FIELD TEST OF POLYMER MODIFIED ASPHALT CONCRETE:
MURPHY ROAD TO LAVA BUTTE SECTION

The Dalles - California Highway
Deschutes County, Oregon

Final Report
FHWA Experimental Project No. 3

by

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16. Abstract

Polymer additives to asphalt materials are claimed to have a high potential for improving long-term pavement performance through their ability to enhance the properties of the asphalt binder and of the resulting asphalt concrete mix. In 1989, the Oregon Department of Transportation (ODOT) initiated a research study to evaluate the field performance of three polymer modified asphalts. The polymer modified asphalts evaluated included: 1) Styrelf[R] - a polymerized binder with a thermoplastic styrene-butadiene block copolymer (SB), 2) AC-20R - a polymerized binder with a thermosetting styrene-butadiene latex anionic polymer (SBR), and 3) CA(P)-1 - a polymerized binder with a thermoplastic ethylene-vinyl-acetate random copolymer. The three polymer modified asphalt concretes were constructed in five separate test sections adjacent to each other. In addition to the use of polymer modified asphalt, two control sections with a conventional AC-20 asphalt were constructed for comparison of performance.

This final report presents a comprehensive evaluation of the materials used on this project and their performance up to June 1993. Field survey results indicate that the primary surface distress on all sections is transverse cracking with varying spacing. This transverse cracking very likely resulted from reflective cracking from the base course and the existing pavement. The level of severity ranged from low to medium. The AC-20 (control) sections showed a more noticeable loss of aggregate than polymer modified AC sections. In general, both the AC-20 (control) sections and polymer modified (test) sections have been performing well. There is no clear distinction as to which section is superior. All sections of pavement have carried over 1.5 million equivalent axle loadings since the construction.

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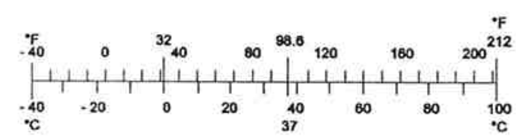
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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FIELD TEST OF POLYMER MODIFIED ASPHALT CONCRETE MURPHY ROAD TO LAVA BUTTE SECTION

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1.0 INTRODUCTION

The use of additives to improve the performance of asphalt cement and asphalt concrete mixtures has increased in recent years (*Carpenter and VanDam, 1987*). Polymer additives to asphalt materials are being advocated as having a high potential for improving long-term pavement performance through their ability to enhance the properties of the asphalt binder and of the resulting asphalt concrete mix (*Rogge, et al, 1989*). Advantages of polymer additives to asphalt include improved adhesion and cohesion, temperature susceptibility, modulus, resistance to fatigue, resistance to rutting, and durability (*Terrel and Walter, 1986*).

In 1989, the Oregon Department of Transportation (ODOT) initiated a research study to evaluate the field performance of three polymer modified asphalts (*Miller and Scholl, 1990*). The polymer modified asphalts evaluated included:

1) Styrelf[R] - A polymerized binder which met Elf Aquitane's PAC-20 specifications. The additive was a thermoplastic styrene-butadiene block copolymer (SB). Penetration graded asphalt from Montana was used as a base stock, and the polymer content was 3% of the binder weight. It was blended by the "Styrelf" process in Elf Aquitane's Grand Junction, Colorado plant.

2) AC-20R - A polymerized binder which met Asphalt Supply and Service's AC-20R specifications. The additive was a thermosetting styrene-butadiene latex anionic polymer (SBR). The base stock was penetration graded asphalt from Montana, and the polymer content was 2% of the binder volume. It was blended in Asphalt Supply and Service's Vancouver, Washington plant.

3) CA(P)-1 - A polymerized binder which met Chevron's CA(P)-1 specifications. The additive was Elvax 150W, a thermoplastic ethylene-vinyl-acetate random copolymer produced by the DuPont Company. The polymer content was 3% of the binder weight. The binder was blended in Chevron USA's Willbridge, Oregon refinery.

In addition to the use of polymer modified asphalt, two control sections with a conventional AC-20 asphalt were also constructed, between the polymer modified asphalt sections, for comparison of performance.

This final report presents a comprehensive evaluation of the materials used on this project and their performance up to June 1993.

2.0 PROJECT DESCRIPTION

This chapter presents a description of project location, project layout, condition of the existing pavement, and traffic information.

2.1 PROJECT LOCATION

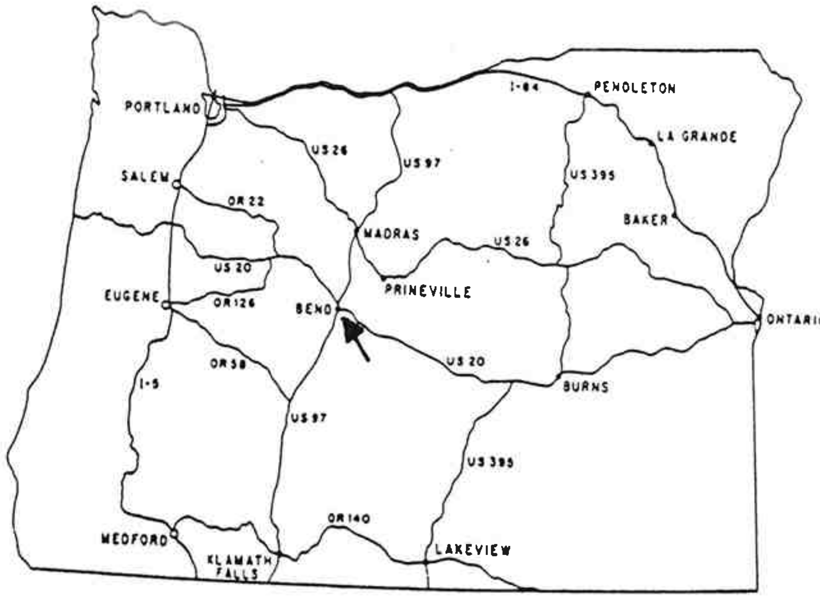
This project is located on The Dalles-California Highway (U.S. Route 97 or Oregon Highway 4) south of the city of Bend, Oregon. The Dalles-California Highway is the main north-south route across the central Oregon plateau. The project is divided into two units: the north unit and the south unit. The north unit begins at mile point (M.P.) 141.5 and ends at M.P. 142.6. The south unit starts at M.P. 146.5 and ends at M.P. 150.8. Figure 2.1 shows the project location.

The project is in a severe environment of cold winters, hot summers, frequent freeze-thaw cycles, snows, and dramatic daily temperature swings. In the winter, the average daily low temperature is about 21°F in January. In the summer, the average daily high temperature is about 82°F in July. Temperatures exceed 90°F about 11 days a year. Annual freeze-thaw cycles are over 150. This area also receives an annual average of 12 inches of rain and 39 inches of snow. The daily temperature variations are typically in a range of 30°F to 40°F. In August, a daily temperature swing of 56°F has been recorded.

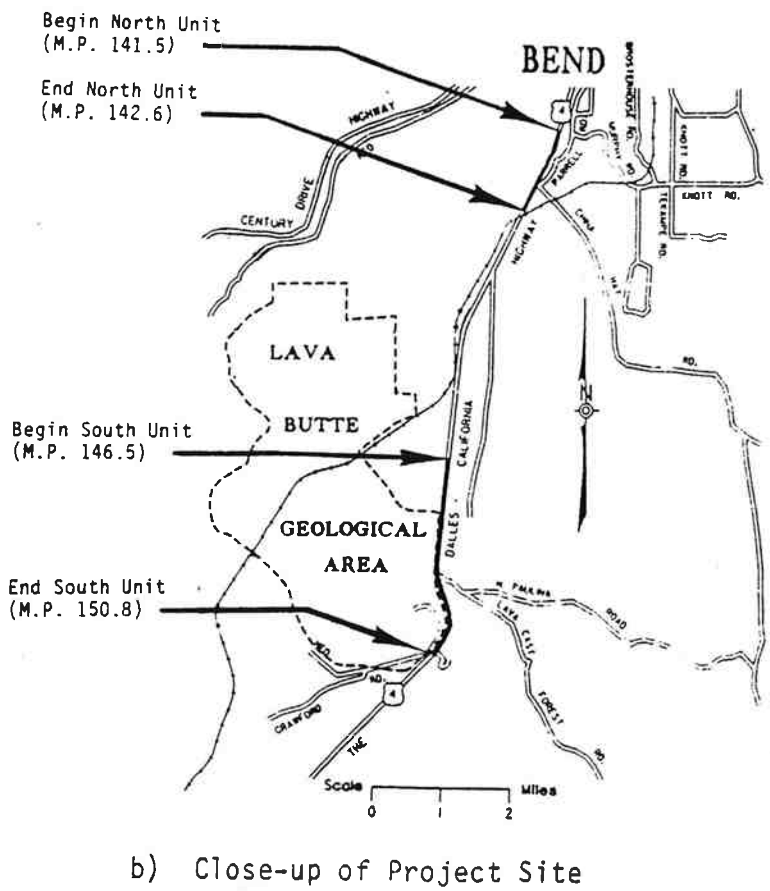
2.2 PROJECT LAYOUT

The project is divided into two units as described earlier. The north unit was paved with Styrelf and named as Section 1. The south unit consists of six sections. Each section varies in length. Figure 2.2 shows the actual layout of each section. Sections 2 and 5 were paved with AC-20 mixture and are the control sections. Section 3 was paved with Styrelf. Sections 4 and 7 were paved with AC-20R mixture. Section 6 was paved with CA(P)-1 mixture. Within each section, there is a 250 ft. long segment used for performance evaluation of the materials.

Cross sections of each evaluation segment are shown in Figure 2.3. The wearing course is 2 inches of Oregon Department of Transportation (ODOT) Class F open-graded asphalt concrete mixture with or without polymer additives. The base course is 2 inches of ODOT Class B dense-graded asphalt concrete mixture with conventional AR-4000 paving grade asphalt. Both mixes have a maximum stone size of ¾ " as shown in Table 2.1. Typical tests on aggregate material were run and the results are shown in Table 2.2. All results are within the limits of the specifications.



a) Project Location



b) Close-up of Project Site

Figure 2.1 Vicinity Map

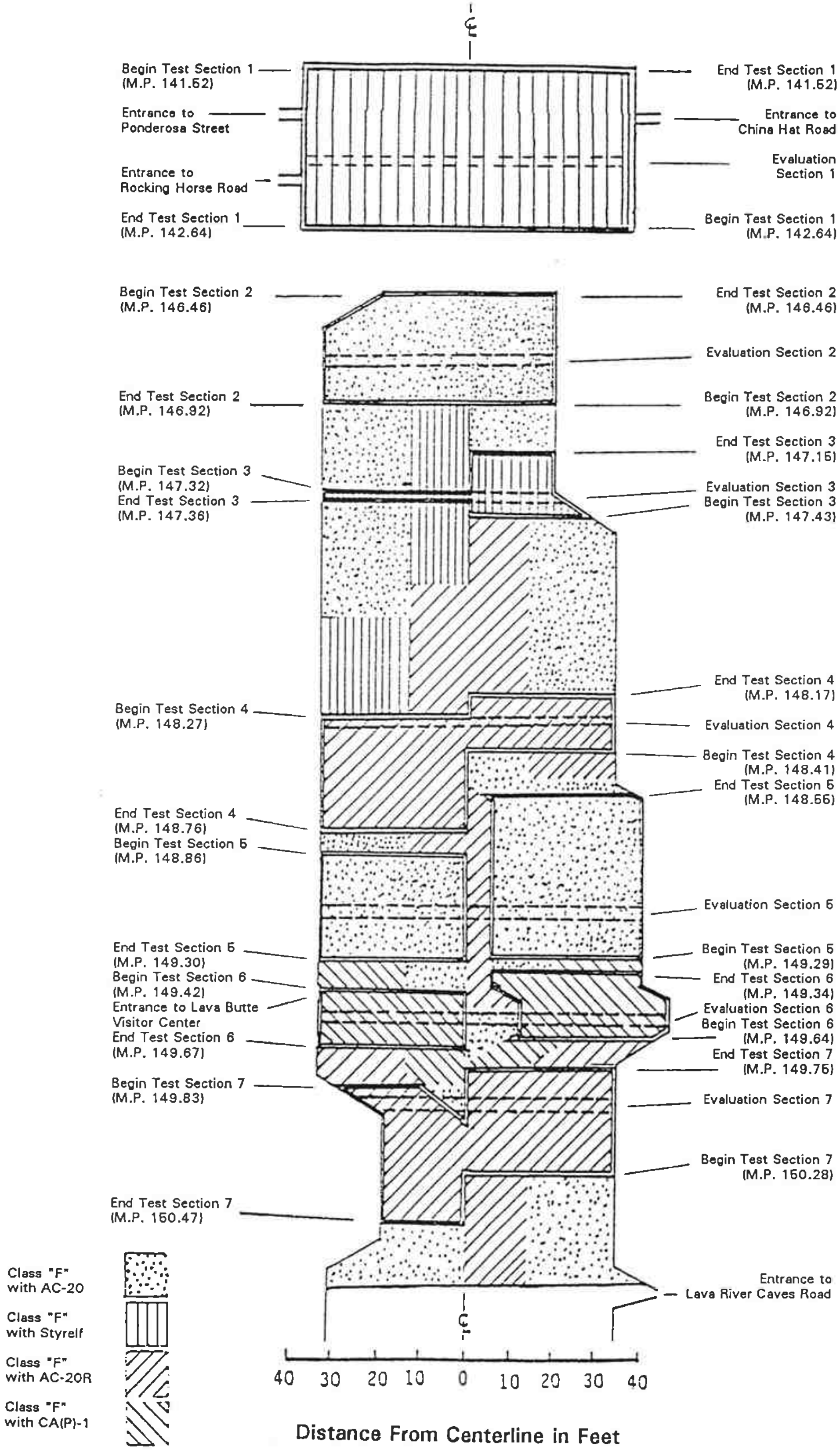


Figure 2.2 Project Layout

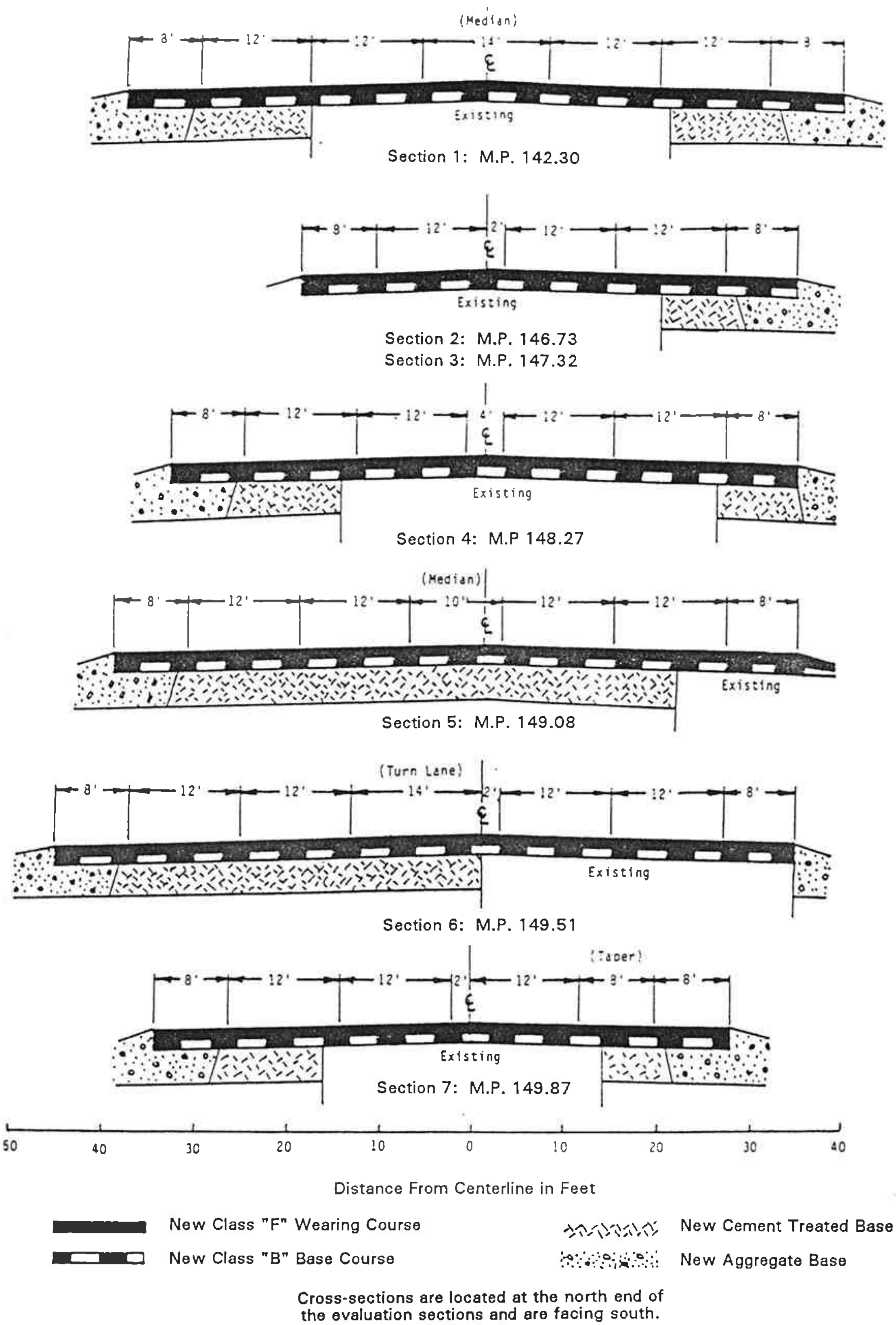


Figure 2.3 Cross Sections

Table 2.1: Gradation of Mix

Sieve Size	F-Mix (% passing)	B-Mix (% passing)
1"	99-100	99-100
¾"	95-100	92-100
½"	66-80	75-91
¼"	19-30	50-70
No. 10	5-13	21-41
No. 40	----	6-24
No. 200	1.6-5.6	2-7

Table 2.2: Aggregate Test Results

Test	Method	Coarse Aggregate		Fine Aggregate	
		Results	Specifications	Results	Specifications
Bulk specific gravity	AASHTO T85/T84	2.73	-	2.62	-
Absorption (%)	AASHTO T85/84	1.75	-	3.33	-
Soundness (%)	ODOT TM206	2.8	12 (max)	3.4	12 (max)
Degradation, Sediment Height (in)	ODOT TM208	1.1	3 (max)	0.9	4 (max)
Degradation, passing #20 Screen (%)	ODOT TM208	15.3	30 (max)	11.3	30 (max)
Fracture, two fractured faces (%)	ODOT TM213	100	90 (min)	-	-
Fracture, one fractured face (%)	ODOT TM213	-	-	100	75 (min)
Abrasion, wear (%)	AASHTO T96	13.5	30 (max)	-	-
Friable particles (%)	AASHTO T112	0.3	1.0 (max)	0.4	1.5 (max)
Light-weight pieces (%)	AASHTO T113	0.0	1.0 (max)	0.1	1.0 (max)
Wood particles (%)	ODOT TM225	0.0	0.1 (max)	0.0	0.1 (max)
Elongated pieces (%)	ODOT TM229	3	10 (max)	-	-

The existing pavement has two 12-foot travel lanes and consists of varying thickness' of asphalt concrete (AC), oil mat, and a cinder base. To accommodate traffic needs, some locations were widened to four travel lanes. The widened sections were constructed with 14 inches of cement treated base and then paved with 2 inches of AC base course and 2 inches of AC wearing course with or without polymer additives. The subgrade is powdered pumice soil, basalt boulders, and volcanic cinders. Occasionally, the roadway cuts through ledges of basalt (*Miller and Scholl, 1990*).

2.3 CONDITION OF THE EXISTING PAVEMENT

Before construction of the overlays, an extensive survey was conducted to evaluate the type and extent of distress of the existing pavement. Within each designated test section, a 250-ft long segment that represented conditions of the entire section was selected. For each 250-ft long segment, distress type and severity, including a map of all cracks, was recorded. Typical crack maps are provided in Appendix A. General conditions of the existing pavement are shown in Appendix B, Figure B.1. All sections of the existing pavement had transverse thermal cracking at a frequency of about 130 cracks per mile. Sections 2, 3, 4, 5, and 6 had block cracking and alligator cracking in the wheelpaths; Sections 1 and 7 had little of this type of distress (Miller and Scholl, 1990). In general, there was considerable alligator and thermal transverse cracking within the project limits. The overall condition rating for the existing pavement was poor.

2.4 TRAFFIC

The traffic data provided by the Transportation Research Section of ODOT indicates that in 1988 the north unit had an average daily traffic (ADT) of 16,000, of which 9.5% was truck traffic. The south unit had an ADT of 8,000, of which 16.4% was truck traffic. In 1991, the ADT on the north unit increased considerably to 26,000 and the percent of truck traffic decreased to 6.4%. On the south unit, both ADT and the percent of truck had decreased to 7,600 and 15.7%, respectively. To calculate the average annual 18-kip equivalent axle loads (EAL), the traffic data from 1988 and 1991 were averaged. For the north unit, the average annual EAL was about 333,000. For the south unit, the average annual EAL was approximately 314,000. It may be noticed that although the south unit had considerably less ADT than the north unit, the percentage of the truck loadings was much higher than that of the north unit, therefore, the average annual EAL was nearly the same. In the last few years (since the construction of the overlay), the pavements have carried over 1.5 million EALs.

3.0 PRE-CONSTRUCTION ENGINEERING

This chapter describes pre-construction engineering activities, including discussion of binder properties and mix design.

3.1 BINDER PROPERTIES

Laboratory tests on both original and residue asphalt (after Rolling Thin Film Oven) were performed in 1989 to measure binder consistency and ductile and resilient properties. The tests included penetration, viscosity, ring and ball softening point, Fraass point, ductility and elastic recovery, force ductility, and toughness and tenacity.

