poor	Sep. 1
479024	6B	June 1977	Clayey Gravel with Sand	0	180 mm Open-Graded Hot Laid Central Plant Mix Asphalt Concrete	145	Good	June 1
479025	6B	Dec. 1979	Rock	305 mm Soil Aggregate Mixture Predominantly Coarse	58 mm Asphalt Treated Mixture	114	Good	June 1

-- = Not Available

Table 129. Description of GPS-6 test sections in Texas.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
481046	6A	Sept. 1955	Clay with Sand	130 mm of Fine Grained Soil	213 mm of Crushed Gravel	274	Poor*	Jan. 1
486079	6A	Aug. 1972	Silty Sand	None	127 mm of Soil Aggregate Mixture Predominantly Coarse	175	Good*	Jan. 1
486086	6A	Jun. 1971	Sandy Lean Clay	152 mm of Lime Treated Subgrade Soil	437 mm of Soil Aggregate Mixture Predominantly Coarse	221	Good*	Jan. 1
486160	6A	Sept. 1962	Silty Sand	122 mm of Fine Grained Soil	213 mm of Soil Aggregate Mixture Predominantly Coarse	61	Poor*	Jan. 1
486179	6A	Jun. 1965	Clayey Sand	152 mm of Fine Grained Soil	188 mm of Soil Aggregate Mixture Predominantly Coarse	41	Poor*	Jan. 1
481093	6B	Apr. 1980	Silty Sand with Gravel	None	432 mm of Crushed Stone	74	Good	Sept. 1

*From state test section nomination forms.

Table 129. Description of GPS-6 test sections in Texas (continued).

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
481113	6B	Jan. 1986	Sandy Lean Clay	None	292 mm of Soil Aggregate Mixture Predominantly Coarse	38	Poor	Jun. 1
481116	6B	Jul. 1987	Sandy Lean Clay	None	277 mm of Soil Aggregate Mixture Predominantly Coarse	38	Good	Oct. 1
481119	6B	May 1975	Sandy Lean Clay	None	183 mm of Soil Aggregate Mixture Predominantly Coarse	135	Poor	Aug. 1
481130	6B	Oct. 1971	Fat Clay with Sand	203 mm of Lime Treated Subgrade Soil	455 mm of Crushed Stone	69	Poor	Oct. 1
483875	6B	Jun. 1984	Lean Clay with Sand	None	424 mm of Soil Aggregate Mixture Predominantly Coarse	41	Good	Jun. 1

-- = Not Available

Table 130. Description of GPS-6 test sections in Utah.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
491004	6A	Aug. 1971	Silty Sand with Gravel	None	234 mm of Crushed Gravel	81	Good	Dec. 1
491005	6A	June 1970	Silty Sand	None	157 mm of Crushed Gravel	150	Good	Dec. 1
491006	6A	Oct. 1971	Clayey Gravel with Sand	None	201 mm of Soil Aggregate Mixture Predominantly Coarse	234	Good	Dec. 1
491007	6A	Aug. 1979	Silty Gravel with Sand	None	81 mm of Soil Aggregate Mixture Predominantly Coarse	239	Good	Dec. 1

-- = Not Available

Table 131. Description of GPS-6 test sections in Vermont and Virginia.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
Vermont 501683	6B	Sep. 1963	Silty Sand with Gravel	305 mm Sand and 610 mm Soil Aggregate Mixture Predominantly Coarse	71 mm Asphalt-Treated Mixture	66	Poor	Sep. 1
Virginia 511417	6B	Feb. 1981	Clayey Gravel	168 mm Crushed Stone	168 mm Cement Aggregate Mixture	183	Poor	Sep. 1
Virginia 511419	6B	Aug. 1979	Gravelly Lean Clay with Sand	0	147 mm Cement Aggregate Mixture	155	Good	Sep. 1
Virginia 511423	6B	Nov. 1978	Clayey Sand with Gravel	216 mm Crushed Gravel	112 mm HMAC	30	Poor	Oct. 1

-- = Not Available

Table 132. Description of GPS-6 test sections in Washington.

SHRP ID	Experiment	Original Pavement						
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Overl
531005	6B	July 1973	Poorly Graded Gravel with Silt	165 mm Crushed Gravel	76 mm Crushed Gravel	267	Poor	July 1
531007	6B	Aug. 1983	Silt with Sand	0	330 mm Crushed Gravel	61	Good	June 1
536020	6A	---	Clayey Sand with Gravel	391 mm Soil Aggregate Mixture Predominantly Coarse	74 mm Gravel	69	Good	July 1
536048	6A	---	Sandy Silt	160 mm Soil Aggregate Mixture Predominantly Coarse	91 mm Soil Aggregate Mixture Predominantly Coarse	160	Good	Oct. 1
536049	6A	---	Clayey Sand with Gravel	353 mm Soil Aggregate Mixture Predominantly Coarse	109 mm Soil Aggregate Mixture Predominantly Coarse	236	Good	April 1
536056	6A	---	Clayey Gravel	0	287 mm Crushed Gravel	97	Poor	Aug. 1
537322	6A	---	Lean Clay	0	244 mm Crushed Gravel	188	Good	Sep. 1

-- = Not Available

Table 133. Description of GPS-6 test sections in Wyoming.

SHRP ID	Experiment	Original Pavement							
		Construction Date	Subgrade Type	Subbase Thickness and Type	Base Thickness and Type	AC Thickness (mm)	Condition Prior to Overlay	Date Over
566029	6A	---	Silty Gravel with Sand	152 mm Gravel	124 mm Crushed Gravel	53	Poor	July 1
566031	6A	Sep. 1978	Clayey Gravel with Sand	0	216 mm HMAC	64	Poor	Jan. 1
566032	6A	June 1971	Silty Gravel with Sand	0	249 mm HMAC	76	Good	Jan. 1

-- = Not Available

APPENDIX C

Measured Cracking Distresses for GPS-6 Test Sections

Table 134. Cracking distresses from manual surveys for GPS-6 test sections.

State	Section ID	Exp.	Construction Date	Overlay Date	Original Pavement: Age Before Overlay (years)	Original Pavement: AC Thick-ness (mm)	Original Pavement: Condition Before Overlay	Original Pavement: Overlay Thick-ness (mm)	Original Pavement: Observation Date	Age of Overlay (years)	Fatigue Cracking (sq m)	Longitudinal Cracking - Wheelpath (m)
Alabama	16012	6A	Jun. 1972	Jan. 1984	11.6	94	Good	33	15-Jul-92	8.5	38.5	14.3
Alabama	16012	6A	Jun. 1972	Jan. 1984	11.6	94	Good	33	30-Mar-93	9.2	105.3	24.5
Alabama	16019	6A	Jun. 1966	Apr. 1981	14.8	163	Poor	89	19-Jun-91	10.2	0	0
Alabama	16019	6A	Jun. 1966	Apr. 1981	14.8	163	Poor	89	29-Mar-93	12.0	0	37.3
Alabama	14127	6B	Aug. 1974	Apr. 1989	14.7	211	Poor	43	30-Mar-93	4.0	0	0
Alabama	14129	6B	Jan. 1976	Jun. 1989	13.4	76	Good	38	19-Sep-91	2.3	8.5	0
Alabama	14129	6B	Jan. 1976	Jun. 1989	13.4	76	Good	38	31-Mar-93	3.8	29.1	2
Alaska	21008	6A	Sep. 1978	Dec. 1988	10.3	33	--	--	29-Aug-91	2.7	8.3	0
Alaska	21008	6A	Sep. 1978	Dec. 1988	10.3	33	--	--	06-Jun-95	6.5	0	61.5
Alaska	26010	6A	Oct. 1969	Dec. 1982	13.2	53	Poor	43	29-May-90	7.5	0	0
Alaska	26010	6A	Oct. 1969	Dec. 1982	13.2	53	Poor	43	28-Aug-91	8.7	0	0
Alaska	26010	6A	Oct. 1969	Dec. 1982	13.2	53	Poor	43	24-Aug-93	10.7	0	9.3
Alaska	26010	6A	Oct. 1969	Dec. 1982	13.2	53	Poor	43	12-Jun-95	12.5	0	0
Alaska	21004	6B	Aug. 1977	Jun. 1991	13.8	91	Poor	46	19-Aug-91	0.2	0	0
Alaska	21004	6B	Aug. 1977	Jun. 1991	13.8	91	Poor	46	27-Aug-93	2.2	0	0
Alaska	21004	6B	Aug. 1977	Jun. 1991	13.8	91	Poor	46	13-Jun-95	4.0	0	6.2
Alaska	29035	6B	Sep. 1971	Jul. 1990	18.8	53	Good	97	26-Aug-91	1.2	0	0
Alaska	29035	6B	Sep. 1971	Jul. 1990	18.8	53	Good	97	31-Aug-93	3.2	0	0
Alberta	811804	6B	Aug. 1982	Jun. 1993	10.8	89	Poor	99	17-Aug-93	0.2	0	0
Arizona	46053	6A	Jan. 1968	Jul. 1988	20.5	81	Poor	120	13-Dec-94	6.5	0	0
Arizona	46054	6A	May 1985	Mar. 1989	3.8	178	Good	53	08-Dec-94	5.8	6.1	61
Arizona	46060	6A	Jan. 1967	Jul. 1988	21.5	99	Poor	102	06-Dec-94	6.4	0	60.4
British Columbia	826006	6A	Jun. 1959	Dec. 1976	17.5	81	Poor	53	24-Aug-92	15.7	35.6	15.5
British Columbia	826007	6A	May 1976	Jan. 1982	2.7	64	Poor	132	03-Jun-91	9.4	27.7	173
British Columbia	826007	6A	May 1976	Jan. 1982	2.7	64	Poor	132	25-Aug-92	10.6	261	0
British Columbia	826007	6A	May 1976	Jan. 1982	2.7	64	Poor	132	15-Dec-92	11.0	0	0

Table 134. Cracking distresses from manual surveys for GPS-6 test sections (continued

State	Section ID	Exp.	Construction Date	Overlay Date	Original Pavement					Age of Overlay (years)	Fatigue Cracking (sq m)	Longitudinal Cracking - Wheelpath (m)
					Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay	Overlay Thick-ness (mm)	Observation Date			
British Columbia	826007	6A	May 1976	Jan. 1982	2.7	64	Poor	132	20-Jun-94	12.5	0	39
British Columbia	826007	6A	May 1976	Jan. 1982	2.7	64	Poor	132	22-Aug-94	12.6	0	0
California	68534	6B	Jan. 1969	Jul. 1991	22.5	119	Poor	89	29-Sep-92	1.2	0	0
Colo rado	86002	6A	Nov. 1969	Jan. 1969	(0.8)	147	Poor*	71	30-Jun-94	25.5	224.6	8.4
Colorado	86002	6A	Nov. 1969	Jan. 1969	(0.8)	147	Poor*	71	11-May-95	26.4	349.9	4
Colorado	86013	6A	May 1985	Jan. 1985	(0.3)	69	Poor*	38	09-Jun-94	9.4	1.4	5.3
Colorado	86013	6A	May 1985	Jan. 1985	(0.3)	69	Poor*	38	15-May-95	10.4	0	14.6
Colorado	87783	6A	May 1981	Jan. 1985	3.7	127	Good*	91	14-Jun-94	9.4	13.6	0.5
Colorado	87781	6B	May 1972	Sep. 1981	9.3	86	Poor	56	25-Oct-91	10.1	0	0
Florida	124101	6B	Apr. 1967	Jul. 1991	24.2	33	Good	114	12-Mar-93	1.7	0	0
Florida	124135	6B	Jan. 1971	Apr. 1992	21.2	36	--	--	12-Mar-93	0.9	0	0
Florida	124136	6B	Jan. 1971	Apr. 1992	21.2	36	Poor	--	12-Mar-93	0.9	0	0
Florida	124137	6B	Dec. 1970	Apr. 1992	21.5	71	Good	--	12-Mar-93	0.9	0	0
Georgia	134420	6B	May 1984	Oct. 1992	8.4	125	Poor	--	05-Nov-93	1.1	0	0
Georgia	134420	6B	May 1984	Oct. 1992	8.4	125	Poor	--	27-Oct-94	2.1	0	1.5
Illinois	176050	6A	Jul. 1959	Jan. 1978	18.5	61	Poor	117	15-Jul-88	10.5	0	0
Illinois	176050	6A	Jul. 1959	Jan. 1978	18.5	61	Poor	117	25-Mar-93	15.2	0	0
Indiana	181037	6B	Jan. 1983	Sep. 1994	11.7	71	Poor	25	13-Oct-94	0.1	0	0
Iowa	196049	6A	Aug. 1962	Jan. 1976	13.4	137	Good	71	25-Jul-88	12.6	0	0
Kansas	206026	6A	Jan. 1962	Jan. 1976	14.0	25	Good	147	24-Aug-88	12.6	0	0
Kentucky	216040	6A	Jan. 1967	Dec. 1981	14.9	155	Good	41	14-Nov-88	7.0	0	0
Kentucky	216043	6A	Jan. 1971	Dec. 1978	7.9	140	Good	51	04-Aug-88	9.7	0	0
Kentucky	216043	6A	Jan. 1971	Dec. 1978	7.9	140	Good	51	13-Dec-94	16.0	0	0
Maine	231028	6B	Nov. 1972	Sep. 1994	21.8	163	--	--	14-Oct-94	0.1	0	0
Manitoba	836450	6B	Sep. 1971	Sep. 1989	18.0	112	Poor	150	11-Jun-93	3.8	0	0
Manitoba	836451	6B	Sep. 1971	Sep. 1989	18.0	104	Poor	66	11-Jun-93	3.8	0	0
Minnesota	276064	6A	Jan. 1968	Jan. 1980	12.0	193	Poor	142	27-Sep-88	8.7	116.3	0
Mississippi	282807	6B	Dec. 1982	Aug. 1993	10.7	269	Poor	--	01-Dec-95	2.3	0	1.2
Mississippi	282807	6B	Dec. 1982	Aug. 1993	10.7	269	Poor	--	01-Dec-95	2.3	0	1.2
Mississippi	283091	6B	Apr. 1979	Aug. 1995	16.3	89	Good	--	20-Nov-95	0.3	0	0

Table 134. Cracking distresses from manual surveys for GPS-6 test sections (continued

State	Section ID	Exp.	Construction Date	Overlay Date	Original Pavement					Age of Overlay (years)	Fatigue Cracking (sq m)	Longitudinal Cracking - Wheelpath (m)
					Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay	Overlay Thick-ness (mm)	Observation Date			
Mississippi	283093	6B	Dec. 1981	Jun. 1989	7.5	104	Good	76	07-Mar-91	1.8	0	0
Mississippi	283094	6B	Dec. 1981	Jun. 1989	7.5	231	Good	76	07-Mar-91	1.8	0	0
Mississippi	283094	6B	Dec. 1981	Jun. 1989	7.5	231	Good	76	19-Jan-93	3.6	0	0
Missouri	296067	6A	Jan. 1965	Dec. 1980	15.9	180	Poor	25	18-Aug-88	7.7	0	0
Missouri	296067	6A	Jan. 1965	Dec. 1980	15.9	180	Poor	25	12-Sep-94	13.8	0	98.6
Missouri	295403	6B	Sep. 1965	Sep. 1989	24.0	102	Good	56	17-Feb-92	2.5	0	0
Missouri	295403	6B	Sep. 1965	Sep. 1989	24.0	102	Good	56	13-Sep-94	5.0	0	0
Missouri	295403	6B	Sep. 1965	Sep. 1989	24.0	102	Good	56	14-Sep-94	5.0	0	0
Missouri	295413	6B	Sep. 1965	Sep. 1989	24.0	97	Poor	79	17-Feb-92	2.5	0	0
Missouri	295413	6B	Sep. 1965	Sep. 1989	24.0	97	Poor	79	13-Sep-94	5.0	0	0
Montana	306004	6A	Apr. 1965	Jan. 1983	17.8	89	Good	180	07-Jun-94	11.4	0	138.7
Montana	307075	6A	Oct. 1964	Jan. 1982	17.3	86	Good	94	25-Jul-94	12.6	0	0
Montana	307076	6B	Aug. 1985	Jun. 1991	5.8	132	Good	61	11-Oct-91	0.4	0	0
Montana	307088	6B	Jun. 1981	Jul. 1991	10.1	124	Poor	43	10-Oct-91	0.3	0	0
New Brunswick	846804	6A	Jul. 1979	Jan. 1979	(0.5)	99	Good	56	31-Jul-95	16.6	0	0
New Mexico	351002	6A	Jun. 1958	Dec. 1984	26.5	109	Poor	99	28-Mar-91	6.3	0	0
New Mexico	351002	6A	Jun. 1958	Dec. 1984	26.5	109	Poor	99	17-Feb-94	9.2	0	0
New Mexico	356033	6A	Jun. 1958	Dec. 1980	22.5	107	Poor	64	28-Mar-91	10.3	0	157.1
New Mexico	356033	6A	Jun. 1958	Dec. 1980	22.5	107	Poor	64	17-Feb-94	13.2	76.3	5.5
New Mexico	356035	6A	Jun. 1965	Dec. 1984	19.5	91	Good	112	15-Feb-94	9.2	58.4	31.4
New Mexico	356401	6A	Jun. 1970	Dec. 1983	13.5	102	Poor	109	26-Mar-91	7.3	18.6	51.2
New Mexico	356401	6A	Jun. 1970	Dec. 1983	13.5	102	Poor	109	15-Feb-94	10.2	7.4	119.5
North Carolina	371040	6B	Sep. 1978	Jun. 1995	16.7	135	--	--	13-Dec-95	0.5	0	0
North Carolina	371803	6B	Dec. 1977	Aug. 1990	12.7	132	Poor	76	22-Apr-96	5.7	4.8	20.8
Oklahoma	406010	6A	Jun. 1970	Dec. 1984	14.5	114	Good	51	09-Oct-91	6.9	0	0
Oklahoma	406010	6A	Jun. 1970	Dec. 1984	14.5	114	Good	51	03-Nov-92	7.9	0	8
Oklahoma	406010	6A	Jun. 1970	Dec. 1984	14.5	114	Good	51	01-Nov-94	9.9	0	11.5
Oklahoma	404086	6B	May 1970	Aug. 1989	19.3	109	Poor	33	14-Oct-91	2.2	0	6.7
Oklahoma	404086	6B	May 1970	Aug. 1989	19.3	109	Poor	33	05-Nov-92	3.3	0	5
Oklahoma	404086	6B	May 1970	Aug. 1989	19.3	109	Poor	33	03-Nov-94	5.3	0	7

Table 134. Cracking distresses from manual surveys for GPS-6 test sections (continued

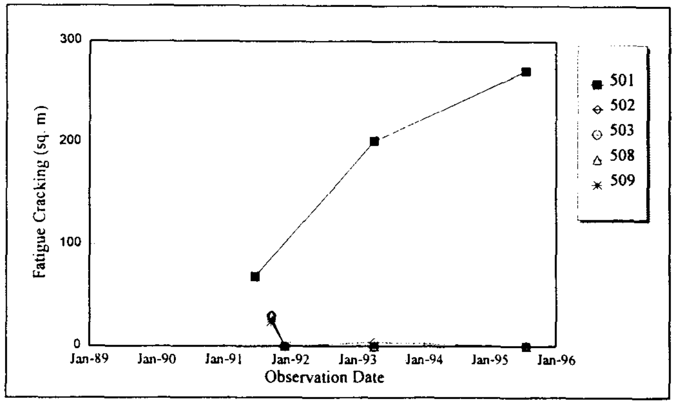
State	Section ID	Exp.	Construction Date	Overlay Date	Original Pavement: Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay	Overlay Thick-ness (mm)	Observation Date	Age of Overlay (years)	Fatigue Cracking (sq m)	Longitudinal Cracking - Wheelpath (m)
Oklahoma	404164	6B	Apr. 1978	Aug. 1994	16.3	117	Poor	--	02-Nov-94	0.3	0	0
Oregon	416011	6A	Jun. 1963	Jul. 1988	25.1	155	Poor	173	19-Oct-93	5.3	0	0
Pennsylvania	421608	6A	Aug. 1988	Aug. 1988	0.0	61	Good	66	30-Aug-94	6.1	0	0
Quebec	891021	6B	Jun. 1981	Aug. 1995	14.2	132	--	--	31-Oct-95	0.2	0	0
Quebec	891127	6B	Nov. 1978	Aug. 1994	15.7	124	--	--	06-Oct-94	0.2	0	0
Saskatchewan	906400	6A	May 1971	Jan. 1981	9.7	196	Poor	61	13-Sep-88	7.7	0	0
Saskatchewan	906400	6A	May 1971	Jan. 1981	9.7	196	Poor	61	17-Aug-94	13.6	0	46.2
Saskatchewan	906801	6A	May 1972	Jan. 1981	8.7	0	Poor	102	14-Sep-88	7.7	0	0
Saskatchewan	906801	6A	May 1972	Jan. 1981	8.7	0	Poor	102	17-Aug-94	13.6	0	15
Saskatchewan	906410	6B	Jul. 1968	Oct. 1989	21.3	117	Poor	94	15-Aug-94	4.9	0	0
Saskatchewan	906412	6B	Jul. 1968	Oct. 1989	21.3	112	Poor	140	15-Aug-94	4.9	0	0
South Dakota	469197	6B	Jan. 1964	Sep. 1989	25.7	89	Poor	94	12-Oct-93	4.1	0	0
Tennessee	476015	6A	Jun. 1974	Jan. 1985	10.6	224	Good	140	12-Aug-91	6.6	0	0
Tennessee	476015	6A	Jun. 1974	Jan. 1985	10.6	224	Good	140	03-Aug-93	8.6	0	0
Tennessee	476022	6A	Jun. 1970	Jan. 1979	8.6	119	Good	51	14-Aug-91	12.6	--	0
Tennessee	473108	6B	Jul. 1972	Feb. 1990	17.6	140	Good	--	04-Aug-93	3.5	0	0
Tennessee	473109	6B	Nov. 1978	Jun. 1989	10.6	132	Poor	--	12-Aug-91	2.2	0	0
Tennessee	473109	6B	Nov. 1978	Jun. 1989	10.6	132	Poor	--	03-Aug-93	4.2	0	0
Tennessee	473110	6B	Aug. 1981	Sep. 1989	8.1	130	Poor	140	12-Aug-91	1.9	0	0
Tennessee	473110	6B	Aug. 1981	Sep. 1989	8.1	130	Poor	140	03-Aug-93	3.9	0	0
Tennessee	479024	6B	Jun. 1977	Jun. 1995	18.0	145	Good	--	18-Apr-95	(0.1)	0	0
Texas	481046	6A	Sep. 1955	Jan. 1971	15.3	274	Poor *	53	11-Jun-91	20.4	22.9	0
Texas	481046	6A	Sep. 1955	Jan. 1971	15.3	274	Poor *	53	19-May-93	22.4	40.6	6
Texas	481046	6A	Sep. 1955	Jan. 1971	15.3	274	Poor *	53	10-Aug-95	24.6	47.8	6.8
Texas	486079	6A	Aug. 1972	Jan. 1985	12.4	175	Good*	66	10-Jun-91	6.4	0.6	80.2
Texas	486079	6A	Aug. 1972	Jan. 1985	12.4	175	Good*	66	17-May-93	8.4	5	78.6
Texas	486079	6A	Aug. 1972	Jan. 1985	12.4	175	Good*	66	08-Aug-95	10.6	4.7	83.1
Texas	486086	6A	Jun. 1971	Jan. 1985	13.6	221	Good*	38	11-Apr-91	6.3	140	G
Texas	486086	6A	Jun. 1971	Jan. 1985	13.6	221	Good*	38	27-Mar-92	7.2	0	0
Texas	486086	6A	Jun. 1971	Jan. 1985	13.6	221	Good*	38	31-Mar-93	8.2	0	0
Texas	486086	6A	Jun. 1971	Jan. 1985	13.6	221	Good*	38	20-Mar-95	10.2	0	0.5
Texas	486160	6A	Sep. 1962	Jan. 1981	18.3	61	Poor*	41	05-Nov-91	10.8	4.8	64

Table 134. Cracking distresses from manual surveys for GPS-6 test sections (continued

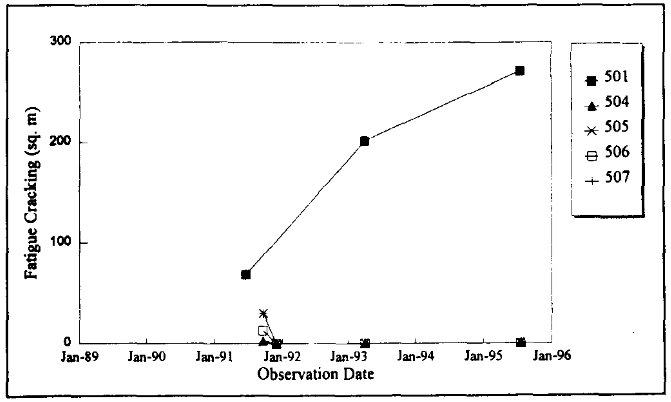
State	Section ID	Exp.	Construction Date	Overlay Date	Original Pavement					Age of Overlay (years)	Fatigue Cracking (sq m)	Longitudinal Cracking - Wheelpath (m)
					Age Before Overlay (years)	AC Thick-ness (mm)	Condition Before Overlay	Overlay Thick-ness (mm)	Observation Date			
Texas	486160	6A	Sep. 1962	Jan. 1981	18.3	61	Poor*	41	07-Jul-93	12.5	11.5	32.4
Texas	486179	6A	Jun. 1965	Jan. 1975	9.6	41	Poor*	112	05-Nov-91	16.8	0	0
Texas	486179	6A	Jun. 1965	Jan. 1975	9.6	41	Poor*	112	07-Jul-93	18.5	0	0
Texas	486179	6A	Jun. 1965	Jan. 1975	9.6	41	Poor*	112	27-Jul-95	20.6	0	0
Texas	481093	6B	Apr. 1980	Sep. 1988	8.4	74	Good	64	26-Mar-91	2.6	0	0
Texas	481093	6B	Apr. 1980	Sep. 1988	8.4	74	Good	64	01-Apr-93	4.6	36	9.7
Texas	481093	6B	Apr. 1980	Sep. 1988	8.4	74	Good	64	23-Mar-95	6.6	36.1	15.4
Texas	481113	6B	Jan. 1986	Jun. 1992	6.4	38	Poor	94	11-Aug-93	1.2	40.4	0
Texas	481113	6B	Jan. 1986	Jun. 1992	6.4	38	Poor	94	19-Jul-95	3.1	0	0
Texas	481116	6B	Jul. 1987	Oct. 1990	3.3	38	Good	84	25-Jun-91	0.7	83.2	0
Texas	481119	6B	May 1975	Aug. 1989	14.3	135	Poor	41	25-Jun-91	1.9	0	0
Texas	481119	6B	May 1975	Aug. 1989	14.3	135	Poor	41	11-Aug-93	4.0	0	0
Texas	481119	6B	May 1975	Aug. 1989	14.3	135	Poor	41	19-Jul-95	6.0	0	3.4
Texas	481130	6B	Oct. 1971	Oct. 1992	21.0	69	Poor	25	01-Apr-93	0.5	0	0
Texas	481130	6B	Oct. 1971	Oct. 1992	21.0	69	Poor	25	23-Mar-95	2.5	0	0
Texas	483875	6B	Jun. 1984	Jun. 1991	7.0	41	Good	25	10-Jun-92	1.0	0	0
Texas	483875	6B	Jun. 1984	Jun. 1991	7.0	41	Good	25	18-May-93	2.0	0.2	5.3
Texas	483875	6B	Jun. 1984	Jun. 1991	7.0	41	Good	25	09-Aug-95	4.2	4.5	11
Utah	491004	6A	Aug. 1971	Dec. 1977	6.3	81	Good	117	19-Jul-91	13.6	0	54.4
Utah	491004	6A	Aug. 1971	Dec. 1977	6.3	81	Good	117	21-Sep-95	17.8	305	0
Utah	491005	6A	Jun. 1970	Dec. 1983	13.5	150	Good	97	05-Aug-91	7.7	4.6	52.5
Utah	491006	6A	Oct. 1971	Dec. 1987	16.2	234	Good	64	15-Jul-91	3.6	0	0
Utah	491006	6A	Oct. 1971	Dec. 1987	16.2	234	Good	64	25-Sep-95	7.8	0	0.5
Utah	491007	6A	Aug. 1979	Dec. 1987	8.3	239	Good	51	01-Aug-91	3.7	0	10.7
Washington	536049	6A	Apr. 1972	Jul. 1988	16.2	236	Good	33	17-Aug-94	6.1	0	39.8
Washington	531005	6B	Jul. 1973	Jul. 1989	16.0	267	Poor	58	29-Aug-94	5.2	1.2	0
Wyoming	566031	6A	Sep. 1978	Jan. 1984	5.3	64	Poor	64	17-Aug-94	10.6	0.4	0.4
Wyoming	566032	6A	Jun. 1971	Jan. 1984	12.6	76	Good	58	28-Sep-94	10.7	0	0

APPENDIX D

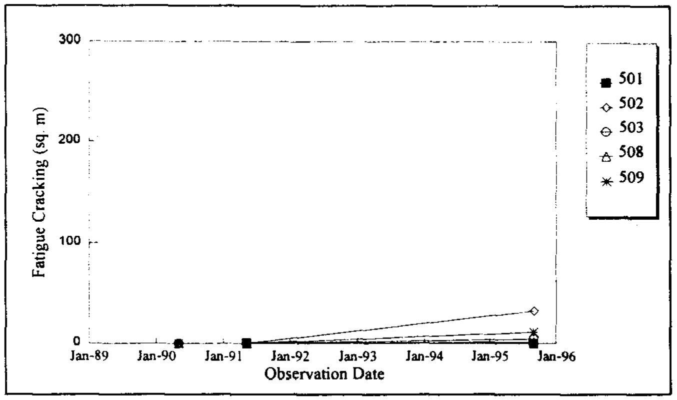
Graphs of Fatigue Cracking Performance for SPS-5 Projects and GPS-6 Test Sections



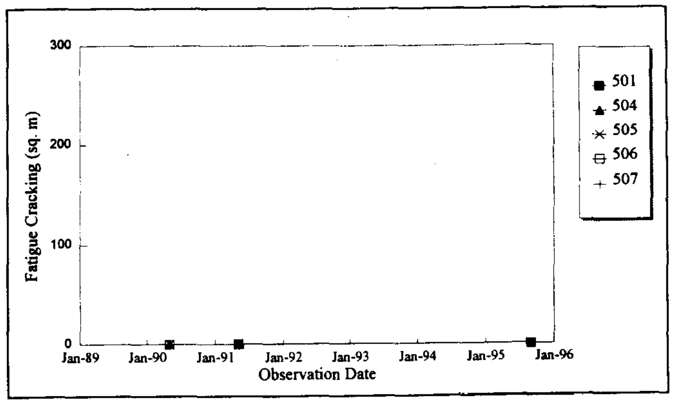
a. Fatigue cracking in recycled overlay mixtures in Alabama.



b. Fatigue cracking in virgin overlay mixtures in Alabama.

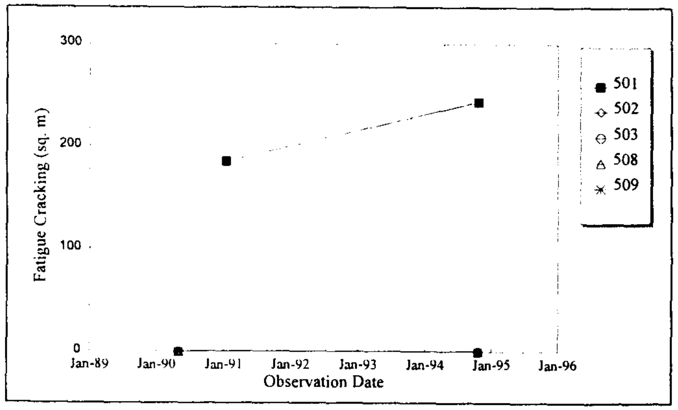


c. Fatigue cracking in recycled overlay mixtures in Alberta.

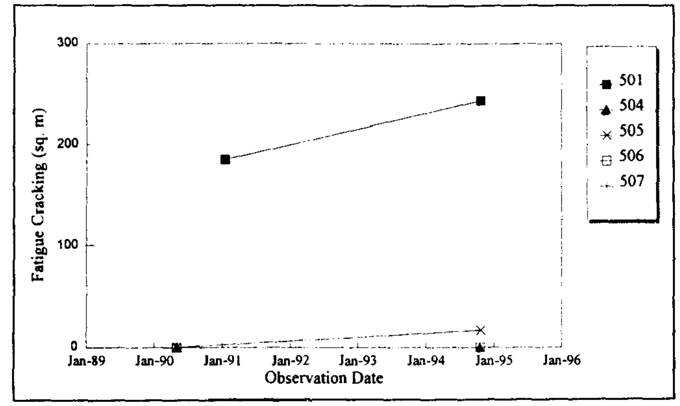


d. Fatigue cracking in virgin overlay mixtures in Alberta.

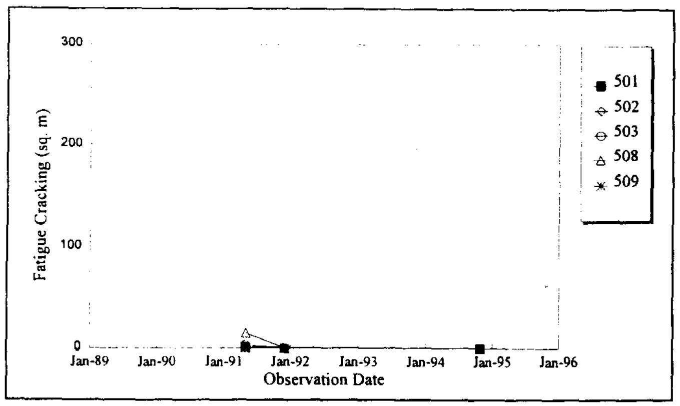
Figure 13. Fatigue cracking in Alabama and Alberta for the SPS-5 project.



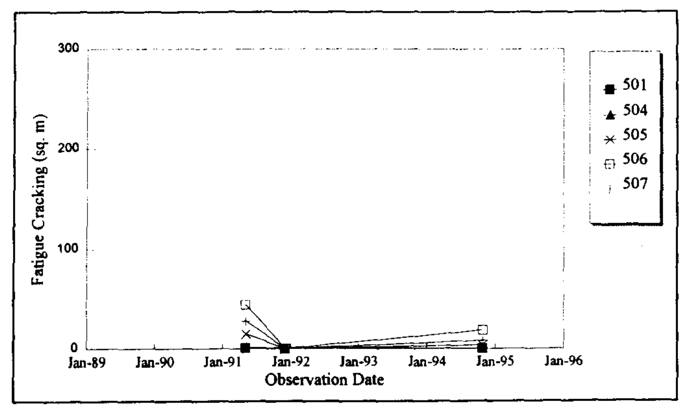
a. Fatigue cracking in recycled overlay mixtures in Arizona.



b. Fatigue cracking in virgin overlay mixtures in Arizona.



c. Fatigue cracking in recycled overlay mixtures in Colorado.



d. Fatigue cracking in virgin overlay mixtures in Colorado.

Figure 14. Fatigue cracking in Arizona and Colorado for the SPS-5 project.

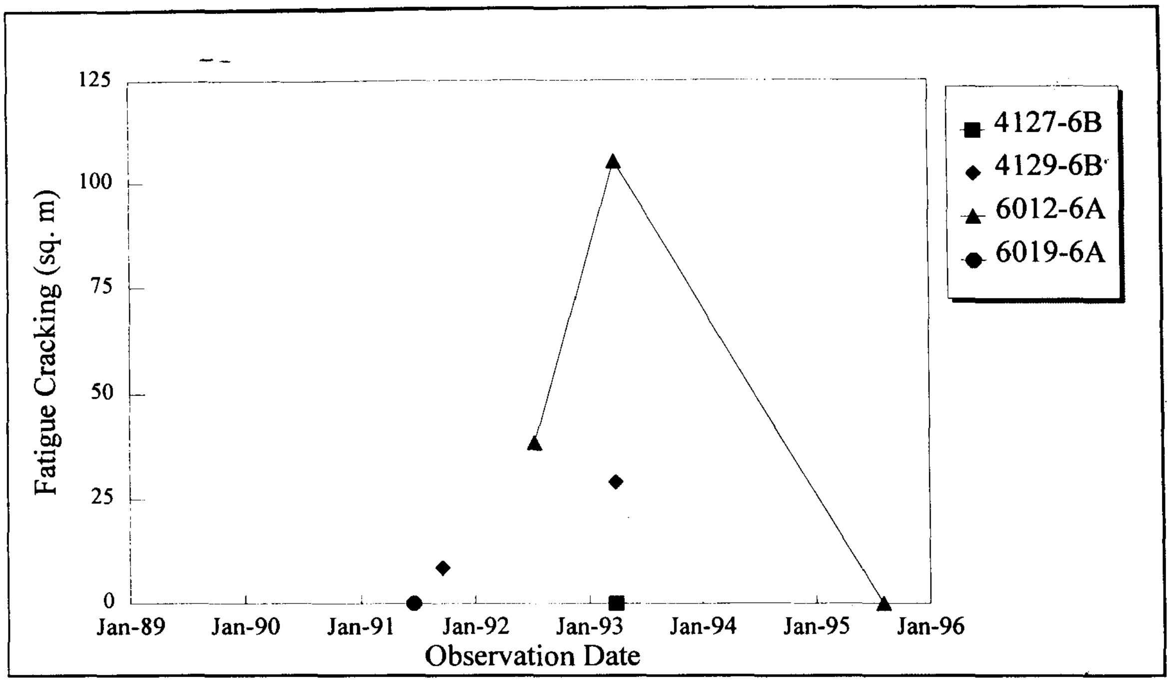


Figure 15. Fatigue cracking in Alabama GPS-6 test sections.

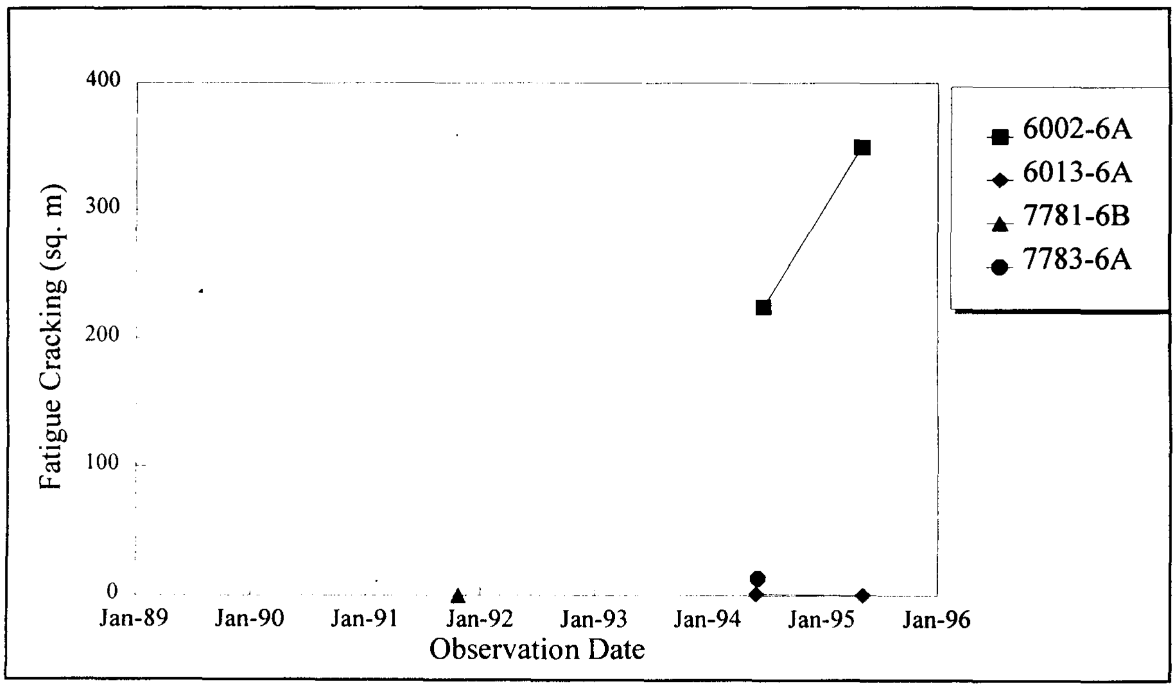


Figure 16. Fatigue cracking in Colorado GPS-6 test sections.

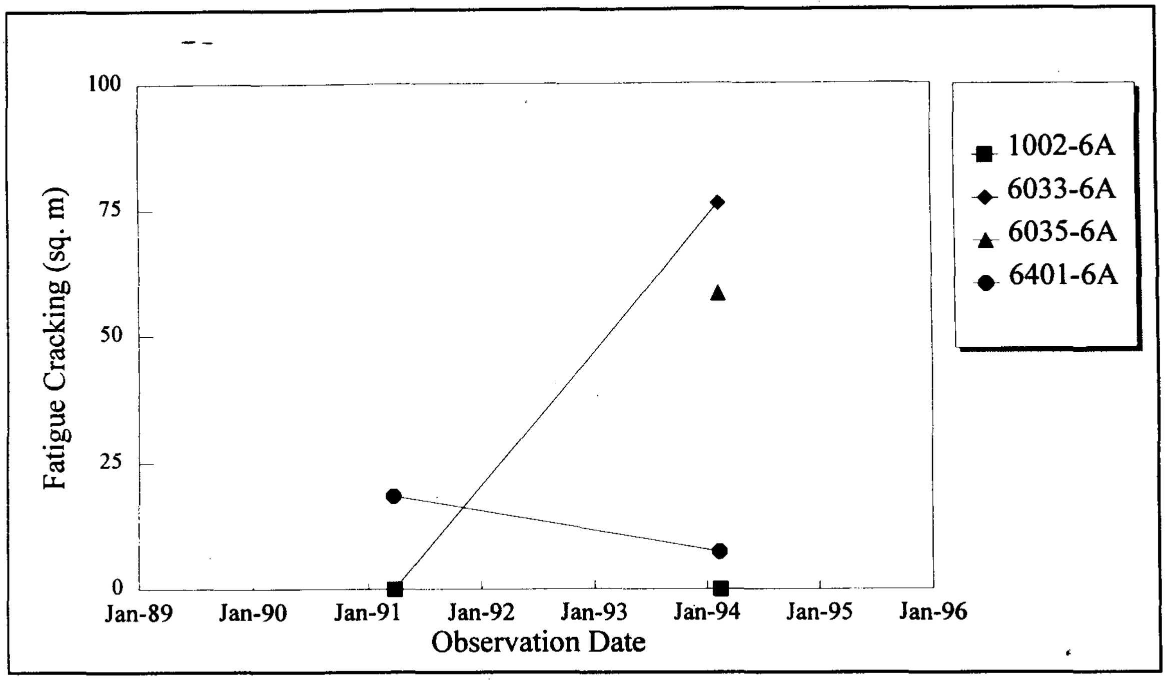


Figure 17. Fatigue cracking in New Mexico GPS-6 test sections.

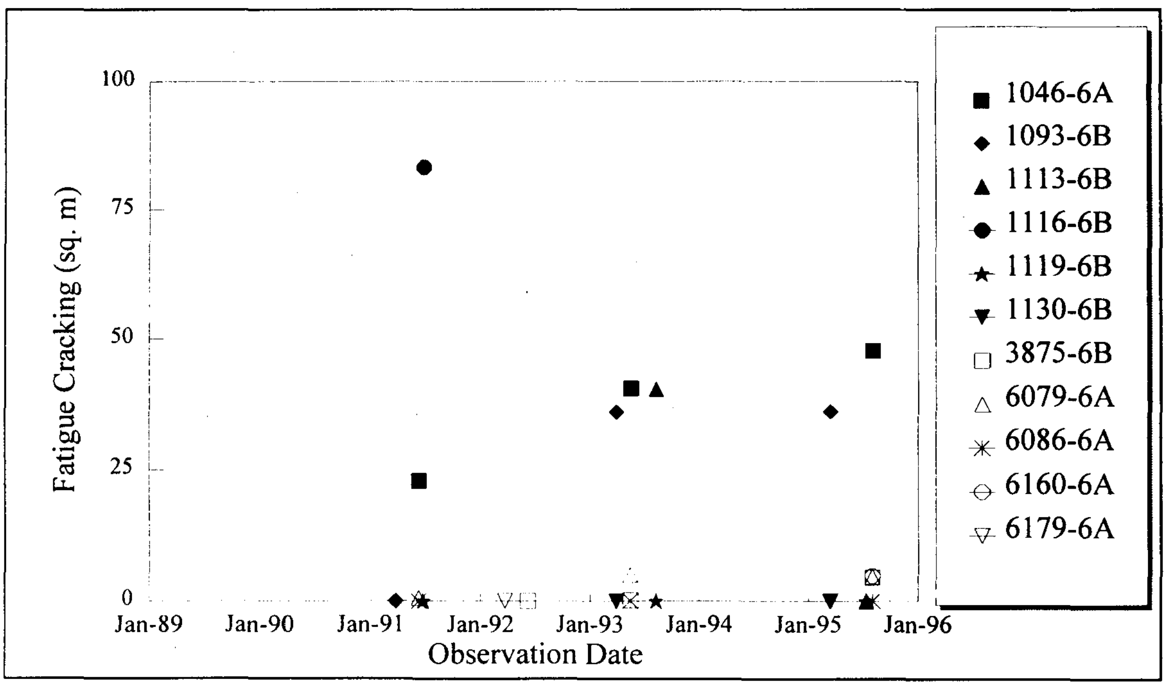


Figure 18. Fatigue cracking in Texas GPS-6 test sections.

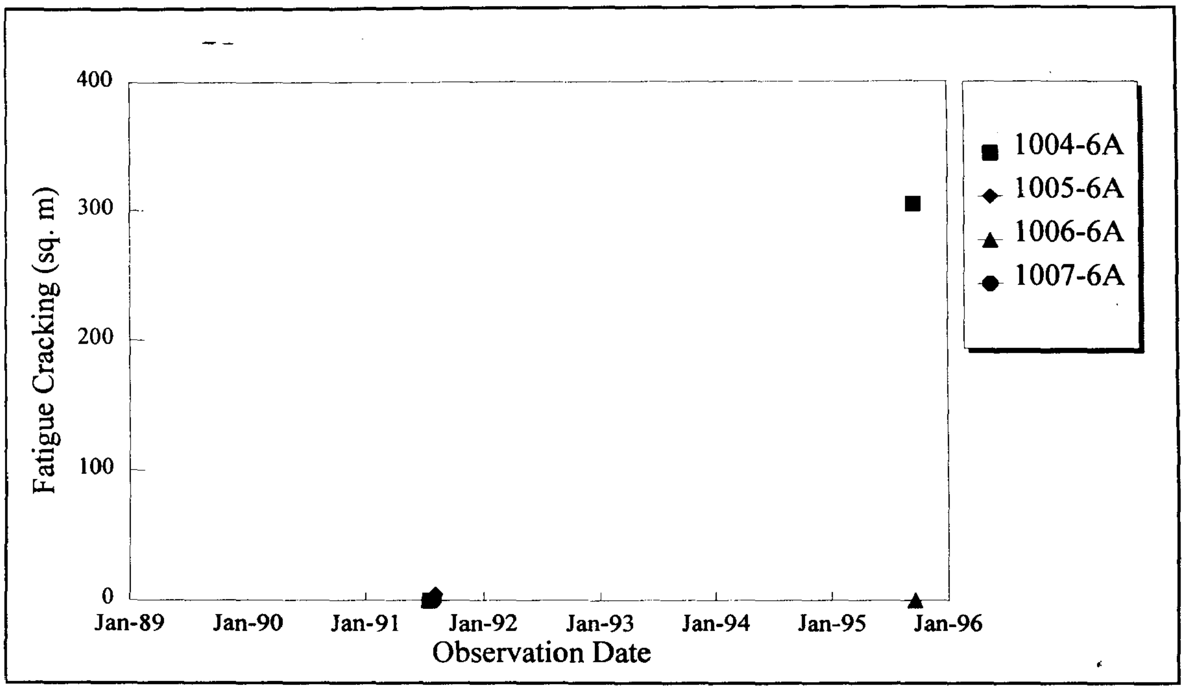
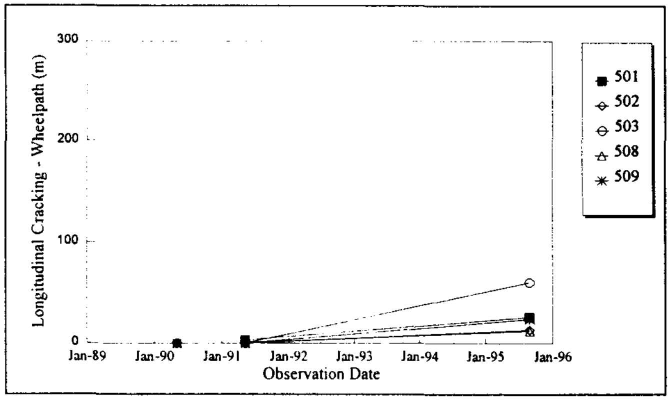


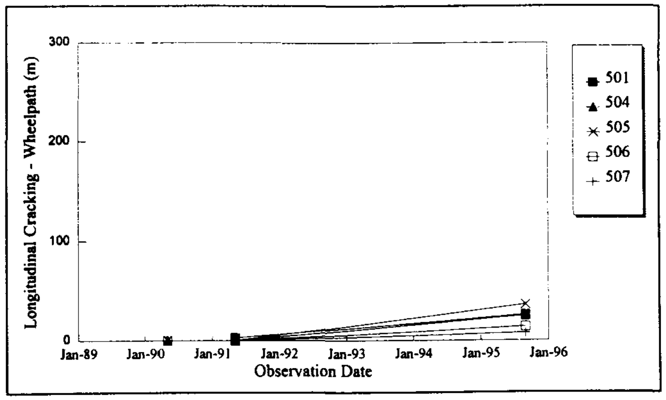
Figure 19. Fatigue cracking in Utah GPS-6 test sections.

APPENDIX E

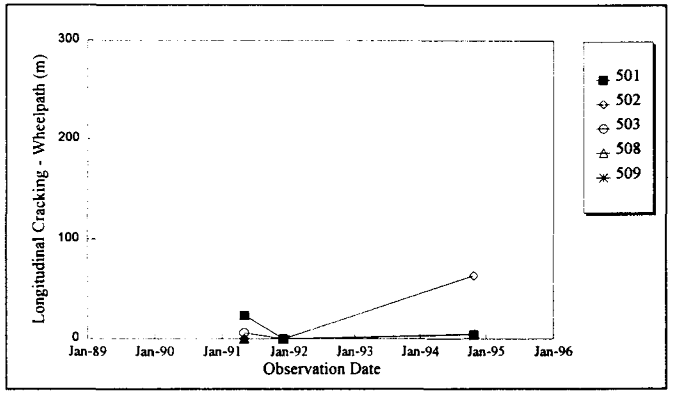
Graphs of Longitudinal Cracking in the Wheel Path for SPS-5 Projects and GPS-6 Test Sections



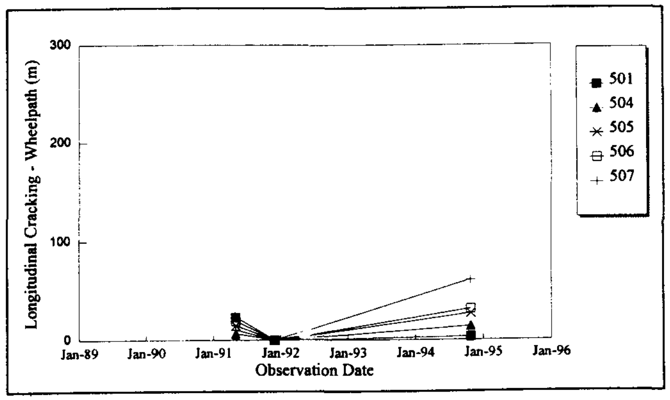
a. Longitudinal cracking in wheel path
in recycled overlay mixtures in Alberta.



b. Longitudinal cracking in wheel path
in virgin overlay mixtures in Alberta.

