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16. ABSTRACT

Caltrans performed a study of sulfur extended asphalt (SEA) blends by constructing cold climate (Benton T.S. - Road 09-Mno-6 -24.54/25.50) and warm climate (Baker T.S. - 08-SBd-15-107.75/110.0) test sections using SEA 20 and 40 weight percent blends which were compared to AR-2000 (blending asphalt) and AR-4000 conventional asphalt binders. Previous reports revealed no significant problems regarding design, mixing, construction, and environmental controls. Long-range findings reveal that the SEA blends appear to age harden more slowly than the control AR-2000 but they appear to have poorer ductile properties. Crack and condition evaluations reveal a greater susceptibility to transverse cracking by the SEA blends, especially the SEA 40% in colder climates. The SEA blends appear to exhibit slightly better resistance to alligator cracking. It appears that SEA blends will provide equal or better performance to conventional asphalts. Thus, they are only cost effective where the cost of sulfur is less than 50 percent of the cost of asphalt.

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DEPARTMENT OF TRANSPORTATION
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OFFICE OF TRANSPORTATION LABORATORY

AN EVALUATION OF SULFUR EXTENDED ASPHALT (SEA) PAVEMENTS IN COLD AND HOT CLIMATES

FINAL REPORT

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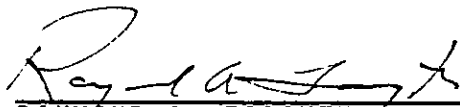

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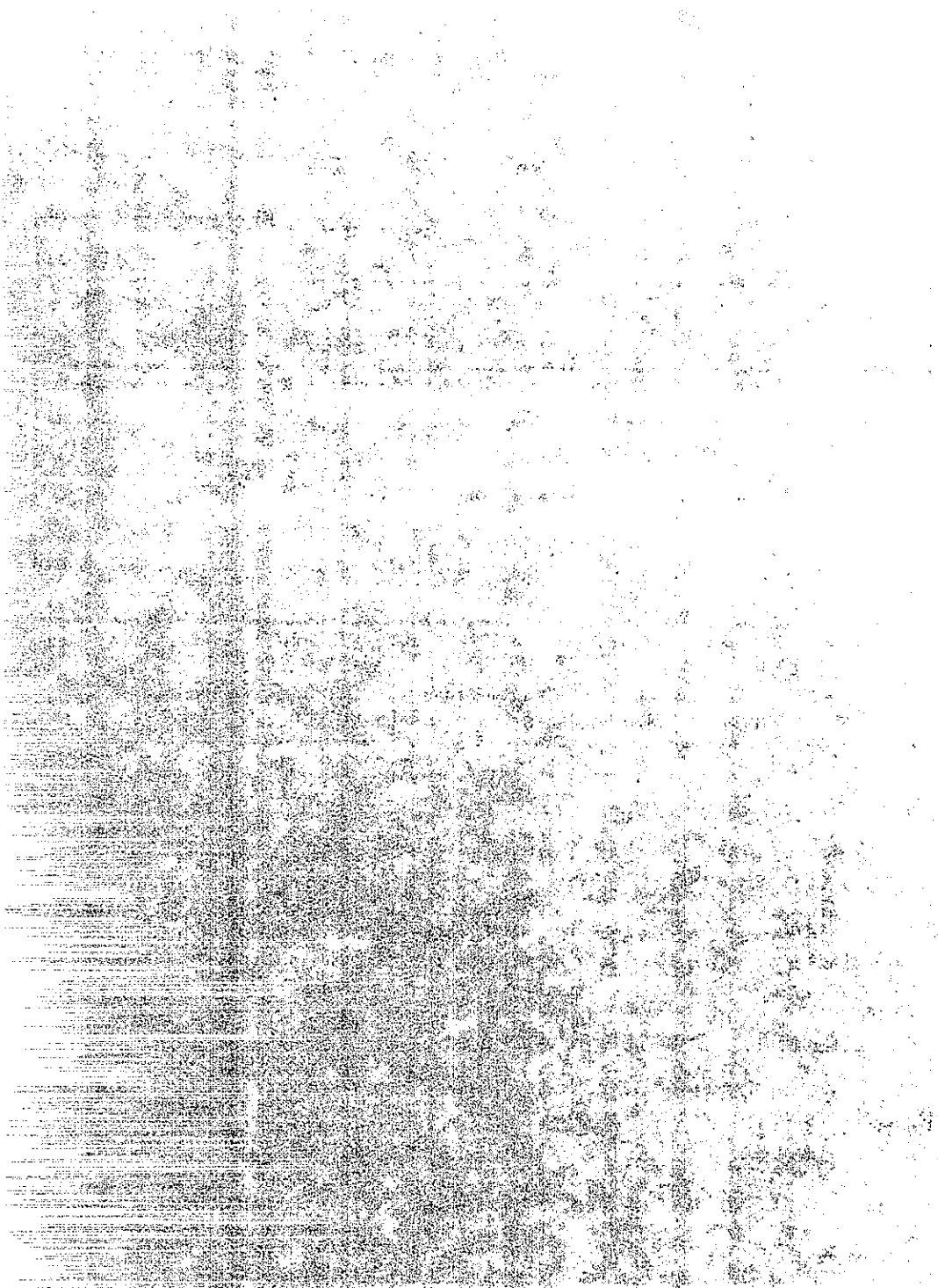

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs)	4.448	newtons (N)
	(1000 lbs) kips	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lbs)	.1130	newton-metres (Nm)
	foot-pounds (ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

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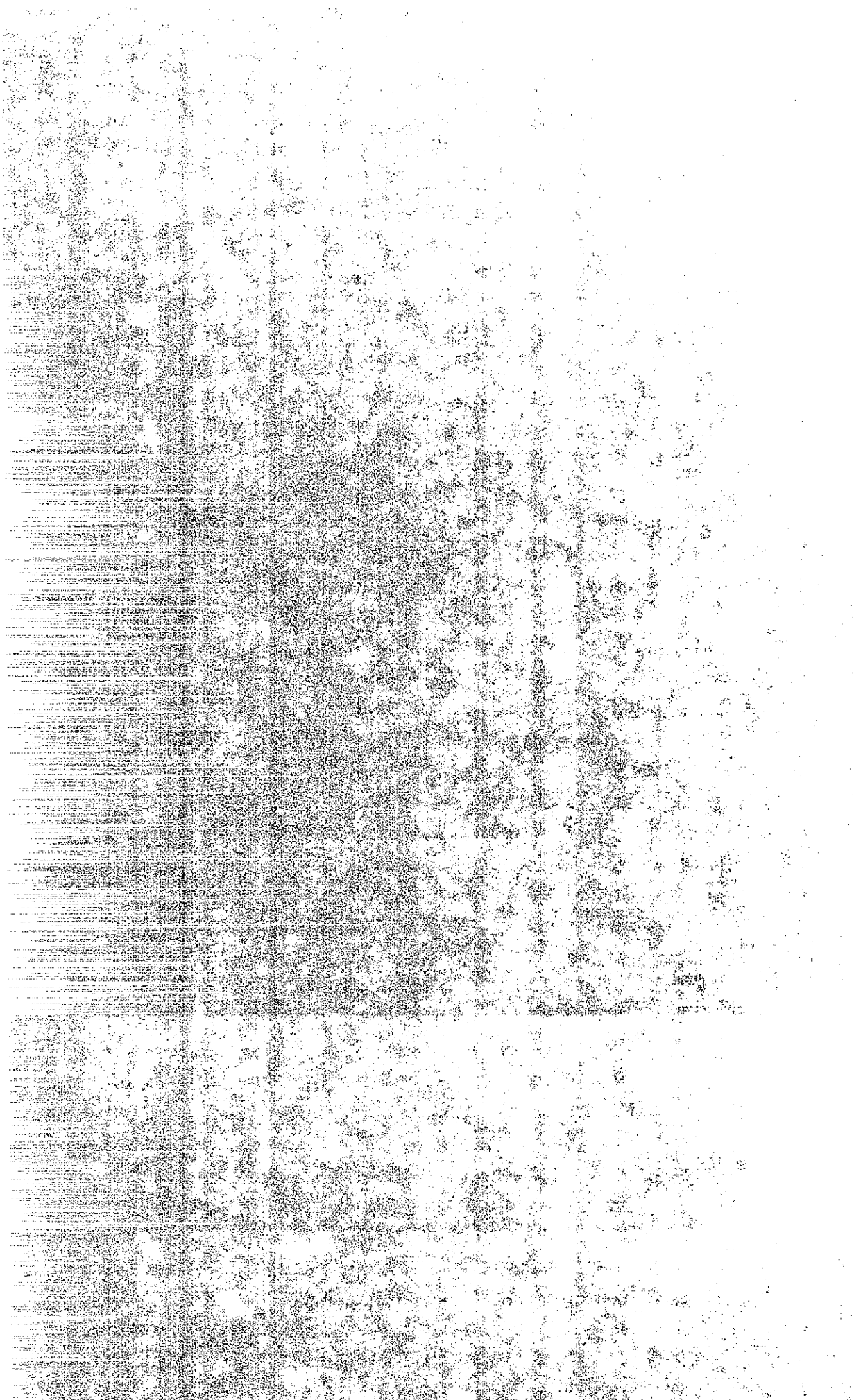

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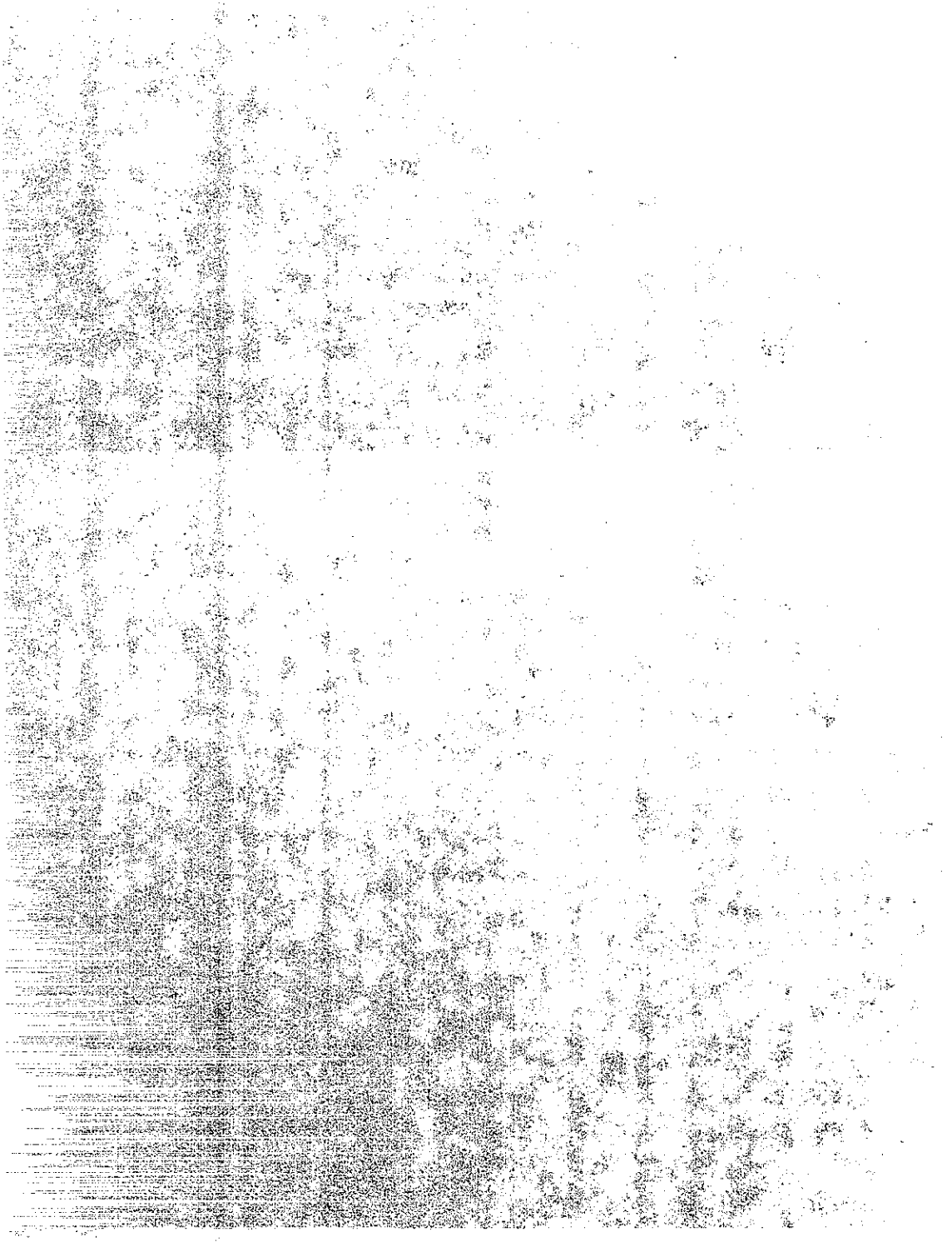

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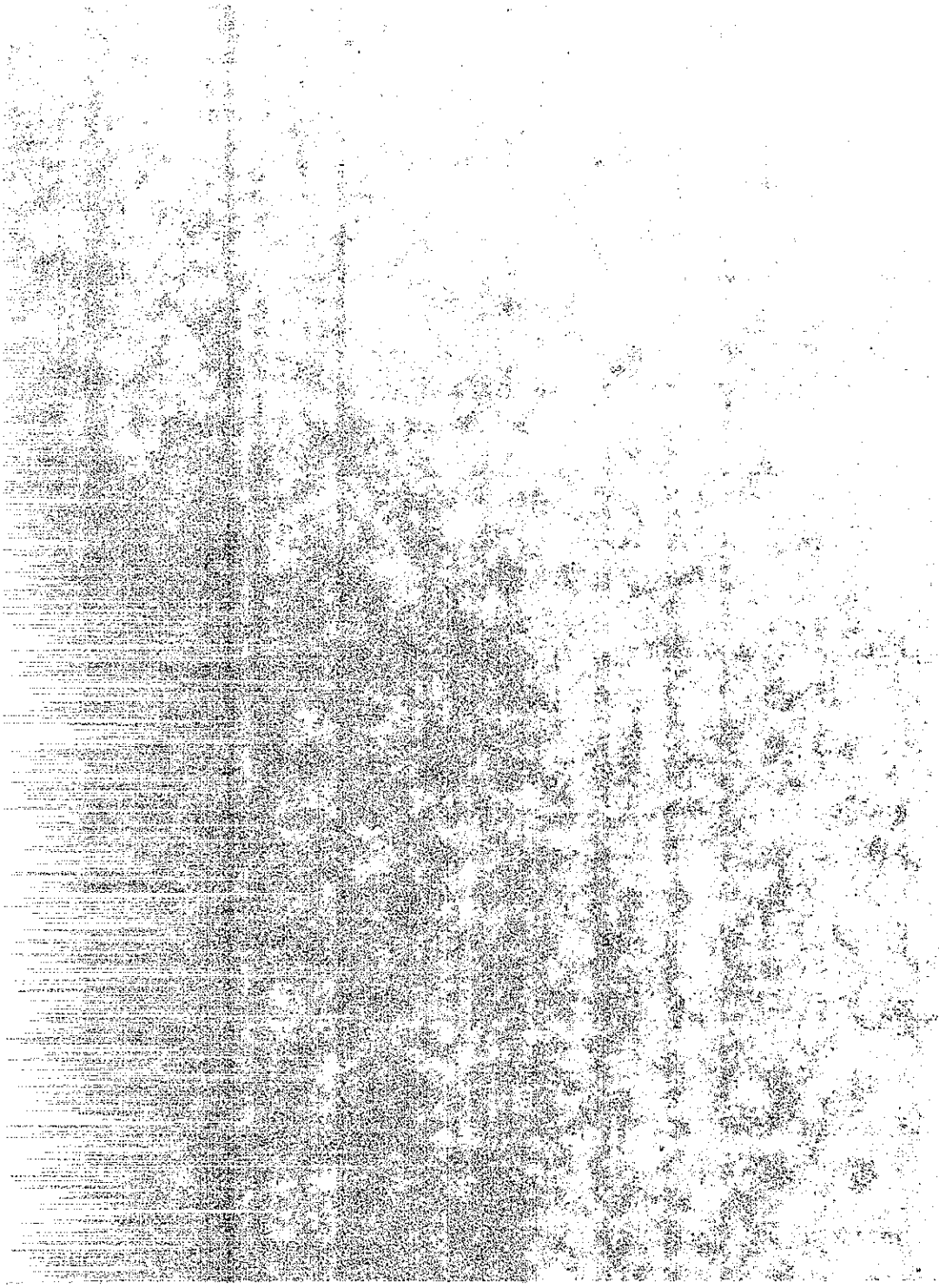

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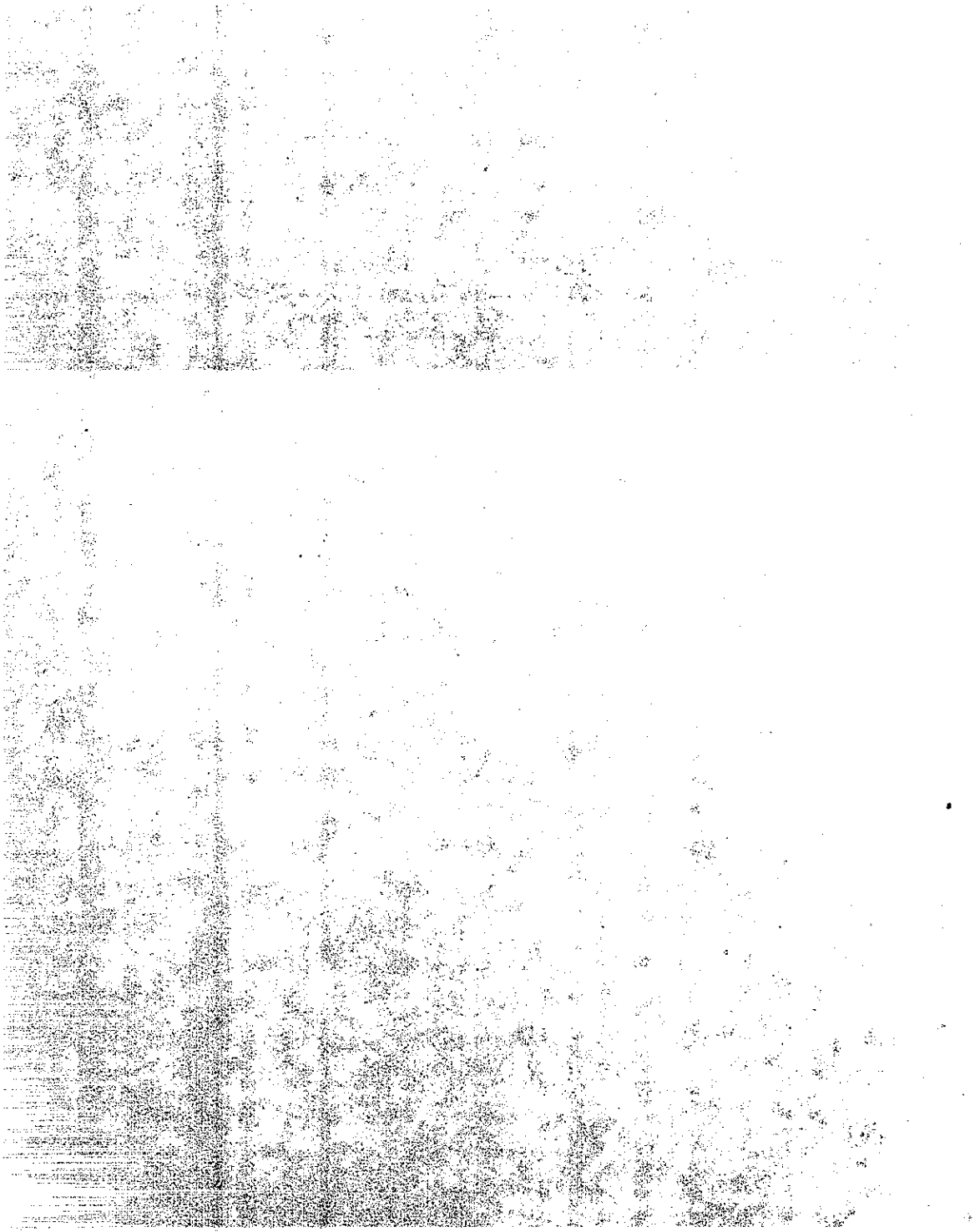

