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

The Dalles - California Highway
Deschutes County, Oregon

Construction Report

FHWA Experimental Project No. 3

by Bo Miller, P.E.
Senior Research Specialist

and

L.G. Scholl, P.E.
Technical Studies Coordinator

Research Unit
Materials and Research Section
Oregon State Highway Division

December 1990

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-OR-RD-90-07		

4. Title and Subtitle	5. Report Date
Field Test of Polymer Modified Asphalt Concrete: Murphy Road to Lava Butte Section	December 1990
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Bo Miller and L. G. Scholl	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Oregon State Highway Division Materials and Research Section 800 Airport Road S.E. Salem, OR 97310	11. Contract or Grant No. DTFH71-99-503-OR-09
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Federal Highway Administration 400 Seventh Street S.W. Washington, D.C. 20590	Construction Report May 1989
	14. Sponsoring Agency Code HTA-21

15. Supplementary Notes

16. Abstract

This report covers the construction of open-graded asphalt concrete test sections using one conventional and three different polymerized binders. The binders were: 1) Chevron's conventional AC-20 as a control, 2) Elf Aquitane's Styrelf with SB polymer, 3) Asphalt Supply and Service's AC-20R with SBS polymer, and 4) Chevron's CA(P)-1 with DuPont's Elvax (EVA) polymer.

This report also includes a summary of: pre-construction conditions, pavement design, test results and methods, the condition of the road just after construction, and cost data.

Satisfactory pavements were made with all of the binders. There were no major design or construction related problems. Minor problems included: 1) Styrelf and AC-20R tended to migrate downward through the mix, 2) AC-20R, and to a lesser degree, Styrelf left deposits on the surface of transport equipment, 3) all polymerized binders presented some problems with mix sample collection and binder extraction. None of these minor problems slowed the progress of the paving, and most were solved with innovations in either equipment or technique.

17. Key Words	18. Distribution Statement
Pavementasphalt, admixtures, chemicals, polymer	Available through the National Technical Information Service (NTIS)

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	94	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The authors thank the crew of Deschutes Ready Mix, and the Oregon State Highway Division (OSHD) construction crew in Bend, for their help in sampling, testing, and providing information for this study. In addition, the authors thank Lloyd Coyne, a consultant, for drainage testing of the job mixes; Todd Scholz, of Oregon State University (OSU), for resilient modulus and fatigue testing of core samples; and Sharon Myhre of the OSHD for information about the binder extraction technique she developed. Furthermore, the authors are grateful to Dr. Gary Hicks of OSU; Glenn Boyle, Tony George, Jeff Gower, and Neil Walker of the OSHD; and Cal Frobig of the Federal Highway Administration for their review of the report drafts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Background

In recent years, the open-graded hot mix asphalt concrete (HMAC) overlay is commonly used for surface rehabilitation on Oregon roads. For this treatment to be successful, it must resist rutting, cracking, and aggregate loss. Manufacturers of polymers claim that their asphalt additives reduce or postpone these pavement problems.

At present, binders with polymers are used extensively in Europe to prolong the life of open-graded pavements [1]. In addition, domestic laboratory research shows that polymerized asphalts have the potential for increasing the durability of open-graded friction courses [2]. However, there is little information about the comparative performance and cost of polymer modified and conventional pavements on Oregon roads.

To evaluate polymerized binders in open-graded friction courses under local conditions, test sections using polymerized binders and control sections using conventional asphalt were built in the Spring of 1989 on US Route 97 (Oregon Highway 4) just south of Bend.

The test section binders were: **Styrelf**®, an asphalt with styrene-butadiene block copolymer (SB); **AC-20R**, an asphalt with styrene-butadiene latex polymer (SBR); and **CA(P)-1**, an asphalt with ethylene-vinyl-acetate polymer (EVA). The control sections used **AC-20**, a conventional asphalt.

1.2 Objectives

The study objective is to determine the performance and cost-effectiveness of the polymer binders used in the test sections.

This is the first of several reports from this study. This report gives details of the project layout, design, materials, construction procedures, in-place unit costs, and the condition of the pavement just after construction. Future reports will describe the pavement's performance over the first three years.

Funding for this study comes two sources: Federal Highway Administration (FHWA) Experimental Project No. 3 - Evaluation of Asphalt Additives, and the Oregon State Highway Division (OSHD).

2.0 DESIGN AND PRE-CONSTRUCTION TESTING DETAILS

This chapter describes the test and control sections, project environment, traffic loadings, overlay design, materials, suppliers, and mix designs.

2.1 Project Location, Layout, and Cross Sections

This project is located between milepoints 141.5 and 150.8 on The Dalles-California Highway (US Route 97 or Oregon Highway 4). This is the main north-south highway across the central Oregon plateau (Figure 2.1).

The project is divided into the north and south units. Test and/or control sections of varying lengths are found on each unit (Figures 2.2 and 2.3). The five test and two control sections have the same binder in the pavement of the shoulder, the travel lane, and if present, the passing lane. The ends of each section are shown by paddles on the side of the roadbed. The control sections are marked by paddles reading "Class F".

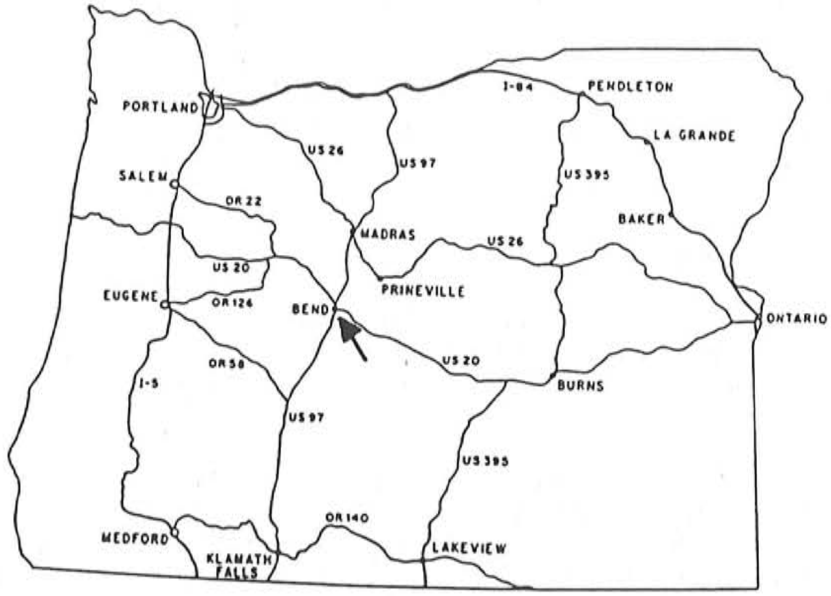
Within the test and control sections, there are 250-foot long evaluation sections extending completely across the roadway. The north ends of the evaluation sections are marked by paddles on the east side of the roadbed. Within these evaluation sections, there are P-K nails at 50-foot intervals along the east shoulder. Deflection measurements are periodically taken adjacent to these nails. Fifty feet to the north of Evaluation Sections 2,3,6, and 7; coring sites are marked by P-K nails on the east shoulder.

The roadway cross sections vary throughout the project (Figure 2.4). In some areas, the pavement base is new material. In the other areas, the wearing and base courses overlay the existing pavement. The components of the pavement structure are described below:

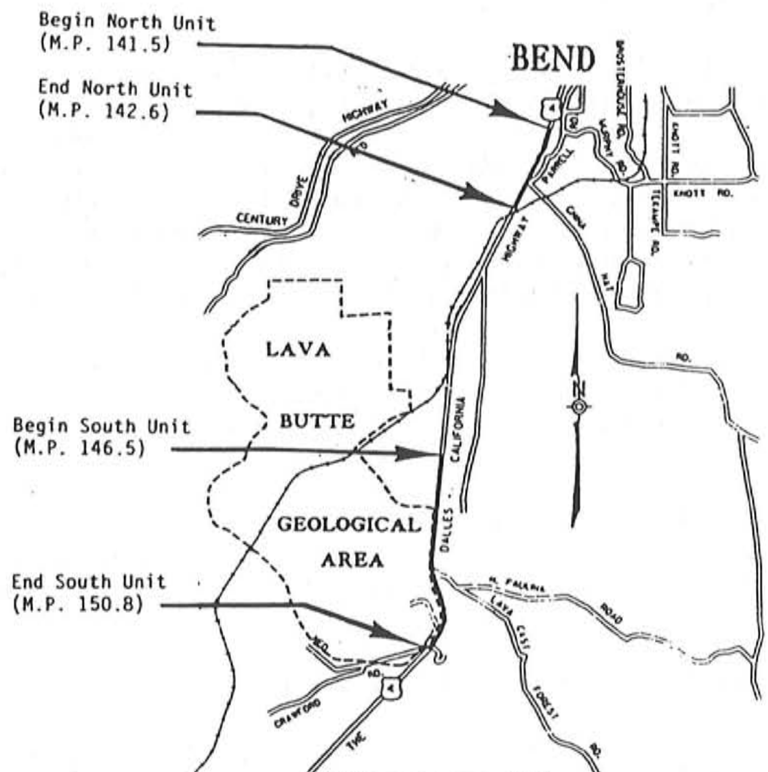
Wearing Course - This is a single 2 to 2-1/2 inch thick lift of OSHD Class "F" open-graded asphalt concrete pavement with and without polymer additives. This mix gradation has a maximum stone size of 3/4-inch.

Tack Coat - Hot applied Chevron AC-20.

Base Course - This is a single 2 to 3 inch thick lift of OSHD Class "B" dense-graded mix using conventional Witco AR-4000 paving grade asphalt. This mix has a 3/4-inch maximum stone size. The base course of the North Unit, placed in the Fall of 1988, extends the full length of the unit. The South Unit base course, placed in the Spring of 1989, extends from the north end of the unit to M.P. 149.65. Between M.P. 149.65 and the south end of the project, there is no base course - the wearing



