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US Highway 84 Chip Seal Field Trials and Laboratory Test Results

Final Report

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16. Abstract

This report contains laboratory and field testing of US Highway 84 in Lincoln county Mississippi. A full scale field test consisting of seven polymer modified asphalt emulsions and a CRS-2 control emulsion was constructed in September of 1989 and subsequently evaluated for two years. Laboratory testing of these emulsions was performed with the Frosted Marble Test and the Tensile Stress Test, alongside standard emulsion test protocols. The goal of the work at the time it was conducted was to add satisfactory performing products to the DOT Approved Products List.

Recent research activities at the Mississippi DOT have focused on preservation and maintenance, indicating a desire to develop performance related specifications and material acceptance procedures. No formal report was generated at the time of testing, but a large of amount of data was present in MDOT files. Additionally, a large amount of data regarding the testing was owned by producers involved with the test sections. This data was combined, organized, synthesized, and developed into this report. Several of the products (or very similar versions) tested on US Highway 84 remain in use at present. The data contained in this report will be used in future research activities aimed toward performance oriented specification and acceptance of chip seal materials.

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NOTICE

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CHAPTER 1 - INTRODUCTION

1.1 General and Background Information

The *Mississippi State Highway Department (MSHD),* or alternatively the *Mississippi Department of Highways (MDOH),* will be referred to hereafter by its current designation of the *Mississippi Department of Transportation (MDOT). MDOT* conducted a full scale field test of polymer modified CRS-2 emulsions in the late 1980’s, and the planning, testing, results, and implications of the work are the focus of this report. No formal report was generated during or after evaluation of the test sections, and with *MDOT* continually seeking to improve its practices in the areas of pavement preservation and maintenance, this report was generated to unify the large volume of information into an organized report for use in future research and implementation.

The primary objective of the test section was to establish an *Approved Products List (APL)* of asphalt additives (i.e., polymer modified CRS-2 emulsions). Within the primary objective was the ability to directly compare performance of the different materials under the same conditions over an extended period of time. Early chip retention was one of, if not the, primary evaluation considerations. The sealing materials were evaluated in terms of performance in the field for a period of two years. Note initial planning stated evaluation would be on the order of one year.

US Highway 84 (*US 84*) in Lincoln county Mississippi east of the Brookhaven Bypass was the test section location. The location was carefully chosen based on key criteria established by a group of *MDOT* employees. The test section criteria established were:

1. Maximum feasible ADT,
2. Appreciable percentage of trucks,
3. A long section allowing constant traffic over all materials,
4. Ability to be evaluated over an extended period of time.

The test section allowed comparison of seven polymer modified binders to the *MDOT* specification material CRS-2. The intent of the test section as stated in an *MDOT* memo on September 5, 1989 was to add any satisfactory performing products to the *APL*. Polymer modified binders must have high early adhesion while the surface is new and tender. While good short term performance of polymer modified binders doesn’t guarantee long term benefits, inadequate short term performance does lead to poor long term performance.

1.2 Previous Information Used During Development

The history of polymer modified binders in Mississippi sealing activities, especially as it pertains to development of the *US 84* test section, is described in the remainder of this section. *MDOT* performed initial field testing between August 1982 and October 1984 where four products were evaluated: 1) *Styrelf*- styrene butadiene; 2) *Riffe*-polymerized-cationic emulsified asphalt provided by Riffe Petroleum; 3) *Owens Corning (O-C)*-chip seal additive that was shipped in drums and mixed with CRS-2; and 4) CRS-2-standard emulsion with no polymer modification. Complete details of this testing can be found in MDOT SS 67-12 (Kidd 1990), while the results pertinent to the current research are repeated herein.

The goals of the research described in Kidd (1990) were to evaluate performance of polymer modified asphalt emulsions in terms of elasticity, adhesion, and cohesion in conditions where standard binders would have difficulty performing. Difficult operating conditions were defined as high volume roadways and/or roadways with sharp turns (often in rural areas). Pertinent information and summaries of the results can be seen in Table 1. The evaluations were based on visual observations of the test sections: e.g. aggregate retention. All test sections utilized No. 7 Slag aggregate.

Table 1. Results of Field Test Sections of Kidd (1990)

Location	Date	Product	Lane Miles	ADT	Trucks	Result
Miss 28: Copiah	Aug 82	Styrelf	3.2	1,570	15%	Note 1
Miss 28: Simpson	Sept 83	Riffe	2.8	4,050	10%	Note 2
Miss 14: Attala	Sept 83	Styrelf	3.0	1,820	15%	Note 3
I-55: Madison	Oct 83	Styrelf	26.0	12,710	25%	Note 4
Miss 26: Stone	Oct 83	Styrelf	3.0	4,190	10%	Note 5
Miss 27: Hinds	Oct 84	O-C	3.0	410	12%	Note 6

Note 1*: Styrelf application rate was (1.1) L/m^2 (0.25 gal/yd^2) and the 4.8 lane miles of CRS-2 placed on either side used (1.36) L/m^2 (0.30 gal/yd^2). The aggregate application rate was (6,700) cm^3/m^3 (0.18 ft^3/yd^3). The pavement had numerous fine cracks and was opened to traffic quickly. Greater adhesive properties were observed relative to the control section. The aggregate stuck to the Styrelf rather than bouncing. The aggregate could be picked up and the Styrelf binder would stretch much more than the CRS-2. Less noise on Styrelf section.*

Note 2*: The pavement had many sharp turns, cracks, and poor skid resistance. Early adhesion was inferior to Styrelf. Large amounts of aggregate loss in sharp turns an breaking sections. In straight areas the aggregate retention was no better than CRS-2.*

Note 3*: Rural section of pavement. Styrelf performed well.*

Note 4*: The surface was slick when wet and was opened to traffic quickly. Styrelf performed well; no loose aggregate.*

Note 5*: Pavement was in a commercially developed area. No meaningful data to report other than there were no problems during construction.*

Note 6*: Section exhibited none of Styrelf's early adhesion and did not appear different than CRS-2.*

Styrelf was the only product deemed successful. While not specifically stated in the report, the test sections were in place for several years prior to the writing of the report so there was a reasonable amount of time with which to evaluate the sections. Also not stated in the report (but implied by the author) is that the superior performance of *Styrelf* in these field trials made it the product of choice prior to the *US 84* testing and evaluation.

MDOT memorandums detailed additional full scale field testing on *US 98* in Franklin County where CRS-2 was modified with *Ductilad* (Polystyrene) and *Ultrapave UP 65K* (SBR-Latex) polymer additives. The section was constructed in the fall of 1987. Two evaluations were performed during the first year of service that consisted of a physical determination and count of aggregate lost in the roadway test areas; no other data was obtained. Field data was reported to be somewhat confounding and not conclusive. None the less both modifiers were reported superior to CRS-2, and that the additional performance warranted temporary use of both polymers as a *Styrelf* alternative.

Memorandums written approximately 5 months prior to construction of *US 84* suggest that conditional approval of *Ductilad* and *Ultrapave UP 65K* should be given as alternative to *Styrelf* as a result of performance when installed on *US 98*. Competition of products was indicated to save considerable amounts of money. A September 5, 1989 memo also stated only one product (not directly named but the product was *Styrelf*) was on the *APL* for a number of years, but that addition of two more materials to the *APL* occurred in 1988 (not directly mentioned but the products were *Ductilad* and *Ultrapave UP 65 K*). It was stated that work thereafter observed a 30% bid price drop as a result of addition of the two products.

