POLYMER MODIFIED CHIP SEAL TEST: OREGON ROUTE 22

Interim Report
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State Funded Project

by

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ABSTRACT

This report describes the construction and performance of ten pavement chip seals applied on June 17 - 18, 1987 using nine different emulsified asphalt binders. Seven of these asphalts were modified with different polymers, and the remaining two were conventional. The polymers used in the emulsions were Styrene Butadiene, Styrene Butadiene Synthetic Rubber, Styrene Butadiene Styrene Block Co-Polymer, Styrene Malam, Neoprene Latex Synthetic Rubber Co-Polymer, Ethylene Vinyl Acetate or Rubber Styrene Butadiene Styrene.

The chip seals were applied in a single pass using conventional construction techniques. Other than the addition of a modifier in each emulsified asphalt, no special procedures were required or used.

The chip seals were rated for overall performance based on both initial chip retention and their condition after two years of service. Three sections containing conventional asphalt and one section with polymerized asphalt were rated in a poor condition after two years. The low ratings may be related to conditions during construction as well as materials properties.

ACKNOWLEDGEMENTS

This report presents the interim results of a state-funded study conducted by the Research Section of the Oregon State Highway Division.

The authors wish to thank the following: John Gunter and the crew of Maintenance District 3, who constructed the project; BASF Chemical (formerly Polysar), who loaned us Vialit testing equipment; Greg Paulsen, formerly of the University of Nevada at Reno, and Lloyd Coyne, who coordinated and performed additional testing; Jo Anne Robison and Stephanie Swetland for typing this report.

DISCLAIMER

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1.0 INTRODUCTION

1.1 Objectives

Recent experience by Oregon Department of Transportation (ODOT) in chip seal construction has been with emulsified asphalts containing the product Styrelf. Since several polymer-based asphalt additives are available for use in Oregon, it is important to determine their effectiveness in improving chip seal performance in a cost-effective manner.

The objective of this study is to compare the specifications, test results, construction, and performance of chip seals made with various polymer modified and conventional emulsified asphalts.

It is expected that through an evaluation of the results of this and other similar tests, a basis can be developed for the selection of the most suitable emulsified asphalts for a given condition. For example, it is possible that for certain materials, traffic, construction, or environmental situations, a particular emulsified asphalt may be satisfactory, and in differing or more severe conditions, another emulsion may perform best.

1.2 Study Approach and Report Contents

In order to compare the construction and performance characteristics of the various chip seals, test sections containing each product were constructed end to end on a secondary state highway. As much as possible, the test section chip seals were placed over sections of roadway with the same cross-section, traffic loading, and pavement distress pattern.

All test sections were monitored during construction and inspected periodically. The inspections included both skid testing and a visual rating of chip seal performance.

This report includes the following information:

1) The layout, traffic characteristics, and environment where the sections are located (Chapter 3).

2) The materials used and the tests performed on the materials (Chapter 4).

3) The construction of the sections (Chapter 5).

4) A summary of the overall performance of the sections, including the rating criteria (Chapter 6).

5) An analysis of the materials test results (Chapter 7).

6) A comparison between the sections' overall performance, laboratory test results, data collected during construction and specifications for the emulsified asphalt products (Chapter 8).

7) Conclusions and recommendations regarding the performance of the various materials, the laboratory tests, construction practices and specifications (Chapter 9).

8) A listing of referenced information used in preparation of this report (Chapter 10).

9) Detailed tables of materials specifications and test results, statistical data on the performance vs. test result comparisons (Appendix).

A second report will be issued at a later date, either after a substantial portion of the sections fail or pavement rehabilitation occurs. This report will include:

1) A summary of overall pavement performance over the life of the project.

2) Conclusions and recommendations for the use of the various materials based on field performance over the life of the project.

1.3 Products Tested

All of the polymer modified and conventional emulsified asphalts tested were readily available in Oregon. These materials include:

1) CRS-2, a rapid setting cationic emulsion manufactured using conventional asphalt,

2) CRS-2P, a rapid setting cationic emulsion, which was CRS-2 modified on the project by the addition of Latex 2217, a styrene-butadiene synthetic latex (SBR),

3) CRS-2R, a rapid setting cationic emulsion produced using AC-20R, which is a polymerized asphalt cement, modified with styrene-butadiene synthetic rubber (SBR),

4) HFE-100S, a high-float anionic emulsion containing Styrelf, an asphalt modified with a styrene-butadiene-styrene block copolymer (SBS),

5) HFE-90, a high-float anionic emulsion containing conventional asphalt,

6) CRS-2D, a rapid setting cationic emulsion containing asphalt modified with LBD Ductilad D1002, a styrene malam,

7) LMCRS-2H, a rapid setting cationic emulsion containing DuPont Neoprene Latex 115, a polychloroprene synthetic rubber,

8) CRS-2(P1), a rapid setting cationic emulsion containing asphalt modified with DuPont Elvax 150 ethylene-vinyl-acetate (EVA) and

9) CRS-2K, a rapid setting cationic emulsion containing asphalt modified with Shell Kraton 4460, an oil extended styrene-butadiene-styrene block polymer (SBS).

The CRS-2, HFE-100S, and HFE-90 emulsified asphalts are included in the current and recent ODOT specifications for asphalt materials. These asphalts have been used extensively throughout the state. Detailed descriptions, data and specifications are given for each product in Chapter 4 and Appendix.

2.0 BACKGROUND

2.1 Chip Seal Use

Prior to 1940, chip seal applications, along with asphalt penetration macadam, were used on many of Oregon's surfaced highways. Most of these pavements were built by experienced highway division maintenance crews. These coverings provided a hard and dust-free surface over some of the then-existing gravel roadways.

As more funding became available for highway maintenance and construction during the depression years, the use of bituminous- type surfacing increased. Specifications for multi-layer penetration macadam and chip seals were developed in Oregon and regularly used on maintenance and contract construction projects. At that time, the Oregon State Highway Department (OSHD) was considered one of the pioneers and leaders in the design and development of various types of asphalt penetration surfacing.

During the period of time prior to and during World War II (1942 -1945), penetration-type surfacings were used extensively to provide smooth, dust-free surfacing on state, county and city highways. Although new construction on non-military roadways were discontinued during the war years, chip seal or penetration- type applications were used to maintain the highway system.

The development of improved equipment for mixing and laydown of asphalt concrete pavements resulted in the growing use of hot mixed surfacing rather than asphalt penetration-type pavements. Although asphalt concrete-type pavements eventually totally replaced penetration macadam, the chip sealing of pavements continued for several years.

During the mid-1950's, chip sealed pavements experienced increased problems due to the loss of chips immediately following construction. As a result of this chip loss, there were complaints about loose chips breaking automobile windshields. In addition, there were problems with the reduced skid resistance on pavement surface caused by remaining excess surface asphalt. This was a major problem in Western Oregon, as in this region, the cool, damp conditions made proper chip seal construction difficult, and the higher traffic volumes placed greater stress on the sealed roadways. There were fewer chip seal problems with the less traveled roads found in the drier climate of Central and Eastern Oregon.

During the winter of 1957, asphalt concrete pavements in Oregon were inspected and sampled to determine the cause of problems resulting from excess surface asphalt. It was found that pavements with this problem had lost cover aggregate placed during the seal application. This was found particularly on pavements with moderate to high traffic volume, high traffic speed, cool and wet conditions during construction.

As a result of the findings of the pavement survey and the problems from loss of cover aggregates during and following construction, the Oregon State Highway Department administration decided to discontinue chip sealing on both recently constructed asphalt concrete pavement and all pavements located west of the Cascade Mountains. Older asphalt concrete pavements and asphalt penetration macadam with low traffic volumes continued to be chip sealed in areas of Central and Eastern Oregon. These seals were placed during warm summer weather conditions.

Since the mid-1970's, asphalt concrete pavement problems have been experienced in Oregon[1] that are similar to those reported in twenty-six other states.[2] Pavement distress, such as surface ravelling, fatigue cracking and stripping from moisture damage, has resulted in an urgent demand for some type of surfacing protection such as a chip seal coating.

With the development of polymer-modified emulsified asphalts and the growing need for a cost-effective protective surfacing over asphalt concrete pavements, the use of chip seals is again increasing in Oregon. For the past few summers, the amount of chip seal construction both by contract and Highway Division maintenance crews has been growing.

During the past few years, several miles of chip seal have been constructed in each of Oregon's five regions. In the eastern and central portion of the state, both CRS-2 and the polymer-modified HFE-100S grades have been used with reasonably good performance. Most chip seal applications in western Oregon, which generally has more of a cool, damp summer climate, have been with HFE-100S. Both newly constructed asphalt concrete pavements and existing surfacings have been chip sealed with reasonably good chip retention and surfacing performance.

With the growing cost of pavement construction and maintenance, it is important that more cost-effective methods be developed to extend pavement life. Through an effective chip seal program, it is believed that:

- Minor fatigue and shrinkage cracks can be sealed.
- Ravelling and moisture damage can be controlled.
- The effects of surface wear and aging can be reduced.

2.2 Inception of Chip Seal Test Project

During the summer of 1986, several vendors approached the ODOT staff with proposals for use of their polymer in emulsified asphalt. They claimed their products would improve the effective life of chip seal pavement treatments. While product specifications and performance results from other agencies had been reviewed, it was believed that a trial installation in Oregon of each locally available product was needed. This study was designed to determine the effectiveness of each polymer product with local material or construction conditions and allow a performance evaluation in the Oregon environment.

In order to provide opportunity for the evaluation of currently available polymer modified emulsified asphalts, a study funded by ODOT was developed during 1986 to construct chip seal test sections on the North Santiam Highway (Oregon Route 22).

3.0 TEST SECTIONS

3.1 Location and Layout

The project is located about ten miles east of Salem, Oregon, or 2 1/2 miles northeast of Stayton, Oregon, on the North Santiam Highway (Oregon Route 22), between milepoints 7.39 and 11.45, as shown in Figure 1. The highway is an east-west route, descending from the summit of the Cascade Mountains eighty miles to the east, into the Willamette Valley to the west. At the test section project, the highway passes through farmland, grassland and low forested foothills. Elevation of the test site is approximately 500 feet.

The project is divided into sections of chip seals constructed with polymer modified and conventional emulsified asphalts, as shown in Figures 2 and 3. Each asphalt emulsion is represented by a primary test section and a secondary test section. In addition, a preliminary "calibration" section was constructed with conventional emulsified asphalt two weeks prior to placing the actual test sections.

The CRS-2 Calibration section lies between milepoints 8.43 and 8.95. The purpose of the calibration section was to evaluate the earlier calculated emulsion and aggregate application rates for the project. Adjustments were made in application rates as needed to accommodate roadway conditions.

The primary chip seal test sections are located between milepoints 8.95 and 11.45. Each of these sections covers both lanes and is one-quarter mile long. Within each test section, a 250-foot long typical section was preselected for extensive evaluation. These evaluation sections are thoroughly inspected on a periodic basis to determine the relative performance of the various products.

The secondary test sections are located between milepoints 7.39 and 8.43. These sections utilized the emulsion remaining after the primary test sections were completed.

The primary and secondary test sections were constructed on June 17-18, 1986, in the order listed for the following emulsions:

1st day: CRS-2, CRS-2P, CRS-2R, HFE-100S and HFE-90.
2nd day: CRS-2D, LMCRS-2H, CRS-2(P1) and CRS-2K.

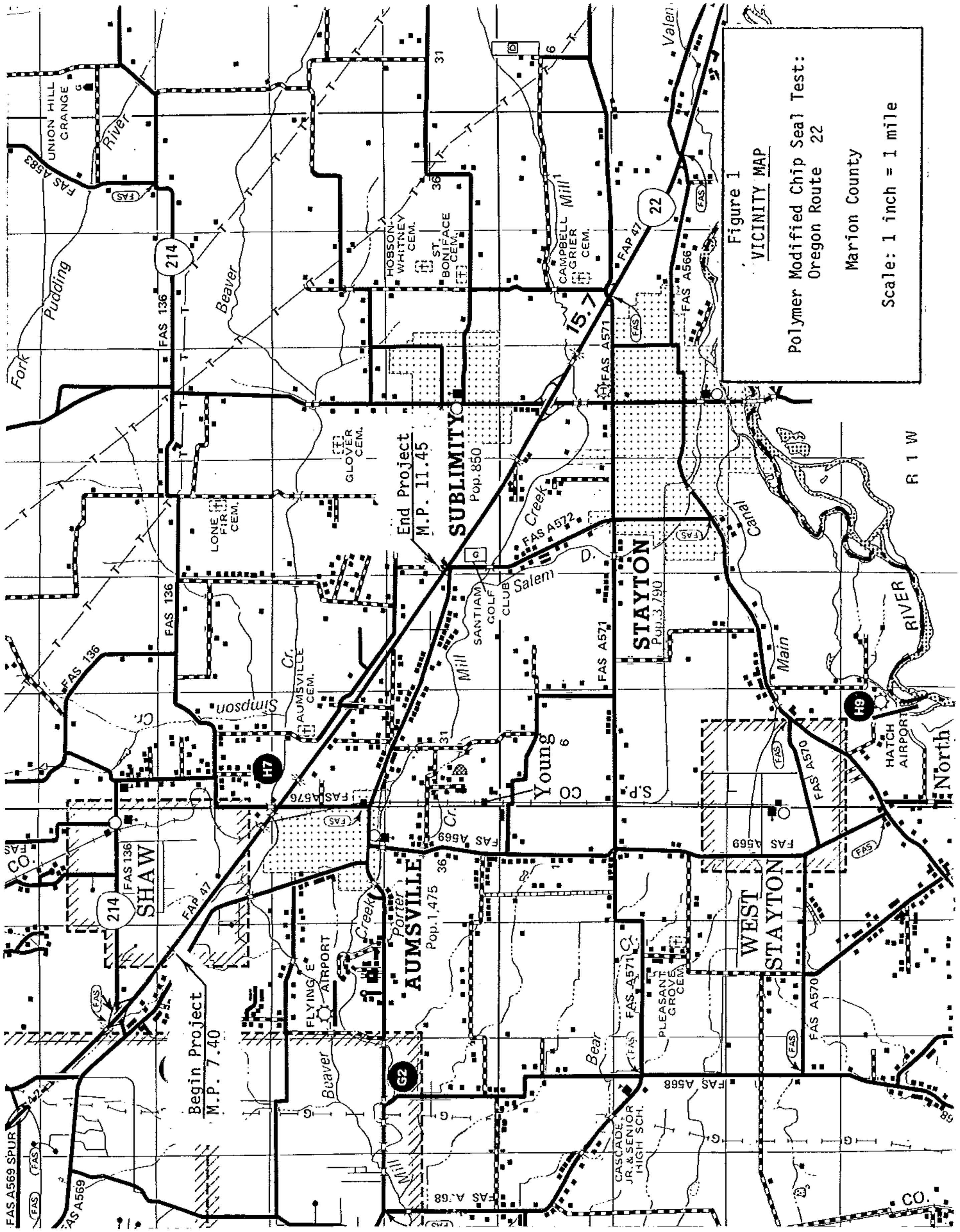

Figure 1
VICINITY MAP

Polymer Modified Chip Seal Test:
Oregon Route 22

Marion County

Scale: 1 inch = 1 mile

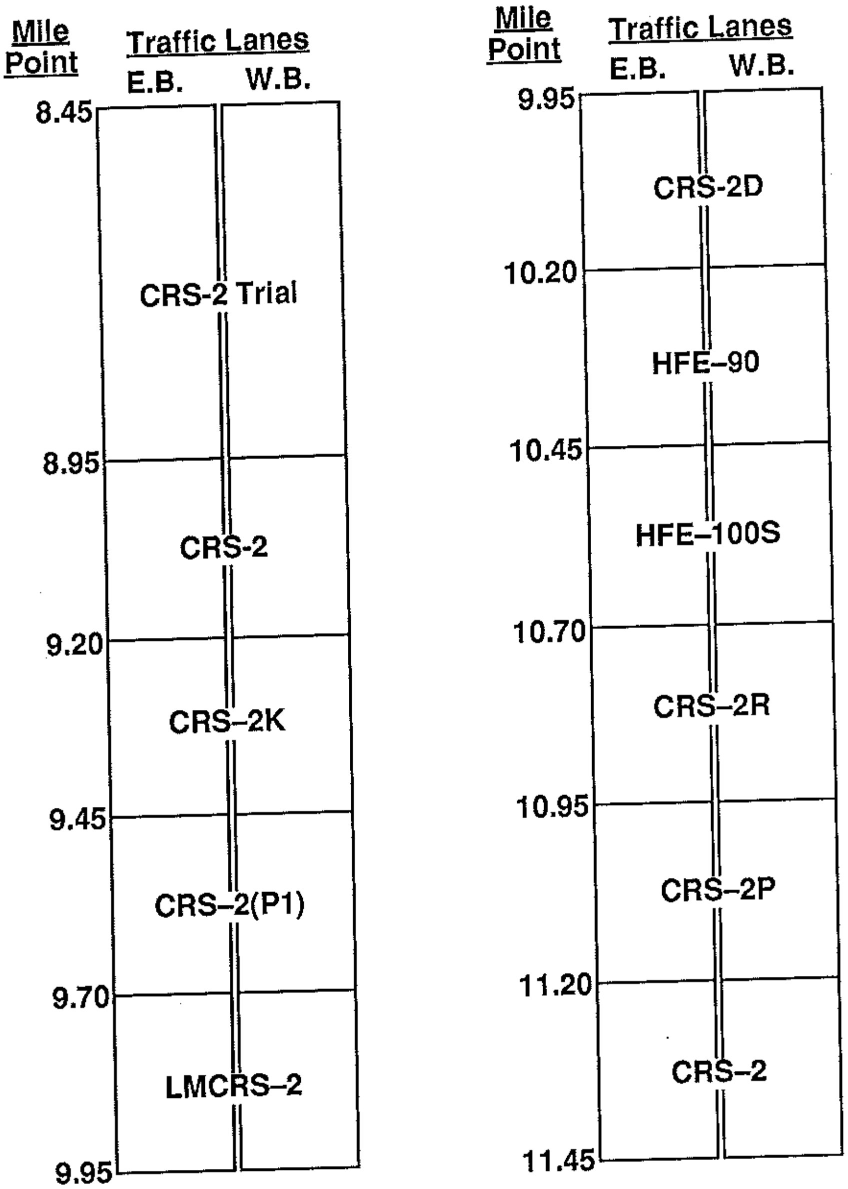

Figure 2: Polymer Modified Chip Seal, Primary Test Sections

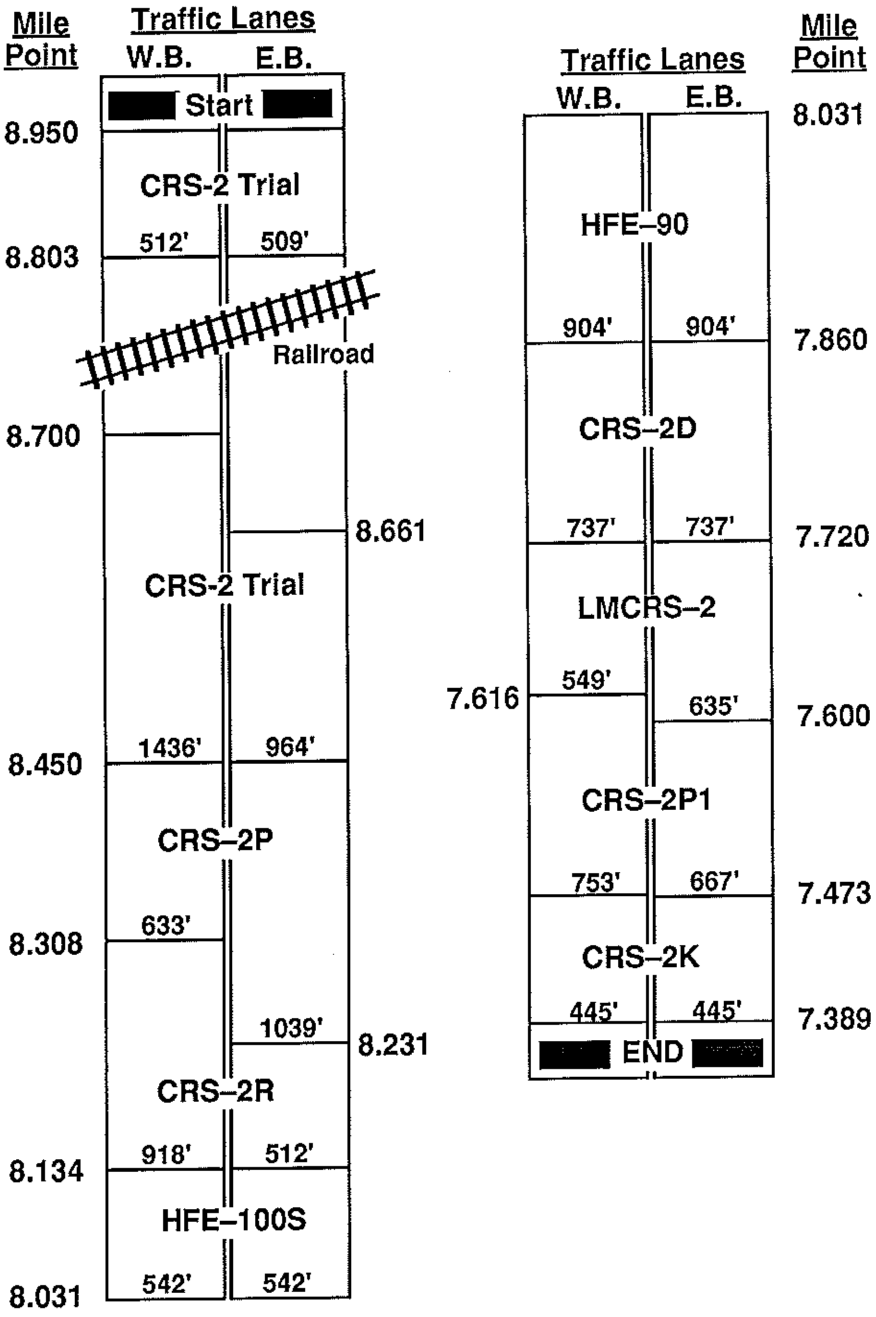

Figure 3: Polymer Modified Chip Seal, Secondary Test Sections

3.2 Climate and Traffic

In July, the warmest month, the average temperature is 64°F, with a mean daily temperature range of 32°F. In January, the coldest month, the average temperature is 37°F, with a mean daily temperature range of 13°F. There is an average of 160 days a year with rain or an occasional snowfall. The total annual precipitation is about 60 inches.[3]

The estimated average daily traffic counts on this section of two-lane and two-way road were 11,700 and 12,100 for 1987 and 1988, respectively. About 8% of this ADT was heavy trucks. Much of this truck traffic consists of loaded westbound log, chip, lumber and freight trucks. The 18-Kip annual equivalent axle loadings per lane were 195,000 and 201,000 for 1987 and 1988, respectively.

3.3 Test Section Physical Characteristics

Roadway Cross-Section

The chip seal was placed over the travel lanes of the existing two-lane highway. The wearing course on this roadway consisted of 1-1/2 inches of ODOT Class "E" open graded asphalt concrete pavement placed in 1977. Under this wearing course, there were 3-1/2 inches of ODOT Class "B" dense graded asphalt concrete and 10 to 17 inches of aggregate base. The "B" mix and aggregate were placed in 1962. A cross-section of the highway is shown in Figure 4.

Roadway Structural Condition

The roadway section strength was determined before construction, in October, 1986 and May, 1987, using a Dynaflect pavement deflection measuring system. The average deflection throughout the project, corrected to 70°F, was .00134 inches. Through the use of conversion equations, the equivalent Benkleman Beam deflection, corrected to 70°F, was .0312 inches. A profile of the pavement deflections throughout the test sections is shown in Figure 5.

Using Oregon's pavement section rating system, the structural quality of the pavement before construction was "weak" and the subgrade "good."

Pre-Construction Pavement Surface Condition

Physical distress descriptions are based on criteria given in the Federal Highway Administration's "Highway Pavement Distress Identification Manual."[4]

In the westbound lane, the side of the road with the greatest heavy truck loading, there were alternating sections with alligator cracking of low to medium severity in both wheel tracks. In the more lightly loaded eastbound lane, there were uncracked sections alternating with

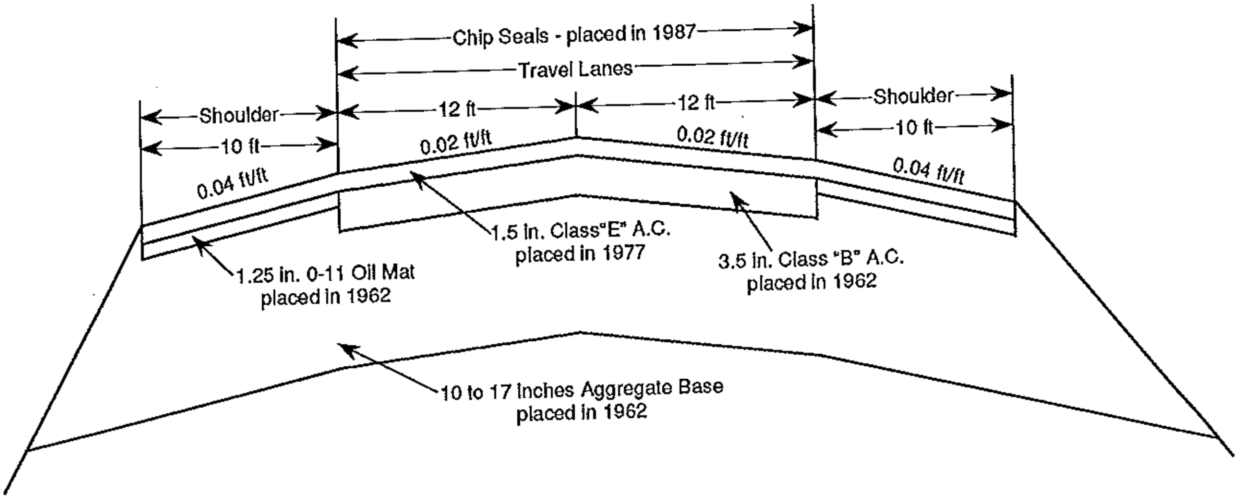

Figure 4: Typical Roadway Cross-Section

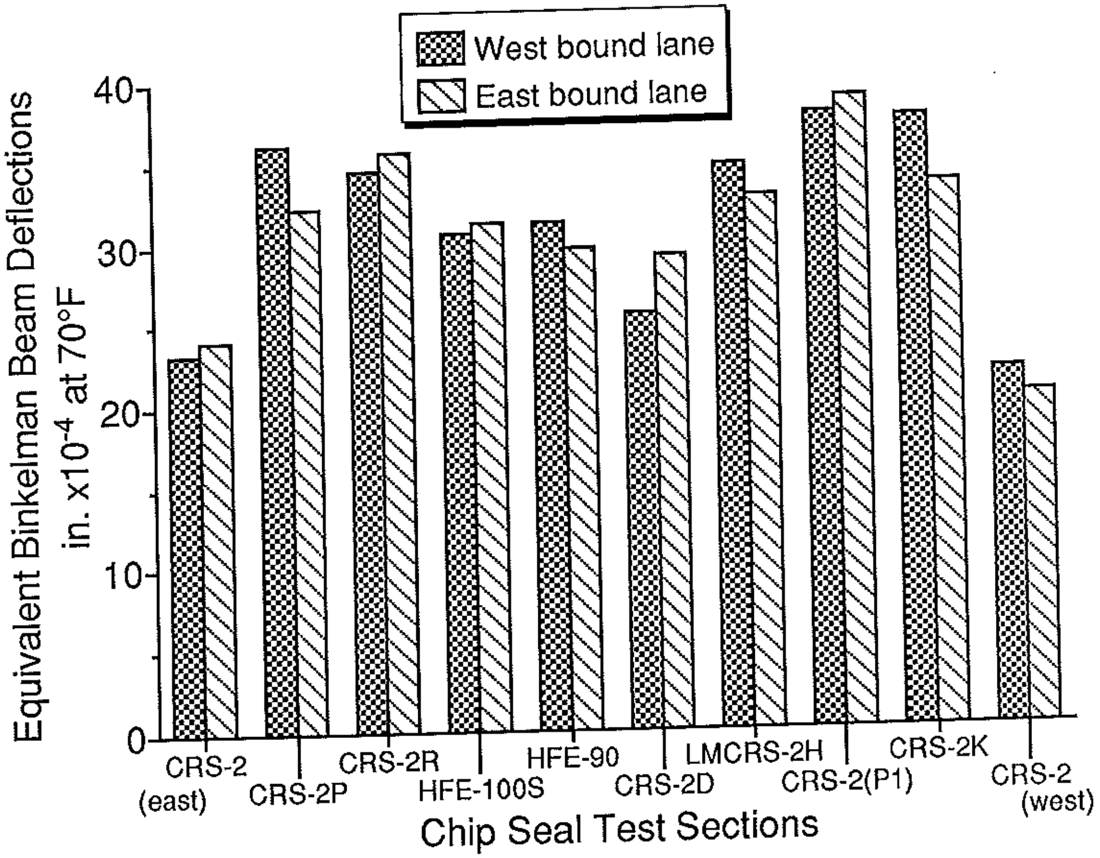

Figure 5: Pavement Deflections Before Chip Seal Application

areas having low severity alligator cracking. There was some low severity pumping in alligator cracking on the west end of the project.