a) Project Location



b) Close-up of Project Site

Figure 2.1: Vicinity Map

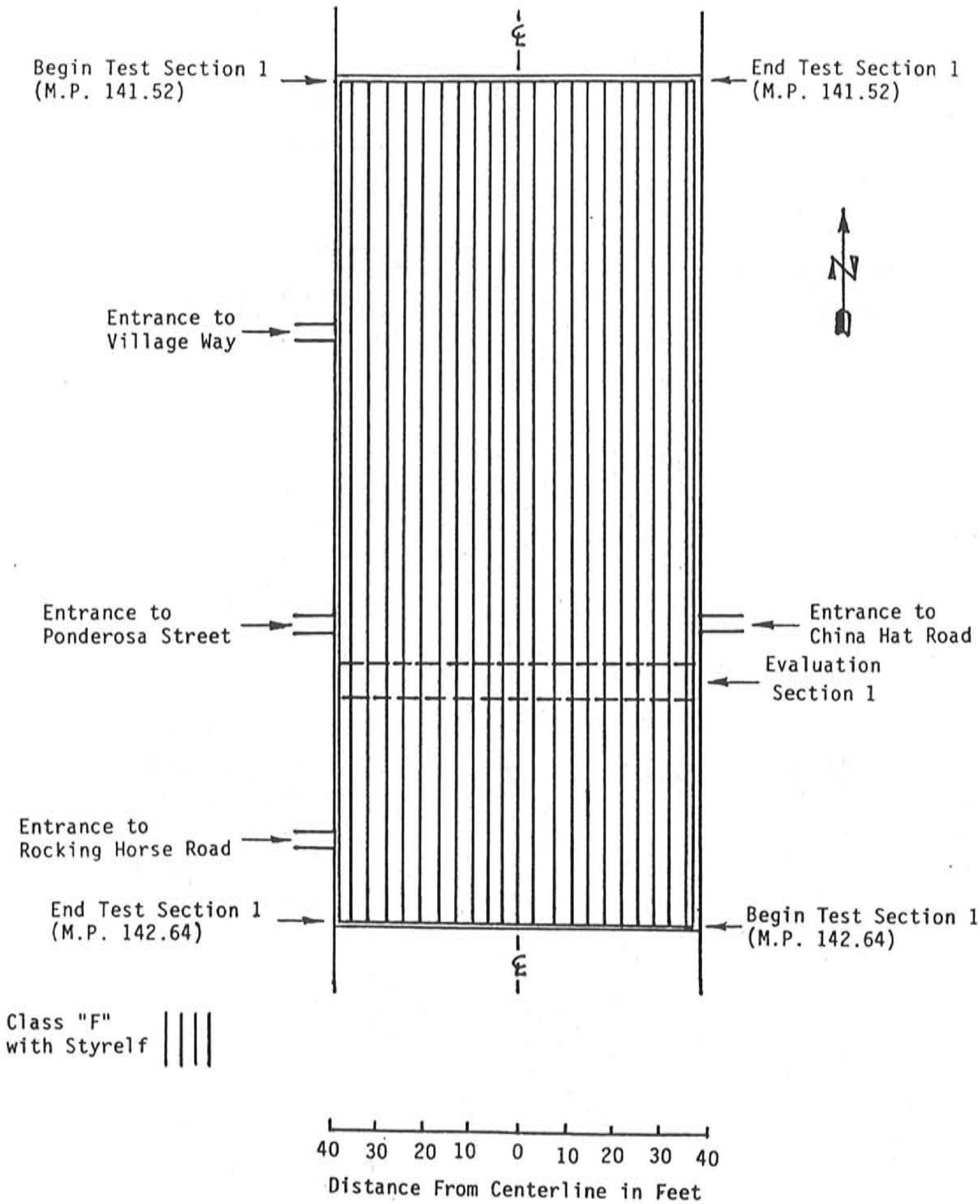


Figure 2.2: North Unit Test Section Location

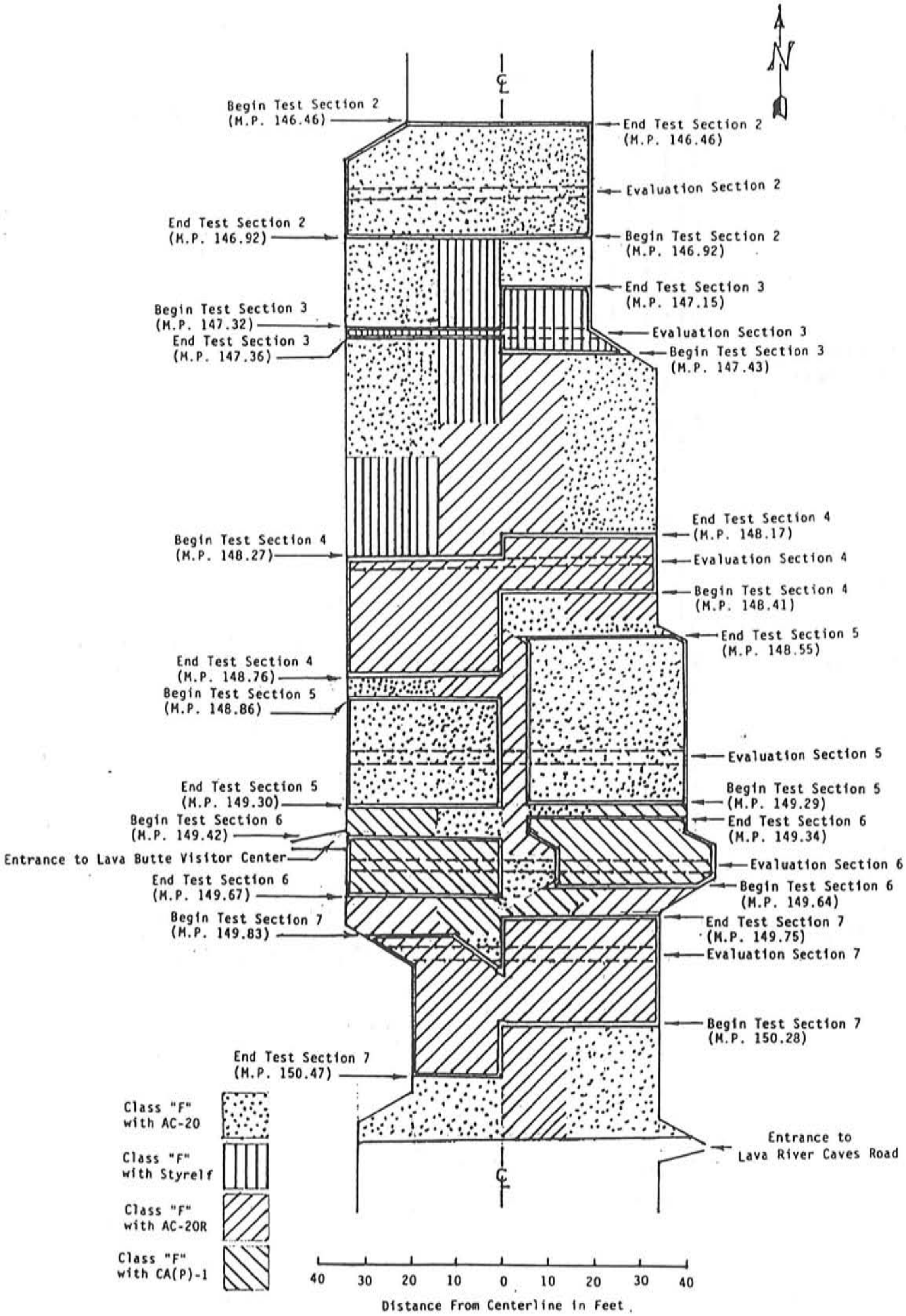
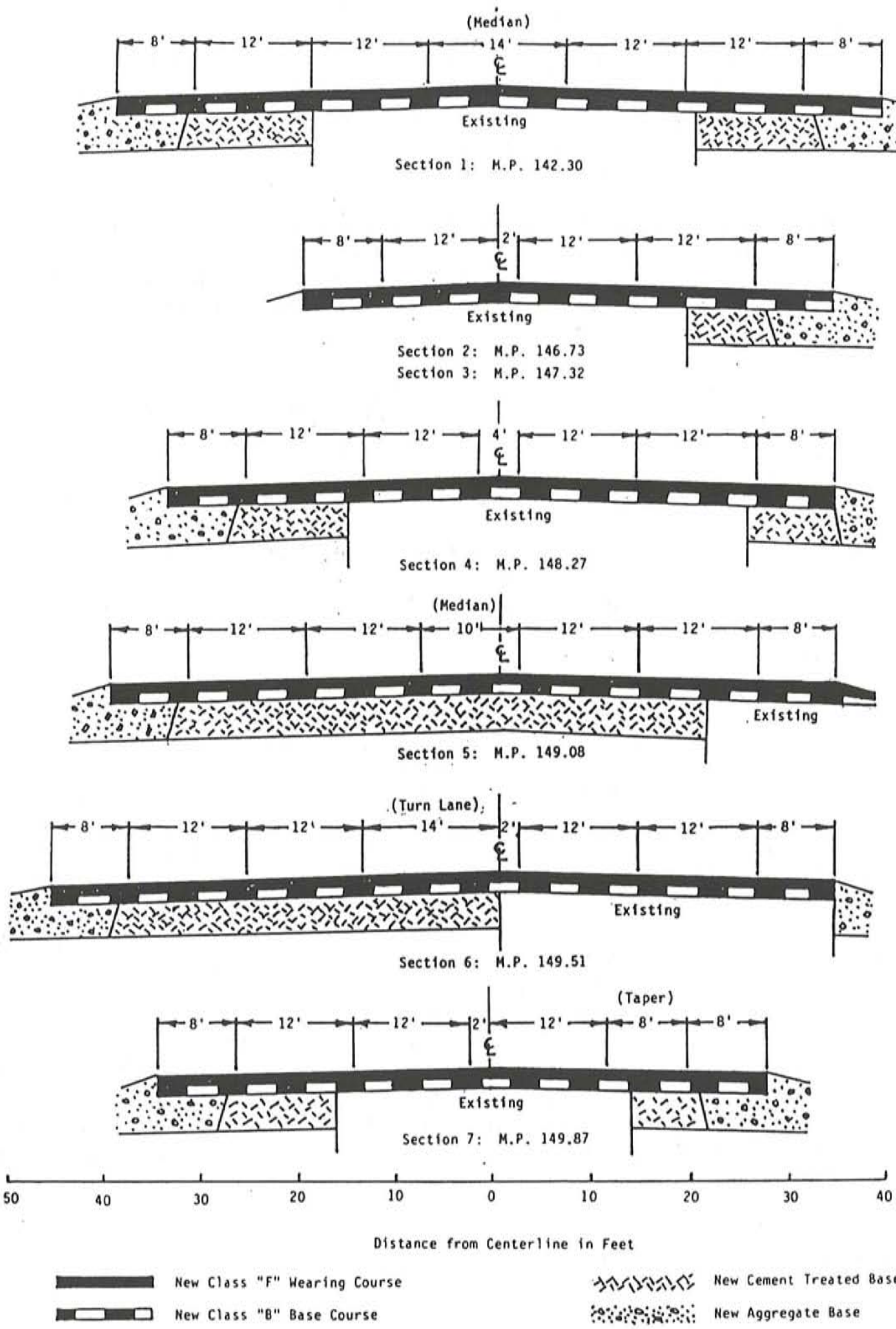


Figure 2.3: South Unit Test Section Location



Cross-sections are located at the north end of the evaluation sections and are facing south.

Figure 2.4: Cross Sections

course was placed directly on the existing pavement.

Base - The new pavement in widened areas is supported by a new 14-inch thick layer of plant mixed cement treated base (CTB).

Shoulders - The newly constructed shoulders are supported by 14 inches of untreated aggregate base.

Existing Pavement - The roadway before construction is shown as "Existing" in Figure 2.4. The condition of this road is described in Chapter 4. The old roadway was not patched or planed prior to the overlay. The pavement consisted of the following layers, in descending order:

Asphalt concrete wearing and base courses of various lengths placed between 1955 and 1985. These lifts form a pavement between 2 to 8 inches total thickness.

An **oil mat**, 1-1/4 to 4 inches thick, placed before 1955.

A **cinder base** placed before the oil mat.

Subgrade - The subgrade is powdered pumice, soil, basalt boulders, and volcanic cinders. Occasionally, the roadway cuts through ledges of basalt.

2.2 Climate and Traffic

This project is in a hostile environment for pavements. It is in an area of cold winters, hot summers, rain, snow, frequent freeze-thaw cycles, and great daily temperature swings. In addition, the roadway lies on a relatively resilient base and is subject to heavy truck traffic.

The climate at the study site was determined from data collected at a nearby weather station. The long term records show that temperatures varied from an average daily low of 21°F in January to an average daily high of 82°F in July. An average of 12 inches of rain and 39 inches of snow fell annually. Records from 1980 through 1986 showed annual averages of 11 days with highs over 90°F and 156 daily freeze-thaw cycles. Examination of 1986 data indicated that daily temperature swings of 30°F to 40°F were the rule, with a 56°F swing noted in August.

This highway is used all year. In the winter, the light and dry snowfalls are quickly plowed and the roadway is sanded with crushed volcanic cinders. In the snow, cars and light trucks use studded tires, chains, or cables. Most of the heavy trucks use chains.

Traffic patterns on this project vary between the north and south units (Table 2.1).

Table 2.1: Projected Traffic Loading
Based on 1988 data.

Location	Section	Year	Two Way Average Daily Traffic	One Way 18-Kip Equivalent Annual Single Axle Loads
North Unit	1	1989	16,300	338,000
		1990	16,800	349,000
		1991	17,300	360,000
		1992	17,900	372,000
South Unit	2 through 7	1989	8,100	327,000
		1990	8,310	336,000
		1991	8,530	345,000
		1992	8,750	354,000

North Unit - Average one-way 18 kip Equivalent Single Axle Loads for 1989-2009: 485,000 ESALs/year or 1,330 ESALs/day

South Unit - Average one-way 18 kip Equivalent Single Axle Loads for 1989-2009: 442,000 ESALs/year or 1,210 ESALs/day

The relatively slow traffic on the urban north unit contains about 10% heavy trucks. These trucks are dispersed over all four lanes of the highway. On the rural south unit, the traffic has about 16% heavy trucks which travel at higher speeds. On most of the south unit, the truck traffic can use either of two travel lanes. However, on each of the south unit test sections, truck traffic is concentrated in the outer travel lane in certain areas due to changes in the number of lanes, tapers, and grades, as noted below:

Section 2: Southbound trucks tend to concentrate in the outer travel lane due to an uphill grade. Northbound trucks concentrate in the outer lane due to the lane configuration.

Section 3: Almost all trucks use the outer southbound travel lane due to an uphill grade and the northbound outer travel lane on the north end of the section due to a taper.

Sections 4, 5, and 6: Trucks tend to concentrate in the outer southbound travel lane due to an uphill grade.

Section 7: Most trucks use the outer northbound travel lane on the north end of the section due to an uphill grade, and the outer southbound travel lane due to the lane configuration.

These loading patterns should be considered during the final evaluation of pavement performance.

2.3 Overlay Design

The OSHD Crushed Base Equivalency Method (CBE) was used to design an overlay capable of carrying 980 one way 18-kip ESALs per day for 20 years (Table 2.2). However, heavier than anticipated truck traffic may cause this pavement to fail sooner. Twenty-year traffic use projections, based on 1988 data, predict an average 18-kip one way ESAL of 1,330 per day for the North Unit, and 1,210 per day for the South Unit (Table 2.1). These projected traffic loadings are 36% and 24% heavier than the assumption used in the pavement design on the North and South Units, respectively.

Table 2.2: Design Data

The design assumptions were:

Design Life:	20 years or 7,160,000 ESALs
Traffic Coefficient:	11.4
Average 18-kip one-way ESALs for the 20-year design life:	980/day or 358,000/year
R Value:	18
Frost Penetration:	30 inches

This design showed that a C.B.E. thickness of 33 inches was needed. To meet this requirement, the following layer thicknesses were recommended:

1) **M.P. 141.52 to M.P. 142.64 (Widening and Overlay), and M.P. 146.65 to M.P. 149.65 (Widening and Overlay)**

   a) A 2-inch thick polymer modified Class "F" asphalt concrete wearing course.

   b) 2 inches of asphalt concrete base course.

   c) 14 inches of cement treated aggregate base in widened areas.

2) **M.P. 149.65 to M.P. 150.80 (Overlay)**

   a) 2 inches of polymer modified Class "F" asphalt concrete wearing course.

2.4 Materials and Suppliers

Binders - The binders listed on the following page were used in the wearing course. Asphalt, binder, and polymer suppliers are listed in Table 2.3.

AC-20 - This conventional asphalt, which met 1989 OSHD specifications, was used in the control sections. It was refined in Chevron USA's Willbridge, Oregon facility.

Styrelf[R] - A polymerized binder which met Elf 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.

AC-20R - A polymerized binder which met Asphalt Supply and Service 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.

CA(P)-1 - A polymerized binder which met Chevron CA(P)-1 specifications. The additive was Elvax 150W, a thermoplastic ethylene-vinyl-acetate random copolymer produced by Du Pont Company. The polymer content was 3% of the binder weight. The binder was blended in Chevron USA's Willbridge, Oregon refinery. Although this Chevron binder specification is obsolete, the product can be produced in limited quantities upon request.

Table 2.3: Suppliers
November 1990

Product	Supplier
AC-20R	Asphalt Supply and Service, Inc., 1300 W. 8th Street, Vancouver, Washington 98660. Contact: M. Scott Rich at (206) 699-4401.
AC-20 and CA(P)-1	Chevron USA, Inc., 5501 N.W. Front Avenue, Portland, Oregon 97208. Contact: Carl Dunlap at (503) 221-7818.
Elvax 150W	Du Pont Company, 16165 S.E. 33rd Circle, Belleview, Washington 98008. Contact: Deborah A. Scott at (213) 692-0964.
Styrelf	Elf Asphalt Inc., P.O. Box 1248, Adams City, Colorado 80022. Contact: Owen S. Hill, Jr. at (303) 287-5376.

Aggregate - The aggregate came from the Kake pit and quarry near Bend. Most of the aggregate was crushed from river cobbles excavated out of the pit. The cobbles were mainly basalt and other extrusive igneous rocks. The rest of the aggregate was crushed from basalt quarried out of a rock ledge located within the pit. The rock was crushed a few weeks before it was used. Immediately after crushing, the aggregate was moistened with water, mixed with dry hydrated lime in a pugmill, and poured into stockpiles.

Mineral Filler - Fly ash was used as a mineral filler to reduce the migration of the binder from the aggregate when the mix was transported and handled.

2.5 Materials Qualification Testing and Mix Design

The first step in the design process was to test binder and aggregate samples from the suppliers for both specifications compliance and the properties needed for mix designs (Tables 2.4, 2.5, 2.6, and 2.7). Next, separate mix designs were made for each binder using the OSHD version of the Hveem method (Table 2.7) [3]. Finally, job mix specifications were developed (Table 3.2). Test methods are listed in Appendix A.

In addition to the specification compliance testing, additional testing was performed on the binders in their original state and after processing in the rolling thin film oven (Tables 2.4 and 2.5). These test results may be used in the later stages of this study to develop correlations between binder properties and performance.

Table 2.4a: Binder Properties - 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/in²)	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/in²)	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	-

[a]Mix design sample.
[b] Considered outlier during calculation of average.

Table 2.4a, contd.: Binder Properties - 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
Fraass Point (°F)	16, 21		19	-
Solubility in Trichloroethylene (%)	99.97[a], 99.99	99.0 (min)	99.98	-

[a]Mix design sample.

Table 2.4b: Binder Properties - 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

[a]Mix design sample.

Table 2.4b, contd.: Binder Properties - Original Styrelf

Test	Test Results	Specifications	Average Value	Standard Deviation
Flash Point, COC, (°F)	570[a], 535	450 (min)	553	-
Fraass Point (°F)	-2, -2, -1		-1	2
Solubility in Trichloroethylene (%)	99.99[a], 99.98		99.0	-
Tensile Stress @ 800% Elongation, 68°F, 500cm/min pull (kg/cm^2)	[b]	.3 (min)	-	-

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

Table 2.4c: Binder Properties - Original 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/in²)	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/in²)	.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	-

[a]Mix design sample.

Table 2.4c, contd.: Binder Properties - Original AC-20R

Test	Test Results	Specifications	Average Value	Standard Deviation
Flash Point, COC, (°F)	550[a], 530	450 (min)	540	-
Fraass Point (°F)	3, 1, 5		3	2

[a]Mix design sample.