In addition to the *MDOT* generated data, the Oregon DOT provided an interim report of full scale testing of seven polymer modified binders and two conventional binders evaluated for 1.5 years. The information was obtained in March of 1989 and was used in planning the Mississippi test section. The Oregon DOT required each product to be placed using a different distributor, which led to some difficulties in controlling the shot rates (rates chosen by suppliers).

1.3 Planning and Development of Test Sections

Organization of the test section began several months prior to construction. The first record of tangible activity (referred to in an inter-departmental memorandum as a "Game Plan") occurred on December 9, 1988. Key Dates during planning are summarized below:

- *March 20, 1989* *MDOT* personnel meeting regarding test section.
- *May 23, 1989* Memos alerting producers their product was selected and alerted them of the June 20, 1989 meeting.
- *June 20, 1989* Pre-construction meeting of suppliers and *MDOT* including a round table discussion and trip to *US 84* site.
- *August 23, 1989* Planning completed and supplier test results requested.
- *September 11 to 15, 1989* Construction of *US 84* test sections.

Supplier was tasked to 1) select base asphalt/emulsion, additive, and deliver one tanker load of polymer modified CRS-2 for the evaluation; 2) design chip seal including binder and aggregate rates, application temperature, and similar; and 3) provide technical assistance including a knowledgeable technical representative on site during construction. The polymer additive supplier was allowed to obtain asphalt from three suppliers: Ergon, Southland, and Chevron. Table 2 provides estimates and sources of the asphalt binders incorporated. The polymers were supplied to *MDOT* at no cost.

Table 2. Material Quantities and Suppliers

Additive Supplier	Asphalt Binder Supplier	Binder Quantity – L (gal)
Textile Rubber & Chemical	Ergon, Inc.	18,500 (4,900)
LBD Asphalts	Southland Oil Co.	16,300 (4,300)
BASF	Ergon, Inc.	16,300 (4,300)
Shell Chemical	Ergon, Inc.	15,900 (4,200)
DuPont	Ergon, Inc.	14,800 (3,900)
Exxon	Ergon, Inc.	18,500 (4,900)
Chevron	Chevron, USA	15,900 (4,200)

Each test section was to be 7.3 m (24 ft) wide and on the order of 1,600 m (1 mile) long. The original plan was to shoot the emulsion onto both lanes simultaneously. However, on June 29, 1989 representative from Shell Chemical expressed concern that the original construction protocol of a single 7.3 m (24 ft) wide shot could cause difficulties in adequately characterizing the behaviors of interest (quick grab and aggregate bonding behavior). A 3.7 m (12 ft) spray was recommended in lieu of the original 7.3 m (24 ft) spray. As seen later in the report, the request was accommodated.

Table 3 contains the test section as it was originally planned. As is typical with large scale construction where many individuals and parameters are involved, adjustments were necessary on site to ensure a representative test where all products were evaluated in a consistent manner. The layout of the as built test section can be seen in Section 2.3.

Table 3. As Designed Layout and Products to be Tested

Log Miles[1]	Section	Manufacturer/Material	Polymer[2]
0 to 1	1	Ergon/CRS-2	None
1 to 2	2	Shell/Kraton	SBS
2 to 3	3	Textile Rubber and Chemical/Ultrapave UP 65K	SBR-Latex
3 to 4	4	Exxon/Polybilt	EVA
4 to 5	5	LBD Asphalt Products/Ductilad	Polystyrene
5 to 6	6	BASF/Butonal NS	SBR-Latex
6 to 7	7	DuPont/Neoprene	Neoprene Latex
7 to 8	8	Ergon/Styrelf	SB
8 to 9	9	Ergon/CRS-2	None

1: Begin at west end of project.
2: See 3.1 for more detailed information on the polymers used

CHAPTER 2 – TEST SECTION CONSTRUCTION

2.1 Design and Construction Parameters

The pavement in place prior to the treatments can be seen in Figure 1. The year of construction of the layers can also be seen in the figure. Information related to the equipment used, specifications in effect, and as built properties is in the following subsections.

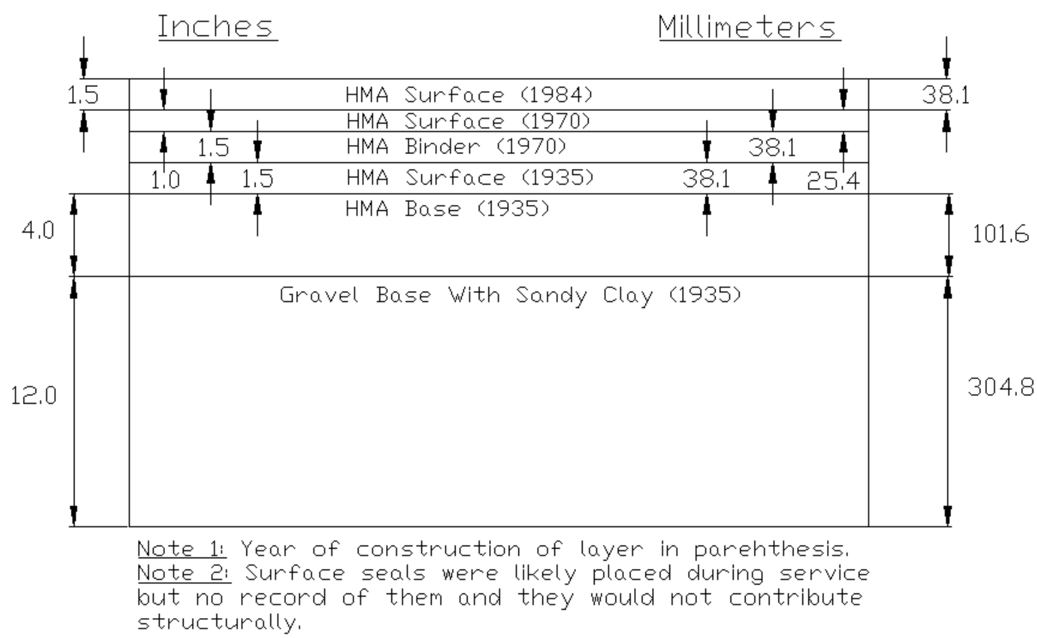


Figure 1. ***US 84*** **Pavement Section Prior to Polymerized Chip Seal Treatments**

2.2 Equipment and Specifications

The equipment used for the research was standard for all sections and is summarized as seen below.

- Asphalt Distributor: Rosco Manufacturing Co, Model RPF, 1988 model, 5,650 L (1,500 gal) capacity.
- Chip Spreader: Rosco Manufacturing Co, Model SPRH, 1989 model.

No materials were allowed that would have required revisions to existing equipment. All equipment and construction personnel were provided by *MDOT*.

MDOT also provided the slag aggregate (AASHTO Size No 7). At the time of construction, *MDOT* grading specifications for Size No 7 size aggregate were those displayed in Table 4. Additional aggregate requirements were a maximum of 15% thin and elongated particles, *AASHTO T 96* LA Abrasion breakdown not exceeding 40%, and no more than 15% loss in 5 cycles of soundness test using magnesium sulfate.

