1969

INSTALLATION REPORT

EXPERIMENTAL MIXES ON RICHMOND-PETERSBURG TURNPIKE -- 1985

by

C. S. Hughes
Senior Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

January 1986
VHTRC 86-R26

1970

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1971

ABSTRACT

This report describes the materials and construction details involved in the design and placement of four experimental mixes on I-95 (Richmond-Petersburg Turnpike) between Maury Avenue and Bells Road in 1985. The mixes were designed to initially resist rutting and to provide several years' service before failing from fatigue or the intrusion of water. The early results indicate that the gradation chosen is more important in minimizing early rutting than are the asphalt cement-additive combinations used. However, some strength tests point to the value of using an AC-30 cement as opposed to an AC-20. Controlling traffic sufficiently long to allow the pavement to cool to a temperature at which traffic does not prolong the compaction process is critical.

-1972

-1973

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INTRODUCTION

Two S-5 mixes placed on the Richmond-Petersburg Turnpike in 1984 displayed either inadequate stability or slow setting characteristics. Ruts as deep as 2-1/2 in occurred within several months of placement. Investigations by the Virginia Highway and Transportation Department's Materials Division and the Asphalt Institute identified some possible causes for the problems in both mixes. Some of these causes were high asphalt contents, ruts in underlying pavement, lack of density, mica content in the aggregate, and allowing traffic on the fresh pavement too soon.

Because the Turnpike is subjected to extremely high traffic volumes (59,390 vehicles per day, roughly 30,000 in each direction) and loads, it was agreed that mixes placed in 1985 should be selected and designed to include experimental variables likely to enhance the strength of the mix and provide information useful in the future design of mixes that must be subjected to heavy traffic.

A paper presented by Button and Epps at the January 1985 meeting of the Transportation Research Board summarizes mix characteristics and construction procedures that contribute to tender mixes and that, conversely, are necessary for high strengths.* Table 1, taken from that paper, shows the characteristics that influence tenderness. Here, a tenderness rating of 1 indicates the materials and mix variables that will produce the highest strengths.

DESIGN OF EXPERIMENT

The new mix design was assigned the designation S-7 and was chosen to be similar to Virginia's nominal 3/4-in top size mix (I-2), except that tolerances were specified on more sieves and the gradation was moved toward the coarse side of the I-2 gradation band to assure that the job mix would not follow the maximum density gradation too closely and also would prevent an excess of -#30 +#50 size material, which can contribute to the tenderness of a mix. The master gradation bands of both the I-2 and S-7 mixes are shown in Figure 1.

*Button, Joe W., and Jon E. Epps, "Identifying Tender Asphalt Mixtures in the Laboratory," Texas Transportation Institute, January 1985.

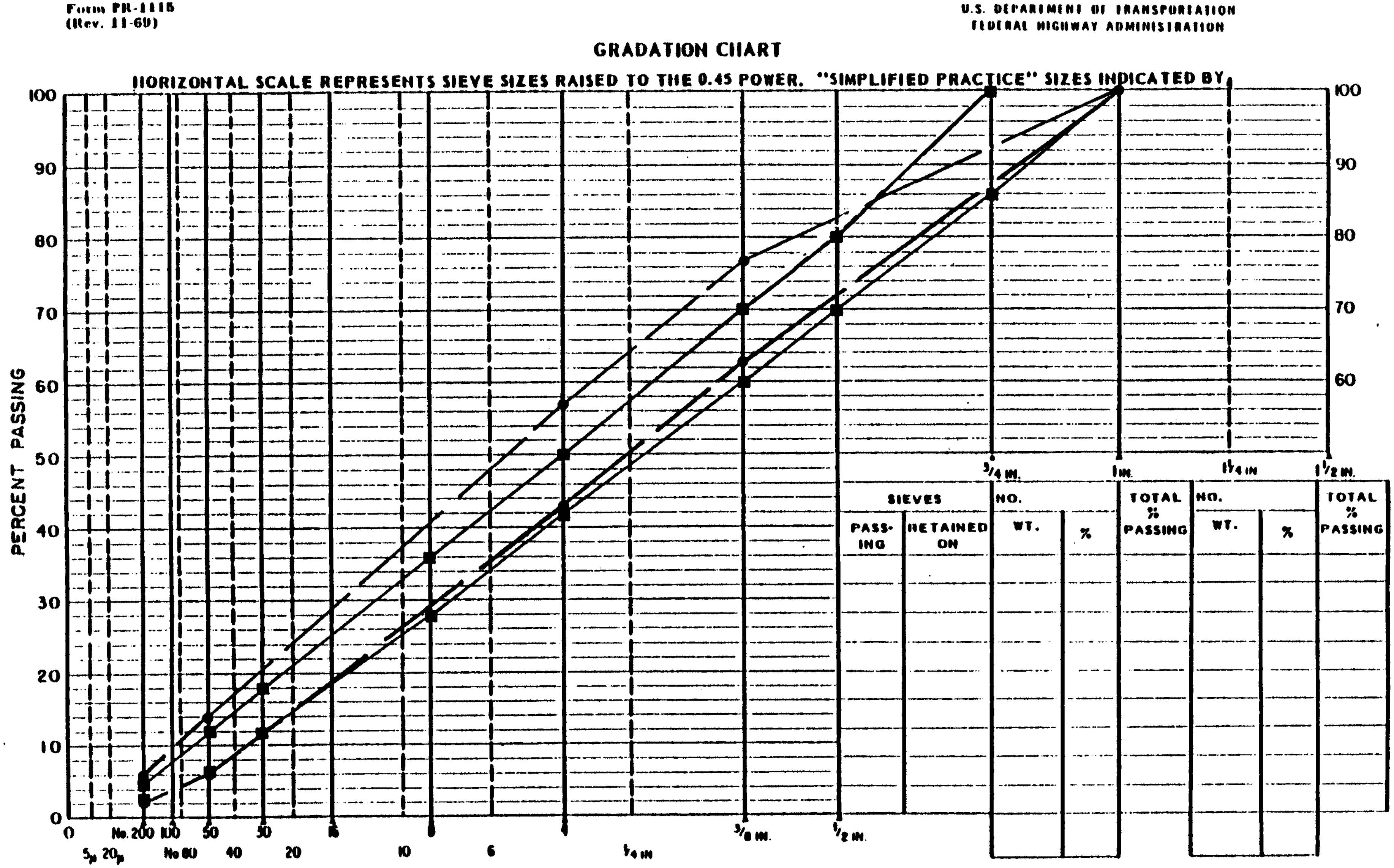
Table 1

RATING SCALE TO IDENTIFY TENDER MIXTURES

Material or Mixture Variable	INCREASING TENDERNESS 1	2	3	4	5	6	7	8	9	10
Aggregate										
Shape	Angular		Subangular					Subrounded		Rounded
Texture	Very Rough		Rough					Smooth		Polished
Maximum Size	>3/4-inch		<5/8-inch			<1/2-inch		>3/8-inch		<1/4-inch
-#30 to + #100	Suitable					Excessive				Large Excess
-#200	>6%		5%			4%		3%		<2%
Asphalt Cement										
Content	Low					Optimum				High
Viscosity	High					Medium				Low
Penetration	Low					Medium				High
Hardening Index	High					Medium				Low
Temp. Susceptibility	Low					Medium				High
Setting Characteristic	Fast					Medium				Slow
Asphaltene Content	>20%					10 to 20%				<10%
Mixture										
Softening Additives	None					Some				Much
Moisture Content	<0.5%					1 to 2%				>2.5%
Construction										
Rolling Temperature	Low					Medium				High
C-value	>50					30 - 50				<30
Ambient Temperature	<70		80					90		>100

Source: Button and Epps

1974



Legend: ● — — I-2 ■ ——S-7

Figure 1. Master gradation bands for I-2 and S-7 mixes.

Additional safeguards taken to produce a strong mix were (1) the use of an AC-30 asphalt cement, (2) the addition of 1% hydrated lime to act as a filler and as an antistrip additive, (3) the use of a 75-blow Marshall design, and (4) the requirement that all areas to be overlaid be milled to a 2-in depth. All of these actions were intended to produce a pavement that would perform well under the heavy traffic conditions on the Turnpike. It was thought that these safeguards would prevent rutting of the pavement, but there was some question as to whether all of them were really necessary.

In an attempt to answer this question, experimental features were considered. It was decided to hold the job mix gradation constant and to vary the type of asphalt cement and the type of additive to minimize stripping. Figure 2 is a schematic showing the mix variables, the lengths of the overlaid sections, the tonnages placed, and the paving dates for the S-7 mix.

Mix #1 should indicate the effect of asphalt cement stiffness. Mix #2 can be considered a control mix, as it uses both AC-20 asphalt cement and a liquid antistrip additive, two materials typically used in Virginia. If this mix performs well, it should indicate that gradation control alone is sufficient to provide a strong mix. Mix #3, using AC-20 and 1% lime, should provide an indication of the value of using lime in combination with a typical asphalt cement. Mix #4, incorporating AC-30 and 1% lime, should be the most rut-resistant of the four mixes.

Lime was included as a variable because it has been used to benefit asphalt mix characteristics in two ways. When it is placed on the aggregate, it can improve the aggregate-asphalt bond, and thus enhance the antistripping characteristics of the mix. When it is added as a filler, it may combine with the asphalt to add stiffness to the mix. In this project, it should serve primarily as an antistripping additive, because it was added to the aggregate in a wet slurry prior to feeding it into the plant. However, there may be enough lime available to combine with the asphalt and act as a stiffener.

