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16. Abstract

ABSTRACT

This report is the final evaluation of a Sand-Asphalt-Sulfur Test Section that was constructed on US 77 in Kenedy County, Texas. The evaluation is based on laboratory tests, in-situ tests, and visual observations. This report is the last in a series of postconstruction reports that document the findings from interim testing.

SUMMARY

The Sand-Asphalt-Sulfur (SAS) mixture that was used as a pavement base material has performed very well. After 14 years of service, the SAS base subsections were still in very good condition with the exception of the 4 inch thick SAS subsection. The SAS subsections outperformed the conventional Type "D" HMAC subsections that were built as control sections for the SAS mixture. The HMAC subsections experienced severe rutting and cracking which ultimately led to the decision to reconstruct the entire experimental section. The 10 inch and 7 inch thick SAS subsections contained minor cracks and virtually no rutting. The 4 inch thick SAS subsection contained some cracks and a considerable amount of patches that were placed due to localized alligator cracking. With regard to pavement performance alone, it appears that SAS mixtures could be used as a suitable base material.

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FINAL EVALUATION OF A SAND-ASPHALT-SULFUR TEST SECTION US 77, KENEDY COUNTY, TEXAS

by
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Engineering Assistant III

Research Report 187-19

conducted by
Texas Department of Transportation
Division of Materials and Tests
Bituminous Section

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

March 1992

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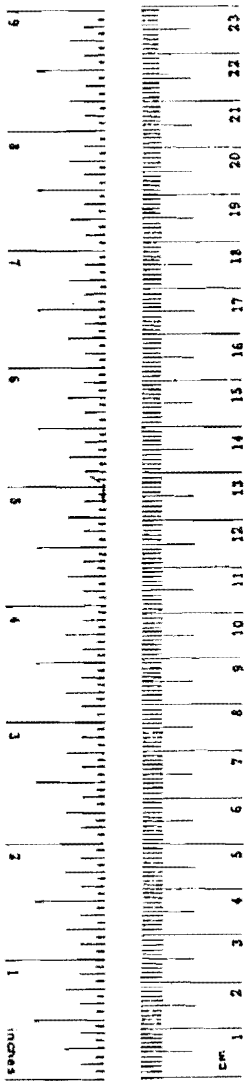
METRIC CONVERSION FACTORS

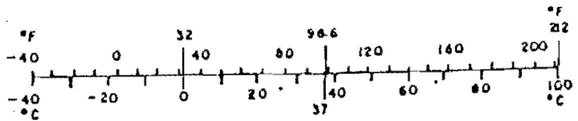
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.6	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.6	acres	
		MASS (weight)		
g	grams	0.036	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/6 (then add 32)	Fahrenheit temperature	°F



DISCLAIMER

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

NOT INTENDED FOR CONSTRUCTION, BIDDING, OR PERMIT PURPOSES.

IMPLEMENTATION STATEMENT

Although the SAS paving mixture performed well over a 14 year period, many factors should be considered before utilizing SAS as a paving material. Economic feasibility, special construction considerations, and environmental and health concerns are only a few of the factors that should be thoroughly investigated prior to using SAS as a paving material.

ACKNOWLEDGMENTS

The research reported herein was conducted under the supervision of Mr. Maghsoud Tahmoressi, Bituminous Engineer, and the general supervision of Mr. Paul E. Krugler, Asphalt Pavements Engineer, both of the Division of Materials and Tests. Acknowledgment is given to:

- Mr. Kenneth Fults, Soils and Aggregates Engineer, for the technical support received during this study.
- Corpus Christi District personnel for performing the pavement coring operation.
- Pharr District personnel for the interest and aid provided in the development of this project as well as providing equipment and personnel to conduct traffic control and FWD testing.
- Division of Materials and Tests personnel for performing the necessary tests for this project.
- Division of Maintenance and Operations personnel for conducting ARAN analysis and summarizing the related data.
- Division of Transportation Planning personnel for providing the traffic analysis and assistance in preparing the final report.

INTRODUCTION AND BACKGROUND

Sand-asphalt-sulfur (SAS) is a product developed by Shell Canada Limited. The concept involves the utilization of sulfur as a structuring agent in paving mixtures which contain poorly graded sands.

The primary purpose of the sulfur in asphaltic pavements is to provide a structuring agent (i.e., act as aggregate) in geographic regions where the availability of quality aggregates is limited. The Gulf Coast region of Texas is one such area that has a limited supply of quality aggregates.

In April of 1977, an experimental SAS test section was constructed as a pavement base in Kenedy County near Sarita, Texas. A 3,000 linear foot test section was constructed on the northbound lanes of US Highway 77, 5 miles south of Sarita (46 miles north of Raymondville), as shown in Figure 1. The 3,000 foot section was divided into six subsections of various thicknesses. Three of the six subsections were constructed using conventional hot mix asphaltic concrete (HMAC) and the other three were constructed with a sand-asphalt-sulfur (SAS) mixture. The two 4 inch thick subsections were purposely under-designed to show distress in two to three years. The entire 3,000 foot test section was constructed with a 1 inch Type "D" surface course.

OBJECTIVE

The objective of this report is to present the results of tests that were conducted during the summer of 1991. These tests were conducted approximately 14 years after the construction of this project. This project was scheduled to be reconstructed beginning in November of 1991. This report will therefore document the final round of testing for this project.

Prior to this 14 year evaluation, testing was performed at 0, 6, 12, 18, 24 and 36 months after the construction of this project in 1977. The results of these evaluations are documented in References 1 through 6. The testing matrix presented in Table 1 lists the tests that were conducted and the time intervals at which they were performed.

The SAS pavement is compared to a conventional hot mix asphaltic concrete pavement that was built as a control section. The comparison is based on laboratory tests, in-situ tests and visual observation.

LOCATION AND SCOPE

The geographical location of the project is shown on the vicinity map, Figure 1. The project was constructed on the northbound lanes of US Highway 77, 5 miles south of Sarita and 46 miles north of Raymondville in Kenedy County, Texas. The project was built under the jurisdiction of the Pharr District of the Texas Department of Transportation.

The experimental section as shown in Figure 2 consists of two traffic lanes (26 ft. wide) and contains six subsections, each 500 ft. in length. From south to north, there are three subsections of sand-asphalt-sulfur base in thicknesses of 10, 7 and 4 inches, respectively. These are followed by three subsections of asphalt concrete base in thicknesses of 4, 7 and 10 inches, respectively. The arrangement of the subsections together with a basic cross section is shown in Figure 2.

The subsections were designed by Texas Transportation Institute, College Station, Texas, to "give a fair comparison of the relative performance of sand-asphalt-sulfur pavement and a deep asphalt concrete pavement" (Reference 7). It is important to note that in Reference 7 the

