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16. Abstract (Limit: 200 words)

In 1987, the Strategic Highway Research Program (SHRP) began developing the SUPERPAVE™ system, which offers a new way of specifying testing and design for asphalt materials to increase performance and longevity.

The Minnesota Department of Transportation (Mn/DOT) completed the first county highway SUPERPAVE™ project in Minnesota in Blue Earth County during August 1995. This project brought SUPERPAVE™ technology from the laboratory to the field and obtained real Minnesota mix comparisons between the standard Marshall mix design and the new SUPERPAVE™ system; gathered and analyzed data from actual field studies; and demonstrated new equipment and testing procedures to state, county, and city staff.

Equipped with a gyratory compactor for on-site testing, the Mn/DOT mobile laboratory provided level I mix design and production testing on a portion of the 3.5 mile overlay project. This project used unmodified asphalt binders. This project showed that SUPERPAVE™ Level I mix design applications are not as expensive as originally perceived. Lower asphalt binder contents offset higher aggregate costs. Researchers learned a great deal of information from this overlay project and a good mix design was provided that is expected to perform at or above the control or current specified requirements.

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Blue Earth County CSAH 30
Superpave Level I Mix Design

Final Report

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I. Executive Summary

The Minnesota Department of Transportation (Mn/DOT) specifies asphalt pavements for approximately 90% of county, city, and state highways. The design life expectancy of asphalt pavements is typically 20 years, but they usually don't perform for that long. The major non-construction related causes of asphalt pavement failures are as follows:

- Pavement deformation.
- Fatigue cracking.
- Thermal cracking from extreme temperature ranges.
- Greater than expected traffic loadings.

In 1987, the Strategic Highway Research Program (SHRP) began developing the Superior Performing Asphalt Pavements (SUPERPAVE ™) system. The five year, $50 million research effort created a new way of specifying testing and design for asphalt materials. Superpave is not only a computer program, but also an improved system for specifying component materials, pavement performance predictions, asphalt mixture design and analysis. Some of the new Superpave criteria are as follows:

- The Gyratory Compactor replaces the Marshall Hammer.
- AASHTO tests T-166 (bulk specific gravity), T-209 (Rice), and ASTM-D4867 (Modified Lottman) provide part of the data required for design.
- Incorporation of volumetric mix design properties into field quality control and quality assurance systems can help identify mix-related problems.
- Testing involves; Voids in Total Mix (VTM), Voids in Mineral Aggregate (VMA), Voids filled with asphalt (VFA), and Fines to Effective Asphalt ratio (F/A).
- Compaction effort is determined based on average high and low air temperature at the paving location and estimated traffic levels.

During the 1995 construction season, Mn/DOT leased a Mobile Laboratory to bring the SUPERPAVE Level I system to six locations throughout the state.

The priorities of this project were threefold:

1. To bring the SUPERPAVE technology from the laboratory setting to the field and obtain real Minnesota mix comparisons between the standard Marshall mix design and the new SUPERPAVE system.
2. Gather and analyze data from actual field studies with the Gyratory Compactor, the Vacuum Saturated Method for determining specific gravity of aggregates, and the Modified Lottman tests.
3. Demonstrate the new equipment and testing procedures to Mn/DOT, County, City, and contractor personnel who may be affected by this new technology.

During August, Mn/DOT provided Superpave Level I testing on Blue Earth County highway 30. Mn/DOT efforts were combined with the staffs of Blue Earth County and the Local Road Research Board (LRRB). The improved testing equipment and the new material quality specifications were used to provide an optimal asphalt pavement mix design for this project. The Mn/DOT mobile laboratory was used to provide mix design and production testing on a portion of the 3.5 mile overlay project. The mobile laboratory was equipped with a gyratory compactor for on-site testing.

The results of this project show that Superpave Level I mix design applications are not as expensive as originally perceived. Higher aggregate costs were offset by lower asphalt binder contents. This project did fail to meet some SHRP Superpave specifications. However, valuable information was learned and the overall experience will help Mn/DOT improve Superpave mixes in the future. A good mix design was provided that is expected to perform at or above the current specifications.

Adequate training and resources are important to successfully meet the new design method requirements. Materials need to be made available at lease two weeks prior to actual production to ensure adequate consensus property determination and mix design testing. Source specific aggregate testing is not required for this Level I mix design.

For projects with high volumes of traffic, these aggregate properties must be determined before production. If required, source specific aggregate testing will increase the time needed for the mix design. Additional test equipment for fine aggregate angularity and clay content should be secured for future design applications. Finally, a thorough search for Superpave field experiences from throughout the country should be made to aid the design staff in producing high quality mix designs in the future.

