UNIVERSITY OF NORTH DAKOTA
Grand Forks

Evaluation of North Dakota's Asphalt Cement Binder Properties and Performance in Locally Produced HMA Mixtures

Final Report

December 2005

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT	EXPERIMENTAL PROJECT NO. 1	STATE: UND	YEAR: 2005	-	NUMBER: 01	SURF	CONSTRUCTION PROJ NO 8	LOCATION 28 Grand Forks
	EVALUATION FUNDING 48 — 1 X HP&R; 2 CONSTRUCTION; 3 DEMONSTRATION; 4 IMPLEMENTATION						NEEP NO. 49	PROPRIETARY FEATURE? 51 Yes; X No
SHORT TITLE	TITLE 52 Evaluation of North Dakota's Asphalt Cement Binder Properties and Performance in Locally Produced HMA Mixtures							
THIS FORM	DATE 140 MO. 12 -- YR. 05						REPORTING 1 INITIAL; 2 ANNUAL; 3 FINAL X	

KEY WORDS		
	KEY WORD 1 145 ASPHALT	KEY WORD 2 167 PAVEMENT
	KEY WORD 3 189 AGGREGATE	KEY WORD 4 211 BINDER
	UNIQUE WORD 233 SUPERPAVE	PROPRIETARY FEATURE NAME 255

CHRONOLOGY	Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
	07-2004 277	281	285	289	12-2005 293

QUANTITY AND COST	QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS)	UNITS	UNIT COST (*Dollars, Cents*)
	297	305 1 LIN. FT 2 SY 3 SY-IN 4 CY 5 TON 6 LBS 7 EACH 8 LUMP SUM	306

AVAILABLE EVALUATION REPORTS	-CONSTRUCTION	-PERFORMANCE	FINAL
	315		X

EVALUATION	CONSTRUCTION PROBLEMS	PERFORMANCE
	318 1 NONE 2 SLIGHT 3 MODERATE 4 SIGNIFICANT 5 SEVERE	319 1 EXCELLENT 2 GOOD 3 SATISFACTORY 4 MARGINAL 5 UNSATISFACTORY

APPLICATION		
	320 1 ADOPTED AS PRIMARY STD. 2 PERMITTED ALTERNATIVE 3 ADOPTED CONDITIONALLY	4 PENDING 5 REJECTED 6 NOT CONSTRUCTED *(Explain in remarks if 3, 4, 5, or 6 is checked)*

REMARKS

321 The HMA with a non-polymer modified binder (partially air-blown) has generally performed well according to the APA depth metric and moisture sensitivity results. Therefore, the PI does not recommend precluding them based on this study. However, the HMA with polymer modification has outperformed the one with non-modified binder; thus, the use of polymer modification is highly recommended.

The results of this study indicate that the addition of a small percentage of lime does help the mix against moisture damage. However, attention should be made so that the %Gmm @ Nmax must not exceed 98%. Accounting for the lime as part of the dust in the aggregate blend could be a safer way of doing it. Further experimentation with lime is necessary such as allowing the lime to cure to gain strength.

University of North Dakota
Department of Civil Engineering

Evaluation of North Dakota's Asphalt Cement Binder Properties and Performance in Locally Produced HMA Mixtures

Final Report Submitted to the

North Dakota Department of Transportation
Bismarck, ND

By:

Dr. Nabil Suleiman, Principal Investigator

December 2005

Disclaimer

ACKNOWLEDGMENT

The Principal investigator (PI) wishes to express his sincere gratitude to the officials of the Materials and Research Division of the North Dakota Department of Transportation (NDDOT) for the financial support they provided to make this research idea a reality.

Furthermore, the author wishes to thank the NDDOT Asphalt laboratory engineers and technicians as well as the Grand Forks and Valley City district engineers and technicians for their help and facility use that contributed to the success of this project. Special thanks and gratitude are extended to the Dakota Asphalt Pavement Association for the equipment grant (Asphalt Pavement Analyzer), which is a key factor in accomplishing this research study.

Finally, the author hopes that NDDOT will continue its research educational relationship with the CE department at UND in the future.

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INTRODUCTION

BACKGROUND

The adoption of the Performance Graded (PG) Binder Specifications (*1, 2*) developed in the Strategic Highway Research Program Superpave study has improved asphalt concrete mixture properties, particularly in the northern states. Asphalt, as a viscoelastic material, can now be specifically engineered for North Dakota's climatic conditions so that the properties of the asphalt binder can be specified to provide the high temperature deformation resistant properties for extreme summer temperatures and the low temperature thermal cracking resistance necessary for extreme cold winter temperatures (*1, 2, 3, 4*).

To meet the expanded PG specifications for high traffic volume or extreme temperature conditions, asphalt suppliers have a number of options including the use of plastomers and elastomers such as SBS and SBR and other styrene compounds, or turn to crude treatment alternatives such as acid treatment, foaming, air blowing, and blending (*3, 4, 5*). However, many states have precluded the use of treated asphalts for fear of artificial aging effects resulting from such treatment that may not be picked up by specification property limits and test sensitivity provided by the Rolling Thin Film Oven (RTFO) Test and Pressure Aging Vessel (PAV) Test included in the PG Binder specification portfolio (2, *6, 7*). North Dakota (*8*) has an extensive performance history with non-polymer modified asphalts that meet PG 58-34. The typical consistency and quality of the asphalt produced from this crude source has for some years been documented.

Although similar in many respects to the normal paving grades of asphalt cement, the air blowing process provides asphalt materials that soften at higher temperatures than kneading asphalt cements. Since the higher softening point is the most important and desirable property of air blown asphalts, they are usually classified in terms of the ring and ball softening point test, rather than viscosity or penetration. The softening point test is used as the basic measurement of consistency for grading blown asphalts (3*, 5, 6, 7*).

The objective of HMA mix design is to develop an economical blend of aggregates and asphalt. Historically asphalt mix design has been accomplished using either the Marshall or the Hveem design method. The most common method was the Marshall. It had been used in about 75% of the DOTs throughout the United States and by the Federal Aviation

Administration (FAA) for the design of airfields. In 1995, the Superpave mix design procedure was introduced into use. It builds on the knowledge from Marshall and Hveem procedures. The primary differences between the three procedures are the machine used to compact the specimens and strength tests used to evaluate the mixes (3).

No matter which design procedure is used, the HMA mixture that is placed on the roadway must have sufficient asphalt to ensure durability, enough stability to satisfy the demands of traffic without displacement or distortion (rutting), sufficient voids to allow a slight amount of added compaction under traffic loading without bleeding and loss of stability, and enough workability to permit placement and proper compaction without segregation (2).

Environmental factors such as temperature and moisture can have a profound effect on the durability of hot mix asphalt pavements. When critical environmental conditions are coupled with poor materials and traffic, premature failure may occur as a result of stripping of the asphalt binder from the aggregate particles. When the aggregate tends to have a preference for absorbing water, the asphalt is often "stripped" away. Stripping leads to loss in quality of mixture and ultimately leads to failure of the pavement as a result of raveling, rutting, or cracking (*2, 13*).

Furthermore, loaded wheel testers have gained popularity in recent years. The test simulates the dynamics of heavy traffic loads by passing laboratory-scale wheels repeatedly over a pavement surface to measure rutting resistance (*9, 10, 11, 12, 13, 14, 15, 16*). Departments of Transportation are increasingly utilizing such tests to improve the predictability of pavement rutting resistance (*11*)

MOTIVATION AND BENEFITS

Due to the extreme temperature conditions prevalent in North Dakota, the NDDOT has used a number of Suppliers of modified asphalt binders including polymer modified and partially air-blown asphalt binders. Since many states have precluded the use of air blown asphalts for fear of artificial aging, the NDDOT is keen on knowing and comparing the properties and performance of the HMA mixtures when different modified binders were used. With the purchase and installation of the Asphalt Pavement Analyzer (APA) in the PI's laboratory a study was devised and conducted to evaluate and compare the hot mix asphalt properties, and performance using Superpave mix design method in locally produced HMA mixtures.

The primary benefit of the study is to evaluate the effectiveness of using various asphalt binders on rut resistance and strength parameters of locally produced HMA mixtures. The addition of lime to the Superpave mix may improve or worsen the pavement mix performance; hence, the performance results of the various mixes with lime and without lime will be examined and compared, if possible.

OBJECTIVES AND SCOPE

The main objectives of this research study are: (1) to evaluate the hot mix asphalt properties and performance Superpave mix design methods utilizing polymer and non-polymer modified asphalts as binders; and (2) to evaluate and compare the hot mix asphalt properties and performance when adding 1% lime to the Superpave mix with polymer and non-polymer modified asphalt binders.

In this research study, a Superpave mix design will be prepared using North Dakota's locally processed aggregates which meet the NDDOT specifications (Sections 816 and 410) that have been historically employed for NDDOT projects. Polymer and non-polymer modified asphalt binders from three suppliers will be used. Appropriate laboratory tests and analysis will be done on the HMA mixes to evaluate the effect of the inherent binder characteristics on the HMA properties and performance.

MATERIAL SELECTION AND TESTING

BINDER AND AGGREGATE SELECTION

Three asphalt binders from three different sources were chosen for this study. One asphalt binder was non-polymerized (air blown) and the other two were polymer modified. All of the binders were taken from field samples and graded at PG 58-34. On the other hand, the aggregates adopted for this study were from one source [Valley City District, Project NH-2-281(025)049, Pit Location E ½ 27-138-64] and specified to meet the requirements of Superpave mixes.

The properties of the selected binders were provided by the NDDOT asphalt laboratory for proper documentation. The consensus and source properties of aggregates were conducted on the Superpave blend. The test results are reported in the subsequent sections.

ASPHALT BINDER TESTING

Certification Method and Binder Control (*16*)

As a prescribe to the combined state binder group on certification method of acceptance for asphalt binders, North Dakota Department of Transportation (NDDOT) enjoys the benefits that all asphalt binder suppliers shall furnish all specification tests and maintain acceptable quality control procedures. The supplier shall maintain the test records and make them available to the designated representative for a period of five years. The supplier shall also inspect each transport tank prior to loading to insure suitability for loading and freedom from containments.

The NDDOT will continue to accept material from a supplier as long as the supplier is determined to be satisfactorily complying with the procedures and that materials are conforming to the requirements. However, if an acid modification process or a modifier (as defined in AASHTO M 320), not including additives such as silicone, is used, the supplier shall assign the modifying process with a unique name and type of modification to be provided to the department for tracking and monitoring purposes. If an anti-strip agent is added at the plant, the HMA producer is considered a supplier and must conform to the requirements. Full test results with and without anti-strip in the asphalt binder at the required dosage will be required before production begins. The department shall be notified of PG grade and/or supplier changes.

Minimum sampling and testing are required from the supplier on annual, daily, and bi-weekly basis. The minimum annual requirements by the certification method of acceptance program for continuation of a supplier certification indicate that prior to the start of the shipping season, adequate testing shall be performed to identify characteristics of tank materials on-hand. Before or at the start of shipping, bi-weekly sample testing shall be completed on a minimum of one sample for each grade of asphalt material anticipated to be shipped to department projects. The facility annual inspections as well as the participation in Combined State Binder Group "Round Robin" program are considered part of the requirements.

As far as the daily requirements are concerned, sampling, testing, and reporting requirements are involved. Taking one sample from the tank or blender representing each grade of material shipped to state work is needed. For material shipped from tanks, the sample may be taken from the tank, from the line during loading, or from the loaded transport. Material produced from a blender may be sampled from the line during loading or from the loaded transport. Performance grade testing: penetration, viscosity measurement, or dynamic shear is required. The dynamic shear will be required if material is modified. The reporting requirement involves sending a record of daily quality control results to the department central laboratory on an approximate weekly basis.

Like the daily requirements, the Bi-Weekly requirements include sampling, testing, and reporting activities. The sampling activities are similar to those mentioned for the daily requirements. The test requirements include all of the tests listed in the schedule of tests for performance graded binder material. The reporting activity requires sending a report of the test results to the department central laboratory when completed.

NDDOT has the option to obtain samples at the source of supply (refinery/terminal). The samples shall be taken by supplier personnel at the request and under observation of an authorized department representative. The supplier shall have equipment and facilities available to obtain samples safely.

Verification field samples will be obtained. NDDOT project personnel will observe the contractor obtain random samples from material delivered to the job site. The sampling rate will be a minimum of one sample for every 250 tons (225 Mg) for each supplier and grade of asphalt cement, or fraction thereof.

A sample will consist of taking two 1-liter (one-quart) samples from the designated transport. The first sample will be used for testing; the second sample will be a check. Both samples will be sent to the NDDOT Central Lab. Samples will be identified with the following information written on the can:

- Project Number-Field Sample Number
- Manifest Number-PG Grade
- Asphalt Supplier-Date
- Original or Check

Project personnel will also obtain samples as directed by the project engineer at any time extra samples are determined to be necessary.

Asphalt Binder Properties

The approach to the PG system represents a change in philosophy. The specification uses tests which evaluate the fundamental material properties (stress, strain, and strain rate). Changes in asphalt properties due to temperature, rate of loading, and the effect of aging are also considered. The specification requirement does not change, rather the temperature which the specification value has to meet, changes with grade (*1, 2*).

The high temperature stiffness is measured with the dynamic shear rheometer (DSR) using the binder in two different aging conditions. The RTFO-aged residue is checked to ensure that the material has sufficient stiffness after mixing with the aggregate in the plant. For fatigue cracking, the DSR is used a third time, to measure an intermediate stiffness on the PAV-aged residual. This is a check to see how stiff the binder will be after it has been in service for a period of time. For low temperature cracking the binder is aged in the PAV. The binder is tested with the bending beam rheometer (BBR) for a maximum stiffness (≤ 300 MPa) and a minimum m-value ($m \geq 0.30$).

Other miscellaneous requirements that have been used for years include viscosity, flash point, solubility, and mass loss. The viscosity requirement obtained by the rotational viscometer (also referred to as a Brookfield viscometer) is there to insure that the material can be pumped properly. The flash point is there for safety reasons. Mass loss indicates the amount of volatiles evaporating during the mixing and construction process (*2*).

The binder properties for this study (displayed in Table 1) were provided by the NDDOT asphalt laboratory. The terms PM1, PM2, and NPM refer to polymer-modified binder number 1, polymer-modified binder number 2, and non-polymer modified binder, respectively.

Table 1 Properties of the selected Asphalt Binders

Binder Tests and Related Specifications	**AASHTO Designation**	**PM1 2003**	**PM1 2005**	**NPM 2003**	**NPM 2004**	**PM2 2004**	**PM2 2005**
Solubility Point ≥ 99.00%	AASHTO T44	99.98	99.95	99.98	99.97	99.93	99.93
Flash Point ≥ 230 °C	AASHTO T48	278	N/A	242	240	N/A	N/A
Brookfield Viscosity Pa.s @ 135 °C ≤ 3.000	AASHTO T316-02	0.653	0.755	0.303	0.310	0.503	0.395
Brookfield Viscosity Pa.s @ 165 °C (for information only)	AASHTO T316-02	0.228	0.270	0.095	0.108	0.185	0.163
Original Binder DSR G*/sinδ ≥ 1.00 kPa @58.0 °C	AASHTO T315-02	1.590	1.673	1.244	1.305	1.394	1.349
RTFO Mass Loss (+ or -), ≤ 1%, Nearest 0.001%	AASHTO T240-00	- 0.357	- 0.449	- 0.993	- 0.875	- 0.685	- 0.690
RTFO Residue DSR G*/sinδ ≥ 2.20 kPa @16.0 °C	AASHTO T315-02	3.153	3.346	3.714	3.567	2.967	2.707
PAV Residue AASHTO R28-02 DSR (G*)(sinδ) ≤ 5000 kPa @58.0 °C	AASHTO T315-02	2070	2095	3552	3353	2674	2719
PAV Residue BBR Estimated Creep Stiffness @ 60 sec ≤ 300 MPa @ -24.0 °C	AASHTO T313-02	232	224	284	273	252	255
PAV Residue BBR m-slope @ 60 sec ≥ 0.300 @ -24.0 °C	AASHTO T313-02	0.329	0.326	0.308	0.315	0.316	0.306

As shown in the table above, all binders have met the specified specifications. Therefore, there is no reason for concern or any reservation on using all the selected binders for this study. The properties of each binder sampled from two different years were very similar, thus, statistical analysis using analysis of variance (ANOVA) was performed on each set of binders for validation. The null hypothesis, H_o, was that the mean values of the binder properties from two different years were equal. The alternate hypothesis, H_1, was that the mean values of the binder properties from two different years were not equal. Failing to reject the null hypothesis at the 5% significance level constituted validation.

The results of the ANOVA statistical analysis (as shown in Table 2) illustrate that the p-value for each case was much larger than the 0.05 significance level (p > 0.05), which means failure to reject the null hypothesis, thus the property values of each binder from two different years were considered statistically the same.

Table 2 ANOVA Statistical Analysis on Binder Sample Properties from Different Years

(a)

PM1-2003	**PM1-2005**	Anova: Single Factor						
99.98	99.95	SUMMARY						
0.653	0.755	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
0.228	0.27	PM1-2003	9	2407.58	267.5084	463085.8		
1.59	1.673	PM1-2005	9	2424.87	269.4301	474484.1		
-0.357	-0.449	ANOVA						
3.153	3.346	*Source of Variation*	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
2070	2095	Between Groups	16.61761	1	16.61761	3.54E-05	**0.995323**	4.494
232	224	Within Groups	7500559	16	468784.9			
0.329	0.326	Total	7500576	17				

(b)

PM2-2004	**PM2-2005**	Anova: Single Factor						
99.93	99.93	SUMMARY						
0.503	0.395	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
0.185	0.163	PM2-2004	9	3030.61	336.7344	775408.4		
1.394	1.349	PM2-2005	9	3078.16	342.0178	801899.6		
-0.685	-0.69	ANOVA						
2.967	2.707	*Source of Variation*	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
2674	2719	Between Groups	125.6112	1	125.6112	0.000159	**0.990087**	4.494
252	255	Within Groups	12618463	16	788654			
0.316	0.306	Total	12618589	17				

(c)

NPM-2003	**NPM-2004**	Anova: Single Factor						
99.98	99.97	SUMMARY						
242	240	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
0.303	0.31	NPM-2003	9	4182.34	464.7048	1352798		
0.095	0.108	NPM-2004	9	3970.39	441.1539	1204150		
1.244	1.305	ANOVA						
-0.993	-0.875	*Source of Variation*	*SS*	*df*	*MS*	*F*	***P-value***	*F crit*
3.714	3.567	Between Groups	2495.9	1	2495.9	0.001952	**0.965304**	4.494
3552	3353	Within Groups	20455578	16	1278474			
284	273	Total	20458074	17				

AGGREGATE TESTING

Once aggregate samples were obtained, several tests were conducted on individual aggregate stockpiles and on the aggregate blend. Consensus and source properties, specific gravities, percent absorption, and gradation were performed on the aggregate samples to test the Superpave blends.

Consensus properties are those which the SHRP researches believed to be critical in achieving high performance HMA (*1, 2*). These properties must be realized at various levels depending on the traffic volume and positioning within the pavement (*1, 2*). These properties include: coarse aggregate angularity (CAA), fine aggregate angularity (FAA), flat and elongated particles, and clay content (or sand equivalence) (*1, 2, 17, 18*).

CAA is the percentage by weight of aggregate larger than 4.75 mm with one or more fractured faces. This property ensures a high degree of aggregate internal friction and rutting resistance. FAA is the percentage of air voids present in loosely compacted aggregates smaller than 2.36 mm (or US Sieve #8). The FAA property ensures a high degree of fine aggregate internal friction and rutting resistance. More fractured faces means higher void content. The flat and elongated particles characteristic is the percentage of mass of coarse aggregates that have a maximum to minimum dimension ratio greater than five. Flat and elongated particles are undesirable because they have a tendency to break during construction and loading. Clay content is the percentage of clay material contained in the aggregate fraction that is finer that 4.75 mm (US #4) sieve. High clay content causes tender mixes (*1, 2, 17, 18*).

Source properties are those which agencies often use to qualify local sources of aggregate. Although important, these properties are source specific, therefore SHRP does not specify critical values. These properties include: toughness, soundness, and deleterious materials.

Toughness is the percent loss of material from an aggregate blend during the Los Angeles Abrasion test. Toughness test estimates the resistance of coarse aggregate to abrasion and mechanical degradation during handling and construction while in service. Soundness is the percent loss of material from an aggregate blend during the sodium or magnesium sulfate soundness test. The soundness test estimates the resistance of aggregate to in-service weathering (durability). Deleterious materials are defined as the mass percentage of contaminants such as clay lumps, shale, wood, mica, and coal in the blended aggregate. This is usually performed by placing the aggregate in a solution with a specific gravity of 1.95. When placed in this solution, the deleterious materials (basically shale) will float. Toughness and shale tests were specified and examined in this study.