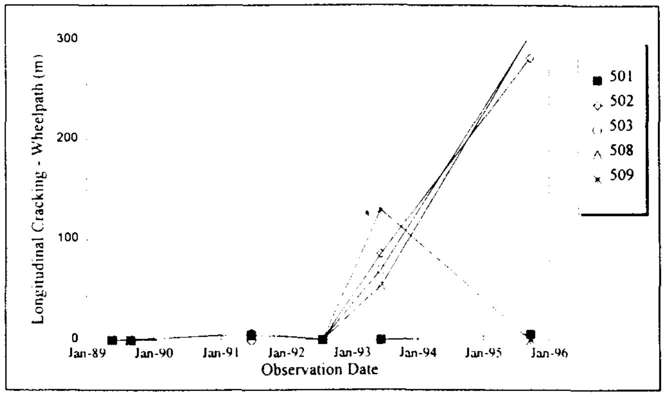


c. Longitudinal cracking in wheel path
in recycled overlay mixtures in Colorado.

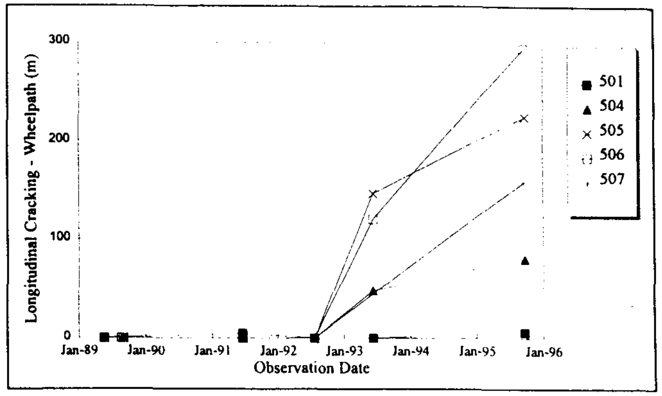


d. Longitudinal cracking in wheel path
in virgin overlay mixtures in Colorado.

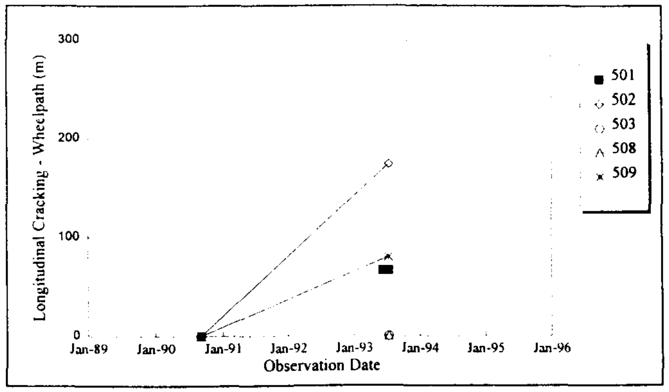
Figure 20. Longitudinal cracking in wheel path in Alberta and Colorado for the SPS-5 project.



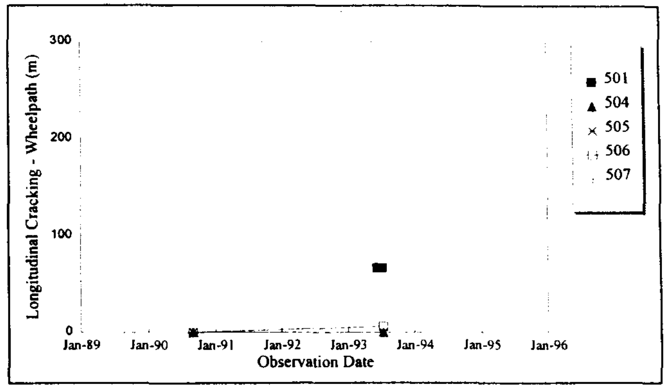
a. Longitudinal cracking in wheel path
in recycled overlay mixtures in Manitoba.



b. Longitudinal cracking in wheel path
in virgin overlay mixtures in Manitoba.



c. Longitudinal cracking in wheel path
in recycled overlay mixtures in Mississippi.



d. Longitudinal cracking in wheel path
in virgin overlay mixtures in Mississippi.

Figure 21. Longitudinal cracking in wheel path in Manitoba and Mississippi for the SPS-5 project.

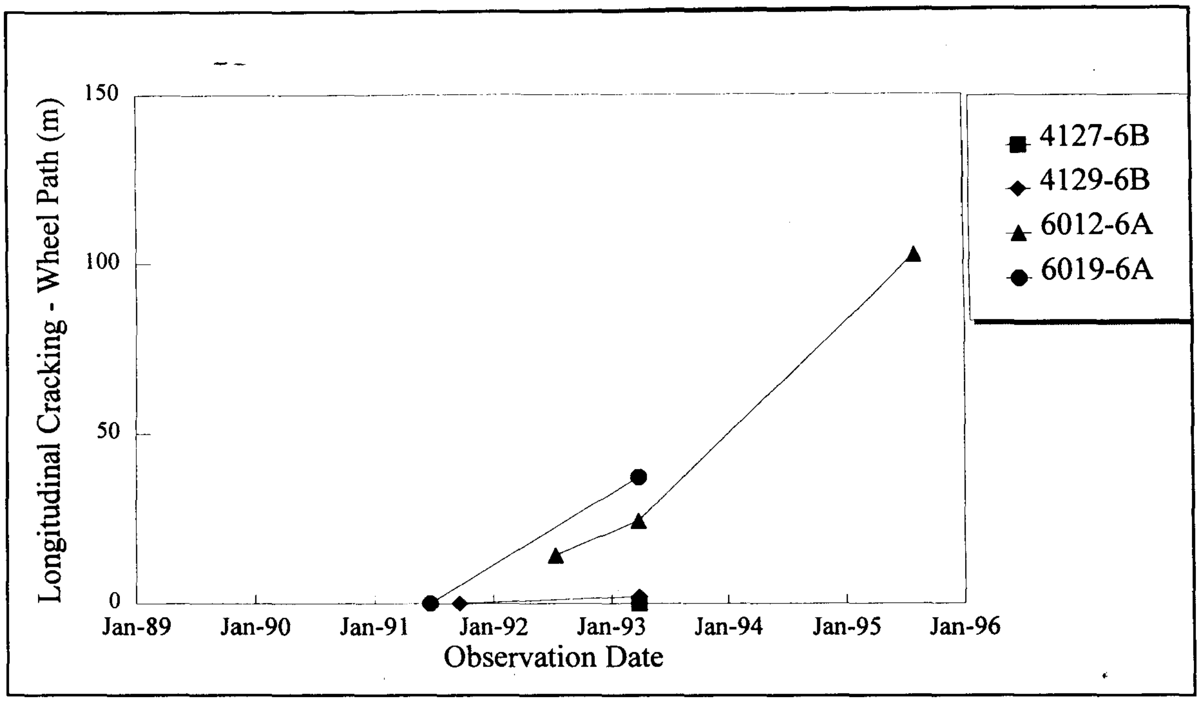


Figure 22. Longitudinal cracking in wheel paths in Alabama GPS-6 test sections.

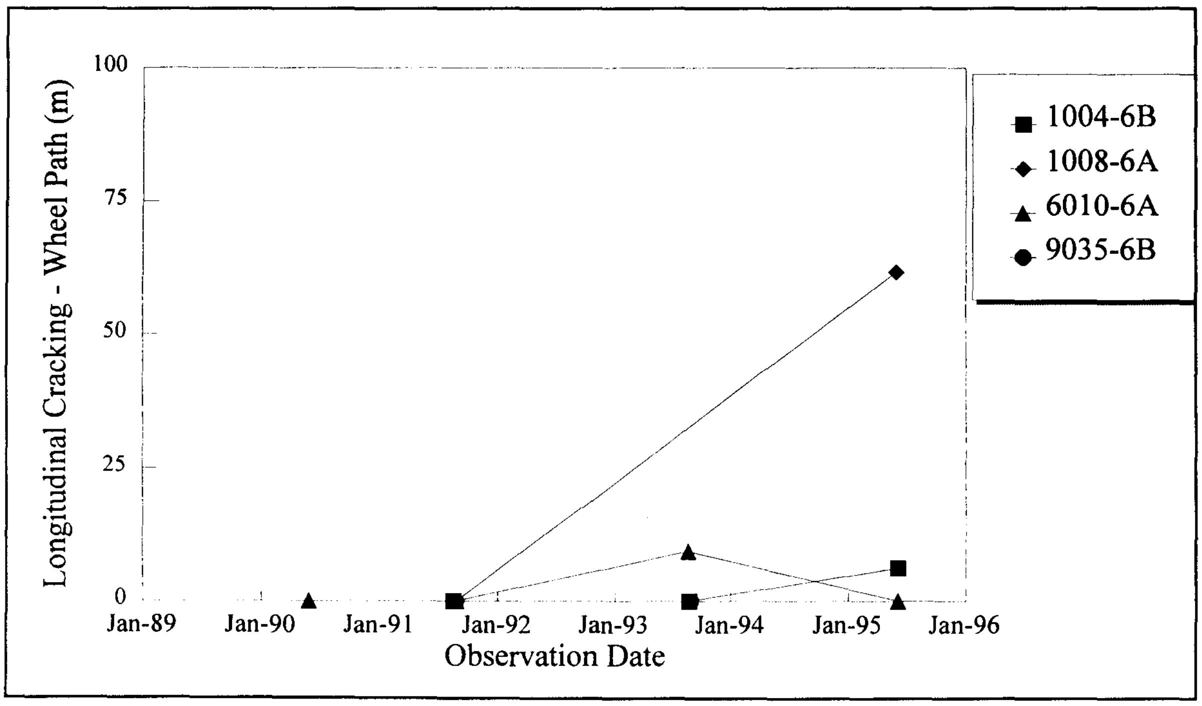


Figure 23. Longitudinal cracking in wheel paths in Alaska GPS-6 test sections.

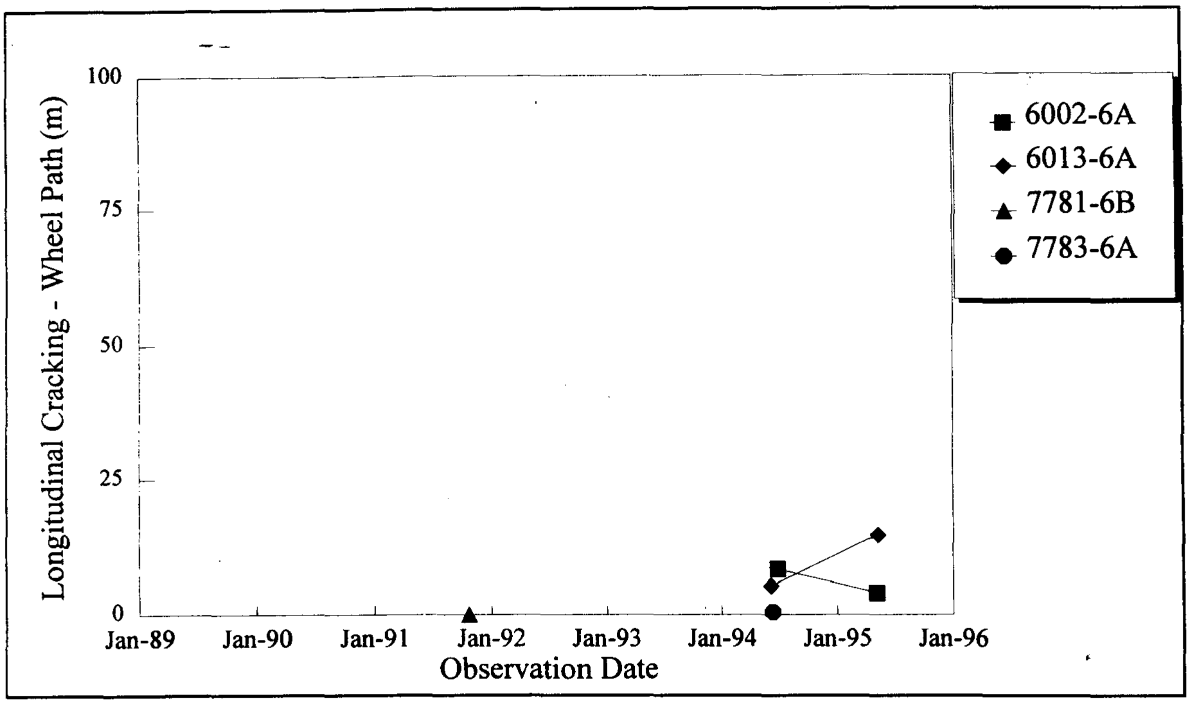


Figure 24. Longitudinal cracking in wheel paths in Colorado GPS-6 test sections.

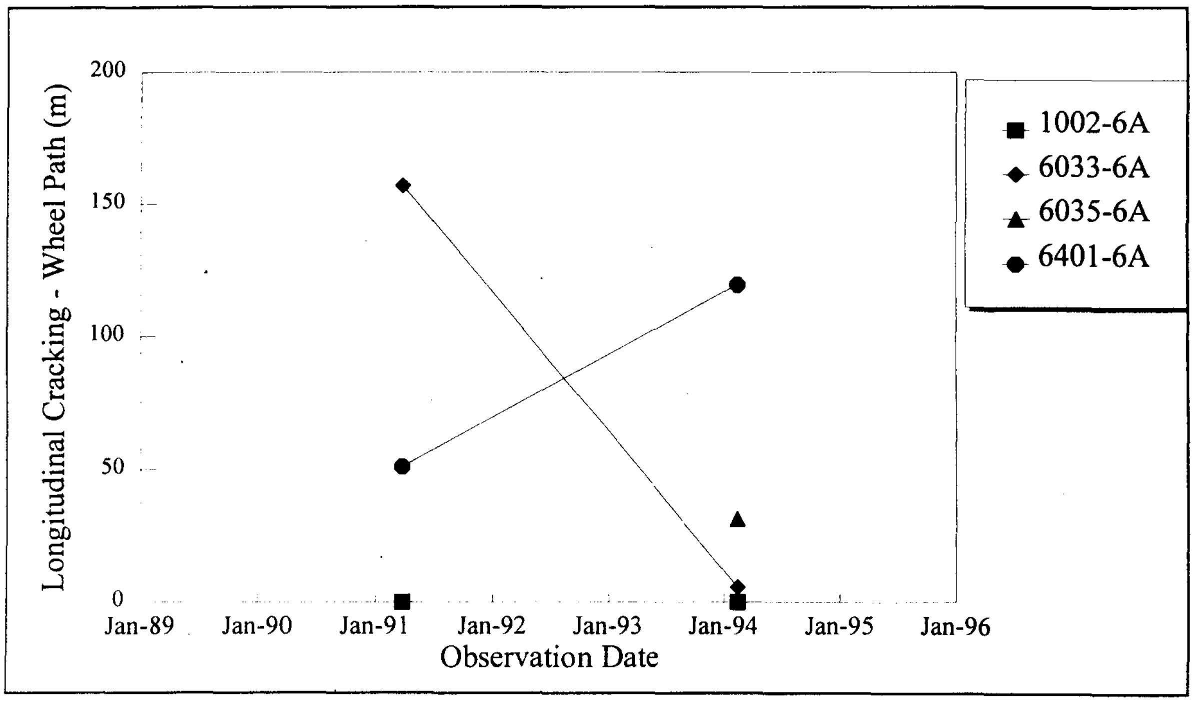


Figure 25. Longitudinal cracking in wheel paths in New Mexico GPS-6 test sections.

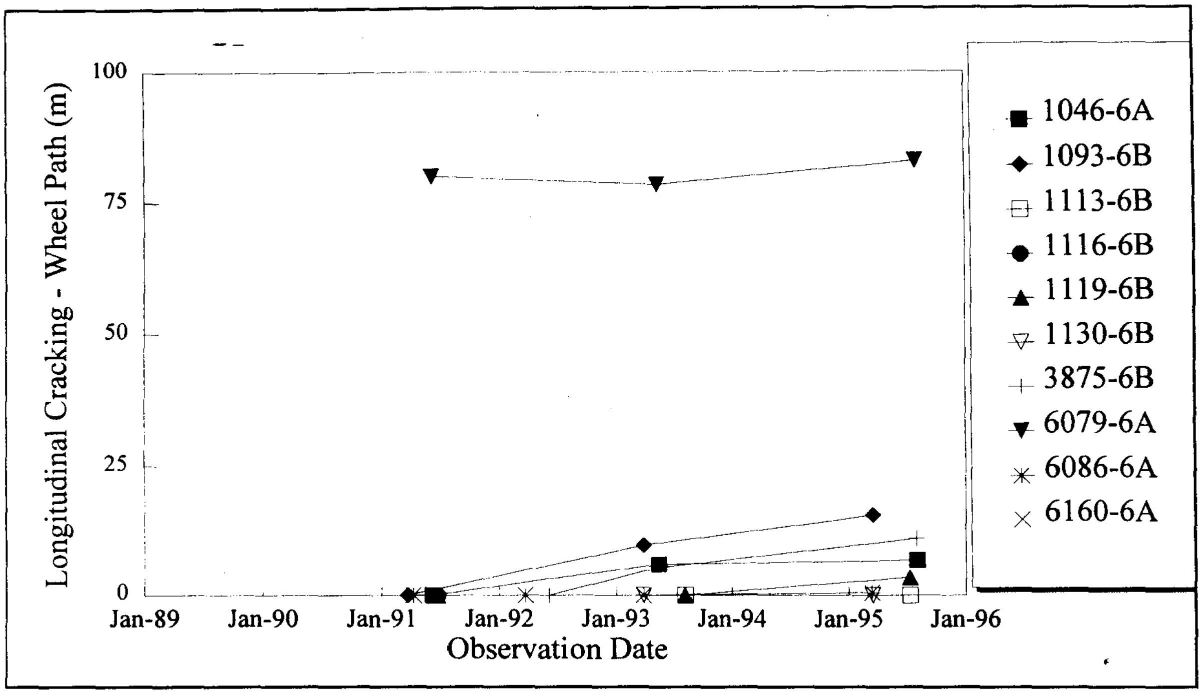
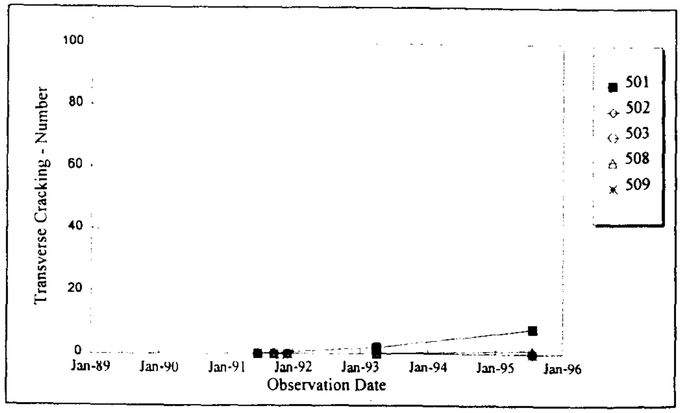


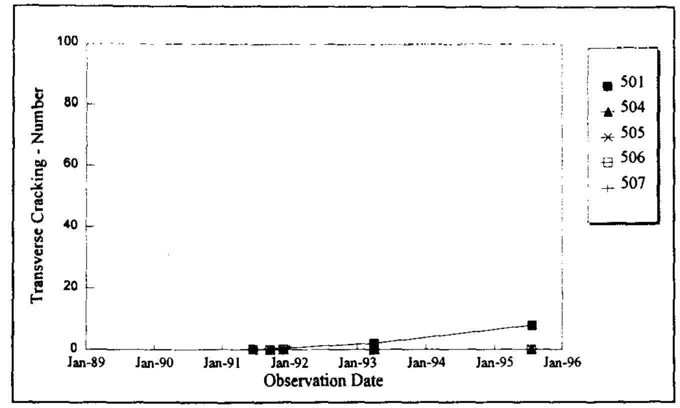
Figure 26. Longitudinal cracking in wheel paths in Texas GPS-6 test sections.

APPENDIX F

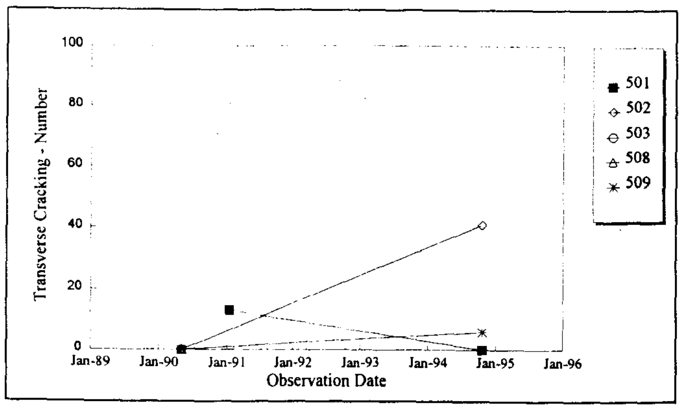
Graphs of Transverse Cracking for SPS-5 Projects and GPS-6 Test Sections



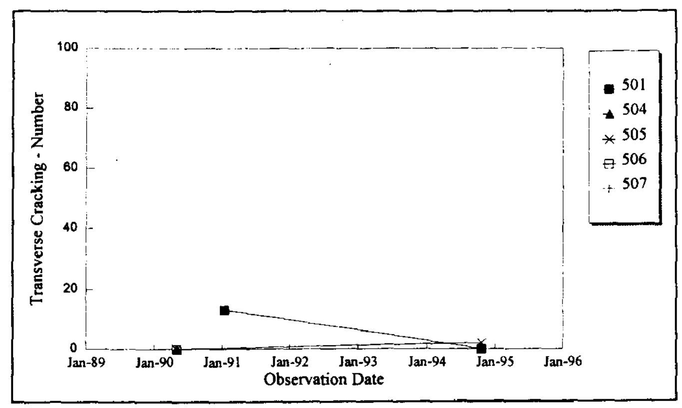
a. Transverse cracking, number, in recycled overlay mixtures in Alabama.



b. Transverse cracking, number, in virgin overlay mixtures in Alabama.

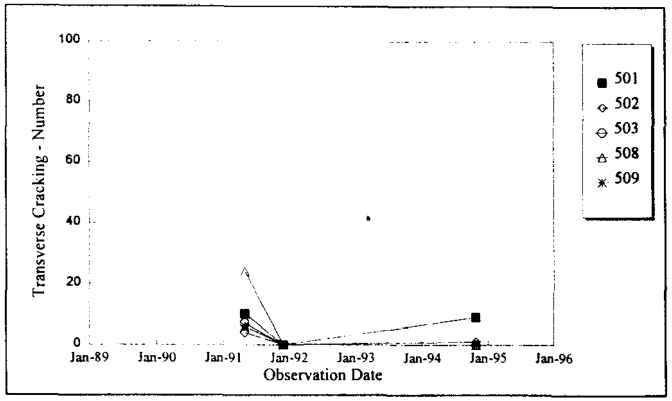


c. Transverse cracking, number, in recycled overlay mixtures in Arizona.

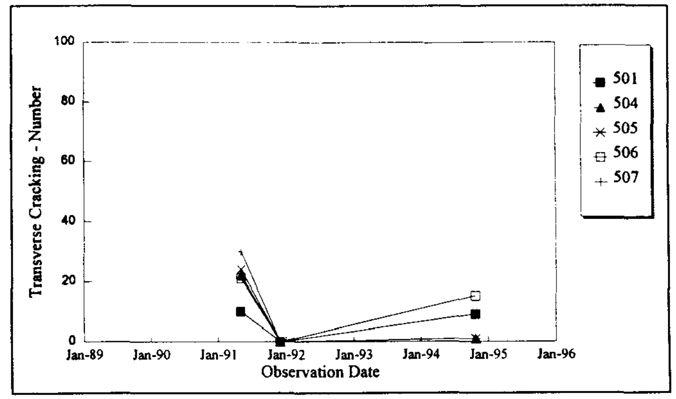


d. Transverse cracking, number, in virgin overlay mixtures in Arizona.

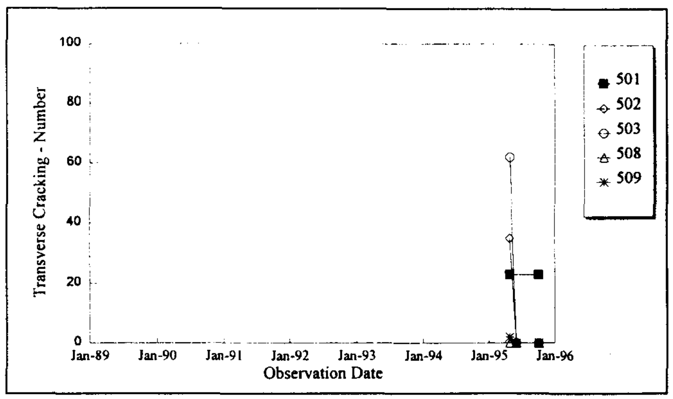
Figure 27. Transverse cracking, number, in Alabama and Arizona for the SPS-5 project.



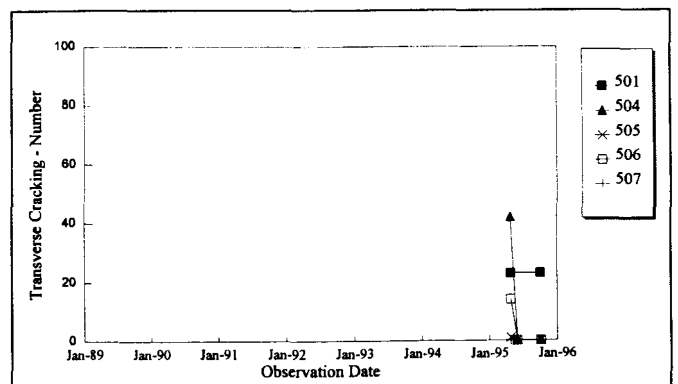
a. Transverse cracking, number, in recycled overlay mixtures in Colorado.



b. Transverse cracking, number, in virgin overlay mixtures in Colorado.

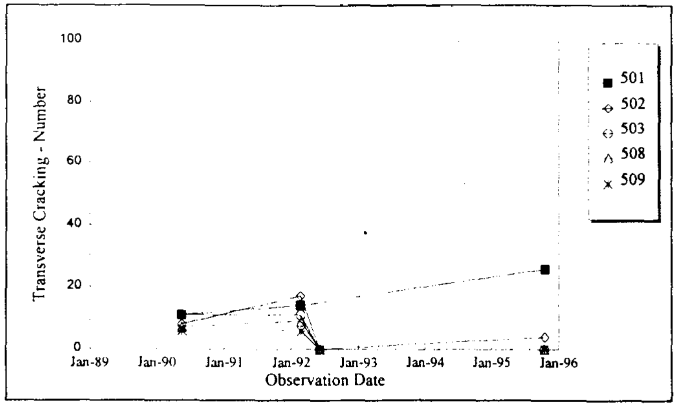


c. Transverse cracking, number, in recycled overlay mixtures in Maine.

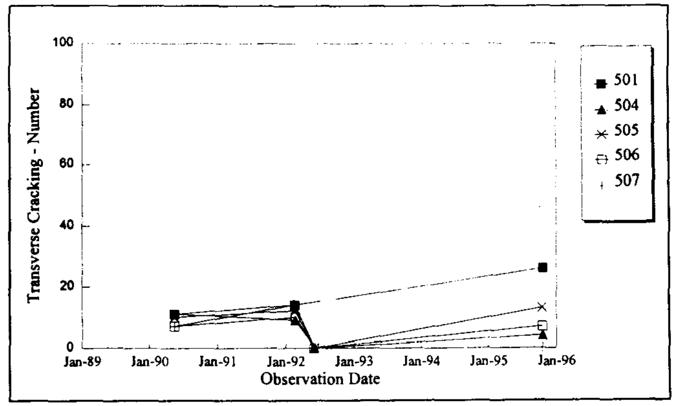


d. Transverse cracking, number, in virgin overlay mixtures in Maine.

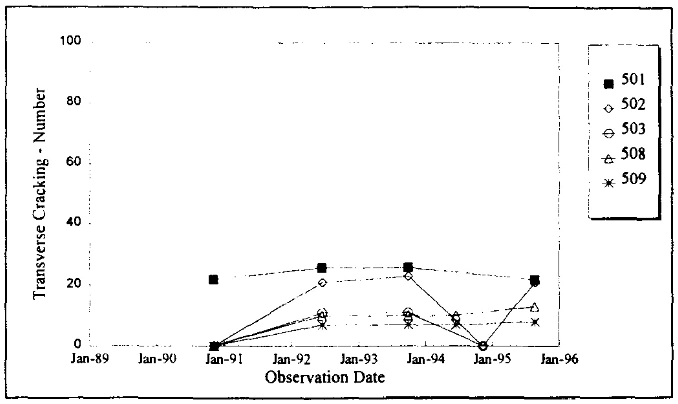
Figure 28. Transverse cracking, number, in Colorado and Maine for the SPS-5 project.



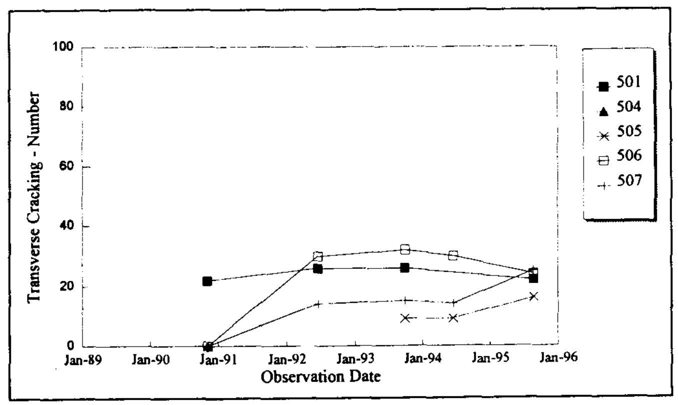
a. Transverse cracking, number,
in recycled overlay mixtures in Maryland.



b. Transverse cracking, number,
in virgin overlay mixtures in Maryland.

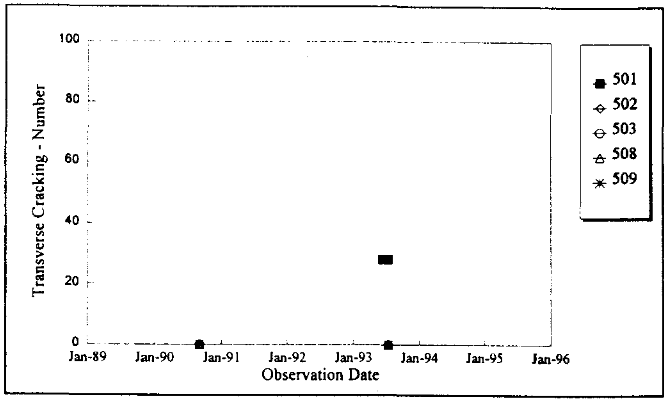


c. Transverse cracking, number,
in recycled overlay mixtures in Minnesota.

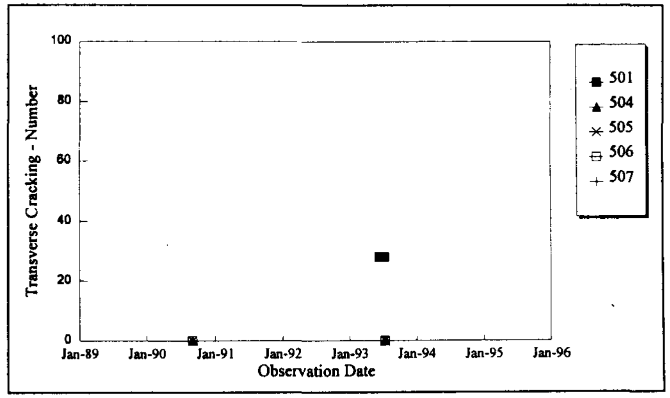


d. Transverse cracking, number,
in virgin overlay mixtures in Minnesota.

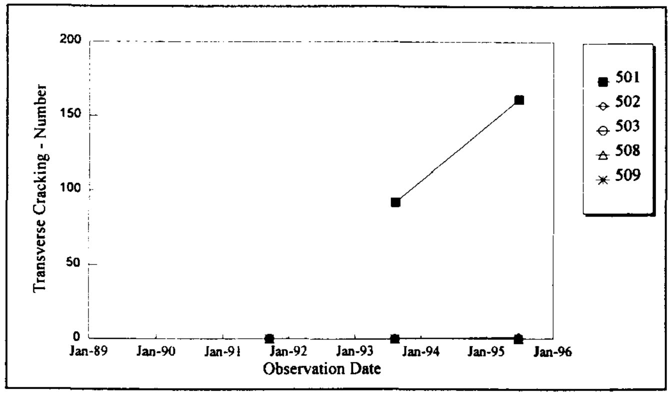
Figure 29. Transverse cracking, number, in Maryland and Minnesota for the SPS-5 project.



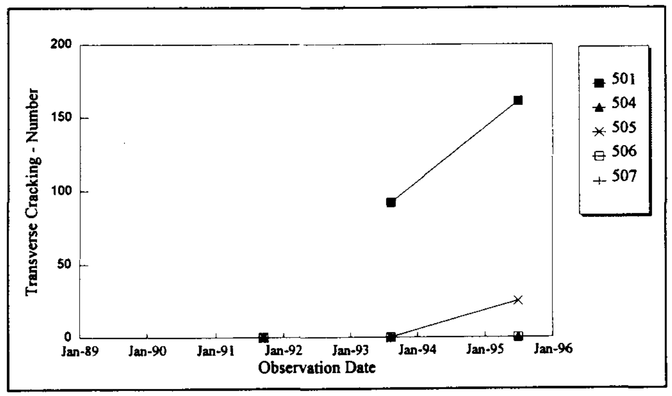
a. Transverse cracking, number,
in recycled overlay mixtures in Mississippi.



b. Transverse cracking, number,
in virgin overlay mixtures in Mississippi.



c. Transverse cracking, number,
in recycled overlay mixtures in Texas.



d. Transverse cracking, number,
in virgin overlay mixtures in Texas.

Figure 30. Transverse cracking, number, in Mississippi and Texas for the SPS-5 project.

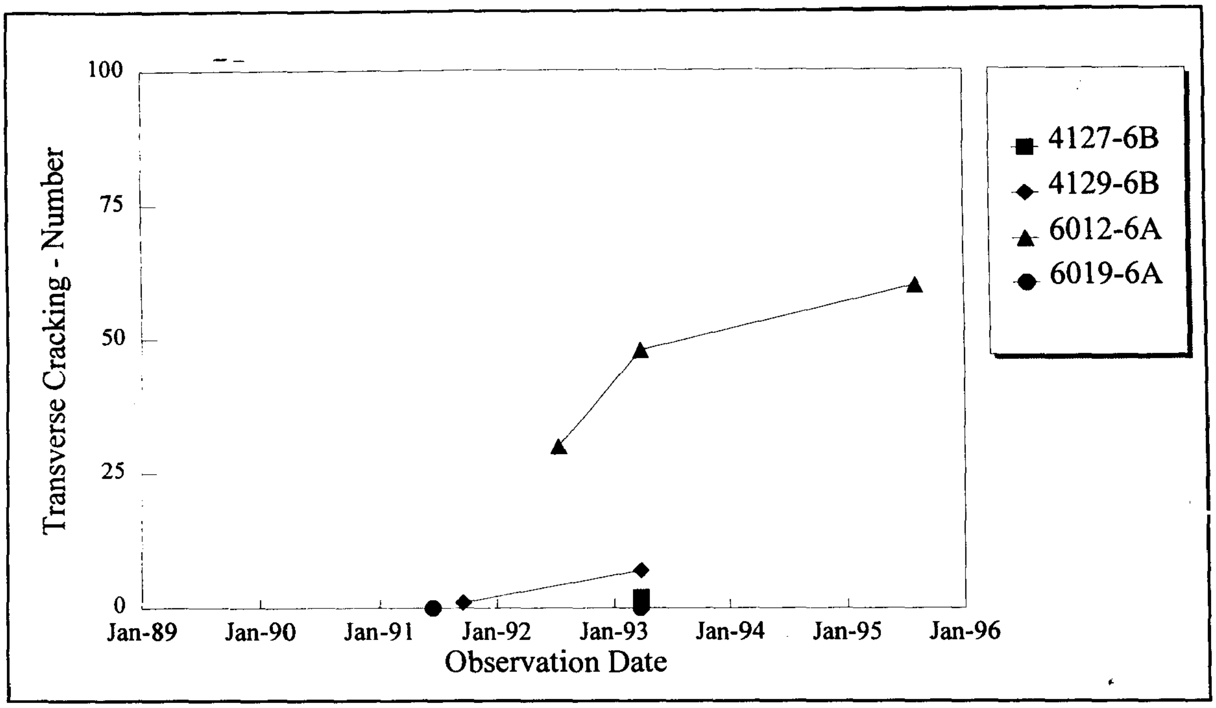


Figure 31. Number of transverse cracks in Alabama GPS-6 test sections.

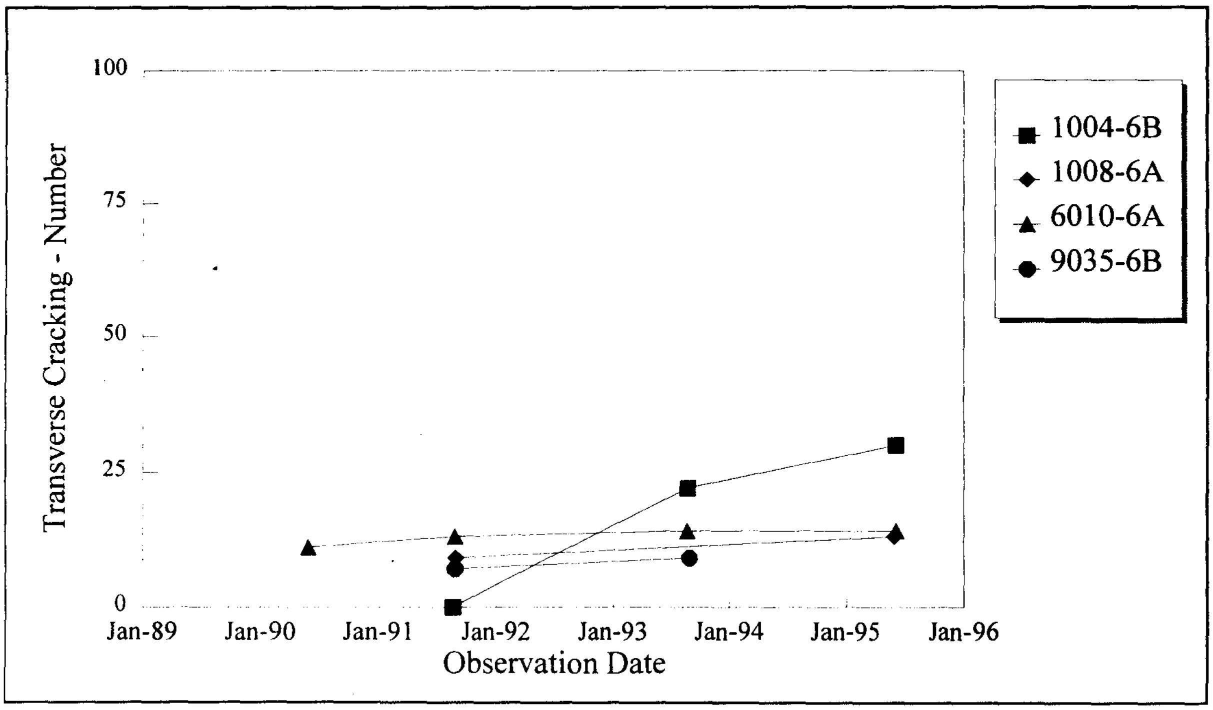


Figure 32. Number of transverse cracks in Alaska GPS-6 test sections.

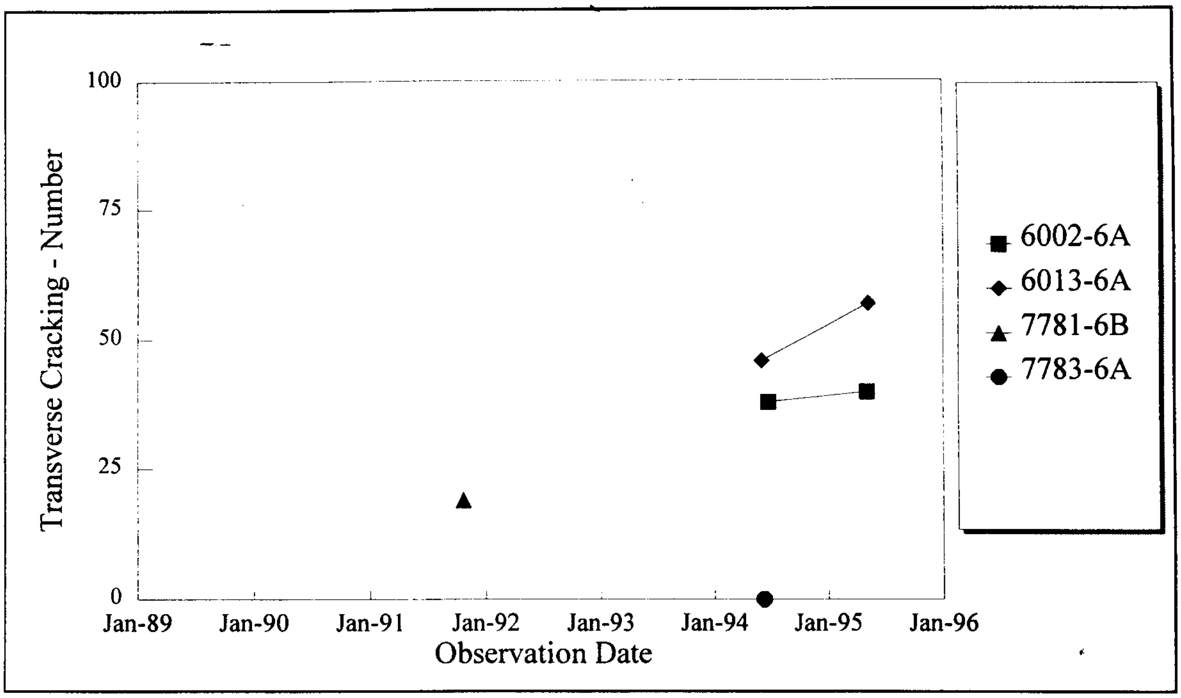


Figure 33. Number of transverse cracks in Colorado GPS-6 test sections.

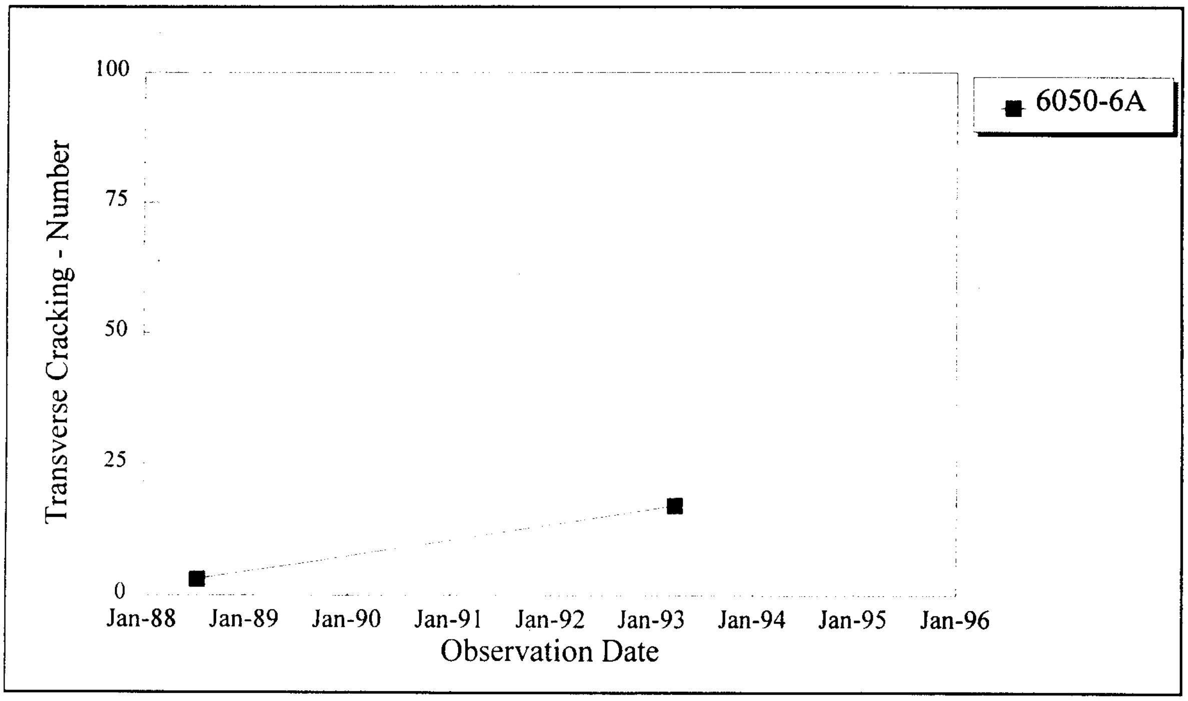


Figure 34. Number of transverse cracks in Illinois GPS-6 test sections.

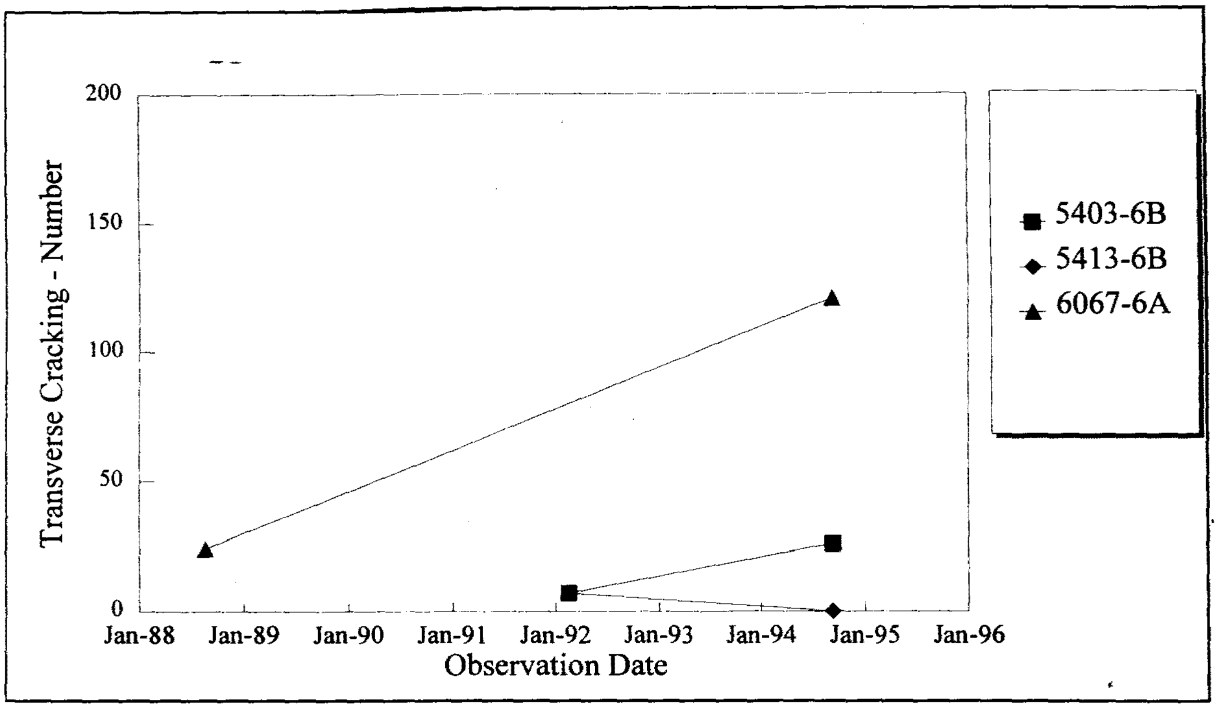


Figure 35. Number of transverse cracks in Missouri GPS-6 test sections.

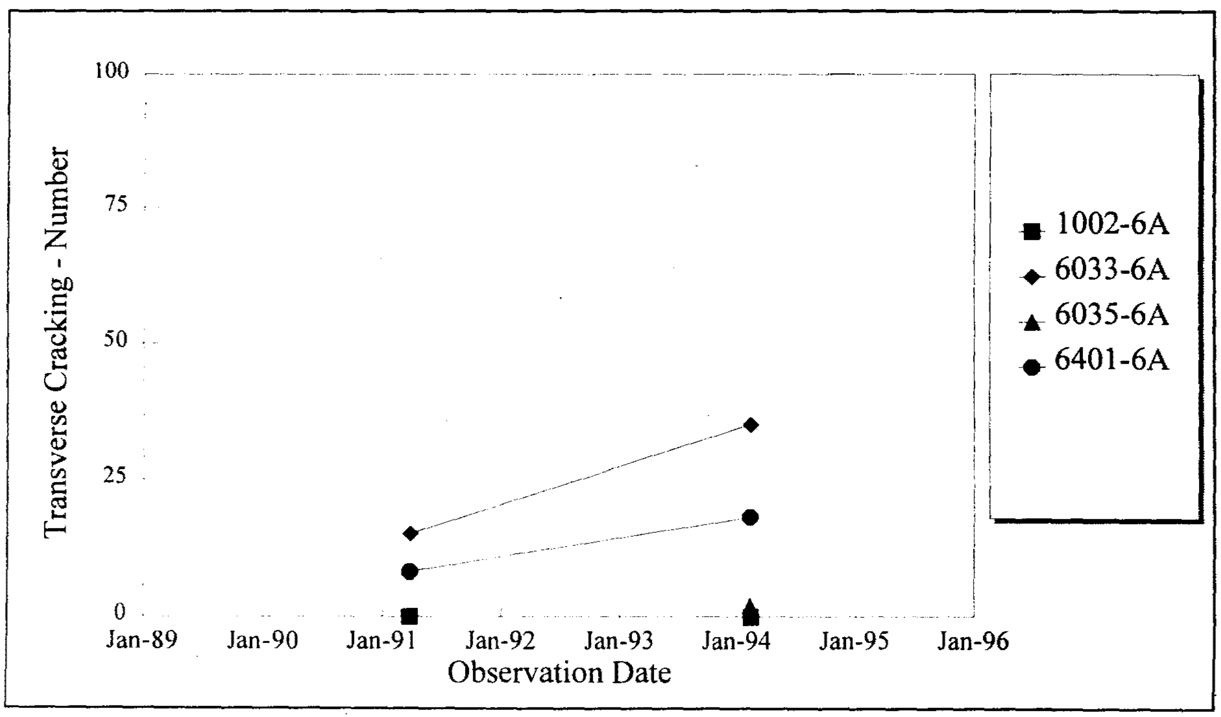


Figure 36. Number of transverse cracks in New Mexico GPS-6 test sections.

