Hot-Mix Asphalt Pavement Construction Report for the 1993-2000 FHWA Accelerated Loading Facility Project

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Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

A study was initiated in 1992 by the Federal Highway Administration (FHWA) in conjunction with the Strategic Highway Research Program to assist the highway community in validating Superpave binder tests and specifications, Superpave mixture tests and performance models, and other laboratory tests that have been developed to predict the performances of asphalt mixtures. Twelve pavements were constructed at the FHWA pavement Testing Facility in 1993 to assist in validating binder and mixture tests for rutting and fatigue cracking. This facility is located at the Turner-Fairbank Highway Research Center in McLean, VA. The pavements are to be tested from 1994 to 2000 using the FHWA Accelerated Loading Facility, which is a full-scale pavement testing machine.

This report documents the asphalt mixture designs, quality control and quality assurance tests for the asphalt pavement layer, and other asphalt binder and mixture tests performed at the time of construction. It will be of interest to research and laboratory personnel involved with testing and evaluating hot-mix asphalt for performance.

This report is being distributed on a limited basis. Copies of this report are available from the National Technical information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161.

T. Paul Teng

T. Paul Teng, P.E.
Director, Office of Infrastructure
Research and Development

NOTICE

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Kevin D. Stuart and Richard P. Izzo

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For additional information on this study, contact Kevin D. Stuart, Office of Infrastructure Research and Development (HRDI), Federal Highway Administration, 6300 Georgetown Pike, McLean, VA 22101-2296

16. Abstract

The Federal Highway Administration is conducting studies to validate Superpave binder and mixture tests using its Accelerated Loading Facility (ALF). The ALF is a full-scale pavement testing machine that applies one-half of a single rear truck axle load. Several other tests that have been developed to predict the performances of asphalt mixtures, such as wheel-tracking devices, are also being evaluated. Twelve pavements were constructed at the Turner-Fairbank Highway Research Center in 1993. The rutting and fatigue cracking susceptibilities of the pavements are to be determined using the ALF. This report documents the mixture designs, construction procedures, and quality control and quality assurance tests for the asphalt pavement layers.

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APT, Accelerated Pavement Testing, ALF, Accelerated Loading Facility, rutting susceptibility, fatigue cracking susceptibility, Superpave

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Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
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		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

(Revised September 1993)

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* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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1. Background

In 1993, a study was initiated by the Federal Highway Administration (FHWA) to assist the highway community in validating Superpave binder tests and specifications, Superpave mixture tests and performance models, and other laboratory tests that have been developed to predict the performances of asphalt mixtures. Twelve pavements were constructed at the FHWA Pavement Testing Facility, located at the Turner-Fairbank Highway Research Center (TFHRC), McLean, VA, to assist in validating binder and mixture tests for rutting and fatigue cracking. Each pavement had a length of 44 m, a width of 4 m, and was divided into four test sites. The pavements were to be tested by the FHWA Accelerated Loading Facility (ALF), which is a full-scale pavement testing machine that applies one-half of a single rear truck axle load. Figure 1 shows a layout of the pavements, designated as lanes 1 through 12. The experimental plan is shown in table 1.

The objectives of the rutting study were to:

- Validate the Superpave binder parameter for rutting, $G^*/\sin\delta$, using ALF pavement performance,
- Validate laboratory mixture tests for rutting when operated according to standardized or customary procedures using ALF pavement performance,
- Compare rankings based on the Superpave binder parameter for rutting to rankings provided by the laboratory mixture tests for rutting,
- Determine the effects of nominal maximum aggregate size on rutting susceptibility, and,
- Determine if the influence of binder grade (high-temperature performance grade) on rutting susceptibility decreases with an increase in nominal maximum aggregate size and the associated decrease in optimum binder content.

The objectives of the fatigue cracking study were to:

- Validate the Superpave binder parameter for fatigue cracking, namely, $G^*\sin\delta$, using ALF pavement performance,
- Determine the effect of asphalt pavement layer thickness on fatigue cracking susceptibility, including the hypothesis that: (1) when the tensile strain at the bottom of an asphalt pavement layer is relatively high, a binder with a low stiffness will provide a lower susceptibility to fatigue cracking than a binder with a high stiffness, and (2) when the tensile strain at the bottom of an asphalt pavement layer is relatively low, the reverse is true: a binder with a high stiffness will provide a lower susceptibility to fatigue cracking than a binder with a low stiffness.

- Validate laboratory mixture tests for fatigue cracking using ALF pavement performance, and,

- Compare rankings based on $G^*\sin\delta$ to rankings provided by the laboratory mixture tests.

The objective of this report is to document the asphalt mixture designs, quality control and quality assurance tests for the asphalt pavement layer, and other asphalt binder and mixture tests performed at the time of construction.

2. Marshall Mixture Designs

Marshall mixture designs were performed by the paving contractor, and verified in the Federal Highway Administration's (FHWA) Bituminous Mixtures Laboratory located at the Turner-Fairbank Highway Research Center (TFHRC). Five surface mixtures were designed to meet the 1991 Virginia Department of Transportation (VDOT) specification for SM-3B mixtures.(1) Two base mixtures were designed to meet a modification of the 1991 VDOT specification for BM-3 mixtures. Both specifications were for mixtures that would be subjected to heavy traffic. All mixtures included 1-percent hydrated lime to reduce the possibility of moisture damage occurring during the project. No reclaimed asphalt pavement materials were included. All binder, aggregate, and mixture tests were performed according to American Association of State Highway and Transportation Officials (AASHTO) test methods.(2)

Design criteria for the SM-3B surface mixtures were as follows:

- 75 blows per side using a 4.536-kg hammer.
- Specimen diameter of 101.6 mm and thickness of 63.5 mm.
- Optimum binder content at 4-percent total air voids.
- Minimum stability of 6672 N.
- Flow between 8 and 14, except for the Styrelf mixture where only a minimum flow of 8 was required.
- Minimum Voids in the Mineral Aggregate (VMA) of 14.0.
- Voids Filled With Asphalt (VFA) between 65 and 80 percent.

The 1991 VDOT specification did not use the Marshall method for designing BM-3 base mixtures. Design gradation ranges and a minimum binder content of 4.4 percent by mixture mass were specified. Typically, a 4.5-percent binder content was used. In this project, Marshall testing with the following design criteria was substituted for the VDOT specification by the FHWA:

- 112 blows per side using a 10.21-kg hammer.
- Specimen diameter of 152.4 mm and thickness of 95.3 mm.
- Optimum binder content at 4-percent air voids.
- Minimum stability of 6672 N.

- Flow between 8 and 14.
- Minimum VMA of 12.0.
- VFA between 65 and 80 percent.

Tables 2 and 3 present the properties of the individual aggregates, properties of the aggregate blends, the design ranges, and the process ranges for plant production. The nominal maximum aggregate sizes were 19.0 mm and 37.5 mm for the SM-3B and BM-3 gradations. The No. 68 and No. 10 diabase coarse aggregates used in the surface mixtures were from Virginia Trap Rock, Leesburg, VA. The No. 357, No. 8, and No. 10 diabase coarse aggregates used in the base mixtures were from Luck Stone Corporation, Leesburg, VA. These are crushed, quarried aggregates from the same vein. (The Virginia Trap Rock quarry is closer to the hot-mix plant used by the paving contractor, but this quarry did not have a stockpile of No. 357 stone.) The natural sand was from the Solite Corporation, Fredericksburg, VA. This sand is highly angular and predominately quartz and quartzite. The hydrated lime was from Chemston, Strasburg, VA. The FHWA obtained significantly lower water absorptions for both No. 10 aggregates compared to the paving contractor.

The initial mixture designs performed by the paving contractor provided an optimum binder content of 5.1 percent for all five surface mixtures and an optimum binder content of 4.0 percent for the two base mixtures. The compaction temperatures used by the paving contractor were 121, 127, 135, 141, and 141 °C for the AC-5, AC-10, AC-20, Novophalt, and Styrelf mixtures, respectively. The hydrated lime was not included in these designs and a specimen thickness of 63.5 mm was used when designing the base mixtures, instead of 95.3 mm. Furthermore, 50 blows were used to compact the surface mixtures and 75 blows for base mixtures. These blows were originally specified in the construction contract, but the contract was modified so that the mixtures would be designed for heavy traffic.

The paving contractor also performed American Society for Testing and Materials (ASTM) D 4867, "Effect of Moisture on Asphalt Concrete Paving Mixtures" on the seven mixtures without hydrated lime and obtained tensile strength ratios ranging from 0.74 to 0.80.(3) Even though these ratios indicated only a slight susceptibility to moisture damage, the 1-percent hydrated lime requirement was maintained.

The mix designs were repeated by the paving contractor so that they met the design criteria. The designs using the AC-10 and Novophalt binders were eliminated because the previous designs provided the same optimum binder contents for all five surface mixtures and there were severe constraints on the time available to repeat the designs. It was assumed that the binder contents for these mixtures could be obtained from the binder contents for the AC-5, AC-20, and Styrelf surface mixtures. The AC-5 and Styrelf binders had the highest and lowest binder stiffnesses. It was also expected that the optimum binder contents of the surface mixtures would be equal, since they were equal in the previous mixture designs.

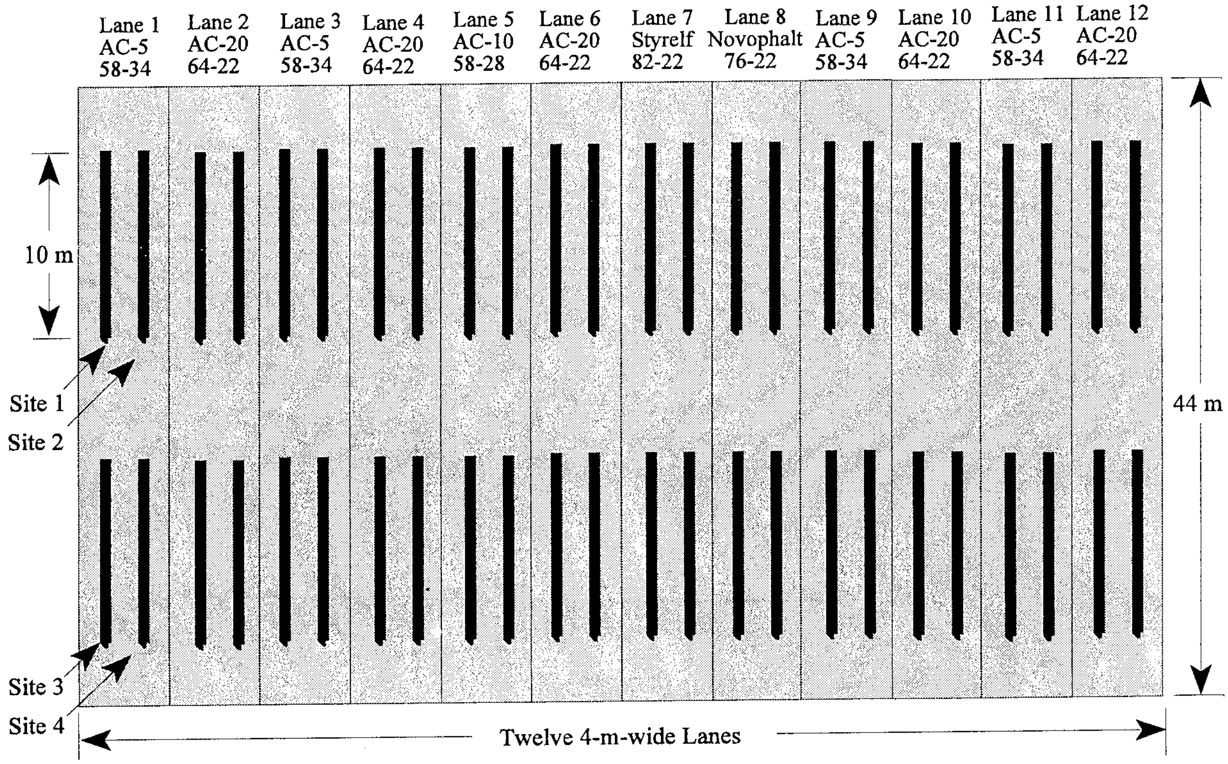

Figure 1. Layout of the test lanes at the FHWA Pavement Testing Facility.

Table 1. Pavement lanes for the Superpave validation study.

	HOT-MIX ASPHALT PAVEMENT LAYER						VDOT 21-A UNBOUND CRUSHED AGGREGATE BASE	AASHTO A-4 UNIFORM SUBGRADE
Lane	Layer Thickness, mm	VDOT Aggregate Gradation	Binder Designation Prior to Superpave	Superpave Performance Grade (PG)	High-Temperature Continuous Grade After RTFO Aging	Intermediate Temperature Continuous Grade After RTFO/PAV	Layer Thickness, mm	Layer Thickness, mm
1	100	SM-3	AC-5	58-34	59	9	560	610
2	100	SM-3	AC-20	64-22	70	17	560	610
3	200	SM-3	AC-5	58-34	59	9	460	610
4	200	SM-3	AC-20	64-22	70	17	460	610
5	200	SM-3	AC-10	58-28	65	15	460	610
6	200	SM-3	AC-20	64-22	70	17	460	610
7	200	SM-3	Styrelf™ I-D	82-22	88	18	460	610
8	200	SM-3	Novophalt™	76-22	77	20	460	610
9	200	SM-3	AC-5	58-34	59	9	460	610
10	200	SM-3	AC-20	64-22	70	17	460	610
11	200	BM-3	AC-5	58-34	59	9	460	610
12	200	BM-3	AC-20	64-22	70	17	460	610

RTFO = Rolling Thin-Film Oven.
PAV = Pressure Aging Vessel.