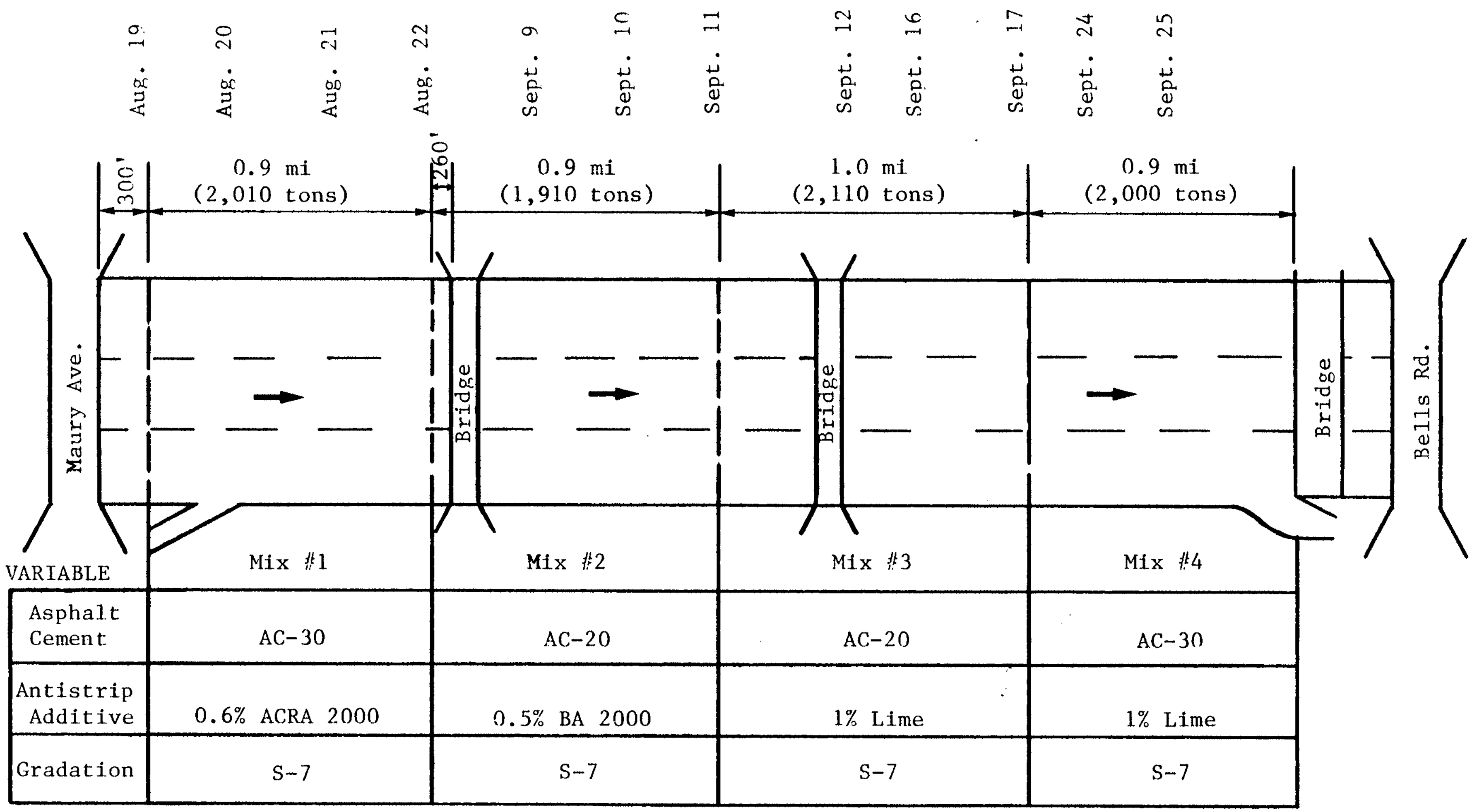


Figure 2. Test sections in southbound lane of Route I-95, the Richmond-Petersburg Turnpike.

1977

1978

PRELIMINARY WORK

Before this project was begun, the Department and the contractor agreed to share the cost of milling and replacing some of the areas of the pavement overlay that had been placed in 1984 and had rutted badly. This allowed the contractor to debug the mix, since the gradation for the S-7 mix proposed by the contractor had not been produced before.

The initial gradation used had 96% to 98% passing the 3/4-in sieve and 13% to 17% passing the No. 30 sieve. It was found that the 2% to 4% retained on the 3/4-in sieve created a coarser texture than was desirable (Figure 3), so the +3/4-in fraction of the mix was eliminated for the job mix formula used in the experimental sections. It also appeared that as the percentage of material passing the No. 30 sieve increased above 14%, the voids in mineral aggregate (VMA) decreased appreciably. This was undesirable because with a relatively low VMA, there might not be sufficient room for the asphalt and under consolidation flushing could become a problem.

The job mix formula was changed slightly to address these two potential problems. The preliminary and revised job mix gradations determined by the contractor are shown in Table 2, and Figure 4 shows the relationship between the maximum density line and the job mix formula that was used.

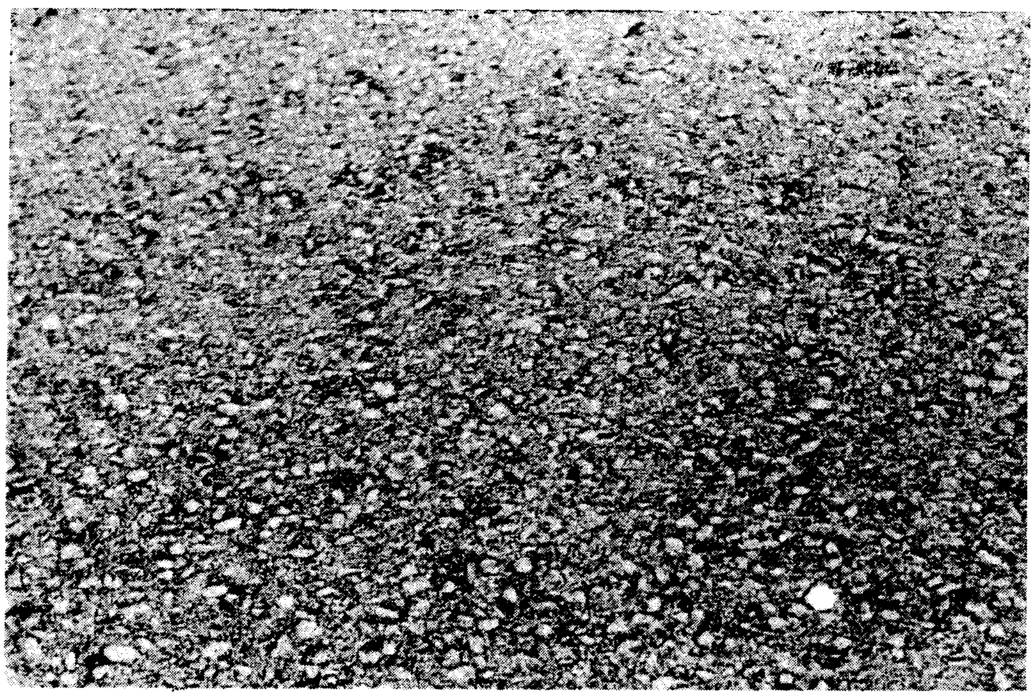


Figure 3. Coarse texture of preliminary mix.

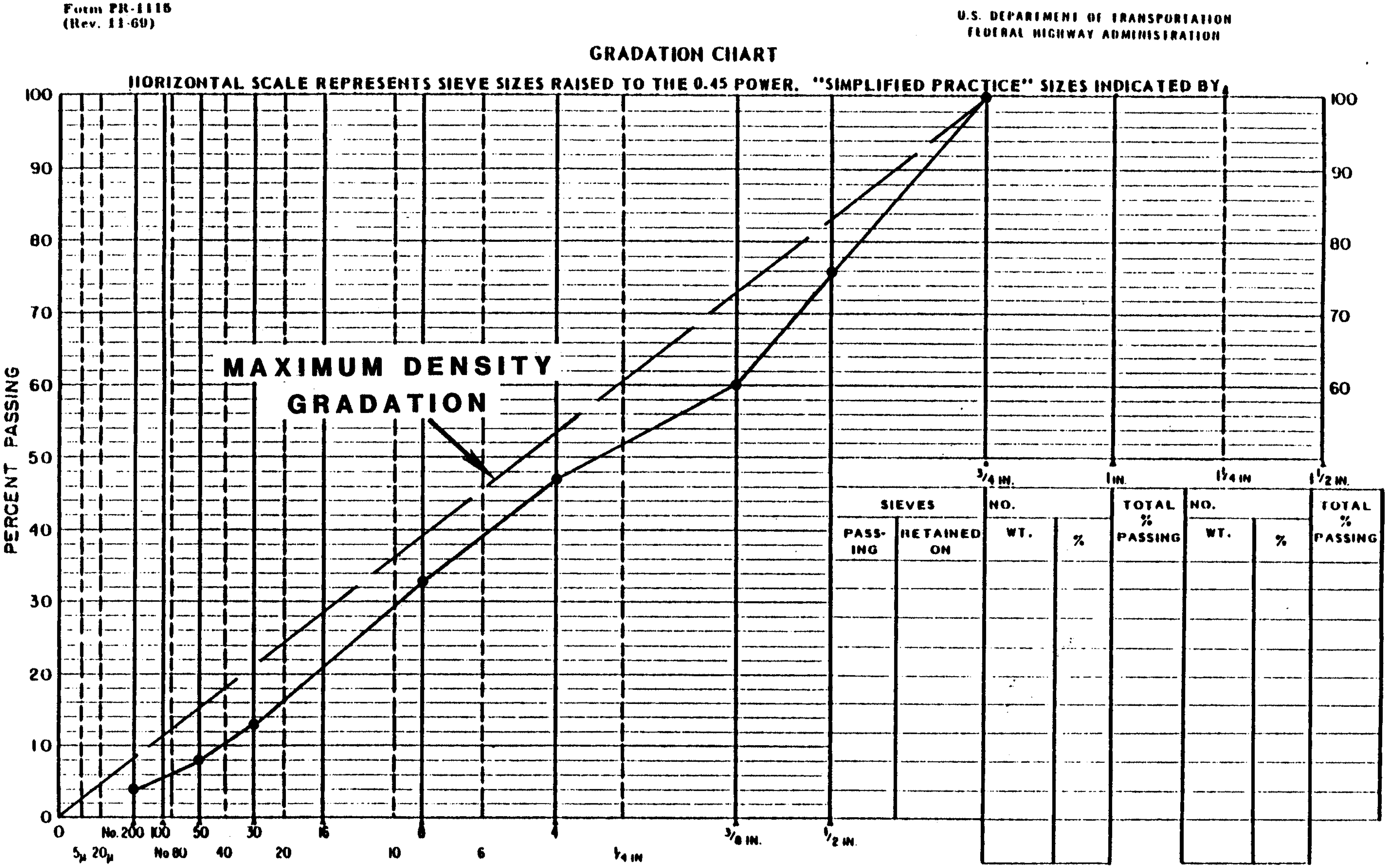


Figure 4. S-7 mix gradation plotted in relation to maximum density gradation.