Table 3.1 presents a summary of the test results on both original and residue asphalt while the details are provided in Appendix C. The consistency test followed American Society for Testing and Materials (ASTM) standard testing procedures. The ductility test was used to measure "extension" properties of the binders and was also used in this project to determine elastic recovery properties of the binders. Force ductility is a non-standard test and is a modification of the conventional ductility test. The test has been described as a means to measure tensile load-deformation characteristics of asphalt and asphalt-rubber binders (*Salam, 1971; Way, 1979*). The toughness and tenacity test was also used to measure tensile strength of the binders.

3.1.1 CONSISTENCY TESTS

Figure 3.1 shows the consistency test results for both original and residue asphalt on a single diagram, which has been used by ODOT as a means of assessing temperature susceptibility of a binder. The binder with a steeper viscosity-temperature slope would be more temperature susceptible than a binder with a flatter viscosity-temperature slope. In Figure 3.1, it is obvious that the AC-20 asphalt binder has a steeper slope than the polymer modified binders. The same trend is true for residue asphalt as shown in the figure.

Temperature susceptibility of a binder may also be evaluated in terms of Penetration Index (PI) and Penetration Viscosity Number (PVN). PI is calculated by the following equation:

$$PI = \frac{30}{1 + 90 \times PTS} - 10 \qquad (3\text{-}1)$$

where PTS is Penetration/Temperature Susceptibility and is expressed as follows:

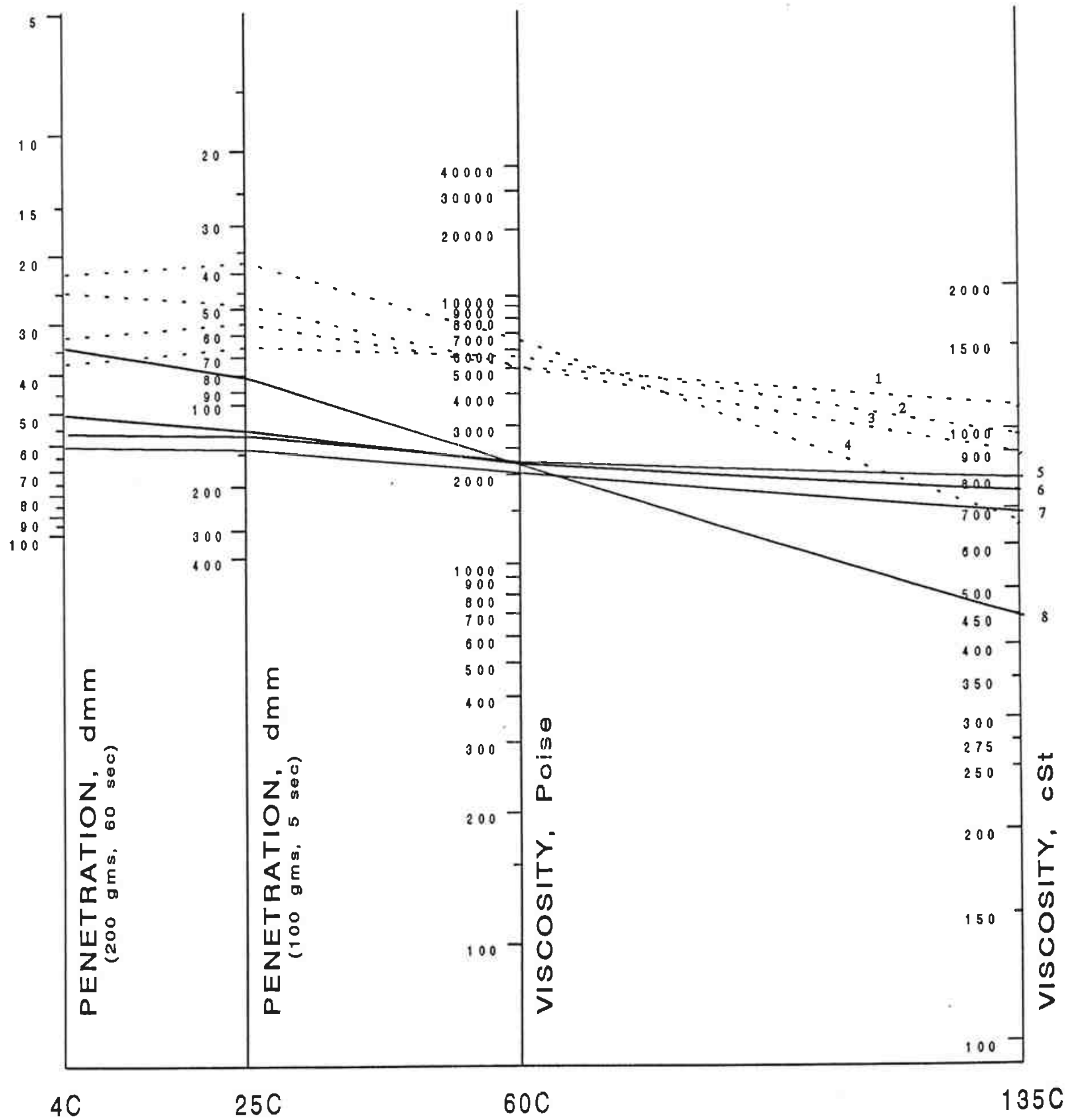
$$PTS = \frac{\log 800 - \log Pen_{77}}{T_{RB} - T_{pen77}} \qquad (3\text{-}2)$$

Pen_{77} = Penetration at 77°F (25°C), 100g, 5s (dmm)
T_{RB} = R&B softening point (°F)
T_{pen77} = 77°F

Table 3.1: Consistency Test Results

Test	AC-20	Styrelf	AC-20R	CA(P)-1
a) Original				
Pen @ 39.2°F, 200g, 60s (dmm)	30	50	48	43
Pen @ 77°F, 100g, 5s (dmm) (specification)	70 (50 min)	111 (60 min)	105 NA	112 (85 min)
Absolute Viscosity @ 140°F (p) (specification)	2150 (1600-2400)	2008 (1600-2400)	1890 (1600-2400)	1857 (1600-2400)
Kin. Viscosity @ 275°F (cSt) (specification)	395 (230 min)	572 (300 min)	649 (325 min)	607 (325 min)
R&B Softening Point (°F)	125	130	133	124
b) Residue				
Pen @ 39.2°F, 200g, 60s (dmm)	23	37	34	25
Pen @ 77°F, 100g, 5s (dmm)	37	67	58	50
Absolute Viscosity @ 140°F (p)	6420	5675	5058	5000
Kin. Viscosity @ 275°F (cSt)	665	960	877	1100
R&B Softening Point (°F)	144	140	140	142

NA = Not Available



Legend:

1 = CA(P)-1 (R)	2 = Styrelf (R)	3 = AC-20R (R)	4 = AC-20 (R)
5 = AC-20R (O)	6 = CA(P)-1 (O)	7 = Styrelf (O)	8 = AC-20 (O)

Figure 3.1 Consistency Test Results on Original and Residue Asphalt

The above relationship indicates that an increase in the PI number is an indication of decrease in temperature susceptibility of a binder.

PVN is another way to evaluate the temperature susceptibility of a binder. It is expressed by the following equation:

$$\mathbf{PVN} = \frac{\mathbf{4.258 - .7967\,(log\,P) - log\,V}}{\mathbf{.7591 - .1858\,(log\,P)}} \mathbf{\times (-1.5)} \qquad \mathbf{(3\text{-}3)}$$

where **P** = Penetration at 77°F (25°C), 100g, 5s (dmm)
V = Kinematic viscosity at 275°F (135°C), cSt

A high value of PVN indicates a binder that has a low temperature susceptibility.

The calculated PI and PVN values are presented in Table 3.2 and illustrated in Figure 3.2. It is apparent that the AC-20 binder has the lowest PI and PVN, indicating this binder is more temperature susceptible than polymer modified binders. The polymer modified binders have similar calculated PIs or PVNs. The difference in the calculated PI and PVN between the polymer modified binders is not as significant as that between the AC-20 and the polymer modified binders.

3.1.2 DUCTILITY AND ELASTIC RECOVERY TESTS

Ductilities were determined in accordance with ASTM D111 testing procedures. The test results are summarized in Table 3.3. The ductility results, obtained at a testing temperature of 39.2°F, are illustrated in Figure 3.3a. For the binders tested at 77°F, all binders had ductility values greater than 100 cm at the testing speed 5cm/min except Styrelf asphalt residue which had an average ductility of 54 cm. This result indicated at 77°F, all binders had similar ductile characteristics except Styrelf which was less ductile than other binders tested at the same temperature. At 39.2°F, ductilities for polymer modified binders were higher than the conventional AC-20 asphalt.

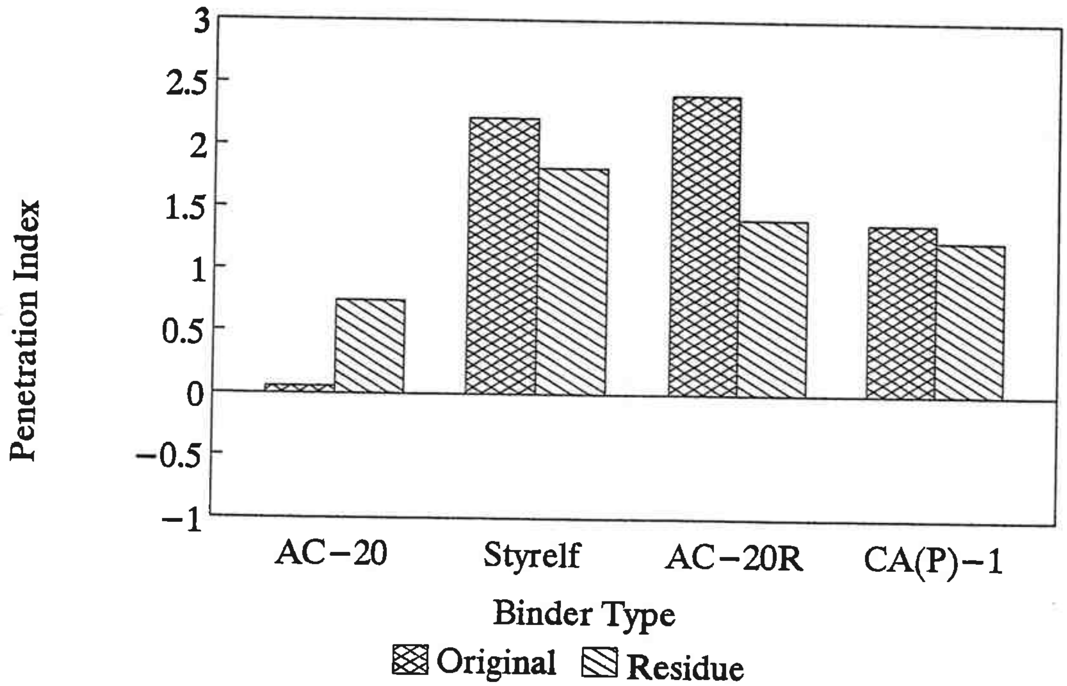
The elastic recovery test results are also presented in Table 3.3. Elastic recovery test results (Figure 3.3b) indicated similar characteristics; binders with polymer additives had considerably higher elastic recovery than conventional AC-20 binder.

3.1.3 FORCE DUCTILITY TESTS

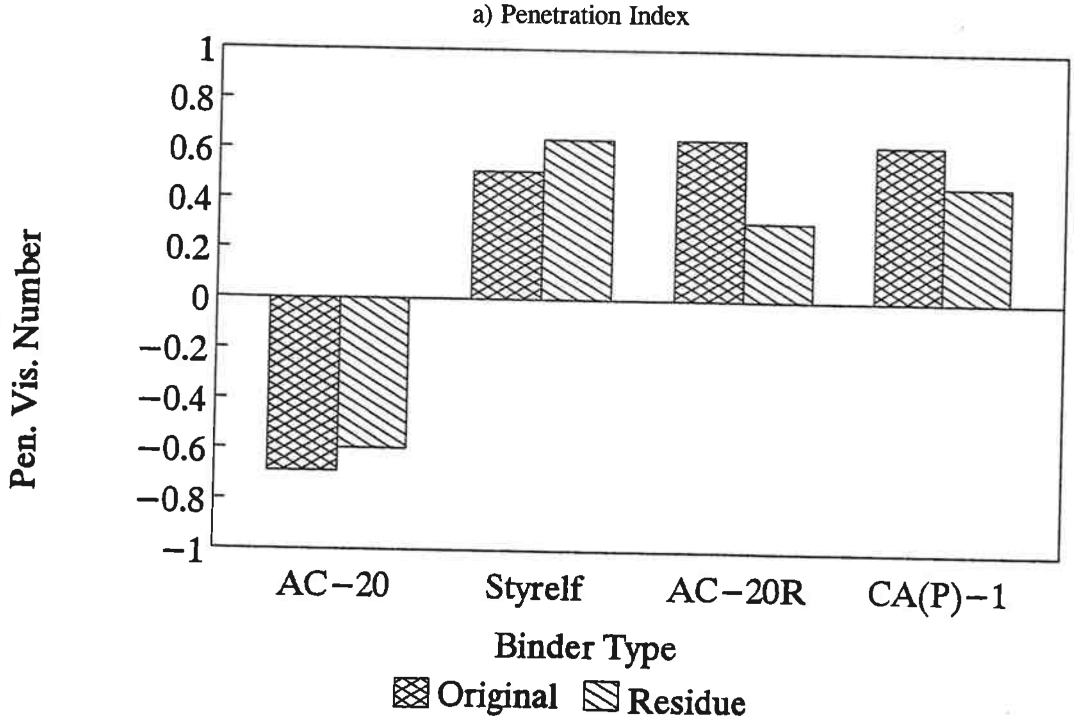
Force ductility tests were conducted in accordance with the conventional ductility test with certain changes. Two force cells are added to the loading chain and the mold is modified to produce a specimen with constant cross-sectional area through the gage length. The force ductility test data was used to determine the maximum engineering stress, engineering strain, and engineering work. Because of these, a majority of researchers seem to believe that this test is a significant binder test and an improvement over the conventional ductility test (*Rogge, et al, 1989*). However, other findings (*Goodrich, 1988*) reported that force ductility test results did not correlate well with low-temperature creep or with fatigue test results for the binder-aggregate mixture.

Table 3.2: Calculations of PI and PVN

Binder Type	Pen @ 77°F	R&B (°F)	Vis @ 275°F	PI	PVN
a) Original					
AC-20	70	125	395	0.05	-0.69
Styrelf	111	130	572	2.21	0.51
AC-20R	105	133	649	2.41	0.64
CA(P)-1	112	124	607	1.38	0.63
b) Residue					
AC-20	37	144	665	0.74	-0.60
Styrelf	67	140	960	1.82	0.64
AC-20R	58	140	877	1.42	0.31
CA(P)-1	50	142	1100	1.25	0.46



a) Penetration Index

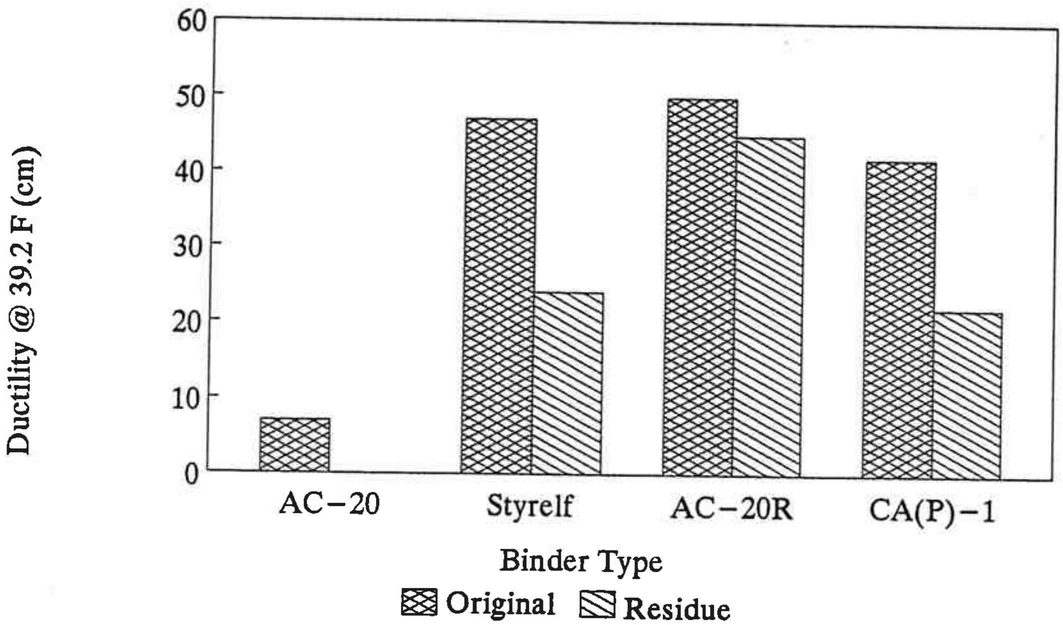


b) Penetration Viscosity Number

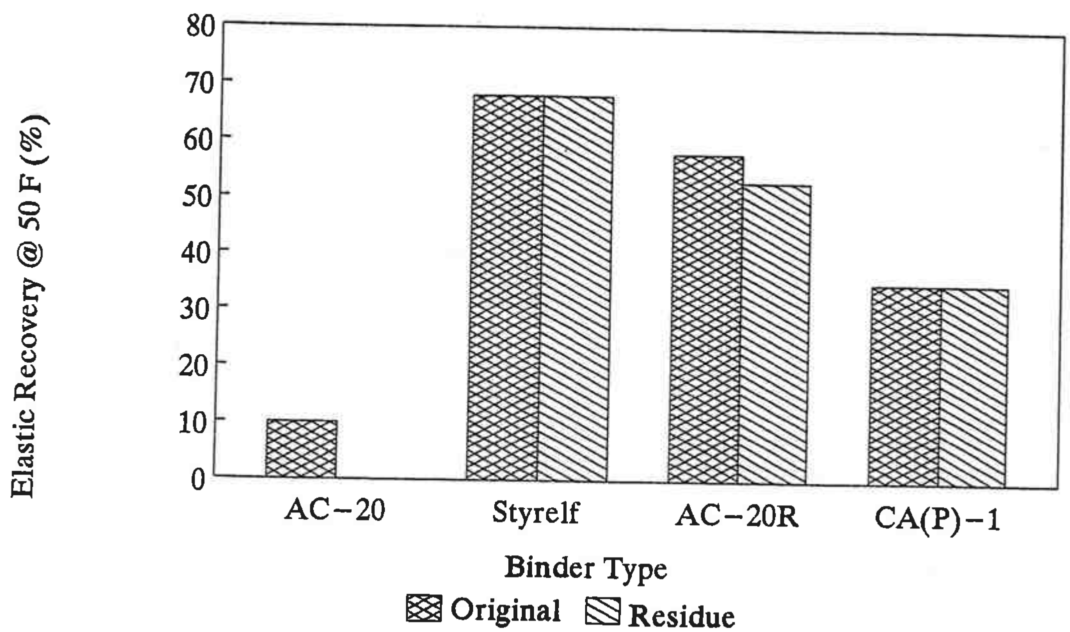
Figure 3.2 Calculations of PI and PVN

Table 3.3: Ductility and Elastic Recovery

Test	AC-20	Styrelf	AC-20R	CA(P)-1
a) Original				
Ductility @ 39.2°F 5cm/min (cm) (specification)	7	47	50+ (50 min)	42+ (25 min)
Ductility @ 77°F 5cm/min (cm) (specification)	150+	150+	100+ (100 min)	100+ (100 min)
Elastic Recovery @ 50°F (%) (specification)	10	68 (58 min)	58 (58 min)	35
Fraass Point (°F)	19	-1	3	9
b) Residue				
Ductility @ 39.2°F 5cm/min (cm)	0	24	45+	22
Ductility @ 77°F 5cm/min (cm)	100+	54	100+	100+
Elastic Recovery @ 50°F (%)	-	68	53	35
Fraass Point (°F)	23	3	4	17



a) Ductility Test Results



b) Elastic Recovery

Figure 3.3 Ductility and Elastic Recovery Test Results

The force ductility test was conducted at both 39.2°F and 77°F and the results are presented in Table 3.4. The maximum engineering stress is obtained by dividing the maximum load by the original cross-sectional area. Maximum engineering strain was calculated by dividing the length at failure of the specimen by the original length. Maximum engineering work is the area under the stress-strain curve and could be considered as energy required to produce failure. For binders containing polymer additives, marked increases in energy required to produce failure may be seen (Figure 3.4). This characteristic may be useful in predicting changes in mixture tensile strength when polymer additives are used in binders.

3.1.4 TOUGHNESS AND TENACITY TESTS

The toughness and tenacity test was performed by placing a tension head into a standard 3 oz penetration tin containing 36 g of binder; the tension head was then pulled at 20 in./min while the force vs. extension plot was recorded. Detailed test procedures were described by Rogge (1989) and Reinke (1985). The total area under the force-extension curve was calculated and reported as Toughness. The declining side of the curve was extended to the horizontal axis in a straight line and the area to the right of this line was reported as Tenacity. Figure 3.5 illustrates the results of the toughness and tenacity test. Apparently, the original binders with polymer additives have higher toughness and tenacity values. The polymer modified asphalt residue also exhibits the similar characteristics except for Styrelf. These test results imply that the binders with polymer additives have a higher tensile strength than the binder without.