Table 4. No 7 Aggregate Grading Requirements

Sieve Size	Percent Passing
19 mm (3/4 in)	100
12.7 mm (1/2 in)	90 to 100
9.5 mm (3/8 in)	40 to 85
No 4	0 to 15
No 8	0 to 5

The specifications for polymerized emulsified asphalts used for surface treatments at the time of the *US 84* test section included: 1) the polymer additive must be on *APL*; and 2) Styrene-Butadiene Rubber (SBR) must be at least 2.5% polymer solids by weight of asphalt cement. Tables 5 and 6 provide the polymerized emulsion requirements tested according to *AASHTO T59*. The required properties of CRS-2 in *AASHTO M 208-86* were in effect at the time of construction and are the same requirements as those in effect in current versions of the specification (e.g. *AASHTO M 208-01*).

Table 5. Tests on Polymer Emulsion in Effect at Time of *US 84* Construction

Test	Minimum	Maximum
Viscosity, Saybolt Furol at 122 F, seconds	200	500
Storage Stability, 24 hours, %	-	1
Classification Test	Pass	Pass
Particle Charge Test	Positive	Positive
Sieve Test, 20 mesh, %	-	0.1
Distillation: Oil Distillate by volume of emulsion, %	-	3
Distillation: Residue from distillation, %	65	-

Note the requirements in effect during the work of Kidd (1990) between 1982 to 1984 were the same except the viscosity range was 100 to 400 seconds.

Table 6. Tests on Polymer Residue in Effect at Time of *US 84* Construction

Test*	Minimum	Maximum
Penetration, 77 F, 100 g, 5 seconds	125	200
Ductility, 77 F, cm	125	-
Ductility, 39F, cm	30	-
Softening Point (R & B), F	100	125
Solubility in Trichloroethylene, %	97.5	-

** These properties remained in effect at least through the 1991 MDOT bid documents.*

2.3 As Built Properties

Table 7 contains the as constructed test section information. One lane was constructed at a time for a distance of approximately 1,600 m (1 mile), and then the other lane of the same section was constructed. Note that originally *Shell/Kraton* was Section 2 (See Table 3), but on site problems led to making this the CRS-2 control section. Also note the temperature range for emulsion transport was 65 to 71 C (150 to 160 F).

Table 7. As Constructed Layout and Products Tested

Log Miles[1]	Section	Manufacturer/Material	Polymer[4]
0 to 1	1	Ergon/Styrelf	SB
1 to 2	2	Ergon/CRS-2	None
2 to 3	3	Textile Rubber and Chemical/Ultrapave UP 65K	SBR-Latex
3 to 4	4	LBD Asphalt Products/Ductilad	Polystyrene
4 to 5	5	BASF/Butonal NS	SBR-Latex
5 to 6	6	DuPont/Neoprene	Neoprene Latex
6 to 7	7	Shell/Kraton[2]	SBS
7 to 8	8	Exxon/Polybilt[3]	EVA
8 to 9	9	Was not sealed	------

1: Begin at west end of project.
2: Truck passing lane present, and evaluation locations were outer main lane and the passing lane.
3: Truck passing lane present, but it was not sealed and both main lanes were evaluated.
4: See. 3.1 for more detailed information on the polymers used

Table 8 contains residual binder and aggregate application rates obtained from plate testing. The plates were 0.61 m (2 ft square), and were placed between the wheel path and lane center. The location of the plates can be seen relative to test locations in Section 4.2. Table 9 contains the overall emulsion application rates, shot lengths, and shot sequences.

Table 8. Application Rates From Plate Testing

Section-Product	Lane*	Plate	Residual Binder-L/m^2 (gal/yd^2)	Aggregate-kg/m^2 (lb/yd^2)
1-Styrelf	WB	1	0.91 (0.20)	8.88 (16.37)
1-Styrelf	EB	2	0.82 (0.18)	8.39 (15.47)
2-CRS-2	WB	3	1.05 (0.23)	8.42 (15.50)
2-CRS-2	EB	4	1.05 (0.23)	9.80 (18.07)
3-Ultrapave UP 65K	WB	5	0.91 (0.20)	8.88 (16.37)
3-Ultrapave UP 65K	EB	6	0.95 (0.21)	9.17 (16.91)
4-Ductilad	WB	7	---------**	9.59 (17.69)
4-Ductilad	EB	8	---------**	10.47 (19.30)
5-Butonal NS	WB	9	0.86 (0.19)	8.98 (16.56)
5-Butonal NS	EB	10	0.86 (0.19)	9.42 (17.37)
6-Neoprene	WB	11	0.68 (0.15)	8.18 (15.09)
6-Neoprene	EB	12	0.82 (0.18)	9.42 (17.37)
7-Kraton	Truck	13	0.55 (0.12)	8.48 (15.64)
7-Kraton	EB	14	0.91 (0.20)	8.44 (15.56)
8-Polybilt	WB	15	0.73 (0.16)	8.74 (16.11)
8-Polybilt	EB	16	0.86 (0.19)	8.16 (15.05)

** EB = Eastbound Lane and WB = Westbound Lane.*
*** Data was not obtained*

Table 9. Overall Test Section As Built Emulsion Properties

Section-Product	Shot	Lane*	Length m (ft)	Quantity L (gal)	Rate L/m^2 (gal/yd^2)
1-Styrelf	1	WB	950 (3,115)	4,730 (1,250)	1.36 (0.30)
	3	WB	740 (2,429)	3,220 (850)	1.18 (0.26)
	2	EB	950 (3,115)	4,730 (1,250)	1.36 (0.30)
	4	EB	740 (2,429)	3,220 (850)	1.18 (0.26)
2-CRS-2	1	WB	1,159 (3,802)	5,488 (1,450)	1.32 (0.29)
	3	WB	901 (2,957)	3,974 (1,050)	1.23 (0.27)
	2	EB	1,175 (3,854)	5,488 (1,450)	1.27 (0.28)
	4	EB	885 (2,904)	3,974 (1,050)	1.23 (0.27)
3-Ultrapave UP 65K	1	WB	837 (2,746)	4,542 (1,200)	1.50 (0.33)
	3	WB	1,046 (3,432)	5,110 (1,350)	1.36 (0.30)
	2	EB	837 (2,746)	4,542 (1,200)	1.50 (0.33)
	4	EB	1,127 (3,696)	5,110 (1,350)	1.23 (0.27)
4-Ductilad	1	WB	1,046 (3,432)	4,164 (1,100)	1.10 (0.24)
	3	WB	918 (3,010)	4,069 (1,075)	1.23 (0.27)
	2	EB	966 (3,168)	4,164 (1,100)	1.18 (0.26)
	4	EB	837 (2,746)	3,974 (1,050)	1.32 (0.29)
5-Butonal NS	1	WB	869 (2,851)	4,164 (1,100)	1.32 (0.29)
	3	WB	837 (2,746)	3,880 (1,025)	1.27 (0.28)
	2	EB	853 (2,798)	4,164 (1,100)	1.36 (0.30)
	4	EB	1,014 (3,326)	3,974 (1,050)	1.10 (0.24)
6-Neoprene	1	WB	885 (2,904)	3,596 (950)	1.14 (0.25)
	2	WB	773 (2,534)	3,596 (950)	1.27 (0.28)
	3	EB	757 (2,482)	3,596 (950)	1.32 (0.29)
	4	EB	580 (1,901)	2,460 (650)	1.18 (0.26)
7-Kraton	1	WB	918 (3,010)	3,974 (1,050)	1.18 (0.26)
	3**	WB	1,046 (3,432)	2,271 (600)	0.59 (0.13)
	3***	WB	451 (1,478)	1,893 (500)	1.14 (0.25)
	2	EB	1,030 (3,379)	5,015 (1,325)	1.32 (0.29)
	4	EB	628 (2,059)	3,028 (800)	1.32 (0.29)
8-Polybilt	1	WB	757 (2,482)	3,785 (1,000)	1.36 (0.30)
	2	WB	724 (2,376)	3,596 (950)	1.36 (0.30)
	3	EB	789 (2,587)	3,785 (1,000)	1.32 (0.29)
	4	EB	563 (1,848)	2,839 (750)	1.36 (0.30)