Table 2.4d: Binder Properties - 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	-

[a]Mix design sample.

Table 2.4d, contd.: Binder Properties - Original CA(P)-1

Test	Test Results	Specifications	Average Value	Standard Deviation
Flash Point, COC, (°F)	560[a], 575	450 (min)	568	-
Fraass Point (°F)	7, 7, 14		9	4

[a]Mix design sample.

Table 2.5a: Binder Properties - RTFC Residue of AC-20

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/in²)	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/in²)	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]		-	-

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

Table 2.5a, contd.: Binder Properties - RTFC Residue of AC-20

Test	Test Results	Specifications	Average Value	Standard Deviation
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.

Table 2.5b: Binder Properties - RTFC Residue of Styrelf

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

[a]Mix design sample.

Table 2.5b, contd.: Binder Properties - RTFC Residue of Styrelf

Test	Test Results	Specifications	Average Value	Standard Deviation
% 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	-

aMix design sample.

Table 2.5c: Binder Properties - RTFC Residue of AC-20R

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

[a]Mix design sample.

Table 2.5c, contd.: Binder Properties - RTFC Residue of AC-20R

Test	Test Results	Specifications	Average Value	Standard Deviation
% 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 2.5d: Binder Properties - RTFC Residue of 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)	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/in²)	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/in²)	2.8, 2.9		2.9	-
b) Maximum Engineering Strain (in/in)	47+, 47+		47+	-
c) Maximum Engineering Work (lbf-in)	3.9, 3.9		3.9	-
Toughness (lb-in)	240[a], 151	100 (min)	196	-
Tenacity (lb-in)	192[a], 102	75 (min)	147	-
Elastic Recovery @ 50°F (%)	35		35	-
Fraass Point (°F)	14, 19, 19		17	3

[a]Mix design sample.

Table 2.5d, contd.: Binder Properties - RTFC Residue of CA(P)-1

Test	Test Results	Specifications	Average Value	Standard Deviation
% 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.

Table 2.6: Aggregate Test Results
(Except Gradations)

Test	Specifications	Test Results (All Sections) Prequalification Testing	Check and Record Testing
Bulk Specific Gravity-			
Coarse Aggregate		2.73	2.75
Fine Aggregate		2.62	2.67
Absorption (%)			
Coarse Aggregate		1.75	1.57
Fine Aggregate		3.33	2.71
Soundness, Sodium Sulfate, 5 cycles (%)			
Coarse Aggregate	12 (max)	2.8	1.0
Fine Aggregate	12 (max)	3.4	1.2
Degradation, Sediment Height (in)			
Coarse Aggregate	3 (max)	1.1	.8
Fine Aggregate	4 (max)	.9	.7
Degradation, Passing #20 Screen (%)			
Coarse Aggregate	30 (max)	15.3	15.5
Fine Aggregate	30 (max)	11.3	11.2
Fracture, Two Fractured Faces (%)			
Coarse Aggregate	90 (min)	100	-
Fracture, One Fractured Face (%)			
Fine Aggregate	75 (min)	100	-
Abrasion, Grading			
Coarse Aggregate		B	B
Abrasion, Wear (%)			
Coarse Aggregate	30 (max)	13.5	15.2
Friable Particles (%)			
Coarse Aggregate	1.0 (max)	.3	.3
Fine Aggregate	1.5 (max)	.4	.5
Lightweight Pieces (%)			
Coarse Aggregate	1.0 (max)	0.0	0.0
Fine Aggregate	1.0 (max)	.1	0.0

Table 2.6, contd.: Aggregate Test Results
(Except Gradations)

Test	Specifications	Test Results (All Sections) Prequalification Testing	Check and Record Testing
Wood Particles (%)			
Coarse Aggregate	.1 (max)	.0	.0
Fine Aggregate	.1 (max)	.0	.0
Elongated Pieces, Aggregate Retained on the 1/4-inch Screen, 5:1 Ratio (%)	10 (max)	3	2

Note: Mix design gradation criteria and mix design briquet gradations are shown in Table 2.7. Job mix gradation specifications and job mix gradation quality control test results are given in Table 3.2.

Table 2.7: Design Mix Characteristics at Design Binder Content

Characteristic		OSHD Class"F" Mix Design Criteria	AC-20	Binder Styrelf	AC-20R	CA(P)-1
Gradation-						
% Passing Screen:	1-inch	99-100[a]	100[b]	100[b]	100[b]	100[b]
	3/4-inch	95-100	100	98	98	98
	1/2-inch	66-80	76	75	75	75
	3/8-inch		57	56	56	56
	1/4-inch	18-30	28	25	25	25
	#10	5-19	11	10	10	10
	#40		6	6	6	6
	#200	1.5 -6.5[c]	3.6[d]	3.6[d]	3.5[d]	3.5[d]
Mineral Filler Content (%)		.5-1.5	1[e]	1[e]	1[e]	1[e]
Voids in Mineral Agg. (%)			19.8	21	21	20
Binder Content (%)		4-8	5.2	5.5	5.5	5.5
Binder Film Thickness		Suff.	Suff.	Suff.	Suff.	Suff.
Sp. Gr. @ 1st Comp. (%)			2.29	2.26	2.27	2.30
Voids @ 1st Comp. (%)		6-9	9.0	11.1	9.5	8.7
Stab. @ 1st Comp.		≥ 26	24	26	22	21
Sp. Gr. @ 2nd Comp. (%)			2.35	2.36	2.37	2.38
Voids @ 2nd Comp. (%)			6.6	7.2	5.5	5.6
Stab. @ 2nd Comp.		≥ 26	37	39	33	32
"Rice" Max. Sp. Gr.			2.518	2.542	2.509	2.520
Index of Ret. Strength (%)		≥ 75	83	73	84+	76

[a]Broadband limits.
[b]Gradation of rock used in mix design samples. Results of additional tests on the aggregate used in the mix design are shown in Table 2.6.
[c]Includes .5% allowance for loose lime from treated aggregate.
[d]Includes loose lime from treated aggregate and 1% fly ash mineral filler.
[e]Estimated.

3.0 CONSTRUCTION

The wearing course placement, sampling, and construction process control testing are covered in this chapter.

3.1 Equipment

The equipment used to mix and construct the wearing course is described below:

Asphalt Concrete Mixing and Storage - A Cedarapids Model 6000 batch plant rated at 200-300 tons/hour was used. The AC-20, was always pumped from a storage tank into the batch plant. The Styrelf and AC-20R were pumped from tankers or storage tanks into the plant. The CA(P)-1 was pumped directly from tankers into the plant.

Hauling - Tractors pulling "belly dump" trailers were used. Most of these trailers had insulated sides.

Placement - A Cedarapids Model 520 paver was used.

Compaction - The breakdown roller was a Dynapac CS12 3-wheeled steel wheel roller. The finish roller was a Tampo RS188A 2-wheeled steel wheel roller.

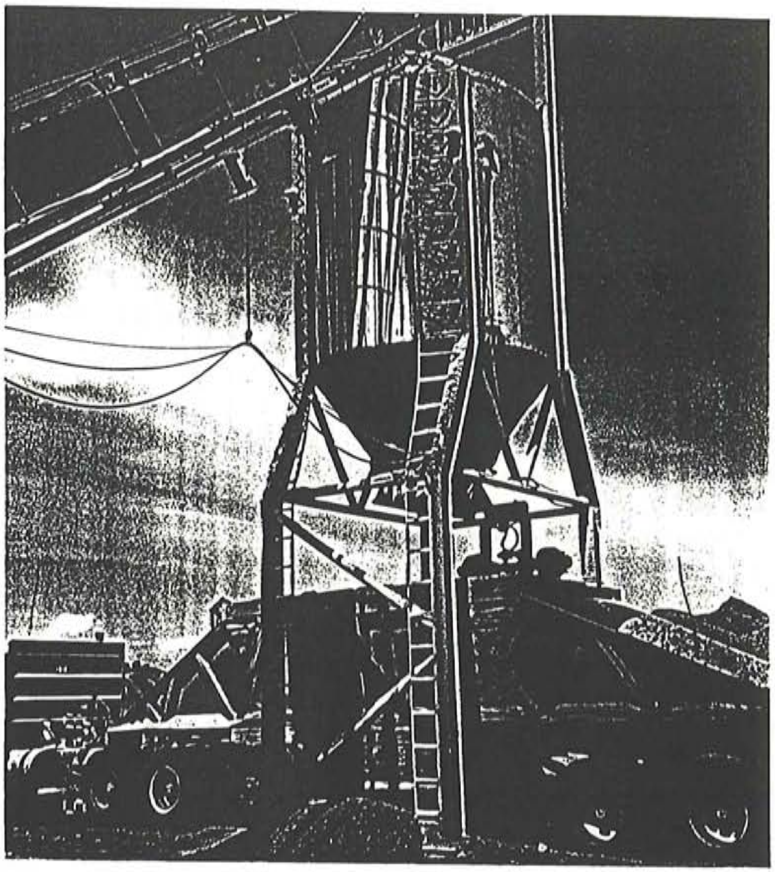
3.2 Mixing

For each batch, the lime treated aggregate and fly ash mineral filler were poured into the weigh hoppers. This material was dumped into the pugmill and mixed with the binder. After mixing, the asphalt concrete was transferred by conveyor to a storage silo and dumped into the trailers (Figure 3.1a). Specifics on the mixing of each binder are presented below:

AC-20 - No unusual behavior.

Styrelf - This binder mixed easily with the aggregate in the pugmill. Unlike the conventional asphalt, the binder tended to cling to the surfaces of the equipment. The buildup was moderate and plant operation was not affected.

The Styrelf binder migrated through the mix to the bottom of the silo when the mix was stored for an extended period. Due to an equipment breakdown, a full silo of mix sat for about 30 minutes. The first truckload from this silo of mix was very rich with binder and was rejected. It was not known if this migration would occur within the other mixes if they were stored for prolonged periods.



(a) Storage silo.

(b) Windblown strands of binder on equipment.

Figure 3.1: Mixing

The Styrelf binder was hard to pump at 275°F. The first tankloads of Styrelf were at this temperature when they were pumped to the pugmill. The binder was too viscous and pumping difficulty slowed the batching of the mix. Some of the binder was pumped into a heated storage tank and held overnight.

This binder was about 310°F when it was pumped to the pugmill the following day. In addition, later shipments of Styrelf arrived with the binder at 320°F. The hotter binder was much easier to pump. No pumping problems were noted with the other binders. However, in almost all cases these binders were pumped at 300°F to 360°F.

AC-20R - Like Styrelf, this binder easily mixed with the rock, tended to cling to surfaces more, and was stringier than conventional asphalt. Unlike Styrelf, however, this binder built up heavy coatings on the surfaces of equipment. This problem is discussed in more detail in the "Hauling" section of this chapter.

Both the Styrelf and AC-20R binders were stringy. Long strands of loose binder would blow from the batching operation onto nearby equipment (Figure 3.1b).

CA(P)-1 - This mix behaved like the conventional AC-20 control mix.

Compared to the other binders, the smell of the fumes from the CA(P)-1 seemed very noxious. A worker near an open access hatch on the top of a trailer tank accidentally took a breath of this binder's fumes, and he lost consciousness for a second and almost fell off the tank.

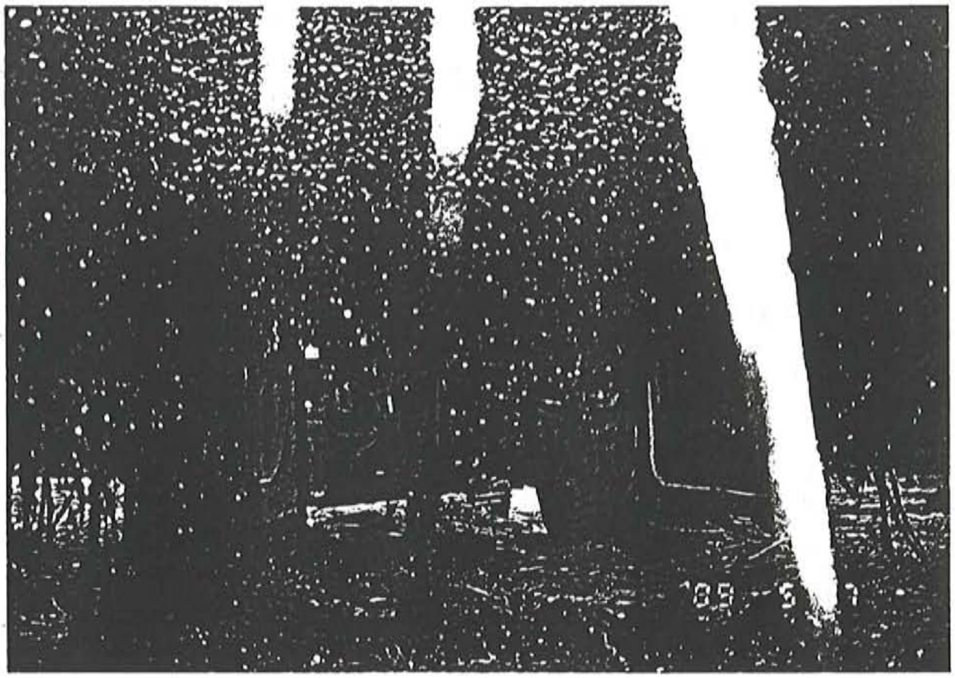
3.3 Hauling

In order to prevent the buildup of mix on the sides of the belly dumps, the drivers sprayed the inside of the trailers with diesel fuel just before loading. This practice was used for all mixes. Each binder had different characteristics, as noted below:

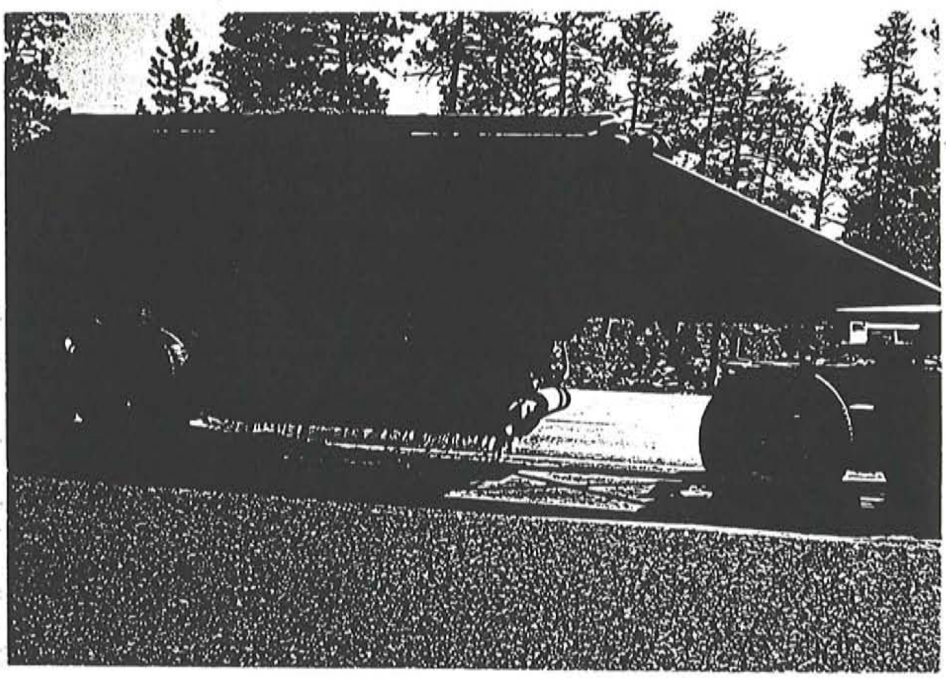
AC-20 - No unusual behavior.