There was slight ravelling and weathering in the wheel tracks of both lanes.

There were no bleeding, transverse cracking, severe rutting, patching, potholing or other forms of physical distress on the pavement before construction. Photos of the pre-construction pavement distress are shown in Figure 6.

The sections were friction tested prior to construction in April and May, 1986, using a two-wheeled skid trailer. ASTM E247-79 and AASHTO T282-84 test methods and equipment were used. From these tests, the average friction value in the left-wheel track of each lane, within the test sections, corrected to 40 mph, was 56.9, with a standard deviation of 1.3. Friction values after construction are described in Section 6.1.2.

4.0 MATERIALS AND TESTING

This chapter describes the materials, sampling and testing procedures used on this project. In addition, the procedures used to determine the initial aggregate and emulsion application rates are presented. The laboratory and field performance of the emulsions, binders and chip seal systems are discussed in Chapters 6, 7 and 8. Laboratory test data, product specifications and a listing of the suppliers are included in the Appendix.

4.1 Aggregate Description

Chip Seal Cover

The chip seal cover aggregate was crushed river rock, composed mainly of extrusive igneous material such as basalt and andesites. The aggregate source for all sections of this project was a Riedel International Inc. (formerly Western Pacific Construction Company) gravel pit on the Willamette River south of Portland, Oregon.

The aggregate used on the project was material remaining from Riedel's production of ODOT 3/8" to No. 10 for another project. This aggregate was hauled to an ODOT stockpile area near the job site. Since it was decided to use a 3/8" to 1/4" chip cover on the project, the aggregate was rescreened at the stockpile site to remove most of the excess material passing the 1/4-inch screen. The 1/4" to No. 10 material removed from the 3/8" to No. 10 material was used for aggregate choke stone on the seals.

The rescreened aggregate stockpile was depleted some time after the seals were 75% completed. To complete the project, additional 3/8" to No. 10 rock was brought in from the original source. The remaining primary and secondary test sections were constructed using chips with a gradation similar to that of the aggregate in the original 3/8" to No. 10 stockpile.

The use of 3/8" to 1/4" chips for cover, rather than the ODOT standard specification 3/8" to No. 10, was desired on the test sections to reduce the amount of finer material. It was believed that this change would improve chip retention and provide greater embedment of the larger chips.

Comments on the additional rock obtained for completion of the test section are found in Chapter 5 of this report. Laboratory test results and gradations for samples from the stockpile are presented in Appendix A-1. Appendix A-1 also includes test results and gradations for the aggregate prior to screening. During construction, samples of aggregate were taken from each test section. The test results for these construction samples are shown in Table 1. Although Appendix A-1 indicates that the rescreened cover aggregate contains less than 10% passing the 1/4-in screen, the samples obtained during construction (Table 1) contain 11 to 18% passing the 1/4-in.

Choke

Choke aggregate was applied to all of the sections after construction. This rock was graded 1/4" to No. 10.

4.2 Emulsion Descriptions

The presence, type and amount of polymer contained in the emulsions used in the test sections are based on information from the manufacturer. No attempt has been made by ODOT to verify this data. Detailed tables of emulsion and residue properties are provided in Appendix B. The following is a description for each type and grade of emulsified asphalt used in construction of the test section:

CRS-2

The CRS-2 was a cationic rapid setting emulsion containing a conventional asphalt cement. This emulsion was manufactured in Albina Fuel's in Vancouver, Washington plant to satisfy the ODOT CRS-2 specifications. Shell AR-1000 asphalt was used in production of the emulsion. In addition, to use in the test sections, this manufacturer's emulsion asphalt was used in the calibration section where the calculated emulsion and 3/8" - 1/4" aggregate application rates were adjusted for the test sections.

This grade of emulsified asphalt has been used in Oregon for more than twenty years, and the requirements are contained in their standard specifications for asphalt materials.

CRS-2P

The CRS-2P was a cationic rapid setting emulsion delivered to the project as CRS-2 grade and modified prior to use with the addition of Polysar Latex 2217, a styrene-butadiene synthetic latex (SBR). The Polymer was supplied by BASF Chemical, which was formerly Polysar Incorporated.

The emulsified asphalt was manufactured by Albina Fuel in Vancouver, Washington. Shell AR-1000 asphalt was used in the emulsion to comply with the ODOT CRS-2 standard specifications. The Polysar Latex was added, from drums to the emulsion in the transport truck, at the jobsite. Prior to application the polymer modified emulsion was circulated in the tank, for about one hour, to blend the materials in the truck. Based on calculations using the weight of CRS-2 contained in the hauling truck tank and volume of Polysar added, the residual asphalt in the CRS-2P emulsion contained 3.3% Polymer. Polysar Modified Emulsified Asphalt is not routinely used by ODOT in chip seal construction.

TABLE 1: LABORATORY TEST DATA FOR SAMPLES OF COVER AGGREGATE

Sampled from Primary Test Sections

TEST SECTION	(WEST) CRS-2	CRS-2K	CRS-2(P1)	LMCRS-2H	CRS-2D	HFE-90	HFE-100S	CRS-2R	CRS-2P	(EAST) CRS-2	* ODOT
Sieve (% Pass): ODOT TM 204, 205											
3/4 "	100	—	—	—	—	—	—	—	—	—	100
1/2 "	99	100	100	100	100	100	100	100	100	100	100
3/8 "	94	95	93	94	94	95	95	94	94	95	85-100
1/4 "	13	17	11	12	15	18	12	13	12	14	—
#4	4	6	3	3	5	6	4	4	3	5	—
#10	—	4	2	2	3	4	3	3	2	3	0-10
#40	—	3	2	2	2	3	3	2	2	3	0-2
#200	2.5	2.6	2.0	1.9	2.1	2.4	2.5	2.1	2.0	2.4	—
Cleanliness: ODOT TM227	77	84	86	81	81	77	81	81	79	75	75 (min.)
Elongated Pieces (%): ODOT TM229M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10 (max.)

*** Specifcations are for the ODOT 3/8" to No. 10 gradation**

CRS-2R

The CRS-2R was a cationic rapid setting emulsion containing asphalt cement modified with a styrene-butadiene synthetic rubber (SBR). The polymer modified asphalt was produced to satisfy the Asphalt Supply and Service's specifications for AC-20R grade. CENEX Asphalt in Laurel, Montana supplied the asphalt cement for production of the AC-20R.

The emulsion was manufactured in Albina's plant in Vancouver, Washington. Since the emulsion mill at the plant could not properly emulsify the high viscosity AC-20R, it was necessary to add 25% Shell AR-1000 without polymer, to manufacture the product. With the AC-20R containing 2% polymer and AR-1000 not containing polymer, the residual asphalt in the CRS-2R contained 1.5% polymer. Emulsified asphalt containing base asphalt supplied by Asphalt Supply and Services is not routinely used by ODOT, in chip seal construction.

HFE-100S

The HFE-100S was a high float anionic emulsion produced using asphalt modified with Elf Asphalt's Styrelf, an asphalt cement modified with a styrene-butadiene-styrene block co-polymer (SBS). Polymer modified asphalt used in the manufacture of the emulsion was produced using Montana asphalt from Elf's plant in Colorado. The emulsified asphalt was manufactured by Elf Asphalt (formerly Pacific Emulsions) in their Madras, Oregon plant to satisfy the ODOT standard specifications for HFE-100S. The residual asphalt in the emulsion was produced to contain 3% polymer.

Emulsified asphalt containing Styrelf has been used in chip seal construction on a regular basis by ODOT for four years prior to this study.

HFE-90

The HFE-90 was a high float anionic emulsified asphalt which did not contain polymer additives. This emulsion was manufactured in Elf Asphalt's plant in Madras, Oregon to satisfy the ODOT standard specification requirements for HFE-90. The source of asphalt contained in the emulsion was Montana Refining.

Emulsified asphalt of HFE-90 grade has been occasionally used by ODOT in chip seal construction.

CRS-2D

The CRS-2D was a cationic rapid setting emulsion containing asphalt modified with LBD Asphalt Products Ductilad D1002, a styrene malam.

The polymer was supplied to the Koch Asphalt Company's Spokane, Washington plant for use in the manufacture of the emulsion with Conoco AR-2000 grade asphalt from Montana Crude. The emulsion was produced to satisfy the ODOT standard specifications for CRS-2 with the residual asphalt containing 3% polymer. Emulsion containing Ductilad styrene malam type polymer had not been used by the ODOT in their chip seal construction.

LMCRS-2H

The LMCRS-2H was a cationic rapid setting emulsion containing a hard base asphalt and DuPont Neoprene Latex 115, a polychloroprene synthetic rubber.

The emulsified asphalt was manufactured by Morgan Paving Company at their Redding, California plant. The material was produced to satisfy the State of California Department of Transportation's LMCRS-2H specification requirements using a hard base Shell asphalt. The addition of the polymer to the asphalt was in the colloid mill during production of the emulsion. The residual asphalt in the emulsion contained 2.25% polymer.

Emulsion containing Neoprene is not routinely used by the ODOT in their chip seal construction.

CRS-2(P1)

The CRS-2(P1) was a cationic rapid setting emulsified asphalt manufactured by Chevron USA. The asphalt was modified with DuPont Elvax 150, an ethylene-vinyl-acetate (EVA) plastic which is a type of polyolefin available from several sources in several molecular combinations.

The emulsified asphalt was produced in Chevron's Richmond Beach, Washington refinery to satisfy their CRS-2(P1) specification requirements. Asphalt used in production of the emulsion was their refinery base stock containing 3% polymer.

Elvax is not routinely used by the ODOT for construction of chip seals.

CRS-2K

The CRS-2K used was a cationic rapid setting emulsified asphalt manufactured by Chevron USA in their Wellbridge (Portland), Oregon refinery. Asphalt from Chevron's refinery stock was modified with 3.5% Kraton 4460, which is an oil extended Styrene -Butadiene Styrene block copolymer (SBS). The polymer, Kraton 1101, was extended in a 50 - 50 ratio with oil before delivery to the refinery by the supplier, Shell Chemical. The emulsified asphalt was produced to satisfy the requirements of Chevron's CRS-2(K) specifications.

Kraton had not be used by the ODOT for construction of chip seals.

4.3 Aggregate, Emulsion and Binder Testing

Aggregate Spread Rate and Quality Testing

During the construction of each test section, the aggregate spread rate was calculated from the weight of rock collected in a four-square-foot (24" x 24") sheet metal pan. The empty pan, of a known weight, was placed in the path of the chip spreader. Following each application of chips, the pan was weighed and the spread rate calculated. The results of these tests are shown in Table 2 and Figure 7 of this report. Table 2 of the ODOT narrative and construction records[14] contains the results of tests made on aggregate sampled during the spread rate determination. A photograph of the aggregate collection pan is shown in Figure 8.

Samples of the aggregate were later tested in the ODOT laboratory for gradation, cleanliness, and elongated pieces. The results of these tests are tabulated in Table 1 of this report.

Emulsion Application Rate Testing

The emulsion application rate was based on the difference in the distributor truck weights both before and after construction of each section and the area of roadway surface covered.

In addition, the emulsion application rate was determined for each test section from the difference in weight of a four-square-foot piece of Fabritex geotextile cloth placed in the path of the distributor truck. The results of these tests are shown in Table 2 and Figure 9. A photograph of the emulsion collection cloth is shown in Figure 8.

Emulsion Quality Testing

Several manufacturers sampled and tested their emulsions either prior to shipment or at the jobsite. Their time of sampling and test methods were not provided for this report.

For each of the test sections, three one-gallon plastic containers of emulsion were sampled from the distributor tank. Portions of these samples were used in testing by the ODOT materials laboratory, the University of Nevada, and Lloyd Coyne.

The results of the ODOT and manufacturer testing are found in Appendix B. An analysis of tests made on the samples of emulsion is summarized and discussed in Chapters 7 and 8.

TABLE 2: CHIP SEAL CONSTRUCTION TEST DATA
Primary and Secondary Sections

		TEMPERATURES °F			EMULSION SPREAD RATE (Gal/Sq. Yds.)		ROCK RATE
Date	Product	Air	Pavement	Emulsion	By Cloth	By Truck Weight	Lbs. per Sq. Yd.
6/17/87	CRS-2 East End EB	66	78	130	0.382	0.354	20.7
	CRS-2 East End WB	66	78	130		0.477	
6/17/87	CRS-2P						
	(Polysar) EB	72	85	140	0.441	0.396	26.7
	(Polysar) WB	72	85	140		0.436	
	(Polysar) Secondary			140		0.409	
6/17/87	CRS-2R EB	74	82	165	0.435	0.396	31.0
	CRS-2R WB	74	82	165		0.587	
	CRS-2R Secondary			165		0.378	
6/17/87	HFE-100S EB	76	88	170	0.416	0.402	31.7
	HFE-100S WB	76	88	170		0.462	
	HFE-100S Secondary			170		0.424	
6/17/87	HFE-90 EB	66	78	175	0.472	0.456	23.9
	HFE-90 WB	66	78	175		0.422	
	HFE-90 Secondary			175		0.487	
6/18/87	CRS-2D						
	(Ductlad)(D1002) EB	64	70	133	0.273	0.236	21.0
	(Ductlad)(D1002) WB	72	82	133		0.506	33.7
	(Ductlad) Secondary	82	100	133		0.502	38.7*
6/18/87	LMCRS-2H						
	(Neoprene) EB	72	78	132	0.467	0.503	27.9
	(Neoprene) WB	72	78	132		0.469	38.5
	(Neoprene) Secondary	84	100	132		0.485	31.6*
6/18/87	CRS-2(P1) EB	72	96	140	0.406	0.443	36.2
	CRS-2(P1) WB	82	100	140		0.430	34.9
	CRS-2(P1) Secondary	82	101	140		0.469	35.2*
6/18/87	CRS-2K EB	84	117	136	0.497	0.518	33.2
	CRS-2K WB	84	117	136		0.559	36.6
	CRS-2K Secondary	81	115	136		0.475	32.4**
6/17/87	CRS-2 West End EB	72	80	130		0.361	
	CRS-2 West End WB	72	80	130	0.454	0.409	27.3

* Eastbound
** Westbound

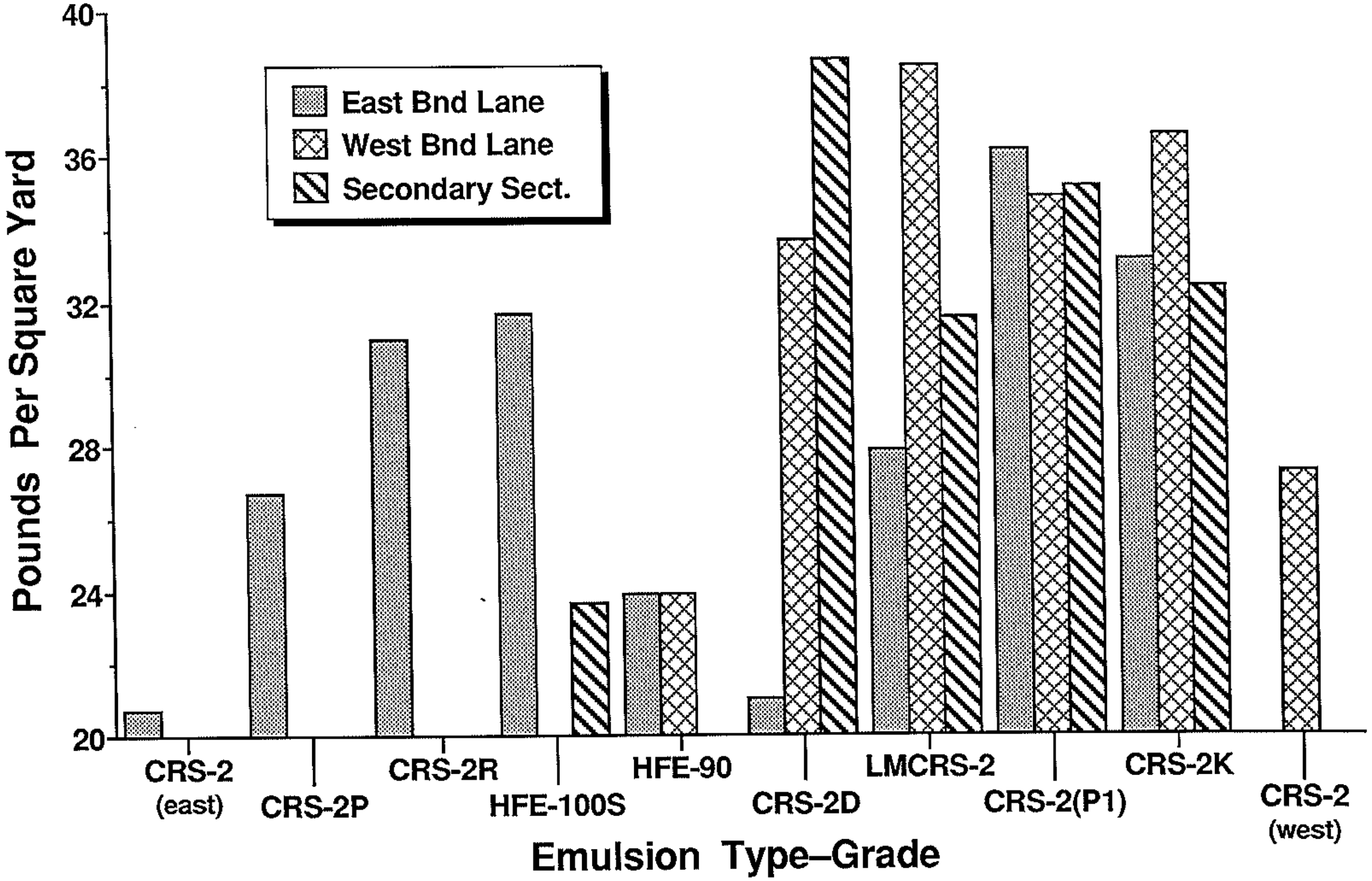

Figure 7: 3/8"– 1/4" Aggregate Chip Spread Rate, by pan net weight

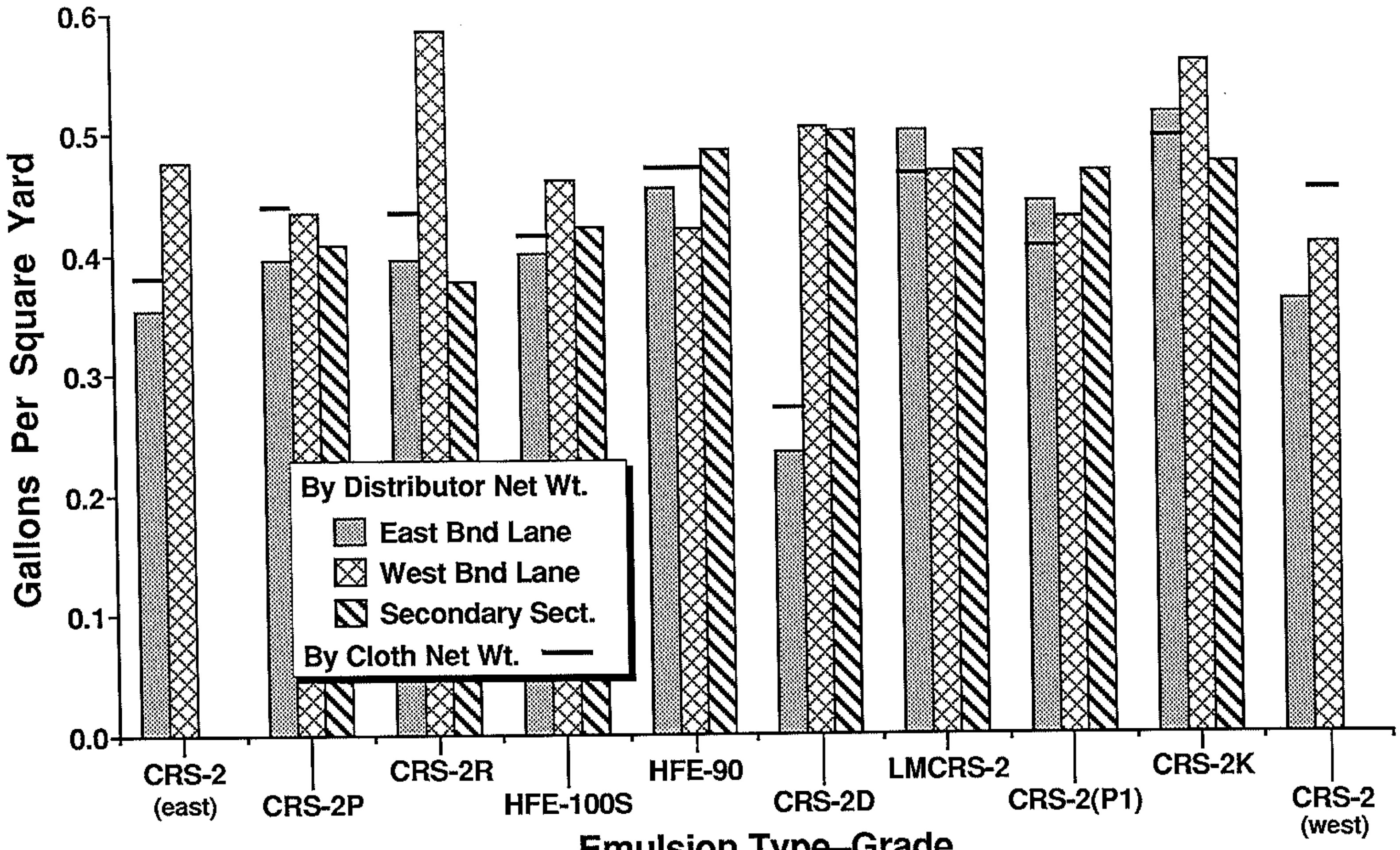

Figure 9: Emulsion Application Rate

ODOT Testing of Field Sampled Emulsified Asphalt

A one-gallon sample of each emulsified asphalt product was used for testing in the ODOT Materials Laboratory. Eleven tests were performed on each of the materials sampled. Six of the tests were for requirements contained in the ODOT standard specifications for CMS-2 grade emulsified asphalt, and five tests were for specification requirements used for one or more of the polymer modified emulsion products.

Tests made to determine conformance to the ODOT specification requirements include Saybolt Furol viscosity at 122°F, sieve test, particle charge, penetration of distillation residue at 177°F, percent oil distillate, and percent asphalt residue. All tests were performed by the AASHTO T59-86 procedure, except for modification of the emulsion distillation temperature. Since research by ODOT and others indicates that use of the AASHTO T59 temperature of 500°F alters the characteristics of the polymer modified asphalt residue, a distillation temperature of 400°F was held for 15 minutes to recover the asphalt residue.

In addition to the ODOT standard specification test for penetration by the AASHTO T49-84 procedure, the residue from distillation was tested for softening point, ductility at 39.2°F, toughness and tenacity, tensile stress at 800% elongation and torsion recovery. Requirements for one or more of these tests have been specified by each of the suppliers of polymer modified emulsified asphalt.

The softening point test was performed by the AASHTO T53-84 method, and ductility was determined by the AASHTO T51-86 procedure. Since the ODOT ductility test machine had problems with elongation measurements near 100cm at 39.2°F, the machine was turned off at 75cm elongation, and the unbroken CRS-2 and CRS-2P samples were removed. Also, the machine was turned off at 50cm elongation, and the unbroken CRS-2(P1) and CRS-2K samples were removed. All four of these samples could have broken at an elongation greater than tested if the test could have been continued until failure.

The test method used for the determination of tensile stress at 800% elongation was the ASTM proposed procedure "Standard Test Method for Force - Ductility of Bituminous Materials."[5] A ductilometer was used at a pull rate of 5 cm per minute with a mold similar to the standard ductility mold. Test results are in pounds per square centimeter.

The torsional recovery test was performed by the Chevron test method B-2D. The procedure requires distillation at a maximum temperature of 400°F and held for 15 minutes.[6]

The Benson method[7] was used for Toughness and Tenacity testing of distillation residue samples from each emulsion used in the test sections.

4.4 Chip Seal System Tests

Several variations of the Vialit test were used in an evaluation of each chip seal system. All versions of the Vialit test used on this project shared the following characteristics:

1) Emulsion and aggregate were placed on sample plates. In some cases, the placement was by hand in a laboratory and for other test placement was by construction equipment at the job site. In each case, the plates were allowed to cool and cure.

2) The test involved inverting each steel plate coated with emulsion and chips onto a frame and dropping a steel ball three times from a prescribed height onto the plate.

3) Results were measured in terms of the percentage of chips that remained embedded in the binder.

ODOT Vialit Testing

A version of the Vialit test identical to or closely approximating the original "French Chip" method was used by ODOT[8]. A summary of the test procedure is described in the following paragraph.

A standard size sample of each emulsion was poured onto a steel plate, and one hundred washed and dried aggregate chips were hand placed on the emulsion mat. Next, the sample was compacted, using six passes of the specified steel roller. The sample was then cured for 48 hours at 60°C in a circulating oven. Prior to testing, the sample was cooled for 30 minutes at 25°C and conditioned in a 5°C water bath for 20 minutes. After the conditioning, the plate was inverted onto a stand, and a steel ball was dropped from a 50cm height onto the back of the plate three times. The number of rocks that fell off of the plate was recorded. Then the sample was placed in a freezer at -22°C for 30 minutes. The sample was removed from the freezer and tested a second time. The percentage of retained aggregate for each test was recorded from the number of stones retained on the plates. The test results are discussed in Chapter 6.

University of Nevada-Reno Vialit Testing

Personnel at the University of Nevada in Reno conducted Vialit testing using a modified procedure.[13] A summary of the test procedure is described in the following paragraph.