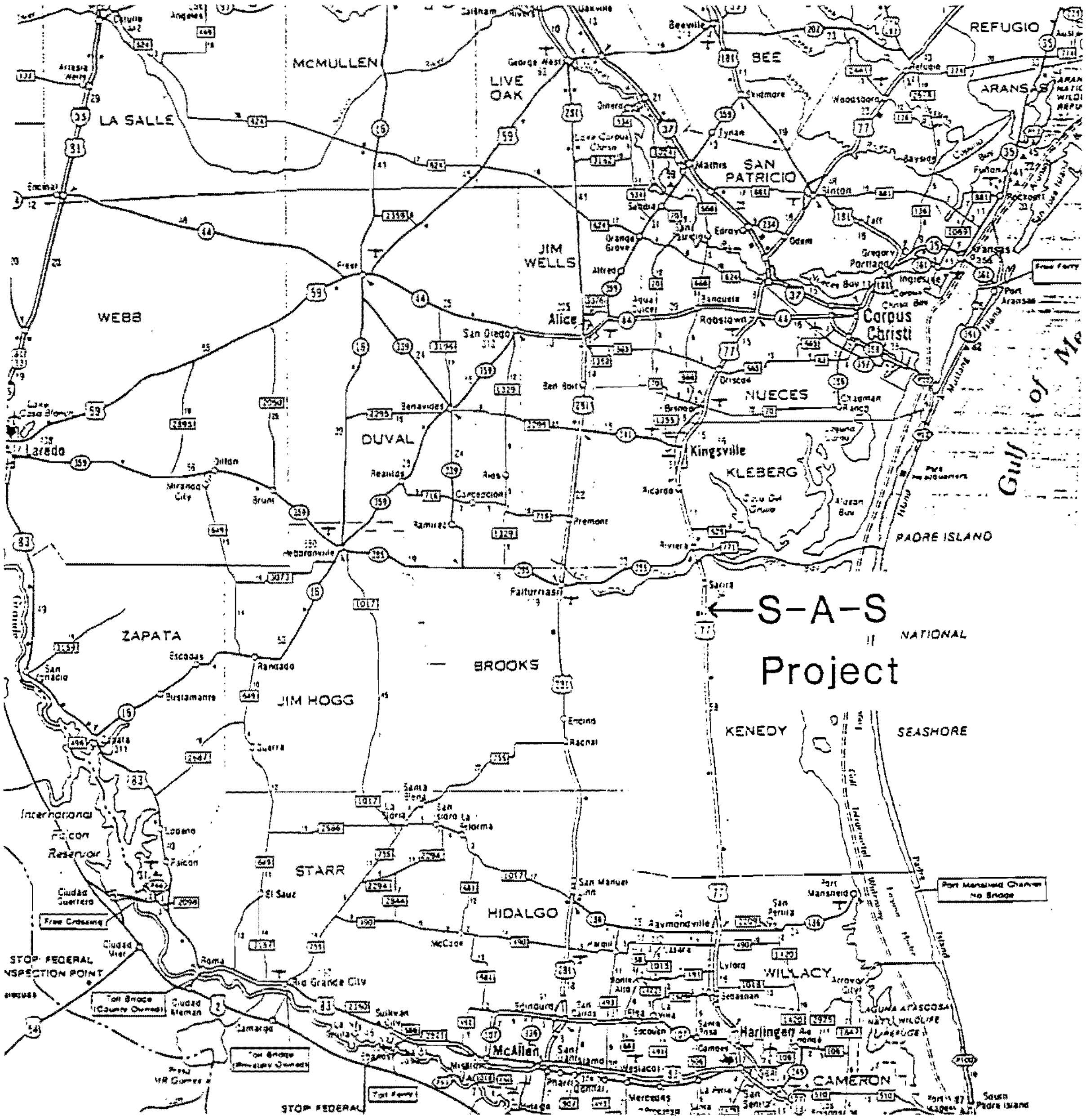


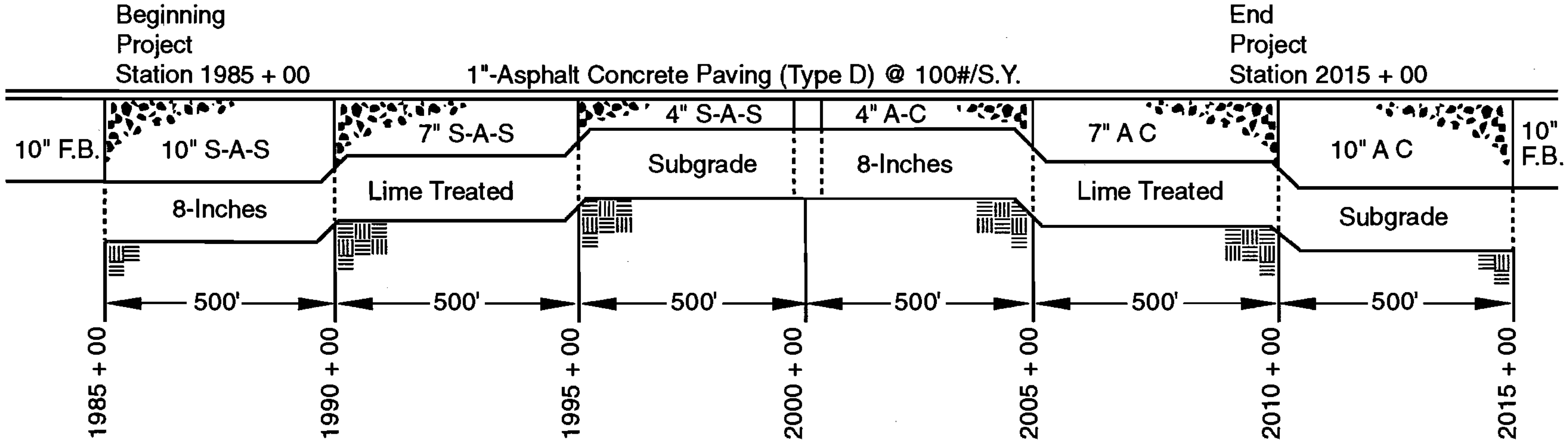
Figure 1. Vicinity map.

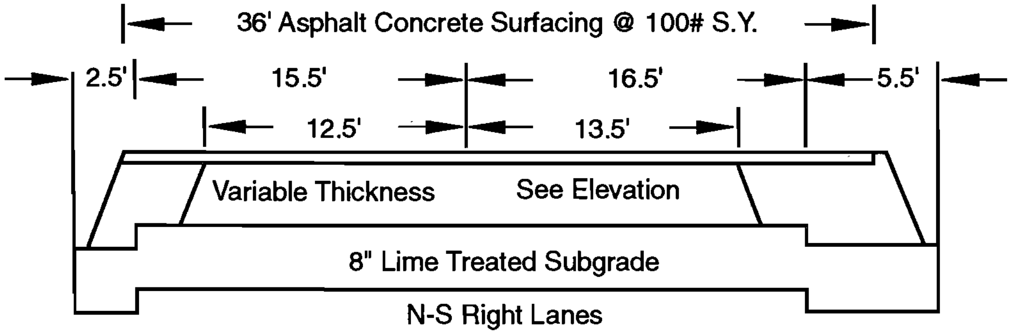
TABLE 1. TESTING MATRIX

	Test Description	Initial*			Pavement Age (months)		
		I	6	12	18	36	173
1.	Traffic Analysis	◄ continuous ►					
2.	Visual Evaluation	■	■	■	■	■	■
3.	Mays Meter (PSI)	■	■	■	■	■	■
4.	Dynaflect Deflections	■	■	■	■	■	■
5.	Falling Weight Deflectometer (FWD)						■
6.	Automated Road Analyzer (ARAN)						■
7.	Core Samples**						
	a. Field Density and Rice Specific Gravity	■	■	■	■	■	■
	b. Marshall Stability	■	■	■	■	■	■
	c. Hveem Stability	■	■	■	■	■	■
	d. Resilient Modulus	■	■	■	■	■	■
	e. Indirect Tensile Strength	■	■	■	■	■	■
8.	Interim Reports	■	■	■	■	■	
9.	Final Report						■

* Initial Testing Performed One Week After Pavement Opened to Traffic.

** Set of 3 Cores (minimum) at Each Test Section Per Sampling Period (Each Lane).





Cross- Section

Notes:

S-A-S	Sulfur-Asphalt-Sand Paving Material
AC	Asphalt Concrete
F.B.	Flexible Base (caliche)
	Schematic Not to Scale

Figure 2. Experimental test section.

"deep asphaltic concrete pavement" was a black base mixture; however, the actual test section was constructed with a Type "D" mixture. The reason for the change in mixtures is unknown to the author.

MIXTURE DESIGNS

The sand-asphalt-sulfur mix design was comprised of 80.8 percent sand, 13.0 percent sulfur and 6.2 percent asphalt. The gradation chart is shown in Figure 3. The 80.8 percent sand portion was comprised of 65 percent "Bluntzer" concrete type sand and 35 percent field sand. The sulfur was elemental sulfur from Fashing, Texas, and Newgulf, Texas, respectively. The asphalt for the SAS mixture was Gulf States AC-20.

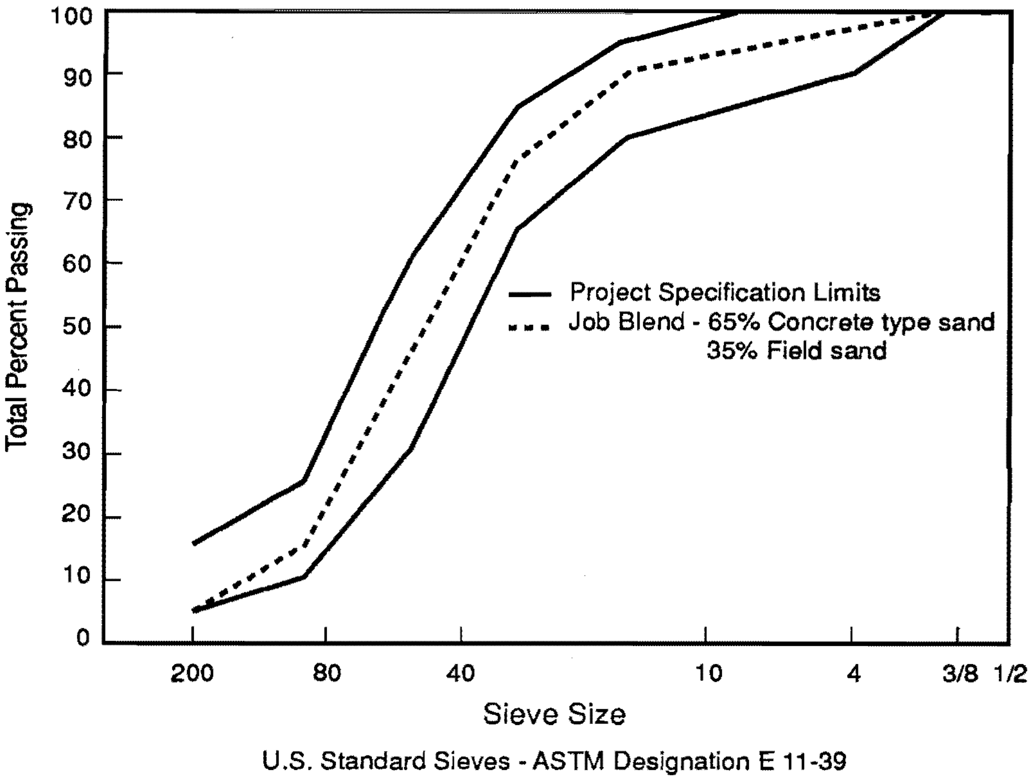


Figure 3. Gradation chart (for SAS mixture).

The HMAC mixture was a conventional Texas Department of Transportation mix which met the specification of a Type "D" mixture. The aggregate blend for the Type "D" mixture consisted of a crushed chert and a field sand. The blend contained 35 percent 7/16 inch chert aggregate, 25 percent 1/4 inch aggregate, 20 percent Hawkins sand, and 20 percent Kenedy field sand. The asphalt for the HMAC test sections was also Gulf States AC-20.

TRAFFIC COUNTS

A summary of traffic counts is provided in Table 2. The total number of Equivalent Single Axle Loads (ESALs) over a 14 year period was 3,716,000. The traffic volumes have increased significantly since the construction of the SAS experimental section in 1977.

TABLE 2. TRAFFIC ANALYSIS.

Year	Average Daily Traffic	Percent Trucks (IN ADT)	ATHWLD*	Percent Tandem Axles in ATHWLD*	Total ESALs
1977	3,990	23.7	11,800	70	154,000
1978	4,480	23.1	11,900	70	167,000
1979	4,450	23.1	11,900	70	166,000
1980	4,700	33.7	12,100	70	265,000
1981	5,100	32.3	12,100	70	282,000
1982	5,000	27.0	12,000	70	228,000
1983	4,700	27.8	12,000	70	221,000
1984	5,100	28.0	12,000	70	238,000
1985	5,100	31.1	12,100	70	251,000
1986	5,400	27.5	12,000	70	235,000
1987	5,500	27.2	12,000	70	246,000
1988	5,800	26.9	12,100	70	254,000
1989	6,400	32.5	12,200	60	320,000
1990	6,700	29.1	12,200	70	343,000
1991	6,800	28.9	12,300	70	346,000
Average =	5,281	28.1	12,047	69	247,733
Total =					3,716,000

* Average of ten heaviest wheel loads

TEST RESULTS AND DISCUSSION

The testing matrix presented in Table 1 illustrates the tests which were performed during each evaluation and the time lapse between evaluations. After each evaluation, an interim report was prepared. These reports are documented in References 1 through 6. This report will be considered the final report for the project. The following tests were performed during each evaluation:

Specific Gravity	ASTM 2041	(Ref. 8)
Marshall Stability and Flow	ASTM D-1559	(Ref. 8)
Hveem Stability	Tex-208-F	(Ref. 9)
Resilient Modulus, 68°F		(Ref. 10)
Indirect Tensile Test	Tex-226-F	(Ref. 9)
Rice Maximum Specific Gravity	Tex-227-F	(Ref. 9)

Table 3 contains the results from all laboratory tests performed to date. In addition to the laboratory tests, various in-situ tests were performed as well as a visual evaluation.