Aggregate specific gravities and gradations also play a crucial role in the HMA. To specify aggregate gradation, Superpave utilizes a 0.45 power gradation chart with initial control limits and a restricted zone (*2, 17*).

The aggregate tests conducted for this study that related to the Superpave blend were (*17, 18*): splitting of aggregate samples using ASTM D75 and AASHTO T248; sieve analysis of the fine and coarse aggregates using AASHTO T11 and T27; bulk specific gravity of fine and coarse aggregates using AASHTO T84 and T85; lightweight pieces of aggregate using AASHTO T113; coarse aggregate angularity according to NDDOT Field Sampling and Testing Manual (one fractured face requirement); the L.A. Abrasion Test using AASHTO T96; fine aggregate angularity using AASHTO T304; clay content using AASHTO T176; and flat & elongated particles using ASTM D 4791.

Aggregate Properties

Specific gravities for coarse and fine aggregates, water absorption, and consensus properties for individual stockpiles were conducted. Table 3 displays the aggregate bulk and apparent specific gravities and absorption properties for individual stockpiles. Table 4 shows the consensus aggregate properties for both individual stockpiles as well as the aggregate blend. Table 5 illustrates additional aggregate blend properties.

By observing the above aggregate properties, one can conclude that the blend has met and exceeded the consensus aggregate properties. The aggregate blend has enough crushed material (%CAA = 100.0 > 75.0, and %FAA = 45.1 > 45.0) to help produce stable and rut resistant mix. The blend also contains low clay content (% sand equivalence value = 59.0 > 40.0) that helps prevent a tender mix. The low percentage of flat & elongated pieces (1.1 < 10.0) gives the blend added stability without risk of breaking under traffic loading.

Table 3 Aggregate Properties for Individual Stockpiles

	Agg #1	Agg #2	Agg #3	Agg #4
	Rock	**Crushed Fines**	**Nat. Fines 1**	**Nat. Fines 2**
Bulk SpG (G_{sb})				
Coarse	2.628	2.628	2.628	2.628
Fine	2.631	2.631	2.572	2.543
Apparent SpG (G_{sa})				
Coarse	2.774	2.774	2.774	2.774
Fine	2.771	2.771	2.733	2.736
Water Absorption				
Coarse	2.000	2.000	2.000	2.000
Fine	1.920	1.920	2.280	2.770
Combined				
Bulk SpG (G_{sb})	2.628	2.631	2.580	2.558
Apparent SpG (G_{sa})	2.774	2.771	2.739	2.743
Water Absorption	1.998	1.924	2.235	2.588

Table 4 Consensus Aggregate Properties

Aggregate Properties	Agg #1	Agg #2	Agg #3	Agg #4	Agg. Blend	Spec's
	Rock	**Crushed Fines**	**Nat. Fines 1**	**Nat. Fines 2**		
Fine Agg. Angularity (% FAA)	47.4	47.4	40.9	42.8	45.1	45 Min
Clay Content (% Sand Equivalent)	71	71	37	47	59.0	40 Min
Coarse Agg. Angularity (%)	On Plus #4 Material				100.00	75 Min
Thin & Elongated Pieces					1.1	10 Max

Table 5 Aggregate Blend Properties

Bulk SpG (G_{sb})	2.607
Apparent SpG (G_{sa})	2.762
Water Absorption (%)	2.108
Light Wt Particles (%)	1.14
Toughness (% Loss)	22.6

The aggregate blend has exceeded the toughness requirement (%loss =22.6 < 40.0) and has very few light weight pieces (1.14% < 5.00%). Conversely, the percent water absorption of 2.108 is relatively high. Overall, the aggregate blend used for this study has met the Superpave aggregate requirements. Since the aggregate was kept the same throughout this research study, there is no specific evaluation or comparisons to be made.

Aggregate Gradation

Gradations for this study was chosen by the NDDOT based on the gradation of Valley City district project NH-2-281(025)049. Tables 6 and 7 display the individual and blend gradations, respectively. Figure 1 exhibits the 0.45 power charts for the Superpave blend gradation.

Table 6 Individual Aggregate Gradation

	Agg #1	Agg #2	Agg #3	Agg #4
Aggregate Description --->	**Rock**	**Crushed Fines**	**Nat. Fines 1**	**Nat. Fines 2**
If Agg. is Crushed, Enter 1	1	1	0	0
Sieve Size	**% Passing**	**% Passing**	**% Passing**	**% Passing**
5/8" (16mm)	100.0	100.0	100.0	100.0
1/2" (12.5mm)	75.1	100.0	99.6	98.7
3/8" (9.5mm)	26.5	99.0	97.2	95.0
#4 (4.75mm)	2.3	94.9	85.5	81.7
#8 (2.36mm)	1.7	71.8	76.7	66.1
#16 (1.18mm)	1.5	47.1	63.5	41.3
#30 (0.6mm)	1.4	31.0	46.6	15.8
#50 (0.3mm)	1.3	18.8	25.2	6.3
#100 (0.15mm)	1.1	11.9	12.4	3.9
#200 (0.075mm)	0.8	8.9	9.0	3.1

Table 7 Aggregate Gradations for the Superpave Blend

Aggregate Description	Aggregate #	Blend %	Sieve Size	Blend Gradation	Control Points (Superpave)	
					Lower	Upper
Rock	1	33	5/8"	100.0	100	100
Crushed Fines	2	34	1/2"	91.4	90	100
Nat. Fines 1	3	8	3/8"	73.9		
Nat. Fines 2	4	25	#4	60.3		
			#8	47.6	28	58
Sum of % =100			#16	31.9		
			#30	18.7		
			#50	10.4		
Nominal Maximum Size = 1/2 inch			#100	6.4		
			#200	4.8	2	7

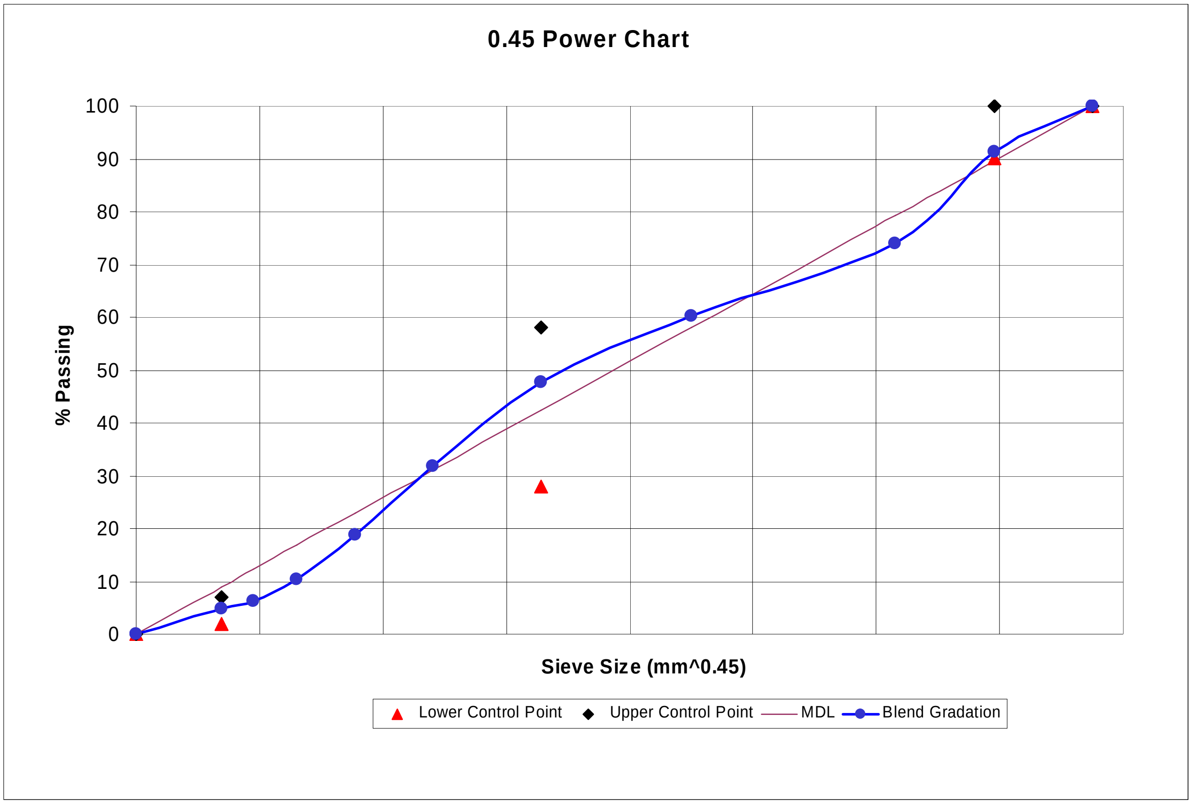

Figure 1 The 0.45 Power Chart for the Aggregate Blend Gradation

LABORATORY MIX DESIGN AND ANALYSIS

Volumetric calculations are the foundation of any good mix design. As with aggregates, it is the specific gravities of materials which define the relationships between mass and the volume it occupies. Air voids, VMA, and voids filled with asphalt (VFA) are the volumetric measurements which are used in mix design calculations (1, 2, *3*). Mass determinations are usually simple and can be done by placing a material on a scale and reading the mass. However, determining volumes can be very difficult. Since the aggregate has surface voids, some of the asphalt fills a portion of these voids. The remainder of the asphalt remains on the surface of the aggregate. This is the asphalt that is available for "sticking" the aggregate together and is referred to as the "effective" asphalt. When the sample is compacted, the total volume will also contain a percentage of air voids (V_a). VMA is the sum of the air voids and the volume of effective asphalt (i.e., the asphalt film). VFA is the volume of the effective asphalt and is expressed as the percent of the VMA which is asphalt. Since specific gravities relate mass to volume, their role in volumetric calculations is very important (*1, 2*).

This research study entailed six mix designs: three Superpave and three Superpave mix designs with the addition of 1% lime (Superpave-L). The aggregate blend used was the same in all the mix designs (Superpave with FAA ≥ 45). The binder grade was also the same in all of the mix designs (PG 58-34). Each set of three mix designs included binders from three different sources: two polymer modified (PM1 and PM2), and one without polymer modification (NPM).

Several measurements and calculations were performed to obtain the various mixtures' volumetric properties. The methods used were consistent with the modified procedures of the NDDOT Field Sampling and Testing Manual. The volumetric results and their specifications are presented in the following subsections.

SUPERPAVE MIX DESIGN RESULTS

Superpave is a mixture design procedure for HMA pavements that was developed from the Strategic Highway Research Program (SHRP) with the potential to simulate the actual conditions in the field such as traffic loading and short term aging of the mix before compaction. The Superpave gyratory compactor (SGC) uses 150 mm molds to allow for larger aggregates, and monitors compaction throughout the process providing a measure of how the mix will compact during construction. The gyratory equipment could also be used for field quality control purposes (1, 2, *3*).

After mixing, short term aging of 2 hours is used to simulate what is happening in the hot mix plant during the mixing, storage and placement operations. Mixing and compaction temperatures are dependent on binder viscosity, especially in the case of polymer modification (2).

Using the measured bulk specific gravity of the final specimen and the recorded change in height during compaction, the change in density (%Gmm) with number of gyrations can be calculated and plotted on a semi-log scale. A smooth sided cylinder is assumed initially and then later corrected based on the measured value for specific gravity.

There are three critical points (Ninitial, Ndesign, and Nmaximum) on the SGC compactor curve that are evaluated in Superpave (*1, 2*). Ninitial is of importance because it is desirable not to have mixes that compact too easily (*2*). Nmaximum is also important to prevent having mixes that continue to compact under traffic loading (*2*). The level of Ndesign is based on the climate and traffic levels (*1, 2*). For this study, Ninitial, Ndesign, and Nmaximum were 7, 75, and 115 gyrations, respectively. These numbers correspond to traffic levels of 0.3 to < 3.0 million ESALs.

The results of the void analysis and mix properties for Superpave and Superpave-L mixes are displayed in the Tables and Figures below. Tables 8 and 9 show the voids analysis for Superpave and Superpave-L mixes at 5.0, 5.5, 6.0, and 6.5 AC contents, respectively. Tables 10 and 11 present the mix properties at the design (optimal) AC for Superpave and Superpave-L, respectively. The terms PM1, PM2, and NPM refer to the mix designs (design cases) that include the corresponding binder. PM1-L, PM2-L, and NPM-L refer to the mix designs (design cases) that include the corresponding binder with the addition of 1% lime. Figure 2 shows the plots of unit weight, air voids, VMA, VFA, % Gmm @ Ninitial, and the theoretical maximum specific gravity versus %AC content for PM1 Superpave mix design. The remainders of the plots are included in Appendix B and Appendix C. Discussion of the analysis results will follow.

Table 8 Voids Analysis of Superpave Mixes @ Ndes for Various Binder Contents

Superpave Mix Designs	**Properties @ Different AC Contents**			
AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
PM1				
Bulk Specific Gravity of the Mix (Gmb)	2.301	2.326	2.366	2.379
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.484	2.462	2.454	2.437
Air Voids, Va (%)	7.3	5.5	3.6	2.4
Voids in Mineral Agg. (VMA)	16.1	15.7	14.7	14.7
Voids in Mineral Agg. Filled (VFA)	54.6	64.9	75.8	83.7
PM2				
Bulk Specific Gravity of the Mix (Gmb)	2.261	2.289	2.301	2.345
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.449	2.429	2.396	2.385
Air Voids, Va (%)	7.7	5.7	4.0	1.7
Voids in Mineral Agg. (VMA)	17.6	17.0	17.0	15.9
Voids in Mineral Agg. Filled (VFA)	56.5	66.3	76.7	89.5
NPM				
Bulk Specific Gravity of the Mix (Gmb)	2.297	2.343	2.379	2.402
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.496	2.490	2.463	2.447
Air Voids, Va (%)	8.0	5.9	3.4	1.9
Voids in Mineral Agg. (VMA)	16.3	15.1	14.2	13.9
Voids in Mineral Agg. Filled (VFA)	51.2	60.9	75.9	86.6

Table 9 Voids Analysis of Superpave-L Mixes @ Ndes for Various Binder Contents

Superpave-L Mix Designs	**Properties @ Different AC Contents**			
AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
PM1-L				
Bulk Specific Gravity of the Mix (Gmb)	2.298	2.325	2.340	2.346
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.484	2.459	2.433	2.420
Air Voids, Va (%)	7.5	5.4	3.8	3.1
Voids in Mineral Agg. (VMA)	16.3	15.7	15.6	15.9
Voids in Mineral Agg. Filled (VFA)	54.1	65.4	75.6	80.7
PM2-L				
Bulk Specific Gravity of the Mix (Gmb)	2.289	2.317	2.359	2.343
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.473	2.453	2.451	2.426
Air Voids, Va (%)	7.4	5.5	3.7	3.4
Voids in Mineral Agg. (VMA)	16.6	16.0	14.9	16.0
Voids in Mineral Agg. Filled (VFA)	55.2	65.4	75.0	78.6
NPM-L				
Bulk Specific Gravity of the Mix (Gmb)	2.296	2.316	2.358	2.343
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.479	2.466	2.451	2.437
Air Voids, Va (%)	7.4	6.1	3.8	3.9
Voids in Mineral Agg. (VMA)	16.3	16.1	15.0	16.0
Voids in Mineral Agg. Filled (VFA)	54.9	62.1	74.7	75.8

Table 10 Mix Properties at Recommended Asphalt Content for Superpave Mixes

Mix Properties	PM1	PM2	NPM	Specification
Optimum AC (%)	5.8	6.0	5.8	
Density (pcf)	147.0	143.6	148.0	
Air Voids (%)	4.0	4.0	4.0	3.0-5.0
VMA (%)	14.7	17.0	14.6	14.0 Min
VFA (%)	73.0	76.7	69.9	65.0-78.0
%Gmm @ Ninitial	87.9	87.8	87.5	89.0 Max
%Gmm @ Nmaximum	95.6	98.5	94.6	98.0 Max
AC Film Thickness (m)	9.5	11.5	9.0	7.5-13.0
Dust/Effective AC Ratio	1.0	0.8	1.1	0.6-1.3
Asphalt Absorption (%)	1.16	0.34	1.43	
Maximum SpG @ Ndes	2.454	2.397	2.462	
Effective (Gme)	2.686	2.630	2.705	

Table 11 Mix Properties at Recommended Asphalt Content for Superpave-Lime

Mix Properties	PM1-L	PM2-L	NPM-L	Specification
Optimum AC (%)	6.0	5.9	5.9	
Density (pcf)	146.0	146.7	146.7	
Air Voids (%)	4.0	4.0	4.0	3.0-5.0
VMA (%)	15.6	15.1	15.2	14.0 Min
VFA (%)	75.0	73.1	72.2	65.0-78.0
%Gmm @ Ninitial	87.5	87.4	86.9	89.0 Max
%Gmm @ Nmaximum	97.4	97.4	97.5	98.0 Max
AC Film Thickness (m)	10.3	10.0	9.8	7.5-13.0
Dust/Effective AC Ratio	0.9	1.0	1.0	0.6-1.3
Asphalt Absorption (%)	0.97	1.01	1.15	
Maximum SpG @ Ndes	2.437	2.449	2.449	
Effective (Gme)	2.673	2.676	2.686	

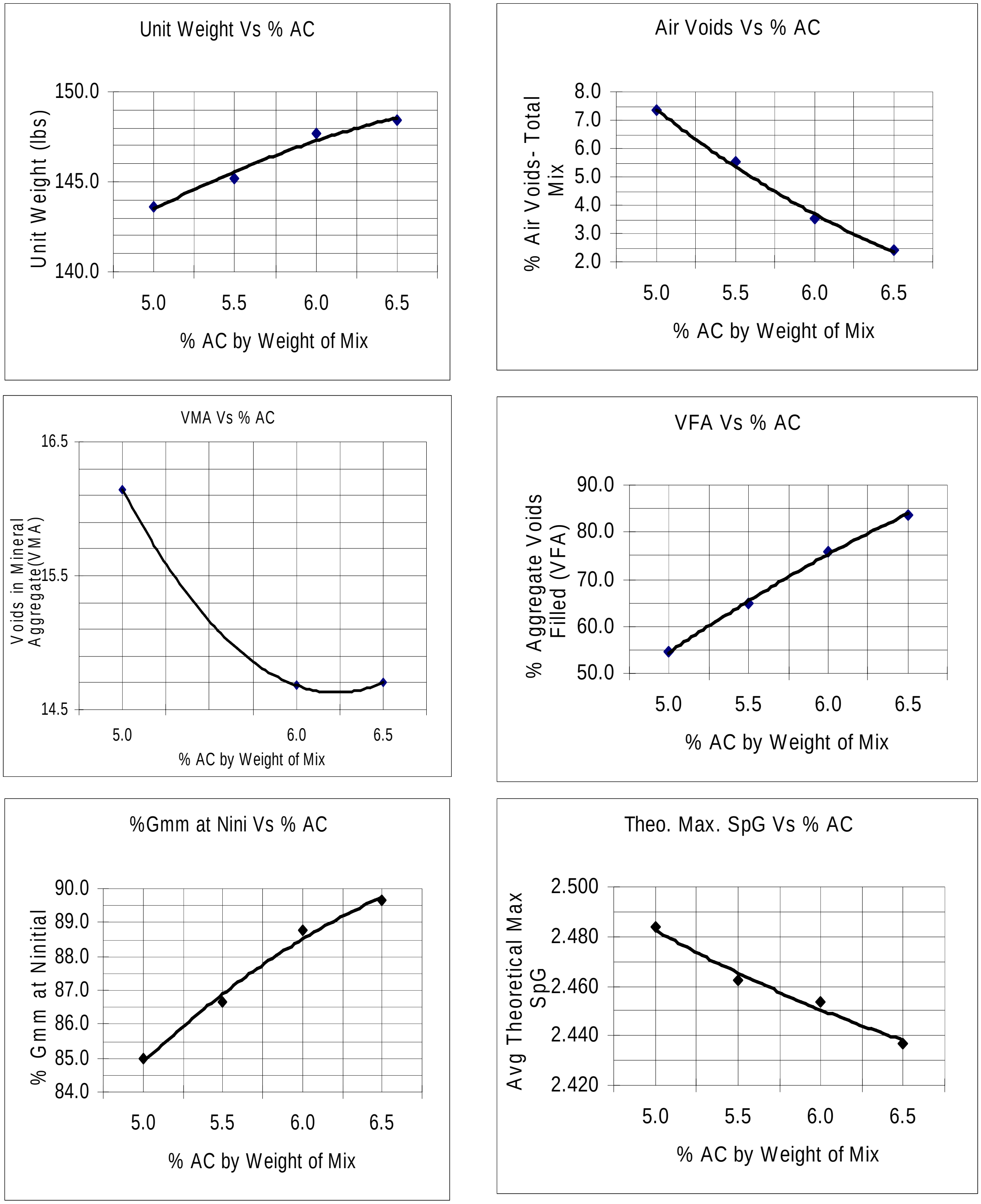

Figure 2 Graphs for PM1 Superpave Mix Design at Various %AC

The design (optimal) %AC content for the Superpave design cases were 5.8%, 6.0%, 5.8% for PM1, PM2, and NPM design cases, respectively. The %AC contents are 6.0%, 5.9%, and 5.9% for PM1-L, PM2-L, and NPM-L, respectively.