II. Introduction

The purpose of this paving project was to demonstrate the application of SHRP Superpave Level I concepts for an asphalt overlay on a low volume road. A partnership was established between the Minnesota Department of Transportation (Mn/DOT) and Blue Earth County Public Works to implement a SHRP Superpave Level I mix design. County State Aid Highway (CSAH) 30 from CSAH 22 to TH 60 in northwestern Blue Earth County was selected to conduct this demonstration project. The 3.5 mile project was divided into three 1.16 mile test sections as follows:

First Section - Segment A was paved under current specifications as a control section using 120/150 pen graded asphalt binders.

Second Section - Segments B and B2 were paved using the SHRP Superpave specifications for level I mix design using 120/150 pen graded asphalt binders.

Third Section - Segment C was paved were paved using the SHRP Superpave specifications for level I mix design using 200/300 pen graded asphalt binders.

A. Pavement History

The road is functionally classified as a minor collector. It serves as a farm to market, commuter, mail and school bus route. This road was originally graded in 1974. Then, it was paved with 8 inches of aggregate base course and another 3 inches of bituminous in 1979. The roadway cross section includes 12' driving lanes and 5' shoulders. There are no embankment or pavement drains. A 2" overlay was chosen to address recent maintenance needs.

B. Traffic Conditions

The design Equivalent Single Axle Loads (ESALs) for the project were determined to be 44,000. This puts the design requirements at the lowest Superpave level of less than 300,000 ESALs. Traffic levels are used to determine design requirements such as; number of design gyrations for compaction, aggregate physical property requirements, and mixture volumetric requirements. At this traffic level, Superpave suggests a level 1 mix design.

III. Material Selection

Superpave uses a completely new system for testing, specifying, and selecting asphalt binders. While no new aggregate tests were developed, current methods for selecting and specifying aggregates were refined and incorporated into the Superpave mix design system. Superpave level 1 volumetric mixture requirements were also established from currently used criteria.

A. Asphalt Binder Selection

The new Superpave binder specification is unique. It is performance based and binders are selected on the basis of the climate and traffic they are intended to serve. The physical property requirements are constant among all grades of binders. What differentiates the various binder grades is the temperature at which the requirements must be met. For example, a binder classified as a PG 64-22 means that the binder must meet high temperature physical property requirements at least up to a temperature of 64 ^{0}C and low temperature physical property requirements at least down to -22 ^{0}C.

This Superpave project required lower asphalt binder contents than levels normally used. The Superpave requirements increased aggregate costs on this project. This increase was offset by lower asphalt binder contents. Therefore, no additional costs were incurred.

Environmental conditions were determined from the Superpave software. Two weather station sites were selected for comparison. North Mankato and St. James are approximately 20 miles on either side of the actual paving location. Table 1 provides information about minimum and maximum temperatures for the pavement.

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Table 1: Project Environmental Conditions

Weather station	Min. Pvmt. Temp. (°C)	Max Pvmt. Temp (° C)	Binder grade	Design Air Temp. (° C)
Low Reliability (50%)				
North Mankato	-25	52	52-28	33
St. James	-27	52	52-28	33
Paving Location	-26	52	52-28	33
High Reliability (98%)				
North Mankato	-39	56	58-40	36
St. James	-36	56	58-40	36
Paving Location	-38	56	58-40	36

From this weather and traffic data, a level of reliability is assigned at 50% for the PG 52-28 binder. This means that there is a 50% probability that a pavement temperature of 52 °C will be exceeded in a given year (based on the 7 day air average). During the six months of winter, there is a 50% chance that the pavement surface temperature would fall below -28 °C. A grade of PG 58-40 is recommended to achieve 98% reliability. The cost of a PG 58-40 was prohibitive and it was not used on this project.

Note: In all of the following tables, a shaded box represents an area of concern or interest.