Samples of aggregate and emulsified asphalt were collected by University personnel at the project site during construction and immediately transported to their laboratory in Reno, Nevada. Vialit plate samples were prepared with various emulsion application rates and temperatures in order to simulate field conditions. The spread rates used for this study were those shown in Table 2 reduced by 0.09 gsy. This reduction is intended to account for the lower absorption of emulsion on the steel plates as compared to the road surface. The emulsion temperatures prior to application were those shown in Table 2 with 10°F added. Prior to the emulsion application, the plates were preheated to 140°F. A 320-gram sample of 3/8 " - 1/4" aggregate was placed by hand in a layer one stone thick and rolled with a rubber-covered drum to simulate field compaction. This resulted in no loose aggregate on the plates. Multiple samples were prepared to provide a reasonable level of statistical validity to the tests. Although the number of plates varied, a typical array of specimens for one emulsion were about sixty plates, which included three plates for each of four curing times, and repeated five times, or 3 x 4 x 5 = 60 plates, for each emulsion tested.

After fabrication, the specimens were cured at room temperature for varying lengths of time, up to three hours. The testing included inverting the plates and measuring the chip loss. Then the plates were inverted onto a frame and subjected to three drops of a steel ball. The chip loss was measured a second time. The percentage of retained aggregate for each test was recorded from calculation by the following formula:

% Retained Aggregate = [(320 grams- Chip Loss in Grams) x 100]/ 320 grams

Lloyd Coyne: Modified Vialit Testing on Field Samples

These tests differed from the original "French Chip" Vialit test in sample preparation, testing apparatus, and curing procedure.[12] The test procedure is summarized as follows:

Rather than preparing the specimens on steel plates in the laboratory, the specimens were prepared on paint can lids, in the field. The one-gallon paint can lids were placed in a plywood template on the pavement in the path of the emulsion distributor and chip spreader. As a result, the shot rates, temperatures, etc., were those that actually occurred on the test sections. Following the application of each chip seal, the can lids were removed from the pavement and cured at ambient temperature on the jobsite. Curing times varied from 15 minutes to 2 hours and 45 minutes, depending on the grade and type of emulsion applied.

During each Vialit test, the can lid was inverted onto an open paint can, and the weight of rock loss was recorded. A two-inch diameter ball was then dropped on the lid three times, and the weight of total rock loss was recorded. The percentage of retained aggregate was calculated from the weight of aggregate, before and after the test, using the following formula:

% Retained = (Cover Retained/Cover Applied) x 100

A laboratory analysis of Lloyd Coyne's field tests by the authors is found in section 7.2 of this report. They determined percentages of retained aggregate through a different method.

Lloyd Coyne: Modified Vialit Testing on Laboratory Samples

Samples of emulsion and aggregate were used in testing of each chip seal system in the laboratory, using a modified Vialit test. The apparatus, testing, and calculation procedures were similar to those used in the field tests. However, the emulsion shot rate was held constant at 0.40 gallon per square yard (gsy), the emulsion temperature was 140°F, and the aggregate application rate was 20 pound per square yard (psy). The aggregate was dampened with water, and the samples were compacted by a person standing on a can lid placed over the sample. After fabrication, the samples were cured from ten minutes to 1-1/2 hours in an oven at 100°F until tested. Other conditions found in the field trials were duplicated as near as possible.

Lloyd Coyne: Modified Surface Abrasion Testing on Laboratory Samples

The tests were performed by a modified surface abrasion test based on the California Department of Transportation's Test method 360-B "Surface Abrasion Test." The test procedure is detailed in a referenced report[12] and is summarized as follows:

Samples for surface abrasion testing of each chip seal system were fabricated on smaller one-quart can lids, rather than the one-gallon can lids used in the field, in a manner similar to that used in the modified Vialit tests. All samples were oven cured at 140°F for 15 hours. One set of specimens was tested dry in the as-cured condition and another set was tested wet after an additional four days of soaking in water at room temperature. Each sample was tested in the California method apparatus for total abrasion durations up to 15 minutes, 45 seconds. Periodically, the machine was stopped, and the rock loss from the sample was noted.

Additional tests were performed on the CRS-2 system. In one series of tests, the emulsion application rates were 0.2, 0.3, 0.4, 0.5, and 0.6 gsy, and samples were at a constant test temperature.

In addition, another series of tests were performed on the CRS-2K system. In the second series of tests, specimen temperatures of 70°F and 80°F were used with a constant emulsion application rate. The total abrasion time was 15 minutes, 45 seconds. As in the previous abrasion tests, the machine was stopped periodically and rock loss noted.

5.0 CONSTRUCTION

This chapter provides details and comments on the equipment and procedures used in placing the calibration section, the test sections, and the remedial choking and sweeping. A test section construction narrative and tables with construction data are contained in records of the Oregon Department of Transportation, for the 1987 Construction of Chip Seal Test Sections.[14]

5.1 Equipment

State maintenance forces and equipment were used throughout the project, with the exception of several dump trucks, asphalt emulsion tanker, and distributor trucks. These vehicles belonged to either the emulsion supplier or trucking companies. The state-owned equipment used in the project was:

1) One Galion Model S35B steel wheeled roller
2) One Bomag Model BW12AS steel wheeled roller
3) One Etnyre chip spreader
4) Several dump trucks
5) One power broom

Figure 10 shows photographs of the chip spreader and emulsion distributer during chip seal construction.

5.2 Calculated Aggregate and Emulsion Application Rates

Prior to construction of the test sections, an application rate for emulsion and aggregate cover was calculated by a standard method.[9] Information required for the calculation included traffic volume, aggregate and emulsion test results and existing pavement condition. For use of CRS-2 grade emulsion, the method indicated a requirement for emulsion of 0.45 gsy and for 3/8 inch to 1/4 inch aggregate at 17.2 psy.

On June 3, five calibration sections were constructed using CRS-2 emulsion and the stockpiled cover aggregate to be used on the test sections. These sections were placed on the roadway between the planned primary and secondary test sections. The emulsion was applied at 0.40, 0.42, 0.44, 0.46, and 0.48 gsy over an approximately 200-foot long section for each application rate. Cover aggregates were spread at rates between 22 and 32 psy. Based on inspection of the calibration sections, it was decided that the calculated emulsion application rate of 0.45 gsy was satisfactory, and an aggregate application rate of 30 psy was necessary rather than the 17.2 pounds calculated.

In order to allow traffic on the calibration sections soon after application, the sections were choked with 1/4-in to No.10 aggregate. The quantities of choke material used were not recorded.

5.3 Test Section Construction

On the morning of June 17, 1987, construction of the ten primary test sections began with application of CRS-2 grade emulsion on the first 1/4-mile section on the east end of the project. This was followed by application of CRS-2 on the second control section on the west end. The 3/8" to 1/4" cover aggregate was spread on the sections as soon as possible following the emulsion applications.

During the laydown of these first sections, the emulsion and rock application rates were readjusted to compensate for variations found in the roadway surface conditions. Emulsion application rates for the westbound lane were increased to compensate for the high level of pavement fatigue cracking in this lane.

In all cases on the primary test section, the initial application of each emulsion was made in the eastbound lane. Since no two emulsions, distributors or operators performed in the same way, some adjustments were required for nearly every initial application. When placement on the westbound lane commenced, few adjustments were made or needed. All of the 250-foot long evaluation sections were in the westbound lane. As a result, the application rates used through the evaluation sections were more consistent and are best for comparing the binders.

Rolling on each of the test sections was done with two steel wheeled rollers, making at least one pass apiece over the fresh seal. It was the opinion of some observers that these rollers could not properly position the chips in the wheeltracks because the rigid wheels would bridge over any aggregate in a wheel track rut. For chip seal construction on rutted pavements, the ODOT standard specifications require that a pneumatic tired roller be used on the second pass over a fresh seal. However, since a pneumatic tired roller was not available for use on the first day of construction and the pavement had minor rutting, it was decided to use steel wheeled rollers throughout the project.

Following the application of the CRS-2 control sections, the CRS-2P, CRS-2R, HFE-100S and HFE-90 sections were placed in the order listed. As in the control sections, each product was first applied in the eastbound lane and then the westbound. Emulsion remaining from construction of the primary sections was used in the secondary test sections. In several cases, oversize aggregate, larger than 1/2" size, was found in the cover aggregate.

Immediately following the addition and blending of Polysar latex to CRS-2 emulsion, the resulting CRS-2P grade was applied to the primary test section at the supplier's recommended application rate. The emulsion was immediately covered with chips, and the remaining emulsion was used in the secondary test section.

During the application of CRS-2R emulsion on the eastbound lane section, the chip spreader ran out of rock. This resulted from a shortage of hauling trucks. While the spreader was waiting for a loaded truck and being refilled, the emulsion on the road broke. When the chips were spread, the emulsion had turned black on the surface. Later inspection of the seal showed an uneven spread of aggregate. This was due to the spreader being stopped and started several times. However, no unusual chip loss was noticed from the emulsion breaking prior to covering.

As observed earlier on Oregon chip seal projects, the HFE-100s emulsion streaked or did not spray uniformly from the distributor nozzles (snivies) during application. With a conventional emulsion, this streaking would suggest clogged spray nozzles or that the emulsion was of an improper temperature or viscosity for an even spray application. In this case, the emulsion appeared to be very viscous, and it did not seem to flow into cracks after it contacted the pavement. This longitudinal streaking was observed in field inspections, and it appeared that less aggregate was retained in areas of greatest streaking.

The HFE-90 primary and secondary test sections were placed in the early to late evening. Since these sections were the last to be constructed on the first day, the air and pavement temperatures were low and had the least cure time before traffic exposure.

Construction of chip seal test sections on the second day, June 18, included sections with CRS-2D, LMCRS-2H, CRS-2(P-1), and CRS-2K emulsions. The sections were placed in the order listed with the eastbound lane applied first and the westbound following for each grade of emulsion.

Problems were experienced in application of the CRS-2D emulsion. The distributor valve setting was improper, which resulted in a low application rate for the beginning of the shot. The distributor was stopped several times within the first few hundred feet of the section, and several attempts were made to get the correct spread rate.

The LMCRS-2H emulsion was applied without problems. At times, the chip spreader had difficulty getting the chip cover on the emulsion at the proper time.

Next, the CRS-2(P1) section was placed, without problems, starting with the eastbound lane and finishing with the westbound lane. During the spreading of chips on this section, the project supervisor indicated that they had begun wetting the aggregate from a dry to a very wet condition. This resulted in considerable variation in moisture content.

The CRS-2K test sections were the last seals placed on the project. Both the primary and secondary sections were constructed without problems. A high application rate (0.57 gsy) was used to improve chip retention.

Aggregate for the CRS-2D, LMCRS-2H, and CRS-2(P-1) secondary sections contained chips of a wider gradation range than the material used in the other sections. The project supervisor indicated that they had used all of the rock originally stockpiled, and ten truckloads of new aggregate had been brought in from the original source. Also, the new rock had not been screened to remove the excess 1/4" to No. 10 fraction. No effort was made during construction to distinguish between the original and new rock. Although it was intended that the unscreened rock would be used in the secondary test sections, some of the material was used in the primary sections.

Examination of the aggregate gradation for samples obtained during construction of the primary test section given in Table 1 indicates considerable variation in gradation ranging from 11 to 18% passing the 1/4" sieve. These field gradations are nearer that of the 3/8" to No. 10 unscreened material than that of the 3/8" to 1/4" material intended for use as shown in Appendix A-1.

Temperature of emulsion, air and pavement was recorded during construction of each test section. The results of these measurements are contained in Table 2 and Figure 11 of this report.

5.4 Remedial Choking and Sweeping

On June 17, the first day of the chip seal test section construction, traffic control was removed as darkness approached, and vehicles were allowed on the sections placed that day. By the following morning, traffic had whipped off a considerable amount of the rock from the wheel track areas on some of the sections placed the previous day. The least amount of chip loss was in the HFE-100S sections.

Because of the chip loss problem, all of the sections placed on June 17 were closed to traffic on the morning of June 18. Each of the sections were choked with 1/4" to No. 10 crushed aggregate. The choke rock was sprinkled on the pavement using truck bed mounted spreaders. Following the application of choke material, the rock was rolled into the seal using steel wheeled rollers.

Traffic was again allowed on the sections at 12:00 noon on June 18 following completion of the choke aggregate application. After traffic resumed, rock pulled out of the chip seal mat and adhered to the vehicle tires. After one hour of traffic, the vehicles were detoured to the shoulder, and these sections were choked a second time.

The chip seals placed on June 18 were choked for the first time that evening starting from the west. At 9:00 that night, traffic was allowed on all of the sections.

All of the sections placed on June 18 were in good condition on the morning of June 19 except the eastbound lane of CRS-2D. There was a considerable amount of loose rock on the road. Since there was some loose rock on all sections, traffic was detoured around the chip seals, and power brooms were used to sweep away the loose rock.

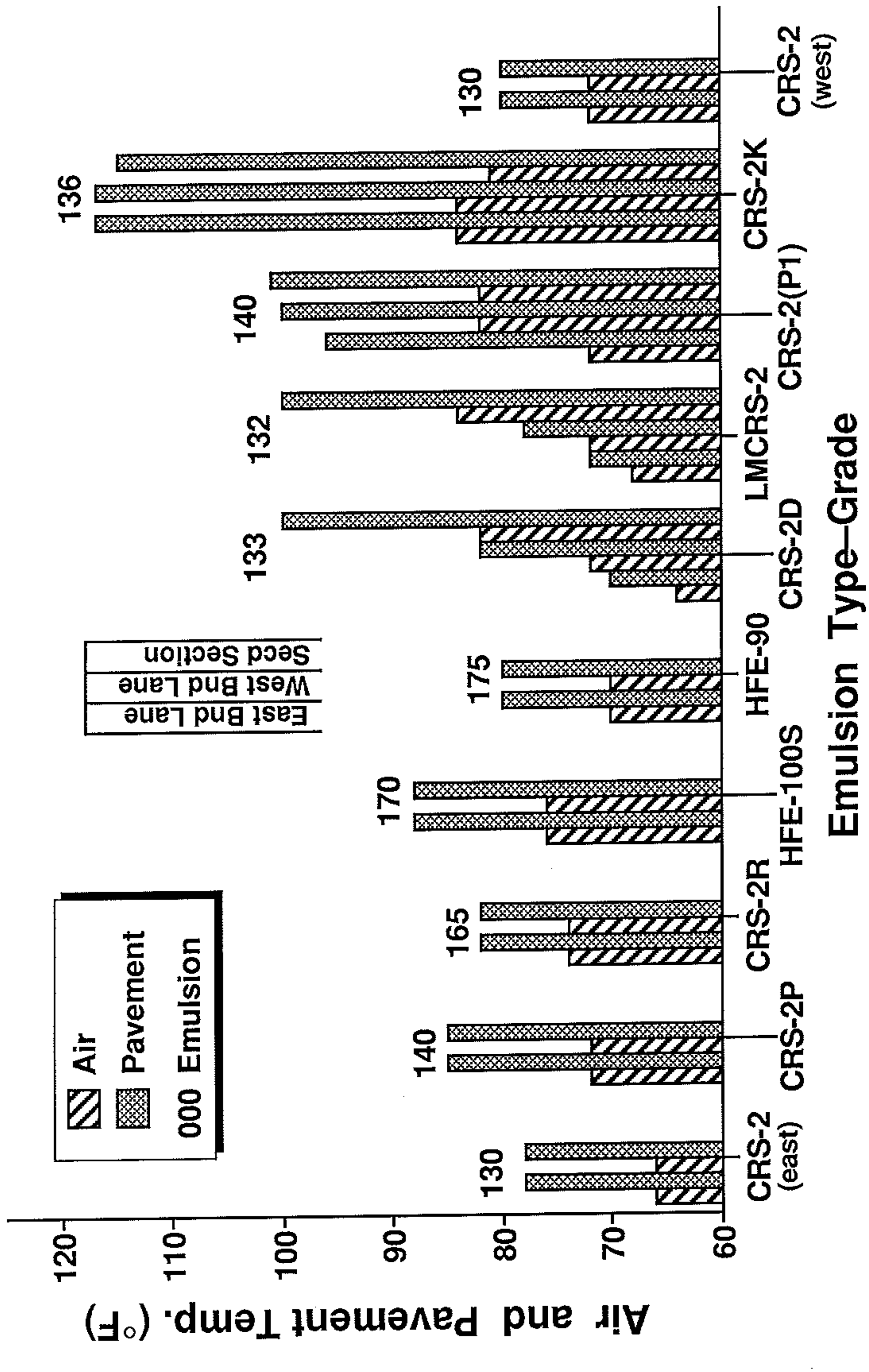

Figure 11: Chip Seal Application Temperatures

The westbound lane of the east section of the CRS-2 and the HFE-90 sections were choked for a third time on the afternoon of June 19. These seals continued to show some excess surface asphalt in the wheel track areas.

On the evening of June 19 and the morning of June 20, the loose aggregate from the choke was swept off the roadway. No further choke application or remedial maintenance has been performed on the chip seal test sections.

6.0 TEST SECTION PERFORMANCE

This chapter presents an evaluation of the performance of the chip seal test sections with regard to surface condition, distress trends and friction resistance. Ratings for surface distress conditions were developed from several inspections of the test sections during the two years following construction. Friction resistance of the sections was evaluated following each inspection using an ASTM standard skid trailer and procedures.

6.1 Surface Condition

Generally, the test sections were inspected and the surface condition evaluated as soon as possible following each summer and winter season. This provides an opportunity to determine seasonal differences for each seal and compare them for the effects of cold temperatures with considerable traffic using studded snow tires and warm temperatures with high traffic volumes.

Each inspection included a thorough evaluation of the 250-foot evaluation sections and a less detailed survey of the total 1/4- mile length in the westbound lane for each of the ten test sections. In addition, the calibration section constructed two weeks prior to the test sections was evaluated.

A numerical rating system was developed for evaluation of the test sections. A value of 5 represented an excellent condition, and 1 an unsatisfactory condition. During each inspection, ratings were made for excess surface asphalt, chip retention, aggregate embedment, resistance to ravelling and crack sealing. The results of the 1988 Fall and 1989 Spring season ratings for each of the five pavement performance criteria and an average value for each test section are shown in Table 3.

Rating System

The following is a detailed description of the numerical rating values used in the evaluation of each test section for the five performance criteria:

1. Excess Surface Asphalt

    5 = Excellent: 0 to 10% exposed surface asphalt
    4 = Good: 11 to 30% exposed surface asphalt
    3 = Fair: 31 to 60% exposed surface asphalt
    2 = Poor: 61 to 90% exposed surface asphalt
    1 = Unsatisfactory: 91 to 100% exposed asphalt

2. Chip Retention (3/8 inch to 1/4 inch chips in wheel track)

   5 = Excellent: 81 to 100% chip retention
   4 = Good: 61 to 80% chip retention
   3 = Fair: 41 to 60% chip retention
   2 = Poor: 21 to 40% chip retention
   1 = Unsatisfactory: 0 to 20% chip retention

3. Aggregate Embedment

   5 = Excellent: 50 to 60% of average aggregate height is embedded
   4 = Good: 61 to 70% of average aggregate height is embedded
   3 = Fair: 71 to 80% of average aggregate height is embedded
   2 = Poor: 81 to 90% of average aggregate height is embedded
   1 = Unsatisfactory: 91 to 100% of average aggregate height is embedded

4. Resistance to Ravelling (Total surface)

   5 = Excellent: 91 to 100% without ravelling
   4 = Good: 71 to 90% without ravelling
   3 = Fair: 41 to 70% without ravelling
   2 = Poor: 11 to 40% without ravelling
   1 = Unsatisfactory: 0 to 10% without ravelling

5. Effectiveness of Crack Sealing (Total Surface)

   5 = Excellent: 0 to 10% reflective cracks through seal
   4 = Good: 11 to 30% reflective cracks through seal
   3 = Fair: 31 to 50% reflective cracks through seal
   2 = Poor: 51 to 90% reflective cracks through seal
   1 = Unsatisfactory: 91 to 100% reflective cracks through seal

6.2 Surface Distress Trends

During the two years following construction of the test section, changes were observed in the surfacing condition. The types of distress which have been evaluated include the amount of surface asphalt, chip retention, aggregate embedment, resistance to ravelling and sealing of reflective cracks.

No excess surface asphalt was found on the CRS-2(P1) section. During July, August and September of 1988, there was unusually hot weather in the area of the test section. This is probably why all test sections except for the CRS-2(P1) section developed a dark surface condition in their wheeltracks. The CRS-2 (calibration) section has continued to have only a minor amount of excess surface asphalt. Over the 1988-89 winter season, the percentage of the seal having excess surface asphalt decreased for the CRS-2 and LMCRS-2H sections. After two years, the sections with the greatest amount of excessive surface asphalt were the CRS-2 control, CRS-2P and HFE-90 seals.

Extensive chip loss occurred in the CRS-2 (control), CRS-2P, CRS-2R and HFE-90 sections during the first night after construction. Although these sections were choked with 1/4-inch #10 material the following day, all have shown a progressive trend toward poor overall performance. Chip retention has been excellent for the HFE-100S, CRS-2D, CRS-2(P1), CRS-2K and CRS-2 (calibration) seals and rated good for the LMCRS-2H seal. Test sections appearing to approach excessive embedment of aggregates for the 1989 spring inspection were the CRS-2 (control), HFE-100S, HFE-90 and CRS-2K seals.

Reflective cracks were sealed most effectively by the CRS-2K emulsion. The CRS-2(P1) and HFE-100s emulsion were rated the most effective in 1988. However, the spring 1989 inspection indicated an increased number of cracks for these seals. For the 1988 fall inspection, the sections with HFE-90, CRS-2D, LMCRS-2H and CRS-2 (calibration) had a minor number of reflective cracks through the seals. However, for the 1989 spring inspection, the HFE-90 and LMCRS-2H sections had a considerable increase in cracking.

The CRS-2K section has the best performance in resistance to ravelling around reflective cracking. A moderate amount of ravelling was found in the reflective cracking for the CRS-2D, LMCRS-2H, CRS-2(P1) and CRS-2 (calibration) sections. Generally the CRS-2 (control), CRS-2P, CRS-2R, HFE-100S and HFE-90 sections had the poorest resistance to ravelling.

Based on a total average rating of the five performance criteria, the CRS-2(P1) section is the best overall chip seal after two years. The CRS-2D, CRS-2K and CRS-2 (calibration) sections have performed nearly as well, and the CRS-2 (control) and HFE-90 sections have the poorest overall performance.

The overall field performance of the test sections are shown in Figure 12. The curves are based on numerical ratings of test section performance using data collected during several field inspections. The rating system and criteria are presented in section 6.1.

6.3 Friction Resistance Testing

The ten chip seal test sections and calibration section were tested for friction resistance periodically using an ASTM standard two-wheeled skid trailer and procedures. The sections were first friction tested on May 26, 1987 prior to sealing. After sealing, they were tested in November, 1987, June through August, 1988, December, 1988 and April, 1989. Friction numbers for the seven series of tests on each test section are shown in Figure 13.

Friction resistance values before application of the seals were uniform and well above the recommended minimum value of 37. The average value for the eleven sections was 57 and ranged from 56 to 58.

TABLE 3: NUMERICAL PERFORMANCE RATING
Fall, 1988 and Spring, 1989

SECTION	EXCESS SURFACE ASPHALT	CHIP RETENTION	AGGREGATE EMBEDMENT	RESISTANCE TO RAVELLING	EFFECTIVENESS OF CRACK SEALING	TOTAL AVERAGE RATING
CRS-2 East	3 (2)	1 (1)	2 (2)	3 (2)	2 (2)	2.2 (1.8)
CRS-2P	3 (2)	3 (3)	3 (3)	2 (2)	1 (2)	2.4 (2.4)
CRS-2R	3 (3)	3 (3)	3 (3)	2 (2)	3 (3)	2.8 (2.8)
HFE-100S	3 (3)	5 (5)	2 (2)	2 (2)	5 (3)	3.4 (3.0)
HFE-90	2 (2)	2 (2)	2 (2)	2 (2)	4 (2)	2.4 (2.0)
CRS-2D	3 (4)	5 (5)	4 (4)	3 (3)	4 (4)	3.8 (4.0)
LMCRS-2H	3 (4)	4 (4)	4 (4)	3 (3)	4 (2)	3.6 (3.4)
CRS-2-(P1)	5 (5)	5 (5)	5 (5)	4 (3)	5 (4)	4.8 (4.4)
CRS-2K	3 (3)	5 (5)	2 (2)	4 (5)	5 (5)	3.8 (4.0)
CRS-2 West	2 (2)	1 (1)	2 (2)	2 (2)	2 (2)	1.8 (1.8)
CRS-2 Cal. *	4 (4)	5 (5)	3 (3)	3.5 (4)	3.5 (4)	3.8 (4.0)

* Average rating of calibration sections in westbound lane

() Values in parenthesis are for 1989

Generally, friction values for the chip sealed sections were at their highest level in the spring before the summer heat. Average values for the eleven sections tested in July 1988 and April 1989 were 56 and 57.

The average friction number for the six tests made from November 1987 to April 1989 on each product test section is shown in Table 4. The values indicate that the sections with non-polymer modified emulsions have lower level friction resistance (49 - 51) than the sections with modified emulsions (52 - 55). This difference in friction values is not great enough to be considered significant.