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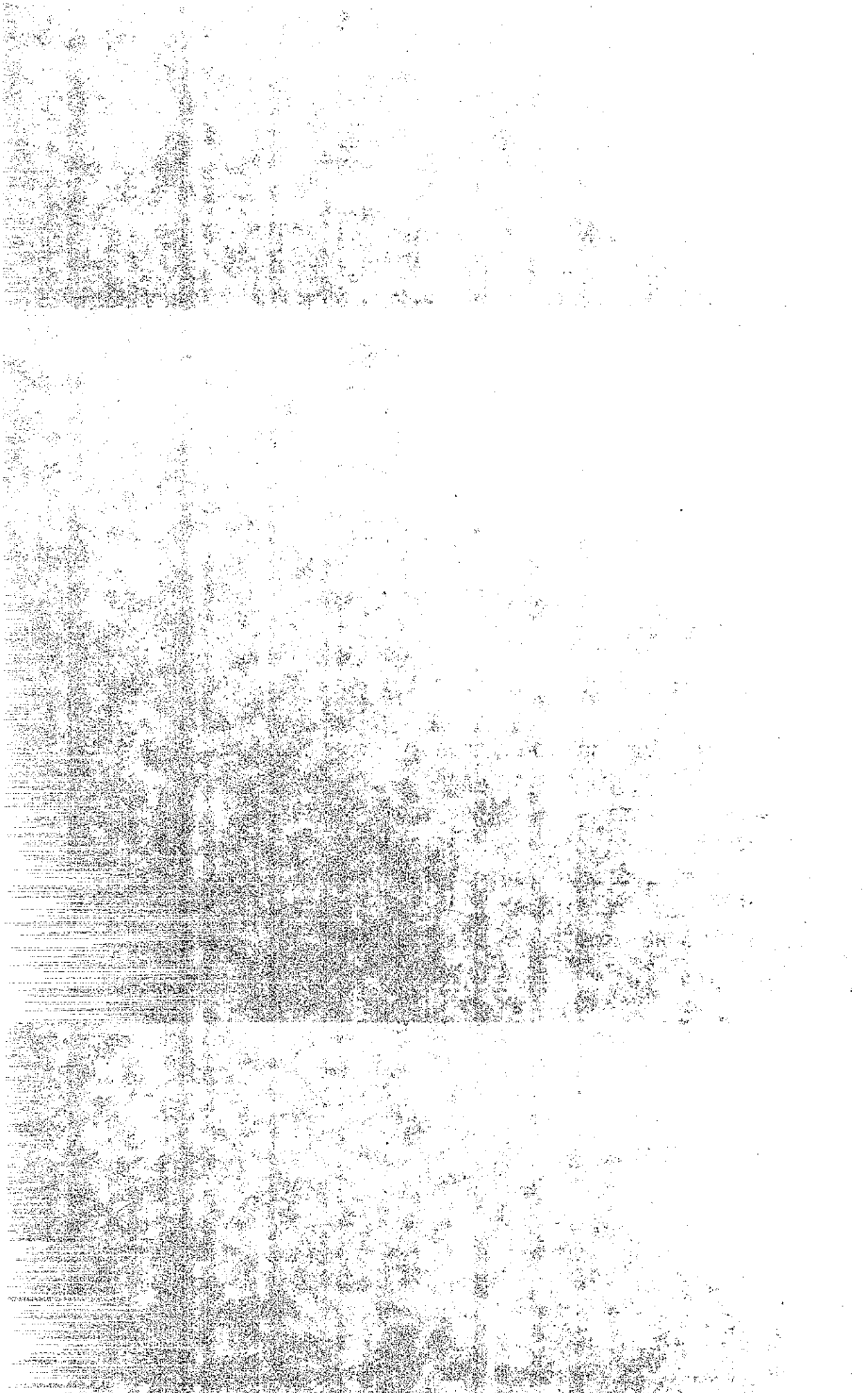

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INTRODUCTION

The California Department of Transportation (Caltrans) Laboratory (TransLab) began an FHWA-sponsored research study of sulfur extended asphalt (SEA) in 1981 with three objectives. The study sought to determine whether the incorporation of sulfur with a soft grade of asphalt could change the temperature-viscosity relationship of the resulting binder, thereby making it more useful in cold and hot climates. The other objectives included determining the performance of SEA pavements and developing a laboratory test procedure to predict SEA binder durability (resistance to oxidative hardening).

To achieve these goals, two field test sections were constructed. A hot climate SEA test section was installed midway between Baker and Barstow, California, on Interstate 15 in September 1982 (1) (Figure 1). Later a cold climate test section was constructed at Benton, California, on U.S. 6 in June 1984 (2) (Figure 2). Complete details of the planning, construction, and early evaluations are available in the interim reports of each project (1,2). Physical and preexisting conditions of each site are listed in Tables 1 and 2.

The two projects utilized the same sulfur asphalt blends, 20 percent and 40 percent sulfur by weight*, and each project used the same blending AR-2000 asphalt from Newhall Refining; however, the blending operations were different. The SEA binders used in the hot climate test section were preblended prior to mixing with the aggregate in a drum mixer, while the SEA binders used in the cold climate section were blended during the mixing in the pugmill of a batch plant mixer. In each instance, the resulting SEA mixture was placed using conventional paving equipment

*All sulfur percentages indicated in the text are by weight of total binder.

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and procedures. No significant difficulties were encountered. Environmental controls were maintained with little difficulty since proper temperature control of the SEA was maintained during the mixing and paving operations. Tables 3 and 4 list the environmental sampling results and mix temperatures obtained at each test site.

This report present an analysis of the field data and observations of the Baker and Benton test sections. The analysis provide answers to the questions of SEA mixture durability and the ability of the California Tilt-Oven Durability (CATOD) test to predict SEA binder durability.

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FINDINGS AND CONCLUSIONS

The following findings and conclusions are presented:

1. The construction phase of this project as reported in the interim reports (1,2) demonstrated that the use of SEA binders in place of conventional asphalt binders will not significantly affect the construction of asphalt concrete (AC) overlays.

2. The use of SEA binders in AC mixes does not affect the skid resistance characteristics of the resulting AC pavements in comparison to conventional asphalt pavements.

3. Results of physical tests (Hveem System) on compacted briquettes and field cores revealed no significant differences in stability, cohesion, and surface abrasion between SEA and conventional asphalt mixes. However, Marshall stability appears to increase with increased amounts of sulfur.

4. The Abson recovery method is a viable method of recovering SEA binders from mixes and cores for testing; however, all methods which dissolve the SEA binders recover only the sulfur which is in solution with the asphalt. This is approximately 20 percent by weight of the binder.

5. The hardening rate of the AR-4000 asphalt binder was faster than the AR-2000 and SEA binders in the Baker test section.

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6. The addition of sulfur to an asphalt binder (AR-2000) slows down the hardening rate compared to the blending asphalt; however, the SEA binders have poorer ductile properties as they age, relative to the AR-2000 control asphalt.

7. Since the CATOD test was modeled after a hot desert test site, the results obtained from it cannot be used to directly predict oxidative age hardening of binders used in a less severe weathering climate. However, when CATOD values for the SEA and control binders are compared, it is possible to determine their comparative aging rates regardless of climate.

8. The pavements in the Baker test section resisted cracking for approximately three years longer than the comparable thickness pavements in the Benton test section. The earlier cracking of the Benton pavements appears to have been the result of a combination of greater deflections, a thinner overlay in one lane, and colder ambient temperatures.

9. It appears that SEA blends may be more susceptible to thermal stresses in colder climates as the sulfur content increases. The SEA 40 percent sections at the Benton site (colder climate) had significant transverse (thermal) cracking 16 months after overlaying, while the adjoining SEA 20 percent and control sections required more than 28 months to reach nearly similar levels of transverse cracking. Transverse cracking was minimal in all the sections at the warmer Baker test site; however, the SEA sections were the first to exhibit beginning transverse cracking at approximately 66 months.

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10. The pavements constructed with SEA blends in the colder Benton site appeared to resist alligator cracking better than the pavements constructed with the control AR-2000 asphalt. The AR-2000 pavements had significant alligator cracking after 46 months, while the SEA pavements had minimal alligator cracking. Cracking of all of the sections in the warmer Baker test sections was minimal 66 months after overlaying.

11. Overall cracking frequency of the pavements at each site appeared to correlate well with binder hardening.

12. The SEA 20% had the best performance in both test sections; however, the control AR-2000 was equal in performance at the warmer Baker site. In warmer areas it appears that the primary factor affecting the cost-effectiveness of SEA binders is whether the cost of sulfur is no more than 50% as much as the asphalt. In colder areas, it appears that SEA mixes with about 20 percent sulfur by weight may offer greater resistance to alligator cracking than conventional asphalt mixes.

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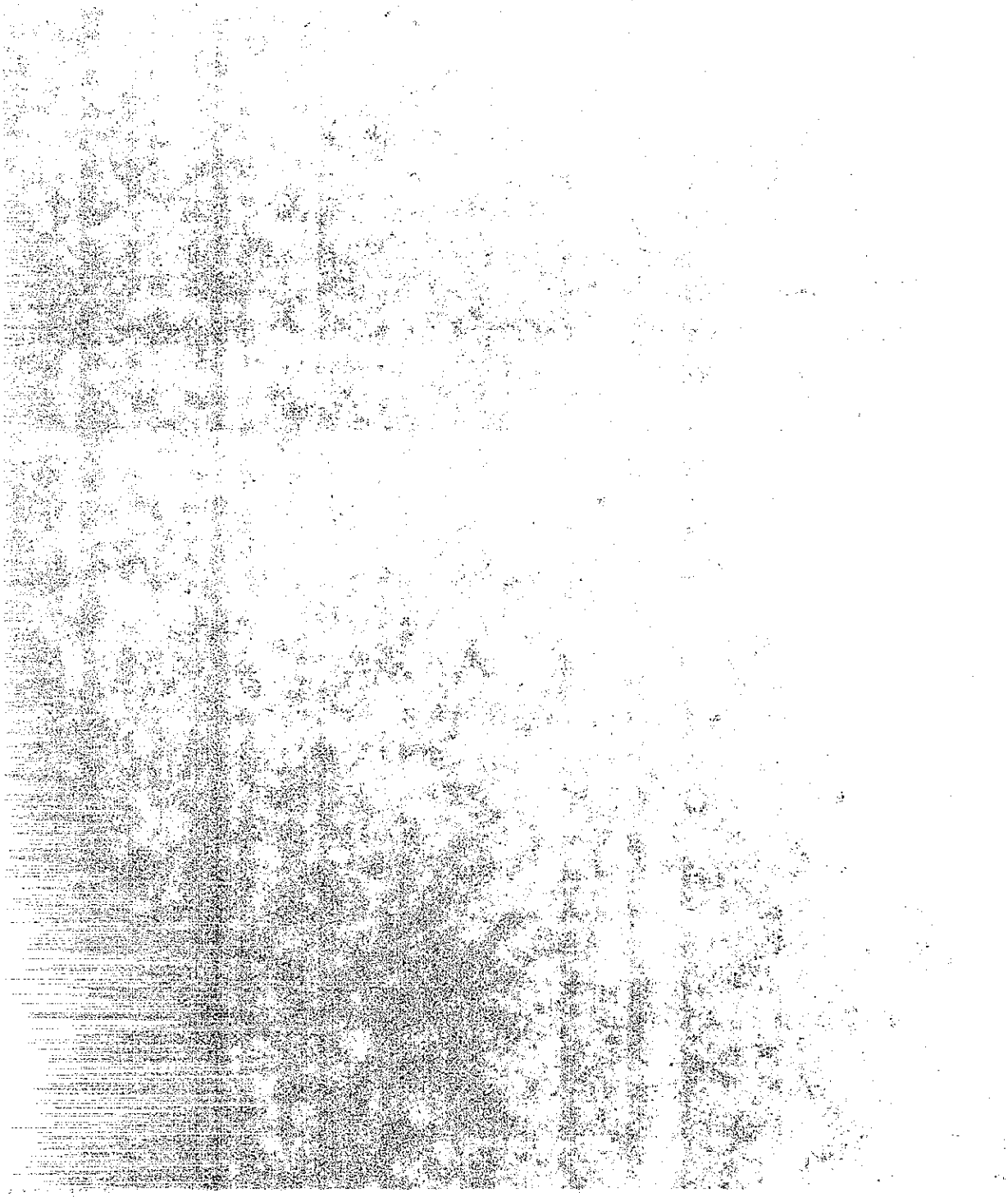

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IMPLEMENTATION

Based on the finding of this study, it appears that SEA blends with over 20 percent sulfur by weight should not be utilized in AC overlays in colder climate areas due to an early thermal crack potential.

Based on the findings of this study, SEA binders are a viable alternative to conventional asphalt binders except for the higher (over 20%) sulfur contents in cold climates.

Based on the finding of this study, SEA blends are not cost-effective unless the cost of sulfur is less than 50 percent of the cost of asphalt.

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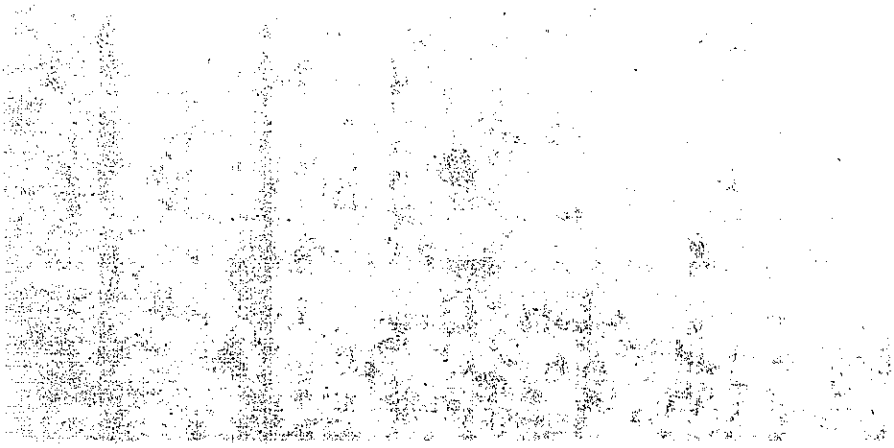

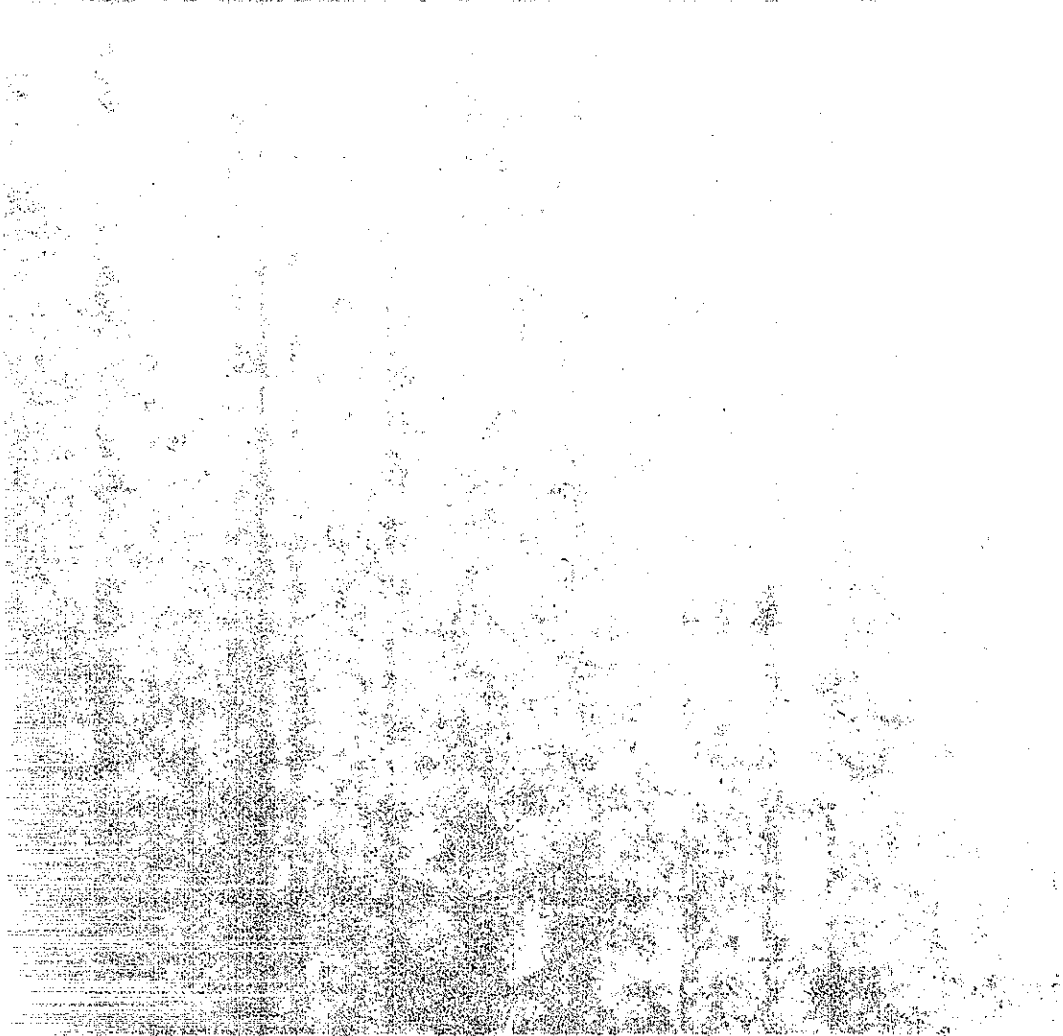

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TEST SECTIONS

I. Preface

This evaluation will focus on the performance of the pavements constructed with SEA and conventional asphalt binders in two environmentally different test sections. It will also compare the effect of these environments on the binder properties.

II. Preconstruction

Prior to the construction of the test sections, condition and crack surveys were performed. In addition, mix design (Hveem-California Test 367) and SEA blending operations were made with samples of the proposed asphalts and aggregates. Design data and binder content recommendations derived from these operations are summarized in Tables 5 and 6. These data show that the physical properties of the aggregates used in both test sections are very similar. Since the mix type, size, and binder quantity recommendations are nearly the same, it follows that the mixes placed in the Baker and Benton sections should be very similar. Therefore, it appears that the mix parameters should have had minimal effect on the performance of the SEA and conventional asphalt concrete pavement overlays in the two test sections. Even though the Marshall design method was not used to design the mixes used in the test sections, Marshall briquettes were fabricated at the Hveem design recommendations and tested for stability and flow. These data are listed in Table 7. (The Marshall stability increased with an increase in sulfur content.)

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III. Construction Phase (1,2)

The construction of the AC overlays with the SEA blends and conventional asphalts was accomplished without significant changes except for the connecting and blending of the sulfur into the mixing operation. The locations and paving operations data are listed in Figures 1 and 2 and Tables 1,2,3,4,8, and 9 for the Baker and Benton test sections. The construction details for each of these sections are reported in the interim reports. (1,2)

IV. Postconstruction Testing

A. Field Testing

Field testing of the completed test section overlays consisted of skid resistance testing and deflection measurements. Coring of samples for laboratory testing and crack and condition surveys are covered later in the text. Skid resistance testing was performed to determine whether the SEA binders affected this property of the resulting pavements. An analysis of the skid resistance test results listed in Table 10 indicates that the SEA binders did not affect the pavement texture. Preoverlay deflections were obtained 2 years and 4 years prior to construction at the Baker and Benton sites, respectively. These deflections and traffic conditions, as outlined in Table 2, were used to determine the recommended overlay thicknesses. Postoverlay deflection measurements were performed when the equipment was available at 5 weeks after at the Baker site and 12 months after at the Benton site. These deflection measurements were performed to determine the uniformity of the test sections at each test site. The data as recorded in Table 2 indicate fair uniformity of postconstruction deflections within each test location and only slight

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variations. Thickness measurements of cores removed 10 and 11 months after construction from the Baker and Benton test sections (listed in Table 2) reveal a thinner than recommended overlay at the Baker test site and a thicker than recommended overlay at the Benton test section, especially in the southbound lane which is approximately 0.10 foot thicker than recommended.

B. Laboratory Testing

1. Whole Core Testing - The laboratory testing of core samples taken periodically was done to determine the uniformity of the materials and mixes and to record the changes that took place as the conventional asphalt and SEA binders weathered. The extraction test results recorded in Tables 11 and 12 show that there is uniformity of all of the mixtures with regards to grading of the aggregates. The results also show that binder contents closely followed the design binder recommendations in most cases.

Results of physical tests performed on the cores are recorded in Tables 13 and 14. These results show that the blending of sulfur into an asphalt binder had virtually no effect on the physical properties of the pavement cores. The results also show little change in the physical properties of the cores as the overlays aged.

2. Testing of Recovered Binders From Cores - The primary goal of this study was to compare the performance of SEA and conventional asphalt binders. To accomplish this, it was necessary to use a reliable method of recovering the weathered field binders from the cores. The conventional method is to use the Abson recovery (California Test 380). According to data contained in the

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interim reports (1,2) and data listed in Table 15, only the sulfur in solution with the asphalt in the SEA blends can be recovered by the Abson recovery process. Previous results indicated this to be about 20 percent by weight. Since this is probably the amount of sulfur in solution in any SEA blend over 20 percent, the test results of residue from SEA 40 percent blends should be acceptable even though the residue from the Abson recovery only contains approximately 20 percent sulfur. Ash content test results (Table 15) include somewhat excessive ash contents on residues from the Baker test section 54 month cores. This probably represents a slight deficiency in the removal of fines from the Abson solution during the recovery period. Other ash contents were below the desired one percent maximum ash content. It does not appear that the test results were influenced adversely.