Table 2: Asphalt Binder Test results

Test	Property, Temp.	Test Results		Criteria
Traditional pen grade	n.a.	120/150	200/300	n.a.
Specific Gravity (G_b)	n.a.	1.0311	1.0257	n.a.
Rotational Viscosity	Viscosity @ 135 °C	0.234	0.176	3 Pa-s max
Rotational Viscosity	Viscosity @ 58 ,52 °C	0.936	1.085	1.0 min
Mass Loss	n.a.	0.39	0.83	+/- 1.0% max
Dynamic Shear Rheometer - RTO	G / sin S @ 58 , 52 °C	2.680	3.707	2.2 kPa min.
Dynamic Shear Rheometer - PAV	G / sin S @ 13 °C	n.a.	3985	5000 kPa max
DSR - PAV	G / sin S @ 16 °C	5518	n.a.	5000 kPa max
DSR - PAV	G / sin S @ 19 °C	3824	n.a.	5000 kPa max
Bending Beam -PAV	Stiffness @ -24 °C	n.a.	279,600	300K kPa max
Bending Beam - PAV	Stiffness @ -18 °C	219,000	n.a.	300K kPa max
Bending Beam - PAV	Slope m @ -24 °C	0.315	n.a.	0.300 min.
Bending Beam - PAV	Slope m @ -18 °C	n.a.	0.316	0.300 min
Mixing temp H/L	°C	147/141	137/132	n.a.
Compact temp. H/L	°C	134/129	126/121	n.a.
PG grade Result	n.a.	PG52-22	PG52-34	n.a.

This project used two readily produced asphalts from Koch Materials Co. that were tested to determine performance grade. The 200/300 asphalt binder was a higher penetration grade than generally used on this type of facility. This asphalt was less expensive than a polymer modified asphalt material required to reach 98% reliability.

As shown in Table 2, the 120/150 pen graded asphalt binder was rated as PG 52-22 while the 200/300 asphalt binder was rated as PG 52-34. The actual % reliability of the 120/150 asphalt was 50 /23. This represents a 50 % reliability for high temperature and 23% reliability on the low temperature condition. The 200/300 pen graded asphalt cement is actually rated at 50/80. Determination of acceptable % risk or reliability in performance of the asphalt is based on agency policy, economics, maintenance and rehabilitation considerations and professional judgement of the Engineer. This project used unmodified asphalt binders. No polymers were utilized on this project.

B. Aggregate Selection

After asphalt binder selection, aggregates are selected for use in the paving mix. This project had four aggregates materials which included two coarse and two fine stockpiles. A New Ulm Quartzite aggregate was hauled to the project to improve the crushing content and size of the blends. The hauling of this non-local material increased costs, but this was offset by a reduction in asphalt binder content. The aggregates were split into representative samples and sent to the district lab for drying and testing. Results for net absorption, bulk and apparent specific gravities are shown in Table 3.

SHRP researchers surveyed pavement experts to determine which aggregate properties were most important. There was general agreement that aggregate properties played the central role in overcoming permanent deformation. Fatigue cracking and low temperature cracking were less affected by aggregate characteristics. SHRP researchers used these survey results to identify two categories that needed to be used in the Superpave system: consensus properties and source properties. In addition, a new way of specifying aggregate gradation was developed - the design aggregate structure.

The pavement experts agreed that certain aggregate characteristics were critical to well performing HMA. These characteristics were called "consensus properties" because there was a wide agreement in their use and specified values.

Those properties are coarse aggregate angularity; fine aggregate angularity; thin and elongated particles; and clay content. In addition to the consensus aggregate properties, SHRP researchers believed that certain other aggregate characteristics were critical. However, critical values of these properties could not be reached by consensus because needed values were source specific. Consequently, a set of "source properties" was recommended. Specific values are established by local agencies. While these properties are relevant during the mix design process, they may also be used as source acceptance control. These properties are toughness, soundness, and deleterious materials.

Table 3: Aggregate Classification: Specific Gravity & Net Absorption

Aggregate	Bulk specific Gravity (G_{sb})	Apparent specific Gravity (G_{sa})	Net absorption %
New Ulm Quartzite	2.641	2.670	0.43
Cedar Grove CA	2.547	2.743	2.80
Cedar Grove BA	2.589	2.708	1.70
Cedar Grove Sand (Fine)	2.549	2.671	1.80

C. Aggregate Testing

Table 4: Aggregate Stockpile Gradations

Sieve Size		Percent Passing			
mm	inch	New Ulm Quartzite	Cedar Grove CA	Cedar Grove BA	Cedar Grove Sand Fine
25	1	100	100	100	100
19	3/4	100	100	100	100
16	5/8	94	94	100	100
12.5	½	75	64	98	100
9.5	3/8	50	45	91	99
4.75	#4	4	26	63	97
3.35	#6	2	22	52	96
2.36	#8	1	18	39	95
1.18	#16	0	14	18	91
0.6	#30	0	10	10	82
0.3	#50	0	8	6	40
0.15	#100	0	6	4	4
0.075	#200	0	4.2	3.5	1.6

Aggregate Quality Results

In addition to sieve analysis and specific gravity determination, the Superpave design method requires conformance to consensus properties. These tests ensure that the aggregate blend selected for the mix design is compatible. Criteria are established based upon current environmental and projected traffic conditions.