3.1.5 FRAASS TEST RESULTS

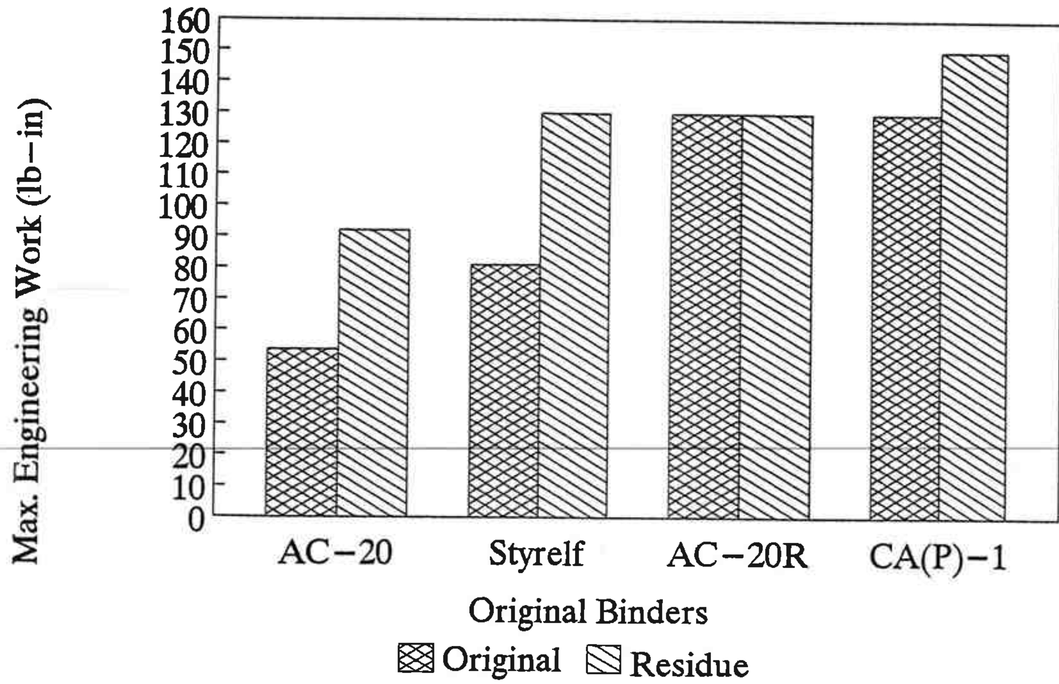
The Fraass test measures the cold temperature flexibility of an asphalt. Detailed test procedures are described by Thenoux, et. al. (1985) and Rogge (1989). Figure 3.6 shows the results of the Fraass test. The figure clearly indicates all polymer modified binders had lower Fraass points than the conventional AC-20 asphalt, this would imply that the polymer modified asphalts are more flexible at cold temperatures than the conventional AC-20 binder.

3.2 MIX DESIGN

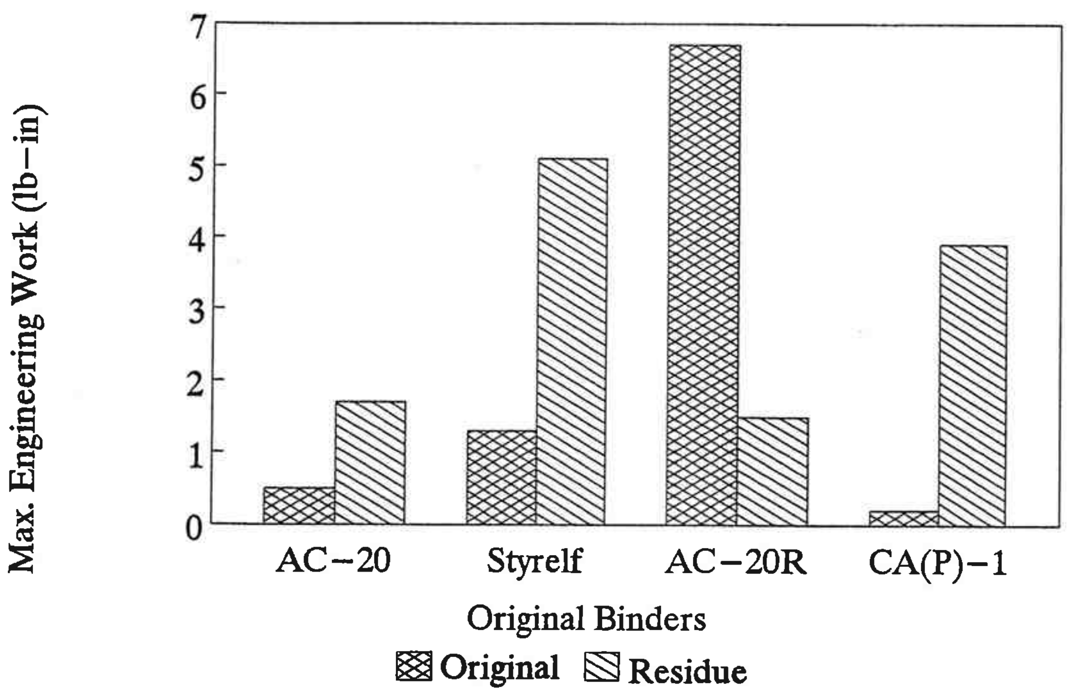
The preparation of the mix designs proceeded after all relevant tests, as described above, were completed. Separate mix designs were made for each binder using the ODOT version of the Hveem method (*Quinn, et al, 1987*). The design mix characteristics at the design binder content for each mix are listed in Table 3.5. For open-graded mixes, the mix design criteria are slightly different from those of dense-graded mixes. The criteria used to evaluate the mix properties are binder film thickness, voids and stability at first compaction, stability at second compaction, and index of retained strength. The values of these criteria are also shown in Table 3.5.

Table 3.4: Force Ductility, Toughness, and Tenacity

Test	AC-20	Styrelf	AC-20R	CA(P)-1
a) Original Asphalt				
Force Ductility @ 39.2°F				
Max. Engr. Stress (lb/in^2)	100	34	49	51
Max. Engr. Strain (in/in)	33+	33	47+	21
Max. Engr. Work (lb-in)	54	81	130	130
Force Ductility @ 77°F				
Max. Engr. Stress (lb/in^2)	0.8	0.4	1.1	0.2
Max. Engr. Strain (in/in)	47+	47+	47+	47+
Max. Engr. Work (lb-in)	0.5	1.3	6.7	0.2
Toughness (lb-in)	76	174	216 100 min	165 75 min
Tenacity (lb-in)	37	152	197 75 min	141 50 min
b) Residue Asphalt				
Force Ductility @ 39.2°F				
Max. Engr. Stress (lb/in^2)	220	77	77	100
Max. Engr. Strain (in/in)	6.5	19	26	15
Max. Engr. Work (lb-in)	92	130	130	150
Force Ductility @ 77°F				
Max. Engr. Stress (lb/in^2)	4.2	1.3	1.5	2.9
Max. Engr. Strain (in/in)	47+	47+	47+	47+
Max. Engr. Work (lb-in)	1.7	5.1	1.5	3.9
Toughness (lb-in)	138	119	164	196
Tenacity (lb-in)	52	68	115	147

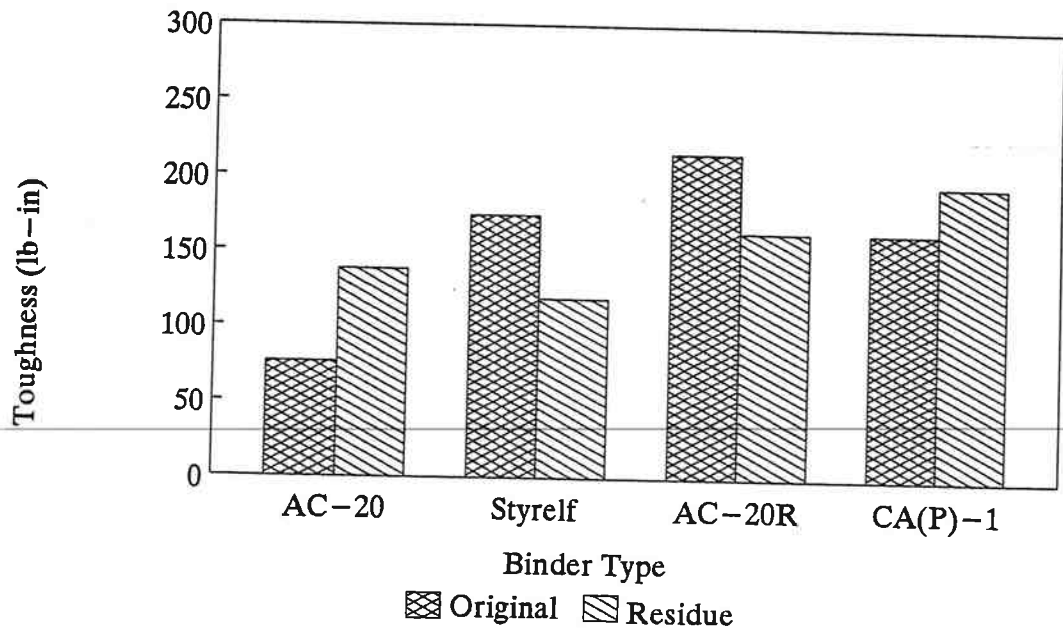


a) At 39.2°F

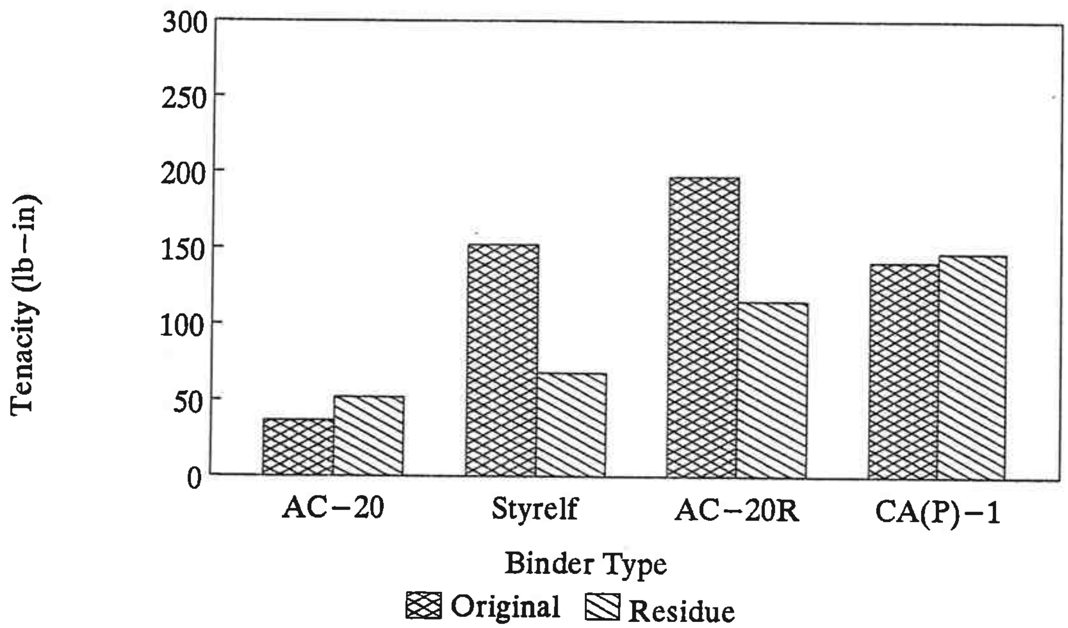


b) At 77°F

Figure 3.4 Maximum Engineering Work



a) Toughness



b) Tenacity

Figure 3.5 Toughness and Tenacity Test Results

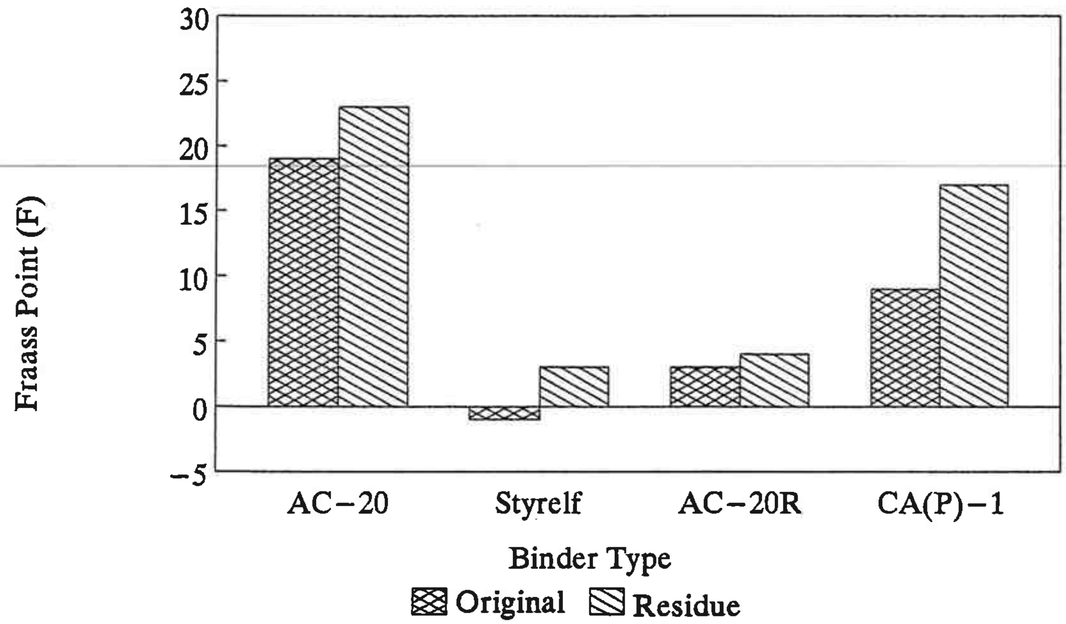


Figure 3.6 Fraass Test Results

Table 3.5: Design Mix Characteristics at Design Binder Content

Item	AC-20	Styrelf	AC-20R	CA(P)-1	ODOT Class F mix design criteria
Percent passing sieve:					
1"	100	100	100	100	99-100
3/4"	100	98	98	98	95-100
1/2"	76	75	75	75	66-80
3/8"	57	56	56	56	
1/4"	28	25	25	25	18-30
#10	11	10	10	10	5-19
#40	6	6	6	6	
#200	3.6[a]	3.6[a]	3.5[a]	3.5[a]	1.5-6.5[b]
Mineral filler (%)	1[c]	1[c]	1[c]	1[c]	.5-1.5
Voids in mineral agg (%)	19.8	21	21	20	
Binder content (%)	5.2	5.5	5.5	5.5	4-8
Binder film thickness	Suff.	Suff.	Suff.	Suff.	Suff.
SG @ 1st compaction	2.29	2.26	2.27	2.30	
Voids @ 1st comp. (%)	9.0	11.1	9.5	8.7	6-9
Stability @ 1st comp.	24	26	22	21	≥26
SG @ 2nd compaction	2.35	2.36	2.37	2.38	
Voids @ 2nd comp. (%)	6.6	7.2	5.5	5.6	
Stability @ 2nd comp.	37	39	33	32	≥26
Rice Specific Gravity	2.518	2.542	2.509	2.52	
Index of Retained Strength (%)	83	73	84+	76	≥75

[a] Includes loose lime from treated aggregate and 1% fly ash mineral filler.
[b] Includes .5% allowance for loose lime from treated aggregate.
[c] Estimated.

4.0 CONSTRUCTION

A brief description of the construction (including the costs) is presented in this chapter.

4.1 PLACEMENT

The AC-20 mix was used for the control sections. No unusual problems were reported for this conventional asphalt. The specified mixing temperature was in the range of 250 to 257°F and the placement temperature was in the range of 238 to 243°F. Five temperature measurements were taken in the windrow. The average temperature was 252°F which is about 10°F higher than specified.

The Styrelf binder mixed easily with the aggregate in the pugmill. Unlike the conventional asphalt, this binder tended to cling to the surfaces of the equipment. Observations indicated that the buildup was moderate, and plant operation was not affected. However, when the Styrelf binder was at 275°F, it became very viscous and caused pumping problems that slowed down the batching of the mix production. Consequently, the pumping temperature was raised to a range of 300°F to 360°F.

Two other observations on the Styrelf binder were that 1) the binder migrated through the mix to the bottom of the silo when the mix was stored for an extended period and 2) the binder was especially sensitive to paver speed and screed setting, compared to other mixes. For any screed setting, there was a definite maximum paver speed. If the paver exceeded this speed, the screed would rapidly lift. In general, this mix was easy to place.

The AC-20R binder was somewhat similar to Styrelf: easily mixed with the aggregate, tended to cling to the surfaces of the equipment, and was more viscous than AC-20. This binder built up heavier coatings on the surfaces of the equipment than Styrelf and the buildup was very hard to remove. Migration problems were also noticed during placement. In addition, this mix was not smoothly finished by the passage of the screed. There was a minor amount of "rolling" and "picking" as the screed passed over the mix. These surface irregularities were not seen after compaction. The mix also tended to harden quicker upon cooling than the conventional AC-20, causing difficulty in raking. In general, placement went smoothly and no unusual problems were noticed.

The CA(P)-1 mix is very much like the conventional AC-20 mix except that the smell of fumes from the CA(P)-1 binder seemed noxious. The placement went easily and no problems were encountered.

A summary of construction test results is presented in Table 4.1. These test results indicate that 1) the asphalt content and mix gradation are within the specification ranges for all mixes and 2) the average mix placement temperatures generally conformed to or were close to the specifications.

Table 4.1: Summary of Construction Tests Results

Gradation (% passing)	AC-20		Styrelf		AC-20R		CA(P)-1	
	Average Value	Spec.	Average Value	Spec.	Average Value	Spec.	Average Value	Spec.
1 in.	100	99-100	100	99-100	100	99-100	100	99-100
3/4 in.	98	95-100	98	95-100	98	95-100	97	95-100
1/2 in.	75	66-80	79	66-80	75	66-80	74	66-80
1/4 in.	23	19-30	24	19-30	22	19-30	21	19-30
No. 10	8	5-13	9	5-13	8	6-14	8	6-14
No. 200	3.4[a]	1.6-5.6[a]	3.5[a]	1.6-5.6[a]	3.2[a]	1.6-5.6[a]	3.4[a]	1.6-5.6[a]
Asphalt content (%)	5.4	4.7-5.7	5.5	5.0-6.0	5.3	5.0-6.0	5.5	5.0-6.0
Moisture content (%)	0.50	0.6 (max)	0.37	0.6 (max)	0.39	0.6 (max)	0.45	0.6 (max)
Mixing Temperature (°F)	-	250-257	-	260-268	-	263-272	-	258-267
Placement Temperature (°F)	252	238-243	250	243-252	250	243-258	257	242-250

[a] Includes loose lime from treated aggregate and 1% fly ash mineral filler.

4.2 COSTS

As expected, the use of polymer additives in the binder increased the unit costs of the mixes. Table 4.2 presents a summary of unit bid prices for this project. It may be seen from the table that for a compacted mix two-inch thick, the Styrelf mix would cost about 15% more than conventional AC-20 mix. The AC-20R and CA(P)-1 mixes would cost 27% more than conventional AC-20 mix. These unit bid prices represent small quantities of binders that the contractor had little experience with. The cost is expected to decrease as larger quantities of mix are used by contractors with more experience with the polymer modified AC.

Table 4.2: Summary of Unit Bid Prices

Item	AC-20 ($)	Styrelf ($)	AC-20R ($)	CA(P)-1 ($)
Asphalt price (ton)	140.00	250.00	300.00	300.00
Aggregate price (ton)	16.00	13.00	13.00	13.00
Mixture price (ton)	23.28	26.75	29.50	29.50
Mix price/sq. yd.	2.45	2.82	3.11	3.11
Comparison (%)	100	115	127	127

Note: Calculations of the cost are for a two-inch thick compacted mix.

5.0 POST CONSTRUCTION ENGINEERING

Post construction engineering, including laboratory tests on binders, mixtures, and cores, was conducted immediately following the construction and is discussed in this chapter.

5.1 MIX SAMPLING

Mix samples were taken from the discharge chute of the pugmill with a shovel. The samples were then sent to the ODOT Materials Laboratory for the determination of asphalt content and aggregate gradation. Some of the observations regarding the mix sampling were that when the mix was hot, the binder would migrate to the bottom of the mix sample; when the mix was cold, it was very difficult to stir the binder into the mix and remove all of the binder from the container when the sample was taken out for testing. In addition, the polymer modified mixes were very tenacious.

5.2 BINDER PROPERTIES

The asphalt in the mixes was extracted to conduct consistency, force ductility, and toughness and tenacity tests. The consistency tests were also performed on recovered asphalt from core samples obtained in 1991, two years after the construction.

5.2.1 CONSISTENCY TESTS

The same consistency tests, as performed on the original binders, were conducted on the recovered binders in 1989 and 1991. These included penetration and viscosity tests. In addition to those tests at 39.2°F, 200g, 60s and at 77°F, 100g, 5s, a penetration test was also run at 39.2°F, 100g, 5s on the binders extracted from core samples obtained in 1991. This test is used in the Gaw procedure (discussed later in this section) to evaluate the binders ability to resist low temperature cracking.