A summary of the test results from the testing of the Abson recovered residue is presented in Tables 16 and 17. The test results in Table 16 (Baker T.S.) indicate slightly less weathering (softer residues) in the Number 2 lane, except for the AR-4000, after 54 months. This may be due to the greater compactive effort produced by more truck traffic in this lane. Specific gravity results listed in Table 13 indicate higher specific gravities after 54 months in the Number 2 lane than the Number 1 lane, thus confirming that the percent of voids is probably less than in the Number 1 lane. Previous studies (3) have shown that the void content of the AC pavement can affect the rate of asphalt hardening. The test results of the binders used in the Benton test section (Table 17) show slightly more hardening in the northbound lane after 36 months. This may also be explained by the higher specific gravity (decrease in voids) of the cores from the southbound lane.

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3. Comparison of Binder Hardening - In comparing the binder hardening (same binders in each site) between the two field sites, several factors should be taken into consideration. These include climate (temperatures, etc.), voids (compaction), and aggregate porosity. In a previous study (3) it was determined that site temperature characteristics could be a significant factor on the binder hardening rate. Following is a list of previous weathering sites (3) and their average yearly temperatures which are compared to the SEA sections (from Table 1).

Weathering Site	Average Yearly Temp(°F)	Comparative Hardening Rates*
Previous (3)		
Fort Bragg (Northern Coastal)	52.9	4.5 years
Sacramento (Central Valley)	61.4	2.5 years
South Lake Tahoe (Sierra Nevada, 6500 feet)	41.6	4.5 years
Indio (Low Desert, -22 feet)	73.0	1 year
SEA Sections (from Table 1)		
Baker T.S. (Medium Desert, 1600+ feet)	67.6	
Benton T.S. (High Desert, 5300 feet)	55.5	

*Time for three different asphalts (average results) to reach 20 kilopoise absolute viscosity @ 140°F.

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The comparison shows how the Baker and Benton sites fit into the climate situations of the previous study (3).

Test results from the Baker and Benton test sections are listed in Table 18. Plots of the absolute viscosity from Table 18 are graphed in Figure 3. A reprint from Vol. 50 of the AAPT proceedings (3) is presented as Figure 4. These plots show that the hardening rates are very similar in the Baker and Benton sites, especially for the AR-2000 control binders. Since the binders used in the previous study (3) were all AR-4000 grade asphalts, the only binder in this study which offers a comparison is the AR-4000 in the Baker test section. A comparison of the previous AR-4000 tests and the Baker AR-4000 can be made by comparing the AR-4000 plot in Figure 3 to the plots in Figure 4. The plots show that the Baker hardening rate falls between the Sacramento and Indio test sites for the AR-4000 binder. The AR-2000 and SEA binders are softer and have slower hardening rates. It appears that the addition of sulfur slows the hardening rate since the AR-2000 blending control asphalt has a slightly greater hardening rate than the SEA binders.

4. Comparison of Recovered Binder Test Results to CATOD Test Predictions - The third objective of this study was to develop a procedure for predicting SEA binder durability (resistance to oxidative hardening and embrittlement). Since the California Tilt-Oven Durability (CATOD) test had been correlated to asphalt binder durability in a hot weather setting (3), it seemed that it could be used to estimate SEA binder durability. Thus, CATOD tests were performed on the SEA and control binders from each project after construction. These CATOD results are listed along with the latest field data for each binder in Table 19.

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These results show that only the AR-4000 binder is approaching the CATOD predictions. This indicates that the Baker test site has a less severe weathering regime than the CATOD standard which is the Indio or low desert climate. In a comparison of CATOD predictions of penetration at 77°F between the SEA binders and the AR-2000 binder, the values indicate that the SEA and AR-2000 binders should age harden at approximately the same rate. The recovered binder test results indicate that this is the case in both test sections. Therefore, the CATOD procedure can be used to predict the hardening rate of SEA binders.

C. Crack and Condition Evaluations

Crack and condition surveys were performed at each test site before construction and periodically afterward. Summaries of these surveys are presented in Tables 20 and 21. A detailed summary of latest cracking is presented in Table 22. The evaluations show that the Baker test section pavements resisted cracking for a significantly longer period than the Benton test pavements. Except for the deficient binder area at the Baker site, the Baker test sections resisted cracking for approximately three years longer than the equal thickness southbound overlay in the Benton test section (see Figures 5 and 6.) Deflection values are compared to cracking frequencies in Table 22. The deflection values are significantly greater at the Benton site than in the Baker test sections (see Figure 7). It appears that the combination of greater deflections, a somewhat thinner overlay in the northbound lane, and the colder climate at the Benton site have made a significant contribution toward the higher incidence of cracking in the Benton sections.

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The cracking data from each test site reveals that the SEA pavements were more susceptible to early transverse (thermal) cracking than the conventional pavements (Figures 8 and 9). This was especially true in the SEA 40% portion of the northbound lane at the Benton test site (Figure 8). It had significant transverse cracking (42.5% reflected) after only 16 months. The SEA 20% section in the northbound lane did not approach this degree of cracking until more than 28 months after overlaying. However, the SEA sections in the Benton test section resisted alligator cracking longer than the control AR-2000 section. The AR-2000 section shows major alligator cracking in the northbound lane after 4 years. It appears that the SEA binders may be more thermally sensitive in colder climates, especially for higher sulfur contents. In the warmer Baker test section, the SEA and AR-2000 control sections have approximately equal cracking after 66 months; however, all of the sections have minimal cracking at that point. The overall cracking frequency correlates fairly well with binder hardening at each test site. Photographs of the Baker sections at 66 months are shown in Figures 10 thru 14, and of the Benton sections at 46 months in Figure 15.

V. Cost Considerations

Based on the results of tests on the binders, it appears that the SEA binders have a slower or equal hardening rate in comparison to the blending AR-2000 control asphalt (Table 18). Based on the crack surveys (Tables 20, 21, and 22), it appears that the pavements constructed with SEA binders appear to resist alligator cracking better than the pavements constructed with the conventional AR-2000 binder; however, the higher sulfur content ($\pm$40%) SEA pavements are more prone to thermal cracking at an early age. In the interim reports (1,2), it was concluded that sulfur was not a cost-effective substitute in the Baker and Benton test sections since it cost more than 50% as much as the

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asphalt. Cost considerations at that time did not include service life potential. Based on the approximately 4 and 5 years of service life at the Benton and Baker sites, respectively, the SEA 20% sections had the best overall performance; however, the control AR-2000 was equal in performance at the warmer Baker site. In warmer areas, it appears that the primary factor affecting the cost-effectiveness of SEA binders is whether the cost of sulfur is no more than 50% as much as the asphalt. In colder areas, it appears that SEA mixes with about 20 percent sulfur by weight may offer greater resistance to alligator cracking than conventional asphalt pavements.

VI. Analysis of Objectives

The objectives of this study were:

1. Determine whether one grade of "soft" asphalt can be used in both cold and hot areas by the addition of sulfur to change mixing characteristics of the resulting binder.

2. Determine the durability (performance) of the resulting SEA pavements in cold and hot environments.

3. Develop a laboratory test procedure which will predict SEA mixture field performance.

A. Objective 1

To accomplish this objective, the same "soft" (AR-2000) blending asphalt was used in both the cold and hot test sites. Table 23 shows that the addition of sulfur caused a marked reduction in original, mixing, and paving viscosities of the resulting SEA binders compared to the control AR-2000 (blending) asphalt binder. This did not affect the

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Hveem stabilities of the resulting AC mixes made from the SEA and control binders; however, Marshall stabilities of the same mixes increased with the addition of more sulfur. It is apparent that the viscosity of sulfur, when melted (240 to 300°F approximately), affects the viscosity of the SEA binders significantly regardless of the blending asphalt. The Marshall stabilities, however, indicate increased stiffness of the resulting mixes.

The effect of the addition of sulfur on temperature susceptibility is indicated in Table 23 by the pen ratio [(pen 39.2°F/pen 77°F) x 100] where lower pen ratio values indicate greater temperature susceptibility. The penetration/viscosity number (PVN)(4) indicates greater temperature susceptibility by a lower or more negative number.

$$PVN = \frac{6.489 - 1.590 \log P - \log X}{1.050 - 0.2234 \log P} (-1.5)$$

where P = penetration at 77°F (25°C), dmm
X = viscosity at 140°F (60°C), poise

The Pen Ratio and PVN values listed in Table 23 indicate virtually no effect on temperature susceptibility by the addition of sulfur.

B. Objective 2

The performance of the SEA and control pavements is discussed earlier. A summary of the findings is as follows:

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1. Pavements constructed in colder climatic areas with higher sulfur (40%±) content SEA binders appear to be more susceptible to early transverse (thermal) cracking.

2. Pavements constructed with SEA binders may be more resistant to alligator cracking than conventional asphalt pavement, especially in colder areas.

C. Objective 3

The CATOD procedure was utilized as a predictor of SEA binder resistance to hardening since it was calibrated against a spectrum of California asphalt's weathering performances in a hot desert test site. Since the SEA test sites were less severe than the CATOD model, the CATOD procedure can not directly predict binder aging rate in these cooler sites. However, when the CATOD values are compared for the SEA and control binders, they indicate that the SEA binders should age at the same rate as the control binders. The field samples of the SEA and control sections indicate that this is generally true. Therefore, the tilt oven can be used to determine the aging rate of SEA binders as well as standard asphalts.

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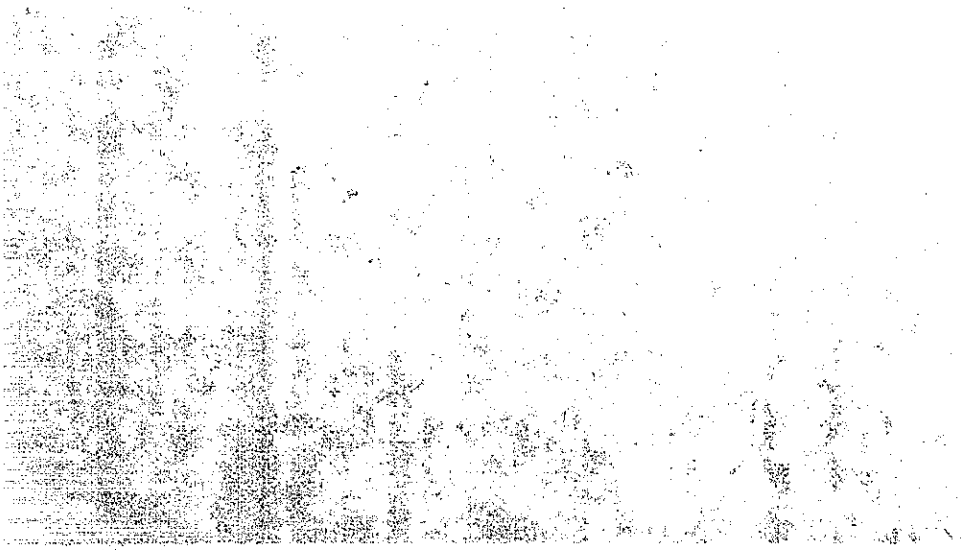

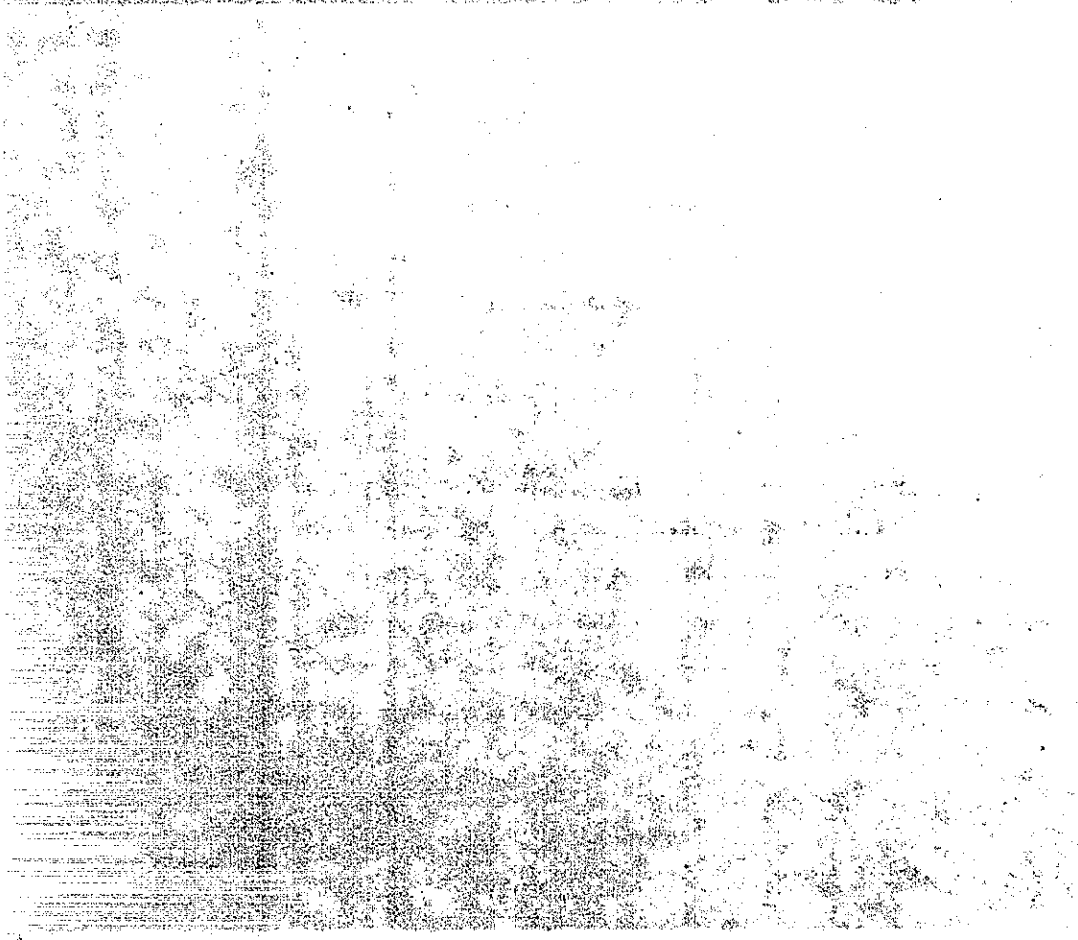

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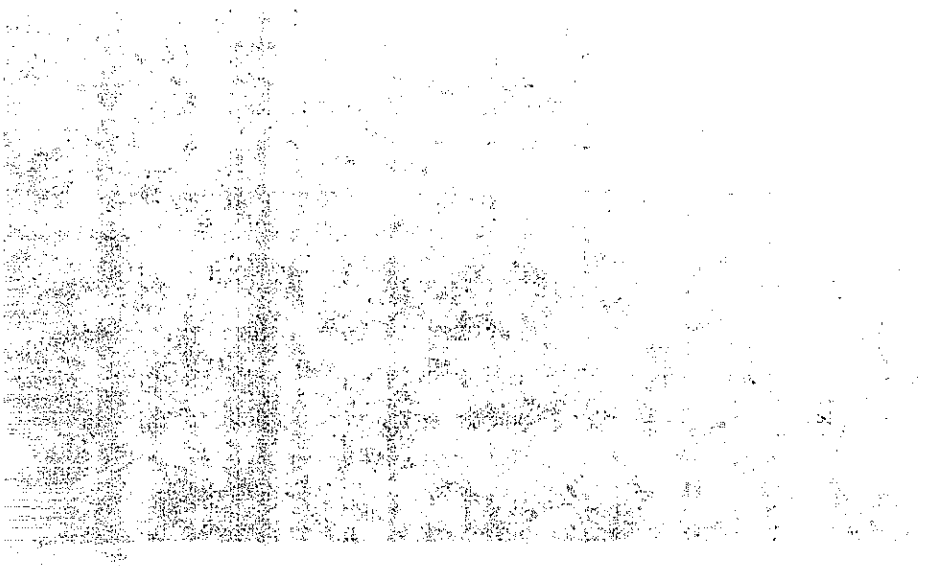

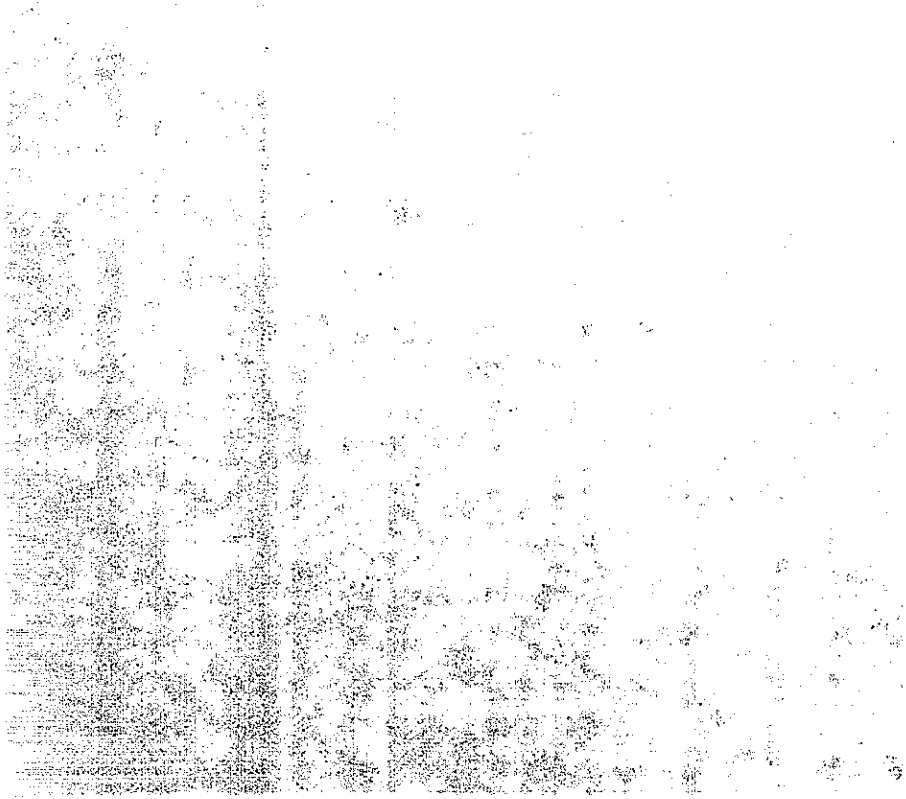

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TABLES AND FIGURES

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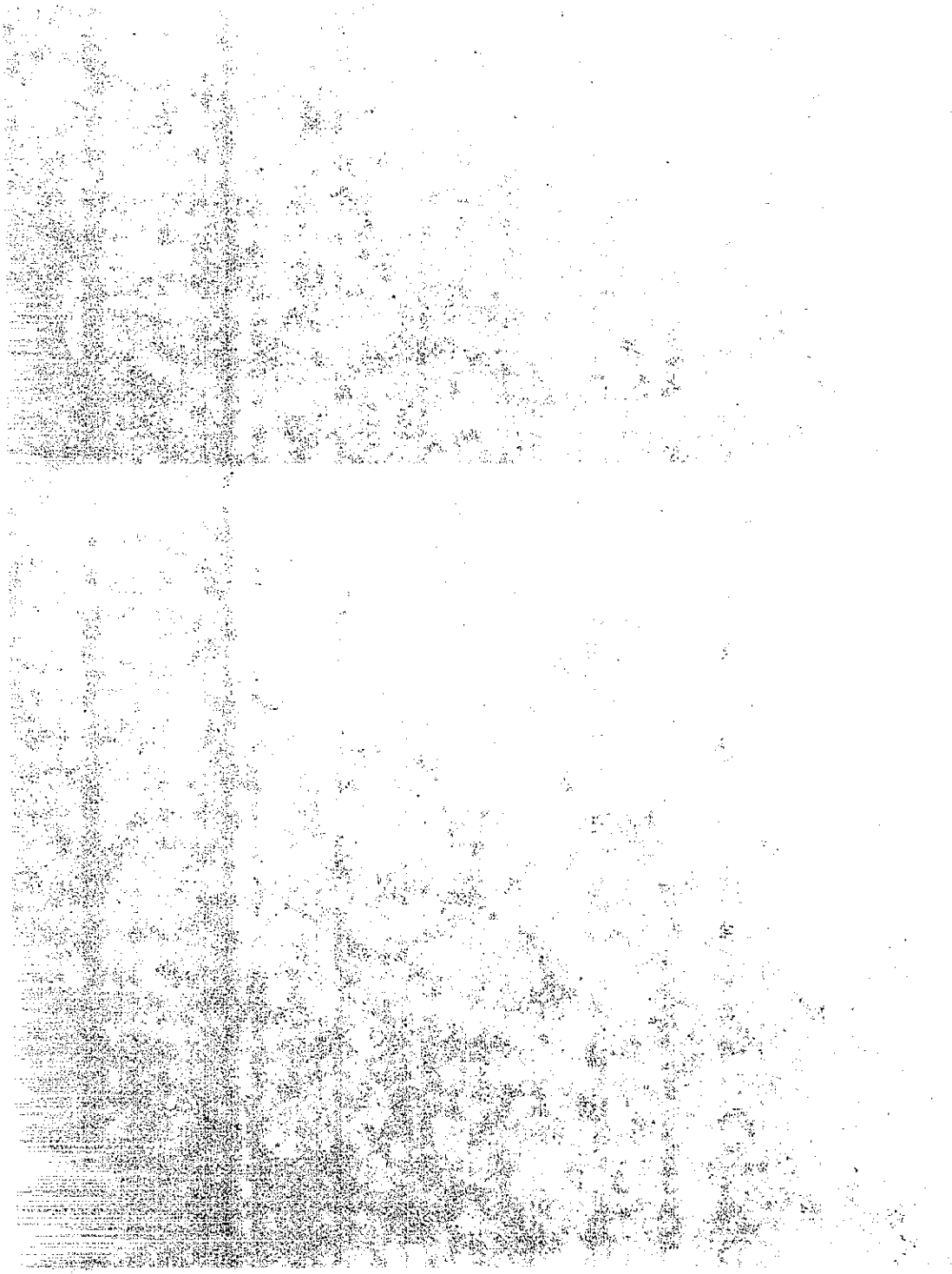

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Table 1

TEST SECTION PHYSICAL CONDITIONS

Test Section	Terrain	Average Altitude (feet)	Weather Conditions* Temperatures (°F) Summer (Maximum) 5 Yr. Avg.	Winter (Minimum) 5 Yr. Avg.	Yearly Average 5 Yrs	Yearly Average Normal	Rainfall (inches) Yearly Average 5 Yrs	Rainfall (inches) Yearly Average Normal
Baker (Hot)	Level and Straight	1700	112	20	67.6	67.2	5.47	3.81
Benton (Cold)	Level and Straight	5300	105	9	55.5	56.1	8.8	-

*Data from U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) Climatological Summaries for 1982 thru 1986. Baker T. S. data from Daggett FAA, (elevation 1922 feet, 25 miles west). Benton T. S. data from Bishop, (elevation 4100 feet, 30 miles south) for temperatures and Benton Inspection Station (elevation 5461 feet, 2 miles east) for rainfall. From conversations with local Benton residents, it is believed that Benton maximum and minimum temperatures should be about 10°F lower than Bishop temperatures.