The following four tests are required:

- Coarse aggregate angularity
- Fine aggregate angularity
- Thin and elongated particle percentage
- Clay content

Optional tests:

- Sulfate soundness or Magnesium Sulfate test
- L.A. abrasion (toughness test)
- Friable content (deleterious materials)
- Asphalt - Aggregate compatibility net adsorption test

The optional tests listed are source specific. These tests are recommended but not required. These optional tests, while periodically performed on a source basis, were not specifically conducted on this project. Also, the fine angularity test was not performed because Mn/DOT did not have the required equipment.

The asphalt - aggregate compatibility net adsorption test gauges the ability of an asphalt binder to adhere to the surface of the fine aggregate portion of the total aggregate. It also assesses the strength of the initial adhesion of the asphalt binder to the aggregate in the presence of moisture. This optional screening procedure evaluates the chemical compatibility of an asphalt binder and fine aggregate fraction as well as the effect of moisture on this compatibility.

Table 5: Aggregate Quality Test Results

	Superpave Criteria	Results
Coarse Aggregate Angularity +4.75 mm material only	+4.75 mm aggregate, 55 % single face crushed	Blend #1 = 77.7 % Blend #2 = 75.0 % Blend #3 = 85.0 %
Fine Aggregate Angularity -2.36 mm material	At this traffic level, there is no minimum.	Not tested
% Thin & Elongated +4.75 mm material	At this traffic level, there is no minimum.	Not tested
Dust Proportion	0.6 - 1.2	Blend #1 = 0.6 Blend #2 = 1.1 Blend #3 = 1.0

D. Design Aggregate Proportioning

Selection of the design aggregate structure was performed by mathematically combining the gradations of individual materials into a single gradation that fit the design criteria for this project. The blends must comply with the appropriate specification requirements at several sieves.

Gradation control is based upon four sieves: the maximum sieve size, the nominal max sieve size, and two or three specific control sieves specified by Superpave. In this particular example, the project was specified to be a 19.0 mm (3/4") nominal max sieve size. By Superpave definition, the nominal max sieve = one sieve size larger than the first sieve to retain more than 10 percent of the aggregate.

As shown in the gradations in Table 4, the New Ulm quartzite and Cedar Grove CA are 19.0 nominal max sieve sized material. The Superpave program does not recognize the 16.0 mm (5/8") sieve when classifying the next larger size. The Cedar Grove BA and Fine material are classified as 9.5 mm (3/8") nominal max sizes. Changes in specifications will result when proportioning is done. This may effect the resulting nominal max sieve size.

Table 6 shows the three selected aggregate trial blends which where chosen from approximately 50 mathematical combinations attempted. These three selections were determined to fit the requirements for the 19.0 nominal max sieve size specifications. The blends in Table 6 are based on the four aggregates from Table 4.

Superpave recommends that three different aggregate blends be used for designing an optimal mix. The objective is to establish three trial blends that provide the following:

- Specified consensus properties.
- Specified gradation requirements.
- A good starting point for optimal design.
- Flexibility in design.
- A range of suitable mixes.
- Establish a defined cost / benefit ratio.

The gradation of the three blends should be fine, medium, and coarse. These three blends were tested in the laboratory, analyzed, and then one was chosen to move onto the next phase of design. Ideally, it is desirable to have a hot mix asphalt design with the highest quality and the best price. Due to time constraints, the ideal situation may not have been achieved in a laboratory.

Table 6: Aggregate Proportioning of the Trial Blends

Sieve Size	Trial Blend #1 (Chosen)	Trial Blend #2 (Not Chosen)	Trial Blend #3 (Not Chosen)
25.0 mm (1")	100	100	100
19.0 mm (3/4")	100	100	100
16.0 mm (5/8")	97.6	97.2	96.1
12.5 mm (1/2")	87.3	84.6	79.4
9.5 mm (3/8")	76.4	72.0	63.4
4.75 mm (#4)	55.7	48.0	35.8
3.35 mm (#6)	51	42.3	30.3
2.36 mm (#8)	46.8	36.9	25.9
1.18 mm (#16)	39.2	27.9	18.5
0.60 mm (#30)	33.2	22.4	14.2
0.30 mm (#50)	17.1	12.1	8.3
0.15 mm (#100)	3.6	3.7	3.5
.075 mm (#200)	2.3	2.6	2.5
NU Quartz	20.0%	20.0%	30.0%
Cedar G. CA	20.0%	27.0%	35.0%
Cedar G. BA	25.0%	33.0%	25.0%
Cedar G. Fine	35.0%	20.0%	10.0%

The trial proportions in Table 6 are plotted on the 0.45 power chart with the appropriate control points and restricted zone as shown in Figure 1. The restricted zone resides along the maximum density gradation between an intermediate sieve and the 0.3 mm sieve. The restricted zone forms a band through which the gradation should not pass. Gradations that pass through the restricted zone have been called "humped gradations" because of their characteristic hump shape in this area.