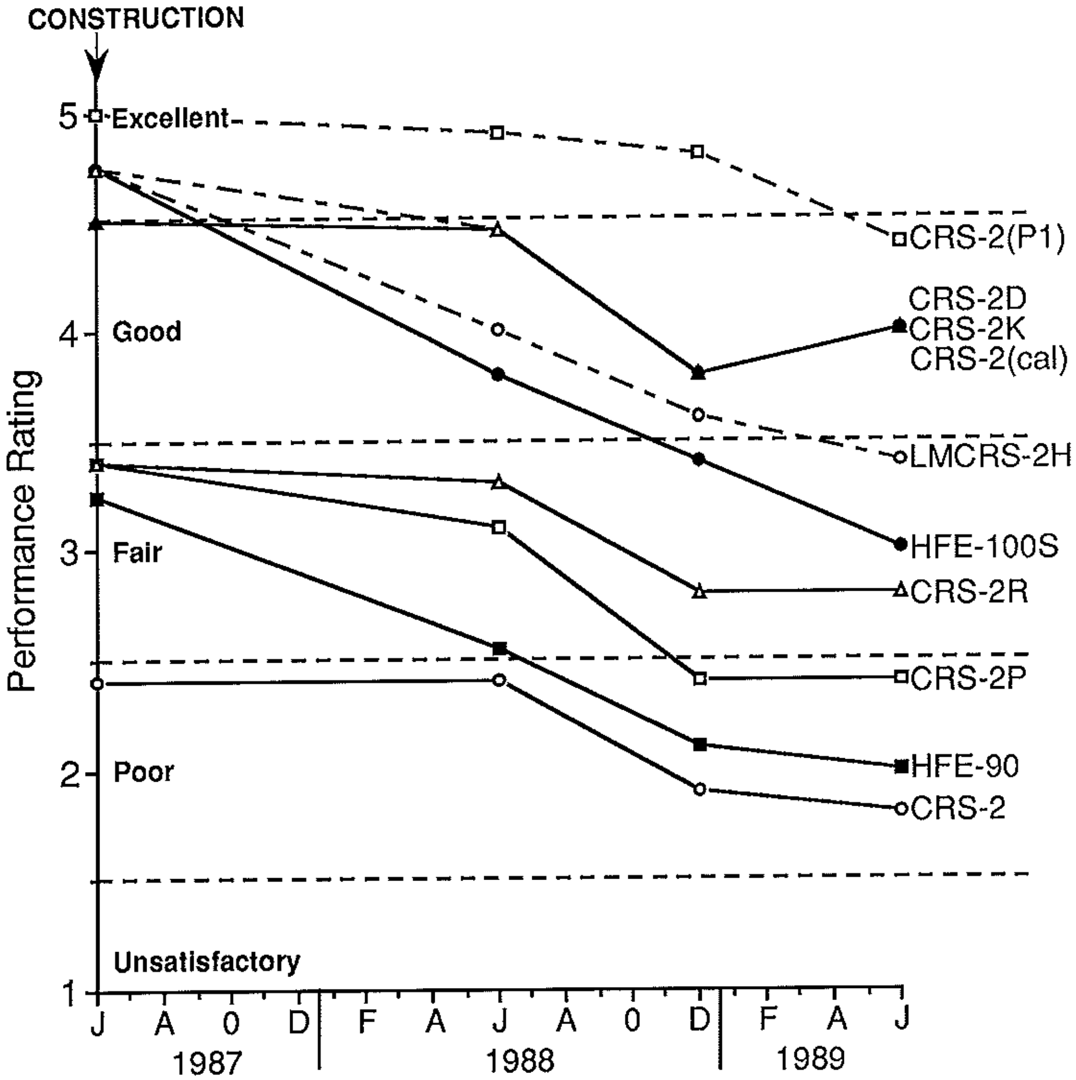

Figure 12: Average Performance Ratings for Test Sections

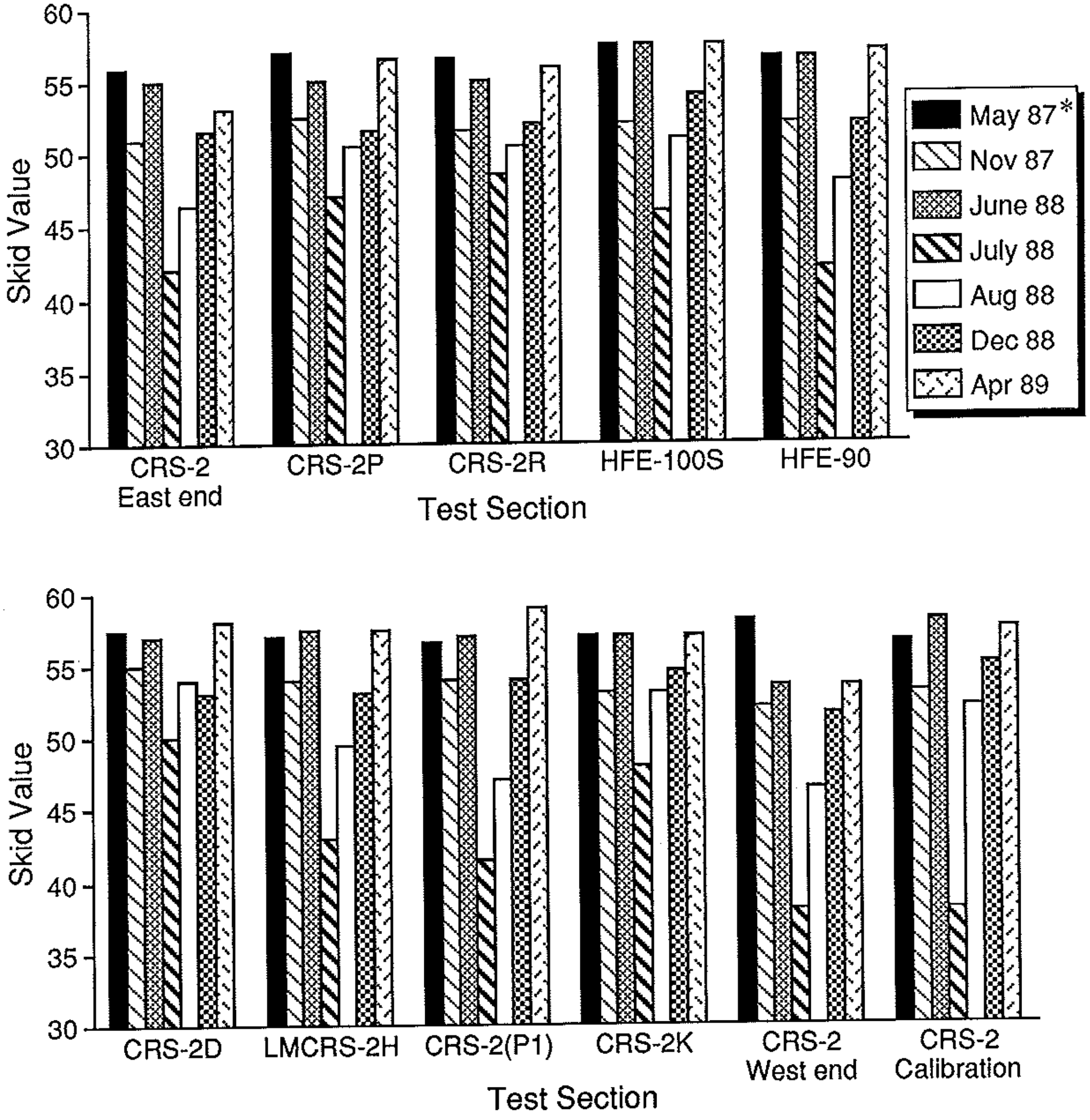

Figure 13: Pavement Skid Resistance (*pavement before chip seal)

TABLE 4: AVERAGE SKID VALUE

Ten Tests (Sections) for Each Series and
Seven Tests (Dates) for Each Test Section

AVERAGE FOR EACH SERIES OF TESTS		AVERAGE FOR EACH TEST SECTION	
TEST DATE	AVERAGE SKID VALUE	TEST SECTION	AVERAGE SKID VALUE
May 1987	57	CRS-2W	49
November 1987	53	CRS-2E	50
June 1988	56	HFE-90	51
July 1988	44	CRS-2 (Cal.)	52
August 1988	50	CRS-2P	52
December 1988	53	LMCRS-2H	52
April 1989	57	CRS-2R	53
		HFE-100S	53
		CRS-2K	54
		CRS-2D	55

7.0 LABORATORY EVALUATION

This project provided an excellent opportunity to evaluate the various chip seal systems and components in numerous ways. Tests were performed by the ODOT and several others with interest through cooperative arrangements.

The objective of this chapter is to briefly provide the background and purpose of the various tests, to comment on the results of tests made on the various materials, to compare the test results with specifications, and to comment on the tests' ability to distinguish the presence of polymers.

For each type of emulsified asphalt, all of the ODOT testing was performed on a single sample taken as described in Section 4.3. Only one test of each type was performed on the sample. Consequently, the test results and conclusions do not have a sound statistical base.

7.1 Emulsified and Residual Asphalt Testing

The relationship between the behavior of emulsified asphalt binders, the physical properties of their residue from distillation, and chip seal field performance is not clear. Various researchers have tried to relate binder properties to field performance with only limited success, as the performance of chip seals on the roadway depends upon many factors in addition to binder characteristics. However, a variety of test requirements has been used to assure the quality and uniformity of emulsions in product specifications. Also, in some cases, test requirements serve as indicators of expected behavior or performance, although the predictability of performance is elusive. Nevertheless, the authors of this report have selected several emulsion and residual asphalt properties for comparison of the emulsified asphalts used in construction of the test sections. These include:

- Viscosity of the Emulsion @ 122°F
- Residue From Distillation, Percent
- Properties of Residue
  - Penetration @ 77°F
  - Ductility @ 77°F
  - Ductility @ 39.2°F
  - Tensile Stress at 800% Elongation
  - Torsional Recovery
  - Toughness and Tenacity

The test results, specifications, and manufacturer's guidelines are tabulated in Table B of the Appendix. Details of the test procedures are presented in Section 4.3, and the complete test method for tensile stress, torsional recovery and toughness and tenacity, referred to as "high strain" tests, are included in the listing of references for this report. The results of the "high strain" tests performed by ODOT on samples of each emulsified asphalt are shown in Figure 14.

7.1.1 Asphalt Emulsions

The viscosity of the emulsion generally relates to its fluidity for pumping and spraying.

Most specifications have Saybolt Furol viscosity values of 100 and 400 sec. at 122°F as required low and high values, respectively, with suppliers of some modified systems having slightly different guidelines. The viscosity test results are shown in Figure 15.

The CRS-2P, CRS-2R, HFE-100S, HFE-90, CRS-2(P1), and CRS-2K emulsions were very fluid when tested by ODOT, with viscosity values near or below 100 sec. The HFE-100S, HFE-90, and CRS-2(P1) emulsions were much more viscous when tested earlier by the supplier. This indicates for some polymer modified emulsions a deterioration, or lowering of viscosity, between the time of testing at manufacture and the time of testing by ODOT. Test results for this study agree well with an 1985 ODOT evaluation, which indicated that the viscosity of HFE-100S emulsion decreased 50 - 100 seconds during a 30-day storage period.

Test results for the CRS-2, CRS-2D and LMCRS-2H emulsions indicate that these products maintain a desired viscosity level with values within the standard limits. The LMCRS-2H and CRS-2K emulsion test results show little change from manufacture to testing by ODOT.

7.1.2 Asphalt Residue

The percent of residue by weight from the distillation at 400°F indicates the amount of paving grade asphalt in the emulsion. The test results are shown in Figure 16, and notes on the distillation process are provided in Section 4.3.

In most standard specifications, a minimum value of 65% is required. As it is costly for a producer to exceed the minimum required residue content, an upper limit has not been needed.

The conventional CRS-2 and HFE-90, and the polymerized CRS-2P, CRS-2D, and LMCRS-2H emulsions, had values near 65%, as expected. However, the 60.1% residue in the CRS-2R emulsion was quite low. This characteristic, and the low viscosity of 165, could indicate an error in the manufacture. The HFE-100S, CRS-2(P1), and CRS-2K polymerized emulsions had relatively high proportions of residue. This was probably the result of the manufacturer increasing the viscosity of the emulsion by adding asphalt. This increase would offset the emulsion viscosity decrease often experienced when polymers are added.

<u>Penetration</u>

The penetration test indicates the hardness of the residue from distillation. This hardness relates to the consistency of the effective binder in the chip seal. The lower the penetration value, the harder the asphalt. The test results for penetration at 77°F are shown in Figure 17.

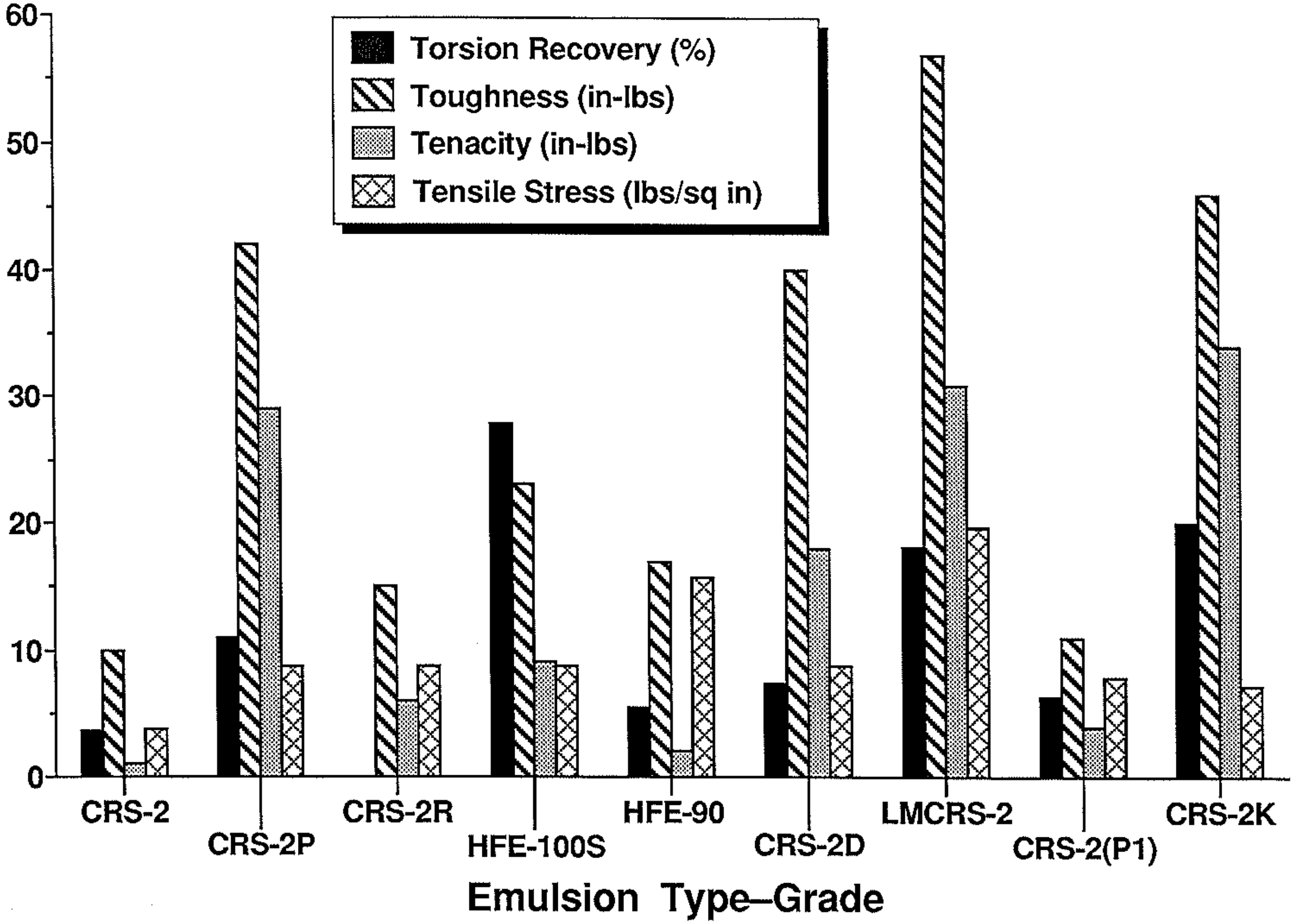

Figure 14: Emulsion Residue Test Results

The asphalt residue penetration specification limits varied greatly, as follows:

	Asphalt Residue Penetration @ 77°F, 100 g., 5s, in dmm	
Emulsion	Minimum	Maximum
CRS-2, CRS-2P	100	250
CRS-2R	None	None
HFE-100S	90	140
HFE-90	90	150
CRS-2D	150	250
LMCRS-2H	40	90
CRS-2(P1)	150	None
CRS-2K	120	None

Test results for the emulsion sampled on the project have a wide range of values. Only the CRS-2D was outside the specification requirements provided by the manufacturer. The LMCRS-2H was provided as a hard-base emulsion, but the penetration value of 89 was not particularly low.

Ductility

The ductility test performed at 77°F and 39.2°F is intended to detect asphalt binder brittleness in cold weather. A low ductility value indicates brittleness. Figure 18 shows the results of testing at 39.2°F. Notes on ductility testing are found in Section 4.3.

Specification requirements for emulsions used on this project had minimum ductility values at 77°F of 40cm for CRS-2, CRS-2P, and LMCRS-2H, 100 cm. for CRS-2R and CRS-2D, and 125 cm. for HFE-100S. Minimum requirements for ductility at 39.2°F are 25 cm for CRS-2R, 40cm for CRS-2(P1) and 100cm for CRS-2K emulsions.

All of the emulsion residue samples tested had values higher than 100cm at 77°F. Except for the HFE-100S specification requirement of 125cm minimum, these products satisfy all other 77°F ductility limits. However, had the tests been continued to 125cm, the HFE-100S specification may have been satisfied. Ductility tests made at 39.2°F on the CRS-2, CRS-2P, CRS-2(P1), and CRS-2K samples passed the CRS-2(P1) requirement of 40cm minimum. These same emulsions may have passed the CRS-2K low temperature ductility requirement of 100cm minimum if the test had been completed to the limit.

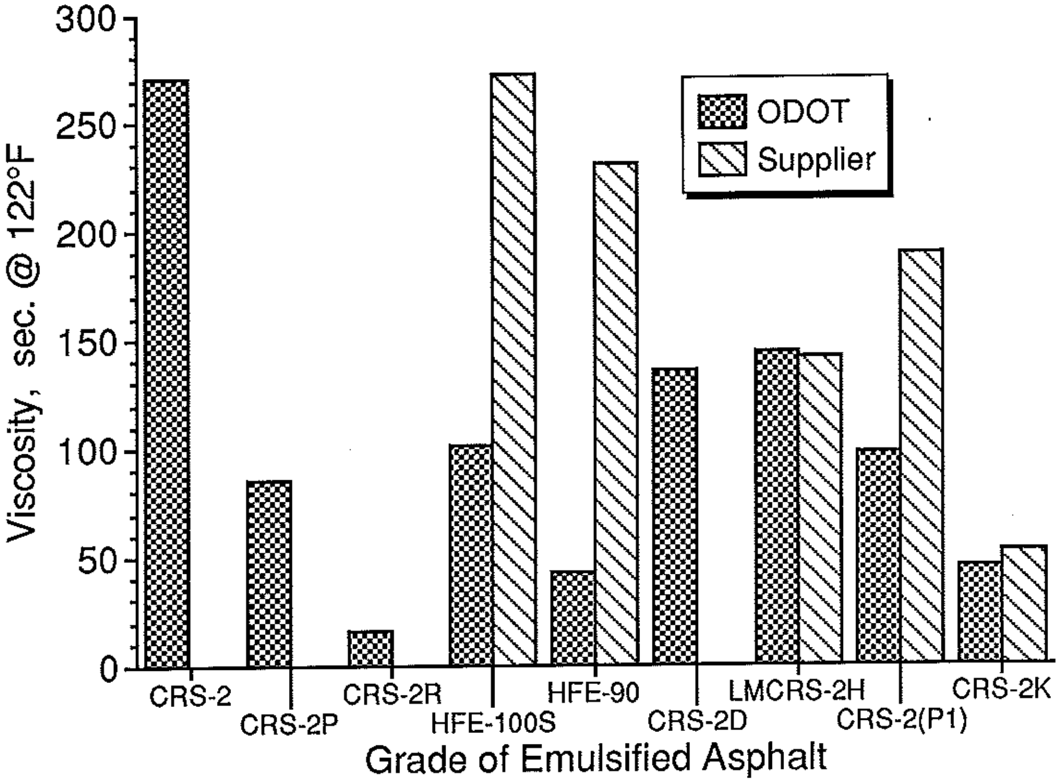

Figure 15: ODOT Viscosity Test Values for Emulsified Asphalt

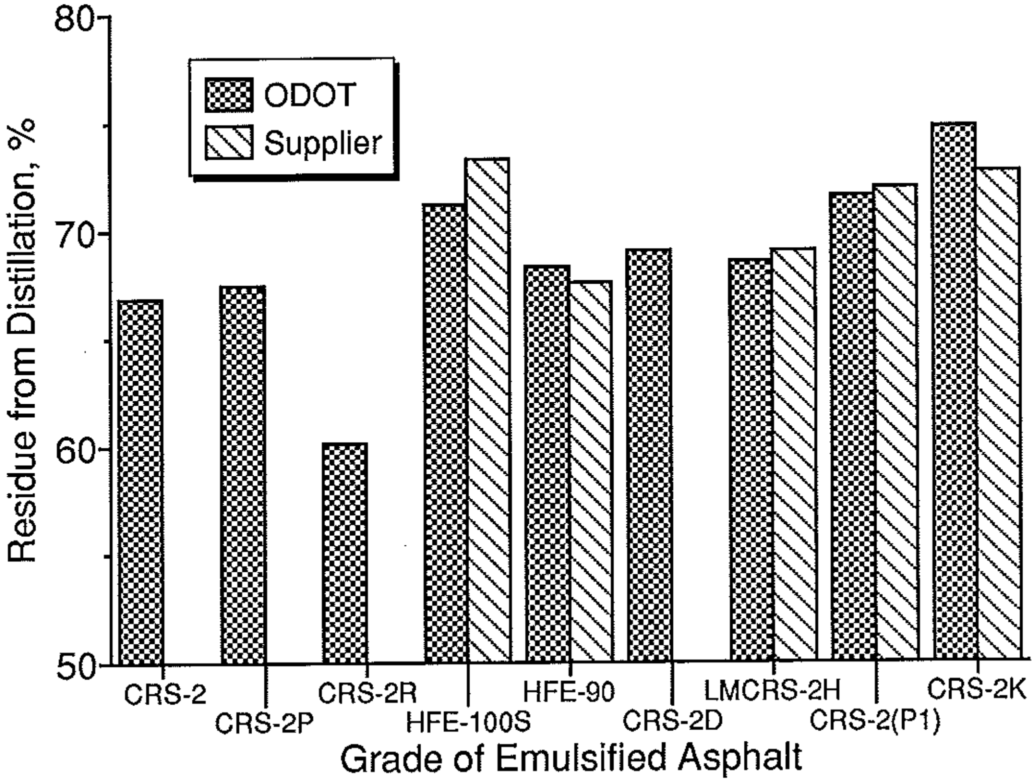

Figure 16: ODOT Percent Residue Values for Emulsified Asphalt Distilled at 400°F

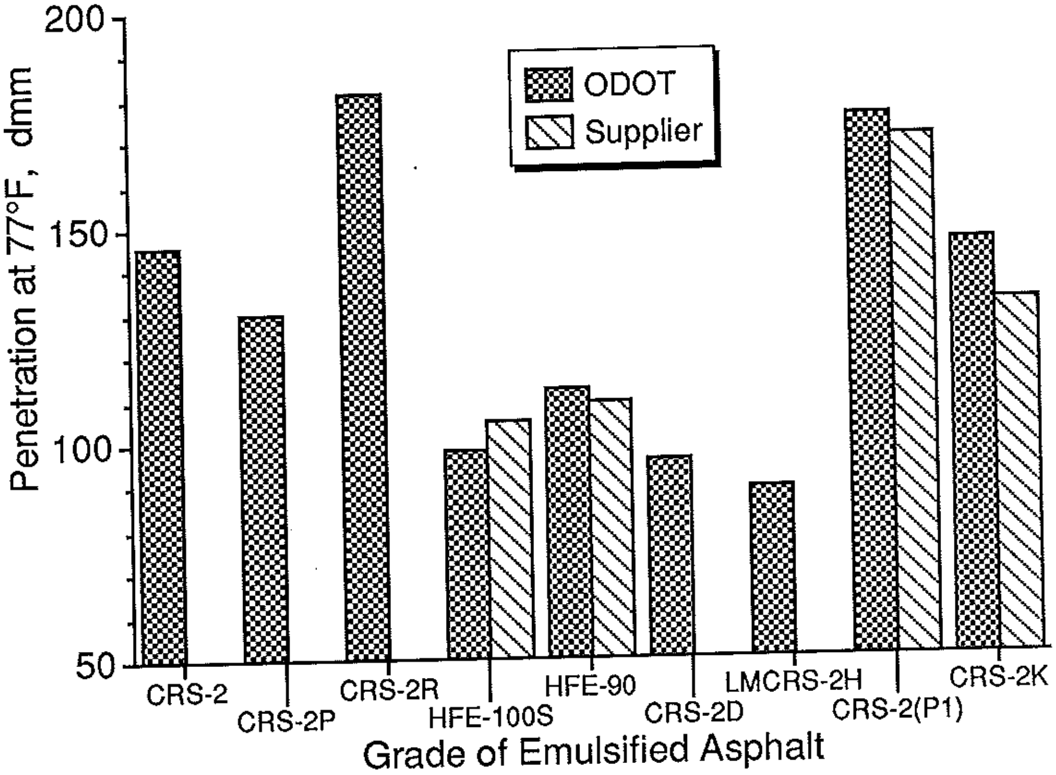

Figure 17: ODOT Penetration Values for Residual Asphalt

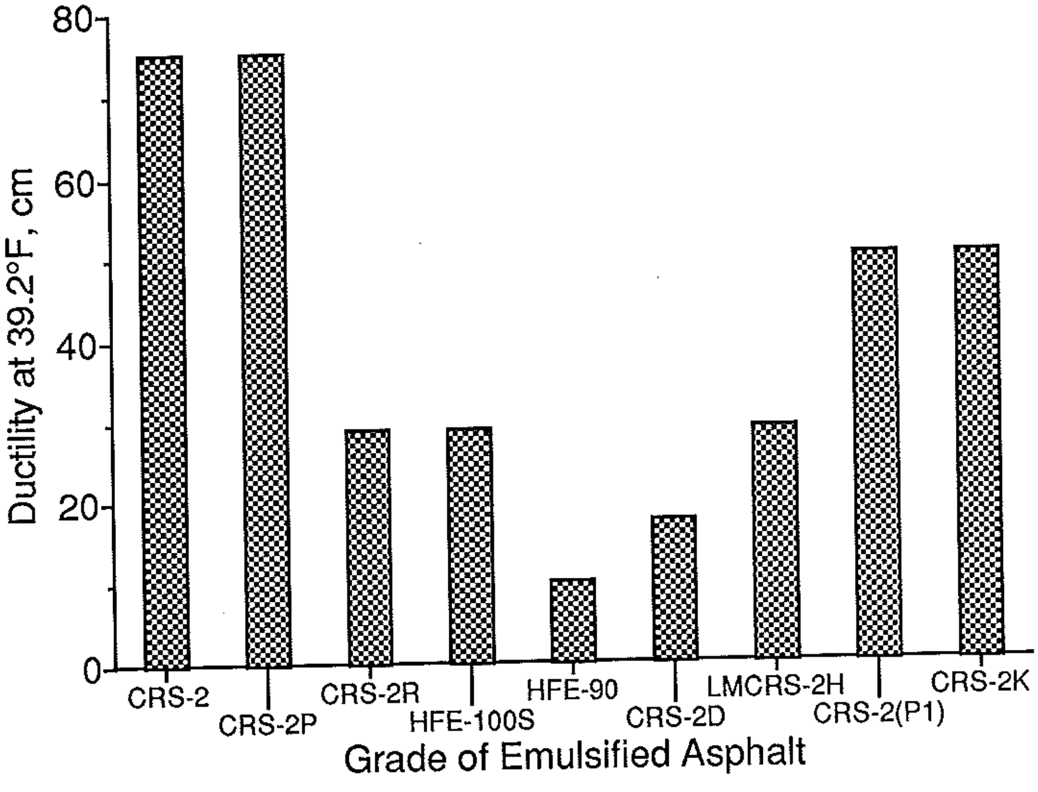

Figure 18: ODOT Ductility Values for Residual Asphalt

The conventional CRS-2 emulsion had a surprisingly high 39.2°F ductility elongation, greater than 75cm, while the other conventional emulsion, HFE-90, had a relatively low ductility of 10cm. This is likely the result of a different asphalt cement source used in manufacture of the emulsions. Although the manufacturer's suggested minimum ductility values varied considerably, all products appear to have similar ductility at 77°F. The products show a considerable difference in low temperature ductility at 39.2°F.

Tensile Stress

The tensile stress properties of a binder can be measured by the Force-Ductility test. Tests made by ODOT used a ductilometer at a pull rate of 5 cm/min with a mold similar to the standard ductility mold. Test results are in lb/in^2, rather than kg/cm^2 used by the supplier. The supplier uses an Instrom testing machine at a pull rate of 50 cm/min with a radically different mold. The most common use of this test is in determining the presence and amount of polymer in "Styrelf" binders. The tensile stress value indicates the pulling force exerted by a binder sample trying to return to its original condition during elongation. A high value indicates an elastic material. The tensile stress that resulted when each binder residue sample was stretched 800%, at 39.2°F, was measured, with the results summarized in Figure 19.