The volumetric properties of the HMA were found in accordance with Superpave Volumetric Mix Design (AASHTO M 323). Obviously, the design air voids (4%) for all Superpave mixes meets the specifications for percent air voids. This is important because if the percentage of air voids is low (i.e. less that 3%) the mix will not be stable; while a mix with higher air voids (i.e. greater than 8%) ends up with a water permeable mix that accelerates oxidation and eventually causing moisture damage and loss of pavement life.

Since the VMA is a function of the nominal maximum aggregate size (1/2″ in this study), a minimum of 14% VMA is specified. The results point out that all the Superpave mixes have met the 14% minimum VMA. The mixes are considered stable and that sufficient asphalt binder is available to coat the aggregates properly which is needed for good durability.

The VFA is inversely related to the air voids and the specifications are based on the ESALs of the project being considered. For this study, a traffic level of 0.3 to < 3.0 million ESALs was adopted to represent traffic on North Dakota's Highways. The following formula is used for the VFA calculation:

$$\text{Dust / Effective Asphalt Ratio} = \frac{\text{\% Passing \#200 Sieve}}{P_{be}} \qquad \text{Equation (1)}$$

where: Pbe = effective asphalt content, % mixture basis

The main purpose of the VFA is to limit maximum levels of VMA and subsequently maximum levels of binder content. The VFA specification restricts the allowable air voids content of the HMA that are near the minimum, thus, ensuring sufficient film thickness and consequently good durability. The VFA specification was achieved for all the Superpave mixes.

The Dust/Effective Asphalt Ratio results were within specification limits. Since these calculated values depend on percent passing the #200 sieve (the same in all mixes) and on the effective asphalt contents the dust to effective asphalt ratios are near similar. This ratio is proportional to the air voids in the mixture and aids in the quality of the HMA by producing mastic that is neither very stiff nor very soft.

The Film Thickness was calculated from the following formula:

$$FT = \frac{P_{be}(4885)}{100(SA)}, \qquad \text{Equation (2)}$$

where:

SA = surface area of aggregates passing #4 sieve, and

Pbe = effective asphalt content, % mixture basis

The low value of the specification is designed to ensure sufficient asphalt binder covering the aggregates, thus improving durability. The upper value of the specification is to safeguard from excessive asphalt binder that may drain down or cause bleeding. The results show that all Superpave mixes were with limits of this specification.

The %Gmm @ Nini and Nmax were also within specification limits except for PM2. The %Gmm @ Nini is a measure of consolidation at a low number of gyrations. The specification limit of 89% is specified to ensure that the mix does not compact too easily. Mixes that compact easily are usually tender or unstable. Therefore, this parameter is a performance indicator of the aggregate and binder properties.

The %Gmm @ Nmax specifies the %Gmm (consolidation) at a high number of gyrations. The importance of this parameter is to prevent having mixes that continue to compact under traffic loading. Therefore, this parameter works as a safety factor if traffic levels increase. The %Gmm @ Nmax for PM2 was 98.5% which exceeded the 98.0% specification. This was the only violation of the mix properties.

LABORATORY PERFORMANCE TESTING AND ANALYSIS

Since the Superpave mixture design and analysis system was developed under the Strategic Highway Research Program (SHRP), many highway agencies in the United States have adopted the volumetric mixture design method (*1, 2*). There is no current strength test to compliment the volumetric mixture design method. The addition of a torture test to evaluate the rutting potential of an asphalt mixture would be welcomed by industry and DOT practitioners (*1, 2, 3*).

It has been recognized that the fundamental tests are very complex while simulative tests are relatively easy to perform. The Asphalt Pavement Analyzer, first manufactured in 1996 by Pavement Technology, Inc, is an automated, new generation of Georgia Load Wheel Tester (GLWT). The APA has been used to evaluate rutting, fatigue, and moisture resistance of HMA mixtures (*9, 10, 11*). In this study, testing with the APA was conducted according to 63-03 "Standard Method of Test for Determining Rutting Susceptibility of Asphalt Paving Mixtures," a provisional AASHTO designation with modifications to accommodate NDDOT project requirements (9, 10*, 11, 12, 13, 14, 15*).

In this study, Superpave specimens were tested at 58^{o}C, corresponding with the high temperature of the binder's performance grades. Testing was carried out to 8,000 cycles for dry condition and 25,000 cycles for submerged (wet) condition. Specimens were conditioned in a 58^{o}C water bath for 24 hours before moisture susceptibility testing. All specimens were prepared at 7.0 ± 0.5% air voids to conform to new construction field density conditions.

Moisture susceptibility is an HMA mixture's tendency toward stripping (*2*). Stripping is the loss of bond between the asphalt and aggregate. To combat moisture susceptibility, proper mix design is essential. If a mix is properly designed, but not compacted correctly, it still may be susceptible to moisture damage. An HMA design should be tested in a situation where moisture does infiltrate air voids of the mixture. For this reason many tests are performed at 7% air voids (*2*).

The modified Lottman Test (or TSR) was used to test resistance of compacted bituminous mixtures to moisture induced damage (AASHTO T283) on Marshall specimens at 7.0 ± 0.5% air voids. TSR value of less than 70% is considered to be moisture susceptible.

The NDDOT modified procedure according to Field Sampling and Testing Manual was used for this study. The TSR results were then compared with the APA results.

APA RESULTS AND ANALYSIS

The APA performance results for the Superpave and Superpave-L mix designs are shown in Table 12 and Figure 3 below. The numbers 1 through 72 in Table 12 represent the specimens used for all the design cases. For example, the numbers 1 through 6 represent the specimens used in testing the PM1 design case; where specimens 1 and 2 were placed under the left wheel, specimens 3 and 4 were placed under the center wheel, and specimens 5 and 6 were placed under the right wheel. The values shown represent the rut depth (in mm) under the corresponding wheel of the APA.

Table 12 APA Performance Results for the Various Design Cases

Design Cases	Left Side Depth (mm)		Center Depth (mm)		Right Side Depth (mm)		AVE (mm)
PM1 Dry	1	2	3	4	5	6	**4.183**
	4.106	4.400	3.568	4.081	4.354	4.592	
PM2 Dry	7	8	9	10	11	12	**4.698**
	4.965	4.528	4.607	4.725	4.416	4.945	
NPM Dry	13	14	15	16	17	18	**4.337**
	4.171	4.520	5.026	5.418	3.396	3.492	
PM1-L Dry	19	20	21	22	23	24	**4.200**
	4.411	4.418	3.946	4.427	4.148	3.849	
PM2-L Dry	25	26	27	28	29	30	**4.175**
	4.365	4.068	3.710	4.182	4.325	4.398	
NPM-L Dry	31	32	33	34	35	36	**4.981**
	4.735	5.546	4.913	5.028	4.898	4.768	
PM1 Wet	37	38	39	40	41	42	**5.901**
	5.536	5.375	6.805	7.117	5.669	4.904	
PM2 Wet	43	44	45	46	47	48	**5.723**
	6.221	5.707	5.620	5.212	5.297	6.281	
NPM Wet	49	50	51	52	53	54	**7.137**
	5.585	5.697	8.413	8.960	7.031	7.134	
PM1-L Wet	55	56	57	58	59	60	**5.635**
	5.814	5.750	6.324	5.818	4.854	5.251	
PM2-L Wet	61	62	63	64	65	66	**5.099**
	5.030	5.434	5.021	5.303	4.818	4.989	
NPM-L Wet	67	68	69	70	71	72	**7.027**
	6.777	7.183	7.498	7.864	6.687	6.154	

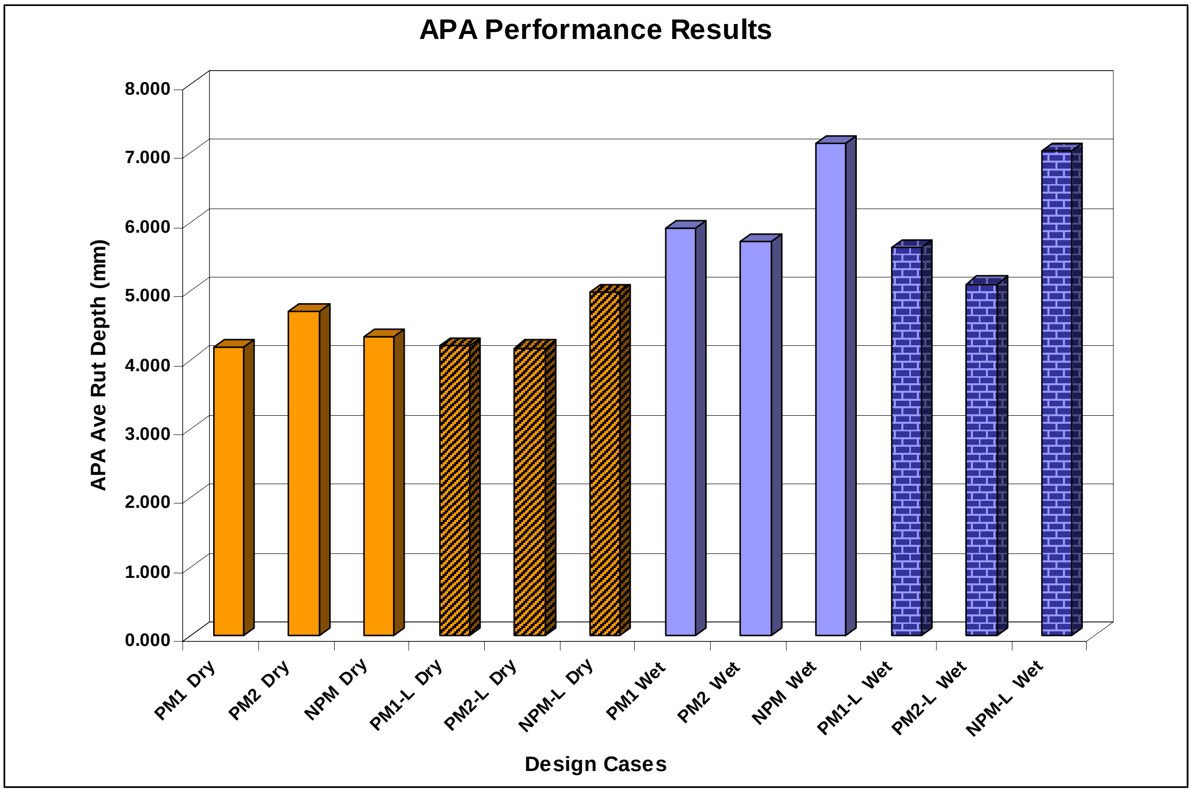

Figure 3 APA Average Performance Results for the Different Design Cases

The Analysis of Variance (ANOVA) statistical analysis was performed on all the APA results, the wet versus dry, and the lime versus no lime subsets. The ANOVA statistical analysis of the APA results is presented in Table 13 below. The null hypothesis is given as, H_o: the means of the results are equal. On the other hand, the alternate hypothesis, H_1: the means of the results are not equal. Rejection of the null hypothesis indicates that the results are significantly different and can be compared.

Observation of the statistical results indicates that the P-value is less than the significance value ($P < 0.05$); therefore, the null hypothesis is rejected. This means that the results within all the subsets of wet versus dry, dry versus dry, and wet versus wet whether with lime or with no lime added are significantly different and can be compared.

Table 13 Analysis of Variance (ANOVA) Statistics on the APA Results

SUMMARY

Groups	Count	Sum	Average	Variance
PM1 Dry	6	25.101	4.1835	0.1276335
PM2 Dry	6	28.186	4.697666667	0.049946267
NPM Dry	6	26.023	4.337166667	0.660766567
PM1-L Dry	6	25.199	4.199833333	0.066798967
PM2-L Dry	6	25.048	4.174666667	0.067210267
NPM-L Dry	6	29.888	4.981333333	0.087766267
PM1 Wet	6	35.406	5.901	0.7507212
PM2 Wet	6	34.338	5.723	0.202566
NPM Wet	6	42.82	7.136666667	1.889010667
PM1-L Wet	6	33.811	5.635166667	0.262178567
PM2-L Wet	6	30.595	5.099166667	0.051149367
NPM-L Wet	6	42.163	7.027166667	0.377394967

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	72.85695494	11	6.62335954	17.30412517	9.3561E-15	1.952212614
Within Groups	22.965713	60	0.382761883			
Total	95.82266794	71				

In comparing the results, the APA performance specification adopted in this study is an average of 7 mm rut depth under the APA wheels (for traffic levels of 0.3 to < 3 million design ESALs). The expression wet here refers to a 24-hour submersion in a 58 ^oC water bath followed by APA testing (also submerged at 58 ^oC). The 58 ^oC was chosen because it is the high temperature of the binder grade (PG 58-34).

The results indicate that each single binder performed better when tested dry rather than wet (or conditioned). The 24-hour conditioning effect can be seen when comparing wet versus dry results.

Traditionally, the addition of lime tends to improve the mix properties when moisture is present (durability), and sometimes the lime stiffens the dry mix. In this study, the results suggest that the addition of lime in Superpave mix design has improved the mix performance in dry and wet samples for the polymer modified cases. For non polymer modified, the addition of lime slightly improved the wet case but was unfavorable in the dry case.

MOISTURE SENSITIVITY RESULTS AND ANALYSIS

AASHTO accepted the Modified Lottman Test (AASHTO T-283) in 1985. It is a combination of the Lottman Test, and the Tunnicliff and Root Test. The AASHTO T-283, as modified by the NDDOT Field Sampling and Testing Manual, was adopted for this study. The specimens were produced using the conventional Marshall Mix Design method. Six specimens were produced with air voids of 7.0 ± 0.5%. The higher percentage of air voids helps to accelerate moisture damage on the cores. Two groups of three specimens were used. The first group is the control group (dry). The second group is vacuum saturated between 70 and 80 percent and is placed in a water bath at 140°F (60°C) for 24 hours. After conditioning, the indirect tensile strength (ITS) test was performed. The ITS Test was performed on both the dry and conditioned specimen sets at 77°F (25°C) with a loading rate of 2 in/min. The minimum acceptable TSR used is 70%.

The moisture sensitivity test results for each mix design case are shown in Table 14 and graphically plotted in Figures 4 and 5. The wet and dry strengths are given in pounds per square inch (psi) units, and the TSR values are in percentage (%).

All mix designs passed the TSR metric of 70%. The addition of lime has improved all the mix design cases (PM1, PM2, and NPM) by 12%, 2%, and 7%, respectively. The wet strength of the PM1, PM2, and NPM cases were influenced by the addition of lime by 8%, 3%, and 15%. The dry strengths of the same designs have also been affected by the addition of lime by -3%, 1%, and 7%, respectively.

Generally, TSR values have improved in all the cases with varying degree of increase. The wet strength has also improved with the addition of lime, but the dry strength produced mixed results.

Table 14 Moisture Sensitivity Test Results

Date	Binder	Wet Strength (psi)	Dry Strength (psi)	TSR (%)
30-May	PM1	69.5	88.0	79.0
30-May	PM2	55.0	62.5	87.9
30-Jun	NPM	55.7	66.4	83.9
8-Jun	PM1-L	75.2	85.4	88.1
30-May	PM2-L	56.8	63.1	90.0
30-May	NPM-L	64.1	71.1	90.1

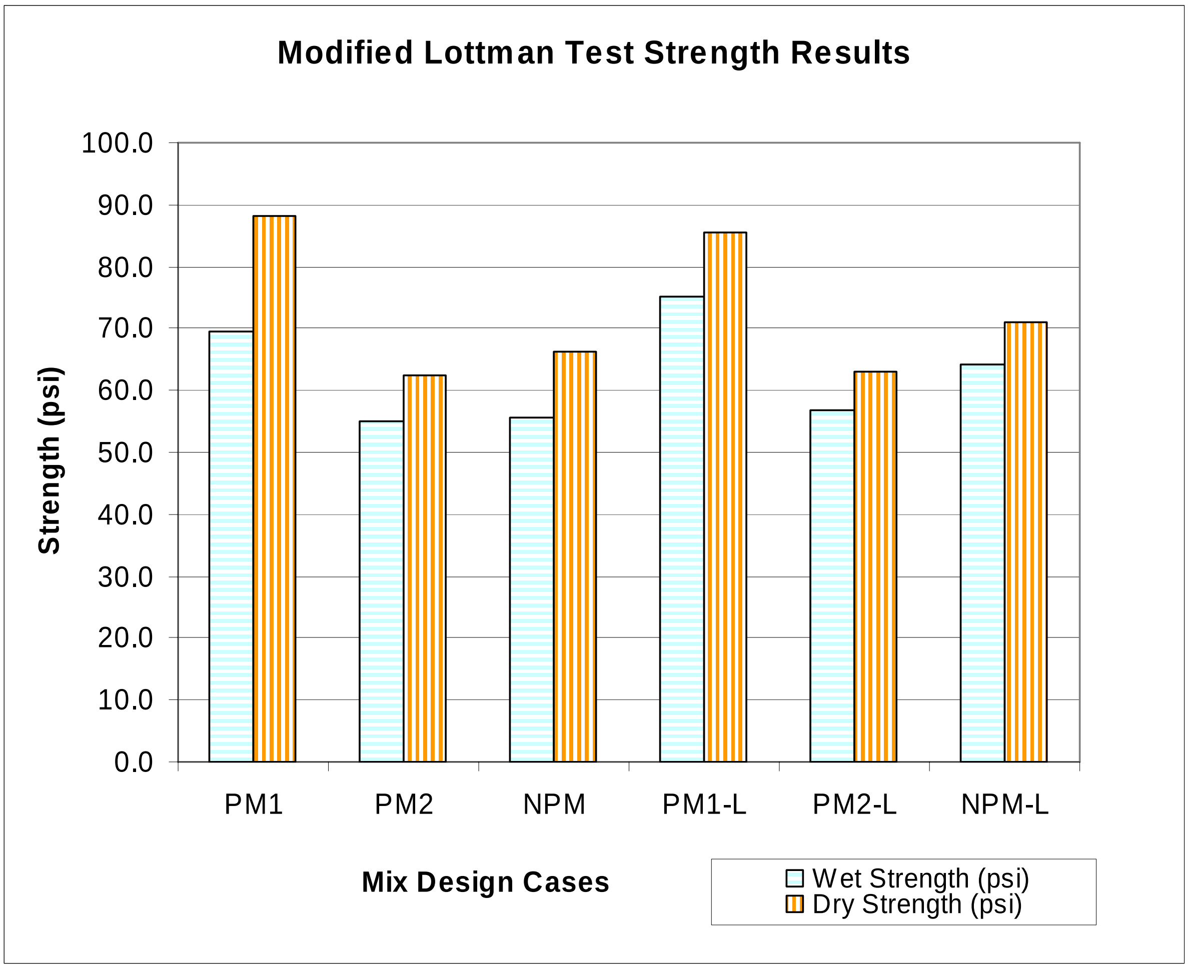

Figure 4 Moisture Sensitivity Strength Results

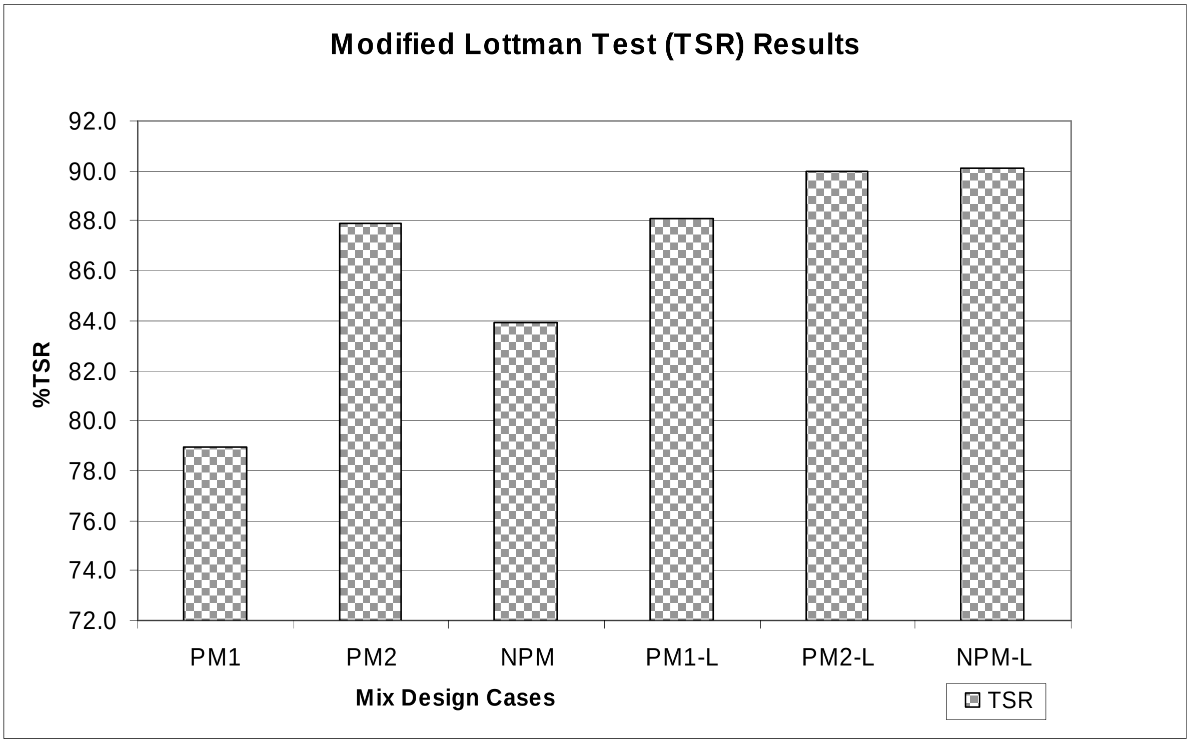

Figure 5 Moisture Sensitivity Test (TSR) Results

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Several laboratory tests, data analysis, and result comparisons were carried out to complete this research study. First, the aggregate and the binders were selected. The aggregate was obtained from Valley City District project and considered constant for all mix designs. The asphalt binders were obtained from field tanks and provided by the NDDOT. The binder types included two polymer modified (PM1 and PM2) and one non polymer modified (NPM) asphalt binders.