In most cases, a humped gradation indicates an over-sanded mixture and/or a mixture that poses compaction problems during construction and offers reduced resistance to permanent deformation during its performance life. Likewise, the restricted zone prevents a gradation from following the maximum density line in the fine aggregate sieves. Aggregate mixtures that follow this maximum density gradation often have inadequate VMA to allow enough asphalt into the mix for adequate durability. These mixtures were very sensitive to the quantity of the asphalt binder and they easily became plastic with even minor increases in the content.

As mentioned previously, there were approximately 50 attempts to find three suitable blends to meet specifications. As shown in Figure 1, the medium trial gradation passed slightly through the restricted zone. There was a lack of communication between the office and the field which resulted in this blend running through the restricted zone. This did not appear to have any undesirable consequences when the material was tested.

0.45 Power Charts: SUPERPAVE TRIAL GRADATIONS CSAH-30 Blue Earth

19.0 mm Nominal Max. Size

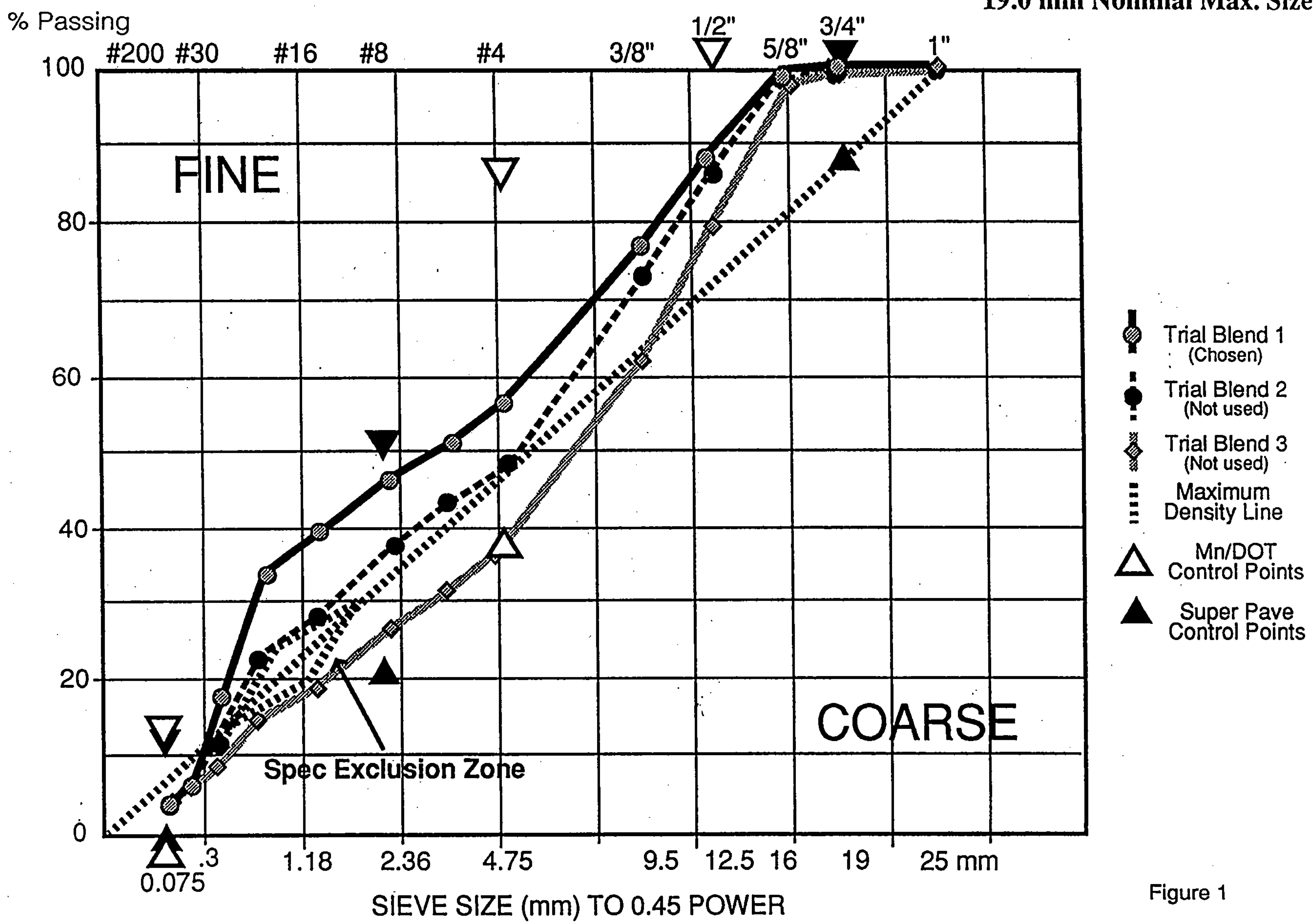

Figure 1

IV. Laboratory Analysis

A. Estimation of Initial Asphalt Binder Content

Evaluation of the three trial blends was completed by compacting specimens using a Gyratory compactor. The asphalt binder content was determined for each trial blend by estimating the effective specific gravity of the blend and using the calculations indicated below.

A. G_{sb} = Bulk specific Gravity &

G_{sa} = Apparent specific Gravity

$G_{xb} = (P_1 + P_2 + P_3 + P_4) / ((P_1 / G_1) + (P_2 / G_2) + (P_3 / G_3) + (P_4 / G_4))$

Where P_1 = Weight % of Aggregate fraction #1

G_1 = Bulk or apparent specific gravity of Aggregate #1

B. G_{se} = Effective Specific Gravity

$G_{se} = G_{sb} + 0.8*(G_{sa} - G_{sb})$

The multiplier 0.8 can be changed at the discretion of the designer.

Absorptive aggregates require values of 0.5 or 0.6.

C. W_s = weight of aggregate

$W_s = \{P_s \times (1 - V_a)\} / \{(P_b / G_b) + (P_s / G_{se})\}$

where P_b = percent binder

P_s = percent of aggregate