The only tensile stress requirement in any of the specifications was for the HFE-100S, an emulsion containing "Styrelf". This minimum allowable value of $8.8kg/cm^2$ can not be directly compared to the ODOT test results because of the differences in procedure. It is interesting to note that the second largest ODOT tensile stress value, $15.7kg/cm^2$, was obtained by the conventional HFE-90 emulsion residue. This test appears to be a poor indicator of the presence of polymers in a diverse assortment of residues.

Torsional Recovery

The torsional recovery test was originally developed as an identification tool to detect the presence and amount of a synthetic rubber (Neoprene) contained in asphalt. The test indicates the amount of elasticity in a binder sample. A high value indicates increased binder elasticity. Figure 20 shows the wide range of results from the various materials used in this study.

On this project, only the LMCRS-2H emulsion containing Neoprene had a specification with a minimum torsional recovery requirement of 18%. Only the residues of the LMCRS-2H, HFE-100S, and CRS-2K emulsions satisfy this requirement. This indicates that the polymer contained in each of these emulsions provide elasticity similar to a Neoprene-type polymer.

As would be expected from a test reflecting polymer content, the conventional CRS-2 and HFE-90 emulsions had low torsional recovery values in relation to the modified asphalts. An exception is the CRS-2R binder, with a torsional recovery of zero. This indicates that the CRS-2R residue probably contains inadequate polymer of the Neoprene type to provide elasticity as measured by the test.

Toughness and Tenacity

These tests are used to measure the elastomeric (rubber-like) behavior of an asphalt binder. The most common use of these tests is for determining the polymer presence and content of a certain type of polymer used in modified asphalt cement or emulsified asphalt residue. The units are in inch-pounds, or area under a load-deformation curve, and are indicative of the amount of work required to stretch a sample. A high value indicates a "rubbery" material. Figure 21 shows the results of tests made on each emulsion asphalt residue sample.

Products used on this project with toughness and tenacity requirements were the CRS-2P and CRS-2R emulsions. The CRS-2R emulsion was manufactured by Albina Asphalt Company using AC-20R polymerized asphalt, made by Asphalt Supply and Service. The CRS-2P was made on the project by the addition of Polysar Latex to CRS-2 emulsion supplied by Albina Asphalt Company. Toughness and tenacity specification requirements for asphalt in CRS-2R are 110 and 75 with CRS-2P requirements of 50 and 25.

The two highest toughness values, 46 in-lb. and 57 in-lb., were for the polymerized CRS-2K and LMCRS-2H residues. However, the two lowest values, 10 in-lb. and 11 in-lb., belong to the conventional CRS-2 and polymerized CRS-2(P1) residues. Based on the test results from this project, the toughness values do not seem to indicate the presence of polymer in all types of emulsified asphalt residue.

The tenacity test results appear to correlate better with polymer presence. The conventional asphalt residues, CRS-2 and HFE-90, provided the lowest test values, at one and two in-lb., respectively. However, the CRS-2(P1) residue, a sample with a typical polymer content of 3%, had a low result of four in-lb. for this test.

It appears that the toughness and tenacity tests are reasonably good indicators of the presence of polymers used in CRS-2P, LMCRS-2H, CRS-2D and CRS-2K emulsions.

7.2 Chip Seal System Testing

As indicated earlier, this project provided an opportunity to evaluate the various chip seals during and after construction, in order to gain an understanding of the expected behavior of each system. To analyze initial chip retention, several tests were conducted on aggregate-binder systems using materials sampled at various stages of construction.

Measuring the adhesion between aggregate and binder on the roadway is a difficult task, and no completely satisfactory method has been developed. However, this chapter discusses several methods tried on this project. These include:

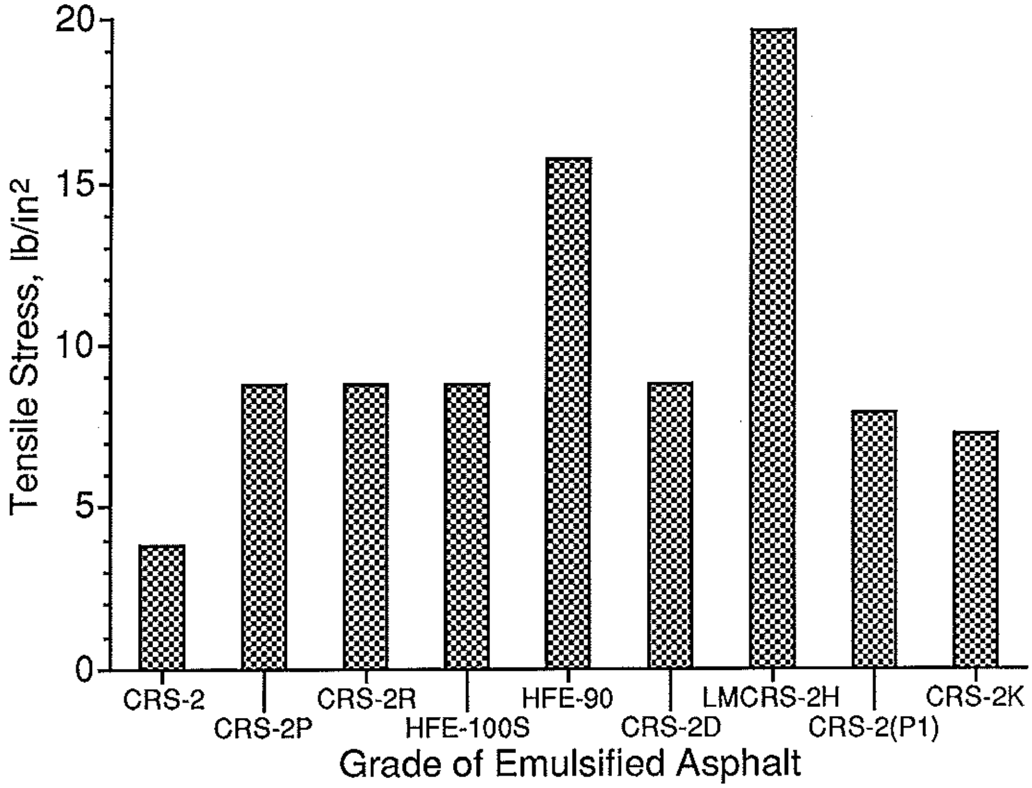

Figure 19: ODOT Tensile Stress Values at 800% Elongation

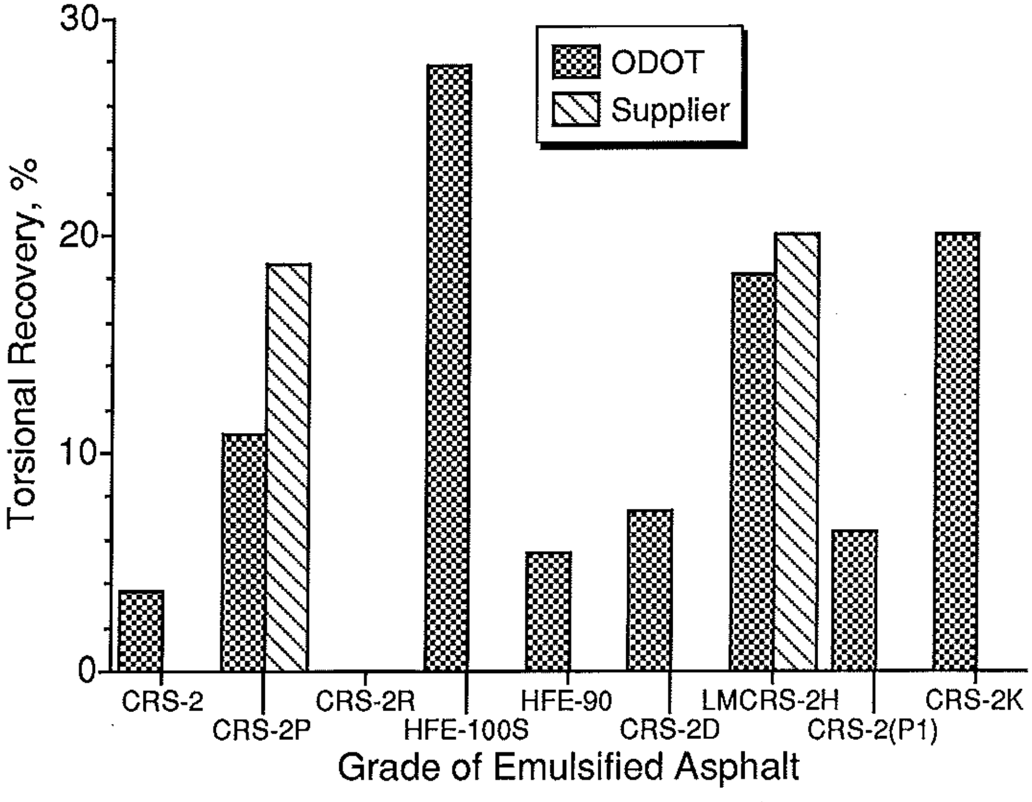

Figure 20: ODOT Torsional Recovery Values

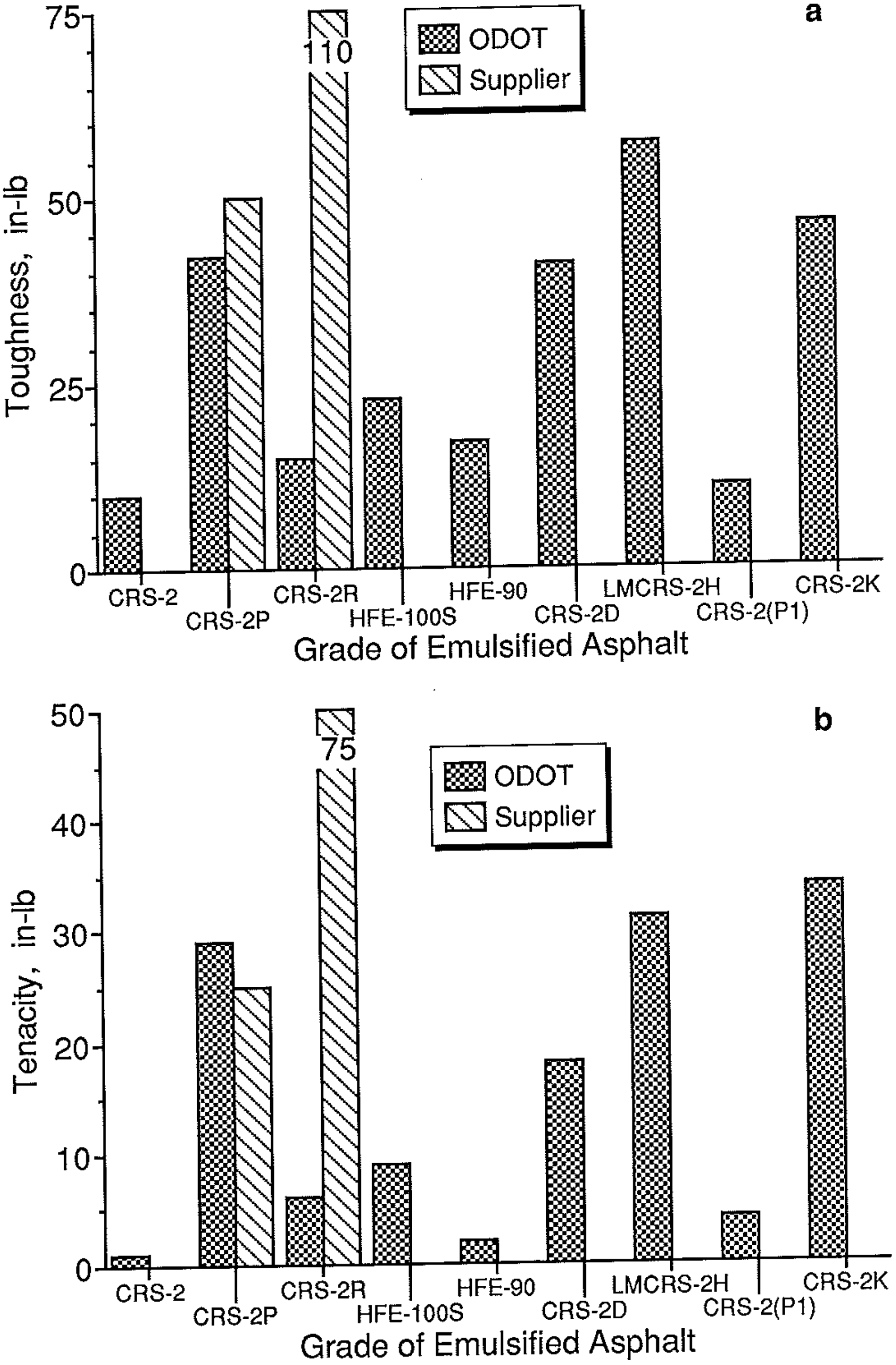

Figure 21a and 21b: ODOT Toughness and Tenacity Values

- Vialit Testing
    - Laboratory Tests on Laboratory Prepared Samples: Uniform Length of Cure and Variable Test Temperatures
    - Laboratory Tests on Laboratory Prepared Samples: Variable Length of Cure
    - Field Tests on Field Prepared Samples: Variable Length of Cure
- Surface Abrasion Testing
    - Laboratory Tests on Laboratory Prepared Samples: Variable Length of Abrasion
    - Laboratory Tests on Laboratory Prepared Samples: Variable Emulsion Application Rate and Length of Abrasion
    - Laboratory Tests on Laboratory Prepared Samples: Variable Test Temperature and Length of Abrasion

There were no specifications or test requirements on this project for chip retention. The above-listed tests were made for this study to evaluate the relationship between test results and performance of the test section chip seals.

7.2.1 Vialit Drop Ball Testing

This test procedure was developed in France, and variations of the method have been used by many researchers. Although the test method is not standardized, it is normally conducted on either fully cured emulsion or hot-applied asphalt cement systems. The results are a measure of the adhesiveness of the binder to the aggregate under the test conditions. Variations of the test have been used to study properties of chip seal materials, such as asphalt aging, aggregate cleanliness and asphalt modifiers.

ODOT

The Vialit test procedure used by the ODOT laboratory was identical to, or very close to, the original French method. Tests were made on laboratory prepared samples using identical aggregate and emulsion application rates for each emulsified asphalt product. The test results for the fully cured emulsion systems are shown in Figures 22 and 23. A summary of the test method is presented in Section 4.3.

Tests made at 5°C show that all systems except the CRS-2, CRS-2D, and LMCRS-2H had 100% chip retention. A difference in cure rate for the non-modified emulsions is indicated by the 32% retention for the CRS-2 system and the 100% retention for the HFE-90 system.

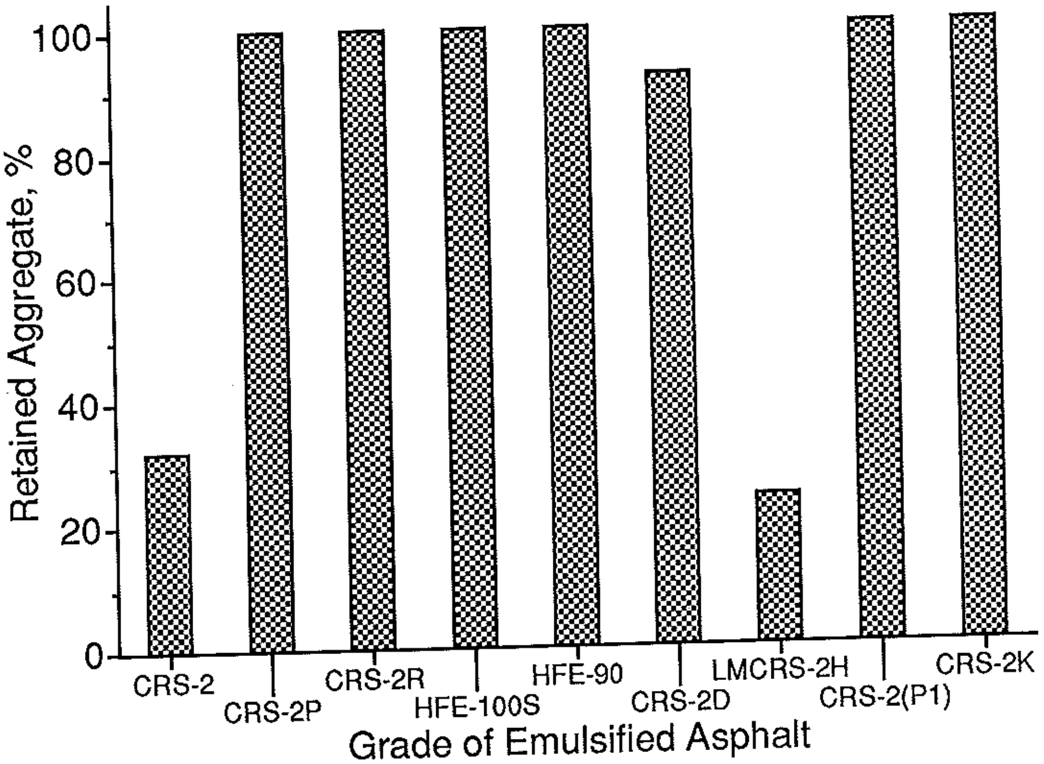

Figure 22: ODOT Standard Vialit Test Values at 5°C, Full Cure

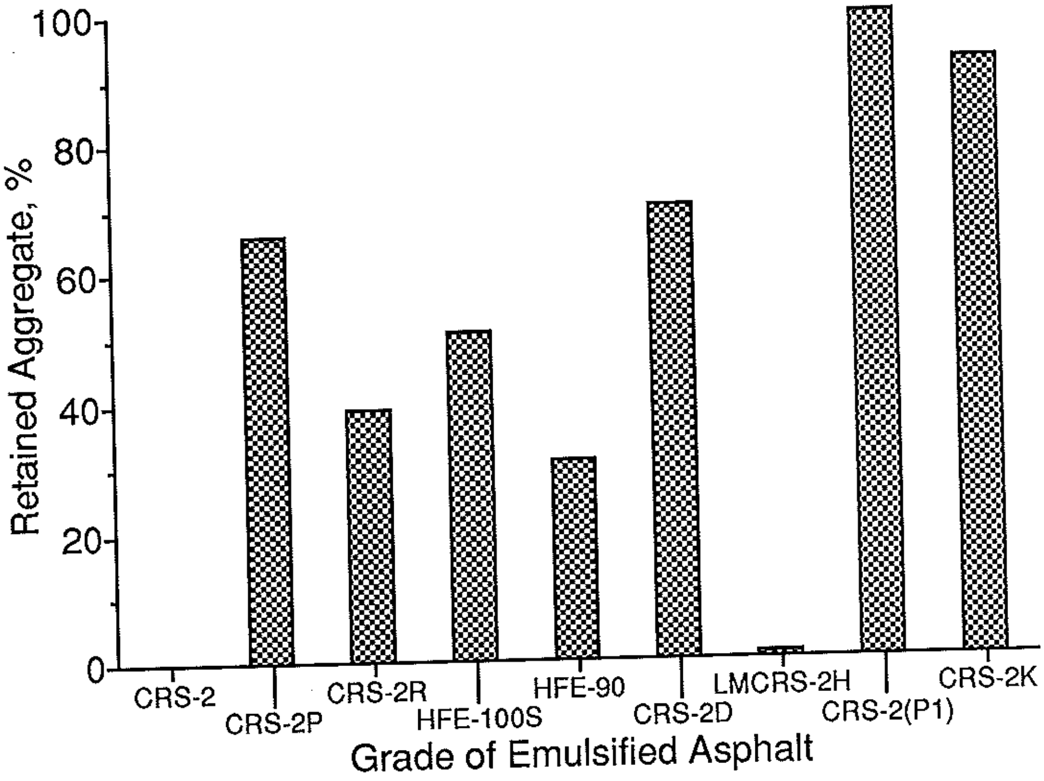

Figure 23: ODOT Standard Vialit Test Values, at -22°C, Full Cure

The LMCRS-2H modified binder, with only 24% retention, shows a lack of adhesion at the standard cure condition, which has been reported as typical of binders modified with Neoprene. Also, the CRS-2D modified emulsion with 92% retention has less adhesion than most polymerized binders.

For these fully cured asphalt emulsion systems, this 5°C test did not discriminate among the various polymerized binders, with the exception of LMCRS-2H. Once cured, most of the modified binders had relatively good chip adhesion.

The -22°C Vialit test was superior to the 5°C test in determining the presence of polymer in the binder. With the exception of the LMCRS-2H, all of the polymerized binders performed better than the conventional asphalts.

It should be noted that the -22°C Vialit test was performed on samples that were first subjected to the test at 5°C. As a result, a sample could not have a higher chip retention on this test than it had on the previous test. In addition, chips may have been loosened on the first test and dislodged on the second test. Consequently, if a more detailed study of this test is made, the effects of the 5°C test need consideration.

University of Nevada

The University of Nevada-Reno was interested in the ODOT study, since they were working on two other related research projects. Their main interest was the early behavior of emulsified asphalt chip seals. Their research was conducted for the Exxon Chemical Co., and was also related to a FHWA contract being conducted by ARE, Inc., of Scotts Valley, California. Accordingly, University personnel collected samples at the project site for a study of emulsion cure rates. The test procedure is discussed in Section 4.3.

A modified Vialit procedure was used for preparation and testing of samples in the laboratory. The major difference between their procedure and the standard was in sample preparation, curing, and conditioning. The emulsion temperature and application rate were varied to simulate field conditions, and a uniform amount of aggregate was placed on each plate. The plates were tested at curing intervals of 0.5, 1.0, 2.0 and 3.0 hours.

Figures 24, 25, and 26, for CRS-2, LMCRS-2H, and CRS-2K, respectively, show the variability between each series of test results. In these figures, the results of an average for each series of three or four individual tests are plotted. The average of all test values within two standard deviations of the mean is also shown.

Both of the modified emulsions show better early chip retention when compared to the conventional CRS-2. One of the modified emulsions, the LMCRS-2H, had a wide variability of test results during the early curing period and an improvement after 2-3 hours. The CRS-2K emulsion, however, illustrated a very small variation in test results throughout the cure period. These trends indicate more uniformity and a rapid early development of adhesion properties in the CRS-2K binder.

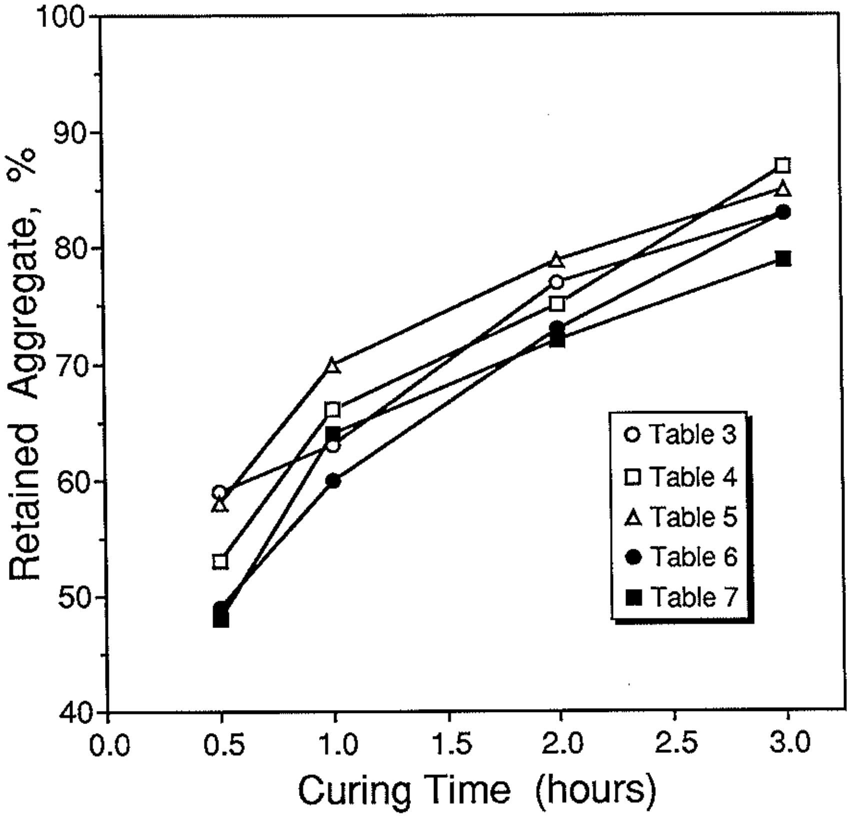

Figure 24: Nevada Vialit Test Values for CRS-2 Emulsified Asphalt
(Average for Tables 3,4,5,6 and 7, Reference 13)

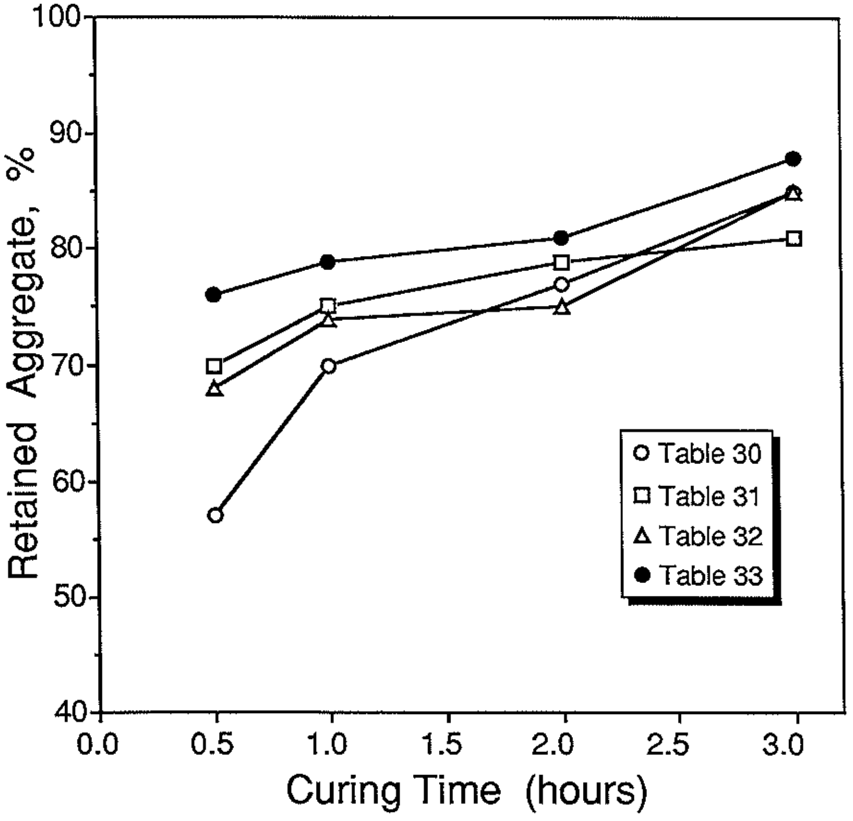

Figure 25: Nevada Vialit Test Values for LMCRS-2H Emulsified Asphalt
(Average for Tables 30,31,32 and 33, Reference 13)