Note 1: Construction issues arose between Section 1 and Section 2. 3,400 L (900 gal) of Styrelf modified binder and 4,160 L (1,100 gal) of Kraton modified binder were applied and subsequently covered. These areas were not part of the test section.
** EB = Eastbound Lane and WB = Westbound Lane.*
*** Truck Lane*
**** Inside Lane*

The aggregates used were Size No 7 slag. Aggregates were tested for moisture content during construction, and the results can be seen in Table 10. Soundness testing performed using five cycles of $MgSO_3$ resulted in a weighted average corrected loss of 2.43%. Two sample fractions (+ 9.5 mm (3/8 in) and + No 4) were tested representing 61.3 and 27.6% of the gradation, respectively. The actual losses of these fractions were 3.33 and 1.40%, respectively.

Table 10. Moisture Content of Cover Aggregate

Log Miles[1]	Section	Manufacturer/Material	Moisture (%)
0 to 1	1	Ergon/Styrelf	5.2
1 to 2	2	Ergon/CRS-2	5.6
2 to 3	3	Textile Rubber and Chemical/Ultrapave UP 65K	4.9
3 to 4	4	LBD Asphalt Products/Ductilad	5.3
4 to 5	5	BASF/Butonal NS	4.8
5 to 6	6	DuPont/Neoprene	4.2
6 to 7	7	Shell/Kraton	---
7 to 8	8	Exxon/Polybilt	4.2
8 to 9	9	Was not sealed	---

1: Begin at west end of project.

CHAPTER 3 – LABORATORY TEST RESULTS

3.1 Fundamental Material Properties

Since construction of the *Hwy 84* test section in 1989, some material related parameters have changed but many have been essentially unaffected. The most substantial change would likely be the source of the crude oil. As a result, there is applicability of some of the materials and their fundamental properties to current practice in polymer modified sealing activities.

The base asphalt from Ergon appeared, at least in most cases, to be 150 Pen material. All material manufactured by Ergon used identical base asphalt and emulsifier. The target polymer content of all modified binders in the field was 3% solids expressed in terms of residue weight. The only additional information was obtained from a memo where the *Neoprene* used by *DuPont* in the field was said to actually contain 2.7% polymer by residue weight. A torsional recovery test resulted in 22% at 2.5% *Neoprene*.

Table 11 contains specific information about each polymer used in the test section. Of the polymers shown in Table 11: 1) *SBR* and *SB* appear to be the most widely used in the current emulsion market; 2) Polystyrene and the latex used in the *Neoprene* section are no longer commercially available; and 3) *EVA* is available but rarely used. One driving force behind the widespread use of *SBR* is the ease and flexibility it provides in terms of introduction into the asphalt.

Table 11. Polymer Descriptions of As Constructed Test Section

Section	Product	Polymer	Polymer Description
1	Styrelf	SB	Styrene-Butadiene Block Co-Polymer (Solid)
2	CRS-2	None	No Polymer
3	Ultrapave UP 65K	SBR-Latex	Styrene-Butadiene Rubber (Liquid)
4	Ductilad	Polystyrene	Polystyrene (Solid)
5	Butonal NS	SBR-Latex	Styrene-Butadiene Rubber (Liquid)
6	Neoprene	Neoprene Latex	Neoprene (Liquid)
7	Kraton	SBS	Styrene-Butadiene-Styrene Block Co-Polymer (Solid)
8	Polybilt*	EVA	Ethylene-Vinyl Acetate (Solid)
9	Was not sealed	------	-----

* Polybilt® 103/XCS-551 was proposed and the polymer was blended into molten asphalt prior to emulsification

Table 12 contains results of material property testing of all the materials performed by Ergon on plant samples prior to construction. This data is as manufactured. Table 13 contains results obtained by *MDOT* on field samples. Note that drastic differences exist in some cases. The Table 12 results are believed to be more reliable than Table 13. The rational being that in 1989 emulsion handling procedures for laboratory testing were not highly advanced. Current methods of handling emulsions from field sites are much more consistent, but would not have been employed on these samples.

The data that could be obtained from Ergon records align more reasonably (especially in terms of viscosity) to the specifications. The lower viscosity limit was violated by some of the products, but this limit was lower in previous years and most of the materials would have met the previous limit. See Tables 5 and 6 for further information.

Table 12. Results of Material Property Testing Performed by Ergon

Property[1]	Styrelf	CRS-2	Ultrapave	Ductilad	Butonal	Neoprene	Kraton[2]	Polybilt
Boil Off (%)	69.2	68.6	69.5	68.2	68.8	66.9	64.8/73.8/74.2	68.9
Viscosity (s)	346	348	340	140	164	124	18/81/87	99
Sieve (%)	0.01	0.01	0.01	0.01	0.01	0.01	0.08/0.04/0.02	0.03
Demul	31.3	98	54	100	64	99	80.5/100/100	70
pH	6.8	8.4	7.7	6.2	7.4	7.6	6.5/8.6/9.8	7.0
Soft Pt (F)	105	109	107	111	109	110	117/106/115	122
Pen 77 F	195	151	175	151	150	164	101/112/107	124
Pen 40 F	27	17	18	15	15	13	12/12/13	13
Made[3]	M	V	V	S	V	V	M/M/M	M

1: Properties tested as manufactured.
2: Three Kraton tests were performed. All are shown in order; 1, 2, then 3.
3: M = Mooreville, S = Southland, and V = Vicksburg.

Table 13. Results of Material Property Testing Performed by *MDOT*

	Product	Styrelf	CRS-2	Ultrapave	Ductilad	Butonal	Neoprene	Kraton	Polybilt
	Section	**1**	**2**	**3**	**4**	**5**	**6**	**7[6]**	**8**
	Date (1989)[1]	**9/11**	**9/12**	**9/11**	**9/12**	**9/13**	**9/13**	**9/14-9/18**	**9/14**
	Location	**Field**	**Field**	**Field**	**Field**	**Field**	**Field**	**Field**	**Field**
	Property[2]	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**
Emulsion	Viscosity, 122F	398	504	20	329	134	776	91/68	113
	Stability	0.4	0.4	0.4	0.2	0.2	1	0.2/0.1	0
	Classification	---	---	---	---	---	---	---	---
	Charge	+	+	+	+	+	+	+/+	+
	Sieve, No 20	0.08	0.01	0.02	0.01	0.01	---[7]	0.02/0.02	0.03
	Oil Distillate	1	1	1	0	1	2	1/0	1
	Residue[4]	69	69	64	70	69	68	74/75	67
Residue	Pen, 77F	147	116	76	118	129	132	92/83	143
	Ductility, 77F[3]	>125	>125	>150	>150	>150	110	>150/>150	28[5]
	Ductility, 39F	---	---	---	---	---	---	---	---
	Softening	---	---	---	---	---	---	---	---
	Solubility	99.9	99.9	99.8	99.9	99.9	99.9	99.9/99.6	Insoluble

1: Date of construction. Test results were reported on Sept 26, 1989.
2: Property names abbreviated but reported in the order of Tables E.5 and E.6.
3: Most samples said to remain large at end of test indicating they had additional ductility.
4: Evaporation method.
5: Residue contained large piece of asphalt material.
6: Test conducted on two samples. Results for both have been shown.
7: Material too viscous to conduct test at room temperature.