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Table 2

PREEXISTING CONDITIONS - STRUCTURAL, TRAFFIC, AND DEFLECTION DATA

Location	Preexisting Structural & Traffic Conditions*	Original Construction Data (age)	Section	(80th Percentile) Preexisting Deflection Measurements (inches)**	Deflections After Overlay 80th Percentile (inches)**	Actual DGAC Overlay Thickness (feet)***
Baker						
	0.04' OGAC	1964	AR-4000			
	0.54' DGAC	(18 years)	NB #1	-	0.006	0.21
	0.67' AB		NB #2	0.007	0.006	0.21
	0.75' AS		AR-2000			
			NB #1	-	0.010	0.22
	1979 ADT =		NB #2	-	0.010	0.19
	15,300 (15% trucks)					
	1995 Estimated					
	ADT = 26,000					
	Estimated 10 years					
	T.I. = 11.5					
			SEA 20%			
			NB #1	-	0.008	0.21
			NB #2	0.013	0.012	0.23
			SEA 40%			
			NB #1	-	0.007	0.19
			NB #2	-	0.012	0.21
Benton						
			AR-2000			
	0.08 DGAC (1977)	Prior to 1950	NB	0.019	0.024	0.14
	0.08 DGAC (1963)		SB	0.018	0.020	0.26
	0.25 DGAC					
	0.50 Imported Borrow					
	1979 ADT =					
	1900 (15% trucks)					
	1995 Estimated					
	ADT = 2500					
	Estimated 10 Years					
	T.I. = 9.0					
			SEA 20%			
			NB	0.019	0.025	0.18
			SB	0.018	0.022	0.24
			SEA 40%			
			NB	0.019	0.018	0.16
			SB	0.018	0.021	0.26

* Thickness in feet, O.G.A.C. = Open Graded Asphalt Concrete
O.G.A.C. = Dense Graded Asphalt Concrete
A.B. = Aggregate Base
A.S. = Aggregate Subbase
O.G.A.C. was removed prior to construction of SEA T.S. overlays.

** Preexisting deflections - 1980, Postconstruction Deflections - Baker 5 weeks, Benton 12 months, after overlaying

***Recommended overlay thicknesses based on deflections and traffic conditions = Baker T.S. = 0.25 feet, Benton T.S. = 0.15 feet. Actual thicknesses are average of two or more cores taken at 10 and 11 months from the Baker and Benton, T.S.

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Table 3

ENVIRONMENTAL SAMPLING APPARATUS AND TEST RESULTS

Apparatus	Sampling Location	Sampling Results* (maximum ppm) Baker T.S.	Benton T.S.
Short Duration (gas detectors)			
H_2S - Interscan Model 1176 - Range 0-10/0-100 ppm	Windrow	3	4
	Paver Auger	5	2
	Roadside	0	0
	Hot Plant Hopper	>1	8
SO_2 - Interscan Model 1248 with H_2S Scrubber - Ranges 0-10/0-25/0-50 ppm	Windrow	1	4
	Paver Auger	1	20 (Burst)
	Roadside	0	2
	Hot Plant Hopper	0	12
Long Duration (gas detector)			
Draeger Polymeter Long Duration Tube for H_2S	On Paver	1.4	0.87
*SO_2	On Paver	0.5	0

Particulate Measurement	Plant	Control Paving	SEA Paving	Control Paving	SEA Paving
General metals high volume air sampler with Sierra Instruments Flow Controller to regulate airflow to 40 CFM. Total Suspended Particulates (TSP), maximum values (mg/m^3)	TSP	0.66	13.6	22.5	1.62
	Sulfates	0.01	0.05	0.05	0.0
	Free Sulfur	0	0.05	0.00007	0.0
	Roadside				
	TSP	0.12	0.11	0.19	0.49
	Sulfates	0.01	0.03	0.01	0.02
	Free Sulfur	0.00009	0.0145	0.0	0.076

*Regulations (1,2)

	Permissible Exposure Limit (PEL)	Excursion Limit	Excursion Duration	Ceiling Limit
H_2S =	10 ppm (25C, 760mmHg)	20 ppm	10min/8hr	50 ppm
SO_2 =	3.5 ppm (25C, 760mmHg)			

Total Suspended Particulates (TSP) = (Dust, Sulfates, & Free Sulfur as Nuisance Dust)

Nuisance Dust (TLV) = Total Dust = 10 mg/m^3, Respirable Dust = 5 mg/m^3

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Table 4

TEST SECTION INSTALLATION TEMPERATURES

Test Section	Binder	Mix Temperatures °F (average) Mixing Plant	Windrow	Behind Screed	Breakdown	Air Temperature	Weather Condition
Baker	AR-4000	282	271	252	233	83/103	Clear
	AR-2000	285	270	243	242	83/100	Cloudy
	SEA 20%	286	279	254	-	68/82	Clear, later Cloudy w/ Showers. Windy
	SEA 40%	287	275	260	252	78/80	Clear, later Cloudy w/ Showers. Windy
Benton	AR-2000	300	272	255	230	72/80	Clear, later Cloudy
	SEA 20%	286	276	260	230	68/71	Cloudy
	SEA 40%	286	282	273	253	68/71	Cloudy

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Table 5

MIX DESIGN DATA

			Baker T.S.	Benton T.S.
1.	Design Method		Hveem (Calif. Test 367)	Hveem
2.	Mix Type, Size, Grading (Calif. Stand. Spec. Sect 39)		Type A, 1/2" Maximum, Coarse	Type A, 1/2" Maximum, Coarse
3.	Aggregate (source)		Opah Ditch Pit (10 miles west of Baker)	Milner Fan Pit (at PM 7.8 south of highway)
4.	Aggregate Properties	Calif. Test		
	Specific Gravity Coarse -	206	2.56	2.64
	Fine -	208	2.69	2.67
	LART Abrasion Loss after 500 Revolutions -	211	26%	19%
	K_c Factor	303	1.2	0.9
	K_f Factor	303	1.1	1.0
	K_m Factor	303	1.1	1.0
	Surface Area ft^2/pound	303	26	26.3
	Sand Equivalent	217	64	79
5.	Blending Asphalt - AR-2000		Newhall	Newhall
6.	Sulfur		Commercial Grade 99.4% Pure	
7.	Binders		AR-4000, AR-2000 SEA 20%, SEA 40%	AR-2000, SEA 20% SEA 40%

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Table 6

MIX DESIGN BINDER RECOMMENDATIONS*

Test Section	Binder	Percent** Binder	Design Briquette Values		
			Stability Calif. Test 366	Percent Voids*	Specific Gravity*
BAKER	AR-4000***	5.4	43	5.3	2.30
	AR-2000	5.4	40	6.0	2.25
	SEA 20%	6.0	41	6.0	2.26
	SEA 40%	8.0	38	4.5	2.27
BENTON	AR-2000	5.5	38	4.5	2.31
	SEA 20%	6.0	39	4.5	2.33
	SEA 40%	7.5	46	4.8	2.31

* California Test 367 (Hveem)
** By weight of dry aggregate
***AR-4000 mix design by District 08 Lab in San Bernardino. Job asphalt.

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Table 7

MARSHALL TEST RESULTS ON
LABORATORY BRIQUETTES
FABRICATED AT DESIGN BINDER CONTENT
(AASHTO T245)

Test Section	Binder	Design Binder* Content (%)	Stability (pounds)	Flow (0.01 inch)	Briquette Specific Gravity
Baker	AR-2000	5.2	1473	23	2.28
	SEA 20%	6.0	1840	21	2.32
	SEA 40%	8.0	2617	23	2.35
Benton	AR-2000	5.4	1184	20	2.30
	SEA 20%	6.0	1430	15	2.32
	SEA 40%	7.5	1790	17	2.34

*By weight of dry aggregate - control AR-2000 binder contents reflect binder contents used on job.

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Table 8

TEST SECTION LAYOUT DATA

BAKER TEST SECTION (Hot Climate)

Section	Location	Lane No.	No. of Layers	Overlay Thickness (feet) Design	Overlay Thickness (feet) Actual*	Binder Contents(%) Design	Binder Contents(%) Actual**
1. AR-4000	PM 107.75-108.25	1	1	0.25	0.21	5.4	5.3
2. AR-4000	PM 107.75-108.25	2	1	0.25	0.21	5.4	5.4
3. AR-2000	PM 108.25-108.96	1	1	0.25	0.22	5.4	5.2
4. AR-2000	PM 108.25-108.96	2	1	0.25	0.19	5.4	5.3
5. SEA 20%	PM 108.96-109.53	1	2	0.10' Surf 0.15' Level	0.21	6.0	5.5
6. SEA 40%	PM 109.53-109.94	1	2	0.10' Surf 0.15' Level	0.19	8.0	7.7
***7. SEA 20%	PM 108.96-109.15	2	1	0.25' one lift	0.23	6.0	4.3
8. SEA 20%	PM 109.15-109.58	2	1	0.25' one lift	0.23	6.0	5.4
9. SEA 40%	PM 109.58-109.94	2	1	0.25' one lift	0.22	8.0	7.7

* From core samples taken 10 months after construction.
** Average of binder content determinations from 4 mix or core samplings.
***Deficient binder area in #2 lane. Binder content 4.3 instead of 6.0 percent.

BENTON TEST SECTION (Cold Climate)

Section	Location*	Lane	No. of Layers	Overlay Thickness (feet) Design	Overlay Thickness (feet) Actual**	Binder Contents(%)*** Design	Binder Contents(%)*** Actual
1. SEA 40%	Sta 1299-1310	NB	1	0.15	0.16	7.5	7.1
2. SEA 40%	Sta 1299-1312+50	SB	1	0.15	0.26	7.5	7.3
3. SEA 20%	Sta 1310-1325	NB	1	0.15	0.18	6.0	5.8
4. SEA 20%	Sta 1312+50-1325	SB	1	0.15	0.24	6.0	5.6
5. AR-2000	Sta 1325-1347	NB	1	0.15	0.14	5.5	5.4
6. AR-2000	Sta 1325-1347	SB	1	0.15	0.26	5.5	5.4

* Sta 1299 = PM 24.62, PM 25.0 = Sta 1319.06
** From core samples taken 11 months after construction.
***Average of binder content determinations from 3 or more core samplings.

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Table 9

COMPACTION DATA

Test Section		Relative Compaction* (Field Density/Design Density x100) Nuclear	Relative Compaction* (Field Density/Design Density x100) Wax Gravity of Field Cores**	% Field Voids* (Field Density/Theo. Max Sp. Gr. x100-100) Nuclear	% Field Voids* (Field Density/Theo. Max Sp. Gr. x100-100) Wax Gravity of Field Cores**
BAKER					
AR-4000	NB#1	-	97.8	-	7.9
	NB#2	-	96.9	-	8.7
AR-2000	NB#1	-	98.2	-	8.6
	NB#2	-	99.6	-	7.4
SEA 20%	NB#1	-	97.8	-	9.8
	NB#2	-	99.1	-	8.6
SEA 40%	NB#1	-	98.0	-	7.6
	NB#2	-	99.8	-	6.0
BENTON					
AR-2000	NB	95.7	98.3		7.4
	SB		99.1	9.8	6.5
SEA 20%	NB	95.3	98.7	9.8	6.5
	SB		98.3		6.9
SEA 40%	NB	97.4	100.0	7.8	5.3
	SB		100.0		5.3

* Relative Compaction - (California Test 375)
% Field Voids - (California Test 367). Based on Nuclear and waxed gravities.
** Waxed gravities performed on four inch cores removed 10 and 11 months after construction.

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Table 10

SKID TEST DATA (ASTM E-274)

Location	Test Section	Limits	Skid Number (ASTM SN_{40}) Lane #1 6mo	Lane #1 29mo	Lane #2 6mo	Lane #2 29mo
BAKER						
	AR-4000	PM 107.75 to 108.25	49	50	47	48
	AR-2000	PM 108.25 to 108.96	47	50	44	47
	SEA 20%	PM 108.96 to 109.58	51	52	49	50
	SEA 40%	PM 109.58 to 109.94	49	51	47	48

Location	Test Section	Limits	NB Lane 8mo	SB Lane 8mo
BENTON				
	AR-2000	NB PM 25.07 to 25.48 SB PM 25.48 to 25.07	52	52
	SEA 20%	NB PM 24.79 to 25.07 SB PM 25.07 to 24.82	55	53
	SEA 40%	NB PM 24.58 to 24.79 SB PM 24.82 to 24.58	52	52

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Table 11

SUMMARY OF EXTRACTION TESTING*
BAKER TEST SECTION - NB LANES
(Road 08-SBd-15)

Size	Operating Range* 1/2" Max. Coarse (% Passing)	Grading (percent passing) AR-4000 Lane #1	AR-4000 Lane #2	AR-2000 Lane #1	AR-2000 Lane #2	SEA 20% Lane #1	SEA 20% Lane #2	#2DBA**	SEA 40% Lane #1	SEA 40% Lane #2
3/4"	100	100	100	100	100	100	100	100	100	100
1/2"	95-100	98	98	98	98	97	97	98	97	98
3/8"	75-90	85	86	85	85	82	83	82	85	84
No. 4	50-66	57	58	57	57	57	56	56	60	59
No. 8	35-50	43	43	43	43	42	41	42	44	44
No. 16		33	32	32	32	32	30	32	32	32
No. 30	15-30	22	22	22	22	21	21	21	23	23
No. 50		14	14	14	14	14	14	14	14	15
No. 100		9	9	9	9	9	9	9	9	10
No. 200	3-7	6.1	6.2	6.3	6.4	5.8	6.0	6.0	6.2	6.4
Binder Content %	Design	5.4	5.4	5.4	5.4	6.0	6.0	6.0	8.0	8.0
	Actual	5.3	5.4	5.2	5.3	5.5	5.4	4.3	7.7	7.7

* Extractions by California Test 310. California Standard Specifications, Section 39, for dense graded asphalt concrete Type A, 1/2 inch maximum, coarse grading. Results are averages of windrow and core samples representing 6 to 12 samples.

** DBA - Samples from deficient binder area.

Table 12

SUMMARY OF EXTRACTION TESTING*

BENTON T.S. NB AND SB LANE
(Road 09-Mno-6)

Size	Operating Range* 1/2" Max. Coarse (% Passing)	Grading (percent passing) AR-2000 NB	AR-2000 SB	SEA 20% NB	SEA 20% SB	SEA 40% NB	SEA 40% SB
3/4"	100	100	100	100	100	100	100
1/2"	95-100	96	96	96	96	96	97
3/8"	75-90	85	83	83	82	83	83
No. 4	50-66	63	64	56	56	53	55
No. 8	35-50	44	44	42	41	38	41
No. 16		31	31	31	30	28	30
No. 30	15-30	21	22	22	21	20	21
No. 50		15	14	14	14	12	13
No. 100		9	9	9	9	7	8
No. 200	3-7	6.5	6.0	5.7	5.6	4.8	5.0
Binder Content %	design	5.5	5.5	6.0	6.0	7.5	7.5
	actual	5.4	5.4	5.8	5.6	7.1	7.3

*Extractions by California Test 310. California Standard Specification, Section 39, for dense graded asphalt concrete Type A, 1/2 inch maximum, coarse grading. Results are averages of windrow and core samples representing six samples.

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Table 13

SUMMARY OF TEST RESULTS OF TESTS ON 4 INCH CORES
(Baker Test Section - 08-SBd-15-NB Lanes)

Test	Test Method	Overlay Age (months)		Test Results (Average of 2 or more samples) AR-4000 Lane #1	AR-4000 Lane #2	AR-2000 Lane #1	AR-2000 Lane #2	SEA 20% Lane #1	SEA 20% Lane #2	SEA 20% Lane DBA	SEA 40% Lane #1	SEA 40% Lane #2
Stability (HVEEM)	Calif. Test 366	Original*	Regular	40		38		37		42	43	
			MVS***	38		38		38		41	39	
		10	Regular	22	25	26	28	26	25	26	26	26
			MVS	26	24	27	26	27	26	24	26	25
		28	Regular	27	27	25	26	23	34	31	25	28
			MVS	26	28	27	28	22	29	25	25	30
		54	Regular	30	29	26	31	30	31	29	28	31
			MVS	-	31	-	23	-	32	-	-	33
Cohesion	Calif. Test 306	Original	Regular	209		150		133		73	141	
			MVS	295		233		261		172	312	
		10	Regular	99	76	91	70	83	115	88	95	151
			MVS	156	140	102	92	92	100	97	148	155
		28	Regular	105	154	149	187	157	115	171	193	225
			MVS	-	-	-	-	-	-	-	-	-
		54	Regular	156	158	80	88	123	101	74	151	160
			MVS	-	454	-	423	-	288	-	-	452
Specific Gravity (waxed)	Calif. Test 308	Original	Regular	2.28		2.26		2.26			2.28	
		10	Regular	2.23	2.21	2.22	2.22	2.21	2.24	2.22	2.24	2.27
			MVS	2.20	2.19	2.25	2.24	2.20	2.22	2.18	2.22	2.24
		28	Regular	2.22	2.24	2.23	2.27	2.18	2.25	2.21	2.25	2.31
			MVS	2.21	2.22	2.22	2.20	2.15	2.22	2.20	2.24	2.28
		54	Regular	2.25	2.29	2.25	2.28	2.25	2.28	2.20	2.26	2.32
			MVS	-	2.24	-	2.22	-	2.24	-	-	2.28
Surface Abrasion (grams loss)	Calif. Test 360 Method B	Original		46.2		43.1		44.4		75.1	35.9	
		10		31.5	33.5	23.7	26.9	34.1	24.8	37.6	22.9	20.0
		28		32.0	27.0	34.7	26.3	46.4	36.6	43.1	29.5	28.1
		54		27.9	26.6	28.8	21.7	35.0	38.8	-	34.2	24.8
Moisture Vapor Susceptibility (MVS) (% moisture absorbed)	Calif. Test 307	Original		0.30		0.23		0.30		0.30	0.26	
		10		0.5	0.4	0.4	0.6	0.5	0.4	0.4	0.4	0.4
		28		-	-	-	-	-	-	-	-	-
		54		-	0.3	-	0.4	-	0.4	-	-	0.4

* Windrow mix was laboratory compacted to method density, field cores as received.
** Deficient Binder Area.
***On cores subjected to MVS Test (Calif. Test 307)

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Table 14

SUMMARY OF TEST RESULTS OF TESTS ON 4 INCH CORES
(Benton T.S. - 06-Mno-6-24.5/25.5)

Test	Test Method	Overlay Age (months)		Test Results (Average of 2 or more samples) AR-2000 NB	AR-2000 SB	SEA 20% NB	SEA 20% SB	SEA 40% NB	SEA 40% SB
Stability (HVEEM)	Calif. Test 366	Original*	Regular	40		41		42	
			MVS**	31		37		40	
		11	Regular	32	33	30	28	31	38
			MVS	29	32	28	29	33	36
		36	Regular	29	38	23	30	29	38
			MVS	26	29	31	29	34	34
Cohesion	Calif. Test 306	Original	Regular	170		211		228	
			MVS	259		304		-	
		11	Regular	154	158	150	143	196	217
			MVS	331	225	225	272	336	350
		36	Regular	235	153	273	159	328	231
			MVS	395	345	245	265	426	274
Specific Gravity (waxed)	Calif. Test 308	Original	Regular	2.32		2.34		2.31	
			MVS	-		-		-	
		11	Regular	2.27	2.29	2.30	2.29	2.31	2.31
			MVS	2.27	2.28	2.28	2.28	2.30	2.32
		36	Regular	2.27	2.31	2.30	2.30	2.30	2.34
			MVS	2.22	2.25	2.25	2.24	2.26	2.30
Surface Abrasion (grams loss)	Calif. Test 360 Method B	Original		34.0		35.8		37.6	
		11		19.8	19.6	25.8	26.6	28.0	27.1
		36		24.0	25.7	24.9	26.7	29.6	26.1
Moisture Vapor Susceptibility (MVS) (% moisture absorbed)	Calif. Test 307	Original		0.20		0.20		0.23	
		11		0.35	0.35	0.65	0.35	0.45	0.15
		36		0.10	-	0.0	0.40	0.10	0.30

* Windrow mix was laboratory compacted to method density, field cores as received.
** On cores subjected to MVS Test (California Test 307)

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Table 15

ASH AND SULFUR CONTENT DATA*

Test Section	Binder Designation	% Ash			% Sulfur		
		Original Binders	Windrow Recoveries	Aged** Recoveries	Original Binders	Windrow Recoveries	Aged** Recoveries
BAKER	AR-4000	0.10	0.60	0.78	2.3	1.6	1.6
	AR-2000	0.14	0.73	1.44	2.6	1.9	1.6
	SEA 20%	0.04	0.65	1.30	24.0	19.5	20.7
	SEA 40%	0.15	0.82	1.20	42.9	18.9	20.5
BENTON	AR-2000	-	0.85	0.67	2.0	2.0	1.8
	SEA 20%	-	0.74	0.68	18.9***	19.3	19.7
	SEA 40%	-	0.59	0.55	29.2***	19.9	22.2

* Ash Determinations - ASTM D482-80 (Ash from petroleum products).
Sulfur Determinations - LECO Induction Furnace method for petroleum products.
Test results - Average of 1 to 3 samples.