Second, the aggregate and binder properties were tested. Aggregates consensus and source properties were within specification limits for Superpave blends. Binder properties also conformed to the PG binder specifications.

Third, mix designs were conducted and tested, and then volumetric properties were calculated and analyzed. Three Superpave mix designs were established based on the three binder types. Three Superpave-L mix designs were also conducted from the same binders and the addition of 1% lime. Volumetric properties suggest that all mix designs were within their prospected specifications. The importance of key properties was discussed.

Fourth, the APA was used to test the performance of the Superpave mixes, while moisture sensitivity was used to test the performance of the Marshall mixes. Statistical analysis was performed on the APA results and found that the data results were significantly different and can be compared. A 7 mm depth specification was adopted for this study (*9*).

Observation of the APA results indicates that dry samples performed better than wet samples. The addition of lime in the Superpave mix design has improved the mix performance in wet samples. In dry samples, the effect of lime on the mix was not conclusive with little or no improvement in the polymer modified and non polymer modified cases. The HMA that contained polymer modified binder outperformed the one without polymer modification in all the design cases. Examining and comparing the polymer modified cases shows that PM1 slightly outperforms PM2 in dry cases (with or without lime) while PM2 outperforms PM1 design cases in wet conditions (with or without lime). Generally all the design cases pass the 7 mm specification. The wet NPM design cases lie slightly above or below the specification.

Inspection of the moisture sensitivity test results indicate that all the mix design cases have passed the TSR metric of 70%. The TSR values have improved with the addition of lime in all the design cases with varying degrees. The wet strength has also improved with the addition of lime, but the dry strength produced mixed results.

The HMA with a non polymer modified binder has generally performed well according to the APA depth metric and moisture sensitivity results. The PI does not recommend precluding their use based on this study. However, the HMA with polymer modification has outperformed the one with non modified binder.

The results of this study indicate that the addition of a small percentage of lime does help the mix against moisture damage. Attention should be made so that the %Gmm @ Nmax must not exceed 98%. Accounting for the lime as part of the dust in the aggregate blend could be more appropriate. Further experimentation with lime is needed to determine the strength gain as the lime is allowed to cure.

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APPENDECIES

APPENDIX A

Aggregates Properties and Gradations

A-1 General Information – Aggregate / Superpave

GENERAL INFORMATION and AGGREGATE GRADATIONS/BLEND

SUPERPAVE MIX DESIGN

Department of Transportation, Materials and Research (Rev. 7-04)

GENERAL INFORMATION

Enter data in shaded boxes.
Absent sieve calculator is at the bottom of the sheet.

Project:	NDDOT Phase 1	Pit #1 Location:	E 1/2 27-138-64
		Pit #2 Location:	
Location:	UND	Pit #3 Location:	
District:		Pit Owner(s):	Richard Klose
County:			
Date (MM/DD/YY):	3/4/05		
		AC Specific Gravity:	1.03
Lab Number:		Project Spec (408 or 409)	410 Superpave
Type of AC (Top Lift):	PG 58-34	Length of Project:	
Type of AC (Bot. Lift):	PG 58-34	Asphalt Supplier:	Cenex
Letting Date:	11/21/03	Contractor:	

INDIVIDUAL AGGREGATE GRADATIONS

	Agg #1	Agg #2	Agg #3	Agg #4	Agg #5	Agg #6
Aggregate---> Description-->	Rock	Crushed Fines	Nat. Fines 1	Nat. Fines 2		
If Agg. is Crushed, Enter 1	1	1	0	0		
Sieve Size	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing
5/8" (16mm)	100.0	100.0	100.0	100.0		
1/2" (12.5mm)	75.1	100.0	99.6	98.7		
3/8" (9.5mm)	26.5	99.0	97.2	95.0		
#4 (4.75mm)	2.3	94.9	85.5	81.7		
#8 (2.36mm)	1.7	71.8	76.7	66.1		
#16 (1.18mm)	1.5	47.1	63.5	41.3		
#30 (0.6mm)	1.4	31.0	46.6	15.8		
#50 (0.3mm)	1.3	18.8	25.2	6.3		
#100 (0.15mm)	1.1	11.9	12.4	3.9		
#200 (0.075mm)	0.8	8.9	9.0	3.1		

BLEND GRADATION

Aggregate Description	Aggregate #	Blend %	Sieve Size	Blend Gradation	Lower Control Pt	Upper Control Pt
Rock	1	33	5/8"	100.0	100	100
Crushed Fines	2	34	1/2"	91.4	90	100
Nat. Fines 1	3	8	3/8"	73.9		
Nat. Fines 2	4	25	#4	60.3		
	5		#8	47.6	28	58
	6		#16	31.9		
	Sum of % =	100	#30	18.7		
			#50	10.4		
			#100	6.4		
			#200	4.8	2	7

% Fine Aggregate Mechanically Produced (Fractured) : 54.8
% Coarse Aggregate Mechanically Produced (Fractured) : 85.6

A-1 General Information – Aggregate / Superpave - Contiued

% PASSING FOR ABSENT SIEVES

Fill in sieve size with metric equivalent and the % passing from the sieves larger and smaller then the absent sieve.

	Sieve Size(m)	% Passing
Largest sieve w/data		
Smallest sieve w/data		
Target sieve size		

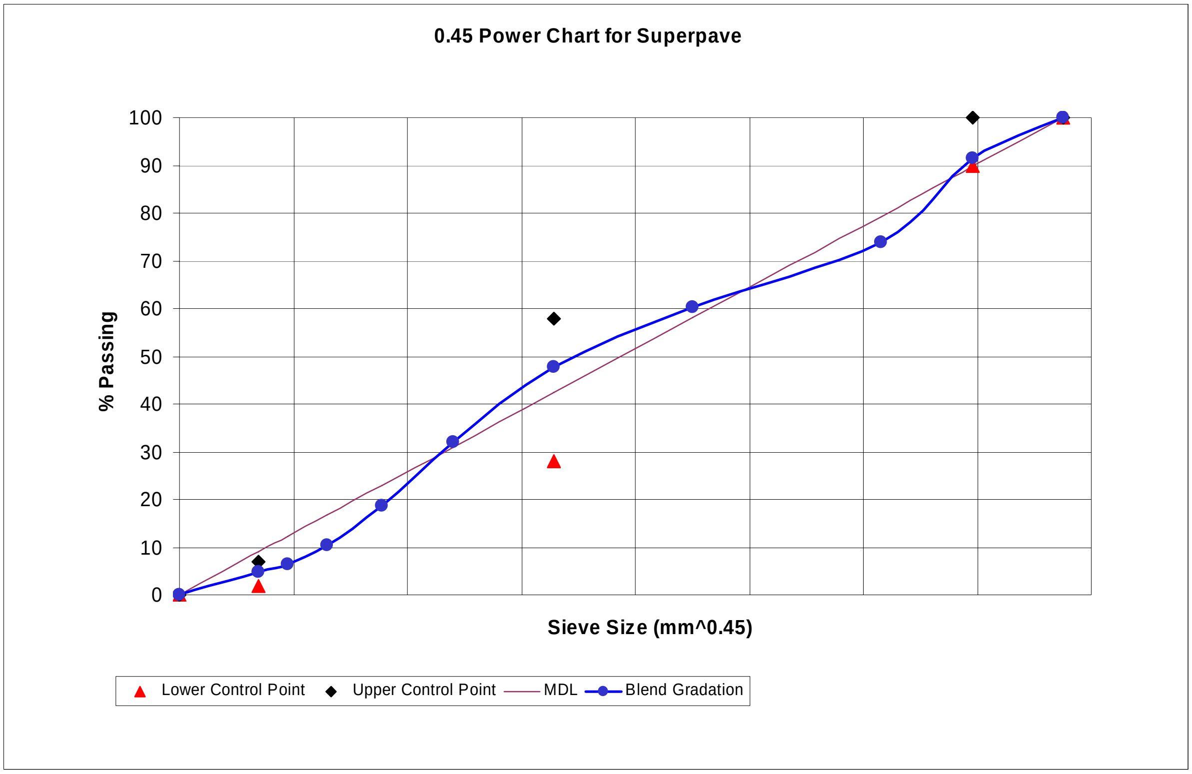
Power chart: 0.45

Percent Passing Absent Sieve: #DIV/0!

Sieve Sizes

Standard	Metric Equivalent
5/8"	0.0159
1/2"	0.0125
3/8"	0.0095
#4	0.004750
#8	0.002360
#16	0.001180
#30	0.000600
#50	0.000300
#100	0.000150
#200	0.000075

A-2 0.45 Power Chart / Superpave



A-3 Aggregate Properties / Superpave

AGGREGATE PROPERTIES NDDOT Phase

SUPERPAVE MIX DESIGN

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

AGGREGATE PROPERTIES

	Agg #1 Rock	Agg #2 Crushed Fines	Agg #3 Nat. Fines 1	Agg #4 Nat. Fines 2
Bulk SpG (Gsb)				
Coarse	2.628	2.628	2.628	2.628
Fine	2.631	2.631	2.572	2.543
Apparent SpG (Gsa)				
Coarse	2.774	2.774	2.774	2.774
Fine	2.771	2.771	2.733	2.736
Water Absorption				
Coarse	2.000	2.000	2.000	2.000
Fine	1.920	1.920	2.280	2.770
Combined				
Bulk SpG (Gsb)	2.628	2.631	2.580	2.558
Apparent SpG (Gsa)	2.774	2.771	2.739	2.743
Water Absorption	1.998	1.924	2.235	2.588

Aggregate Blend Properties	Bulk SpG (Gsb) =	2.607
	Apparent SpG (Gsa)=	2.762
	Water Absorption =	2.108

SUPERPAVE CONSENSUS AGGREGATE PROPERTIES

	Agg #1 Rock	Agg #2 Crushed Fines	Agg #3 Nat. Fines 1	Agg #4 Nat. Fines 2
Fine Agg. Angularity				
% FAA	47.4	47.4	40.9	42.8
Clay Content				
% Sand Equivalent	71	71	37	47

Coarse Aggregate Angularity (+ No. 4 Material)

Nominal maximum Size	Sample Size
3/8" (9.5 mm)	200 g
½" (12.5 mm)	500 g
3/4" (19 mm)	1500 g

Wt. of Total Sample =	740.7
Wt. of Fractured Material =	740.7
Wt. of Questionable Material =	0
Wt. of Uncrushed Material =	0

Flat and Elongated Particles

Nominal maximum Size	Sample Size
3/8" (9.5 mm)	1000 g
½" (12.5 mm)	2000 g
3/4" (19 mm)	5000 g

Wt. of Total Sample =	5379.3
Wt. of Material Larger then 3/8" =	212.8
Wt. of Flat and Elongated Particles =	2.3

Superpave Consensus Aggregate Properties	Fine Agg. Angularity % =	45.1
	Sand Equivalent % =	59.0
	Coarse Agg. Angularity % =	100.0
	Thin & Elongated Pieces % =	1.1

A-4 Batch Weights / Superpave

Batch Weights NDDOT Phase 1

Superpave Mix Design

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

MIX DESIGN BATCH WEIGHTS

	Batch 1	Batch 2	Batch 3	Batch 4
AC Contents Used in Mix Design (%):	5.0	5.5	6.0	6.5

Aggregate Wt per Batch (g):	4500
# of AC Percentages used in Design:	4

Batch Weights

	Agg #1	Agg #2	Agg #3	Agg #4	Agg #5
	Rock	Crushed Fines	Nat. Fines 1	Nat. Fines 2	
Tot./Batch (g)	1485	1530	360	1125	0
COURSE					
+3/8 Material	1091.5	15.3	10.1	56.3	0.0
-3/8, +#4 Material	359.4	62.7	42.1	149.6	0.0
-#4 Material	34.2	1452.0	307.8	919.1	0.0

AC and Total Batch Weight

AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
Weight AC (g)	236.8	261.9	287.2	312.8
Total Batch Wt (g)	4736.8	4761.9	4787.2	4812.8

APPENDIX B

Superpave Mix Design

B-1 Summary Sheet for PM1 Superpave Mix Design

HOT MIX DESIGN DATA - SUPERPAVE

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Lab. No.			
Location	UND	Project Specification	410 Superpave
Project	NDDOT Phase 1	Type of AC (top lift)	PG 58-34
		Type of AC (bot lift)	PG 58-34
District		Letting Date	11/21/03
County		Plus #4 (%)	39.7
Date	3/4/2005 0:00	Minus #4 (%)	60.3
Pit Owner(s)	Richard Klose		
		Gyratory Compactive Effort	
Pit #1 Location	E 1/2 27-138-64	Ninitial	7
Pit #2 Location		Ndesign	75
Pit #3 Location		Nmaximum	115

Mix Properties at Recommended Asphalt Content

	Mix Design	Specification
Optimum AC (%)	5.8	
Density (pcf)	147.0	
Air Voids (%)	4.0	3.0-5.0
VMA (%)	14.7	14.0 Min
VFA (%)	73.0	65-78
%Gmm @ Ninitial	87.9	89 Max
%Gmm @ Nmaximum	95.6	98Max
AC Film Thickness (m)	9.5	7.5-13
Dust/Effective AC Ratio	1.0	0.6-1.3
Fine Agg Angularity (%)	45.1	45 Min
Sand Equivalent (%)	59.0	40 Min
Coarse Agg Angularity (%)	100.0	75 Min
Flat/Elongated Pieces (%)	1.1	10 Max
Maximum SpG @ Ndes	2.454	
Frac. Faces Fine (%)	54.8	
Frac. Faces Course (%)	85.6	

Summary of Aggregate Characteristics from Mix Design

Gradation (% passing)	
5/8"	100.0
1/2"	91.4
3/8"	73.9
#4	60.3
#8	47.6
#16	31.9
#30	18.7
#50	10.4
#100	6.4
#200	4.8

Asphalt Absorption (%)	1.16
Water Absorption (%)	2.11
Light Wt Particles (%)	1.1
Toughness (% Loss)	22.6

Final Aggregate Blend (%)

33	Rock
34	Crushed Fines
8	Nat. Fines 1
25	Nat. Fines 2

Specific Gravity Information

Bulk (Gsb)	2.607
Apparent (Gsa)	2.762
Effective (Gme)	2.686

Remarks:

Aggregate properties from project NH-2-281(025)049

Polymer Modified (PM1) mix design

Distribution:

Materials and Research

0

B-2 Mix Data for PM1 Superpave Mix Design

SUPERPAVE MIX DESIGN DATA

NDDOT Phase 1

Department of Transportation, Materials and Research (Rev. 7-04)

3/4/05

Bulk Specific Gravity of the Mix (Gmb) @ Ndes

%AC Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.0						
A	4675.7	4708.8	2668.5	2040.3	2.292	143.0
B	4634.2	4649.5	2644.3	2005.2	2.311	144.2
			Average =	**2022.8**	**2.301**	**143.6**
5.5						
A	4762.2	4773.0	2730.3	2042.7	2.331	145.5
B	4823.5	4837.7	2760.1	2077.6	2.322	144.9
			Average =	**2060.2**	**2.326**	**145.2**
6.0						
A	4758.7	4761.9	2757.1	2004.8	2.374	148.1
B	4711.6	4718.6	2721.6	1997.0	2.359	147.2
			Average =	**2000.9**	**2.366**	**147.7**
6.5						
A	4840.6	4842.3	2816.3	2026.0	2.389	149.1
B	4794.3	4796.4	2771.8	2024.6	2.368	147.8
			Average =	**2025.3**	**2.379**	**148.4**

Rice Test: Theoretical Maximum SpG of the Mix (Gmm) @ Ndes

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Flask Number	1	2	1	2	1	2	1	2
Samp., Cont. & Sol.	3926.5	3925.3	3917.7	3922.9	3919.4	3938.1	3920.7	3920.2
Cont. & Sol. (g)	3274.6	3275.1	3274.6	3275.1	3274.6	3275.1	3274.6	3275.1
Samp. in Air (g)	1091.1	1088.7	1084.0	1089.8	1090.0	1117.4	1096.4	1093.3
Samp. in Sol. (g)	651.9	650.2	643.1	647.8	644.8	663	646.1	645.1
Vol. of Voidless Mix	439.2	438.5	440.9	442	445.2	454.4	450.3	448.2
Theoretical Max. SpG	2.484	2.483	2.459	2.466	2.448	2.459	2.435	2.439
Difference Between Flasks	0.002 In Tolerance		0.007 In Tolerance		0.011 In Tolerance		0.004 In Tolerance	
Avg Theor. Max. SpG	2.484		2.462		2.454		2.437	
Effective SpG	2.683		2.679		2.691		2.693	
Effective SpG (each plug)	**2.684**	**2.682**	**2.675**	**2.683**	**2.684**	**2.698**	**2.690**	**2.696**
AC Absorption	1.1		1.1		1.2		1.3	

Avg Effective SpG: 2.686

Voids Analysis of the Mix @ Ndes

AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
Bulk Specific Gravity of the Mix (Gmb)	2.301	2.326	2.366	2.379
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.484	2.462	2.454	2.437
Air Voids, Va (%)	7.3	5.5	3.6	2.4
Voids in Mineral Agg. (VMA)	16.1	15.7	14.7	14.7
Voids in Mineral Agg. Filled (VFA)	54.6	64.9	75.8	83.7
Asphalt Absorption (%)	1.16			

B-3 Gyratory Data for PM1 Superpave Mix Design

SUPERPAVE MIX DESIGN NDDOT Phase 1

Gyratory Compactor Information

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Superpave Gyratory Compaction Effort

Number of Gyrations @ Ninitial:	7
Number of Gyrations @ Ndesign:	75
Number of Gyrations @ Nmaximum:	115

Gyratory Plugs Compacted to Ninital and Ndesign

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Plug Number	1	2	1	2	1	2	1	2
Plug Weight (g)	4675.7	4634.2	4762.2	4823.5	4758.7	4711.6	4840.6	4794.3
Plug Height @ Nini (mm)	127.7	126.0	128.3	130.2	124.9	125.0	126.1	127.1
Plug Height @ Ndes (mm)	117.0	115.6	117.6	119.4	115.1	114.9	116.3	116.3
% Gmm initial	84.9	85.0	86.6	86.7	88.9	88.7	90.0	89.3
Avg. % Gmm initial	85.0		86.6		88.8		89.7	

Gyratory Plugs Compacted to Nmaximum at Design Optimum Asphalt Content

%AC @ Optimum Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.8						
A	4805.4	4810.4	2773.0	2037.4	2.359	147.2
B	4663.6	4670.9	2671.7	1999.2	2.333	145.6
			Average =	**2018.3**	**2.346**	**146.4**