3.2 Frosted Marble Test

The ideal behavior of a chip seal emulsion is to achieve a reasonably high adhesion value, quickly followed by a leveling off with additional curing. This indicates high early aggregate retention strength followed by a ductile early service period. If the binder stiffens excessively cracking and aggregate loss are likely problems. A unique test method (frosted marble) was used during the project to evaluate chip seal binder curing. *C. Robert Benedict Consulting* of Dayton, Ohio was involved with the original testing. See Figure 2a for drawings of the entire equipment set up.

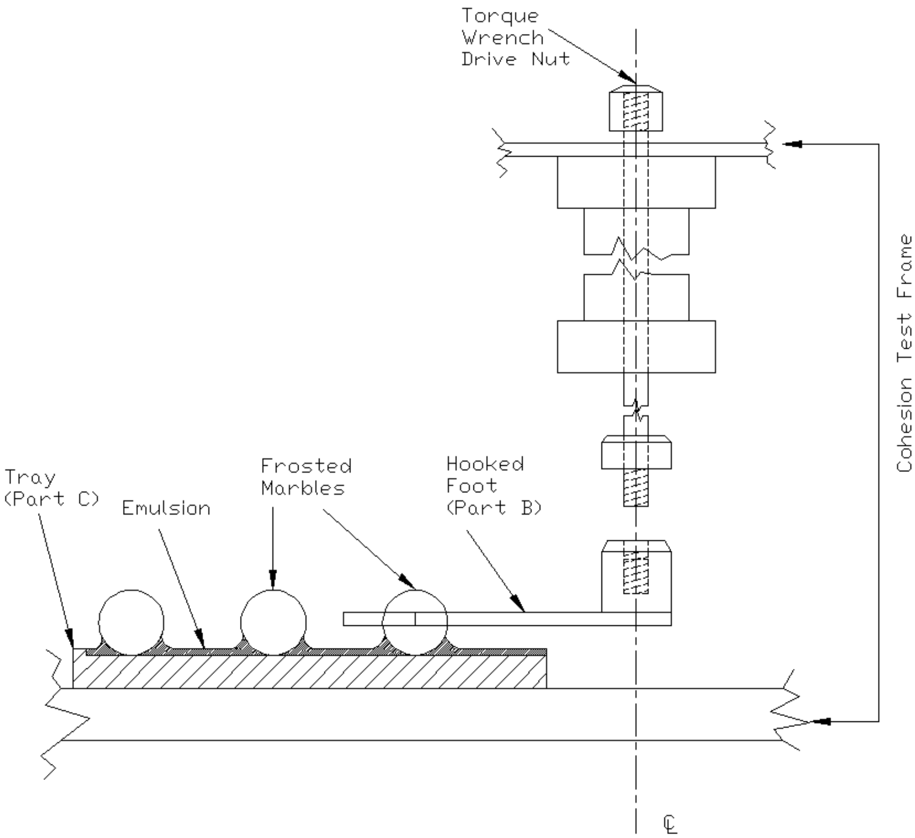
An *ISSA Technical Bulletin No. 139* modified cohesion tester was the primary piece of equipment used for the test. The standard cohesion tester foot was replaced with a 50 mm (2 in) hooked foot (Figure 2b). The hooked foot was rotated horizontally with a torque wrench to dislodge a 14.3 mm (9/16 in) acid etched (i.e., frosted) glass bead (i.e., marble) from asphalt emulsion contained in a flat steel trough (Figure 2c). The emulsion depth is 1.6 mm (1/16 in) and corresponds to an application rate of 1.5 L/m^2 (0.33 gal/yd^2). The average torque required to dislodge 5 frosted marbles was recorded as the chip retention strength.

The test was conducted within a trough plate containing 3 rows that each held 5 frosted marbles. At the time of testing, the standard approach was to average the five results per row and report as one test. The testing was ran in triplicate; the equivalent of one trough plate was required for triplicate tests. The test was performed at three curing conditions and the results can be seen in Table 14. Note all tests were conducted at room temperature. An air pressure of up to 200 kPa (29 psi) was used during the testing described in Table 14. Air pressure is not directly a part of the test and can slightly affect results (estimate of at most $\pm$ 1 kg-cm (0.87 in-lb)). The air pressure is used to raise and lower the foot, as well as keep it in position during testing.

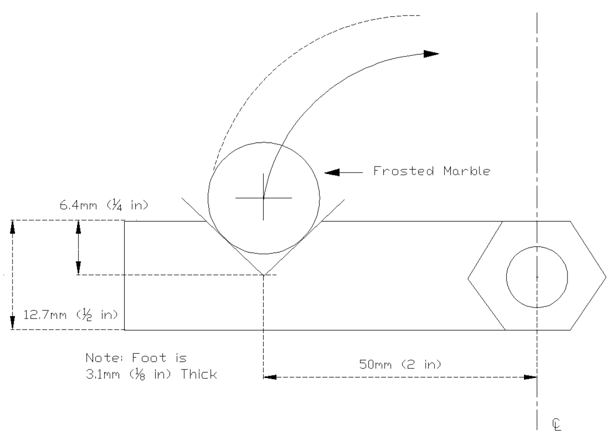
Initial tests were 3 rows of 5 marbles in 1 trough with each row tested after a prescribed amount of curing. It is important to note that to conduct the test in the manner described the troughs must be separate to avoid flowing of binder into troughs after they have been tested and their marbles removed. This is undesirable since it reduces the immersion depth of troughs yet to be tested. Informal documents at the time indicated positive feelings about the potential of the frosted marble test. It was reported that results correlated reasonably well with field tests. The test procedure is summarized in the following steps.

Frosted Marble Test Procedure:

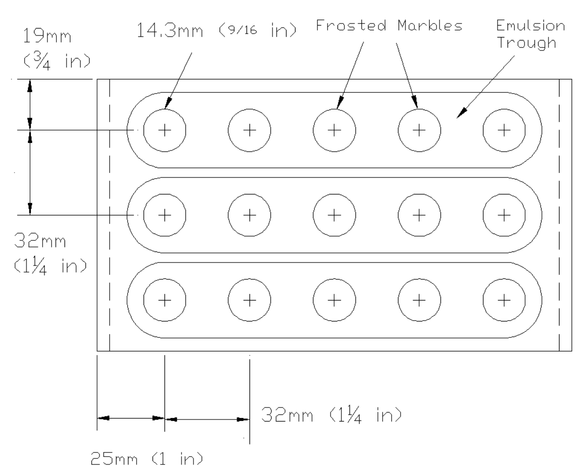
1. Replace the 28.6 mm (1.13 in) diameter cohesion tester foot with the 50 mm (2 in) hooked foot and adjust to contact the frosted marbles slightly below the center of the marble. Lock in place with the jamb nut.
2. Adjust air pressure to 70 kPa (10 psi) to minimize friction. The equipment can be operated without the air pressure, but convenience is lost as a result.
3. Add 9.0 $\pm$ 0.2 g of chip seal emulsion to each of the three, 1.6 mm (1/16 in) deep troughs of the plate. Place on a level surface and allow the emulsion to seek a level position. When the emulsion is level, place the acrylic template directly over the trough plate and add 15 frosted marbles (5 per trough). The template may be removed in a few minutes or when the initial set occurs; it is merely for alignment.
4. Cure specimens. The following protocol was used for Table 14 data: A) 15 hours at ambient conditions; B) 4 hours at 60 C (140 F) in a forced draft oven followed by two hours cooling (tested 6 hours from when emulsion placed onto trays); and C) 15 hours at 60 C (140 F) in a forced draft oven followed by two hours cooling.
5. After each specified curing period, the trough plate was positioned on the cohesion tester base with the hooked foot for 2-point static contact. The trough plate was held firmly in place while the torque wrench was applied to the upper rod end and twisted with a firm but smooth horizontal motion through a 30 to 45 degree arc in about half of a second. The torque required to dislodge the marble was read by the follow up pointer and recorded. The average torque values of five successive tests in each trough for the curing period stated was recorded as the chip retention strength. All 3 rows per trough were tested in one interval. Each row contained a different emulsion.
6. After the test, the residual bitumen in the trough may be removed and tested for moisture or solvent content.



