Performance analysis of an experimental field project utilizing asphalt modifiers
by David Richard Johnson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering
Montana State University
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Abstract:
Utilization of a mix design that will resist rutting is crucial to the life expectancy of a pavement. Drainage problems associated with rutting distress contribute to safety problems and accelerate pavement deterioration. In an effort to combat rutting in Montana, a series of experimental test sections utilizing polymer modifiers were installed along Interstate 94 Prairie County Line West Project, in eastern Montana. These sections were monitored for a period of five years by Montana State University - Bozeman.

Monitoring of the test sections consisted of annual evaluations of the test sections via the use of a visual distress survey and the production of transverse pavement profiles at set locations. In addition to the annual evaluations, laboratory testing was performed on pavement cores acquired before construction of the existing pavement and after placement of the overlays to determine if a correlation existed between Marshall pavement properties and rutting.

This thesis focuses on results of the five-year monitoring of the polymer-modified test sections and the results of the laboratory testing of the pavement cores. The findings of this study indicate that utilization of polymer modifiers has quantifiable benefits in rut resistance for an asphalt pavement. These benefits extend beyond improvements in resistance to rutting, and into resistance to raveling, weathering, and bleeding. The core study indicated that the air void property of a pavement was inversely related to the level of rutting witnessed in these test sections. Moreover, the benefits were found to be economically valuable. It was concluded, therefore, that polymer utilization was advisable for Montana highway construction and rehabilitation.

PERFORMANCE ANALYSIS OF AN EXPERIMENTAL FIELD PROJECT UTILIZING ASPHALT MODIFIERS

By

David Richard Johnson

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Utilization of a mix design that will resist rutting is crucial to the life expectancy of a pavement. Drainage problems associated with rutting distress contribute to safety problems and accelerate pavement deterioration. In an effort to combat rutting in Montana, a series of experimental test sections utilizing polymer modifiers were installed along Interstate 94 Prairie County Line West Project, in eastern Montana. These sections were monitored for a period of five years by Montana State University - Bozeman.

Monitoring of the test sections consisted of annual evaluations of the test sections via the use of a visual distress survey and the production of transverse pavement profiles at set locations. In addition to the annual evaluations, laboratory testing was performed on pavement cores acquired before construction of the existing pavement and after placement of the overlays to determine if a correlation existed between Marshall pavement properties and rutting.

This thesis focuses on results of the five-year monitoring of the polymer-modified test sections and the results of the laboratory testing of the pavement cores. The findings of this study indicate that utilization of polymer modifiers has quantifiable benefits in rut resistance for an asphalt pavement. These benefits extend beyond improvements in resistance to rutting, and into resistance to raveling, weathering, and bleeding. The core study indicated that the air void property of a pavement was inversely related to the level of rutting witnessed in these test sections. Moreover, the benefits were found to be economically valuable. It was concluded, therefore, that polymer utilization was advisable for Montana highway construction and rehabilitation.

CHAPTER 1

INTRODUCTION

In pursuit of solutions to problems with the rutting of asphalt pavements, the Montana Department of Transportation (MDT) contracted with the Department of Civil Engineering of Montana State University - Bozeman (MSU) in 1988 to investigate asphalt modifiers. Laboratory testing of 120/150 penetration grade samples from four Montana refineries, incorporating six separate commercial modifiers, were evaluated during the interval July 1, 1988 to April 1, 1989. A direct consequence of the positive results from the laboratory work was the implementation of this field study. All of the modified asphalts tested by the 1988 study outperformed their unmodified counterparts. Based on their performance in the lab study, two of those modifiers were selected for inclusion in the field study. Those modifiers were Kraton D4141G from Shell Chemical Company, and Exxon's Polybilt X-1. (*1*)

The primary objective of the field study was to quantify differences in rutting and economic costs of polymer-modified versus unmodified asphalt concretes in Montana. The primary deliverable for MDT would be detailed recommendations for the construction of pavement sections incorporating polymers within the asphalt, emphasizing normal construction practices to the extent possible. Information was

collected on pre-construction conditions, the overlay construction process, the original condition of the completed overlay, and on their subsequent performance for a period of five years.

The pre-construction pavement surface condition survey included the selection of the profilograph test stations, profilograph data collection at those stations, and pavement crack surveys about those stations. A Rainhart Transverse Profilograph was used for the surveying and monitoring of the pavement.

The existing pavement surface in the test section exhibited visible rutting, cracking, and bleeding (Figure 1). Most of the thermal transverse cracks ran the full width of the pavement. The crack maintenance was apparent from sealed cracks (Figure 1). The driving and passing lanes each displayed contrasting appearances. The driving lane was black from recent maintenance activities, including chip sealing and thin lift overlays to cover the ruts in the original pavement surface (Figure 1). The surface was worn, exposing coarse aggregates which were glossy in appearance and smooth to the touch. Most driving lane wheel paths were bleeding, and isolated patches of bleeding in the passing lanes were noticed. During an observed rain, water ran in the ruts along the pavement surface in a longitudinal direction exhibiting poor drainage characteristics. In addition, some water pools were noticed on the pavement.



Figure 1. Pre-construction pavement condition.

Monitoring of construction activities consisted of documenting the production of the modified asphalt, recording asphalt-aggregate mix temperatures, recording placement and rolling performance of the mix, and photographing all operations. Equipment utilization was noted, and any special deviations from normal paving operations were detailed (i.e., mixing requirements, lay-down temperatures, rolling effort and patterns).

Following construction, initial conditions were surveyed to determine pre-traffic rutting and surface conditions. Overall conditions were noted and rutting measurements were done at test stations. String-line and leveling techniques were used at referenced

transect locations. The number of transects were sufficient to adequately represent the condition of the test sections. Again, photographs were utilized as well as established pavement management techniques for assessing surface conditions.

For a five year period after construction, monitoring of the experimental project was done at a fixed time each year, in the summer. Rutting measurements were taken at this time. A distress survey was also completed as part of the evaluation.

CHAPTER 2

EXISTING BODY OF KNOWLEDGE

The concept of using modifiers, including polymers, within asphalt road surfaces is not new. It has long been known that modified asphalt cements offer advantages over their unmodified counterparts. In general, modifiers are used to increase a pavement's ability to resist permanent deformations, or rutting, and/or to reduce the occurrence of low temperature cracking. The drawback to modifiers is that while improving a pavement's performance, they were not considered cost effective. Increasing traffic loading and tire pressures have lead to reevaluations into the use of modifiers over the last 20 to 25 years. Today modifiers are an integral and common component of many pavements.

The earliest reference to the use of polymers within an asphalt aggregate matrix was associated with some minor experiments done by the state of Arizona. This work was done in the 1930s, and the cost of incorporating polymers could not be justified. (*4*) The economic viability of polymers did not change for at least the next 35 years. In fact, the 1965 edition of The Asphalt Handbook, the Asphalt Institute makes no mention of modifying asphalt. (*5*)

Extensive research into the use of modifiers began in the late 1960s and accelerated through the 1980s. Following the Arab oil embargo of 1973, the quality of the crude available to produce asphalt was believed to have decreased. One of the ways producers attempted to rectify this perceived situation was to modify the asphalt base. Various forms of polymers, manganese, and recycled rubber products were tried as asphalt modifiers. The performance of these materials as modifiers varied primarily as a result of practitioners learning and developing effective means for their use. (*6 - 14*)

Research into the benefits of asphalt modification has continued into this decade. The emphasis has been on polymers and recycled rubber products as modifiers. By the mid-1980s, proper means of modifying and placing these mixes had been developed. Research has focused on trying to quantify the benefits from modification, in addition to showing that it is beneficial.

In 1990, English researchers demonstrated that within the confines of their research, polymers improved the fatigue characteristics of the asphalt binders used. (*15*) Namely, they found greater resistance to fatigue, low temperature, cracking in modified test specimens.

Oregon researchers expounded in 1990 on the need to classify asphalt cements based on their expected in-place performance. (*16*) This research was part of the Strategic Highway Research Project (SHRP) program that, among other things, helped develop a performance grading system for asphalt. This development is particularly important for modified asphalt, as their field performance was poorly correlated with traditional grading methods (penetration or viscosity).

Research had progressed in 1993 to the point that differences in performance of modified mixtures were noted dependent on the type of recycled tires used and the size of the rubber particles. When mixed with asphalt, recycled passenger car tires yielded properties that differed from recycled commercial tires. (*17*) These researchers also found that passenger car tires tended to produce more consistent modification results than were seen with commercial tires. The effect of rubber particle size produced mixed results in an investigation of traditional material properties (penetration, specific gravity, ductility, softening point, and flash point) of modified mixes. (*18*)

By 1996 researchers were reporting on the proper tests that should be conducted to determine which modifier may be best for a particular application. (*19*) A mixture of traditional (softening point and penetration) and SHRP (dynamic shear rheometer) tests were found useful in assisting engineers n choosing which modifier is best for their particular application.

An Ontario study in the early 1990s was remarkably similar to that reported herein. (*20*) These investigators evaluated two test sections incorporating a total of nine modified materials and one unmodified 85/100 penetration graded asphalt control section. Conclusions of note from Ontario include that many of the modified mixtures seemed to offer superior resistance to thermal cracking than their unmodified counterpart. Rutting resistance was improved through the introduction of modifiers. A life-cycle cost analysis found that modified mixtures were cost-effective in these installations.

CHAPTER 3

TEST SECTION

A section of Interstate Highway I-94 was selected as the experimental test section and identified by Federal Aid Project No. IR 94-5(25)185, Plant Mix Overlay, Prairie County Line-West, Prairie County. The total length of the project was 6.7 miles, consisting of 3.35 miles in the eastbound direction and 3.35 miles in the westbound direction. The test sections in each direction included a section of Kraton D4141G modified asphalt, a control section, and a section of Polybilt X-1 modified asphalt. Asphalt type for the control, as found in Table 1, was selected by the contractor.

Table 1. Station, Length, and Asphalt Binder on East and Westbound Lanes

Station	**Length (feet)**	**Binder on Eastbound Lane**	**Binder on Westbound Lane**
2126+92 to 2174+73	4781	Polybilt Modified Asphalt	Kraton Modified Asphalt
2174+73 to 2204+73	3000	85/100 Exxon Asphalt	85/100 Exxon Asphalt
2204+73 to 2264+25	5952	Kraton Modified Asphalt	Polybilt Modified Asphalt

The test section, near Fallon, Montana, experiences diverse climatic conditions annually. Temperatures in this area exceed 90°F for an average of 44 days annually. Monthly highs average 81.1°F, 89.4°F, and 88.5°F for June, July and August, respectively. Daily lows fall below 0°F for an average of thirty-five days annually. Average lows in December, January and February are 21.4°F, 13.5°F, and 21.8°F, respectively. The annual precipitation is about ten inches. The elevation of the area is about 2200 feet. (*2*)

Traffic loadings for this section of Montana Interstate highway average about 300,000 equivalent single axle loads (ESALs) per year, with commercial trucks accounting for approximately 25 percent of the traffic. (*3*) The average daily traffic (ADT) on this section of I-94 over the test period ranged between 2210 vehicles per day (vpd) and 3128 vpd, with a mean of 2628 vpd and a standard deviation of 318. It should also be noted that the ADT counts during the months of June, July, and August were approximately 135 percent of the ADT calculated using annual data. (*3*) This situation is significant as the majority of rutting occurs during the warmest months, which in this case also corresponds to the period of highest usage.

Table 1 shows the lengths and locations of the highway overlays and the utilized binder within each section for both the eastbound and westbound lanes. The detail of the layout of the test section and the location of the test sections with different binders are shown in Figure 2.

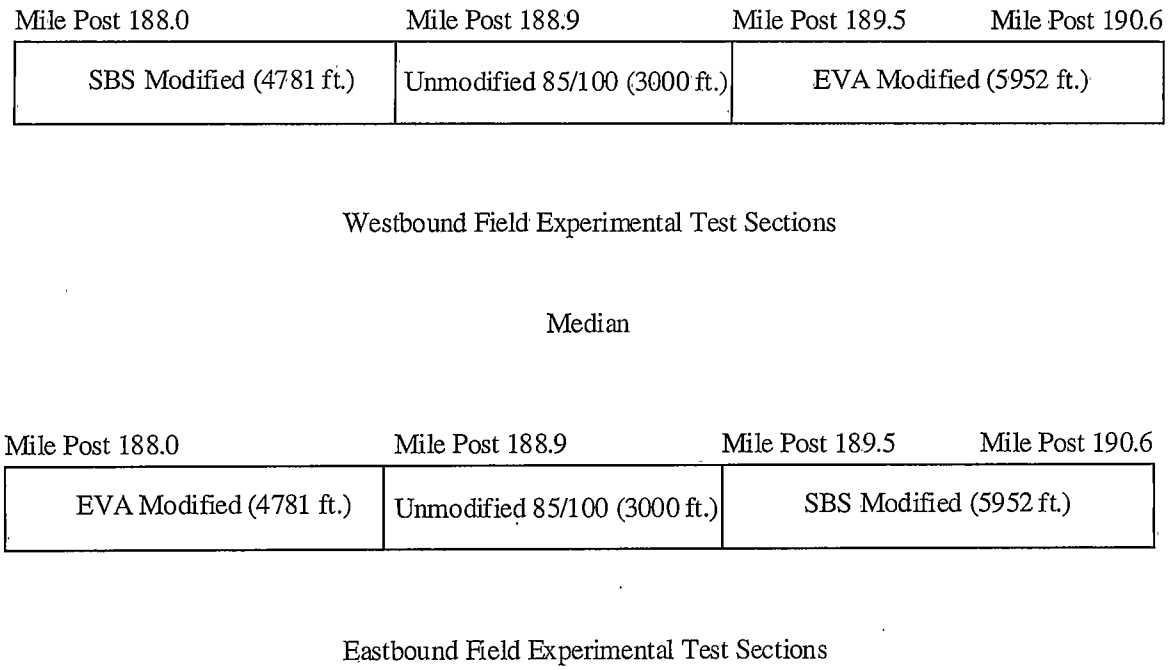


Figure 2. Layout of Test Sections - Interstate Highway I-94

The existing pavement consisted of 0.50 feet of plant mix bituminous base and 0.40 feet of plant mix bituminous surface (PMBS). Twenty-hundredths (0.20) feet of the driving lane was trenched by a cold milling machine and was back-filled with the respective PMBS as the overlay material. A final overlay of 0.35 feet with the respective PMBS was then placed in two lifts. Figure 3 shows the typical cross section of the pavement following the placement of the overlays.

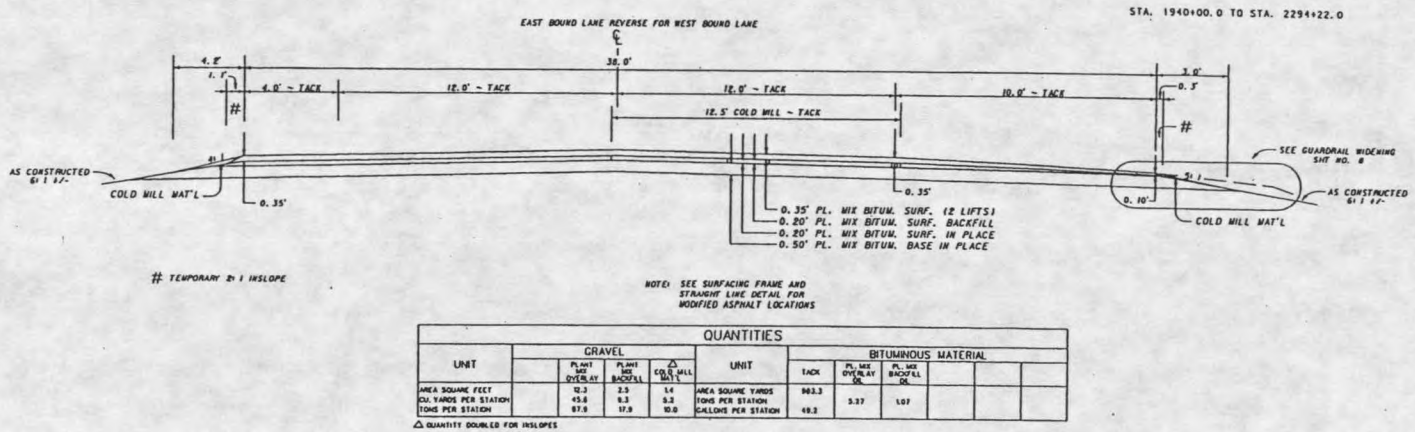
LINEAR AND LEVEL DATA

LENGTH OF ROADWAY IR 94-5(25)185	34,177.85 FEET	= 6.473 MILES
LENGTH OF BRIDGES IR 94-5(25)185	1,398.95 FEET	= 0.265 MILES
TOTAL LENGTH OF IR 94-5(25)185	35,576.80 FEET	= 6.738 MILES

BEARING SOURCE

TAKEN FROM PROJECT I - IG 94-5(141)181

TYPICAL SECTION NO. 1



QUANTITIES

UNIT	GRAVEL				UNIT	BITUMINOUS MATERIAL					
		PLANT MIX OVERLAY	PLANT MIX BACKFILL	△ COLD MILL MAT'L		TACK	PL. MIX OVERLAY 2"	PL. MIX BACKFILL 2"			
AREA SQUARE FEET		12.3	2.5	1.4	AREA SQUARE YARDS	903.3					
CU. YARDS PER STATION		45.5	9.3	5.2	TONS PER STATION		5.27	1.07			
TONS PER STATION		87.5	17.9	10.0	GALLONS PER STATION	48.2					

△ QUANTITY DOUBLED FOR INSLOPES

Figure 3. Typical cross-section.

Pre-Construction Pavement Surface Condition

The condition of the existing pavement could substantially effect the performance of the overlays, and thus the pre-overlay pavement surface was closely documented. Cracking and rutting were visually documented, supplementing transverse pavement profiles measured at stations established by MSU.

Cracking. Both transverse and longitudinal cracks were studied with reference to the MSU stations. The distance of the closest transverse crack, both ahead of and behind each MSU station, were measured and recorded. The severity levels of the cracks were classified according to the Strategic Highway Research Project's (SHRP) Distress Identification Manual for the Long Term Pavement Performance Project. (*21*) The majority of these were found to be of moderate or high severity cracks. (*2*) The longitudinal cracks found in the vicinity of the station were also classified according to the manual. These too were mostly moderate or high severity cracks. (*2*)

Rutting. Rutting is described in the Distress Identification Manual for the Long Term Pavement Performance Project as longitudinal surface depressions in the wheel path. Severity levels can be defined in relation to inches of rut depth. Rut depths were measured to the nearest 1/10-inch at set stations. (*21*) For the field study, 52 stations were chosen randomly at distances ranging from 200 to 600 feet.

A summary of the pre-construction rutting is found in Table 2. The maximum rut depths at each station's wheel paths for the westbound driving and passing lanes were

measured from the transverse profilograph record provided by the Rainhart Profilograph. It was observed that the rut depth on the driving lane was greater than that in the passing lane, even though the driving lane had undergone several maintenance activities to fill the ruts on the original pavement surface. The average rut depths on the left and right wheel paths were 0.26 and 0.18 inches for the passing lane, and 0.31 and 0.29 inches for the driving lane. The maximum rut depths on left and right wheel paths were 0.45 and 0.55 inches for the driving lane, and were 0.55 and 0.45 inches for the passing lane.