1979

1980

Table 2

GRADATION FOR PRELIMINARY AND EXPERIMENTAL MIXES

Sieve Size	% Passing	
	Preliminary	Experimental
1 in	100	100
3/4 in	98	100
1/2 in	80	76.0
3/8 in	66	60.0
#4	49	47.0
#8	35	32.5
#30	14	13.0
#50	10	8.0
#200	4	3.5

MIX DESIGNS

Two Marshall compactive efforts were used for each of the four experimental mixes -- one being the 50-blow effort normally used in Virginia and the other the 75-blow effort specified for the experiment. This was done because Virginia has had very little experience in using the 75-blow compactive effort and to obtain comparison information for the four mixes.

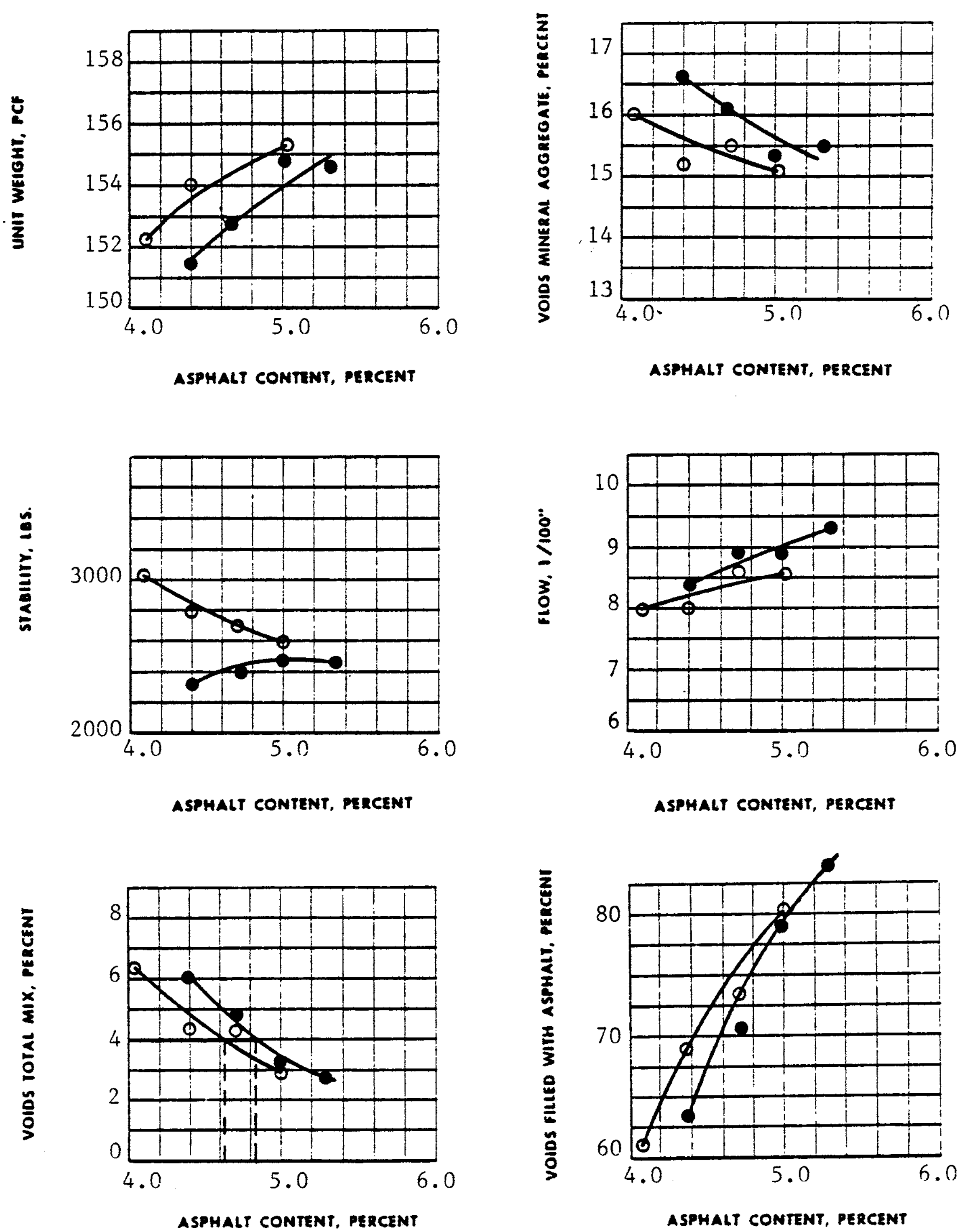
In addition to four experimental mixes, the two mixes shown in Figures A-1 and A-2 of Appendix A were fabricated and tested but were not used.

The designs for the four experimental mixes are shown on the charts in Figure 5, 6, 7, and 8. Since these mix designs were made prior to the preliminary work, they used the preliminary gradation proposed by the contractor and shown in Table 2. Fortunately, the changes in the job mix formula were not so great as to invalidate these designs.

As the figures indicate, the properties of all four mixes were very similar for a given compactive effort. It is the recommended practice in Virginia to select the optimum asphalt content as that occurring at a voids total mix (VTM) of 4.0%, and this value is indicated by a dashed line on each design chart. Each property is then checked at the optimum asphalt content to ascertain whether the other design criteria are met. The criteria for the S-7 mix are shown in Table 3.

1981

Marshall Design Charts



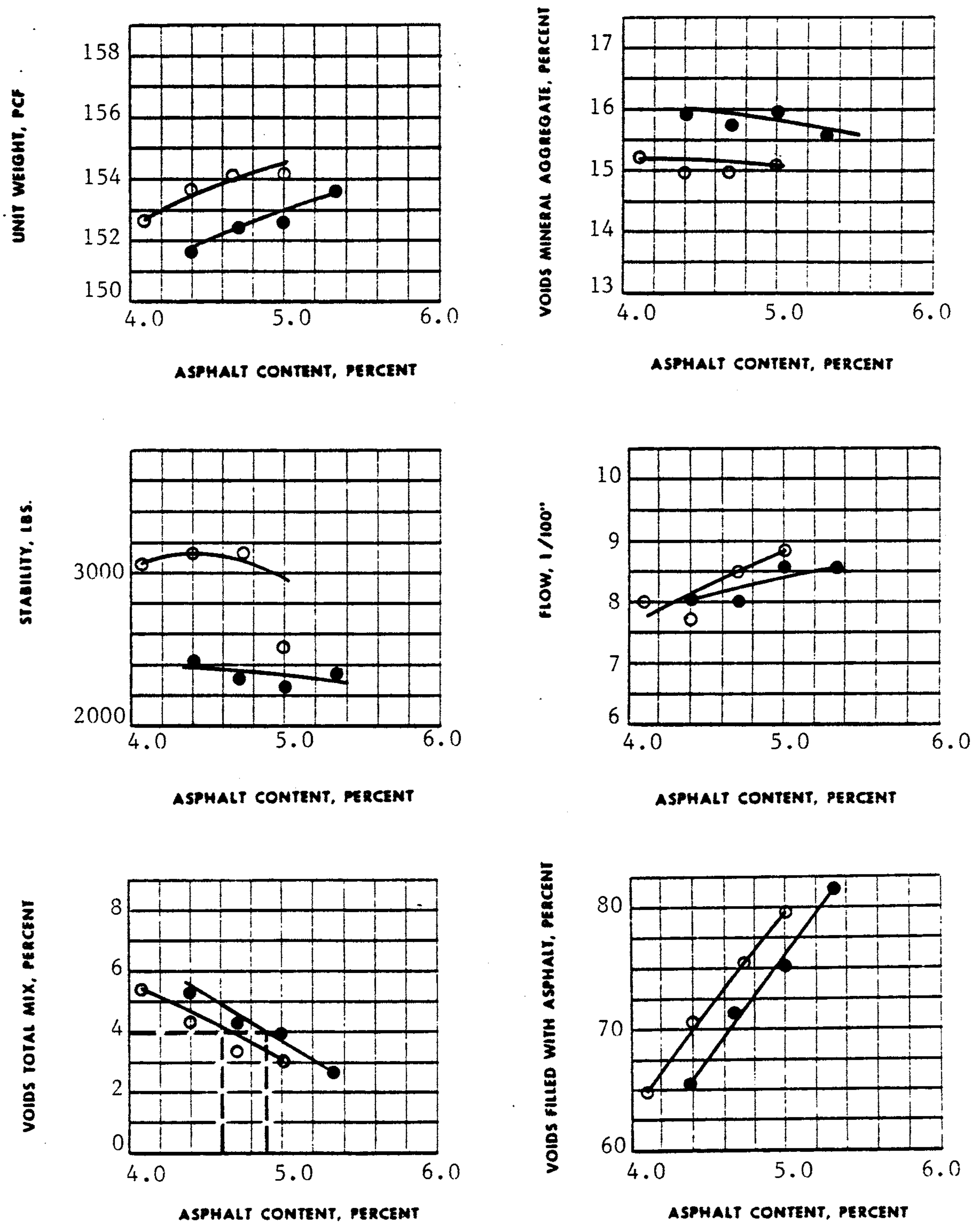
Legend

● 50-blow (Optimum AC 4.8%) ○ 75-blow (Optimum AC 4.6%)

Figure 5. Design for Mix #1, AC-30 with 0.6% ACRA 2000.