Table 2. Aggregate properties and blends for the SM-3B surface mixtures.

Aggregate Gradations, Percent Passing

Sieve Size (mm)	56% No. 68 Diabase	21% No. 10 Diabase	22% Natural Sand	1% Hydrated Lime	Design Range	Job-Mix Blend	Process Range
25.0	100.0				100	100.0	100
19.0	99.4				97-100	99.7	92-100
12.5	60.0				72-86	77.6	73-83
9.5	29.7	100.0	100.0		---	60.6	---
4.75	6.4	99.0	98.2		40-58	47.0	40-54
2.36	2.1	78.0	90.5		---	38.5	---
0.600	1.7	40.0	40.0		14-24	19.1	15-23
0.300	1.6	30.0	13.8		---	11.0	---
0.150	1.4	20.0	3.8		---	6.8	---
0.075	1.1	13.6	1.9	100.0	3-6	4.9	3-7

Specific Gravities and Percent Absorption (Paving Contractor):

Bulk Dry	2.945	2.876	2.563			2.830	
Bulk SSD	2.983	2.978	2.579			2.874	
Apparent	3.063	3.207	2.606	2.300		2.967	
% Abs	1.3	3.6	0.6			1.6	

Specific Gravities and Percent Absorption (FHWA):

Bulk Dry	2.943	2.929	2.565			2.840	
Bulk SSD	2.962	2.958	2.601			2.865	
Apparent	2.999	3.016	2.659	2.300		2.912	
% Abs	0.6	1.0	1.4			0.9	

Bulk Dry = Bulk-Dry Specific Gravity.
Bulk SSD = Bulk-Saturated-Surface-Dry Specific Gravity.
Apparent = Apparent Specific Gravity.
% Abs = Percent Water Absorption.

Table 3. Aggregate properties and blends for BM-3 base mixtures.

Aggregate Gradations, Percent Passing

Sieve Size (mm)	46% No. 357 Diabase	16% No. 8 Diabase	23% No. 10 Diabase	14% Natural Sand	1% Hydrated Lime	Design Range	Job-Mix Blend	Process Range
50.0	100.0					100	100.0	100
37.5	98.7					97-100	99.4	90-100
25.0	67.5					80-92	85.1	80-90
19.0	42.0					---	73.3	---
12.5	21.0	100.0				60-74	63.7	59-69
9.5	13.5	89.0	100.0	100.0		---	58.4	---
4.75	2.2	25.0	98.0	98.2		40-52	42.2	35-49
2.36	1.3	4.0	73.0	90.5		---	31.7	---
0.600	1.0	2.5	39.0	40.0		14-24	16.5	13-21
0.300	0.8	2.0	27.0	13.8		---	9.7	---
0.150	0.6	1.7	18.0	3.8		---	6.2	---
0.075	0.4	1.4	13.6	1.9	100.0	3-6	4.8	3-7

Specific Gravities and Percent Absorption (Paving Contractor):

	46% No. 357 Diabase	16% No. 8 Diabase	23% No. 10 Diabase	14% Natural Sand	1% Hydrated Lime	Design Range	Job-Mix Blend	Process Range
Bulk Dry	2.997	2.989	2.883	2.563			2.892	
Bulk SSD	3.012	3.001	2.965	2.579			2.922	
Apparent	3.048	3.051	3.140	2.606	2.300		2.988	
% Abs	0.5	0.7	2.8	0.6			1.1	

Specific Gravities and Percent Absorption (FHWA):

	46% No. 357 Diabase	16% No. 8 Diabase	23% No. 10 Diabase	14% Natural Sand	1% Hydrated Lime	Design Range	Job-Mix Blend	Process Range
Bulk Dry	2.971	2.956	2.929	2.565			2.886	
Bulk SSD	2.984	2.981	2.958	2.601			2.909	
Apparent	3.013	3.030	3.016	2.659	2.300		2.952	
% Abs	0.5	0.8	1.0	1.4			0.8	

Bulk Dry = Bulk-Dry Specific Gravity.
Bulk SSD = Bulk-Saturated-Surface-Dry Specific Gravity.
Apparent = Apparent Specific Gravity.
% Abs = Percent Water Absorption.

As shown in table 4, the paving contractor obtained an optimum binder content of 4.9 percent for the three surface mixtures and an optimum binder content of 4.0 percent for the two base mixtures. The mixture designs performed by the FHWA indicated that the 4.9-percent binder content would not provide 4.0-percent air voids in the surface mixtures using the compaction temperatures given in table 4. In order to obtain 4.0-percent air voids, the Styrelf mixture would require more binder than the AC-5 and AC-20 mixtures. Additional specimens using 4.9-percent binder were compacted by the FHWA, but the same differences in air voids were obtained. It was decided to use the 4.9-percent binder content recommended by the paving contractor because using the same binder content in all surface mixtures was beneficial to the study. The effects of binder type on performance would not be confounded with binder content. The 4.9-percent binder content did provide air voids within the typically specified range of 3 to 5 percent using the FHWA mixture design data. A 4.0-percent binder content was approved for the base mixtures.

All Marshall stabilities, flows, VMA's, and VFA's met specifications. The flow for the Styrelf mixture was higher than for the other two surface mixtures. This was typical of Styrelf mixtures. Theoretically, the use of the larger Marshall specimen increases the stability by a factor of 2.25 and the flow by a factor of 1.5 for a given mixture. Even though the surface and base mixtures were of different composition, higher stabilities and slightly higher flows were expected for the base mixtures. The FHWA data for the two base mixtures are closer to what was expected than the data provided by the paving contractor. The designs submitted by the paving contractor were accepted, although these discrepancies were not resolved.

3. Pavement Construction

The pavements were constructed by the paving contractor from October 4 to October 15, 1993. The sequence used to pave the lanes is shown in table 5. Paving started with lane 3 because lanes 1 and 2 had crushed aggregate base layers that were 101.6 mm higher in elevation than the other lanes. A thin tack coat of CRS-1 emulsion, obtained from Superior Emulsions, Centreville, VA, was applied between lifts. This practice is used in VDOT to promote bonding between lifts.

Weather data were obtained from an on-site automatic weather station. The temperature, relative humidity, and rainfall during paving in increments of 1 h were stored in a computer file. Paving occurred from 8:00 a.m. to 5:00 p.m. The average temperature during paving was 15.8 °C. The minimum and maximum temperatures during paving were 0.8 °C and 27.6 °C. The relative humidity during paving varied from 32 to 100 percent.

The paving contractor produced the mixtures in a batch plant manufactured by the Cedar Rapids Company. The batch plant was located in Leesburg, VA. The plant had a five-bin cold feed, a 181.4-Mg heated hot-mix storage silo, a 120-m^3 binder storage tank, and a 90.7-Mg storage silo for hydrated lime. The hydrated lime was added to the damp aggregate on the cold feed belt. The plant had a 181.4-Mg/h maximum capacity. The pug mill had a capacity of 4.5 Mg. The target mixing temperature was 138 °C. A heated storage silo was not used on this project; the mixtures were dropped directly into either an end dump truck having a capacity of approximately 14.5 Mg or a live bottom truck (flow boy) having a capacity of approximately 22.7 Mg. The 50.8-mm lifts of surface mixture required approximately 22 Mg of material, while the 101.6-mm lifts of base mixture required approximately 45 Mg of material.

The AC-20 asphalt was placed in the hot-mix plant's asphalt binder storage tank. The AC-5, AC-10, and Styrelf binders were stored in the tank trucks used to transport the binders from Pettys Island, NJ, to the hot-mix plant. These trucks had capacities of 20.8 to 22.7 m^3. Storage temperatures ranged from 149 to 163 °C. The Novophalt binder was in-line blended with the AC-10 at the hot-mix plant.

The hauling distance from the batch plant to the construction site was approximately 40 km. The temperature of the mixture in each truck was measured before it was dumped into the paver. These temperatures ranged from 138 to 150 °C and averaged 143 °C. The paver was a Blaw-Knox PF-200 weighing approximately 13.6 Mg. The roller was a Blaw-Knox SR-55 weighing approximately 5.9 Mg. The number of roller passes was 6 to 8 per lift.

4. Quality Control and Quality Assurance Testing

Quality control and quality assurance testing consisted of measuring binder properties during construction; determining the gradations and binder contents of the plant-produced mixtures; performing analyses on compacted plant-produced mixtures; and measuring in-place densities, thicknesses, and air voids.

a. Binder Properties

The following three tests were performed on the five binders to verify that they had not been contaminated during transport or excessively hardened during storage at the hot-mix plant:

- Brookfield viscosity at 135 °C.
- $G^*/\sin\delta$ at 20 °C and 10 rad/s using a Dynamic Shear Rheometer (DSR).
- Computerized Infrared (IR) Analysis.

The IR technique was used to monitor the functional groups (chemistry) of the binders. The Brookfield viscosities were determined at the Superpave-specified temperature of 135 °C and the $G^*/\sin\delta$ at 20 °C in order to monitor rheological properties at both high and intermediate temperatures. All tests were performed on unaged binder samples.

Table 4. Marshall mixture design properties.

Mix Type	Binder Type	Optimum Binder Content (%)	MSG	Stability (N)	Flow (0.25 mm)	Air Voids (%)	VMA (%)	VFA (%)
Paving Contractor								
Surface	AC-5	4.90	2.650	9 941	10.3	4.0	14.5	72.4
Surface	AC-20	4.90	2.647	12 797	11.2	4.0	14.6	72.6
Surface	Styrelf	4.90	2.653	13 059	13.8	4.0	14.3	72.7
Base	AC-5	4.00	2.730	13 166	10.5	4.0	13.4	71.6
Base	AC-20	4.00	2.727	13 464	10.9	4.0	13.6	71.3
Federal Highway Administration (Verification Tests)								
Surface	AC-5	4.90	2.643	10 102	11.2	3.2	14.5	78.0
Surface	AC-20	4.90	2.647	11 640	12.3	3.4	14.6	76.4
Surface	Styrelf	4.90	2.645	12 993	17.8	4.8	15.8	69.9
Base	AC-5	4.00	2.718	23 205	14.8	3.6	13.3	70.7
Base	AC-20	4.00	2.713	29 134	15.8	3.7	13.2	72.4

Marshall Design Blows:

Surface = 75
Base = 112

Compaction Temperatures:

AC-5 = 121 °C
AC-20 = 135 °C
Styrelf = 141 °C

MSG = Maximum Specific Gravity of the Mixture.
VMA = Voids in the Mineral Aggregate.
VFA = Voids Filled With Asphalt.

Table 5. Placement of lifts.

Date	Lane	Lift	Binder
10/4	3	1	AC-5
10/4	4	1	AC-20
10/5	5	1	AC-10
10/5	6	1	AC-20
10/5	7	1	Styrelf
10/5	8	1	Novophalt
10/6	9	1	AC-5
10/6	10	1	AC-20
10/7	1	1	AC-5
10/7	2	1	AC-20
10/7	11	1	AC-5
10/7	12	1	AC-20
10/8	3	2	AC-5
10/8	4	2	AC-20
10/8	5	2	AC-10
10/8	6	2	AC-20
10/8	9	2	AC-5
10/8	10	2	AC-20
10/9	7	2	Styrelf
10/9	8	2	Novophalt
10/9	3	3	AC-5
10/9	4	3	AC-20
10/11	5	3	AC-10
10/11	6	3	AC-20
10/11	9	3	AC-5
10/11	10	3	AC-20
10/11	1	2	AC-5
10/11	2	2	AC-20
10/13	7	3	Styrelf
10/13	8	3	Novophalt
10/13	3	4	AC-5
10/13	4	4	AC-20
10/13	5	4	AC-10
10/13	6	4	AC-20
10/14	7	4	Styrelf
10/14	8	4	Novophalt
10/14	9	4	AC-5
10/14	10	4	AC-20
10/15	11	2	AC-5
10/15	12	2	AC-20

Note: Lanes 1 and 2 had two 50.8-mm lifts. Lanes 11 and 12 had two 101.6-mm lifts. Lanes 3 through 10 had four 50.8-mm lifts.

The following samples were tested:

- Five binders used in the mixture designs.
- Four binders sampled at the terminal at Pettys Island, NJ, when the binder tank trucks were loaded.
- These same four binders upon their arrival at the hot-mix plant in Leesburg, VA.
- Samples obtained during construction.

The four binders sampled at the terminal and at the hot-mix plant did not include the Novophalt binder. The polyethylene used in the Novophalt process was blended with the AC-10 at the hot-mix plant. The other four binders were sampled at both locations to verify that they had not been contaminated during transport. Samples at the terminal were taken by Koch Materials Company. Samples at the hot-mix plant were taken by the paving contractor. Samples were also tested during construction each time a binder was used. The Styrelf binder was used immediately after being shipped to the hot-mix plant. Therefore, the data for the first day of construction also represents the data upon arrival at the hot-mix plant.

The Brookfield viscosities and $G^*/\sin\delta$'s are given in table 6. Both tests indicated that the AC-5 asphalt was slightly stiffer on the last day of construction. This sample of binder was used in the upper half of lane 11. It is expected that the majority of the rutting will occur in the upper half of the pavement. Thus, this increase in stiffness will have to be verified and, if necessary, taken into account when analyzing the pavement performance data. No other binder hardened to any significant degree over time, and none of the binders had been contaminated with foreign materials according to the IR data. (The IR data were extensive and were stored in a computer file; these data are not included in this report.)