G_b = specific gravity of binder

V_a = volume of air voids

D. V_{ba} = % by volume of asphalt absorbed into aggregate

$V_{ba} = w_s \{(1/G_{sb}) - (1/G_{se})\}$

E. V_{be} = Volume of effective binder

$V_{be} = 0.176 - 0.0675 \times \text{Log}(S_n)$ where S_n = Nominal max sieve size mm selected

F. P_{bi} = Estimation of Initial asphalt cement content

$P_{bi} = G_b (V_{be} + V_{ba}) / \{(G_b x (V_{be} + V_{ba})) + W_s$

Table 7: Summary of Initial Asphalt Binder Content Estimation

	Trial Blend #1 (Chosen)	Trial Blend #2 (Not Chosen)	Trial Blend #3 (Not Chosen)
Total Agg. Bulk S.G. (G_{sb})	2.576	2.580	2.585
Total Agg. Apparent S.G. (G_{sa})	2.694	2.702	2.705
Effective S.G. (G_{se})	2.671	2.678	2.681
Weight % of Agg 120/150 (W_s)	2.256	2.261	2.264
Weight % of Agg 200/300 (W_s)	2.255	2.260	2.263
% 120/150 asphalt absorbed into aggregate (V_{ba})	0.031	0.032	0.031
% 200/300 asphalt absorbed into aggregate (V_{ba})	0.031	0.032	0.031
Volume of effective binder (V_{be})	0.089	0.089	0.089
Est. of initial AC 120/150 (P_{bi})	5.2 %	5.3%	5.2%
Est. of initial AC 200/300 (P_{bi})	5.2 %	5.3%	5.2%

B. Gyratory Compaction and Estimation of Mix Volumetrics

After estimating an initial asphalt content, a minimum of two specimens for each trial blend are compacted using the Gyratory compactor. Two additional specimens were prepared for determination of the mixture's maximum theoretical specific gravity (G_{mm}).

Specimens were mixed at 141 to 147 °C for the 120/150 asphalt binder and 132 to 137 °C for the 200/300 asphalt binder. The specimens were then short-term aged by placing the loose mixture in a flat pan, in a forced air oven for 4 hours at 135°C. After this aging, they were brought to the compaction temperature of 129 to 134°C for the 120/150 asphalt binder and 121 to 126°C for the 200/300 asphalt binder. The material was removed and compacted using the Gyratory compactor or left loose for the maximum specific gravity determination. The number of gyrations used for compaction is determined based on the design high air temperature of the paving location (33°C) and the traffic level. Table 8 indicates the number of gyrations required at initial design and final compaction.