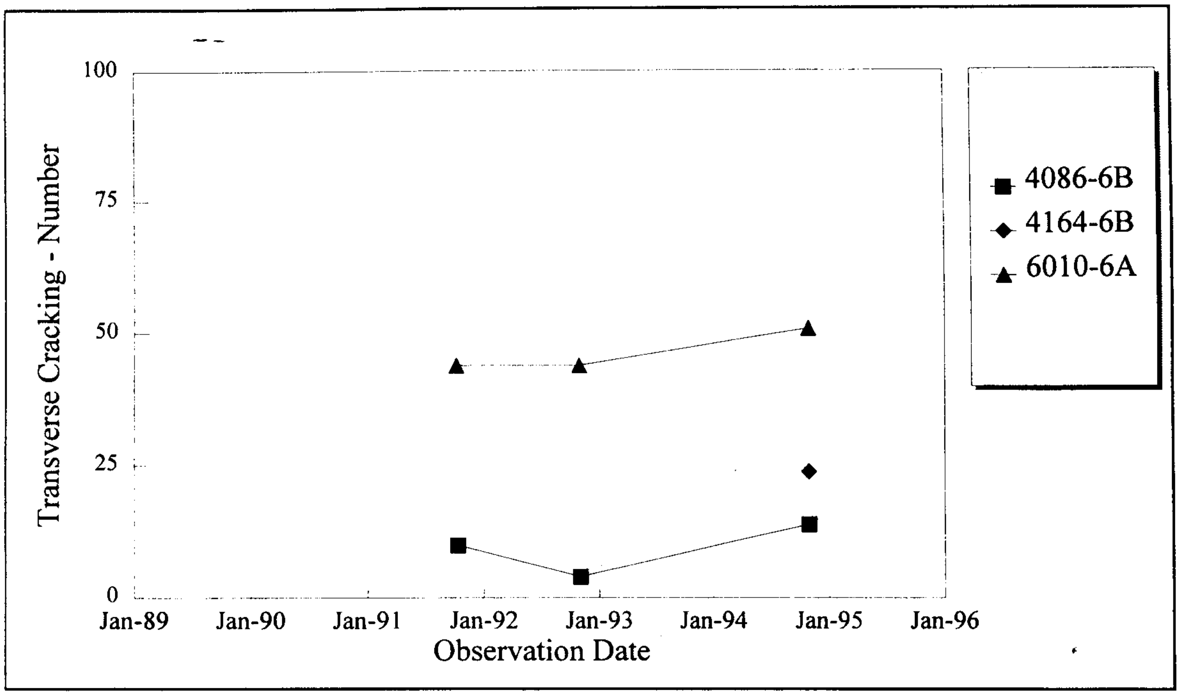


Figure 37. Number of transverse cracks in Oklahoma GPS-6 test sections.

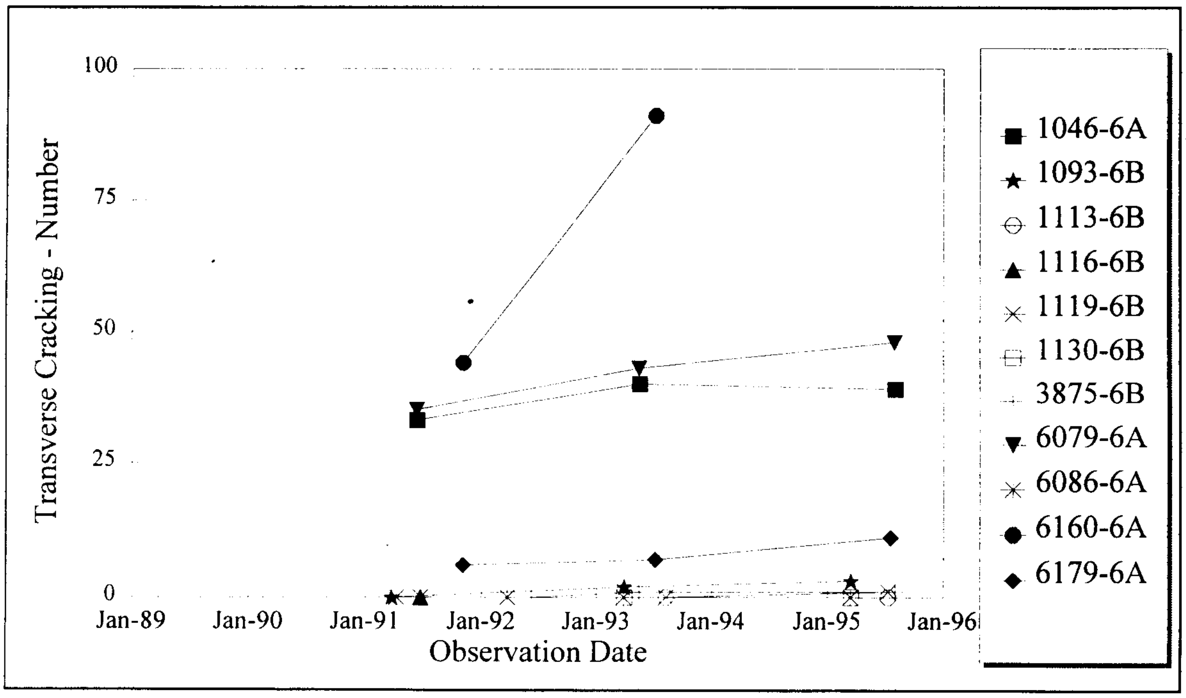


Figure 38. Number of transverse cracks in Texas GPS-6 test sections.

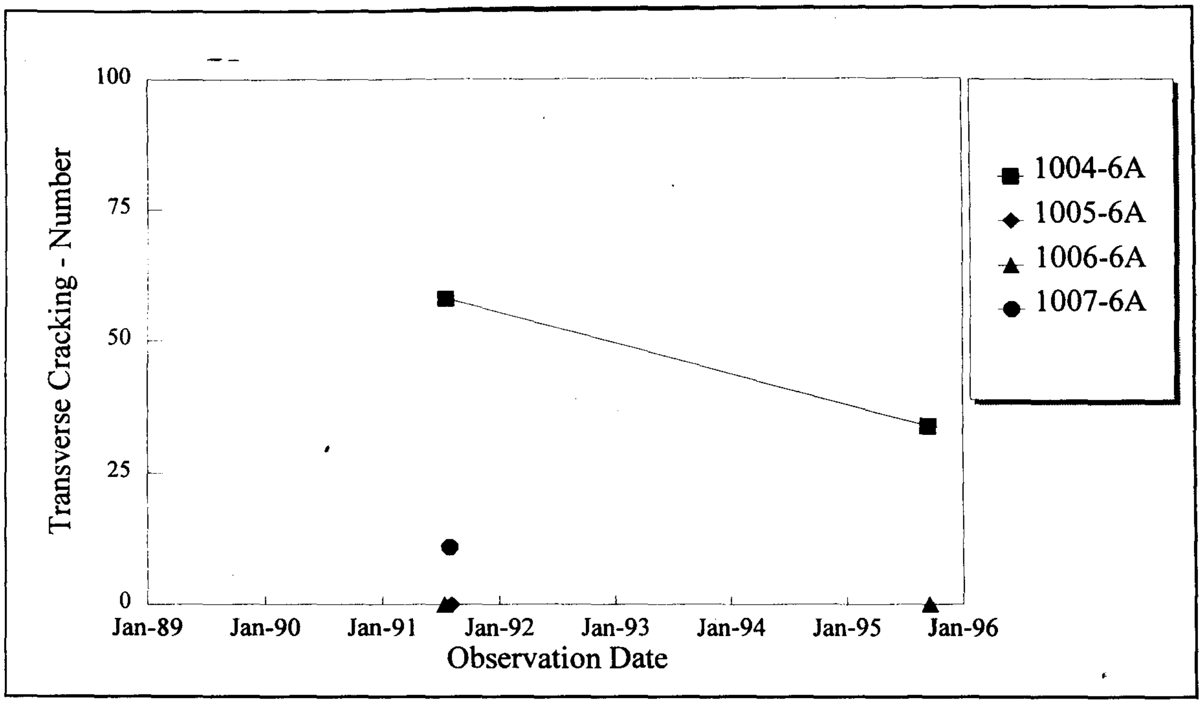
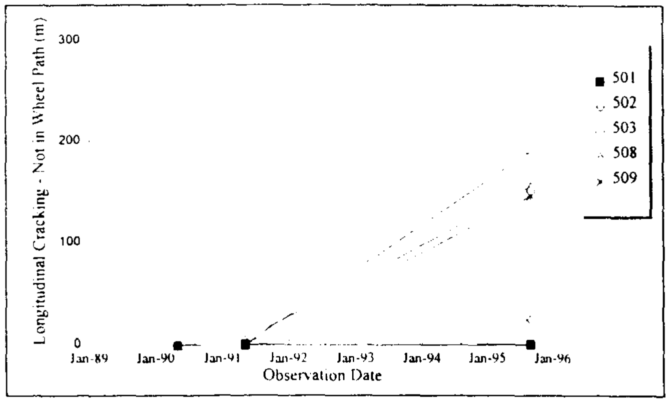


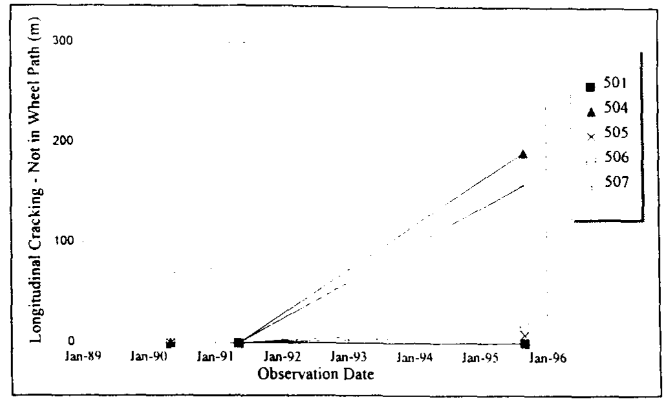
Figure 39. Number of transverse cracks in Utah GPS-6 test sections.

APPENDIX G

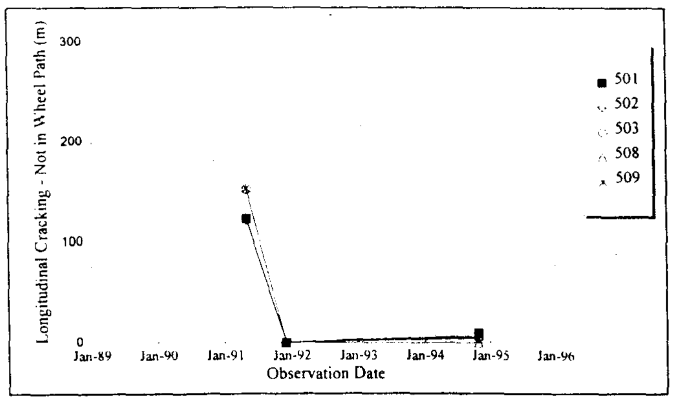
Graphs of Longitudinal Cracking Not in the Wheel Path for SPS-5 Projects and GPS-6 Test Sections



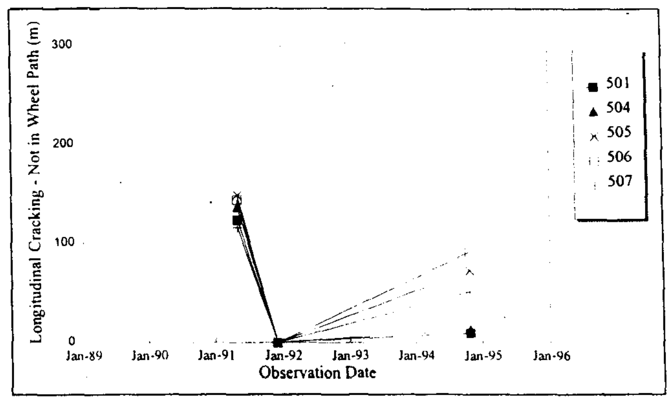
a. Longitudinal cracking not in wheel path in recycled overlay mixtures in Alberta.



b. Longitudinal cracking not in wheel path in virgin overlay mixtures in Alberta.

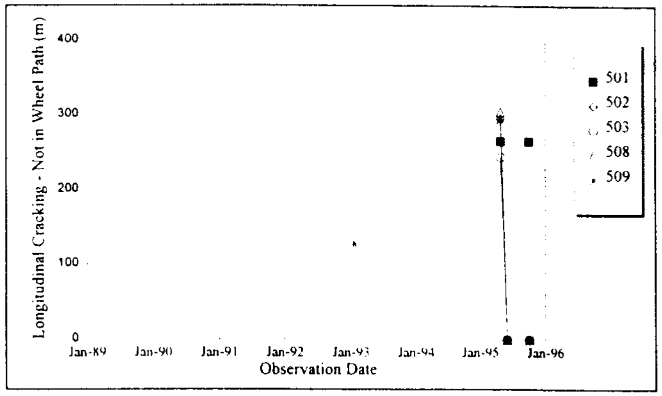


c. Longitudinal cracking not in wheel path in recycled overlay mixtures in Colorado.

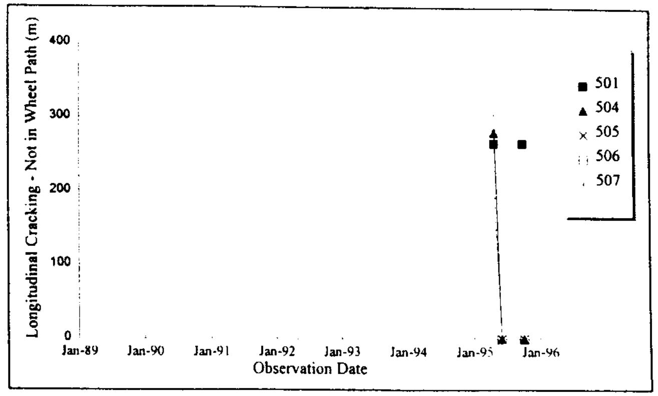


d. Longitudinal cracking not in wheel path in virgin overlay mixtures in Colorado.

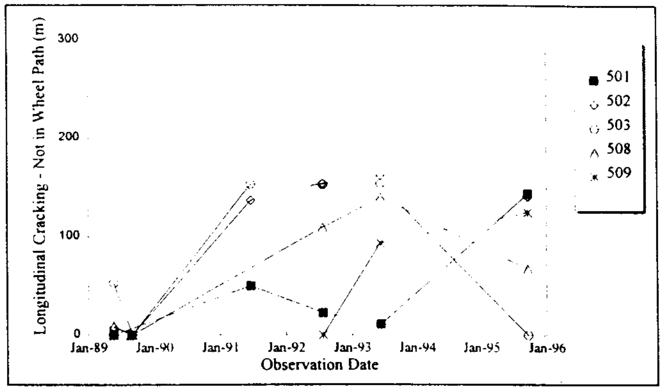
Figure 40. Longitudinal cracking not in wheel path in Alberta and Colorado for the SPS-5 project.



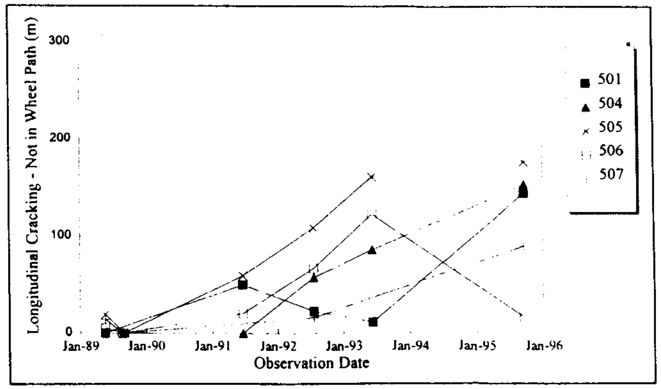
a. Longitudinal cracking not in wheel path in recycled overlay mixtures in Maine.



b. Longitudinal cracking not in wheel path in virgin overlay mixtures in Maine.

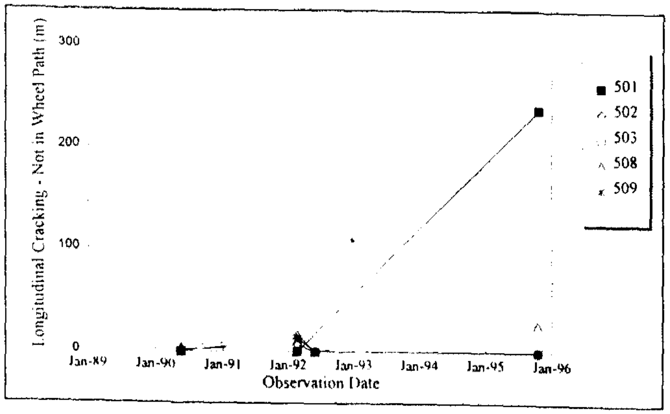


c. Longitudinal cracking not in wheel path in recycled overlay mixtures in Manitoba.

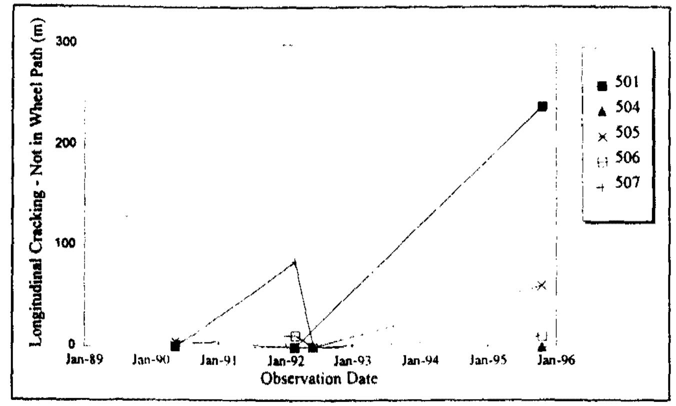


d. Longitudinal cracking not in wheel path in virgin overlay mixtures in Manitoba.

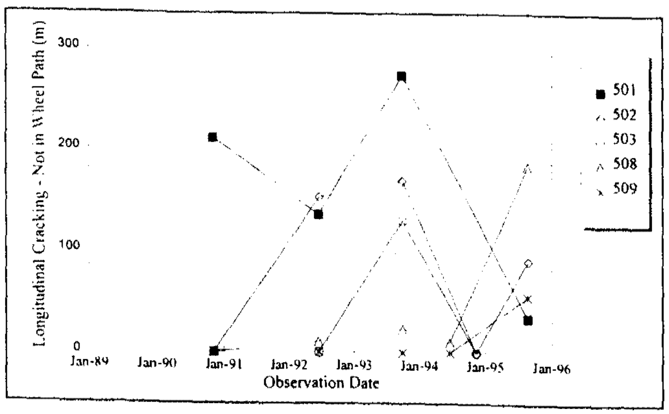
Figure 41. Longitudinal cracking not in wheel path in Maine and Manitoba for the SPS-5 project.



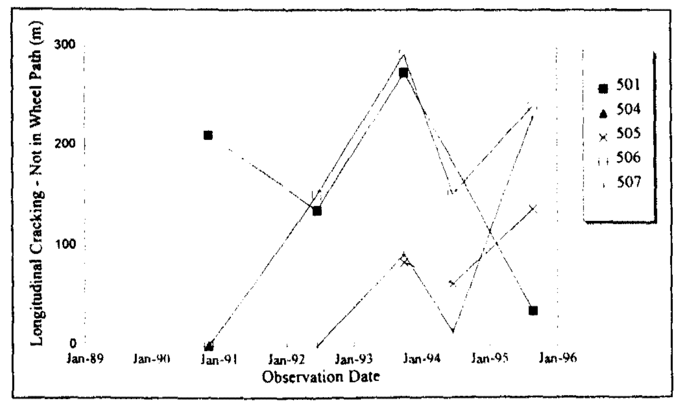
a. Longitudinal cracking not in wheel path in recycled overlay mixtures in Maryland.



b. Longitudinal cracking not in wheel path in virgin overlay mixtures in Maryland.

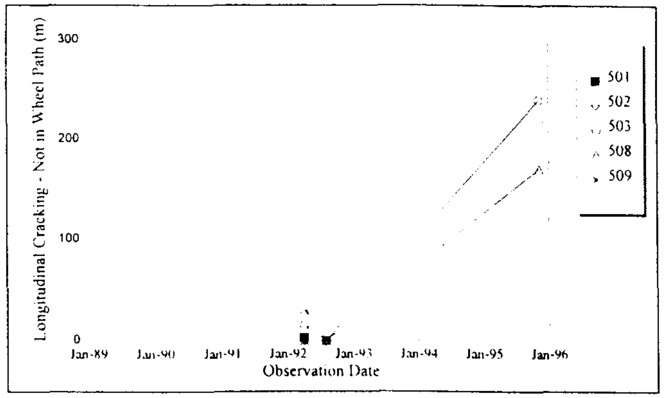


c. Longitudinal cracking not in wheel path in recycled overlay mixtures in Minnesota.

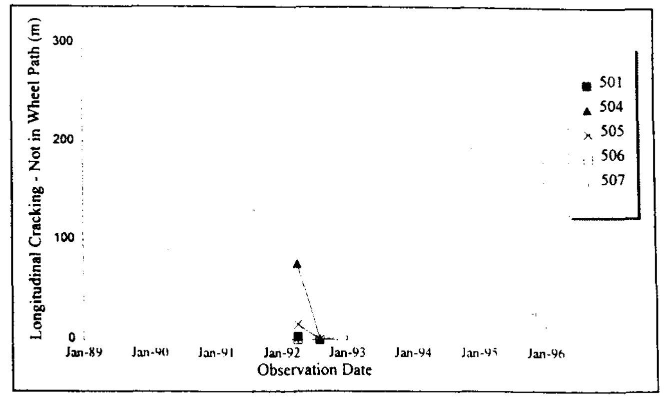


d. Longitudinal cracking not in wheel path in virgin overlay mixtures in Minnesota.

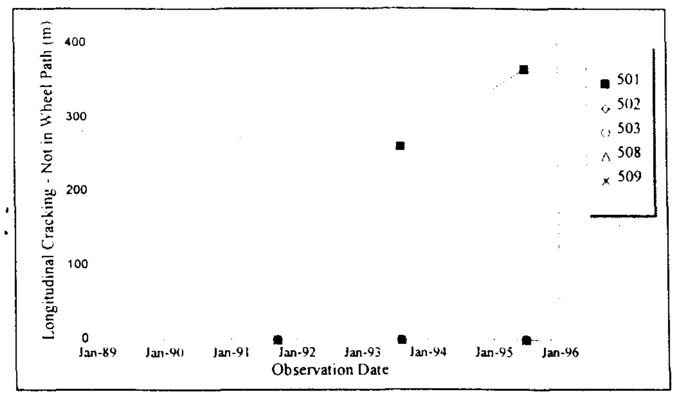
Figure 42. Longitudinal cracking not in wheel path in Maryland and Minnesota for the SPS-5 project.



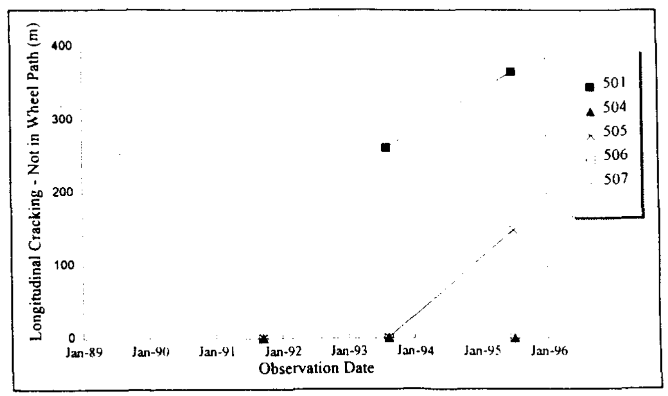
a. Longitudinal cracking not in wheel path in recycled overlay mixtures in New Jersey.



b. Longitudinal cracking not in wheel path in virgin overlay mixtures in New Jersey.



c. Longitudinal cracking not in wheel path in recycled overlay mixtures in Texas.



d. Longitudinal cracking not in wheel path in virgin overlay mixtures in Texas.

Figure 43. Longitudinal cracking not in wheel path in New Jersey and Texas for the SPS-5 project.

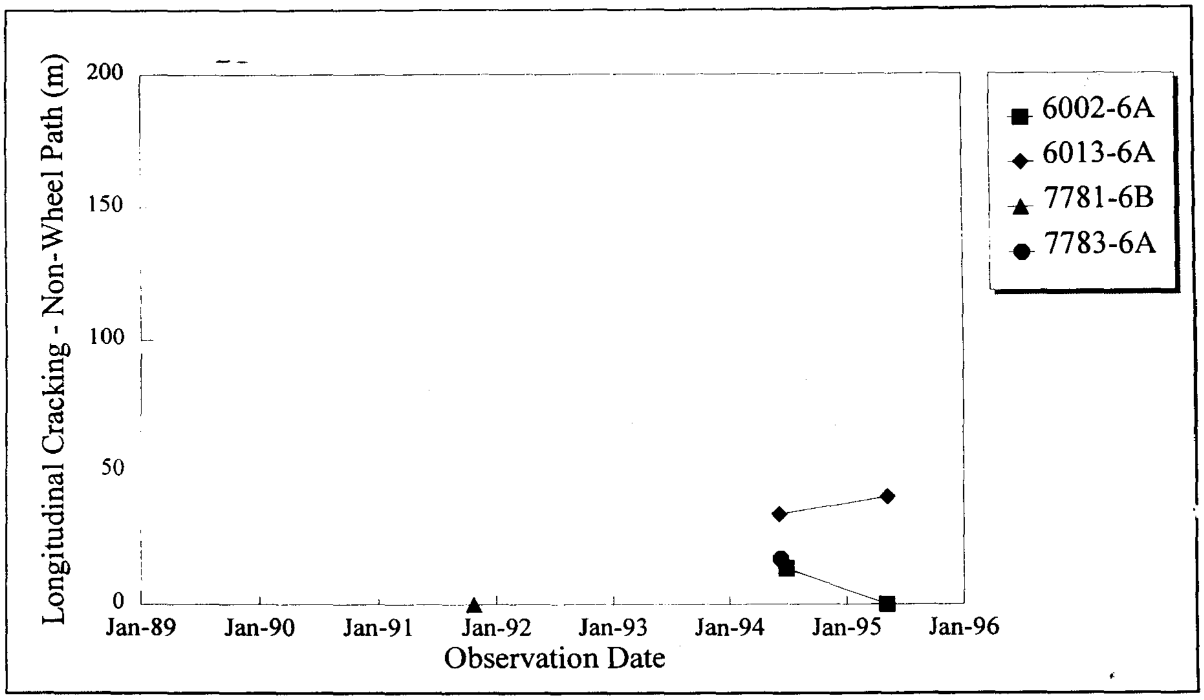


Figure 44. Longitudinal cracking not in wheel path in Colorado GPS-6 test sections.

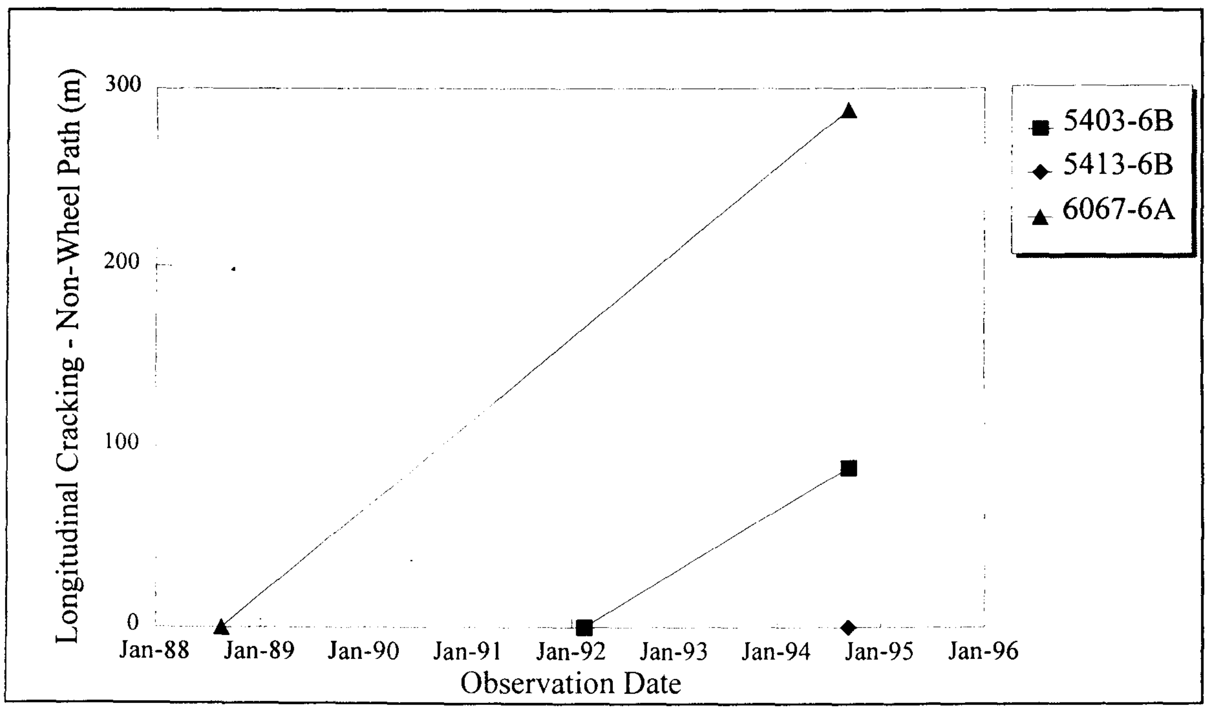


Figure 45. Longitudinal cracking not in wheel path in Missouri GPS-6 test sections.

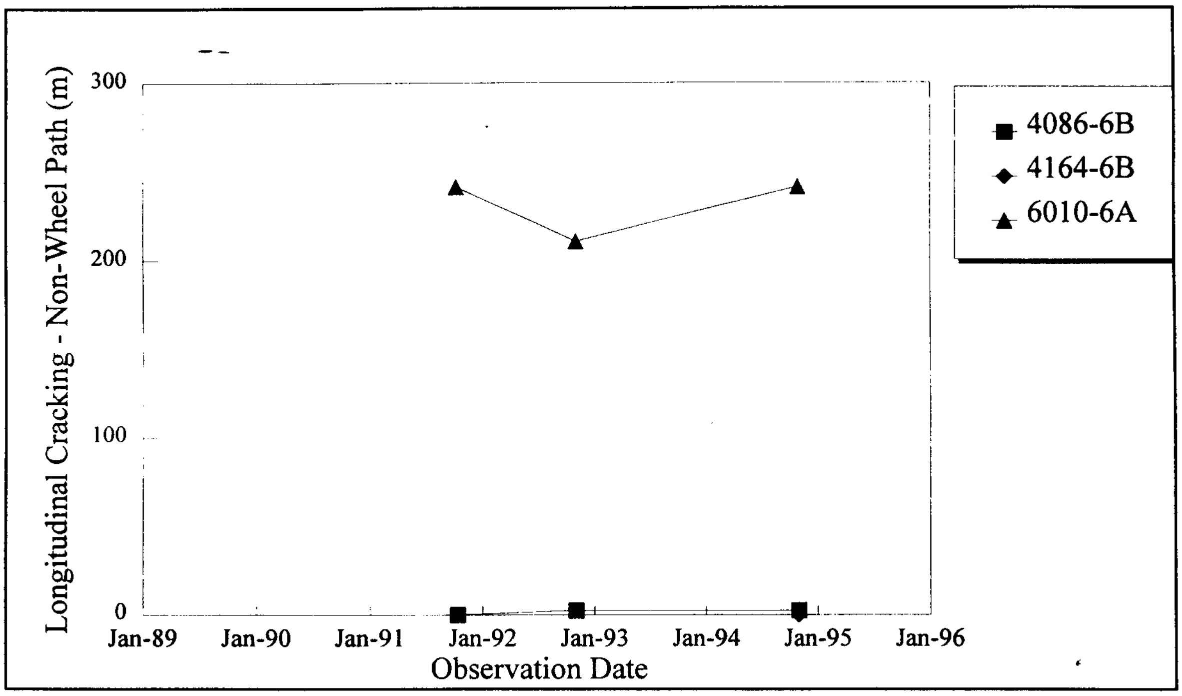


Figure 46. Longitudinal cracking not in wheel path in Oklahoma GPS-6 test sections.

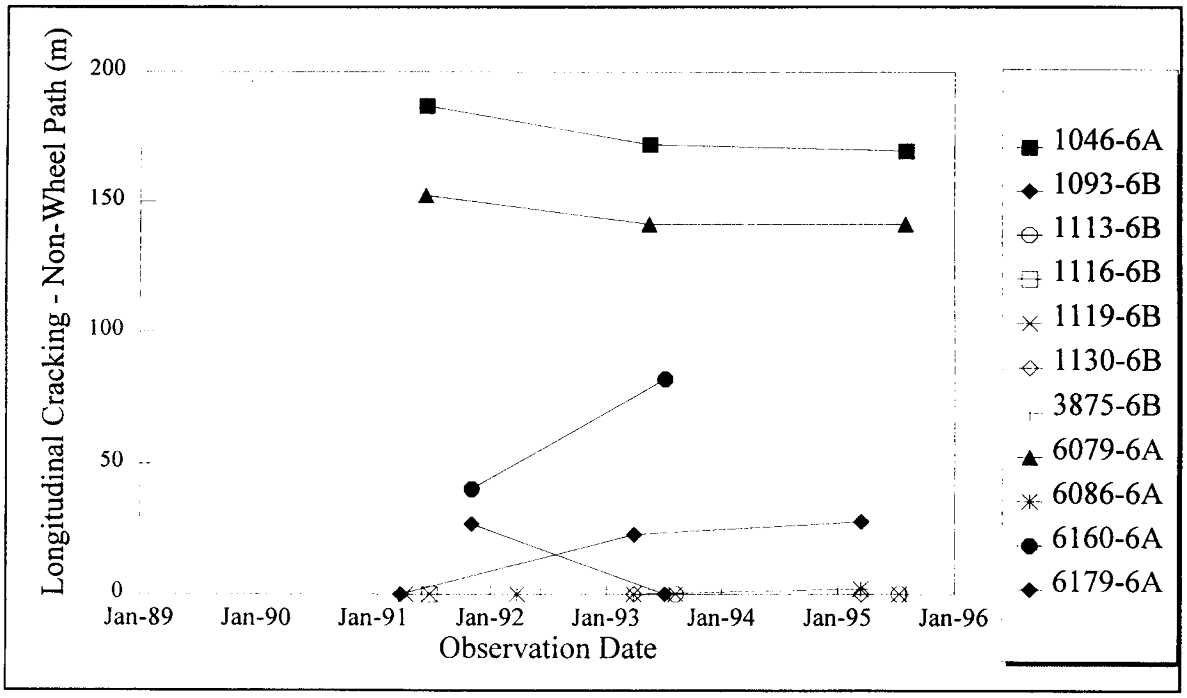


Figure 47. Longitudinal cracking not in wheel path in Texas GPS-6 test sections.

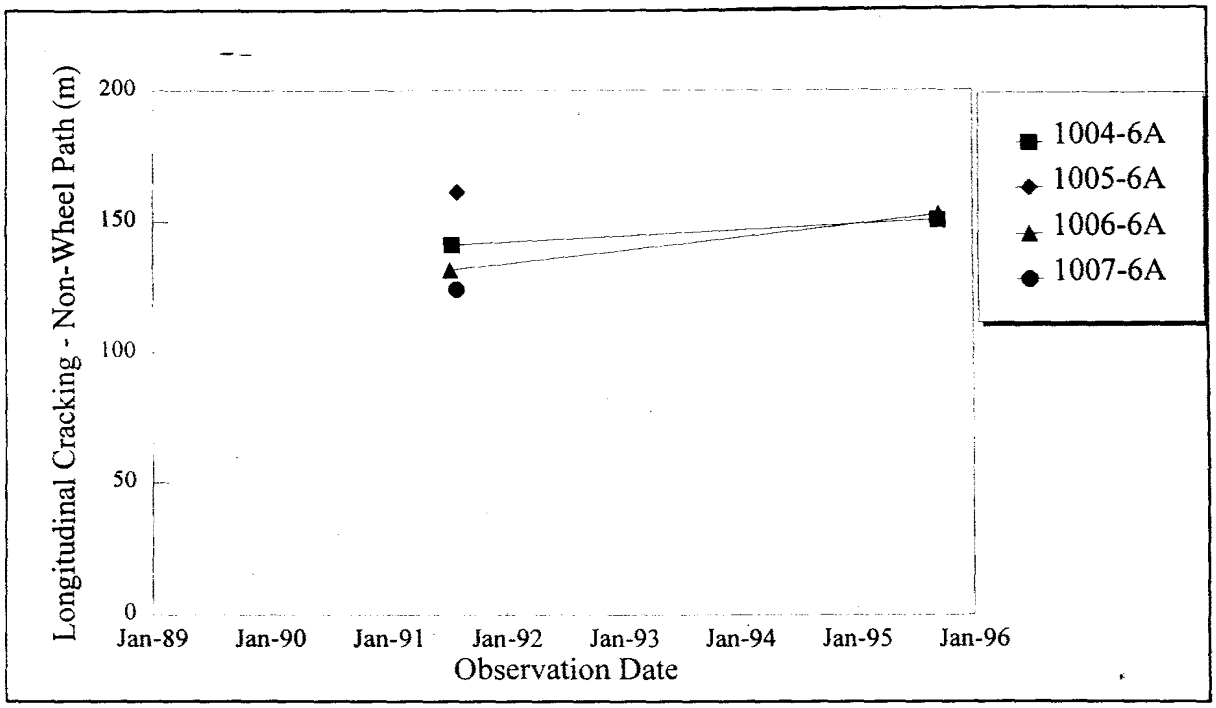
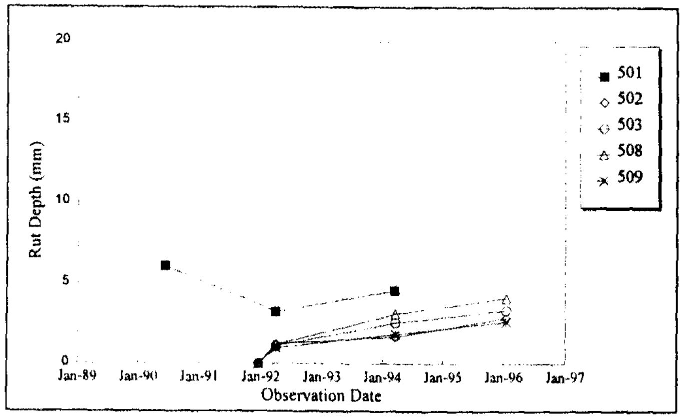


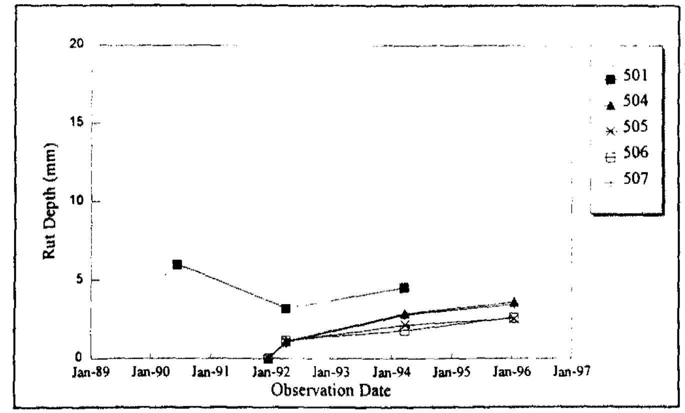
Figure 48. Longitudinal cracking not in wheel path in Utah GPS-6 test sections.

APPENDIX H

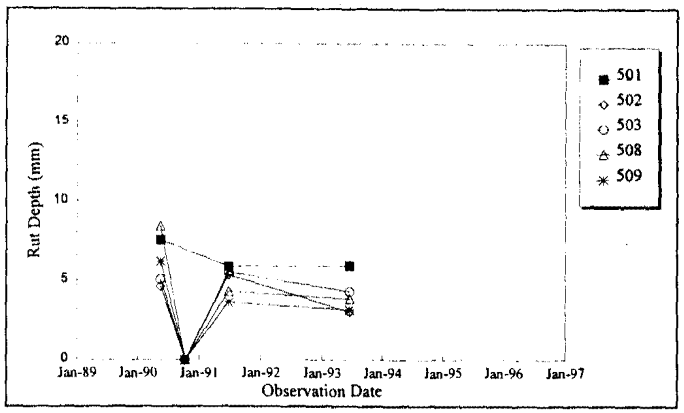
Graphs of Rut Depths for SPS-5 Projects and GPS-6 Test Sections



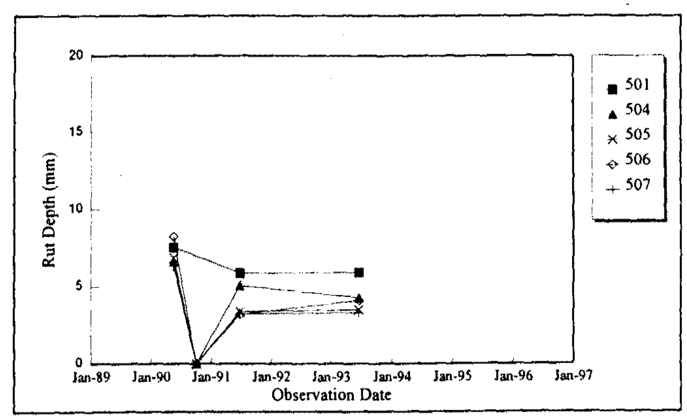
a. Rut depth in recycled overlay mixtures in Alabama.



b. Rut depth in virgin overlay mixtures in Alabama.

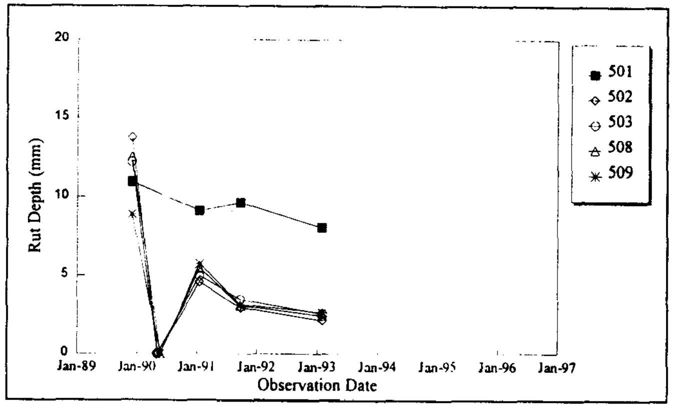


c. Rut depth in recycled overlay mixtures in Alberta.

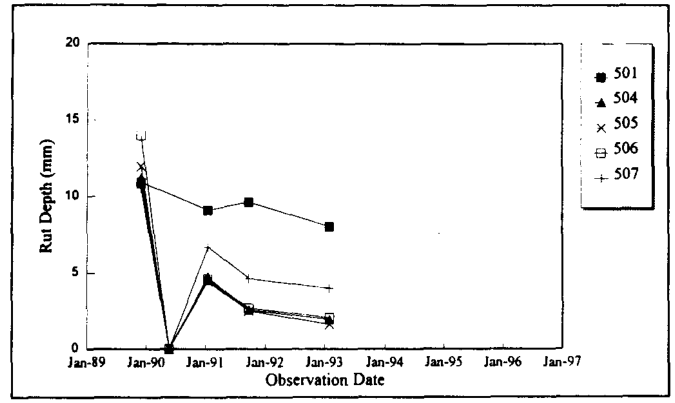


d. Rut depth in virgin overlay mixtures in Alberta.

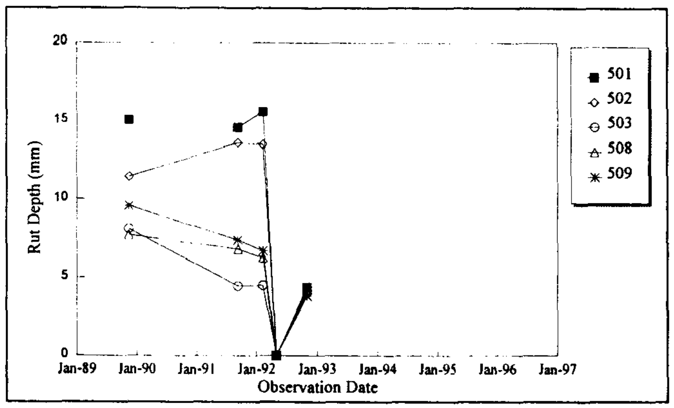
Figure 49. Rut depth in Alabama and Alberta for the SPS-5 project.



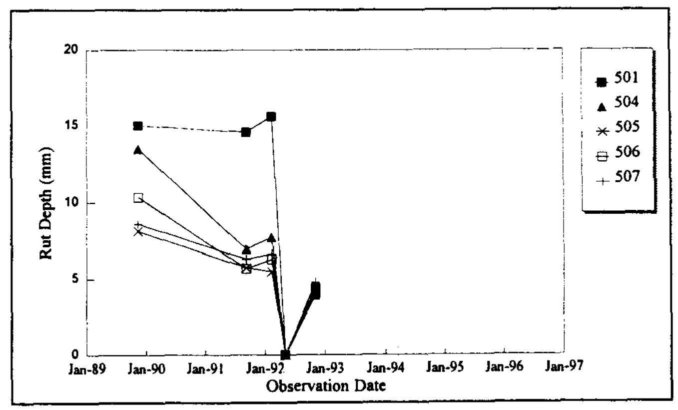
a. Rut depth in recycled overlay mixtures in Arizona.



b. Rut depth in virgin overlay mixtures in Arizona.

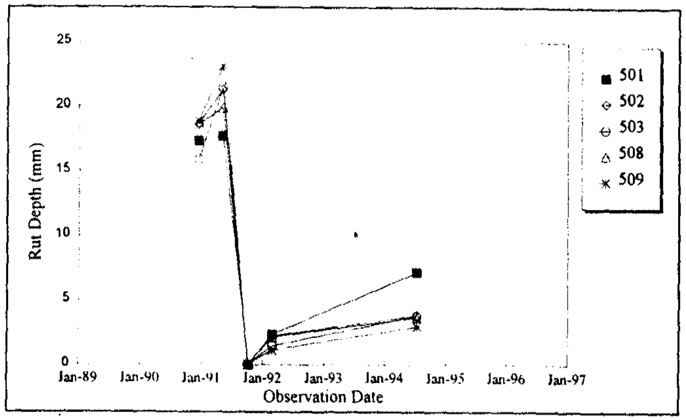


c. Rut depth in recycled overlay mixtures in California.

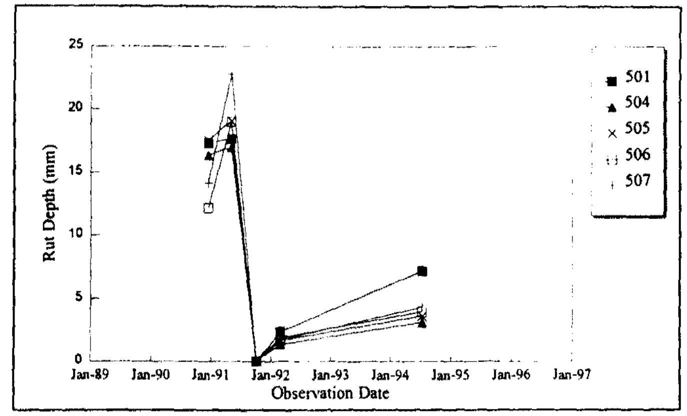


d. Rut depth in virgin overlay mixtures in California.

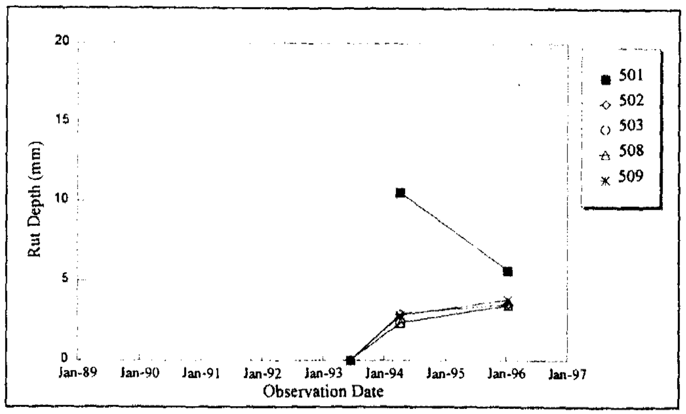
Figure 50. Rut depth in Arizona and California for the SPS-5 project.



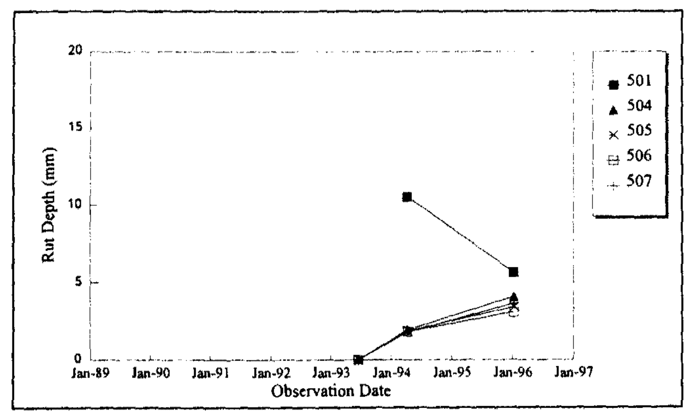
a. Rut depth in recycled overlay mixtures in Colorado.



b. Rut depth in virgin overlay mixtures in Colorado.

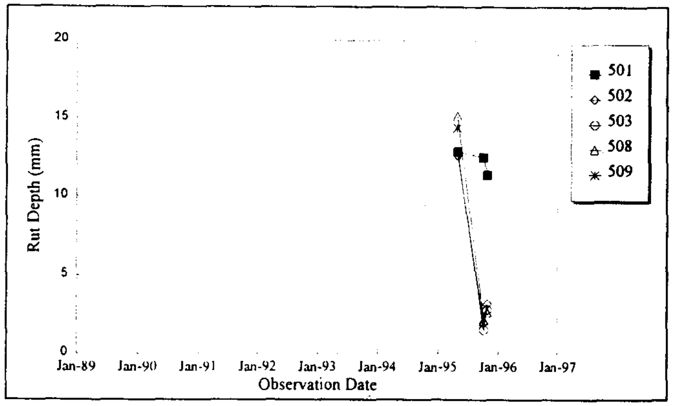


c. Rut depth in recycled overlay mixtures in Georgia.