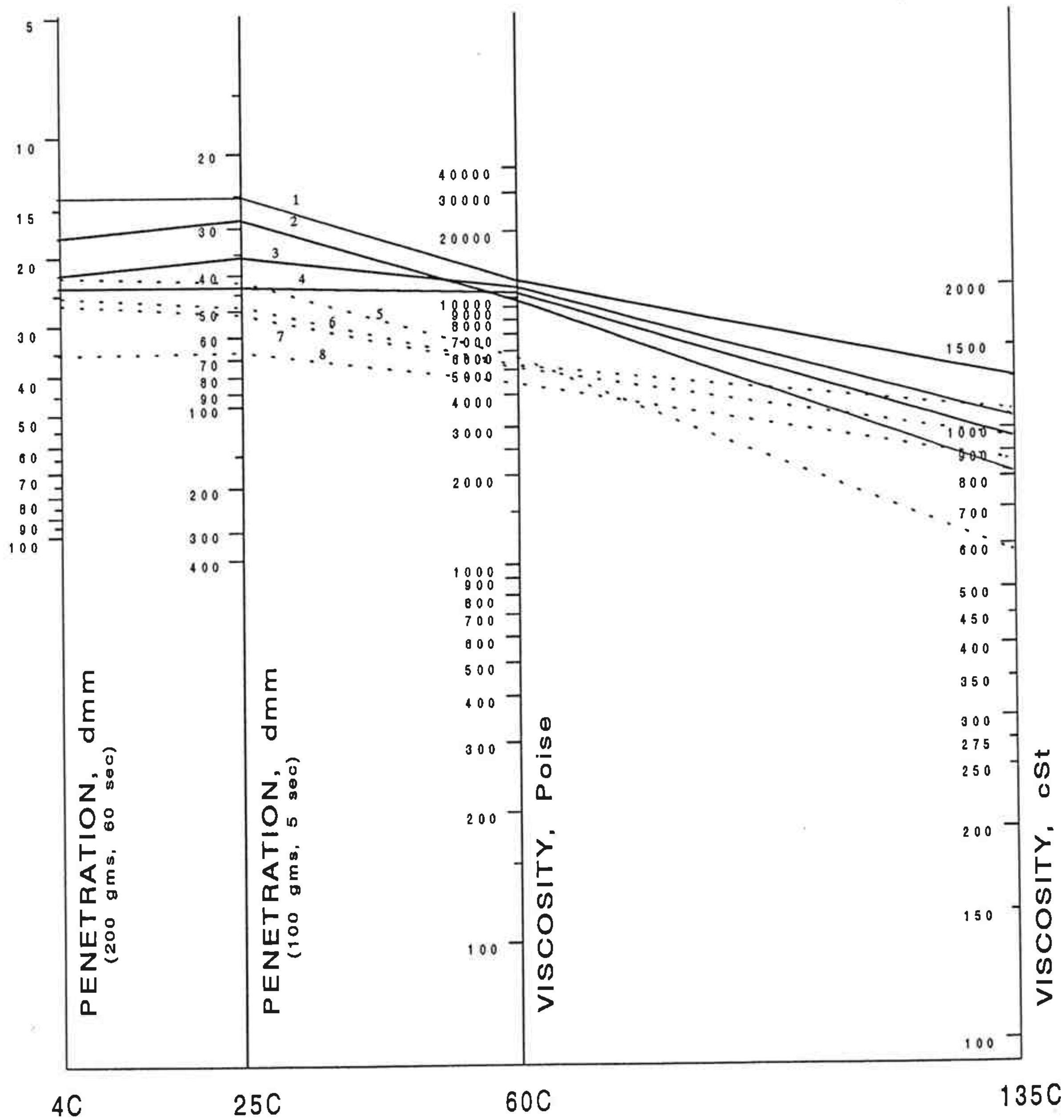
Table 5.1 summarizes the consistency test results of recovered asphalts for both 1989 and 1991. These results are also illustrated in Figure 5.1 for comparison.

It is apparent that in two years the binders' properties have changed considerably: viscosities at 140°F (60°C) changed from approximately 5000p to over 10000p; at 275°F (135°C), viscosities also increased, but at a different rate, depending on the binders. These changes indicate that the asphalt binders become more viscous after two years of road service. The penetration test results also reflect these changes: at two temperature levels (39.2°F and 77°F), the penetration values have decreased nearly proportionally, indicating the binders were much harder in 1991 than they were in 1989.

Table 5.1: Consistency Test Results on Recovered Binder

Test	AC-20	Styrelf	AC-20R	CA(P)-1
a) 1989 Test Results				
Pen @ 39.2°F, 200g, 60s (dmm)	22	35	26	25
Pen @ 77°F, 100g, 5s (dmm)	41	63	50	48
Abs Vis @ 140°F (p)	5790	4850	5210	5240
Kin Vis @ 275°F (cSt)	598	861	964	1090
R&B Softening Point (°F)	144	140	136	140
b) 1991 Test Results*				
Pen @ 39.2°F, 200g, 60s (dmm)	17	24	22	14
Pen @ 39.2°F, 100g, 5s (dmm)	5	8	7	3
Pen @ 77°F, 100g, 5s (dmm)	29	43	35	25
Abs Vis @ 140°F (p)	10200	10680	11000	11500
Kin Vis @ 275°F (cSt)	811	970	1040	1380

* The R&B Softening Point Test was not performed in 1991.



Legend:
1 = CA(P)-1 (91)
2 = AC-20 (91)
3 = AC-20R (91)
4 = Styrelf (91)
5 = AC-20 (89)
6 = CA(P)-1 (89)
7 = AC-20R (89)
8 = Styrelf (89)

Figure 5.1 Consistency Test Results on Recovered Asphalt

These test results permitted the reevaluation of temperature susceptibility of the binders in terms of penetration index and penetration viscosity number (Table 5.2). Figure 5.2 shows a comparison of the calculated penetration index and penetration-viscosity number for each recovered binder. Based on the penetration index calculations, the 1989 results indicated the AC-20R binder is the most temperature susceptible. However, the 1991 results indicate the CA(P)-1 binder would be the most susceptible to temperature change. Penetration viscosity number calculations present a different picture: AC-20 has the lowest calculated PVN and therefore is the most susceptible to temperature change.

One additional penetration test at 39.2°F, 100g, 5s was performed in 1991 on binders used in the wearing course as well as in the base course. This test was intended to evaluate the binder's ability to resist low temperature cracking using the procedure developed by Gaw (1978). The Gaw procedure uses penetration values tested at 39.2°F and 77°F to predict the temperature at which the binder will crack. Based on the Gaw procedure, the predicted temperatures for the binders to crack are: -40°F for AC-20; -49°F for Styrelf; -49°F for AC-20R; and -22°F for CA(P)-1.

5.2.2 FORCE DUCTILITY AND TOUGHNESS AND TENACITY TESTS

Force ductility and toughness and tenacity tests were run on recovered binders in 1989. Table 5.3 presents the summary of these test results.

Considerable differences in engineering work at 39.2°F may be seen in Figure 5.3; the recovered AC-20 asphalt has the lowest value, meaning that this binder requires the least energy to produce failure.

The toughness and tenacity test results show a similar tendency (Figure 5.4); the AC-20 binder has the lowest toughness and tenacity. The polymer modified binders all have higher toughness and tenacity values, implying that they are tougher and more tenacious than the conventional AC-20 asphalt.

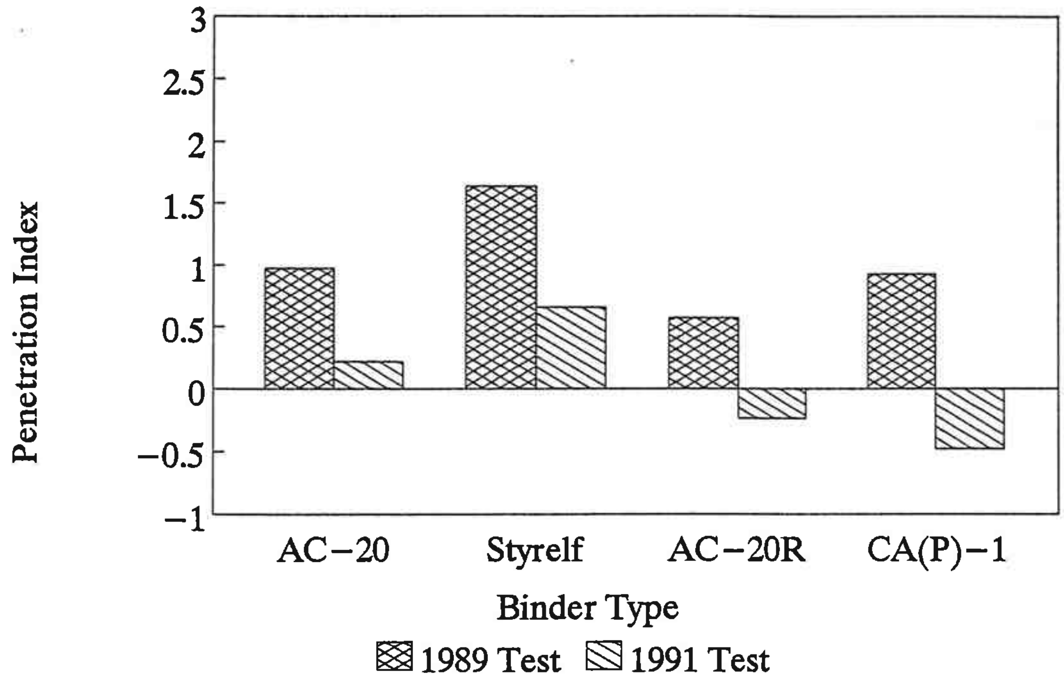
5.3 MIXTURE PROPERTIES

Mixture properties were measured on core samples obtained from the site. The laboratory tests included measurements of bulk specific gravity, Rice specific gravity, Hveem stability, resilient modulus, and fatigue. All tests were run following ASTM or ODOT standard testing procedures. Table 5.4 presents the results of various tests.

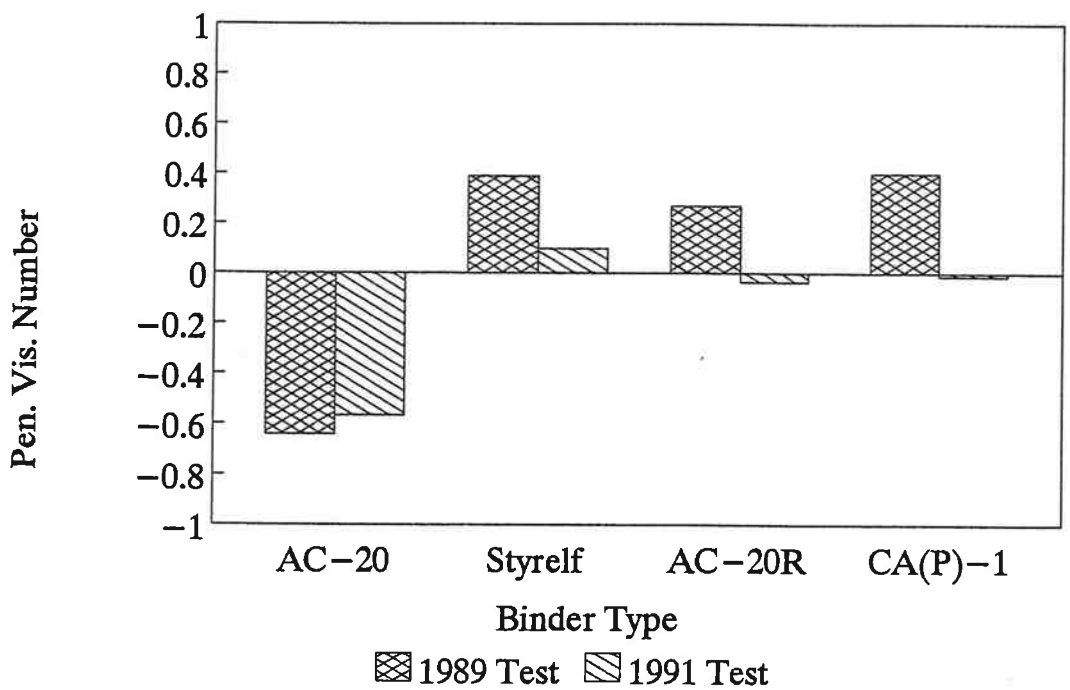
Table 5.2: Calculations of Penetration Index and Penetration Viscosity Number on Recovered Asphalt

Material	Pen @ 77°F	R&B Softening Point (°F)	Vis @ 275°F (cSt)	Penetration Index	Pen-Vis Number
a) 1989 Test					
AC-20	41	144	598	0.98	-0.64
Styrelf	63	140	861	1.64	0.39
AC-20R	50	136	964	0.58	0.27
CA(P)-1	48	140	1090	0.93	0.40
b) 1991 Test*					
AC-20	29	144	811	0.22	-0.57
Styrelf	43	140	970	0.66	0.10
AC-20R	35	136	1040	-0.24	-0.03
CA(P)-1	25	140	1380	-0.48	-0.01

* R&B Softening Point Test was not performed in 1991. The 1989 test results were used to calculate the penetration index for each recovered binder.



a) Penetration Index

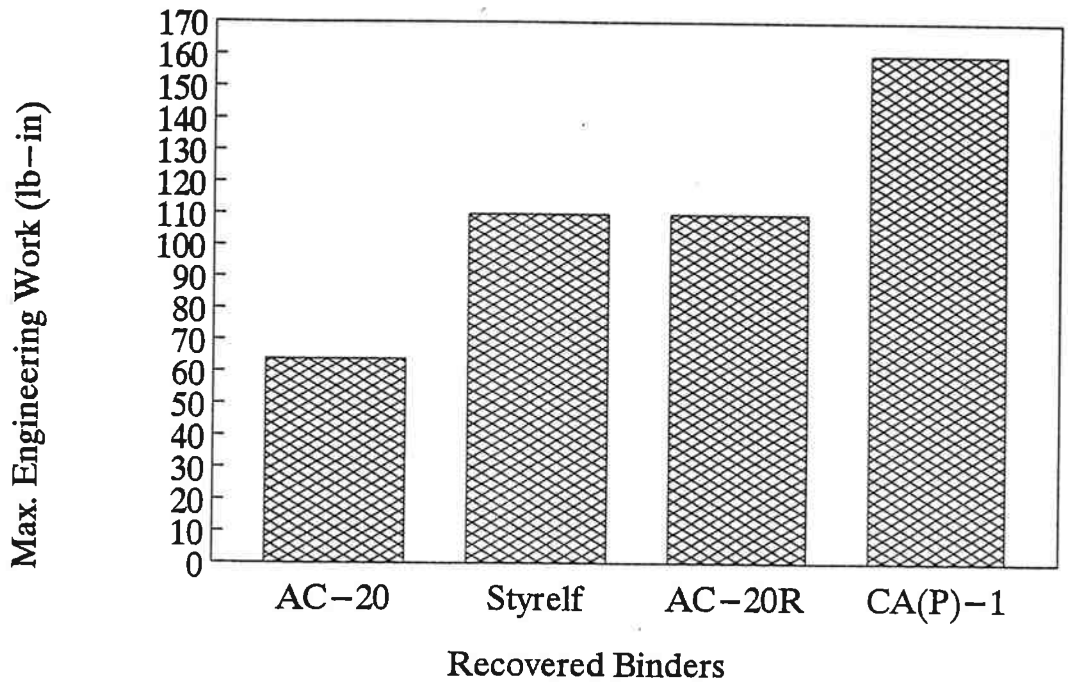


b) Penetration Viscosity Number

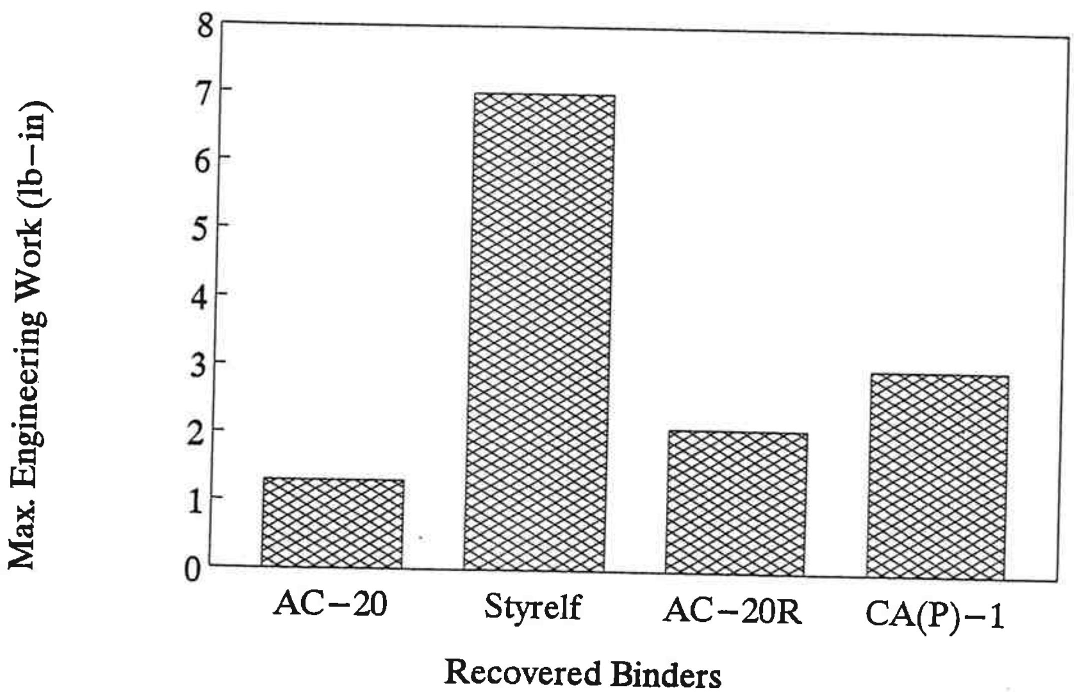
Figure 5.2 Comparison of Temperature Susceptibility

Table 5.3: Force Ductility Test Results (1989) on Recovered Asphalt

Test	AC-20	Styrelf	AC-20R	CA(P)-1
Force-Ductility @ 39.2°F				
Max. Engr. Stress (lb/in^2)	150	64	77	110
Max. Engr. Strain (in/in)	7.2	16	19	14
Max. Engr. Work (lb-in)	64	110	110	160
Force-Ductility @ 77°F				
Max. Engr. Stress (lb/in^2)	2.5	1.5	1.6	2.4
Max. Engr. Strain (in/in)	47+	47+	47+	47+
Max. Engr. Work (lb-in)	1.3	7.0	2.1	3.0
Toughness (lb-in)	80	87	124	219
Tenacity (lb-in)	18	48	56	101

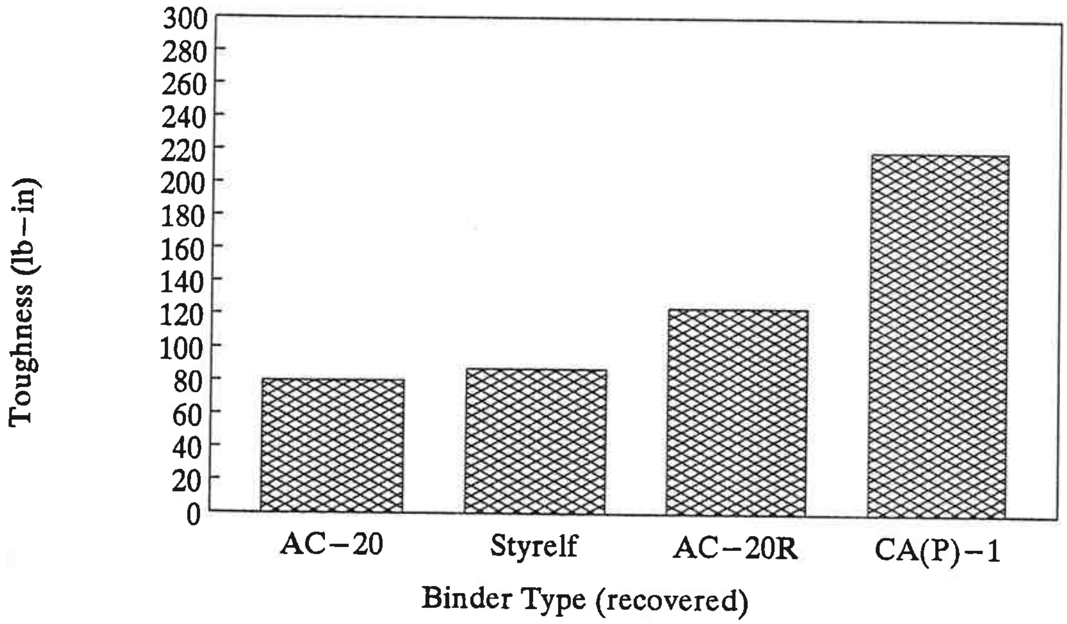


a) At 39.2°F

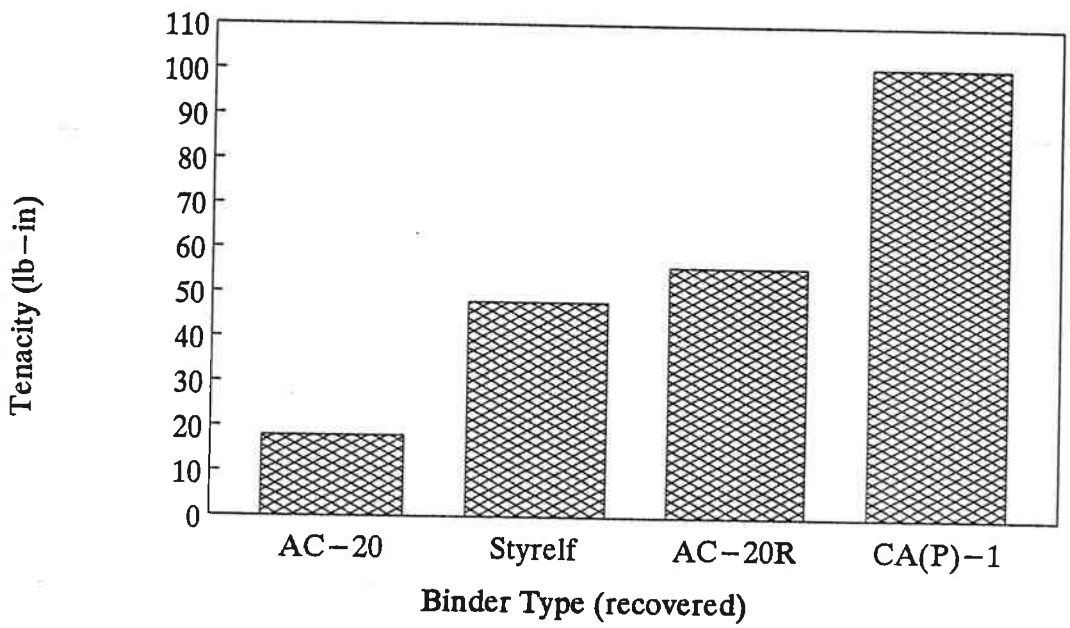


b) At 77°F

Figure 5.3 Calculated Maximum Engineering Work for Recovered Asphalt



a) Toughness of Recovered Binders



b) Tenacity of Recovered Binders

Figure 5.4 Toughness and Tenacity Test Results (1989)

Table 5.4: Summary of Core Sample Mix Properties

Test	AC-20	Styrelf	AC-20R	CA(P)-1
a) In-Place				
Bulk Specific Gravity	2.12 (89) 2.26 (90) 2.25 (91)	2.16 (89) 2.26 (90) 2.26 (91)	2.17 (89) 2.24 (90) 2.29 (91)	2.17 (89) 2.25 (90) 2.22 (91)
Voids (%)	14.9 (89) 12.0 (90) 10.7 (91)	17.6 (89) 10.5 (90) 11.3 (91)	14.5 (89) 12.3 (90) 9.4 (91)	14.5 (89) 10.9 (90) 11.6 (91)
Hveem Stability	N/A (89) 11 (90) 15 (91)	13 (89) 16 (90) 22 (91)	14 (89) 15 (90) 15 (91)	13 (89) 16 (90) 14 (91)
Resilient Modulus (ksi)	715[1]	613[2]	339[1]	761[2]
Fatigue (repetitions to failure)	7190[1]	18400[2]	32100[1]	3220[2]
b) Recompacted				
Bulk Specific Gravity	2.33 (89) 2.31 (90) 2.39 (91)	2.29 (89) 2.38 (90) 2.37 (91)	2.30 (89) 2.36 (90) 2.38 (91)	2.29 (89) 2.39 (90) 2.37 (91)
Rice Specific Gravity	2.492 (89) 2.568 (90) 2.519 (91)	2.540 (89) 2.525 (90) 2.550 (91)	2.549 (89) 2.553 (90) 2.525 (91)	2.537 (89) 2.525 (90) 2.516 (91)
Voids (%)	6.5 (89) 10.0 (90) 5.1 (91)	9.8 (89) 5.8 (90) 6.9 (91)	9.8 (89) 7.6 (90) 5.7 (91)	9.7 (89) 5.3 (90) 5.4 (91)
Hveem Stability	17 (89) 32 (90) 30 (91)	25 (89) 28 (90) 50 (91)	23 (89) 51 (90) 37 (91)	24 (89) 29 (90) 31 (91)

N/A = Not Available.
[1] Average of two samples. Tested in 1989.
[2] Average of three samples. Tested in 1989.