The initial calculation for asphalt binder content included an estimate of its specific gravity. This estimate was not accurate and it resulted in the first calculation showing 5.5% to be the appropriate amount for blend #1. Subsequent calculations resolved this error so that blend # 2 and blend #3 where mixed with the appropriate asphalt cement content. All three trials of 200/300 asphalt cement were mixed using the correct amount.

Table 8: Gyratory Compaction Effort

Design ESALs Millions	Average 7 - Day Design High Air Temperature											
	< 39 °C			39 - 41			41 - 43			43 - 45		
	N_i	N_d	N_m	N_i	N_d	N_m	N_i	N_d	N_m	N_i	N_d	N_m
< 0.3	7	68	104	7	74	114	7	78	121	7	82	127
0.3 - 1	7	76	117	7	83	129	7	88	138	8	93	146
1 - 3	7	86	134	8	95	150	8	100	158	8	105	167
3 - 10	8	96	152	8	106	169	8	113	181	9	119	192
10 - 30	8	109	174	9	121	195	9	128	208	9	135	220
30 - 100	9	126	204	9	139	228	9	146	240	10	153	253
> 100	9	143	235	10	158	262	10	165	275	10	172	288

The lowest design level was chosen, due to the low traffic demand on this highway. Each specimen was compacted to the maximum number of gyrations and recorded. During compaction, the height of the specimen was continually monitored. Density was also continually calculated using the initial mass of the mixture, the fixed volume of the mold and the measured height of the compacted specimen.

After compaction is complete, the specimens are extruded from the mold and allowed to cool. The bulk specific gravity (G_{mb}) and the maximum specific gravity (G_{mm}) of the mixture are determined. A comparison of the estimated bulk specific gravity (G_{mb} est) and measured bulk specific gravity (G_{mb} meas) shows a slight difference between the two parameters. This is due to the over simplification of the specimen volume represented by a smooth-sided cylinder. The actual volume of the specimen is slightly smaller due to the presence of surface voids surrounding the perimeter of the specimen.

The uncorrected gyratory compaction results are shown in Table 9. Therefore, the estimated bulk specific gravity of the specimen at any given gyration must be corrected by a factor that is the ratio of the measured to the estimated bulk specific gravity. This corrected step is shown in the following tables as G_{mb} (corr).

In these tests, the correction factor was generally low due to the fineness of the mixtures. If the mixes are coarse, the smooth side approximation is less accurate. The final step from this initial compactive effort is to report the corrected $\%G_{mm}$ for each specimen as shown in Table 10. The data in Table 10 is from hand calculations based on the initial mix design.

The Densification of each trial blend is reported for all three levels, initial, design and final. Densification information on each trial blend is presented in the appendix (Tables A-1 to A-7). After Gyratory compaction, % air voids and %VMA need to be corrected. The following equations highlight these calculations. All of the corrected data for the trial mixtures is presented in Table 10.

F. % Air Voids = 100 - % G_{mm} @ N_{des}

G. %VMA = Voids in Mineral Aggregate

% VMA = 100 - (%G_{mm}@ N_{des} x G_{mm} x P_s) / G_{sb}

Where: % G_{mm} @ N_{des} = compaction at design gyrations

G_{mm} = Measured maximum specific gravity of mixture

P_s = Decimal % aggregate in mixture

G_{sb} = Bulk specific gravity of Aggregate blend

Table 9: Uncorrected Gyratory Compaction Results

Trial Blend	% A.C.	% G_{mm} @ $N_{initial}$	% G_{mm} @ N_{design}	% G_{mm} @ N_{final}	% Air Voids	% VMA
120 / 150 Asphalt Binder						
#1 Fine	5.5	93.0	97.3	97.9	2.1	12.6
#2 Med	5.3	94.2	99.8	100.3	0.3	10.3
#3 Coarse	5.2	90.5	99.0	100.1	0.1	10.6
*#1 Fine	5.0	90.6	95.0	96.0	5.0	14.0
200 / 300 Asphalt Binder						
#1 Fine	5.2	91.6	95.6	96.4	4.4	13.6
#2 Med	5.3	93.3	99.1	99.9	0.9	10.6
#3 Coarse	5.2	90.4	98.6	100	1.4	11.0

*Retest

C. Corrected Volumetrics @ 4.0% Design Air Voids

The following equations use compaction test results from the three trial blends to estimate the properties at the desired 4% design voids level. This process gives the designer the ability to compare all blends, assuming that the correct amount of asphalt was added. This step saves time in the design process by providing estimates for another trial blend.