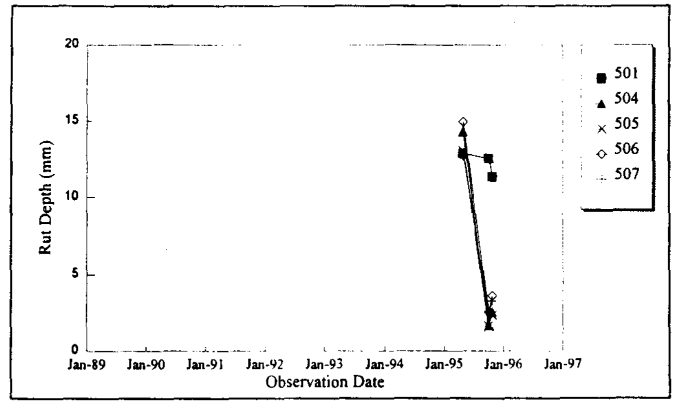


d. Rut depth in virgin overlay mixtures in Georgia.

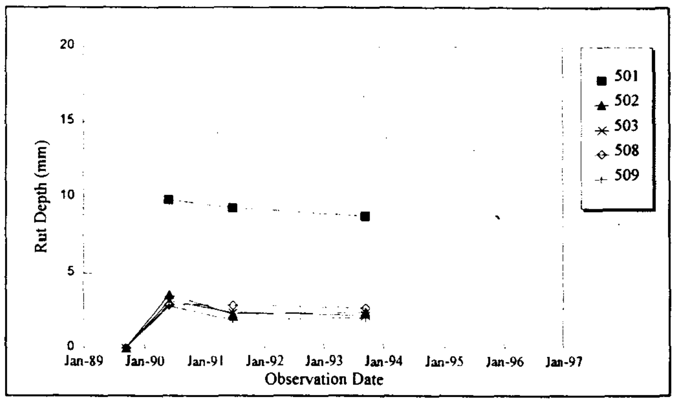
Figure 51. Rut depth in Colorado and Georgia for the SPS-5 project.



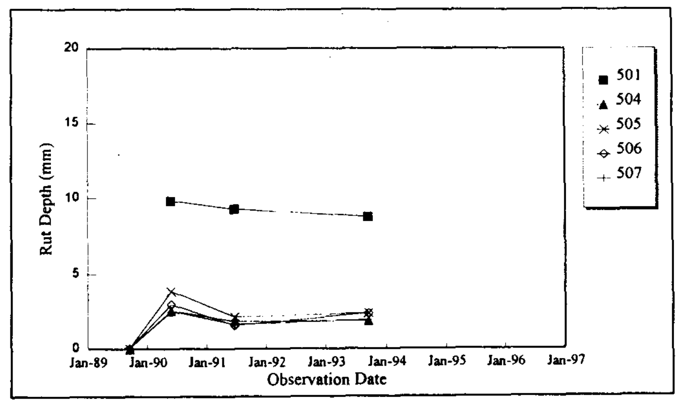
a. Rut depth in recycled overlay mixtures in Maine.



b. Rut depth in virgin overlay mixtures in Maine.

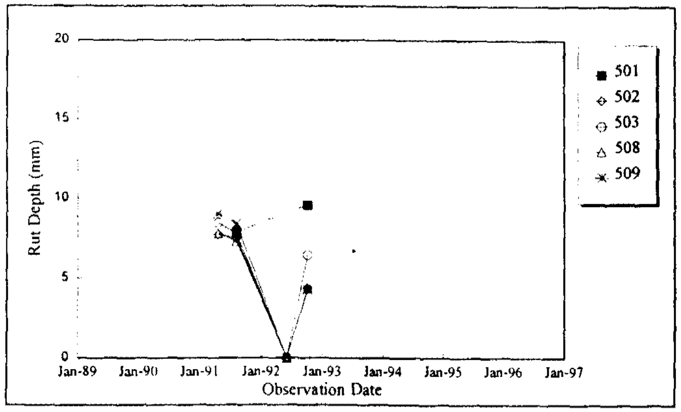


c. Rut depth in recycled overlay mixtures in Manitoba.

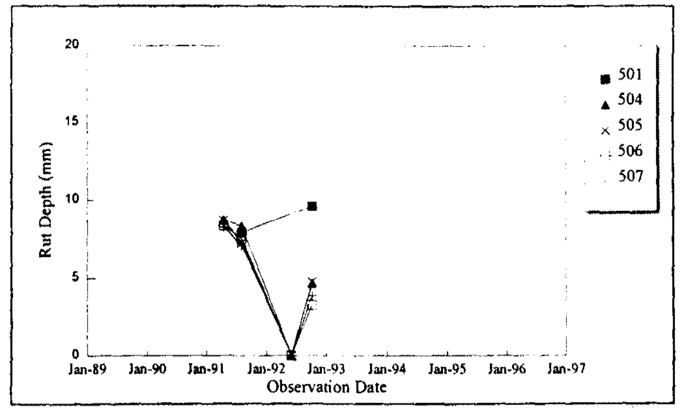


d. Rut depth in virgin overlay mixtures in Manitoba.

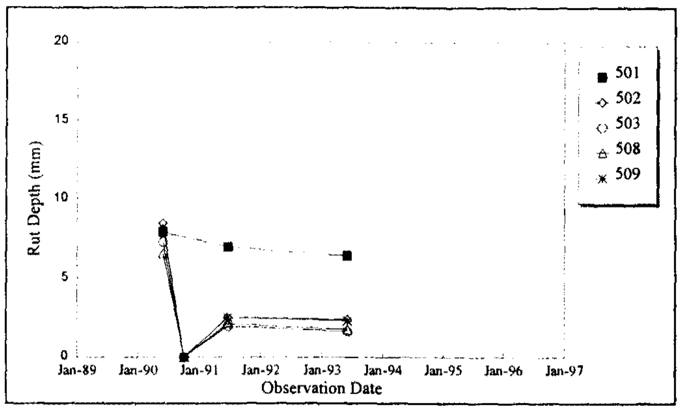
Figure 52. Rut depth in Maine and Manitoba for the SPS-5 project.



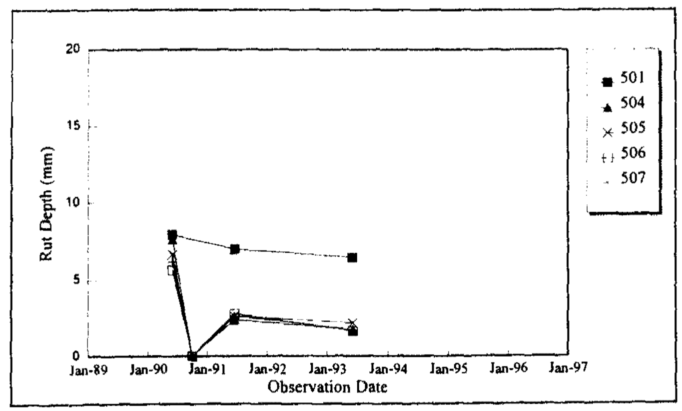
a. Rut depth in recycled overlay mixtures in Maryland.



b. Rut depth in virgin overlay mixtures in Maryland.

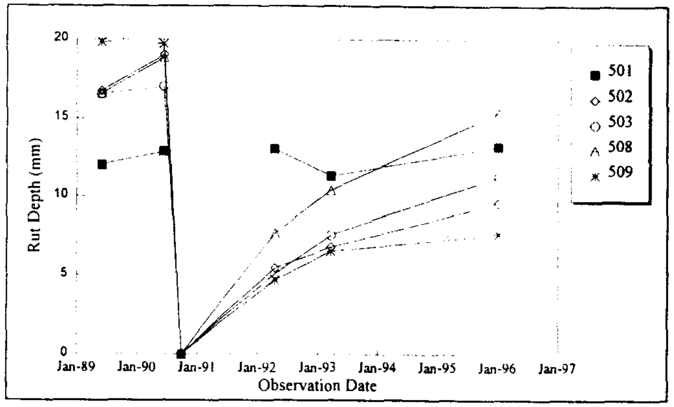


c. Rut depth in recycled overlay mixtures in Minnesota.

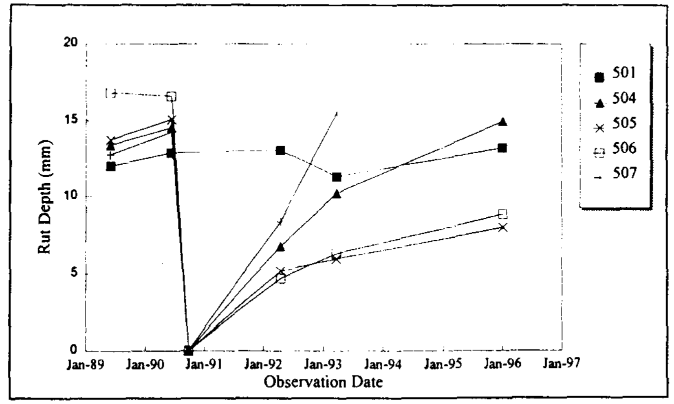


d. Rut depth in virgin overlay mixtures in Minnesota.

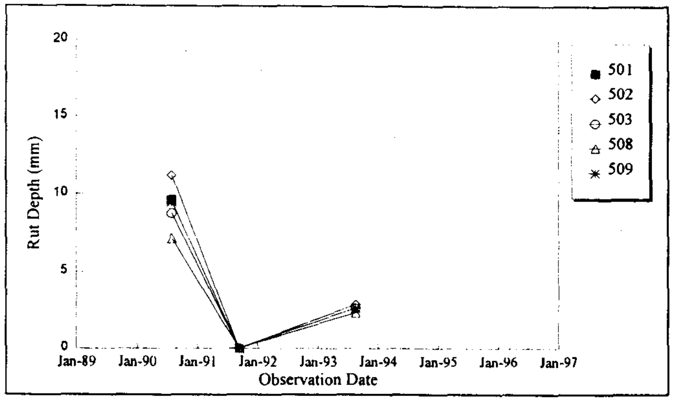
Figure 53. Rut depth in Maryland and Minnesota for the SPS-5 project.



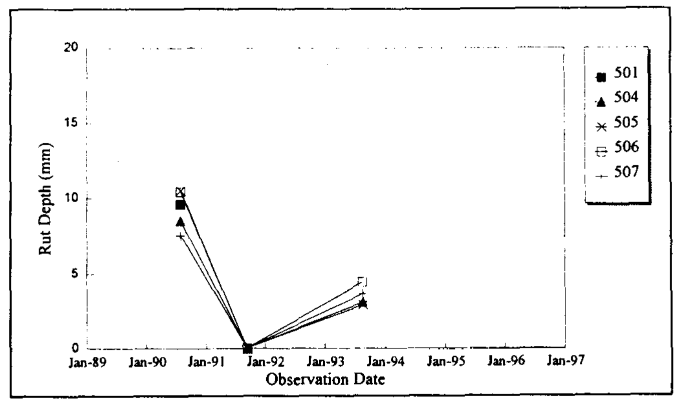
a. Rut depth recycled overlay mixtures in Mississippi.



b. Rut depth in virgin overlay mixtures in Mississippi.

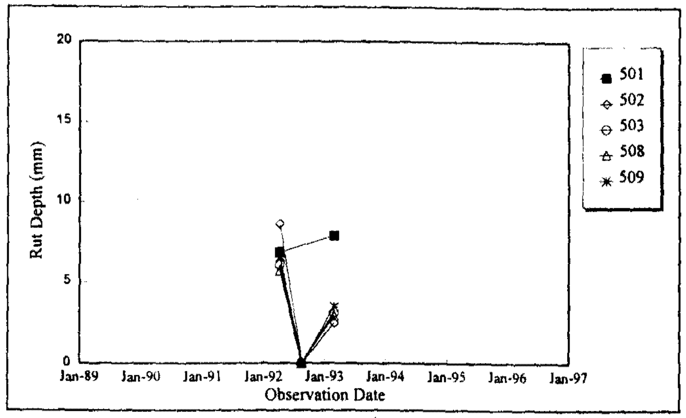


c. Rut depth in recycled overlay mixtures in Montana.

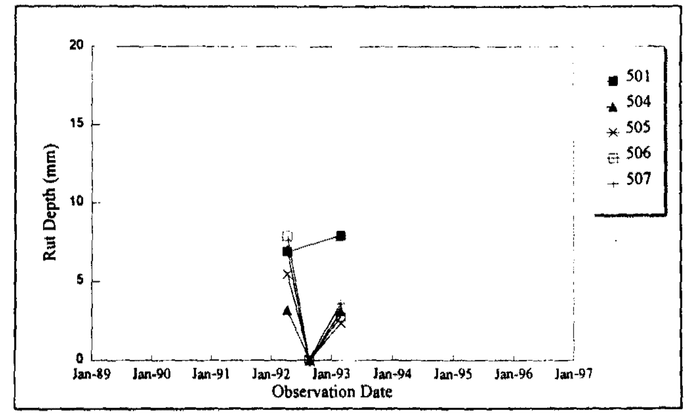


d. Rut depth in virgin overlay mixtures in Montana.

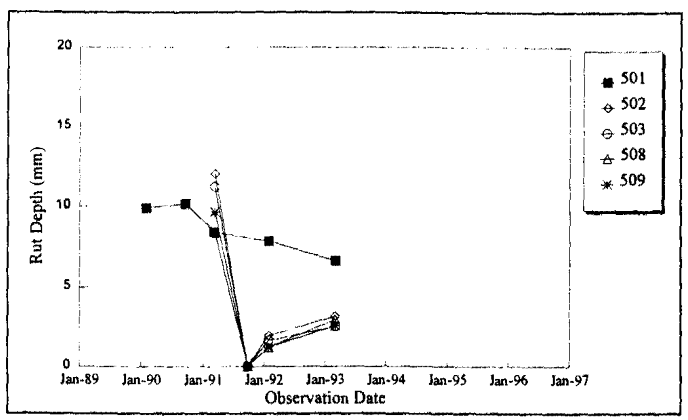
Figure 54. Rut depth in Mississippi and Montana for the SPS-5 project.



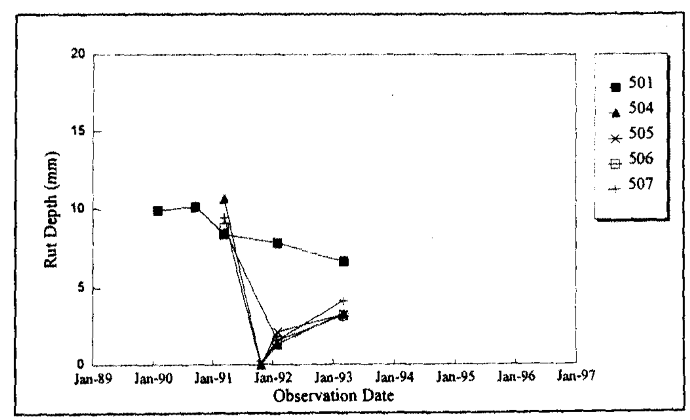
a. Rut depth in recycled overlay mixtures in New Jersey.



b. Rut depth in virgin overlay mixtures in New Jersey.



c. Rut depth in recycled overlay mixtures in Texas.



d. Rut depth in virgin overlay mixtures in Texas.

Figure 55. Rut depth in New Jersey and Texas for the SPS-5 project.

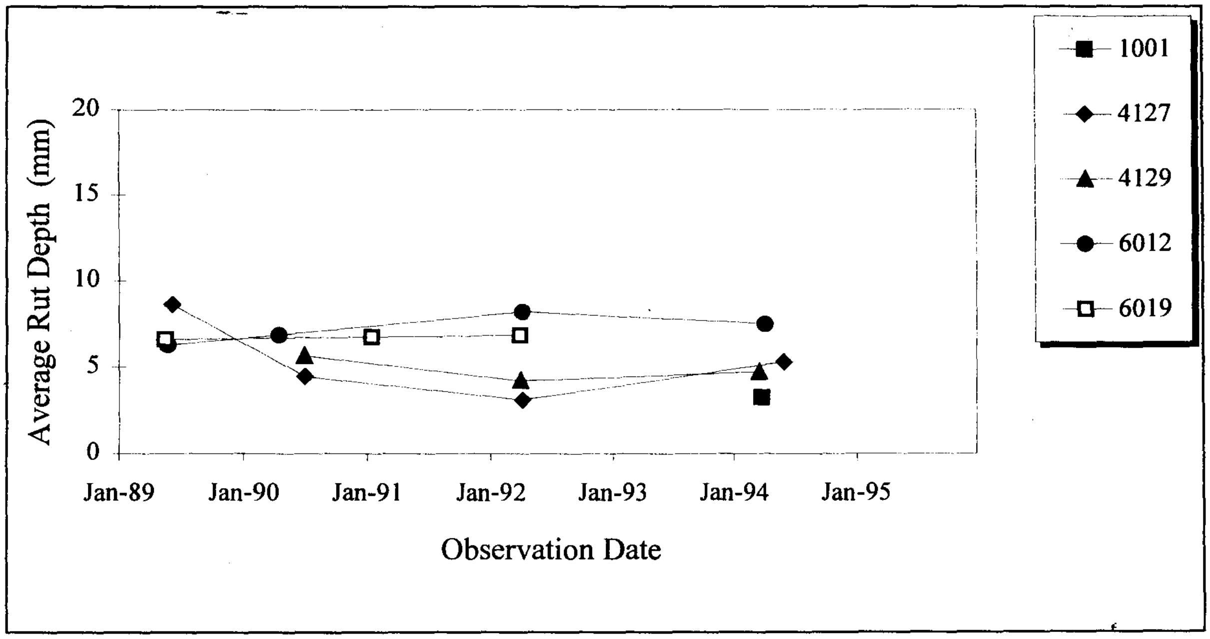


Figure 56. Rut depths in Alabama GPS-6 test sections.

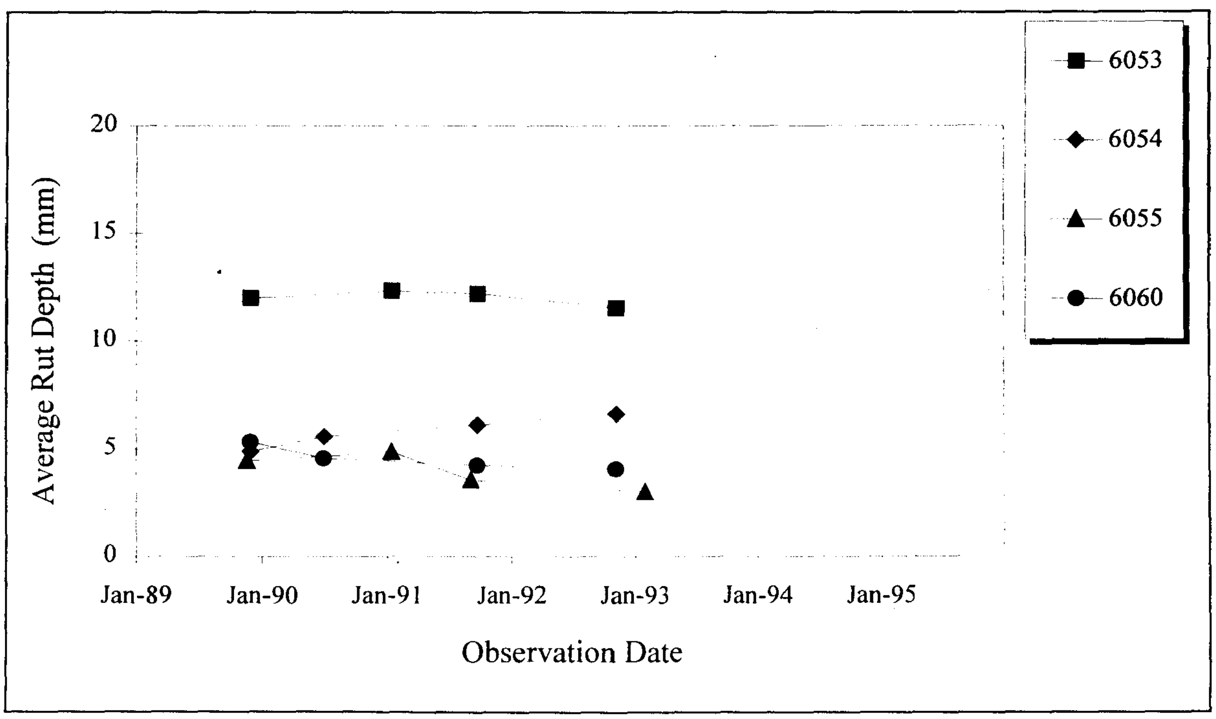


Figure 57. Rut depths in Arizona GPS-6 test sections.

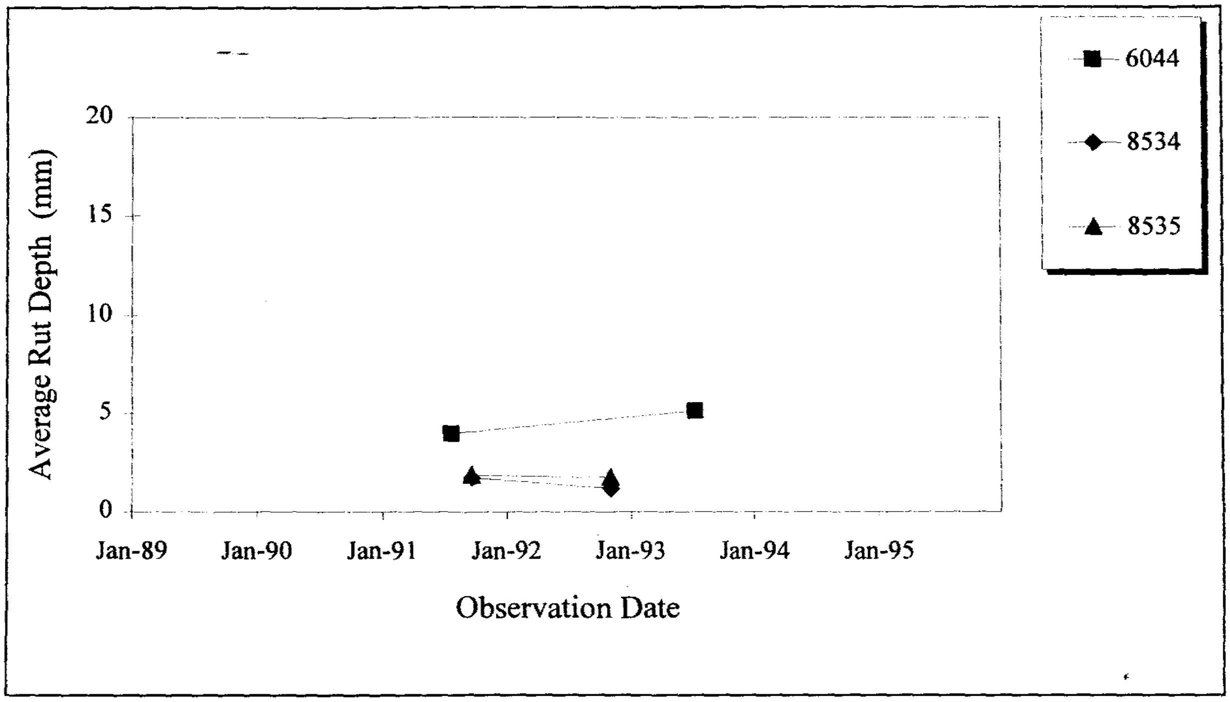


Figure 58. Rut depths in California GPS-6 test sections.

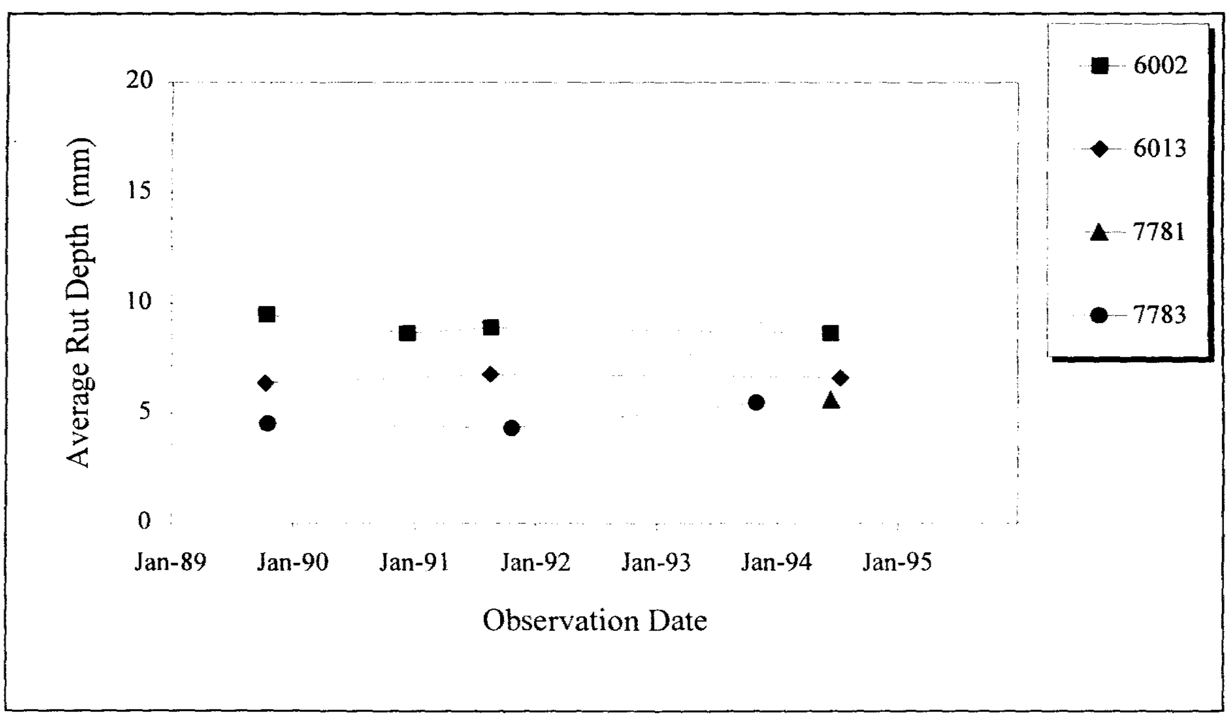


Figure 59. Rut depths in Colorado GPS-6 test sections.

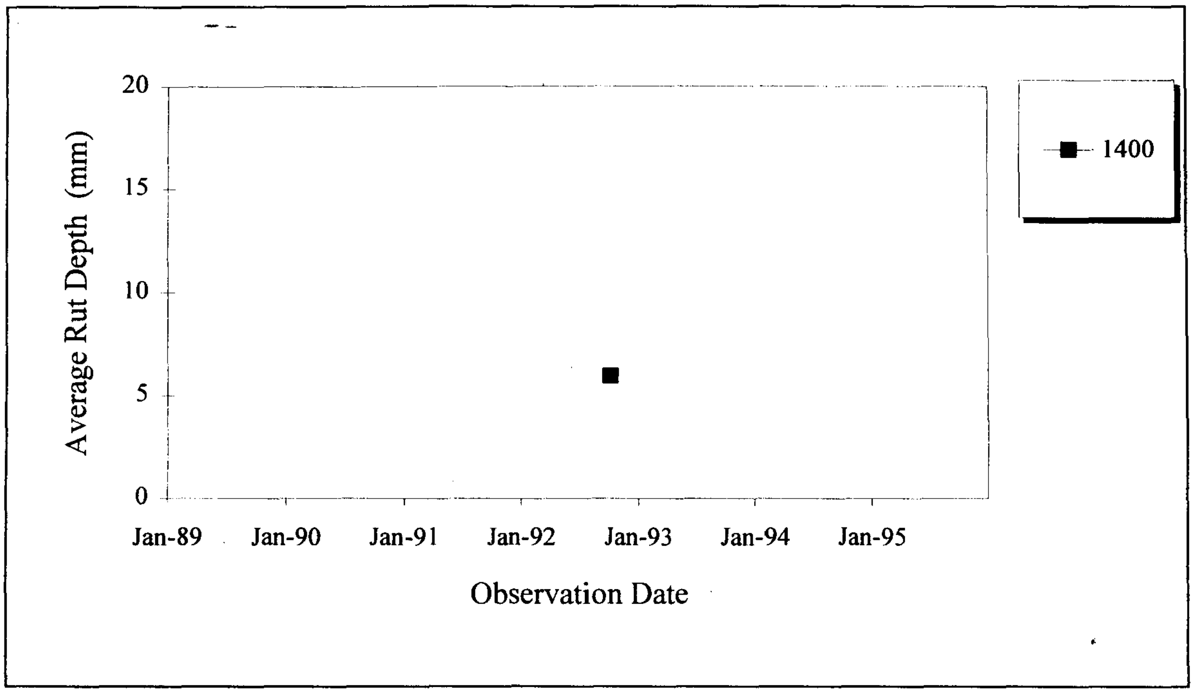


Figure 60. Rut depths in District of Columbia GPS-6 test sections.

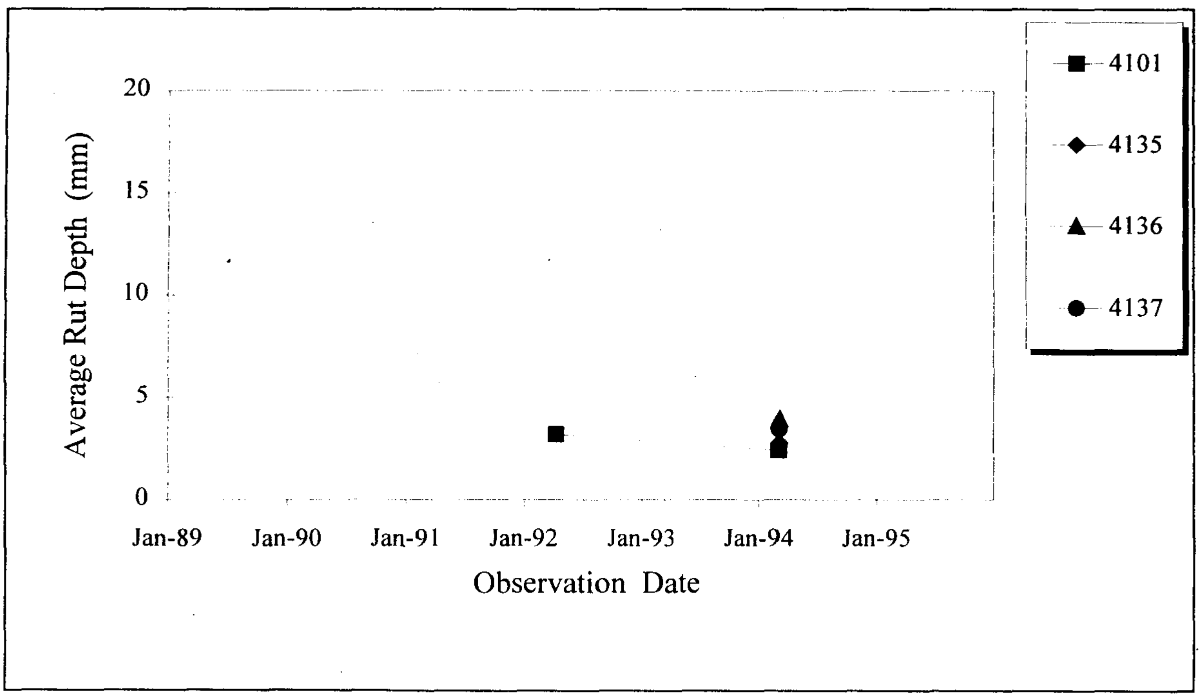


Figure 61. Rut depths in Florida GPS-6 test sections.

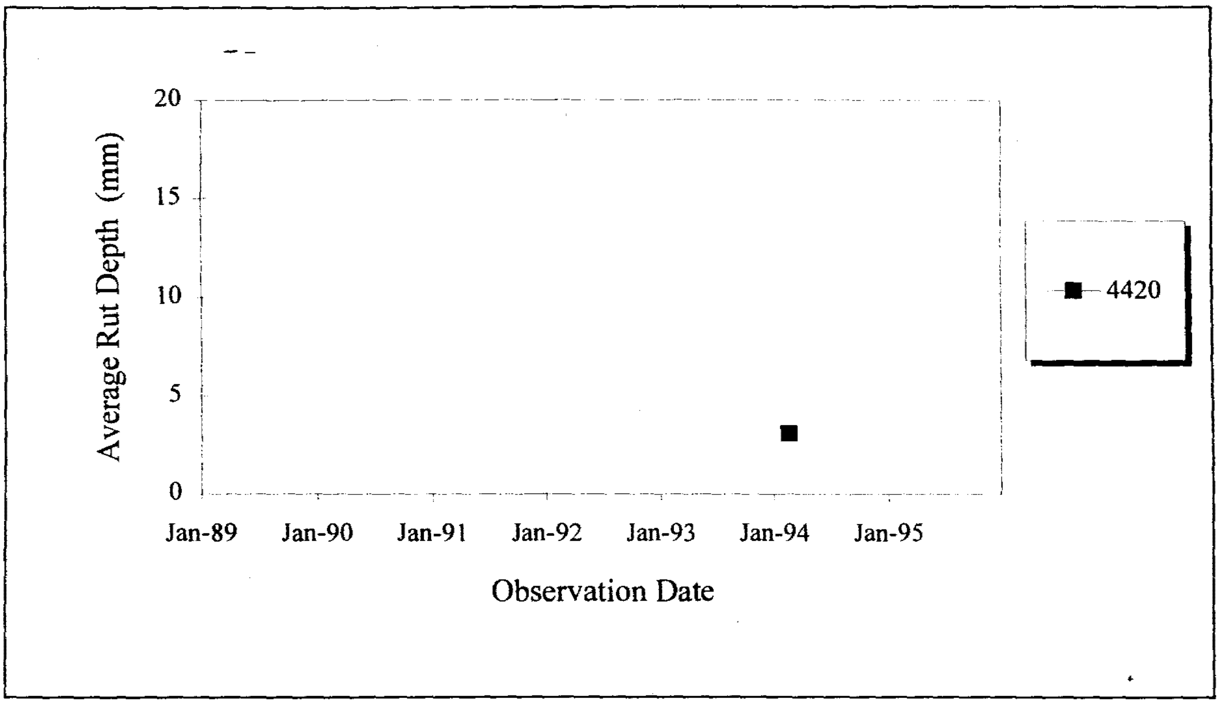


Figure 62. Rut depths in Georgia GPS-6 test sections.

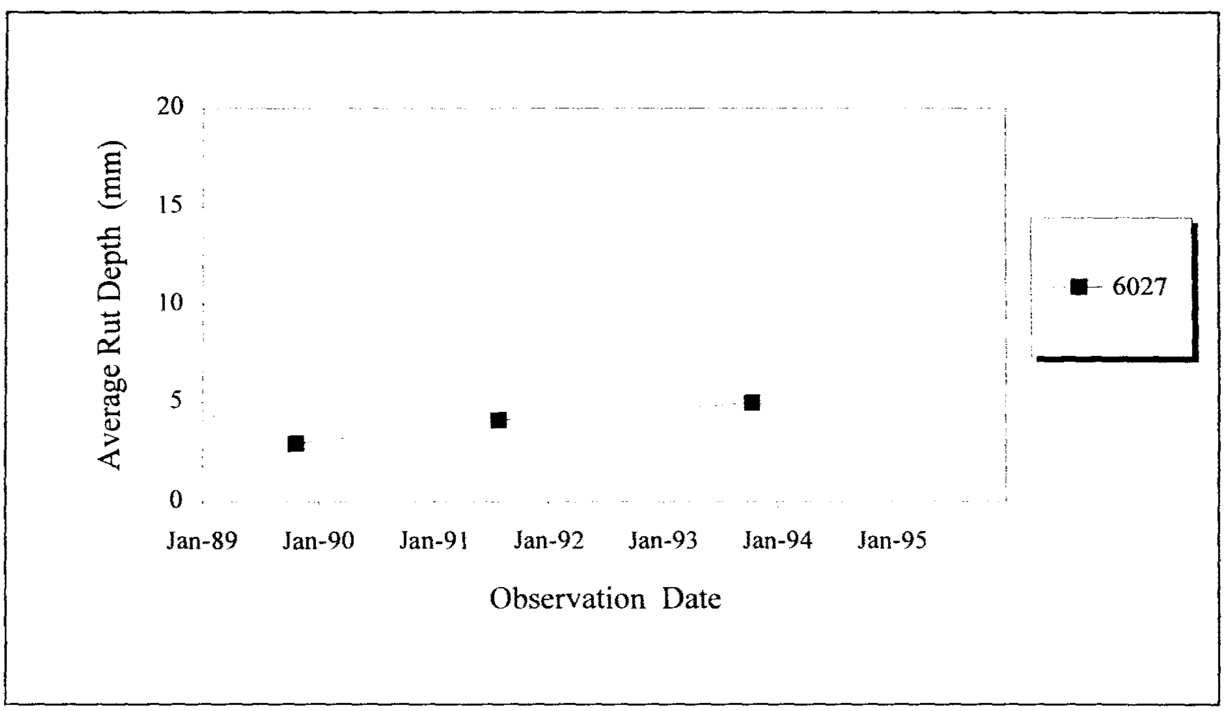


Figure 63. Rut depths in Idaho GPS-6 test sections.

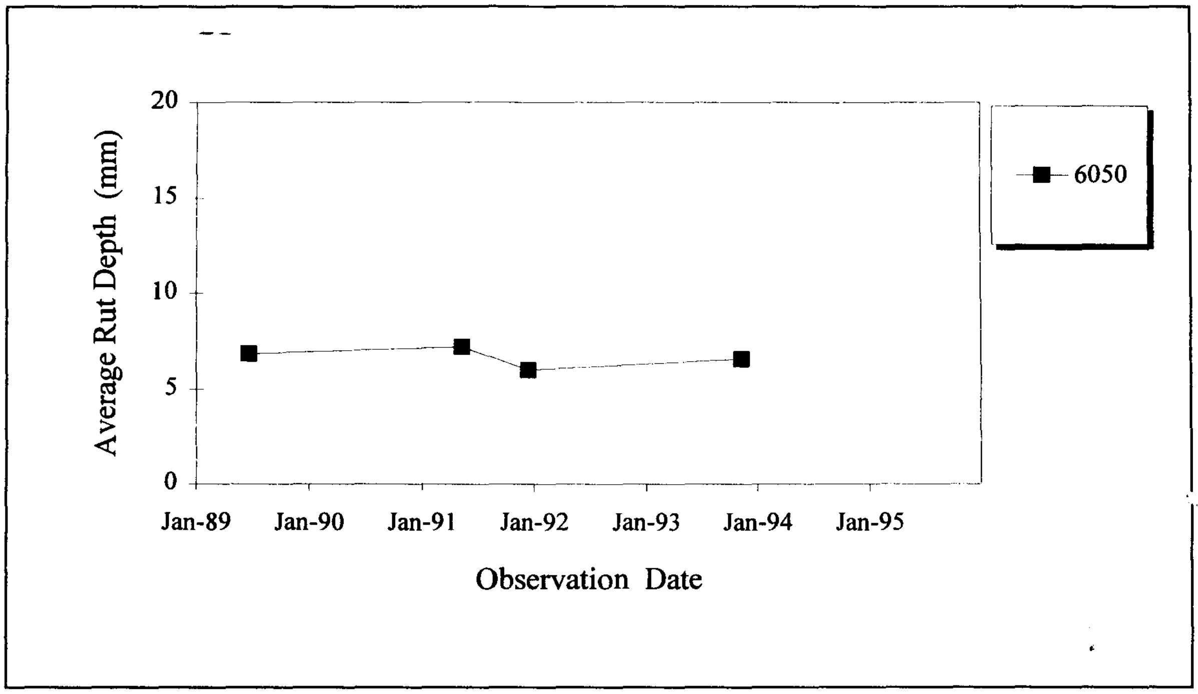


Figure 64. Rut depths in Illinois GPS-6 test sections.

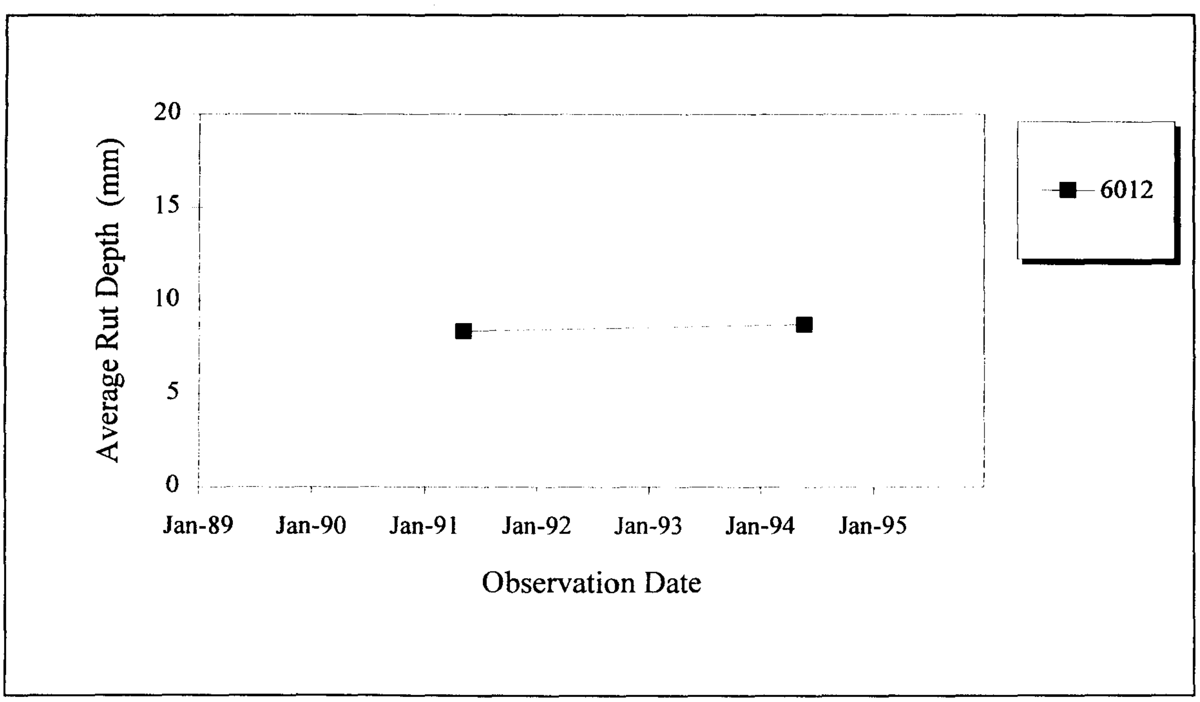


Figure 65. Rut depths in Indiana GPS-6 test sections.

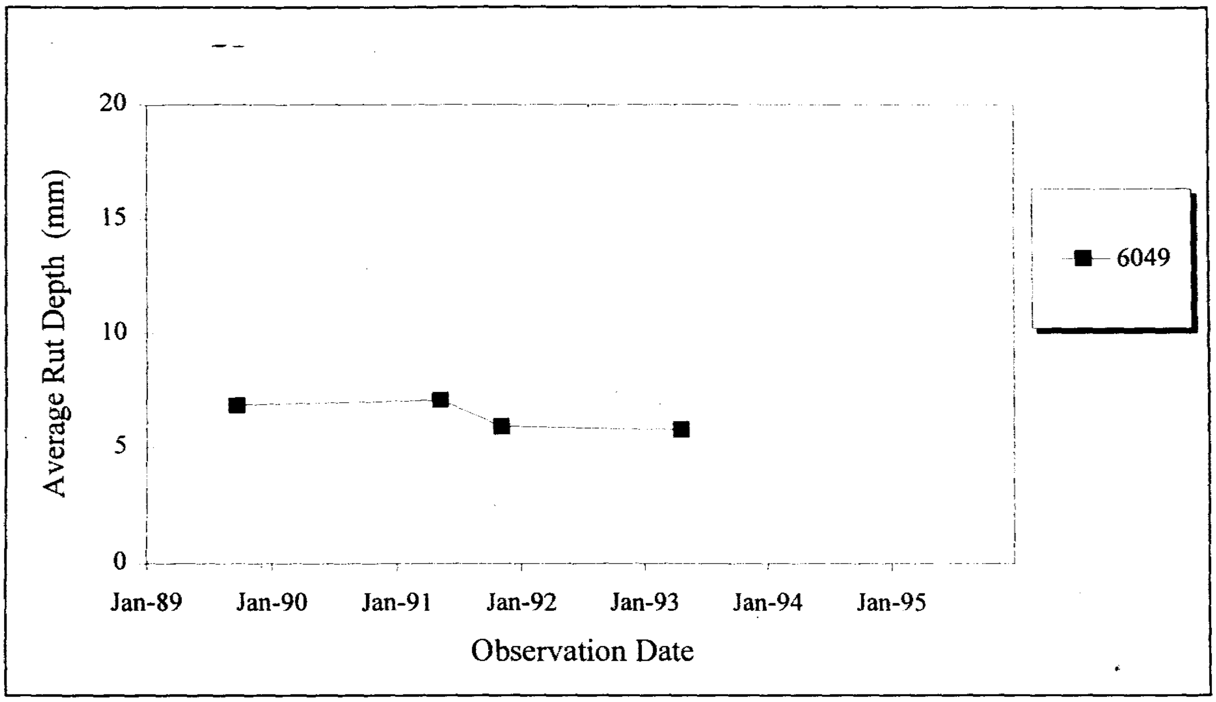


Figure 66. Rut depths in Iowa GPS-6 test sections.

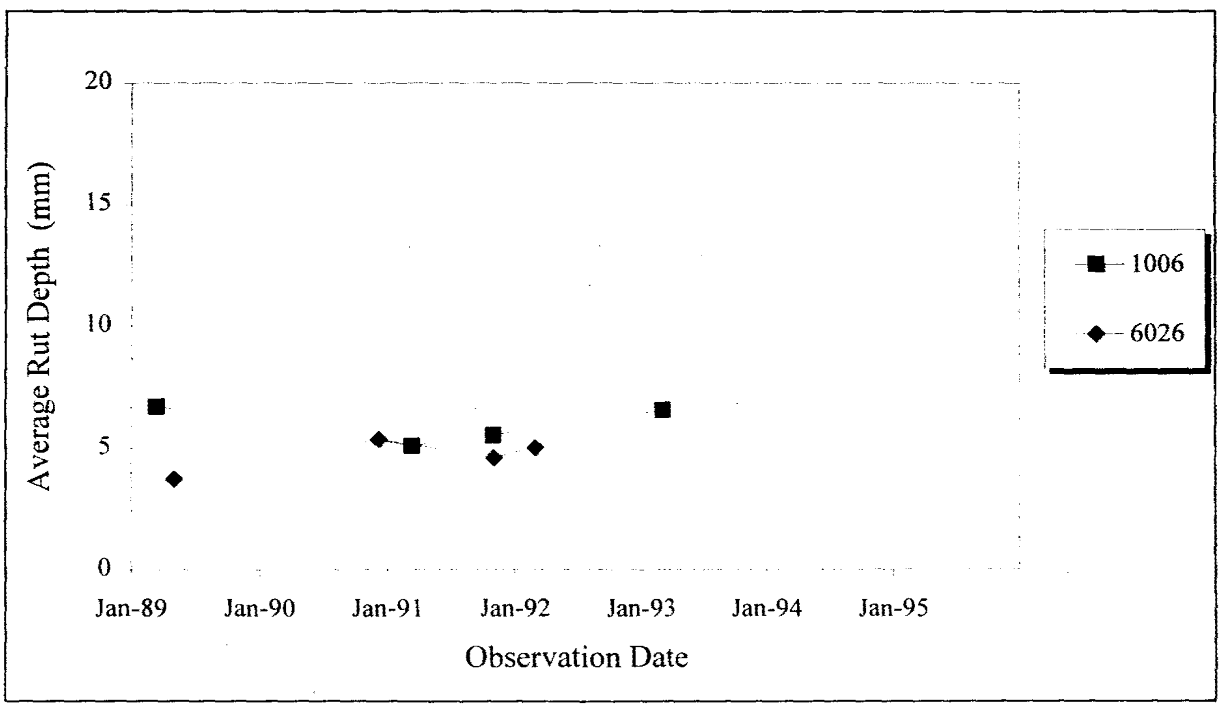


Figure 67. Rut depths in Kansas GPS-6 test sections.

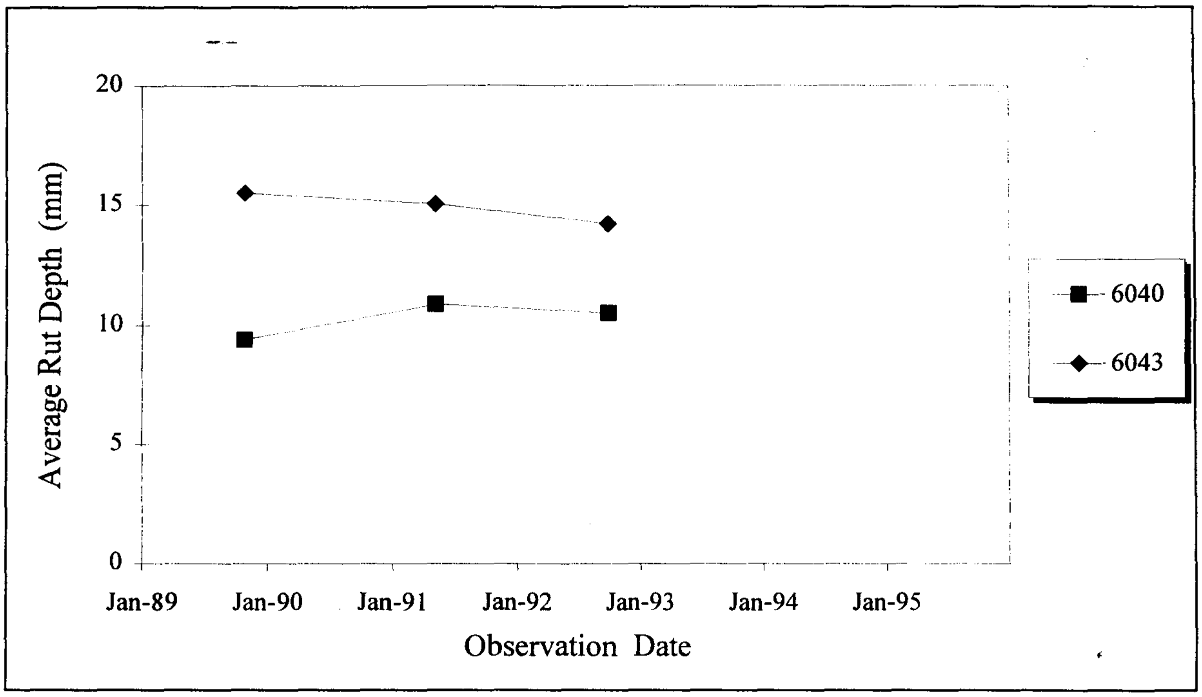


Figure 68. Rut depths in Kentucky GPS-6 test sections.