Styrelf - This mix coated the insides of the belly dumps with a slightly thicker film than the conventional mix. This buildup did not affect the operation of the trailer doors or cause other problems.

AC-20R - In spite of the diesel washes, trailers hauling this material had a heavy buildup of mix on the inside of their walls and doors (Figure 3.2a). This buildup was very hard to remove, and at air temperatures below 45°F, the buildup made



(a) AC-20R deposits on sides of belly dump.
(White streaks are strands of binder near the camera.)



(b) AC-20R dripping from closed doors of empty trailer.

<u>Figure 3.2: Hauling</u>

the belly dump doors hard to open. In addition, when the doors were closed after the trailers dumped their loads, chunks of mix would hang from the door edges (Figure 3.2b). This excess mix would fall off of the trailers and stick to the highway when the trucks returned to the batch plant.

As an experiment, one trailer was not washed with diesel between loads. It was believed that the buildup of mix on the sides of the trailer would become very thick and heavy. Hopefully, this heavy layer would cleanly peel off the sides of the trailer when a load was dumped. This did not happen. To remove the thick buildup that did occur, two men worked on the inside of the trailer for an hour with a blowtorch, hammers, and prybars.

CA(P)-1 - This mix behaved like the conventional material.

3.4 Placement

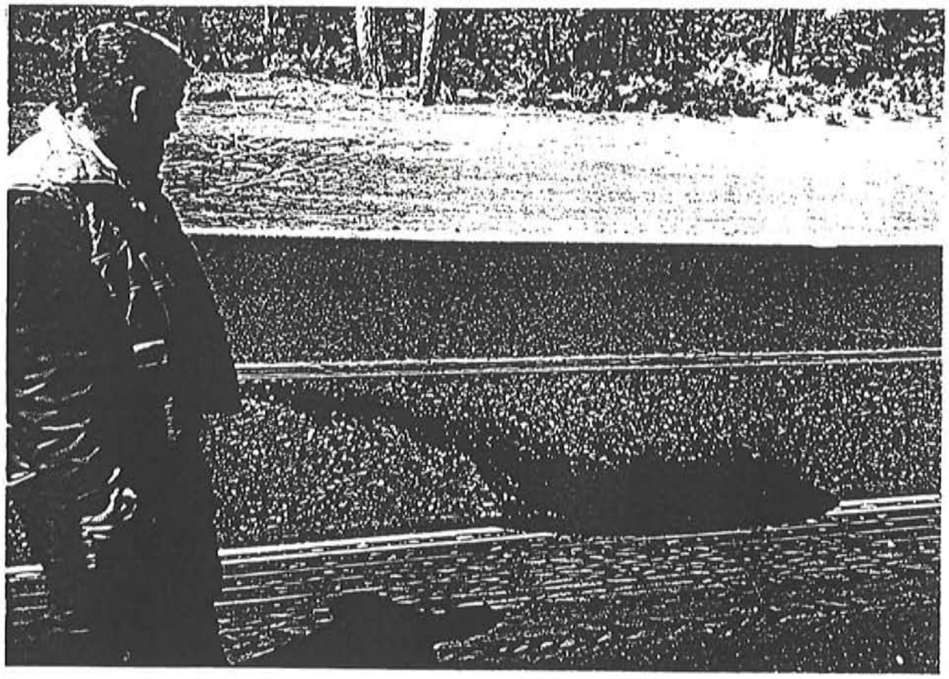
The roadway was paved in continuous panels. The panels on the west side of the road were placed first. The paver travelled the full length of the unit, from north to south, without stopping. A different mix was dumped in front of the paver when a new section was started.

The air temperature during paving varied between 40°F and 70°F, and portions of each type of mix were placed at air temperatures below the 60°F minimum specified by the OSHD. When the air temperature was lower than 45°F, hardened chunks of mix fell off of the inside walls of the belly dumps. These pieces were pulled out of the windrow and discarded. This was the only placement problem related to cold weather.

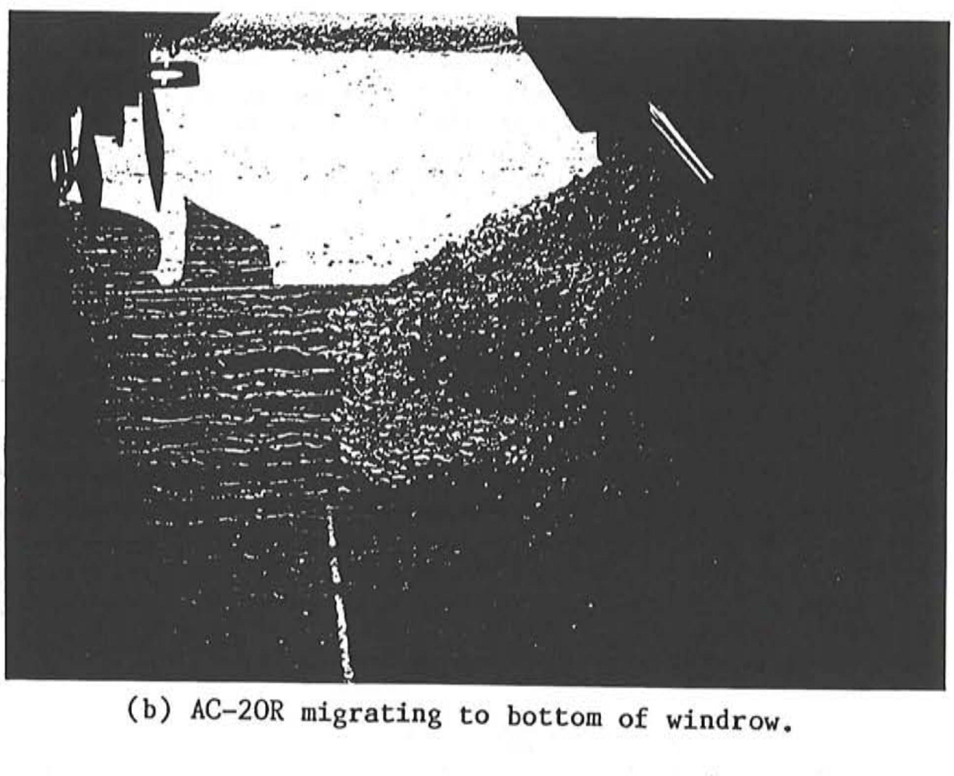
Placement temperatures in the windrow varied between 240°F and 270°F (Table 3.2). At windrow temperatures higher than 255°F, all of the binders tended to migrate down to the roadway surface. Consequently, the mix temperatures were regulated to keep the windrow temperatures as close to 250°F as possible. Even at this temperature, some migration problems were noted. Binder tests such as absolute viscosity, kinematic viscosity, ring and ball softening point, and the California Department of Transportation (CALTRANS) mix drainage test did not predict this migration, as discussed in Appendix B. Specific observations for each binder are noted below:

AC-20 - No unusual behavior noted.

Styrelf - Portions of many loads were rich with binder that migrated to the bottom of the belly dump. After dumping, the free binder migrated downward from the top of the windrow to the roadway surface (Figure 3.3a). These "fat" spots were not seen after compaction.



(a) Styrelf migrating from windrow.



(b) AC-20R migrating to bottom of windrow.

Figure 3.3: Placement

Compared to the other mixes, the Styrelf was especially sensitive to paver speed and screed setting. For any screed setting, there was a definite maximum paver speed. If the paver exceeded this speed, the screed would rapidly lift. This sensitivity did not slow or delay the work. In all other respects, this mix was easy to place.

AC-20R - This mix had the same problems with binder migration as the Styrelf material (Figure 3.3b). Unlike the Styrelf, 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 tended to harden quicker upon cooling than the conventional AC-20. Once the mix hardened, it was very hard to rake. In other respects, this mix did not cause placement problems.

CA(P)-1 - This mix behaved like the conventional material.

3.5 Compaction

The mix was compacted by two passes of the breakdown roller and two passes of the finishing roller. The rollers were not allowed to vibrate. No problems or unusual behavior were noted with any of the mixes.

3.6 Sampling

Mix samples were taken from the discharge chute of the pugmill with a shovel. Some of the samples were placed into a round bottomed pan and taken to the laboratory trailer for asphalt content and aggregate gradation testing. When the samples arrived at the trailer, a large percentage of the binder had migrated to the bottom of the mix sample. As the mix cooled, this binder adhered to the pan. The polymerized binders were very tenacious. It was very difficult to stir the binder into the mix and remove all of the binder from the pan when the sample was taken out for quartering, extraction, and asphalt content testing. As some binder was left in the pan, the asphalt content test results may have been low.

To overcome this problem, contractor personnel made a special sample collection pan, and the OSHD testing crew developed a new sample processing technique (Appendix C). The new method allowed the crew to recover all binder from the pan.

3.7 Testing

Test methods are listed in Appendix A.

Binder Tests - To obtain binder for testing, mix samples were taken at the plant discharge and sent to the central laboratory. The binder was recovered using an OSHD modification of the Abson procedure [4]. The binder samples were subjected to a series of tests similar to the those performed on the original and rolling thin film - convection oven (RTFC) residue samples (Table 3.1). These test results may be used in the later stages of this study to develop correlations between binder properties and performance.

Mix Tests - After the mixture sample was split into quarters in the laboratory trailer, asphalt content and gradation testing was performed in both the trailer and the central laboratory on separate portions of the mix (Table 3.2). In both laboratories, the binder was separated from the aggregate by vacuum extraction.

The binders behaved differently during the extractions, as noted:

> **AC-20 and Styrelf** - No unusual behavior.
>
> **AC-20R and CA(P)-1** - In the laboratory trailer, a vacuum extraction on these mixes took between 2-1/2 to 5 hours using OSHD TM 309-86 [4]. In contrast, using the same method and equipment in the laboratory trailer, an extraction on a conventional mix usually took less than one hour. In the central laboratory, using a change in technique for OSHD TM 309-86, extraction times for polymerized binders were shortened considerably. This change in procedure is described in Appendix D.

Core Tests - Cores removed from the pavement just after construction were tested for void contents and Hveem stabilities (Table 3.2). The test results show that the void contents of the cores were much higher than the void contents of the mix design briquets, and the Hveem stabilities of the cores were lower than the stabilities of the mix design briquets. In addition, the void contents of the cores were higher, and the Hveem stabilities were lower, than the mix design criteria (Table 3.3).

The void contents and stabilities in the OSHD open-graded mix criteria are not the same as those expected in the pavement, as the criteria were developed empirically. Using this method, briquets are fabricated at varying asphalt contents using standard compactive efforts to determine materials proportions and mixing and placement temperatures. The void contents and stabilities of these briquets, and their relationship to the mix design criteria, are part of the information needed to determine the asphalt content for the job mix formula.

Although the voids and stabilities of the mix design criteria and briquets are not representative of the pavement as constructed, mix designs that meet the criteria perform well in the field. In

Table 3.1a: Binder Properties - Recovered AC-20

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 (%)	-	-	-	-

Table 3.1b: Binder Properties - 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/in²)	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/in²)	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 3.1c: Binder Properties - 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 3.1d: Binder Properties - 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	-	48	-
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	-

Table 3.2a: Job Mix Specifications, Mix, and Core Properties - AC-20

Test	Test Results	Job Mix Specifications	Average Value	Standard Deviation
Mix Tests -				
Gradation-				
% Passing				
Screen: 1-inch	[c]	99-100[a]	100	0
3/4-inch	[c]	95-100	98	1
1/2-inch	[c]	66-80	75	3
1/4-inch	[c]	19-30	23	3
#10	[c]	5-13	8	1
#200	[c]	1.6-5.6[b]	3.4[b]	.6
Moisture Content (%)	[c]	.6 (max)	.5	.1
Binder Content (%)	[c]	4.7-5.7	5.4	.4
Mixing Temp (°F)	[d]	250-257	-	-
Placement Temp (°F)	250, 250, 260 260, 240	238-243	252	8
Core Tests (In-Place Compaction) -				
Bulk Specific Gravity	2.12		2.12	-
Void Content (%)	14.9		14.9	-
Hveem Stability	-		-	-
Resilient Modulus @ 32°F (ksi)	679, 751		715	-
Fatigue @ 32°F (repetitions)	6880, 7500		7190	-
Core Tests (Recompacted) -				
Bulk Specific Gravity	2.33		2.33	-
Void Content (%)	6.5		6.5	-
Hveem Stability	17		17	-
"Rice" Maximum Specific Gravity	2.492		2.492	-

[a]Narrowband limits.
[b]Includes loose lime from treated aggregate and 1% fly ash mineral filler.
[c]Eleven samples were tested. Test results are not listed.
[d]Mix temperature data is suspect.

Table 3.2b: Job Mix Specifications, Mix, and Core Properties - Styrelf

Test	Test Results	Job Mix Specifications	Average Value	Standard Deviation
Mix Tests -				
Gradation-				
% Passing				
Screen: 1-inch	[c]	99-100[a]	100	0
3/4-inch	[c]	95-100	98	2
1/2-inch	[c]	66-80	79	4
1/4-inch	[c]	19-30	24	2
#10	[c]	5-13	9	2
#200	[c]	1.6-5.6[b]	3.5[b]	1.2
Moisture Content (%)	[c]	.6 (max)	.37	.07
Binder Content (%)	[c]	5.0-6.0	5.5	.4
Mixing Temp (°F)	[d]	260-268	-	-
Placement Temp (°F)	250, 250	243-252	250	-
Core Tests (In-Place Compaction) -				
Bulk Specific Gravity	2.16		2.16	-
Void Content (%)	17.6		17.6	-
Hveem Stability	13		13	-
Resilient Modulus @ 32°F (ksi)	671, 517, 650		613	84
Fatigue @ 32°F (repetitions)	7690, 18700, 28700		18400	10500
Core Tests (Recompacted) -				
Bulk Specific Gravity	2.29		2.29	-
Void Content (%)	9.8		9.8	-
Hveem Stability	25		25	-
"Rice" Maximum Specific Gravity	2.540		2.540	-

[a]Narrowband limits.
[b]Includes loose lime from treated aggregate and 1% fly ash mineral filler.
[c]Eight samples were tested. Test results are not listed.
[d]Mix temperature data is suspect.

Table 3.2c: Job Mix Specifications, Mix, and Core Properties - AC-20R

Test	Test Results	Job Mix Specifications	Average Value	Standard Deviation
Mix Tests -				
Gradation-				
% Passing				
Screen: 1-inch	[c]	99-100[a]	100	0
3/4-inch	[c]	95-100	98	1
1/2-inch	[c]	66-80	75	2
1/4-inch	[c]	19-30	22	2
#10	[c]	6-14	8	1
#200	[c]	1.6-5.6[b]	3.2[b]	.5
Moisture Content (%)	[c]	.6 (max)	.39	.11
Binder Content (%)	[c]	5.0-6.0	5.3	.3
Mixing Temp (°F)	[d]	263-272	-	-
Placement Temp (°F)	245, 250, 255 250, 250, 250	243-258	250	3
Core Tests (In-Place Compaction) -				
Bulk Specific Gravity	2.17		2.17	-
Void Content (%)	14.9		14.9	-
Hveem Stability	14		14	-
Resilient Modulus @ 32°F (ksi)	380, 298		339	-
Fatigue @ 32°F (repetitions)	21500, 42700		32100	-
Core Tests (Recompacted) -				
Bulk Specific Gravity	2.30		2.30	-
Void Content (%)	9.8		9.8	-
Hveem Stability	23		23	-
"Rice" Maximum Specific Gravity	2.549		2.549	-

[a]Narrowband limits.
[b]Includes loose lime from treated aggregate and 1% fly ash mineral filler.
[c]Eleven samples were tested. Test results are not listed.
[d]Mix temperature data is suspect.