LABORATORY TEST RESULTS

Four inch diameter core samples were obtained from each 500 foot subsection. A total of six cores were taken from each subsection. Cores were taken in the right and left wheelpaths and between the wheelpaths for each lane (right and left) in each subsection. A series of laboratory tests were performed on the sets of cores. The results from the laboratory tests are presented in Table 3 and represent the average of all six cores in each subsection.

Bulk Specific Gravity

The final bulk specific gravity of the SAS sections is 2.06, equating to approximately 11 percent air voids. All three SAS sections have approximately the same air void content. The reduction in air voids due to traffic over the 173 month life of the project is less than one percent.

The final bulk specific gravity of the HMAC material is approximately 2.30, representing an average air void content of approximately 3.5 percent. The initial average air void content was approximately 7 percent; therefore, the reduction in air voids due to traffic is about 3.5 percent. A bar graph of the air voids content versus pavement age is illustrated in Figure 4.

Marshall Stability and Flow

The Marshall stability and flow versus pavement age are shown in Figures 5 and 6, respectively. The Marshall stability of the SAS mixture has been consistently higher than that of the conventional HMAC material. There is no consistent trend between changes in Marshall stability and pavement age. This lack of trend may be attributed to inherent variability in the Marshall test procedure.

The Marshall flow values have been generally higher for the conventional HMAC material than for the SAS material. After 173 months (approximately 14 years), the Marshall flow values are approximately equal for both materials.

Hveem Stability

The Hveem stability values are shown in Figure 7. All of the cores have a Hveem stability of approximately 25 percent after 173 months of pavement life, a slight decrease over the years. Based on these figures, it appears that the aggregate interlock properties are approximately equal for both mixtures.

TABLE 3. SUMMARY OF FIELD CORE TEST RESULTS

Base Type	Sulfur/ Asphalt Ratio	Specific Gravity	Marshall Stability (lbf)	Marshall Flow (0.01 in.)	Hveem Stability (%)	Resilient Modulus @ 68°F (psi)	Splitting Tensile (psi)	Date Sampled	Pavement Age (months)	Rice Max. Specific Gravity
10 in. SAS	13/6.2	2.02	1,350	17	25	460,000	155	4/77	0	2.29 ◆
		2.20	1,445	8	31	700,000	160	12/77	8	2.29 ◆
		2.04	2,070	10	42	480,000	200	6/78	14	2.29 ◆
		2.02	1,725	9	30	730,000	178	12/78	20	2.29 ◆
		2.04	1,535	9	38	570,000	169	6/79	26	2.29 ◆
		2.02	1,500	11	24	670,000	158	6/80	38	2.29 ◆
		2.06	1,251	12	25	940,000	194	9/91	173	2.32
7 in. SAS	13/6.2	2.01	1,885	15	34	440,000	145	4/77	0	2.24 ◆
		2.04	1,740	9	30	640,000	150	12/77	8	2.24 ◆
		1.99	1,210	10	28	480,000	205	6/78	14	2.24 ◆
		2.04	1,975	9	36	770,000	168	12/78	20	2.24 ◆
		2.02	1,430	9	29	520,000	160	6/79	26	2.24 ◆
		2.04	1,991	11	30	680,000	166	6/80	38	2.24 ◆
		2.06	1,718	13	25	880,000	175	9/91	173	2.32
4 in. SAS	13/6.2	2.01	1,890	14	32	450,000	155	4/77	0	2.31 ◆
		2.05	1,875	10	38	770,000	185	12/77	8	2.31 ◆
		2.05	1,450	9	30	550,000	235	6/78	14	2.31 ◆
		2.05	1,785	10	30	910,000	183	12/78	20	2.31 ◆
		2.05	1,190	10	33	560,000	184	6/79	26	2.31 ◆
		2.03	1,408	14	27	870,000	188	6/80	38	2.31 ◆
		2.06	1,130	12	24	860,000	206	9/91	173	2.33
4 in. AC	0/6.2	2.13	340	11	36	730,000	215	4/77	0	2.38 ◆
		2.25	580	13	26	1,280,000	290	12/77	8	2.38 ◆
		2.25	930	14	27	1,160,000	325	6/78	14	2.38 ◆
		2.29	660	13	25	1,520,000	291	12/78	20	2.38 ◆
		2.29	730	18	31	1,100,000	278	6/79	26	2.38 ◆
		2.26	475	10	27	1,640,000	218	6/80	38	2.38 ◆
		2.30	934	14	25	1,550,000	327	9/91	173	2.38
7 in. AC	0/6.2	2.26	675	18	*	810,000	240	4/77	0	2.38 ◆
		2.26	665	11	27	1,230,000	255	12/77	8	2.38 ◆
		2.25	685	14	26	990,000	273	6/78	14	2.38 ◆
		2.29	520	11	28	1,410,000	279	12/78	20	2.38 ◆
		2.31	500	9	29	740,000	247	6/79	26	2.38 ◆
		2.29	*	*	28	980,000	207	6/80	38	2.38 ◆
		2.31	776	13	24	1,120,000	294	9/91	173	2.38
10 in. AC	0/6.2	*	*	*	*	*	*	4/77	0	2.40 ◆
		2.24	705	12	29	1,120,000	255	12/77	8	2.40 ◆
		2.27	420	12	24	1,020,000	310	6/78	14	2.40 ◆
		2.29	645	11	29	1,540,000	262	12/78	20	2.40 ◆
		2.32	730	12	22	750,000	256	6/79	26	2.40 ◆
		2.28	522	8	32	1,360.000	215	6/80	38	2.40 ◆
		2.30	641	13	26	1,220,000	298	9/91	173	2.40

* Difficulty Collecting Sample

◆ Rice Maximum Specific Gravity as Tested in 1977

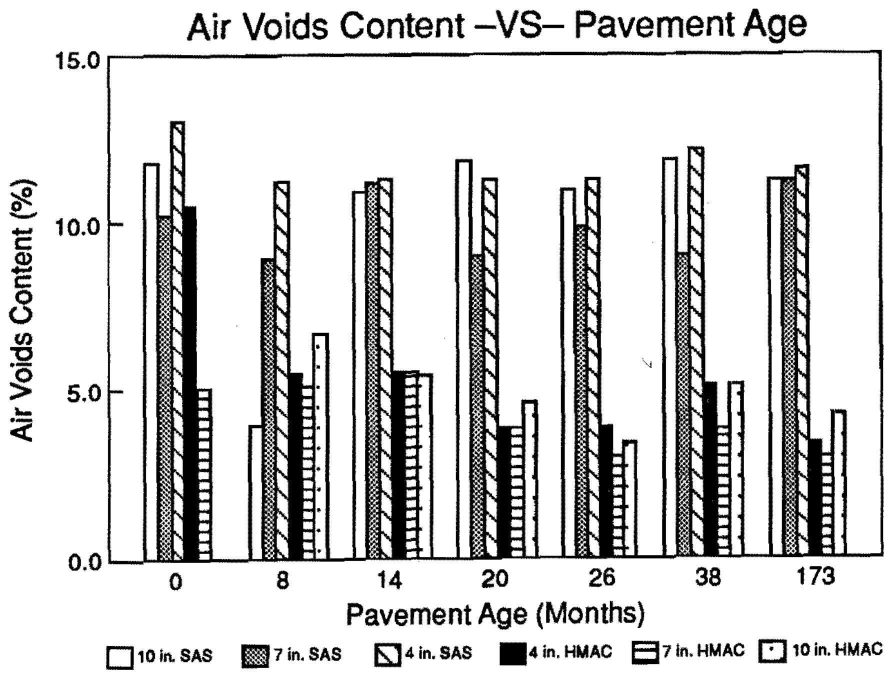


Figure 4. Air voids versus pavement age.

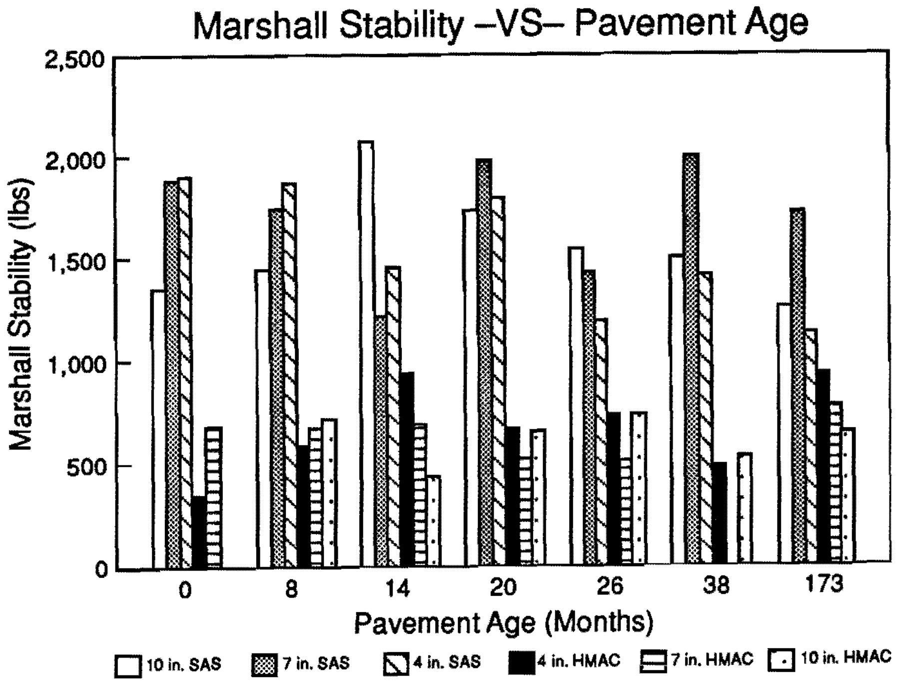


Figure 5. Marshall stability versus pavement age.