(a) Overall View of Test Frame, Hooked Foot, and Frosted Marble Tray



(b) Hooked Foot



(c) Frosted Marble Tray

Figure 2. Frosted Marble Test Components

Table 14. Frosted Marble Test Results

kg-cm (in-lb)		Curing Condition		
Emulsion	**Test**	**15 h Air**	**4 h oven + 2 hr air**	**15 h oven + 2 hr air**
Control	1	12.4 (10.8)	17.6 (15.3)	32.9 (28.6)
CRS-2	2	16.8 (14.6)	18.2 (15.8)	35.2 (30.6)
	3	10.5 (9.1)	21.2 (18.4)	34.3 (29.8)
	Avg	***13.2 (11.5)***	***19.0 (16.5)***	***34.1 (29.6)***
Ergon	1	10.5 (9.1)	22.8 (19.8)	36.0 (31.2)
Styrelf	2	11.9 (10.3)	23.1 (20.1)	36.0 (31.2)
	3	15.8 (13.7)	21.1 (18.3)	37.0 (32.1)
	Avg	***12.7 (11.0)***	***22.3 (19.4)***	***36.3 (31.5)***
TRC	1	15.9 (13.8)	23.8 (20.7)	38.0 (33.0)
Ultrapave	2	13.9 (12.1)	21.9 (19.0)	36.0 (31.2)
UP65K	3	19.9 (17.3)	21.9 (19.0)	34.3 (29.8)
	Avg	***16.6 (14.4)***	***22.5 (19.5)***	***36.1 (31.3)***
BASF	1	18.5 (16.1)	22.7 (19.7)	28.2 (24.5)
Butonal NS	2	15.2 (13.2)	22.2 (19.3)	35.2 (30.6)
	3	17.8 (15.5)	22.9 (19.9)	37.0 (32.1)
	Avg	***17.2 (14.9)***	***22.6 (19.6)***	***36.0 (31.2)***
LBD*	1	14.1 (12.2)	14.0 (12.2)	16.0 (13.9)
Ductilad	2	12.0 (10.4)	12.4 (10.8)	17.7 (15.4)
	3	10.0 (8.7)	14.1 (12.2)	17.8 (15.5)
	Avg	***12.0 (10.4)***	***13.5 (11.7)***	***17.2 (14.9)***
Exxon**	1	26.8 (23.3)	24.2 (21.0)	41.1 (35.7)
Polybilt	2	27.8 (24.1)	26.3 (22.8)	37.6 (32.6)
	3	37.7 (32.7)	26.0 (22.6)	39.3 (34.1)
	Avg	***28.9 (25.1)***	***25.5 (22.1)***	***39.3 (34.1)***
DuPont***	1	19.0 (16.5)	24.9 (21.6)	27.1 (23.5)
Neoprene	2	18.0 (15.6)	24.2 (21.0)	29.0 (25.2)
	3	23.2 (20.1)	23.9 (20.7)	29.8 (25.9)
	Avg	***20.1 (17.4)***	***24.3 (21.1)***	***28.6 (24.8)***
Shell****	1	19.0 (16.5)	24.6 (21.4)	38.2 (33.2)
Kraton 2	2	20.0 (17.4)	25.0 (21.7)	36.5 (31.7)
	3	19.9 (17.3)	25.1 (21.8)	39.2 (34.0)
	Avg	***19.6 (17.0)***	***24.9 (21.6)***	***38.0 (33.0)***
Shell	1	22.5 (19.5)	31.1 (27.0)	31.0 (26.9)
Kraton 1	2	21.2 (18.4)	21.2 (18.4)	33.0 (28.6)
	3	25.0 (21.7)	31.8 (27.6)	32.9 (28.6)
	Avg	***22.9 (19.9)***	***28.0 (24.3)***	***32.3 (28.0)***
Shell	1	34.0 (29.5)	29.2 (25.3)	30.5 (26.5)
Kraton 3	2	32.8 (28.5)	30.0 (26.0)	35.2 (30.6)
	3	32.1 (27.9)	30.2 (26.2)	39.2 (34.0)
	Avg	***33.0 (28.6)***	***29.8 (25.9)***	***35.0 (30.4)***

** Ductilad was reported to be greasy and soft.*
*** Polybilt was very tough and had a short strength.*
**** Neoprene had no cold or hot flow.*
***** Kraton 2 had a very long strength.*

Frosted marble test results were also obtained from three *Long Term Pavement Performance (LTPP) Specific Pavement Studies (SPS)* within Class 3 (*SPS-3*: Preventative Maintenance Effects of Flexible Pavements). Three locations within three regions were tested that all utilized CRS-2 emulsion. While this data is not from *US 84,* it has applicability to the work and has been presented. The testing of these materials was performed in the same time frame and in the same conditions as the materials from *US 84*. The results of testing can be seen in Table 15.

Table 15. Frosted Marble Results of CRS-2 From *SPS-3* Sites Across US

kg-cm (in-lb)	**Curing Condition**		
Location	**15 h Air**	**4 h oven + 2 hr air**	**15 h oven + 2 hr air**
Midwest	10.5 (9.14)	17.0 (14.79)	21.5 (18.71)
Northeast	16.0 (13.92)	19.0 (16.53)	21.0 (18.27)
South	17.5 (15.23)	21.0 (18.27)	31.5 (27.41)

Original moisture contents of all materials were about 33%. After the 15 hour air drying period, the moisture contents of the *Midwest*, *Northeast*, and *South* samples were 4.3, 3.8, and 6.0%, respectively. Moisture contents were believed to have dropped to 1 to 2% after the 4 hour oven curing at 60 C (140 F), and to near zero after the 15 hr oven curing period.

3.3 Tensile Stress Test

Tensile behaviors of the emulsions were evaluated using *ASTM D 412-87*. For these materials, 800 % elongation was the threshold; i.e. the material should be able to elongate 8 times its original length prior to failure. The emulsion is poured into a rubber tray that molds individual specimens. The emulsions are cured in the tray and then removed so their width and thickness can be measured. There are 8 to 10 specimens created in this manner, but not all of them are tested. The procedure used to evaluate which are tested is described in the following paragraph.

The width (three measurements taken) must be 4 mm (0.157 in), otherwise the specimen is discarded. To facilitate consistency, only the specimens with cured thicknesses (three measurements taken) very close to one another are tested. The thicknesses of the specimens tested can be seen in Table 16, alongside the number of specimens of each emulsion type that were suitable to be tested.