Similarly, the rut depths of the pre-construction pavement on the eastbound driving and passing lanes were obtained from the profilograph output. Again, the rut depths on the driving lane were higher than those on the passing lane, even though the eastbound driving lane also had been subjected to overlays and chip seals to reduce the rutting on the original pavement surface. The average rut depths on the left and right wheel paths of the passing lane were 0.20 and 0.12 inches, with maximum rut depths of 0.30 and 0.20 inches, respectively. The average rut depths on the left and right wheel paths of the driving lane were 0.39 inches for both wheel paths, with maximum rut depths of 0.60 and 0.70 inches for the respective wheel paths.

Transverse Pavement Profile. The profilograph records illustrate the actual profile of the pavement surface referenced to the straight profilograph beam. The output of the profilograph was electronically reproduced by taking the coordinates of the profile at intervals of four inches. The results of the differential leveling survey gave the elevation of the profilograph legs' positions.

The transverse slope of the pavement no longer matched the original intended shape. The distortions were so excessive that the pavement no longer drained as intended in the design. This situation could affect the stability of vehicles and reduce the performance of the pavement. In general, the distortion of the driving lanes was more extensive than that of the passing lanes.

Table 2. Pre-Construction Rutting

Direction	**Driving Lane**		**Passing Lane**	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Westbound				
Average Depths	0.31	0.29	0.26	0.18
Maximum	0.45	0.55	0.55	0.45
Standard Deviation	0.12	0.08	0.07	0.10
Eastbound				
Average Depths	0.39	0.39	0.20	0.12
Maximum	0.60	0.70	0.30	0.20
Standard Deviation	0.12	0.16	0.04	0.03

CHAPTER 4

OVERLAY CONSTRUCTION

The specifications and requirements for the construction of the overlay on the experimental test section, using the modified binders, were stipulated in the special provisions section of the contract document. An overview of the materials used and the construction process is given in the following sections.

Mix and Thickness Designs

A medium-traffic (10^4 – 10^6 ESAL) Marshall Mix Design process was used for the development of the each of the asphalt concrete mixtures. (Recall, the ESAL count for this stretch of Montana highway was approximately 300,000 annually.) The Marshall method produces a 4-inch specimen compacted by applying 50 blows to each side of the specimen with a standard Marshall hammer.

Compacted and cooled specimens are tested to determine their unit weight, Marshall flow and stability, and air void content. These quantities are then plotted to indicate the asphalt content in percent versus the individual property. An optimum asphalt content for each property was than determined. (For example, the asphalt content that corresponds to four percent air voids, or that produced the highest stability.) The

average of these values was then determined to indicate the optimum asphalt content. Properties of this mixture were then compared to established medium-traffic threshold values to assure that the design criteria were meet. The individual mix designs for the modified and unmodified asphalts used with the aggregate for this installation are shown in Table 3.

Table 3. Mix designs

Material	Stability (Pounds)	Air Voids (Percent)	Flow ($1/100^{th}$ Inch)	Unit Weight (gm/cc)	Asphalt Content (Percent)
Exxon 85/100	1615	3.30	9.00	2.325	5.90
Kraton D4141G	1725	3.50	11.00	2.315	6.00
Polybilt X-1	1620	3.50	8.00	2.319	5.60

The overlay thickness was designed following the 1988 Guide for Design of Pavement Structures from the American Association of State Highway and Transportation Officials (AASHTO). (*22*) This design procedure requires two inputs, a material strength parameter and the projected traffic loading over the design period. The strength parameter will be specific to the components used. Thus, asphalt concretes with modified cements will have different strengths (generally higher) than otherwise identical unmodified mixes.

Only one thickness design was performed for all of the sections installed under this project. This single design was performed for the unmodified control material. Using the control design thickness for the modified sections was a conservative

approach. Moreover, this approach resulted in a single thickness for all of the sections irrespective of the binder used, simplifying the construction process.

Aggregates

Plant mix surfacing Grade B (3/4-inch maximum size aggregate) was used throughout the experimental test section. The source of the aggregate was the Denby pit, which supplies a Yellowstone River gravel. The aggregate gradation for the job mix, including the high and low range of gradation, are shown in Table 4 and graphed in Figure 4. The required mix gradation was obtained by mixing two stock piles of crushed rock and one pile of natural fines. The bin split percentages used to obtain the job mix specification are shown in Table 5. The field aggregate gradation was constantly monitored by running wet and dry sieve analyses to assure that the mix gradation met the specification. These quality control tests were conducted by the MDT.

Table 4. Aggregate Gradations for Grade B PMBS

Sieve Size	Job Mix	Tolerance	
	Percent	Low	High
3/4-inch	100	100	100
1/2-inch	88	81	95
3/8-inch	77	70	84
4M	53	46	60
10M	34	28	40
40M	17	12	22
200M	6.5	5	8

Table 5. Bin Split Percentages

	Coarse Percent	Crushed Fines Percent	Natural Fines Percent
Design	43	37	20
Field	42	37	21

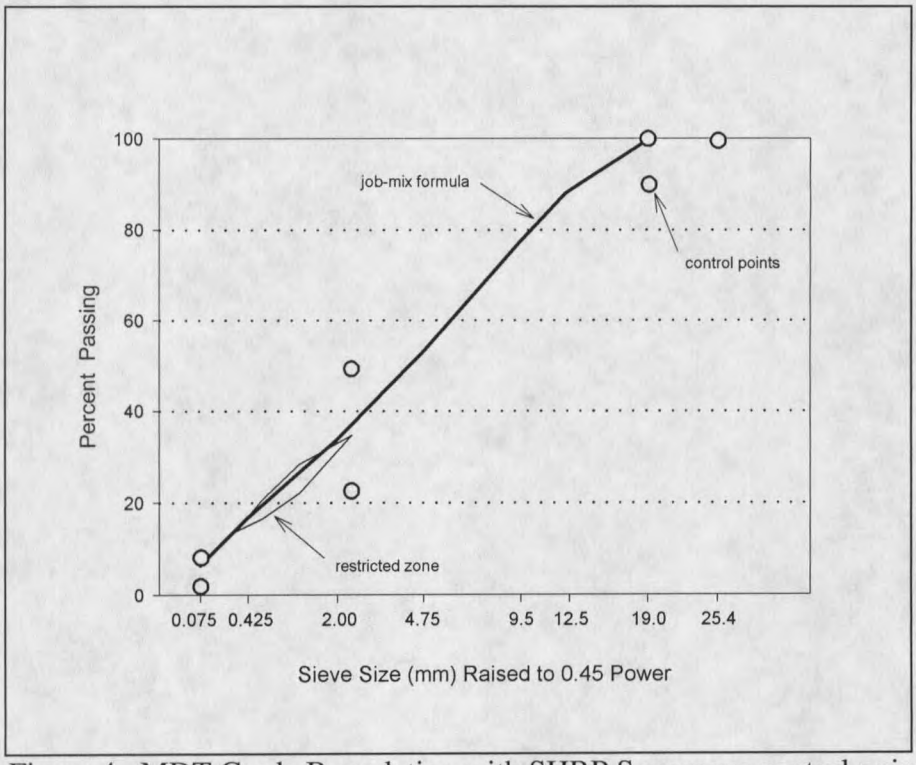


Figure 4. MDT Grade B gradation with SHRP Superpave control points.

Asphalt

The 85/100 penetration grade asphalt from Exxon Company, USA, Billings, as selected by the contractor, was used in the control section. The Kraton and Polybilt products were recommended for the modified sections, based on the laboratory study on 120/150 penetration grade of base asphalt. This grade of asphalt was used in the MSU

laboratory study, and it was recommended for the field evaluation. However, for the Polybilt modified asphalt, the Exxon Chemical Company chose to use Exxon 85/100 penetration grade asphalt from its Billings refinery and an AC-3/Polybilt concentrate as the cement in the experimental test section; this modified asphalt was designated as Polybilt X-1. The base asphalt for the Kraton modified asphalt section was 120/150 penetration grade asphalt from Exxon.

Modifiers

Kraton. Kraton thermoplastic rubber polymers are in a unique class of rubber designed for use without vulcanization (the combining of sulfur with other additives in the presence of heat and pressure so as to increase its strength and resiliency). Kraton D4141G is a linear SBS (Styrene-Butadiene-Styrene) block copolymer. Kraton D4141G differs fundamentally in molecular structure from the typical plastic or commercial rubber (homopolymer or random copolymers); it is a tri-block copolymer with an elastic block in the center and a thermoplastic block on each end. The first "4" identifies the polymer as containing process oil, usually a napthenic/paraffinic type, which is added to the polymer to aid in the mixing of the polymer into bitumen and to affect desirable changes in the physical properties of the final binder blend. Kraton D4141G contains about 29 percent oil. The designation "G" refers to the polymer being in the ground "powder" form, again for the purpose of decreasing blending time. (*2*)

Polybilt. The EVA modifier was a Polybilt product provided by the Exxon Corporation. Polybilt is an ethylene vinyl acetate (EVA) resin and encompasses a large

family of petrochemical polymers and polymer concentrates designed for asphalt modification. (*2*) The EVA was blended into a "concentrate" by Exxon in Houston, TX. The concentrate consisted of 88 percent AC-3 asphalt cement and 12 percent EVA. The concentrate was later blended with Exxon 85/100 penetration grade asphalt by an Exxon production facility in Billings, Montana. The proportion of concentrate in this blending process was 29.4 percent, producing an overall polymer modification of 3.5 percent by mass of the total binder.

Placement of Overlays

The purpose of the installation of these test and control sections was to determine the appropriateness of modifying Montana produced asphalts with polymers. A test location in eastern Montana was chosen on Interstate highway I-94 as previously introduced in Chapter 3. Both east and westbound directions were used for this evaluation.

The placement of the overlays started on April 24, 1991. The day was warm and breezy with an ambient temperature of 78°F. The construction process began with the cold milling of 0.20 feet of the 0.50 feet existing pavement's driving lanes. This trench was back-filled with the corresponding PMBS material. Upon this surface, 0.35 feet of PMBS was placed in two lifts.

Both the modifiers, Polybilt and Kraton, were mixed in Billings. The modified asphalts were then trucked by tanker to the job site, a distance of approximately 200 miles. The Polybilt concentrate was blended with 85/100 penetration grade Exxon

asphalt at 350°F in a 5000-gallon tank with an agitator at the Exxon Company, Billings. The Kraton D4141G polymer granules were mixed with 120/150 penetration grade of Exxon asphalt at a private asphalt mixing company in Billings. The modified mixed asphalts were delivered to the site on time without interrupting the paving schedule.

The Polybilt modified asphalt was brought to the site in an 8900-gallon insulated tanker, with an in-tank asphalt temperature of 350°F. The modified asphalt was then transferred to the drained stationary insulated tank of a drum-type continuous bituminous mix plant, and pumped into the continuous flow mixing plant. The average output of the plant was 407 tons per hour. The plant mix bituminous material was carried in belly dump trucks to the paver. Similar operations were repeated for the Kraton modified asphalt delivered in a 9000-gallon insulated tanker. The modified asphalt temperatures in the tank were 320°F for the first tank and 344°F for the second tank. Unfortunately, no record of the tanker or its temperature was located for the unmodified control.

Prior to placing the PMBS and leveling courses, the existing 0.20 feet of bituminous surfacing on the driving lane was removed by a cold milling machine. The bituminous surfacing, removed from all cold milled sections, was replaced with PMBS the same day that the milling was done. A tack coat of SS-1 emulsified asphalt was applied to a 79°F surface prior to the placement of PMBS in the trench. The PMBS was placed by dump trucks, which left a windrow of PMBS, closely followed by a paver. The paver used in the operation was a Blow Knox NE 85 1B PI1804 paver with a capacity of 750 tons per hour. The lay down temperature ranged from 238-259°F. The paver was closely followed by two 18-ton Dynapak vibrating rollers. Two passes were made to

compact seams, followed by four more passes. The break down roller-compacted mat was thus produced from a total of six passes by the vibrating rollers. The rolling operation was completed with the final pass of a 10-ton finishing steel roller. Identical processes were repeated for placement of aggregate and unmodified asphalt in the control section. No difficulties were noticed in the placement of the PMBS with modified asphalt or the unmodified control section. The daily average of the data collected on the placement of the PMBS are presented in tabulated form by date, section, temperature, tonnage placed, and binder type in Table 6.

The average, maximum, and minimum placement temperatures were 320.6°F, 325.0°F, and 300.0°F for the Polybilt X-1 modified PMBS; 304.6°F, 308.0°F, and 302.0°F for Kraton D4141G modified PMBS; and 307.3°F, 312.0°F, and 302°F for unmodified 85/100 Exxon PMBS. The average binder temperature of Polybilt modified asphalt was the highest at 346.2°F, compared to 339.3°F for Kraton modified asphalt and 300.6°F for unmodified Exxon asphalt. Average asphalt percentages of the PMBS were 5.50 for Polybilt modified asphalt, 5.63 for Kraton modified asphalt, and 5.76 for unmodified asphalt. These values are consistent with MDT specifications for this project. (*23*)

The first lift over those cracks with crack sealer caused a swelling phenomena of the PMBS after the break down rolling. This phenomena was observed in all sections of untrenched pavement, with or without modified asphalt. The swelled materials were scraped off prior to the placement of the second lift. Also, down time of the continuous drum type mixing plant occurred whenever the asphalt was changed from unmodified

Table 6. Placement Data Surface-Grade B Asphalt Concrete

Date	Station (From)	Distance (Feet)	Asphalt Modifier	Tonnage Placed	Temp. Mix (F)	Asphalt Percent	Asphalt Temp. (F)
4/24	2126+92	4756	Polybilt	830.65	325	5.63	348
4/24	2174+49	3025	Exxon	517.28	303	5.73	295-306
4/24	2204+73	5952	Kraton	1099.74	308	6.04	348
4/25	2264+25	5975	Polybilt	1079.56	300	5.34	352
5/1	2202+03	2730	Exxon	506.20	302	5.65	295-306
5/1	2174+73	4781	Kraton	857.01	305	5.50	333
5/6	2126+22	4851	Polybilt	1025.18	325	5.39	344
5/6	2174+73	3000	Exxon	626.20	308	5.71	295-306
5/6	2204+73	5952	Kraton	1246.61	305	5.51	330
5/7	2126+47	4826	Polybilt	949.66	325	5.51	344
5/7	2174+73	3000	Exxon	600.13	310	5.71	295-306
5/7	2204+73	5952	Kraton	1174.40	305	5.68	340
5/8	2264+25	5952	Polybilt	1219.38	322	5.50	360
5/8	2204.73	3000	Exxon	623.37	312	6.00	295-306
5/8	2174+73	4781	Kraton	996.87	305	5.60	340
5/8	2264+25	5952	Polybilt	1179.60	322	5.50	356
5/9	2204+73	3000	Exxon	597.69	307	5.76	295-306
5/9	2174+73	4781	Kraton	945.55	305	5.60	332
5/9	2126+92	4781	Polybilt	1227.49	320	5.53	351
5/10	2174+73	3000	Exxon	809.47	304	5.76	295-306
5/10	2204+73	5918	Kraton	1597.85	304	5.57	345
5/14	2126+62	4811	Polybilt	1049.59	323	5.52	338
5/14	2174.73	3000	Exxon	646.08	308	5.76	295-306
5/14	2204+73	5952	Kraton	1273.22	303	5.55	334
5/16	2264+25	5952	Polybilt	1616.98	323	5.50	338
5/16	2204+73	3000	Exxon	842.00	312	5.85	295-306
5/16	2174+73	4781	Kraton	1282.14	302	5.60	343
5/17	2264+25	5952	Polybilt	1262.51	321	5.55	331
5/17	2204+73	3000	Exxon	623.70	307	5.71	295-306
5/17	2174+73	4781	Kraton	1022.85	304	5.66	348

85/100 Exxon to one of the modified asphalts or vice versa. Emptying the asphalt tank of the continuous drum mix plant to the storage tank and refilling the asphalt tank with

appropriate asphalt caused a minor time loss. Obviously, this would not be a concern in an ordinary paving operation in which one material is utilized on each lift.

Field Testing

Quality control tests were done by MDT-Glendive District, utilizing 50-blow Marshall specimens. Table 7 presents a summary of the gathered field test data. The average, maximum, and minimum values of Marshall stability were 2136, 2226, and 2003 pounds for Polybilt X-1 modified asphalt; 2008, 2151, and 1647 pounds for Kraton modified asphalt; and 2068, 2259, and 1851 pounds for unmodified Exxon asphalt. The minimum stability of the Kraton modified asphalt (1647 lb.) was lower than its design specification of 1725 pounds. The variations between the maximum and minimum stability of the Kraton modified asphalt were the highest of the three materials. Similarly, the average percent air voids of 3.34 percent for Kraton modified asphalt was the highest; the Polybilt modified asphalt had 2.77 percent air voids and the unmodified Exxon asphalt had 2.90 percent. The average Marshall flow values varied between 10 and 11 1/100 inches. The average unit weight had a range of 2.339 to 2.355 grams per cubic centimeter, which was higher than the design specification of 2.315 to 2.325 grams per cubic centimeter.

The field densities of the compacted mat at each section were measured using a nuclear gauge. Four readings were taken at each location. The average densities measured by the nuclear gauge were compared with the densities of the laboratory test specimens prepared with the respective plant mix of aggregate and binder using 50

compaction blows with a Marshall hammer. None of the test results of the pavement were less than 95 percent of the target density; in fact, some of them were between 97 and 98 percent.

Table 7. Field Data (provided by MDT-Glendive District)

Material	Stability (Pounds)	Air Voids (Percent)	Flow ($1/100^{th}$ inch)	Unit Weight (gm/cc)	Asphalt Content (Percent)
AC 85/100 Exxon					
Average	2068	2.90	10.10	2.354	5.76
Maximum	2259	3.30	11.00	2.361	6.00
Minimum	1851	2.40	9.00	2.349	5.65
Design Specification	1615	3.30	9.00	2.325	5.90
Kraton D4141G (Ave.)					
Average	2008	3.34	11.00	2.339	5.63
Maximum	2151	4.30	12.00	2.350	6.04
Minimum	1647	1.70	10.00	2.327	5.50
Design Specification	1725	3.50	11.00	2.315	6.00
Polybilt X-1 (Ave.)					
Average	2136	2.77	10.10	2.355	5.50
Maximum	2226	4.30	11.00	2.362	5.63
Minimum	2003	2.00	9.00	2.332	5.34
Design Specification	1620	3.50	8.00	2.319	5.60

Cores of the pavement were taken on May 23, and May 24, 1991 from the eastbound and westbound lanes. A summary of the air void data from the cores is displayed in Table 8. Unfortunately, the only unmodified cores came from the passing lane. These were also the only cores obtained from the passing lane. The lifts were separated from each other, and bulk specific gravity and Rice specific gravity were run on each lift. This procedure was followed to increase the accuracy of the in-place percent air voids determinations. The average percent air voids ranged from 3.2 percent for

Polybilt modified asphalt to 4.5 percent for the unmodified asphalt control section. However, the ranges of percent air voids of cores from all three sections were large. The maximum percent air voids was 6.8 percent for Kraton modified pavement, 5.4 percent for unmodified asphalt, and 5.2 percent for Polybilt modified section. Similarly, the minimum percent air voids for the Kraton modified section was the lowest at 1.8 percent, compared to that of the Polybilt modified section at 1.9 percent and the unmodified control section at 3.5 percent. The most consistent product, in terms of air voids, was the unmodified Exxon 85/100 penetration grade asphalt from the control section. Density data collected from the cores are also shown in Table 7. These data were found to be much more consistent than the air void data.