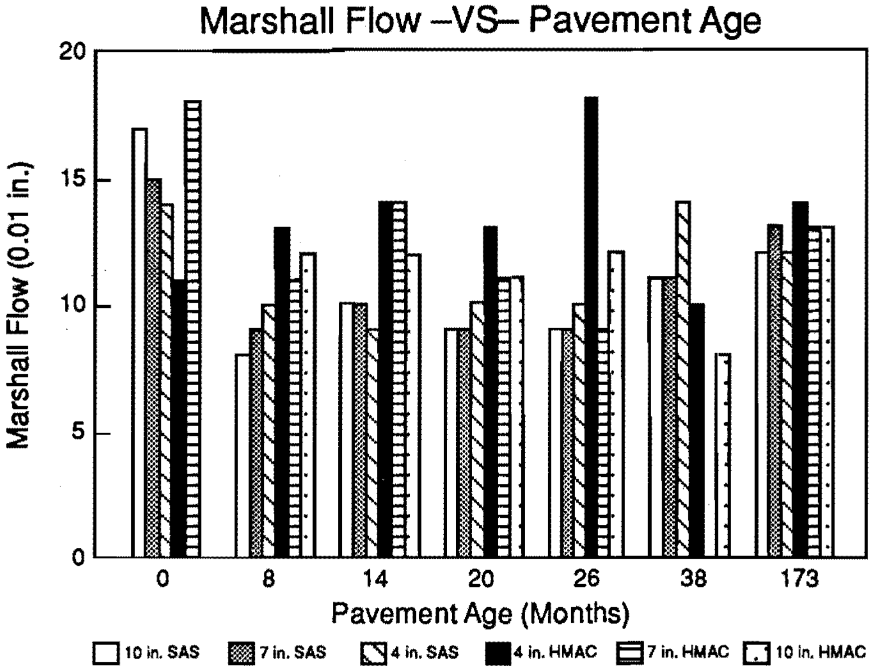


Figure 6. Marshall flow versus pavement age.

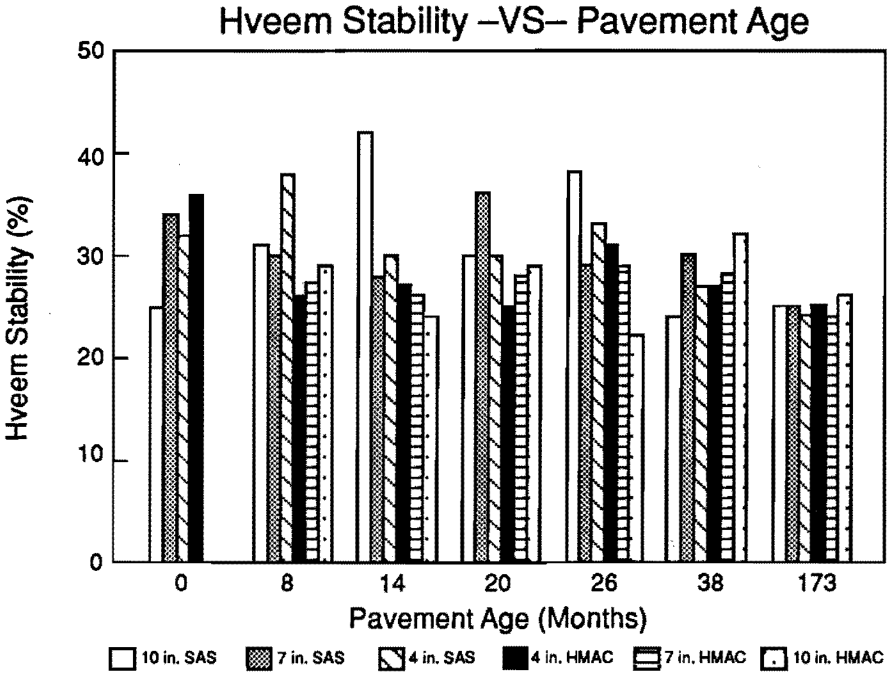


Figure 7. Hveem stability versus pavement age.

Resilient Modulus

The HMAC material has consistently shown higher resilient modulus values than the SAS material, as demonstrated in Figure 8. There is no consistent trend between changes in resilient modulus and pavement age. It is believed that a major portion of the difference in resilient modulus values between the SAS and HMAC is attributable to the air void content. The SAS cores averaged about 11 percent air voids, whereas the HMAC cores averaged about 3.5 percent air voids. Resilient modulus values decrease with increased air void contents.

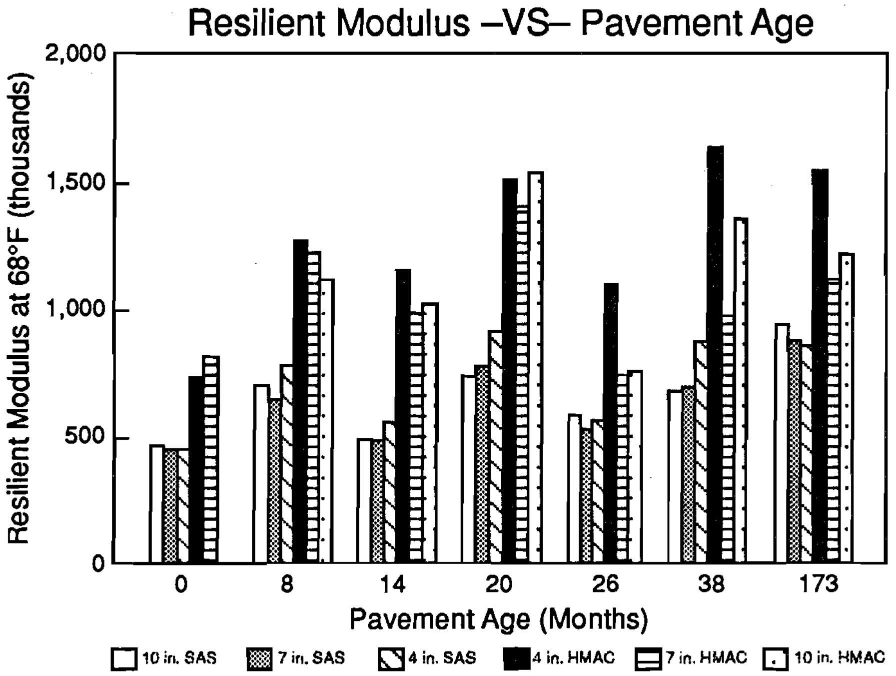


Figure 8. Resilient modulus versus pavement age.

Indirect Tensile Strength

As with resilient modulus, indirect tensile strength is a function of air void content. Figure 9 illustrates that the HMAC material has consistently higher indirect tensile strength values than the SAS material. The indirect tensile strength test differences can be partially attributed to the air void content differences between the materials. There is no consistent trend between changes in indirect tensile strength and pavement age.

IN-SITU TEST RESULTS

Several in-situ tests were run in conjunction with the laboratory tests. The in-situ testing consisted of the following tests: Dynaflect, Falling Weight Deflectometer (FWD), and Automated Road Analysis (ARAN).

Dynaflect Deflections

Dynaflect deflections were measured by the Division of Maintenance and Operations. The maximum deflections are listed in Table 4, and a bar graph of maximum deflections versus time is presented in Figure 10 and illustrates clearly that the maximum deflections are a function of pavement depth. All of the pavement subsections appear to have become less stiff since the three year evaluation was performed. Based on the maximum Dynaflect deflections, the 10 inch and 7 inch SAS subsections appear slightly stiffer than the corresponding HMAC subsections. The 4 inch SAS subsection appears to be the weakest of all the subsections.

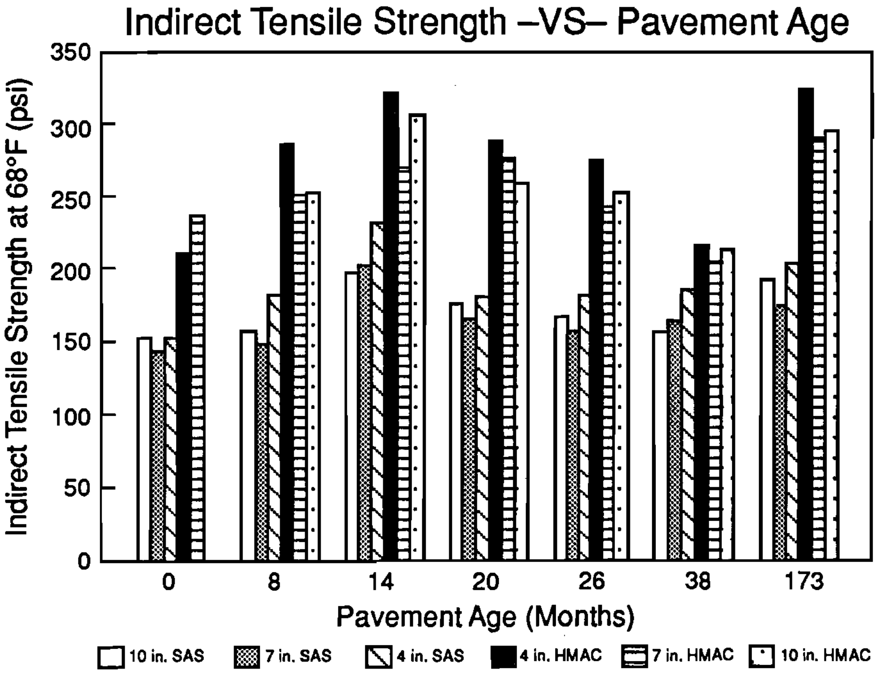


Figure 9. Indirect tensile strength versus pavement age.