5.3.1 BULK AND RICE SPECIFIC GRAVITY

The bulk and Rice specific gravity tests were run on cores taken in three consecutive years, thus allowing an examination of changes on in-place density (Figure 5.5) and in-place voids (Figure 5.6) of each mixture. Bulk specific gravities of all mixes increased from 1989 to 1990. The rate of change slowed or decreased from 1990 to 1991. As expected, the voids had been decreasing except for the Styrelf and CA(P)-1 mixtures, which show an increase in voids. It should be pointed out that the determination of voids was based on the test results of both bulk specific gravity and Rice specific gravity which were determined using recompacted samples. It is possible that samples obtained from two boreholes may have slightly different bulk specific gravities.

5.3.2 HVEEM STABILITY

Hveem stability tests were performed on cores obtained in-place and recompacted in the laboratory. The tests were conducted in accordance with ODOT Test Method 305-86 (ODOT, 1986). Figure 5.7 illustrates the test results. Two general observations may be drawn from the figure: 1) polymer modified mixes have a similar or slightly higher Hveem stability than the conventional AC-20 mix, and 2) recompacted samples have much higher Hveem stability than cores obtained in-place.

5.3.3 RESILIENT MODULUS

Resilient modulus tests were conducted on cores obtained in-place in 1989. The tests were performed in accordance with ASTM D4123 test procedures. Figure 5.8 shows the test results. The AC-20R mixture has the lowest resilient modulus. The AC-20 and CA(P)-1 mixtures have a similar resilient modulus. The Styrelf mix has a resilient modulus between those of AC-20 and AC-20R mixtures.

5.3.4 FATIGUE

The fatigue tests followed the same procedures as those for the resilient modulus tests. Instead of measuring the load applied to the sample and the deformation caused by the load, the total repetitions of the load to cause failure of the sample were recorded as the fatigue life of the sample. Figure 5.9 presents a comparison of the test results. Although these test results may have little meaning to the field performance of each mixture, the AC-20R mixture does show a relatively longer life than other mixtures in resisting repeated loadings in the controlled laboratory environment. The CA(P)-1 mix shows a much shorter fatigue life, even shorter than the conventional AC-20 mix.

When the fatigue test results are compared to the resilient modulus test results, it is found that mixes with higher resilient modulus would have lower fatigue life and vice versa.

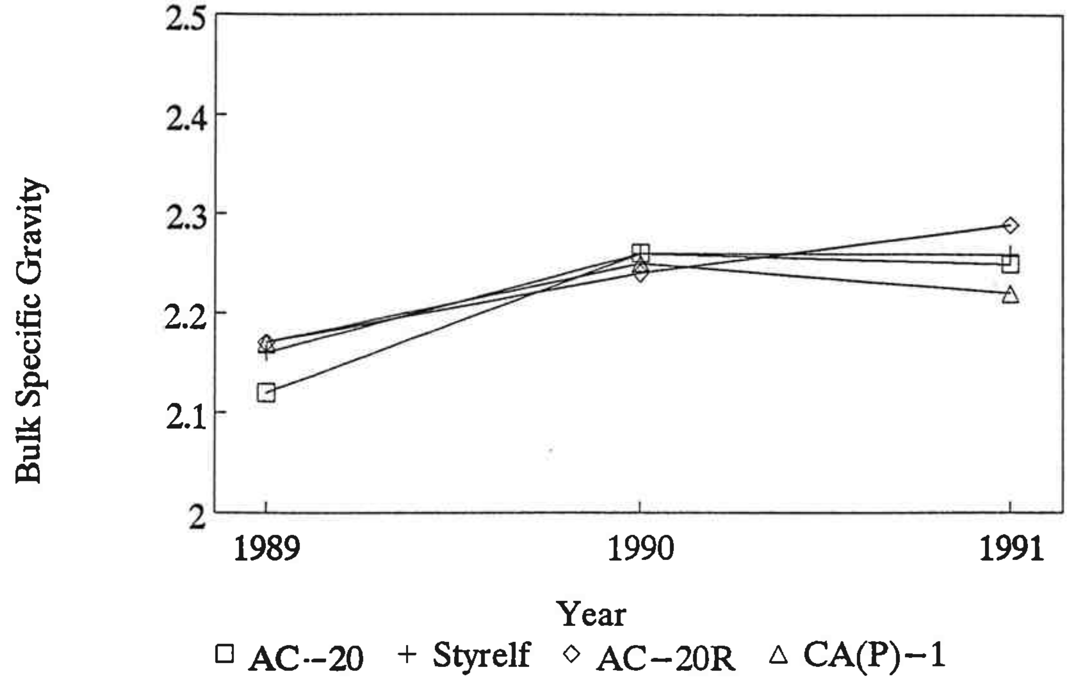


Figure 5.5 Bulk Specific Gravity Test Results

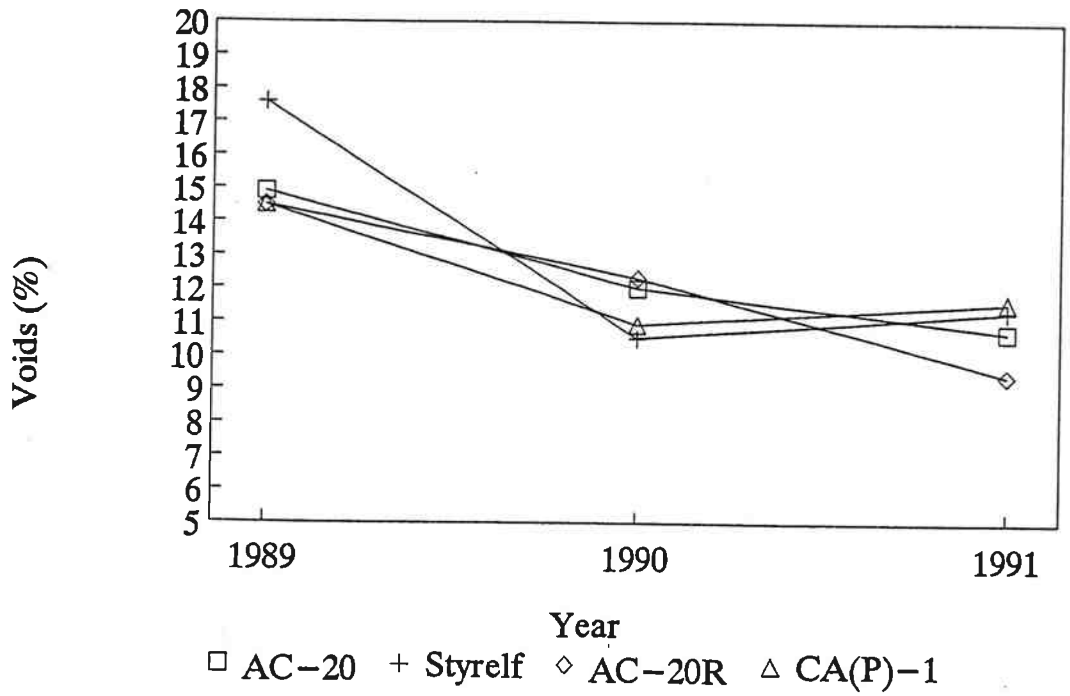
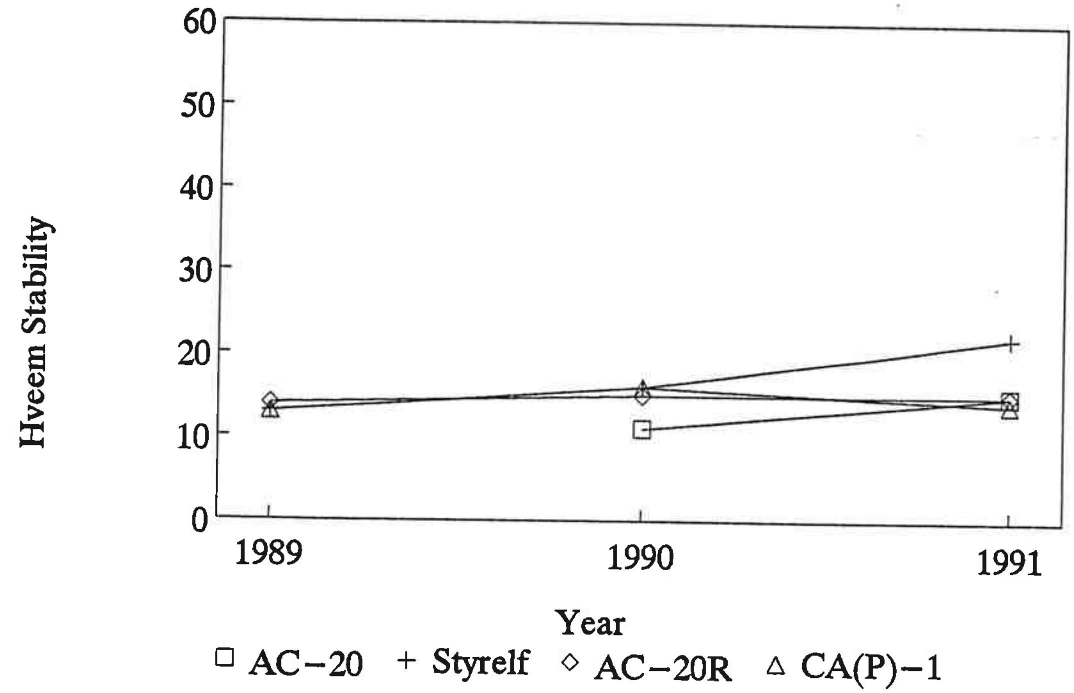
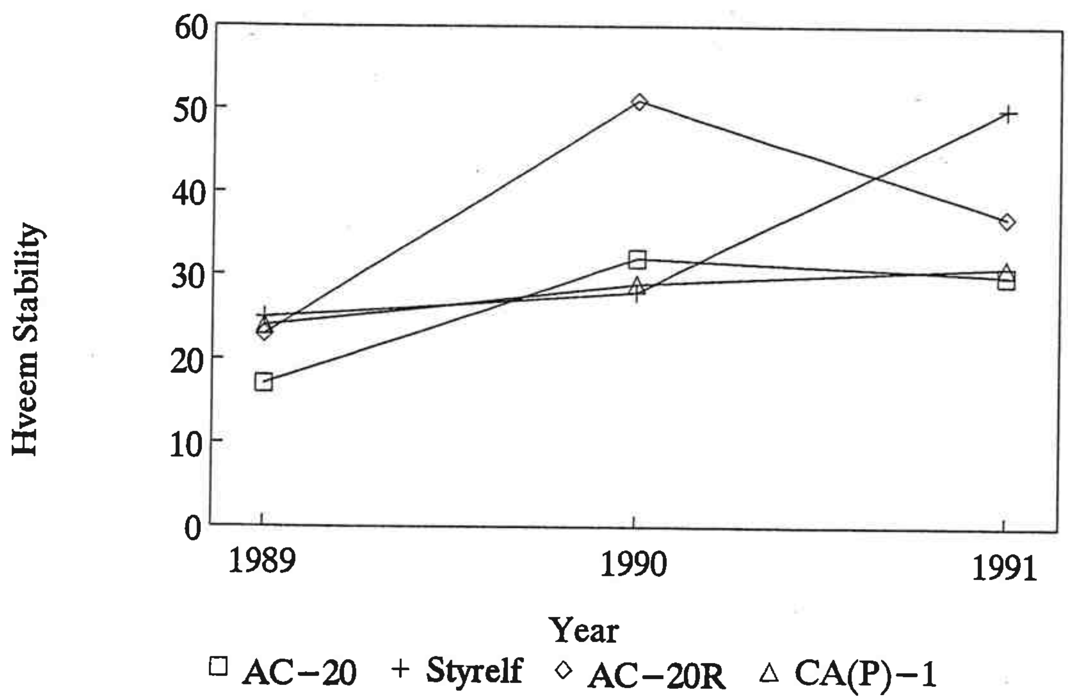


Figure 5.6 In-Place Voids



a) In-Place



b) Recompacted

Figure 5.7 Hveem Stability Test Results

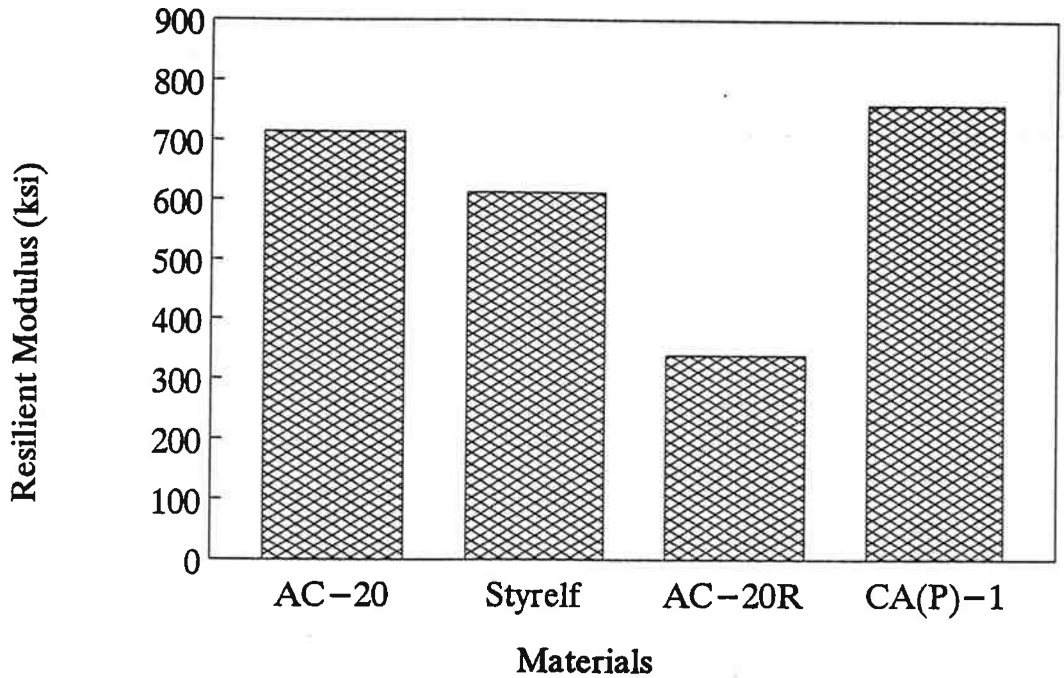


Figure 5.8 Resilient Modulus Test Results

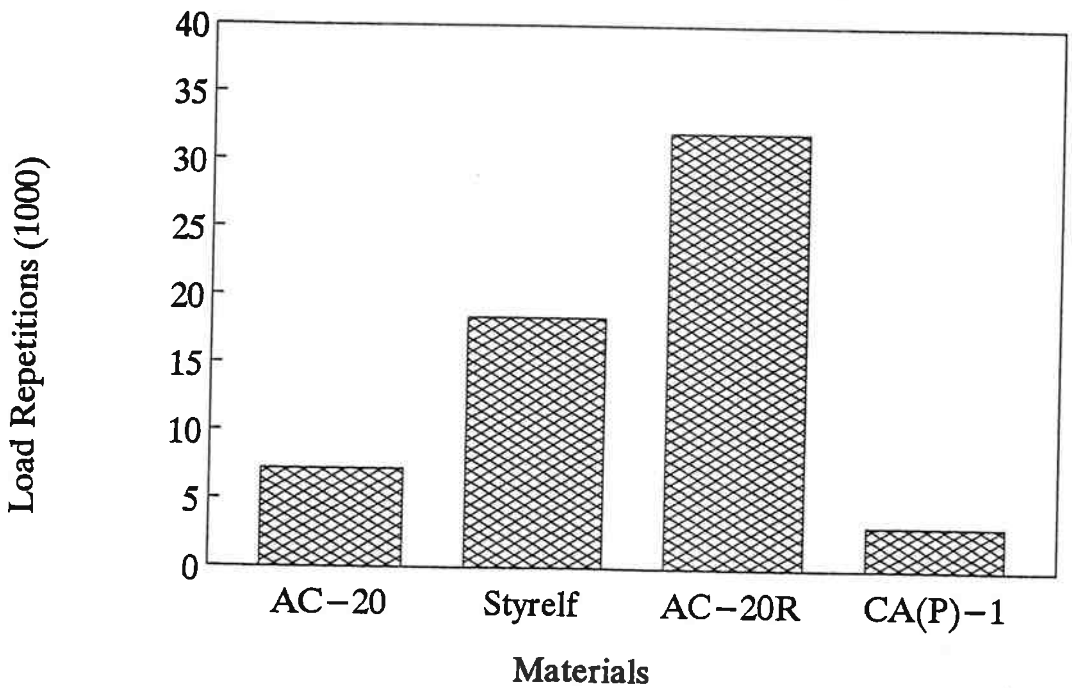


Figure 5.9 Laboratory Fatigue Test Results

6.0 PERFORMANCE EVALUATION

Performance evaluations were conducted by the ODOT Research Unit on an annual basis since the completion of the construction. The evaluations included visual surface inspections and friction and roughness tests.

6.1 1989 SURVEY

6.1.1 VISUAL INSPECTIONS

Visual inspections conducted in 1989 (shortly after the construction) indicated that the new wearing course of all materials was in an excellent condition. There were no cracks or other types of surface distress. However, it was noticed that before the wearing course was placed in 1989, there were 1/16" to 1/8" wide transverse cracks completely across the roadway at a frequency of 90 cracks per mile in the new base course. The base course was constructed directly on the existing pavement in the Fall of 1988. There were three possible causes for the transverse cracks: 1) reflective cracking from the existing pavement, 2) shrinkage cracking caused from the cement treated base, and 3) binder's inability to resist lower temperature cracking. As mentioned in Chapter 2, the base course was constructed with AR-4000 paving asphalt which, from the laboratory test result, had a penetration value of 1 at 39.2°F, 100g, 5s. Based on Gaw's procedure (Gaw, 1978), the binder with this penetration value would crack at a temperature below approximately 5°F (through extrapolation). The lowest temperature in this area is generally below 0°F.

Regardless of what caused these cracks in the base course, these cracks could have considerable effects on the performance of the wearing course.

6.1.2 FRICTION TEST

The pavement surface friction was measured before construction in 1988 and shortly after construction. All testing was done in accordance with AASHTO T242-84 and was performed at speeds near 40 mph in the left wheel path of the outer lane. The test data was adjusted to standard 40-mph friction number (FN_{40}) using correlation equations. Table 6.1 summarizes the test results. All test sections had acceptable FNs_{40}s, but the FN_{40}s were lower than that of the old roadway. There are two possible reasons: 1) the old pavement surface was much rougher due to raveling and cracking than the new overlay, and 2) the asphalt coating on the surface of the new mixtures reduces the friction between vehicle tires and pavement surface. Based on ODOT experience with open-graded pavements, these lower friction numbers are typical compared to other new pavements and as the asphalt coating on the top of the surface wears off, the friction numbers will increase.

Table 6.1: Summary of 1989 Friction Test Result

Section	Surface Material	Friction Number
Old Roadway	Conventional AC	55
1	Styrelf	46
2	AC-20	46
3	Styrelf	46
4	AC-20R	46
5	AC-20	46
6	CA(P)-1	43
7	AC-20	46

Table 6.2: Summary of 1989 Roughness Test Results

Section	Surface Material	Roughness Mays Inch/mile
Old Roadway	Conventional AC	48
1	Styrelf	45
2	AC-20	38
3	Styrelf	56
4	AC-20R	43
5	AC-20	30
6	CA(P)-1	36
7	AC-20	44

6.1.3 ROUGHNESS TEST

The pavement roughness was measured using a May's ride meter shortly after construction in 1989. The roughness values are summarized in Table 6.2. As expected, all test sections were smooth using the ODOT paving award criteria *(Miller and Scholl, 1990)*.

6.2 SURVEYS SINCE 1990

6.2.1 VISUAL INSPECTIONS

From 1990 to 1993, four separate pavement condition surveys were conducted. The surveys were taken in the spring or summer of the year. Table 6.3 presents the summary of the survey results. General observations from these surveys are:

1) In 1990, there were no transverse cracking on sections 1 to 4. There was an average of 10 cracks per mile on section 5 (AC-20); and 2 cracks per mile on section 6 (Styrelf) and section 7 (AC-20R). There was no rutting on section 1 (Styrelf), approximately 1/8" ruts on section 2 (AC-20), and about 1/16" ruts on all other sections.

2) In 1991, all sections showed transverse cracking at varying spacing and with a low level of severity. Section 1 (Styrelf) had more transverse cracks per mile than other sections. Section 4 (AC-20R) had the least amount of transverse cracks per mile. All transverse cracks were low level in severity. Rut depths on all sections were generally the same as measured the previous year. No stripping was found during visual examination of the cores.