Table 8. Air Void Data from Cores

Material	Air Void (Percent)	Density (lb/ft^2)
85/100 Exxon		
Average	4.5	145.7
Maximum	5.4	146.9
Minimum	3.5	144.5
Kraton D4141G		
Average	4.0	146.4
Maximum	6.8	151.7
Minimum	1.8	142.1
Polybilt X-1		
Average	3.2	146.4
Maximum	5.2	150.8
Minimum	1.9	143.2

Post-Construction Evaluation

The post-construction pavement surface survey was conducted on May 31 and June 1, 1991. There were no cracks on the freshly laid pavement overlays. The pavement surface was smooth and black, with closely held aggregates in all three test sections (Figure 5). There was no visible bleeding, rutting, or any other distress.

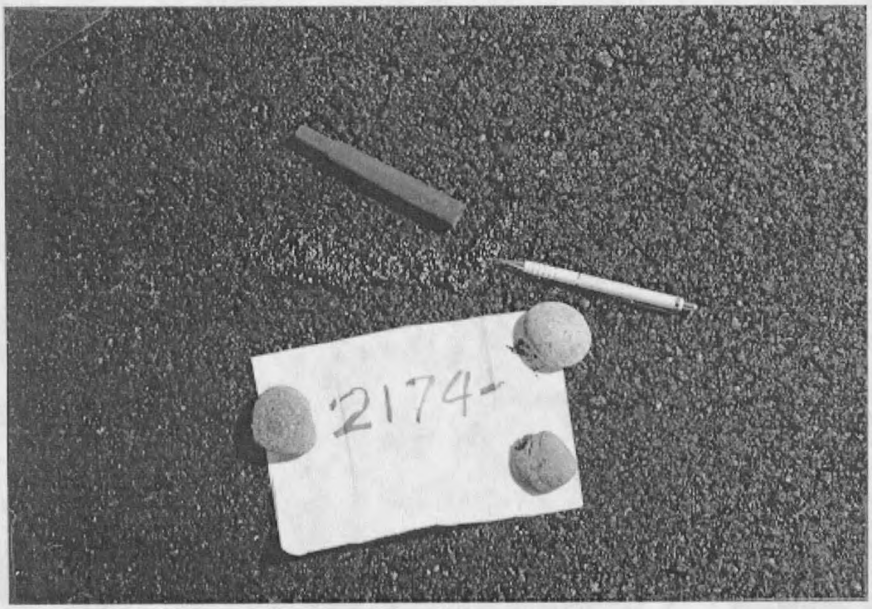


Figure 5. New asphalt concrete.

Transverse profiles were taken about fifteen days after construction. These profiles were obtained by running the Rainhart Transverse Profilograph at the same stations as used in the pre-construction survey.

The rut depths, as defined in the distress identification manual, were measured on the left and right wheel paths of each passing and driving lane. The rut depths were

measured from the records of the profilograph. A summary of the westbound post-construction rut depths can be found in Table 9

Rut depths for all of the installed materials were, in general, minimal. Within individual materials, the rut depths were generally deeper in the passing lanes when compared to those from the driving lanes. Between materials, the unmodified control had slightly deeper ruts than either of the modified sections, which were similar in depth. Variations in rut depth were about the same for all materials and lanes

Table 9 Post-Construction Rutting - Westbound

	Driving Lane		**Passing Lane**	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.04	0.03	0.04	0.04
Maximum	0.05	0.05	0.10	0.05
Standard Deviation	0.02	0.03	0.04	0.02
Kraton				
Average Depths	0.02	0.01	0.03	0.07
Maximum	0.05	0.05	0.05	0.15
Standard Deviation	0.03	0.02	0.03	0.04
Control				
Average Depths	0.08	0.06	0.06	0.09
Maximum	0.10	0.10	0.10	0.15
Standard Deviation	0.03	0.02	0.02	0.05

A summary of the eastbound post-construction rut depths can be found in Table 10 Data for the eastbound post-construction rut depths were similar to the westbound data. Overall depths were quite minimal and passing lane depths were deeper than the driving lanes. However, in this direction, differences between materials were not noted.

Table 10 Post-Construction Rutting - Eastbound

	Driving Lane		Passing Lane	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.00	0.02	0.03	0.08
Maximum	0.00	0.10	0.05	0.10
Standard Deviation	0.00	0.04	0.03	0.03
Kraton				
Average Depths	0.01	0.01	0.04	0.07
Maximum	0.05	0.05	0.05	0.10
Standard Deviation	0.02	0.02	0.02	0.03
Control				
Average Depths	0.04	0.03	0.04	0.09
Maximum	0.10	0.05	0.05	0.10
Standard Deviation	0.03	0.03	0.02	0.02

CHAPTER 5

COST INFORMATION

The bid cost for the modified asphalt and the plant mix are given in Table 11 Table 11lso includes 1996 average bid information for both modified and unmodified asphalt concrete. 1996 represents the final year penetration graded asphalt could be obtained from in-state Montana suppliers; performance graded asphalt is all that has been produced thereafter. The asphalt cement in the Kraton section cost nearly three times as much as the unmodified control section, while the Polybilt sections cost almost twice as much as the unmodified material. By 1996, contractors were more familiar with modified materials, and the average bid cost of all modified cements was only about 80 percent more than standard asphalt cement.

Table 11 Bid Information (provided by MDT)

Material	Cost Bid
AC 85/100 Exxon (unmodified)	$126.20/Ton
Kraton D4141G modified 120/150 Exxon	$376.20/Ton
Polybilt X-1 modified 85/100 Exxon	$239.20/Ton
Plant mix	$9.20/Ton
Asphalt cement 85/100 (1996)	$115.63/Ton
Asphalt cement polymer-modified (1996)	$208.01/Ton

The material costs for each binder/aggregate combination can be determined from the placement data and bid prices. By breaking the placement values into their respective

asphalt cement and plant mix quantities, and then summing these values, the amount placed of each material is determined. Multiplying the bid amounts by their respective quantities placed yields the total costs. If the total cost of material is then divided by the number of miles paved with the given material, the cost per mile is produced. Thus, for the Polybilt modified sections a total of 628.78 tons of asphalt cement was placed with 10,811.82 tons of plant mix. At $239.20 per ton for the asphalt and $9.20 for the plant mix, the cost is $249,872.92. The total length of the Polybilt sections is 2.03 miles, resulting in a cost of $120,909.11 per mile. Utilizing the same procedure for the Kraton and control sections yields a cost per mile of $169,112.79 and $89,437.08 respectively. Table 12 provides a summary of the in-place material costs.

Table 12 In-place Material Costs

Material	Asphalt Cement (Tons)	Plant Mix (Tons)	Cost	Miles	Cost per Mile
Polybilt X-1	628.78	10811.82	$249,872.92	2.03	$120,090.11
Kraton D4141G	647.08	10855.16	$343,298.97	2.03	$169,112.79
85/100 Exxon	368.81	6023.31	$101,958.27	1.14	$89,437.08

CHAPTER 6

ANNUAL EVALUATIONS

Annual evaluations were made of the sections in late summer for a five-year period. Due to limited changes following the third annual evaluation, the forth year evaluation was subsequently eliminated. The annual evaluations were consistent with the pre- and post-construction evaluations. Visual distress surveys of the entire section supplemented transverse pavement profiles at the same 52 stations, and crack surveys about those stations.

The first annual evaluation found the primary distress to be rutting. Other distress seen at that time included raveling, bleeding, and polished aggregate. No cracking of the pavement was observed. The first cracking was seen following the second winter of service. While the other distresses (rutting, raveling, bleeding, and polished aggregate) continued to be seen during the second year, only the bleeding in the wheel paths had seemed to increase in both severity and occurrences. For the third and fifth annual evaluations, no new forms of distress had developed. However, in the unmodified control sections, the severity levels for, and the areas affected by, all forms of distress seemed to have increased more quickly than for the modified sections.

First Annual Evaluation

The first annual field evaluation took place August 11 through August 13, 1992, about 18 months after completion of construction. The pavement was in good condition overall. No cracks had formed during the first winter. Observed distresses included rutting, raveling, bleeding, and polished aggregate (Figure 6).

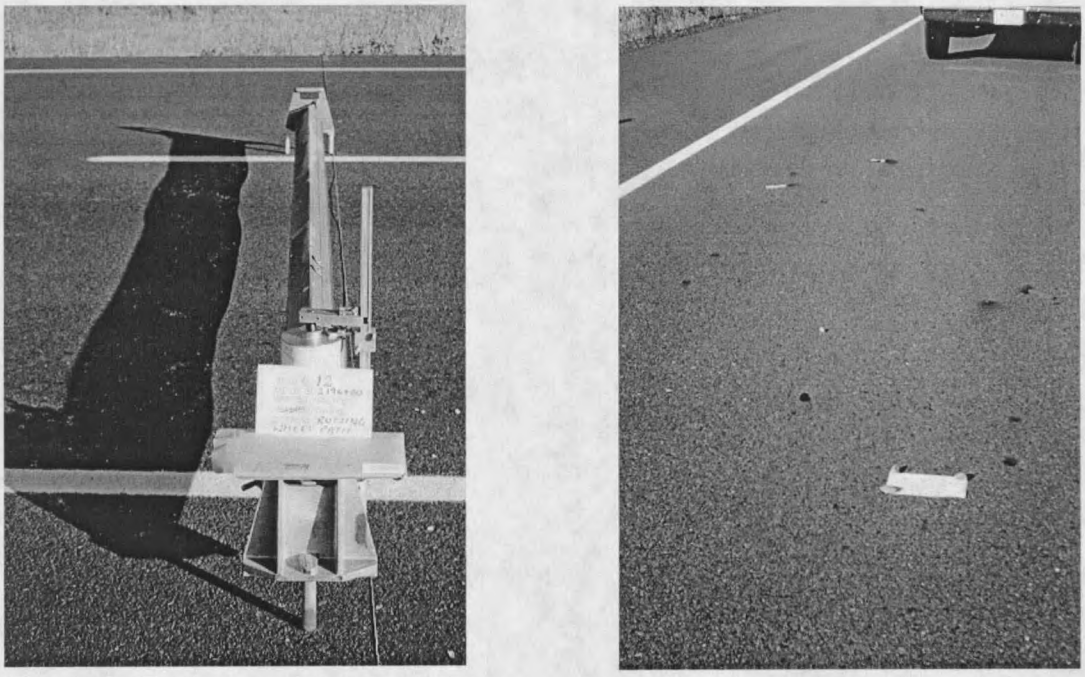


Figure 6. Test pavement at one year.

The primary distress witnessed after one year of service was rutting. The average rut depths of the control sections in the driving lanes in both directions of travel were over three times the average rut depth of the Polybilt and Kraton modified asphalt sections, which were similar in magnitude. The rut depths for the driving lanes of the control

sections were similar to pre-construction rutting in just over one year. For the westbound direction only, the average rut depths of the passing lane control section were also higher than those of the modified sections. The difference, however, was not as great as in the driving lane, measured as 0.03 to 0.05 inches deeper. Tables 13 and 14 provide summaries of the rutting measurements.

Table 13. First Annual Post-Construction Rutting - Westbound

	Driving Lane		**Passing Lane**	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.12	0.12	0.06	0.07
Maximum	0.16	0.17	0.09	0.10
Standard Deviation	0.02	0.03	0.02	0.02
Kraton				
Average Depths	0.11	0.09	0.06	0.06
Maximum	0.12	0.16	0.10	0.10
Standard Deviation	0.01	0.02	0.03	0.03
Control				
Average Depths	0.37	0.38	0.11	0.10
Maximum	0.40	0.43	0.13	0.18
Standard Deviation	0.04	0.06	0.02	0.04

After 18 months of service, the pavement profiles of the control section were already distorted from excessive rutting relative to their condition at the completion of construction. The transverse slope of the pavement no longer had the original intended shape. This condition could affect pavement drainage, the stability of the traffic, and reduce the overall performance of the pavement. The distortion of the driving lanes was more extensive than the passing lanes.

Table 14. First Annual Post-Construction Rutting - Eastbound

	Driving Lane		Passing Lane	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.12	0.13	0.06	0.10
Maximum	0.15	0.20	0.08	0.16
Standard Deviation	0.02	0.03	0.02	0.03
Kraton				
Average Depths	0.12	0.13	0.03	0.08
Maximum	0.15	0.15	0.08	0.12
Standard Deviation	0.02	0.02	0.02	0.03
Control				
Average Depths	0.35	0.39	0.06	0.09
Maximum	0.48	0.50	0.10	0.13
Standard Deviation	0.10	0.10	0.03	0.03

Second Annual Evaluation

The second annual field evaluation was conducted June 24 through June 28, 1993, a little over two years after construction. By the second year, pavement rutting seemed to have stabilized. The wheel path bleeding of the control section appeared to be greater than observed during the first annual evaluation. By comparison, the globules of the polymer-modified asphalt in the modified sections did not seem changed. Isolated spots of polished aggregates and raveling again were noticed, but their severity levels were similar with those from the first annual pavement evaluation.

The distresses observed in the second year on the test section were transverse cracks, spot bleeding, rutting, polished aggregate, raveling, and weathering. Distress levels were generally greater in the control sections. The raveling and weathering of the pavement surface of the second annual study were similar to those of the first annual

survey. Spots of polished (exposed) aggregate were observed, again in all three sections (Figure 7). The globules of the polymer modifier that had separated during construction were still visible at previous levels (Figure 7). However, the spot bleeding on the wheel path of the control section had increased in both number and size. The transverse cracks and ruts were again measured at each station.

Transverse Cracks. The major new distress observed in the second annual pavement was the occurrence of thermal transverse cracking (Figure 7). Table 15 summarizes the second year transverse cracking. The transverse cracks were in the developmental stage, with primarily low and moderate severity levels. Most of these cracks were reflective, as seen from the location of the pre-construction cracks. The severe winter of 1993 was felt to be the reason for the emergence of cracks. Not a single transverse crack was observed in the first annual pavement evaluation, but extensive cracking was found in the second annual pavement evaluation. Temperatures were below -20°F for several days in 1993. (*24*) Strategic Highway Research Project tests, including direct tension and bending beam rheometer, conducted on the modified asphalt in the Rocky Mountain User and Producer Group Truck, predicted thermal cracking in this temperature range. Both the direct tension test, which measures the tensile failure properties of asphalt cement binder at low in-service temperatures, and the bending beam rheometer, which tests the low temperature creep response of asphalt binder, failed before reaching -20°F. (*24*) Although the riding quality of the pavement is not reduced by these cracks, drainage-related maintenance problems can develop.





Figure 7. Second annual pavement condition.

Table 15. Second Annual Transverse Cracking Summary

Material	Severity Level		
	Low	Moderate	High
Polybilt	60.7	37.7	1.6
Kraton	86.3	13.8	0.0
Control	74.1	24.1	1.9

In the first post-construction winter, climatological data reported minimum temperatures of -10°F for two days in December, 1991, and -15°F for one day in January, 1992. In the second winter, the climatological data recorded the minimum temperature of -30°F for one day in December, 1992, and below -20°F for five days in January, 1993, with one day of -28°F during that month. These temperature records were taken for the Mildred 5 N station, which is located in Prairie county and is the station closest to the test

location. Consistent with SHRP tests, the severe winter temperatures resulted in thermal cracks on both modified and control sections.

The transverse cracks were studied with reference to the 52 fixed MSU stations. The number of cracks within 160 feet of the stations was recorded. The distance to the cracks both ahead of and behind the stations were measured. Nearly all of the cracks were classified as low (75.9%) or moderate (24.1%) severity, as directed by the SHRP Distress Identification Manual for Long Term Pavement Performance Projects, and were at different stages of formation. Most of the cracks originated from the shoulders and passing lane, which were not trenched before construction. These cracks propagated to the driving lanes. The overlays were placed over the cracks in the shoulders and the passing lane of the pre-construction pavement. Recall the pre-construction driving lane was trenched 0.20 feet prior to the placement of the overlays, essentially removing the original transverse cracks.

Rutting. Tables 16 and 17 summarize the rut depth information for the second annual evaluation, the other major distress after two years of service. Increases in rut depth over those seen after the first year were not observed. The average rut depths of the control section were over three times the average depths of the Polybilt and Kraton modified asphalt sections. The rut depths of the passing lane on the control section also were higher than those of the polymer-modified sections for the westbound direction. It was also observed that the rut depths in the driving lanes were greater than those in the passing lanes.

Table 16. Second Annual Post-Construction Rutting - Westbound

	Driving Lane		Passing Lane	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.13	0.12	0.06	0.09
Maximum	0.16	0.16	0.07	0.16
Standard Deviation	0.02	0.02	0.01	0.03
Kraton				
Average Depths	0.11	0.10	0.07	0.07
Maximum	0.13	0.14	0.09	0.09
Standard Deviation	0.03	0.02	0.01	0.02
Control				
Average Depths	0.37	0.39	0.10	0.12
Maximum	0.41	0.44	0.13	0.22
Standard Deviation	0.04	0.07	0.02	0.05

Table 17. Second Annual Post-Construction Rutting - Eastbound

	Driving Lane		Passing Lane	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.13	0.14	0.07	0.11
Maximum	0.19	0.22	0.09	0.13
Standard Deviation	0.04	0.04	0.02	0.02
Kraton				
Average Depths	0.12	0.13	0.05	0.09
Maximum	0.14	0.14	0.06	0.16
Standard Deviation	0.02	0.01	0.02	0.04
Control				
Average Depths	0.37	0.42	0.06	0.10
Maximum	0.47	0.50	0.08	0.16
Standard Deviation	0.08	0.10	0.01	0.04

Third Annual Evaluation

The third annual interim monitoring of the field experimental project was conducted from August 19, to August 22, 1994. Rumble strips had been cut into the pavement following the second annual interim monitoring, and are located on the driving lane shoulders for both eastbound and westbound lanes.

The distresses observed in the test section were transverse cracking, longitudinal cracking, bleeding, rutting, raveling, polished aggregate, and weathering. The globules of the polymer modifier seen in previous years were still visible. The distresses observed at each station for a distance of approximately 100 feet ahead of and behind the station, were recorded.

Transverse Cracks. Transverse cracking was again one of the major distresses observed during the third annual evaluation. A summary of the transverse cracks is shown in Table 18. Most cracks were classified in the low to moderate severity levels; however, there were some high severity level cracks present in the Polybilt modified sections. While the distance before and after the MSU stations was reduced from 160 feet to 100 feet, the total number of cracks studied increased over those observed in the second year.

Of the 361 transverse cracks recorded, 74.5 percent were considered low severity, 22.2 percent were considered moderate severity, and the remaining 3.3 percent were considered high severity. Over the entire test section, 203 transverse cracks were full

width in length, 98 affected the shoulder only, while the remaining 60 fell into the range between full width and shoulder only.