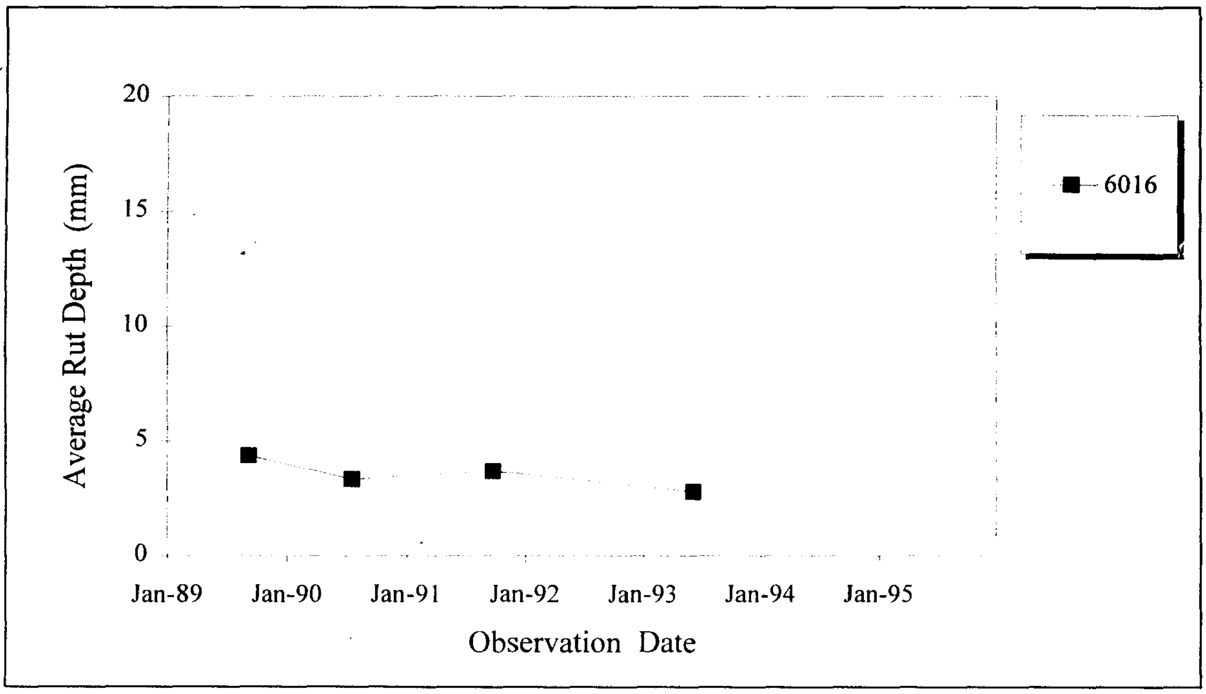


Figure 69. Rut depths in Michigan GPS-6 test sections.

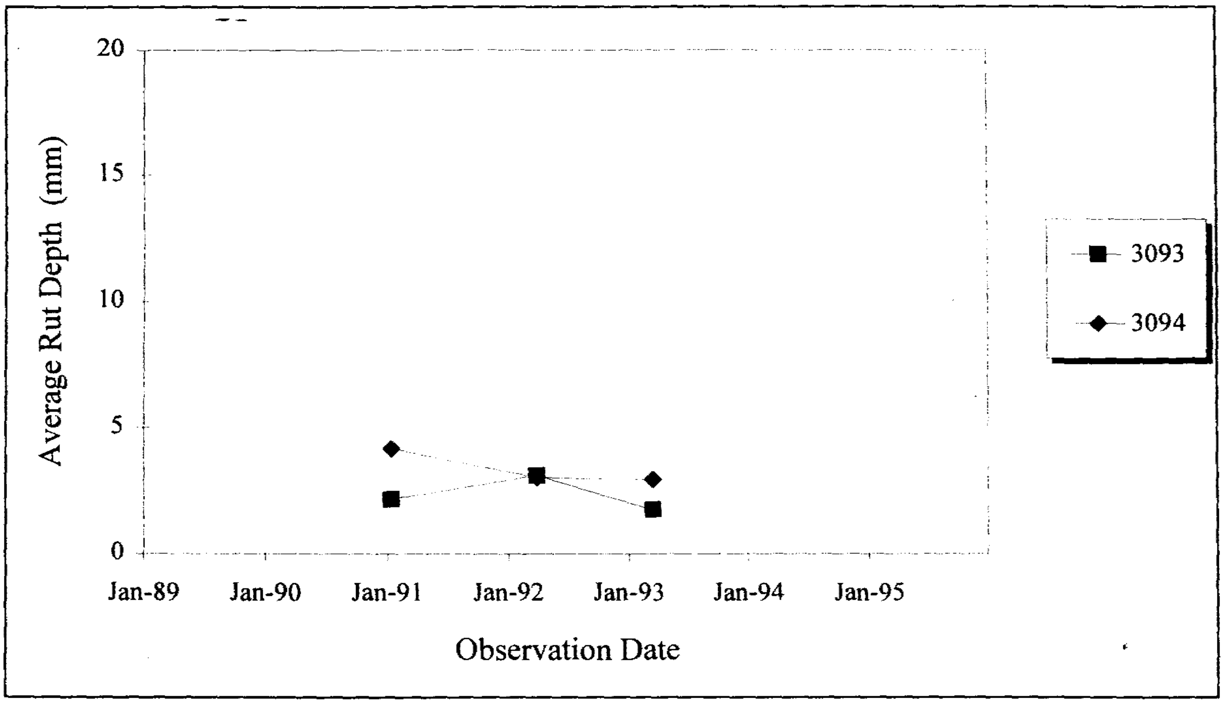


Figure 70. Rut depths in Mississippi GPS-6 test sections.

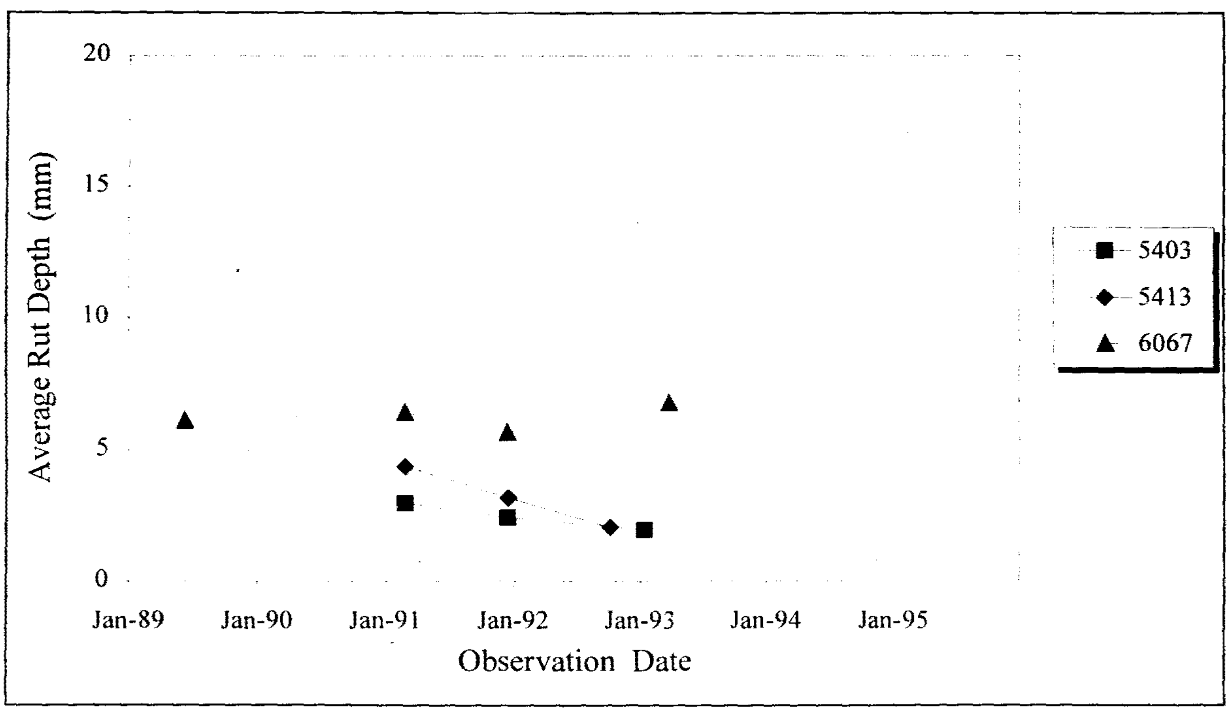


Figure 71. Rut depths in Missouri GPS-6 test sections.

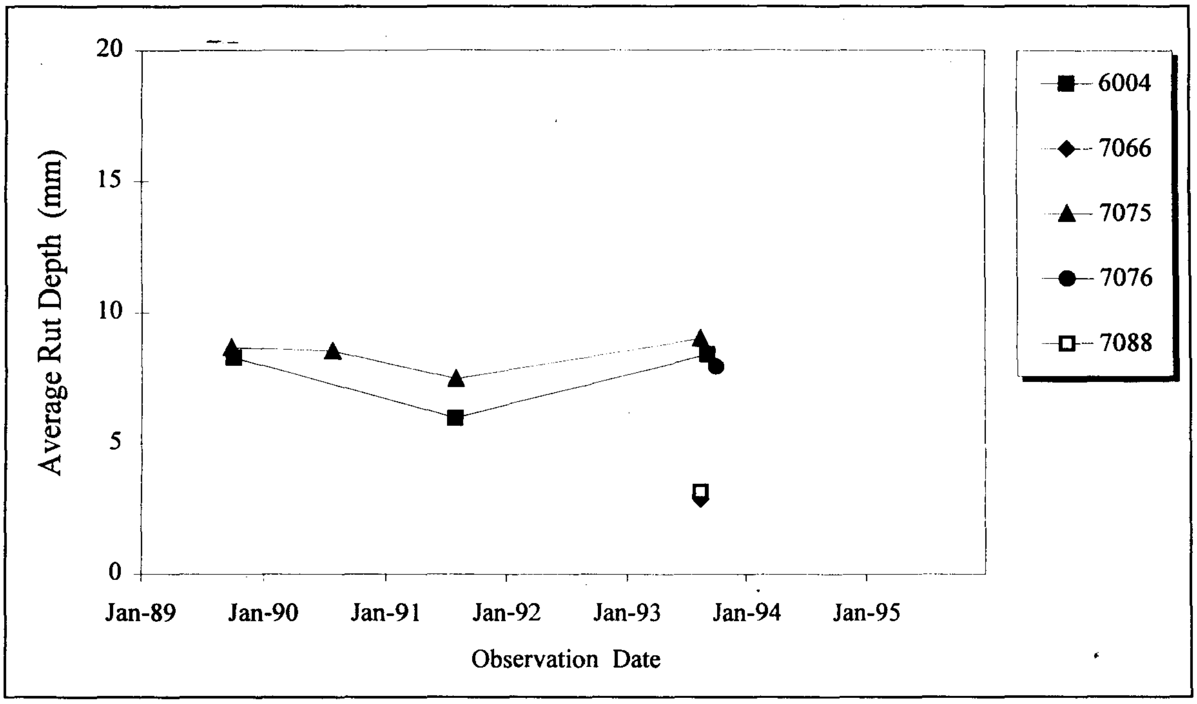


Figure 72. Rut depths in Montana GPS-6 test sections.

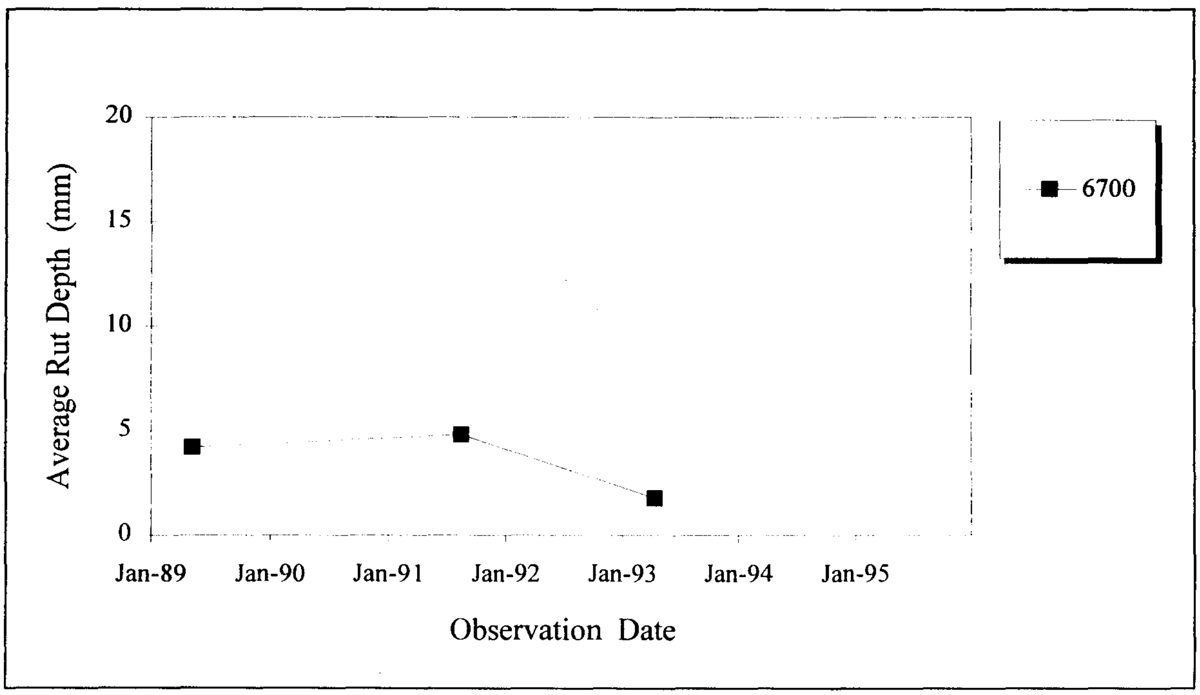


Figure 73. Rut depths in Nebraska GPS-6 test sections.

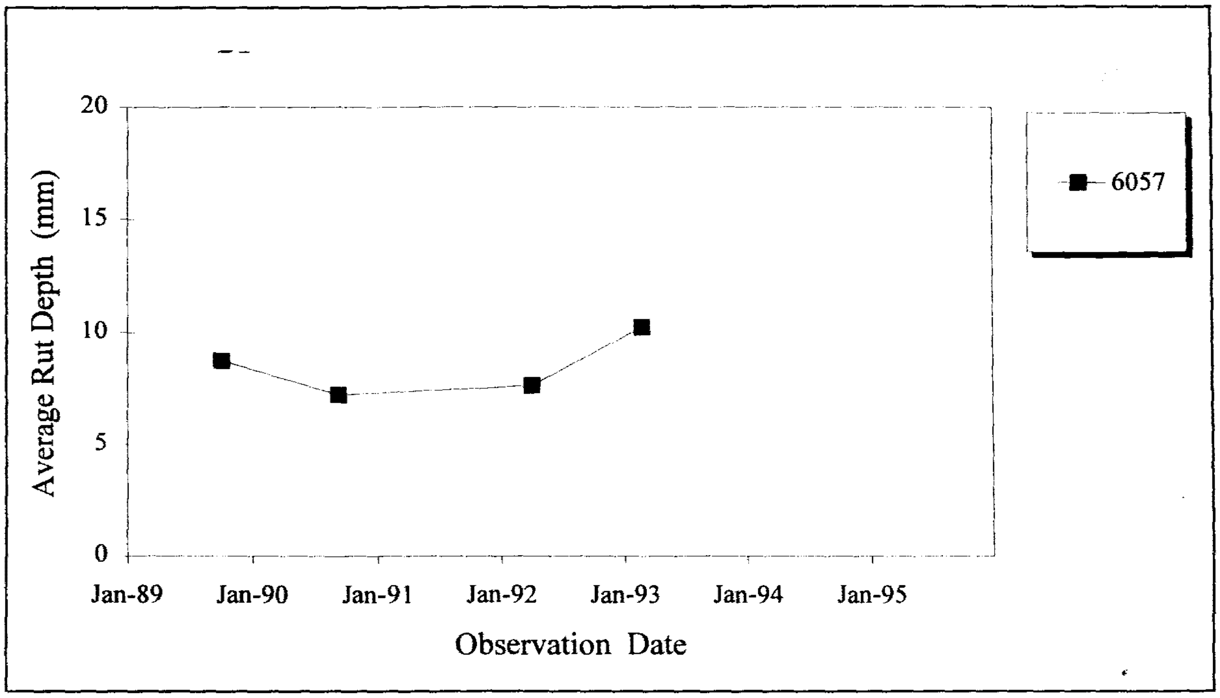


Figure 74. Rut depths in New Jersey GPS-6 test sections.

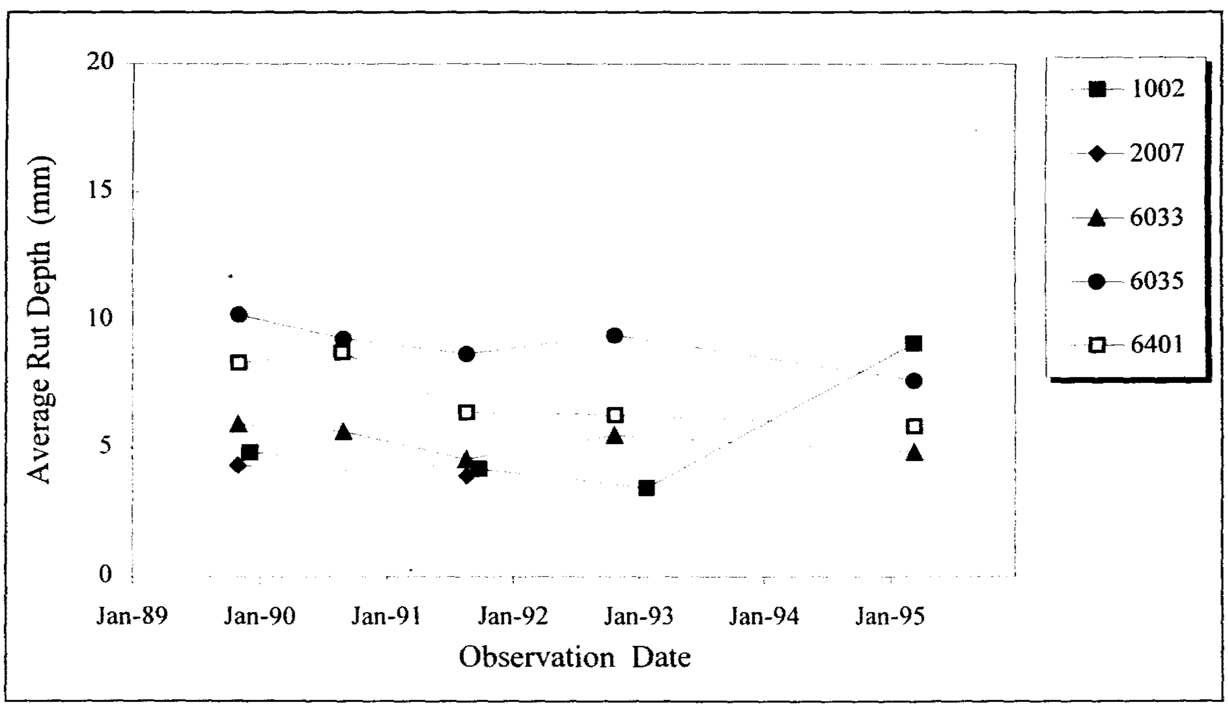


Figure 75. Rut depths in New Mexico GPS-6 test sections.

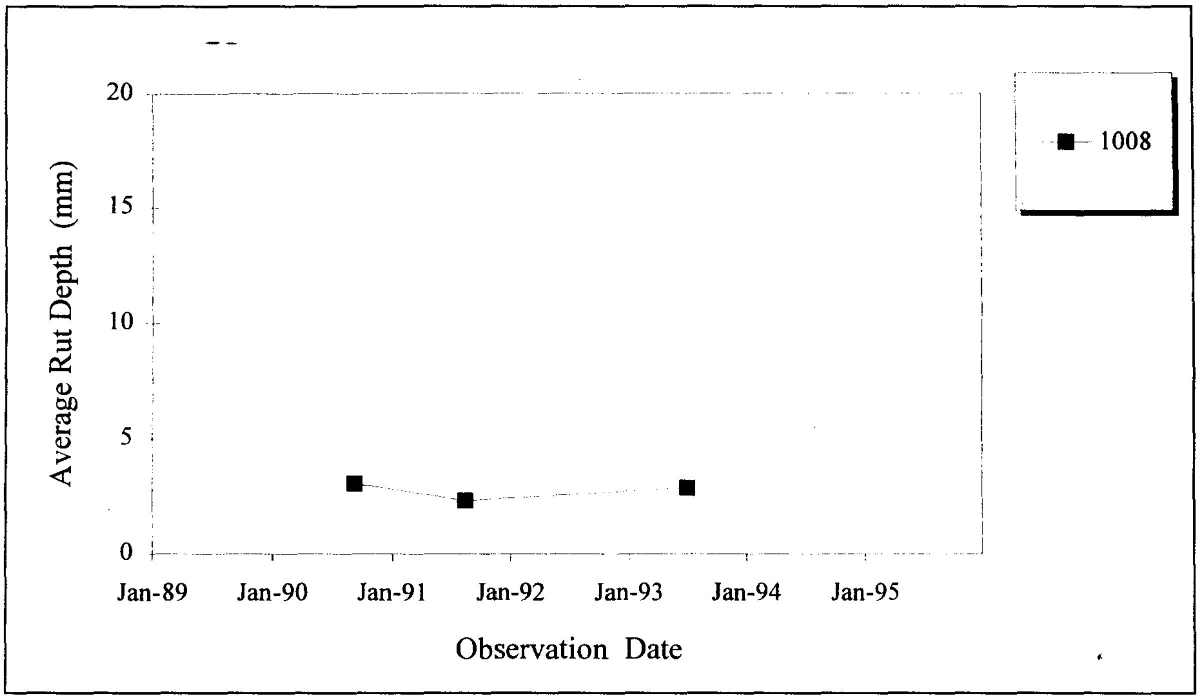


Figure 76. Rut depths in New York GPS-6 test sections.

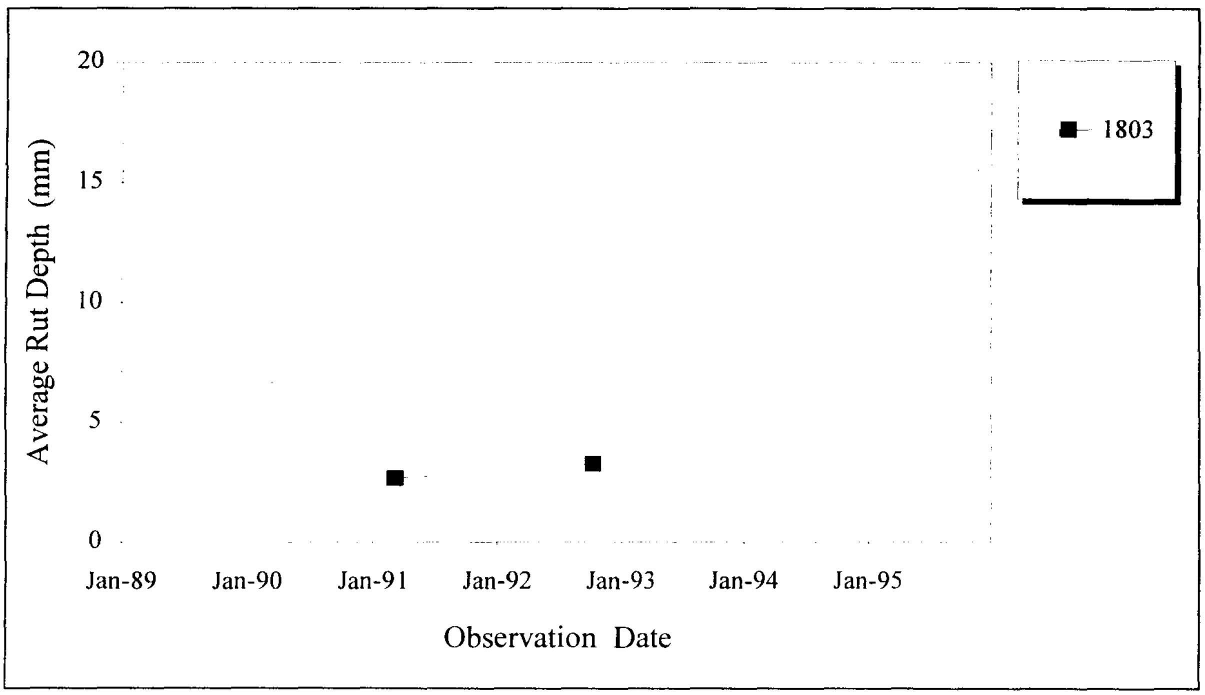


Figure 77. Rut depths in North Carolina GPS-6 test sections.

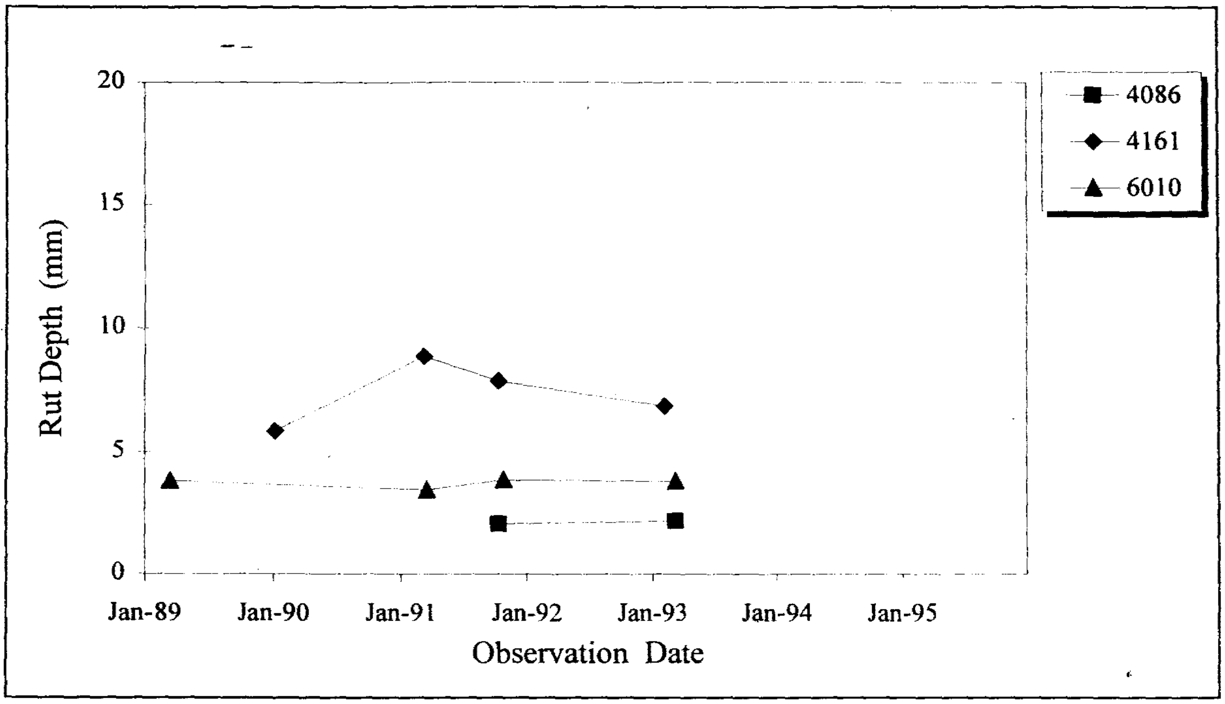


Figure 78. Rut depths in Oklahoma GPS-6 test sections.

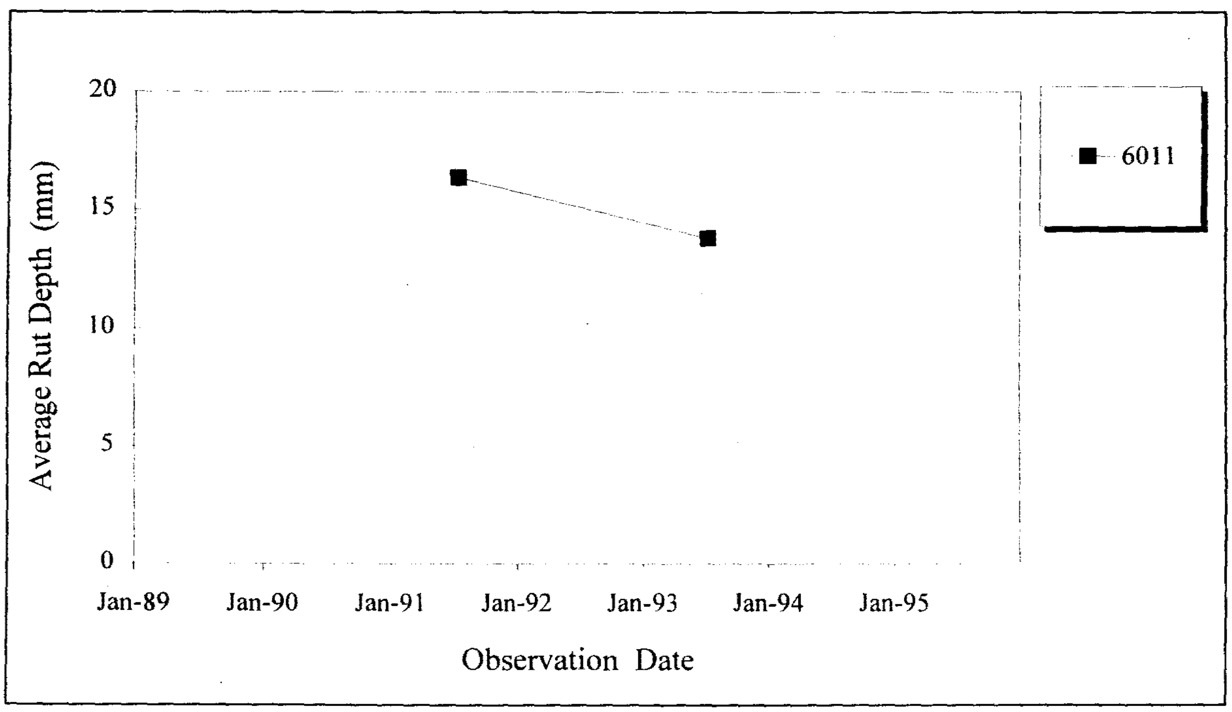


Figure 79. Rut depths in Oregon GPS-6 test sections.

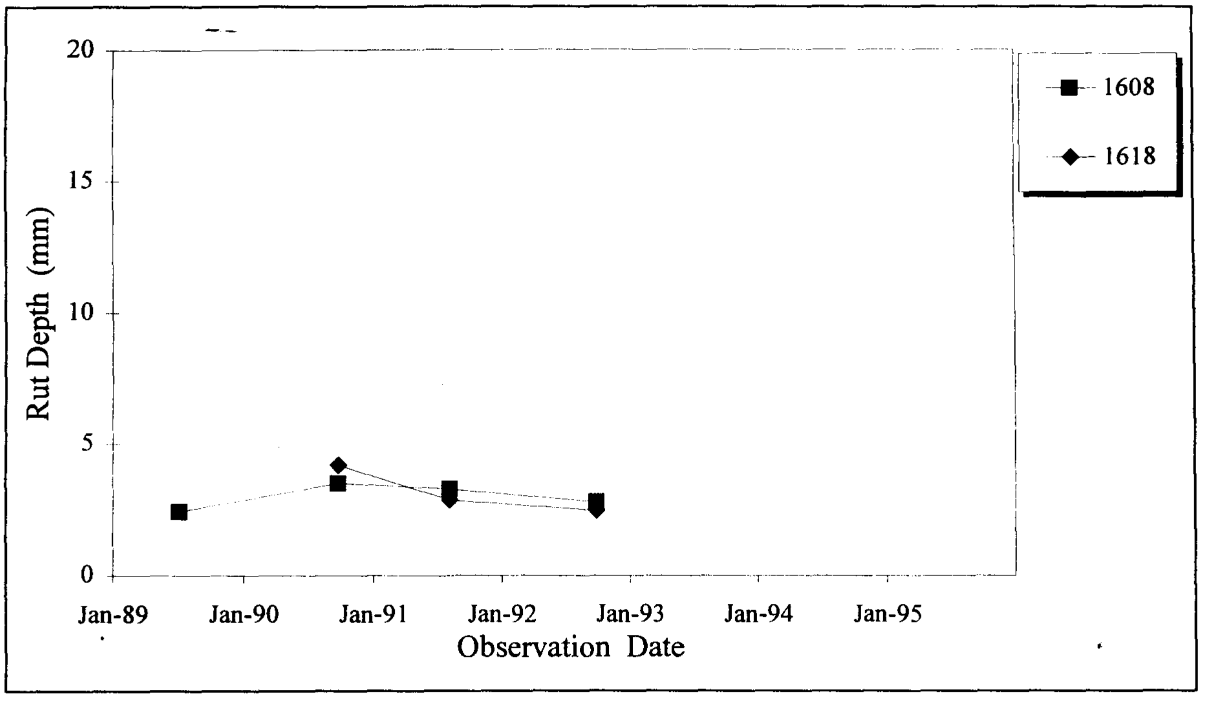


Figure 80. Rut depths in Pennsylvania GPS-6 test sections.

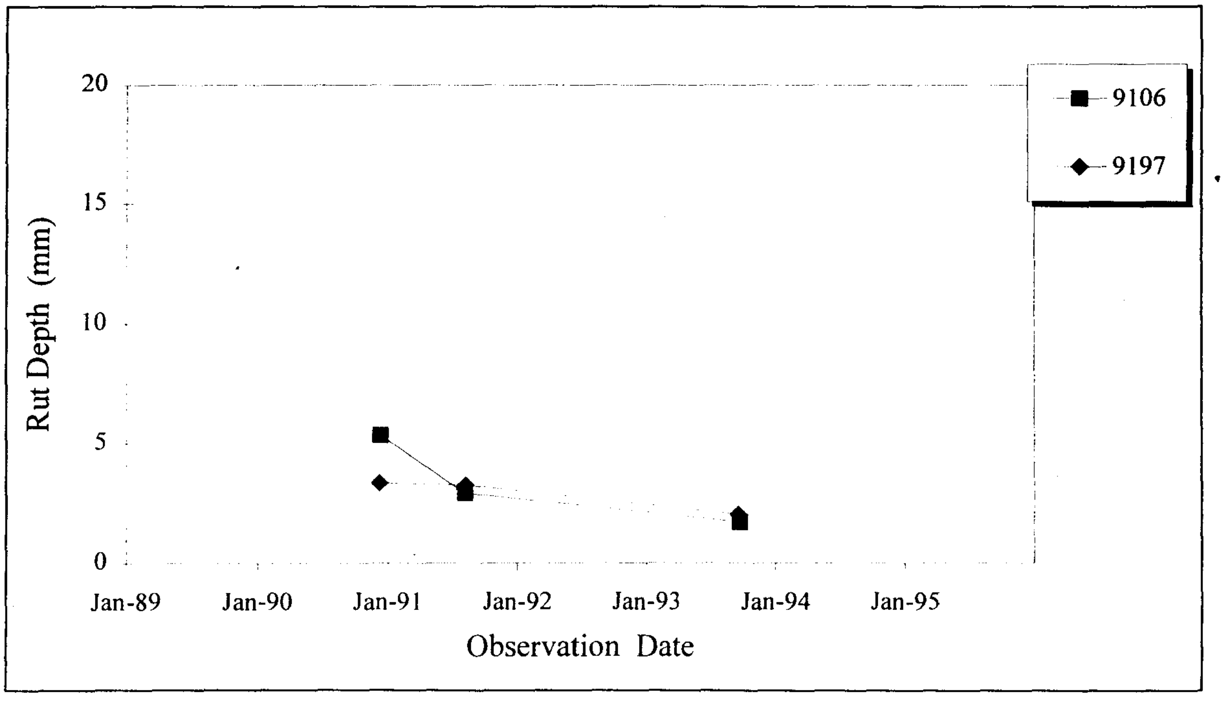


Figure 81. Rut depths in South Dakota GPS-6 test sections.

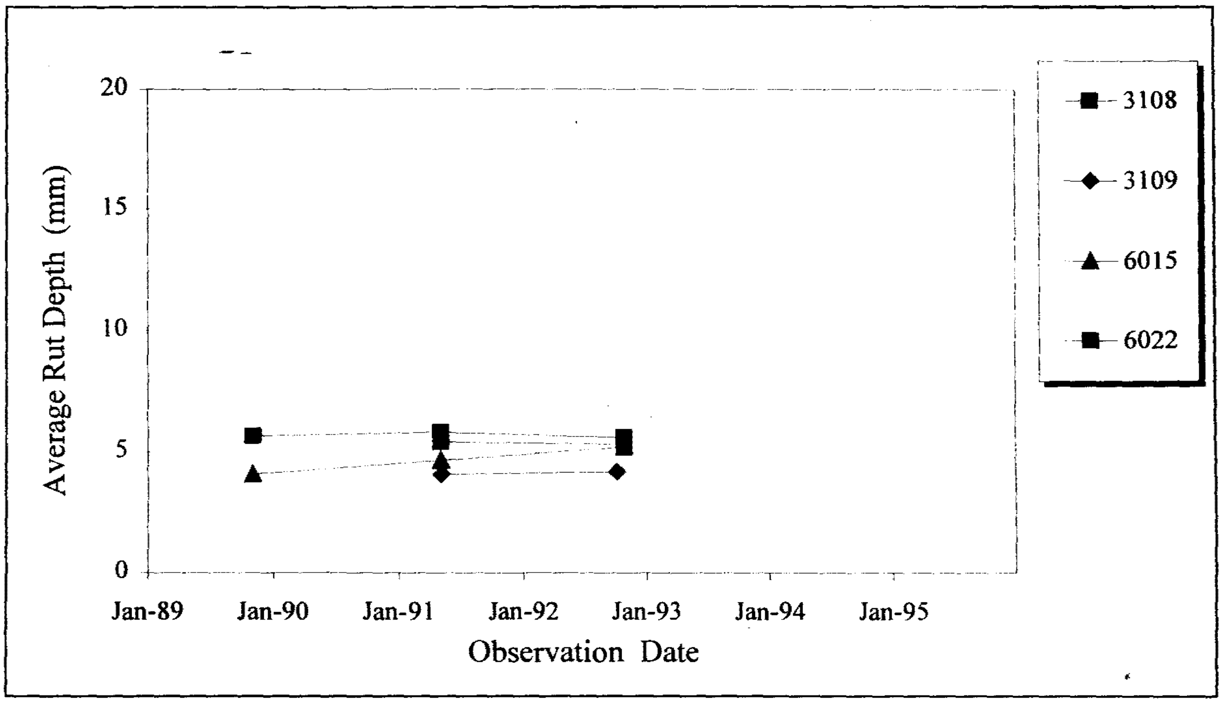


Figure 82. Rut depths in Tennessee GPS-6 test sections.

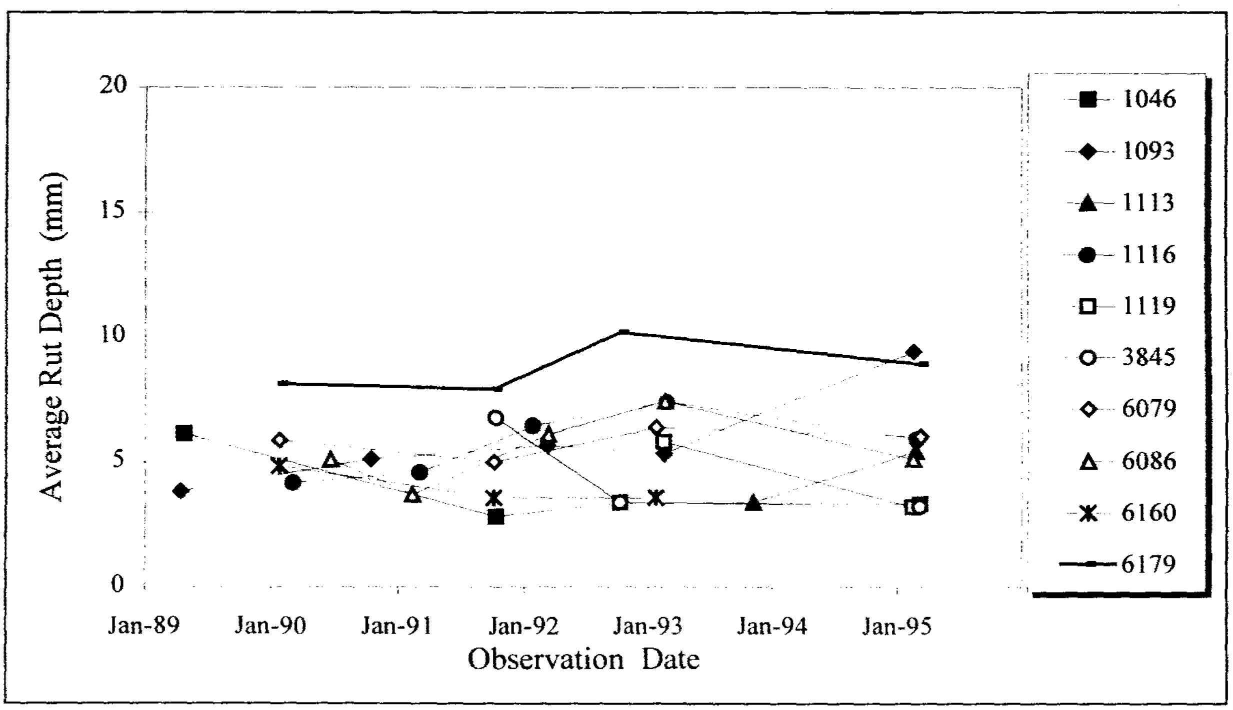


Figure 83. Rut depths in Texas GPS-6 test sections.

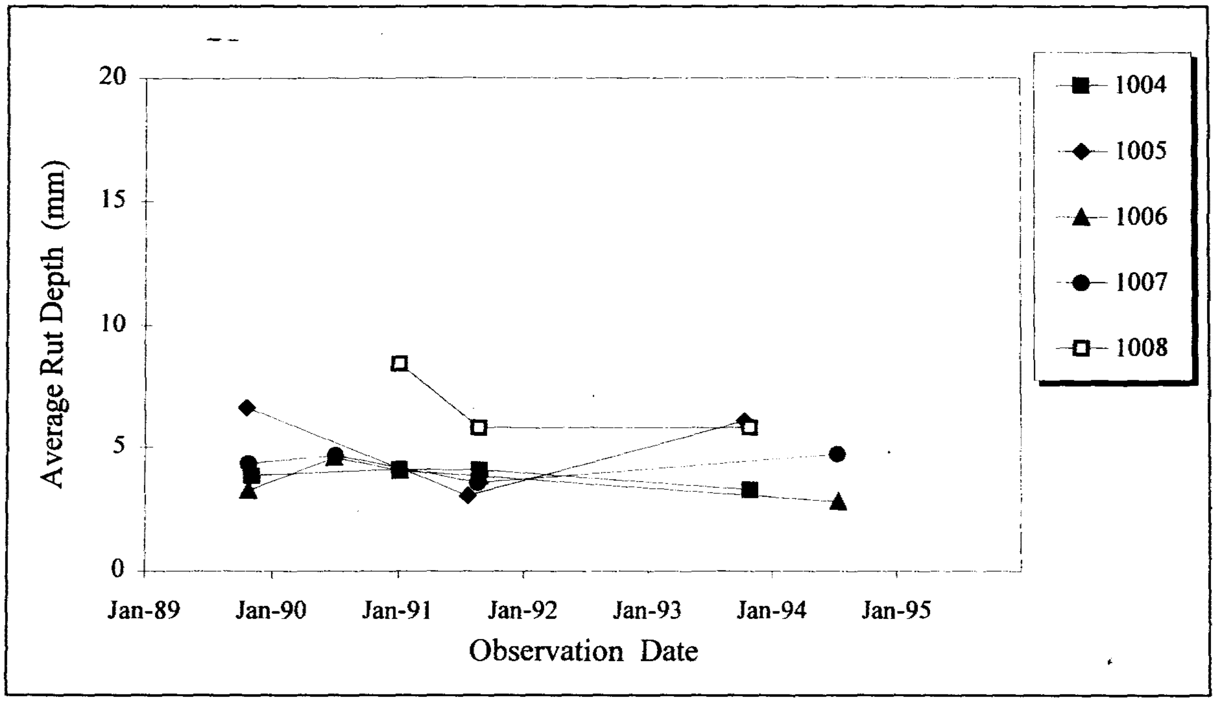


Figure 84. Rut depths in Utah GPS-6 test sections.

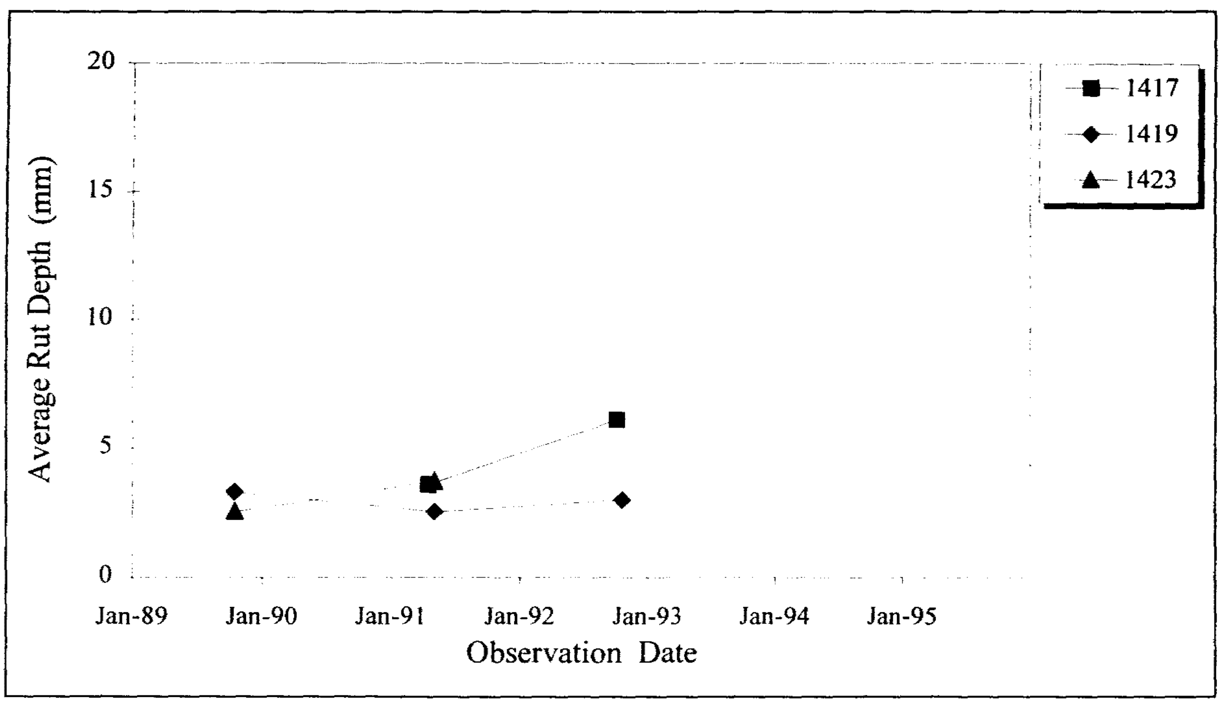


Figure 85. Rut depths in Virginia GPS-6 test sections.

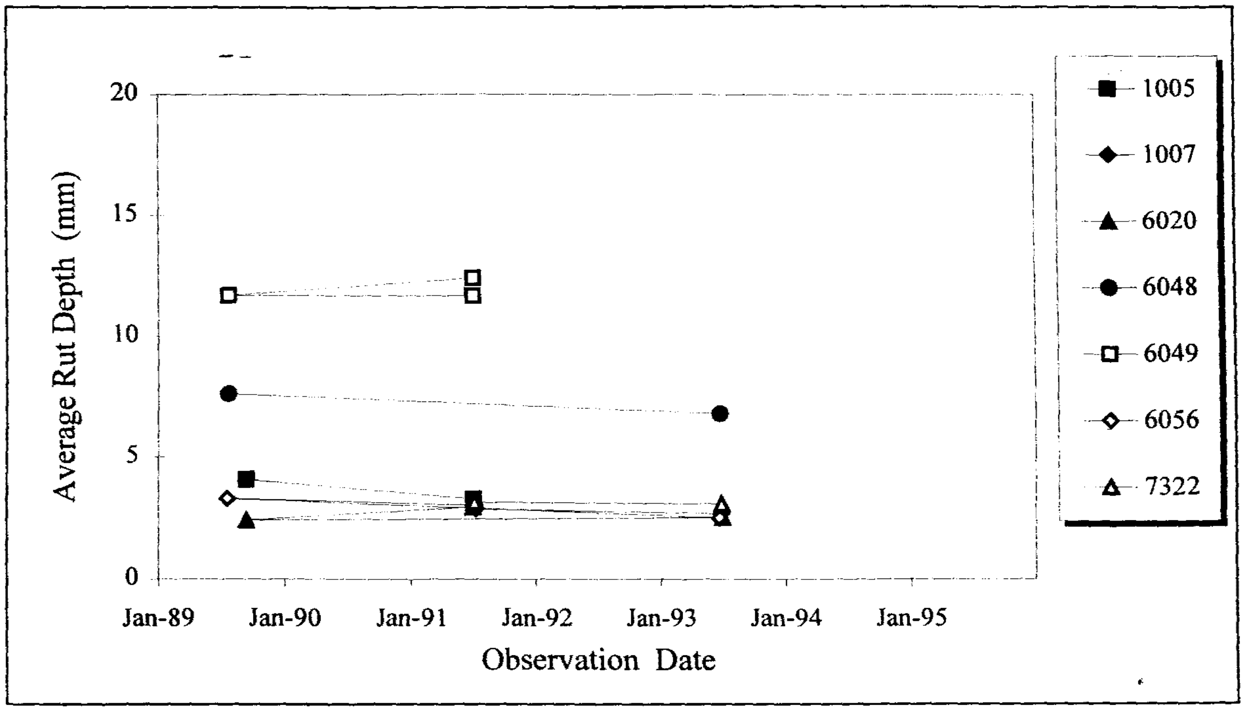


Figure 86. Rut depths in Washington GPS-6 test sections.