3) The survey results from 1992 and 1993 indicate that there were no new transverse cracks. Some of the existing ones extended slightly towards the pavement edge. The level of severity of the cracks increased on most of the sections from low to medium, particularly on the AC-20 and CA(P)-1 sections. Rut depths on most of the sections also increased slightly from 1992 to 1993. Current (1993) pavement conditions of each section are shown in Figures B.2 to B.8 (see Appendix B).

Table 6.3: Summary of Condition Survey 1990-1993

Section	Mix Type	Average Crack Spacing (ft)	Severity	Rutting (inch)	Remarks
1990					
1	Styrelf	No crack	N/A	0	All sections were in an excellent condition.
2	AC-20	No crack	N/A	1/8	
3	Styrelf	No crack	N/A	1/16	
4	AC-20R	No crack	N/A	1/16	
5	AC-20	~530	L	1/16	
6	CA(P)-1	~2640	L	1/16	
7	AC-20R	~2640	L	1/16	
1991					
1	Styrelf	~80	L	1/16	Cores were taken from all sections for examination of stripping. No stripping was found.
2	AC-20	~140	L	1/8	
3	Styrelf	~135	L	1/16	
4	AC-20R	~165	L	1/16	
5	AC-20	~115	L	1/16	
6	CA(P)-1	~120	L	1/16	
7	AC-20R	~110	L	1/16	

N/A = Not Applicable: L = Low

Table 6.3: Summary of Condition Survey 1990-1993 (cont.)

Section	Mix Type	Average Crack Spacing (ft)	Severity	Rutting	Remarks
1992					
1	Styrelf	~80	L	1/6	There appear to be no more new transverse cracks. Some of the existing ones extended towards the pavement edge.
2	AC-20	~140	L	1/4	
3	Styrelf	~135	L	1/8	
4	AC-20R	~165	L	1/8	
5	AC-20	~115	L	1/8	
6	CA(P)-1	~120	L	1/8	
7	AC-20R	~110	L	1/8	
1993					
1	Styrelf	~80	L to M	1/6	No new transverse cracks were found. There were noticeable losses of aggregate on the AC-20 sections.
2	AC-20	~140	M	1/4	
3	Styrelf	~135	L to M	1/6	
4	AC-20R	~165	L to M	1/6	
5	AC-20	~115	M	1/6	
6	CA(P)-1	~120	M	1/6	
7	AC-20R	~110	L	1/6	

L = Low: M = Medium.

6.2.2 FRICTION TEST

A second friction test was performed in the summer of 1991. The test results are summarized in Table 6.4. The FNs are about the same on all sections and have increased compared to the 1989 measurements (Table 6.1).

6.2.3 ROUGHNESS TEST

Roughness tests performed in 1990 indicate that the pavement surfaces are slightly rougher than they were in 1989. This can be seen from the Mays meter readings provided in Table 6.5. Percent of change from 1989 to 1990 varies for each section. The AC-20 sections showed greatest changes (>30%) among all the sections. However, all sections of pavement surface were considered "smooth" based on OSHD Paving Award Criteria.

6.3 DISCUSSION ON THE LABORATORY TEST RESULTS WITH FIELD PERFORMANCE

Based on the field performance data collected so far, it appears all sections of the pavement have been performing well. There is no clear evidence as to which section or material is superior.

Comparing the laboratory test results to field performance, it appears that the force ductility, toughness and tenacity tests may be able to assess the binder's tensile and tenacious properties. In the 1993 survey, the loss of coarse aggregate in the wheel paths on the AC-20 sections was more noticeable than that from the polymer modified AC sections. This seems to support the force ductility, toughness and tenacity test results which all indicated that AC-20 asphalt had lowest values among all binders.

The Gaw procedure predicted much lower cracking temperatures than those measured in the laboratory Fraass test. Based on the Gaw procedure, all binders should be able to resist low temperature cracking to at least -22°F. In the last few years, the lowest temperature recorded at the project site was not less than -22°F. Therefore, the transverse cracks observed in all sections of the pavement may have resulted from either reflective cracking of the AC base course and/or shrinkage cracking of the CTB. Or the Gaw procedure may have overestimated the temperature at which the binder would crack.

Table 6.4: Summary of 1991 Friction Test Results

Section	Surface Material	Friction Number
1	Styrelf	54
2	AC-20	57
3	Styrelf	56
4	AC-20R	53
5	AC-20	55
6	CA(P)-1	N/A
7	AC-20	53

N/A = Not Available

Table 6.5: Summary of 1990 Roughness Test Results

Section	Surface Material	Roughness Mays Inch/mile	% Change Compared to 1989's
1	Styrelf	50	11
2	AC-20	51	34
3	Styrelf	55	-2
4	AC-20R	49	14
5	AC-20	41	37
6	CA(P)-1	44	22
7	AC-20	49	11

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory test results and field performance data collected to date, the following conclusions and recommendations can be drawn.

7.1 CONCLUSIONS

1) The laboratory test results suggest polymer modified asphalt (Styrelf, AC-20R, and CA(P)-1) could be less temperature susceptible than the conventional AC-20 asphalt.

2) The polymer modified binders are much tougher and more tenacious and ductile than the conventional AC-20 asphalt.

3) Fraass test results show the Styrelf, AC-20R, and CA(P)-1 asphalts have lower cracking temperatures than the conventional AC-20 asphalt.

4) Conventional construction processes are suitable to the construction of the Styrelf, AC-20R, and CA(P)-1 modified asphalt mixtures. The Styrelf and AC-20R asphalt tended to migrate to the bottom of the mix. Therefore, appropriate control of mixing temperature is important.

5) The laboratory test results show that the conventional AC-20 has higher resilient modulus than the Styrelf and AC-20R modified AC and a similar resilient modulus to that of the CA(P)-1 modified AC. While the laboratory fatigue test showed that the conventional AC-20 AC had a lower fatigue life than the Styrelf and AC-20R modified AC, but had a slightly higher fatigue life than that of CA(P)-1 modified AC.

6) The primary surface distress on all sections is transverse cracking. This transverse cracks very likely resulted from reflective cracking from the base course and the existing pavement. The level of severity ranged from low to medium. The AC-20 sections also showed a more noticeable loss of aggregate than other polymer modified AC sections.

7) The roughness test results showed the Styrelf sections are slightly rougher than other sections, but the AC-20 sections had the greatest increase in roughness from 1989 to 1990.

8) In general, both the AC-20 (control) sections and polymer modified (test) sections have been performing well. There is no clear distinction as to which section is superior. As of today, all sections of pavement have carried over 1.5 million EALs.

7.2 RECOMMENDATIONS

If funding is available, the performance of both the test and control sections should be monitored periodically until the pavement sections fail. The friction and roughness tests are recommended to be conducted every two years. Resilient modulus and fatigue tests on core samples from each section should be ideally performed every year. Consistency tests on recovered asphalt from both conventional and polymer modified AC sections are also recommended to be performed every two years. The above recommended tests should be useful to the evaluation of the pavement performance and the determination of changes in material properties after years of road service.

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APPENDIX A
CRACK MAPS OF ORIGINAL PAVEMENT SECTION

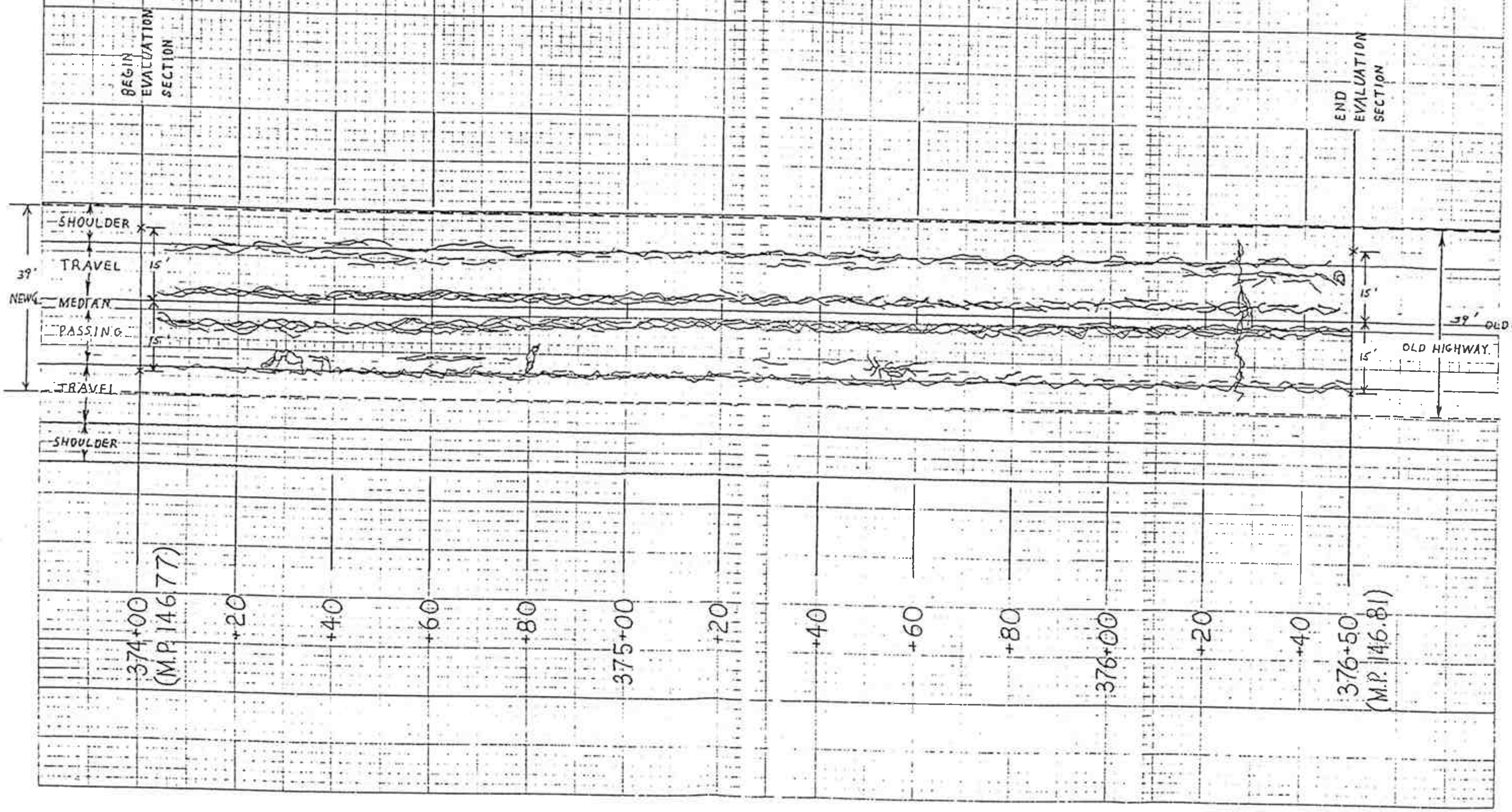
CRACK MAP

CLASS "F" EVALUATION SECTION No. 1: STATIONS 374+00 to 376+50

DATE: MAY 20, 88 SCALE: 1in=20ft

MAPPER: J. RUSNAK COMMENTS:

1. IN SIDE WHEEL PATHS MEDIUM SEVERITY ALLIGATOR CRACKING (NB & SB)
2. LOW - SEVERITY ALLIGATOR CRACKING NEAR LONGITUDINAL JOINT IN SHOULDER (NB & SB)
3. FINE LONGITUDINAL CRACKS IN WHEEL PATHS (NB & SB)
4. LOW SEVERITY LONGITUDINAL NEAR STATION 376+25 ACROSS BOTH LANES
5. LOW SEVERITY BLOCK CRACKING BETWEEN STATION 374+20 and 374+40 SOUTH BOUND

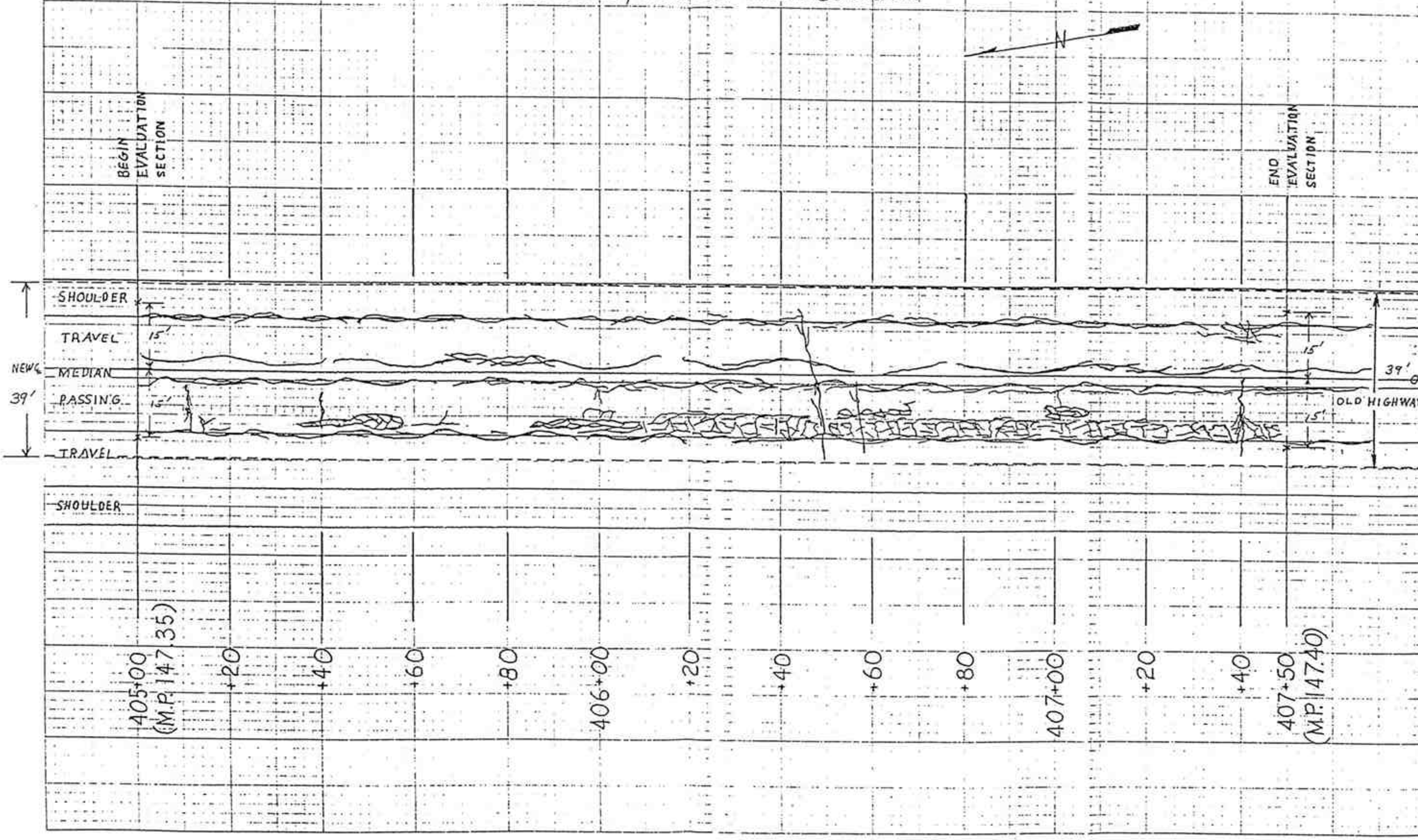


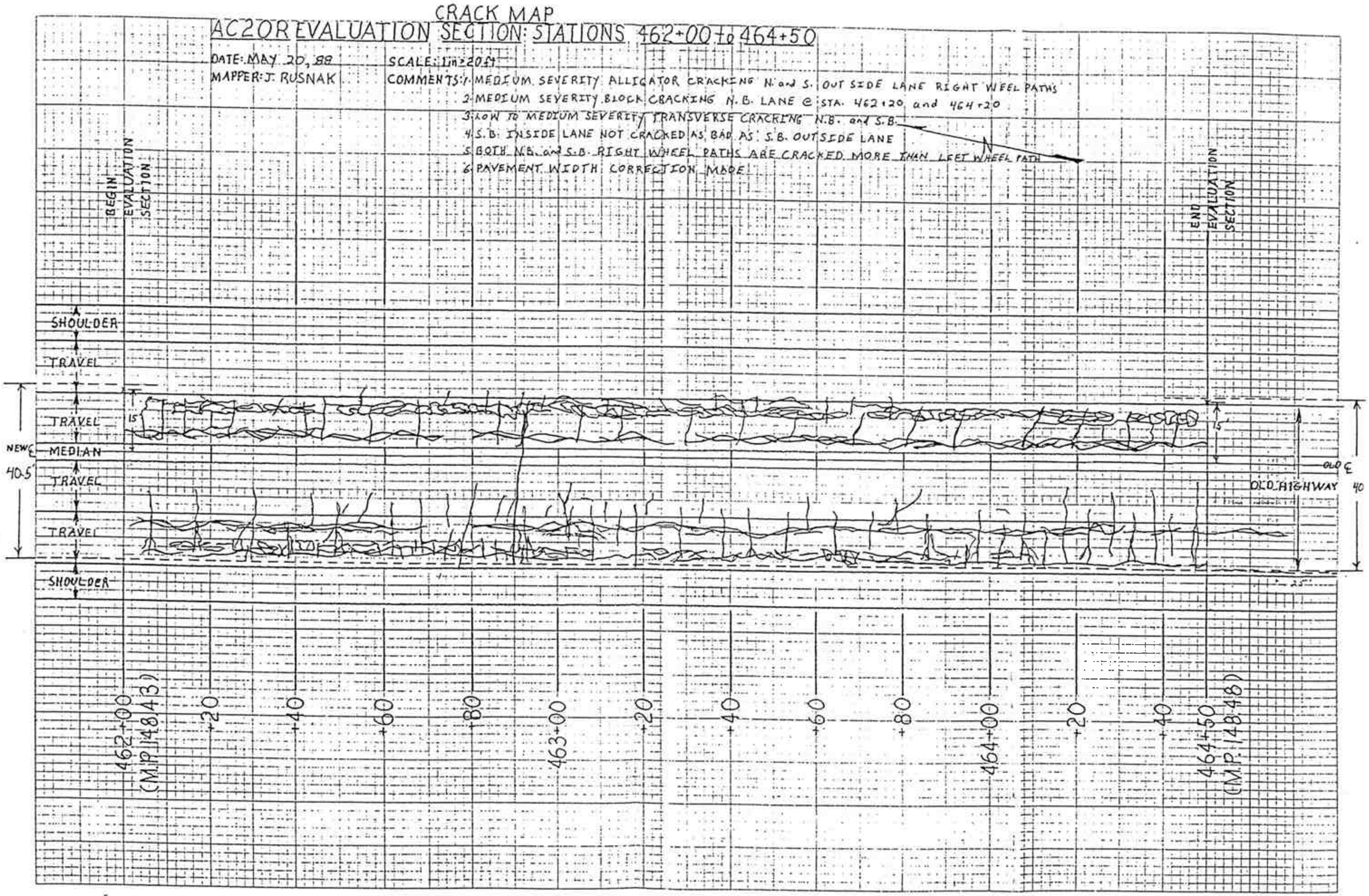
CRACK MAP

STYRELF EVALUATION SECTION No. 2: STATIONS 405+00 to 407+50

DATE: MAY 20, 1988. SCALE: 1in = 20 ft

MAPPER: J. RUSNAK COMMENTS: 1. LOW-MEDIUM-HIGH SEVERITY ALLIGATOR CRACKING IN WHEEL PATHS.
2. MEDIUM SEVERITY TRANSVERSE CRACKING @ STA. SHOWN