Table 18. Third Annual Transverse Cracking Summary

Material	Severity Level		
	Low	Moderate	High
Polybilt	53.7	36.6	9.8
Kraton	74.1	25.9	0.0
Control	95.9	4.1	0.0

Similar results were found for the modified asphalt sections. The Polybilt section had 53.7 percent low severity cracks, 36.6 percent moderate severity cracks, and 9.8 percent high severity cracks. The Kraton section had 74.1 percent low severity cracks, and 25.9 percent moderate severity cracks. The control section had 95.9 percent low severity cracks, and 4.1 percent moderate severity cracks.

Rutting. The rut depths in the driving lanes were still found to be significantly greater than the rut depths in the passing lanes. Tables 19 and 20 provide a summary of the rutting following three years of service. In the driving lanes of the modified materials, and all of the passing lanes, rut depths were approximately equal to previously measured depths. However, for the driving lanes of the control sections, rut depths had increased slightly over the previous year's depths.

Table 19. Third Annual Post-Construction Rutting - Westbound

	Driving Lane		Passing Lane	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.13	0.12	0.04	0.07
Maximum	0.19	0.19	0.07	0.13
Standard Deviation	0.03	0.05	0.02	0.03
Kraton				
Average Depths	0.09	0.08	0.04	0.05
Maximum	0.14	0.14	0.06	0.09
Standard Deviation	0.03	0.03	0.01	0.02
Control				
Average Depths	0.42	0.41	0.09	0.10
Maximum	0.46	0.46	0.11	0.18
Standard Deviation	0.04	0.06	0.02	0.04

Table 20. Third Annual Post-Construction Rutting - Eastbound

	Driving Lane		Passing Lane	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.12	0.12	0.05	0.08
Maximum	0.15	0.24	0.07	0.11
Standard Deviation	0.03	0.05	0.01	0.02
Kraton				
Average Depths	0.12	0.11	0.04	0.08
Maximum	0.15	0.14	0.06	0.11
Standard Deviation	0.03	0.02	0.01	0.02
Control				
Average Depths	0.40	0.43	0.05	0.07
Maximum	0.52	0.53	0.07	0.12
Standard Deviation	0.11	0.11	0.02	0.02

Fifth Annual Evaluation

As previously noted, no formal evaluation occurred during the fourth year of the project as there were minimal changes observed in the pavement sections, compared with the third year evaluation. Photographs taken by Dr. Joe Armijo testified to this fact.

The fifth annual evaluation, conducted in August 1996 was the final evaluation for this project. The pavement surfaces had not changed significantly since the third annual evaluation. Specifically, distresses were found to be identical to those noted in the third year evaluation (cracking, bleeding, rutting, raveling, polished aggregate, and weathering). Severity levels were approximately the same for the polymer-modified sections, but had increased for the unmodified control section. Moreover, the size of the affected areas was increasing in the unmodified sections at a faster pace.

Cracking. The conclusions drawn about crack resistance have changed since the second annual evaluation. The initial cracking, first witnessed in the second year, led investigators to the conclusion that the modified sections were not resisting cracking as well as the control section. Further analysis of the data from the second year reveals that this conclusion was premature. On a per station basis, there were 3.2 cracks per station for Polybilt, 3.9 for the control, and 4.2 for Kraton. These numbers are not statistically different. Moreover, as was noted when the cracks first appeared after the second winter, nearly all the cracks were found to be reflective in nature. Thus, all of the materials were exhibiting similar reflective cracking behavior. It is felt the error in the original analysis occurred due to an oversight in how the test sections were set up (i.e., there are more

stations in the modified sections than in the control, nineteen verses fourteen), and the reflectiveness of the cracking. If the number of cracks is analyzed without accounting for these differences, the results are skewed in favor of the control section.

For the fifth annual evaluation, transverse cracks within 200 feet of an MSU station were analyzed, and their distance from the station and severity level were recorded (Figure 8). Crack sealing operations had been conducted on the western end of the project in the Spring 1996 (Figure 8). The sealing operation encompasses portions of the Polybilt and Kraton sections. Severity levels of the sealed cracks are not included in this analysis because these were routed. The Polybilt and Kraton sections had 26.9 and 26.6 percent of their cracks sealed, respectively. The reflective cracking, as first witnessed in the second year, had propagated to the driving lanes from the shoulders and the passing lane. Complete information on studied cracks is found in the Appendix; a summary is seen on Table 21.

Table 21. Fifth Annual Transverse Cracking Summary

Material	Severity Level		
	Low	Moderate	High
Polybilt	61.9	26.3	11.9
Kraton	91.4	8.6	0.0
Control	86.6	11.9	1.5

Analysis of all cracking on a per station basis, including those sealed, yields a crack density of 14.4 cracks per station for the control section, 11.7 for the Polybilt section, and 8.3 for the Kraton section. When compared to pre-construction conditions, it appears that most of these cracks are reflective in nature.

Severity level analysis of the unsealed cracks indicates 86.6 percent of the control sections cracks were low severity cracks. Moderate severity cracking accounted for 11.9 percent of the cracks. The remaining 1.5 percent were high severity cracks. Within the Polybilt section, 61.9 percent of the unsealed cracks were of the low severity variety. Moderate severity cracks accounted for 26.3 percent of those not sealed, and high severity cracks accounted for 11.9 percent. Rounding errors caused the total percentage to exceed 100 percent. Kraton's unsealed cracks broke down as 91.4 percent and 8.6 percent low and moderate, respectively. Kraton did not have any high severity cracks.

When looking at the longitudinal cracking, the control section resisted this phenomena better then the modified sections. The majority of the longitudinal cracking occurred at the seam between the driving and passing lanes. Only 3.8 percent of the total station length for the control was found to have longitudinal cracking. By contrast, 27.5 percent of the Kraton section and 34.5 percent of the Polybilt section were cracked longitudinally. An investigation of edge cracking revealed that only 0.1 percent of the Kraton section's length was cracked, a mere eight feet out of 7,600 feet possible. By comparison, 5.6 percent of the control section was experiencing edge cracking and 15.3 percent of the Polybilt section exhibited this phenomenon. It should be noted that when looking at both longitudinal and edge cracking, at least 64 percent of the cracking of each type by modified asphalt combination occurred in the westbound lanes. A review of the construction data does not give any indication of an observed problem during construction. Nonetheless, with such a disparity in the pavement's performance across the different directions of travel, it can be assumed the difference was construction-

related. Namely, it is believed that the longitudinal seams for the modified sections were not adequately compacted. While these seams received the same attention as was given to the unmodified material, they appear to have require additional passes by rollers. It is likely that if additional compaction of the modified section's seams had occurred, longitudinal cracking at these seams would been reduced.

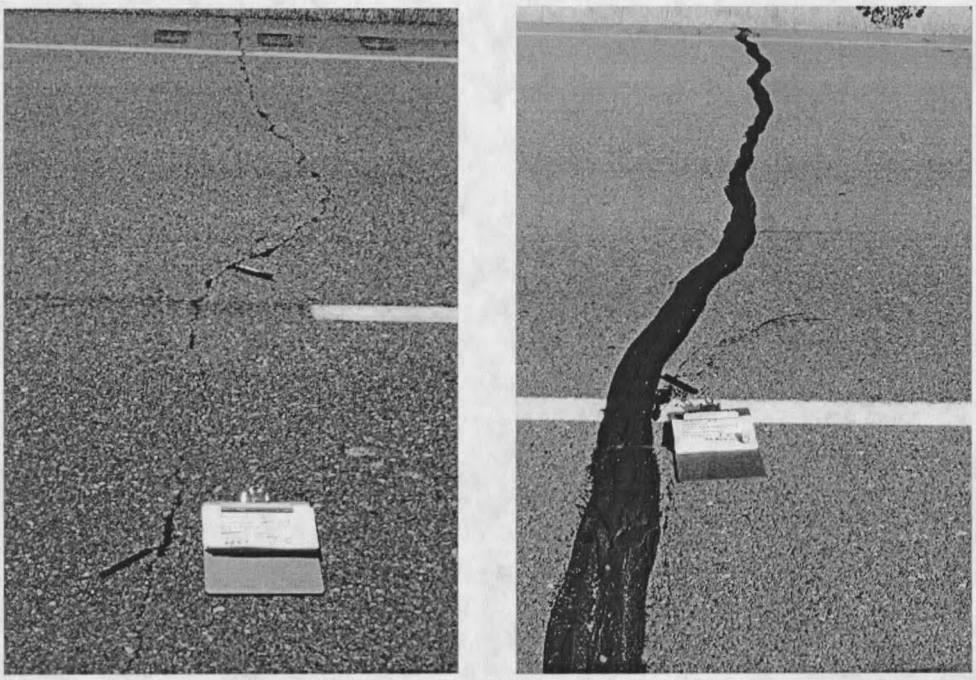


Figure 8. Fifth annual pavement condition.

Rutting. The observations of rutting from previous years remained essentially unchanged. Rut resistance in the driving lanes was greatest for the modified sections and all materials had deeper ruts in their driving lanes than in their passing lanes. Rut depths of the modified sections driving lanes were about 0.05 inches deeper than the third year measurements. However, the control section's driving lane ruts had grown by more than

0.10 inches and were exceeding MDT maximum tolerances (0.50 inches). Three stations incorporating Polybilt and Kraton, and one station from the control section, were chosen at random from those available in the westbound direction. These, and their corresponding eastbound counterparts, were graphed relative to the centerline. These graphs can be found in the Appendix. Summaries of the fifth year rutting data are presented in Tables 22 and 23, and visually shown by Figure 9. Figures 10 and 11 show how the ruts evolved on the test sections.

Table 22. Fifth Annual Post-Construction Rutting - Westbound

	Driving Lane		**Passing Lane**	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.15	0.18	0.06	0.09
Maximum	0.22	0.24	0.09	0.15
Standard Deviation	0.04	0.04	0.02	0.04
Kraton				
Average Depths	0.12	0.15	0.07	0.10
Maximum	0.18	0.21	0.10	0.16
Standard Deviation	0.04	0.05	0.02	0.04
Control				
Average Depths	0.51	0.55	0.11	0.13
Maximum	0.59	0.60	0.15	0.20
Standard Deviation	0.06	0.04	0.03	0.04

Table 23. Fifth Annual Post-Construction Rutting - Eastbound

	Driving Lane		Passing Lane	
	LWP (Inches)	RWP (Inches)	LWP (Inches)	RWP (Inches)
Polybilt				
Average Depths	0.17	0.18	0.08	0.08
Maximum	0.21	0.30	0.11	0.12
Standard Deviation	0.04	0.05	0.02	0.02
Kraton				
Average Depths	0.18	0.17	0.05	0.07
Maximum	0.21	0.21	0.10	0.09
Standard Deviation	0.03	0.03	0.02	0.02
Control				
Average Depths	0.52	0.53	0.10	0.08
Maximum	0.68	0.63	0.13	0.12
Standard Deviation	0.14	0.12	0.03	0.03

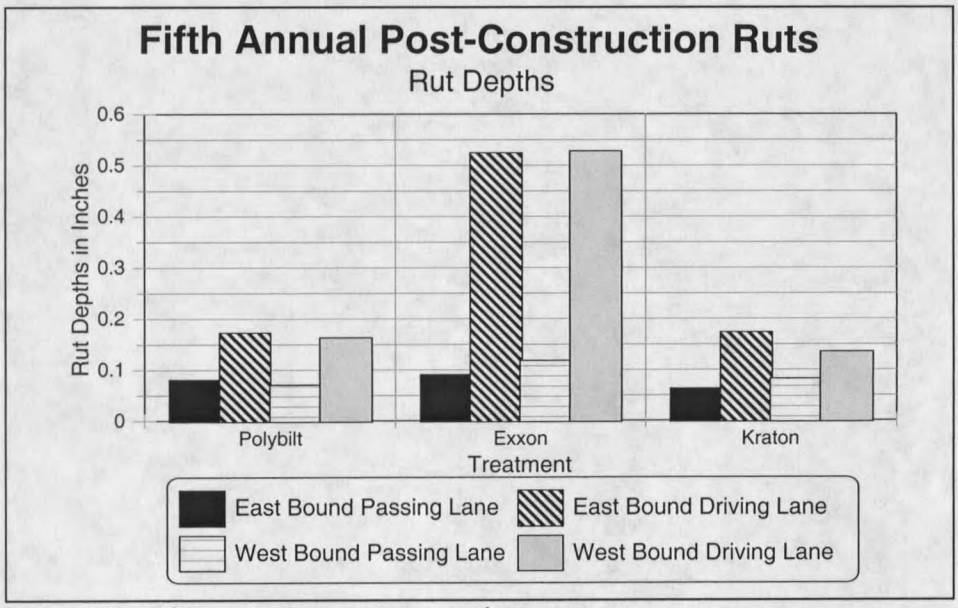


Figure 9. Fifth annual post-construction ruts.

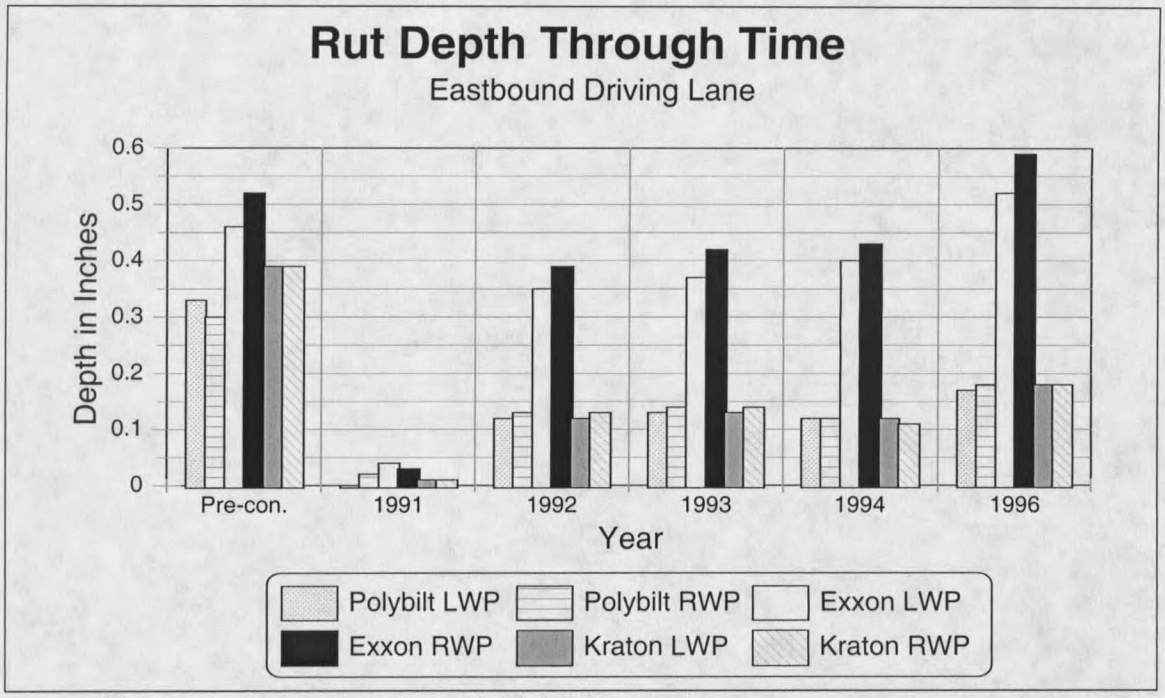


Figure 10. Rut evolution – eastbound driving lane.

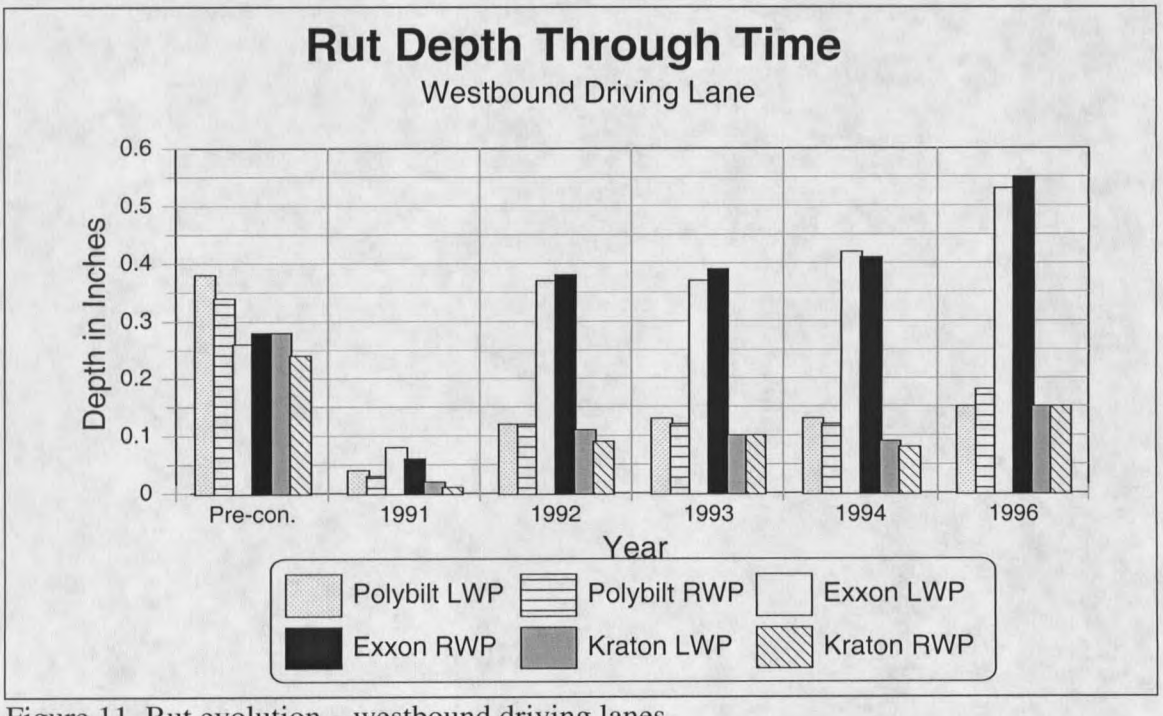


Figure 11. Rut evolution – westbound driving lanes.

A series of statistical analyses, presented in the Appendix, were conducted to see if rutting depths were significantly different. This analysis was done with the aid of a computer program from GraphPad Software, Inc., Prism 2.01. The means were tested for significant differences via the t-test. A 95 percent confidence interval (alpha equal to 0.05) was chosen. The variances were tested with an F-test. Alpha was again set at 0.05. Tables 24 and 25 provide a summary of the statistics on the rutting data. Individual sections, without regard for wheel paths, were used in the analysis. Therefore, the ruts of the right and left wheel paths of each utilized treatment and direction were analyzed to see if their means were significantly different. In every instance, the means within each wheel path did not differ significantly.

The statistical comparison process was repeated to evaluate Polybilt versus Kraton, Polybilt versus unmodified Exxon, and Kraton versus unmodified Exxon. These comparisons were done for driving and passing lanes individually. The modified sections were found to perform significantly better than the control section in the driving lanes. In the passing lanes, which were not loaded to the same extent as the driving lanes, the difference was not as pronounced. In fact, in the eastbound passing lane, differences between Polybilt and the control section were not statistically significant. In every direct comparison in which a difference existed, Kraton performed better than Polybilt. It is unclear if the difference arose from better performance from Kraton, or is a by-product of the methodology utilized in preparing the Polybilt modified binder.