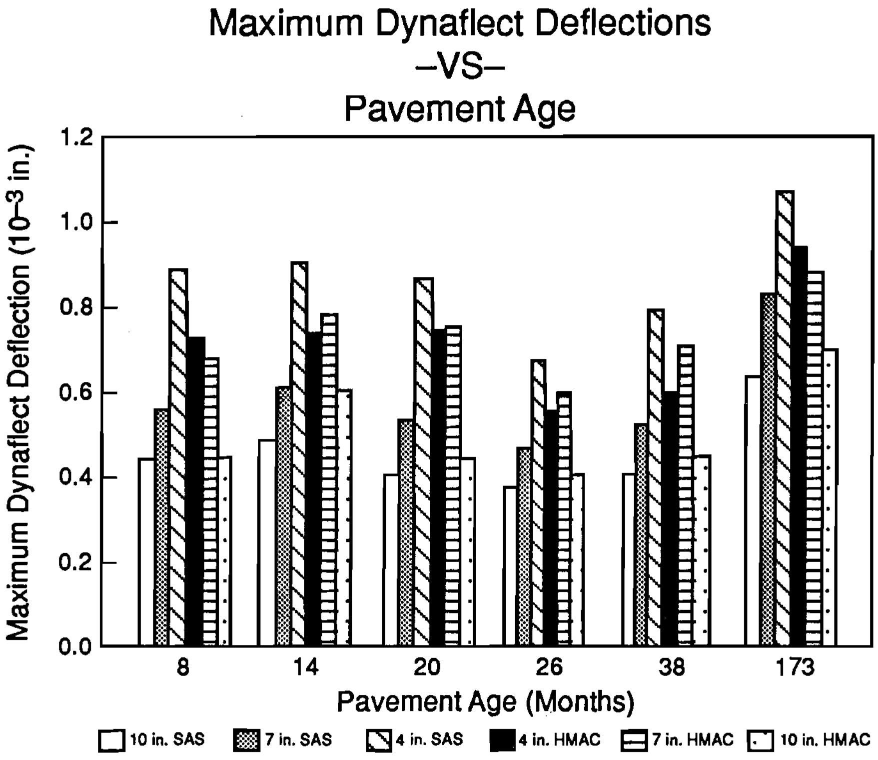


Figure 10. Maximum Dynaflect deflections versus pavement age.

TABLE 4. MAXIMUM DYNAFLECT DEFLECTIONS

Base Type	Sulfur/ Asphalt Ratio	Station	Pavement Thickness (inches)*	Maximum Dynaflect Deflection (10^{-3} in.)	Date Sampled	Pavement Age (months)
10 in. SAS	13/6.2	1985+00 to 1990+00	11	N/A	4/77	0
				0.44	12/77	8
				0.48	6/78	14
				0.40	12/78	20
				0.37	6/79	26
				0.40	6/80	38
				0.63	9/91	173
7 in. SAS	13/6.2	1990+00 to 1995+00	8	N/A	4/77	0
				0.56	12/77	8
				0.61	6/78	14
				0.53	12/78	20
				0.46	6/79	26
				0.52	6/80	38
				0.82	9/91	173
4 in. SAS	13/6.2	1995+00 to 2000+00	5	N/A	4/77	0
				0.88	12/77	8
				0.90	6/78	14
				0.86	12/78	20
				0.67	6/79	26
				0.79	6/80	38
				1.06	9/91	173
4 in. AC	0/6.2	2000+00 to 2005+00	5	N/A	4/77	0
				0.72	12/77	8
				0.73	6/78	14
				0.74	12/78	20
				0.55	6/79	26
				0.60	6/80	38
				0.93	9/91	173
7 in. AC	0/6.2	2005+00 to 2010+00	8	N/A	4/77	0
				0.68	12/77	8
				0.78	6/78	14
				0.75	12/78	20
				0.59	6/79	26
				0.70	6/80	38
				0.87	9/91	173
10 in. AC	0/6.2	2010+00 to 2015+00	11	N/A	4/77	0
				0.44	12/77	8
				0.60	6/78	14
				0.44	12/78	20
				0.40	6/79	26
				0.44	6/80	38
				0.69	9/91	173

* All sections have 1 inch asphaltic wear course and 8 inches of lime treated subgrade

The Dynaflect deflections were also used to calculate surface curvature indices (SCI). The surface curvature index is an indication of how a given load is distributed throughout a pavement. The surface curvature index values for each subsection are presented in Table 5. The SAS subsections yielded slightly higher surface curvature indices than the HMAC subsections did.

There is an appreciable increase in SCI from the three year evaluation to the final evaluation for all subsections. This increase in SCI may be attributed to weakening of the surface layer as shown by increase in maximum deflections (Figure 10). For all subsections, SCI decreases as the pavement thickness increases. The final SCI values of SAS and HMAC subsections are comparable for given pavement thicknesses, indicating that SAS subsections can spread the load as well as conventional HMAC subsections.

Falling Weight Deflectometer

The Texas Department of Transportation's falling weight deflectometer (FWD) equipment was used to measure deflections that were in turn used to back-calculate a pavement modulus for each subsection. Division of Maintenance and Operations personnel provided the pavement modulus information. Table 6 lists the modulus for each pavement subsection.

The HMAC subsections showed higher modulus values than the corresponding SAS subsections for all pavement thicknesses. However, the 4 inch HMAC and SAS subsection had modulus values approximately equivalent to the corresponding 10 inch subsections.

The data shown in Table 6 represent the average modulus values determined for the driving and passing lanes. The modulus values calculated for the driving lane were substantially lower than those for the passing lane. Limited sampling and testing of the subgrade soil were performed for both driving and passing lanes in order to determine the causes for this difference in modulus. With the limited data that was gathered, the difference in the modulus of the two lanes cannot be explained.

Serviceability Index

The serviceability indices for the SAS subsections and the HMAC subsections are listed in Table 7. The 1991 readings were taken using Automated Road Analysis (ARAN) equipment. Readings from all previous years were taken with a Mays Ride Meter vehicle. The 4 inch SAS section has a 3.2 serviceability index, the lowest of all of the subsections. There is very little difference in the serviceability indices from the 10 inch and 7 inch SAS subsections as compared to the corresponding HMAC subsections. All of the serviceability indices indicate that the subsections were generally still in good condition. There is no significant drop in serviceability indices over the life of this pavement.

Rut Depth Measurements

Rut depths were measured using the ARAN equipment. A summary of the rut depth values are listed in Table 8. The left lane (i.e., passing lane) had virtually no rutting. The right lane (i.e., driving lane) had minimal rutting in the SAS subsections; however, the HMAC subsections had ruts that would be considered severe. During the visual evaluation, a brief rain caused considerable channelized ponding in the right lane of the HMAC subsection, as shown in Figure 11. Figure 12 is a bar graph that illustrates the rut depths for all of the subsections. The rut depths are broken down into right and left wheelpaths as well as right and left lanes.

VISUAL OBSERVATION

A visual observation of the experimental section was made. The visual observation revealed that the SAS subsections were performing much better than the HMAC subsections.

TABLE 5. SURFACE CURVATURE INDEX VALUES

Base Type	Sulfur/ Asphalt Ratio	Station	Pavement Thickness (inches)*	Surface Curvature Index	Date Sampled	Pavement Age (months)
10 in. SAS	13/6.2	1985+00 to 1990+00	11	N/A	4/77	0
				0.040	12/77	8
				0.057	6/78	14
				0.030	12/78	20
				N/A	6/79	26
				N/A	6/80	38
				0.170	9/91	173
7 in. SAS	13/6.2	1990+00 to 1995+00	8	N/A	4/77	0
				0.077	12/77	8
				0.134	6/78	14
				0.091	12/78	20
				N/A	6/79	26
				N/A	6/80	38
				0.260	9/91	173
4 in. SAS	13/6.2	1995+00 to 2000+00	5	N/A	4/77	0
				0.160	12/77	8
				0.189	6/78	14
				0.155	12/78	20
				N/A	6/79	26
				N/A	6/80	38
				0.310	9/91	173
4 in. HMAC	0/6.2	2000+00 to 2005+00	5	N/A	4/77	0
				0.121	12/77	8
				0.165	6/78	14
				0.130	12/78	20
				N/A	6/79	26
				N/A	6/80	38
				0.280	9/91	173
7 in. HMAC	0/6.2	2005+00 to 2010+00	8	N/A	4/77	0
				0.080	12/77	8
				0.165	6/78	14
				0.130	12/78	20
				N/A	6/79	26
				N/A	6/80	38
				0.200	9/91	173
10 in. HMAC	0/6.2	2010+00 to 2015+00	11	N/A	4/77	0
				0.031	12/77	8
				0.072	6/78	14
				0.087	12/78	20
				N/A	6/79	26
				N/A	6/80	38
				0.150	9/91	173

* All sections have 1 inch asphaltic wear course and 8 inches of lime treated subgrade

TABLE 6. PAVEMENT MODULUS

Base Type	Sulfur/ Asphalt Ratio	Station	Pavement Thickness (inches)**	Pavement Modulus (Backcalculated From FWD*) (psi)	Date Sampled	Pavement Age (months)
10 in. SAS	13/6.2	1985+00 to 1990+00	11	257,000	9/91	173
7 in. SAS	13/6.2	1990+00 to 1995+00	8	187,000	9/91	173
4 in. SAS	13/6.2	1995+00 to 2000+00	5	244,000	9/91	173
4 in. AC	0/6.2	2000+00 to 2005+00	5	380,000	9/91	173
7 in. AC	0/6.2	2005+00 to 2010+00	8	270,000	9/91	173
10 in. AC	0/6.2	2010+00 to 2015+00	11	397,000	9/91	173

* Refers to Falling Weight Deflectometer

** Thickness Includes One Inch of Type "D" Surface Course

TABLE 7. SERVICEABILITY INDEX

Base Type	Sulfur/ Asphalt Ratio	Station	Date Tested	Pavement Age (months)	Serviceability Index
10 in. SAS	13/6.2	1985+00 to 1990+00	4/77	0	N/A
			12/77	8	N/A
			6/78	14	3.6
			12/78	20	3.3
			6/79	26	2.7
			6/80	38	2.5
			9/91	173	3.6
7 in. SAS	13/6.2	1990+00 to 1995+00	4/77	0	N/A
			12/77	8	N/A
			6/78	14	3.2
			12/78	20	3.4
			6/79	26	3.5
			6/80	38	3.0
			9/91	173	4.0
4 in. SAS	13/6.2	1995+00 to 2000+00	4/77	0	N/A
			12/77	8	N/A
			6/78	14	2.8
			12/78	20	2.9
			6/79	26	3.4
			6/80	38	2.7
			9/91	173	3.2
4 in. AC	0/6.2	2000+00 to 2005+00	4/77	0	N/A
			12/77	8	N/A
			6/78	14	3.9
			12/78	20	4.4
			6/79	26	4.2
			6/80	38	3.8
			9/91	173	4.3
7 in. AC	0/6.2	2005+00 to 2010+00	4/77	0	N/A
			12/77	8	N/A
			6/78	14	4.1
			12/78	20	4.2
			6/79	26	3.9
			6/80	38	3.8
			9/91	173	4.2
10 in. AC	0/6.2	2010+00 to 2015+00	4/77	0	N/A
			12/77	8	N/A
			6/78	14	4.4
			12/78	20	4.4
			6/79	26	4.2
			6/80	38	3.5
			9/91	173	3.6

N/A No measurements taken in wheelpath.