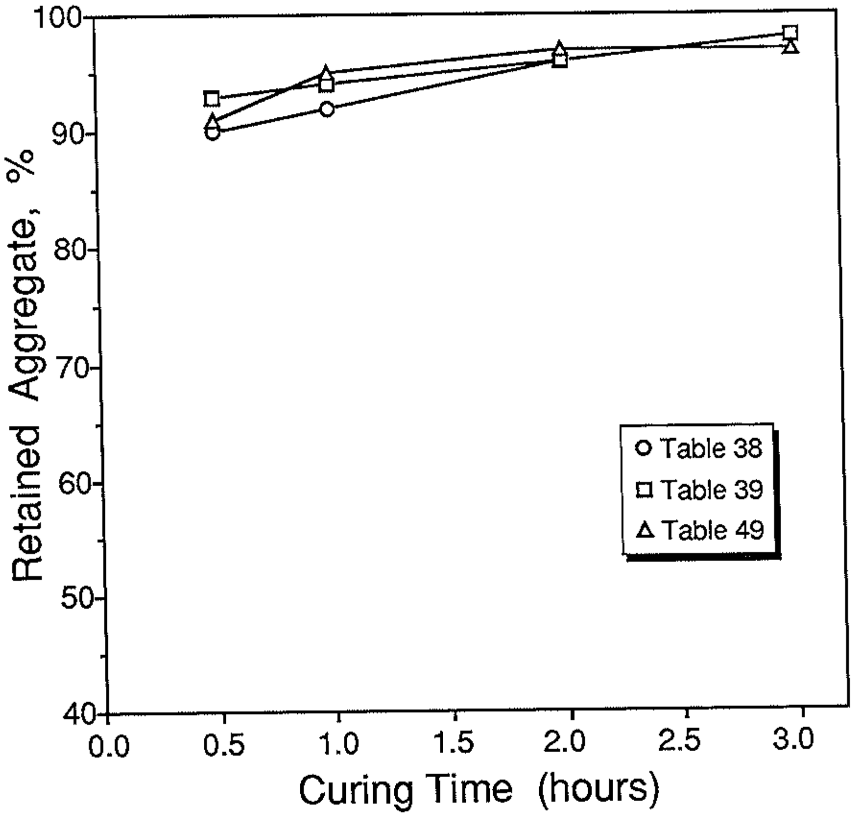

Figure 26: Nevada Vialit Test Values for CRS-2K Emulsified Asphalt (Average for Tables 38,39 and 40, Reference 13)

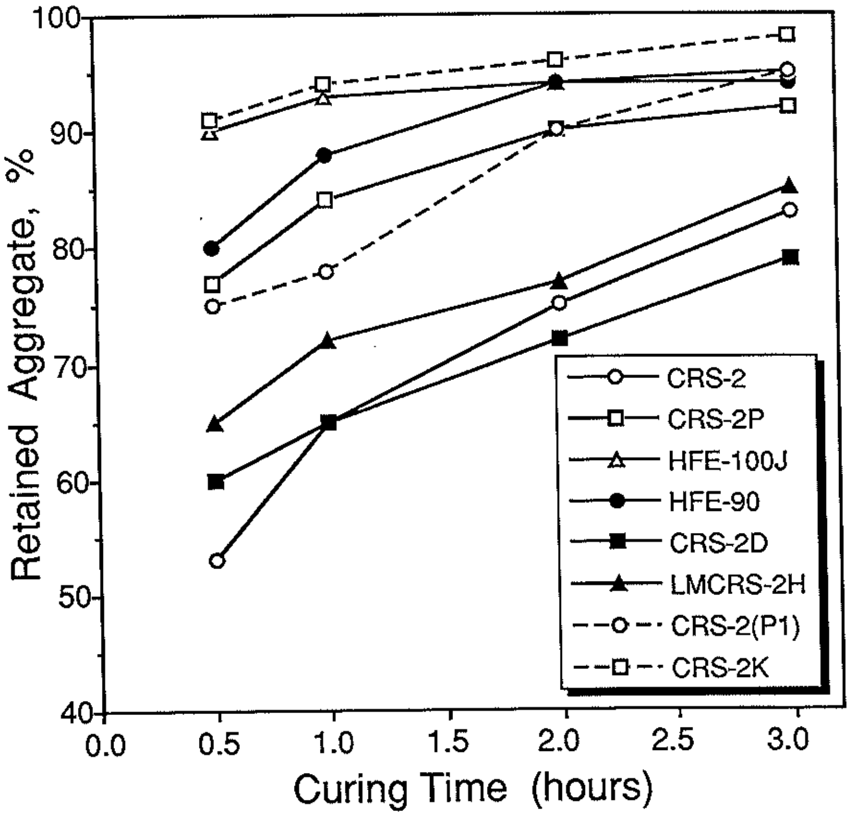

Figure 27: Nevada Vialit Test Values for Each Emulsified Asphalt

The University of Nevada tests results are summarized in Figure 27. All of the asphalt emulsions are represented except the CRS-2R, which required a 3-hour cure for 41% chip retention. The average aggregate retention values between two standard deviations are shown for each emulsion, which illustrates the wide range of early curing behavior. As expected, the test results show the greatest variation after 30 minutes' curing, when compared to results for the later stages. After 3 hours' cure, all of the products show greater than 70% chip retention.

The tests indicate that CRS-2K and HFE-100S emulsion systems have very good early adhesion properties with 30-minute cure values of near 90%. The CRS-2P, HFE-100S, HFE-90, CRS-2(P1) and CRS-2K systems all have high retention values after a 3-hour cure.

Coyne Field Modified

During the construction phase of this project, Mr. Lloyd Coyne, serving as a consultant to others, conducted various tests on the jobsite. Of particular interest was the modified Vialit testing he conducted, using a technique he had evaluated earlier. The initial results of this study were reported to ODOT and were summarized in a paper presented to the Association of Asphalt Paving Technologists in 1988. The results of the modified Vialit testing on field samples from the chip seal test sections are discussed in Section 4.3.

These tests were made on samples of chip seal obtained from the roadway test sections containing the varying emulsion and aggregate application rates used in construction. In addition, tests were made on the samples after various periods of cure.

The results of the modified Vialit testing are not fully comparable to the ODOT Vialit tests, as the ball dropped from a lesser height onto the specimen, and the adhesion, flexibility, etc. of the can lid are different from that of the steel plate. However, as field prepared samples were used for testing by Coyne, the results should more closely simulate the actual emulsion curing conditions on the project. A comparison between Coyne's method and the standard Vialit test is found in his AAPT paper. The comparison indicates that use of the modified Vialit test, rather than the standard test, results in less chip loss at earlier cure periods.

The recalculated values for the percent of aggregate chips retained after the drop ball test were plotted in Figures 28 and 29. The "Aggregate Retention, %" values were calculated by the following formula:

> Aggregate Retention, % = (Total Retained, psy x 100)/ 30 psy, where the "Total Retained" values were from the last column in Table 3 of Coyne's AAPT paper.

The curing rate of the seals placed on June 17, 1987, shown in Figure 28, appears to be slower than the curing rate of seals placed the following day, presented in Figure 29. This difference in cure rates may be related to the relatively higher temperatures of the second day. Temperatures during construction and curing were noted in Table 2 and Figure 11.

The CRS-2R chip seal system has very low aggregate retention during the period of cure time under observation. This behavior is also shown in the University of Nevada Vialit tests. Also, the HFE-90 system cured slowly compared to the remaining systems, which cured continuously with time at varying rates. In general, the aggregate retained versus curing time relationships are similar to those found in the University of Nevada tests. Further analysis and comparisons will be addressed later.

Coyne Laboratory Modified

In these tests, the chip seal specimens were prepared and tested in the laboratory. Constant emulsion and aggregate application rates and varying cure times were used.

Data from Table 3 of referenced report[12] have been plotted in Figures 30 and 31. These figures show that most of the chip seal systems have improved aggregate retention with time. The CRS-2R system, as indicated in other tests, has failed to cure during the period of time observed in the test. Another exception from most of the tests was the LMCRS-2H system, in which aggregate retention decreased during the first hour. It is interesting that the CRS-2, LMCRS-2H and CRS-2K emulsions show the best early retention of aggregate, and the HFE-100S, CRS-2D and CRS-2(P1) are best at a later cure period.

Further analysis of this laboratory-derived data is found in a later chapter.

7.2.2 Coyne Modified Surface Abrasion Tests

The testing discussed in previous sections of this chapter, with the exception of the standard Vialit test, addressed the rate of curing during early chip seal life. None of these tests considered the effects of traffic during the early service life of the seal coat. Coyne[12] described a surface abrasion test that was modified from a State of California Department of Transportation test originally developed for hot mix asphalt concrete briquets. The test is intended to represent abrasion that simulates traffic wear. Although no correlation has been made between the test results and actual traffic and abrasion aggregate loss, the relative behavior of the chip seal systems could be ranked as to expected durability.

A wet and dry series of tests were made on each emulsion system using laboratory-prepared specimens with a uniform cure and varying abrasion times. In addition, the CRS-2 system was tested with both varying emulsion application rates and abrasion times, and the CRS-2K emulsion was tested with varying test temperatures and abrasion times.

Data from Table 6 of Coyne's paper[12] were graphed and included in this report. Figures 32 and 33 show the results of the dry surface abrasion testing. These figures show a wide range of durability among the chip seal systems. Figures 34 and 35 show the results of wet surface abrasion tests. A similar spread of system durability is shown with a greater percentage of aggregate loss overall. The LMCRS-2H system, which failed very early, both dry and wet, also showed very poor performance in the ODOT Vialit test. The poor performance of LMCRS-2H may be a result of the hard-based asphalt in combination with the relatively low test temperatures for both the standard Vialit and surface abrasion tests.

The dry surface abrasion tests indicate low level abrasion resistance for the CRS-2 and LMCRS-2H systems and very good long- term resistance for the HFE-100S and CRS-2(P1) systems. The wet tests showed a similar trend with CRS-2, CRS-2R, and LMCRS-2H with low resistance and the HFE-100S and CRS-2K with the higher levels of abrasion resistance.

Coyne Effect of Asphalt Emulsion Spread Rate On Surface Abrasion

In a laboratory testing program, Coyne[12] compared the effect of asphalt spread rate to durability of a CRS-2 system. Specimens were fabricated with a range of spread rates and tested dry in the surface abrasion testing apparatus for abrasion times of up to 15 minutes. Using data from this laboratory testing program, a range of durability was noted, as shown in Figure 36. As expected from field experience and verified by this test, the greater the asphalt application rate, the better the aggregate retention. It is interesting that abrasion retention values are near the same level for emulsion application rates of 0.5 and 0.6 gallon per square yard. Results of tests, such as those shown in Figure 32, could be used to determine the minimum emulsion application rate to provide optimum resistance to surface abrasion.

Coyne Effect of Test Temperature on Surface Abrasion

Coyne[12] evaluated the effect of surface abrasion test temperatures of 70°F and 80°F for the CRS-2K chipseal system. The results of these tests are shown in Figure 37. It was found that better durability was achieved at 80°F rather than 70°F. This indicates that careful temperature control would improve the accuracy and repeatability of the testing. Also, it is noted that the failure mechanism in the surface abrasion test was fatigue cracking induced by repeated flexing of the interface between aggregate particles and the binder. These tests confirm that chip seals have better resistance to surface abrasion at warmer pavement temperatures.

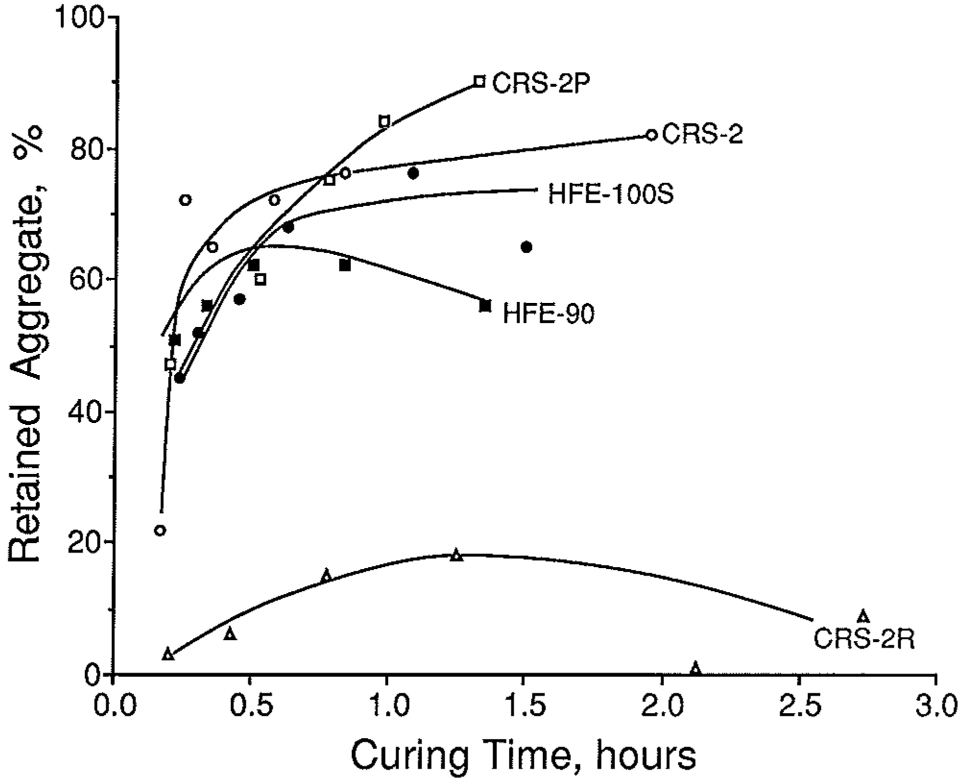

Figure 28: Coyne Vialit Field Test Values, 6-17-87

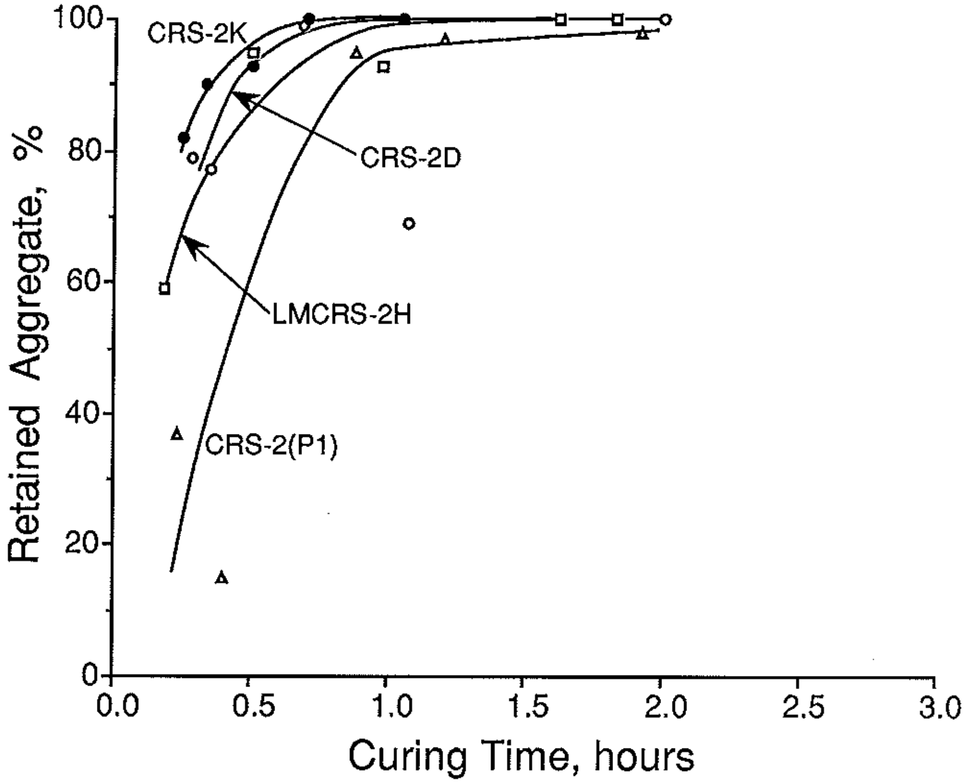

Figure 29: Coyne Vialit Field Test Values, 6-18-87

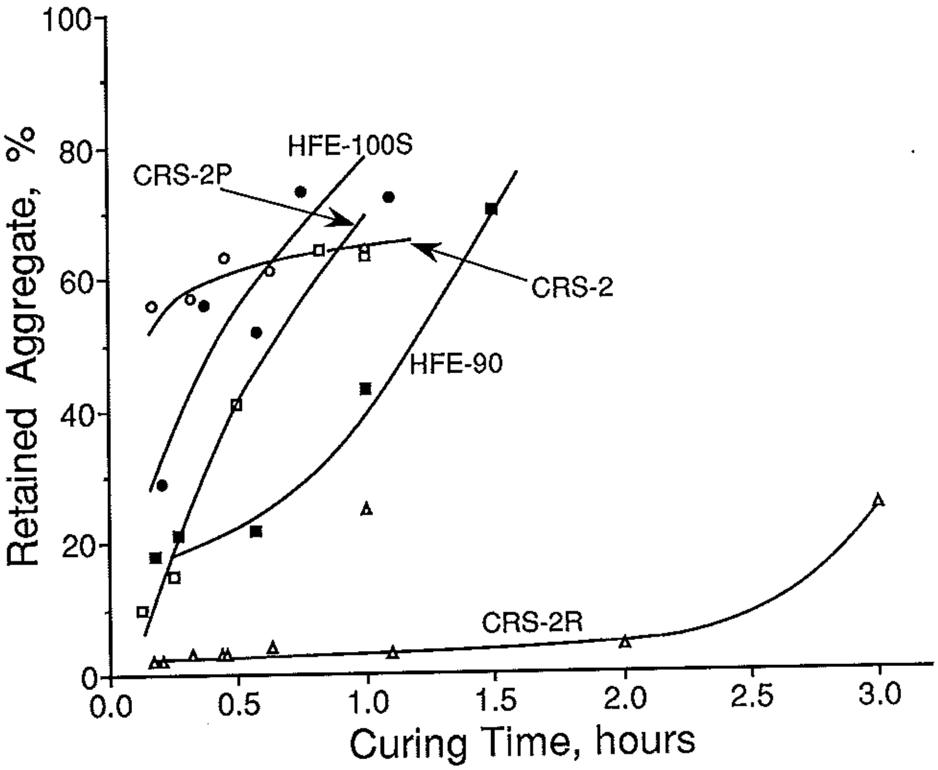

Figure 30: Coyne Vialit Laboratory Test Values for Emulsions Applied 6-17-87 (oven cured at 100°F)

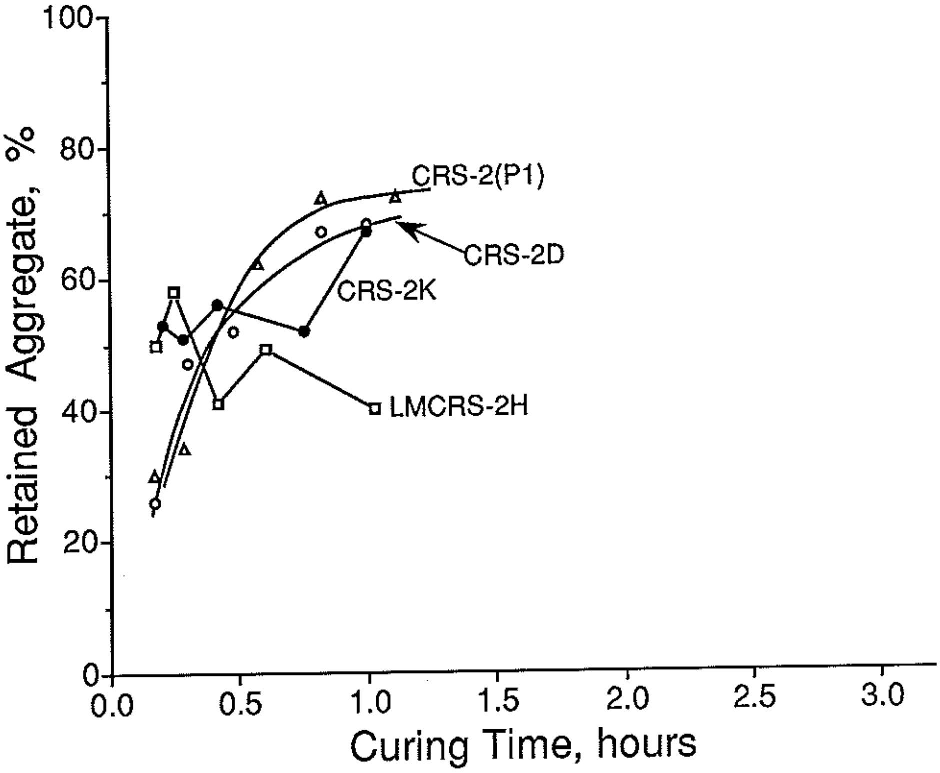

Figure 31: Coyne Vialit Laboratory Test Values for Emulsions Applied 6-18-87 (oven cured at 100°F)