Table 24. Rutting Performance (Left Wheel Path vs. Right Wheel Path)

Item	Means Significantly Different?*	Variance Significantly Different?**	Statistically Better Performer.
Polybilt			
Eastbound Passing Lane	No	No	Neither
Eastbound Driving Lane	No	No	Neither
Westbound Passing Lane	No	**Yes**	Left Wheel Path
Westbound Driving Lane	No	No	Neither
Kraton			
Eastbound Passing Lane	No	No	Neither
Eastbound Driving Lane	No	No	Neither
Westbound Passing Lane	No	**Yes**	Left Wheel Path
Westbound Driving Lane	No	No	Neither
Exxon			
Eastbound Passing Lane	No	No	Neither
Eastbound Driving Lane	No	No	Neither
Westbound Passing Lane	No	No	Neither
Westbound Driving Lane	No	No	Neither

*t-test performed on means, Alpha=0.05

**F-test performed on variance, Alpha=0.05.

Table 25. Rutting Performance Comparison by Product and Lane

Item	Means Significantly Different?*	Variance Significantly Different?**	Statistically Better Performer.
Eastbound Passing Lane			
Polybilt vs. Kraton	**Yes**	No	Kraton
Polybilt vs. Exxon	No	No	Neither
Kraton vs. Exxon	**Yes**	No	Kraton
Eastbound Driving Lane			
Polybilt vs. Kraton	No	**Yes**	Kraton
Polybilt vs. Exxon	**Yes**	**Yes**	Polybilt
Kraton vs. Exxon	**Yes**	**Yes**	Kraton
Westbound Passing Lane			
Polybilt vs. Kraton	No	No	Neither
Polybilt vs. Exxon	**Yes**	No	Polybilt
Kraton vs. Exxon	**Yes**	No	Kraton
Westbound Driving Lane			
Polybilt vs. Kraton	No	No	Neither
Polybilt vs. Exxon	**Yes**	No	Polybilt
Kraton vs. Exxon	**Yes**	No	Kraton

*t-test performed on means, Alpha=0.05

**F-test performed on variance, Alpha=0.05.

CHAPTER 7

ECONOMIC ANALYSIS

To evaluate whether the added costs of the polymer modifiers is justified, an economic analysis using an estimation of the Remaining Service Life (RSL) of the evaluated sections is required. Based on a road condition survey conducted by MDT Pavement Management Systems (PvMS) on June 27, 1996, a prediction of the remaining life was made by the MDT. This prediction was done for a number of factors, including alligator cracking, miscellaneous cracking, and rutting.

The RSL for both cracking categories is based on a survey of the first 250 feet of a given one mile section. In the case of alligator cracking, all of the sections (with the exception of the westbound passing lane of Kraton and the control material) had the maximum of fifteen years of life left in them. The Kraton section had 14.6 years of RSL, and the control section had 12.6 years. All of the sections had between 13.95 and 14.85 years RSL under the miscellaneous cracking criteria.

The RSL for rutting is based on a continuous rolling survey of an entire one-mile section. It is probable that in the collection of the rutting data, the operator would not remain oriented so as to record the maximum rut depth at all times. If this is true, the results will be optimistic. Also, because the value of the RSL was based on an entire

mile section, the inputs for each mile section were based on more than one material. For instance, for milepost 188, one-tenth of the data came from the unmodified control sections and nine-tenths from modified sections. For milepost 189, half of the data came from the unmodified sections and half from the modified sections. For milepost 190, six-tenths were from the modified sections and four-tenths were from unmodified, non-control sections. Nonetheless, the data contain useful information. As shown by the rutting RSL data, the one-mile sections with longer reaches of modified influence have, in general, more years of service remaining. The exception to this observation is the driving lane of the westbound 189 milepost. Its 10.63 years of RSL is greater than the values for its companion sections with greater modifier influence. The explanation for this situation is twofold. First, the potential wandering of the survey vehicle could be biasing the results. Second, the modified portions of milepost 189 are performing well, and thus countering the effects of the unmodified portion within the milepost 189 sections. Recall that in every comparison of hard rutting data from the modified test sections versus the unmodified control, the test sections performed better statistically. Remember too, that the data for those comparisons were based on the highly accurate profilograph survey data. It is felt, therefore, that if it were possible to drive the survey vehicle in a perfect fashion, this anomaly would not be seen, and the modified sections would have higher RSL values. The RSL values can be found in Table 26.

Table 26. Remaining Service Life, in Years (provided by MDT – PvMS)

Milepost	Lane	Primary Material	Alligator Cracking Index RSL	Miscellaneous Cracking Index RSL	Rutting RSL
188	Westbound Passing	Kraton	14.6	14.85	13.13
	Westbound Driving	Kraton	15	14.85	9.38
	Eastbound Passing	Polybilt	15	14.1	15
	Eastbound Driving	Polybilt	15	14.7	14.38
189	Westbound Passing	Exxon	12.6	14.55	10.63
	Westbound Driving	Exxon	15	13.95	10.63
	Eastbound Passing	Exxon	15	14.85	15
	Eastbound Driving	Exxon	15	14.7	6.75
190	Westbound Passing	Polybilt	15	14.7	13.13
	Westbound Driving	Polybilt	15	13.95	8.75
	Eastbound Passing	Kraton	15	14.1	15
	Eastbound Driving	Kraton	15	14.85	10

With the RSL estimated for each section, an estimate of the annual costs can be produced. Differences in annual costs will arise from differences in initial costs and maintenance costs. The total cost of construction of each section varied only by the difference in the costs for the asphalt concrete. Identical methods were used to prepare the sites and compact the materials. Thus, there would be no differences in preparation, compaction, or costs. Therefore, for those sections with shorter service lives, the construction costs will be greater on a per year of service life basis. For those sections

with fifteen years RSL, they are at the maximum possible value. Thus, there may be more then fifteen years RSL in those sections.

Annualized costs for the materials used in each section of the test are presented in Table 27. These costs were determined by dividing the cost per mile by the RSL, which provides a cost per mile per year. Only the driving lanes were calculated, using the rutting RSL, because they had the fewest years left in them. The RSL value was rounded to the nearest year and increased five years to include the first five years of service. Unfortunately, this value could be skewed by the combination of materials in a given mile stretch. In an effort to help eliminate this bias, it was assumed that a linear relationship exists between the costs of the material in a section. The most unbiased values are found in the 188 stretch, as they contain nine-tenths of a mile of a single material.

Table 27. Annualized Costs

Milepost	Primary Material	Rutting RSL (rounded)	Cost Per Mile	Cost Per Mile Per Year
188	Kraton	9	$161,145.22	$11,510.37
	Polybilt	14	$117,024.81	$6,159.20
189	Exxon/Kraton	11	$129,274.94	$8,079.68
	Exxon/Polybilt	7	$104,763.60	$8,730.30
190	Polybilt	9	$107,828.90	$7,702.06
	Kraton	10	$137,242.51	$9,149.50

While at first glance, Kraton seems to not offer a good return for the invested dollar, it must be remembered that these numbers are based on the actual bid dollars for this project. If more contemporary (1996) cost figures are used in conjunction with the

rounded RSL estimates, then the annualized costs for Kraton and Polybilt are slightly lower than those for Polybilt found in Table 27. Moreover, cost differences between the two have disappeared. When 1996 costs are used to calculate annualized costs for the control sections, they too experience slight improvements.

CHAPTER 8

CORING STUDY RESULTS

The Marshall test properties of the cores from different phases (i.e., pre-construction, post-construction, and first annual pavement surveys) indicated that only one of the Marshall test properties, air voids, correlated with rut depths. A comparison of the air voids and rut depths of the modified and the control sections of the pre-construction and first annual pavements, and pre-construction and post-construction pavement cores indicated an inverse relationship between these parameters.

The purpose of the pavement core study was to see if a correlation existed between observed rut depths in the test sections and the Marshall test properties of the cores from those sections. The pre-construction pavement cores provided Marshall test properties for a pavement distressed to the extent of failure. These cores established the limit of a distressed pavement parameter. The Marshall test properties of the cores from the new overlays established a base for the possible starting limit that could be expected for the modified and unmodified test sections, for these specific designs. These are the values before any distress was observed.

Since there were no significant differences in observed rutting following the first annual pavement evaluation, no cores were taken after the first year of service.

Moreover, additional funding for a core study on the test sections following five years of service was not provided for in the original budget, nor were these activities part of the scope of work.

Comparisons were made between the first annual rut depths and the Marshall test properties of the first annual pavement cores. The data utilized for the evaluation are found in the second annual report. (*24*) It was observed that the pavement cores of the Kraton modified section had significantly larger air voids and the smallest rut depths. The control section, which had the largest rut depths, had the lowest values of air voids. The air voids values of cores from between the wheel path were significantly higher than those of the cores from within the wheel path. Similarly, for the passing lanes, the modified section with the smallest ruts had the largest air voids. The rut depths of the driving lane were significantly higher than the passing lane, while the values of the air voids were significantly lower in the driving lane relative to the driving lane.

The values of the air voids of the post-construction pavement cores were significantly higher than those of the first annual cores, but the values of the rut depth were significantly lower than those of first annual values. Similarly, the air voids values of the post-construction pavement cores were significantly higher than those of both the pre-construction and first annual pavement cores. But the rut depth values of post-construction pavement cores were significantly lower than those of both the pre-construction and first annual pavement cores.

CHAPTER 9

SUMMARY AND CONCLUSIONS

The performance of a pavement can deteriorate rapidly because of premature rutting and cracking. Increasing truck traffic, heavier loads, different wheel configurations, higher tire pressures, and radial tires have accelerated the problems. Extreme climatic conditions, as experienced in eastern Montana, contribute to accelerated losses of pavement integrity. The pre-construction pavement surface conditions on the test sections involved in this research provided testimony of the extent a pavement can deteriorate. The drainage pattern of the pavement surface was severely changed because of rutting. Conventional methods of asphalt concrete mix design were developed for single axle loads of eighteen kips, with conventional wheel pressures of 70-90 psi. These design parameters no longer reflect actual in-service conditions. Adjustments of the components of a pavement are now required to strengthen pavements to meet contemporary demands.

Asphalt mixes modified with polymers seem to offer a solution to the rutting of pavements. The production and placement of polymer-modified asphalt pavement were not significantly different than those for conventional asphalt binders. The asphalt can be modified at in-state refineries. The identical compaction pattern for both unmodified and

modified asphalt sections demonstrated that modified asphalt does not require special efforts to obtain the specified level of compaction (note comments on longitudinal seams below). Marshall stability and flow and unit weight fell within design specifications. The field density of all modified and unmodified asphalt sections were within 95 to 98 percent of the target density.

The control section, paved with a conventional mix using regular asphalt, was rutted to about the same depth as the pre-construction level after the first year. The ruts in the modified asphalt sections were significantly lower than the unmodified control section. This can only be attributed to the properties of modified asphalt binders, both Polybilt and Kraton, as they represent the only significant difference in the sections.

Isolated spots of distress (such as weathering, raveling and polished aggregate) started to appear in all of the test sections after the first year of traffic. It was thought that these distresses would spread over larger areas, and their severity levels would increase over time. This has been the case for the unmodified control section. In the modified sections, however, the distresses have not propagated as quickly. The benefits of polymer utilization seem to extend beyond rutting.

The extensive study of the Marshall test properties from cores taken at various stages of this project resulted in showing an inverse relationship between the air voids and rut depth. The air void parameter should be taken seriously in the designing of an asphalt mixture, and in the construction of the pavement. If sufficient control in the volumetrics of an asphalt mixture is maintained, air voids could be controlled as desired.

In analyzing the data from the past five years, Kraton consistently performed better structurally than either Polybilt or Exxon 85/100 penetration grade asphalt. The higher air voids found in the Kraton cores are felt to be the primary factor in its higher performance. Polybilt consistently performed better structurally than the unmodified control section, which was evident in its superior resistance to rutting. All of the modified sections suffered less from weathering, raveling, polished aggregate, and bleeding than did the control section. However, the best resistance to longitudinal cracking was exhibited by the Exxon 85/100 section. This behavior may be explained by the construction of longitudinal seams. Nearly all of the longitudinal cracking occurred along the centerline seam between driving and passing lanes. Thus, it appears that insufficient compaction during the construction of the longitudinal seams occurred for the modified material. Additional attention to this aspect of the construction process seems warranted. Exxon also outperformed Polybilt in its ability to resist edge cracking. No explanation can be offered for this without additional information, such as the in-place thicknesses of the shoulders.

Economically, Polybilt is providing the greatest return for the invested dollar, based strictly on material costs alone. However, if 1996 costs are examined, than both modifiers produce significant cost savings when compared to an unmodified binder.

Results of this long-term study have shown that polymer modifiers are highly beneficial in the reduction of pavement rutting. Their use improves the structural capabilities of a pavement, and is economically justified.

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APPENDIX

Table 28. Crack Density Data

Polybilt	Exxon	Kraton
Cracks per Station		
11	13	14
15	12	9
9	19	8
12	19	6
8	22	6
13	20	4
12	15	11
8	8	11
13	11	7
15	13	8
8	14	8
9	14	9
6	13	8
12	9	9
14		9
14		7
11		4
19		10
14		9

Polybilt vs. Kraton (Cracking)

Unpaired t test
P value 0.0006
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=3.790 df=36

How big is the difference?
Mean ± SEM of Polybilt. 11.74 ± 0.7329 N=19
Mean ± SEM of Kraton. 8.263 ± 0.5506 N=19
Difference between means 3.474 ± 0.9167
95% confidence interval -5.334 to -1.613
R squared 0.2852

F test to compare variances

F,DFn, Dfd 1.772, 18, 18
P value 0.1173
Are variances significantly different? No

Polybilt vs. Exxon (Cracking)

Unpaired t test
P value 0.0436
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=2.104 df=31

How big is the difference?
Mean ± SEM of Polybilt. 11.74 ± 0.7329 N=19
Mean ± SEM of Exxon. 14.43 ± 1.113 N=14
Difference between means -2.692 ± 1.280
95% confidence interval 0.08158 to 5.302
R squared 0.1249

F test to compare variances
F,DFn, Dfd 1.699, 13, 18
P value 0.1469
Are variances significantly different? No

Kraton vs. Exxon (Cracking)

Unpaired t test
P value P<0.0001
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=5.372 df=31

How big is the difference?
Mean ± SEM of Exxon. 14.43 ± 1.113 N=14
Mean ± SEM of Kraton. 8.263 ± 0.5506 N=19
Difference between means 6.165 ± 1.148
95% confidence interval -8.506 to -3.824
R squared 0.4821

F test to compare variances
F,DFn, Dfd 3.010, 13, 18
P value 0.0160
Are variances significantly different? Yes

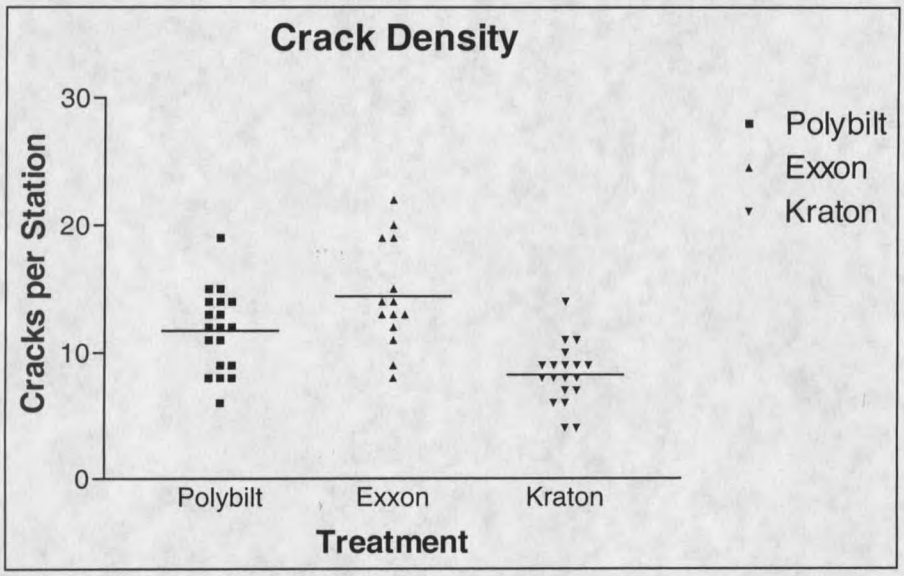


Figure 12. Scattering of Crack Density.

Table 29. Polybilt Eastbound Driving Lane

Station #	LWP	RWP
	Rut Depth in Inches	
27	0.21	0.18
28	0.17	0.17
29	0.19	0.17
30	0.20	0.19
31	0.17	0.30
32	0.17	0.16
33	0.10	0.15
34	0.19	0.17
35	0.10	0.12

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.5742
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=0.5736 df=16

How big is the difference?
Mean ± SEM of LWP. 0.1667 ± 0.01344 N=9
Mean ± SEM of RWP. 0.1789 ± 0.01654 N=9
Difference between means -0.01222 ± 0.02131
95% confidence interval -0.03295 to 0.05739
R squared 0.02015
F test to compare variances
F,DFn, Dfd 1.515, 8, 8

P value 0.2853
Are variances significantly different? No

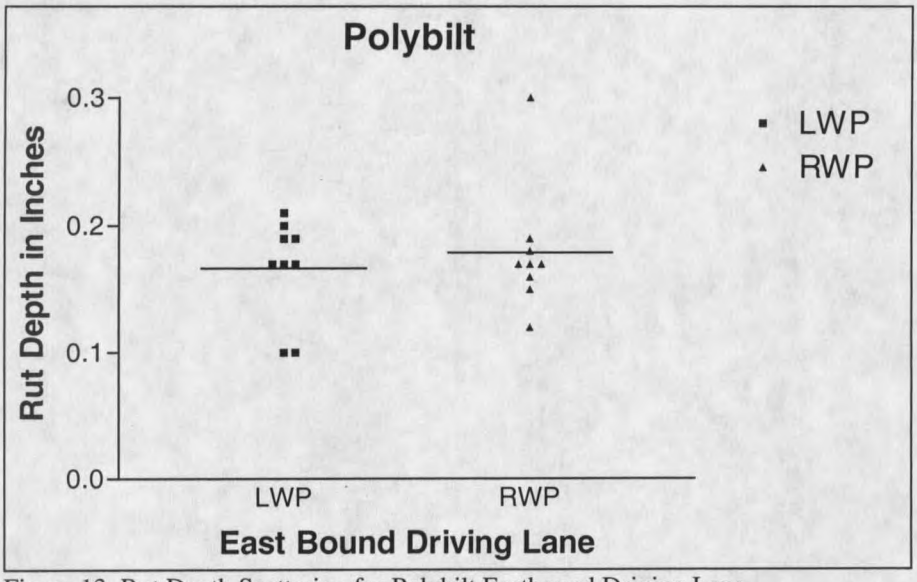


Figure 13. Rut Depth Scattering for Polybilt Eastbound Driving Lane.