Table 3.2d: Job Mix Specifications, Mix, and Core Properties - CA(P)-1

Test	Test Results	Job Mix Specifications	Average Value	Standard Deviation
Mix Tests -				
Gradation-				
% Passing				
Screen: 1-inch	[c]	99-100[a]	100	0
3/4-inch	[c]	95-100	97	2
1/2-inch	[c]	66-80	74	7
1/4-inch	[c]	19-30	21	1
#10	[c]	6-14	8	1
#200	[c]	1.6-5.6[b]	3.4[b]	.3
Moisture Content (%)	[c]	.6 (max)	.45	.11
Binder Content (%)	[c]	5.0-6.0	5.5	.4
Mixing Temp (°F)	[d]	258-267	-	-
Placement Temp (°F)	250, 250, 270	242-250	257	11
Core Tests (In-Place Compaction) -				
Bulk Specific Gravity	2.17		2.17	-
Void Content (%)	14.5		14.5	-
Hveem Stability	13		13	-
Resilient Modulus @ 32°F (ksi)	594, 775, 913		761	160
Fatigue @ 32°F (repetitions)	1520, 6170, 1960		3220	2570
Core Tests (Recompacted) -				
Bulk Specific Gravity	2.29		2.29	-
Void Content (%)	9.7		9.7	-
Hveem Stability	24		24	-
"Rice" Maximum Specific Gravity	2.537		2.537	-

[a] Narrowband limits.
[b] Includes loose lime from treated aggregate and 1% fly ash mineral filler.
[c] Three samples were tested. Test results are not listed.
[d] Mix temperature data is suspect.

Table 3.3: Comparison - Mix Design Criteria, Mix Design Briquets, and Cores

Property	Mix Design Criteria	Mix Design Briquet Average Value	Field Core Average Value
First Compaction Void Content	6% to 9%	9.6%	15.4%[a]
First Compaction Hveem Stability	≥ 26	23	13[a]
Second Compaction Hveem Stability	≥ 26	35	22[b]

[a]In-Place Compaction
[b]Recompacted

addition, the difference between design and in-place void contents has not caused problems in pavement quality control; as compaction of open-graded pavements is specified by the "roller pattern" method, and a minimum density is not required.

As a result, when it is necessary to know the void content of an OSHD open-graded friction course, the mix design cannot be used as a reference. Void content measurements are needed from cores.

In addition to void content and stability testing, resilient modulus and fatigue tests were performed on cores (Table 3.2). These results may be compared to pavement performance in subsequent reports.

3.8 Summary

In almost all aspects, conventional equipment and methods were used to build and test open-graded friction courses using these polymerized binders. However, mixes using the experimental binders behaved differently than conventional mixes, as noted below:

Pumping Binder Through Hoses - Compared to AC-20, the Styrelf binder was harder to pump from the tanker to the batch plant. This problem was greatest when the Styrelf was delivered at temperatures below 300°F. Problems were not noted with the other binders. However, the other binders were almost always over 300°F during pumping.

Fumes - The fumes from the CA(P)-1 were especially noxious in comparison to the other binders.

Coating of Mix on Equipment - Compared to the AC-20 and CA(P)-1 mixes, the Styrelf and AC-20R mixes left a thicker coating on handling and transport equipment. Problems were noted with buildup of the AC-20R mix on the insides and door edges of the belly dumps. In spite of diesel washes between loads; the AC-20R mix buildup was the thickest, it was hard to remove, and it made the belly dump doors hard to open in cold weather.

Migration - Mix temperature within the windrow was critical. At temperatures above 255°F, all mixes had excessive downward migration. Compared to the AC-20 and CA(P)-1 binders, the Styrelf and AC-20R binders had greater downward migration through the mix in the windrow, as well as during transport and storage. Binder tests such as absolute viscosity, kinematic viscosity, ring and ball softening point, and the CALTRANS mix drainage test did not predict this migration.

Mix Sampling - Unlike conventional mixes, the polymerized mixes were hard to remove from the round bottomed pan used to collect samples. To solve this problem, a flat bottomed sampling pan was used, and the pan and sample were kept warm during the sample splitting process.

Binder Extraction - It was very hard to remove the AC-20R and CA(P)-1 binders from the aggregate during vacuum extractions. A modified technique was developed to perform quick extractions.

Void Contents: Mix Design Briquets vs Cores - The void contents of the mix design briquets were not representative of the in-place void contents measured on cores. This is typical of OSHD open-graded mix designs. This discrepancy does not cause trouble with compaction quality control, as the roller pattern method is used to specify compaction.

4.0 FIELD PERFORMANCE

This chapter provides the results of roadway inspections before and after construction.

4.1 Pavement Evaluation - Visual Inspection

Cracking - About one half of the newly constructed pavement is an overlay over the old roadway (Figure 2.4). The performance of this overlay may be affected by the condition of the underlying pavement. As an example, cracks in the old road may reflect up through the new pavement.

All sections of the existing pavement had transverse thermal cracking across the roadway at a frequency of about 130 cracks per mile (Figure 4.1a). Sections 2, 3, 4, 5,and 6 had alligator cracking in the wheeltracks and block cracking (Figure 4.1b). Sections 1 and 7 had little of this distress. The old roadway was not patched or planed prior to the overlay.

The base course of the North Unit was placed in the Fall of 1988. In the Spring of 1989, when this base course was overlaid, there were 1/16 to 1/8 inch wide transverse cracks completely across the roadway at a frequency of 90 cracks per mile. There was little spalling on the crack edges. The base course of the South Unit, placed in the Spring of 1989, was not cracked when it was overlaid.

There were no cracks in the new overlay just after construction.

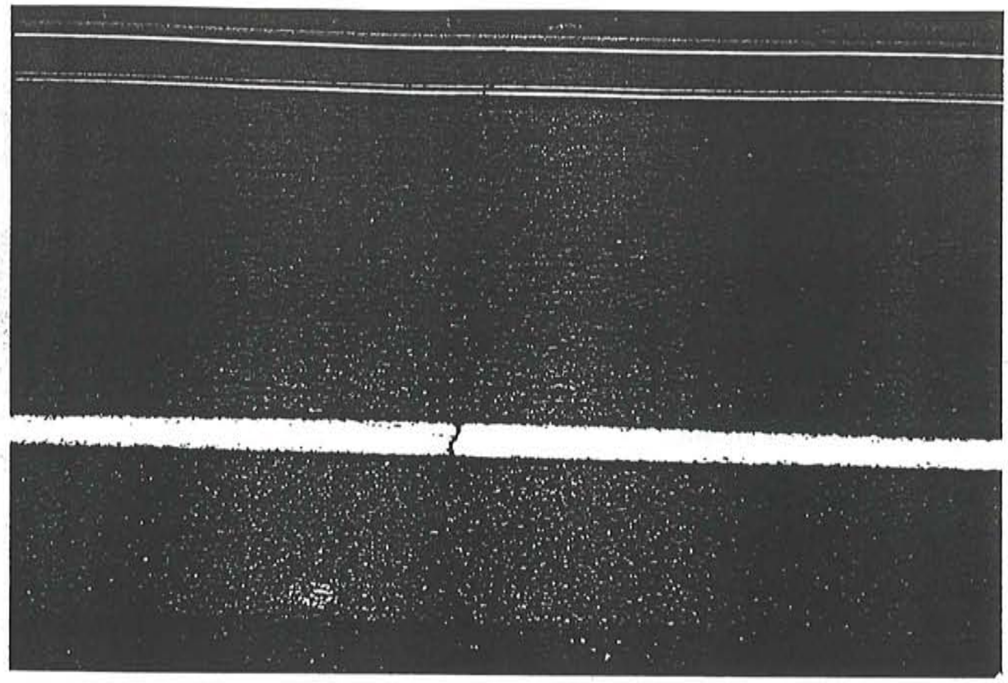
Rutting - The roadway had 1/2-inch deep ruts before construction. There were no ruts immediately after the overlay.

Ravelling and Weathering - No unusual ravelling or weathering was seen on the old roadway. None of this distress was noted on the new overlay.

Aggregate Coating - When the cores broken by the fatigue test were visually examined, all aggregate adjacent to the break was fully coated.

4.2 Friction

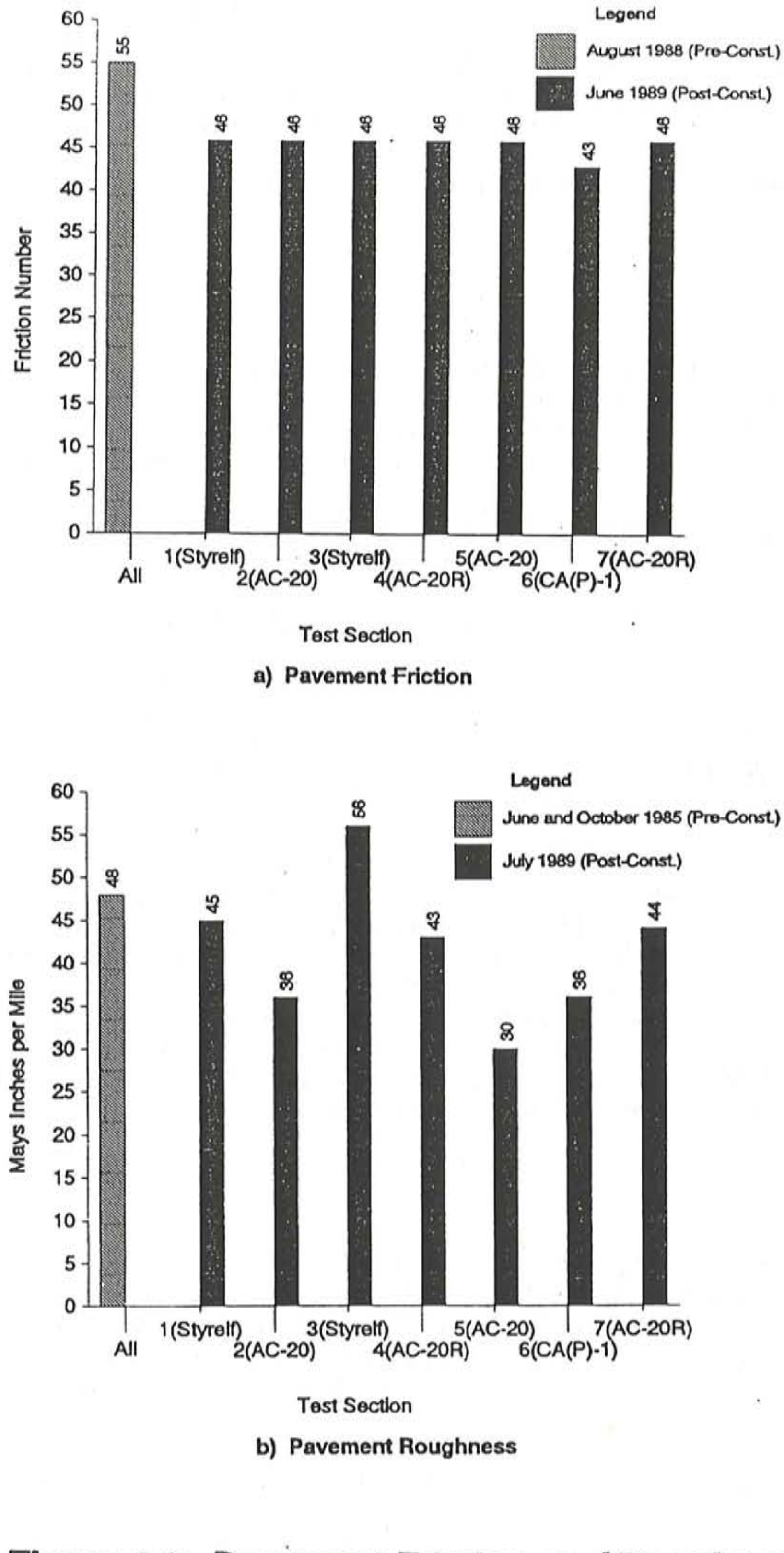
The pavement friction was measured before construction in 1988 and shortly after construction (Figure 4.2a). All testing was done at speeds near 40 mph in the left wheelpath of the outer lane. The test data was adjusted to standard 40-mph friction numbers (FN_{40}) using correlation equations. The test methods, calibration techniques, and equipment conformed to AASHTO T 242-84 [5]. The FHWA recommends a friction number of 45 or higher for a high speed



(a) Typical transverse thermal crack.

(b) Typical alligator and block cracking.

Figure 4.1: Cracking on Old Roadway



a) Pavement Friction

b) Pavement Roughness

Figure 4.2: Pavement Friction and Roughness

road with large radius curves, such as this project [6].

All sections had friction numbers lower than the old roadway's average of 55, and in some cases, the values were at, or just below, the FHWA recommended value of 45. Based on OSHD experience with open-graded pavements; these lower friction numbers are temporary, and they increase as the binder wears off the top of the surface aggregate.

4.3 Roughness

The pavement roughness, or ride, was measured using a Mays ride meter before construction in 1985 and just after construction in 1989 (Figure 4.1b). The old roadway and the new test sections were "smooth" based on the OSHD Paving Award Criteria (Table 4.1).

Table 4.1: OSHD Paving Award Criteria

Description	(inches/mile)
Smooth	0 - 74
Average	75 - 99
Slightly Rough	100 - 149
Rough	150 - 199
Very Rough	200 +

The Mays meter was not calibrated to the International Roughness Index (IRI) for every year the tests were performed. Consequently, the roughness values were not converted to commonly used IRI values. However, all measurements were made with the same machine and converted to roughness values using the same equations and correction factors. As a result, the ride information in this report is useful for comparing both the relative roughness and changes in roughness of the test sections.

4.4 Deflections

Deflections were measured after construction in 1989 with a KUAB Falling Weight Deflectometer (Figure 4.3). With an average deflection .0064 inches, both the overlay and new roadway were structurally strong and well supported. The deflections shown are of the central sensor adjusted to a 9,000 lb load and a pavement temperature of 70°F.