** Baker T.S. aged residues - 54 month coring
Benton T.S. aged residues - 36 month coring

***Original SEA binders from Benton represent job asphalt laboratory mixed with 20% and 40% by wt. No sampling of production SEA binders was possible.

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Table 16

SUMMARY OF TEST RESULTS OF RECOVERED BINDER RESIDUES* - BAKER TEST SECTION

Test on Residue	Test Method No. AASHTO	Overlay Age (months)	Test Results (Avg. of 2 or more samples.) AR-2000 #1 Lane	AR-2000 #2 Lane	SEA 20% #1 Lane	SEA 20% #2 Lane	SEA 20% #2** Lane D.B.A.	SEA 40% #1 Lane	SEA 40% #2 Lane	AR-4000 #1 Lane	AR-4000 #2 Lane
Absolute Viscosity at 140°F (poise)	T-202	Orig.	2675		1101		1828	1103		4447	
		10	4402	4400	1810	1909	2171	1797	1849	9314	10904
		28	6653	9285	8241	4027	7035	3390	2699	16415	26360
		54	11495	9728	9371	7631	8837	6544	5424	35256	39100
Kinematic Viscosity at 275°F (cst)	T-201	Orig.	356		155		161	154		445	
		10	396	431	190	199	200	165	167	564	590
		28	499	580	389	242	299	230	203	707	881
		54	595	565	342	362	327	306	334	915	980
Penetration at 77°F (dmm)	T-49	Orig.	40		68		51	70		27	
		10	31	30	53	50	46	51	53	21	19
		28	27	21	24	32	29	33	40	18	13
		54	22	22	22	27	26	27	26	13	13
Softening Point (°F)	T-53	Orig.	127		121		125	121		131	
		10	131	131	123	125	127	123	124	139	139
		28	134	135	136	129	132	129	125	139	145
		54	139	142	140	139	140	138	136	151	154
Ductility at 77°F (cm)	T-51	Orig.	100+		100+		100+	100+		100+	
		10	100+	100+	100+	98	64	88	96	100+	100+
		28	100+	100+	67	81	33	100+	100+	18	13
		54	91	87	37	24	39	72	71	10	10

*Original mix from windrow, remaining samples from 12-inch cores.
Test on binder residue recovered by California Test 380 (Abson recovery).

Table 17

SUMMARY OF RECOVERED BINDER*
TEST RESULTS - BENTON T.S.

Test on Residue	Test Method No. AASHTO-	Overlay Age (months)	Test Results of Binders (Average of two or more). AR-2000 NB Lane	AR-2000 SB Lane	SEA 20% NB Lane	SEA 20% SB Lane	SEA 40% NB Lane	SEA 40% SB Lane
Absolute Viscosity at 140°F (poise)	T202	Orig.	2025		1477		1605	
		10	4848	5202	2775	2871	2813	2205
		36	9835	7702	6262	5323	7089	6686
Kinematic Viscosity at 275°F (cst)	T201	Orig.	293		154		150	
		10	443	440	214	230	207	189
		36	560	540	382	453	296	277
Penetration at 77°F (dmm)	T49	Orig.	50		56		57	
		10	30	27	40	41	39	44
		36	23	25	27	30	27	27
Penetration at 39.2°F (dmm)		Orig.	15		16		17	
		36	8	9	13	14	11	12
Softening Point (°F)	T53	Orig.	123		122		121	
		10	131	133	127	128	127	127
		36	136	134	135	132	135	134
Ductility at 77°F (cm)	T51	Orig.	150+		94		84	
		10	100+	100+	92	83	100+	82
		36	100+	100+	53	68	40	51

*Original Mix - from windrow, remaining samples 12 inch cores. Test on binder residues recovered by California Test 380 (Abson recovery).

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Table 18

COMPARISON OF TEST RESULTS OF ABSON* RECOVERED RESIDUES FROM THE BAKER AND BENTON T.S.

Test	Overlay Age ** (months)	Test Result - (Averages) AR-4000 Baker	AR-4000 Benton	AR-2000 Baker	AR-2000 Benton	SEA 20% Baker	SEA 20% Benton	SEA 40% Baker	SEA 40% Benton
Absolute Viscosity 140°F (poise)	Orig.	4744	-	2675	2025	1101	1477	1103	1605
	10/11	10109	-	4401	5025	1859	2823	1823	2509
	28/36	21387	-	7969	8768	6134	5792	3044	6887
	54	37178	-	10611	-	8501	-	5984	-
Kinematic Viscosity at 275°F. (centistokes)	Orig.	445	-	356	293	155	154	154	150
	10/11	577	-	413	441	194	222	166	198
	28/36	794	-	539	550	315	417	217	281
	54	947	-	580	-	352	-	320	-
Penetration at 77°F (dmm)	Orig.	27	-	40	50	68	56	70	57
	10/11	20	-	31	29	52	40	52	42
	28/36	16	-	24	24	28	29	36	30
	54	13	-	22	-	24	-	27	-
Softening Point (°F)	Orig.	131	-	127	123	121	122	121	121
	10/11	139	-	131	132	124	127	123	127
	28/36	142	-	134	135	133	134	127	135
	54	152	-	140	-	139	-	137	-
Ductility at 77°F (cm)	Orig.	100+	-	100+	100+	100+	94	100+	84
	10/11	100+	-	100+	100+	99	88	92	91
	28/36	16	-	100+	100+	74	61	100+	46
	54	10	-	89	-	30	-	72	-
PVN***	Orig.	-1.103		-1.115	-1.077	-1.249	-1.228	-1.206	-1.121

* Abson Recovery - California Test 380 - Test results are the combining of both lanes. Test results listed in Tables 16 and 17.

**Overlay Age = Baker/Benton

***PNV on penetration (dmm) at 77°F and absolute viscosity (poise) at 140°F.

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Table 19

COMPARISON OF FIELD RESIDUE TEST RESULTS TO CATOD* TEST RESULTS

Test on Residue	Test Method AASHTO	Site	Test Results on Residue (Averages) AR-4000 Field**	AR-4000 CATOD	AR-2000 Field	AR-2000 CATOD	SEA 20% Field	SEA 20% CATOD	SEA 40% Field	SEA 40% CATOD
Absolute Viscosity at 140°F (poise)	T202	Baker	37,178	102,601	10,611	83,592	8,613	348,518	5,984	90,326
		Benton			8,768	101,468	5,792	541,225	6,887	122,346
Kinematic Viscosity at 275°F (centistokes)	T201	Baker	947	1,435	580	1,240	344	1,305	320	680
		Benton			550	1,375	417	1,875	281	657
Penetration at 77°F (dmm)	T49	Baker	13	9	22	12	25	11	26	14
		Benton			24	12	29	11	30	14
Softening Point (°F)	T53	Baker	153	158	141	158	140	167	137	160
		Benton			135	152	133	163	135	155
Ductility at 77°F (cm)	T51	Baker	10	6	89	7	33	2	71	2
		Benton			100+	5	60	1	45	1

* Field residue test results on Abson recovery residue (California Test 380).
CATOD = California Tilt-Oven Durability (California Test 374) predicts effects of approximately two years in hot desert climate.

**Field results = Baker, 54 months, Benton, 36 months.

Table 20

CRACK SURVEY DATA SUMMARY*
(Baker T. S.)

LANE #1

Section	Length (feet)	Orig. 3-82	11 mo. 3-83	17 mo. 2-84	22 mo. 7-84	43 mo. 5-86	54 mo. 3-87	66 mo. 3-88
AR-4000 (control)	2,000	1590	0	0	0	0	0	0
	% of Total Length Cracked	79.5	0	0	0	0	0	0
	No. of Transverse Cracks	19	0	0	0	0	0	0
	% Reflected	-	0	0	0	0	0	0
AR-2000 (control)	3,600	2755	0	0	0	0	0	70
	% of Total Length Cracked	76.5	0	0	0	0	0	1.9
	No. of Transverse Cracks	13	0	0	0	0	0	0
	% Reflected	-	0	0	0	0	0	0
SEA 20%	2,400	366	0	0	0	0	0	0
	% of Total Length Cracked	15.3	0	0	0	0	0	0
	No. of Transverse Cracks	7	0	0	0	0	0	0
	% Reflected	-	0	0	0	0	0	0
SEA 40%	2,400	1070	0	0	0	0	0	1
	% of Total Length Cracked	44.6	0	0	0	0	0	0
	No. of Transverse Cracks	15	0	0	0	0	0	1
	% Reflected	-	0	0	0	0	0	6.6

LANE #2

Section	Length (feet)	Orig. 3-82	11 mo. 3-83	17 mo. 2-84	22 mo. 7-84	43 mo. 5-86	54 mo. 3-87	66 mo. 3-88
AR-4000 (control)	2,000	1875	0	0	0	0	0	303
	% of Total Length Cracked	93.7	0	0	0	0	0	15.1
	No. of Transverse Cracks	14	0	0	0	0	0	1
	% Reflected	-	0	0	0	0	0	7.1
AR-2000 (control)	3,600	2555	0	0	0	0	0	75
	% of Total Length Cracked	71.0	0	0	0	0	0	2.1
	No. of Transverse Cracks	53	0	0	0	0	0	0
	% Reflected	-	0	0	0	0	0	0
SEA 20%	1,800 (1216)	1740	0	0	0	0	0	21
	% Total Length Cracked	96.6	0	0	0	0	0	1.7
	No. of Transverse Cracks	64 (27)	0	0	0	0	0	2
	% Reflected	-	0	0	0	0	0	7.4
	**DBA 1000 (1584)	765	0	0	0	122	**	**
	% of Total Length Cracked	76.5	0	0	0	7.7	**	**
	No. of Transverse Cracks	27 (64)	0	0	0	10	**	**
	% Reflected	-	0	0	0	15.6	**	**
SEA 40%	1,800	1625	0	0	0	0	1	118
	% of Total Length Cracked	90.3	0	0	0	0	0.1	6.6
	No. of Transverse Cracks	54	0	0	0	0	1	3
	% Reflected	-	0	0	0	0	1.9	5.5

* Cracking as represented in this table indicated all cracking per running foot of roadway including longitudinal, transverse, and alligator cracking. Original survey performed prior to Sept. 1982 overlay construction date. Time period indicate months after overlaying.

** DBA = Deficient Binder Area - defined area from PM 108.96 to PM 109.15 - after the 43 mo. survey, a chip seal was placed on the #2 lane from PM 109.0 to 109.3 covering the DBA area and an adjoining unstable area of regular SEA 20%. Lengths in ( ) represent lengths of areas for 5-86 and following.

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Table 21

CRACK SURVEY DATA SUMMARY*
(Benton T.S.)

SB LANE

Section	Length (ft)	Orig. (8-83)	16 mo. (10-85)	24 mo. 6-86	28 mo. 10-86	46 mo. 3-88
AR-2000	2200'	2200'	0	40	71	291
(Control)	% of Total Length Cracked	100%	0	1.8	3.2	13.2
	No. Transverse Cracks	164	0	0	1	85
	% Reflected	-	0	0	0.6	51.8
SEA 20%	1250'	1250'	0	0	0	41
	% of Total Length Cracked	100%	0	0	0	3.3
	No. Transverse Cracks	90	0	0	0	31
	% Reflected	-	0	0	0	34.4
SEA 40%	1350'	1315'	9'	12	47	100
	% of Total Length Cracked	97.4%	0.7%	0.9	3.5	7.4
	No. of Transverse Cracks	74	9	12	12	35
	% Reflected	-	12.1%	16.2	16.2	47.3

NB LANE

Section	Length (ft)	Orig. (8-83)	16 mo. (10-85)	24 mo. 6-86	28 mo. 10-86	46 mo. 3-88
AR-2000	2200'	1830'	68'	143	145	1434
(Control)	% of Total Length Cracked	83.2%	3.1%	6.5	6.6	65.2
	No. Transverse Cracks	123	4	13	15	86
	% Reflected	-	3.3%	10.6	12.2	69.9
SEA 20%	1500'	1480'	1	1	2	114
	% of Total Length Cracked	98.7%	0.1%	0.1	0.1	7.6
	No. Transverse Cracks	82	1%	1	2	28
	% Reflected	-	1.2%	1.2	2.4	34.1
SEA 40%	1100'	798'	20'	27	27	85
	% of Total Length Cracked	72.5%	1.8%	2.5	2.5	7.7
	No. of Transverse Cracks	47	20	22	22	32
	% Reflected	-	42.5%	46.8	46.8	68.1

*Cracking as represented in this table indicates all cracking per running foot of roadway including longitudinal, transverse, and alligator cracking. Original survey performed prior to June 1984 overlay construction date. Time periods indicate months after overlaying.

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Table 22

Final Crack Survey Summary
(Baker 66 mo - Benton 46 mo)

Site	Section	Lane	Average Deflections (inches) 80th Percentile *	Overlay Thickness (feet)	Length of Section (feet)	Wheel Track Length of Alligator Cracking (feet)	% of Wheel Track Alligator Cracking	Number of Transverse Cracks	Number of Transverse Cracks/100 Feet	% Transverse Cracks Reflected See Table 20 & 21	Feet of Longitudinal Cracking	Type Longitudinal Cracking
Baker	SEA 40%	#1	0.007	0.19	2400	0	0	1	<1	6.6	0	-
		#2	0.012	0.21	1800	110	3.1	3	<1	5.5	0	-
	SEA 20%	#1	0.008	0.21	2400	0	0	0	0	0	0	-
		#2	0.012	0.23	1216	20	0.8	2	<1	7.4	0	-
	AR-2000	#1	0.010	0.22	3600	70	1.0	0	0	0	0	-
		#2	0.010	0.19	3600	75	1.0	0	0	0	0	-
	AR-4000	#1	0.006	0.21	2000	0	0	0	0	0	0	-
		#2	0.006	0.21	2000	7	0.2	1	<1	7.1	295	Edge
Benton	SEA 40%	NB	0.018	0.16	1100	50	2.3	32	2.9	68.1	135	CenterLine
		SB	0.021	0.26	1350	40	1.5	35	2.6	47.3	20	CenterLine
	SEA 20%	NB	0.025	0.18	1500	60	2.0	28	1.9	34.1	53	CenterLine
		SB	0.022	0.24	1250	5	0.2	31	2.5	34.4	0	-
	AR-2000	NB	0.024	0.14	2200	1370	31.1	86	3.9	69.9	30	CenterLine
		SB	0.020	0.26	2200	220	5.0	85	3.9	51.8	0	-

*Deflections after overlay.

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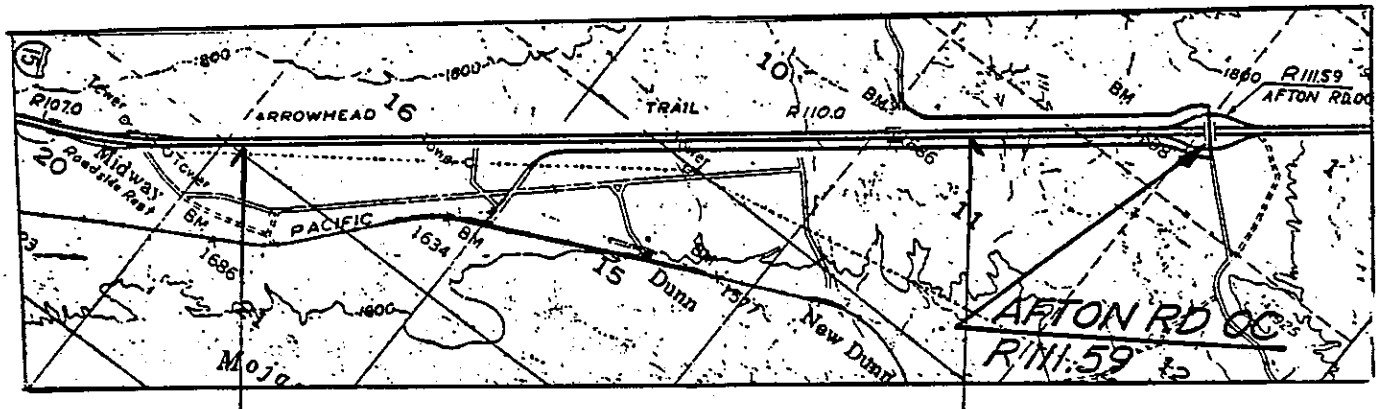
Table 23

Comparison of Mixing Viscosities and Temperature Susceptibility Measurements

Product (location)		*Viscosities (On Original and Abson Binder) Absolute Viscosity at 140°F (Poise) Orig.	Windrow	Kinematic Viscosity at 275°F (cst) Orig.	Windrow	*Stability (from Windrow) Hveem	Marshall (pounds)	*Temperature Susceptibility Measurements Pen Ratio	PVN
SEA 20%	Baker	486	1101	93	155	37	1840	24.3	-1.249
	Benton	499	1605	92	154	41	1430	23.1	-1.228
SEA 40%	Baker	333	1103	100	154	43	2617	24.6	-1.206
	Benton	553	1477	98	150	42	1790	22.0	-1.121
AR-2000 (control & blending asphalt*)	Baker	946	2675	196	356	38	1473	24.2	-1.115
	Benton	943	2025	219	293	40	1184	21.5	-1.077

*Absolute Viscosity - AASHTO T202
Kinematic Viscosity - AASHTO T201
Stability - California Test 366
Pen Ratio = penetration (AASHTO T49, dmm) at 39.2°F/penetration at 77°F x 100.
PVN = Penetration viscosity number, based on values of penetration at 77°F and absolute viscosity at 140°F.
Control and blending asphalt were the same AR-2000 asphalt.