The specimen is placed in a tensile frame with suitable grips. The rate of pull is 27 mm/min (1.06 in/min). The % elongation is recorded periodically and at failure. A specimen not achieving 800 % elongation is considered a failure. The tensile strength must be 1 kg/cm^2 (14.2 psi) or greater at an acceptable elongation. The results for all polymer modified emulsions can be seen in Table 16.

Table 16. Tensile Stress Test Results

Emulsion	**Thickness - mm(in)**	**Tensile Strength - kg/cm^2 (lb/in^2)**	***Rating***
BASF	2.85 (0.112)	0.68 (9.68)	*0.88*
Butonal NS	2.79 (0.110)	1.05 (14.94)	*Fail*
	2.87 (0.113)	0.91 (12.95)	
Exxon[1]	2.97 (0.117)	-------------	*0.00*
Polybilt	2.90 (0.114)		*Fail*
	3.00 (0.118)		
LBD[1]	2.92 (0.115)	-------------	*0.00*
Ductilad	2.95 (0.116)		*Fail*
TRC	3.05 (0.120)	0.75 (10.67)	*1.12*
Ultrapave	3.02 (0.119)	1.13 (16.10)	*Pass*
UP 65K	3.00 (0.118)	1.10 (15.65)	
	3.05 (0.120)	1.49 (21.20)	
Ergon	2.87 (0.113)	1.27 (18.10)	*1.52*
Styrelf	2.92 (0.115)	1.67 (23.76)	*Pass*
	2.82 (0.111)	1.61 (22.91)	
Du Pont[1]	2.82 (0.111)	-------------	*0.00*
Neoprene	2.74 (0.108)		*Fail*
Shell	3.00 (0.118)	2.70 (38.42)	*2.91*
Kraton 1	2.82 (0.111)	3.03 (43.12)	*Pass*
	2.82 (0.111)	2.99 (42.55)	
Shell	2.85 (0.112)	2.39 (34.01)	*2.36*
Kraton 2	2.85 (0.112)	2.32 (33.01)	*Pass*
Shell	2.97 (0.117)	*2.41 (34.29)*	*2.40*
Kraton 3	2.90 (0.114)	*2.08 (29.60)*	*Pass*
	2.92 (0.115)	*2.73 (38.85)*	

1: Specimens failed below 800% elongation.

CHAPTER 4 – FIELD TEST RESULTS

4.1 Skid Testing

Skid measurements were taken on either side of the aggregate retention test sites and are shown in Table 17. It should be noted that the primary transducer malfunctioned and a spare one was used. Only a small variance was observed at the calibration site used by *MDOT*, however the device could not be certified as calibrated during the testing.

Table 17 - Skid Test Results of *US 84*

Date	**October 10, 1989**			**August 30, 1990**			**November 13, 1991**		
Weather	**Clear**			**Partly Cloudy**			**Partly Cloudy**		
Temp	**24 C (75 F)**			**36 C (97 F)**			**18 C (64 F)**		
Sections	***1***	***2***	***Avg***	***1***	***2***	***Avg***	***1***	***2***	***Avg***
1-Styrelf	47	41	44.0	42	43	42.5	42	45	43.5
2-CRS-2	46	47	46.5	42	40	41.0	44	45	44.5
3-Ultrapave UP 65K	46	48	47.0	45	42	43.5	48	44	46.0
4-Ductilad	47	46	46.5	36*	41	41.0	45	45	45.0
5-Butonal NS	46	49	47.5	49	43	46.0	47	47	47.0
6-Neoprene	48	45	46.5	45	42	43.5	50	47	48.5
7-Kraton	47	46	46.5	40	42	41.0	48	50	49.0
8-Polybilt	46	49	47.5	45	45	45.0	48	47	47.5

** Asphaltic type material in the wheel path.*

Discussion of the friction results occurred in December of 1991 between *MDOT* and Shell regarding the *Kraton* results. In the discussion, *Kraton* friction numbers were said to be exceptionally high, but that they did not explain obvious roadway problems. Inspection results were upheld in spite of the skid numbers by the State Testing Engineer. Section 7 (*Kraton*) skid numbers were the highest, but the material was rated last (8^{th}) by the review team (See 4.2 for details). *Styrelf* was rated with the lowest skid numbers in two of the three test intervals, but was rated the best or next to best section by the reviewers.

4.2 Pavement Inspections

A standard template was used for the pavement evaluations. The information contained within the template can be summarized as follows. Overall condition was rated from 0 to 10 with: 0 to 3 being ***poor***; 3 to 7 being ***fair***; and 7 to 10 being ***good***. Aggregate retention and bleeding could be separately evaluated at four locations: 1) outer wheel path, 2) inner wheel path, 3) between wheel path, and 4) centerline. Other information that could be recorded on the template was aggregate embedment, surface texture, and skid number. Table 18 summarizes the bleeding and aggregate retention scales. Note that aggregate retention and bleeding were evaluated separately and were shown in the same table for convenience only.

Table 18. Aggregate Retention and Bleeding Evaluation Scales

Rating	Percent Aggregate Loss	Bleeding
10	0	Slight
9	2	Slight
8	5	Slight
7	10	Moderate
6	15	Moderate
5	25	Moderate
4	38	Moderate
3	50	Severe
2	67	Severe
1	84	Severe
0	100	Severe

The data and drawings obtained indicate that aggregate retention data was only taken in the outer wheel path and lane center. No information on specific locations of bleeding assessment were obtained, but it would be logical to assume they were the same locations as the aggregate retention. The evaluation locations were always at the same distance into the test section in both lanes. The schematic of evaluation locations seen in Figure 3 was extracted from blueprints drawn during construction. Two lanes were evaluated for each section in the center of the lane and the outer wheel path. Figure 3 is the layout that would be present in each lane.

To determine aggregate retention a clear Plexiglas template with dimensions of 0.3 m (1 ft) square was used. The template was divided into 144 equal squares and the locations of aggregate loss marked. The results of all locations (6 per lane) were averaged and reported as the aggregate retention.

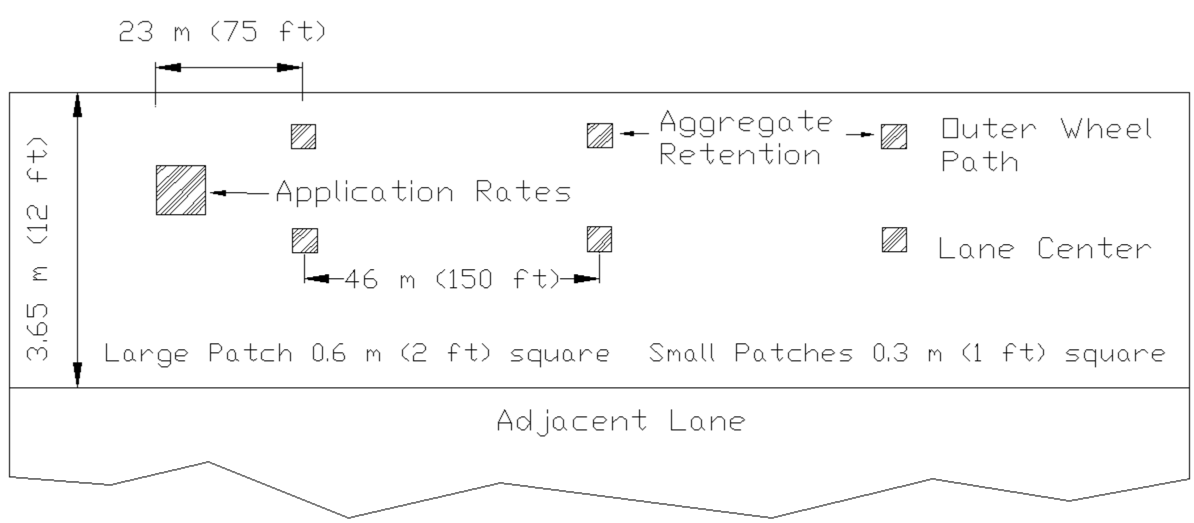


Figure 3. Evaluation Layout of Test Sections

Table 19 provides the overall rankings compiled during the two years of field evaluation. Table 20 uses the Table 19 data to rank the sections in order of best performance

(1) to worst performance (8). Criteria were established and an acceptable product: 1) was required to have a minimum initial overall rating (panel average) of 9.0; 2) was to have a minimum overall rating (panel average) of 8.5 at one year of age; 3) a maximum rating loss (panel average) of 0.8 from initial rating to one year rating; and 4) a maximum drop in skid number of 5 from the initial readings and those taken approximately one year later.