Note: Measurements taken in wheelpath of outside lane.

At the time of the observation, a crack and distress survey was made. The original plan was to measure and record all of the distresses using the video made with the ARAN equipment; however, the cracks did not show up well enough on the video to measure. As a result, all cracks were measured and recorded manually. A summary of cracking is listed in Table 9.

There was a very substantial amount of longitudinal cracking throughout the 4 inch and 7 inch HMAC subsections. The cracks were generally isolated to the wheelpaths. The sketches in Figures 13 through 18 and the photograph in Figure 19 indicate the extent of the cracking problem. As with the rut depths, the distresses were more prevalent in the HMAC subsections.

The 4 inch SAS subsection had experienced a considerable amount of localized alligator cracking. The cracked locations were removed and patched prior to the final evaluation. The cause of the cracking is unknown. Texas Department of Transportation personnel reported that the lime treated subgrade was in excellent condition. Their observations were made during the recent reconstruction of the experimental project (November of 1991). The 10 inch SAS subsection also experienced an apparent base failure. Photographs of the pavement failures in the 10 inch and 4 inch SAS subsections are illustrated in Figures 20 and 21 respectively. As mentioned previously, a video of the project was made to document the condition of the experimental project prior to the scheduled reconstruction of the project.

TABLE 8. SUMMARY OF RUT DEPTHS

Base Type	Sulfur/ Asphalt Ratio	Station	Date Tested	Pavement Age (months)	Left Lane Left Wheelpath (inches)	Left Lane Right Wheelpath (inches)	Right Lane Left Wheelpath (inches)	Right Lane Right Wheelpath (inches)
10 in. SAS	13/6.2	1985+00 to 1990+00	9/91	173	0.05	0.01	0.02	0.11
7 in. SAS	13/6.2	1990+00 to 1995+00	9/91	173	0.04	0.00	0.07	0.08
4 in. SAS	13/6.2	1995+00 to 2000+00	9/91	173	0.01	0.02	0.08	0.11
4 in. AC	0/6.2	2000+00 to 2005+00	9/91	173	0.00	0.04	0.14	0.28
7 in. AC	0/6.2	2005+00 to 2010+00	9/91	173	0.05	0.04	0.31	0.39
10 in. AC	0/6.2	2010+00 to 2015+00	9/91	173	0.04	0.05	0.13	0.22

NOTE: All Measurements Refer to Northbound Lanes of U.S. Highway 77.

Figure 11. Channelized ponding in 7-inch HMAC subsection. (View is from south to north.)

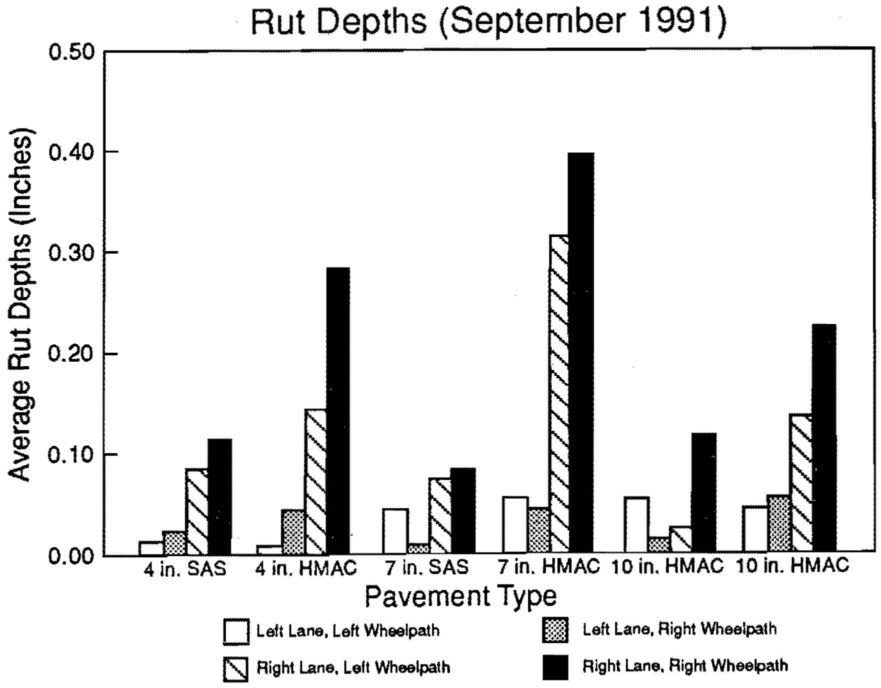


Figure 12. Rut depths.

TABLE 9. SUMMARY OF CRACKING

Base Type	Sulfur/ Asphalt Ratio	Date Sampled	Pavement Age (months)	Longitudinal Cracks (ft)	Transverse Cracks (number)	Patches/ Failures (number)
10 in. SAS	13/6.2	9/91	173	22	5	1
7 in. SAS	13/6.2	9/91	173	91	1	0
4 in. SAS	13/6.2	9/91	173	170	7	6
4 in. HMAC	0/6.2	9/91	173	1,250	0	0
7 in. HMAC	0/6.2	9/91	173	1,163	3	1
10 in. HMAC	0/6.2	9/91	173	335	0	0

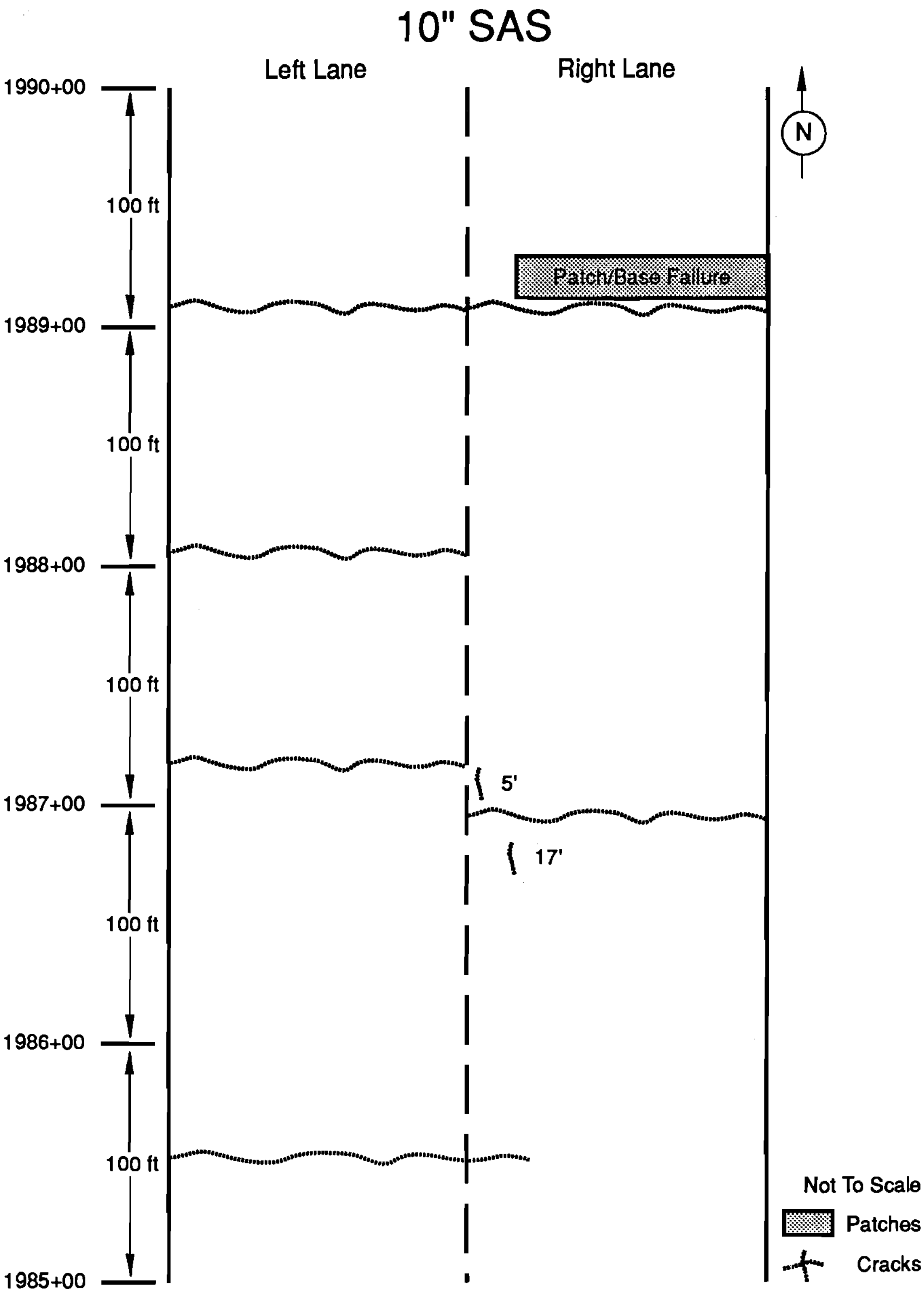


Figure 13. Crack survey in 10-inch SAS subsection.