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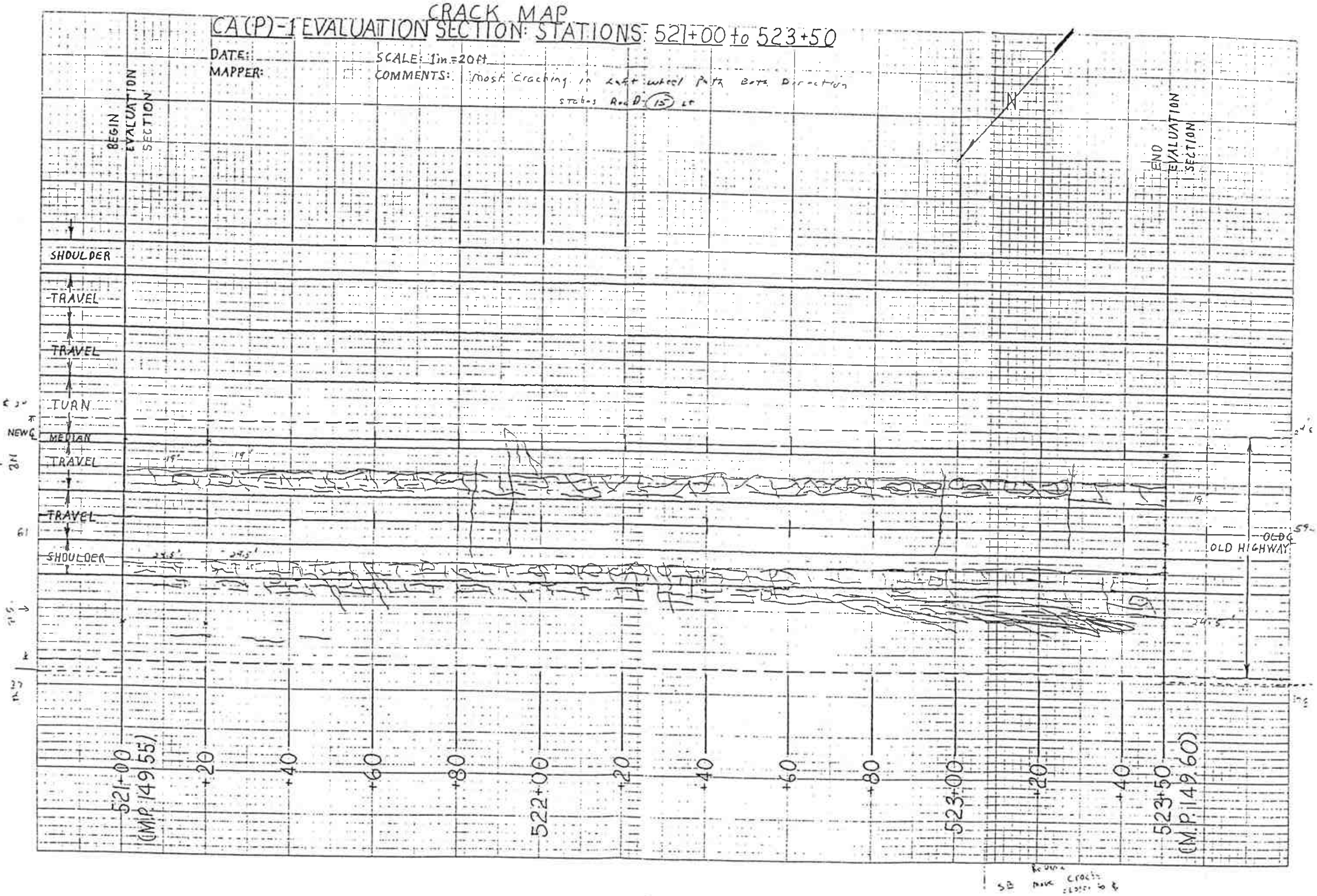
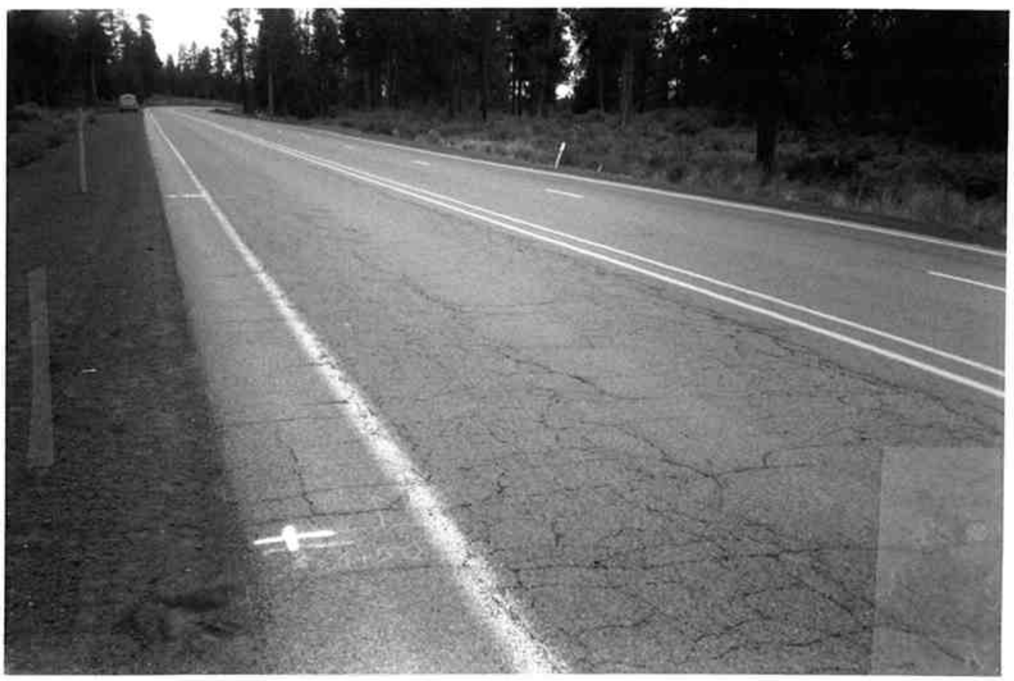


CRACK MAP
CA(P)-1 EVALUATION SECTION: STATIONS: 521+00 to 523+50
DATE:
MAPPER:
SCALE: 1in.=20ft
COMMENTS: most cracking in left wheel path both direction
BEGIN EVALUATION SECTION
END EVALUATION SECTION
SHOULDER
TRAVEL
TRAVEL
TURN
NEW ℄
MEDIAN
TRAVEL
TRAVEL
SHOULDER
OLD ℄
OLD HIGHWAY
N
521+00
(MP 149.55)
+20
+40
+60
+80
522+00
+20
+40
+60
+80
523+00
+20
+40
523+50
(M.P. 149.60)
19'
24.5'

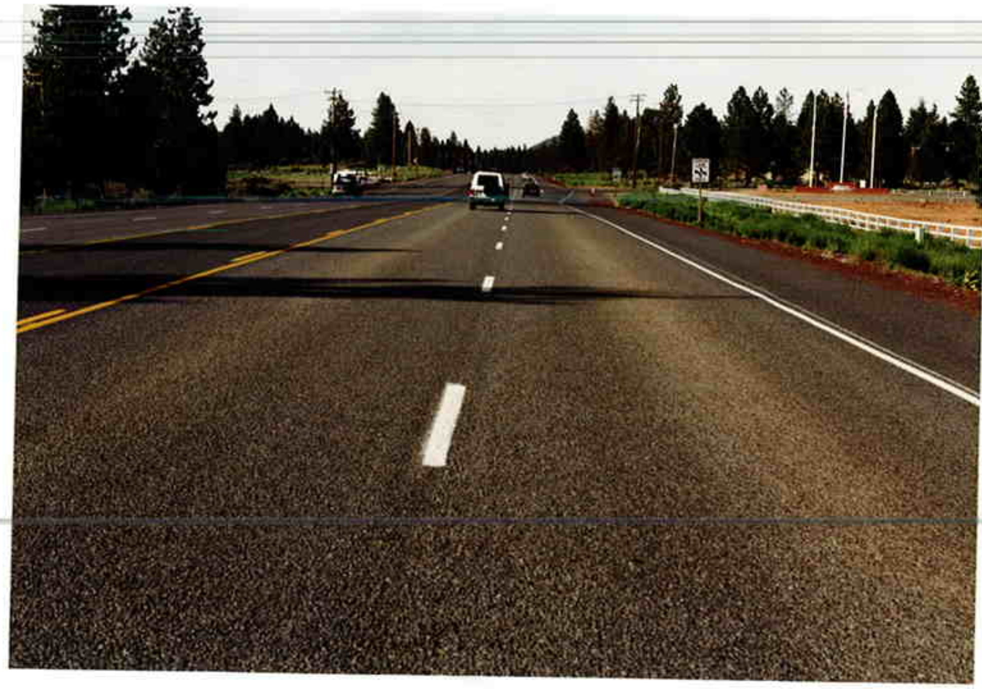
APPENDIX B
PHOTOGRAPHS

a) At M.P. 148.46

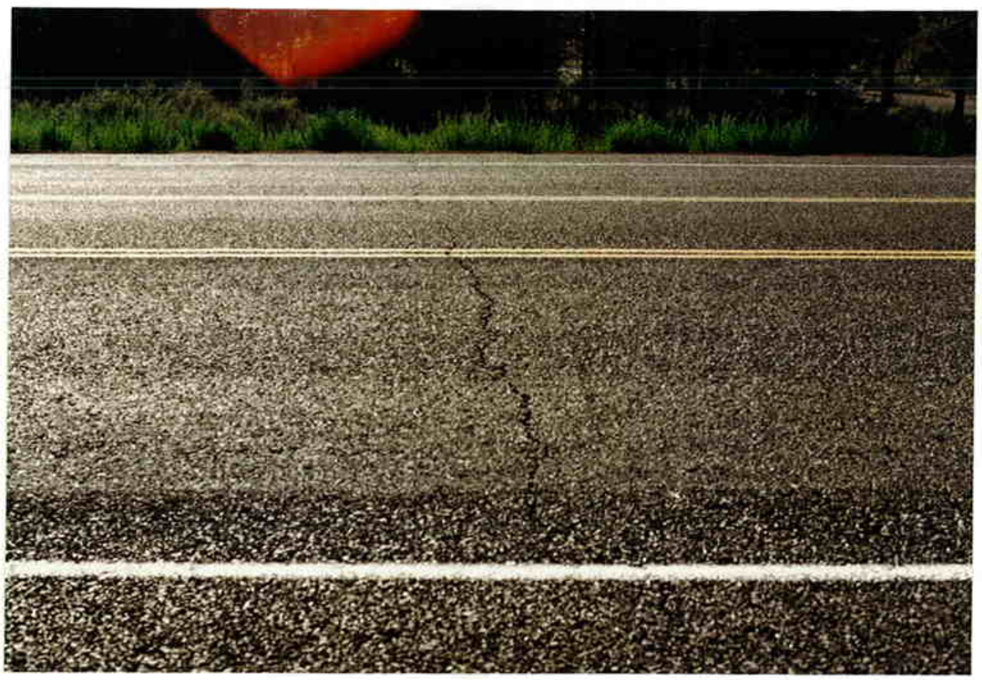


b) At M.P. 148.48

Figure B.1 Typical Pavement Condition Prior to Construction

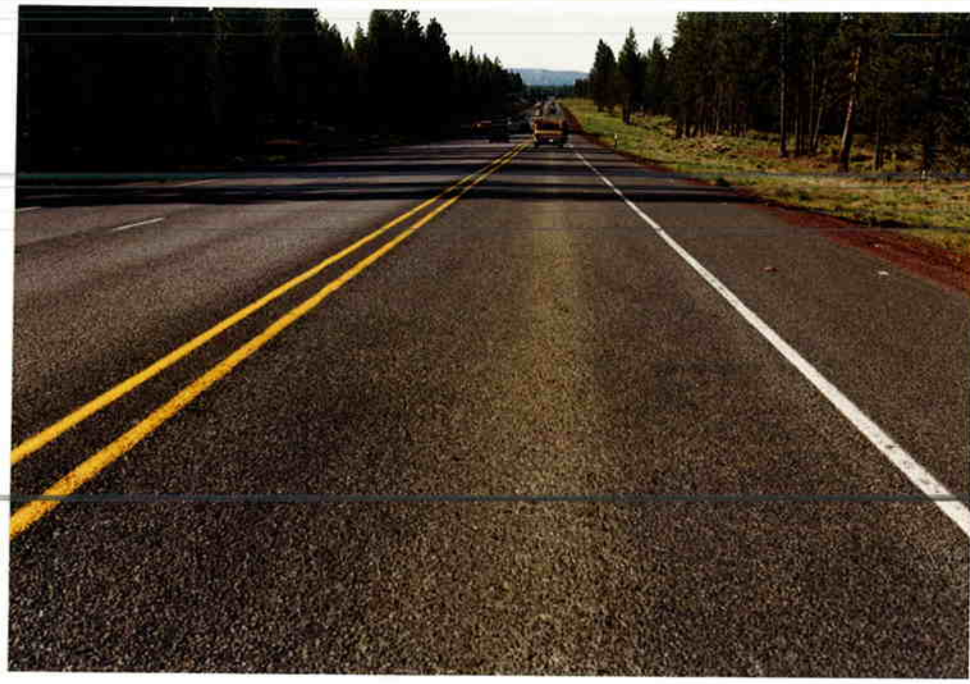


a) Typical Pavement Condition

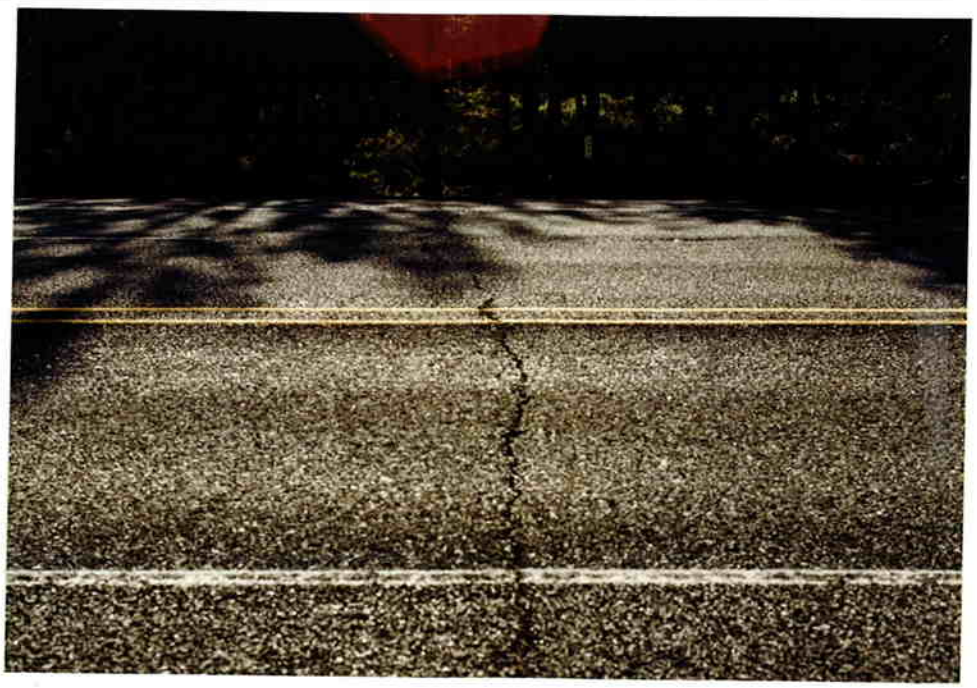


b) Typical Transverse Cracking

Figure B.2 1993 Pavement Condition, Section 1 - Styrelf



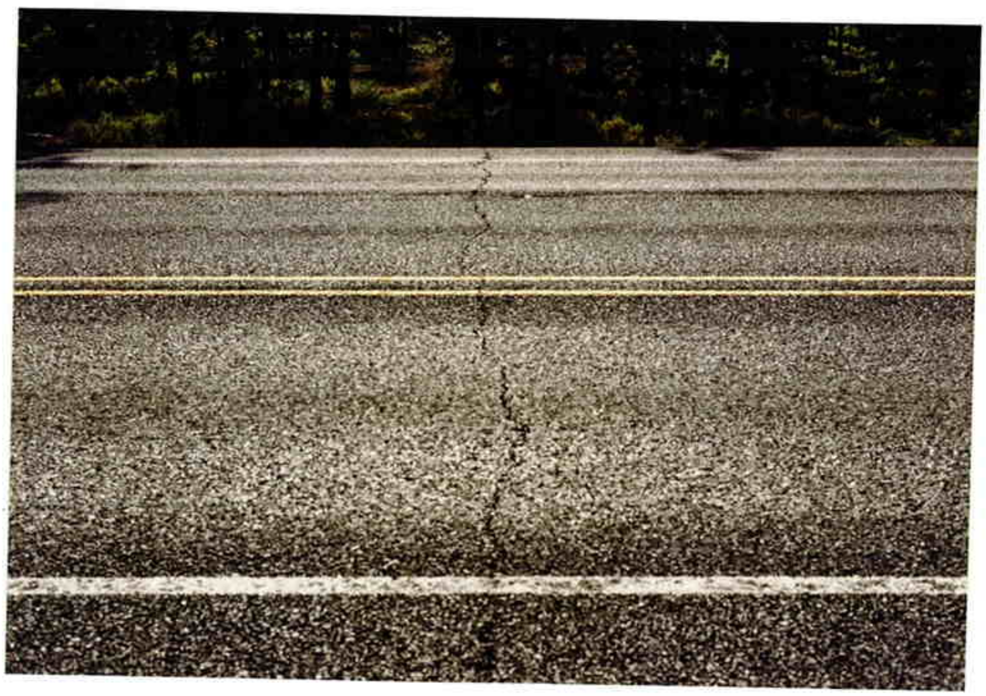
a) Typical Pavement Condition



b) Typical Transverse Cracking

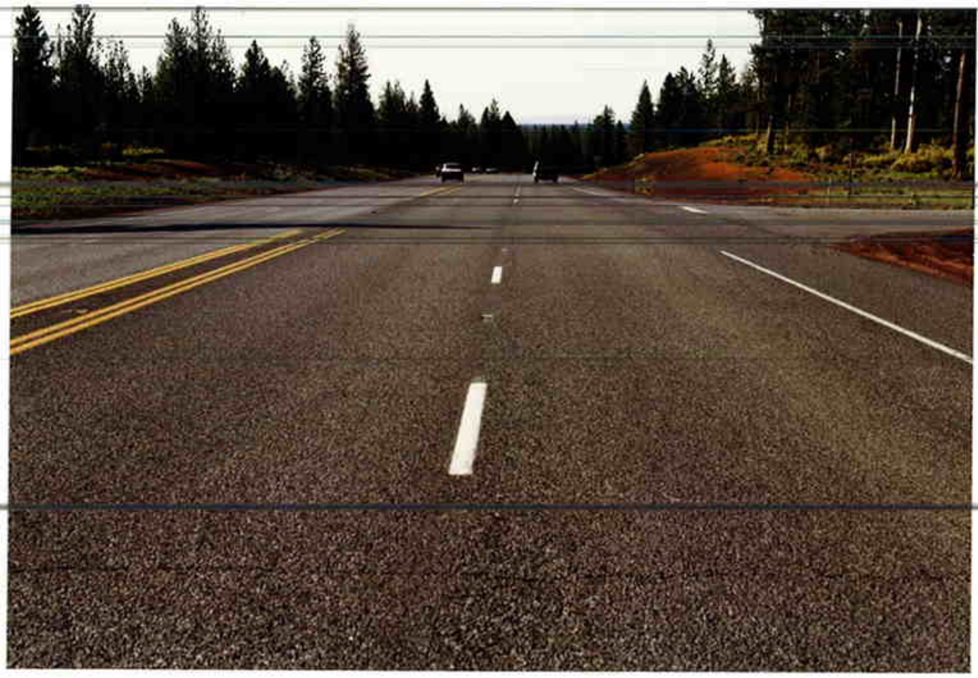
Figure B.3 1993 Pavement Condition, Section 2 - AC-20

a) Typical Pavement Condition

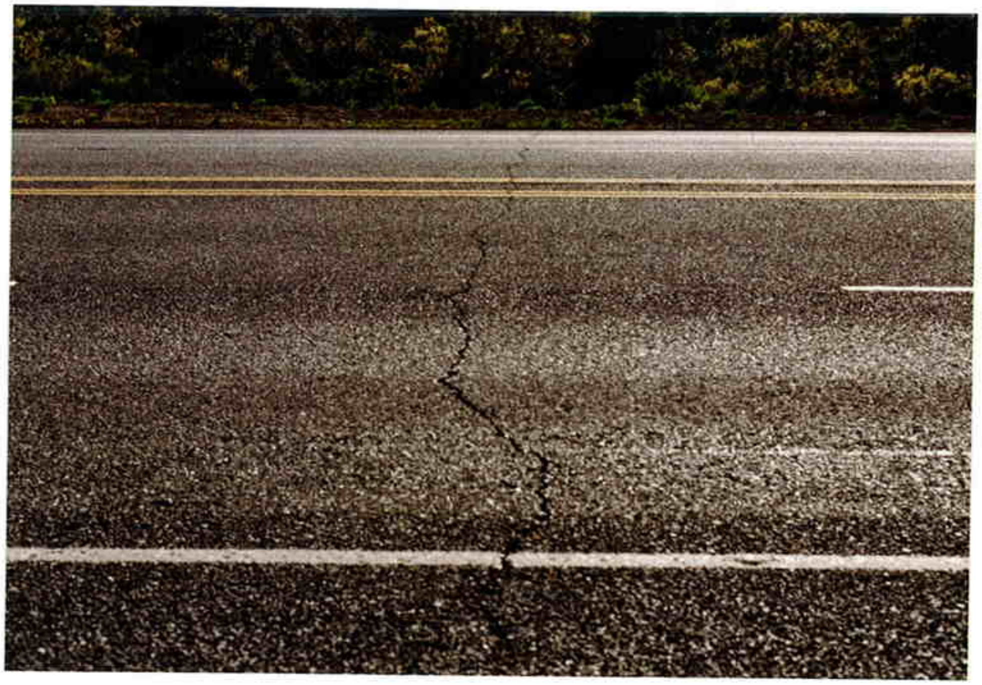


b) Typical Transverse Cracking

Figure B.4 1993 Pavement Condition, Section 3 - Styrelf

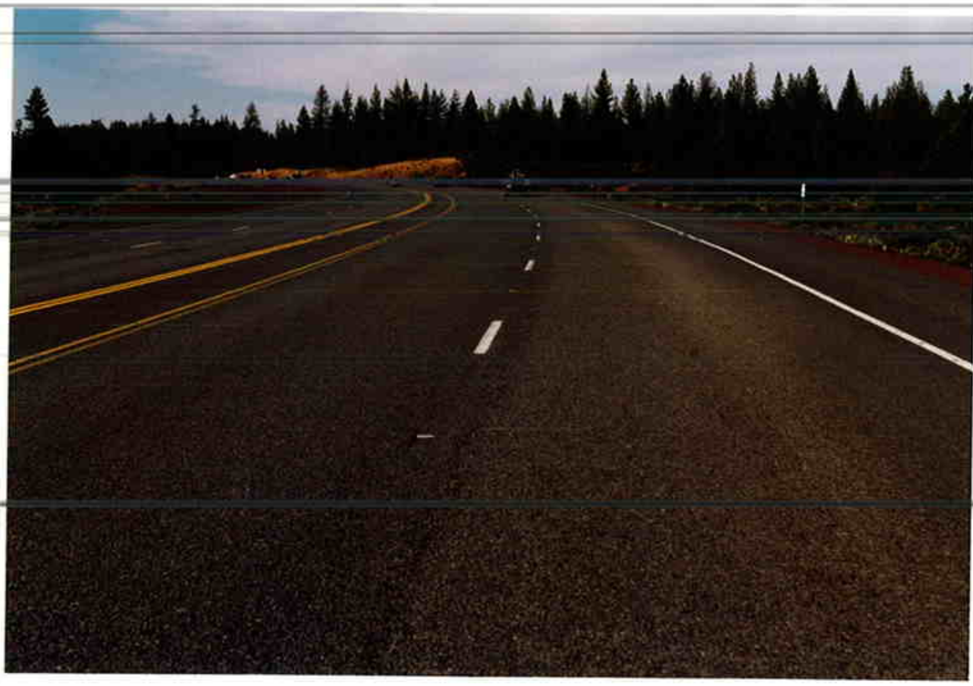


a) Typical Pavement Condition



b) Typical Transverse Cracking

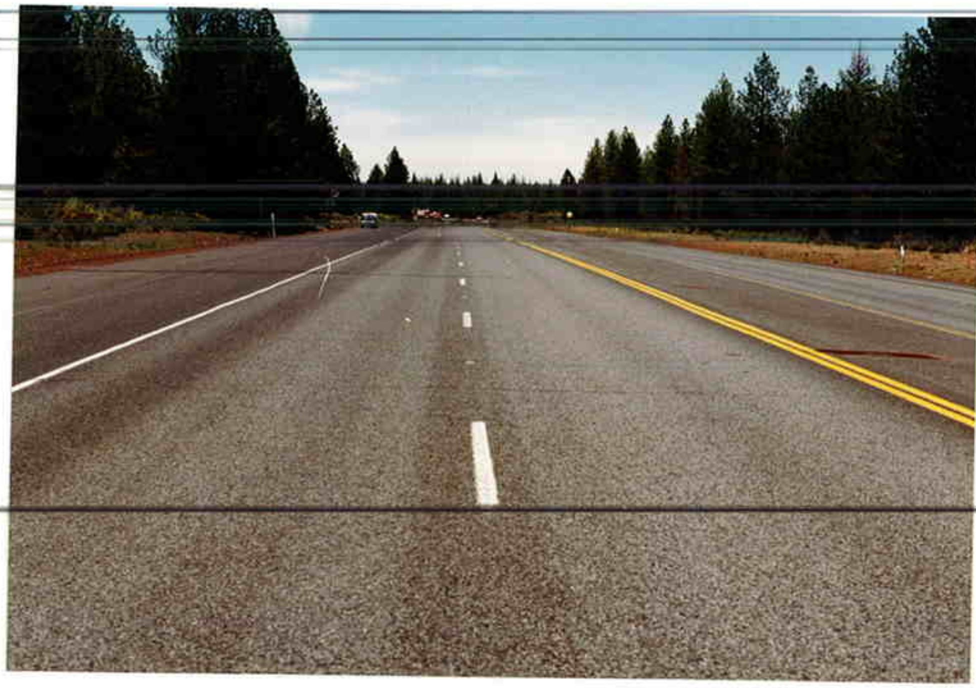
Figure B.5 1993 Pavement Condition, Section 4 - AC-20R