Both test measurements indicated that the Styrelf binder sampled at the terminal was stiffer than the sample used when designing the mixture. This could be expected because these samples came from different batches of modified binder. The samples tested during construction were also stiffer than the sample used when designing the mixture, but not as stiff as the terminal sample. A reason for the differences between the terminal sample and the samples taken during construction was not apparent. The AC-20 asphalt was always used before Styrelf. Whether any samples of the Styrelf binder were contaminated with AC-20 asphalt could not be determined, although the data did not show that contamination occurred.

The Novophalt binder provided the lowest Brookfield viscosity and highest $G^*/\sin\delta$ on October 13. A reason for these results was not apparent. Styrelf was always used before Novophalt. Contamination with Styrelf would have provided the opposite trend. The high variability shown by some of the data could not be explained.

The paving contractor also delivered 0.6 m^3 of each binder to the TFHRC Bituminous Mixtures Laboratory at the end of construction. These binders were to be used for preparing mixtures needed for laboratory tests. The pre-Superpave AASHTO binder tests were performed on these binders.(2) The data are shown in table 7. The ranking of the binders according to both unaged and aged absolute viscosities at 60 °C, from lowest to highest, was AC-5, AC-10, AC-20, Novophalt, and Styrelf. As expected, the order was reversed based on the penetrations at 25 °C, except that the penetrations of the Novophalt and Styrelf binders were not significantly different at a 95-percent confidence level. The solubility of the Novophalt binder was only 95.92 percent because polyethylene is not soluble in trichloroethylene and most of the polyethylene cannot pass through the glass filter pad used in the test. (Technical Note: The absolute viscosities of the modified binders may not be correct. ASTM D 2171 is valid for Newtonian flow, but many modified binders exhibit non-Newtonian flow at 60 °C. One reason for the development of new binder tests and specifications was to effectively account for various types of binder rheology. At the time of construction, the paving industry recommended using ASTM D 4957 for modified binders, but the FHWA did not have the viscometer required for this method.)

Samples of the binders taken during the first few days of construction and at the end of construction were tested using the Superpave binder tests to further investigate whether any of the five binders excessively hardened during storage. The samples representing the end of construction were taken from the 0.6-m^3 asphalt binder shipments delivered at the end of construction. Both high- and low-temperature properties were measured. These data are shown in the middle of table 7. The high-temperature continuous grade is the temperature at a $G^*/\sin\delta$ of 1.00 kPa using unaged binder. The low-temperature continuous grade is the temperature at an m-value of 0.30 after aging in a Rolling Thin-Film Oven and Pressure Aging Vessel. These are the two extreme levels of aging used by Superpave to test binders. An independent laboratory, designated as Lab A, tested both conditions. Their data suggests that, possibly, the AC-5 aged slightly. The table also includes FHWA data measured using samples from the 0.6-m^3 shipments, and data measured by another independent laboratory, Lab B, using samples collected during construction. Overall, the data show that the differences from laboratory to laboratory were greater than the differences from the start to the end of construction.

As shown at the bottom of table 6, the two Superpave tests ranked Novophalt and Styrelf differently. The Brookfield viscosities at 135 °C ranked these two binders the same as the absolute and kinematic viscosities in table 7. Styrelf had the higher values. However, Styrelf had a lower $G^*/\sin\delta$ at 20 °C compared to Novophalt. This indicated that Styrelf had a lower temperature susceptibility.

The Superpave performance grades for the binders are included at the bottom of table 7. These grades were determined using the standard Dynamic Shear Rheometer frequency of 10 rad/s. However, the Superpave binder tests to be performed in this study will account for the temperature and frequency used by the various laboratory mixture tests and the ALF pavement tests.

Table 6. Quality control test results for the binders.

Binder	Date Used	Brookfield Viscosity, 135 °C (mPa-s)	DSR $G^*/\sin\delta$, 20 °C (MPa)
AC-5	Design	222	0.2394
	Terminal	227	0.2289
	Hot-Mix Plant	221	0.2279
	10/04/93	240	0.2861
	10/05/93	250	0.3235
	10/07/93	260	0.3376
	10/07/93	242	0.3177
	10/08/93	245	0.3060
	10/09/93	252	0.3122
	10/11/93	242	0.3371
	10/13/93	265	0.3543
	10/14/93	297	0.3592
	10/15/93	332	0.5002
AC-10	Design	277	0.4742
	Terminal	275	0.5540
	Hot-Mix Plant	277	0.5659
	10/05/93	300	0.5957
	10/08/93	290	0.5463
	10/11/93	287	0.6078
	10/13/93	287	0.6415
AC-20	Design	430	1.4382
	Terminal	380	1.0265
	Hot-Mix Plant	392	1.0746
	10/04/93	455	1.2415
	10/05/93	437	1.3467
	10/06/93	450	1.2504
	10/07/93	429	1.2925
	10/08/93	467	1.3698
	10/09/93	460	1.3026
	10/11/93	450	1.3030
	10/13/93	445	1.2569
	10/14/93	390	0.8531
	10/15/93	442	1.2002

Table 6. Quality control test results for the binders (continued).

Binder	Date Used	Brookfield Viscosity, 135 °C (mPa-s)	DSR $G^*/\sin\delta$, 20 °C (MPa)
Novophalt	Design	2017	1.9247
	10/05/93	1782	1.8212
	10/09/93	2182	2.0309
	10/13/93	1657	2.3979
	10/14/93	1905	1.8582
Styrelf	Design	1992	1.4366
	Terminal	3035	2.0260
	10/05/93	2787	1.5923
	10/09/93	2457	1.7448
	10/13/93	2250	1.5299
	10/14/93	2280	1.6851
Average Data During Construction			
AC-5		262	0.3434
AC-10		291	0.5978
AC-20		442	1.2417
Novophalt		1882	2.0270
Styrelf		2444	1.6380
Average Data During Construction by Lane			
AC-5, Lane 1		251	0.3374
AC-5, Lane 3		250	0.3146
AC-5, Lane 9		258	0.3314
AC-5, Lane 11		287	0.4090
AC-10, Lane 5		291	0.5978
AC-20, Lane 2		440	1.2978
AC-20, Lane 4		457	1.2927
AC-20, Lane 6		450	1.3191
AC-20, Lane 10		439	1.1941
AC-20, Lane 12		436	1.2464
Novophalt, Lane 8		1882	2.0270
Styrelf, Lane 7		2444	1.6380

Table 7. Physical properties of the binders.

Virgin Binder	AC-5	AC-10	AC-20	Novo-phalt	Styrelf
Penetration, 25 °C, 0.1 mm	172	113	73	54	47
Absolute Viscosity, 60 °C, dPa·s	665	1 195	2 644	13 814	60 308
Kinematic Viscosity, 135 °C, mm^2/s	256	322	476	2 184	2 484
Specific Gravity, 25/25 °C	1.007	1.024	1.022	1.022	1.020
Solubility in Trichloroethylene, %	100.00	100.00	100.00	95.92	100.00
Flash Point, COC, °C	304	304	304	326	312
Thin-Film Oven Test Residue					
Weight Loss, %	0.01	0.33	0.13	0.34	0.12
Penetration, 25 °C, 0.1 mm	102	66	47	40	35
Absolute Viscosity, 60 °C, dPa·s	1 758	3 223	7 183	29 844	208 185
Kinematic Viscosity, 135 °C, mm^2/s	372	509	684	3 686	4 197
Continuous Grade (Lab A, Start)	58-26	61-21	68-24	76-15	89-20
Continuous Grade (Lab A, End)	63-24	62-21	67-23	77-14	87-18
Continuous Grade (FHWA, End)	59-25	62-20	68-17	83-13	87-17
Continuous Grade (Lab B, Middle)	58-26	62-23	68-18	83-12	87-19

Start = samples obtained during the first days of construction.
End = samples obtained at the end of construction.
Middle = samples obtained during the middle of construction.

Performance Grade (Design Samples)	52-34	58-28	64-22	70-22	76-28
Performance Grade (Bulk Samples)	58-34	58-28	64-22	76-22	82-22

b. Aggregate Gradations and Binder Contents

Two samples of each mixture per lift were taken during construction for quality control and quality assurance testing. One sample was representative of the mixture at sites 1 and 2; the other was representative of the mixture at sites 3 and 4. The samples were obtained by the paving contractor from different locations in the truck before the mixture was dumped into the paver. Each sample was split by quartering. Half of the sample was used by the paving contractor to perform quality control testing. The other half was used by the FHWA Eastern Federal Lands Highway Division (EFLHD) for quality assurance testing. The reflux method of extraction was used to determine the binder contents and to recover the aggregates. Maximum specific gravities were also measured. Additional samples of the loose mixtures were taken by the TFHRC Bituminous Mixtures Laboratory at the same time.

The paving contractor tested both samples taken from each lift. This provided eight sets of data for lanes 3 through 10, since these lanes consisted of four lifts. Only four samples were obtained from lanes 1, 2, 11, and 12, since these lanes consisted of two lifts. A total of 80 sets of data were analyzed. (The paving contractor actually performed the tests for lanes 1, 2, 11, and 12 in duplicate, thereby performing 96 sets of tests.) One sample per lane was tested by EFLHD on a random basis.

The average gradations and binder contents provided by the paving contractor are given in tables 8 and 9. Based on the data, the gradations of the surface mixtures were slightly coarser at the middle sieve sizes compared to the design gradation. The quantity of aggregate passing the 2.36-mm sieve given by the job-mix formula was 38.5 percent while it averaged 33.2 percent according to the extractions. The base mixtures had slightly finer gradations below the 12.5-mm sieve compared to the design gradation. The quantity of aggregate passing the 4.75-mm sieve given by the job-mix formula was 42.2 percent, while it averaged 47.6 percent according to the extractions. The aggregate passing the 0.075-mm sieve increased slightly from 4.8 percent to an average of 5.6 percent. However, all 80 gradations were within the process ranges given in tables 2 and 3, and the average gradations met within-lane and between-lane variability requirements. The complete set of aggregate gradations, binder contents, maximum specific gravities, and the standard deviations of these data were stored in a computer file.

All 80 individual binder contents were within the VDOT-specified tolerance of ±0.60 percent, and the average binder contents met the within-lane and between-lane variability requirements. The paving contractor obtained average binder contents of 4.83 and 4.05 percent by total mass of the mixture for the surface and base mixtures. These same averages were obtained when the upper two lifts were only considered. It was expected that the majority of the rutting would occur in the upper two lifts.

The paving contractor's binder contents and the majority of their gradations were confirmed by EFLHD's data. The paving contractor's data in table 8 appear less variable from lane to lane. One reason for this is that their data are the averages of either four or eight tests. Table 8 does show discrepancies for lanes 3, 6, and 8, where EFLHD obtained low amounts of aggregate passing the 4.75- and 0.600-mm sieves. EFLHD's binder content for lane 8 with Novophalt was also low. Since EFLHD only tested one sample per lane, their data was also compared to the paving contractor's data for the matching split sample (same lane, same lift, same site). This comparison indicated that the paving contractor's gradation and EFLHD's gradation for lane 3 were equivalent. For lanes 6 and 8, the same differences shown in table 8 were obtained.

To investigate the differences, six tests for gradation and binder content were performed in the TFHRC Bituminous Mixtures Laboratory using two samples from lanes 3, 6, and 8. Single samples from lanes 7, 9, and 12 were also tested as additional checks on the extraction results. The data are shown in table 10. Slight differences in the minus 0.075-mm sieve contents could be expected because the paving contractor and EFLHD did not correct the data for the material that passed through the filter during the extractions. The TFHRC Bituminous Mixtures Laboratory measured this material and corrected both the dust and binder contents. However, this correction only decreased the binder content and increased the minus 0.075-mm content by 0.1 percent, or less, when using the reflux method. (Note: The centrifuge method of extraction was used for the majority of the extractions performed by the TFHRC Bituminous Mixtures Laboratory for convenience, whereas the paving contractor and EFLHD always used the reflux method.)

The first sample of surface mixture tested for lanes 3, 6, and 8 corresponded to the sample tested by EFLHD. The gradation for lane 3-lift 1 was equivalent to both the paving contractor's gradation and EFLHD's gradation. The gradations for lane 6–lift 4 and lane 8–lift 4 were closer to EFLHD's gradations. The gradations for the other lifts and lanes were equal to the paving contractor's gradations, except that the gradations from the TFHRC Bituminous Mixtures Laboratory exhibited more variability at the 0.075-mm sieve. It was concluded that there may be more variability in the gradations than indicated by the paving contractor's data.

All binder contents were equivalent to the paving contractor's binder contents, except for lane 7. The 4.4-percent binder content for this lane was low. This sample was taken from lift 3 at site 3-4. Additional extractions were then performed using the sample from lift 3 at site 1-2, and both samples from lift 4, which was the top lift. This meant that all four samples from the upper two lifts were tested. These three additional tests provided binder contents of 5.0, 5.0, and 5.1 percent. It was hypothesized that the 4.4-percent binder content was related to sampling error. The gradations of all four samples were the same as the gradation shown in table 10.

c. Analyses of Compacted Specimens

The TFHRC Bituminous Mixtures Laboratory performed volumetric analyses and stability and flow tests during construction to obtain supplementary information on the plant-produced mixtures. Three samples of each mixture were placed in an oven and compacted into Marshall specimens immediately upon reaching the design compaction temperature. This amounted to a total of 240 Marshall specimens. The specimens were tested for bulk specific gravity, Marshall stability, and Marshall flow. The TFHRC Bituminous Mixtures Laboratory did not perform maximum specific gravity tests. The maximum specific gravities determined by the paving contractor for quality control testing were used because they were equivalent to those obtained during the mixture designs. The paving contractor was not required by the contract to use volumetric analyses for process control.