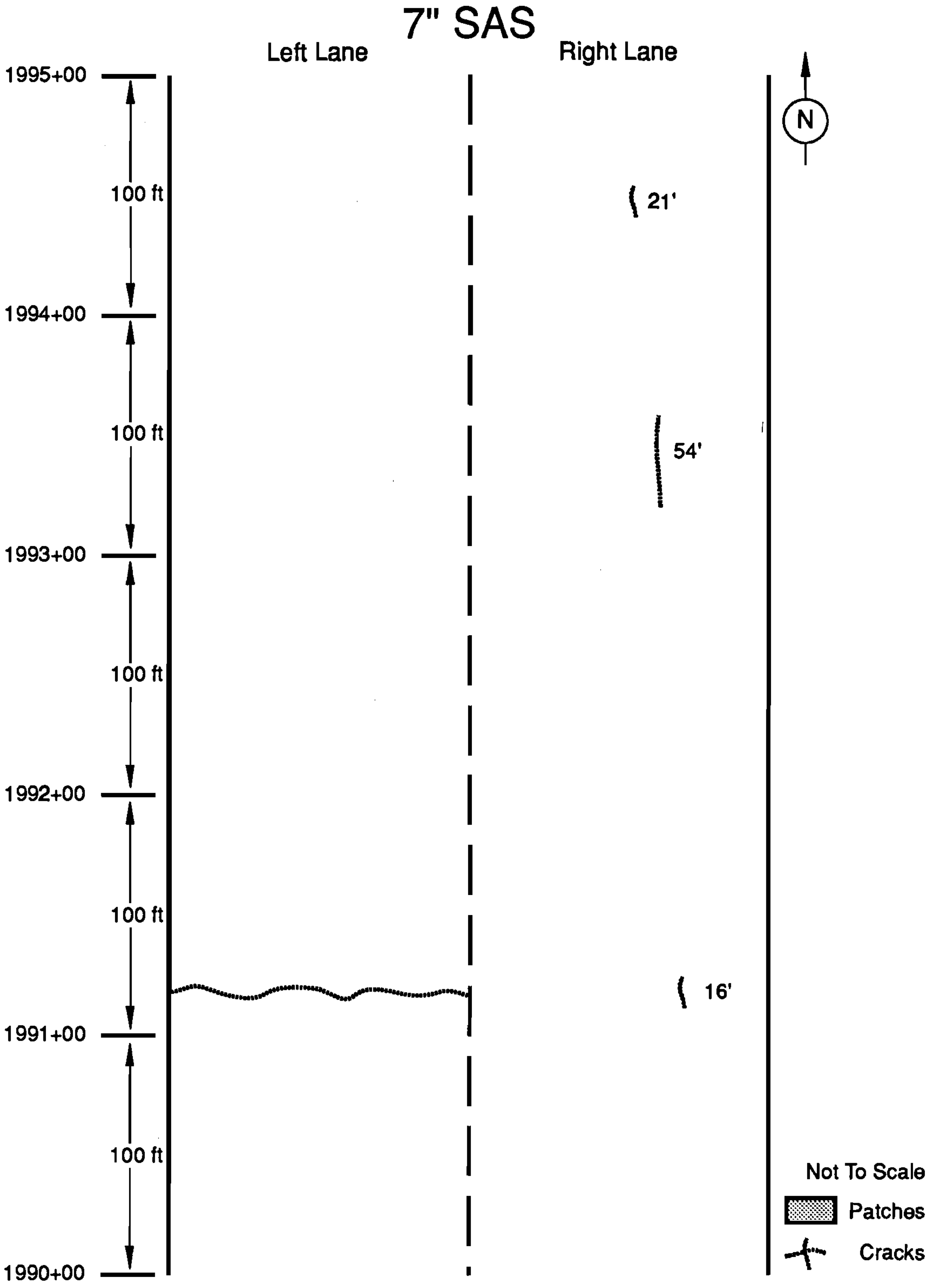


Figure 14. Crack survey in 7-inch SAS subsection.

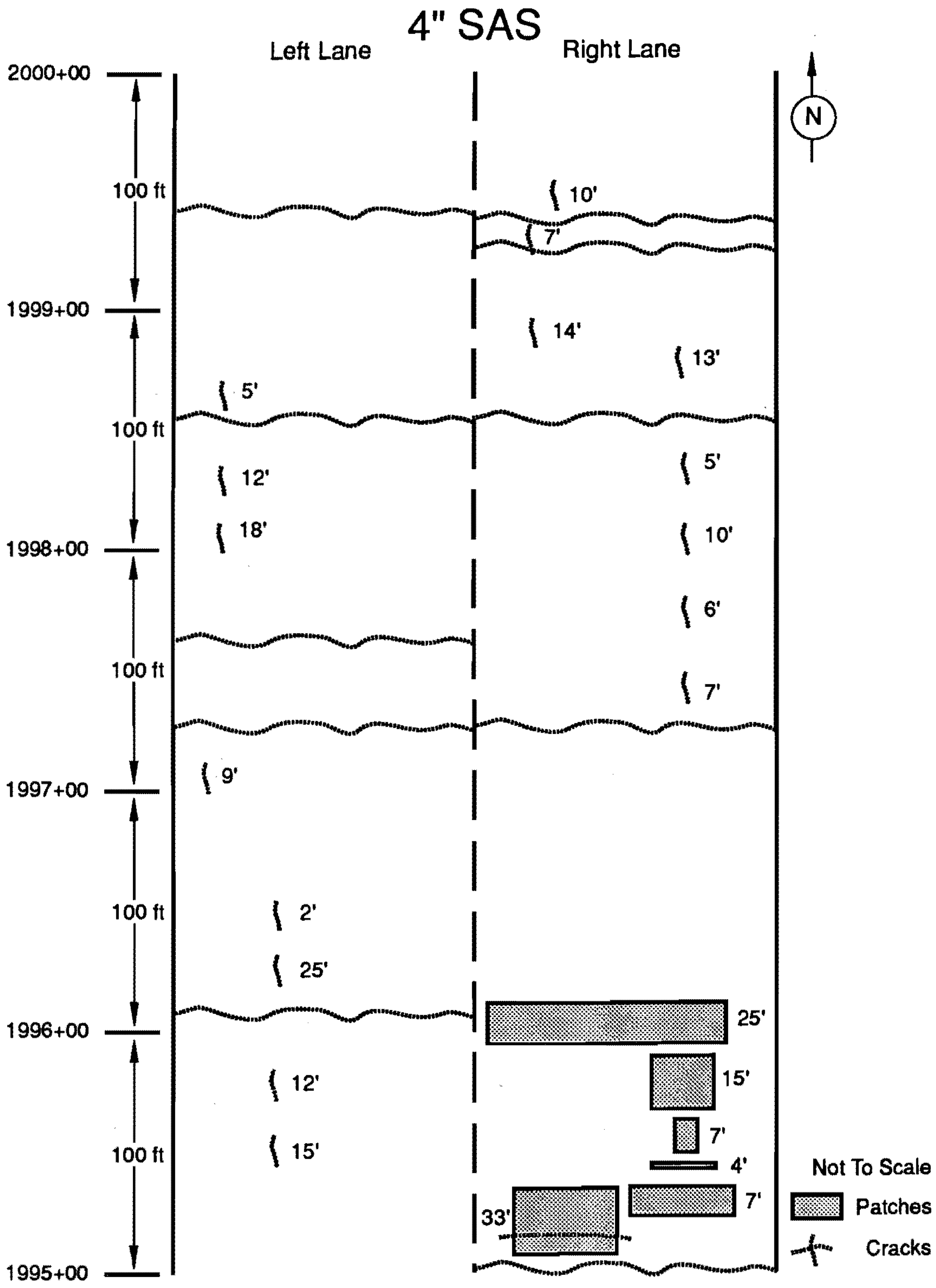


Figure 15. Crack survey in 4-inch SAS subsection.

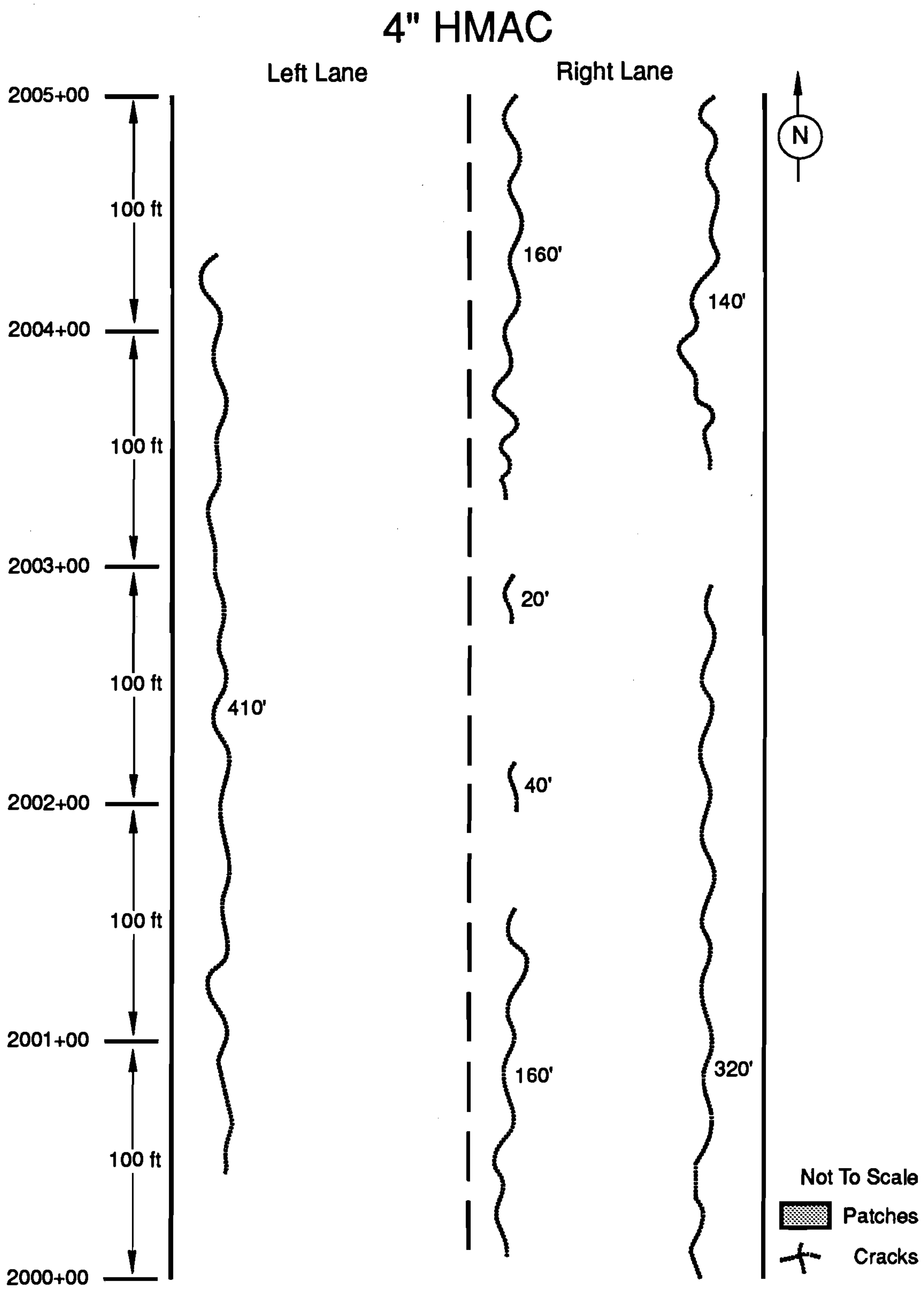


Figure 16. Crack survey in 4-inch HMAC subsection.