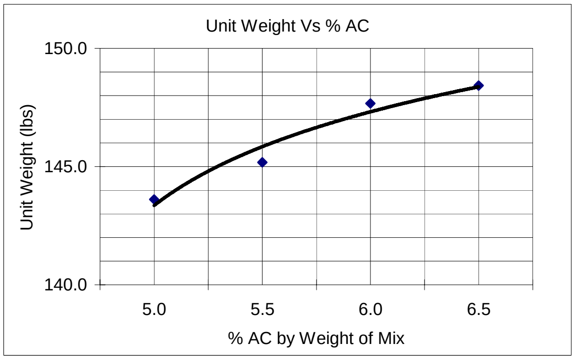
%Gmm at Nmaximum = 95.6

B-4 Graphs for PM1 Superpave Mix Design

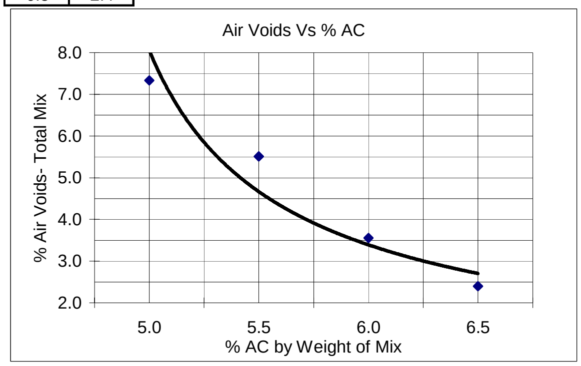
SUPERPAVE HOT MIX DESIGN GRAPHS **NDDOT Phase 1** **3/4/05**

Department of Transportation, Materials and Research (Rev. 7-04)

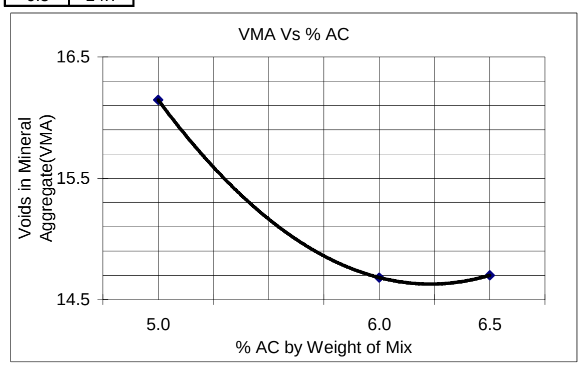
AC%	UNIT WT.
5.0	143.6
5.5	145.2
6.0	147.7
6.5	148.4



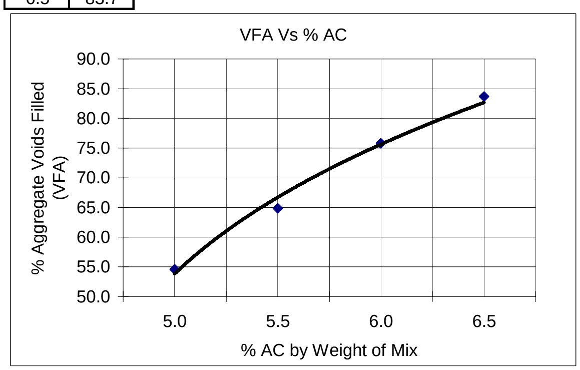
AC%	Air Voids
5.0	7.3
5.5	5.5
6.0	3.6
6.5	2.4



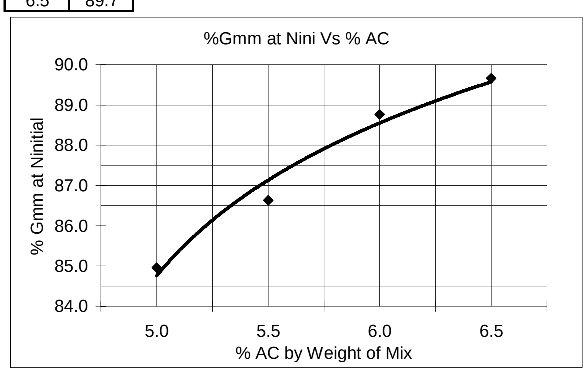
AC%	VMA
5.0	16.1
6.0	14.7
6.5	14.7



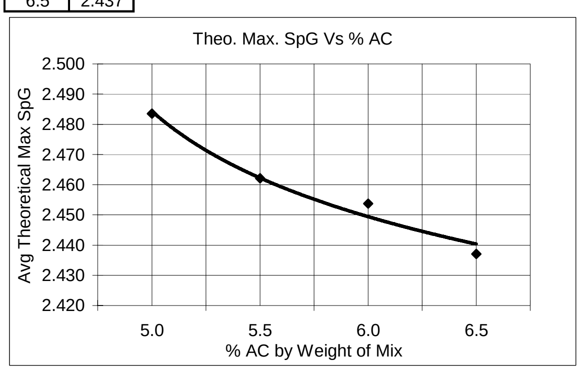
AC%	VFA
5.0	54.6
5.5	64.9
6.0	75.8
6.5	83.7



AC%	%Gmm
5.0	85.0
5.5	86.6
6.0	88.8
6.5	89.7



AC%	Max SpG
5.0	2.484
5.5	2.462
6.0	2.454
6.5	2.437



B-5 Summary Sheet for PM2 Superpave Mix Design

HOT MIX DESIGN DATA - SUPERPAVE

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Lab. No.	1
Location	UND
Project	NDDOT Phase 1
District	
County	
Date	3/4/2005 0:00
Pit Owner(s)	Richard Klose
Pit #1 Location	E 1/2 27-138-64
Pit #2 Location	
Pit #3 Location	

Project Specification	410 Superpave
Type of AC (top lift)	PG 58-34
Type of AC (bot lift)	PG 58-34
Letting Date	11/21/03
Plus #4 (%)	39.7
Minus #4 (%)	60.3

Gyratory Compactive Effort

Ninitial	7
Ndesign	75
Nmaximum	115

Mix Properties at Recommended Asphalt Content

	Mix Design	Specification
Optimum AC (%)	6.0	
Density (pcf)	143.6	
Air Voids (%)	4.0	3.0-5.0
VMA (%)	17.0	14.0 Min
VFA (%)	76.7	65-78
%Gmm @ Ninitial	87.8	89 Max
%Gmm @ Nmaximum	98.5	98Max
AC Film Thickness (m)	11.5	7.5-13
Dust/Effective AC Ratio	0.8	0.6-1.3
Fine Agg Angularity (%)	45.1	45 Min
Sand Equivalent (%)	59.0	40 Min
Coarse Agg Angularity (%)	100.0	75 Min
Flat/Elongated Pieces (%)	1.1	10 Max
Maximum SpG @ Ndes	2.397	
Frac. Faces Fine (%)	54.8	
Frac. Faces Course (%)	85.6	

Summary of Aggregate Characteristics from Mix Design

Gradation (% passing)	
5/8"	100.0
1/2"	91.4
3/8"	73.9
#4	60.3
#8	47.6
#16	31.9
#30	18.7
#50	10.4
#100	6.4
#200	4.8

Asphalt Absorption (%)	0.34
Water Absorption (%)	2.11
Light Wt Particles (%)	1.1
Toughness (% Loss)	22.6

Final Aggregate Blend (%)

33	Rock
34	Crushed Fines
8	Nat. Fines 1
25	Nat. Fines 2

Specific Gravity Information

Bulk (Gsb)	2.607
Apparent (Gsa)	2.762
Effective (Gme)	2.630

Remarks:

Aggregate properties from project NH-2-281(025)049

PM2 mix design (all points redone)

B-6 Mix Data for PM2 Superpave Mix Design

SUPERPAVE MIX DESIGN DATA NDDOT Phase 1

Department of Transportation, Materials and Research (Rev. 7-04)

Bulk Specific Gravity of the Mix (Gmb) @ Ndes

%AC Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.0						
A	4728.0	4753.3	2671.0	2082.3	2.271	141.7
B	4727.3	4762.1	2661.5	2100.6	2.250	140.4
			Average =	**2091.5**	**2.261**	**141.1**
5.5						
A	4765.7	4788.7	2706.4	2082.3	2.289	142.8
B	4726.0	4745.8	2681.5	2064.3	2.289	142.9
			Average =	**2073.3**	**2.289**	**142.8**
6.0						
A	4746.2	4758.9	2698.2	2060.7	2.303	143.7
B	4736.3	4748.8	2688.5	2060.3	2.299	143.4
			Average =	**2060.5**	**2.301**	**143.6**
6.5						
A	4796.9	4802.9	2745.7	2057.2	2.332	145.5
B	4791.9	4799.6	2768.0	2031.6	2.359	147.2
			Average =	**2044.4**	**2.345**	**146.3**

Rice Test: Theoretical Maximum SpG of the Mix (Gmm) @ Ndes

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Flask Number	1	2	1	2	1	2	1	2
Samp., Cont. & Sol.	3962.1	3977.0	8215.5	8128.5	8178.5	8173.7	3905.3	3904.5
Cont. & Sol. (g)	3274.6	3275.1	7556.8	7558.8	7556.8	7558.8	3274.6	3275.1
Samp. in Air (g)	1161.7	1186.9	1120.3	968.0	1066.9	1055.3	1085.8	1084.2
Samp. in Sol. (g)	687.5	701.9	658.7	569.7	621.7	614.9	630.7	629.4
Vol. of Voidless Mix	474.2	485	461.6	398.3	445.2	440.4	455.1	454.8
Theoretical Max. SpG	2.450	2.447	2.427	2.430	2.396	2.396	2.386	2.384
Difference Between Flasks	0.003 In Tolerance		0.003 In Tolerance		0.000 In Tolerance		0.002 In Tolerance	
Avg Theor. Max. SpG	2.449		2.429		2.396		2.385	
Effective SpG	2.640		2.637		2.618		2.625	
AC Absorption	0.5		0.4		0.2		0.3	

Avg Effective SpG: 2.630

Voids Analysis of the Mix @ Ndes

AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
Bulk Specific Gravity of the Mix (Gmb)	2.261	2.289	2.301	2.345
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.449	2.429	2.396	2.385
Air Voids, Va (%)	7.7	5.7	4.0	1.7
Voids in Mineral Agg. (VMA)	17.6	17.0	17.0	15.9
Voids in Mineral Agg. Filled (VFA)	56.5	66.3	76.7	89.5
Asphalt Absorption (%)	0.34			

B-7 Gyratory Data for PM2 Superpave Mix Design

SUPERPAVE MIX DESIGN NDDOT Phase 1

Gyratory Compactor Information

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Superpave Gyratory Compaction Effort

Number of Gyrations @ Ninitial:	7
Number of Gyrations @ Ndesign:	75
Number of Gyrations @ Nmaximum:	115

Gyratory Plugs Compacted to Ninital and Ndesign

	AC % =	5.0	AC % =	5.5	AC % =	6.0	AC % =	6.5
Plug Number	1	2	1	2	1	2	1	2
Plug Weight (g)	4728.0	4727.3	4765.7	4726.0	4746.2	4736.3	4796.9	4791.9
Plug Height @ Nini (mm)	131.7	132.5	130.2	127.7	127.9	129.8	129.2	127.1
Plug Height @ Ndes (mm)	120.1	121.0	119.4	117.3	116.9	118.6	118.0	116.3
% Gmm initial	84.2	84.3	86.4	86.6	87.8	87.7	89.8	90.0
Avg. % Gmm initial	84.3		86.5		87.8		89.9	

Gyratory Plugs Compacted to Nmaximum at Design Optimum Asphalt Content

%AC @ Optimum Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
6.0						
A	4772.4	4776.3	2750.3	2026.0	2.356	147.0
B	4794.8	4797.5	2769.9	2027.6	2.365	147.6
			Average =	**2026.8**	**2.360**	**147.3**

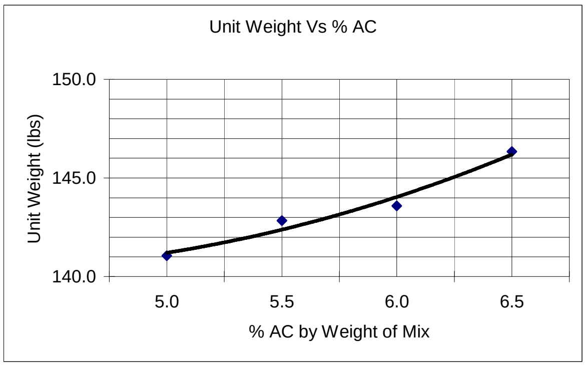
%Gmm at Nmaximum = 98.5

B-8 Graphs for PM2 Superpave Mix Design

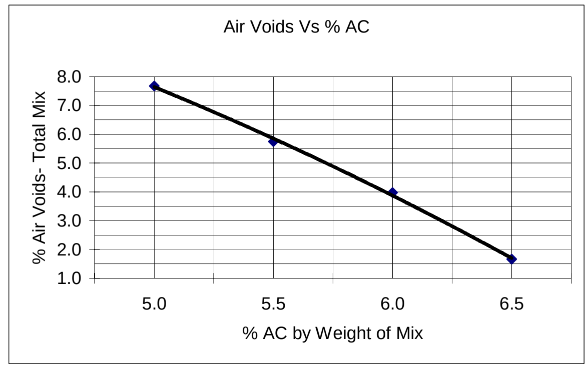
SUPERPAVE HOT MIX DESIGN GRAPHS **NDDOT Phase 1** **3/4/05**

Department of Transportation, Materials and Research (Rev. 7-04)

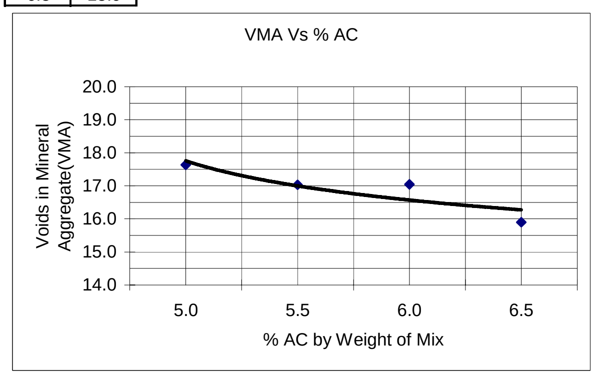
AC%	UNIT WT.
5.0	141.1
5.5	142.8
6.0	143.6
6.5	146.3



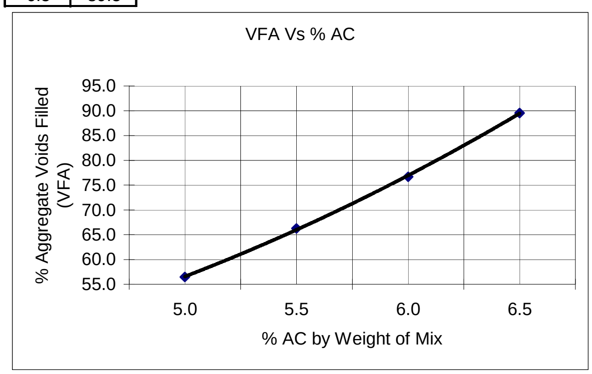
AC%	Air Voids
5.0	7.7
5.5	5.7
6.0	4.0
6.5	1.7



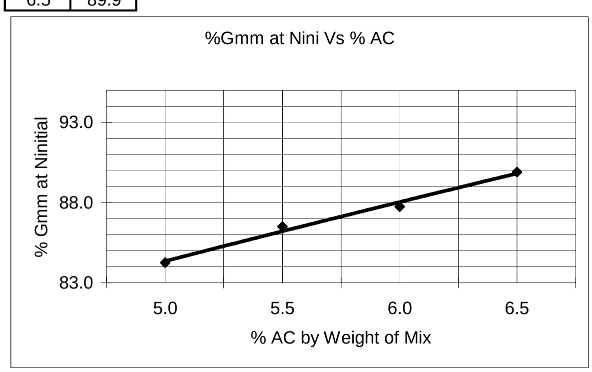
AC%	VMA
5.0	17.6
5.5	17.0
6.0	17.0
6.5	15.9



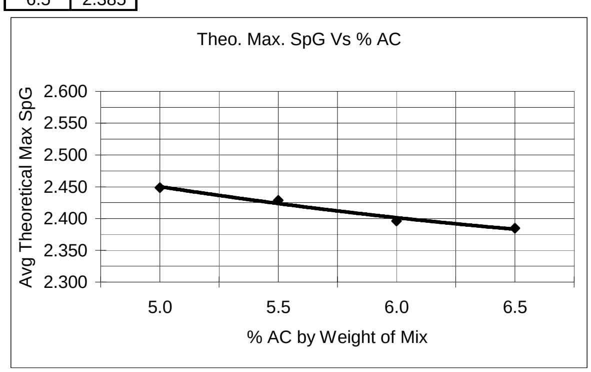
AC%	VFA
5.0	56.5
5.5	66.3
6.0	76.7
6.5	89.5



AC%	%Gmm
5.0	84.3
5.5	86.5
6.0	87.8
6.5	89.9



AC%	Max SpG
5.0	2.449
5.5	2.429
6.0	2.396
6.5	2.385



B-9 Summary Sheet for NPM Superpave Mix Design

HOT MIX DESIGN DATA - SUPERPAVE

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Lab. No.	1		
Location	UND	Project Specification	410 Superpave
Project	NDDOT Phase 1	Type of AC (top lift)	PG 58-34
		Type of AC (bot lift)	PG 58-34
District		Letting Date	11/21/03
County		Plus #4 (%)	39.7
Date	3/4/2005 0:00	Minus #4 (%)	60.3
Pit Owner(s)	Richard Klose		
		Gyratory Compactive Effort	
Pit #1 Location	E 1/2 27-138-64	Ninitial	7
Pit #2 Location		Ndesign	75
Pit #3 Location		Nmaximum	115

Mix Properties at Recommended Asphalt Content

	Mix Design	Specification
Optimum AC (%)	5.8	
Density (pcf)	148.0	
Air Voids (%)	4.0	3.0-5.0
VMA (%)	14.6	14.0 Min
VFA (%)	69.9	65-78
%Gmm @ Ninitial	87.5	89 Max
%Gmm @ Nmaximum	94.3	98Max
AC Film Thickness (m)	9.0	7.5-13
Dust/Effective AC Ratio	1.1	0.6-1.3
Fine Agg Angularity (%)	45.1	45 Min
Sand Equivalent (%)	59.0	40 Min
Coarse Agg Angularity (%)	100.0	75 Min
Flat/Elongated Pieces (%)	1.1	10 Max

Maximum SpG @ Ndes	2.471
Frac. Faces Fine (%)	54.8
Frac. Faces Course (%)	85.6

Summary of Aggregate Characteristics from Mix Design

Gradation (% passing)	
5/8"	100.0
1/2"	91.4
3/8"	73.9
#4	60.3
#8	47.6
#16	31.9
#30	18.7
#50	10.4
#100	6.4
#200	4.8

Asphalt Absorption (%)	1.43
Water Absorption (%)	2.11
Light Wt Particles (%)	1.1
Toughness (% Loss)	22.6

Final Aggregate Blend (%)

33	Rock
34	Crushed Fines
8	Nat. Fines 1
25	Nat. Fines 2

Specific Gravity Information

Bulk (Gsb)	2.607
Apparent (Gsa)	2.762
Effective (Gme)	2.705

Remarks:

Aggregate properties from project NH-2-281(025)049

NPM mix design (all points dedone)

B-10 Mix Data for NPM Superpave Mix Design

SUPERPAVE MIX DESIGN DATA

NDDOT Phase 1

Department of Transportation, Materials and Research (Rev. 7-04)

3/4/05

Bulk Specific Gravity of the Mix (Gmb) @ Ndes

%AC Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.0						
A	4747.6	4769.2	2702.9	2066.3	2.298	143.4
B	4698.8	4722.5	2676.9	2045.6	2.297	143.3
			Average =	**2056.0**	**2.297**	**143.4**
5.5						
A	4763.3	4770.9	2735.3	2035.6	2.340	146.0
B	4754.3	4762.2	2735.9	2026.3	2.346	146.4
			Average =	**2031.0**	**2.343**	**146.2**
6.0						
A	4777.0	4778.9	2779.6	1999.3	2.389	149.1
B	4769.5	4771.5	2757.6	2013.9	2.368	147.8
			Average =	**2006.6**	**2.379**	**148.4**
6.5						
A	4806.9	4808.1	2806.3	2001.8	2.401	149.8
B	4794.7	4796.0	2800.5	1995.5	2.403	149.9
			Average =	**1998.7**	**2.402**	**149.9**