Table 11 presents the average properties of the compacted specimens. The binder contents and maximum specific gravities given in the first two columns of the table were determined by the paving contractor. The average air voids were very low. They ranged from 1.2 to 3.1 percent. It was anticipated that the air voids would be close to the design level of 4 percent. The low air-void levels also provided high VFA (Voids Filled With Asphalt). The VMA's (Voids in the Mineral Aggregate) were low by an average of 0.8 percent for the surface mixtures and 1.3 percent for the base mixtures. The Marshall stabilities and flows were slightly higher than those obtained by the FHWA during the mixture designs, which are shown in table 4. The complete set of test results, given in table 12, shows that the data for both types of mixtures had low variabilities. The standard deviations of the paving contractor's binder contents and maximum specific gravities are included in table 12.

It was found that EFLHD had obtained higher maximum specific gravities when testing the plant-produced mixtures compared to the paving contractor for both types of mixtures. The discrepancies were greater for the surface mixtures. Only one sample per lane was tested by EFLHD, but their maximum specific gravities were consistently higher. EFLHD's maximum specific gravities were also higher than those measured during the mixture designs. The 10 maximum specific gravities determined by EFLHD for the surface mixtures ranged from 2.670 to 2.713, whereas the paving contractor's data for all 80 samples ranged from 2.653 to 2.667. Based upon these discrepancies, the TFHRC Bituminous Mixtures Laboratory tested 20 samples of surface mixture, two from each lane, and obtained data ranging from 2.675 to 2.703. These data were also higher than the paving contractor's data and the data obtained during the mixture designs.

Table 13 presents the average properties of the same compacted specimens using the maximum specific gravities determined by the TFHRC Bituminous Mixtures Laboratory. These maximum specific gravities increased the air voids to a range of 2.3 to 4.1 percent.

Table 8. Aggregate gradations (percent passing) and binder contents (percent by mixture mass) for the SM-3B surface mixtures.

Sieve Size (mm)	Lane Number 1	2	3	4	5	6	7	8	9	10	Average
Paving Contractor (Average of Eight Tests)											
25.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	98.7	98.8	98.1	98.7	98.4	98.8	99.5	98.7	98.9	98.6	98.7
12.5	76.4	74.9	76.7	76.2	76.0	76.0	76.2	76.0	75.5	75.8	76.0
9.5	62.6	61.3	62.5	62.9	62.0	62.4	62.5	61.7	62.7	62.4	62.3
4.75	44.3	43.7	43.9	44.3	43.5	44.9	44.4	43.9	44.6	44.9	44.2
2.36	32.8	33.2	32.3	32.9	32.3	34.4	32.7	32.8	33.9	34.2	33.2
1.18	No data obtained										
0.600	17.2	17.3	17.1	17.4	17.4	17.3	17.9	17.5	17.6	18.1	17.5
0.300	11.4	11.9	11.3	11.6	11.5	11.9	11.8	11.7	11.5	12.1	11.7
0.150	No data obtained										
0.075	4.9	5.4	4.8	5.0	5.0	5.0	5.1	5.0	4.9	5.0	5.0
% Binder	4.7	4.8	4.8	4.9	4.8	4.9	4.9	4.7	4.9	4.9	4.8
Eastern Federal Lands Highway Division (Single Test)											
25.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	100.0	99.0	99.0	99.0	98.0	99.0	100.0	99.0	100.0	99.0	99.0
12.5	79.0	80.0	71.0	78.0	72.0	75.0	80.0	76.0	82.0	79.0	77.0
9.5	63.0	61.0	56.0	62.0	58.0	55.0	62.0	53.0	66.0	64.0	60.0
4.75	42.0	41.0	37.0	43.0	41.0	35.0	46.0	31.0	48.0	47.0	41.0
2.36	31.0	30.0	24.0	29.0	30.0	25.0	35.0	21.0	35.0	34.0	29.0
1.18	23.0	22.0	18.0	22.0	23.0	19.0	26.0	17.0	26.0	26.0	22.0
0.600	17.0	16.0	13.0	16.0	17.0	14.0	19.0	12.0	19.0	18.0	16.0
0.300	11.0	11.0	9.0	10.0	11.0	9.0	12.0	8.0	12.0	12.0	10.5
0.150	7.0	7.0	6.0	7.0	8.0	6.0	8.0	6.0	8.0	8.0	7.0
0.075	4.6	4.5	3.9	4.4	5.2	4.4	4.7	3.5	5.1	5.0	4.5
% Binder	4.9	5.0	4.6	4.9	4.9	4.7	5.3	4.3	5.3	5.0	4.9

Table 9. Aggregate gradations (percent passing) and binder contents (percent by mixture mass) for the BM-3 base mixtures.

Sieve Size (mm)	Contractor (Avg of Eight Tests) Lane Number 11	12	Average	EFLHD (Single Test) Lane Number 11	12	Average
37.5	100.0	100.0	100.0	100.0	100.0	100.0
25.0	85.7	85.6	85.7	90.0	88.0	89.0
19.0	73.0	74.8	73.9	75.0	76.0	75.5
12.5	64.3	65.9	65.1	64.0	68.0	66.0
4.75	47.3	47.9	47.6	45.0	48.0	46.5
2.36	No data obtained			29.0	32.0	30.5
1.18	No data obtained			22.0	23.0	22.5
0.600	17.4	17.3	17.4	16.0	17.0	16.5
0.300	12.4	12.2	12.3	12.0	11.0	11.5
0.150	No data obtained			9.0	8.0	8.5
0.075	5.6	5.5	5.6	6.3	5.1	5.7
% Binder	4.0	4.1	4.0	4.2	4.3	4.25

Note: Data was not obtained for the 9.5-mm sieve size.

Table 10. Aggregate gradations (percent passing) and binder contents (percent by mixture mass) determined by the TFHRC Bituminous Mixtures Laboratory.

Sieve Size (mm)	Surface Mixtures								Base
	Lane 3		Lane 6		Lane 8		Lane 7	Lane 9	Lane 12
	Lift 1	Lift 3	Lift 4	Lift 2	Lift 4	Lift 1	Lift 3	Lift 3	Lift 1
37.5									100.0
25.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	82.4
19.0	96.6	97.4	98.2	97.5	99.7	98.4	98.6	97.4	74.4
12.5	73.8	82.4	78.0	76.2	81.0	75.6	77.5	75.9	67.2
9.5	58.8	62.2	60.9	60.2	57.2	60.6	63.4	62.2	62.7
4.75	40.5	42.6	39.0	43.8	34.2	43.6	46.0	45.6	48.1
2.36	27.2	32.9	27.4	32.2	23.8	32.3	33.4	33.6	31.0
1.18	20.4	25.2	20.2	24.4	18.2	24.2	24.5	25.0	22.4
0.600	14.6	18.6	14.5	18.1	13.5	17.2	17.7	17.8	18.4
0.300	9.6	12.6	9.8	12.6	9.3	11.2	11.9	11.6	11.7
0.150	6.4	8.8	7.0	9.0	6.4	7.4	8.3	7.8	8.4
0.075	4.2	6.0	4.9	6.4	4.2	4.8	6.0	5.4	5.9
Binder Content, percent									
	4.8	5.0	4.8	4.9	4.8	4.8	4.4	4.9	4.0
Maximum Specific Gravity									
	2.678	2.677	2.695	2.676	2.695	2.677	2.693	2.684	2.755

Table 11. Summary of average voids analysis data using the paving contractor's maximum specific gravities.

Lane Number	Binder Content (%)	Maximum Specific Gravity	Air Voids (%)	VMA (%)	VFA (%)	Stability (N)	Flow (0.25 mm)
1	4.7	2.659	2.1	14.3	85.2	12 018	15
2	4.8	2.656	1.2	13.6	91.2	14 910	16
3	4.8	2.656	1.7	14.1	87.9	12 325	15
4	4.9	2.657	1.6	14.1	88.6	15 350	17
5	4.8	2.660	1.6	13.9	88.5	13 046	16
6	4.9	2.658	1.3	13.8	90.5	15 483	16
7	4.9	2.658	2.5	14.8	83.1	19 794	21
8	4.7	2.658	3.1	15.1	79.5	16 573	16
9	4.9	2.660	1.8	14.1	87.2	12 926	16
10	4.9	2.658	1.5	13.9	89.2	16 204	17
11	4.0	2.732	2.0	11.6	82.8	30 776	20
12	4.1	2.730	2.5	12.2	79.5	36 994	20

VMA = Voids in the Mineral Aggregate.
VFA = Voids Filled With Asphalt.

Table 12. Average voids analysis data using the paving contractor's maximum specific gravities.

Lane Number	Binder Content (%)	Maximum Specific Gravity	Air Voids (%)	VMA (%)	VFA (%)	Stability (N)	Flow (0.25 mm)
Lane 1							
L1T1S12	4.8	2.657	1.8	14.1	87.2	12 641	16
L1T1S34	4.6	2.653	2.9	15.1	80.7	12 121	15
L1T2S12	4.7	2.657	1.9	14.1	86.5	11 378	14
L1T2S34	4.8	2.657	1.8	14.1	87.2	11 934	15
Average	**4.7**	**2.659**	**2.1**	**14.4**	**85.4**	**12 018**	**15**
Std Dev	**0.13**	**0.002**					
Lane 2							
L2T1S12	4.9	2.656	1.4	13.9	89.9	14 309	18
L2T1S34	4.7	2.654	1.5	13.9	89.2	14 901	16
L2T2S12	4.9	2.657	0.6	13.2	95.5	15 012	16
L2T2S34	4.9	2.658	1.4	13.8	89.9	15 421	13
Average	**4.8**	**2.656**	**1.2**	**13.7**	**91.1**	**14 910**	**16**
Std Dev	**0.10**	**0.003**					
Lane 3							
L3T1S12	4.7	2.657	2.2	14.4	84.7	11 823	14
L3T1S34	4.8	2.657	2.9	15.1	80.8	11 231	14
L3T2S12	4.8	2.655	1.4	13.8	89.9	11 565	12
L3T2S34	4.8	2.654	2.4	14.7	83.7	11 565	13
L3T3S12	4.7	2.657	1.3	13.6	90.4	13 936	15
L3T3S34	4.7	2.655	1.4	13.7	89.8	14 603	20
L3T4S12	4.8	2.658	0.8	13.2	93.9	13 233	15
L3T4S34	4.8	2.656	1.5	13.9	89.2	10 640	13
Average	**4.8**	**2.656**	**1.7**	**14.1**	**87.8**	**12 325**	**15**
Std Dev	**0.04**	**0.001**					

L = Lane; T = Lift; S = Site.

MSG = Maximum Specific Gravity of the Mixture.
VMA = Voids in the Mineral Aggregate.
VFA = Voids Filled With Asphalt.

Lanes 1, 3, 9, and 11 are AC-5.
Lanes 2, 4, 6, 10, and 12 are AC-20.
Lane 5 is AC-10.
Lane 7 is Styrelf.
Lane 8 is Novophalt.

Table 12. Average voids analysis data using the paving contractor's maximum specific gravities (continued).

Lane Number	Binder Content (%)	Maximum Specific Gravity	Air Voids (%)	VMA (%)	VFA (%)	Stability (N)	Flow (0.25 mm)
Lane 4							
L4T1S12	4.8	2.660	2.4	14.5	83.4	14 567	18
L4T1S34	4.9	2.658	2.3	14.6	84.2	13 678	15
L4T2S12	4.9	2.661	1.4	13.7	89.8	15 012	17
L4T2S34	4.9	2.654	1.4	13.9	89.9	13 824	15
L4T3S12	5.1	2.659	2.1	14.6	85.6	17 792	19
L4T3S34	5.0	2.654	2.0	14.6	86.3	17 756	17
L4T4S12	4.9	2.654	1.0	13.6	92.6	15 346	17
L4T4S34	4.9	2.655	0.6	13.2	95.5	15 048	16
Average	**4.9**	**2.657**	**1.6**	**14.1**	**88.4**	**15 350**	**17**
Std Dev	**0.10**	**0.003**					
Lane 5							
L5T1S12	4.6	2.667	2.5	14.2	82.4	11 898	13
L5T1S34	4.8	2.659	2.0	14.2	85.9	14 122	16
L5T2S12	4.6	2.660	0.9	13.0	93.1	12 379	16
L5T2S34	4.9	2.658	1.7	14.1	87.9	12 752	20
L5T3S12	4.8	2.661	1.5	13.7	89.1	14 087	16
L5T3S34	5.0	2.659	1.3	13.8	90.6	13 864	15
L5T4S12	4.9	2.658	1.3	13.7	90.5	12 601	15
L5T4S34	4.9	2.656	1.6	14.0	88.6	12 677	15
Average	**4.8**	**2.660**	**1.6**	**13.8**	**88.5**	**13 046**	**16**
Std Dev	**0.13**	**0.003**					
Lane 6							
L6T1S12	5.1	2.658	1.6	14.2	88.7	14 643	13
L6T1S34	4.9	2.654	1.4	13.9	89.9	15 755	17
L6T2S12	5.0	2.660	1.0	13.5	92.6	15 048	17
L6T2S34	4.8	2.660	1.4	13.7	89.8	16 791	17
L6T3S12	4.7	2.658	1.4	13.6	89.7	17 125	17
L6T3S34	4.7	2.657	1.5	13.8	89.1	15 234	14
L6T4S12	4.9	2.659	2.4	14.7	83.7	14 865	17
L6T4S34	4.9	2.655	0.2	12.9	98.4	14 420	16
Average	**4.9**	**2.658**	**1.3**	**13.8**	**90.2**	**15 483**	**16**
Std Dev	**0.13**	**0.002**					

L = Lane; T = Lift; S = Site.