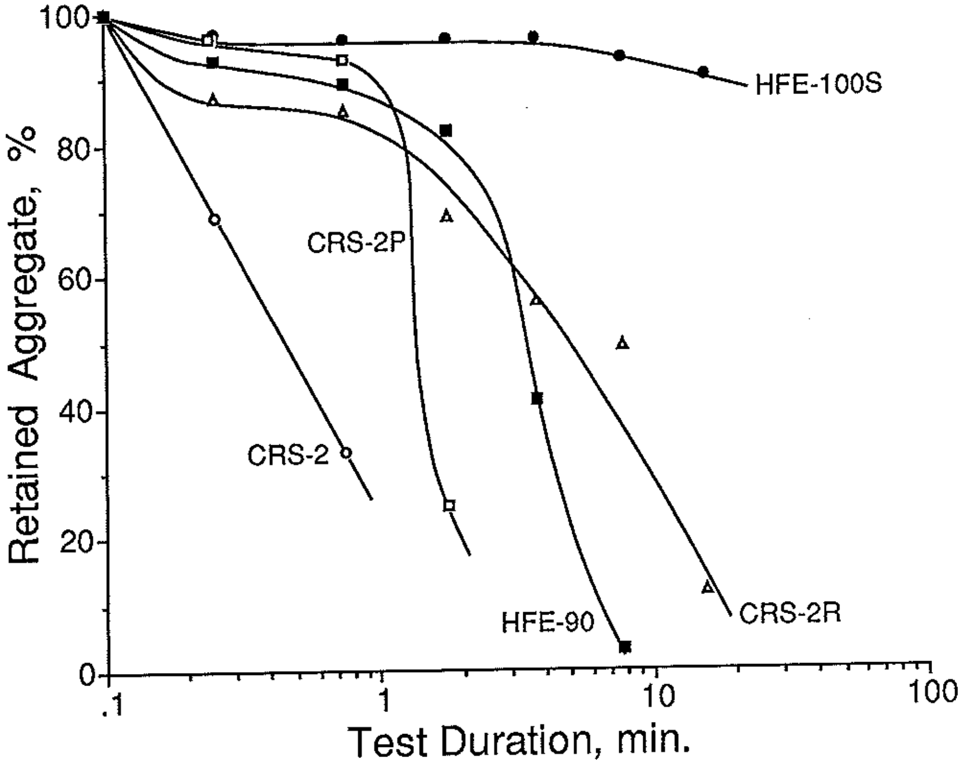

Figure 32: Coyne Surface Abrasion Test Values for Emulsions Applied 6-17-87, Dry

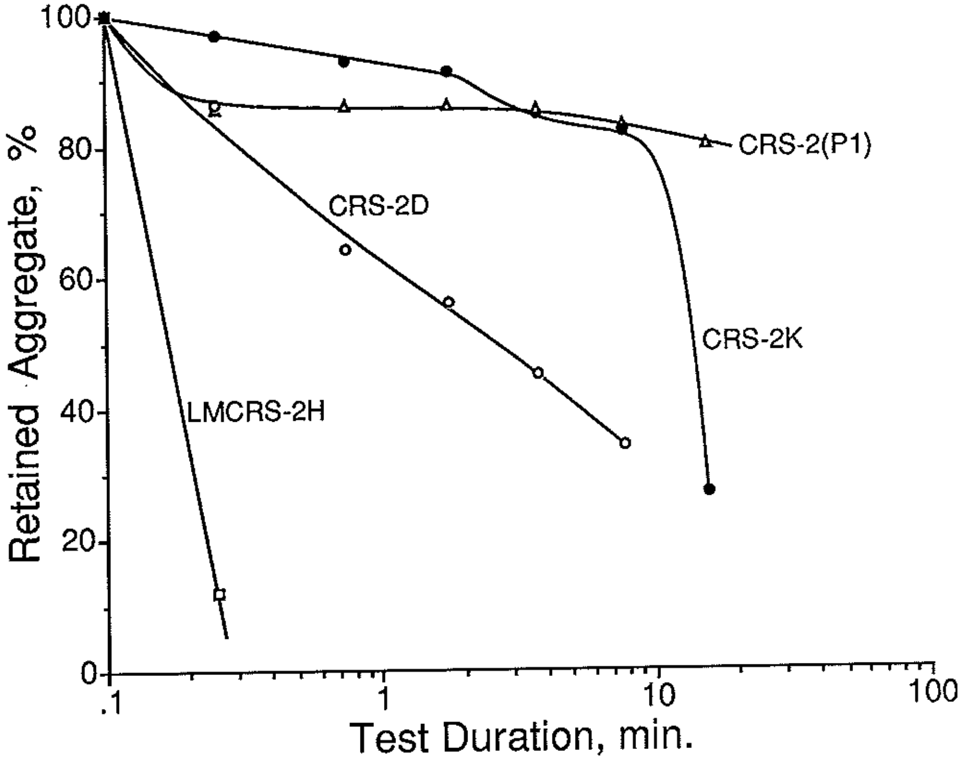

Figure 33: Coyne Surface Abrasion Test Values for Emulsions Applied 6-18-87, Dry

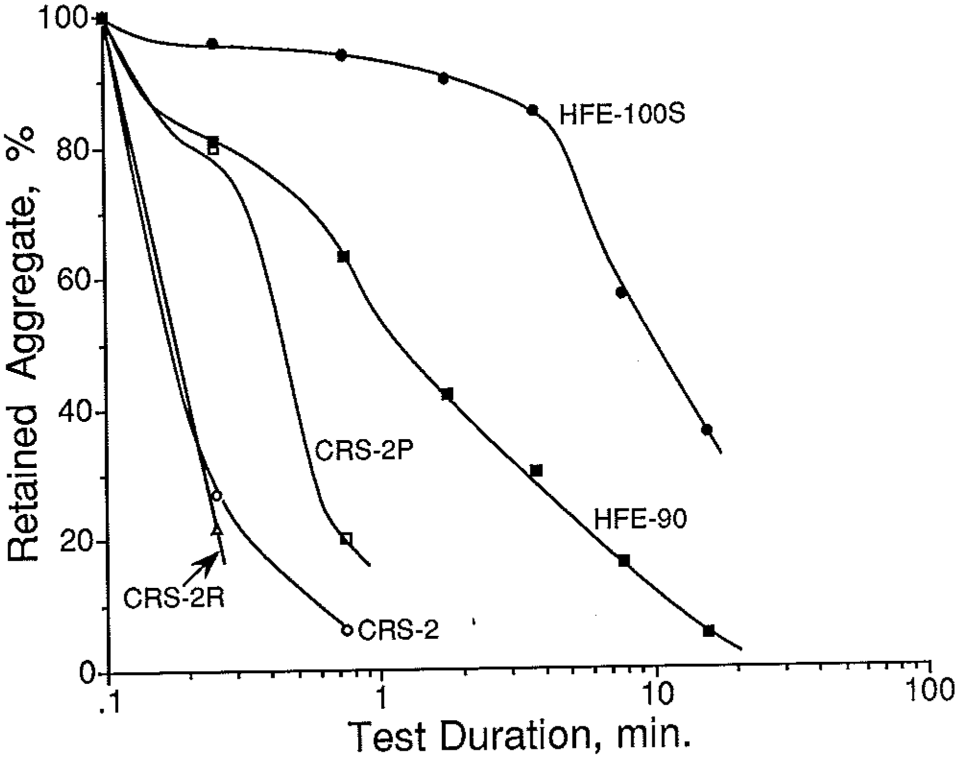

Figure 34: Coyne Surface Abrasion Test Values for Emulsions Applied 6-17-87, Wet

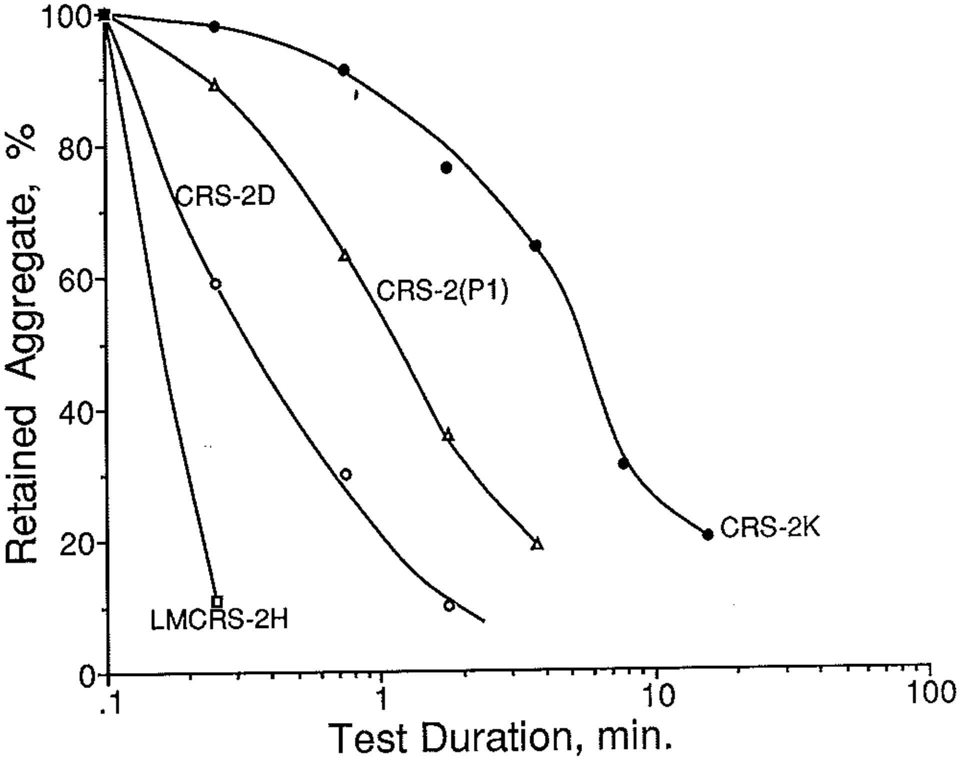

Figure 35: Coyne Surface Abrasion Test Values for Emulsions Applied 6-18-87, Wet

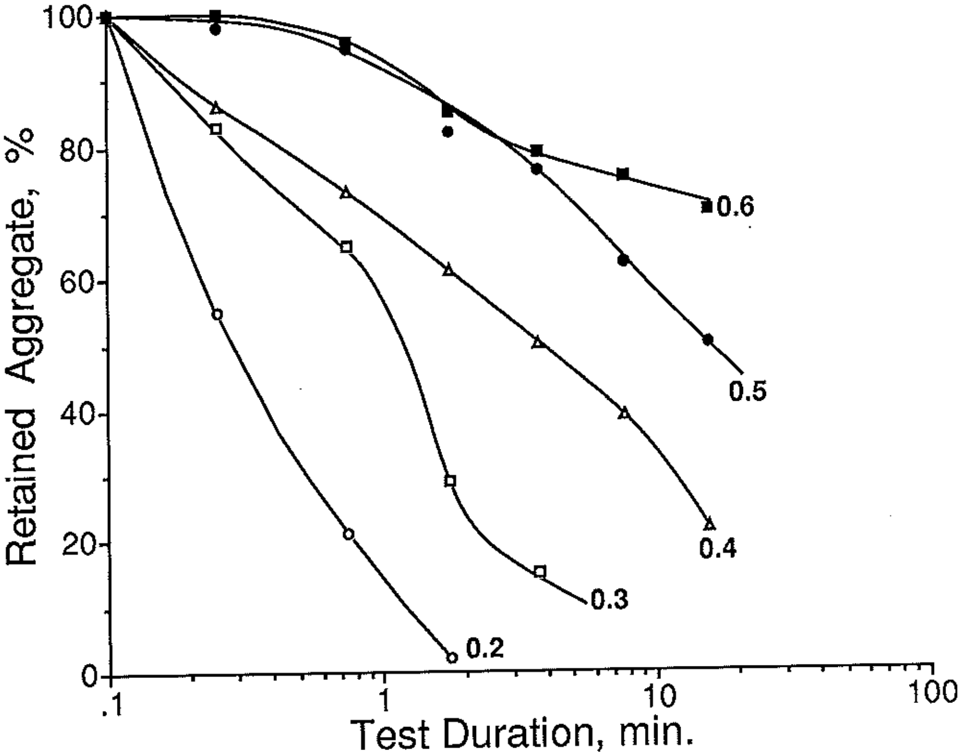

Figure 36: Coyne Surface Abrasion Test Values for Emulsions Application Rates (gallons/sq yd), Dry

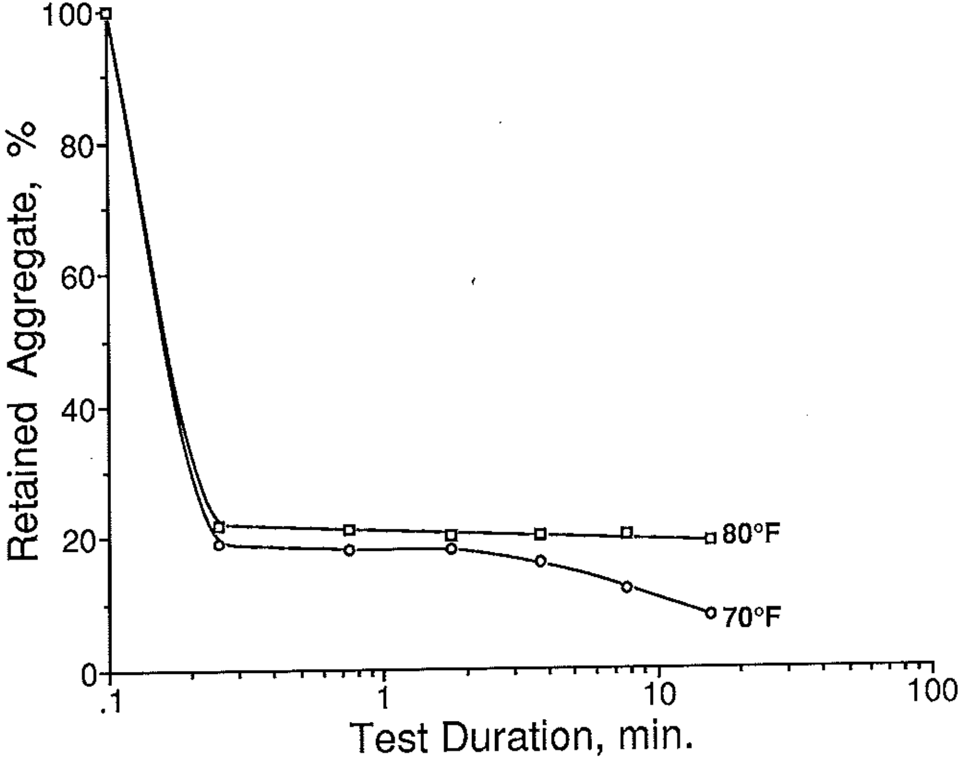

Figure 37: Coyne Surface Abrasion Test Values for Various Test Temperatures, Dry

8.0 FIELD PERFORMANCE VS. LABORATORY PERFORMANCE

This chapter compares overall test section performance after 1-1/2 years to materials test results, construction data, and ODOT CRS-2 emulsion specifications as follows:

1) Correlations were evaluated between field performance ratings of the test sections and the results of both materials tests and construction data (Table 5).

   The correlations show the relationship between seal performance and materials test results and construction data. A positive correlation shows that a higher test result or construction characteristic value results in better performance. A negative correlation means the opposite; the test results or construction characteristics are inversely proportional to performance. The correlations were rated using the following criteria:

   a) A correlation coefficient (R) between -1.000 and -.900, or 1.000 and .900 was "excellent."

   b) A coefficient between -.750 and -.900, or between .750 and .900 was "good."

   c) A coefficient between -.500 and -.750, or .500 and .750 was "fair."

   d) A coefficient between -.500 and 0, or 0 and .500 was "poor."

2) Test results and construction data were examined to see if a materials property or construction condition was unique to test sections with above average performance.

3) The ODOT CRS-2 specifications[10] and the Special Provisions[11] applying to chipseal construction were evaluated in the following areas:

   a) Did materials that did not conform to the CRS-2 specifications perform well? Did materials which passed the specifications perform poorly?

   b) Did seals placed under conditions or with procedures that did not conform to the requirements in the Special Provisions perform well? Did seals constructed in compliance with the Special Provisions perform poorly?

The authors are aware that only three of the nine emulsions on this project used ODOT CRS-2 specifications requirements. However, a comparison between the CRS-2 specifications and the materials test results and field performance ratings for all of the emulsions may be valuable for the following reasons. First, users throughout Oregon are familiar with the behavior of CRS-2.

Secondly, if a conventional emulsion was used on this project, it would be CRS-2. Finally, if a generic specification covering a variety of polymerized emulsions based on the existing CRS-2 specifications is considered, information from this comparison is useful.

TABLE 5: CORRELATIONS

TEST RESULTS OR CONSTRUCTION DATA	CORRELATION RATING	CORRELATION COEFFICIENT (R)	ANALYSIS COMMENT
Emulsion Viscosity @ 77°F	Poor	- .137	(1)
Sieve Test	Poor	.028	(2)
Oil in Emulsion	Poor	- .285	(3)
Percent Asphalt Residue	Fair	.529	(4)
ODOT Vialit @ 5°C	Poor	.077	
* ODOT Vialit @ -22°C	Fair	.509	(5)
Penetration @ 77°F	Poor	.093	(6)
Softening Point	Poor	- .025	
Ductility @ 39.2°F	Poor	.149	
Ductility @ 77°F	Poor	.000	(7)
Tension Stress @ 800% Elong	Poor	.090	
Torsional Recovery	Poor	.340	
Toughness	Poor	.169	
Tenacity	Poor	.178	
U of V Mod. Vialit (1/2 hr.)	Poor	.218	
U of V Mod. Vialit (1 hr.)	Poor	.143	
U of V Mod. Vialit (2 hr.)	Poor	.153	
U of V Mod. Vialit (3 hr.)	Poor	.202	
Coyne Field Vialit (1/2 hr.)	Poor	.239	
Coyne Field Vialit (1 hr.)	Poor	.450	
Coyne Field Vialit (1 1/2 hr.)	Poor	.445	
Coyne Laboratory Vialit (1/2 hr.)	Poor	.390	(8)
Coyne Laboratory Vialit (1 hr.)	Poor	.219	

TABLE 5: CORRELATIONS CONTINUED

TEST RESULTS OR CONSTRUCTION DATA	CORRELATION DATA	CORRELATION COEFFICIENT (R)	ANALYSIS COMMENT
Coyne Dry Surface Abrasive (30 sec.)	Poor	.219	
Coyne Dry Surface Abrasive (1 min.)	Poor	- .081	
* Coyne Dry Surface Abrasive (3 min.)	Fair	.511	
* Coyne Dry Surface Abrasive (5 min.)	Fair	.654	
Coyne Wet Surface Abrasive (30 sec.)	Poor	.360	
Coyne Wet Surface Abrasive (1 min.)	Poor	.380	(10)
Coyne Wet Surface Abrasive (3 min.)	Poor	.300	
Coyne Wet Surface Abrasive (5 min.)	Poor	.264	
Emulsion Temperature	Poor	- .245	(11)
* PMT Temperature During Laydown	Fair	.550	(12)
* Air Temperature During Laydown	Good	.754	(12)
First Night Low Temperature	Poor	- .049	
* Laydown Day High Temperature	Good	.780	(12)
Emulsion Application Rate	Poor	.158	(13)
* Aggregate Application Rate	Good	.864	(14)
Duration End of Laydown to First Traffic	Poor	.370	

*** "Fair" or better correlations**

The test section performance ratings in the Field Performance Chapter were used. Chipseals with an overall 1-1/2 year performance rating above 3.0 were "Above Average," as shown below:

Above Average: HFE-100S, CRS-2D, LMCRS-2H, CRS-2(P1), CRS-2K, and CRS-2 Calibration Section

Below Average: CRS-2 Control Sections, CRS-2P, CRS-2R, and HFE-90

The CRS-2 Calibration Section is not included in the individual statistical analyses unless noted.

8.1 Analysis of Correlations, Test Results, and Specifications

1) Emulsion Viscosity at 77°F

Emulsions with viscosities near or below the lower limit of 100 SSF in the CRS-2 specifications performed well (Figure 38). The emulsions used on two of these five "Above Average" sections would have failed the CRS-2 viscosity requirement. Only one of the four "Below Average" test sections contained emulsions that would have satisfied the CRS-2 specifications.

2) Sieve Test

The sieve test requirements in the CRS-2 specifications did not relate to overall performance (Figure 38). All samples of emulsions on this project, regardless of performance, would have failed the CRS-2 sieve test maximum of .1%.

3) Oil Distillate in Emulsion

All five emulsions used in the "Above Average" sections, with the highest value at 1.0%, were well below the maximum allowable CRS-2 value of 3% (Figure 38).

4) Emulsion, Percent Asphalt Residue

All sections with "Above Average" performance had emulsion residue contents above 68.4% (Figure 38). This was the only test that separated all the "Above Average" from the "Below Average" test sections.

All of the "Above Average" and three of the four "Below Average" sections used emulsions that would have passed the CRS-2 minimum of 65%.

5) ODOT Vialit Test @ -22°C

With a marginally "Fair" correlation of .509, this was the best Vialit test (Figure 39).

6) Penetration @ 77°F of Residue

The allowed penetration values of 100 to 250 dmm for CRS-2 residue would have excluded emulsions with harder residues that had good field performance (Figure 39). Only two out of the five emulsions used in the "Above Average" test sections would have passed CRS-2 requirements. The three emulsions that would not pass had residues slightly harder than the minimum limit. All of the emulsions used on the "Below Average" sections would have passed the CRS-2 requirement.

7) Ductility @ 77°F of Residue

Regardless of field performance, all emulsion residues would have passed the CRS-2 minimum of 40 cm (Figure 39). The correlation is not valid, as the samples were stretched to 100 mm rather than their breaking point.

8) Coyne Modified Vialit Test in the Field: 1 Hour Cure

Data for this correlation was scaled from curves in Figures 24 and 25.

9) Coyne Modified Vialit Test in the Laboratory: 1/2 Hour Cure

Data for this correlation was scaled from the curves in Figures 26 and 27.

10) Coyne Modified Dry Surface Abrasion Test: 5 Minute Abrasion

At .654, this test had the highest correlation with field performance of any of the surface abrasion tests, either wet or dry (Figure 39). Data for this correlation was scaled from curves in Figures 28 and 29.

11) Emulsion Temperature

None of the emulsions were within the allowable emulsion application temperature range of 140 to 165°F specified by ODOT for chipseal construction (Figure 40). Four of the five emulsions used in the "Above Average" sections were at or below the lower limit in the special provisions. The remaining emulsion in the "Above Average" sections was above the higher limit. Of the emulsions in the "Below Average" sections, two were at or below the minimum ODOT requirements and the other two were at or above the higher limit.

12) Pavement Temperature During Laydown, Air Temperature During Laydown, and Laydown Day High Temperature

The emulsion, pavement, and air temperatures during laydown were recorded at the jobsite and are listed in Table 2 of this report. The daily high temperatures were obtained from records for Stayton, a nearby town. The daily high temperature analysis includes data for each test section and the CRS-2 Calibration Section.

The pavement, air, and daily high temperature had "Fair" to "Good" correlations (Figure 40). As all these correlations show the same trends, chipseal performance is clearly related to the temperature of the pavement and air during and after laydown. However, the correlations for "Laydown Day High Temperature" may not be as significant, as only three different days are represented.

All sections were constructed when the air temperature was above the minimum of 65°F required in the region where the project is located.

13) Emulsion Application Rate

Coyne[12] analyzed the effect of emulsion application rates on surface abrasion test results. The Coyne study found that test samples with higher emulsion application rates had better chip retention. This relationship was not seen on this study, as the emulsion application rate had a "Poor" (.158) relationship to performance.

14) Aggregate Application Rate

The correlation between the aggregate application rate and overall performance was "Good" (.864). However, this correlation may not be valid, as the application rate data was only for the rock placed after the emulsion was spread and before the initial compaction.

All of the sections with "Above Average" performance had initial rock application rates above 32.0 lbs/yd^3. Additional chips were placed on all sections after the initial compaction. On five of the six sections with "Above Average" performance, including the CRS-2 Calibration Section, the sections were choked with 1/4" to No. 10 aggregate and recompacted between the initial compaction and exposure to traffic. On the remaining "Above Average" section and all of the "Below Average" sections, choking occurred after traffic had torn out a considerable amount of the original rock.

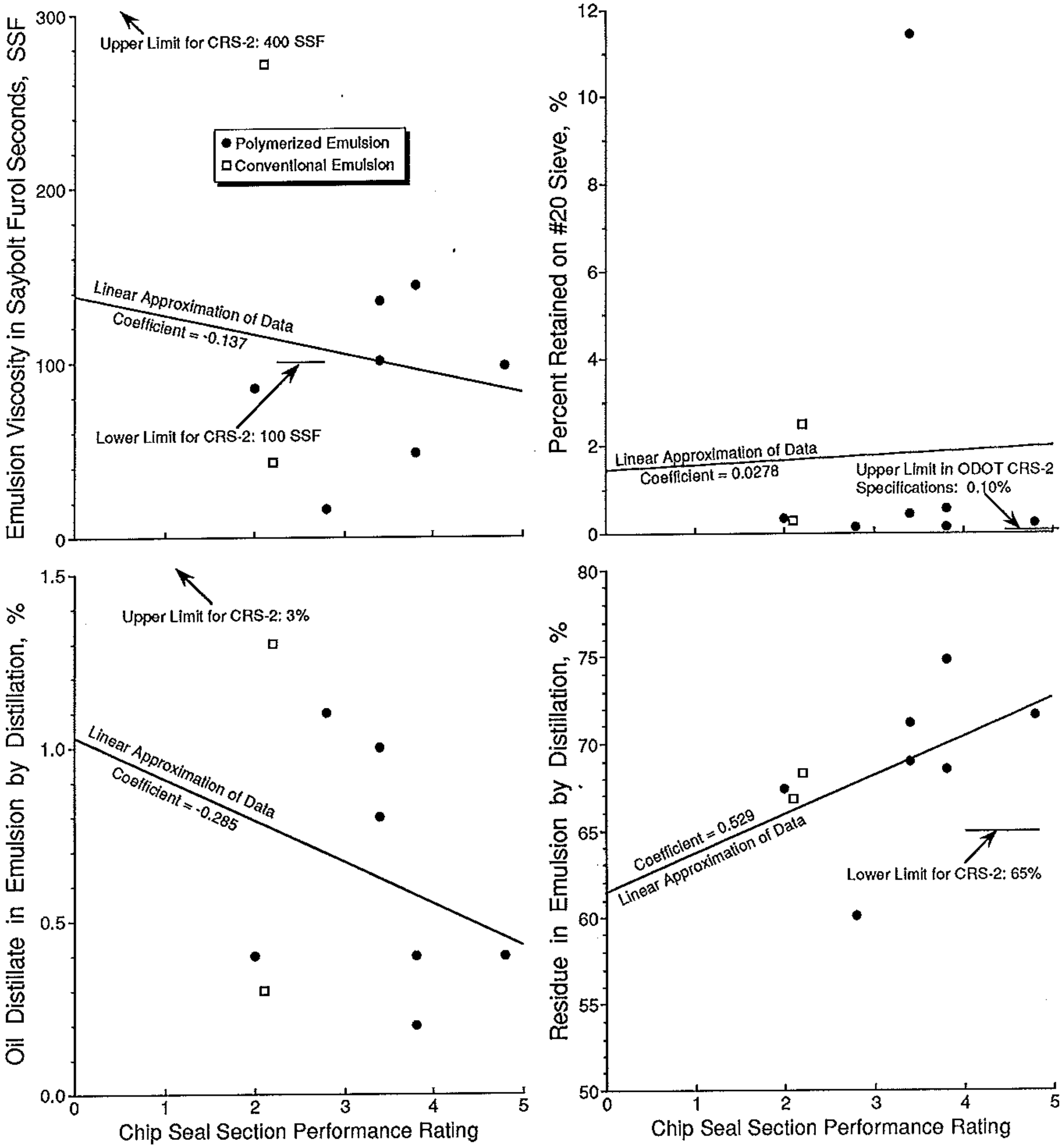

Figure 38: Performance Correlations

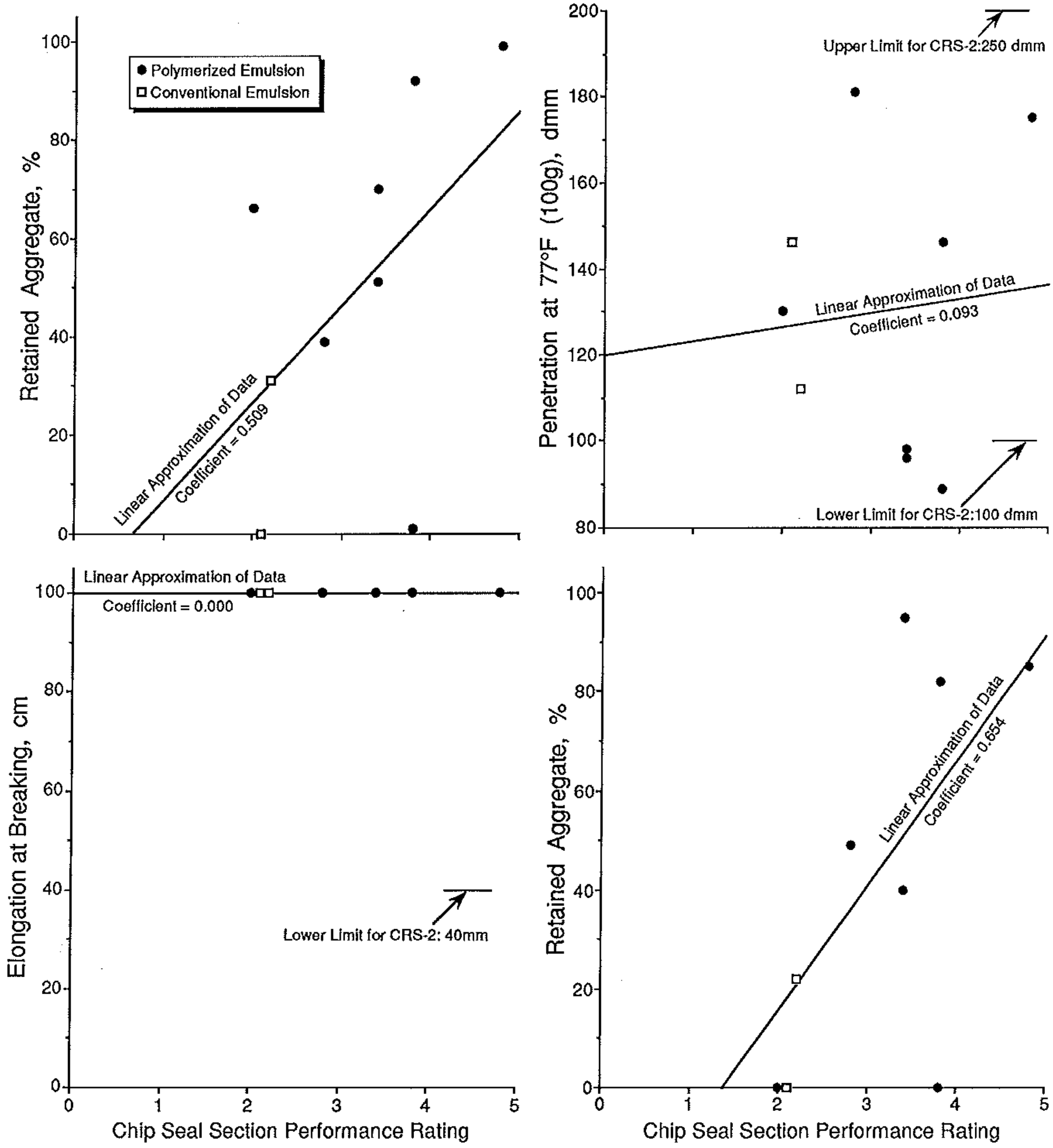

Figure 39: Performance Correlations

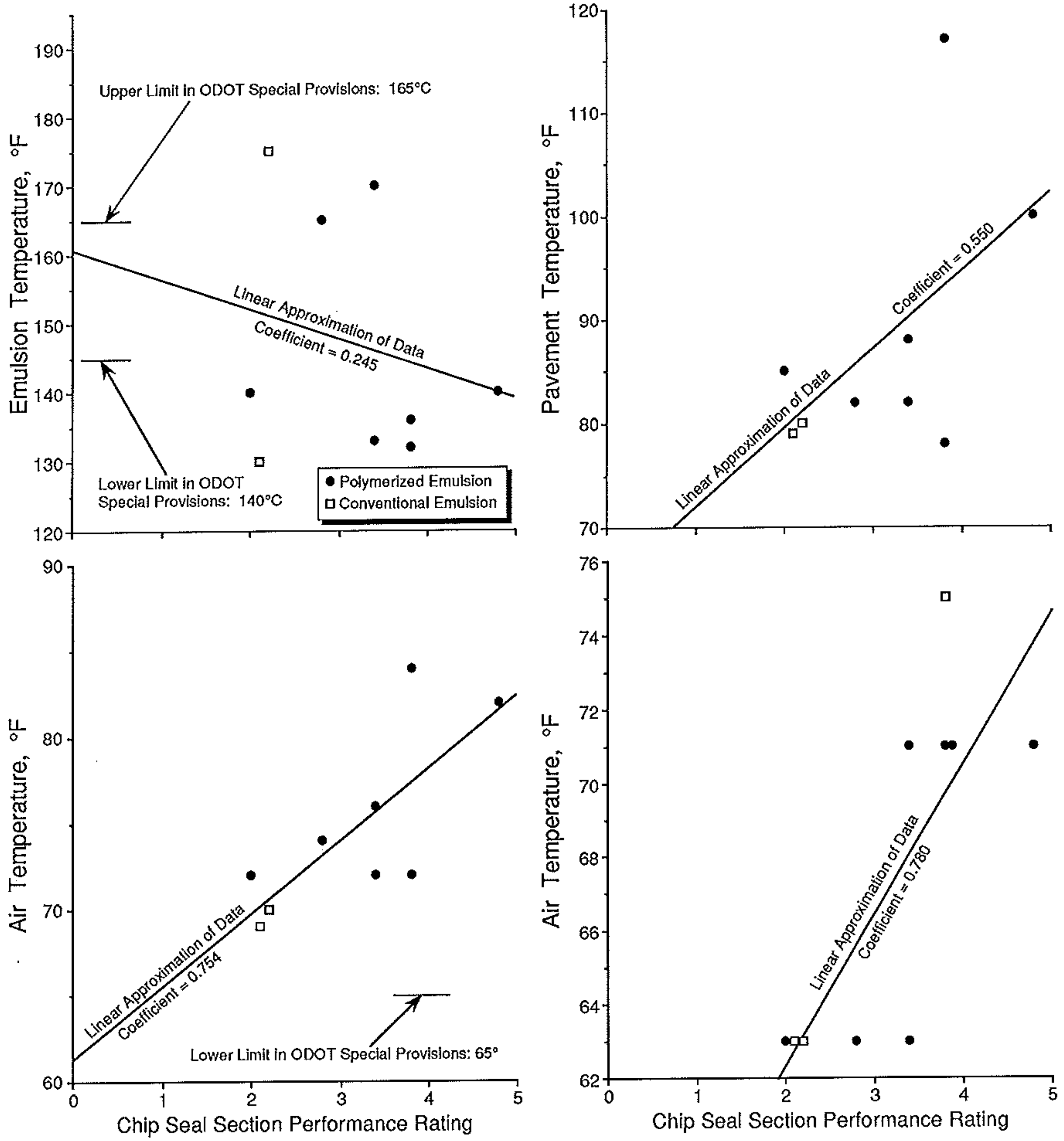

Figure 40: Performance Correlations

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The following conclusions summarize the important findings of this study:

1) Polymer modification of emulsified asphalt for construction of pavement chip seals was effective in providing improved seal performance. Inspection of the ten test sections for this study show considerable benefit in performance from the use of polymers.