Rice Test: Theoretical Maximum SpG of the Mix (Gmm) @ Ndes

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Flask Number	1	2	1	2	1	2	1	2
Samp., Cont. & Sol.	8217.9	8141.7	4094.5	4188.6	4038.2	4249.7	4111.1	4175.2
Cont. & Sol. (g)	7556.8	7558.8	3275.0	3398.5	3275.0	3398.5	3275.0	3398.5
Samp. in Air (g)	1103.3	972.3	1368.4	1321.4	1282.8	1435.1	1413.4	1313.7
Samp. in Sol. (g)	661.1	582.9	819.5	790.1	763.2	851.2	836.1	776.7
Vol. of Voidless Mix	442.2	389.4	548.9	531.3	519.6	583.9	577.3	537
Theoretical Max. SpG	2.495	2.497	2.493	2.487	2.469	2.458	2.448	2.446
Difference Between Flasks	0.002 In Tolerance		0.006 In Tolerance		0.011 In Tolerance		0.002 In Tolerance	
Avg Theor. Max. SpG	2.496		2.490		2.463		2.447	
Effective SpG	2.698		2.714		2.703		2.706	
AC Absorption	1.3		1.6		1.4		1.4	

Avg Effective SpG: 2.705

Voids Analysis of the Mix @ Ndes

AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
Bulk Specific Gravity of the Mix (Gmb)	2.297	2.343	2.379	2.402
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.496	2.490	2.463	2.447
Air Voids, Va (%)	8.0	5.9	3.4	1.9
Voids in Mineral Agg. (VMA)	16.3	15.1	14.2	13.9
Voids in Mineral Agg. Filled (VFA)	51.2	60.9	75.9	86.6
Asphalt Absorption (%)	1.43			

B-11 Gyratory Data for NPM Superpave Mix Design

SUPERPAVE MIX DESIGN NDDOT Phase 1

Gyratory Compactor Information

Department of Transportation, Materials and Research (Rev. 7-04)

Superpave Gyratory Compaction Effort

Number of Gyrations @ Ninitial:	7
Number of Gyrations @ Ndesign:	75
Number of Gyrations @ Nmaximum:	115

Gyratory Plugs Compacted to Ninital and Ndesign

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Plug Number	1	2	1	2	1	2	1	2
Plug Weight (g)	4747.6	4698.8	4763.3	4754.3	4777.0	4769.5	4806.9	4794.7
Plug Height @ Nini (mm)	126.9	126.9	127.7	127.4	125.0	126.2	124.9	124.1
Plug Height @ Ndes (mm)	116.6	116.6	117.0	116.5	114.7	115.6	114.8	114.2
% Gmm initial	84.6	84.6	86.2	86.0	88.6	88.5	90.2	90.3
Avg. % Gmm initial	84.6		86.1		88.5		90.3	

Gyratory Plugs Compacted to Nmaximum at Design Optimum Asphalt Content

%AC @ Optimum Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.8						
A	4768.6	4776.5	2743.1	2033.4	2.345	146.3
B	4747.1	4758.5	2706.3	2052.2	2.313	144.3
			Average =	**2042.8**	**2.329**	**145.3**

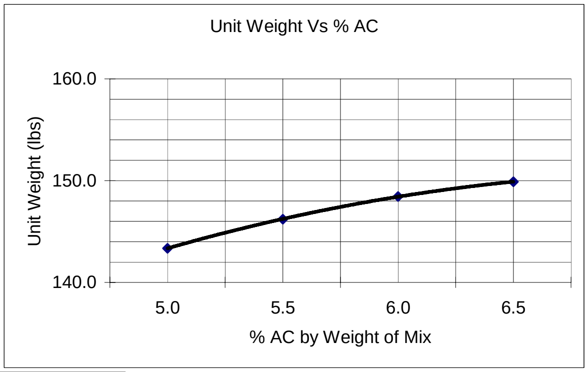
%Gmm at Nmaximum = 94.3

B-12 Graphs for NPM Superpave Mix Design

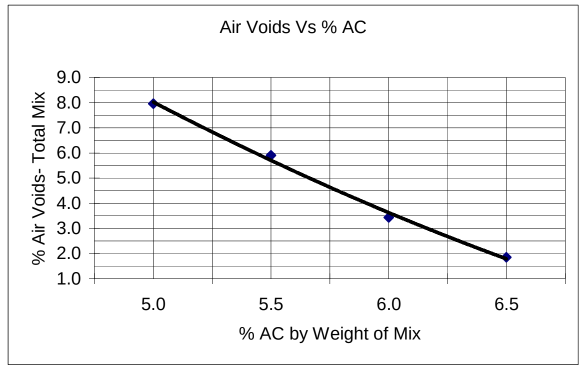
SUPERPAVE HOT MIX DESIGN GRAPHS **NDDOT Phase 1** **3/4/05**

Department of Transportation, Materials and Research (Rev. 7-04)

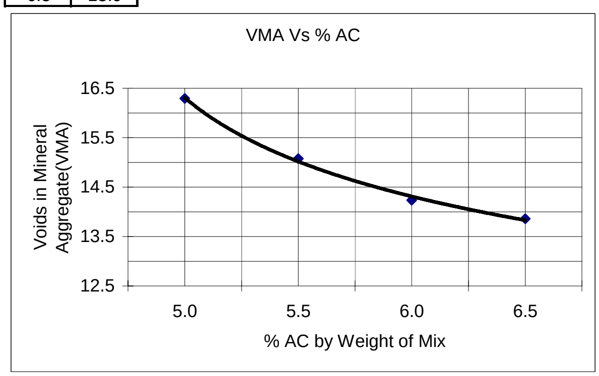
AC%	UNIT WT.
5.0	143.4
5.5	146.2
6.0	148.4
6.5	149.9



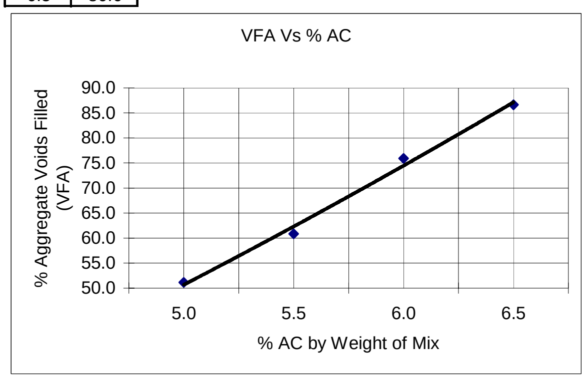
AC%	Air Voids
5.0	8.0
5.5	5.9
6.0	3.4
6.5	1.9



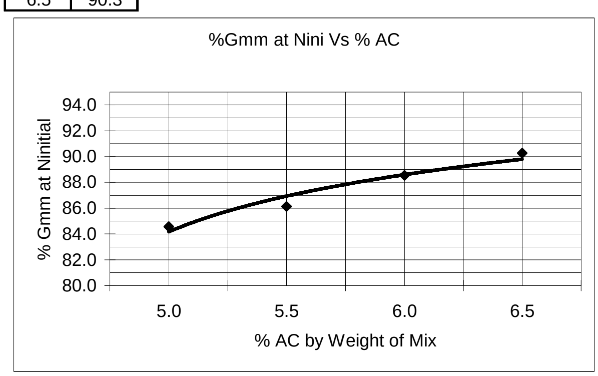
AC%	VMA
5.0	16.3
5.5	15.1
6.0	14.2
6.5	13.9



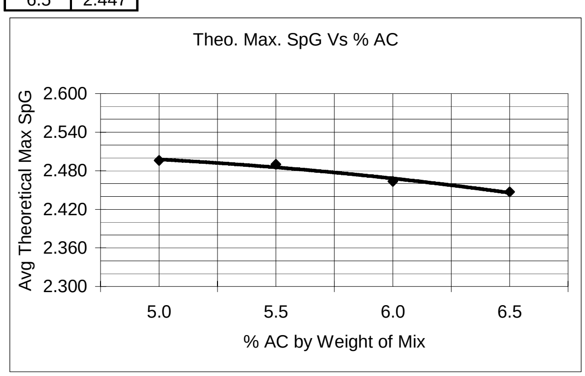
AC%	VFA
5.0	51.2
5.5	60.9
6.0	75.9
6.5	86.6



AC%	%Gmm
5.0	84.6
5.5	86.1
6.0	88.5
6.5	90.3



AC%	Max SpG
5.0	2.496
5.5	2.490
6.0	2.463
6.5	2.447



APPENDIX C

Superpave-L Mix Design
(1% Lime Added)

C-1 Summary Sheet forPM1-L Superpave Mix Design with Lime

HOT MIX DESIGN DATA - SUPERPAVE

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Lab. No.	1
Location	UND
Project	NDDOT Phase 1
District	
County	
Date	3/4/2005 0:00
Pit Owner(s)	Richard Klose
Pit #1 Location	E 1/2 27-138-64
Pit #2 Location	
Pit #3 Location	

Project Specification	410 Superpave
Type of AC (top lift)	PG 58-34
Type of AC (bot lift)	PG 58-34
Letting Date	11/21/03
Plus #4 (%)	39.7
Minus #4 (%)	60.3

Gyratory Compactive Effort

Ninitial	7
Ndesign	75
Nmaximum	115

Mix Properties at Recommended Asphalt Content

	Mix Design	Specification
Optimum AC (%)	6.0	
Density (pcf)	146.0	
Air Voids (%)	4.0	3.0-5.0
VMA (%)	15.6	14.0 Min
VFA (%)	75.0	65-78
%Gmm @ Ninitial	87.5	89 Max
%Gmm @ Nmaximum	97.4	98Max
AC Film Thickness (m)	10.3	7.5-13
Dust/Effective AC Ratio	0.9	0.6-1.3
Fine Agg Angularity (%)	45.1	45 Min
Sand Equivalent (%)	59.0	40 Min
Coarse Agg Angularity (%)	100.0	75 Min
Flat/Elongated Pieces (%)	1.1	10 Max
Maximum SpG @ Ndes	2.437	
Frac. Faces Fine (%)	54.8	
Frac. Faces Course (%)	85.6	

Summary of Aggregate Characteristics from Mix Design

Gradation (% passing)	
5/8"	100.0
1/2"	91.4
3/8"	73.9
#4	60.3
#8	47.6
#16	31.9
#30	18.7
#50	10.4
#100	6.4
#200	4.8

Asphalt Absorption (%)	0.97
Water Absorption (%)	2.11
Light Wt Particles (%)	1.1
Toughness (% Loss)	22.6

Final Aggregate Blend (%)

33	Rock
34	Crushed Fines
8	Nat. Fines 1
25	Nat. Fines 2

Specific Gravity Information

Bulk (Gsb)	2.607
Apparent (Gsa)	2.762
Effective (Gme)	2.673

Remarks:

Aggregate properties from project NH-2-281(025)049

Polymer Modified (1) with 1% lime added to total batch weight

C-2 Mix Data for PM1-L Superpave Mix Design with Lime

SUPERPAVE MIX DESIGN DATA

NDDOT Phase 1

Department of Transportation, Materials and Research (Rev. 7-04)

3/4/05

Bulk Specific Gravity of the Mix (Gmb) @ Ndes

%AC Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.0						
A	4775.3	4793.9	2716.7	2077.2	2.299	143.5
B	4761.0	4782.3	2710.5	2071.8	2.298	143.4
			Average =	**2074.5**	**2.298**	**143.4**
5.5						
A	4809.2	4818.0	2745.2	2072.8	2.320	144.8
B	4773.9	4782.8	2733.7	2049.1	2.330	145.4
			Average =	**2061.0**	**2.325**	**145.1**
6.0						
A	4787.3	4792.3	2737.1	2055.2	2.329	145.4
B	4809.2	4812.5	2766.2	2046.3	2.350	146.7
			Average =	**2050.8**	**2.340**	**146.0**
6.5						
A	4857.3	4859.6	2789.5	2070.1	2.346	146.4
B	4851.7	4855.1	2786.5	2068.6	2.345	146.4
			Average =	**2069.4**	**2.346**	**146.4**

Rice Test: Theoretical Maximum SpG of the Mix (Gmm) @ Ndes

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Flask Number	1	2	1	2	1	2	1	2
Samp., Cont. & Sol.	8192.7	8163.7	8210.4	8161.2	8173.6	8198.8	8202.5	8163.0
Cont. & Sol. (g)	7556.7	7556.7	7557.1	7558.4	7557.1	7558.4	7557.1	7558.4
Samp. in Air (g)	1063.4	1017.2	1100.8	1016.4	1046.7	1087.5	1101.5	1028.8
Samp. in Sol. (g)	636	607	653.3	602.8	616.5	640.4	645.4	604.6
Vol. of Voidless Mix	427.4	410.2	447.5	413.6	430.2	447.1	456.1	424.2
Theoretical Max. SpG	2.488	2.480	2.460	2.457	2.433	2.432	2.415	2.425
Difference Between Flasks	0.008 In Tolerance		0.002 In Tolerance		0.001 In Tolerance		0.010 In Tolerance	
Avg Theor. Max. SpG	2.484		2.459		2.433		2.420	
Effective SpG	2.683		2.675		2.664		2.671	
Effective SpG (each plug)	**2.688**	**2.678**	**2.676**	**2.673**	**2.665**	**2.664**	**2.664**	**2.677**
AC Absorption	1.1		1.0		0.8		0.9	

Avg Effective SpG: 2.673

Voids Analysis of the Mix @ Ndes

AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
Bulk Specific Gravity of the Mix (Gmb)	2.298	2.325	2.340	2.346
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.484	2.459	2.433	2.420
Air Voids, Va (%)	7.5	5.4	3.8	3.1
Voids in Mineral Agg. (VMA)	16.3	15.7	15.6	15.9
Voids in Mineral Agg. Filled (VFA)	54.1	65.4	75.6	80.7
Asphalt Absorption (%)	0.97			

C-3 Gyratory Data for PM1-L Superpave Mix Design with Lime

SUPERPAVE MIX DESIGN

NDDOT Phas

Gyratory Compactor Information

Department of Transportation, Materials and Research (Rev. 7-04)

3/4/05

Superpave Gyratory Compaction Effort

Number of Gyrations @ Ninitial:	7
Number of Gyrations @ Ndesign:	75
Number of Gyrations @ Nmaximum:	115

Gyratory Plugs Compacted to Ninital and Ndesign

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Plug Number	1	2	1	2	1	2	1	2
Plug Weight (g)	4775.3	4761.0	4809.2	4773.9	4787.3	4809.2	4857.3	4851.7
Plug Height @ Nini (mm)	130.4	130.2	130.1	129.2	130.2	129.3	130.8	131.2
Plug Height @ Ndes (mm)	119.3	119.2	119.1	117.9	118.3	117.7	119.1	119.3
% Gmm initial	84.7	84.7	86.6	86.3	87.4	87.6	88.3	88.1
Avg. % Gmm initial	84.7		86.4		87.5		88.2	

Gyratory Plugs Compacted to Nmaximum at Design Optimum Asphalt Content

%AC @ Optimum Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
6.0						
A	4878.4	4881.8	2826.6	2055.2	2.374	148.1
B	4790.3	4794.6	2776.2	2018.4	2.373	148.1
			Average =	**2036.8**	**2.374**	**148.1**

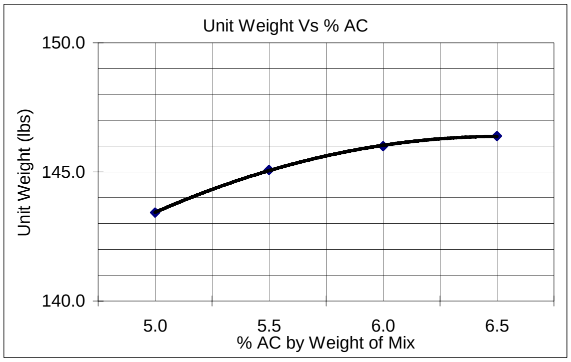
%Gmm at Nmaximum = 97.4

C-4 Graphs for PM1-L Superpave Mix Design with Lime

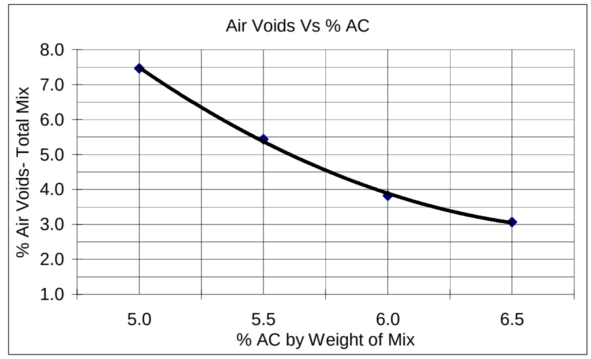
SUPERPAVE HOT MIX DESIGN GRAPHS **NDDOT Phase 1** **3/4/05**

Department of Transportation, Materials and Research (Rev. 7-04)

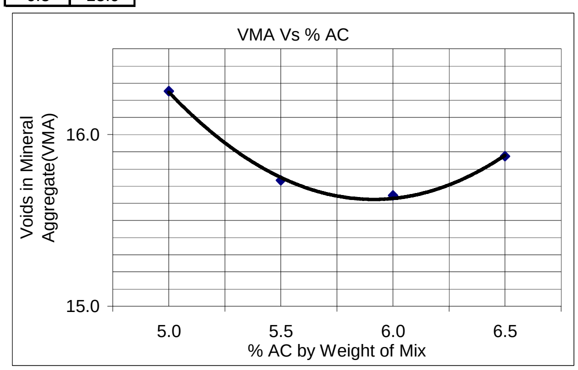
AC%	UNIT WT.
5.0	143.4
5.5	145.1
6.0	146.0
6.5	146.4



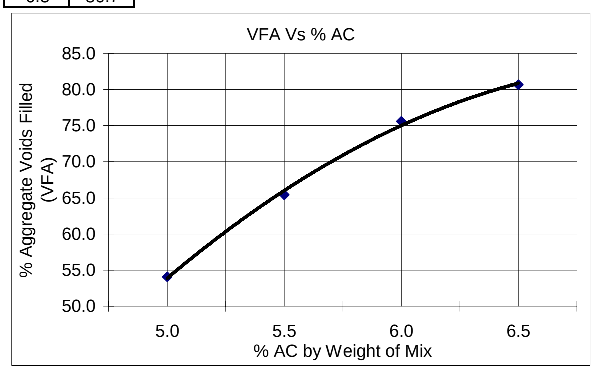
AC%	Air Voids
5.0	7.5
5.5	5.4
6.0	3.8
6.5	3.1



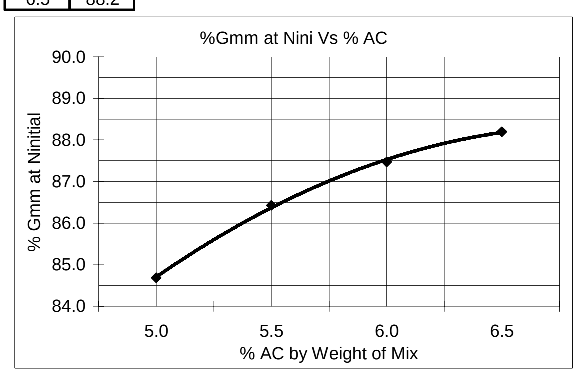
AC%	VMA
5.0	16.3
5.5	15.7
6.0	15.6
6.5	15.9



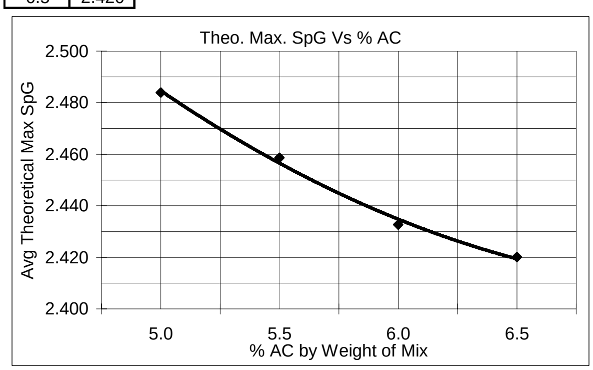
AC%	VFA
5.0	54.1
5.5	65.4
6.0	75.6
6.5	80.7



AC%	%Gmm
5.0	84.7
5.5	86.4
6.0	87.5
6.5	88.2



AC%	Max SpG
5.0	2.484
5.5	2.459
6.0	2.433
6.5	2.420



C-5 Summary Sheet forPM2-L Superpave Mix Design with Lime

HOT MIX DESIGN DATA - SUPERPAVE

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Lab. No.	1		
Location	UND	Project Specification	410 Superpave
Project	NDDOT Phase 1	Type of AC (top lift)	PG 58-34
		Type of AC (bot lift)	PG 58-34
District		Letting Date	11/21/03
County		Plus #4 (%)	39.7
Date	3/4/2005 0:00	Minus #4 (%)	60.3
Pit Owner(s)	Richard Klose		
		Gyratory Compactive Effort	
Pit #1 Location	E 1/2 27-138-64	Ninitial	7
Pit #2 Location		Ndesign	75
Pit #3 Location		Nmaximum	115