There may be some cracking over the joint where the new base meets the existing roadway, as the old roadway deflects more under load than the new cement treated base. On Sections 1, 4, 5, 6, and 7, the deflection sites supported by cement treated base, the average

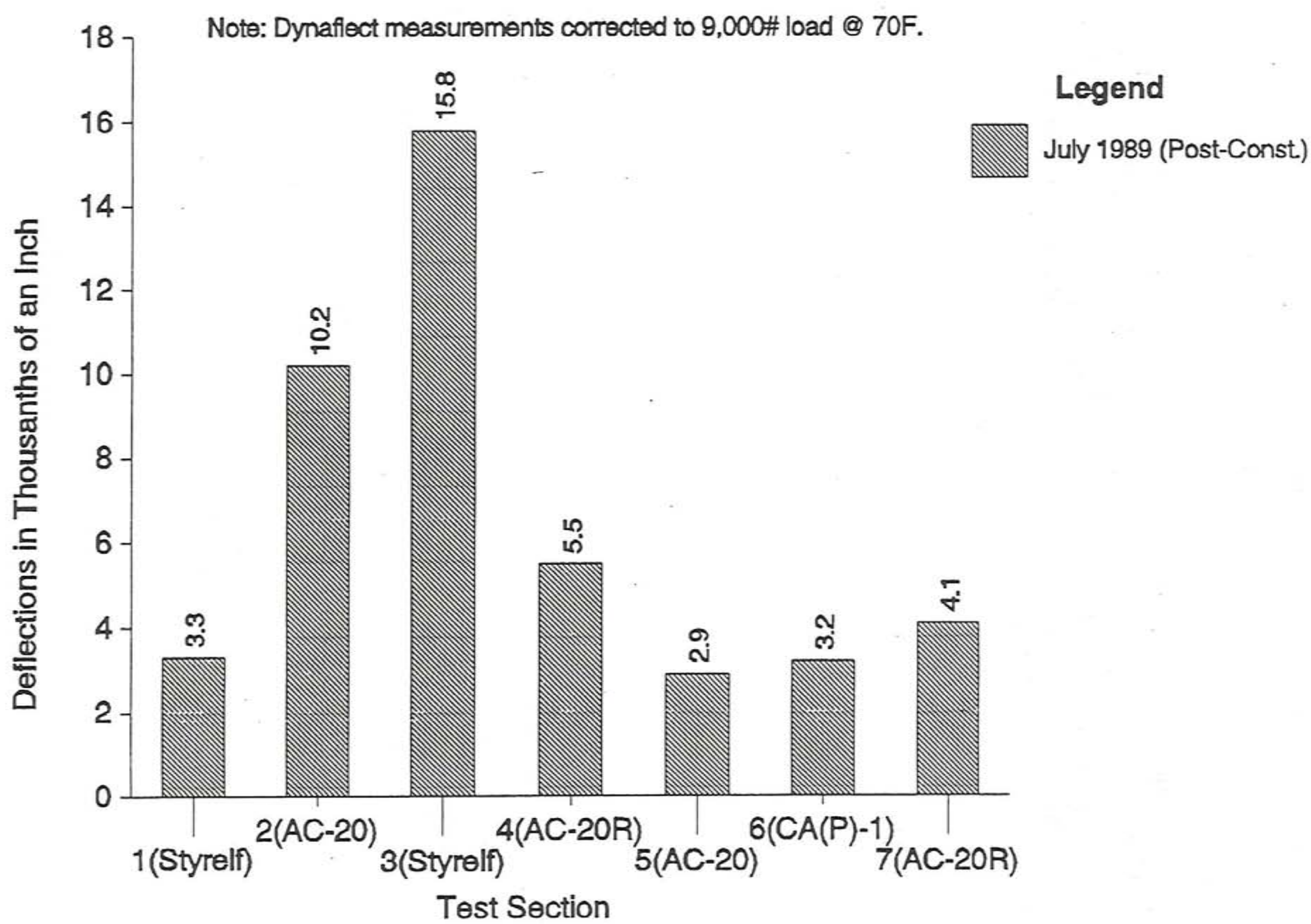


Figure 4.3: Pavement Deflections in Outer Wheeltrack

deflection is .0038 inches. This is about 70% lower than the average deflection of .0130 inches for Sections 2 and 3, which are deflection sites over the old roadway.

4.5 Summary

Just after construction, the new roadway was uncracked, smooth, had no rutting, and was adequately supported. In addition, cores broken during fatigue testing showed that the aggregate was fully coated. Friction numbers were near the FHWA recommended minimum. However, this low friction is usually temporary and is typical of freshly constructed open-graded pavements.

5.0 COST COMPARISON

The polymers used in the binders increased the unit costs of the mixes (Table 5.1). The design mix binder contents, binder bid prices, and mix bid prices were used to get the mix price per ton. This information, and the bulk specific gravities of the cores, were used to calculate the mix price per square yard.

These unit bid prices represent small quantities of binders that the contractor had little experience with. Consequently, they may not represent the bid prices of the binders purchased in larger quantities by a contractor experienced with their use. These prices should be used with caution in any life-cycle cost analysis.

Table 5.1: Unit Prices

Mix	Binder Content (%)	x	Binder Bid Price/Ton ($)	=	Binder Price/ Ton of Mix ($)	+	Mix Bid Price/Ton ($)	=	Total Mix Price/Ton ($)	Mix Price Comparison: Polymer to Control (%)
AC-20	5.2		140		7.28		16.00		23.28	100
Styrelf	5.5		250		13.75		13.00		26.75	120
AC-20R	5.5		300		16.50		13.00		29.50	140
CA(P)-1	5.5		300		16.50		13.00		29.50	140

To cover 1 square yard of surface area with compacted mix 2-inches deep, the unit prices were:

Mix	Mix Price/sq.yd. ($)	Mix Price Comparison: Polymer to Control
AC-20	2.45	100%
Styrelf	2.82	115%
AC-20R	3.11	127%
CA(P)-1	3.11	127%

Note: In general, for the same weight of mix and depth of lift, the typical OSHD open-graded mix covers 6% more surface area and uses 1/2% more binder than the typical OSHD dense-graded "B" mix.

6.0 OBSERVATIONS AND RECOMMENDATIONS

This chapter presents conclusions and recommendations based on experience with the construction of the test sections.

Observation - No major construction problems occurred with any of the mixes. The need for special construction techniques and equipment was minimal (Chapter 3). Just after construction, all pavements were in good condition (Chapter 4).

Recommendation - Mixes using these additives should undergo long term testing. However, to assure trouble free construction, the minor construction problems described in the remainder of this chapter should be addressed.

Observation - The Styrelf binder was hard to pump below 300°F. It is not known if this problem would have occurred with the other binders, as they were hotter upon delivery (Chapter 3).

Recommendation - Styrelf should be delivered and stored at a warm enough temperature to be easily handled.

Observation - In comparison to the other binders, the fumes from the CA(P)-1 binder were very noxious (Chapter 3).

Recommendation - For this binder, a conspicuous and effective warning system is needed in addition to the Materials Safety Data Sheet. Such a warning may be signs placed on all equipment storing and hauling this material.

Observation - Both the Styrelf and AC-20R mixes left a heavy coating rich with binder on the surfaces of mixing and hauling equipment. The AC-20R coating caused problems. In cold weather, heavy deposits of this mix "glued" the doors of some belly dumps together and make them hard to open, and chunks of mix hanging from the dump doors fell onto the highway. In addition, this coating was hard to remove. Although washing the insides of the belly dumps with diesel between loads reduced problems with this binder, diesel was a minimally effective release agent (Chapter 3).

Recommendation - When AC-20R is used, a release agent superior to diesel fuel is needed for the insides of the dump beds and other equipment.

Observation - The Styrelf and AC-20R binders had excessive migration during transport and placement. None of the tests used in this study predicted with confidence the migration of the various binders (Chapter 3 and Appendix B).

Recommendation - Experimentation should continue with more promising binder viscosity and migration tests. When adequate tests are found, excess migration may be addressed during the mix design. Solutions may be: reducing the binder content, addition of more or a different type of mineral filler, or lowering the recommended mix placement temperature.

Observation - The mix sampling and binder extractions needed for quality control testing were difficult with these polymerized mixes (Chapter 3).

Recommendation - Special sampling equipment and testing techniques need to be developed for users of polymerized mixes. One solution is to use the methods developed on this project for mix sampling and binder extraction (Appendices C and D). To determine asphalt contents without using extractions; nuclear asphalt content gauges, tank stickings, or flow meter readings may be used.

Observation - The wearing course had much higher void contents and lower stabilities than either the mix design criteria or the mix design samples (Chapters 2 and 3).

Recommendation - The mix design briquet fabrication and construction compactive efforts should be compared and evaluated. The mix design samples should represent the void content that can be achieved in the field.

7.0 REFERENCES

1. G. Van Heystraeten and C. Moraux, "Ten Years Experience of Porous Asphalts in Belgium"; Thomas Isenring et al, "Experiences with Porous Asphalt in Switzerland"; F.E. Perez-Jimenez and J. Gordillo, "Optimization of Porous Mixes Through the Use of Special Binders"; Aurelio Ruiz et al, "Porous Asphalt Mixtures in Spain"; Porous Asphalt Pavements: An International Perspective 1990, Transportation Research Record No. 1265 (Washington D.C.: Transportation Research Board, 1990).

2. Scott Shuler and Douglas I. Hanson, "Improving Durability of Open-Graded Friction Courses", Chip Seals, Friction Courses, and Asphalt Pavement Rutting 1990, Transportation Research Record No. 1259 (Washington D.C.: Transportation Research Board, 1990).

3. W.J. Quinn et al, Mix Design Procedures and Guidelines for Asphalt Concrete, Cement Treated Base, and Portland Cement Concrete (Salem, Oregon: Oregon Department of Transportation, April 1987).

4. Oregon State Highway Division, Materials Section, Laboratory Manual of Test Procedures (Salem, Oregon: Oregon Department of Transportation, 1986).

5. American Association of State Highway and Transportation Officials, Standard Specifications for Transportation Materials and Methods of Sampling and Testing - Part II: Methods of Sampling and Testing (Washington D.C.: American Association of State Highway and Transportation Officials, August 1986).

6. W.E. Meyer, Synthesis of Frictional Requirements Research, FHWA Report No. FHWA/RD-81/159 (Washington D.C.: Federal Highway Administration, June 1982).

7. Harold Muncy of Elf Aquitane, Inc., memorandum to author, July 3, 1990.

8. David F. Rogge et al, Polymer Modified Asphalt in Hot Mix Pavement, Final Report, (Salem, Oregon: Oregon Department of Transportation, August 1989).

9. Jewell R. Benson, Tentative Standard Method of Test for Toughness and Tenacity of Rubberized Asphalts (Denver, Colorado: Jewell R. Benson, February 1955).

10. Elf Aquitane, Inc., memorandum to Oregon State Highway Division, September 4, 1986.

11. Guillermo Thenoux et al, Laboratory Investigation of the Fraass Brittle Test, Volume 54, Proceedings: Association of Asphalt Paving Technologists Technical Sessions, San Antonio, Texas, February 11,12 and 13, 1985.

12. The Asphalt Institute, Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, Manual Series No. 2, 4th Edition (College Park, Maryland: Asphalt Institute, March 1974).

13. American Society for Testing and Materials, 1987 Annual Book of ASTM Standards: Road and Paving Materials; Traveled Surface Characteristics, Volume 4.03 (Philadelphia, Pennsylvania: American Society of Testing and Materials, 1987).

14. Todd Scholz and R. Gary Hicks, Repeatability of Testing Procedures for Resilient Modulus and Fatigue, (Salem, Oregon: Oregon Department of Transportation, September 1989), Appendix B.

15. Lloyd Coyne, letter to author, June 13, 1989.

APPENDIX A: TEST METHODS

Table A-1: Binder Tests

Test	Method
Recovery of Binder	OSHD TM314-87 [4]
Conditioning of Residue	AASHTO T240-86 [5]
Penetration	AASHTO T49-84
Absolute Viscosity	AASHTO T202-84
Kinematic Viscosity	AASHTO T201-86
Ring and Ball Softening Point	AASHTO T53-84
Ductility	AASHTO T51-86
Force-Ductility	ASTM D113 Modified [7], [8]
Toughness and Tenacity	Benson Method [9]
Elastic Recovery	ASTM D113 Modified [10]
Fraass Brittle Point	[11]
Solubility in Trichloroethylene	AASHTO T44-85
Loss on Heating	AASHTO T47-83
"C" Value	OSHD TM425-89

Table A-2: Aggregate Tests

Test	Method
Gradation, Dry Sieve	AASHTO T27-84 [5]
Gradation, Wet Sieve	AASHTO T11-85
Bulk Specific Gravity and Absorption of Coarse Aggregate	AASHTO T85-85
Bulk Specific Gravity and Absorption of Fine Aggregate	AASHTO T84-86
Absorption of Coarse Aggregate	AASHTO T85-85
Absorption of Fine Aggregate	AASHTO T84-86
Soundness, Sodium Sulfate	OSHD TM206-86 [4]
Degradation	OSHD TM208-86
Fracture	OSHD TM213-86
Abrasion	AASHTO T96-83
Friable Particles	AASHTO T112-81
Lightweight Pieces	AASHTO T113-86
Wood Particles	OSHD TM225-86
Elongated Pieces	OSHD TM229-86

Table A-3: Mix and Core Tests

Test	Method
Extraction of Binder, Gradation, Binder Content - Mix and Cores	OSHD TM309-86 [4]
Binder Film Thickness - Mix	Visual Inspection [3]
Voids in Mineral Aggregate - Mix	[12]
Specific Gravity and Voids, First and Second Compaction, As-Received and Recompacted - Mix and Cores	AASHTO T166-83B [5]
Hveem Stability, First Compaction and As-Received - Mix and Cores	OSHD TM303-86
Hveem Stability, Second Compaction and Recompacted - Mix and Cores	OSHD TM305-86
"Rice" Maximum Specific Gravity - Mix and Cores	AASHTO T209-82
Index of Retained Strength - Mix and Cores	AASHTO T165-86 AASHTO T167-84
Mixing and Compacting of Samples - Mix	OSHD TM303-86
Moisture Content - Mix	OSHD TM311(M)-86
Resilient Modulus - Cores	ASTM D4123-82 [13]
Fatigue - Cores	[14]

APPENDIX B: BINDER MIGRATION

In this Appendix, the observed migration of the binders during construction are compared to the binder test results. The downward migration of the binder through hot open-graded mix can result in a thin coating on the aggregate near the top of the pavement lift. Mixes with thinly coated rock may be susceptible to moisture damage and other problems.

A test that can predict migration in an open-graded mix may help an engineer choose a suitable binder, asphalt content, mix and laydown temperature, and the need for a mineral filler. In Table B-1, visual observations of migration are compared to the results of various tests. The data consists of:

Binder Content - The binder content, in percent of mix weight, indicated by construction quality control testing.

Visual Observations - The ranking of the mixes based on the amount of migration seen in the windrow. The mixes with the least migration have the highest rankings. In most cases the windrow temperatures were around 250°F.

Absolute Viscosity, Kinematic Viscosity - The results of OSHD testing on rolling thin film - convection oven (RTFC) residue and recovered binder (Tables 2.5 and 3.1). The binders with the highest viscosities have the highest rankings.

Ring and Ball Softening Point - The results of OSHD testing on the RTFC residue and the recovered binder (Tables 2.5 and 3.1). The binders with the hottest softening points have the highest rankings.

Drainage - This is the drainage, in grams, of mixes made from job aggregate with binder contents of 5.5% and 7.0%, based on total mix weight. This test was conducted at 275°F using the "Tentative Method of Test for Determination of Optimum Bitumen Content (OBC) for Open Graded Mixes" developed by the California Department of Transportation (CALTRANS). Lloyd Coyne, a consultant, performed the tests [15].