Table 30.Polybilt Eastbound Passing Lane

Station #	LWP	RWP
	Rut Depth in Inches	
27	0.11	0.08
28	0.05	0.05
29	0.07	0.08
30	0.08	0.08
31	0.07	0.08
32	0.08	0.07
33	0.08	0.09
34	0.11	0.12
35	0.07	0.09

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.8069
Are means significantly different? ($P < 0.05$) No
One- or two-tailed P value? Two-tailed
t, df t=0.2485 df=16
How big is the difference?
Mean ± SEM of LWP. 0.0800 ± 0.006455 N=9
Mean ± SEM of RWP. 0.08222 ± 0.006186 N=9
Difference between means -0.002222 ± 0.008941
95% confidence interval -0.01673 to 0.02118
R squared 0.003846

F test to compare variances
F,DFn, Dfd 1.089, 8, 8
P value 0.4536
Are variances significantly different? No

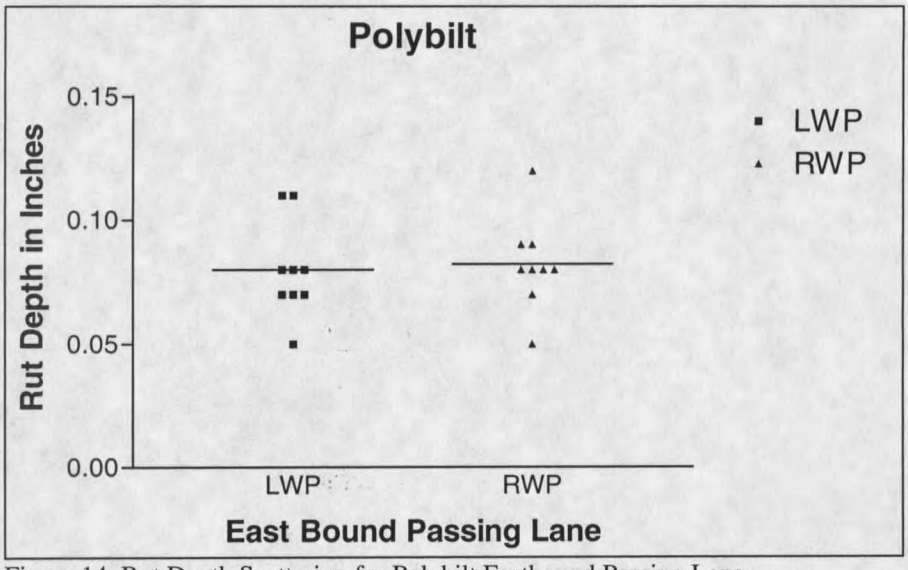


Figure 14. Rut Depth Scattering for Polybilt Eastbound Passing Lane.

Table 31. Polybilt Westbound Driving Lane

Station #	LWP	RWP
	Rut Depth in Inches	
1	0.19	0.24
2	0.22	0.20
3	0.12	0.24
4	0.20	0.17
5	0.14	0.20
6	0.12	0.14
7	0.09	0.16
8	0.12	0.14
9	0.12	0.17
10	0.13	0.15

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.0607
Are means significantly different? ($P < 0.05$) No
One- or two-tailed P value? Two-tailed
t, df t=2.001 df=18
How big is the difference?
Mean ± SEM of LWP. 0.1450 ± 0.01352 N=10
Mean ± SEM of RWP. 0.1810 ± 0.01187 N=10
Difference between means -0.0360 ± 0.01799

95% confidence interval -0.001805 to 0.07381
R squared 0.1819
F test to compare variances
F,DFn, Dfd 1.296, 9, 9
P value 0.3527
Are variances significantly different? No

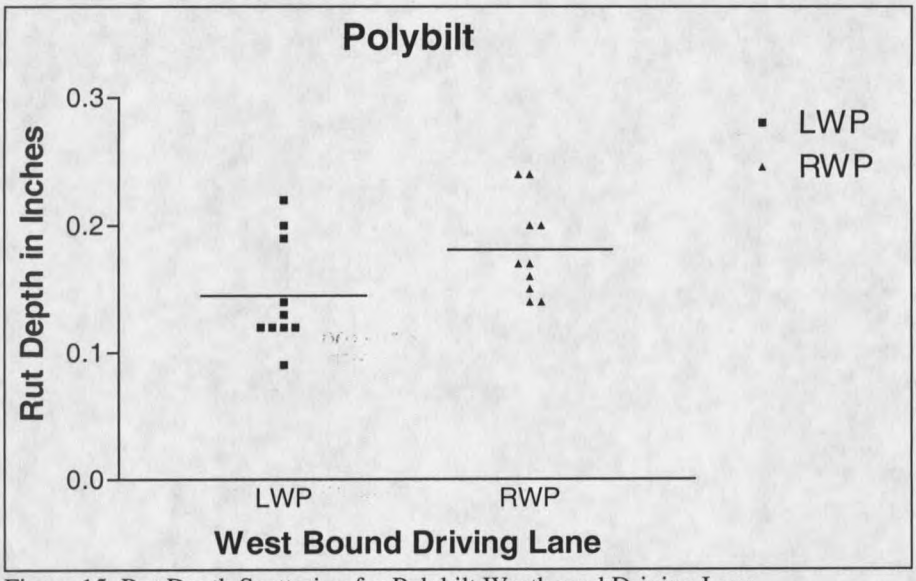


Figure 15. Rut Depth Scattering for Polybilt Westbound Driving Lane.

Table 32. Polybilt Westbound Passing Lane

Station #	LWP	RWP
	Rut Depth in Inches	
1.	0.06	0.07
2.	0.09	0.07
3.	0.06	0.06
4.	0.07	0.09
5.	0.03	0.03
6.	0.05	0.08
7.	0.07	0.14
8.	0.04	0.10
9.	0.07	0.07
10.	0.08	0.15

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.0776
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=1.872 df=18

How big is the difference?
Mean ± SEM of LWP. 0.0620 ± 0.005735 N=10
Mean ± SEM of RWP. 0.0860 ± 0.01147 N=10
Difference between means -0.0240 ± 0.01282
95% confidence interval -0.002942 to 0.05094
R squared 0.1629

F test to compare variances
F,DFn, Dfd 4.000, 9, 9
P value 0.0255
Are variances significantly different? Yes

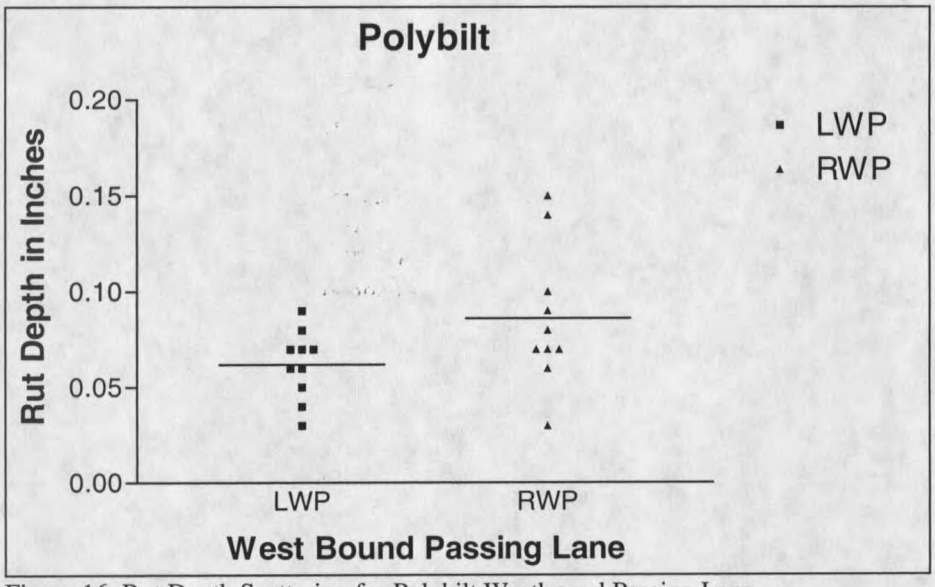


Figure 16. Rut Depth Scattering for Polybilt Westbound Passing Lane.

Table 33. Exxon Eastbound Driving Lane

Station #	LWP	RWP
	Rut Depth in Inches	
36	0.25	0.30
37	0.49	0.49
38	0.50	0.56
39	0.54	0.61
40	0.51	0.51
41	0.68	0.63
42	0.64	0.63

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.8064
Are means significantly different? ($P < 0.05$) No

One- or two-tailed P value? Two-tailed
t, df t=0.2505 df=12

How big is the difference?
Mean ± SEM of LWP. 0.5157 ± 0.05223 N=7
Mean ± SEM of RWP. 0.5329 ± 0.04422 N=7
Difference between means -0.01714 ± 0.06844
95% confidence interval -0.1320 to 0.1663
R squared 0.005202

F test to compare variances
F,DFn, Dfd 1.395, 6, 6
P value 0.3482
Are variances significantly different? No

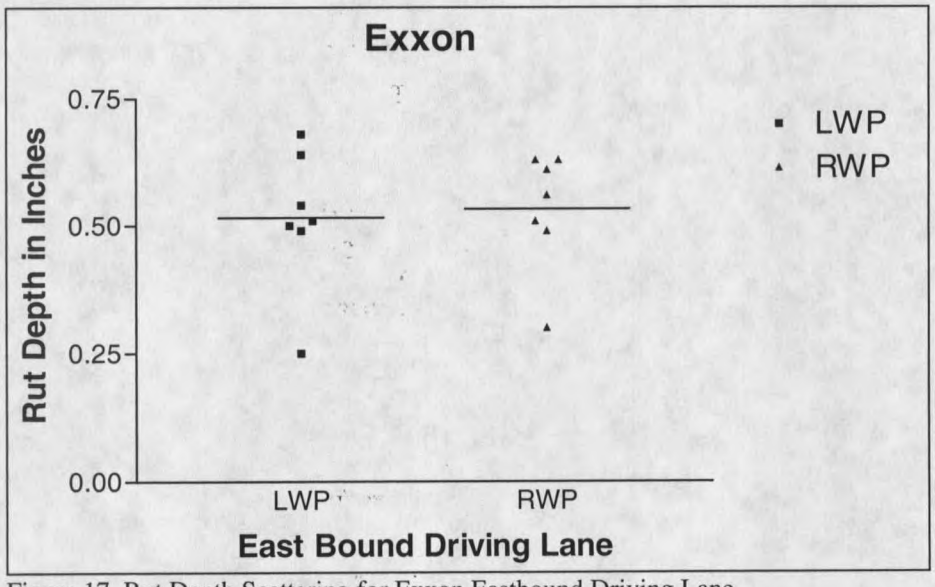


Figure 17. Rut Depth Scattering for Exxon Eastbound Driving Lane.

Table 34. Exxon Eastbound Passing Lane

Station #	LWP	RWP
	Rut Depth in Inches	
36	0.06	0.06
37	0.09	0.05
38	0.09	0.09
39	0.12	0.12
40	0.11	0.08
41	0.13	0.06
42	0.12	0.09

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.0850
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=1.877 df=12

How big is the difference?
Mean ± SEM of LWP. 0.1029 ± 0.009184 N=7
Mean ± SEM of RWP. 0.07857 ± 0.009110 N=7
Difference between means 0.02429 ± 0.01294
95% confidence interval -0.05247 to 0.003902
R squared 0.2270

F test to compare variances
F,DFn, Dfd 1.016, 6, 6
P value 0.4924
Are variances significantly different? No

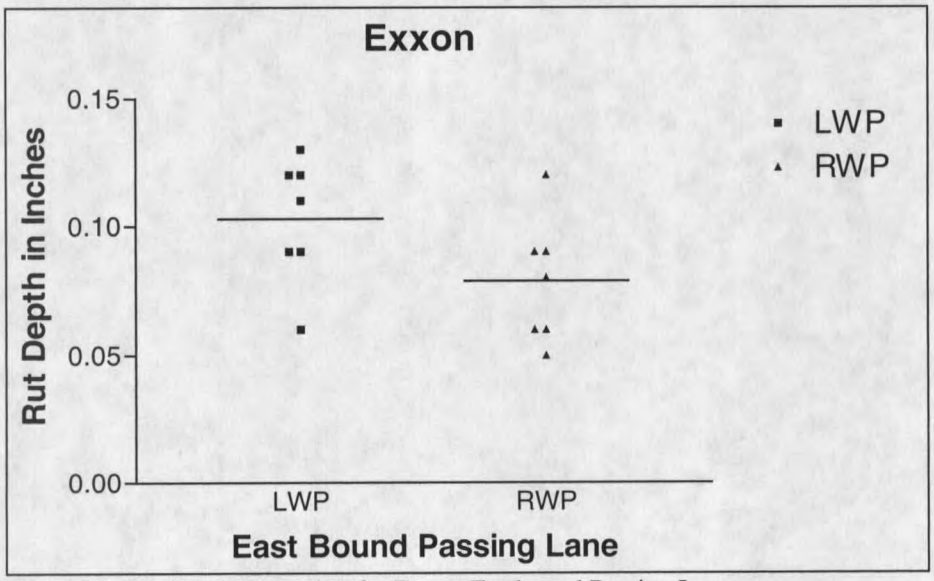


Figure 18. Rut Depth Scattering for Exxon Eastbound Passing Lane.

Table 35. Exxon Westbound Driving Lane

Station #	LWP	RWP
	Rut Depth in Inches	
11.	0.53	0.57
12.	0.59	0.60
13.	0.56	0.57
14.	0.54	0.50
15.	0.49	0.53
16.	0.45	0.51
17.	0.41	0.54

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.2199
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=1.294 df=12

How big is the difference?
Mean ± SEM of LWP. 0.5100 ± 0.02400 N=7
Mean ± SEM of RWP. 0.5457 ± 0.01360 N=7
Difference between means -0.03571 ± 0.02759
95% confidence interval -0.02440 to 0.09583
R squared 0.1225

F test to compare variances
F,DFn, Dfd 3.114, 6, 6
P value 0.0963
Are variances significantly different? No

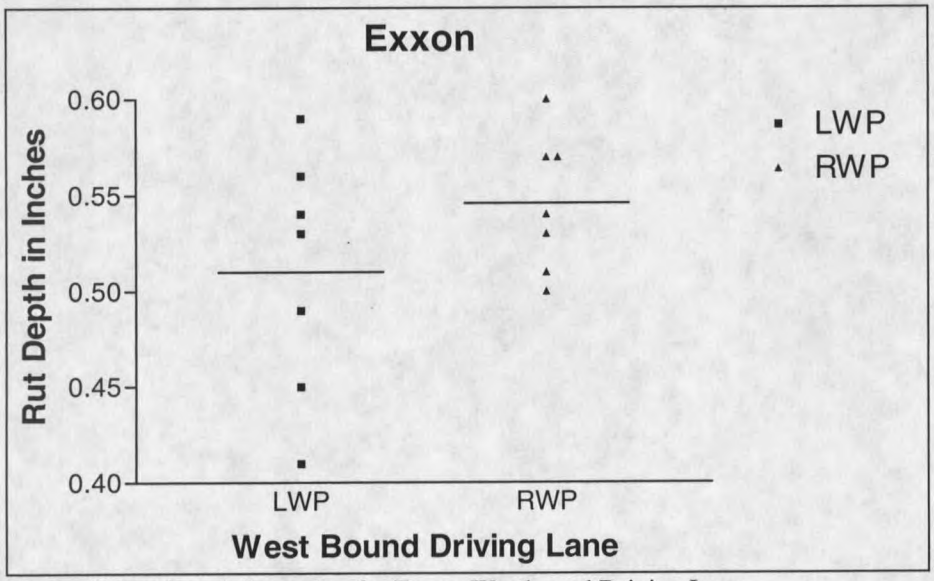


Figure 19. Rut Depth Scattering for Exxon Westbound Driving Lane.

Table 36. Exxon Westbound Passing Lane

Station #	LWP	RWP
	Rut Depth in Inches	
11.	0.08	0.09
12.	0.08	0.13
13.	0.12	0.20
14.	0.09	0.10
15.	0.14	0.15
16.	0.09	0.10
17.	0.15	0.13

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.2605
Are means significantly different? ($P < 0.05$) No
One- or two-tailed P value? Two-tailed
t, df t=1.181 df=12
How big is the difference?
Mean ± SEM of LWP. 0.1071 ± 0.01107 N=7
Mean ± SEM of RWP. 0.1286 ± 0.01438 N=7
Difference between means -0.02143 ± 0.01815
95% confidence interval -0.01811 to 0.06097
R squared 0.1041
F test to compare variances
F,DFn, Dfd 1.689, 6, 6
P value 0.2701
Are variances significantly different? No

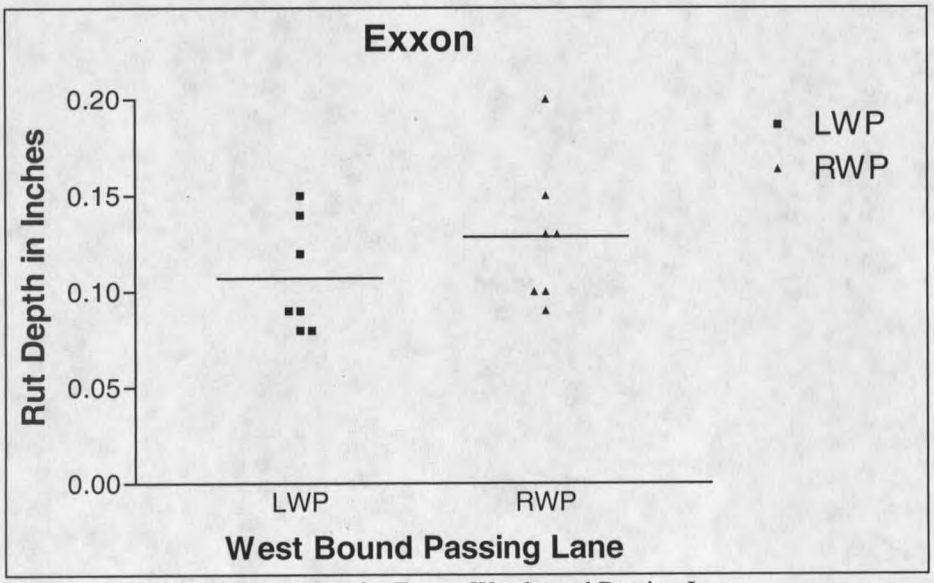


Figure 20. Rut Depth Scattering for Exxon Westbound Passing Lane.