Table 12. Average voids analysis data using the paving contractor's maximum specific gravities (continued).

Lane Number	Binder Content (%)	Maximum Specific Gravity	Air Voids (%)	VMA (%)	VFA (%)	Stability (N)	Flow (0.25 mm)
Lane 7							
L7T1S12	4.9	2.659	2.0	14.3	86.0	21 350	20
L7T1S34	4.8	2.660	5.3	17.1	69.0	16 382	22
L7T2S12	5.1	2.656	2.1	14.7	85.7	**	**
L7T2S34	5.1	2.661	2.3	14.7	84.4	**	**
L7T3S12	5.0	2.657	2.5	14.9	83.2	**	**
L7T3S34	4.9	2.656	1.4	13.9	89.9	20 830	20
L7T4S12	4.7	2.659	2.6	14.7	82.3	**	**
L7T4S34	4.7	2.658	2.0	14.2	85.9	20 608	21
Average	**4.9**	**2.658**	**2.5**	**14.8**	**83.3**	**19 794**	**21**
Std Dev	**0.14**	**0.002**					
Lane 8							
L8T1S12	4.7	2.656	2.6	14.8	82.4	18 126	16
L8T1S34	4.6	2.657	2.7	14.7	81.6	20 648	17
L8T2S12	4.7	2.660	2.7	14.7	81.6	16 644	15
L8T2S34	4.7	2.655	3.0	15.1	80.1	17 272	20
L8T3S12	4.8	2.657	3.4	15.5	78.1	13 602	17
L8T3S34	4.8	2.660	3.7	15.7	76.4	15 048	13
L8T4S12	4.8	2.659	2.4	14.6	83.6	16 604	16
L8T4S34	4.8	2.660	3.9	15.9	75.5	14 643	17
Average	**4.7**	**2.658**	**3.1**	**15.1**	**79.9**	**16 573**	**16**
Std Dev	**0.07**	**0.002**					
Lane 9							
L9T1S12	4.8	2.657	1.1	13.5	91.9	12 156	15
L9T1S34	4.7	2.658	1.7	13.9	87.8	13 157	16
L9T2S12	4.8	2.662	1.8	14.0	87.1	13 380	17
L9T2S34	5.2	2.660	1.7	14.3	88.1	13 900	16
L9T3S12	5.1	2.662	2.2	14.6	84.9	14 492	16
L9T3S34	4.9	2.660	2.1	14.4	85.4	14 491	15
L9T4S12	4.9	2.659	1.7	14.0	87.9	11 676	13
L9T4S34	4.9	2.658	2.0	14.3	86.0	11 156	16
Average	**4.9**	**2.660**	**1.8**	**14.1**	**87.4**	**12 926**	**16**
Std Dev	**0.16**	**0.002**					

** No peak was obtained.
L = Lane; T = Lift; S = Site.

Table 12. Average voids analysis data using the paving contractor's maximum specific gravities (continued).

Lane Number	Binder Content (%)	Maximum Specific Gravity	Air Voids (%)	VMA (%)	VFA (%)	Stability (N)	Flow (0.25 mm)
Lane 10							
L10T1S12	4.8	2.656	1.5	13.9	89.2	17 014	18
L10T1S34	5.3	2.657	1.5	14.3	89.5	15 457	18
L10T2S12	4.8	2.661	1.6	13.8	88.4	16 680	19
L10T2S34	4.7	2.660	1.8	13.9	87.1	17 681	19
L10T3S12	4.7	2.657	1.8	14.0	87.1	17 605	15
L10T3S34	5.0	2.659	1.8	14.2	87.3	14 492	17
L10T4S12	4.8	2.656	0.7	13.2	94.7	14 790	16
L10T4S34	4.9	2.658	1.2	13.6	91.2	15 902	15
Average	**4.9**	**2.658**	**1.5**	**13.9**	**89.3**	**16 204**	**17**
Std Dev	**0.17**	**0.002**					
Lane 11							
L11T1S12	4.2	2.735	1.6	11.3	85.8	28 098	21
L11T1S34	3.9	2.737	2.8	12.1	76.9	33 658	19
L11T2S12	4.0	2.729	2.1	11.8	82.2	29 210	21
L11T2S34	4.0	2.728	1.6	11.4	86.0	32 137	20
Average	**4.0**	**2.732**	**2.0**	**11.7**	**82.7**	**30 776**	**20**
Std Dev	**0.16**	**0.004**					
Lane 12							
L12T1S12	4.1	2.732	2.4	12.1	80.2	38 288	19
L12T1S34	4.0	2.732	2.9	12.3	76.4	35 695	21
L12T2S12	4.1	2.728	2.5	12.2	79.5	**	**
L12T2S34	4.0	2.729	2.4	12.0	80.0	**	**
Average	**4.1**	**2.730**	**2.5**	**12.2**	**79.0**	**36 994**	**20**
Std Dev	**0.07**	**0.002**					

** No peak was obtained.
L = Lane; T = Lift; S = Site.

Table 13. Average voids analysis data using the FHWA's maximum specific gravities.

Lane Number	Binder Content (%)	Maximum Specific Gravity	Air Voids (%)	VMA (%)	VFA (%)	Stability (N)	Flow (0.25 mm)
1	4.7	2.686	3.2	14.3	77.6	12 018	15
2	4.8	2.686	2.3	13.6	83.1	14 910	16
3	4.8	2.678	2.6	14.1	81.6	12 325	15
4	4.9	2.692	2.9	14.1	79.3	15 350	17
5	4.8	2.691	2.7	13.9	80.4	13 046	16
6	4.9	2.686	2.4	13.8	82.6	15 483	16
7	4.9	2.684	3.4	14.8	76.9	19 794	21
8	4.7	2.686	4.1	15.1	72.8	16 573	16
9	4.9	2.684	2.6	14.1	81.4	12 923	16
10	4.9	2.680	2.3	13.9	83.5	16 204	17
11	4.0	2.746	2.5	11.6	78.4	30 776	20
12	4.1	2.755	3.4	12.2	72.1	36 994	20

VMA = Voids in the Mineral Aggregate.
VFA = Voids Filled With Asphalt.

Lanes 1, 3, 9, and 11 are AC-5.
Lanes 2, 4, 6, 10, and 12 are AC-20.
Lane 5 is AC-10.
Lane 7 is Styrelf.
Lane 8 is Novophalt.
Lanes 11 and 12 are the BM-3 base mixtures.

d. Investigation of Plant-Produced Mixtures

An extensive investigation of the plant-produced mixtures was performed to determine why the properties of these mixtures did not duplicate the mixture design properties. The specific gravities of the aggregates used in designing the mixtures and the specific gravities of the aggregates stockpiled at TFHRC after construction were compared to investigate the discrepancies in maximum specific gravity. Differences in the aggregate specific gravities were minor and could not account for the differences in the maximum specific gravities. As an additional check, surface mixtures at the target binder content of 4.9 percent were prepared from both samples of aggregate. The aggregates were blended according to the original job-mix formula. Both mixtures provided equivalent maximum specific gravities ranging from 2.652 to 2.657 after oven-aging for 1 h at 135 °C. The discrepancies in maximum specific gravity were also not related to differences in binder content since the binder contents of the plant-produced mixtures were either equal to, or very close to, the design contents.

A surface mixture was then prepared and tested for maximum specific gravity after 0, 1, 2, and 4 h of oven-aging at 135 °C. These aging periods provided maximum specific gravities of 2.651, 2.657, 2.662, and 2.664, respectively. It was concluded that the higher maximum specific gravities of the plant-produced mixtures were not primarily related to aging and increased binder absorption.

The various stockpiles of diabase aggregates had similar apparent specific gravities. The natural sand had an apparent specific gravity that was significantly lower than the values for the diabase aggregates. Based on these specific gravities, the maximum percentage of natural sand used in the plant-produced surface mixtures was calculated to be 16 percent. The aggregates stockpiled at TFHRC were blended to meet the plant-produced surface mixture gradation. It was estimated that the natural sand content was between 5 and 14 percent. This percentage depended on the sieve size used in the calculation, which meant that the gradation of at least one of the stockpiled aggregates was slightly different from the gradation used in the plant-produced mixture. The gradation of the stockpiled natural sand was found to be different from the gradation of the sample used in the mixture designs, but which one of these two gradations should be used in the calculations could not be established.

The natural sand content in the surface mixture was then reduced from 22 to 14 percent. This increased the average maximum specific gravity to 2.671 using 1 h of oven-aging at 135 °C. Comparing 2.671 to the maximum specific gravities in tables 10 and 13 indicated that less than 14-percent natural sand was used in the surface mixtures. All values were above 2.671.

Extracted aggregates from lane 6–lift 2, lane 8–lift 1, and lane 12–lift 1 were than separated according to the standard sieve sizes. The percentage of natural sand by mass in each size fraction above the 0.300-mm sieve was measured. A microscope was used to separate particles. The percent natural sand contents in the 0.300- to 0.150-mm size fraction was estimated to be the same as in the 0.600- to 0.300-mm size fraction. The average natural sand contents are given in table 14. The gradation of the natural sand, shown in table 15, was estimated from these contents. This gradation was closer to the gradation used in the mixture designs than to the gradation of the stockpiled sand received after construction.

The percentages of natural sand used in the two types of mixtures were calculated by two methods. First, the percentages of each aggregate were varied until the blend met the plant-produced gradation as close as possible. The gradation of table 15 was used for the natural sand. Second, the percentage of natural sand that was needed to exactly meet the plant-produced gradation was calculated for each individual size fraction above the 0.300-mm sieve. If the gradations of the various aggregates used in these calculations were correct, then the percentages of natural sand calculated for the various size fractions would be equal. If they were not equal, then one or more of the gradations was not correct. The blend percentages of the diabase coarse aggregates used in these analyses had to be fixed; otherwise, there would be too many unknown variables. These percentages were fixed based on what was needed to meet the larger sizes of the plant-produced gradation. The blend percentages of the No. 10 diabase aggregate and the natural sand were then calculated for each size fraction. Based on both analyses, the natural sand contents of the plant-produced surface and base mixtures were determined to be 8 ±2 and 5 ±2 percent. (Slight, inconsequential adjustments to the gradation of the natural sand on the 0.300-, 0.150-, and 0.075-mm sieves were later made so that the FHWA stockpiled sand only had to be sieved to the 0.600-mm size. The normal practice used in the TFHRC Bituminous Mixtures Laboratory is to sieve all aggregates to the 2.36-mm sieve.)

The natural sand and the No. 10 diabase aggregates were tested for shape and texture using the National Aggregate Association's (NAA) Method A.(4) Determining the exact percentage of natural sand would be less critical for the research studies if the materials had similar shapes and textures. The NAA method evaluates shape and texture in terms of the percentage of voids in a dry, uncompacted sample. High voids usually indicate high angularity and a rough texture. Low voids usually indicate the material is rounded and smooth. The 2.36- to 0.150-mm fraction of a material is tested. The uncompacted voids for the Virginia Trap Rock No. 10 diabase, Luck Stone No. 10 diabase, and natural sand were 49, 48, and 45 percent, respectively. All three values indicated moderately high angularity and roughness. The two diabase aggregates had significantly higher uncompacted voids at a 95-percent confidence level, indicating some slight difference in the materials. Microscopic analyses indicated that particles in the larger size fractions of the natural sand were slightly more cubic in shape.

Gradation analyses were performed on the minus 0.075-mm aggregate fractions of surface mixtures because changes in this gradation can affect the air voids and VMA of a mixture. Hot-mix plant processes may decrease the air voids and VMA if they increase the amount of very small particles in the mixture. The reduction in the natural sand contents of the mixtures increased the bulk-dry specific gravity of the combined aggregate. This should increase the VMA, whereas the VMA's of the plant-produced mixtures were less than those obtained during the designs. Therefore, other factors were responsible for decreasing the air voids and VMA of the plant-produced mixtures.

Samples were taken from the aggregate blend used in the mixture designs and from aggregates extracted from two of the plant-produced mixtures. These samples were analyzed using a Horiba LA-500 laser diffraction particle size analyzer. The gradations are shown in table 16. These gradations do not show higher levels of very small particles in the extracted aggregates. It was concluded that the decreases in the air voids and VMA were not related to changes in the gradation of the minus 0.075-mm fraction of the aggregate. Changes in this gradation were not expected because the material collected in the hot-mix plant baghouse was not metered back into the mixtures.

It was concluded that the changes in air voids and VMA had to be related to the changes in overall aggregate gradation and changes in particle shape resulting from the increase in diabase fine aggregate and decrease in natural sand. The natural sand contents of the plant-produced surface and base mixtures were 8 and 5 percent. The job-mix formula listed natural sand contents of 22 and 14 percent for these two mixtures.

e. Pavement Densities

Table 17 presents the comparison of the densities from a thin lift nuclear density gauge to the densities of pavement cores taken from the bottom lifts of eight lanes immediately after placement. This comparison was performed to verify the calibration of the nuclear density gauge at the start of construction. The cores were taken close to the ends of the lanes, nearest to site 3-4, to avoid disturbing the pavements as much as possible. Some of the densities were different on an individual basis. A difference of 25 kg/m^3 is approximately equivalent to 1-percent air voids. An average difference of -12 kg/m^3, or approximately 0.5-percent air voids was obtained. A negative sign indicates that the nuclear density gauge provided a lower density and a higher percent air voids relative to the cores. A paired t-test showed that there was no overall difference between the two sets of densities, and thus the nuclear gauge was assumed to be calibrated.