1982

Marshall Design Charts



Legend:

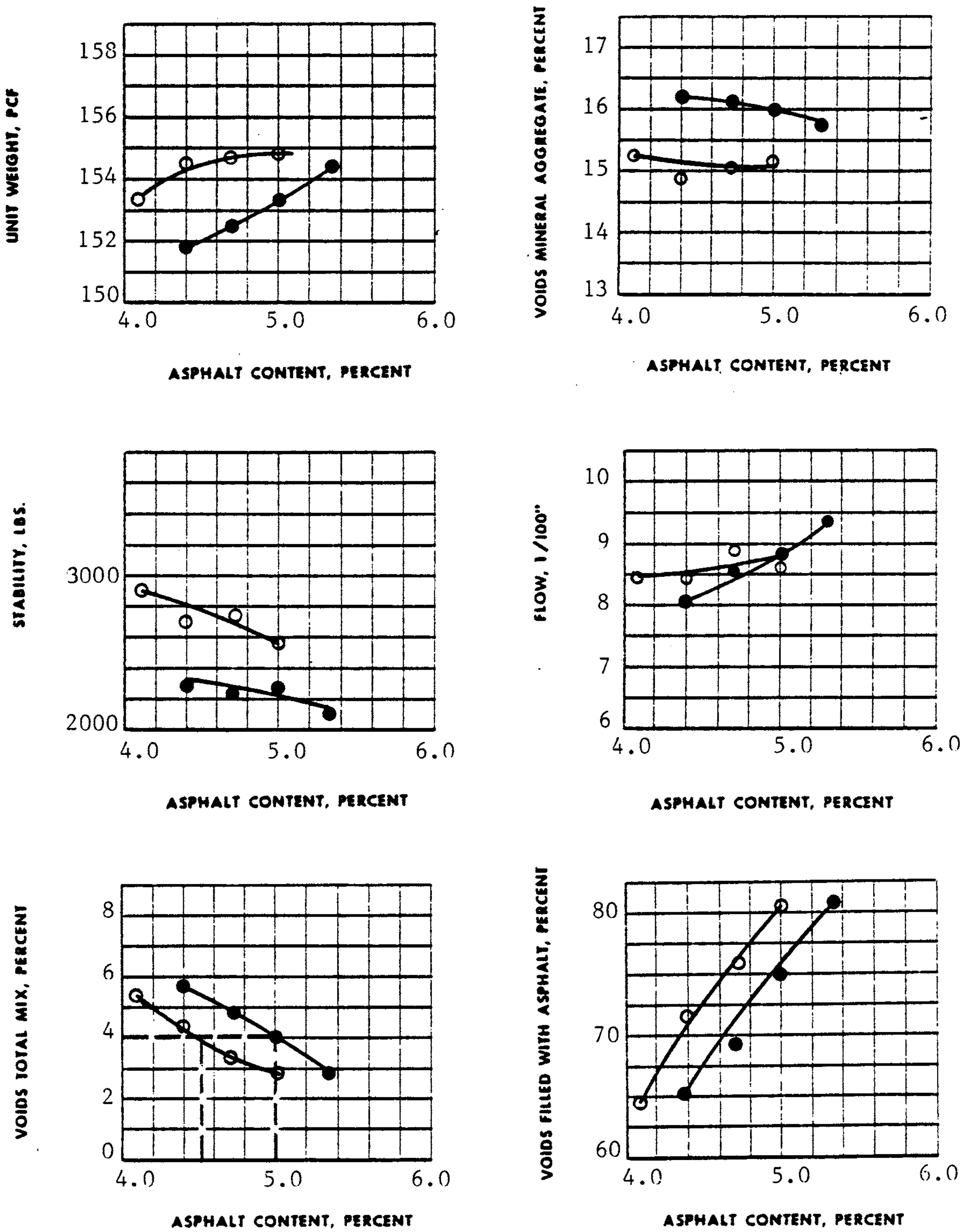
● 50-blow (Optimum AC 4.9%)

○ 75-blow (Optimum AC 4.6%)

Figure 6. Design for Mix #2, AC-20 with 0.5% BA 2000.

1983

Marshall Design Charts



Legend:

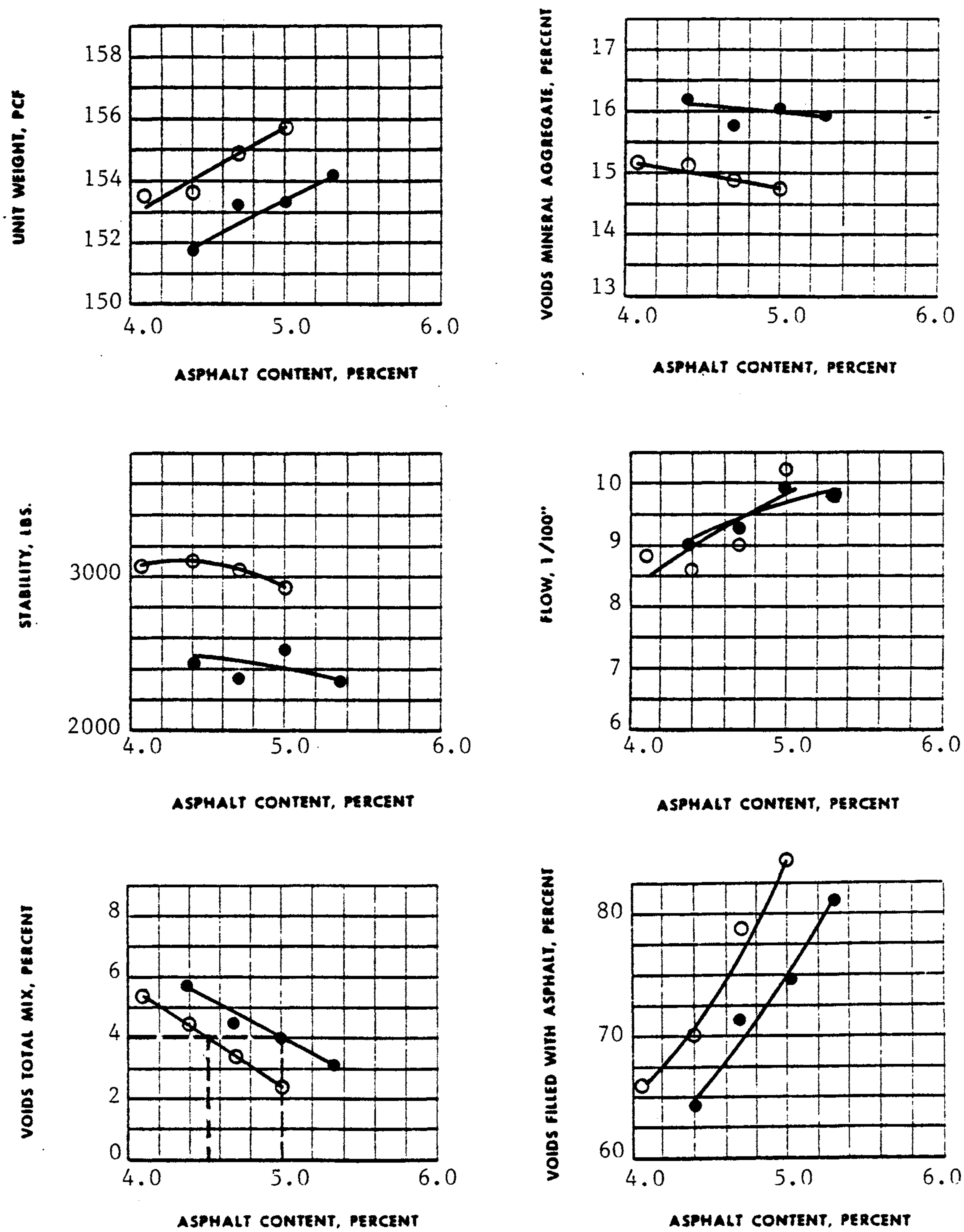
● 50-blow (Optimum AC 5.0%)

○ 75-blow (Optimum AC 4.5%)

Figure 7. Design for Mix #3, AC-20 with 1% lime.

-1984

Marshall Design Charts



Legend:
● 50-blow (Optimum AC 5.0%)
○ 75-blow (Optimum AC 4.5%)

Figure 8. Design for Mix #4, AC-30 with 1% lime.

-1985

Table 3

DESIGN CRITERIA FOR S-7 MIX

Stability, lb.	2,400 (min.)
Flow, 0.01 in	8-19
VMA, %	14.8-19.0
VFA, %	70-85
VTM, %	3-5

As shown in Figures 5 through 8, for the 75-blow design the optimum asphalt contents for the mixes varied between only 4.5% and 4.6%, and for the 50-blow design between only 4.8% and 5.0%. It does not appear that either the liquid antistrip additive, lime, or grade of asphalt cement affected the volumetric properties significantly. The differences between stability and flow for the four mixes were probably due to testing variation rather than real differences. Thus, it would not be expected that one mix would perform appreciably differently from another. Said differently, it appears that the gradation is more important than the binder and additive type, which verifies the theory of mix design as well as experience.

PROPERTIES OF MIX INGREDIENTS

Aggregates

As mentioned earlier, because of the previous rutting failures and because the VMA results in the preliminary work were relatively low, there was concern that the mix gradation would not provide sufficient VMA to accommodate the asphalt and thus could result in flushing or instability. This concern led to a thorough analysis of the specific gravity and absorptive properties of the aggregates to ensure that the void data were accurate. The results are listed in Table 4.

Table 4

AGGREGATE SPECIFIC GRAVITY AND ABSORPTION

Bulk Specific Gravity	2.76
Apparent Specific Gravity	2.78
Effective Specific Gravity	2.78
Absorption, percent	0.3

1986

Asphalt

The asphalts initially tested were Chevron AC-20 and West Bank AC-30. Earlier in the construction season, the Department had become concerned with the field behavior of the Chevron AC-20 because it did not appear to set up properly and exhibited some apparent temperature susceptibility problems on hot days. Because of this concern, it was decided that a West Bank AC-20 should be used in experimental mixes #2 and #3. The properties before and after the thin film oven test (TFOT) of the two asphalts used, i.e. West Bank AC-20 and AC-30, as well as those of Chevron AC-20 are shown in Table 5.

The viscosity at 140^{o}F of the West Bank asphalts is slightly higher than the specification allows, but not unreasonably so. When plotted on a viscosity-temperature graph, viscosities of the AC-20 asphalts do not differ appreciably, and the AC-30 asphalt appears slightly less temperature susceptible between 77^{o}F and 140^{o}F, but has about the same slope as the AC-20s above 140^{o}F.