Table 37. Kraton Eastbound Driving Lane

Station #	LWP	RWP
	Rut Depth in Inches	
43	0.12	0.13
44	0.20	0.19
45	0.18	0.19
46	0.21	0.19
47	0.16	0.16
48	0.19	0.13
49	0.17	0.18
50	0.18	0.15
51	0.15	0.18
52	0.20	0.21

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.6860
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=0.4108 df=18

How big is the difference?
Mean ± SEM of LWP. 0.1760 ± 0.008589 N=10
Mean ± SEM of RWP. 0.1710 ± 0.008622 N=10
Difference between means 0.005000 ± 0.01217
95% confidence interval -0.03057 to 0.02057
R squared 0.009290F test to compare variances
F,DFn, Dfd 1.008, 9, 9
P value 0.4956
Are variances significantly different? No

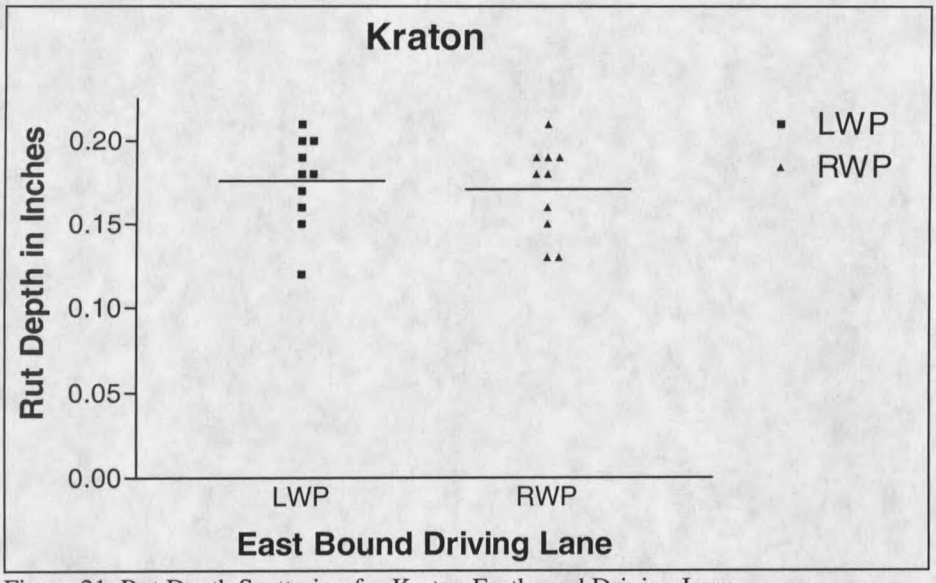


Figure 21. Rut Depth Scattering for Kraton Eastbound Driving Lane.

Table 38. Kraton Eastbound Passing Lane

Station #	LWP	RWP
	Rut Depth in Inches	
43	0.07	0.04
44	0.08	0.08
45	0.07	0.04
46	0.06	0.04
47	0.09	0.02
48	0.07	0.04
49	0.03	0.06
50	0.10	0.07
51	0.07	0.09
52	0.08	0.06

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.0626
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=1.985 df=18
How big is the difference?
Mean ± SEM of LWP. 0.0720 ± 0.005925 N=10
Mean ± SEM of RWP. 0.0540 ± 0.006864 N=10
Difference between means 0.0180 ± 0.009068
95% confidence interval -0.03705 to 0.001051
R squared 0.1796
F test to compare variances
F,DFn, Dfd 1.342, 9, 9
P value 0.3343
Are variances significantly different? No

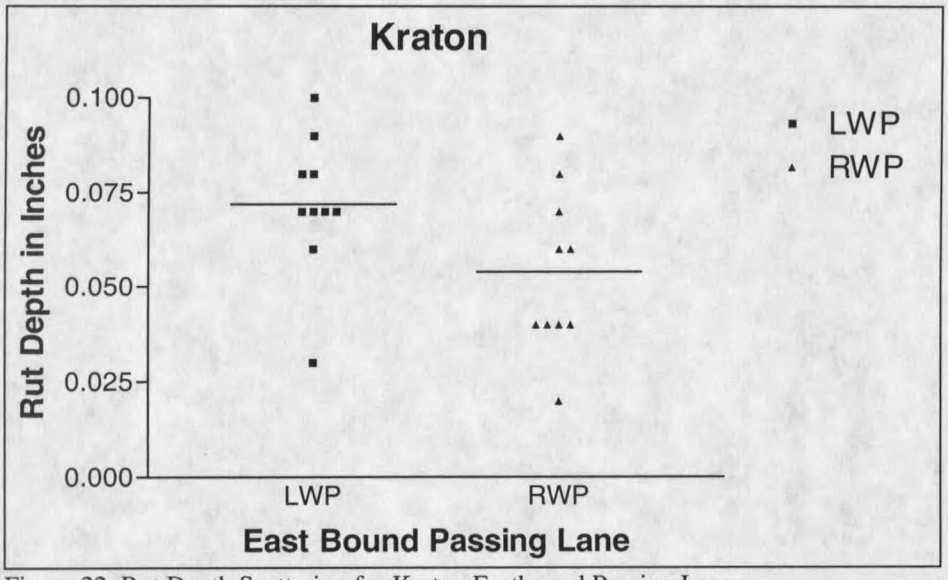


Figure 22. Rut Depth Scattering for Kraton Eastbound Passing Lane.

Table 39. Kraton Westbound Driving Lane

Station #	LWP	RWP
	Rut Depth in Inches	
18	0.18	0.20
19	0.17	0.21
20	0.11	0.18
21	0.17	0.13
22	0.11	0.12
23	0.09	0.18
24	0.11	0.10
25	0.10	0.10
26	0.08	0.09

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.3104
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=1.048 df=16

How big is the difference?
Mean ± SEM of LWP. 0.1244 ± 0.01271 N=9
Mean ± SEM of RWP. 0.1456 ± 0.01564 N=9
Difference between means -0.02111 ± 0.02015
95% confidence interval -0.02161 to 0.06384
R squared 0.06418

F test to compare variances

F,DFn, Dfd 1.516, 8, 8
P value 0.2848
Are variances significantly different? No

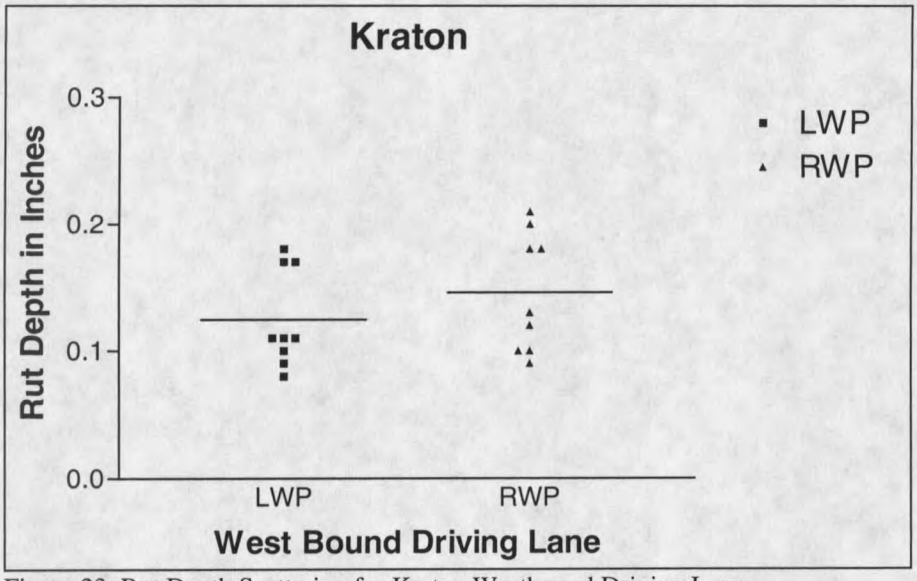


Figure 23. Rut Depth Scattering for Kraton Westbound Driving Lane.

Table 40. Kraton Westbound Passing Lane

Station #	LWP	RWP
	Rut Depth in Inches	
18	0.09	0.16
19	0.07	0.10
20	0.06	0.13
21	0.10	0.08
22	0.04	0.03
23	0.07	0.13
24	0.05	0.09
25	0.06	0.08
26	0.07	0.07

Left Wheel Path vs. Right Wheel Path (Rutting)

Unpaired t test
P value 0.0607
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=2.018 df=16

How big is the difference?
Mean ± SEM of LWP. 0.06778 ± 0.006186 N=9
Mean ± SEM of RWP. 0.09667 ± 0.01291 N=9
Difference between means -0.02889 ± 0.01432
95% confidence interval -0.001460 to 0.05924

R squared 0.2029

F test to compare variances
F,DFn, Dfd 4.355, 8, 8
P value 0.0263
Are variances significantly different? Yes

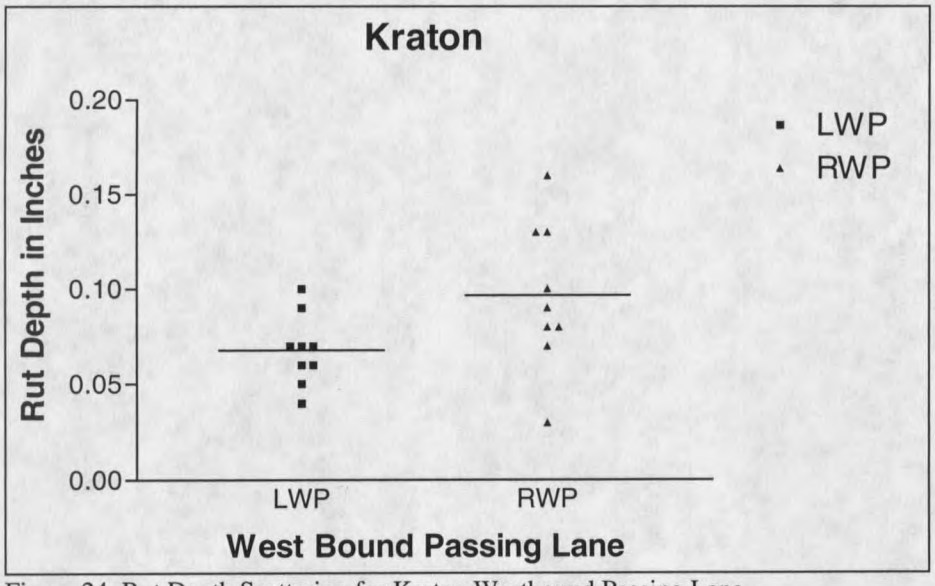


Figure 24. Rut Depth Scattering for Kraton Westbound Passing Lane.

Table 41. Eastbound Driving Lane Rut Depth in Inches:

Eastbound Driving Lane	Polybilt	Exxon	Kraton
LWP	0.21	0.25	0.12
	0.17	0.49	0.20
	0.19	0.50	0.18
	0.20	0.54	0.21
	0.17	0.51	0.16
	0.17	0.68	0.19
	0.10	0.64	0.17
	0.19		0.18
	0.10		0.15
			0.20
RWP	0.18	0.30	0.13
	0.17	0.49	0.19
	0.17	0.56	0.19
	0.19	0.61	0.19
	0.30	0.51	0.16
	0.16	0.63	0.13
	0.15	0.63	0.18
	0.17		0.15
	0.12		0.18

Polybilt vs. Kraton (Rutting)

Unpaired t test
P value 0.9512
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=0.06164 df=36

How big is the difference?
Mean ± SEM of Polybilt. 0.1728 ± 0.01044 N=18
Mean ± SEM of Kraton. 0.1735 ± 0.005950 N=20
Difference between means -0.0007222 ± 0.01172
95% confidence interval -0.02305 to 0.02450
R squared 0.0001055

F test to compare variances
F,DFn, Dfd 2.771, 17, 19
P value 0.0173
Are variances significantly different? Yes

Polybilt vs. Exxon (Rutting)

Unpaired t test
P value P<0.0001
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=11.24 df=30

How big is the difference?
Mean ± SEM of Polybilt. 0.1728 ± 0.01044 N=18
Mean ± SEM of Exxon. 0.5243 ± 0.03296 N=14
Difference between means -0.3515 ± 0.03128
95% confidence interval 0.2876 to 0.4154
R squared 0.8081

F test to compare variances
F,DFn, Dfd 7.751, 13, 17
P value P<0.0001
Are variances significantly different? Yes

Kraton vs. Exxon (Rutting)

Unpaired t test
P value P<0.0001
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=12.39 df=32
How big is the difference?
Mean ± SEM of Exxon. 0.5243 ± 0.03296 N=14
Mean ± SEM of Kraton. 0.1735 ± 0.005950 N=20
Difference between means 0.3508 ± 0.02831
95% confidence interval -0.4085 to -0.2931
R squared 0.8275

F test to compare variances
F,DFn, Dfd 21.48, 13, 19
P value P<0.0001
Are variances significantly different? Yes

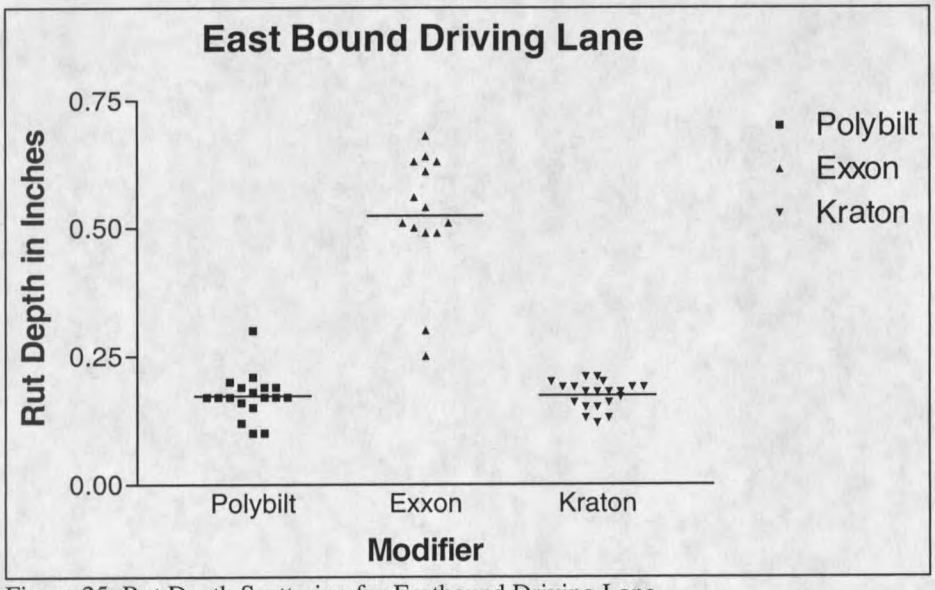


Figure 25. Rut Depth Scattering for Eastbound Driving Lane.

Table 42. Eastbound Passing Lane Rut Depth in Inches:

Eastbound Passing Lane	Polybilt	Exxon	Kraton
LWP	0.11	0.06	0.07
	0.05	0.09	0.08
	0.07	0.09	0.06
	0.08	0.12	0.06
	0.07	0.11	0.09
	0.08	0.13	0.07
	0.08	0.12	0.03
	0.11		0.10
	0.07		0.08
			0.08
RWP	0.08	0.06	0.04
	0.05	0.05	0.08
	0.08	0.09	0.04
	0.08	0.09	0.04
	0.08	0.08	0.02
	0.07	0.06	0.04
	0.09	0.12	0.06
	0.12		0.07
	0.09		0.09
			0.06

Polybilt vs. Kraton (Rutting)

Unpaired t test
P value 0.0097
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=2.731 df=36

How big is the difference?
Mean ± SEM of Polybilt. 0.08111 ± 0.004345 N=18
Mean ± SEM of Kraton. 0.0630 ± 0.004926 N=20
Difference between means 0.01811 ± 0.006631
95% confidence interval -0.03157 to -0.004653
R squared 0.1716

F test to compare variances
F,DFn, Dfd 1.428, 19, 17
P value 0.2325
Are variances significantly different? No

Polybilt vs. Exxon (Rutting)

Unpaired t test
P value 0.2356
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed

t, df t=1.210 df=30

How big is the difference?
Mean ± SEM of Polybilt. 0.08111 ± 0.004345 N=18
Mean ± SEM of Exxon. 0.09071 ± 0.007068 N=14
Difference between means -0.009603 ± 0.007934
95% confidence interval -0.006598 to 0.02580
R squared 0.04656

F test to compare variances
F,DFn, Dfd 2.058, 13, 17
P value 0.0818
Are variances significantly different? No

Kraton vs. Exxon (Rutting)

Unpaired t test
P value 0.0022
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=3.325 df=32
How big is the difference?
Mean ± SEM of Exxon. 0.09071 ± 0.007068 N=14
Mean ± SEM of Kraton. 0.0630 ± 0.004926 N=20
Difference between means 0.02771 ± 0.008336
95% confidence interval -0.04470 to -0.01073
R squared 0.2567
F test to compare variances
F,DFn, Dfd 1.441, 13, 19
P value 0.2281
Are variances significantly different? No

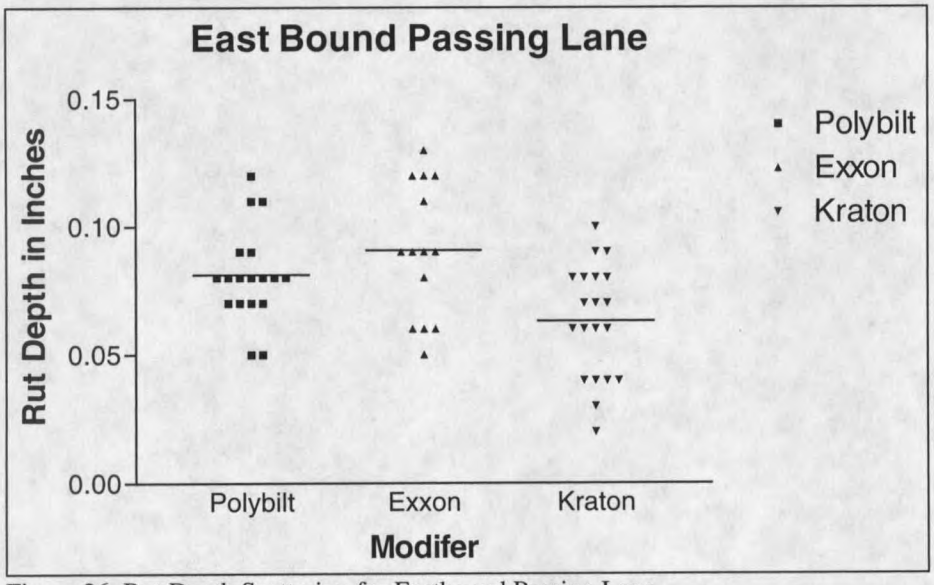


Figure 26. Rut Depth Scattering for Eastbound Passing Lane.