Densities were measured during compaction by the paving contractor using the nuclear density gauge. Fifteen measurements were recorded per lane per lift on a random basis. The average density per lane, the average percent air voids based on the paving contractor's maximum specific gravities, and the standard deviations of these air voids are given in table 18. The air voids met the within-lane and between-lane variabilities, and were within the FHWA-specified 4- to 8-percent range. The complete set of nuclear gauge densities was stored in a computer file.

f. Pavement Thicknesses

Table 18 includes the average total thicknesses of the pavement lifts, the standard deviations of these thicknesses, and the total mass of mixture placed per lane, based on the nuclear gauge densities. Thicknesses were measured using a rod and level at 1.22-m intervals down the centerline of each pavement and 1.07 m left and right of the centerline. This amounted to 108 measurements per lane. A complete set of elevations and thicknesses for all layers was stored in a computer file.

The specification required an average thickness of 101.6 ±12.7 mm for lanes 1 and 2, and an average thickness of 203.2 ±12.7 mm for lanes 3 to 6. Small tolerances were specified for the lanes to be used in the fatigue study because thickness significantly affects fatigue life. Lane 1, with an average thickness of 87.9 mm, did not meet this requirement by 1.0 mm. A minimum thickness of 203.2 mm was specified for lanes 7 through 12. Only lane 12, having a thickness of 207.8 mm, met this requirement. Lanes 7 through 11 were less than 203.2 mm by an average of 4.8 mm.

The standard deviation of the 108 thicknesses within each lane was specified to be less than 6.4 mm. All lanes met this specification with the exception of lane 11, which had a standard deviation of 9.14 mm.

The average total thickness of lane 1 could not be significantly different at a 95-percent confidence level from the average total thickness of lane 2. The standard deviations of these thicknesses also could not be significantly different. These requirements also applied to the following pairs of lanes: 3 and 4, 5 and 6, 7 and 8, 9 and 10, and 11 and 12. The standard deviation requirements were met, but only lanes 3 and 4 had thicknesses that were not significantly different. The difference in thickness between two lanes could not be greater than 1.72 mm.

How these deviations from the specifications would affect pavement performance was unknown. The most important lanes, in terms of thickness, were those designated for the fatigue cracking studies, especially lanes 1 and 2, which were the two thin lanes. For the lanes to be tested for fatigue cracking, lane 1 was thinner than lane 2 by an average of 4.3 mm; lanes 3 and 4 had equal thicknesses, and lane 5 was thinner than lane 6 by an average of 3.8 mm. Lanes 7 and 8 were added to the fatigue study after the construction contract was awarded. Lane 7 was thinner than lane 8 by an average of 4.3 mm. Besides differences in thicknesses, fatigue life may also be affected by differences in the properties of the crushed aggregate base and the subgrade layers, and any differences in asphalt pavement aging that occur during the lives of the pavements. It was decided to establish whether pairs of lanes were equivalent using falling weight deflections. These deflections would be measured before the lanes were tested by the ALF.

Table 14. Percent natural sand in the fractions.

Sieve Size (mm)	Surface	Base
9.5 to 4.75	3.13	2.23
4.75 to 2.36	8.46	3.36
2.36 to 1.18	18.1	10.5
1.18 to 0.600	47.6	33.8
0.600 to 0.300	61.0	48.2

Table 15. Gradation of the natural sand.

Sieve Size (mm)	Percent Passing
9.5	100.0
4.75	95.8
2.36	88.2
1.18	74.8
0.600	46.0
0.300	13.8
0.150	3.8
0.075	1.9

Table 16. Particle size analyses.

Sieve Size (mm)	Aggregate Used in Mixture Design	Extracted Aggregate, Lane 3 Lift 1	Extracted Aggregate, Lane 6 Lift 4
0.075	100.0	100.0	100.0
0.050	88.5	89.8	88.5
0.030	71.0	71.3	55.6
0.020	58.3	56.9	40.9
0.010	39.4	33.9	27.1
0.005	19.5	14.6	11.1
0.003	8.4	5.6	4.5
0.001	0.0	0.0	0.0

Table 17. Comparison of core densities to nuclear gauge densities.

Core Number	Lane Number	Core Density (kg/m^3)	Nuclear Gauge Density (kg/m^3)	Difference (kg/m^3)
1	3	2449	2467	+ 18
2	3	2464	2398	- 66
3	5	2481	2459	- 22
4	5	2448	2443	- 5
5	6	2462	2424	- 38
6	6	2472	2436	- 36
7	7	2452	2457	+ 5
8	7	2459	2448	- 11
9	8	2446	2459	+ 13
10	8	2377	2435	+ 58
11	9	2484	2441	- 43
12	9	2416	2470	+ 54
13	10	2494	2432	- 62
14	10	2464	2454	- 10
15	12	2550	2512	- 38
Average				- 12

Note: Each nuclear gauge density is an average of four measurements recorded by rotating the gauge in four different directions, except for cores 1 and 2, where they were recorded in only one direction.

Table 18. Average in-place nuclear gauge densities, air voids, thicknesses, and total quantity of mixture placed per lane.

Lane Number	Average Nuclear Gauge Density (kg/m^3)	Average Air Voids (%)	Standard Deviation, Air Voids (%)	Average Thickness (mm)	Standard Deviation, Thickness (mm)	Total Quantity Placed (Mg)
1	2464	7.20	0.8	87.9	3.05	37.9
2	2462	7.26	0.9	92.2	3.05	39.7
3	2467	7.08	0.9	196.1	6.10	84.7
4	2467	7.11	1.1	196.1	6.10	84.7
5	2467	7.21	1.0	194.8	6.10	84.1
6	2467	7.14	1.0	198.6	3.05	85.8
7	2464	7.28	1.0	193.6	6.10	83.5
8	2460	7.39	0.9	197.9	6.10	85.3
9	2475	6.90	1.1	200.4	6.10	86.8
10	2478	6.73	1.0	198.6	3.05	86.2
11	2520	7.73	0.5	201.7	9.14	89.0
12	2521	7.60	0.6	207.8	6.10	91.7

g. Pavement Air Voids From Cores Taken at the Centerline

Twenty-four pavement cores were taken after construction and tested for air voids. Two 152.4-mm-diameter cores were taken per lane, one from each end of the lane at its centerline. One core was representative of sites 1 and 2; the other was representative of sites 3 and 4. The cores were sawed by lift and each specimen was tested for bulk specific gravity. Lift 1 was the bottom lift. The percent air voids in each core was calculated using the average maximum specific gravity of the associated plant-produced loose mixture that was measured in the TFHRC Bituminous Mixtures Laboratory. These maximum specific gravities were verified by testing cores for maximum specific gravity on a random basis.

The air voids for the lifts were averaged by site; then an overall average for the lane was computed. The data are given in table 19. Only lanes 11 and 12 with the base mixtures met the specified 4- to 8-percent air-void range. The air voids were greater at site 1-2 compared to site 3-4 for all lanes. This indicated that more density was achieved as the laydown of a mixture proceeded.

The average air-void level in the surface mixtures was 9.6 percent, while the nuclear gauge densities in table 18 had an average level of 7.1 percent. One reason for this difference was that the paving contractor's maximum specific gravities were significantly lower than the FHWA's maximum specific gravities. A second reason was that the nuclear gauge densities of the mixtures were significantly higher than the core densities. (Multiply the bulk specific gravities in table 19 by 997.1 for a direct comparison.) Both discrepancies led to the lower air-void levels reported by the paving contractor. Table 19 also shows that the air voids for lane 7 with Styrelf and for lane 8 with Novophalt were higher than those for the other lanes. The nuclear gauge densities in table 18 did not show these differences.

Table 19 shows that the average air-void level for the base mixtures in lanes 11 and 12 was 7.6 percent, while the nuclear gauge densities in table 18 had an average level of 7.7 percent. The slightly lower average nuclear gauge densities in table 18 compared to the average core densities in table 19 negated the effects of the slight differences in the maximum specific gravity.

The densities of the cores from lift 1 at site 3-4 in table 19 were compared to the densities of the cores in table 17, which were used to check the calibration of the nuclear density gauge. (Multiply the bulk specific gravities in table 19 by 997.1 for a direct comparison.) The densities reasonably agreed with each other, except for lane 7 where the average density was 2456 kg/m^3 for the calibration cores and 2386 kg/m^3 for the cores taken after construction. This difference could have been due to inadequate sampling. This comparison of densities indicated that the nuclear density gauge was calibrated at the start of the construction and, therefore, did not provide an explanation for the discrepancies in the densities.

h. Pavement Air Voids From Cores Taken in the Wheelpaths

Forty-eight additional cores were obtained to verify the air voids. One core was taken from each wheelpath at both ends of a lane. The air voids are given in table 20. The cores taken from the wheelpaths had lower air voids than the centerline cores, but one wheelpath did not consistently have higher, or lower, air voids than the other wheelpath. Except for lane 3, the average air voids were higher at site 1-2 compared to site 3-4. This indicated that more density was achieved as the laydown of a mixture proceeded. The air voids in lane 3 were higher at site 1-2 in the top two lifts, but not in the bottom two lifts.

The average air-void level in the surface mixtures was 8.2 percent, while the nuclear gauge densities in table 18 had an average level of 7.1 percent. The air voids in the wheelpath cores were 1.4 percent lower than in the centerline cores. The average air-void level in the base mixtures of lanes 11 and 12 was 7.1 percent, while the nuclear gauge densities in table 18 had an average level of 7.7 percent. The air voids in the wheelpath cores were 0.6 percent lower than in the centerline cores.

Table 20 shows that the air voids in lane 7 with Styrelf and in lane 8 with Novophalt were 10.0 and 9.8 percent, while the remaining eight surface mixtures averaged 7.7 percent. The averages for the AC-5, AC-10, and AC-20 mixtures were 7.4, 8.0, and 7.9 percent, respectively. Lanes 7 and 8, along with lanes 4 and 9, did not meet the specified 4- to 8-percent air-void range. Reasons why the paving contractor's nuclear gauge densities in table 18 did not provide higher air-void levels for lanes 7 and 8 could not be established.

The average air voids in the two lower and two upper lifts of lanes 3 through 10 are given in table 21. This divided the pavements into two halves, each having a thickness of approximately 100 mm. The air voids in the upper lifts may be more important for the rutting evaluations because the majority of the rutting should occur in the upper lifts. The air voids in the lower lifts may be more important for the fatigue evaluations. For lanes 11 and 12, there was only one lower lift and one upper lift. Table 21 includes the average air voids for all lifts. The air voids in the lower and upper halves of the pavements differed by more than 1 percent in a few cases, although they were not significantly different and provided no trend. Reasons why the paving contractor's nuclear gauge densities did not show these differences could not be established. The data also show that the air voids at site 1-2 were often greater than at site 3-4 by more than 1 percent.

A difference of 1-percent air voids should result in a 1-percent difference in consolidation when a pavement is tested by the ALF. The intent of the construction specification to provide low within-lane and between-lane variabilities was not always achieved. Air voids, binder contents, and aggregate gradations will be measured after each site is failed by the ALF.

Table 19. Percent air voids from cores taken at the centerline.

	Bulk Specific Gravity		Maximum Specific Gravity	Air Voids (%)	
	Site 1-2	Site 3-4		Site 1-2	Site 3-4
Lane 1, AC-5					
Lift 1	2.474	2.499	2.686	7.89	6.96
Lift 2	2.406	2.434	2.686	10.42	9.38
Site Average	2.440	2.467	2.686	9.16	8.17
Lane 1 Average	**2.454**		**2.686**	**8.66**	
Lane 2, AC-20					
Lift 1	2.453	2.482	2.686	8.67	7.59
Lift 2	2.414	2.451	2.686	10.13	8.75
Site Average	2.434	2.467	2.686	9.40	8.17
Lane 2 Average	**2.451**		**2.686**	**8.75**	
Lane 3, AC-5					
Lift 1	2.436	2.434	2.678	9.04	9.12
Lift 2	2.423	2.462	2.678	9.51	8.06
Lift 3	2.450	2.515	2.678	8.52	6.10
Lift 4	2.439	2.453	2.678	8.92	8.40
Site Average	2.437	2.466	2.678	9.00	7.92
Lane 3 Average	**2.452**		**2.678**	**8.46**	
Lane 4, AC-20					
Lift 1	2.412	2.479	2.692	10.40	7.91
Lift 2	2.352	2.381	2.692	12.63	11.55
Lift 3	2.439	2.493	2.692	9.40	7.19
Lift 4	2.399	2.448	2.692	10.88	9.06
Site Average	2.401	2.450	2.692	10.81	8.99
Lane 4 Average	**2.426**		**2.692**	**9.88**	
Lane 5, AC-10					
Lift 1	2.402	2.441	2.691	10.74	9.29
Lift 2	2.404	2.468	2.691	10.67	8.29
Lift 3	2.451	2.482	2.691	8.92	7.77
Lift 4	2.432	2.446	2.691	9.62	9.10
Site Average	2.422	2.459	2.691	10.00	8.62
Lane 5 Average	**2.441**		**2.691**	**9.29**	

Table 19. Percent air voids from cores taken at the centerline (continued).