In addition to the tests performed on the asphalts before construction, the Abson recovery procedure was used on samples of each mix taken daily. Table 6 gives a comparison of the averages for the original, TFOT, and Abson results on asphalts and mixes sampled the same day. As can be seen, the values of the original and TFOT samples differ slightly from those shown in Table 5.

Table 5

ASPHALT PROPERTIES

Property at indicated temp.	West Bank AC-30			West Bank AC-20			Chevron AC-20		
	Original	TFOT	Ratio	Original	TFOT	Ratio	Original	TFOT	Ratio
Viscosity, 140°F, poises	3612	10038	2.78	2465	5946	2.41	2115	5771	2.73
275°F, Cs	540	799	1.48	450	624	1.39	433	677	1.56
Penetration, 77°F	70	50		69	46		85	56	
66°F	31	22		30	23		34	22	
50°F	20	16		19	14		21	16	
45°F	15	14		13	12		14	11	
39.2°F	12	10		9	8		11	9	
Ductility, 77°F, cm	150+	133.5		150+	150+		150+	150+	
60°F, cm	65.5	10.5		113.5	14.0		150+	21.8	
50°F, cm	9.2	4.8		17.0	6.0		28.8	6.8	
45°F, cm	5.8	4.0		6.8	4.2		8.2	5.0	
39.2°F, cm	4.2	3.2		4.8	3.5		4.2	0.5	

1987

1988

Table 6

COMPARISON OF AVERAGES FOR ORIGINAL AND RECOVERED ASPHALTS

Property	Mix #1: West Bank AC-30, and 0.6% ACRA 2000 Original	TFOT	Abson	Mix #2: West Bank AC-20 and 0.5% BA 2000 Original	TFOT	Abson
Viscosity: 140°F, poises	3356	9987	13990	2489	6427	4689
275°F, Cs	505	767	897	433	608	580
Penetration, 77°F	64	40	40	70	45	56
% Loss		0.2			0.2	

Property	Mix #3: AC-20, No add., 1% lime Original	TFOT	Abson	Mix #4: AC-30, No add., 1% lime Original	TFOT	Abson
Viscosity: 140°F, poises	2564	6024	6296	3573	9767	10931
275°F, Cs	448	618	681	534	768	798
Penetration, 77°F	69	46	51	65	43	42
% Loss		0.1			0.1	

The AC-20 with additive didn't appear to harden as much in the plant as the TFOT would predict. The AC-30 with additive appeared to harden slightly more than this test would predict, and the AC-20 and AC-30 with lime hardened in the plant about as predicted.

STRIPPING TESTS

Since one of the experimental variables was the type of antistripping additive used, an analysis of the stripping potential of the aggregate with and without additives was made. The aggregate used in the mixes has historically had a tendency to strip, as evidenced by the modified Lottman test,* with Tensile Strength Ratio (TSR) values in the high 40's.

*Maupin, G. W., Jr., "Implementation of Stripping Test for Asphaltic Concrete," TRR 712, 1979.

1989

Modified Lottman stripping tests made in 1985, however, indicated that even without an antistripping additive the aggregate had quite high values, as shown in Table 7. The asphalts containing no additive were tested prior to construction; the tests for those with additives were made on samples taken during construction.

Table 7

STRIPPING TEST RESULTS, STRENGTH IN LB/IN^2

Asphalt	Additive	Conditioned	Dry	Tensile Strength Ratio
AC-20	None	78	87	0.90
AC-30	None	76	83	0.92
AC-30	ACRA 2000 (Mix #1)	108	120	0.90
AC-20	BA 2000 (Mix #2)	89	96	0.93
AC-20	Lime (Mix #3)	106	117	0.91
AC-30	Lime (Mix #4)	97	118	0.82

There is a statistically significant difference between the TSR value for Mix #4 and those for the other mixes. Although the conditioned and dry strengths appeared to be higher for the asphalts with additives than for those without, this difference was very likely attributable to testing variability. Since all TSR values were very high, it is unlikely that any stripping will occur in any of the experimental mixes.

INSTALLATION

The dates of installation were shown in Figure 2. The experimental mixes were placed in all three lanes of adjoining sections for a total length of the four sections of 3.7 mi. A total of 8,030 tons of mix was laid on the 78,144 yd^2 that was milled, for an average application rate of 205 lb/yd^2. The ambient temperature varied from the low 60's to the upper 90's. The higher temperatures, combined with the thickness of the overlay and laydown temperature, caused some problems in delaying the opening of the pavement to traffic. This will be discussed later.

The installation went fairly typically. There were a few problems with roller breakdowns, and the milling operation, which had to be done at night, often delayed the paving. But other than in traffic control, no major problems were encountered.

1990

TESTS ON FIELD SAMPLES

Extractions

In addition to the acceptance samples taken and tested by the contractor and monitor samples tested by the Department's Materials Division, samples were taken daily by the Research Council for determinations of asphalt content and gradation. For convenience, the Council samples were taken initially from the paver hopper whereas the acceptance and monitor samples were taken from the haul truck at the plant. A difference in asphalt contents (and volumetric properties of the Marshall specimens) between the two sources sampled led to the belief that the truck samples were not representative of the asphalt content of the mix in the truck. The Council results are shown in Table 8 and the acceptance and monitor samples results are shown in Appendix B. As is typically the case, the averages and standard deviations of the acceptance and monitor tests agreed very closely.

Table 8

AVERAGE GRADATION AND ASPHALT CONTENT OF EXPERIMENTAL MIXES

Sieve Size	Mix #1	Mix #2		Mix #3		Mix #4		J. M.
	Road	Road	Plant	Road	Plant	Road	Plant	
3/4 in	99.9	98.8	99.7	99.4	99.3	99.7	99.4	100
1/2 in	79.5	71.3	74.9	76.7	74.8	76.8	73.3	76
3/8 in	65.4	58.4	64.3	63.3	61.6	63.7	61.7	60
#4	45.4	42.3	46.3	43.5	44.5	45.8	44.7	47
#8	31.9	31.6	33.9	30.8	31.2	32.5	31.7	32.5
#30	13.8	14.1	14.1	14.6	14.7	13.5	13.6	13
#50	9.0	9.0	8.7	9.8	9.7	8.3	8.6	8
#100	6.0	6.0	5.7	6.3	6.2	5.3	5.6	-
#200	3.2	3.8	3.4	3.7	3.6	3.2	3.5	3.5
AC, %	4.60	4.48	4.27	4.42	4.30	4.68	4.22	4.5

The average asphalt contents from the plant samples were consistently lower than those of the road samples. The uniformity of the gradation across mix type indicates that the contractor controlled this property very well. The addition of lime did not affect the gradation, particularly the -#200 portion. Although the asphalt contents obtained from the plant samples were consistently lower than those from the road, the differences seen in the gradations would not indicate appreciable segregation.

Marshall Results

Marshall results for the mixes compacted with a 75-blow effort were determined on the samples taken daily and are shown in Table 9. The contractor and state Marshall results are given in Appendix C.

Table 9

AVERAGE MARSHALL PROPERTIES FOR EXPERIMENTAL MIXES

Property	Mix #1	Mix #2		Mix #3		Mix #4	
	Road	Road	Plant	Road	Plant	Road	Plant
AC, %	4.58	4.48	4.27	4.42	4.30	4.68	4.22
Density, lb/ft^3	150.6	149.7	147.6	151.2	150.7	149.6	149.6
Stability, lb.	3235	2973	2755	3075	3216	3066	3325
Flow, 0.01 in	8.2	8.9	8.3	9.7	9.2	9.2	9.1
VTM, %	4.0	4.0	6.3	3.3	4.0	4.4	4.6
VMA, %	14.8	14.5	16.1	13.8	14.2	15.4	14.5
VFA, %	73.0	72.4	60.1	76.1	71.6	71.4	68.3
Max. Theo. Sp. Gr.	2.518	2.508	2.528	2.512	2.520	2.512	2.516

The lower asphalt contents of the plant samples made a considerable difference in some of the volumetric properties. For instance, for mix #2 it appears from the results for the plant samples that the VTM values were too high and, conversely, the VFA values too low. However, the results for the road samples agreed very closely with the original design values. As the project progressed, the plant operator did attempt to change the operation of the discharge gates to try to reduce what was thought to be segregation and the resultant discrepancy in asphalt contents. As anticipated from the design data, no differences were found in the Marshall properties among the mixes.

Resilient Modulus and Tensile Strength

It was known from the mix design that Marshall stabilities would not differ appreciably from one mix to another, so other measures of strength were used to try to discern a difference among mixes. The resilient modulus test was run with a load pulse of 0.1 sec at a stress level of approximately 2 lbf/in^2. Both resilient modulus and tensile strengths were tested at 104^oF. The results of both tests are shown in Table 10. The compactive effort used was such as to simulate the VTM in the compacted pavement.

1992

Table 10

AVERAGE RESILIENT MODULUS AND TENSILE STRENGTH RESULTS

Property		Mix #1	Mix #2	Mix #3	Mix #4
VTM, %		7.5	8.3	8.1	8.1
Res. Mod.:	$\overline{X}$, lbf/in^2	33,000	17,000	20,000	28,000
	σ, lbf/in^2	300	300	200	400
Tensile Strength:	$\overline{X}$, lbf/in^2	46	31	33	42
	σ, lbf/in^2	3.5	7.2	3.8	4.0

These data indicate that mixes #1 and #4 were significantly stiffer than mixes #2 and #3 at an α probability of 2.5%. The results of these two tests indicate that AC-30 has a greater role in determining the mix stiffness than does the type of antistrip additive used.

Density Results

Obtaining adequate density is, in the author's opinion, always necessary for good pavement performance. But it was particularly important for the mixes used in the present project, because if high densities were not achieved during construction, it was certain that the heavy truck loads and high tire pressures would consolidate the wheel paths and create ruts.

The results of the density tests on the mixes are shown in Table 11.