In Table B-1, the mixes with the least migration have the highest rankings. The following trends were noted:

- The differences in observed migration among the mixes were not due to varying binder content, as all mixes had similar percentages of binder.

- None of the tests used on this project predicted with confidence the migration of the binder in the windrow. The

Ring and Ball Softening Point test results, both on RTFC residue and extracted binder, correlated the best with migration observed in the windrow. However, the test results were too close together to have significant meaning. Due to the level of precision of this test, the same operator performing another series of tests on the same samples may yield different rankings, as the precision allowed by the AASHTO standards (95% probability) is 3.5°F [5].

Several tests for determining binder viscosity have been developed that were not used in this study. Among these methods are: Brookfield viscosity, the Schweyer Rheometer, sliding plate viscosity, and Koppers viscosity [8]. Some of these methods may be superior to the tests used in this project.

Table B-1: Binder Migration Test Results
(1% fly ash added)

Mix	Binder Content (%)	Visual. Obser. (Rank)	Resid. Abs. Vis. (p)	(Rank)	Extra. Abs. Vis. (p)	(rank)	Resid. Kin. Vis. (cSt)	(Rank)	Extra. Kin. Vis. (cSt)	(Rank)
AC-20	5.4	4	6420	4	4450	1	665	1	598	1
CA(P)-1	5.5	3	5000	1	5240	4	1100	4	1090	4
Styrelf	5.5	2	5675	3	4850	2	960	3	861	2
AC-20R	5.3	1	5058	2	5210	3	877	2	964	3

Mix	Binder Content (%)	Visual Obser. (Rank)	Resid. Ring & Ball Soft. Point (°F)	(Rank)	Extra. Ring & Ball Soft. Point (°F)	(Rank)	Mix Drainage 5.5% B.C. (g)	(Rank)	Mix Drainage 7.0% B.C. (g)	(Rank)
AC-20	5.4	4	144	4	144	4	12.9	2	32.2[a]	3
CA(P)-1	5.5	3	142	3	140	2	11.4	3	19.7	4
Styrelf	5.5	2	140	1	140	2	11.2	4	37.3	1
AC-20R	5.3	1	140	1	136	1	13.1	1	32.7	2
AC-20[b]							14.1		16.7[c]	

[a]Average of two results: 31.6 grams and 32.7 grams.
[b]No fly ash used.
[c]Average of two results: 16.0 grams and 17.3 grams.

- The addition of fly ash filler did not always reduce drainage. The fly ash reduced the drainage of AC-20 at 5.5% binder content and increased the drainage at 7.0% binder content.

- All mixes were rich with binder when compared to CALTRANS standards, as California recommends an optimum drainage value of 4.0 grams. However, the prevailing opinion within the OSHD is that richer mixes provide greater film thickness and better resistance to binder oxidation and stripping.

APPENDIX C: MODIFIED MIXTURE SAMPLING TECHNIQUE AND COLLECTION PAN

On most projects using open-graded mixes, warm samples are scooped from the pugmill discharge stream and placed in a round bottomed sheet metal pan. The sample is taken to the laboratory trailer, poured onto an unheated metal table top, and quartered. Some quarters are sent to the central laboratory and others are tested in the trailer for asphalt content and gradation.

Problems occurred when the sampling procedure described above was tried with polymerized mixes. After the mix was placed in the collection pan, some binder would migrate downward through the hot mix onto the pan surface. As the mix cooled, this binder would form into a tenacious and viscous film that was hard to remove from the pan. The greatest migration occurred with the Styrelf and AC-20R mixes, and the most tenacious film occurred with the CA(P)-1 mix. With a conventional binder, the film would be a very small portion of the total asphalt in the sample, and the film would easily scrape off of the pan. In addition, compared to conventional mixes, the polymerized mixes became very rigid upon cooling, and they were very hard remove from the pan and divide into quarters. To solve these problems, the following technique was developed:

> A rectangular sample collection pan was welded together from 3/16-inch thick metal plates. The pan was 18 inches wide, 24 inches deep, and the sides were 3 inches tall. All inside surfaces were smooth and flat.
>
> To make the pan easier to clean, the inside was sprayed with a light film of cooking oil before sampling. The sample was placed in the pan, quickly brought to the laboratory trailer, placed on a hot plate, quartered in the warm pan with a straight edged putty knife, and the quarters were removed for testing or other purposes. All binder near the quarter was scraped off the pan and included with the sample. Heat was essential - if the sample and plate were warm, it was much easier to handle the polymerized mixes and binders.

APPENDIX D: MODIFIED TECHNIQUE FOR THE VACUUM EXTRACTION PROCEDURE

Extractions of polymerized binders from cores and mix samples can be difficult. In many cases, when the solvent is poured into the pan holding the sample, the binder will strip off of the aggregate and form a gelatinous mass on the free surface of the solvent. When the solvent is poured onto the filter, this gelatinous material will not easily dissolve and pass through the filter. Sometimes the filter will clog.

A change in technique developed in the central laboratory was used on this project. With this new technique, more of the binder was dissolved in solvent before it reached the filter. Consequently, the binder passed through the filter medium with more ease.

The modified technique is outlined below for informational purposes. A formal analysis has not been done of any effect that this procedure could have on the test results.

This procedure is based on OSHD TM309-86: PROCEDURE -- METHOD B-2 - Vacuum (Slow Filtering Paving Mixture). 1,1,1 Trichloroethane was the solvent. The effectiveness of other solvents was not determined. As a reference, OSHD TM309-86 is included.

Change in Technique

Solvent was added to the pan holding the sample until the mix was covered by approximately 1/2 inches of liquid. The sample was soaked for 15 to 30 minutes. **It was not stirred.** The solvent darkened. In most cases, some of the binder floated to the top of the solvent, and more binder remained attached to the rock.

The layer of solvent was gently decanted from the container holding the sample. It was poured over a watch glass or spoon in the extractor. This was done very slowly so that any binder floating on the surface of the solvent remained in the pan with the sample. Not all of the solvent was poured off. Enough liquid was left to cover the rock.

Additional solvent was added to the pan until there was approximately 1/2 inches of solvent over the mixture. The mix was stirred well. The sample was soaked for another 10 to 15 minutes. The solvent was decanted onto the watch glass or spoon. The step described in this paragraph was continued until the aggregate was free of binder. For the remainder of the test, OSHD TM309-86 was followed.

MATERIALS SECTION
OSHD Test Method 309-86

Method of Test for

QUANTITATIVE EXTRACTION OF BITUMEN FROM BITUMINOUS PAVING MIXTURES AND MECHANICAL ANALYSIS OF EXTRACTED AGGREGATE

SCOPE

1.1 This method covers procedures for the quantitative determination of bitumen in asphalt concrete paving mixtures and pavement samples and the determination of the particle size distribution of fine and coarse aggregates extracted from bituminous mixtures.

SUMMARY OF METHODS

2.1 The paving mixture is extracted with 1,1,1 Trichloroethane, Trichloroethylene or Methylene Chloride using the extraction equipment applicable to each particular method. The bitumen content is calculated from the difference between the dry weight of the extracted aggregate and the dry weight of the paving mixture sample before extraction.

2.2 The mechanical analysis (US Standard Series) is to determine particle sizes using sieves with square openings.

APPARATUS

3.1 An electric oven capable of maintaining the temperature at 110 ±5 degrees C (230 ± 9 degrees F) or a microwave oven.

3.1.1 The same type of drying source should be used for the determination of percent moisture for Section 7.1 as that used to dry the aggregates after extraction in accordance with Sections 10.5, 15.6 and 22.1.

3.2 Pan (flat-bottom) 12 inches (30 cm) long, 8 inches (20 cm) wide and 1 inch (2.5 cm) deep, or container of suitable size to hold the sample.

3.3 Balance capable of weighing 2000 grams to an accuracy of 0.1 gram.

3.4 Balance capable of weighing 800 grams to an accuracy of 0.01 gram.

3.5 Face mask, goggles and gloves as required by Oregon Safety Regulations.

REAGENTS

4.1 1,1,1 Trichloroethane conforming to Federal Specification O-T-620a (Int. Amd. 3).

4.2 Trichloroethylene, reagent grade, Type 1, Federal Specification O-T-634, latest revision.

4.2 Methylene chloride, reagent grade.

PRECAUTIONS (SAFETY)

5.1 Provide adequate ventilation when handling any of the reagents. Avoid inhalation of vapors.

NOTE: Safety regulations recommend an average minimum face air velocity sufficient to keep solvent vapor concentrations below a threshold limit value of 100 ppm (parts per million).

5.2 The exhaust from the vacuum pump must be vented outside.

5.3 The vacuum tank should be drained daily. Never leave effluent solvent in the extractor for an extended period of time.

PREPARATION OF SAMPLE

6.1 A sample of the paving mixture shall be obtained in accordance with OSHD TM368(F), contained in the A.C. PAVING GUIDE published by the Construction Section. The sample shall be reduced by splitting or quartering to the test size listed in Section 6.3.

6.2 If the mixture is not sufficiently soft to separate with a spatula or trowel, place it in a large flat pan and warm to 110 ± 5 degrees C (230 ± 9 degrees F) only until it can be separated, not to exceed 2 hours. A microwave oven may also be used for this purpose. Separate the particles of the mixture as uniformly as possible using care not to fracture the mineral particles.

6.3 Minimum size of sample:

ODOT MIX DESIGN	MINIMUM WTS.
Plant Mix Bitum. Base, Max. 1-1/2" Agg	4000 grams
Class B and Class F	2000 grams
Class C and Class E	1500 grams
Class D and Class M	1000 grams

DETERMINATION OF % MOISTURE IN PORTION OF SAMPLE FOR EXTRACTION

7.1 Refer to OSHD TM311(M) for procedure when using a microwave oven for drying moisture sample. Refer to OSHD TM311(O) when using a convential drying oven to dry the moisture sample.

METHOD A - Centrifugal

SCOPE

8.1 This method covers determination of the bitumen content in paving mixtures by use of a rotarex asphalt separator. This method may be used by Contractor personnel for process control testing. It is not to be used by Highway Division personnel for job control testing (See Method B).

APPARATUS

9.1 In addition to the apparatus listed in Section 3, the following apparatus is required for Method A:

9.1.1 Extraction apparatus, consisting of a bowl and a device in which the bowl may be revolved at controlled variable speeds up to 3600 rpm. (See Fig. 1). The apparatus shall be provided with a container for catching the solvent passing through the filter from the bowl and a drain for removing the solvent. The apparatus preferably shall be provided with explosion proof features and installed in a hood to provide adequate ventilation.

NOTE: Similar appparatus of a larger size may be used.

9.1.2 Filter paper, to fit the bowl. Filter must be dried to a constant weight at 110 ± 5 degrees C (230 ± 9 degrees F) prior to use.

PROCEDURE

10.1 Determine the percent moisture in the sample in accordance with Section 7.

10.2 Weigh a 1000 to 1500 gram sample into the bowl.

10.3 Cover the sample in the bowl with Trichloroethylene, 1,1,1 Trichloroethane or Methylene Chloride and allow sufficient time for the solvent to disintegrate the sample (not over 1 hour). Place the bowl containing the sample and the solvent in the extraction apparatus, and place filter paper over the bowl. Clamp the cover on the bowl tightly and place a beaker, or container, under the drain to collect the extract.

10.4 Start the centrifuge revolving slowly and gradually increase the speed to a maximum of 3600 rpm or until solvent ceases to flow from the drain. Allow the machine to stop, add 200 ml of solvent and repeat the procedure. Use a sufficient number of 200 ml solvent additions (not less than three) so that the extract is clear and not darker than a light straw color. Collect the extract and the washings in a suitable graduate for mineral matter determination (if applicable).

10.5 Remove the filter paper and ring from the bowl. Place filter paper in a pan. Remove sample from the bowl with the aid of a fine brush. Place in pan along with filter paper. Dry contents of the pan to constant weight in an oven as described in Section 3.1.

10.6 If the filter paper has not been dried and weighed prior to use, ignite the filter paper. Weigh sample immediately after burning is completed to determine the dry weight of the aggregate.

METHOD B-1 & B-2 - Vacuum

SCOPE

11.1 This method covers determination of the bitumen content in paving mixtures by use of a vacuum extractor. This method may also be used to control the paving mixture bitumen content during construction. Aggregate recovered may be used for sieve analysis.

APPARATUS

12.1 In addition to the apparatus listed in Section 3, the following apparatus is required for Method B-1 and B-2:

12.1.1 Vacuum extractor, complete with vacuum pump, gasket, rubber tubing, filter paper support plate, and funnel ring. (See Fig. 2)

12.1.2 Filter paper, medium grade, fast filtering, 33 cm in diameter. Dry filter paper to a constant weight at 110 ± 5 degrees C (230 ± 9 degrees F) prior to use.

12.1.3 Container having a minimum capacity of 2 qts.

12.1.4 The glass erlenmeyer flasks, having a capacity of 4000 ml each or containers having sufficient capacity to catch the effluent.

12.1.5 Glass graduate, having a capacity of 500 ml or equivalent.

12.1.6 Plastic wash bottle, having a capacity of 500 ml.

12.1.7 Dial thermometer, having a range of 50 to 400 degrees F (10 to 204 degrees C).

12.1.8 Drying pan, 9 in. x 16 in. x 2 1/2 in. (229 mm x 406 mm x 64 mm), or equivalent.

12.1.9 Mixing spoon, 12 inches 305 mm) long.

12.1.10 Spatula, 9 inches (229 mm) long.

12.1.11 Stiff bristled brush, 1 inch (25 mm) wide.

REAGENTS AND MATERIALS

13.1 In addition to the reagents specified in Section 4, the following reagents are recommended:

13.1.1 Denatured ethyl alcohol. (This material is used only as a wetting agent and may not be required for the extraction of every sample.)

PREPARATION OF SAMPLE

14.1 Prepare the sample as outlined in Sections 6.1 and 7.1. The sample size shall conform to the weight requirements in Section 6.3.

14.2 Place the sample into the tared pan and weigh.

14.3 If the sample temperature is above 130 degrees F (54 degrees C), allow it to cool to a lower temperature. When sufficiently cool, pour 200 ml of alcohol over the specimen, (optional). Add approx. 300 to 500 ml of solvent and stir until the asphalt is visually in the solution.

PROCEDURE -- METHOD B-1 (Fast Filtering Paving Mixture)

15.1 Place a dried and weighed filter paper on the vacuum extractor, taking care to center the filter, and tighten the retaining nuts.

15.2 Start the vacuum pump and decant the solvent from the prepared sample into the extractor. Gently pour the sample into the extractor, being sure to wash the container completely clean with solvent from the plastic wash bottle. Gently distribute the sample evenly over the filter paper with a spatula.

15.3 When the solvent added under Section 15.2 has been vacuumed off, stop the vacuum pump and open the vacuum valve. Then pour 300 to 500 ml of solvent over the sample and stir gently with a spatula until all aggregate has been moved slightly. Close the valve. Then vacuum off the solvent.

This procedure is repeated until the solvent in the inspection tube is a light straw color. For extractors not equipped with inspection tube, check extracted solvent after each vacuum cycle.

15.4 Leave the vacuum pump running and stir the aggregate for a few minutes while it is in the extractor. This will aid in drying the sample and will reduce the time required for oven drying.