2) Polymers used in the test section emulsified asphalts had individual effects on chip seal performance properties. As an example, the CRS-2(P1) system provided very good resistance to excess surface asphalt, retention of chips and development of proper aggregate embedment while the CRS-2K system provided very good resistance to reflective cracking and crack ravelling. The CRS-2D and HFE-100S seals had very good chip retention but were less effective in other performance properties.

3) The most effective polymer modified chip seal systems of those evaluated for this study were the seals containing CRS-2(P1), CRS-2K, CRS-2D, LMCRS-2H and HFE-100S emulsified asphalts. Overall performance ratings for these systems were above average.

4) Skid resistance values for chip seals containing polymer were greater than those for seals without polymer. Also, most polymer seals had less than normal change (i.e., most consistent) in skid resistance from the typical winter high value to the summer low value.

5) Pavement and air temperature during construction related well to chip seal performance. Both polymer modified and conventional chip seal systems had the best performance when temperatures were warmest. The warmer weather during application of the CRS-2 calibration sections constructed two weeks prior to the ten test sections is certainly a factor in the higher performance level of the calibration sections.

6) Aggregate spread rate during construction related well to chip seal performance. All test sections with chip coverage of greater than 32 lbs/yd^2 had better than average performance.

7) The ODOT Vialit test made at -22°C provided the best relationship between laboratory Vialit chip retention and the chip seal field performance ratings. Vialit tests made by Coyne in the field after one hour cure had a similar correlation level.

8) The dry surface abrasion tests for a five minute abrasion period provided a fair relationship between chip retention and the chip seal field section performance ratings. Other tests made with less abrasion time or in a wet condition had a poorer correlation.

9) Polymers had somewhat unique effects on properties measured by tests used to determine

the presence of polymer in emulsified asphalts. The Torsional Recovery test discerned polymers contained in three of the five best performing chip seals (CRS-2K, LMCRS-2H and HFE-100S) and the Toughness and Tenacity test indicated the presence of polymer in four (CRS-2K, LMCRS-2H, CRS-2D and CRS-2P) of the seven polymer modified emulsified asphalts for this study. None of the tests used in this study indicated the presence of polymer contained in the CRS-2(P1) emulsified asphalt which was rated as the best overall chip seal section.

10) Polymer modified emulsified asphalt sections with above average performance ratings for this study had high percentages of asphalt residue.

11) The ASTM Test Method for calculation of emulsified asphalt application rate for chip seal construction provided a reliable guide for use of both conventional and polymer modified emulsified asphalts. This calculated rate was near that applied on the best performing chip seals.

9.2 Recommendations

The following recommendations concerning changes to the current policy, design and specification procedures for the utilization of polymer modified chip seal systems are based on the results of this study:

1) Include CRS-2(P1), CRS-2K, CRS-2D and LMCRS-2H grades of emulsified asphalt in specification for asphalt materials along with HFE-100S already in the specification. This would allow the use of these polymer modified emulsified asphalts in chip seal construction and provide considerable benefit in performance.

2) Require the use of polymer modified emulsified asphalts in construction of chip seals west of the Cascade Mountains summit, and east of the Cascades when air temperatures are between 60°F minimum and 80°F. Conventional asphalt could be used east of the Cascades with temperatures greater than 80°F. This will provide improved chip retention, resistance to excess surface asphalt (bleeding), aggregate embedment, crack sealing and resistance to crack ravelling.

3) Increase the use of both polymer modified and non-modified chip seals as a preventative maintenance tool as well as for repair of asphalt concrete pavements. With the increased use of hard grades of asphalt in paving, it is necessary that asphalt aging be kept to minimum through chip sealing to provide an increased pavement service life.

4) Develop a training program for construction and maintenance personnel involved in the design, application and control of chip seal surfacings. Training sessions similar to those provided by CAL TRANS for the past several years have resulted in an increased use and improved performance of both polymer modified and conventional chip seals in California.

5) Require testing of cover aggregate and emulsified asphalt produced for each chip seal project for calculation of emulsion application rate and aggregate spread rate by Vialit and ASTM standard procedures. This will reduce problems on projects from the use of trial and error methods to establish application and spread rates.

6) Require a minimum asphalt residue from 400°F distillation of 68% along with other manufacturer standard specification requirements for use of CRS-2(P1), CRS-2K, CRS-2D, LMCRS-2H and HFE-100S emulsified asphalts.

7) The Torsional Recovery test requirement of 18% minimum is appropriate for only CRS-2K, HFE-100S and CRS-2K emulsions. Develop a method of test similar to the Torsional Recovery test to identify the presence and amount of polymer required in CRS-2D and CRS-2(P1) emulsified asphalt.

8) Require the use of aggregate spreaders in chip seal construction that will place the larger fraction ahead of the finer fraction (or in separate applications) in spreading chips. Also require the use of a pneumatic tire type roller for compacting cover aggregate in all chip seal construction.

10.0 REFERENCES

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12. Coyne, Lloyd, "Evaluation of Polymer Modified Chip Seal Coats," Paper presented at the Annual Meeting of the Association of Asphalt Paving Technologists, 1989.

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APPENDIX A

Cover Aggregate Test Data

TABLE A-1: LABORATORY TEST DATA ON COVER AGGREGATE PRIOR TO CONSTRUCTION

ODOT TM 204, 205; Percent Passing			
SIZE	**ORIGINAL**	**RESCREENED**	**ODOT SPECIFICATIONS FOR 3/8"-#10**
1/2"	100	100	100
3/8"	97	95	85-100
1/4"	20	8	---
#4	4	2	---
#10	2	2	0-10
#40	2	1	0-2
#200	1.5	1.0	---
ODOT TM 201; Loose Unit Weight:		91.0 lbs/ft^3	
ODOT TM 203; Bulk specific gravity: Apparent specific gravity: Percent Absorption		2.66 2.80 1.87	
ODOT TM 211; Abrasion Loss, Grading C: Maximum allowable in ODOT Specifications:		14.2% 30.0%	
ODOT TM 227; Cleanness Value: Minimum allowable in ODOT Specifications:		89 75	
ODOT TM 229N; Elongated Pieces: Maximum allowable in ODOT Specifications:		1.4% 10%	
ODOT TM 231; Average least dimension: Flakeness Index:		0.21" 11.4	

APPENDIX B

Emulsion Test Results and Specifications

TABLE B-1: CRS-2 EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES		
TEST	**MIN**	**MAX**	**MIN**	**MAX**	**ODOT LAB TESTS**
Tests on Emulsion: Viscosity SSF @ 122°F, sec.	100	400			271
Settlement, 5 days, % (a)	---	5			
Storage Stability, 1 day (b)	---	1			
Demulsibility, % (c)	40	---			
Particle Charge Test	Positive				Positive
Sieve Test, %	---	0.10			0.3
Cement Mixing, %	---	---			
Distillation: oil, % by volume (d) residue, %	--- 65	3 ---			0.3 66.8
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %	--- ---	--- ---			32 0
Tests on Residue From Distillation: (d) Viscosity @ 140°F, poise Viscosity @ 275°F, cst.	--- ---	--- ---			
Penetration, 100 g. @ 77°F, dmm.	100	250			146
Float Test @ 140°F, sec.	---	---			
Softening Point, °C	---	---			40.0
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm	--- 40	--- ---			75+ 100+
Solubility in Trichlorethylene, %	97.5	---			
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm^2 (f)	---	---			3.8
Torsional Recovery, % (e)	---	---			3.6
Toughness in lbs.	---	---			10
Tenacity in lbs.	---	---			1
Tests after TFOT: Mass Loss, %	---	---			
Viscosity Ratio	---	---			
Retained Penetration, %	---	---			

TABLE B-2: CRS-2P EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES (f,g,h)		
TEST	MIN	MAX	MIN	MAX	ODOT LAB TESTS
Tests on Emulsion: Viscosity SSF @ 122°F, sec.			100	400	85
Settlement, 5 days, % (a)			---	5	
Storage Stability, 1 day (b)			---	1	
Demulsibility, % (c)			40	---	
Particle Charge Test			Positive	---	Positive
Sieve Test, %			---	0.10	0.35
Cement Mixing, %			---	---	
Distillation: oil, % by volume (d) residue, %			--- 65 [60]	3	0.4 67.4
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %			--- ---	--- ---	100 66
Tests on Residue From Distillation:(d) Viscosity @ 140°F, poise Viscosity @ 275°F, cst.			--- ---	--- ---	
Penetration, 100 g. @ 77°F, dmm.			100	250	130
Float Test @ 140°F, sec.			---	---	
Softening Point, °C			---	---	43
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm			--- 40	--- ---	75+ 100+
Solubility in Trichlorethylene, %			97.5	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm² (0)			---	---	8.8
Torsional Recovery, % (e)			(18)	---	10.9
Toughness in lbs.			(50)	---	42
Tenacity in lbs.			(25)	---	29
Tests after TFOT: Mass Loss, %			---	---	
Viscosity Ratio			---	---	
Retained Penetration, %			---	---	
Viscosity @ 140°F			---	---	

TABLE B-3: CRS-2R EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES [f]		
TEST	MIN	MAX	MIN	MAX	ODOT LAB TESTS
Tests on Emulsion: Viscosity SSF @ 122°F, sec.			100		16
Settlement, 5 days, % [a]			---	---	
Storage Stability, 1 day [b]			---	1	
Demulsibility, % [c]			---	---	
Particle Charge Test			---	---	Positive
Sieve Test, %			---	0.10	0.15
Cement Mixing, %			---	---	
Distillation: oil, % by volume [d] residue, %			 --- 65	 4 ---	 1.1 60.1
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %			 --- ---	 --- ---	 100 39
Tests on Residue From Distillation:[d] Viscosity @ 140°F, poise Viscosity @ 275°F, cst.			 (1600) (325)	 8000 (2400) ---	
Penetration, 100 g. @ 77°F, dmm.			---	---	181
Float Test @ 140°F, sec.			---	---	
Softening Point, °C			---	---	43.5
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm			25 (50) 100 (100)	--- ---	29 100+
Solubility in Trichlorethylene, %			---	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm^2 [f]			---	---	8.8
Torsional Recovery, % [e]					0.0
Toughness in lbs.			(110)	---	15
Tenacity in lbs.			(75)	---	6
Flash Point, COC, °F			(450)		
Tests after TFOT: Mass Loss, %			 ---	 ---	
Viscosity Ratio			---	---	
Retained Penetration, %			---	---	

TABLE B-4: HFE-100S EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES		
TEST	MIN	MAX	MIN	MAX	ODOT LAB TESTS (f)
Tests on Emulsion: Viscosity SSF @ 122°F, sec.	50	---	50	---	101 (272)
Settlement, 5 days, % (a)	---	---	---	---	
Storage Stability, 1 day (b)	---	1.0	---	1.0	(Passed)
Demulsibility, % (c)	40	---	40	---	(42)
Particle Charge Test	---	---	---	---	Negative
Sieve Test, %	---	0.1	---	0.1	11.4 (Pass)
Cement Mixing, %	---	---	---	---	
Distillation: oil, % by volume (d) residue, %	--- 65	2.0 ---	--- 65	2.0 ---	1.0 (Trace) 71.2 (73.3)
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %	--- ---	--- ---	--- ---	--- ---	100 51
Tests on Residue From Distillation:(d) Viscosity @ 140°F, poise Viscosity @ 275°F, cst.	--- ---	--- ---	--- ---	--- ---	
Penetration, 100 g. @ 77°F, dmm.	90	140	90	140	98 (105)
Float Test @ 140°F, sec.	1200	---	1200		(1200+)
Softening Point, °C	---	---	---	---	53.3
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm	--- 125	--- ---	--- 125	--- ---	29 100+ (Pass)
Solubility in Trichlorethylene, %	97.5	---	97.5	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm^2 (f)	2.5	---	2.5	---	8.8
Torsional Recovery, % (e)	---	---	---	---	27.8
Toughness in lbs.	---	---	---	---	23
Tenacity in lbs.	---	---	---	---	9
Tests after TFOT: Mass Loss, %	---	0.4	---	0.4	
Viscosity Ratio	---	2.0	---	2.0	
Retained Penetration, %	60	---	60	---	

TABLE B-5: HFE-90 EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES		
TEST	**MIN**	**MAX**	**MIN**	**MAX**	**ODOT LAB TESTS (j)**
Tests on Emulsion: Viscosity SSF @ 122°F, sec.	50	---	50	---	43 (231)
Settlement, 5 days, % (a)	---	---	---	---	
Storage Stability, 1 day (b)	---	1	---	1	(Passed)
Demulsibility, % (c)	30	---	30	---	(58)
Particle Charge Test	---	---	---	---	Negative
Sieve Test, %	---	0.10	---	0.10	2.5 (Pass)
Cement Mixing, %	---	---	---	---	
Distillation: oil, % by volume (d) residue, %	 --- 65	 7 ---	 --- 65	 7 ---	 1.3 (Trace) 68.3 (67.5)
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %	 --- ---	 --- ---	 --- ---	 --- ---	 100 31
Tests on Residue From Distillation:(d) Viscosity @ 140°F, poise Viscosity @ 275°F, cst.	 --- ---	 --- ---	 --- ---	 --- ---	
Penetration, 100 g. @ 77°F, dmm.	90	150	90	150	112 (109)
Float Test @ 140°F, sec.	1200	---	1200		(1200+)
Softening Point, °C	---	---	---	---	54.5
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm	--- ---	--- ---	--- ---	--- ---	10 100
Solubility in Trichlorethylene, %	---	---	---	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm² (f)	---	---	---	---	15.7
Torsional Recovery, % (e)	---	---	---	---	5.4
Toughness in lbs.	---	---	---	---	17
Tenacity in lbs.	---	---	---	---	2
Tests after TFOT: Mass Loss, %	 ---	 ---	 ---	 ---	
Viscosity Ratio	---	---	---	---	
Retained Penetration, %	---	---	---	---	

TABLE B-6: CRS-2D EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES (k)		
TEST	**MIN**	**MAX**	**MIN**	**MAX**	**ODOT LAB TESTS**
Tests on Emulsion: Viscosity SSF @ 122°F, sec.			150	400	135
Settlement, 5 days, % (a)			---	---	
Storage Stability, 1 day (b)			---	---	
Demulsibility, % (c)			Pass	---	
Particle Charge Test			Positive	---	Positive
Sieve Test, %			---	0.10	0.44
Cement Mixing, %			---	---	
Distillation:					
oil, % by volume (d)			---	4	0.8
residue, %			63	---	69
Tests on Residue from Evaporation:					
Vialit Test @ 5°C, %			---	---	92
Vialit Test @ -22°C, %			---	---	70
Tests on Residue From Distillation:(d)					
Viscosity @ 140°F, poise			---	---	
Viscosity @ 275°F, cst.			---	---	
Penetration, 100 g. @ 77°F, dmm.			150	250	96
Float Test @ 140°F, sec.			---	---	
Softening Point, °C			---	---	46.5
Ductility @ 39.2°F, cm.			---	---	17.5
Ductility @ 77°F, 5 cm/min., cm			100+	---	100+
Solubility in Trichlorethylene, %			97.5	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm^2 (0)			---	---	8.8
Torsional Recovery, % (e)			---	---	7.3
Toughness in lbs.			---	---	41
Tenacity in lbs.			---	---	18
Tests after TFOT:			---	---	
Mass Loss, %			---	---	
Viscosity Ratio			---	---	
Retained Penetration, %			---	---	

TABLE B-7: LMCRS-2H EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES		
TEST	MIN	MAX	MIN	MAX	ODOT LAB TESTS (l)
Tests on Emulsion: Viscosity SSF @ 122°F, sec.			75	300	144 (142)
Settlement, 5 days, % (a)			---	5	
Storage Stability, 1 day (b)			---	1	
Demulsibility, % (c)			40	---	
Particle Charge Test			Positive	---	Positive (Positive)
Sieve Test, %			---	0.3	0.55
Cement Mixing, %			---	---	
Distillation: oil, % by volume (d) residue, % (n)			--- 65	--- ---	0.4 68.5 (69)
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %			--- ---	--- ---	23 1
Ash Content, %				0.2	
Tests on Residue From Distillation:(d) Viscosity @ 140°F, poise Viscosity @ 275°F, cst.			--- ---	--- ---	
Penetration, 100 g. @ 77°F, dmm.(n)			40	90	89
Float Test @ 140°F, sec.			---	---	
Softening Point, °C			---	---	46
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm (n)			--- 40	--- ---	29 100+
Solubility in Trichlorethylene, %			---	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm^2 (o)			---	---	19.6
Torsional Recovery, % (e,n)			18	---	18.2 (20)
Toughness in lbs.			---	---	57
Tenacity in lbs.			---	---	31
Tests after TFOT: Mass Loss, %			---	---	
Viscosity Ratio			---	---	
Retained Penetration, %			---	---	

TABLE B-8: CRS-2(P1) EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES		
TEST	MIN	MAX	MIN	MAX	ODOT LAB TESTS (m)
Tests on Emulsion: Viscosity SSF @ 122°F, sec.			100	400	98 (189)
Settlement, 5 days, % (a)			---	---	
Storage Stability, 1 day (b)			---	1.0	
Demulsibility, % (c)			40	---	
Particle Charge Test			---	Positive	Positive (Positive)
Sieve Test, %			---	0.10	0.25 (0.0)
Cement Mixing, %			---	---	
Distillation: oil, % by volume (d) residue, %			 --- 65	 3.0 ---	 0.4 (0.67) 71.6 (72)
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %			 --- ---	 --- ---	 100 99
Tests on Residue From Distillation:(d) Viscosity @ 140°F, poise Viscosity @ 275°F, cst.			 750 ---	 --- ---	 (812) (355)
Penetration, 100 g. @ 77°F, dmm.			150	---	175 (170)
Float Test @ 140°F, sec.			1200	---	
Softening Point, °C			---	---	43.5
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm			40 ---	--- ---	50+ 100+
Solubility in Trichlorethylene, %			---	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm² (0)			---	---	7.9
Torsional Recovery, % (e)			---	---	6.4
Toughness in lbs.			---	---	11
Tenacity in lbs.			---	---	4
Tests after TFOT: Mass Loss, %			---	---	
Viscosity Ratio			---	---	
Retained Penetration, %			---	---	

TABLE B-9: CRS-2K EMULSIFIED ASPHALT

	ODOT SPECIFICATIONS		SUPPLIER GUIDELINES		
TEST	MIN	MAX	MIN	MAX	ODOT LAB TESTS [m]
Tests on Emulsion: Viscosity SSF @ 122°F, sec.			100	400	48 (52)
Settlement, 5 days, % [a]			---	---	
Storage Stability, 1 day [b]			---	1.0	
Demulsibility, % [c]			40	---	
Particle Charge Test			Positive	---	Positive (Positive)
Sieve Test, %			---	0.1	0.15 (0.0)
Cement Mixing, %			---	---	
Distillation: oil, % by volume [d] residue, %			 --- 65	 3.0 ---	 0.2 (0.33) 74.8 (72.7)
Tests on Residue from Evaporation: Vialit Test @ 5°C, % Vialit Test @ -22°C, %			 --- ---	 --- ---	 100 92
Tests on Residue From Distillation:[d] Viscosity @ 140°F, poise Viscosity @ 275°F, cst.			 1000 ---	 --- ---	 (1118) (454)
Penetration, 100 g. @ 77°F, dmm.			120	---	146 (132)
Float Test @ 140°F, sec.			1200	---	
Softening Point, °C			---	---	44
Ductility @ 39.2°F, cm. Ductility @ 77°F, 5 cm/min., cm			100 ---	--- ---	50+ 100+
Solubility in Trichlorethylene, %			---	---	
Tensile Stress @ 800% elongation, 39.2°F, 50 cm/min., kg/cm² [f]			---	---	7.2
Torsional Recovery, % [e]			---	---	20.0
Toughness in lbs.			---	---	46
Tenacity in lbs.			---	---	34
Tests after TFOT: Mass Loss, %			---	---	
Viscosity Ratio			---	---	
Retained Penetration, %			---	---	

FOOTNOTES ON EMULSIONS

(a) AASHTO T 59 - 86 (Settlement)

(b) AASHTO T 59 - 86

(c) AASHTO T 59 - 86 (using 35 ml of 0.8% sodium dioctyl sulffosuccinate)

(d) AASHTO T 59 - 86 (with a 400°F distillation temperature)

(e) Chevron Test Method B-20 (with a 400°F maximum distillation temperature held for 15 minutes)

(f) ODOT CRS-2 specifications were used as a guideline for the blending of the emulsion prior to the addition of the latex.

(g) Figures in parentheses are State of Washington specifications. These figures are provided for reference only; they were not used on the job.

(h) Figures in brackets are manufacturer's specifications.

(i) Figures in parentheses are the results of tests on the base asphalt prior to emulsification.

(j) Figures in parentheses are Pacific Emulsion lab test results.

(k) ODOT CRS-2 specifications were used as a guideline by the manufacturer.

(l) Figures in parentheses are Morgan Paving Lab test results.

(m) Figures in parentheses are Chevron Lab test results.

(n) Specifications and supplier's test results use residue obtained by drying.

(o) An Instrom testing machine and a special mold rather than a ductility mold is required by supplier for testing. ODOT tests used a ductilometer at a pull rate of 5 cm/mm with a mold similar to a ductility mold. ODOT test results are in lb/cm^2 rather than K8/cm^2.

APPENDIX C

Statistical Data

TABLE C-1: AVERAGE FIELD PERFORMANCE VS. MATERIALS TESTS

TEST	CORR.	STD. DEV.	SLOPE	Y-INTERCEPT
Viscosity @ 77°F	-.137	75.4	-10.9	139
Sieve	.028	3.68	.108	1.45
Oil in Emulsion	-.285	.400	-.108	1.03
Residue in Emulsion	.529	4.05	2.27	61.5
ODOT Vialit @ 5°C	.077	31.7	2.59	74.9
ODOT Vialit @ -22°F	.509	35.7	19.3	-10.7
Penetration @ 77°F	.093	34.1	3.36	120
Softening Point	-.025	4.84	-.129	46.4
Ductility @ 39.2°F	.149	15.6	2.46	27.2
Ductility @ 77°F	0.00	0.00	0.00	100
Tensile Stress @ 800% Elongation	.090	4.58	.455	8.50
Torsional Recovery	.340	9.06	3.26	.820
Toughness	.169	17.5	3.13	19.3
Tenacity	.178	13.3	2.51	6.99
U of N Mod. Vialit 1/2 hour	.218	27.8	6.40	45.5
U of N Mod. Vialit 1 hour	.143	28.8	4.37	57.3
U of N Mod. Vialit 2 hours	.153	30.1	4.86	61.2
U of N Mod. Vialit 3 hours	.202	17.6	3.76	72.8
Coyne's Field Vialit 1/2 hour	.239	25.3	6.42	47.3
Coyne's Field Vialit 1 hour	.450	26.5	12.6	38.9

TABLE C-1: AVERAGE FIELD PERFORMANCE VS. MATERIALS TESTS CONTINUED

TEST	CORR.	STD. DEV.	SLOPE	Y-INTERCEPT
Coyne's Field Vialit 1 1/2 hours	.445	27.6	13.0	38.8
Coyne's Lab Vialit 1/2 hour	.390	19.5	8.04	18.4
Coyne's Lab Vialit 1 hour	.219	23.5	5.45	37.7
Coyne's Dry Surface Abr. 30 sec.	-.081	32.8	-2.82	82.6
Coyne's Dry Surface Abr. 1 min.	.027	34.2	.980	65.9
Coyne's Dry Sufrace Abr. 3 min.	.511	39.1	21.2	-17.4
Coyne's Dry Surface Abr. 5 min.	.654	38.7	26.8	-42.8
Coyne's Wet Surface Abr. 30 sec.	.360	38.8	14.8	.291
Coyne's Wet Surface Abr. 1 min.	.380	37.5	15.1	-11.0
Coyne's Wet Surface Abr. 3 min.	.300	33.4	10.6	-9.37
Coyne's Wet Surface Abr. 5 min.	.264	28.1	7.83	-5.95

TABLE C-2: AVERAGE FIELD PERFORMANCE VS. CONSTRUCTION DATA

TEST	CORR.	STD. DEV.	SLOPE	Y-INTERCEPT
Emulsion Temperature	-.245	17.9	-4.65	161
Pavement Temperature During Laydown	.550	12.8	7.45	64.4
Air Temperature During Laydown	.754	5.22	4.17	61.4
First Night Low Temperature *	-.049	1.49	-.080	47.3
Laydown Day High Temperature *	.780	4.79	4.09	54.3
Emulsion Application Rate	.158	.059	.010	.448
Aggregate Application Rate	.864	5.34	4.88	15.9
Duration: End of Laydown to First Traffic	.370	2.74	1.07	2.38

*** These analyses include data from the CRS-2 Calibration section**

APPENDIX D

SUPPLIERS

TABLE D-1: EMULSIFIED ASPHALT POLYMER SUPPLIERS

Albina Fuel 3246 N.E. Broadway Portland, OR 97212	Asphalt Supply & Service 4310 E. 60th Avenue Commerce City, CO 80022
BASF Chemical Inc. (Formerly Polysar Inc.) 2200 Polymer Drive Chattanooga, TN 37421	Chevron USA Inc. 575 Market Street San Francisco, CA 94105
DuPont Company Industrial Polymers Division Barley Hill Plaza 11-2217 Wilmington, DE 19898	Elf Aquitane Asphalt Inc. (Formerly Pacific Emulsions) 1000 Executive Parkway St. Louis, MO 63141
Koch Asphalts P.O. Box 6226 Spokane, WA 99207	LBD Asphalt Products P.O. Box 158 Dear Park, TX 77536-0158
Morgan Paving P.O. Box 1500 Redding, CA 96099	Riedel International Inc. Western Pacific Division (Formerly Western Pacific Construction) 3510 S.W. Bond Portland, OR 97201
Shell Chemical 1415 W. 22nd Street Oak Brook, IL 60521	