Table 11

DENSITY RESULTS, PERCENTAGES MAXIMUM THEORETICAL

Mix	Average Density	σ
#1	91.5	0.8
#2	92.0	1.6
#3	92.2	1.5
#4	92.7	2.0

As the results show, the density results tended to improve as the paving progressed. Some of this improvement was very likely due to the improved procedure in taking the test sample, which will be discussed subsequently.

1993

Pavement Roughness

Roughness tests were run with the May's meter in October to gain an early indication of roughness so that a baseline could be established against which future roughness values could be compared. It was not anticipated that significant differences attributable to mix type would be found. In other words, if any differences in roughness were found among the test sections, they would likely be due to construction techniques or traffic. The roughness values are shown in Table 12.

Table 12

ROUGHNESS RESULTS, IN/MI

Lane	Mix #1	Mix #2	Mix #3	Mix #4
Traffic	88.0	88.8	88.0	95.0
Middle	85.2	79.3	74.2	75.7
Inside	96.2	84.0	80.6	91.5
Average	90.2	84.0	80.9	87.2

It appears that mix #1 was slightly rougher than the other mixes. The greatest contributor to this roughness value was the roughness of the inside lane, and the greatest contributor to the roughness of that lane was the first 100 ft of pavement, which was the first laid on the job.

Rut Depths

Measurement

Obtaining a realistic measure of the rut depth was a problem, and several devices were tried. The first was a 4-ft bow (Figure 9) with the scale in the center of the bow calibrated to measure ruts in 0.05-in increments. This device was used on the first two mixes, after rolling and after one day's traffic. The left side of the lane tended to show a slight hump, which gave a negative reading generally of 0.05-in to 0.10-in. The center of the lane showed a slight depression due to minor segregation of the mix at the center of the paver. Generally, the right side of the lane showed a zero reading. This inconsistency across the lane caused a great deal of consternation.

1994

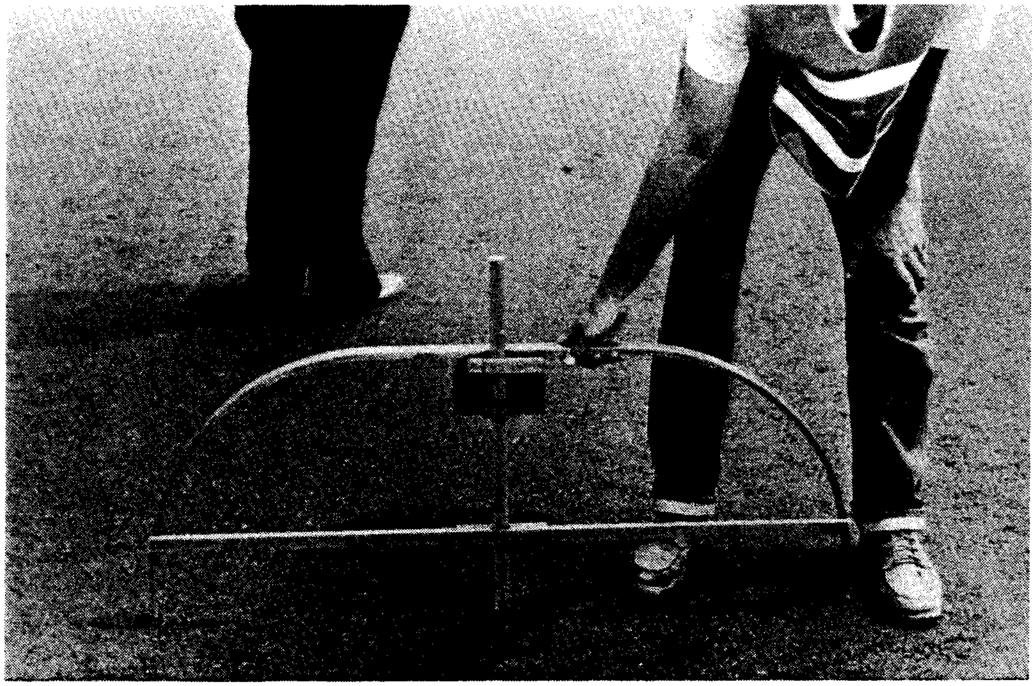


Figure 9. Four-foot bow used initially to measure ruts.

In an attempt to reduce the "left side hump - centerline depression" problem, a 6-ft aluminum straightedge was used with a machinist scale on the last two mixes, after rolling and after one day's traffic. This device was not convenient to use and presented some problems in the accuracy of measurements.

To overcome these problems the 4-ft bow was modified to 6 ft (Figure 10) and some degree of solution was achieved. Then, it was finally concluded that some of the inconsistency found was due to the relatively coarse texture of the mix and to the accuracy of the scale, probably being greater than warranted. Therefore, an attempt was made to determine the "within test" variability due to pavement texture and measuring device. A series of repeat tests were made at a single site, and the within test standard deviation was found to be 0.03 in.

1995

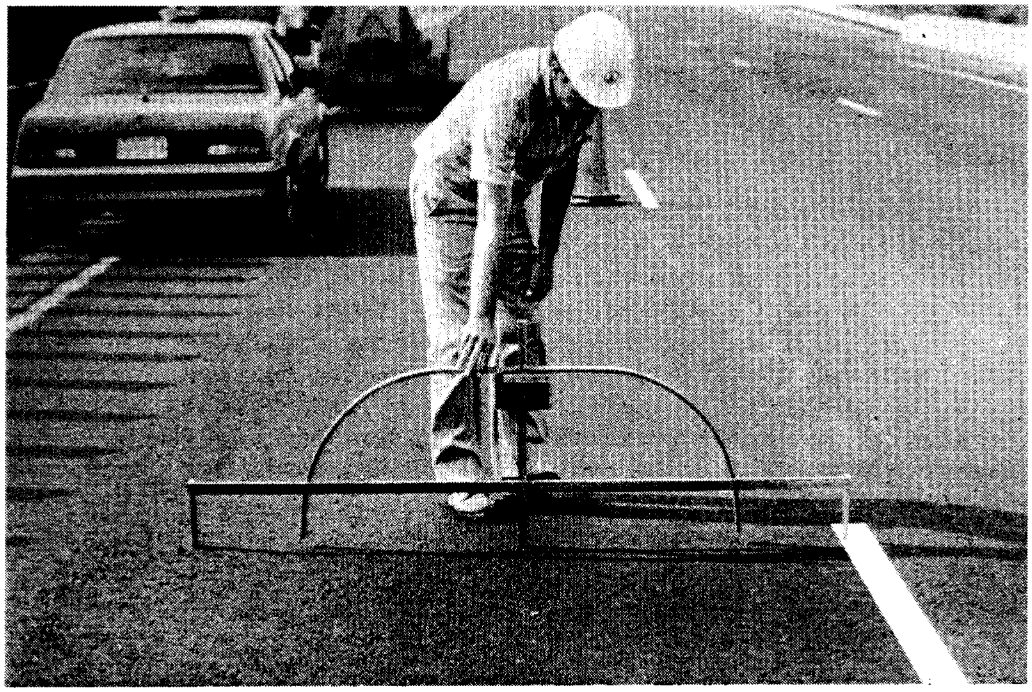


Figure 10. Bow modified to 6 ft to measure ruts.

Rut Depths -- 1st 24 Hours

No ruts greater than 0.05 in were found between the times rolling was completed and the lane was opened to traffic. The minor rutting that was found after one day's traffic appeared to occur most frequently in the inside and middle lanes and toward the end of the paved lane. This leads to the belief that the rutting that did occur was caused by early traffic, even though the maximum surface temperature of 150°F was observed. One other observation was that the rutting was not a static condition but tended to change slightly under traffic and on hot days. While some of the change was probably due to the inconsistencies mentioned earlier, it was the author's observation that some rutted areas tended to "iron out" while others appeared to rut slightly more. This occurrence was more associated with temperature than with the type of binder or additive.

1996

Rut Depths -- 1 and 3 Months

The 6-ft bow was used to measure rut depths in the right and left wheel paths of all three lanes approximately 1 and 3 months after construction. The results are presented in Table 13.

Conclusions

The first conclusion from the early rut measurements is that, at worst, only slight rutting had occurred. The 1-month data indicated that the left wheel path of mix #1 - middle lane, mix #2 - inside and middle lanes, and mix #4 - inside and middle lanes had very slight rutting. Comparing the 3-month and 1-month data indicated that only the right wheel path of mix #1 - traffic lane appeared to have changed in a positive (rutted) direction. It remains to be seen if this was an actual change in rut depth or whether it was due to measurement variability. There were no discernible differences in rut depths due to the type of binder or additive.

Table 13

RUT DEPTHS AT 1 AND 3 MONTHS AFTER CONSTRUCTION (IN.)

Time	Inside Lane		Middle Lane		Traffic Lane	
Mix #4						
3 Months	.02 (.08)	- .01 (.05)	.02 (.07)	0.0 (.07)	.01 (.05)	.04 (.05)
1 Month	.02 (.07)	.02 (.07)	.02 (.07)	-.02 (.09)	0.0 (0.0)	-.02 (.07)
Mix # 3						
3 Months	-.04 (.06)	- .06 (.04)	0.0 (.08)	-.09 (.02)	-.04 (.06)	-.12 (.07)
1 Month	-.02 (.09)	- .06 (.06)	-.02 (.09)	-.07 (.04)	-.02 (.06)	-.07 (.05)
Mix #2						
3 Months	.06 (.06)	0.0 (.05)	.05 (.08)	-.13 (.08)	-.04 (.06)	-.06 (.08)
1 Month	.05 (.07)	-.04 (.05)	.05 (.07)	-.08 (.05)	-.01 (.07)	-.05 (.05)
Mix #1						
3 Months	-.01 (.02)	- .06 (.05)	.05 (.09)	-.12 (.02)	-.01 (.07)	.03 (.08)
1 Month	0.0 (0.0)	- .06 (.04)	.04 (.09)	-.08 (.04)	-.02 (.08)	-.08 (.06)

Note: First number = average, number in ( ) = standard deviation.