15.5 Scrape the aggregate away from the side of the funnel ring toward the center of the filter to avoid loss when the ring is removed. With the spoon, remove the major portion of the aggregate. Rest the pan upon the ring to avoid any loss of aggregate. Remove the ring and brush the clinging aggregate into the drying pan, then pick up the filter paper and aggregate by holding the paper on opposite sides and raising it straight up. Place the sample in the tared pan and brush the clinging aggregate from the filter into the pan.

15.6 Dry the contents of the pan to a constant weight in an oven specified in Section 3.1.

PROCEDURE -- METHOD B-2 - Vacuum (Slow Filtering Paving Mixture)

APPARATUS

16.1 In addition to the apparatus listed in Sections 3 and 12.1, the following apparatus is required for method B-2:

16.1.1 Watch glass, having a 4 inch (102 mm) diameter.

16.1.2 Metal tongs, 6 in. to 8 inch (152 mm to 203 mm) long.

16.1.3 1000 ml flask or beaker.

REAGENTS AND MATERIALS

17.1 In addition to the reagents specified in Section 4, the following reagents are recommended:

17.1.1 Denatured ethyl alcohol. (optional)

17.1.2 Diatomaceous silica filtering aid conforming to ASTM D 604, diatomaceous silica pigment, Type B. The material must be oven dried to a constant weight at 110 ± 5 degrees C (230 ± 9 degrees F) and be screened to pass the 0.075 mm (No. 200) sieve. Storage of the material prior to use must be in a dry environment to prevent absorption of moisture. (This material is not required for fast filtering mixes.)

NOTE: Celite 110 manufactured by Johns-Manville has been found to be suitable.

PREPARATION OF SAMPLE

18.1 Prepare the sample as outlined in Sections 6.1 and 7.1. The sample size shall conform to the weight requirements in Section 6.3.

18.2 Place the sample into the tared pan and weigh.

18.3 If the sample temperature is above 130 degrees F (54 degrees C) allow it to cool to a temperature less than 130 degrees F (54 degrees C). When sufficiently cool, pour 200 ml of alcohol over the specimen, (optional). Add approximately 300 to 500 ml of solvent and stir until the asphalt is visually in the solution.

18.4 Place a dry tared filter paper on the vacuum extractor, taking care to center the filter, and tighten the retaining nuts on the retaining ring.

18.5 Weigh approximately 50 grams of previously screened and oven dried diatomaceous silica. Place the material into a 1000 ml flask or beaker, add 500 ml of solvent and swirl until the filtering aid is completely in suspension. Immediately pour the filtering aid solution onto the filter. Care must be taken to include the total 50 grams of silica.

18.6 Start the vacuum pump and let it run until the pad formed by the diatomaceous silica is surface dry and begins to crack slightly.

18.7 Place the watch glass, or a spoon, in the extractor and gently pour the solvent from the sample over it. If a watch glass is used, remove it with the tongs and wash with solvent from a wash bottle. Add the rest of the sample and proceed as in Sections 15.3 through 15.6, Method B-1. Subtract the weight of the drying pan, filter paper, and diatomaceous silica from the total weight to determine the oven dry weight of the aggregate.

ASPHALT CONTENT COMPUTATION AND MECHANICAL ANALYSIS OF EXTRACTED AGGREGATE

SCOPE

19.1 This method of test covers a procedure for the determination of the particle size distribution of fine and coarse aggregates extracted from bituminous mixtures, using sieves with square openings.

APPARATUS

20.1 The apparatus shall consist of the following:

20.1.1 Balance - A balance shall conform to AASHTO M 231, for the class of general purpose balance required for the principal sample weight of the sample being tested.

20.1.2 Sieves - The sieves with square openings shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sieving. Suitable sieve sizes shall be selected to furnish the information required by the specifications covering the material to be tested. The woven wire cloth sieves shall conform to the requirements of AASHTO M 92 for Sieves for Testing Purposes.

SAMPLE

21.1 The sample shall consist of the entire lot or sample of aggregate from bituminous paving mixtures from which the bituminous material has been extracted.

PROCEDURE

22.1 The sample shall be dried until further drying at 110 ± 5 degrees C (230 ± 9 degrees F) does not alter the weight 0.1 percent, the precision of weighing. The total weight of aggregate in the bituminous mixture being tested is the sum of the weights of the dried aggregates.

22.2 The aggregate shall be sieved over sieves of the various sizes required by the specification covering the mixture, including the 0.075 mm (No. 200) sieve. The weight of material passing each passing each sieve and retained on the next and the amount passing the 0.075 mm (No. 200) sieve shall be recorded.

The summation of these various weights must check the dried weight in 21.1 within 0.2 percent of the the total weight. The weights of fraçtions retained on the various sieves and the total passing the 0.075 mm (No. 200) sieve shall be converted to percentages by dividing each by the total dry weight of aggregate in the bituminous mixture.

REPORT

23.1 The results of the sieve analysis shall be reported as follows:

(a) total percentages passing each sieve,
(b) total percentages retained on each sieve, or
(c) percentages retained between consecutive sieves, depending upon the form of the specifications for the use of the material under test. Percentages shall be reported to the nearest whole number except for the percentage passing the 0.075 mm (No. 200) sieve which shall be reported to the nearest 0.1 percent.

COMPUTATIONS

24.1 Compute the moisture, bitumen, and aggregate in the samples as follows:

24.1.1 Record the wet weight of the sample of mix for extraction, (a)

24.1.2 Record the percent of moisture in the mix (From a separate test, See Par. 7.1) (b)

24.1.3 Compute oven dry weight of the sample: (c)

$$\frac{(a)}{100 + (b)} \times 100 = (c)$$

24.1.4 Record the oven dry weight of the extracted aggregate. (Subtract the dry weight of the filters and diatomaceous silica as required.) (d)

24.1.5 Record the weight of the extracted asphalt: (e)

$$(c) - (d) = (e)$$

24.1.6 Compute the percent of extracted asphalt: (f)

$$\frac{(e)}{(c)} \times 100$$

FORMULAS FOR COMPUTATIONS

25.1 Calculate the Asphalt Content as Follows:

$$\frac{(A - B)}{B} \times 100 = C \qquad \frac{D}{C + 100} \times 100 = E$$

$$\frac{(E - F)}{E} \times 100 = G \qquad \frac{H}{F} \times 100 = J$$

G + Retention (if shown on mix design) = Total G

Where:

A = Wet weight of the mixture moisture sample (Sec. 7.1)
B = Dry weight of the mixture moisture (Section 7.1)
C = Percent of moisture of the mixture (Sec. 7.1, 24.1(b)
D = Wet weight of extraction sample (Sec. 10.2, 14.2, 24.1(a)
E = Corrected dry weight of extraction sample (Sec. 24.1(d)
F = Dry weight of the aggreg. (Sec. 10.6, 15.5, 18.7, 24.1(d)
G = Percent of asphalt in mix. (Section 24.1(f)
H = Accumulative weights retained on each sieve. (Sec. 22.2)
J = Percent aggregates retained on each sieve. (Section 23.1)

REPORT

26.1 Report as follows:

Moisture to the nearest	0.01%
Asphalt to the nearest (Including Retention, if shown on mix design)	0.10%
Passing 0.075 mm sieve (#200) to the nearest	0.10%
Aggregates to the nearest	1.00%

PROCEDURE FOR THE DETERMINATION OF PERCENT RESIDUAL ASPHALT IN ASPHALT CONCRETE MIXES USING EMULSION OR CUTBACKS

1. Obtain a representative sample of the mix. Emulsion cold mixes are to be dried at 230 ± 9 degrees F for one hour to remove excess liquid. This step does not apply to cutbacks.

2. Weigh a minimum sample of 1000 gram for extraction (sample A). Weigh a minimum sample of 1000 gram for moisture/volatile test (B). Samples should be weighed at the same time to eliminate variations due to moisture volatile loss.

   A = Initial weight of the extraction sample.
   B = Initial weight of the moisture sample.

3. Dry the moisture sample (B) to a constant weight at 240 ± 9 degrees F. Extract sample A as outlined using method A, B-1, or B-2. Determine the dry weight of the aggregate from the extracted mix and the moisture sample of mix (B). Dry to a constant weight at 240 ± 9 degrees F).

   C = Dry weight of the aggregate.
   D = Dry weight of the moisture sample (sample B).

4. Determine percent residual asphalt (E) (based on the dry weight of aggregate (C) and dry weight of mix sample for extraction).

   E = The percent of residual asphalt extracted from the mix

$$E = \frac{(D/B \times A) - C \times 100}{C}$$

   The factor (D/B x A) is the dry weight of the mix and is replaced with weight D when the moisture specimen is used for the extraction test (mix specimen dried to a constant weight prior to extraction).

5. Determine total percent residual asphalt in mix.

   E_T = E + Retention Factor from mix Design.

6. Determine the percent of emulsion or cutback.

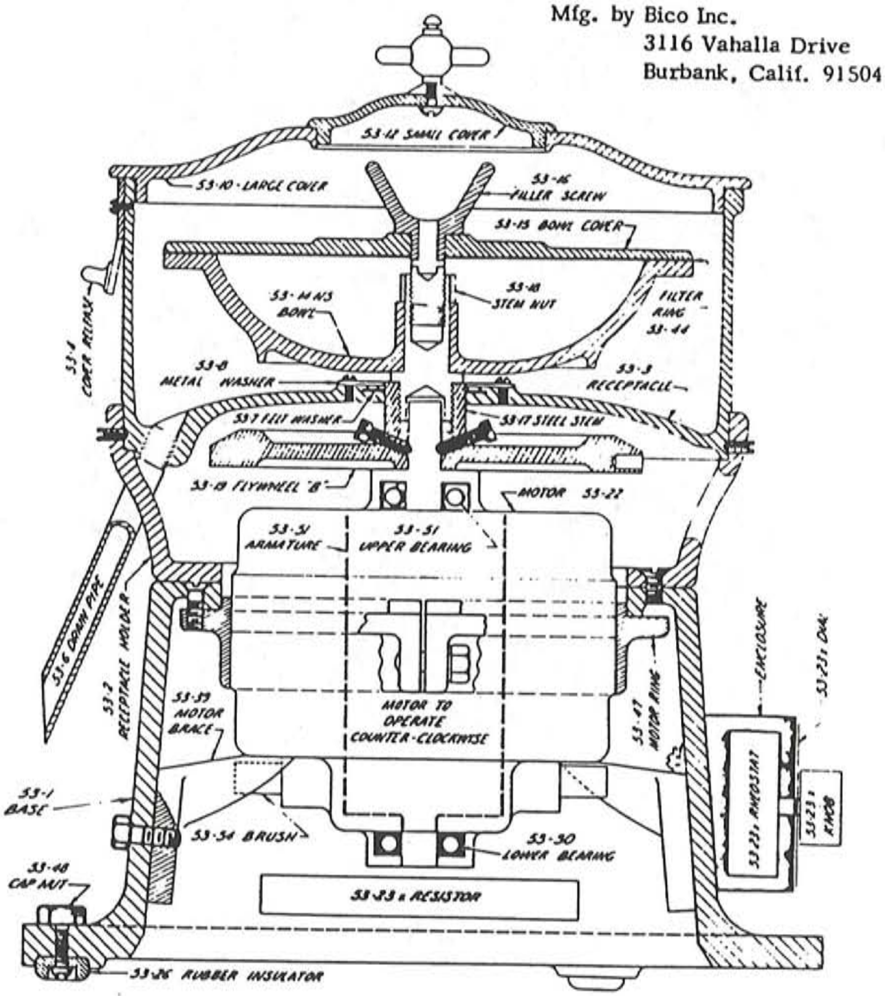
   F = Emulsion or cutback (based on the dry weight of the aggregate).
   R = Ratio of percent residual asphalt to percent initial liquid emulsion or cutbacks as determined by central laboratory.

$$\text{Percent emulsion or cutback} \quad F = \frac{E}{R}$$

DULIN ROTAREX ASPHALT SEPARATOR
Model 111-70 - 1000 gr. capacity
111-70S - 1500 gr. capacity

Press flywheel "B" down firmly on tapered motor shaft before setscrews are tightened. This will seat flywheel properly and avoid unbalance and vibration.

Mfg. by Bico Inc.
3116 Vahalla Drive
Burbank, Calif. 91504

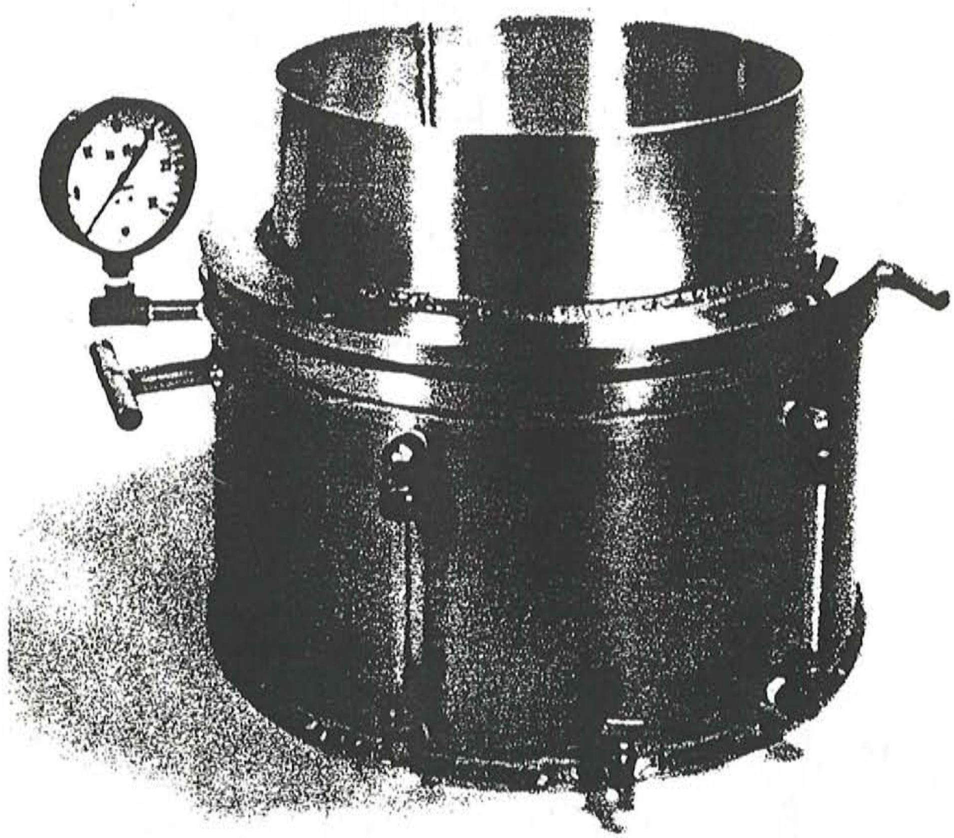


To remove aluminum Bowl "A", place 1/4" steel pin in hole in edge of flywheel "B", which is located below aluminum receptacle "C", rotate bowl assembly by hand, counter-clockwise to unscrew steel stem, which has standard right-hand thread at "D". Pin supplied with Rotarex.

Note: Rotarex is equipped with double seal ball bearings that require no lubrication.

When ordering replacement parts please give serial number of machine.

FIGURE 1



VACUUM EXTRACTOR

FIGURE 2