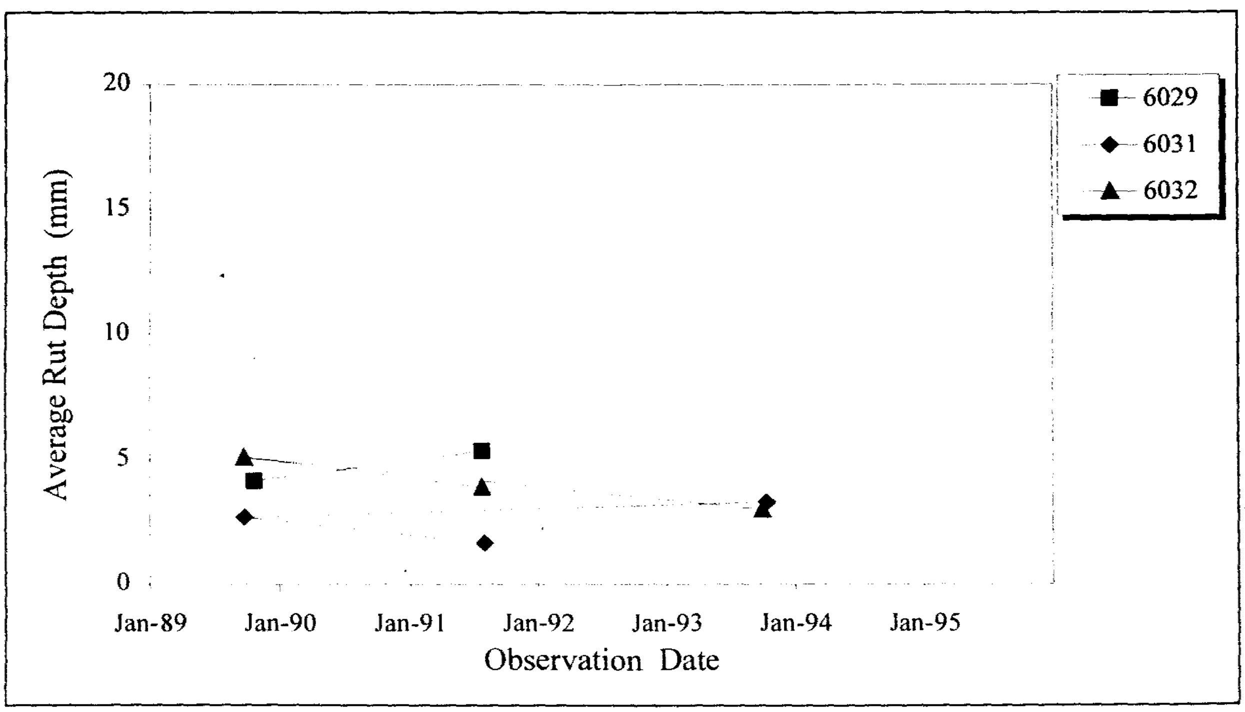


Figure 87. Rut depths in Wyoming GPS-6 test sections.

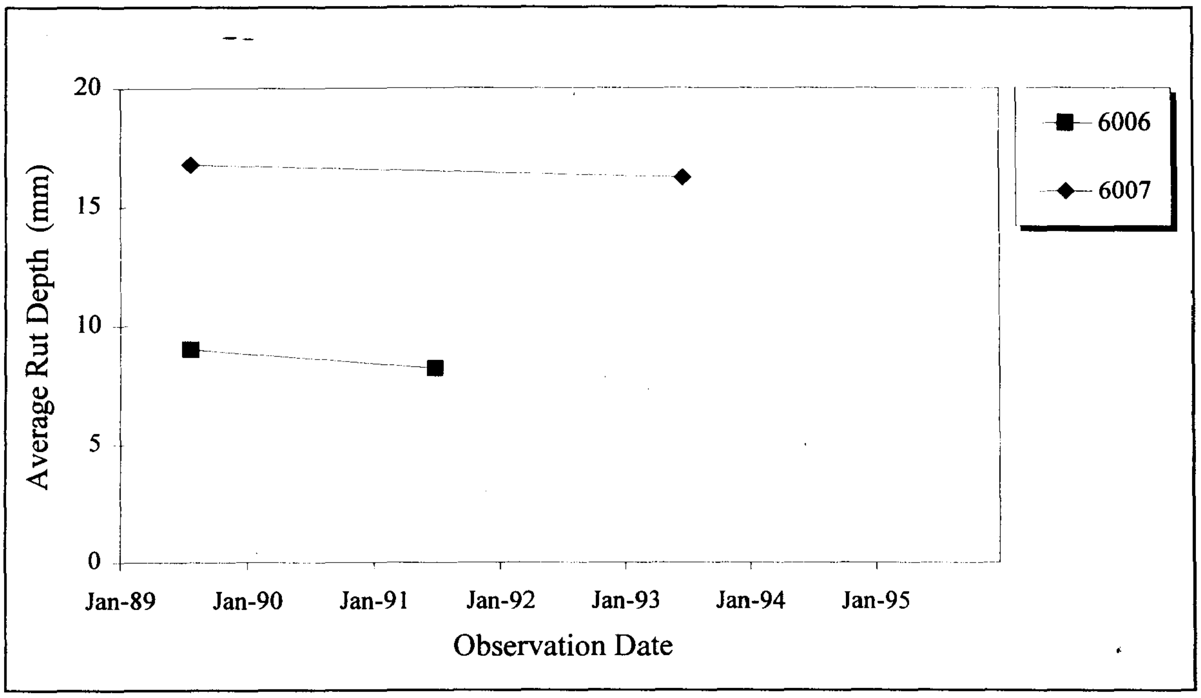


Figure 88. Rut depths in British Columbia GPS-6 test sections.

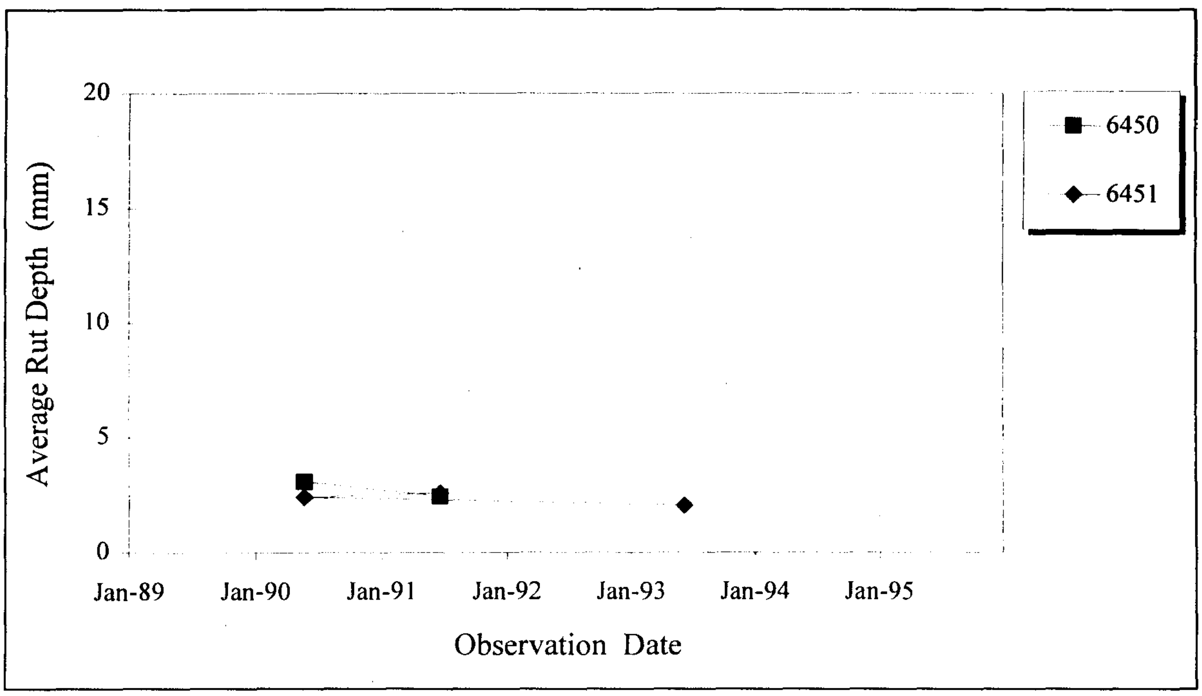


Figure 89. Rut depths in Manitoba GPS-6 test sections.

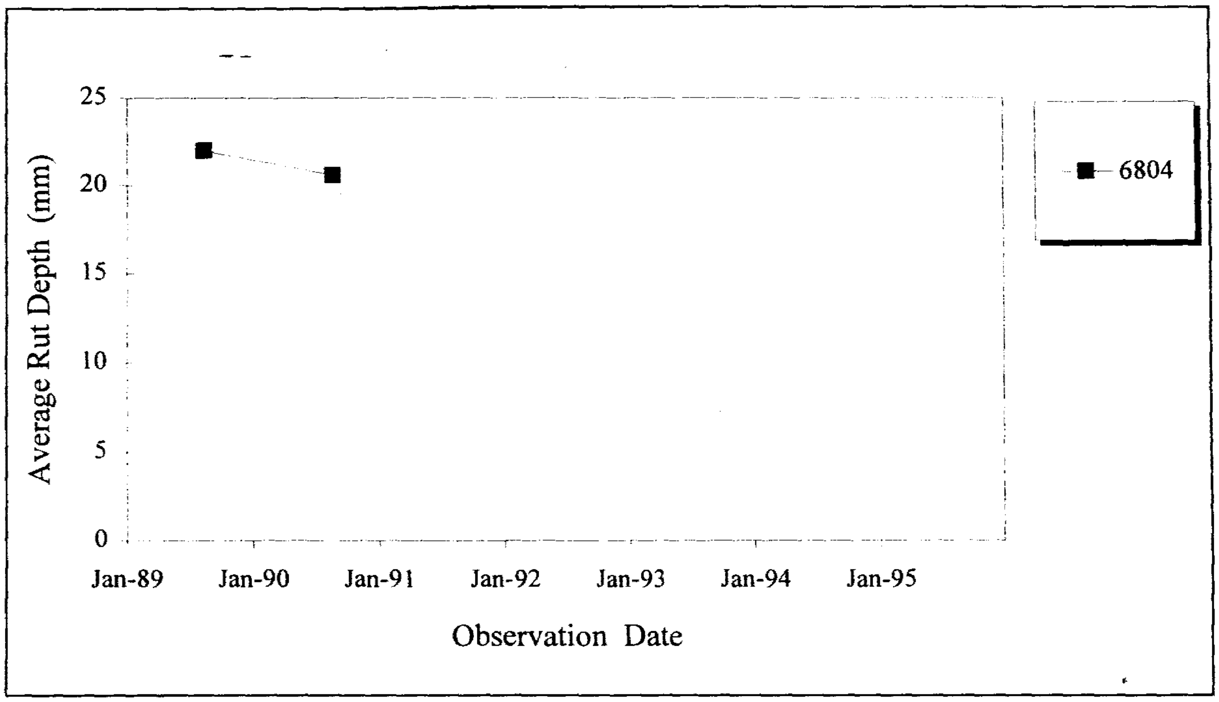


Figure 90. Rut depths in New Brunswick GPS-6 test sections.

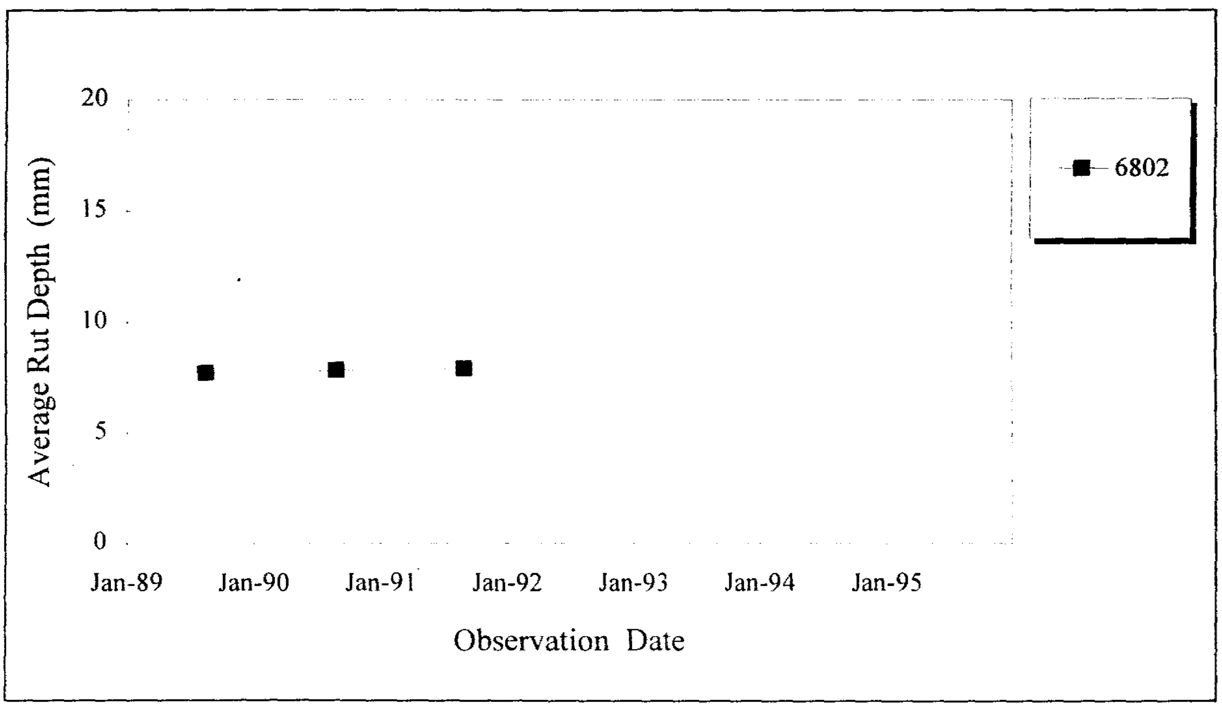


Figure 91. Rut depths in Nova Scotia GPS-6 test sections.

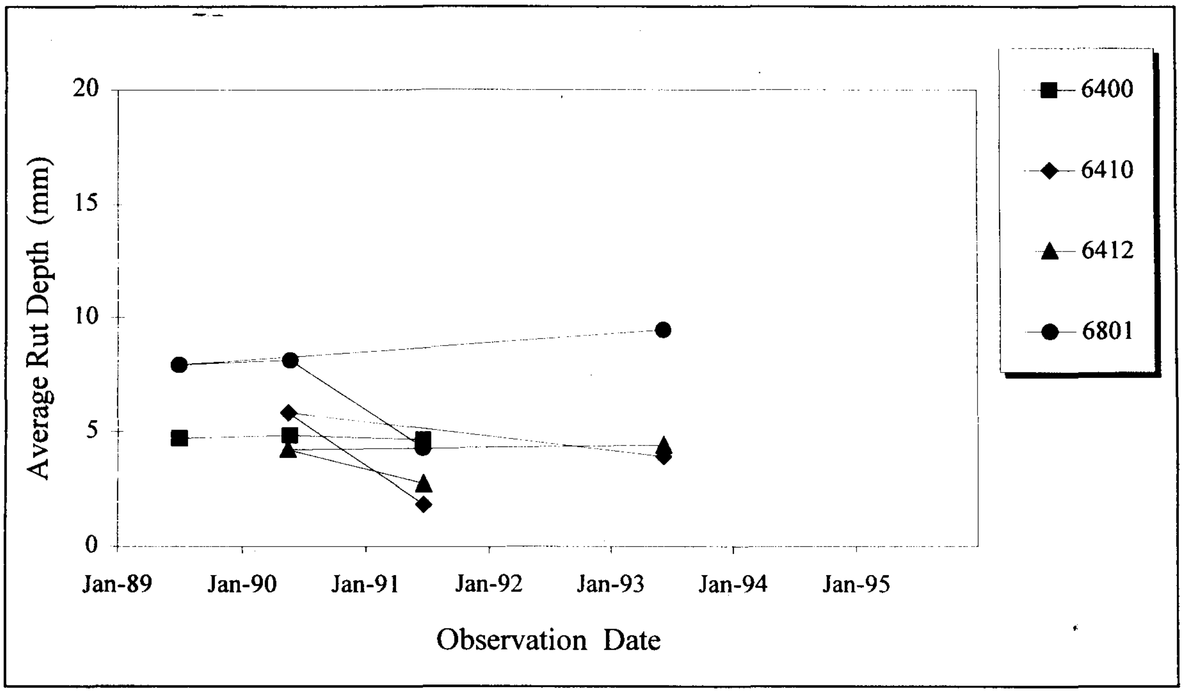
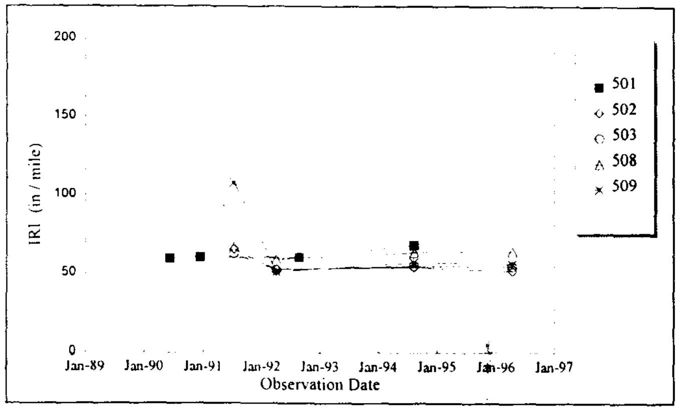


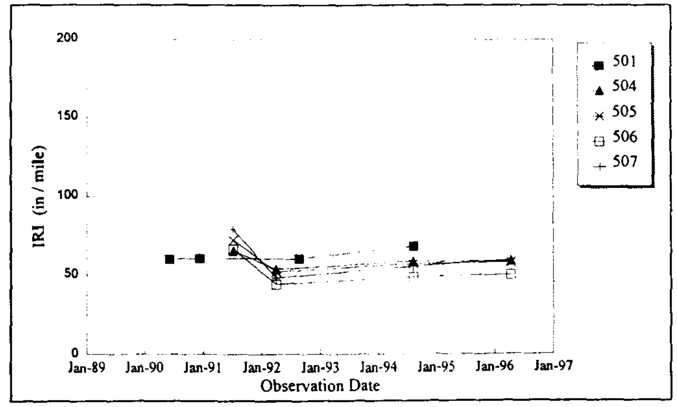
Figure 92. Rut depths in Saskatchewan GPS-6 test sections.

APPENDIX I

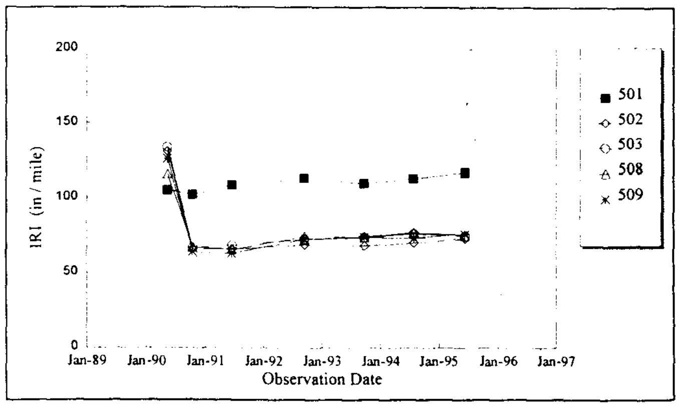
Graphs of Roughness (IRI) for SPS-5 Projects and GPS-6 Test Sections



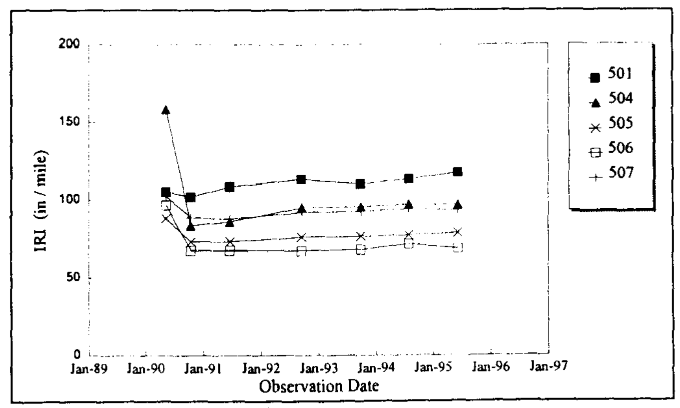
a. IRI in recycled overlay mixtures in Alabama.



b. IRI in virgin overlay mixtures in Alabama.

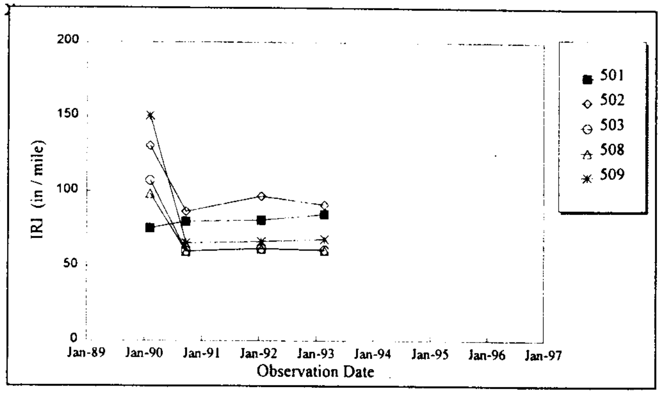


c. IRI in recycled overlay mixtures in Alberta.

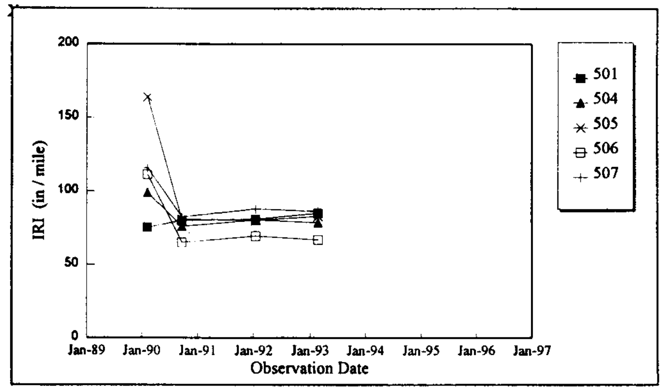


d. IRI in virgin overlay mixtures in Alberta.

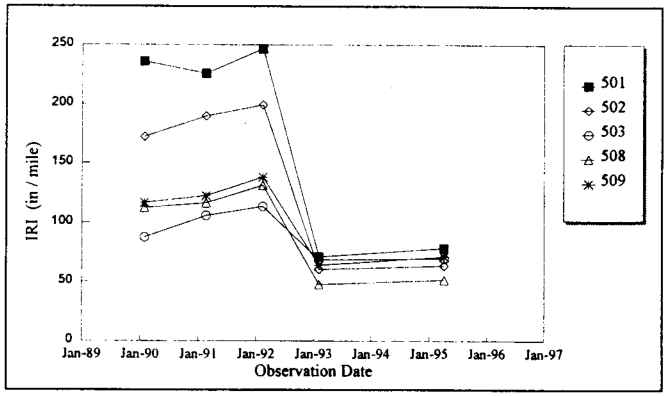
Figure 93. IRI in Alabama and Alberta for the SPS-5 project.



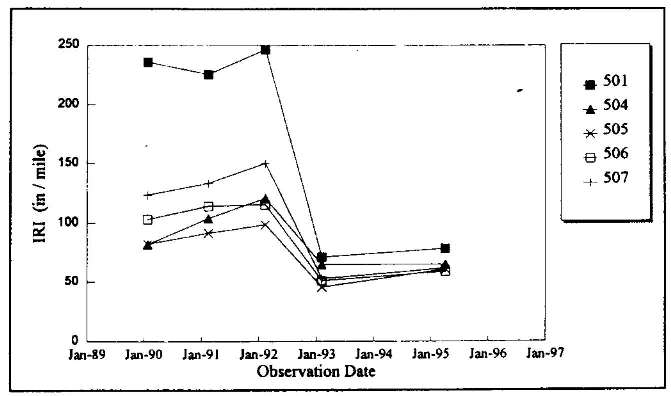
a. IRI in recycled overlay mixtures in Arizona.



b. IRI in virgin overlay mixtures in Arizona.

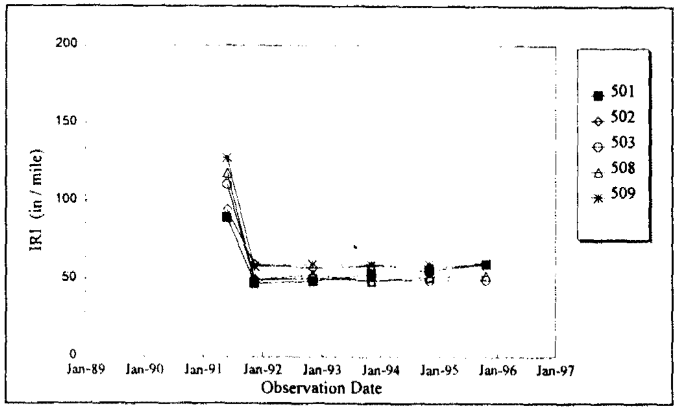


c. IRI in recycled overlay mixtures in California.

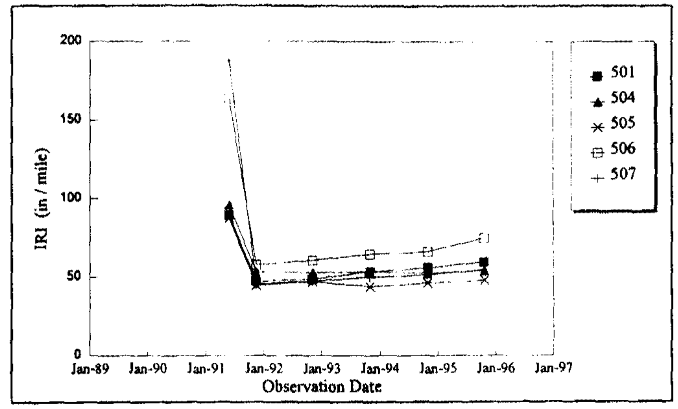


d. IRI in virgin overlay mixtures in California.

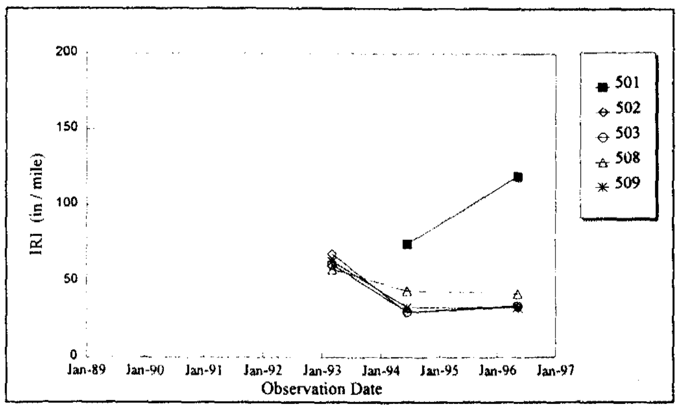
Figure 94. IRI in Arizona and California for the SPS-5 project.



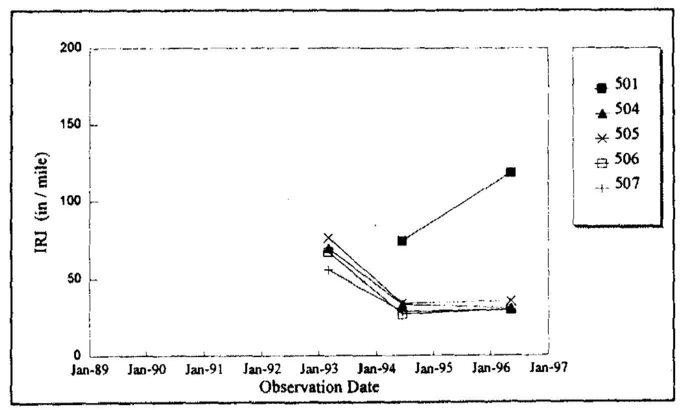
a. IRI in recycled overlay mixtures in Colorado.



b. IRI in virgin overlay mixtures in Colorado.

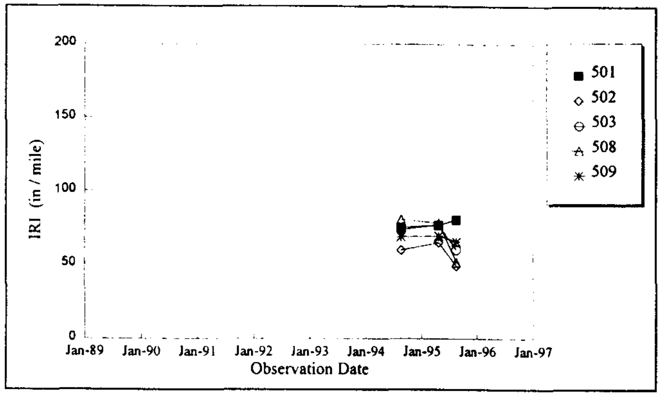


c. IRI in recycled overlay mixtures in Georgia.

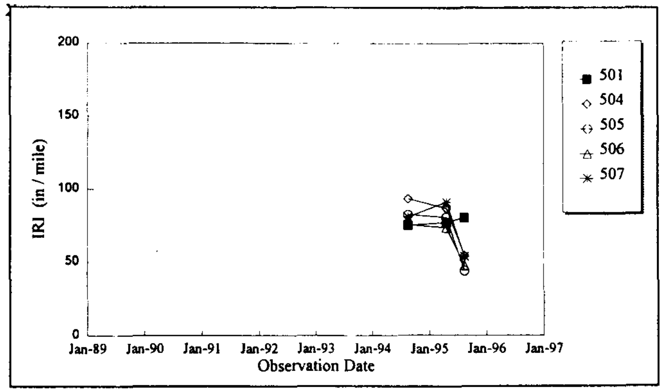


d. IRI in virgin overlay mixtures in Georgia.

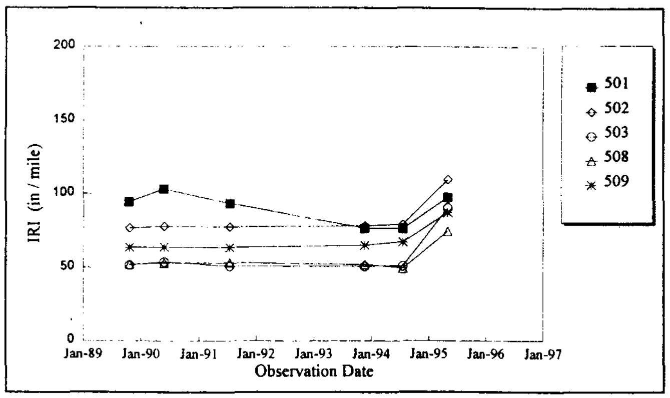
Figure 95. IRI in Colorado and Georgia for the SPS-5 project.



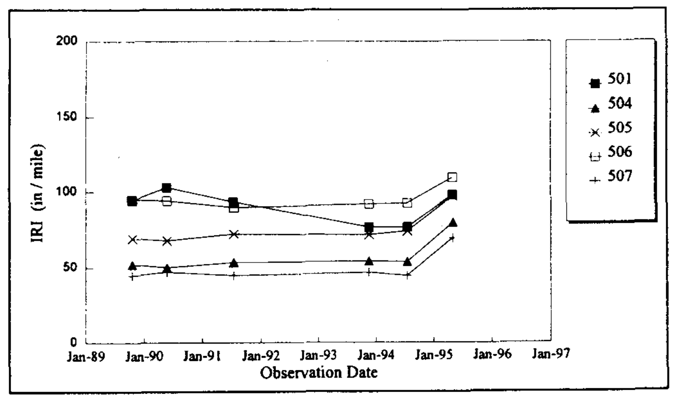
a. IRI in recycled overlay mixtures in Maine.



b. IRI in virgin overlay mixtures in Maine.

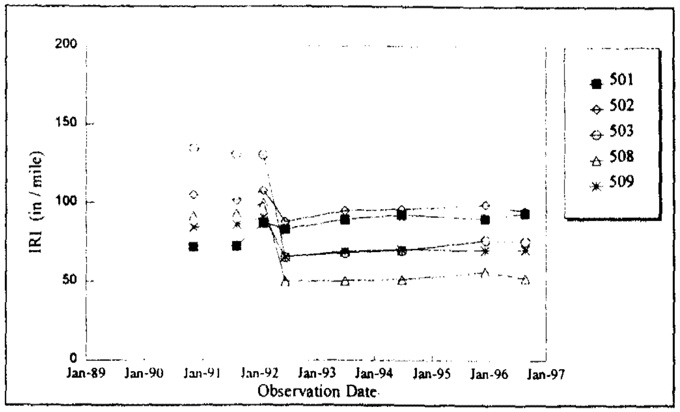


c. IRI in recycled overlay mixtures in Manitoba.

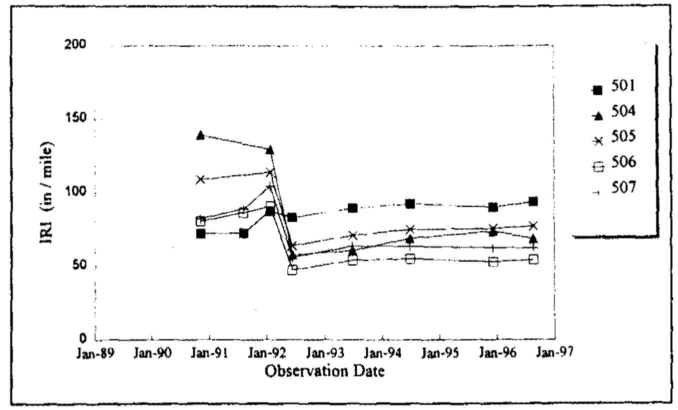


d. IRI in virgin overlay mixtures in Manitoba.

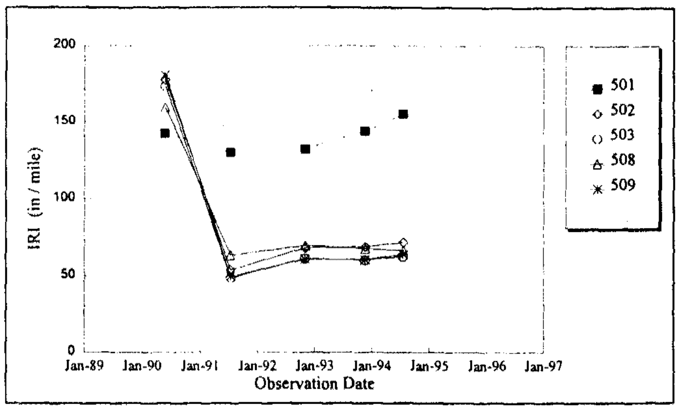
Figure 96. IRI in Maine and Manitoba for the SPS-5 project.



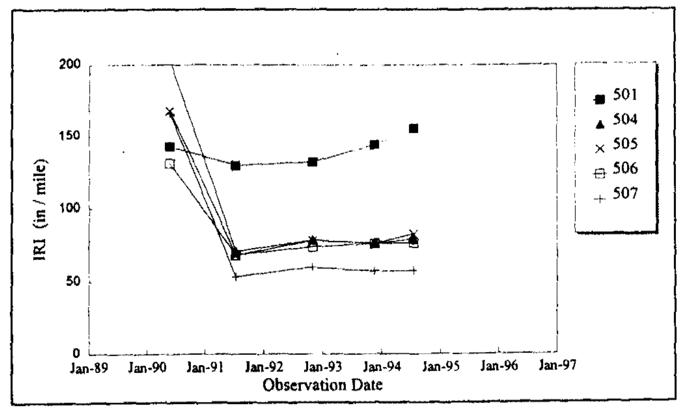
a. IRI in recycled overlay mixtures in Maryland.



b. IRI in virgin overlay mixtures in Maryland.

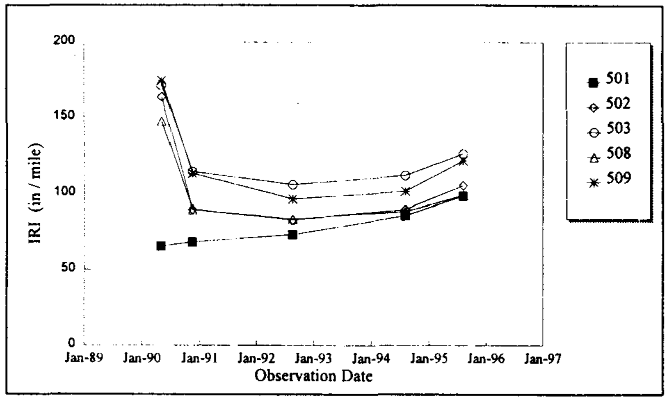


c. IRI in recycled overlay mixtures in Minnesota.

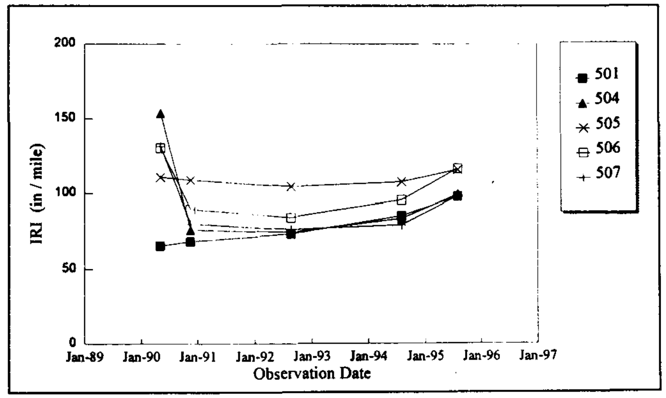


d. IRI in virgin overlay mixtures in Minnesota.

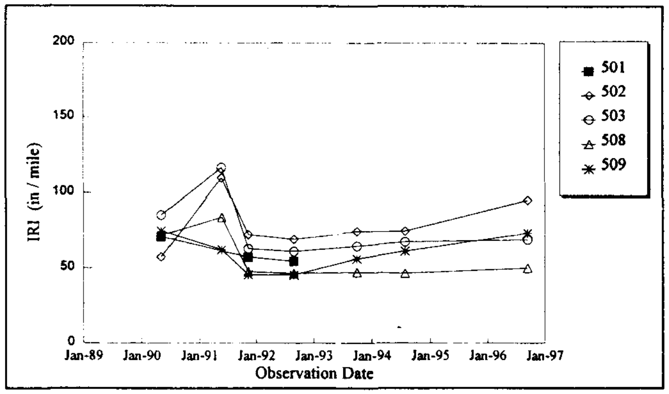
Figure 97. IRI in Maryland and Minnesota for the SPS-5 project.



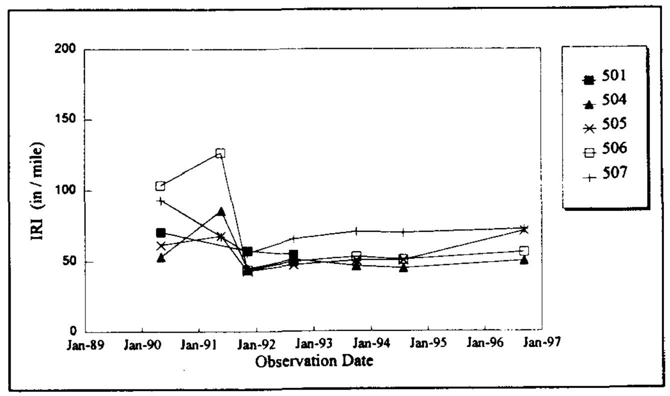
a. IRI in recycled overlay mixtures in Mississippi.



b. IRI in virgin overlay mixtures in Mississippi.

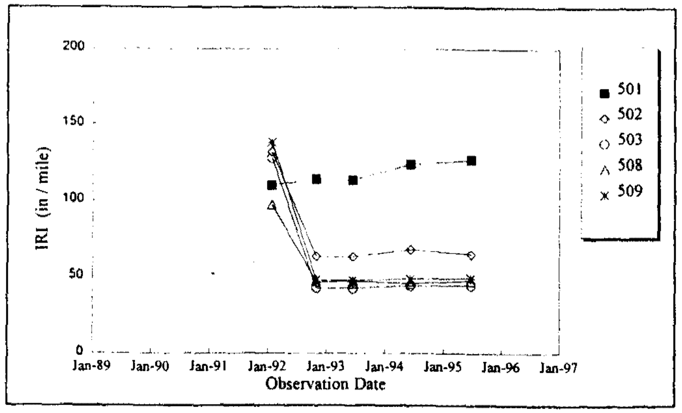


c. IRI in recycled overlay mixtures in Montana.

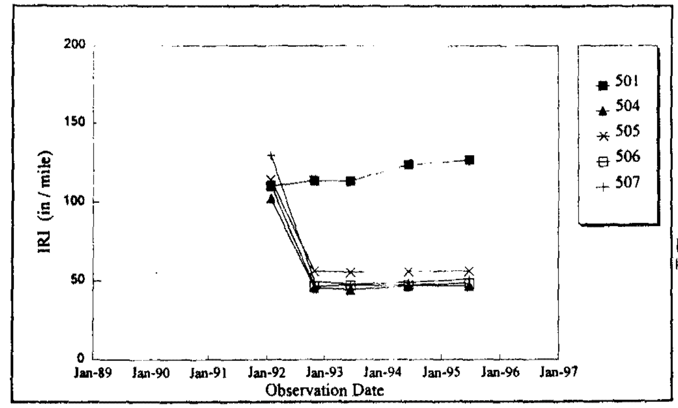


d. IRI in virgin overlay mixtures in Montana.

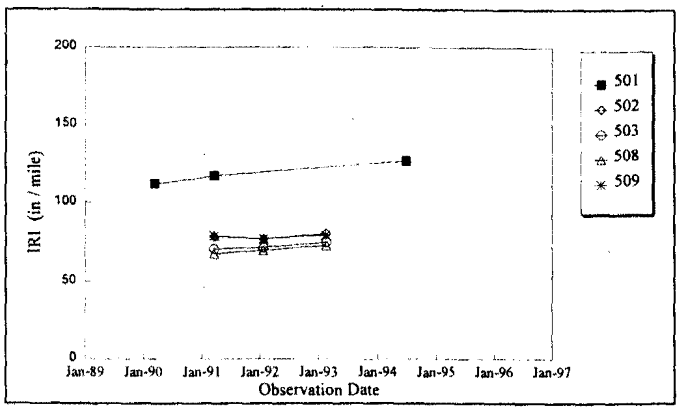
Figure 98. IRI in Mississippi and Montana for the SPS-5 project.



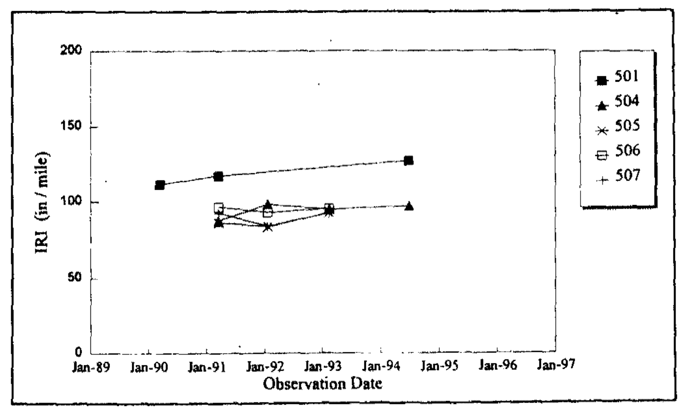
a. IRI in recycled overlay mixtures in New Jersey.



b. IRI in virgin overlay mixtures in New Jersey.



c. IRI in recycled overlay mixtures in Texas.



d. IRI in virgin overlay mixtures in Texas.

Figure 99. IRI in New Jersey and Texas for the SPS-5 project.

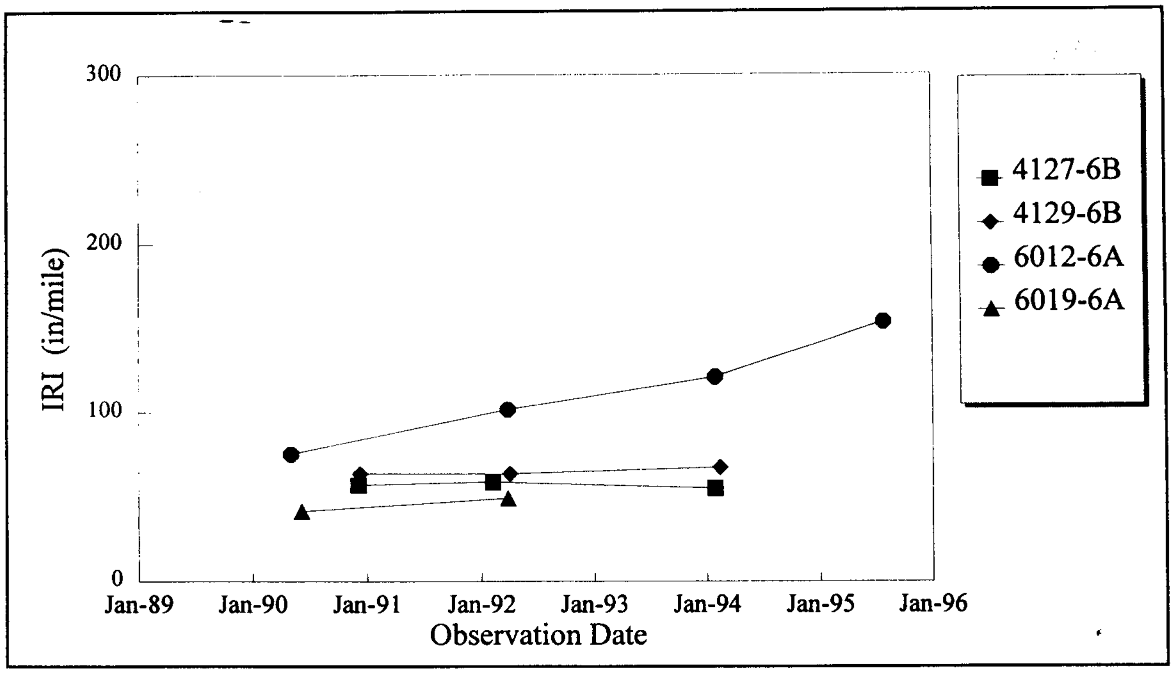


Figure 100. Roughness in Alabama GPS-6 test sections.

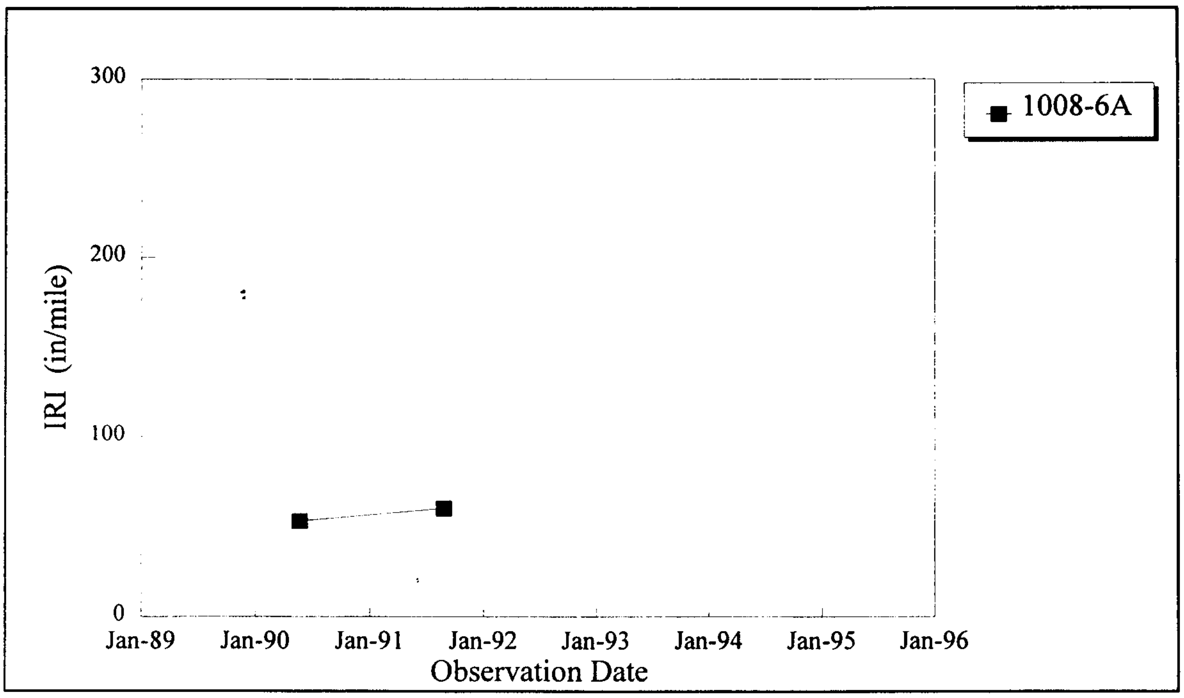


Figure 101. Roughness in Alaska GPS-6 test sections.

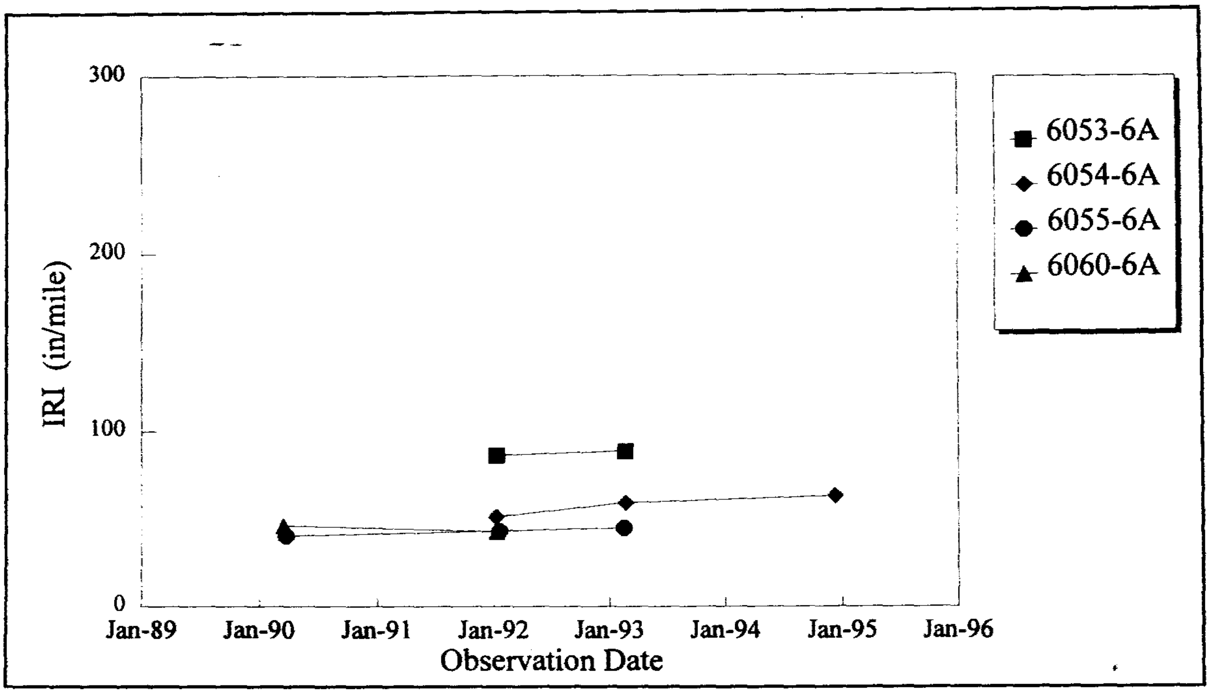


Figure 102. Roughness in Arizona GPS-6 test sections.