H. $P_{b,\,estimate}$ = Estimated binder for 4% voids at the N_{design}

$P_{b,\,estimate} = P_{bi} - (0.4 \times (4-V_a))$

Where P_{bi} = initial (trial) % binder

V_a = % air voids at N_{des}

I. $\%VMA_{est}$ = Estimated Voids in Mineral Aggregate

$\%\,VMA_{est} = \%\,VMA_{initial} + C \times (4- V_a)$

Where $\%VMA_{initial}$ = % VMA from trial asphalt binder content

C = Constant (0.1 or 0.2)

$C = 0.1$ if $V_a < 4.0\%$

$C = 0.2$ if $V_a > 4.0\,\%$

J. $\%\,VFA_{estimate}$ = Voids filled with asphalt estimate

$\%\,VFA_{estimate} = 100\% \times (\%VMA_{estimated} - 4.0) / \%\,VMA_{estimated}$

K. $\%G_{mm}$ @ $N_{initial}$ = % compaction at initial gyrations

$\%G_{mm} @ N_{initial} = \%G_{mm\ trial} @ N_{initial} - (4.0 - V_a)$

L. $\%G_{mm}$ @ N_{max} = % compaction at maximum gyrations

$\%G_{mm} @ N_{max} = \%G_{mm} @ N_{max} - (4.0 - V_a)$

The final requirement is on the proportion of dust in the mixture. This criteria is equivalent at all traffic levels. It is calculated as the percent by mass of material passing the 0.075 mm sieve divided by the effective asphalt binder content (expressed as a % by mass of mixture).

M. $P_{be,est}$ = Effective Asphalt binder estimate

$P_{be,est} = -(P_s \times G_b) \times ((G_{se} - G_{sb}) / (G_{se} \times G_{sb})) + P_{b,est}$.

Where: P_s = Percent of Aggregate (100 - % ac est.)

G_b = Specific Gravity of binder

G_{se} = Aggregate effective specific gravity

G_{sb} = Bulk Specific Gravity of total aggregate mix

$P_{b,est}$ = estimated percent binder

N. DP = Dust Proportion

$DP = P_{0.075} / P_{be,est}$

Table 10: Corrected Volumetric Mixture Properties @ 4% Design air Voids

Blend Number	Trial % A.C.	Est. % A.C.	% Air Voids	% VMA_{est}	% VFA_{est}	$\%G_{mm}$@ $N_{initial}$	$\%G_{mm}$ @ N_{max}	Dust Proportion
Criteria	Na	Na	4.0	> 13.0%	70 - 80	< 89%	< 98%	0.6 - 1.2
120 / 150 Asphalt Binder								
1 - Fine (Chosen)	5.5	5.3	4.0	12.63	68.3	92.7	97.6	0.58
2 - Med	5.3	3.8	4.0	10.68	62.5	90.4	96.5	1.09
3 - Coarse	5.2	4.0	4.0	10.90	63.3	87.5	97.1	0.96
*1 - Fine (Chosen)	5.0	5.4	4.0	13.75	70.9	91.6	97.0	0.62
200 / 300 Asphalt Binder								
1 - Fine (Chosen)	5.2	5.4	4.0	13.5	70.4	92.0	96.8	0.63
2 - Med	5.3	4.1	4.0	10.9	63.4	90.2	96.8	0.97
3 - Coarse	5.2	4.2	4.0	11.3	64.5	87.8	97.4	0.90

*Retest

D. Results of Initial Trial Mix Design

Based upon the results shown in Table 10, Blend #1 was chosen for both the 120/150 and 200/300 asphalt binders. The decision was made by the following criteria:

- Blend #1 was the only one to pass the VMA and VFA requirements (200/300 binder).
- All three blends passed the %G_{mm} @ max requirement.
- All three blends passed the dust proportion requirement.
- Only Blend #3 passed the %G_{mm} @ initial, but it wasn't allowed to govern.

At this point, blend #1 (the fine mix) was retested at a more appropriate estimated asphalt binder content. If this retest met the Superpave Criteria, then the remaining tests could proceed at various asphalt binder content levels to determine the optimal mix design. If this test did not show passing of the desired criteria, then we would go back to the beginning. The other tests which were omitted could be performed and/or choose new gradation blends. If these tests showed a particular problematic material, then the aggregates could be changed.