BAKER TEST SECTION

Road 08-SBd-15-R101.0/139.0 Contract 08-228004

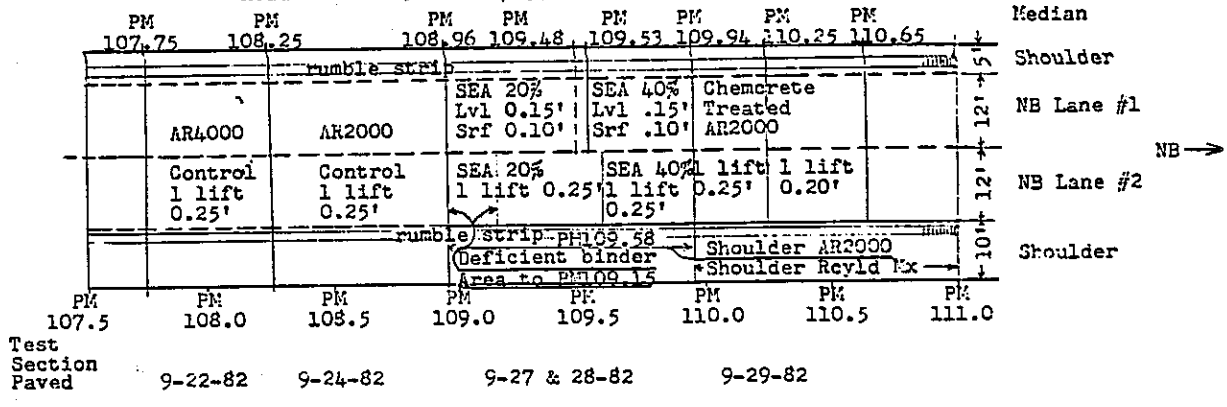


Figure 1

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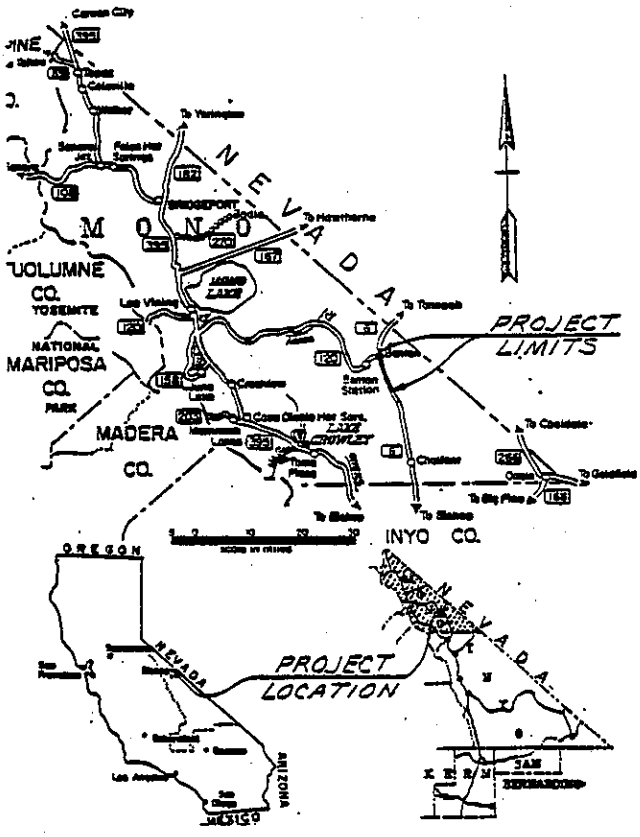

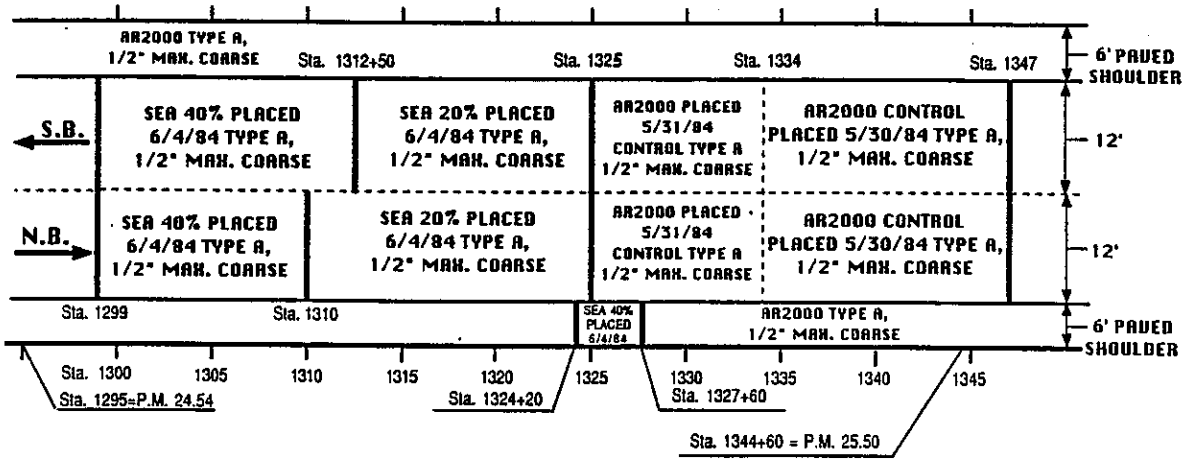

LAYOUT OF TEST SECTIONS
BENTON, CA - ROAD 09-MNO-6-18.2/26.4
CONTRACT 09-071004

Figure 2

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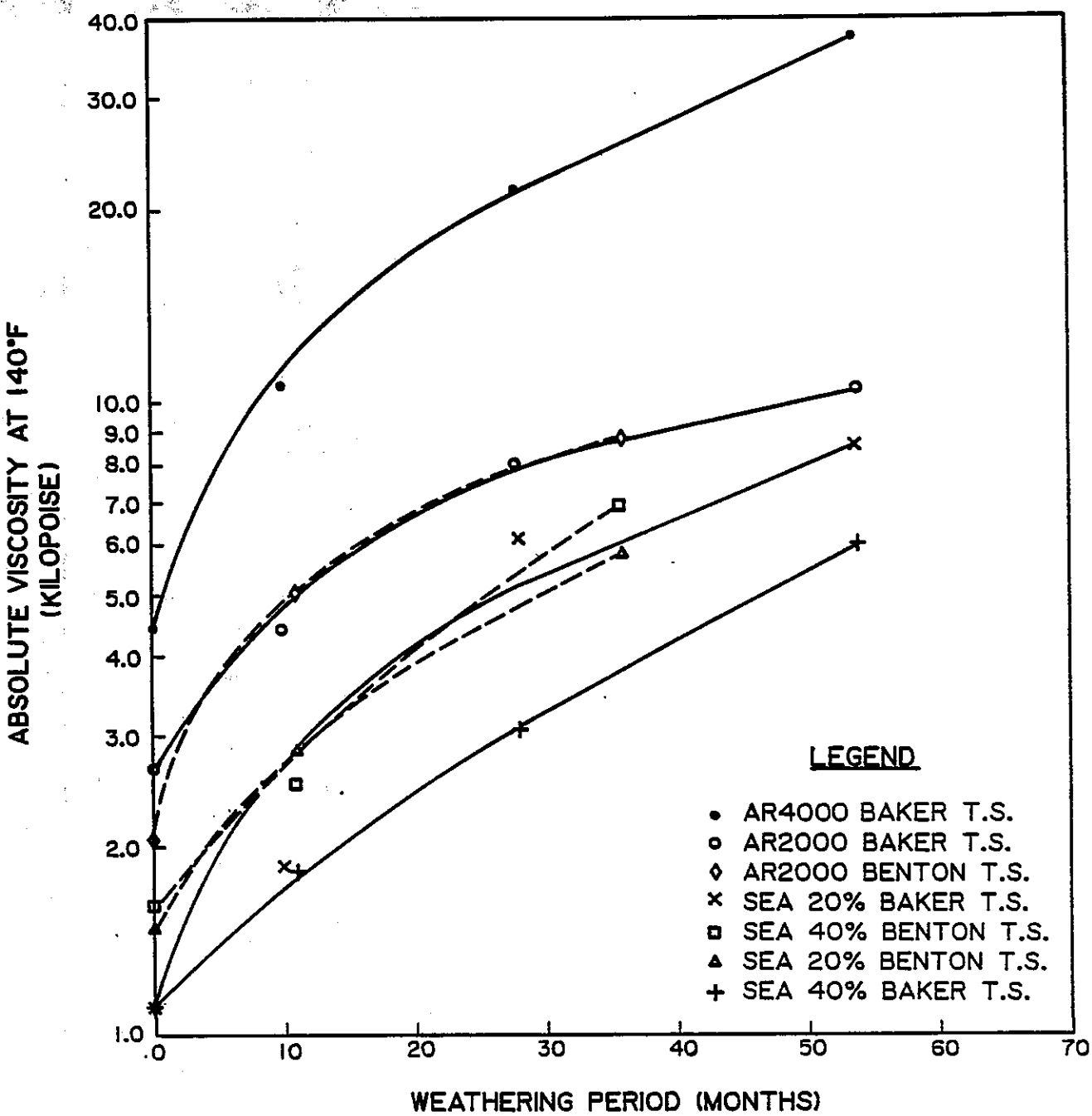

COMPARISON OF BINDER HARDENING RATES
OF BAKER AND BENTON
(ABSON RECOVERED RESIDUES)

Figure 3

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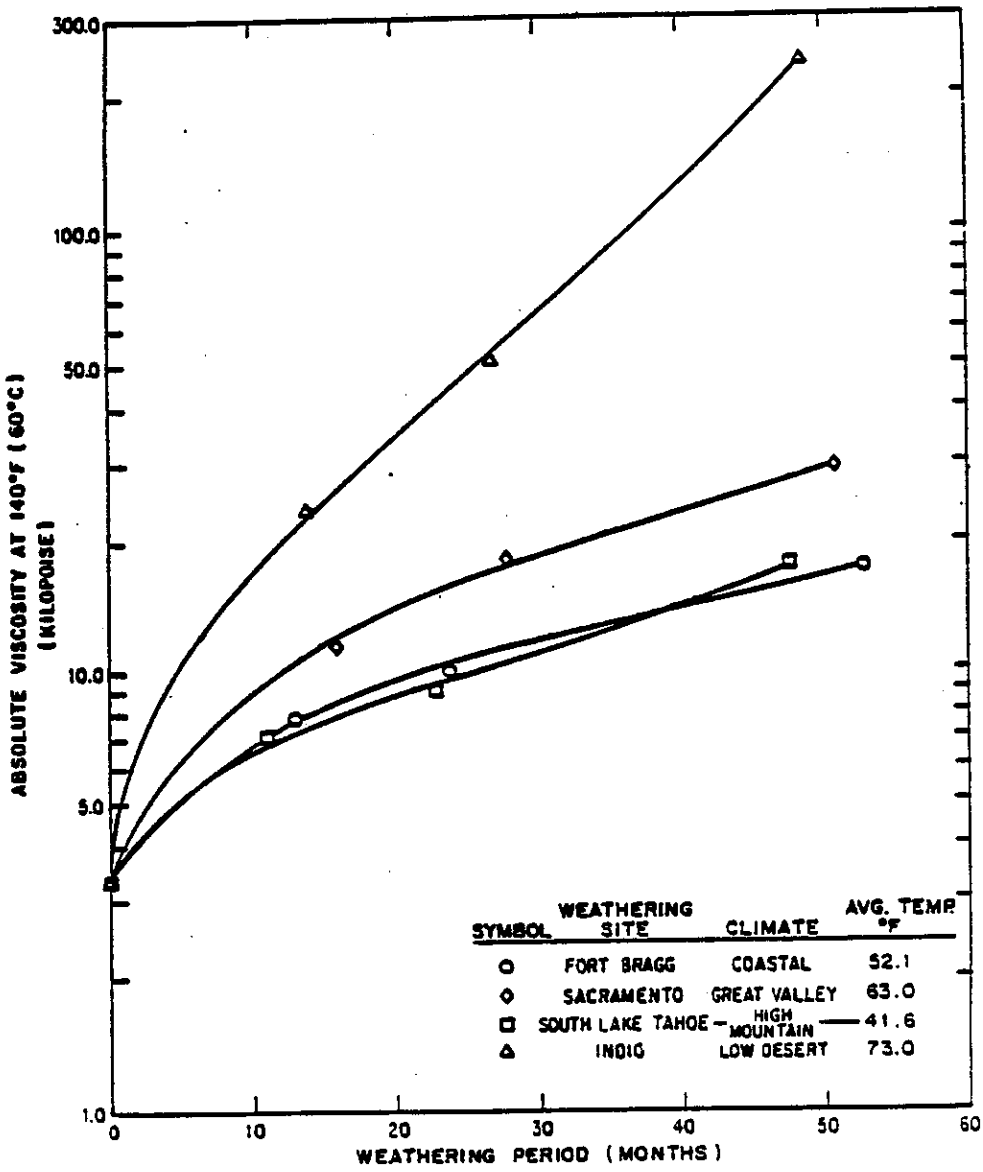

Fig.4, EFFECT OF CLIMATE ON HARDENING (4 CLIMATIC SITES)
COMBINED ASPHALTS, AGGREGATES & VOIDS AT 140°F (60°C)
(From AAPT Proceedings-Volume 50, page 503)

Figure 4

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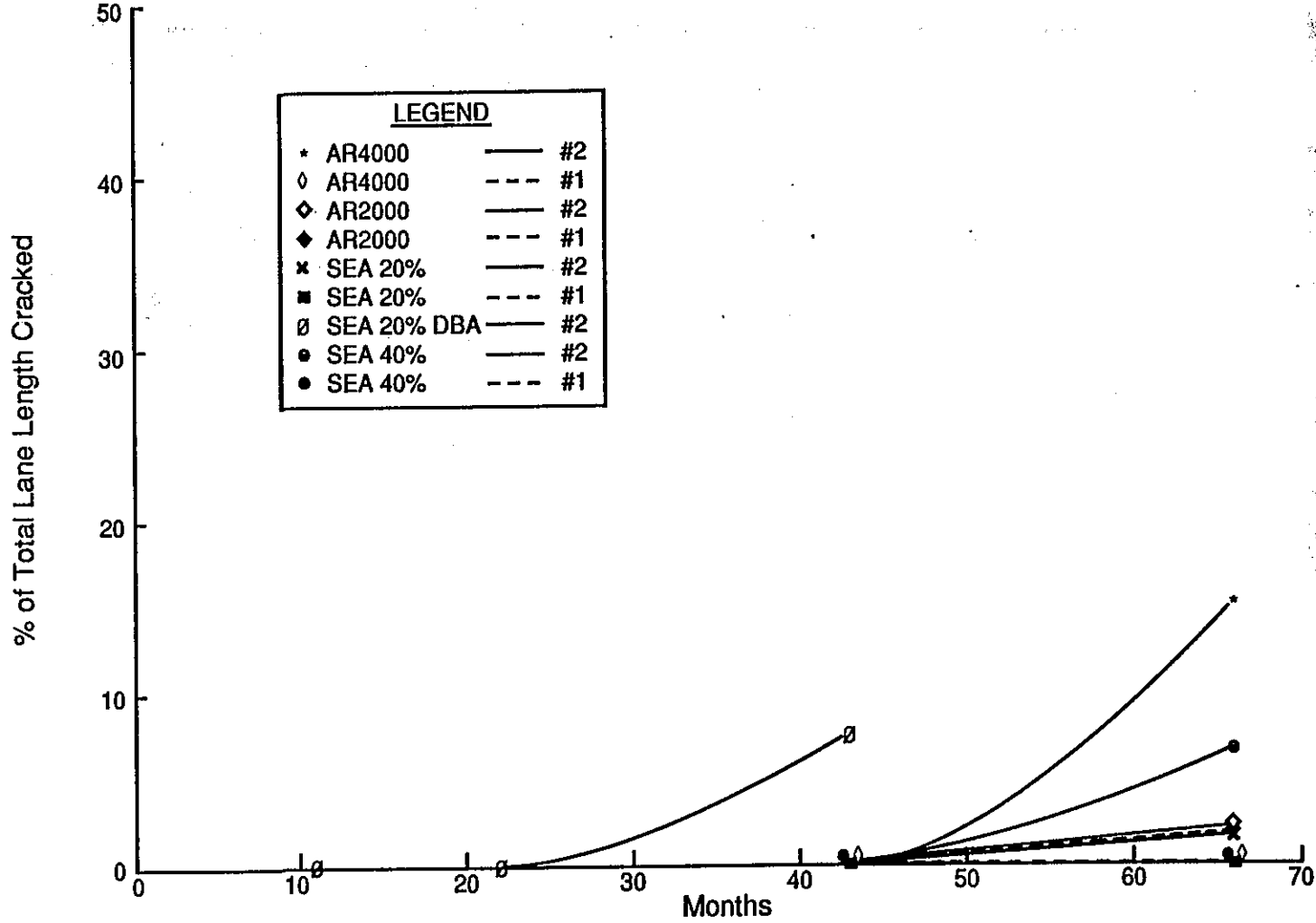
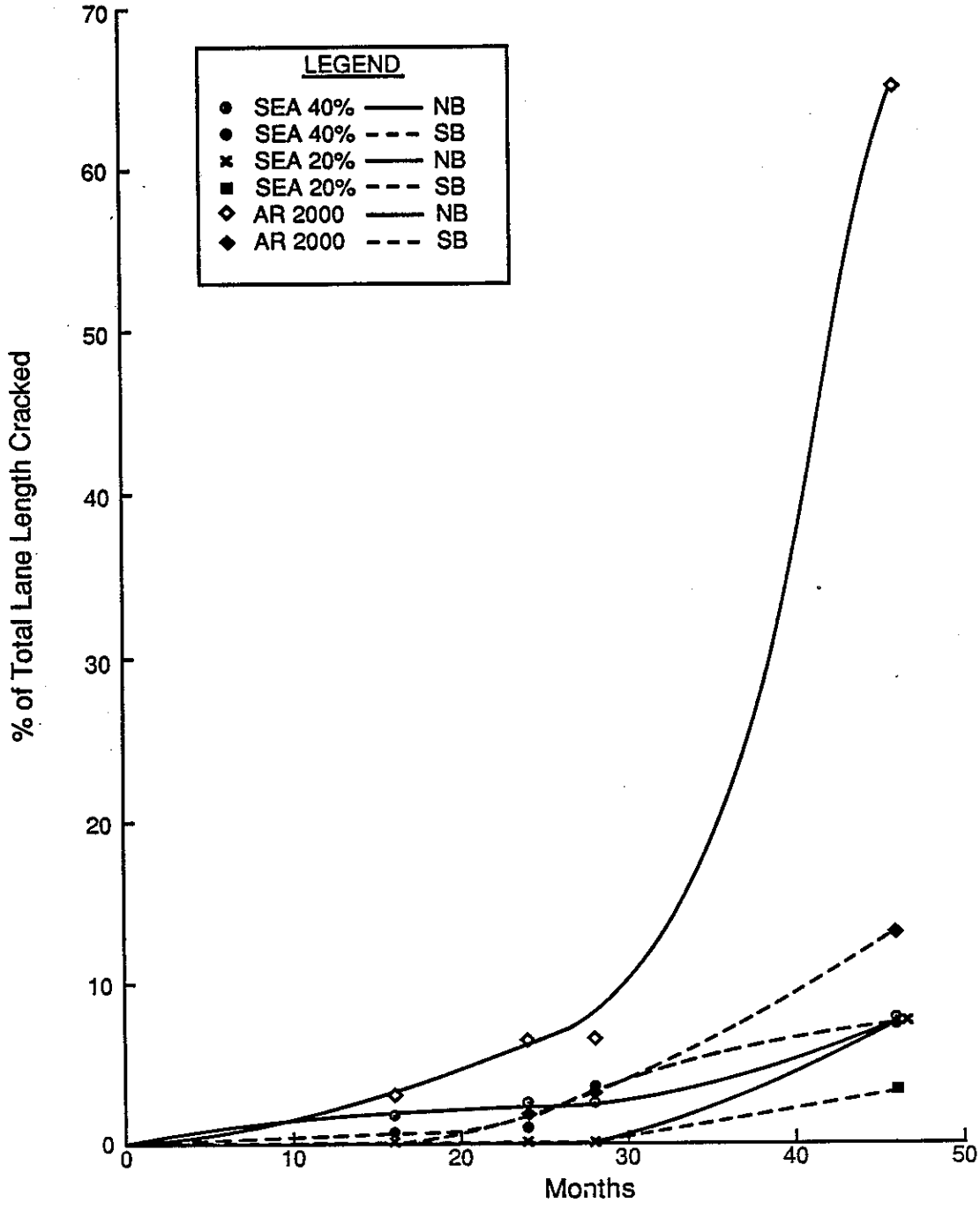