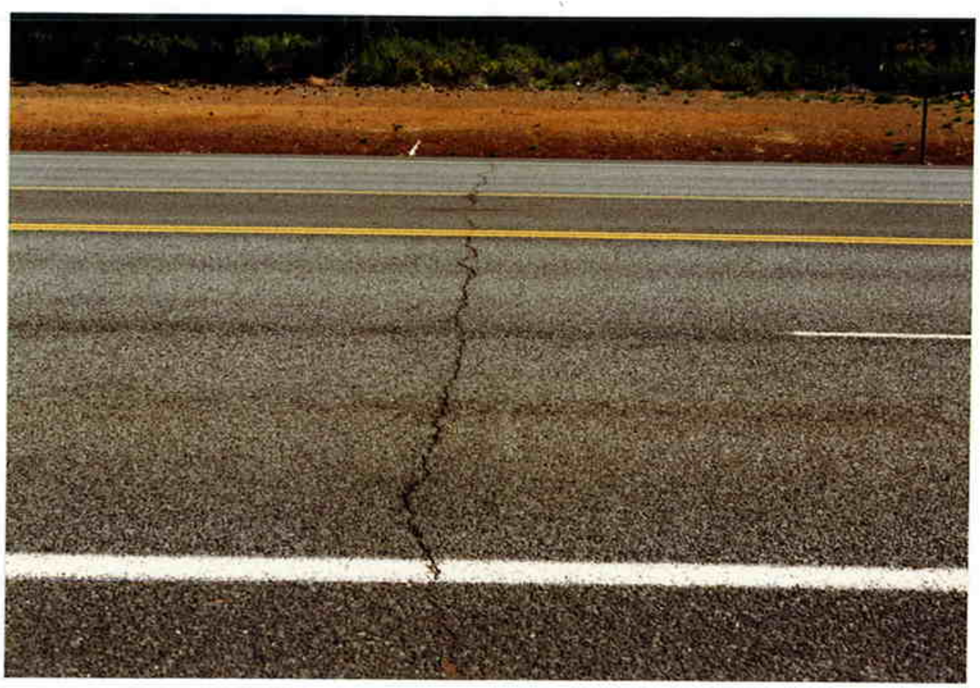
a) Typical Pavement Condition

b) Typical Transverse Cracking

Figure B.6 1993 Pavement Condition, Section 5 - AC-20



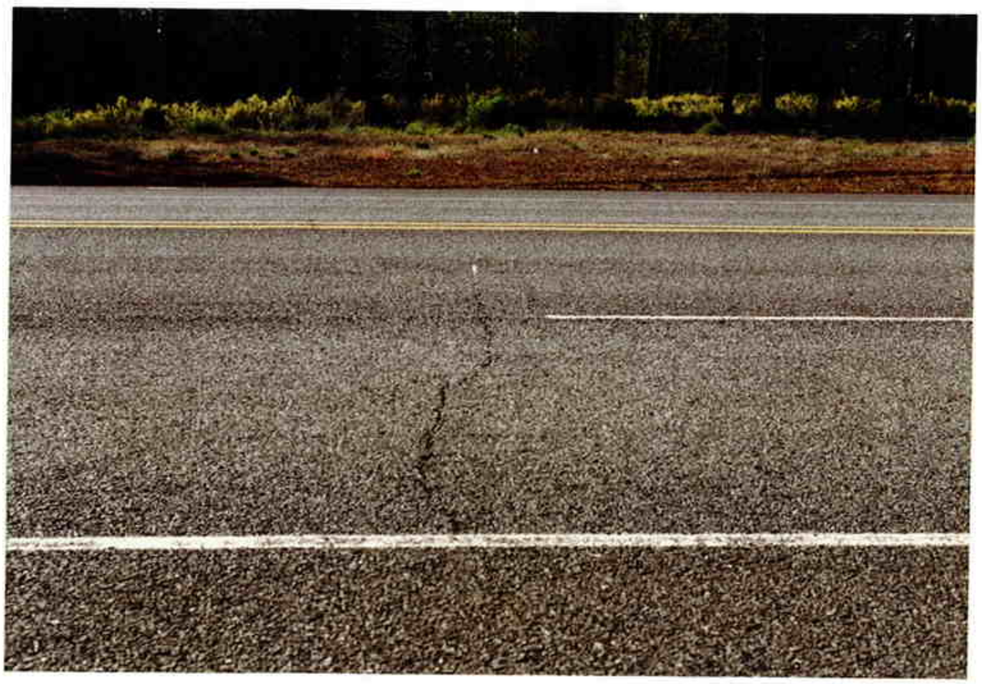
a) Typical Pavement Condition



b) Typical Transverse Cracking

Figure B.7 1993 Pavement Condition, Section 6 - CA(P)-1

a) Typical Pavement Condition



b) Typical Transverse Cracking

Figure B.8 1993 Pavement Condition, Section 7 - AC-20R

APPENDIX C
ORIGINAL BINDER PROPERTIES

Table C.1: Binder Properties of Original AC-20

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	30[a], 29, 29, 33, 28		30	2
Pen @ 77°F, 100g, 5 sec (dmm)	67[a], 72, 70 71, 70	50 (min)	70	2
Abs Vis @ 140°F (poise)	2200[a], 1980, 2190, 2170, 2210	1600 (min) 2400 (max)	2150	96
Kin Vis @ 275°F (cSt)	398[a], 391	230 (min)	395	-
Ring & Ball Softening Point (°F)	120[a], 130		125	-
Duct @ 39.2°F, 5cm/min (cm)	7		7	-
Duct @ 77°F, 5cm/min (cm)	150+		150+	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	110, 97, 100		100	10
b) Maximum Engineering Strain (in/in)	35, 17, 47+		33+	-
c) Maximum Engineering Work (lbf-in)	58, 46, 58		54	7
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	.62[b], .97, .65		.81	-
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	1.2, .25, 0		.48	.6
Toughness (lb-in)	76		76	-
Tenacity (lb-in)	37		37	-
Elastic Recovery @ 50°F (%)	10		10	-
Pen @ 39.2°F, 200g 60 sec (dmm)	30[a], 29, 29, 33, 28		30	2
Fraass Point (°F)	16, 21		19	-
Solubility in Trichloroethylene (%)	99.97[a], 99.99	99.0 (min)	99.98	-

[a] Mix design sample

[b] Considered outlier during calculation of average.

Table C.2: Binder Properties of Original Styrelf

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	50[a], 50		50	-
Pen @ 77°F, 100g, 5 sec (dmm)	111[a], 110	60 (min)	111	-
Abs Vis @ 140°F (poise)	1770[a], 1970, 2040, 2250	1600 (min) 2400 (max)	2008	198
Kin Vis @ 275°F (cSt)	555[a], 588	300 (min)	572	-
Ring & Ball Softening Point (°F)	124[a], 136		130	-
Duct @ 39.2°F, 5cm/min (cm)	47		47	-
Duct @ 77°F, 5cm/min (cm)	150+		150+	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	32, 33, 38		34	3
b) Maximum Engineering Strain (in/in)	25, 34, 41+		33	8
c) Maximum Engineering Work (lbf-in)	71, 82, 89		81	9
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	0, .48, .65		.38	.34
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	0, 1.9, 1.9		1.3	1.1
Toughness (lb-in)	174		174	-
Tenacity (lb-in)	152		152	-
Elastic Recovery @ 50°F (%)	65[a], 70, 68, 68	58 (min)	68	2
Flash Point, COC, (°F)	570[a], 535	450 (min)	553	-
Fraass Point (°F)	-2, -2, -1		-1	2
Solubility in Trichloroethylene (%)	99.97[a], 99.99	99.0 (min)	99.98	-
Tensile Stress @ 800% Elongation, 68°F, 500cm/min pull (kg/cm^2)	b	3 (min)	-	-

[a] Mix design sample
[b] Test not used.

Table C.3: Binder Properties of AC-20R

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	- 48		48	-
Pen @ 77°F, 100g, 5 sec (dmm)	103[a], 107		105	-
Abs Vis @ 140°F (poise)	1860[a], 1980, 1900 1890, 1820	1600 (min) 2400 (max)	1890	59
Kin Vis @ 275°F (cSt)	645[a], 653	325 (min)	649	-
Ring & Ball Softening Point (°F)	138[a], 128		133	-
Duct @ 39.2°F, 5cm/min (cm)	50+[a], 50+, 50+ 50+ 50+	50 (min)	50+	-
Duct @ 77°F, 5cm/min (cm)	100+[a], 100+	100 (min)	100+	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	39, 62, 48		49	12
b) Maximum Engineering Strain (in/in)	47+, 47+, 46		47+	-
c) Maximum Engineering Work (lbf-in)	120, 120, 140		130	10
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	.65, 1.3, 1.3		1.1	. 4
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	7.8, 7.3, 5.5		6.7	1.2
Toughness (lb-in)	223[a], 208	100 (min)	216	-
Tenacity (lb-in)	205[a], 189	75 (min)	197	-
Elastic Recovery @ 50°F (%)	58		58	2
Flash Point, coc, (°F)	550[a], 530	450 (min)	540	-
Fraass Point (°F)	3, 1, 5		3	2

[a] Mix design sample

Table C.4: Binder Properties of Original CA(P)-1

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	-, 43		43	-
Pen @ 77°F, 100g, 5 sec (dmm)	112[a], 112	85 (min)	112	-
Abs Vis @ 140°F (poise)	1850[a], 1810, 1910	1600 (min) 2400 (max)	1857	50
Kin Vis @ 275°F (cSt)	586[a], 627	325 (min)	607	-
Ring & Ball Softening Point (°F)	124		124	-
Duct @ 39.2°F, 5cm/min (cm)	50+[a], 50+, 25	25 (min)	42+	-
Duct @ 77°F, 5cm/min (cm)	100+[a], 100+	100 (min)	100+	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	50, 52		51	-
b) Maximum Engineering Strain (in/in)	23, 19		21	-
c) Maximum Engineering Work (lbf-in)	140, 120		130	-
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	.03, .03, .65		.24	.36
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	.05, .05, .53		.21	.28
Toughness (lb-in)	133[a], 196	75 (min)	165	-
Tenacity (lb-in)	116[a], 166	50 (min)	141	-
Elastic Recovery @ 50°F (%)	35		35	-
Flash Point, coc, (°F)	560[a], 575	450 (min)	568	-
Fraass Point (°F)	7, 7 14		9	4

[a] Mix design sample

Table C.5: Binder Properties of Residue AC-20 after RTFO

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	- 23		23	-
Pen @ 77°F, 100g, 5 sec (dmm)	37[a], 36		37	-
Abs Vis @ 140°F (poise)	6150[a], 6690	8000 (max)	6420	-
Kin Vis @ 275°F (cSt)	649[a], 681		665	-
Ring & Ball Softening Point (°F)	144		144	-
Duct @ 39.2°F, 5cm/min (cm)	0		0	-
Duct @ 77°F, 5cm/min (cm)	100+[a], 100+	75 (min)	100+	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	210, 230		220	-
b) Maximum Engineering Strain (in/in)	5.2, 7.8		6.5	-
c) Maximum Engineering Work (lbf-in)	82, 100		92	-
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	3.9, 4.5, 4.2		4.2	.3
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	.98, 1.9, 2.2		1.7	.6
Toughness (lb-in)	138		138	-
Tenacity (lb-in)	52		52	-
Elastic Recovery @ 50°F (%)	[b]		-	-
Fraass Point (°F)	21, 25 23		23	2
% Original Pen @ 77°F, Res/Orig (%)	55[a], 51		53	-
Visc Ratio @ 140°F, Res/Orig (%)	2.80[a], 3.08		2.94	-
Loss on Heating (%)	.54, .02		.28	-
"C" Value	35	30 (min)	35	-

[a] Mix design sample
[b] Sample broke at 10cm elongation. Unable to run test.

Table C.6: Binder Properties of Residue Styrelf after RTFO

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	- 37		37	-
Pen @ 77°F, 100g, 5 sec (dmm)	66[a], 67		67	-
Abs Vis @ 140°F (poise)	4850[a], 5780, 6000 6070		5675	564
Kin Vis @ 275°F (cSt)	960		960	-
Ring & Ball Softening Point (°F)	140		140	-
Duct @ 39.2°F, 5cm/min (cm)	24		24	-
Duct @ 77°F, 5cm/min (cm)	54		54	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	76, 74, 81		77	4
b) Maximum Engineering Strain (in/in)	18, 21, 19		19	2
c) Maximum Engineering Work (lbf-in)	120, 130, 130		130	10
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	1.6, .97, 1.3		1.3	. 3
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	6.2, 3.5, 5.7		5.1	1.5
Toughness (lb-in)	119		119	-
Tenacity (lb-in)	68		68	-
Elastic Recovery @ 50°F (%)	68		68	-
Fraass Point (°F)	3, -2, 7		3	5
% Original Pen @ 77°F, Res/Orig (%)	59[a], 61	50 (min)	60	-
Visc Ratio @ 140°F, Res/Orig (%)	2.74[a], 2.93, 2.94, 2.70	3.0 (max)	2.83	.12
Loss on Heating (%)	.24[a], .13		.19	-

[a] Mix design sample

Table C.7: Binder Properties of Residue AC-20R after RTFO

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	- 34		34	-
Pen @ 77°F, 100g, 5 sec (dmm)	58		58	-
Abs Vis @ 140°F (poise)	5040[a], 5360, 4910, 5140, 4840	8000 (max)	5058	205
Kin Vis @ 275°F (cSt)	877		877	-
Ring & Ball Softening Point (°F)	140		140	-
Duct @ 39.2°F, 5cm/min (cm)	41[a], 50+, 43, 44, 45	25 (min)	45+	-
Duct @ 77°F, 5cm/min (cm)	100+[a], 100+	100 (min)	100+	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	67, 88, 94		77	15
b) Maximum Engineering Strain (in/in)	25, 30, 22		26	4
c) Maximum Engineering Work (lbf-in)	130, 120, 150		130	10
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	.97, 1.8, 1.6		1.5	. 4
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	1.1, 2.1, 1.4		1.5	.5
Toughness (lb-in)	164		164	-
Tenacity (lb-in)	115		115	-
Elastic Recovery @ 50°F (%)	53		53	-
Fraass Point (°F)	5, 5, 1		4	2
% Original Pen @ 77°F, Res/Orig (%)	54		54	-
Visc Ratio @ 140°F, Res/Orig (%)	2.71[a], 2.71, 2.58, 2.72, 2.66		2.68	.06

[a] Mix design sample

Table C.8: Binder Properties of Residue CA(P)-1 after RTFO

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	- 25		25	-
Pen @ 77°F, 100g, 5 sec (dmm)	50		50	-
Abs Vis @ 140°F (poise)	4640[a], 5170, 5190,	10,000 (max)	5000	312
Kin Vis @ 275°F (cSt)	1100		1100	-
Ring & Ball Softening Point (°F)	142		142	-
Duct @ 39.2°F 5cm/min (cm)	27[a], 18, 21,	8 (min)	22	5
Duct @ 77°F, 5cm/min (cm)	100+[a], 100+	100 (min)	100+	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	79, 99, 130		100	26
b) Maximum Engineering Strain (in/in)	17, 13, 15		15	2
c) Maximum Engineering Work (lbf-in)	140, 130, 190		150	30
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	2.8, 2.9		2.9	-
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+		47+	-
c) Maximum Engineering Work (lbf-in)	3.9, 3.9		3.9	-
Toughness (lb-in)	140[a], 151	100 (min)	196	-
Tenacity (lb-in)	192[a], 102	75 (min)	147	-
Elastic Recovery @ 50°F (%)	35		35	-
Fraass Point (°F)	14, 14, 19		17	3
% Original Pen @ 77°F, Res/Orig (%)	45		45	-
Visc Ratio @ 140°F, Res/Orig (%)	2.51[a], 2.86, 2.72		2.70	.18

[a] Mix design sample

APPENDIX D
RECOVERED BINDER PROPERTIES

Table D.1: Binder Properties of Recovered AC-20R

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	- 22	-	22	-
Pen @ 77°F, 100g, 5 sec (dmm)	41	-	41	-
Abs Vis @ 140°F (poise)	3110, 5790	-	4450	-
Kin Vis @ 275°F (cSt)	598	-	598	-
Ring & Ball Softening Point (°F)	144	-	144	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	140, 150, 160	-	150	10
b) Maximum Engineering Strain (in/in)	5.0, 6.7, 10	-	7.2	2.5
c) Maximum Engineering Work (lbf-in)	56, 64, 72	-	64	8
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	2.3, 2.6, 2.7	-	2.5	. 2
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+	-	47+	-
c) Maximum Engineering Work (lbf-in)	.98, 1.5, 1.4	-	1.3	.3
Toughness (lb-in)	80	-	80	-
Tenacity (lb-in)	18	-	18	-
Elastic Recovery @ 50°F (%)	a	-	-	-

Table D.2: Binder Properties of Recovered Styrelf

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	35	-	35	-
Pen @ 77°F, 100g, 5 sec (dmm)	63	-	63	-
Abs Vis @ 140°F (poise)	4850	-	4850	-
Kin Vis @ 275°F (cSt)	861	-	861	-
Ring & Ball Softening Point (°F)	140	-	140	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	59, 71, 63	-	64	6
b) Maximum Engineering Strain (in/in)	17, 13, 17	-	16	2
c) Maximum Engineering Work (lbf-in)	110, 110, 110	-	110	0
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	1.6, 1.5,, 1.5	-	1.5	. 1
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+	-	47+	-
c) Maximum Engineering Work (lbf-in)	7.3, 7.0, 6.6	-	7.0	.3
Toughness (lb-in)	87	-	87	-
Tenacity (lb-in)	48	-	48	-
Elastic Recovery @ 50°F (%)	[b]	-	-	-

[a] Sample broke at 8cm elongation. Unable to complete test

[b] Sample broke at 6cm elongation. Unable to complete test.

Table D.3: Binder Properties of Recovered AC-20R

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	26	-	26	-
Pen @ 77°F, 100g, 5 sec (dmm)	50	-	50	-
Abs Vis @ 140°F (poise)	5210	-	5210	-
Kin Vis @ 275°F (cst)	964	-	964	-
Ring & Ball Softening Point (°F)	136	-	136	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	64, 79, 87	-	77	12
b) Maximum Engineering Strain (in/in)	20, 20, 17	-	19	2
c) Maximum Engineering Work (lbf-in)	94, 120, 110	-	110	10
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	1.8, 1.5, 1.6	-	1.6	.1
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+	-	47+	-
c) Maximum Engineering Work (lbf-in)	3.1, 1.3, 1.8	-	2.1	.9
Toughness (lb-in)	124	-	124	-
Tenacity (lb-in)	56	-	56	-
Elastic Recovery @ 50°F (%)	50	-	50	-

Table D.4: Binder Properties of Recovered CA (P)-1

Test	Test Results	Specifications	Average Value	Standard Deviation
Pen @ 39.2°F, 200g, 60 sec (dmm)	25	-	25	-
Pen @ 77°F, 100g, 5 sec (dmm)	48	-	480	-
Abs Vis @ 140°F (poise)	5240	-	5240	-
Kin Vis @ 275°F (cSt)	1090	-	1090	-
Ring & Ball Softening Point (°F)	140	-	140	-
Force-Duct @ 39.2°F:				
a) Maximum Engineering Stress (lbf/in^2)	97, 130, 110	-	110	20
b) Maximum Engineering Strain (in/in)	12, 12, 18	-	14	3
c) Maximum Engineering Work (lbf-in)	130, 180, 180	-	160	30
Force-Duct @ 77°F:				
a) Maximum Engineering Stress (lbf/in^2)	2.4, 2.3, 2.6	-	2.4	.1
b) Maximum Engineering Strain (in/in)	47+ 47+ 47+	-	47+	-
c) Maximum Engineering Work (lbf-in)	3.4, 2.7, 3.0	-	3.0	.3
Toughness (lb-in)	219	-	219	-
Tenacity (lb-in)	101	-	101	-
Elastic Recovery @ 50°F (%)	35	-	35	-