Mix Properties at Recommended Asphalt Content

	Mix Design	Specification
Optimum AC (%)	5.9	
Density (pcf)	146.7	
Air Voids (%)	4.0	3.0-5.0
VMA (%)	15.1	14.0 Min
VFA (%)	73.1	65-78
%Gmm @ Ninitial	87.4	89 Max
%Gmm @ Nmaximum	97.4	98Max
AC Film Thickness (m)	10.0	7.5-13
Dust/Effective AC Ratio	1.0	0.6-1.3
Fine Agg Angularity (%)	45.1	45 Min
Sand Equivalent (%)	59.0	40 Min
Coarse Agg Angularity (%)	100.0	75 Min
Flat/Elongated Pieces (%)	1.1	10 Max
Maximum SpG @ Ndes	2.449	
Frac. Faces Fine (%)	54.8	
Frac. Faces Course (%)	85.6	

Summary of Aggregate Characteristics from Mix Design

Gradation (% passing)	
5/8"	100.0
1/2"	91.4
3/8"	73.9
#4	60.3
#8	47.6
#16	31.9
#30	18.7
#50	10.4
#100	6.4
#200	4.8

Asphalt Absorption (%)	1.01
Water Absorption (%)	2.11
Light Wt Particles (%)	1.1
Toughness (% Loss)	22.6

Final Aggregate Blend (%)

33	Rock
34	Crushed Fines
8	Nat. Fines 1
25	Nat. Fines 2

Specific Gravity Information

Bulk (Gsb)	2.607
Apparent (Gsa)	2.762
Effective (Gme)	2.676

Remarks:

Aggregate properties from project NH-2-281(025)049

PM2-L (1% lime added to total batch weight)

C-6 Mix Data forPM2-L Superpave Mix Design with Lime

SUPERPAVE MIX DESIGN DATA

NDDOT Phase 1

Department of Transportation, Materials and Research (Rev. 7-04)

3/4/05

Bulk Specific Gravity of the Mix (Gmb) @ Ndes

%AC Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.0						
A	4749.2	4772.5	2695.9	2076.6	2.287	142.7
B	4775.8	4794.7	2710.8	2083.9	2.292	143.0
			Average =	**2080.3**	**2.289**	**142.9**
5.5						
A	4785.8	4793.6	2737.7	2055.9	2.328	145.3
B	4783.3	4795.7	2721.2	2074.5	2.306	143.9
			Average =	**2065.2**	**2.317**	**144.6**
6.0						
A	4793.9	4799.7	2754.0	2045.7	2.343	146.2
B	4817.9	4820.0	2791.3	2028.7	2.375	148.2
			Average =	**2037.2**	**2.359**	**147.2**
6.5						
A	4832.6	4835.0	2778.0	2057.0	2.349	146.6
B	4831.4	4834.4	2767.3	2067.1	2.337	145.8
			Average =	**2062.1**	**2.343**	**146.2**

Rice Test: Theoretical Maximum SpG of the Mix (Gmm) @ Ndes

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Flask Number	1	2	1	2	1	2	1	2
Samp., Cont. & Sol.	8208.2	8159.4	8185.5	8185.6	8185.9	8180.0	8165.4	8210.5
Cont. & Sol. (g)	7556.8	7558.7	7556.8	7558.7	7556.8	7558.8	7558.7	7556.8
Samp. in Air (g)	1095.2	1006.9	1062.9	1056.9	1064.4	1047.7	1033.5	1110.5
Samp. in Sol. (g)	651.4	600.7	628.7	626.9	629.1	621.2	606.7	653.7
Vol. of Voidless Mix	443.8	406.2	434.2	430	435.3	426.5	426.8	456.8
Theoretical Max. SpG	2.468	2.479	2.448	2.458	2.445	2.457	2.422	2.431
Difference Between Flasks	0.011 In Tolerance		0.010 In Tolerance		0.011 In Tolerance		0.010 In Tolerance	
Avg Theor. Max. SpG	2.473		2.453		2.451		2.426	
Effective SpG	2.670		2.667		2.687		2.679	
AC Absorption	0.9		0.9		1.2		1.1	

Avg Effective SpG: 2.676

Voids Analysis of the Mix @ Ndes

AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
Bulk Specific Gravity of the Mix (Gmb)	2.289	2.317	2.359	2.343
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.473	2.453	2.451	2.426
Air Voids, Va (%)	7.4	5.5	3.7	3.4
Voids in Mineral Agg. (VMA)	16.6	16.0	14.9	16.0
Voids in Mineral Agg. Filled (VFA)	55.2	65.4	75.0	78.6
Asphalt Absorption (%)	1.01			

C-7 Gyratory Data forPM2-L Superpave Mix Design with Lime

SUPERPAVE MIX DESIGN

NDDOT Phase 1

Gyratory Compactor Information

Department of Transportation, Materials and Research (Rev. 7-04)

3/4/05

Superpave Gyratory Compaction Effort

Number of Gyrations @ Ninitial:	7
Number of Gyrations @ Ndesign:	75
Number of Gyrations @ Nmaximum:	115

Gyratory Plugs Compacted to Ninital and Ndesign

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Plug Number	1	2	1	2	1	2	1	2
Plug Weight (g)	4749.2	4775.8	4785.8	4783.3	4793.9	4817.9	4832.6	4831.4
Plug Height @ Nini (mm)	131.1	131.5	129.6	131.5	129.5	131.4	130.4	131.3
Plug Height @ Ndes (mm)	119.5	120.1	118.5	119.7	118.1	119.5	118.7	119.3
% Gmm initial	84.4	84.5	86.4	86.0	87.8	87.5	87.9	87.8
Avg. % Gmm initial	84.5		86.2		87.7		87.8	

Gyratory Plugs Compacted to Nmaximum at Design Optimum Asphalt Content

%AC @ Optimum Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.9						
A	4809.8	4813.2	2786.8	2026.4	2.374	148.1
B	4813.8	4815.5	2808.0	2007.5	2.398	149.6
			Average =	**2017.0**	**2.386**	**148.9**

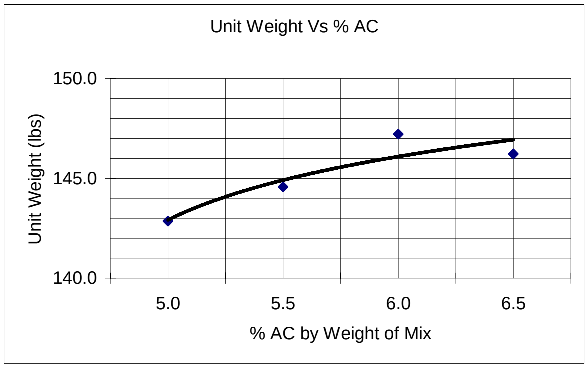
%Gmm at Nmaximum = 97.4

C-8 Graphs forPM2-L Superpave Mix Design with Lime

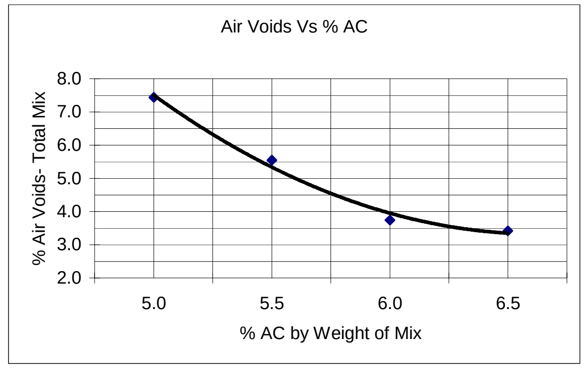
SUPERPAVE HOT MIX DESIGN GRAPHS **NDDOT Phase 1** **PM2-L(6.0)** **3/4/05**

Department of Transportation, Materials and Research (Rev. 7-04)

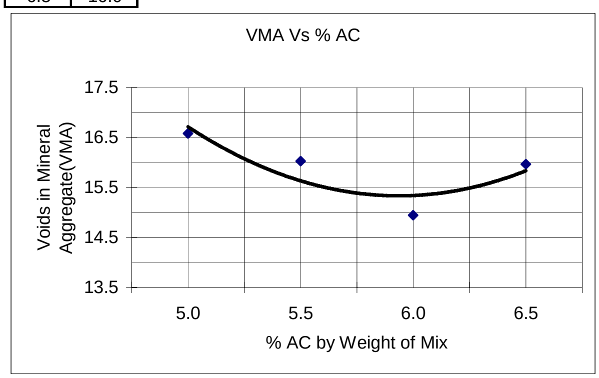
AC%	UNIT WT.
5.0	142.9
5.5	144.6
6.0	147.2
6.5	146.2



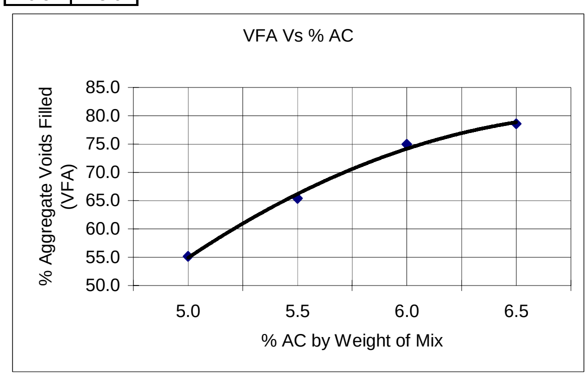
AC%	Air Voids
5.0	7.4
5.5	5.5
6.0	3.7
6.5	3.4



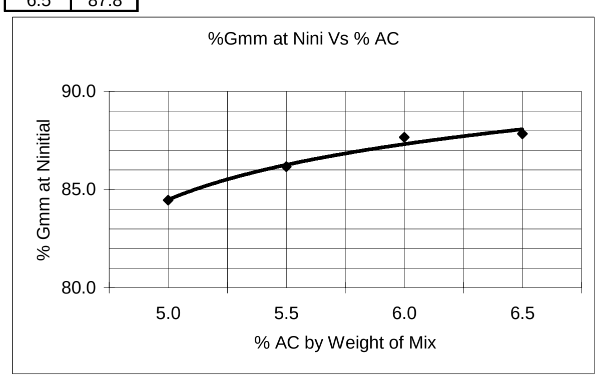
AC%	VMA
5.0	16.6
5.5	16.0
6.0	14.9
6.5	16.0



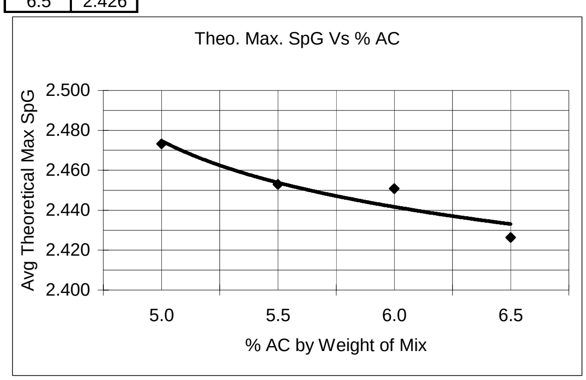
AC%	VFA
5.0	55.2
5.5	65.4
6.0	75.0
6.5	78.6



AC%	%Gmm
5.0	84.5
5.5	86.2
6.0	87.7
6.5	87.8



AC%	Max SpG
5.0	2.473
5.5	2.453
6.0	2.451
6.5	2.426



C-9 Summary Sheet for NPM-L Superpave Mix Design with Lime

HOT MIX DESIGN DATA - SUPERPAVE

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Lab. No.	1		
Location	UND	Project Specification	410 Superpave
Project	NDDOT Phase 1	Type of AC (top lift)	PG 58-34
		Type of AC (bot lift)	PG 58-34
District		Letting Date	11/21/03
County		Plus #4 (%)	39.7
Date	3/4/2005 0:00	Minus #4 (%)	60.3
Pit Owner(s)	Richard Klose		
		Gyratory Compactive Effort	
Pit #1 Location	E 1/2 27-138-64	Ninitial	7
Pit #2 Location		Ndesign	75
Pit #3 Location		Nmaximum	115

Mix Properties at Recommended Asphalt Content

	Mix Design	Specification
Optimum AC (%)	5.9	
Density (pcf)	146.7	
Air Voids (%)	4.0	3.0-5.0
VMA (%)	15.2	14.0 Min
VFA (%)	72.2	65-78
%Gmm @ Ninitial	86.9	89 Max
%Gmm @ Nmaximum	97.5	98Max
AC Film Thickness (m)	9.8	7.5-13
Dust/Effective AC Ratio	1.0	0.6-1.3
Fine Agg Angularity (%)	45.1	45 Min
Sand Equivalent (%)	59.0	40 Min
Coarse Agg Angularity (%)	100.0	75 Min
Flat/Elongated Pieces (%)	1.1	10 Max
Maximum SpG @ Ndes	2.449	
Frac. Faces Fine (%)	54.8	
Frac. Faces Course (%)	85.6	

Summary of Aggregate Characteristics from Mix Design

Gradation (% passing)	
5/8"	100.0
1/2"	91.4
3/8"	73.9
#4	60.3
#8	47.6
#16	31.9
#30	18.7
#50	10.4
#100	6.4
#200	4.8

Asphalt Absorption (%)	1.15
Water Absorption (%)	2.11
Light Wt Particles (%)	1.1
Toughness (% Loss)	22.6

Final Aggregate Blend (%)

33	Rock
34	Crushed Fines
8	Nat. Fines 1
25	Nat. Fines 2

Specific Gravity Information

Bulk (Gsb)	2.607
Apparent (Gsa)	2.762
Effective (Gme)	2.686

Remarks:

Aggregate properties from project NH-2-281(025)049

NPM with 1% lime added to total batch weight

C-10 Mix Data for NPM-L Superpave Mix Design with Lime

SUPERPAVE MIX DESIGN DATA

NDDOT Phase 1

Department of Transportation, Materials and Research (Rev. 7-04)

3/4/05

Bulk Specific Gravity of the Mix (Gmb) @ Ndes

%AC Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.0						
A	4731.3	4765.1	2706.8	2058.3	2.299	143.4
B	4773.3	4795.7	2714.8	2080.9	2.294	143.1
			Average =	**2069.6**	**2.296**	**143.3**
5.5						
A	4746.4	4762.1	2714.1	2048.0	2.318	144.6
B	4762.5	4774.9	2716.8	2058.1	2.314	144.4
			Average =	**2053.1**	**2.316**	**144.5**
6.0						
A	4786.4	4790.8	2764.5	2026.3	2.362	147.4
B	4796.4	4801.9	2764.6	2037.3	2.354	146.9
			Average =	**2031.8**	**2.358**	**147.2**
6.5						
A	4839.4	4845.8	2749.1	2096.7	2.308	144.0
B	4844.7	4847.0	2810.3	2036.7	2.379	148.4
			Average =	**2066.7**	**2.343**	**146.2**

Rice Test: Theoretical Maximum SpG of the Mix (Gmm) @ Ndes

	AC % = **5.0**		AC % = **5.5**		AC % = **6.0**		AC % = **6.5**	
Flask Number	1	2	1	2	1	2	1	2
Samp., Cont. & Sol.	8181.9	8191.0	8185.2	8193.3	8187.9	8191.6	8147.8	8226.8
Cont. & Sol. (g)	7556.8	7558.8	7556.8	7558.8	7556.8	7558.8	7556.8	7558.8
Samp. in Air (g)	1046.4	1061.0	1056.2	1068.1	1064.4	1070.6	1001.2	1133.8
Samp. in Sol. (g)	625.1	632.2	628.4	634.5	631.1	632.8	591	668
Vol. of Voidless Mix	421.3	428.8	427.8	433.6	433.3	437.8	410.2	465.8
Theoretical Max. SpG	2.484	2.474	2.469	2.463	2.456	2.445	2.441	2.434
Difference Between Flasks	0.009 In Tolerance		0.006 In Tolerance		0.011 In Tolerance		0.007 In Tolerance	
Avg Theor. Max. SpG	2.479		2.466		2.451		2.437	
Effective SpG	2.677		2.684		2.688		2.693	
AC Absorption	1.0		1.1		1.2		1.3	

Avg Effective SpG: 2.686

Voids Analysis of the Mix @ Ndes

AC Content (%)	**5.0**	**5.5**	**6.0**	**6.5**
Bulk Specific Gravity of the Mix (Gmb)	2.296	2.316	2.358	2.343
Percent Aggregate	95	94.5	94	93.5
Theor. Maximum SpG of Mix (Gmm)	2.479	2.466	2.451	2.437
Air Voids, Va (%)	7.4	6.1	3.8	3.9
Voids in Mineral Agg. (VMA)	16.3	16.1	15.0	16.0
Voids in Mineral Agg. Filled (VFA)	54.9	62.1	74.7	75.8
Asphalt Absorption (%)	1.15			

C-11 Gyratory Data for NPM-L Superpave Mix Design with Lime

SUPERPAVE MIX DESIGN NDDOT Phase 1

Gyratory Compactor Information

Department of Transportation, Materials and Research (Rev. 7-04) 3/4/05

Superpave Gyratory Compaction Effort

Number of Gyrations @ Ninitial:	7
Number of Gyrations @ Ndesign:	75
Number of Gyrations @ Nmaximum:	115

Gyratory Plugs Compacted to Ninital and Ndesign

	AC % =	**5.0**	AC % =	**5.5**	AC % =	**6.0**	AC % =	**6.5**
Plug Number	1	2	1	2	1	2	1	2
Plug Weight (g)	4731.3	4773.3	4746.4	4762.5	4786.4	4796.4	4839.4	4844.7
Plug Height @ Nini (mm)	130.2	130.9	131.7	131.5	131.2	132.7	133.6	129.6
Plug Height @ Ndes (mm)	118.7	119.4	119.7	119.3	119.3	120.2	120.7	117.3
% Gmm initial	84.4	84.5	85.3	85.2	87.5	87.2	86.9	87.0
Avg. % Gmm initial	84.5		85.3		87.3		86.9	

Gyratory Plugs Compacted to Nmaximum at Design Optimum Asphalt Content

%AC @ Optimum Specimen#	Weight in Air	SSD Weight	Weight in Water	Volume	Gmb @Ndes	Unit Weight
5.9						
A	4821.1	4823.3	2800.1	2023.2	2.383	148.7
B	4806.7	4808.9	2801.2	2007.7	2.394	149.4
			Average =	**2015.5**	**2.389**	**149.0**

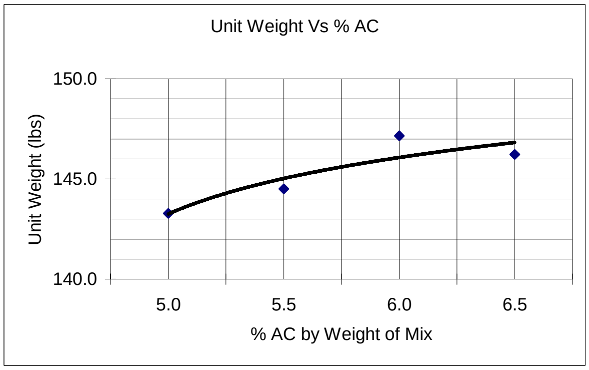
%Gmm at Nmaximum = 97.5

C-12 Graphs for NPM-L Superpave Mix Design with Lime

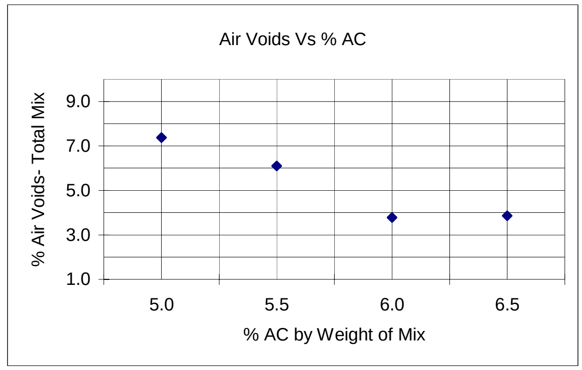
SUPERPAVE HOT MIX DESIGN GRAPHS **NDDOT Phase 1** **NPM-L(5.5&6.0)** **3/4/05**

Department of Transportation, Materials and Research (Rev. 7-04)

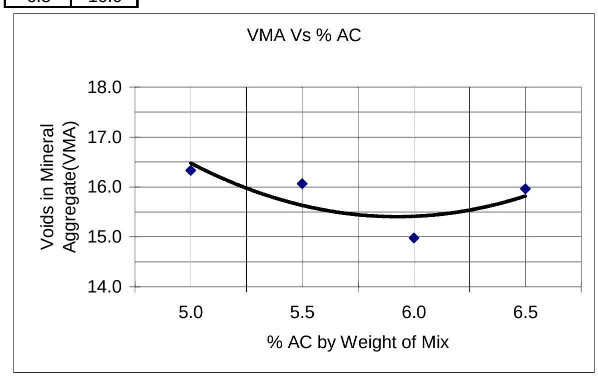
AC%	UNIT WT.
5.0	143.3
5.5	144.5
6.0	147.2
6.5	146.2