	Bulk Specific Gravity		Maximum Specific Gravity	Air Voids (%)	
	Site 1-2	Site 3-4		Site 1-2	Site 3-4
Lane 6, AC-20					
Lift 1	2.479	2.466	2.686	7.69	8.17
Lift 2	2.372	2.481	2.686	11.70	7.64
Lift 3	2.444	2.450	2.686	9.00	8.78
Lift 4	2.379	2.442	2.686	11.42	9.09
Site Average	2.419	2.460	2.686	9.95	8.42
Lane 6 Average	**2.440**		**2.686**	**9.19**	
Lane 7, Styrelf					
Lift 1	2.311	2.393	2.684	13.90	10.84
Lift 2	2.202	2.365	2.684	***	11.87
Lift 3	2.330	2.312	2.684	13.21	13.85
Lift 4	2.384	2.405	2.684	11.16	10.39
Site Average	2.308	2.369	2.684	12.76	11.74
Lane 7 Average	**2.339**		**2.684**	**12.25**	
Lane 8, Novophalt					
Lift 1	2.320	2.428	2.686	13.62	9.61
Lift 2	2.398	2.381	2.686	10.72	11.34
Lift 3	2.353	2.399	2.686	12.38	10.69
Lift 4	2.366	2.382	2.686	11.91	11.33
Site Average	2.359	2.398	2.686	12.16	10.74
Lane 8 Average	**2.379**		**2.686**	**11.45**	
Lane 9, AC-5					
Lift 1	2.414	2.444	2.689	10.22	9.10
Lift 2	2.467	2.484	2.689	8.27	7.62
Lift 3	2.443	2.454	2.689	9.15	8.75
Lift 4	2.473	2.454	2.689	8.03	8.75
Site Average	2.449	2.459	2.689	8.92	8.56
Lane 9 Average	**2.454**		**2.689**	**8.74**	

*** Damaged core specimen.

Table 19. Percent air voids from cores taken at the centerline (continued).

	Bulk Specific Gravity		Maximum Specific Gravity	Air Voids (%)	
	Site 1-2	Site 3-4		Site 1-2	Site 3-4
Lane 10, AC-20					
Lift 1	2.428	2.475	2.680	9.40	7.65
Lift 2	2.401	2.473	2.680	10.41	7.72
Lift 3	2.442	2.482	2.680	8.89	7.39
Lift 4	2.385	2.439	2.680	11.01	8.99
Site Average	2.414	2.467	2.680	9.93	7.95
Lane 10 Average	**2.441**		**2.680**	**8.92**	
Lane 11, AC-5					
Lift 1	2.537	2.563	2.746	7.61	6.66
Lift 2	2.533	2.537	2.746	7.76	7.61
Site Average	2.535	2.550	2.746	7.68	7.14
Lane 11 Average	**2.543**		**2.746**	**7.39**	
Lane 12, AC-20					
Lift 1	2.556	2.561	2.755	7.24	7.03
Lift 2	2.511	2.520	2.755	8.85	8.51
Site Average	2.534	2.541	2.755	8.05	7.77
Lane 12 Average	**2.538**		**2.755**	**7.91**	

Table 20. Percent air voids from cores taken from the wheelpaths.

	Bulk Specific Gravity		Maximum Specific Gravity	Air Voids (%)	
	Site 1-2	Site 3-4		Site 1-2	Site 3-4
Lane 1, AC-5					
Lift 1	2.529	2.515	2.686	5.85	6.38
	2.533	2.521	2.686	5.70	6.15
Lift 2	2.445	2.501	2.686	8.96	6.88
	2.457	2.471	2.686	8.53	8.01
Site Average	2.491	2.502	2.686	7.26	6.86
Lane 1 Average	**2.497**		**2.686**	**7.06**	
Lane 2, AC-20					
Lift 1	2.473	2.521	2.686	7.93	6.14
	2.463	2.508	2.686	8.32	6.64
Lift 2	2.428	2.538	2.686	9.61	5.52
	2.466	2.496	2.686	8.19	7.08
Site Average	2.458	2.516	2.686	8.51	6.35
Lane 2 Average	**2.487**		**2.686**	**7.43**	
Lane 3, AC-5					
Lift 1	2.498	2.472	2.678	6.73	7.68
	2.446	2.431	2.678	8.68	9.22
Lift 2	2.551	2.518	2.678	4.74	5.98
	2.490	2.459	2.678	7.00	8.17
Lift 3	2.488	2.518	2.678	7.08	5.99
	2.428	2.521	2.678	9.33	5.85
Lift 4	2.495	2.494	2.678	6.85	6.99
	2.471	2.440	2.678	7.71	8.89
Site Average	2.483	2.482	2.678	7.26	7.35
Lane 3 Average	**2.483**		**2.678**	**7.30**	

Note: The first measurement listed for each lift is for the right wheelpath. The second measurement is for the left wheelpath.

Table 20. Percent air voids from cores taken from the wheelpaths (continued).

	Bulk Specific Gravity		Maximum Specific Gravity	Air Voids (%)	
	Site 1-2	Site 3-4		Site 1-2	Site 3-4
Lane 4, AC-20					
Lift 1	2.454	2.503	2.692	8.82	7.02
	2.441	2.465	2.692	9.32	8.44
Lift 2	2.434	2.425	2.692	9.59	9.91
	2.394	2.399	2.692	11.09	10.90
Lift 3	2.514	2.507	2.692	6.61	6.88
	2.492	2.538	2.692	7.42	5.72
Lift 4	2.418	2.523	2.692	10.18	6.28
	2.421	2.521	2.692	10.07	6.34
Site Average	2.446	2.485	2.692	9.14	7.69
Lane 4 Average	**2.466**		**2.692**	**8.42**	
Lane 5, AC-10					
Lift 1	2.463	2.475	2.691	8.46	8.01
	2.418	2.476	2.691	10.16	7.97
Lift 2	2.503	2.487	2.691	7.00	7.56
	2.478	2.509	2.691	7.93	6.76
Lift 3	2.495	2.491	2.691	7.27	7.42
	2.484	2.499	2.691	7.69	7.14
Lift 4	2.447	2.466	2.691	9.07	8.37
	2.416	2.506	2.691	10.21	6.89
Site Average	2.463	2.489	2.691	8.47	7.52
Lane 5 Average	**2.476**		**2.691**	**8.00**	
Lane 6, AC-20					
Lift 1	2.464	2.494	2.686	8.27	7.15
	2.462	2.510	2.686	8.34	6.56
Lift 2	2.452	2.489	2.686	8.69	7.33
	2.403	2.509	2.686	10.53	6.58
Lift 3	2.489	2.505	2.686	7.32	6.75
	2.475	2.506	2.686	7.87	6.71
Lift 4	2.446	2.489	2.686	8.95	7.34
	2.435	2.462	2.686	9.36	8.32
Site Average	2.453	2.500	2.686	8.67	7.09
Lane 6 Average	**2.477**		**2.686**	**7.88**	

Note: The first measurement listed for each lift is for the right wheelpath. The second measurement is for the left wheelpath.

Table 20. Percent air voids from cores taken from the wheelpaths (continued).

	Bulk Specific Gravity Site 1-2	Bulk Specific Gravity Site 3-4	Maximum Specific Gravity	Air Voids (%) Site 1-2	Air Voids (%) Site 3-4
Lane 7, Styrelf					
Lift 1	2.450	2.417	2.684	8.71	9.95
	2.413	2.468	2.684	10.11	10.72
Lift 2	2.419	2.460	2.684	9.88	8.03
	2.392	2.469	2.684	10.86	8.99
Lift 3	2.378	2.396	2.684	11.42	8.33
	2.291	2.443	2.684	14.66	9.75
Lift 4	2.383	2.422	2.684	11.23	8.01
	2.442	2.419	2.684	9.02	9.88
Site Average	2.396	2.437	2.684	10.74	9.21
Lane 7 Average	**2.417**		**2.684**	**9.98**	
Lane 8, Novophalt					
Lift 1	2.371	2.451	2.686	11.73	8.76
	2.387	2.467	2.686	11.14	8.14
Lift 2	2.399	2.432	2.686	10.69	9.45
	2.433	2.453	2.686	9.40	8.67
Lift 3	2.416	2.442	2.686	10.04	9.07
	2.446	2.457	2.686	8.95	8.51
Lift 4	2.429	2.392	2.686	9.58	10.96
	2.370	2.442	2.686	11.78	9.07
Site Average	2.406	2.442	2.686	10.41	9.08
Lane 8 Average	**2.424**		**2.686**	**9.75**	
Lane 9, AC-5					
Lift 1	2.392	2.494	2.689	11.03	7.26
	2.435	2.510	2.689	9.43	6.65
Lift 2	2.424	2.482	2.689	9.85	7.69
	2.445	2.518	2.689	9.07	6.38
Lift 3	2.461	2.450	2.689	8.46	8.88
	2.437	2.501	2.689	9.37	6.98
Lift 4	2.455	2.500	2.689	8.71	7.02
	2.438	2.480	2.689	9.32	7.76
Site Average	2.436	2.492	2.689	9.41	7.33
Lane 9 Average	**2.464**		**2.689**	**8.37**	

Note: The first measurement listed for each lift is for the right wheelpath. The second measurement is for the left wheelpath.

Table 20. Percent air voids from cores taken from the wheelpaths (continued).

	Bulk Specific Gravity Site 1-2	Bulk Specific Gravity Site 3-4	Maximum Specific Gravity	Air Voids (%) Site 1-2	Air Voids (%) Site 3-4
Lane 10, AC-20					
Lift 1	2.443	2.520	2.680	8.85	5.96
	2.445	2.490	2.680	8.77	7.10
Lift 2	2.408	2.481	2.680	10.14	7.41
	2.442	2.491	2.680	8.88	7.04
Lift 3	2.471	2.481	2.680	7.79	7.44
	2.452	2.496	2.680	8.51	6.88
Lift 4	2.477	2.472	2.680	7.56	7.78
	2.454	2.468	2.680	8.41	7.90
Site Average	2.449	2.487	2.680	8.61	7.19
Lane 10 Average	**2.468**		**2.680**	**7.90**	
Lane 11, AC-5					
Lift 1	2.534	2.579	2.746	7.74	6.09
	2.570	2.589	2.746	6.41	5.72
Lift 2	2.482	2.566	2.746	9.61	6.56
	2.540	2.575	2.746	7.51	6.23
Site Average	2.532	2.577	2.746	7.82	6.15
Lane 11 Average	**2.555**		**2.746**	**6.99**	
Lane 12, AC-20					
Lift 1	2.595	2.579	2.755	5.82	6.39
	2.553	2.578	2.755	7.33	6.43
Lift 2	2.523	2.560	2.755	8.43	7.07
	2.516	2.562	2.755	8.68	7.00
Site Average	2.547	2.570	2.755	7.57	6.72
Lane 12 Average	**2.559**		**2.755**	**7.15**	

Note: The first measurement listed for each lift is for the right wheelpath. The second measurement is for the left wheelpath.

Table 21. Average percent air voids from wheelpath cores for all lifts, lower lifts, and upper lifts.

	Site 1-2			Site 3-4		
	All Lifts	Lower Lifts	Upper Lifts	All Lifts	Lower Lifts	Upper Lifts
Lane 1, AC-5	7.26	NA	NA	6.86	NA	NA
Lane 2, AC-20	8.51	NA	NA	6.35	NA	NA
Lane 3, AC-5	7.26	6.79	7.74	7.35	7.76	6.93
Lane 4, AC-20	9.14	9.70	8.57	7.69	9.07	6.31
Lane 5, AC-10	8.47	8.39	8.56	7.52	7.58	7.46
Lane 6, AC-20	8.67	8.96	8.38	7.09	6.90	7.28
Lane 7, Styrelf	10.74	9.89	11.58	9.21	9.42	8.99
Lane 8, Novophalt	10.41	10.74	10.09	9.08	8.76	9.40
Lane 9, AC-5	9.41	9.84	8.97	7.33	7.00	7.66
Lane 10, AC-20	8.61	9.16	8.07	7.19	6.88	7.50
Lane 11, AC-5	7.82	7.08	8.56	6.15	5.90	6.40
Lane 12, AC-20	7.57	6.58	8.56	6.72	6.41	7.04

NA = Not Applicable. Lanes 1 and 2 were the thin pavements.

5. Aggregate Blends for the Laboratory Research Studies

Based on the quality control and quality assurance data, the aggregate blends to be used in the laboratory research studies were finalized. These blends are shown in tables 22 and 23 and in figures 2 and 3. The target binder content was 4.85 percent for the SM-3B surface mixtures and 4.0 percent for the BM-3 base mixtures. The two gradations are similar below 9.5 mm.

Marshall specimens fabricated from the stockpiled materials were tested as a final check on the aggregate blends. The data are given in table 24. Included in this table are the average data for the plant-produced mixtures, based on the data in table 13. The data in table 13 were generated in the TFHRC Bituminous Mixtures Laboratory, except for the average binder contents, which were generated by the paving contractor. The two sets of data in table 24 are similar. For example, the air voids for the plant-produced mixtures ranged from 2.5 to 4.1 percent, while the air voids for the laboratory-prepared mixtures ranged from 2.9 to 4.3 percent.

The small differences in the properties of the mixtures were probably related to small differences in the compositions of the mixtures and to differences in short-term aging. The laboratory-prepared mixtures were oven-aged at 135 °C for 2 h before compaction. This short-term oven-aging procedure was based on the average amount of age hardening that occurred during mixture production and pavement construction. The plant-produced loose mixtures were not oven-aged in the laboratory before compaction.

The development of the 2-h oven-aging period will be discussed in a future FHWA report on this study. It is important to establish accurate aging periods because the amount of aging can have a significant impact on the properties of a mixture. For example, the AC-20 surface mixture using a binder content of 4.85 percent provided an average air-void level of 2.9 percent with oven-aging and 1.6 percent without oven-aging.

Table 22. Aggregate properties for the SM-3B surface mixtures.