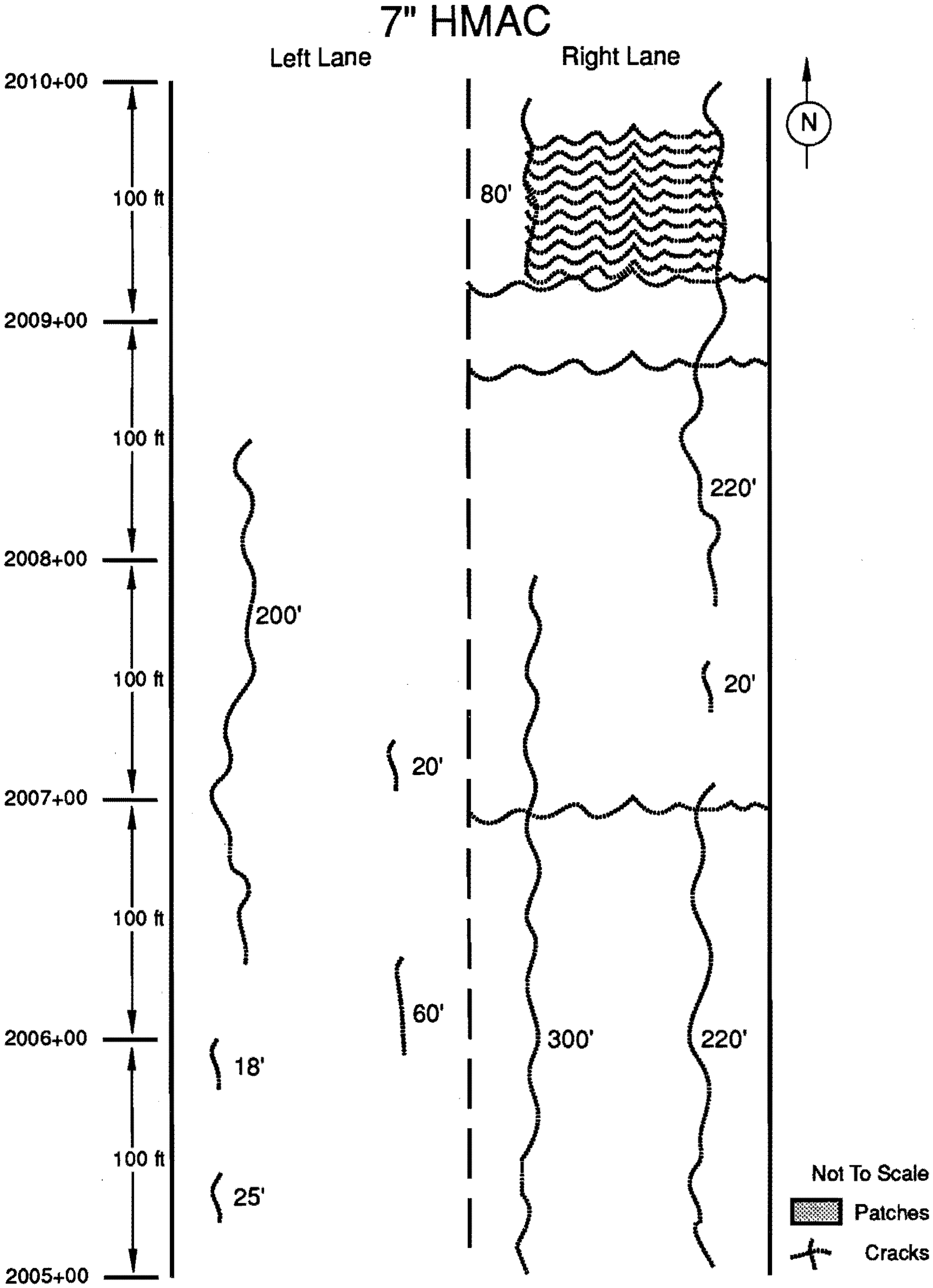


Figure 17. Crack survey in 7-inch HMAC subsection.

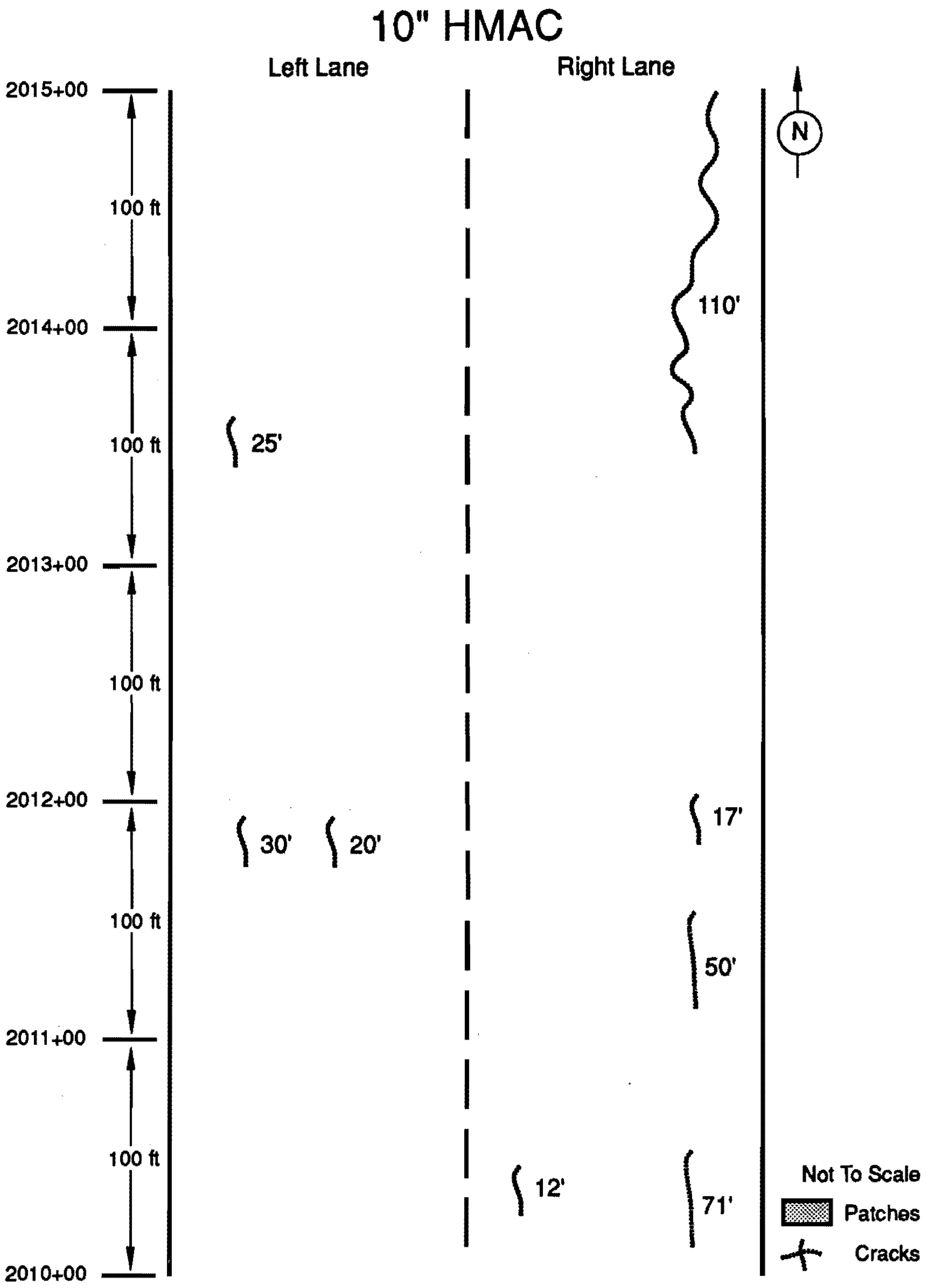


Figure 18. Crack survey in 10-inch HMAC subsection.

Figure 19. Longitudinal cracking in 4-inch HMAC subsection. (View is from north to south.)

Figure 20. Pavement failure in 10-inch SAS subsection.

Figure 21. Pavement failure in 4-inch SAS subsection. (View is from south to north.)

CONCLUSIONS

The SAS experimental pavement section was built in six subsections. Three of the subsections were conventional Type "D" HMAC. The HMAC subsections were built as "controls" to compare with the SAS subsections. It should be noted, however, that the 10 inch, 7 inch and 4 inch HMAC subsections are not representative of typical Texas Department of Transportation pavements. Generally, a Type "D" HMAC is used as a relatively thin surface course.

The experimental pavement section was built as part of a 7 mile project. The remainder of the project was built with 8 inches of lime treated subgrade, 10 inches of flexible base (caliche), and 1 inch of Type "D" hot mix. This pavement structure is representative of a typical TxDOT pavement design, and might have served as a good control section, but unfortunately testing and documentation were not performed on this section. According to Pharr District personnel, this pavement section exhibited some cracking in 1978. Since the time of construction, this section has had a fog seal and one Type "D" overlay, placed approximately 5 years ago.

The characteristics of the SAS subsection such as high air voids, resistance to rutting and resistance to cracking are very similar to those of Hot Sand Asphalt (HSA), which has been used successfully by the Department. It appears that a comparison between SAS and HSA would be necessary in order to determine what benefits, if any, the sulfur provides.

After approximately 14 years of service, the SAS subsections appeared to be in good condition with the exception of the 4 inch thick SAS subsection. The 4 inch SAS subsection that was originally designed to fail after two to three years experienced a considerable amount of distress after 14 years.

The conventional HMAC subsections were rutted and cracked much more severely than the SAS subsections. The entire 3,000 foot test section was rebuilt in November of 1991. The primary reasons for reconstruction were the rutting in the three HMAC subsections and the failures in the 4 inch SAS subsection. In addition to being rutted, the conventional HMAC subsections contained numerous longitudinal cracks.

With regard to pavement performance alone, it appears that SAS could be used as a suitable base material. The overall performance of the 7 inch and 10 inch SAS subsections could be considered at least equal to the expected performance of a conventional Texas Department of Transportation pavement.

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