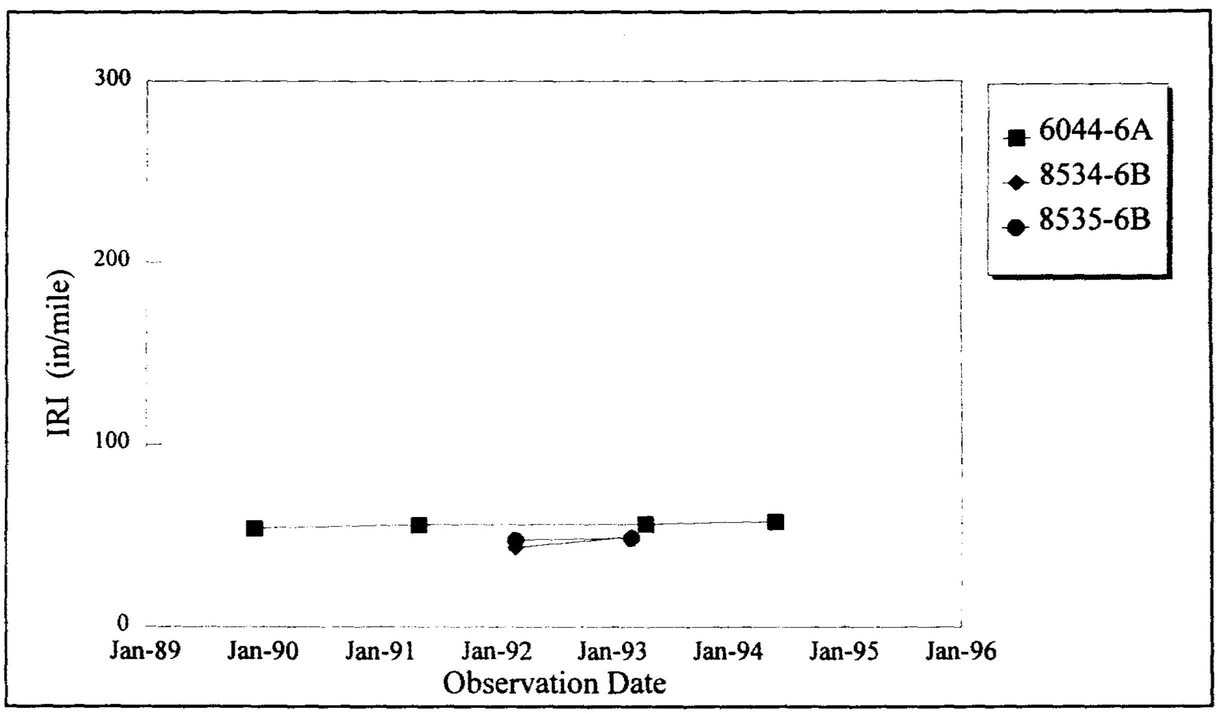


Figure 103. Roughness in California GPS-6 test sections.

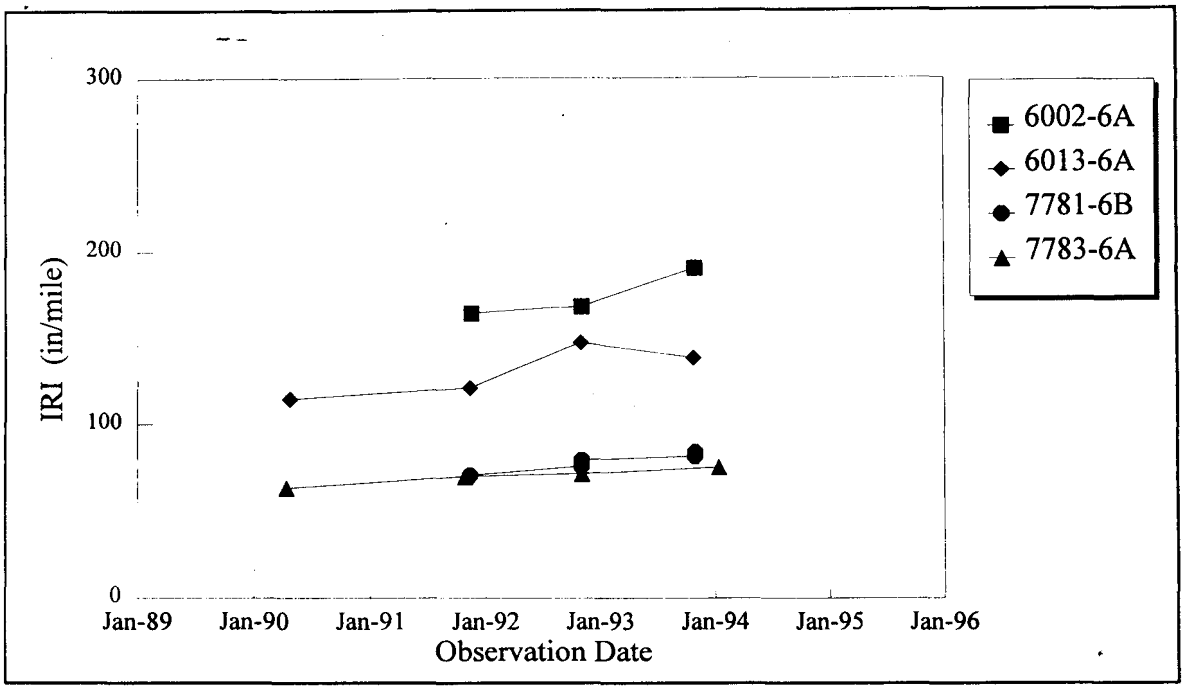


Figure 104. Roughness in Colorado GPS-6 test sections.

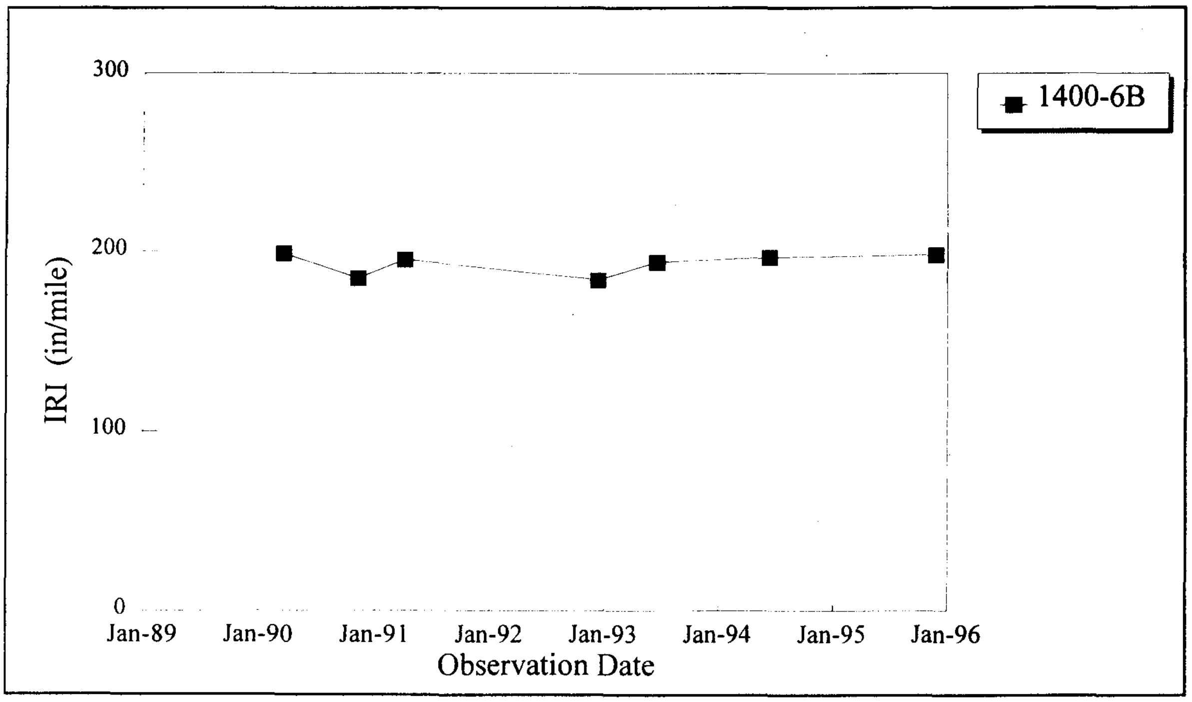


Figure 105. Roughness in District of Columbia GPS-6 test sections.

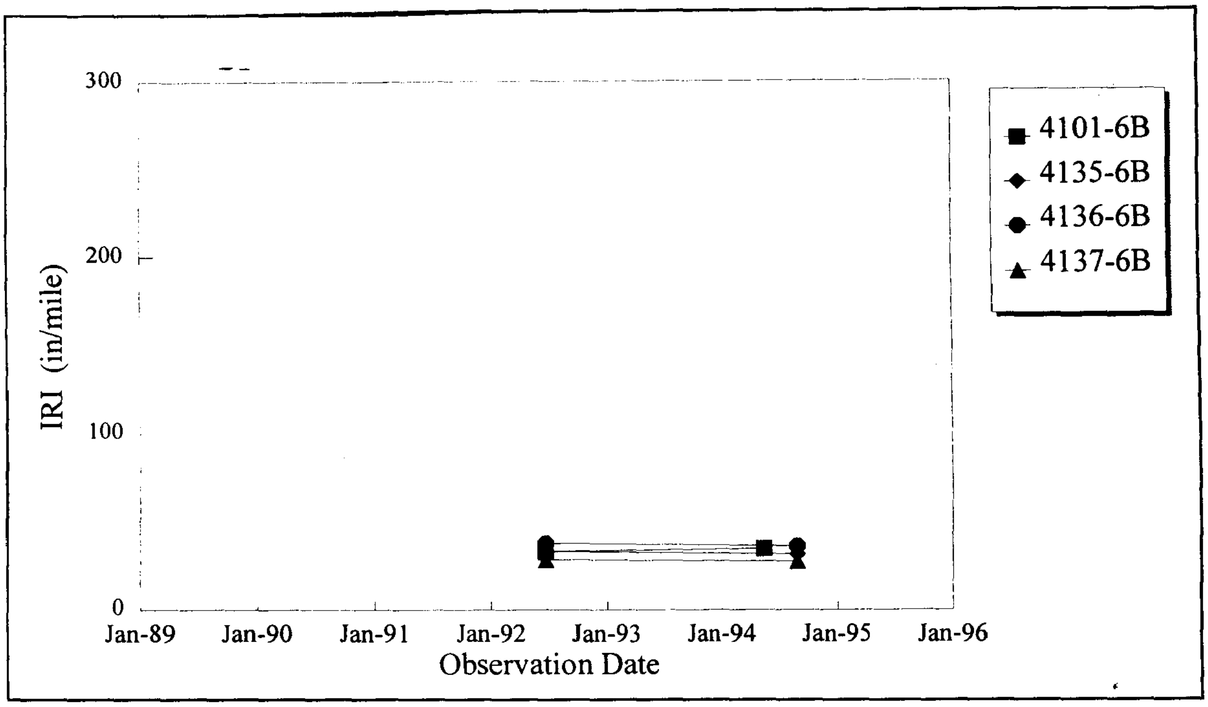


Figure 106. Roughness in Florida GPS-6 test sections.

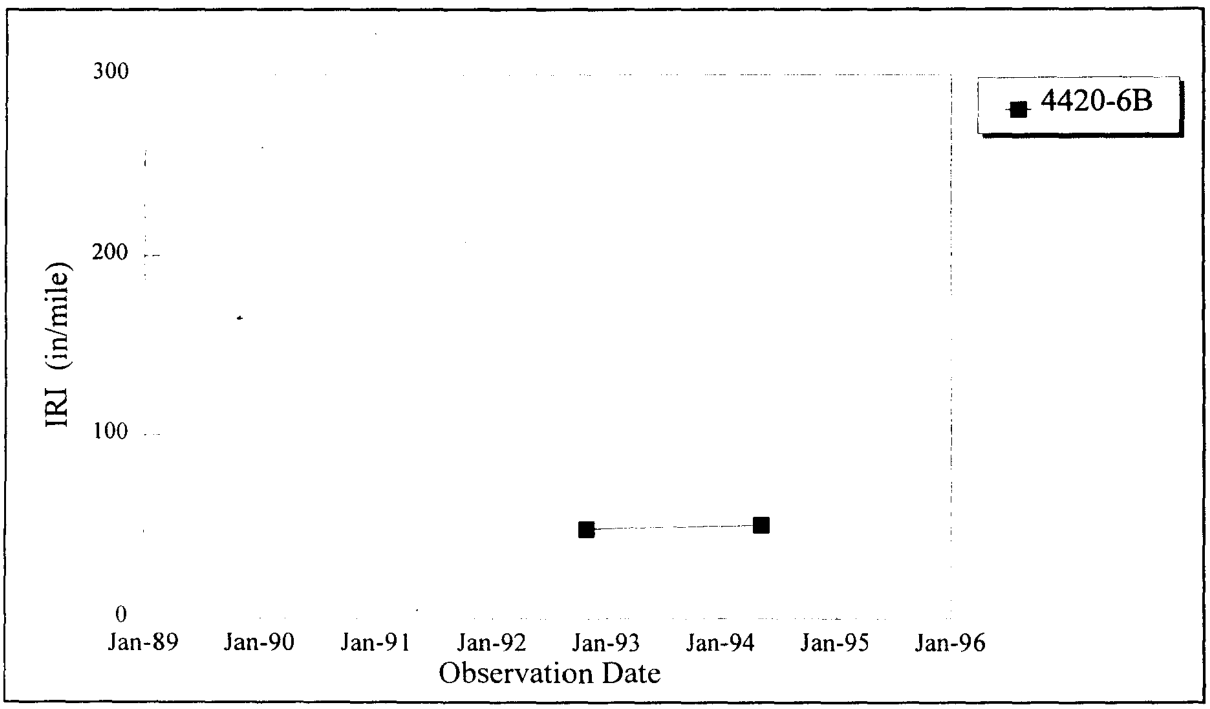


Figure 107. Roughness in Georgia GPS-6 test sections.

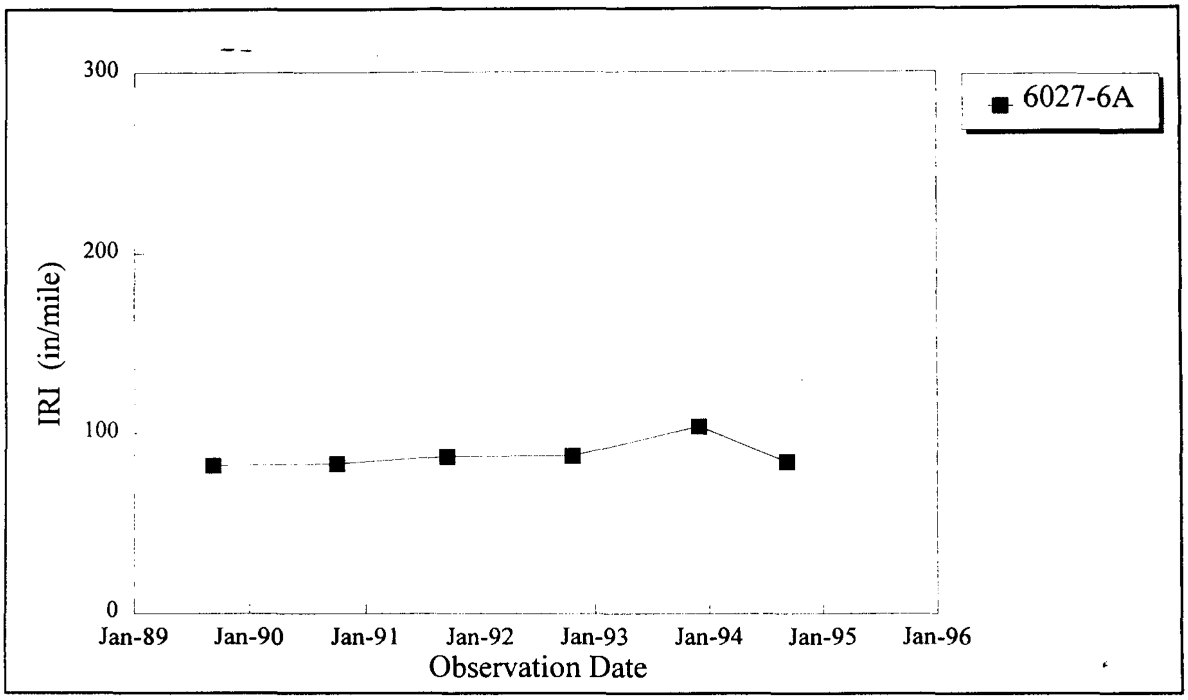


Figure 108. Roughness in Idaho GPS-6 test sections.

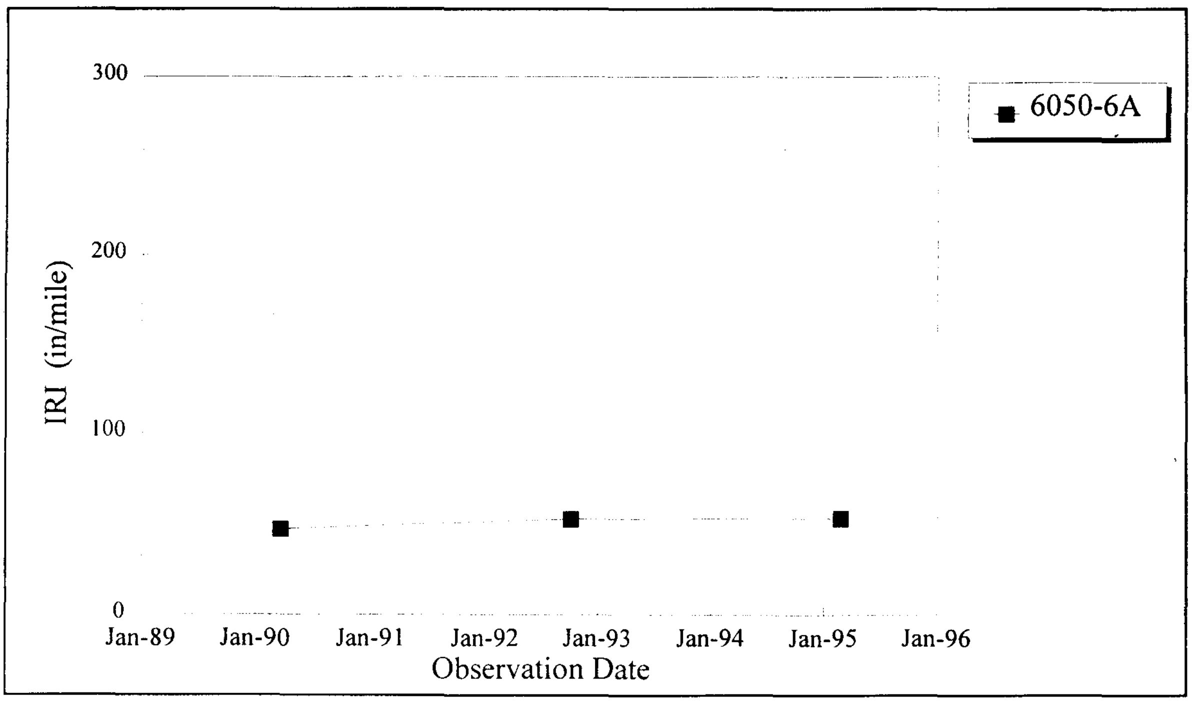


Figure 109. Roughness in Illinois GPS-6 test sections.

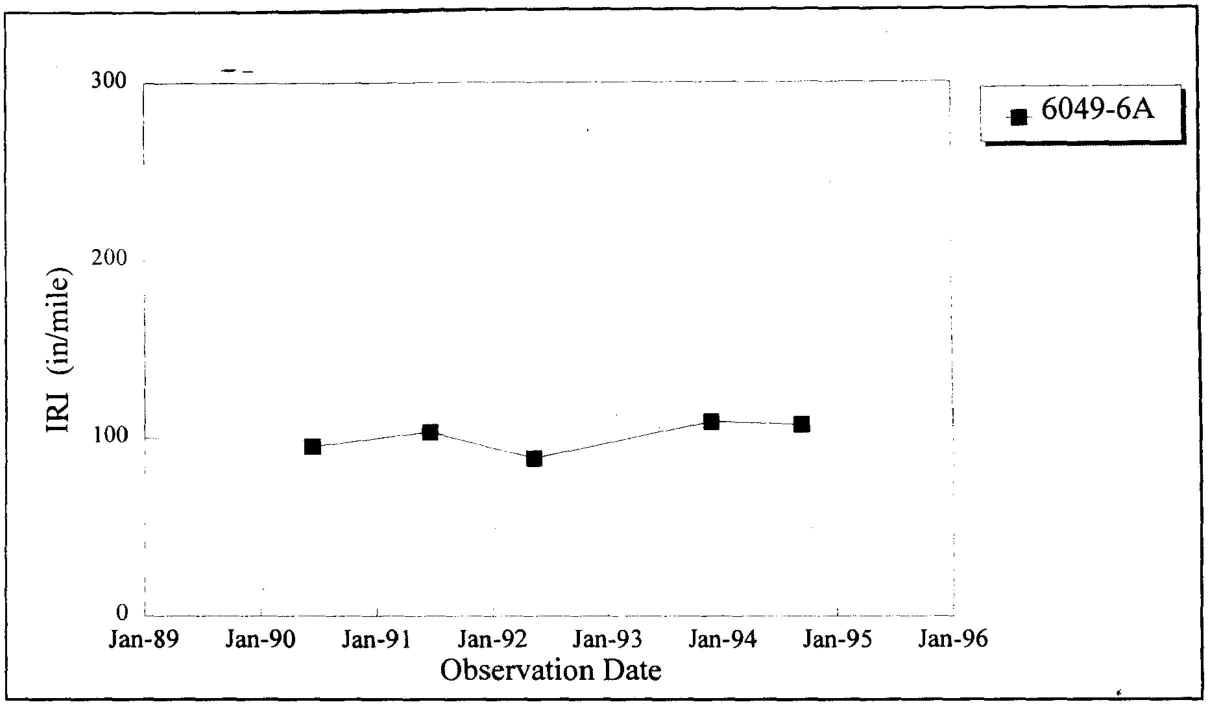


Figure 110. Roughness in Iowa GPS-6 test sections.

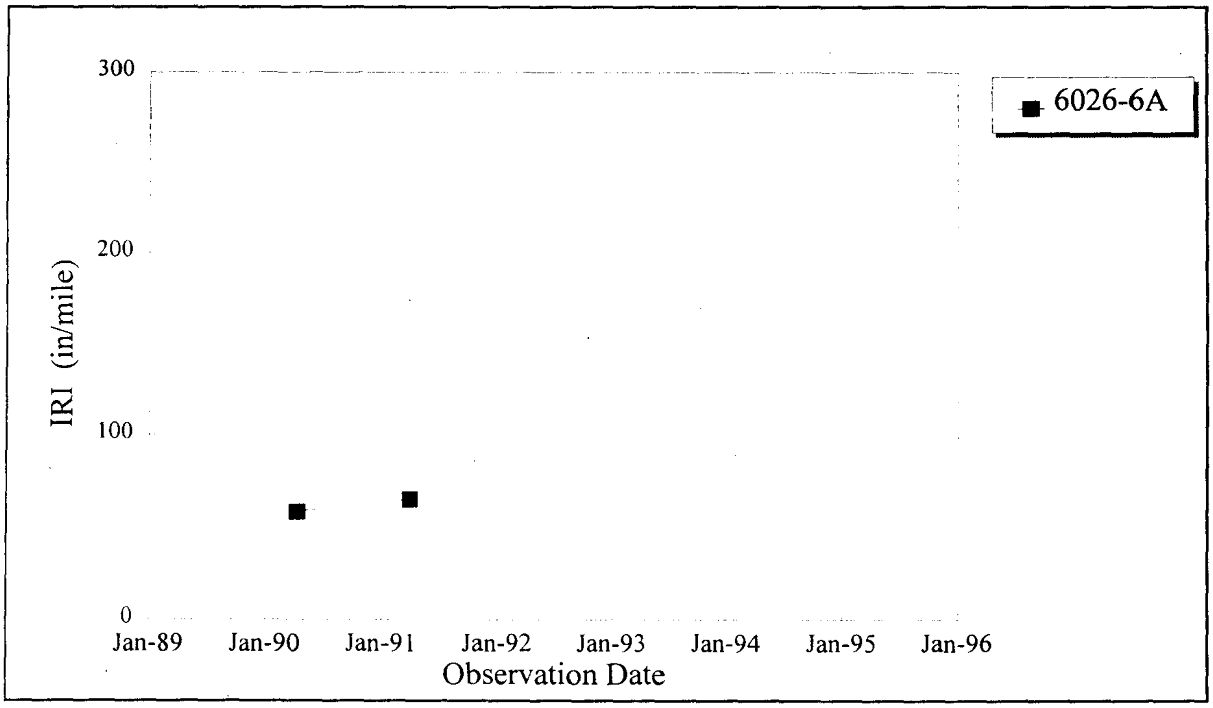


Figure 111. Roughness in Kansas GPS-6 test sections.

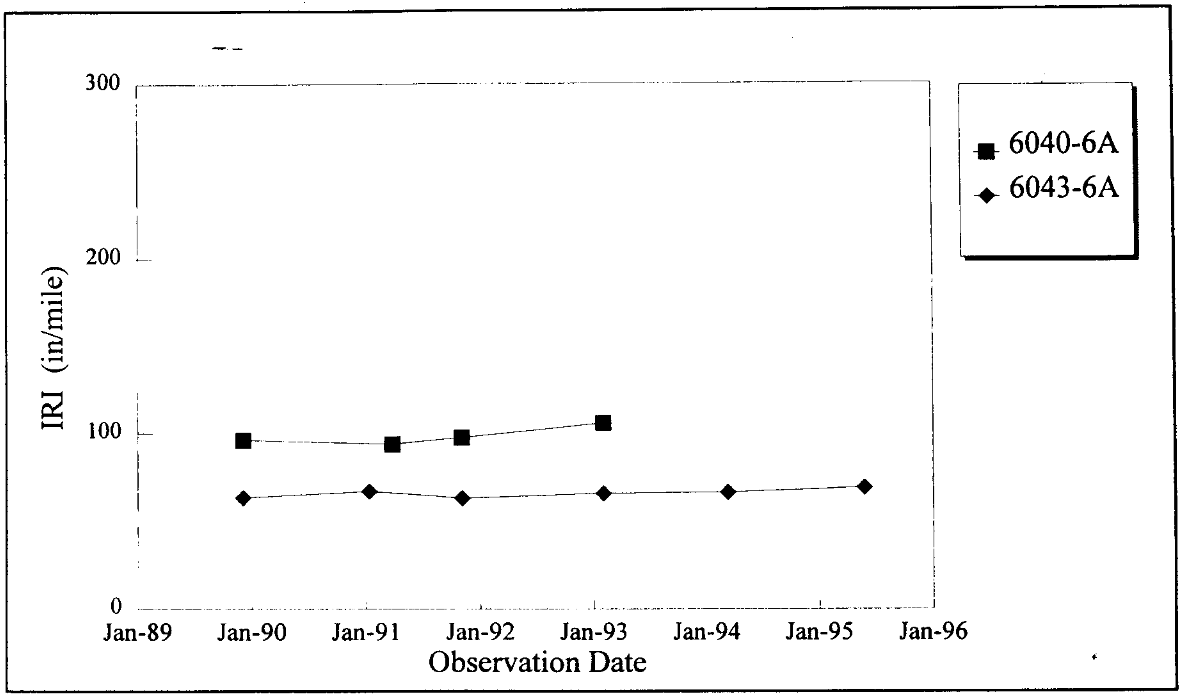


Figure 112. Roughness in Kentucky GPS-6 test sections.

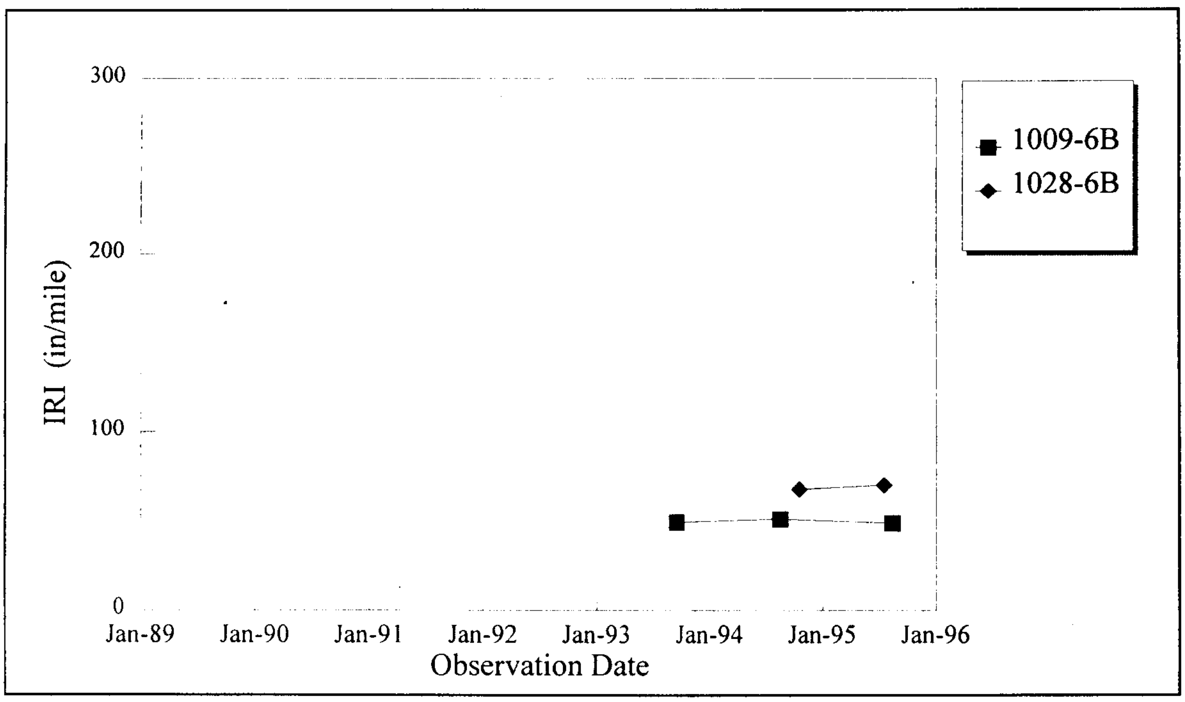


Figure 113. Roughness in Maine GPS-6 test sections.

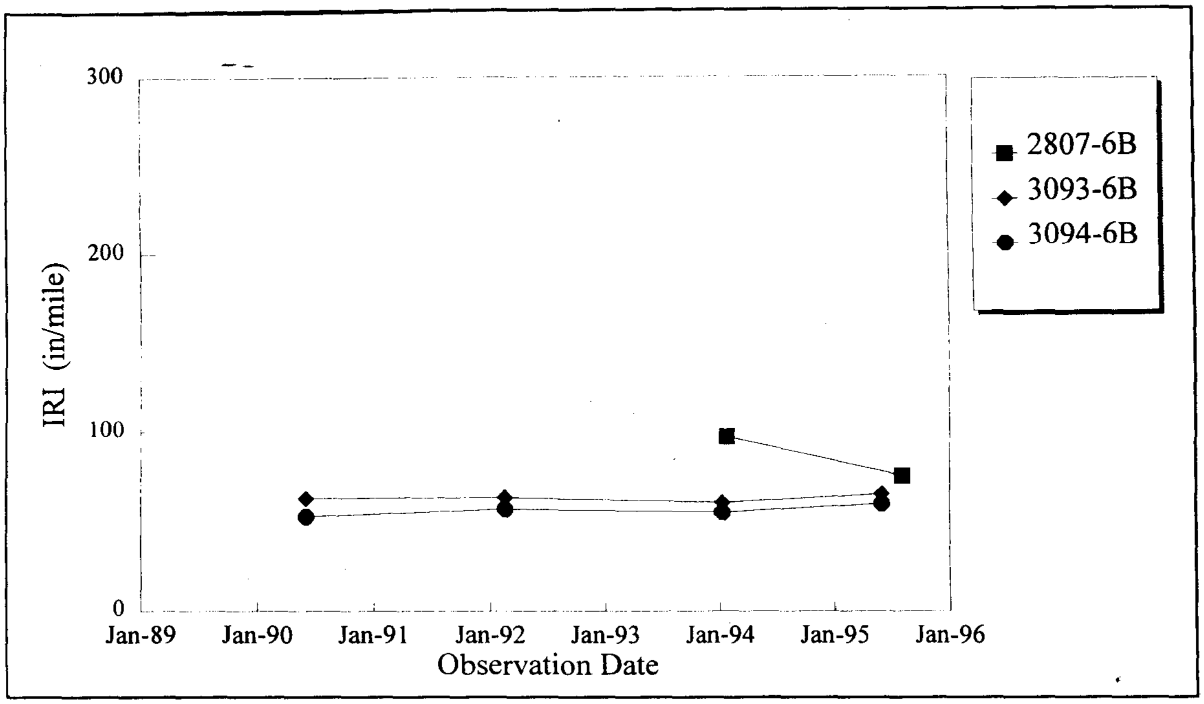


Figure 114. Roughness in Mississippi GPS-6 test sections.

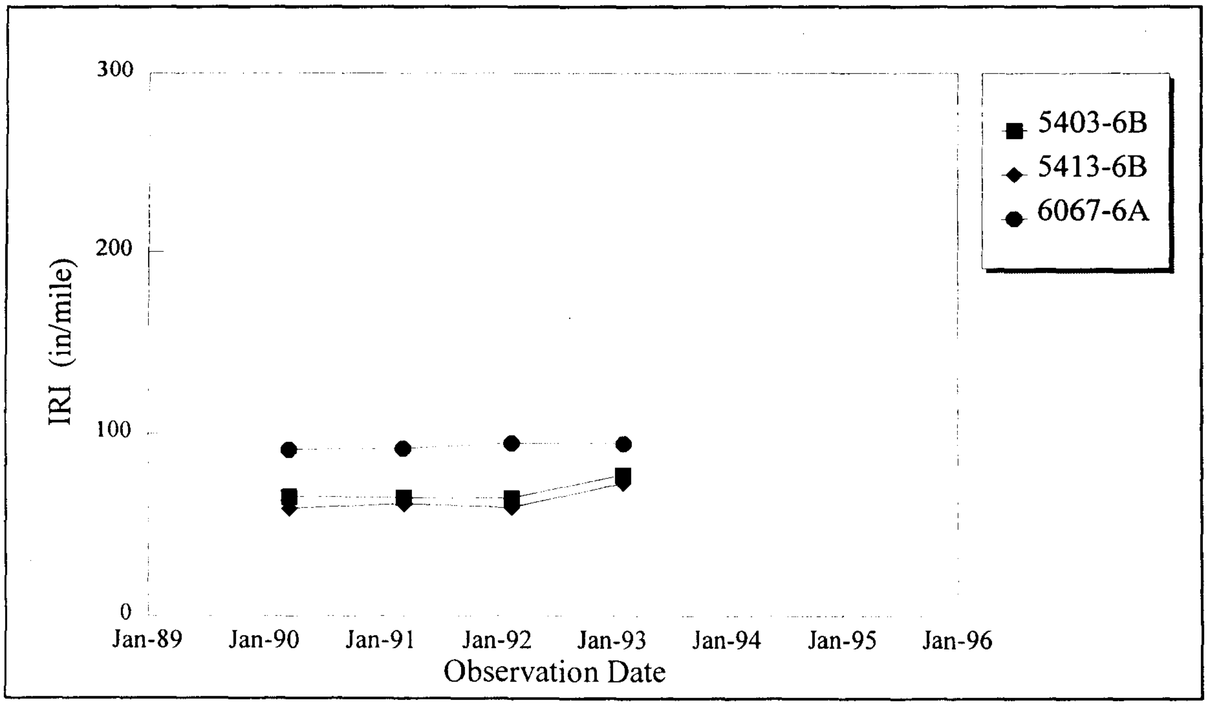


Figure 115. Roughness in Missouri GPS-6 test sections.

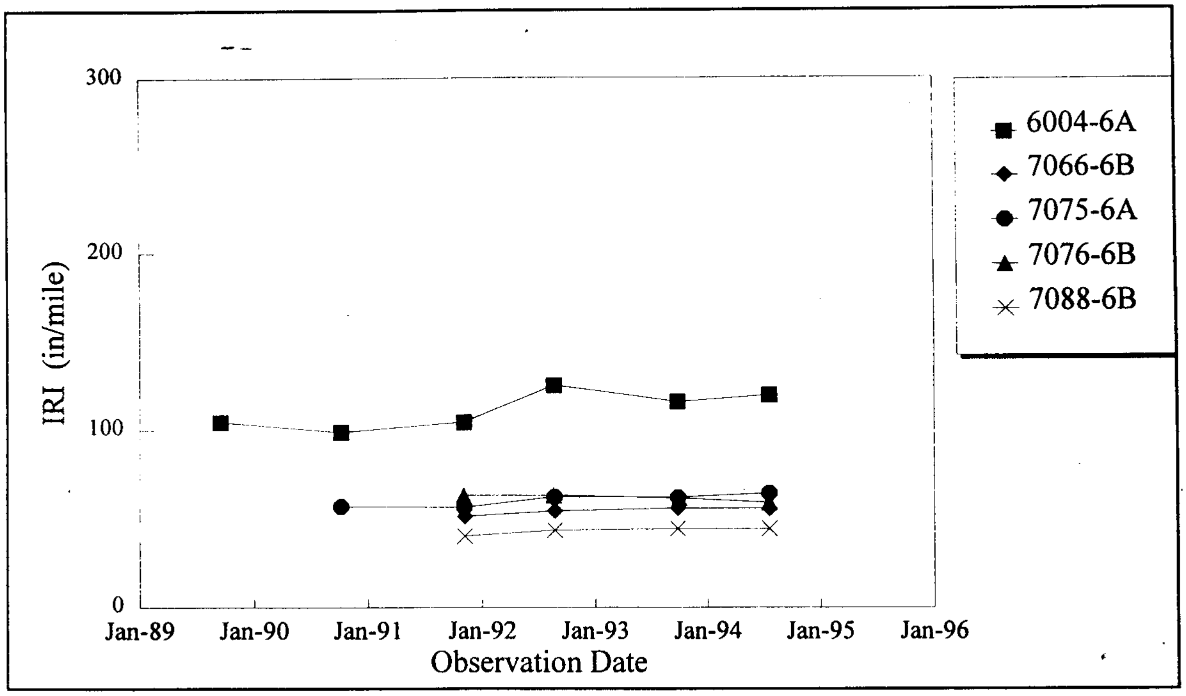


Figure 116. Roughness in Montana GPS-6 test sections.

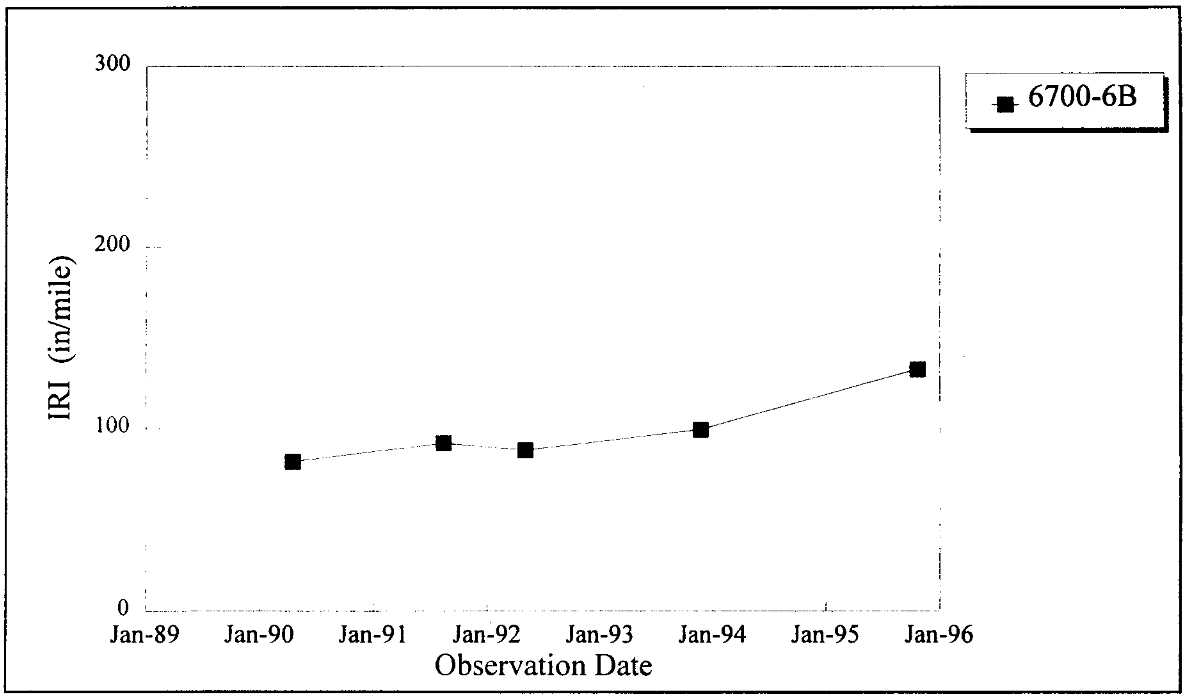


Figure 117. Roughness in Nebraska GPS-6 test sections.

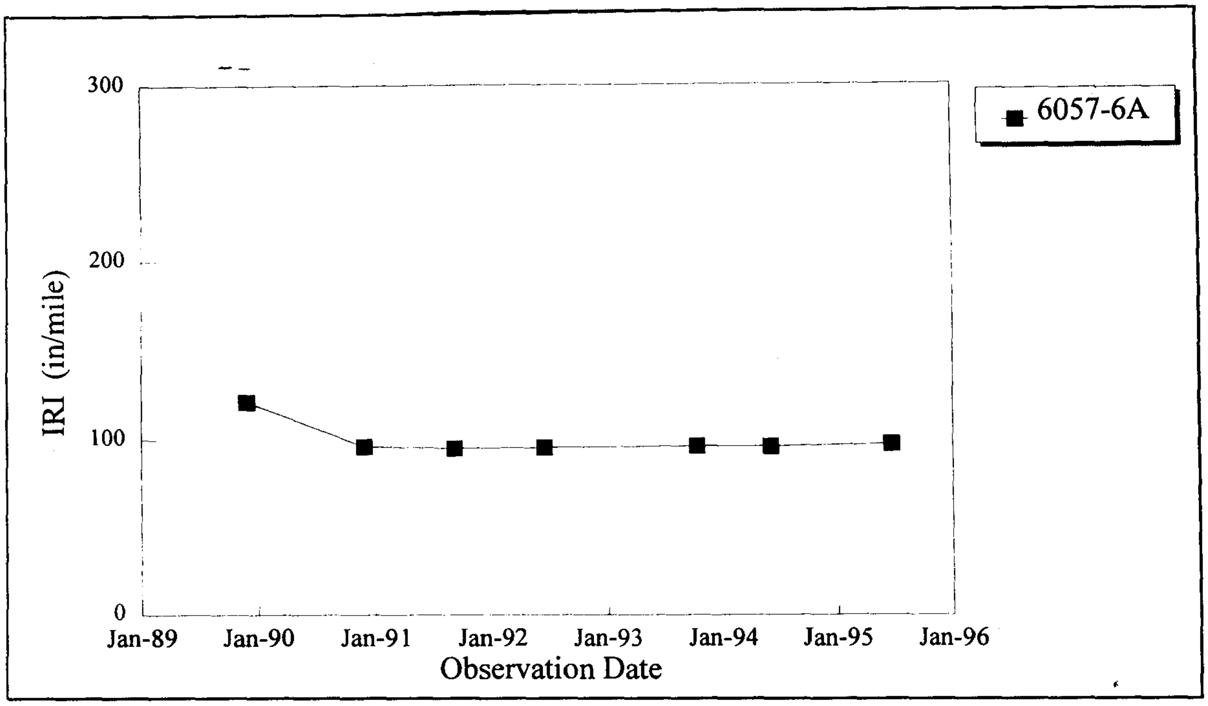


Figure 118. Roughness in New Jersey GPS-6 test sections.

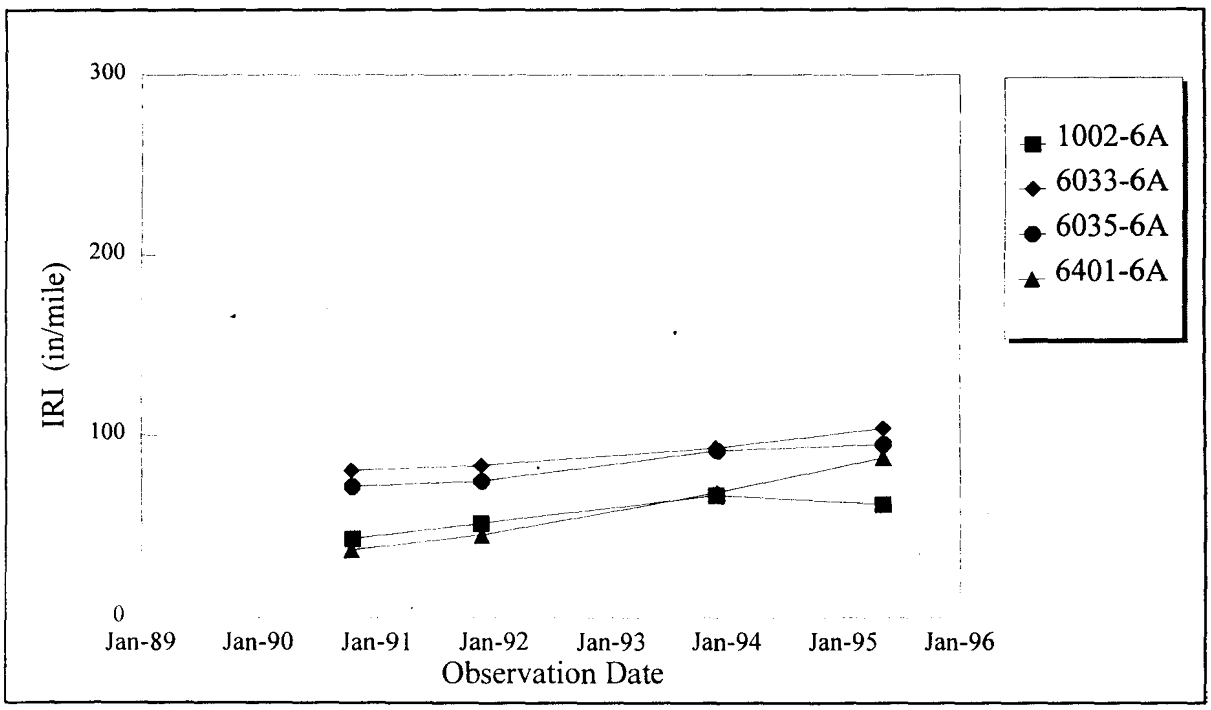


Figure 119. Roughness in New Mexico GPS-6 test sections.

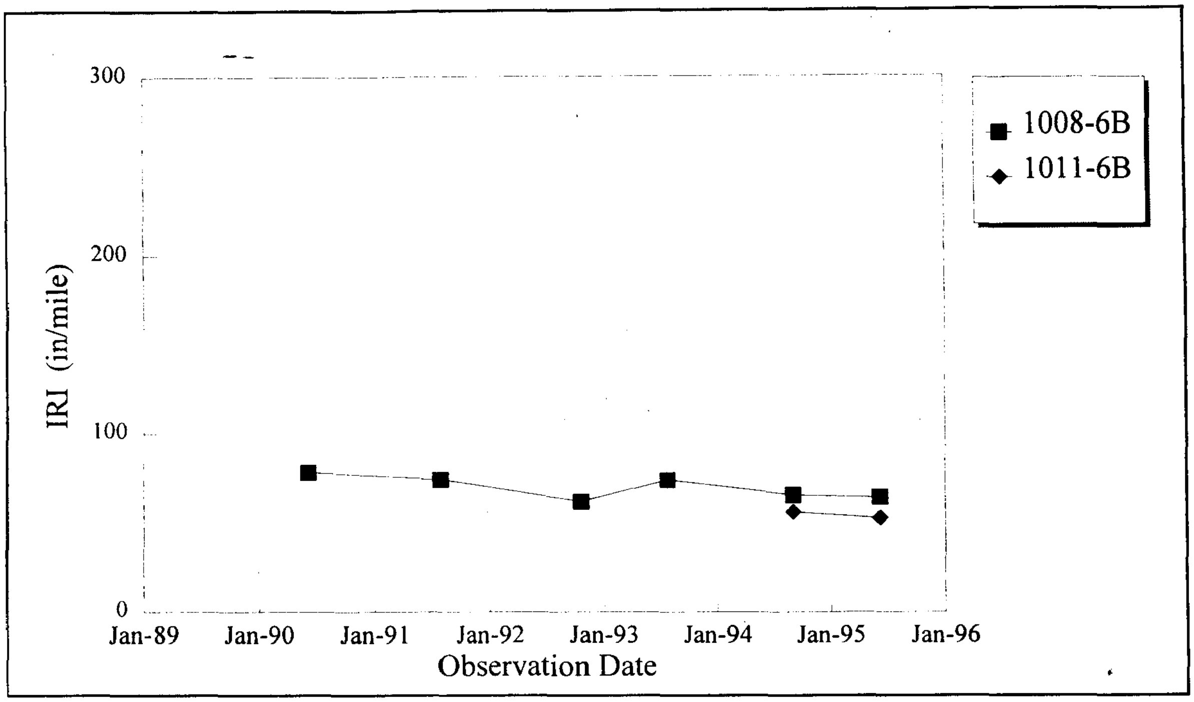


Figure 120. Roughness in New York GPS-6 test sections.