Baker Test Section
% of Total Lane Length Cracked

Figure 5



Benton Test Section
% of Total Lane Length Cracked

Figure 6

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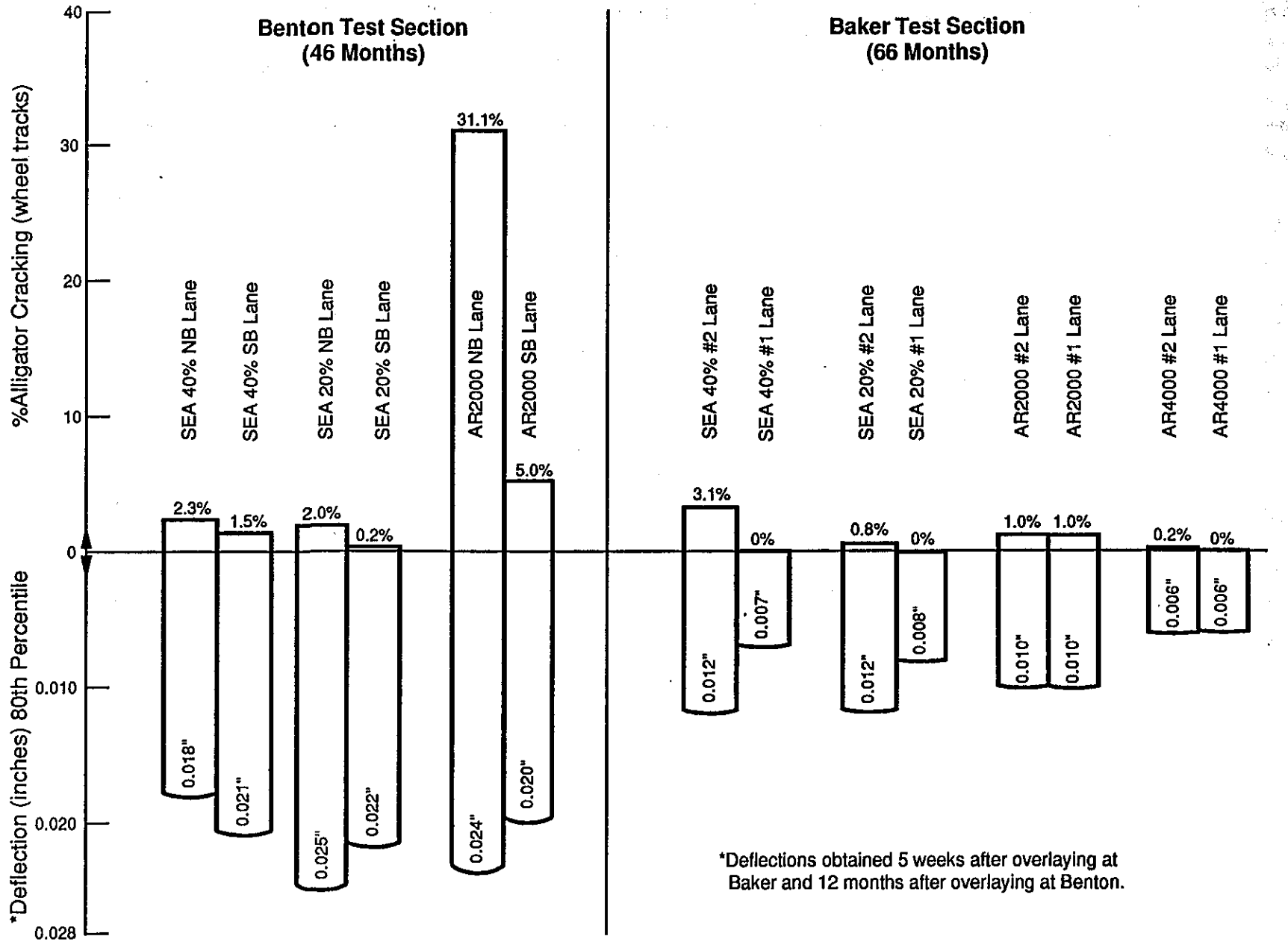
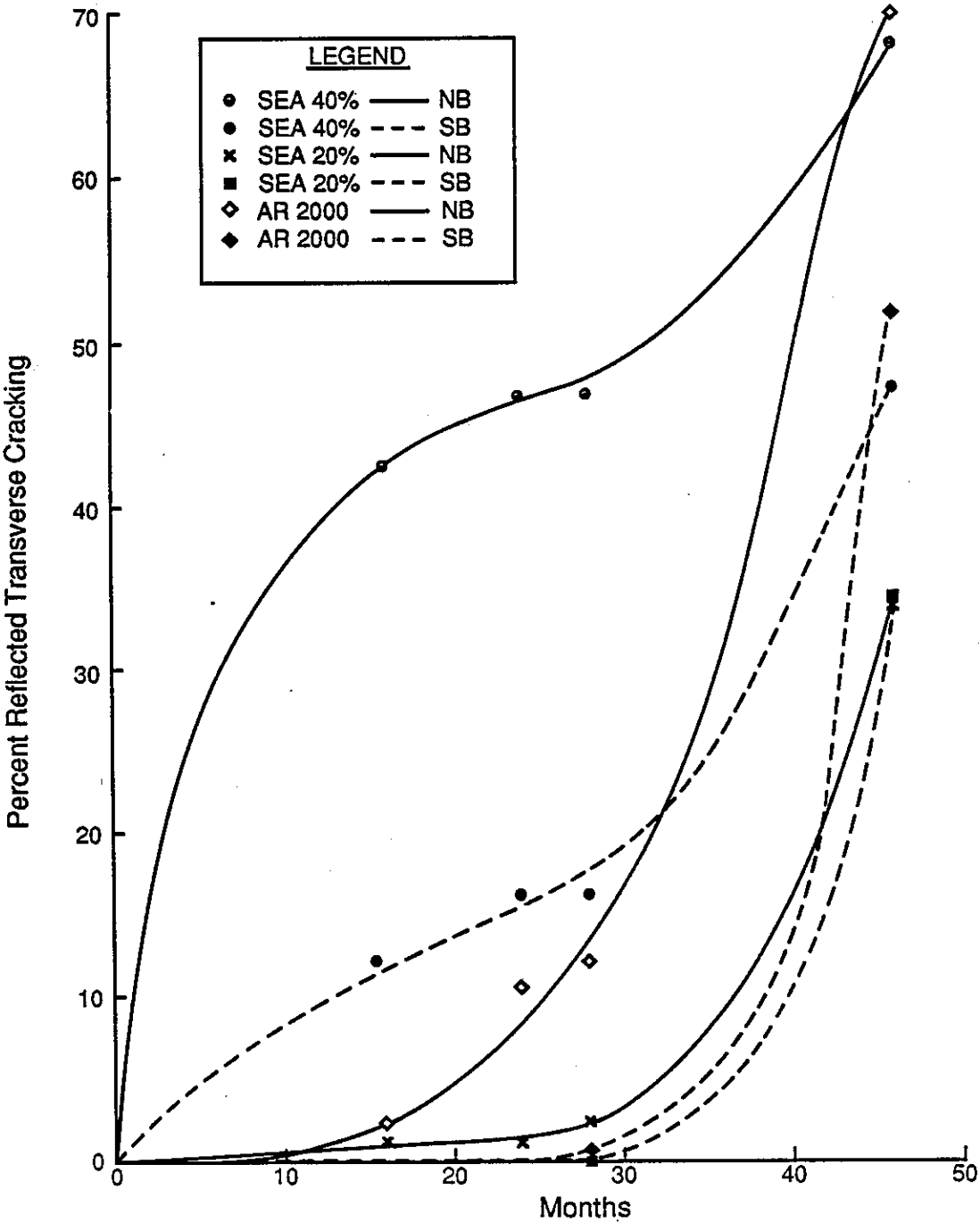


Comparison of % Alligator Cracking and Deflection Measurements at Baker and Benton Sites.

Figure 7



Benton Test Section
Reflected Transverse Cracks

Figure 8

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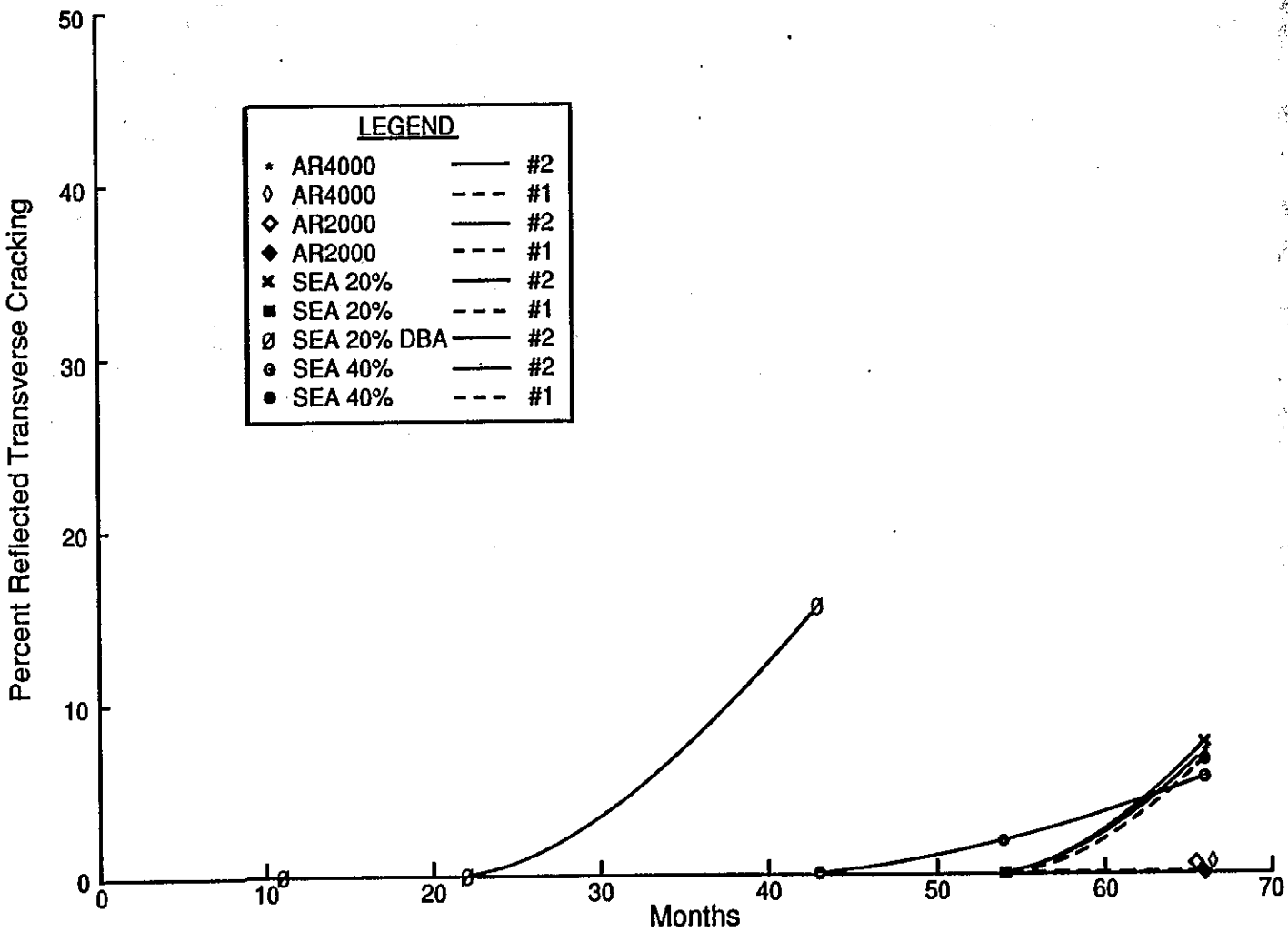
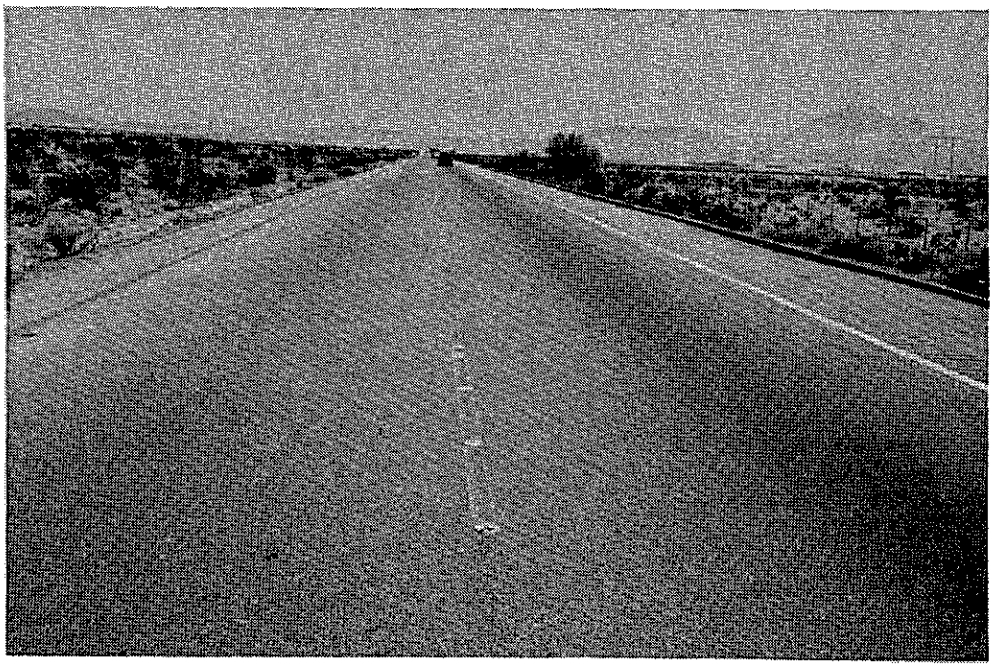


Baker Test Section
Reflected Transverse Cracks

Figure 9



East View

Close-up of No. 2 Lane

Baker Test Section
AR 4000 Section - 66 Months

Figure -10-

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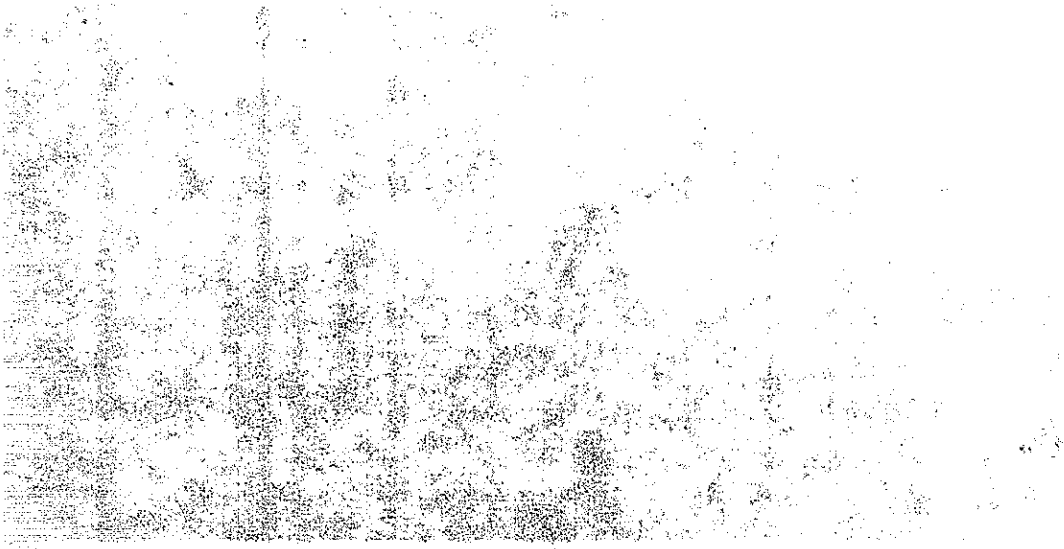

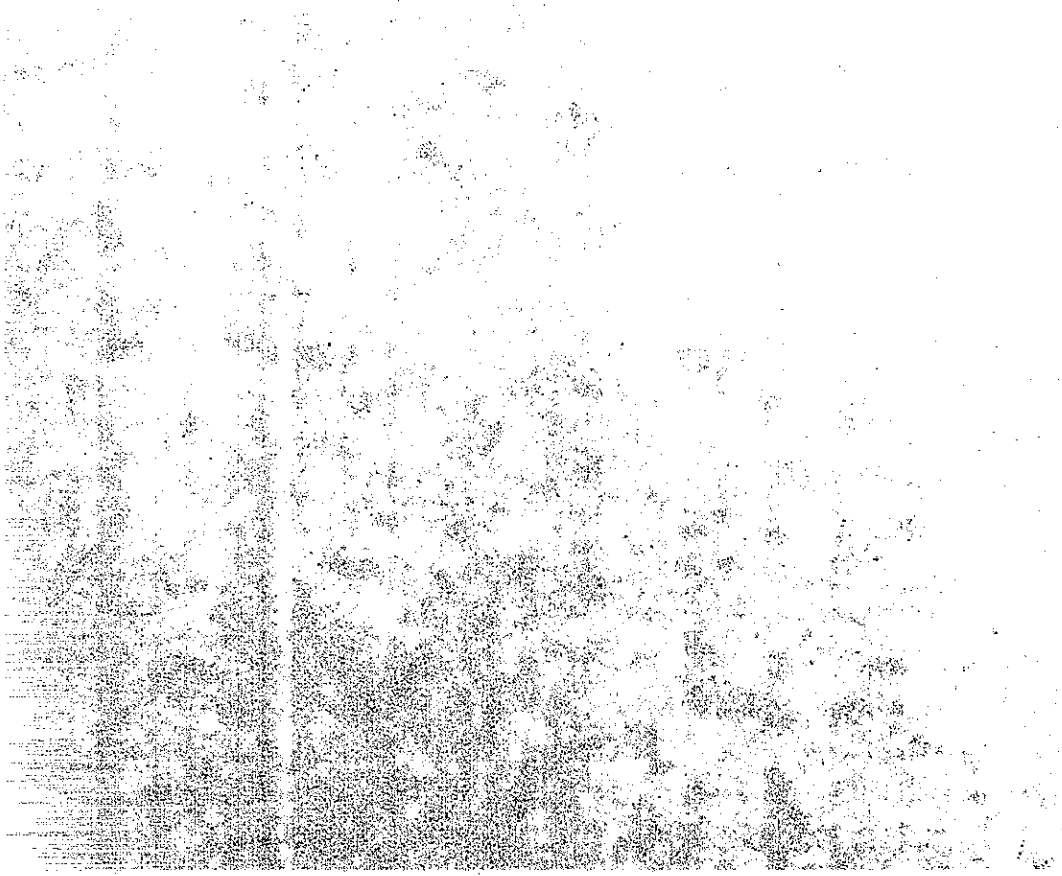

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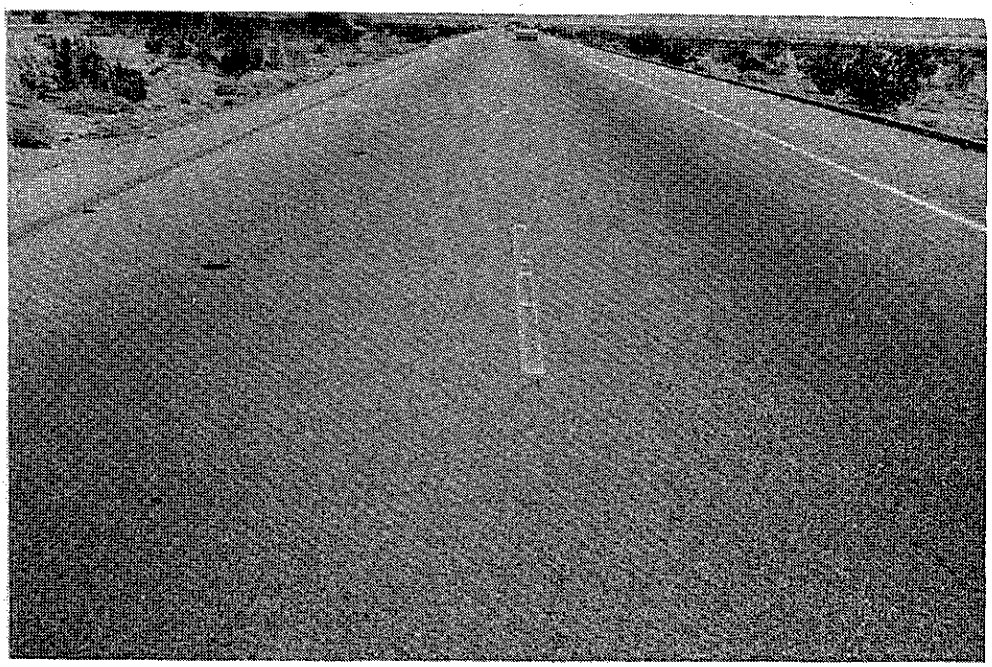
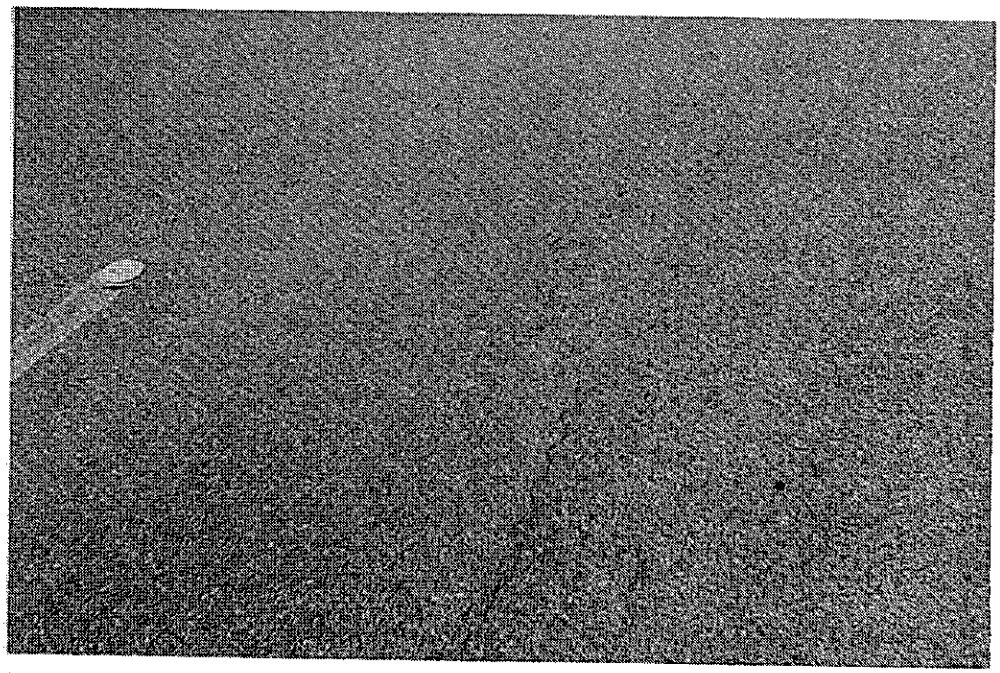