Table 43. Westbound Driving Lane Rut Depth in Inches:

Westbound Driving Lane	Polybilt	Exxon	Kraton
LWP	0.19	0.53	0.18
	0.22	0.59	0.17
	0.12	0.56	0.11
	0.20	0.54	0.17
	0.14	0.49	0.11
	0.12	0.45	0.09
	0.09	0.41	0.11
	0.12		0.10
	0.12		0.08
	0.13		
RWP	0.24	0.57	0.20
	0.20	0.60	0.21
	0.24	0.57	0.18
	0.17	0.50	0.13
	0.20	0.53	0.12
	0.14	0.51	0.18
	0.16	0.54	0.10
	0.14		0.10
	0.17		0.09
	0.15		

Polybilt vs. Kraton (Rutting)

Unpaired t test
P value 0.0531
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=2.000 df=36

How big is the difference?
Mean ± SEM of Polybilt. 0.1630 ± 0.009682 N=20
Mean ± SEM of Kraton. 0.1350 ± 0.01011 N=18
Difference between means 0.02800 ± 0.01400
95% confidence interval -0.05642 to 0.0004166
R squared 0.09997

F test to compare variances
F,DFn, Dfd 1.020, 19, 17
P value 0.4871
Are variances significantly different? No

Polybilt vs. Exxon (Rutting)

Unpaired t test
P value P<0.0001
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=22.06 df=32

How big is the difference?
Mean ± SEM of Polybilt. 0.1630 ± 0.009682 N=20
Mean ± SEM of Exxon. 0.5279 ± 0.01415 N=14
Difference between means -0.3649 ± 0.01654
95% confidence interval 0.3312 to 0.3986
R squared 0.9383

F test to compare variances
F,DFn, Dfd 1.495, 13, 19
P value 0.2070
Are variances significantly different? No

Kraton vs. Exxon (Rutting)

Unpaired t test
P value P<0.0001
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=23.21 df=30
How big is the difference?
Mean ± SEM of Exxon. 0.5279 ± 0.01415 N=14
Mean ± SEM of Kraton. 0.1350 ± 0.01011 N=18
Difference between means 0.3929 ± 0.01693
95% confidence interval -0.4274 to -0.3583
R squared 0.9472

F test to compare variances
F,DFn, Dfd 1.525, 13, 17
P value 0.2050
Are variances significantly different? No

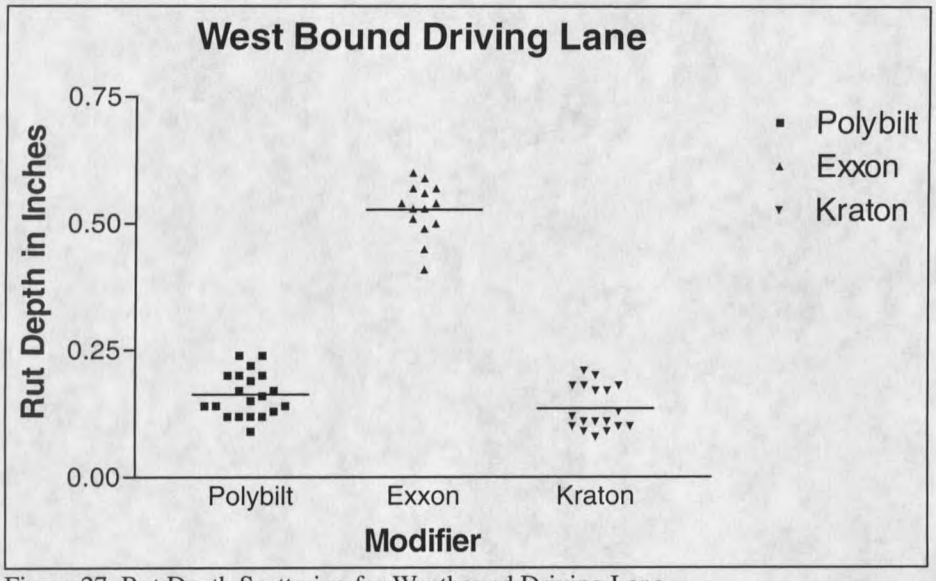


Figure 27. Rut Depth Scattering for Westbound Driving Lane.

Table 44. Westbound Passing Lane Rut Depth in Inches:

Westbound Passing Lane	Polybilt	Exxon	Kraton
LWP	0.06	0.08	0.09
	0.09	0.08	0.07
	0.06	0.12	0.06
	0.07	0.09	0.10
	0.03	0.14	0.04
	0.05	0.09	0.07
	0.07	0.15	0.05
	0.04		0.06
	0.07		0.07
	0.08		
RWP	0.07	0.09	0.16
	0.07	0.13	0.10
	0.08	0.20	0.13
	0.09	0.10	0.08
	0.03	0.15	0.03
	0.08	0.10	0.13
	0.14	0.13	0.09
	0.01		0.08
	0.07		0.07
	0.15		

Polybilt vs. Kraton (Rutting)

Unpaired t test
P value 0.2815
Are means significantly different? (P < 0.05) No
One- or two-tailed P value? Two-tailed
t, df t=1.093 df=36

How big is the difference?
Mean ± SEM of Polybilt. 0.0705 ± 0.007380 N=20
Mean ± SEM of Kraton. 0.08222 ± 0.007778 N=18
Difference between means -0.01172 ± 0.01072
95% confidence interval -0.01004 to 0.03348
R squared 0.03214

F test to compare variances
F,DFn, Dfd 1.000, 19, 17
P value 0.5033
Are variances significantly different? No

Polybilt vs. Exxon (Rutting)

Unpaired t test
P value 0.0003
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=4.044 df=32

How big is the difference?
Mean ± SEM of Polybilt. 0.0705 ± 0.007380 N=20
Mean ± SEM of Exxon. 0.1179 ± 0.009209 N=14
Difference between means -0.04736 ± 0.01171
95% confidence interval 0.02350 to 0.07122
R squared 0.3383

F test to compare variances
F,DFn, Dfd 1.090, 13, 19
P value 0.4210
Are variances significantly different? No

Kraton vs. Exxon (Rutting)

Unpaired t test
P value 0.0058
Are means significantly different? (P < 0.05) Yes
One- or two-tailed P value? Two-tailed
t, df t=2.973 df=30

How big is the difference?
Mean ± SEM of Exxon. 0.1179 ± 0.009209 N=14
Mean ± SEM of Kraton. 0.08222 ± 0.007778 N=18
Difference between means 0.03563 ± 0.01199
95% confidence interval -0.06011 to -0.01116
R squared 0.2275

F test to compare variances
F,DFn, Dfd 1.090, 13, 17
P value 0.4258
Are variances significantly different? No

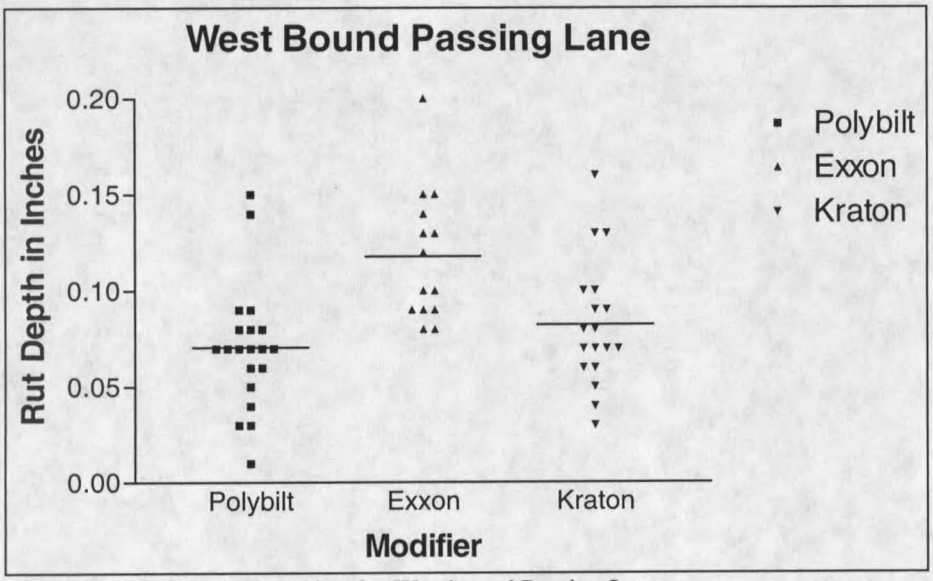


Figure 28. Rut Depth Scattering for Westbound Passing Lane.

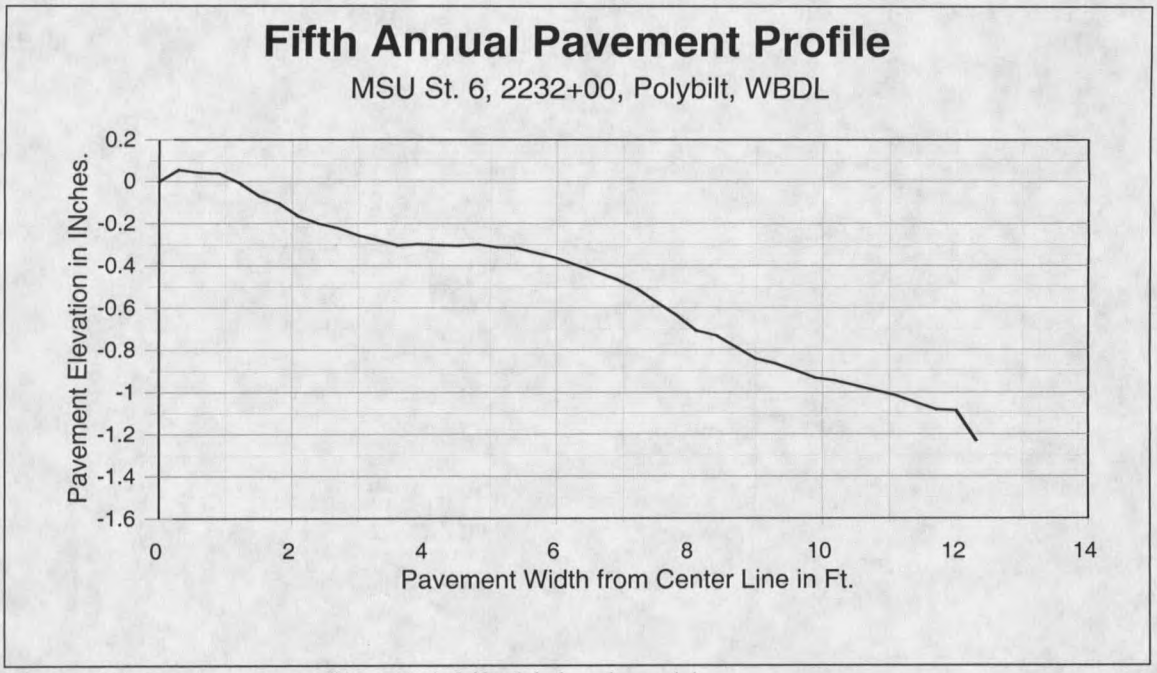


Figure 29. Pavement profile – Polybilt driving lane (a).

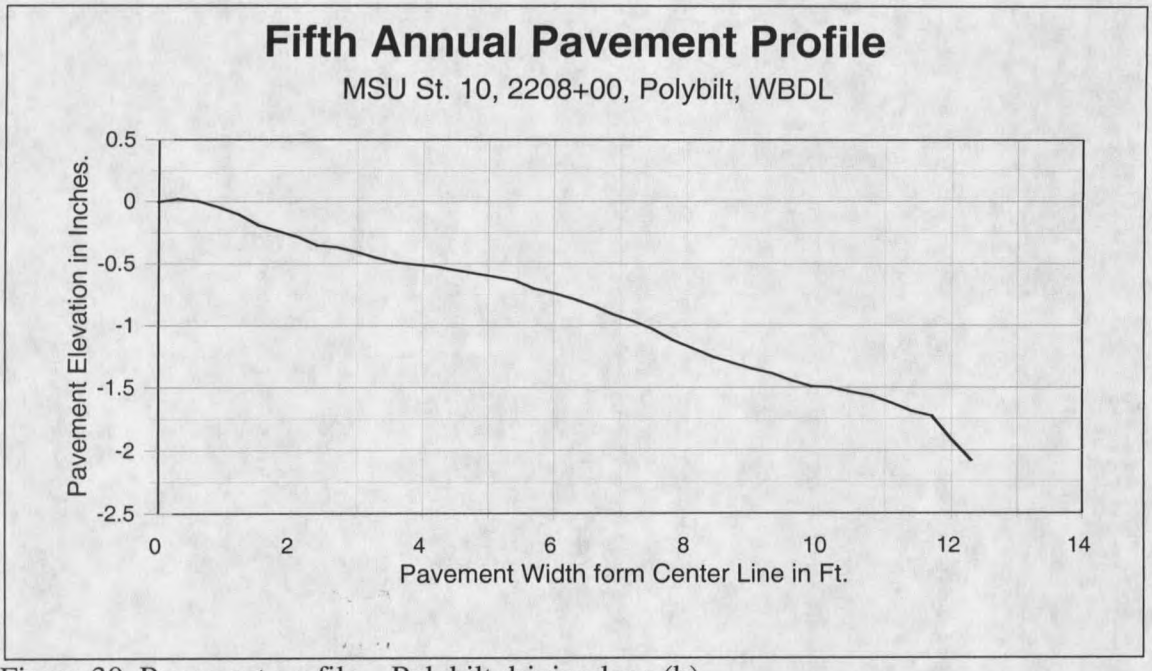


Figure 30. Pavement profile – Polybilt driving lane (b).

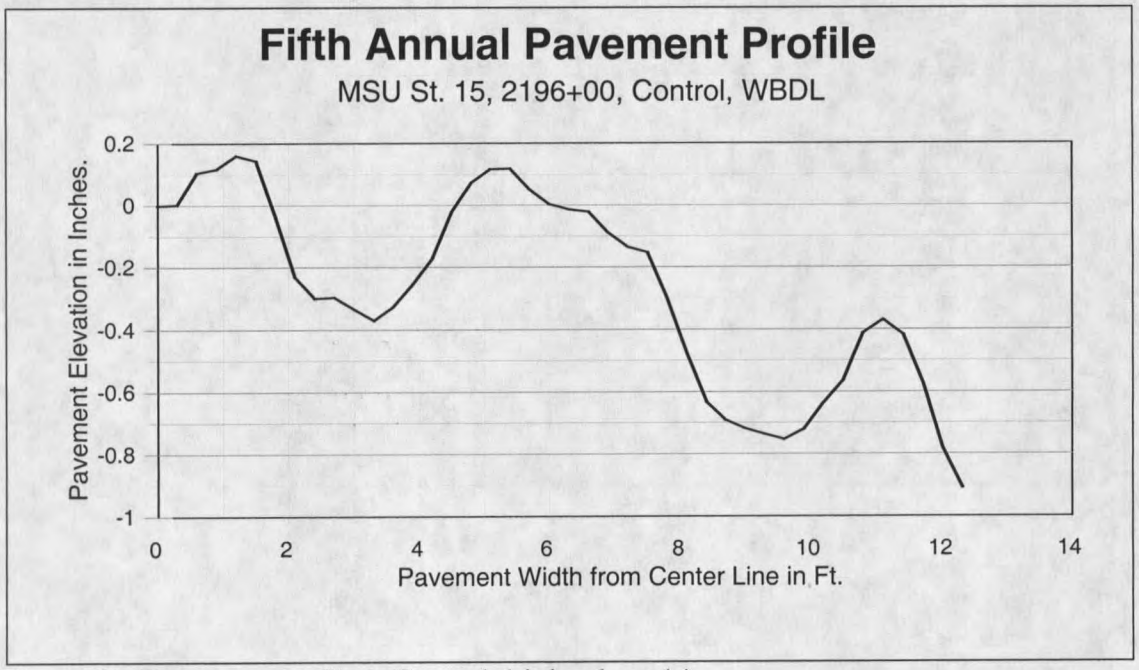


Figure 31. Pavement profile – Control driving lane (a)

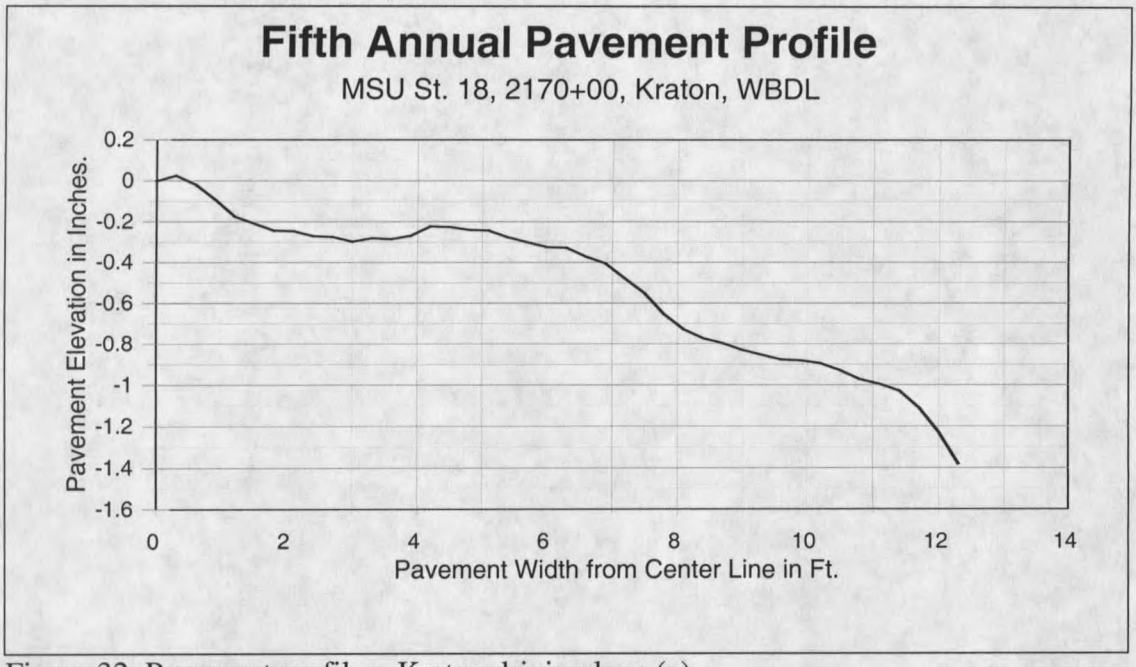


Figure 32. Pavement profile – Kraton driving lane (a).

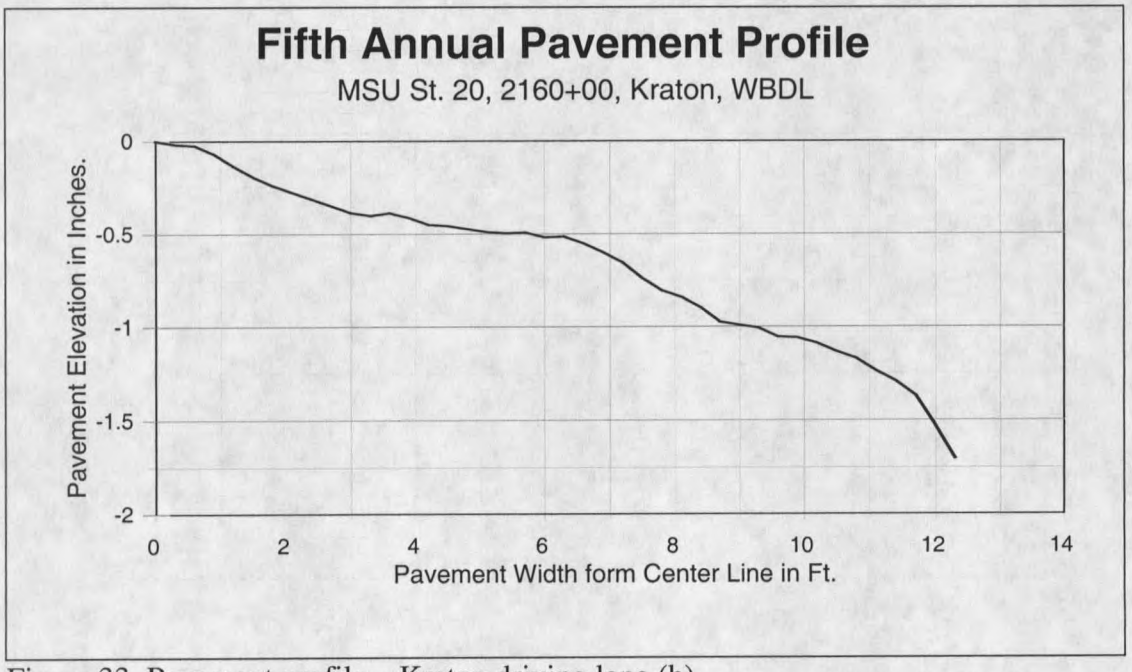


Figure 33. Pavement profile – Kraton driving lane (b).

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