Aggregate Gradations, Percent Passing:

Sieve Size (mm)	61% No. 68 VA Trap Rock	30% No. 10 Diabase	8% Natural Sand	1% Hydrated Lime	Target	Blend
25.0	100.0				100.0	100.0
19.0	97.9				98.7	98.7
12.5	60.7				76.0	76.0
9.5	37.7	100.0	100.0		62.0	62.0
4.75	9.2	99.2	95.8		44.0	44.0
2.36	2.2	75.6	88.2		32.5	32.1
1.18	1.7	52.5	74.8		23.5	23.8
0.600	1.4	37.8	46.0		17.5	16.9
0.300	1.3	27.9	14.1		11.5	11.3
0.150	1.1	19.6	4.8		8.0	7.9
0.075	0.9	12.5	2.9	100.0	5.1	5.5

Specific Gravities and Percent Absorption:

	61% No. 68 VA Trap Rock	30% No. 10 Diabase	8% Natural Sand	1% Hydrated Lime	Target	Blend
Bulk Dry	2.943	2.914	2.565			2.892
Bulk SSD	2.962	2.945	2.601			2.916
Apparent	2.999	3.007	2.659	2.262		2.961
% Abs	0.6	1.1	1.4			0.8

Los Angeles Abrasion, Percent Weight Loss:

	61% No. 68 VA Trap Rock	30% No. 10 Diabase	8% Natural Sand
	13.8	NT	NT

Flat and Elongated Particles at a 3-to-1 (Length-to-Thickness) Ratio, Percent by Weight:

	61% No. 68 VA Trap Rock	30% No. 10 Diabase	8% Natural Sand
	21.5	NT	NT

Bulk Dry = Bulk-Dry Specific Gravity
Bulk SSD = Bulk-Saturated-Surface-Dry Specific Gravity
Apparent = Apparent Specific Gravity
% Abs = Percent Water Absorption
NT = Not Tested

Table 23. Aggregate properties for BM-3 base mixtures.

Aggregate Gradations, Percent Passing:

Sieve Size (mm)	41% No. 357 Luck	15% No. 8 Stone	38% No. 10 Diabase	5% Natural Sand	1% Hydrated Lime	Target	Blend
37.5	100.0					100.0	100.0
25.0	64.9					85.6	85.6
19.0	36.3					73.9	73.9
12.5	14.9	100.0				65.1	65.1
9.5	5.5	85.0	100.0	100.0		59.0	59.0
4.75	3.0	25.3	96.8	95.8		47.6	47.6
2.36	1.8	2.7	68.0	88.2		32.5	32.4
1.18	1.6	2.0	47.5	74.8		24.0	23.7
0.600	1.4	1.5	34.3	46.0		17.4	17.1
0.300	1.2	1.2	24.9	14.1		12.3	11.8
0.150	1.1	0.9	17.3	4.8		8.0	8.4
0.075	0.8	0.8	11.5	2.9	100.0	5.7	6.0

Specific Gravities and Percent Absorption:

Bulk Dry	2.971	2.956	2.894	2.565			2.907
Bulk SSD	2.984	2.981	2.935	2.601			2.934
Apparent	3.013	3.030	3.017	2.659	2.262		2.987
% Abs	0.5	0.8	1.4	1.4			0.9

Los Angeles Abrasion, Percent Weight Loss:

	19.6	21.0	NT	NT

Flat and Elongated Particles at a 3-to-1 (Length-to-Thickness) Ratio, Percent by Weight:

	18.7	12.0	NT	NT

Bulk Dry = Bulk-Dry Specific Gravity
Bulk SSD = Bulk-Saturated-Surface-Dry Specific Gravity
Apparent = Apparent Specific Gravity
% Abs = Percent Water Absorption
NT = Not Tested

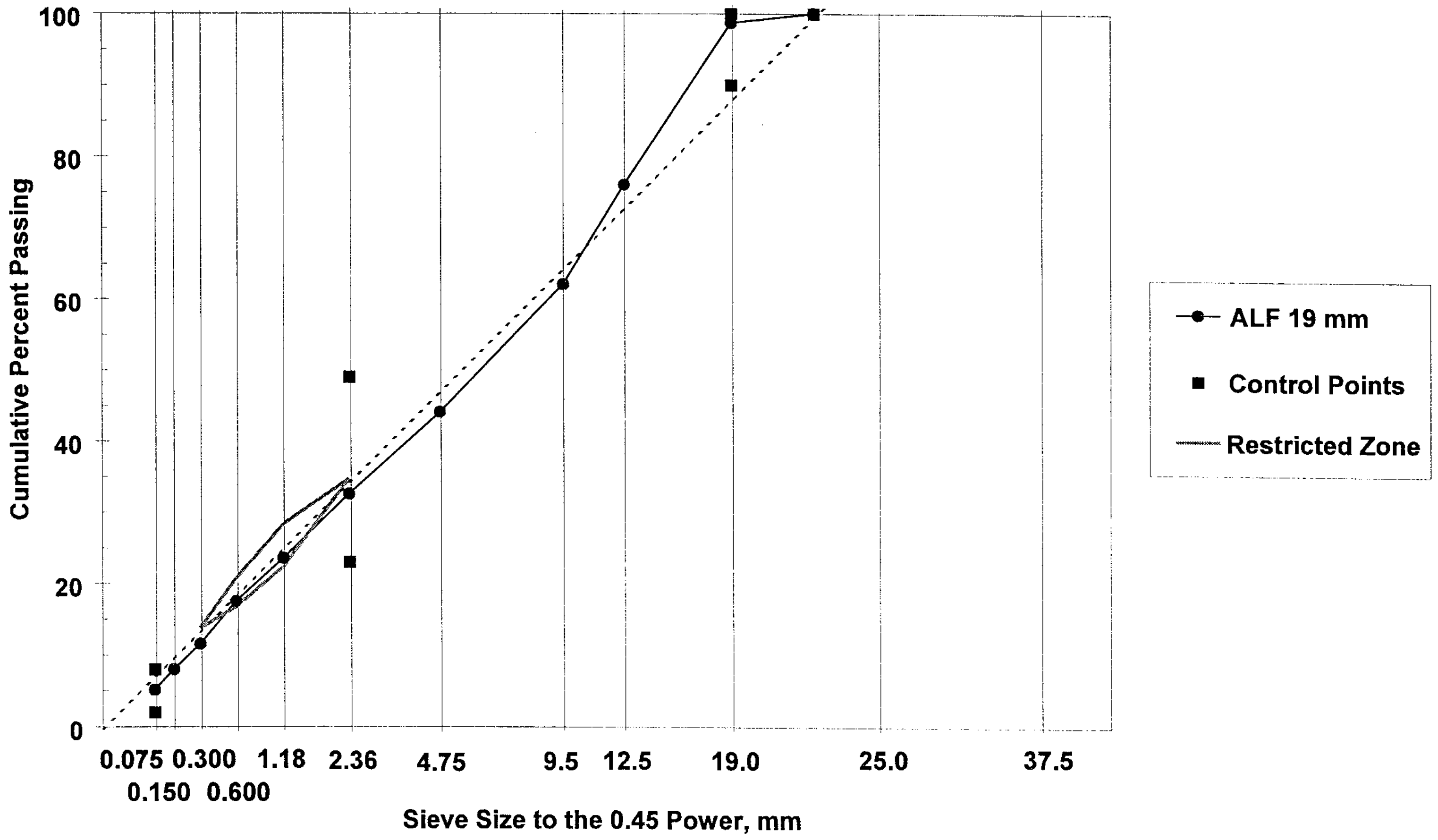

Figure 2. SM-3 aggregate gradation for the surface mixtures.

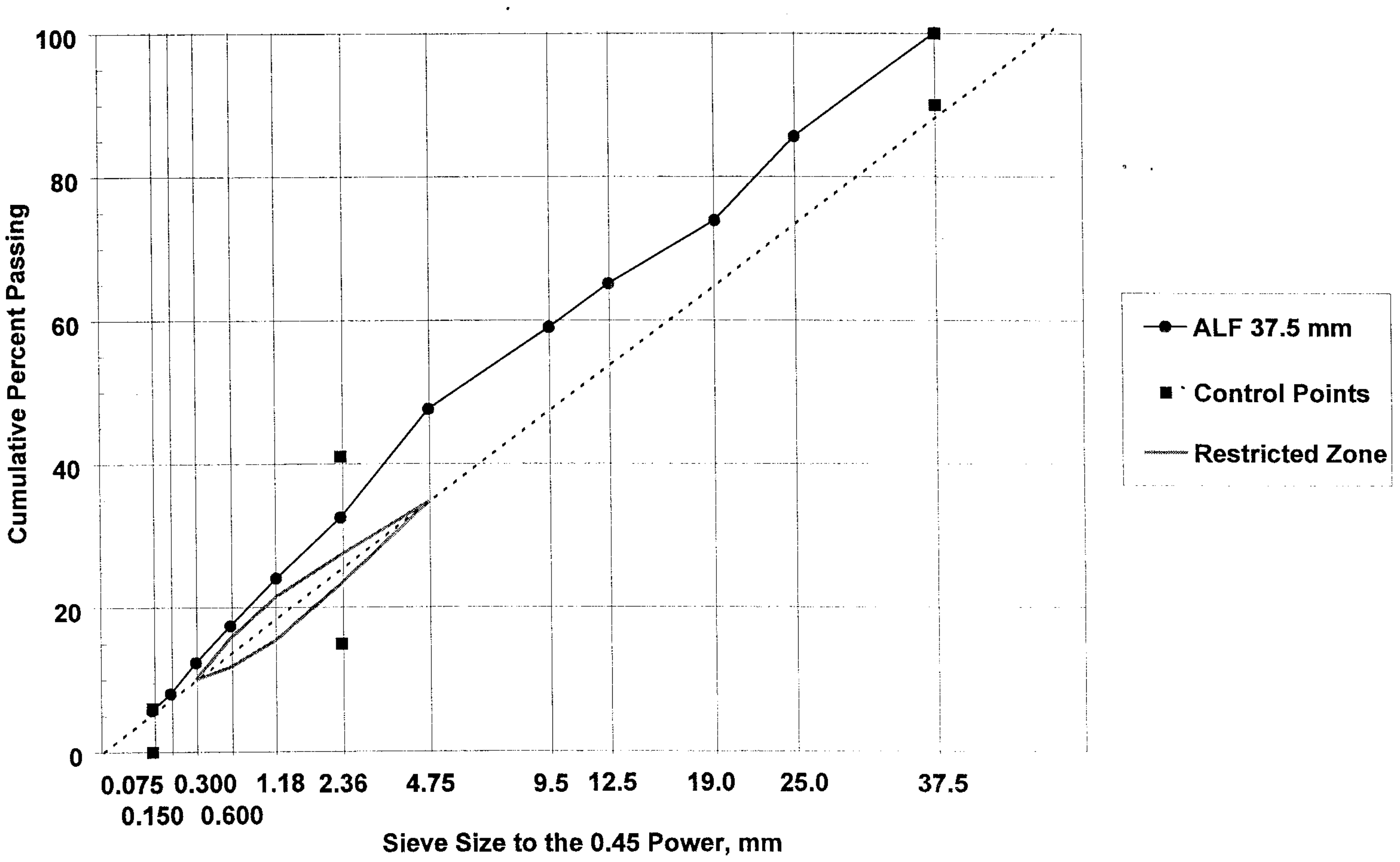

Figure 3. BM-3 aggregate gradation for the base mixtures.

Table 24. Comparison of the Marshall properties of the plant-produced mixtures to the Marshall properties of the laboratory-prepared mixtures.

Mix Type	Binder Type	Optimum Binder Content (%)	MSG	Stability (N)	Flow (0.25 mm)	Air Voids (%)	VMA (%)	VFA (%)
Plant-Produced Mixtures								
Surface	AC-5	4.80	2.683	12 400	15.0	2.8	14.1	80.2
Surface	AC-10	4.80	2.691	13 000	16.0	2.7	13.8	80.4
Surface	AC-20	4.90	2.688	15 200	16.0	2.5	13.8	81.7
Surface	Novophalt	4.70	2.686	16 600	21.0	4.1	15.1	72.8
Surface	Styrelf	4.90	2.684	19 800	16.0	3.4	14.7	76.9
Base	AC-5	4.00	2.746	13 700	13.0	2.5	11.6	78.4
Base	AC-20	4.10	2.755	16 400	13.0	3.4	12.2	72.1
Laboratory-Prepared Mixtures								
Surface	AC-5	4.85	2.699	11 600	15.0	3.0	13.9	78.4
Surface	AC-10	4.85	2.707	12 000	15.0	3.6	14.1	74.5
Surface	AC-20	4.85	2.706	11 200	18.0	2.9	13.5	78.5
Surface	Novophalt	4.85	2.699	16 100	17.0	4.2	14.9	71.8
Surface	Styrelf	4.85	2.701	18 500	23.0	4.0	14.7	72.8
Base	AC-5	4.00	2.750	13 300	13.0	4.3	13.1	67.2
Base	AC-20	4.00	2.750	14 200	12.0	4.2	13.0	67.7

Note: The stabilities of the base mixtures have been divided by 2.25, and the flows by 1.5, to account for the differences in specimen size.

Marshall Design Blows:
Surface = 75
Base = 112

Compaction Temperatures:
AC-5 = 121 °C
AC-10 = 127 °C
AC-20 = 135 °C
Novophalt = 141 °C
Styrelf = 141 °C

MSG = Maximum Specific Gravity of the Mixture
VMA = Voids in the Mineral Aggregate
VFA = Voids Filled With Asphalt

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4. Standard Test Method for Uncompacted Void Content of Fine Aggregate (As Influenced by Particle Shape, Surface Texture, and Grading), National Aggregates Association, Silver Spring, MD, June 1993.