Table 19. Average Ratings of Test Sections in Terms of Overall Condition

		Section**							
Date	**Raters***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
9/29/89	5	9.5	8.3	9.4	7.9	9.4	9.3	9.0	9.1
3/01/90	5	9.1	8.0	9.2	7.9	8.0	6.3	8.8	8.9
8/24/90	5	8.9	8.1	8.7	7.8	8.1	8.6	6.3	8.3
3/27/91	5	9.1	7.9	8.5	7.3	7.2	8.8	6.5	8.0
9/12/91	5	8.6	8.2	8.3	7.1	8.1	8.9	6.0	8.5
9/12/91	8	8.6	8.3	8.0	7.2	7.8	8.5	5.8	8.1

**Number of individuals rating test sections. Five individuals rated in all three intervals.*
*** See Table 7 for description of test section numbers.*

Table 20. Overall Ranking of Sections Based on Original Five Raters

	Section**							
Date	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
9/29/89	1	7	2	8	3	4	6	5
3/01/90	2	5	1	7	6	8	4	3
8/24/90	1	5	2	7	6	3	8	4
3/27/91	1	5	3	6	7	2	8	4
9/12/91	2	5	4	7	6	1	8	3

Note: The sections were ranked from 1 to 8 with 1 being the best.
*** See Table 7 for description of test section numbers.*

Not all raw evaluation data was recovered. However, all overall ratings were recovered, which take the raw data into consideration. The exact details of the methods in which the raw data were used by an individual to compile their overall ranking, though, were not obtained. All raw data available can be seen in Tables 21 and 22. The data in Table 21 is partial sets of individual rater data (used to generate Table 19), and the data in Table 22 is partial aggregate retention and bleeding data used to generate Table 21.

Table 21. Individual Rating Data

Rater*	Section** 1	2	3	4	5	6	7	8
1	9.0/9.0	8.3/8.8	8.8/8.8	7.0/7.0	8.0/8.5	9.0/9.0	6.0/6.0	8.0/8.5
2	9.5/8.0	7.2/7.0	9.0/8.0	6.2/6.0	7.0/8.0	9.0/9.5	5.0/5.0	7.0/8.0
3	8.0/8.0	7.0/7.0	8.0/8.0	8.0/6.0	7.0/7.0	8.0/8.0	5.0/6.0	8.0/8.0
4	10.0/9.0	9.0/9.0	9.0/8.8	8.0/8.5	7.0/8.5	9.0/9.0	8.0/7.0	8.0/9.0
5	9.2/9.0	8.0/9.0	7.5/8.0	7.5/8.0	7.0/8.5	9.0/8.8	8.5/6.0	9.0/8.8
6	9.8/9.6	8.5/9.1	7.0/8.5	7.0/8.4	9.0/8.5	9.0/7.8	6.0/6.6	7.5/7.1
7	5.0/6.5	8.0/7.5	6.0/6.0	5.0/6.5	5.0/6.0	9.0/7.0	5.0/6.0	7.0/7.0
8	-/9.5	-/9.0	-/7.5	-/7.0	-/7.0	-/9.0	-/4.0	-/8.0

Note: The values are shown (3-27-91)/ (9-1-91)
**Raters 1 through 5 are the original raters used throughout testing.*
*** See Table 7 for description of test section numbers.*

Table 22. Aggregate Retention and Bleeding Data

	Aggregate Retention			Bleeding		
Section*	9/29/89	3/01/90	8/24/90	9/29/89	3/01/90	8/24/90
1	9.8	9.0	8.9	9.7	9.8	9.3
2	8.8	7.7	8.3	10.0	9.7	8.8
3	9.8	9.2	8.6	9.8	9.8	9.3
4	8.8	7.7	7.8	9.8	9.7	8.8
5	9.4	8.2	8.1	9.6	9.9	9.1
6	9.4	6.6	8.6	9.7	9.8	9.5
7	8.9	8.8	7.9	8.8	9.4	7.3
8	9.1	8.8	8.4	9.8	9.9	8.9

** See Table 7 for description of test section numbers.*

CHAPTER 5 – SUMMARY AND CONCLUSIONS

5.1 Approved Products

In October of 1990, the *Product Evaluation Committee* recommended the following products for approval: *Styrelf, Ultrapave UP 65K, and Neoprene*. The decision regarding *Butonal NS* (Test Section 5) was questioned, but the test section was rated the same as the *CRS-2*. The manufacturer (BASF) claimed the product was functionally identical to *Ultrapave UP 65K*.

An internal memo on April 6, 1992 sent to the State Aid Division discussed the adoption of the approved products list. As discussed in the memo, *Ductilad* was removed from the original *APL*. The proposed State Aid Division Supplemental Specifications (901-S-702-2) was stated to be similar to *MDOT* Maintenance Contract Specifications prior to the *US 84* test sections, and that *Ductilad* was capable of meeting these specifications even though its field performance was poor. *MDOT* recommended State Aid to adopt the most current version of the specification if they wanted to base their approach after the *US 84* test sections.

As of February 1991, the approved products consisted of those seen in Table 23. This list was part of the proposal for *Furnishing Certified Bitumens*. It should be noted that evidence of satisfactory performance of other products was provided by the material suppliers. For example, *Polybilt* was said to have been placed in several other states offering early brooming capability, improved chip retention, and flushing resistance. California, Pennsylvania, and Virginia all have field projects. *Polybilt*, though, was not approved by the *US 84* testing program.

Table 23. *MDOT* Approved Products as of February 1991

Name of Product	Name of Company	Test Section[1]
Styrelf	Elf Asphalt, St Louis, MO	1
Ultrapave UP 65k	Textile Rubber & Chemical Co, Dalton, GA	3
Neoprene	Dupont Polymer Products, Nashville, TN	6

Note: Unsatisfactory performance warranted removal from the list.
1: See Table 7 for description of test section numbers.

Recent information obtained from *MDOT* engineers indicated that *MDOT* never established an official category for the aforementioned approved polymers, and currently there is no approved list of these types of products. *MDOT* currently approves producers and/or production facilities of asphalt emulsions. Materials related parameters are addressed in section 702 of *MDOT's* standard specifications (MDOT 2004), while other surface treatment information is contained in section 410.

CHAPTER 6 - REFERENCES

Kidd, S.Q. (1990). *Polymerized Asphalt Emulsion.* Mississippi State Highway Department Report No MSHD-RD-90-67-12, pp. 32.

MDOT. (2004). *Mississippi Standard Specifications for Road and Bridge Construction.* Mississippi Department of Transportation, Jackson, MS.