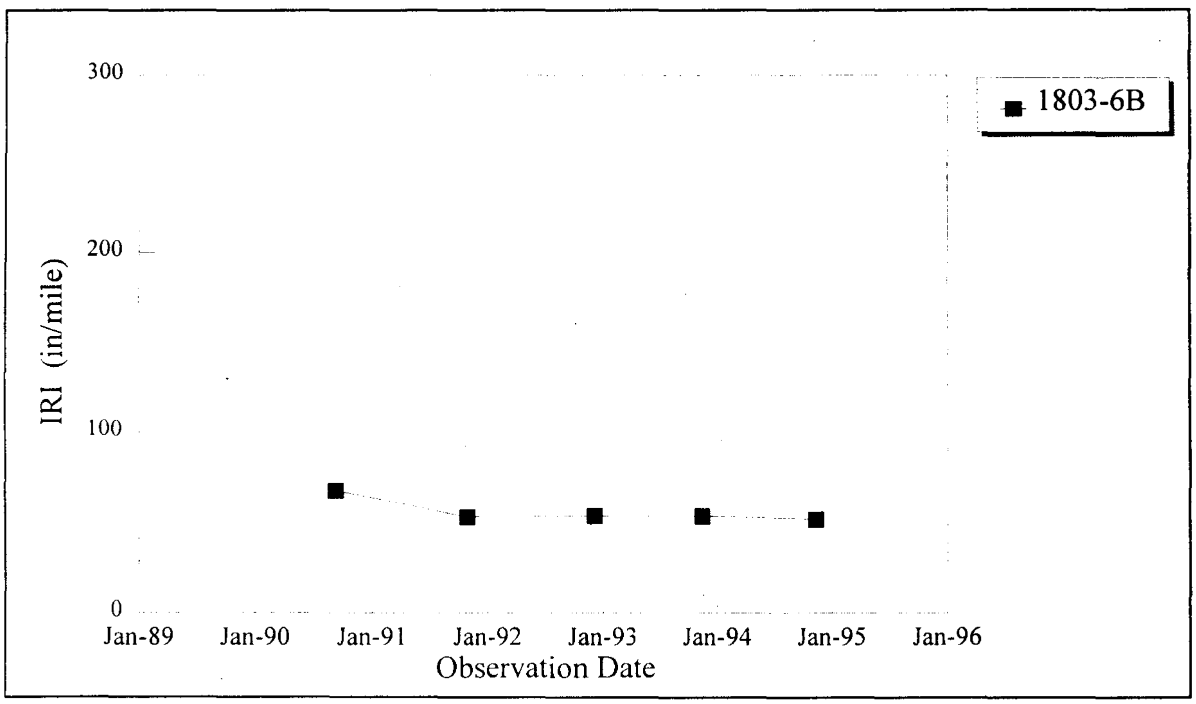


Figure 121. Roughness in North Carolina GPS-6 test sections.

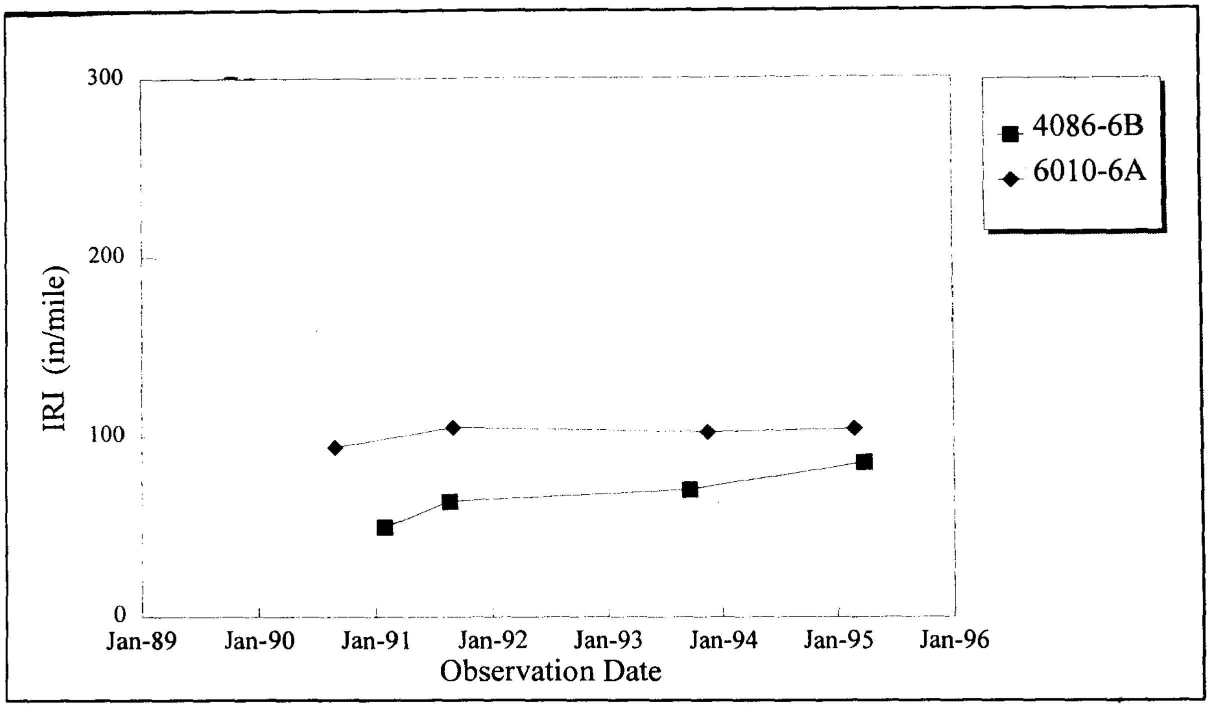


Figure 122. Roughness in Oklahoma GPS-6 test sections.

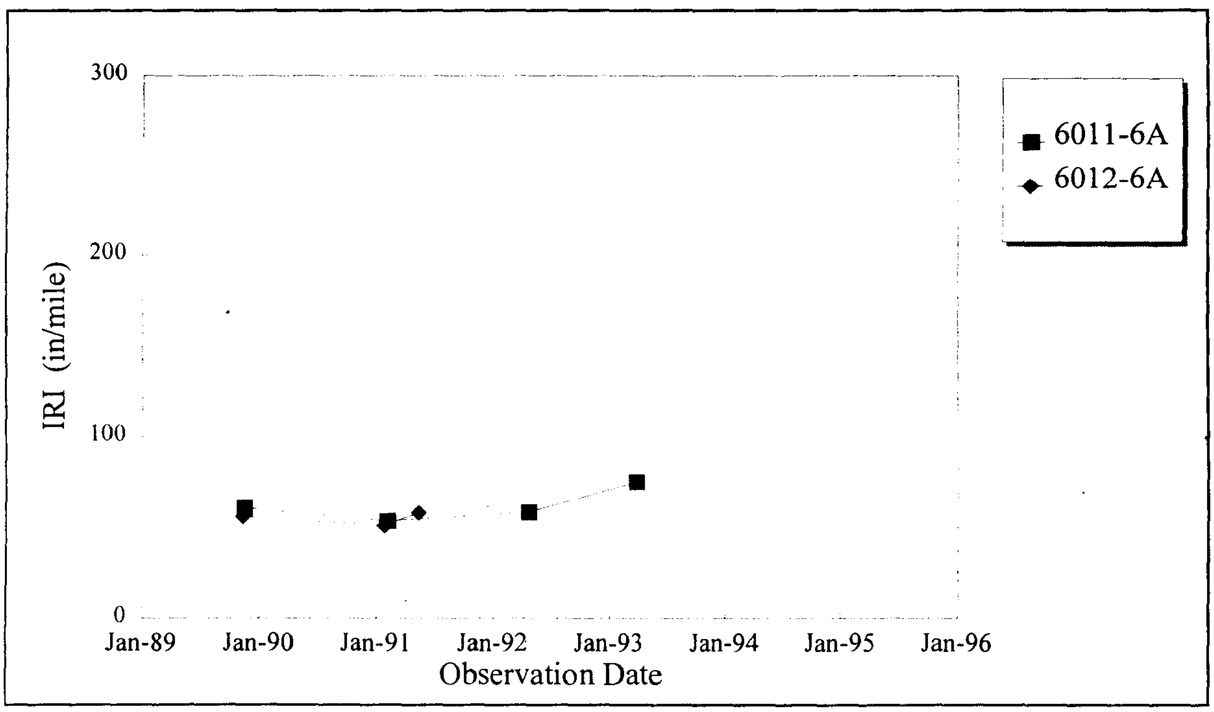


Figure 123. Roughness in Oregon GPS-6 test sections.

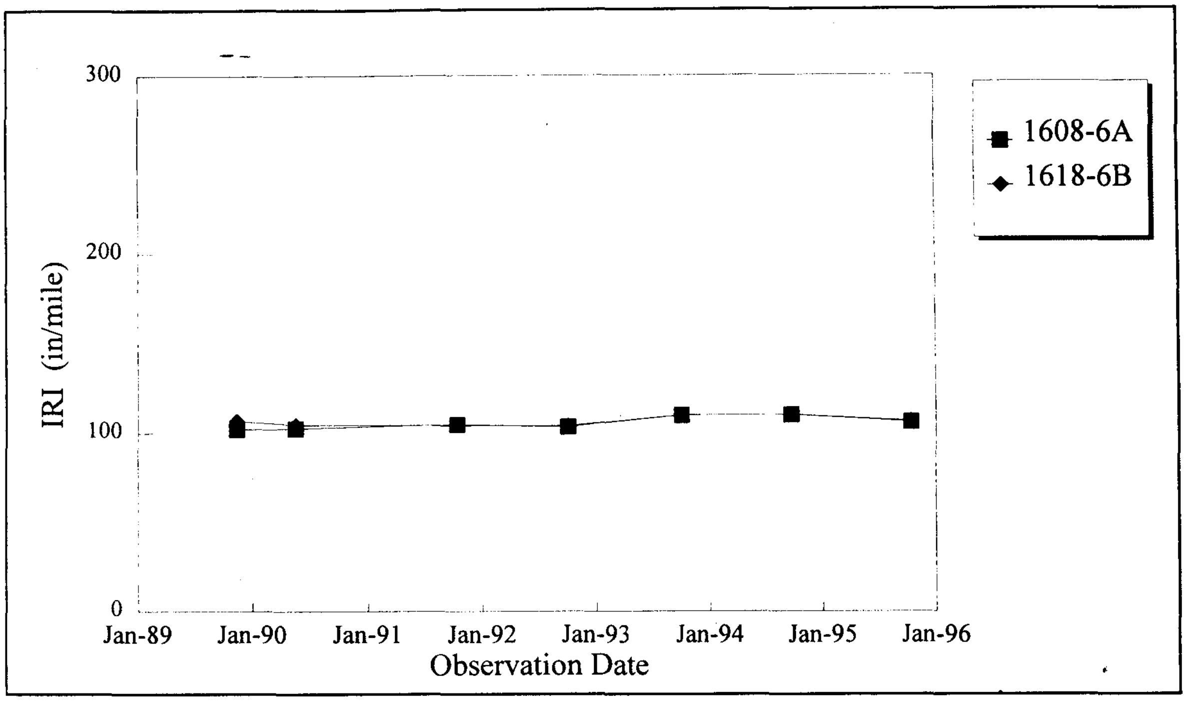


Figure 124. Roughness in Pennsylvania GPS-6 test sections.

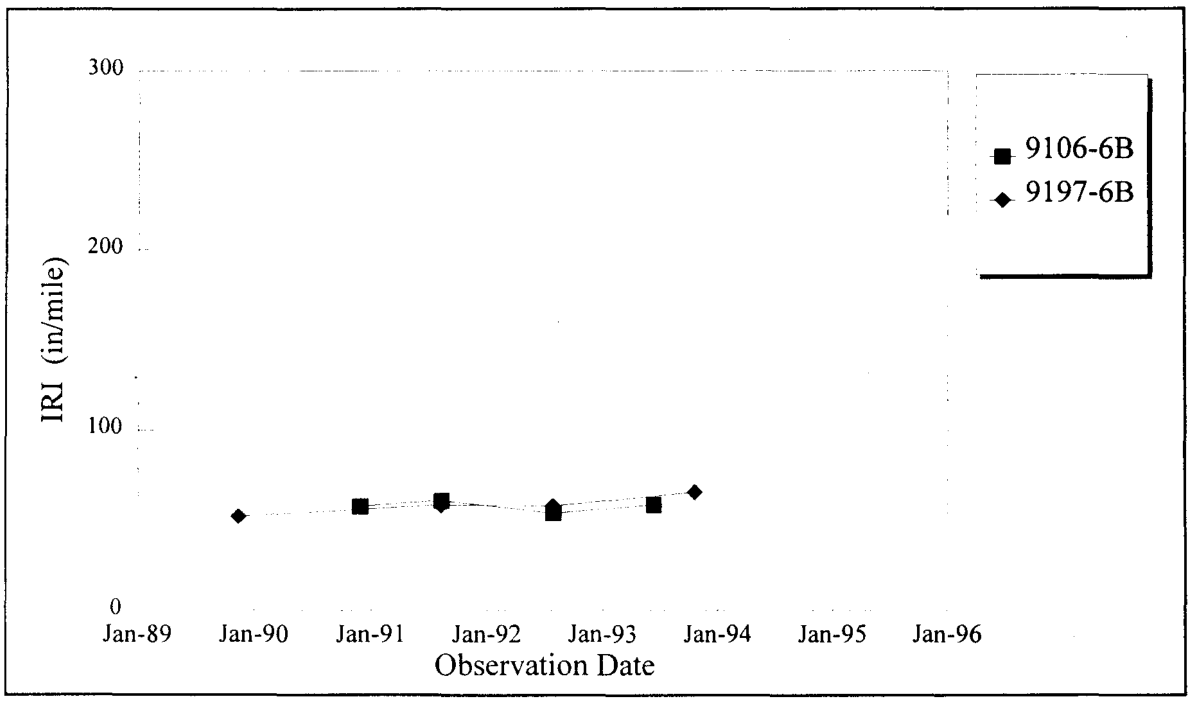


Figure 125. Roughness in South Dakota GPS-6 test sections.

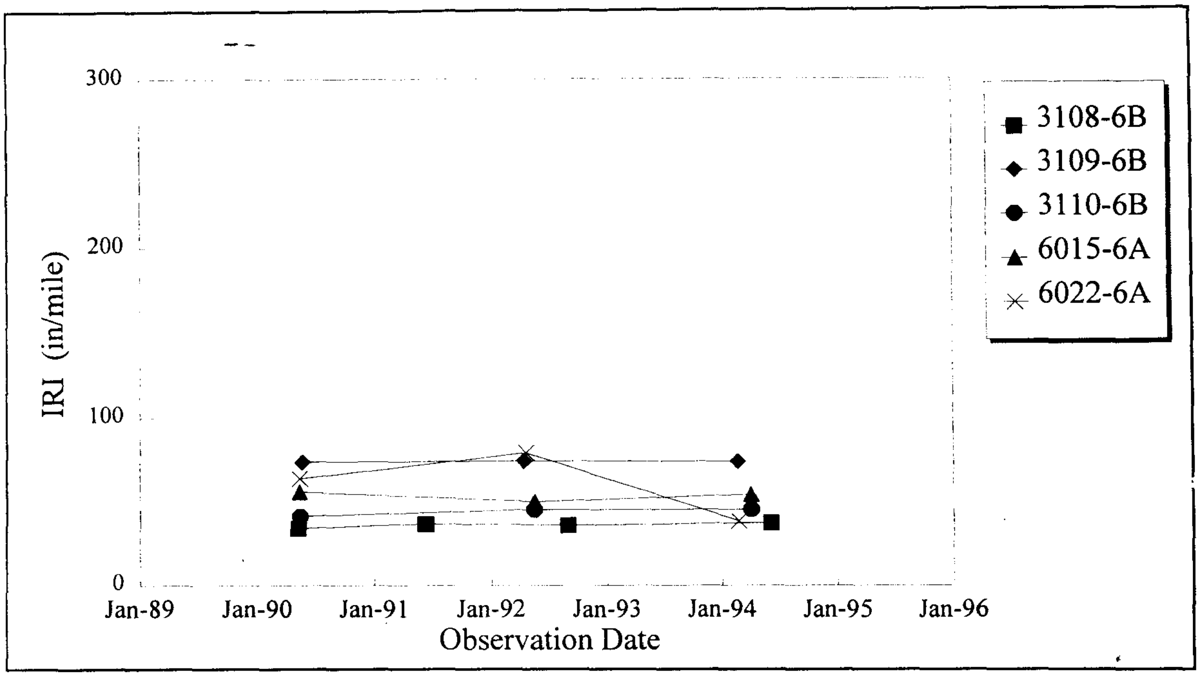


Figure 126. Roughness in Tennesse GPS-6 test sections.

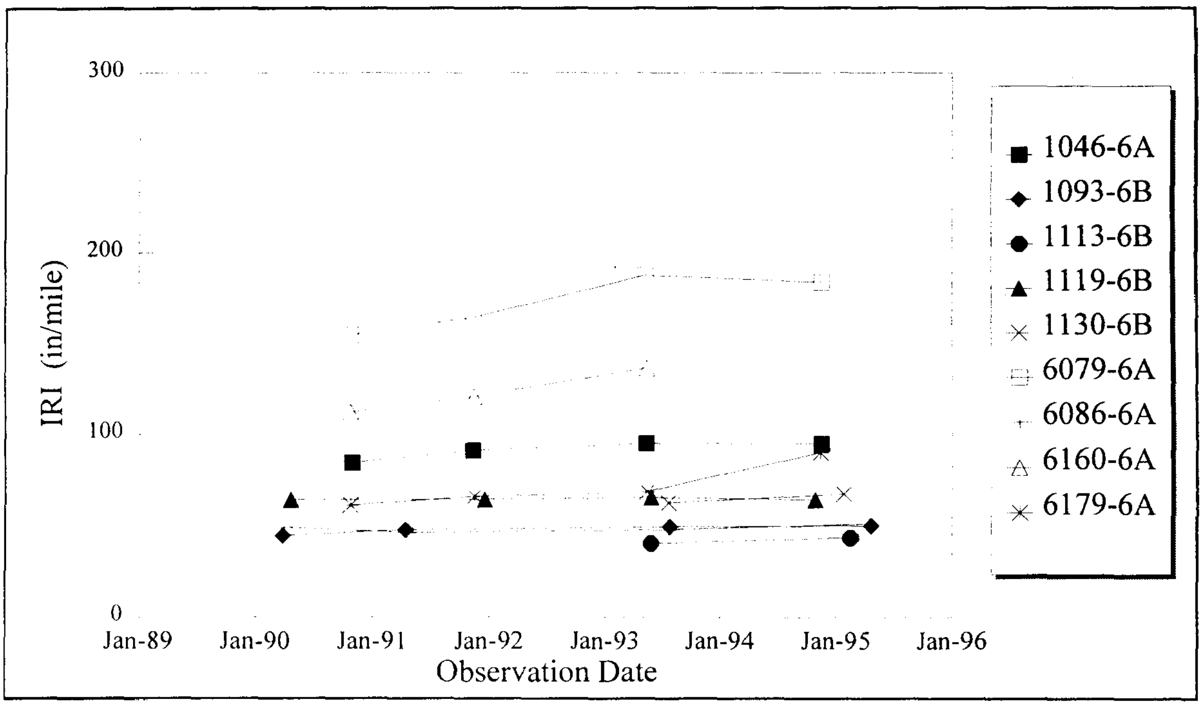


Figure 127. Roughness in Texas GPS-6 test sections.

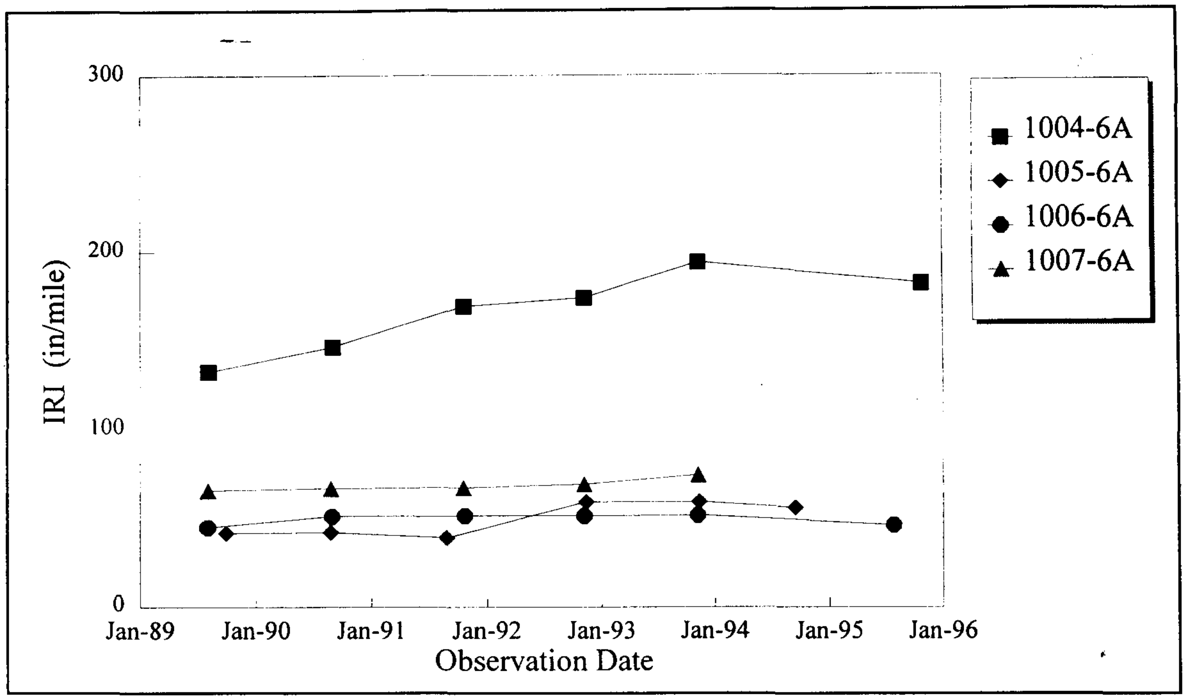


Figure 128. Roughness in Utah GPS-6 test sections.

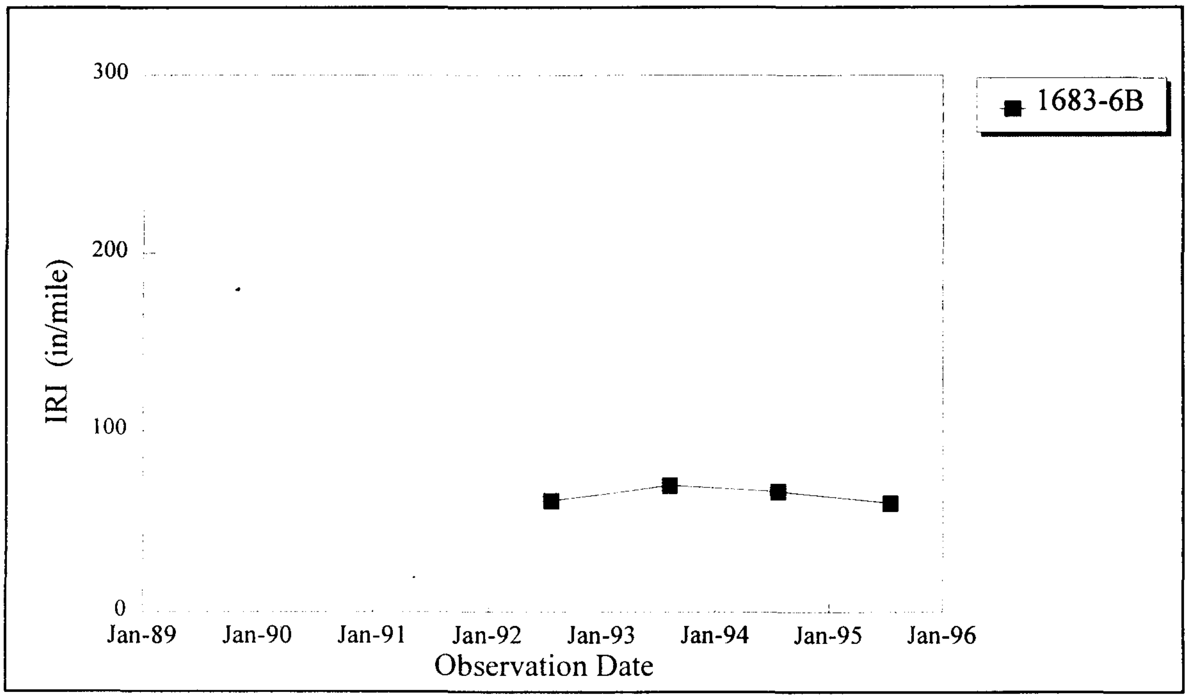


Figure 129. Roughness in Vermont GPS-6 test sections.

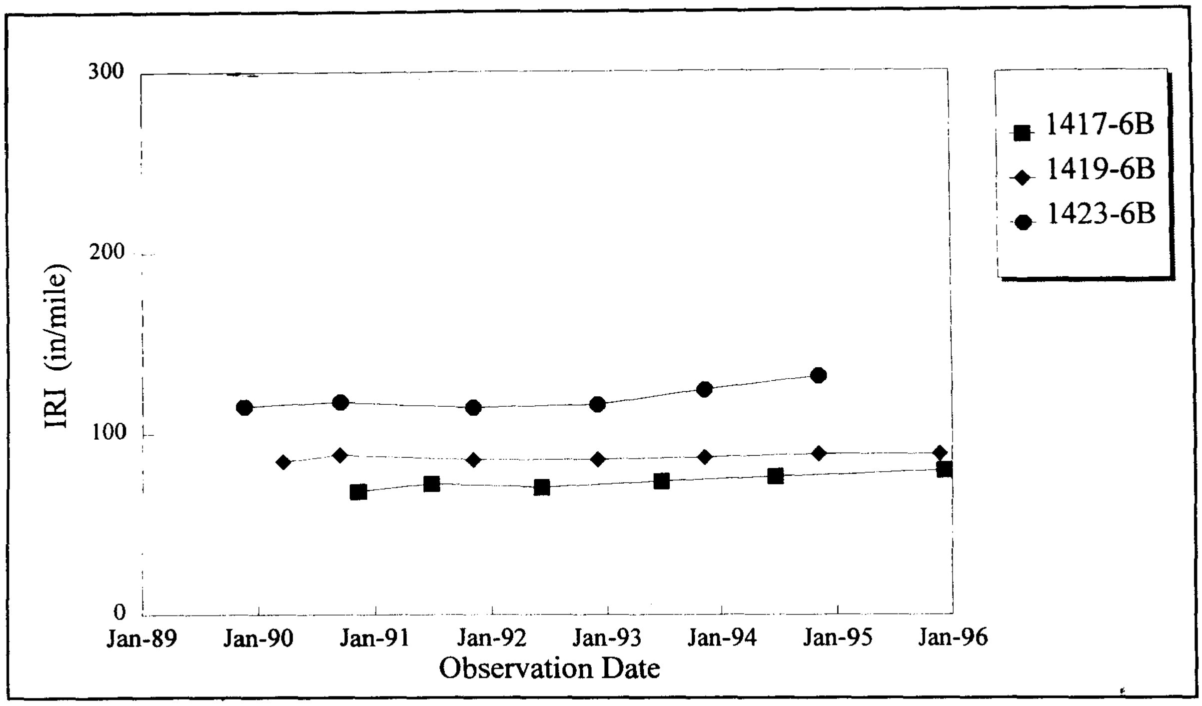


Figure 130. Roughness in Virginia GPS-6 test sections.

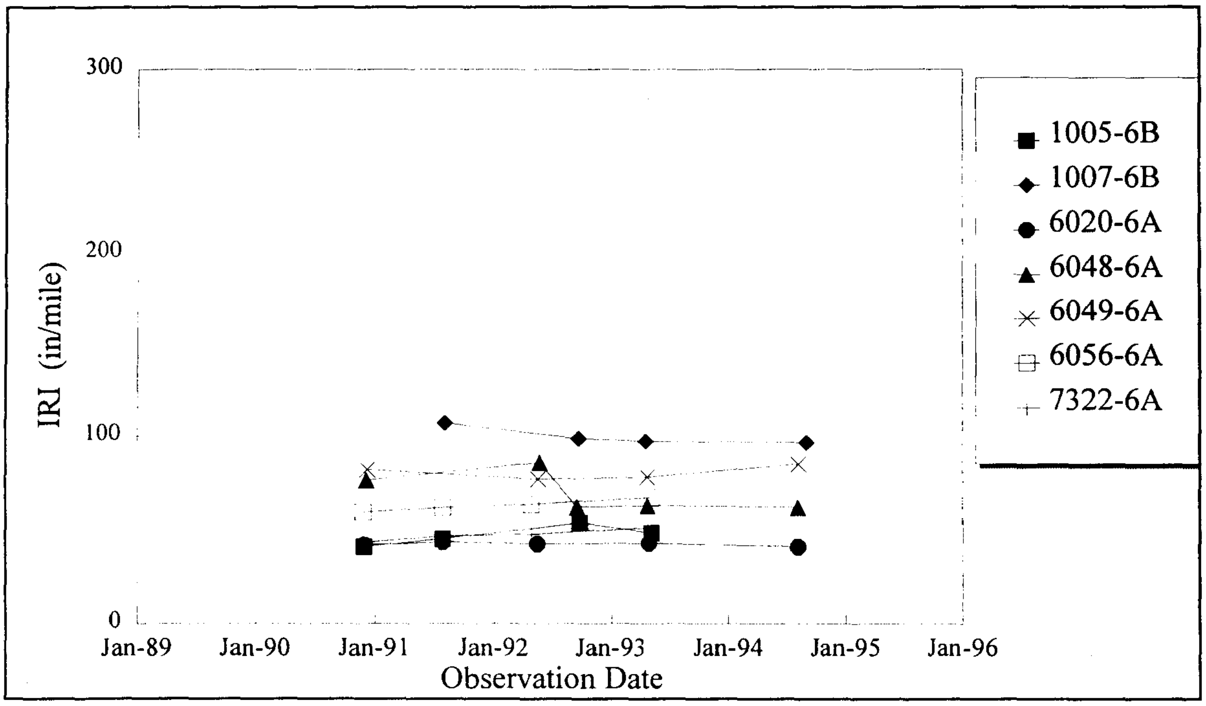


Figure 131. Roughness in Washington GPS-6 test sections.

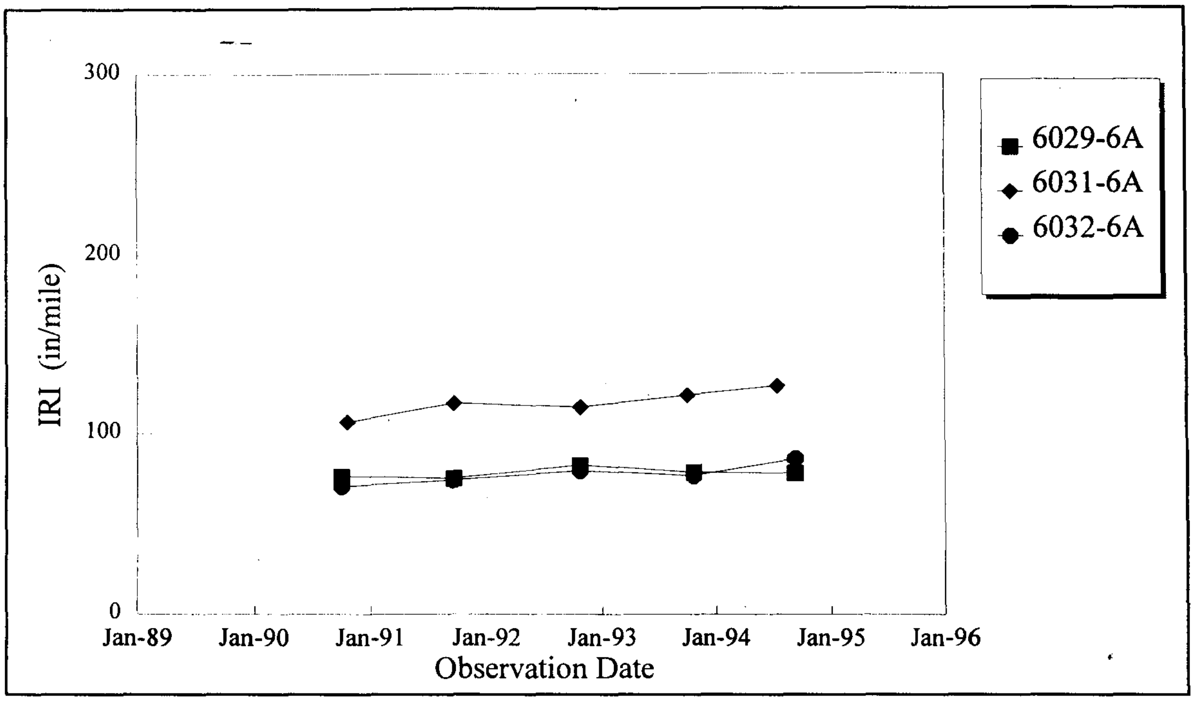


Figure 132. Roughness in Wyoming GPS-6 test sections.

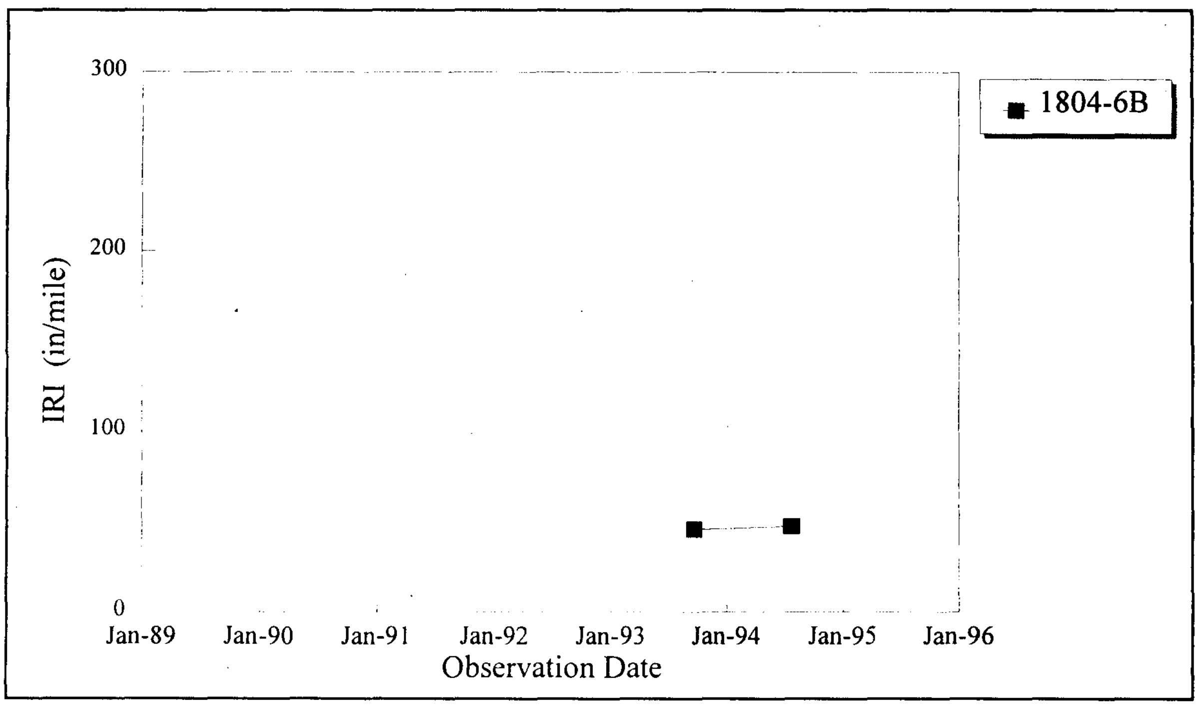


Figure 133. Roughness in Alberta GPS-6 test sections.

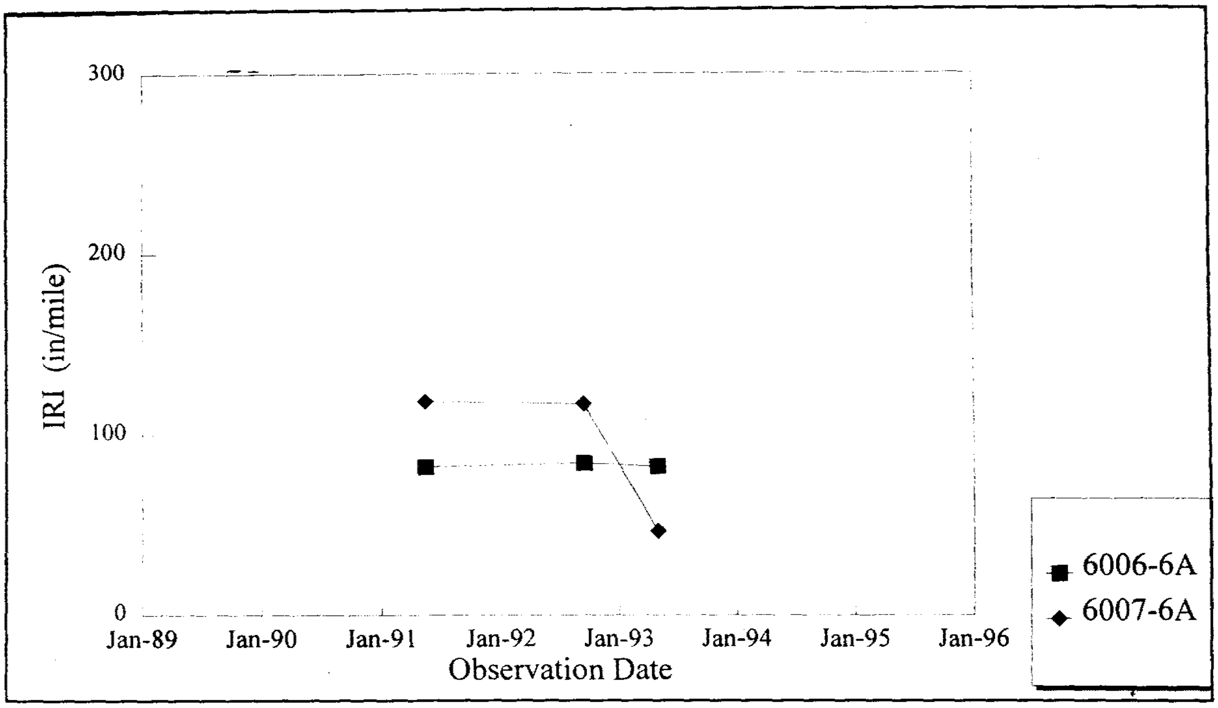


Figure 134. Roughness in British Columbia GPS-6 test sections.

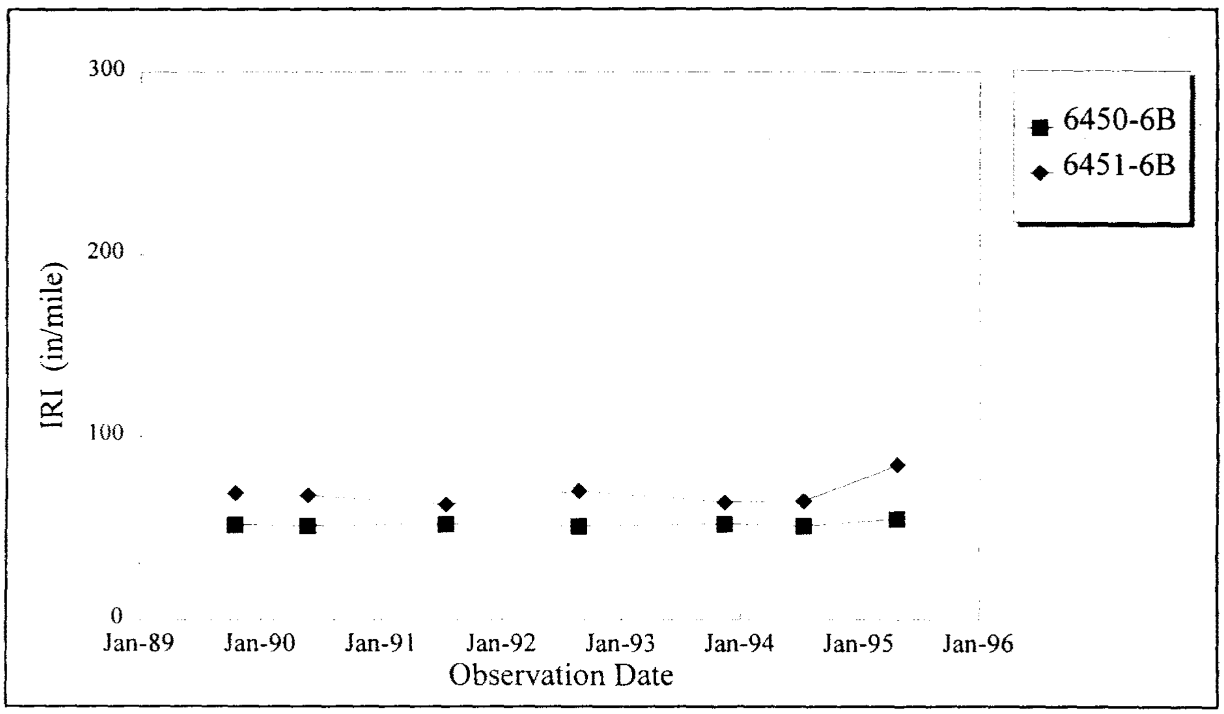


Figure 135. Roughness in Manitoba GPS-6 test sections.

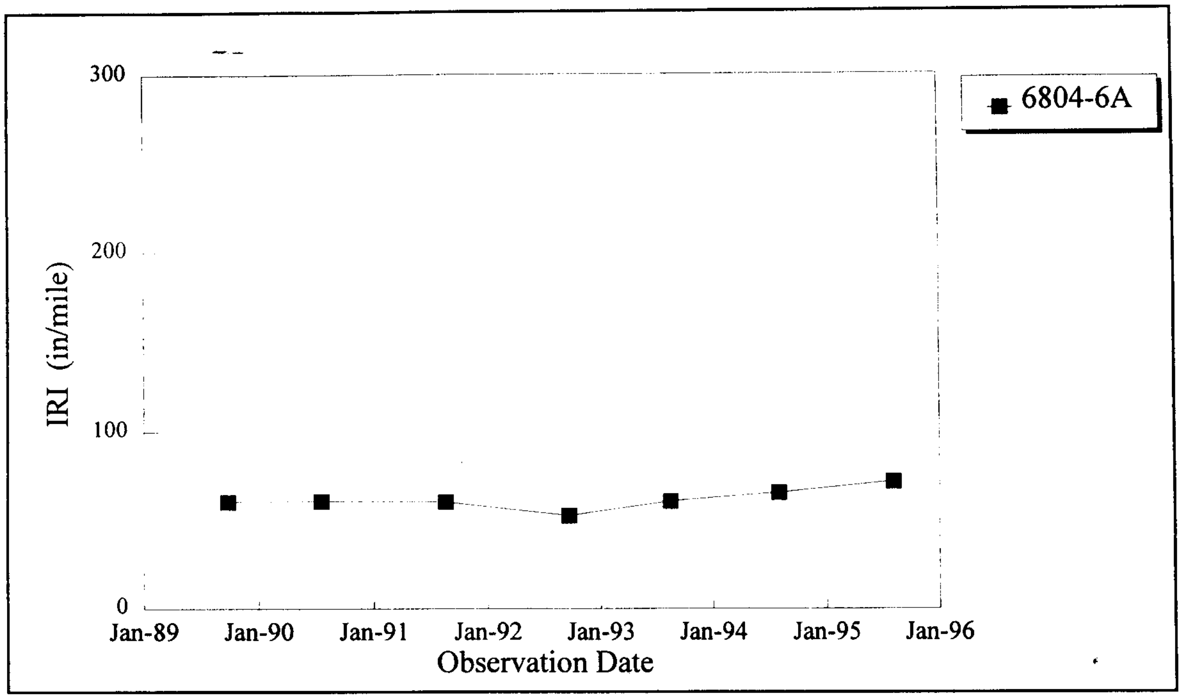


Figure 136. Roughness in New Brunswick GPS-6 test sections.

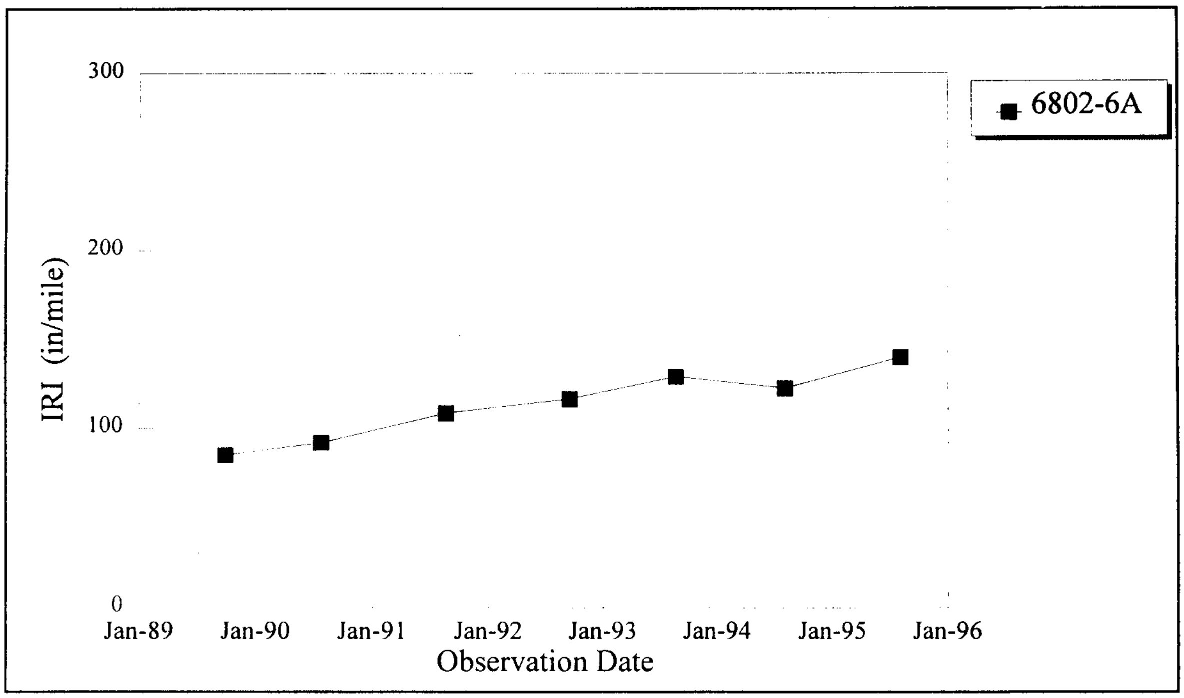


Figure 137. Roughness in Nova Scotia GPS-6 test sections.

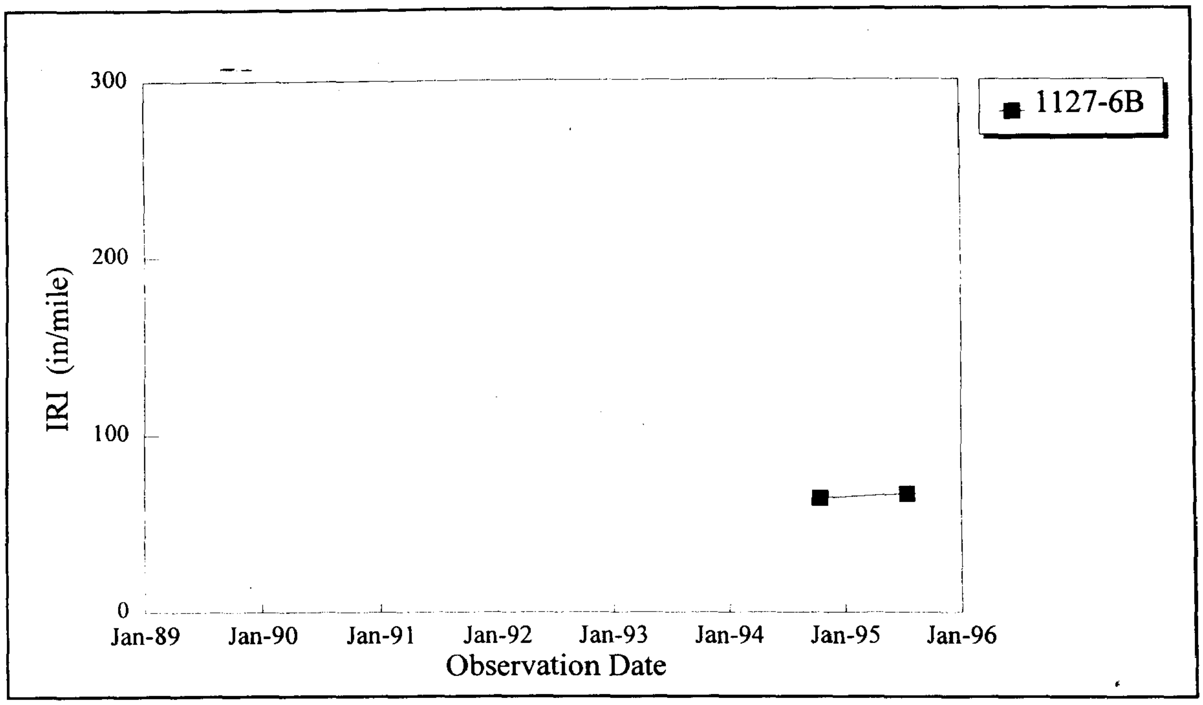


Figure 138. Roughness in Quebec GPS-6 test sections.

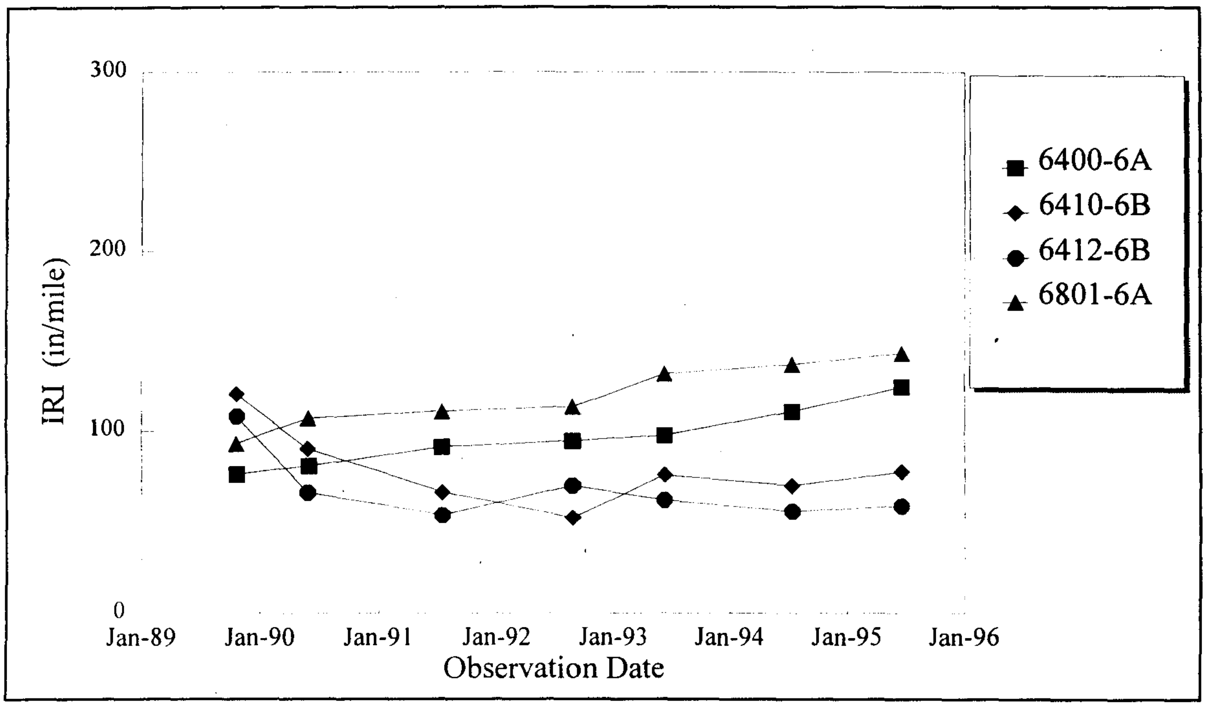


Figure 139. Roughness in Saskatchewan GPS-6 test sections.

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