+ = Rut
- = Hump

1997

1998

PROBLEMS ENCOUNTERED

Traffic

As mentioned under INSTALLATION, few major problems were encountered. The biggest problem was with traffic control and the psychological effects associated with working among 30,000 vpd in one direction. With the restricted paving hours included in the contract and the requirement of squaring up three lanes daily, only about 1,600 lin ft of roadway could be paved each day. This problem was never overcome and it was a great relief for all concerned when the paving was completed.

Density

Some problem was experienced in removing sawed samples for density tests from the overlay. The problem was caused by two primary factors. One, the milled surface on which the overlay was placed was very rough and provided a good texture for aggregate interlock and adhesion, but a difficult surface from which to remove a sample. Second, the mix, laid about 2 in thick, took a considerable time to cool, which in turn led to deformation of the specimen unless considerable care was taken to artificially cool the pavement. The contractor used CO_2 to cool the pavement, but did not have a complete understanding of the need to be very careful in cutting and removing the sample. All of these factors led to early problems which indicated low density results. As an example of the importance of the need for care in taking a sample, a difference in density of 4.4% was measured between damaged and undamaged samples taken in the same area. In order to overcome this problem, the following steps were taken:

1. Aluminum foil was placed on the tacked surface prior to paving.
2. The pavement was allowed to cool as long as possible before sawing (usually about one hour).
3. A template was used that allowed a 2-in x 4-in sawed plug not used for density determination to be removed, thus providing better access to the two 4-in x 4-in samples that were used for density tests.
4. CO_2 was used for about one minute on the area marked by the template.
5. A saw blade with a cutting depth in excess of 2 1/4 in was used.
6. CO_2 was again used on the sawed area.

1999

7. The 2-in x 4-in plug was removed.

8. Finally, the two 4-in x 4-in samples were carefully removed from the pavement.

This procedure was very effective in obtaining undisturbed samples that provided meaningful density results.

Plant vs. Field Sampling

As mentioned earlier, differences in asphalt contents were measured between samples taken from the plant and those from the road. The greatest concern was that the contractor would "correct" his asphalt content based on the plant samples, which possibly would increase the asphalt content in the road samples to a detrimentally high value. Fortunately, the contractor recognized the problem and attempted to correct it by adjusting the discharge gates to minimize the effect of the mix drop on the asphalt content. The contractor's technician also attempted to sample from deeper than usual in the truck to minimize the influence of sample location. These attempts did not appear to make much of a difference that could be seen in the results of the asphalt content analysis.

Surface Temperature

Because of the relatively short distance paved daily in each lane, there was a problem in keeping the lanes closed until the overlay had cooled sufficiently to carry traffic, particularly on days with the temperature in the high 90's. A guideline of a maximum of 150°F for the surface temperature was used to determine when a lane could be opened. An infrared thermometer was effectively used to measure the surface temperature. Beginning on September 9, the second day of paving with mix #2, the surface temperature was 190°F-220°F for the last 500 ft of the paved lane after rolling was completed and the contractor was ready to open the lane to traffic. It was decided to allow the contractor to use a water truck to sprinkle the surface to reduce the temperature (Figure 11). With two passes of the water truck, the surface temperature was reduced from the 190°F-220°F range to an acceptable range of 130°F-140°F. Unfortunately, the water truck had to approach the paved lane from the hottest end so as to place water on the mix before the wheels were on the pavement. (As can be imagined, logistical problems in dealing with 30,000 vpd prevented the truck from being turned around and backing from the cool end.) The water truck did cause some rutting (Figure 12) and part of the lane had to be re-rolled (Figure 13).

-2009

However, applying water to the pavement did reduce the surface temperature sufficiently to allow the lane to be opened to traffic within a reasonable length of time.

Figure 11. Water truck used to cool pavement.

2001

Figure 12. Ruts caused by water truck.

Figure 13. Pavement being re-rolled to eliminate ruts caused by water truck.

-2002

OBSERVATIONS AND DISCUSSION OF EARLY PERFORMANCE

As concerns rutting, it appears that for the mixes used in the project, the interaction between surface temperature and traffic had the greatest influence on early performance. When the surface temperature was reduced to a maximum of 150°F, the mix appeared to be sufficiently stable to resist rutting. But this appeared to be a critical relationship. First of all, although the surface temperature was reduced to 150°F, the interior of the 2-in mat most certainly was higher. Second, on a hot sunny day, the sun contributes greatly to the surface temperature remaining in the 150°F range and the delay in cooling of the interior. Thus, the longer traffic can be kept off the hot asphalt, the less initial rutting will occur.

Since no rutting occurred on any of the 4 mixes, the viscosity of the asphalt-additive binder combination was not as important as the gradation. This very likely was because the gradation was chosen to provide sufficient aggregate interlock to minimize the effect of binder viscosity. This observation has two implications. First, if sufficient aggregate interlock had not been obtained, binder viscosity would have been more important and, based on the Abson and resilient modulus results, the AC-30 with either lime or liquid antistrip would have been beneficial. Second, after the pavement goes through several months with traffic similar to that of the Turnpike without rutting, other failures likely to appear are cracking due to binder hardening or stripping. The AC-30 asphalt cement is harder than the AC-20 and will probably continue to be harder, assuming an equal rate of hardening. If so, mixes #1 and #4 may exhibit cold temperature or load associated cracking before mixes #2 and #3. Given the results of the stripping tests, stripping should not be a problem in any of the mixes.

TRAFFIC ANALYSIS

The experimental sections are located in the southbound lanes of a three-lane roadway carrying about 30,000 vpd in one direction. The test section starts adjacent to an on-ramp from Maury Street, a heavy industrial area, and ends at an off-ramp to Bells Road, also a heavy industrial area. In an attempt to estimate the daily 18-kip equivalent loads per lane, Highway Capacity Manual* Table 2-7 was used. Data from the table for the Lodge Freeway in Detroit were used to provide the vehicle count listed in Table 14.

*Special Report #209, Transportation Research Board, Washington, D. C., 1985.

2003

Table 14

ESTIMATED DAILY VEHICLES PER LANE ON EXPERIMENTAL MIXES

Vehicle Type	Traffic Lane	Middle Lane	Inside Lane
Passenger cars, pickups, etc.	6,400	8,400	7,100
2-axle, 4-6 tire trucks	2,200	4,400	500
3-axle, 6-10 tire trucks	100	200	100
Buses	100	100	40
Tractor trailers	6,700	200	700

To obtain the estimated 18-kip equivalents given in Table 15, an equation by Vaswani* was used with this distribution of vehicles as follows:

$$18 \text{ kip Equiv.} = 0.88\ N_{TT} + 0.28\ N_{3A} + 0.20\ N_{2A} + 0.22\ N_{B} + .0003\ Np,$$

where

N_{TT} = No. of tractor trailers,
N_{3A} = No. 3-axle, 6-10 tire trucks,
N_{2A} = No. 2-axle, 4-6 tire trucks,
N_{B} = No. buses, and
Np = No. of passenger cars, pickups, etc.

Table 15

ESTIMATED DAILY 18-KIP EQUIVALENT LOADS

Traffic Lane	Middle Lane	Inside Lane
6,400	1,100	800

*Vaswani, N. K. and D. E. Thacker, "Estimation of 18-Kip Equivalents on Primary and Interstate Road Systems in Virginia," Virginia Highway and Transportation Research Council, May 1972.

-2004

COSTS

The cost for each mix in place is shown in Table 16. Based on these figures, the average increase in cost of using 1% lime over that of using liquid antistrip was $2.62/ton, and the average increase in cost of using AC-30 asphalt over that of using AC-20 was $1.12/ton.

Table 16

MIX COST

Mix	Cost/Ton
1	$34.45
2	33.40
3	35.95
4	37.14

ADDED STUDY -- EFFECTS OF BAGHOUSE FINES

The Materials Division was concerned with the effect of fines from the baghouse on the performance of the mix. Therefore, the contractor agreed to waste all the fines from the baghouse for one day's production. All tests on this material were coordinated by the Materials Division. This mix is located in the three SBL's just below the Colonial Heights Toll Plaza from mile marker (MM) 53.5 to MM 53.8. The control for this section is from MM 53.1 to MM 53.5.

The gradation and Marshall results are in Appendix D.

CONCLUSIONS

This report is intended primarily to document the installation and tests conducted during the fabrication and placement of the experimental mixes. A few of the observations thought to be of especial interest are noted below.

1. The binder type does not appear to be as important as does gradation in minimizing early rutting.

2. Early rutting appears to be influenced greatly by the temperature of the mix when it is opened to traffic.

2005

3. The degree of care taken in removing plugs for density tests can greatly affect the density results. Special care is necessary when taking samples from a milled surface.