East View at Site of Alligator Cracking



Close-up of Alligator Cracking in No. 2 Lane

Baker Test Section
AR 2000 Section - 66 Months

Figure -11-

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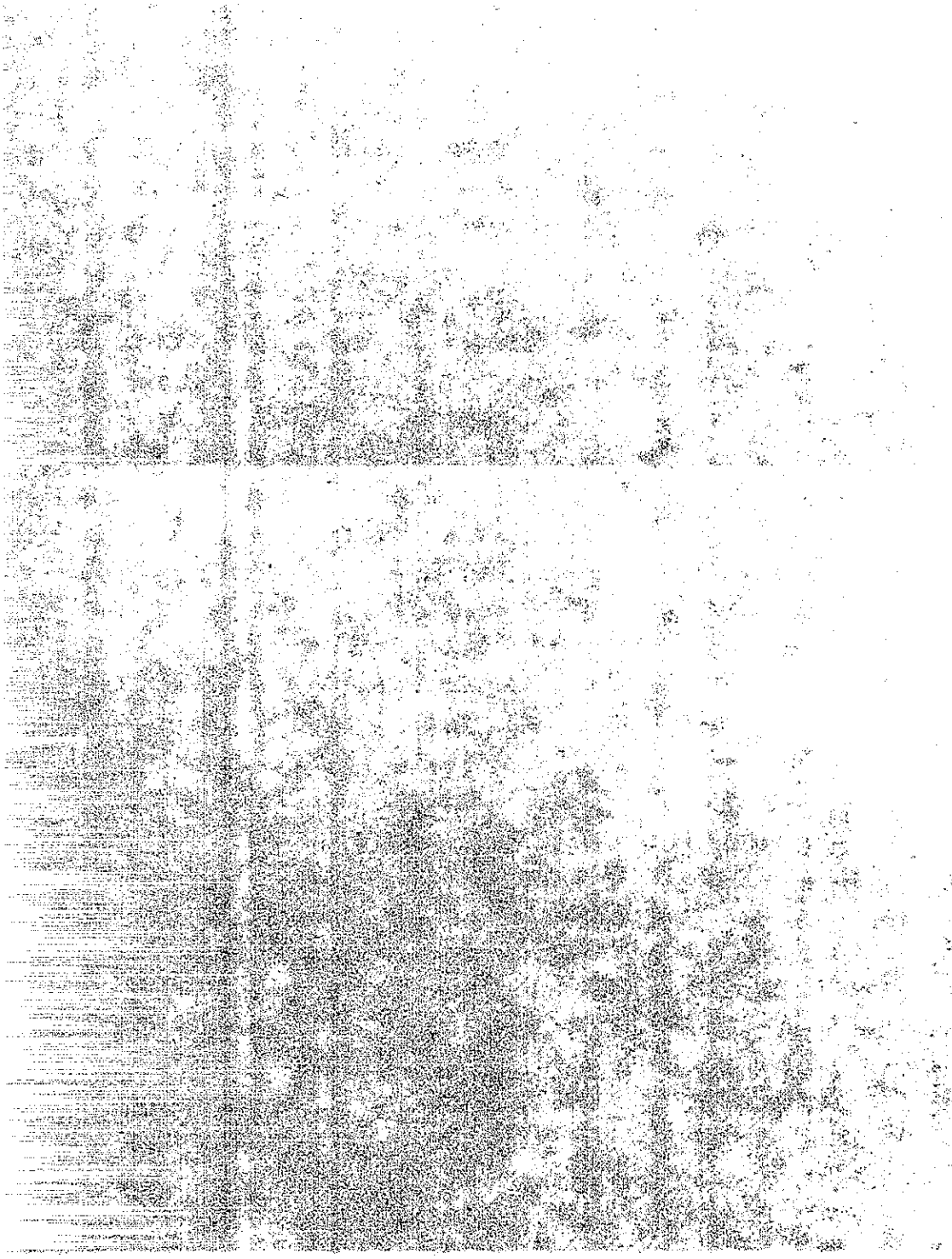

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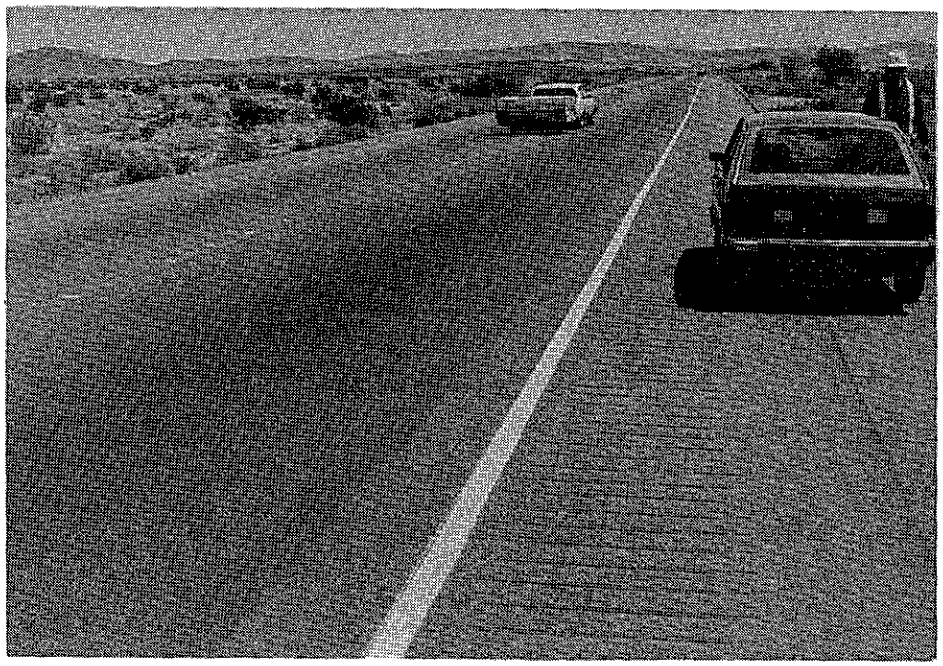
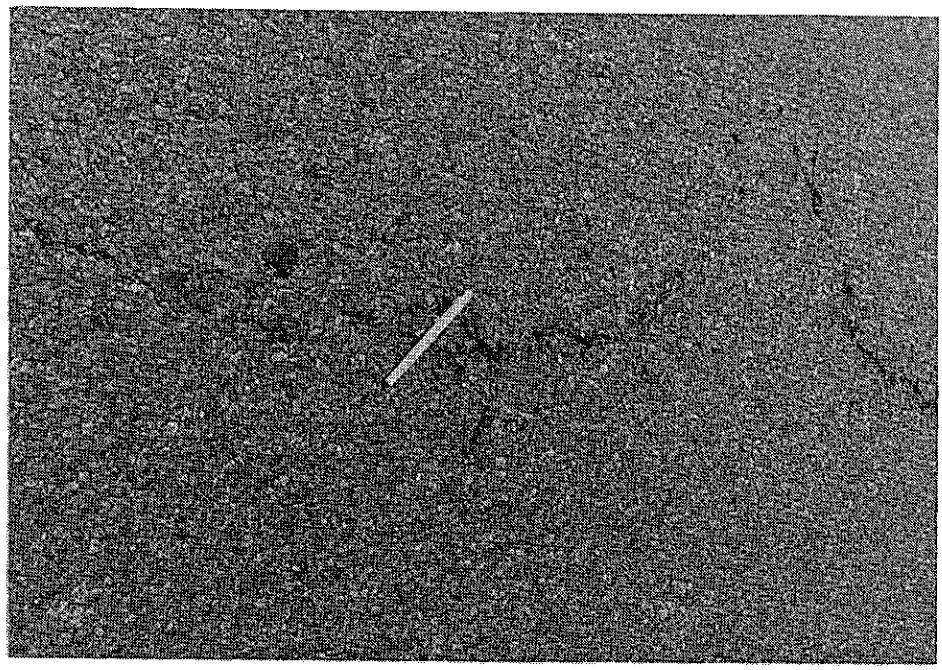


East View Showing Alligator Cracking



Close-up of Alligator Cracking

Baker Test Section
SEA 20% Deficient Binder Area
at 43 Months Prior to Chip Seal

Figure -12-

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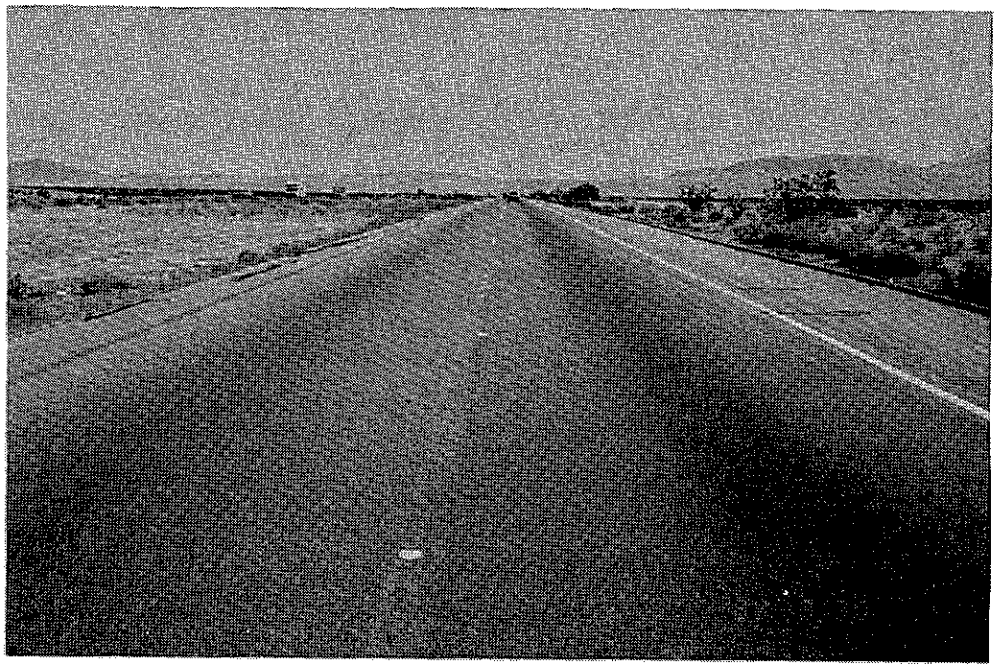
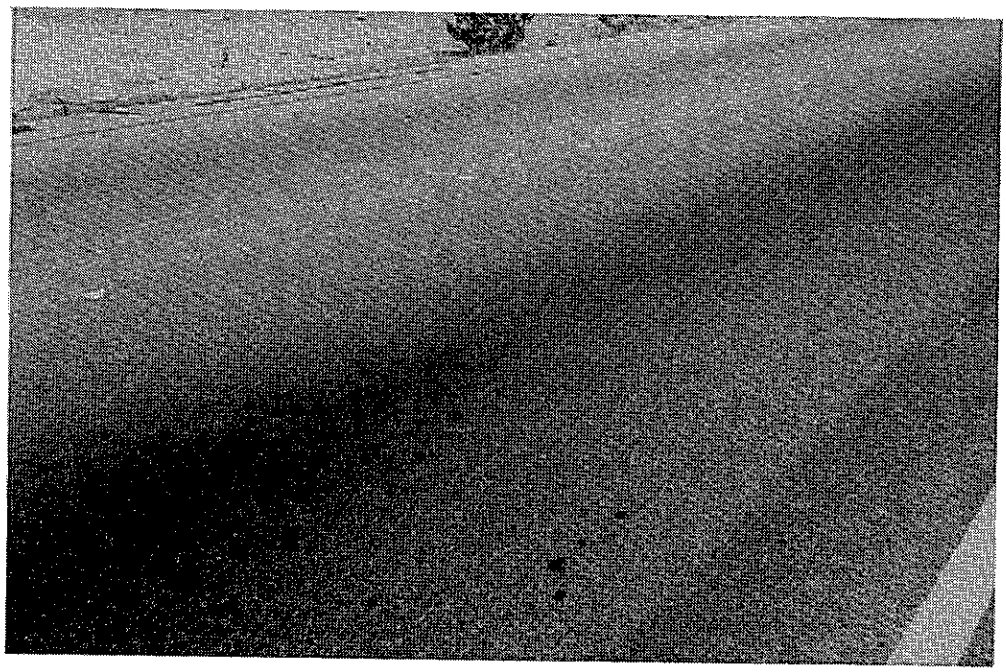


East View



Close-up of SEA 20% Across Lanes

Baker Test Section
SEA 20% Section - 66 Months

Figure -13-

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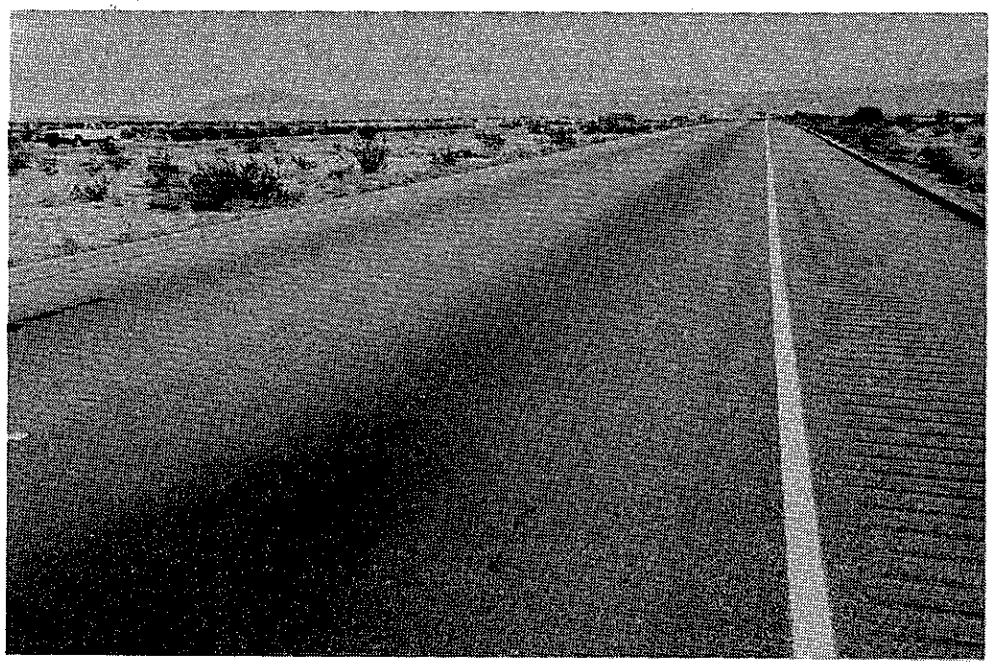

East View

Close-up at Site of Transverse Crack Starting From Shoulder

Baker Test Section
SEA 40% Section - 66 Months

Figure -14-

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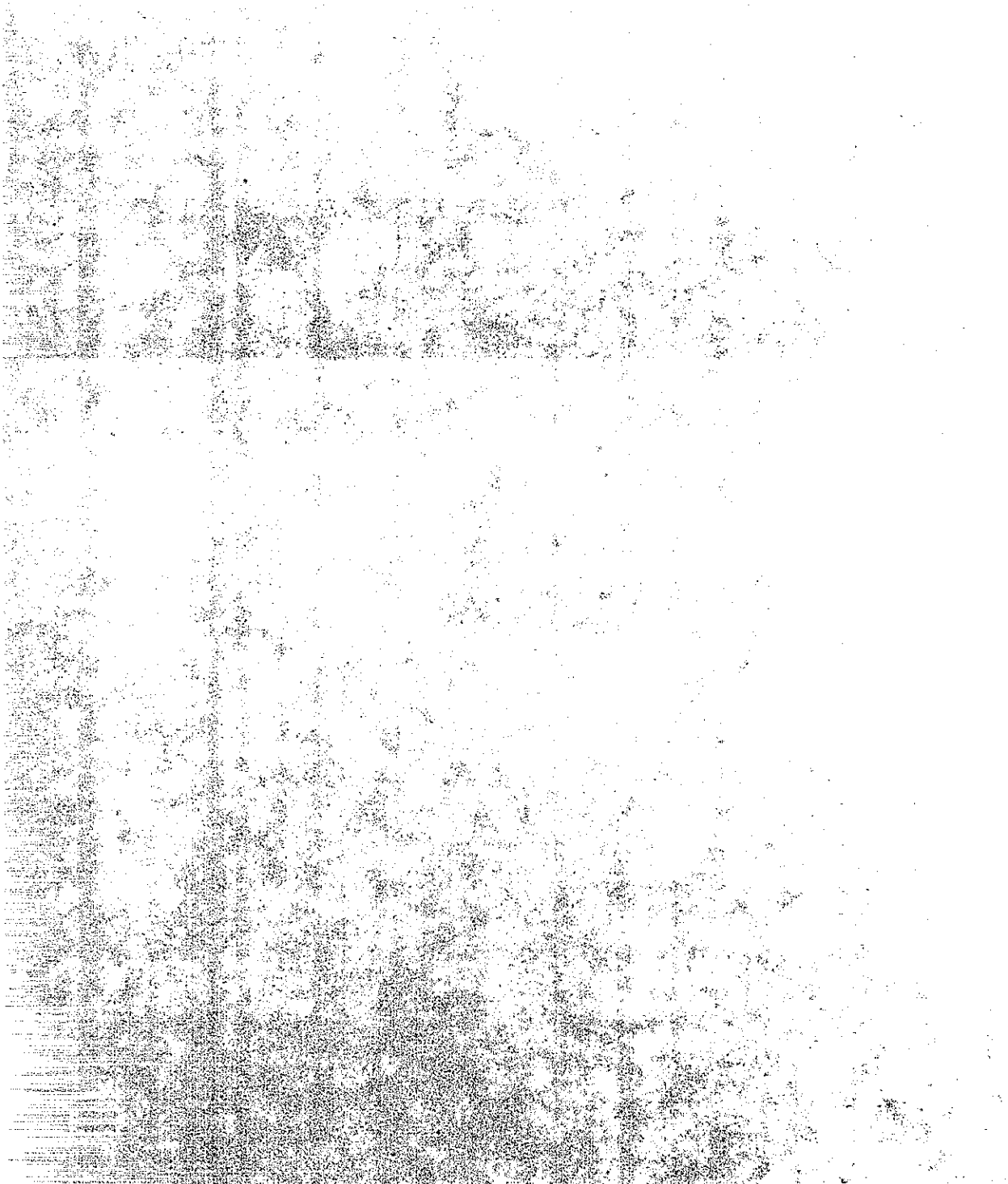

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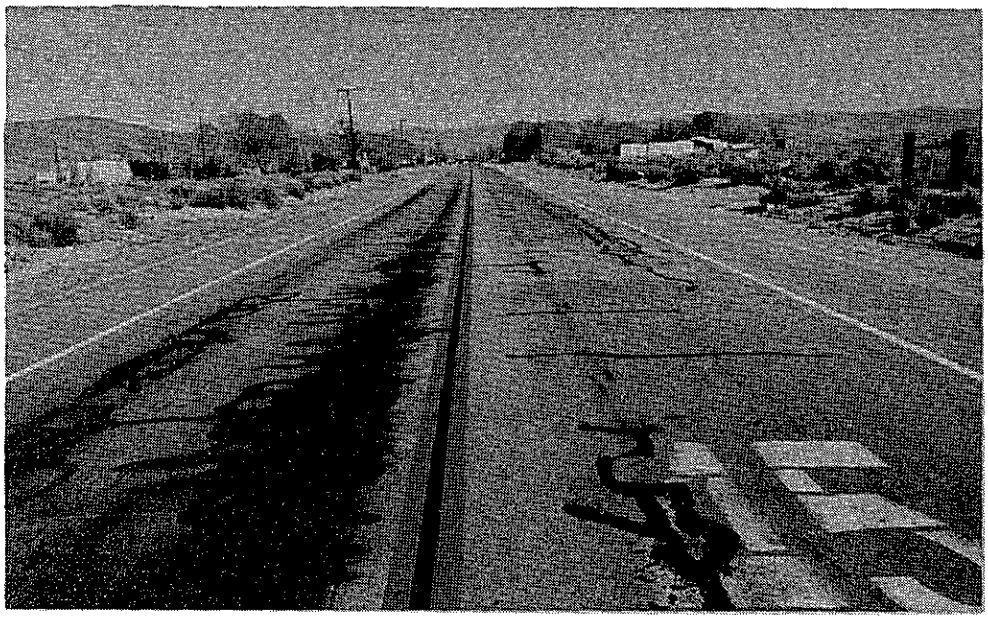
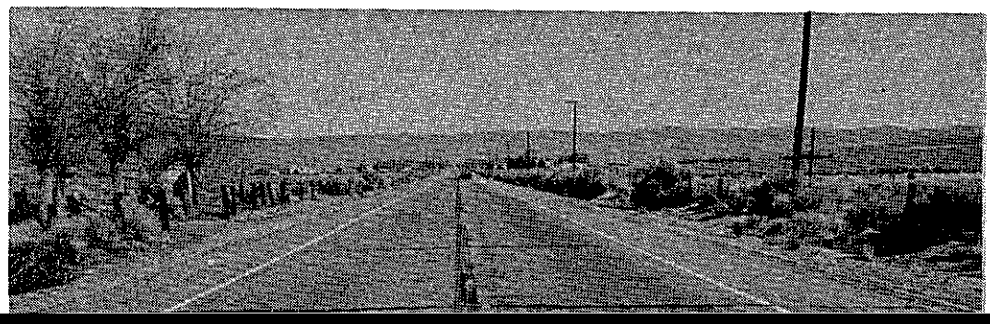


AR 2000
Section

SEA 20%
Section



SEA 40%
Section

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