4. A 6-ft linear base appears to be better than a 4-ft linear base for measuring rut depths.

5. The application of water is a practical means of cooling an overlay to expedite opening it to traffic.

-2006

2007

ACKNOWLEDGEMENTS

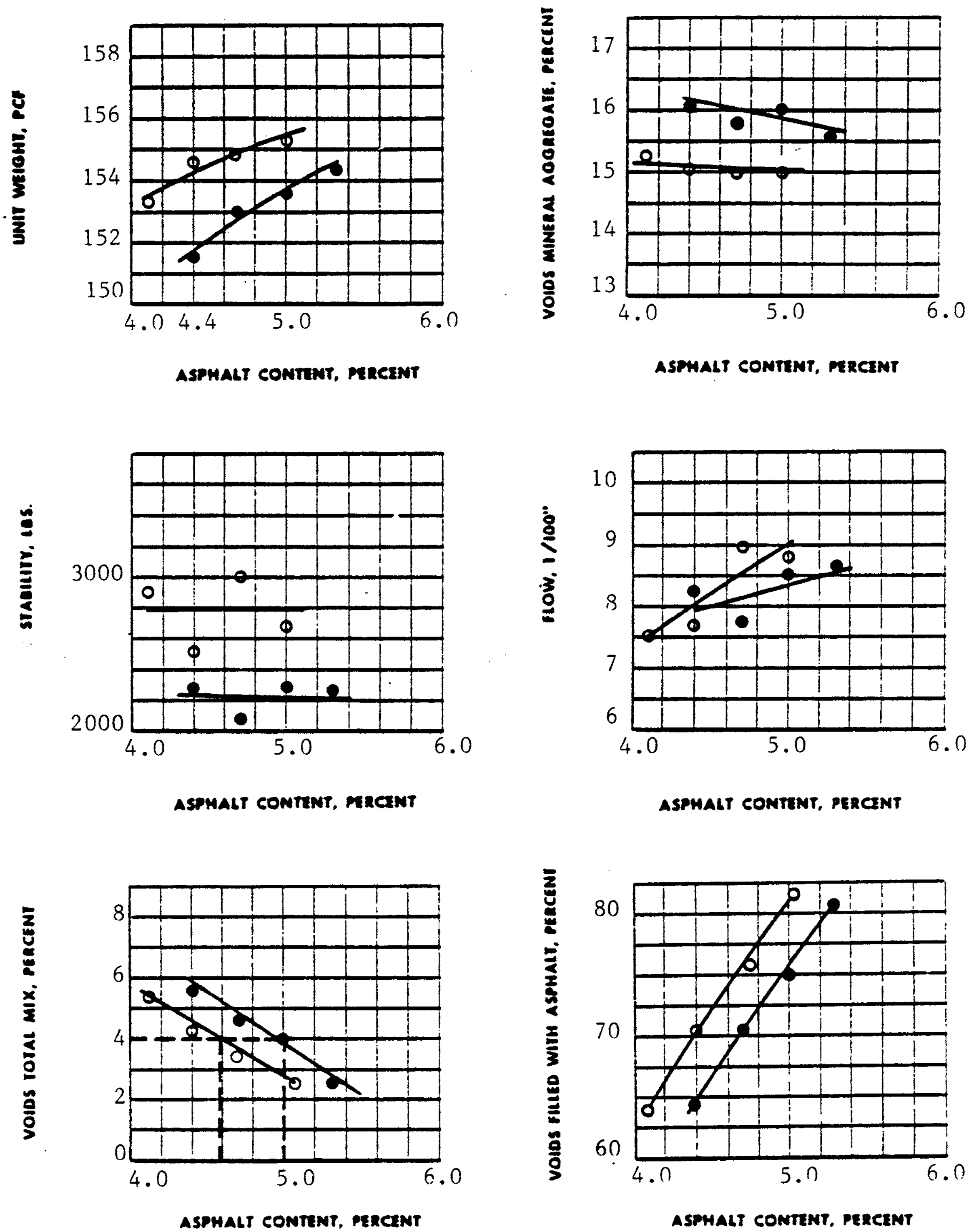
As indicated earlier, this project was carried out under very difficult traffic conditions. Without the cooperation of everyone involved, the data collection would have been much more difficult. Thanks go to the contractor, APAC-Va., and particularly Bob Lambeth, Art Pryor, and Jim Fause. Also, Frank Fee of the asphalt supplier, West Bank Oil, was extremely cooperative in trying to produce asphalts with a reasonably low temperature susceptibility. The Turnpike personnel were also extremely helpful; particularly David Cosby, Ken Alkire, and F. A. Hendricks, Jr. The Materials Division, as usual, was most cooperative with the monitor tests performed under the direction of Joe Love and Tommy Spicer. Often Council personnel are not acknowledged because the research is part of their job. But in this case L. E. Wood went beyond what is normally expected in being on the job, collecting samples, and running the lab tests. He was aided by A. J. Mills. Special thanks go to G. W. Maupin for his encouragement and advice.

2008

2009

Designs for Two Mixes Fabricated
and Tested but not Placed on Project

Marshall Design Charts

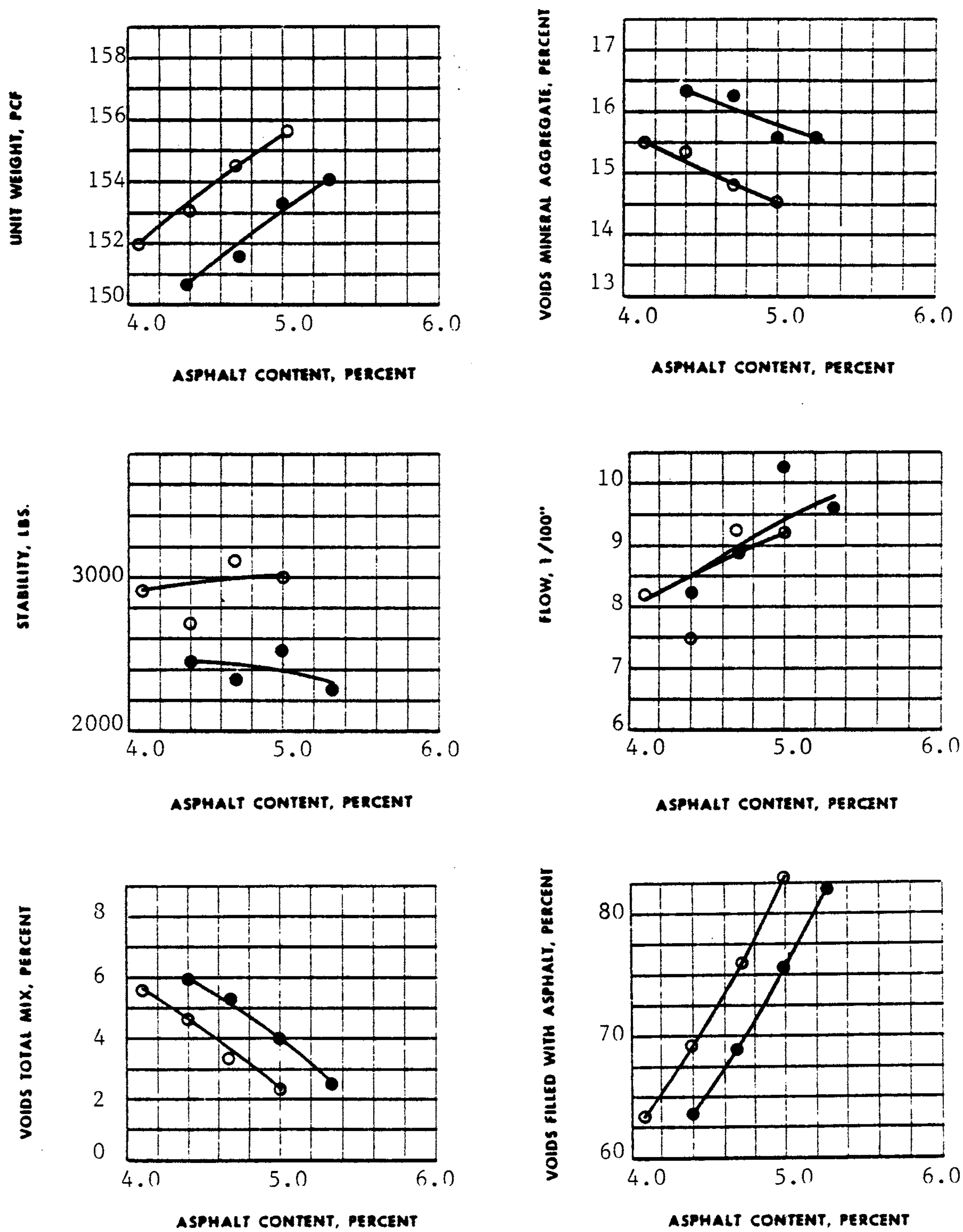


Legend:
● 50-blow (Optimum AC 5.0%)   O 75-blow (Optimum AC 4.6%)

Figure A-1. Mix design using Chevron AC-20 with 0.6% ACRA 2000.

2010

Marshall Design Charts



Legend:

● 50-blow (Optimum AC 5.0%)　　○ 75-blow (Optimum 4.6%)

Figure A-2. Mix design using West Bank AC-20 with no additive.

2011

APPENDIX B

RESULTS OF PRODUCTION AND MONITOR EXTRACTION TESTS

(Percent Passing)

	Acceptance N = 35		Monitor N = 41		
Sieve Size	$\bar{X}$	σ	$\bar{X}$	σ	J. M.
3/4 in	99.1	1.1	99.5	0.8	100
1/2 in	75.4	3.1	75.1	2.8	76.0
3/8 in	62.7	3.2	62.1	2.8	60.0
#4	46.1	2.6	45.1	2.4	47.0
#8	34.1	2.4	32.8	2.1	32.5
#30	14.7	1.4	14.3	1.1	13.0
#50	9.3	1.1	9.1	0.9	8.0
#200	3.6	0.6	3.1	0.5	3.5
AC, %	4.33	0.17	4.30	0.17	4.50
F/A	0.82	0.10	0.71	0.11	0.78

-2012

APPENDIX C

2013

CONTRACTOR AND STATE MARSHALL RESULTS

	Contractor N = 33		State N = 33	
	$\bar{X}$	σ	$\bar{X}$	σ
Stability, lb.	3140	280	2900	310
Flow, 0.01 in	10.9	1.0	9.8	1.0
VMA, %	14.4	0.8	14.9	0.8
VFA, %	71.7	3.7	67.5	4.4
VTM, %	4.1	0.7	4.9	0.9
Max. Theor. Sp. Gr.	2.520	0.02	2.512	0.01

2014

2015

APPENDIX D

RESULTS ON S-7 WITH NO BAGHOUSE FINES

Gradation and Asphalt Contents

Production Tests

Sieve Size	3/4"	1/2"	3/8"	#4	#8	#30	#50	#100	#200	AC %
N	3	3	3	3	3	3	3	3	2	2
$\bar{X}$	99.5	75.1	60.7	45.6	33.8	14.6	9.3	5.9	3.4	4.47
σ	0.9	3.1	3.3	2.5	1.9	0.9	1.0	0.7	0.3	0.01

Monitor Tests

N	1	1	1	1	1	1	1	1	1	1
Value	98.6	70.1	55.9	41.1	30.1	13.7	8.7	5.0	2.6	4.00

Marshall Results

Contractor

Sieve Size	Stability	Flow	VMA	VFA	VTM	RICE
N	3	3	2	2	3	3
$\bar{X}$	3,050	11.0	14.6	72.8	3.7	2.520
σ	80	0.6	0.6	2.6	0.6	-

State

N	1	1	1	1	1	1
X	3,617	10.7	14.0	67	4.6	2.521

-2016