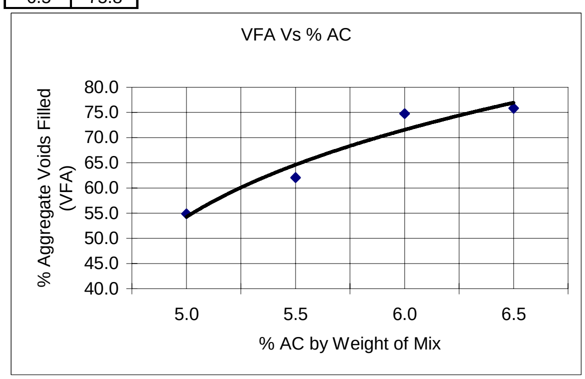
AC%	Air Voids
5.0	7.4
5.5	6.1
6.0	3.8
6.5	3.9



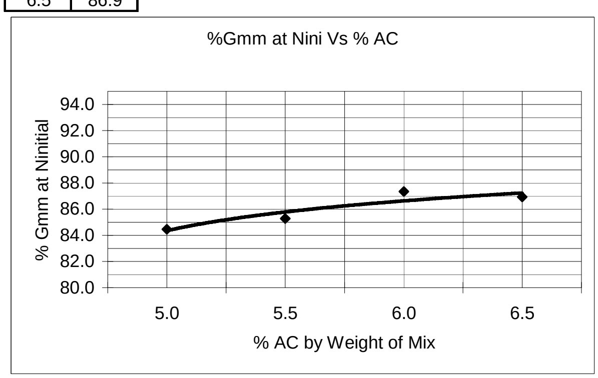
AC%	VMA
5.0	16.3
5.5	16.1
6.0	15.0
6.5	16.0



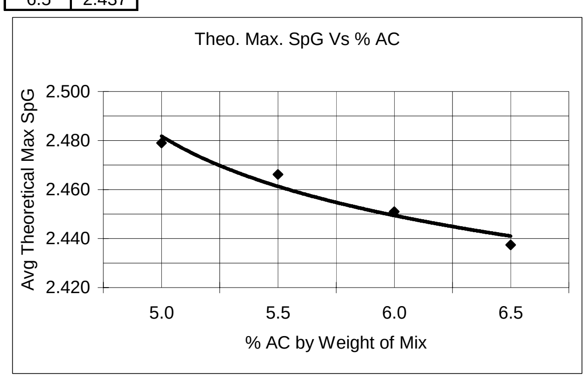
AC%	VFA
5.0	54.9
5.5	62.1
6.0	74.7
6.5	75.8



AC%	%Gmm
5.0	84.5
5.5	85.3
6.0	87.3
6.5	86.9



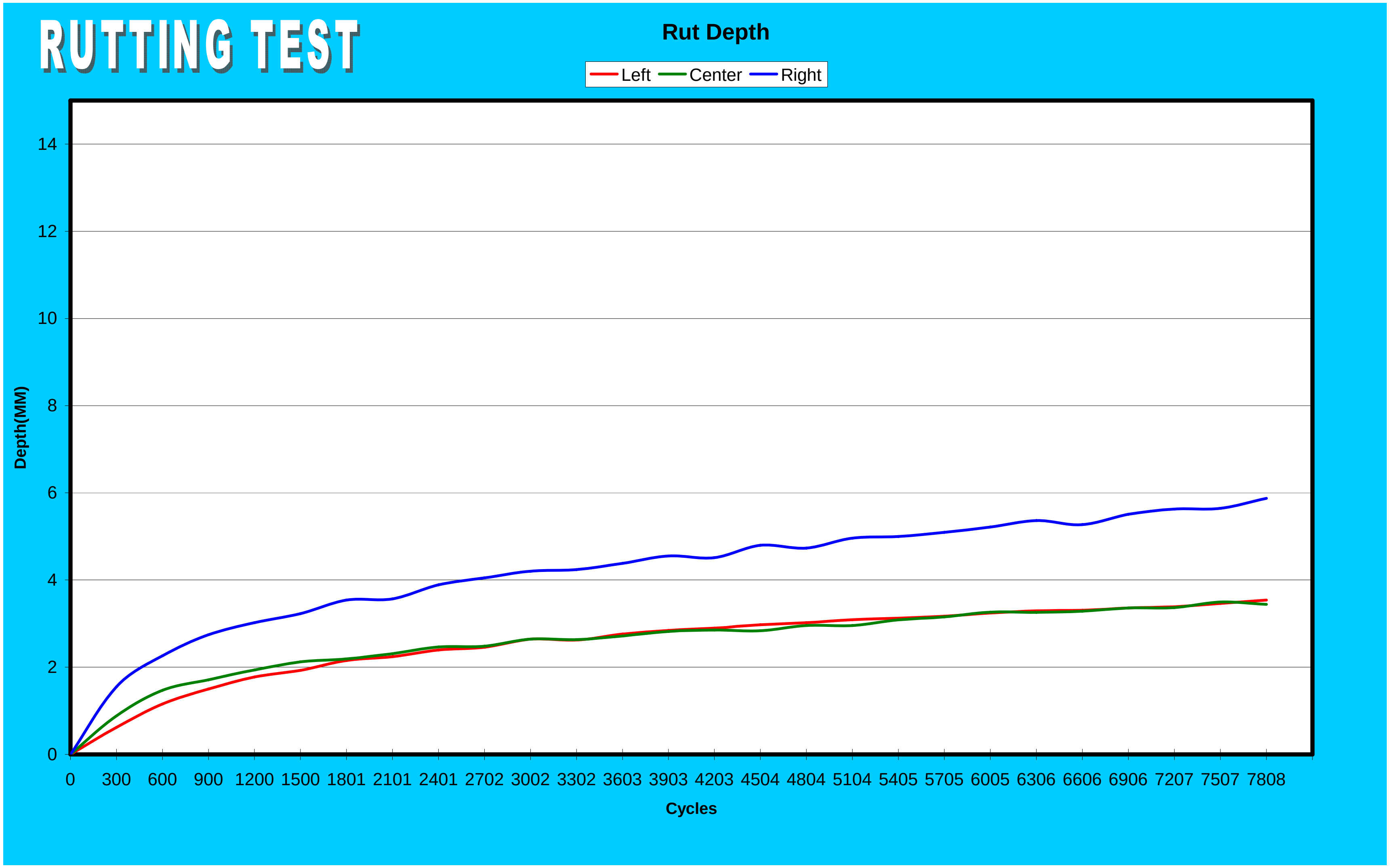
AC%	Max SpG
5.0	2.479
5.5	2.466
6.0	2.451
6.5	2.437



APPENDIX D

Asphalt Pavement Analyzer (APA) Testing

D-1 APA Rutting Test Chart for a Dry Test (8,000 Cycles)



D-2 APA Data Sheet for a Dry Rutting Test (8,000 Cycles)

RUTTING TEST DATA SHEET

Project No. ______________	**Test No.** ____________	**Temperature** ______________
Mix ID No. ______________	**Test Date** ____________	**Wheel Load** ______________
Mix Type ______________	**Data File** ____________	**Hose Pressure** ______________
Mold Type ______________	**Operator** ____________	**Lab ID** ______________

Left Sample ID			Bulk S Gravity					% Air Void		
	Temperature		Depth Gauge Reading							
STROKE COUNT	**F**	**C**	**1**	**2**	**3**	**4**	**5**	**Man Average Depth**	**APA Average**	**Percent Change**
0	32	0						0		
25	138.2	59	0.248447418	0.066745758	0	-0.185409546	-0.745342255		-0.153889656	
4000	138.2	59	3.189023972	2.855289459	0	2.681005478	2.621675491		2.8367486	105.42%
7975	138.2	59	3.926950455	3.485677719	0	3.411514282	3.278020859		3.525540829	19.54%
8000	32	0						0		

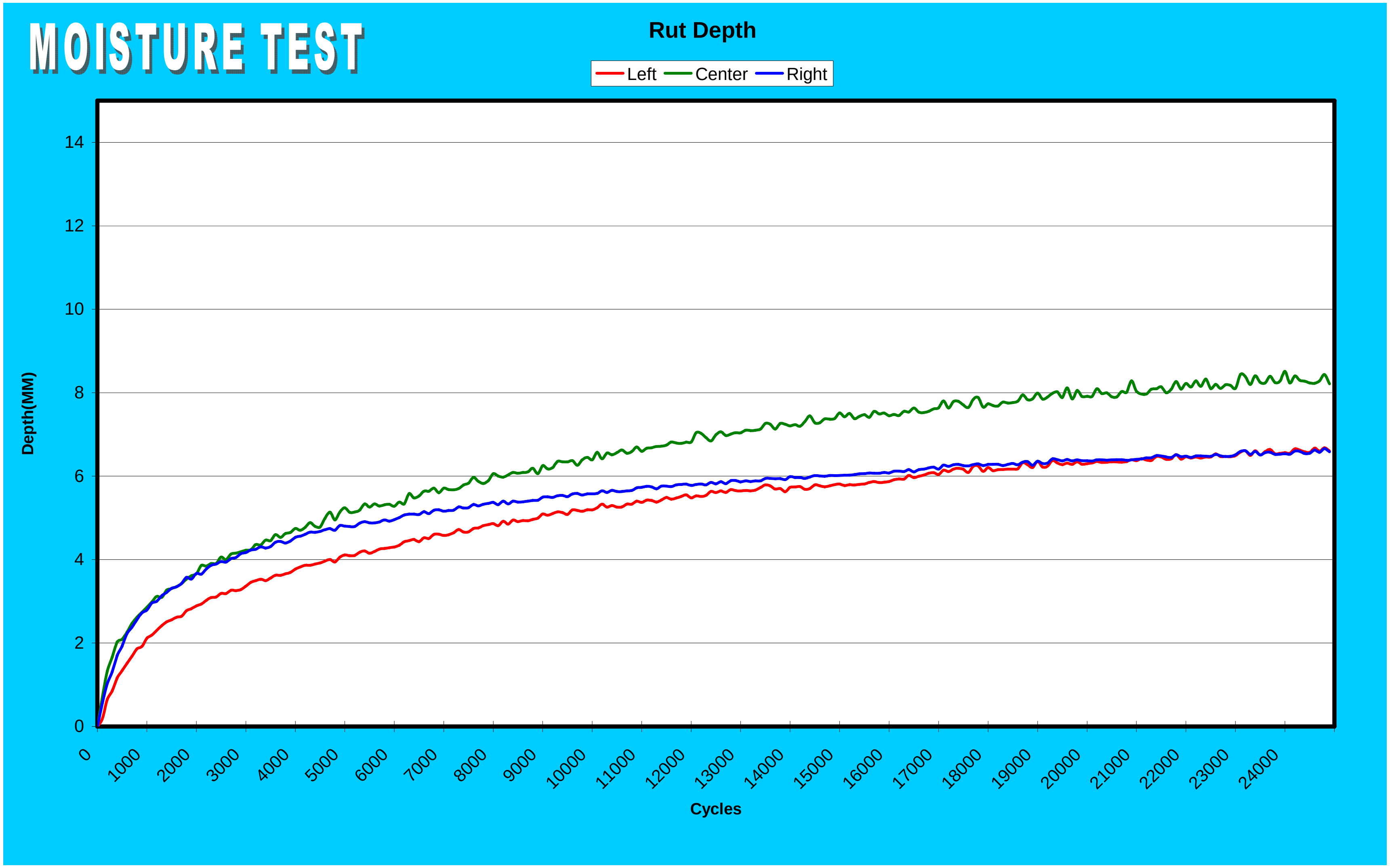
Center Sample ID			Bulk S Gravity					% Air Void		
	Temperature		Depth Gauge Reading							
STROKE COUNT	**F**	**C**	**1**	**2**	**3**	**4**	**5**	**Man Average Depth**	**APA Average**	**Percent Change**
0	32							0		
25	138.2	59	0.269012451	0.108352661	0	-0.089670181	-0.32131958		-0.008406162	
4000	138.2	59	3.097366333	2.843299866	0	2.675168991	2.671432495		2.821816921	100.30%
7975	138.2	59	4.094949722	3.254289627	0	3.153409958	3.116046906		3.404674053	17.12%
8000	32							0		

Right Sample ID			Bulk S Gravity					% Air Void		
	Temperature		Depth Gauge Reading							
STROKE COUNT	**F**	**C**	**1**	**2**	**3**	**4**	**5**	**Man Average Depth**	**APA Average**	**Percent Change**
0	32							0		
25	138.2	59	0.356664658	0.323226929	0	0.248922348	0.12260437		0.262854576	
4000	138.2	59	4.101640701	3.852720261	0	4.514034271	5.190210342		4.414651394	94.05%
7975	138.2	59	5.13448143	5.227363586	0	6.698604584	6.390237808		5.862671852	24.70%
8000	32							0		

D-3 APA Raw Data for a Dry Rutting Test (8,000 Cycles)

Left Stroke Count	Left Depth Value 1	Left Depth Value 2	Left Depth Value 3	Left Depth Value 4	Left Depth Value 5	Center Stroke Count	Center Depth Value 1	Center Depth Value 2	Center Depth Value 3	Center Depth Value 4	Center Depth Value 5	Right Stroke Count	Right Depth Value 1	Right Depth Value 2	Right Depth Value 3	Right Depth Value 4	Right Depth Value 5	Cabin Temp	Water Temp	Add Stroke	L Avg	C Avg	R Avg
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	59	0	0	0	0
1	0.0630379	-0.114954	0	-0.3782349	-0.9047928	1	0.1643963	-0.0448341	0	-0.2316475	-0.523077	1	0.0445843	0.0408688	0	-0.0817356	-0.1634712	59	59	1	-0.3337359	-0.1587906	-0.0399384
2	0.0630379	-0.114954	0	-0.3782349	-0.9047928	2	0.1643963	-0.0448341	0	-0.2316475	-0.523077	2	0.0445843	0.0408688	0	-0.0817356	-0.1634712	59	59	2	-0.3337359	-0.1587906	-0.0399384
3	0.0630379	-0.114954	0	-0.3782349	-0.9047928	3	0.1643963	-0.0448341	0	-0.2316475	-0.523077	3	0.0445843	0.0408688	0	-0.0817356	-0.1634712	59	59	3	-0.3337359	-0.1587906	-0.0399384
4	0.0630379	-0.114954	0	-0.3782349	-0.9047928	4	0.1643963	-0.0448341	0	-0.2316475	-0.523077	4	0.0445843	0.0408688	0	-0.0817356	-0.1634712	59	59	4	-0.3337359	-0.1587906	-0.0399384
5	0.0630379	-0.114954	0	-0.3782349	-0.6192646	5	0.1643963	-0.0448341	0	-0.2316475	-0.1494503	5	0.0445843	0.0408688	0	-0.0817356	-0.0037155	59	59	5	-0.2623539	-0.0653839	4.768E-07
6	0.0630379	-0.114954	0	-0.5710583	-0.6192646	6	0.1643963	-0.0448341	0	-0.4072533	-0.1494503	6	0.0445843	0.0408688	0	-0.0185757	-0.0037155	59	59	6	-0.3105597	-0.1092854	0.0157905
7	0.0630379	-0.114954	0	-0.5710583	-0.5895996	7	0.1643963	-0.0448341	0	-0.4072533	-0.1569233	7	0.0445843	0.0408688	0	-0.0185757	0.0222931	59	59	7	-0.3031435	-0.1111536	0.0222926
8	0.0927029	-0.114954	0	-0.5710583	-0.5895996	8	0.0224171	-0.0448341	0	-0.4072533	-0.1569233	8	0.1040287	0.0408688	0	-0.0185757	0.0222931	59	59	8	-0.2957273	-0.1466484	0.0371537
9	0.0927029	-0.114954	0	-0.5710583	-0.5710583	9	0.0224171	-0.0448341	0	-0.4072533	-0.1270332	9	0.1040287	0.0408688	0	-0.0185757	0.0520134	59	59	9	-0.2910919	-0.1391759	0.0445838
10	0.1372013	-0.114954	0	-0.5710583	-0.5710583	10	0.0186825	-0.0448341	0	-0.4072533	-0.1270332	10	0.1374645	0.0408688	0	-0.0185757	0.0520134	59	59	10	-0.2799673	-0.1401095	0.0529428
11	0.1372013	-0.114954	0	-0.5710583	-0.5710583	11	0.0186825	-0.0448341	0	-0.4072533	-0.1270332	11	0.1374645	0.0408688	0	-0.0185757	0.0520134	59	59	11	-0.2799673	-0.1401095	0.0529428
12	0.1631584	-0.114954	0	-0.2706966	-0.5710583	12	0.295166	-0.0448341	0	-0.2615376	-0.1270332	12	0.2006245	0.0408688	0	0.0965977	0.0520134	59	59	12	-0.1983876	-0.0345597	0.0975261
13	0.1631584	-0.114954	0	-0.2706966	-0.8232136	13	0.295166	-0.0448341	0	-0.2615376	-0.3810997	13	0.2006245	0.0408688	0	0.0965977	0	59	59	13	-0.2614264	-0.0980763	0.0845227
14	0.1631584	-0.114954	0	-0.2706966	-0.8232136	14	0.295166	-0.0448341	0	-0.2615376	-0.3810997	14	0.2006245	0.0408688	0	0.0965977	0	59	59	14	-0.2614264	-0.0980763	0.0845227
15	0.1631584	-0.114954	0	-0.2706966	-0.8232136	15	0.295166	-0.0448341	0	-0.2615376	-0.3810997	15	0.2006245	0.0408688	0	0.0965977	0	59	59	15	-0.2614264	-0.0980763	0.0845227
4000	3.189024	2.8552895	0	2.6810055	2.6216755	4000	3.0973663	2.8432999	0	2.675169	2.6714325	4000	4.1016407	3.8527203	0	4.5140343	5.1902103	59	59	4000	2.8367486	2.8218169	4.4146514
4001	3.189024	2.8552895	0	2.6810055	2.6216755	4001	3.0973663	2.8432999	0	2.675169	2.667696	4001	4.1016407	3.8527203	0	4.5140343	5.2496548	59	59	4001	2.8367486	2.8208828	4.4295125
4002	3.189024	2.8552895	0	2.6810055	2.6216755	4002	3.0973663	2.8432999	0	2.6789036	2.667696	4002	4.1016407	3.8527203	0	4.4285831	5.2496548	59	59	4002	2.8367486	2.8218164	4.4081497
4003	3.189024	2.8552895	0	2.6921291	2.5994263	4003	3.0973663	2.8432999	0	2.6901131	2.6714325	4003	4.1016407	3.8527203	0	4.7220898	5.271946	59	59	4003	2.8339672	2.8255529	4.4870992
4004	3.189024	2.8552895	0	2.6921291	2.5994263	4004	3.0973663	2.8432999	0	2.6901131	2.6714325	4004	4.1016407	3.8527203	0	4.7220898	5.271946	59	59	4004	2.8339672	2.8255529	4.4870992
4005	3.189024	2.8552895	0	2.6921291	2.5957184	4005	3.0973663	2.8432999	0	2.6901131	2.6714325	4005	4.1016407	3.8527203	0	4.7220898	5.2459393	59	59	4005	2.8330402	2.8255529	4.4805975
4006	3.189024	2.8552895	0	2.7180882	2.5957184	4006	3.0973663	2.8432999	0	2.6863766	2.6714325	4006	4.1016407	3.8527203	0	4.6552143	5.2459393	59	59	4006	2.83953	2.8246188	4.4638786
4007	3.189024	2.8552895	0	2.7180882	2.6031342	4007	3.0973663	2.8432999	0	2.6863766	2.6789036	4007	4.1016407	3.8527203	0	4.6552143	5.2013569	59	59	4007	2.8413839	2.8264866	4.452733
4008	3.189024	2.8552895	0	2.7180882	2.6031342	4008	3.0973663	2.8432999	0	2.6863766	2.6789036	4008	4.1016407	3.8527203	0	4.6552143	5.2013569	59	59	4008	2.8413839	2.8264866	4.452733
4009	3.189024	2.8552895	0	2.7143784	2.5994263	4009	3.0973663	2.8432999	0	2.6863766	2.6826401	4009	4.1016407	3.8527203	0	4.81497	5.2830925	59	59	4009	2.8395295	2.8274207	4.5131059
4010	3.189024	2.8552895	0	2.7143784	2.5994263	4010	3.0973663	2.8432999	0	2.6863766	2.6826401	4010	4.1016407	3.8527203	0	4.81497	5.2830925	59	59	4010	2.8395295	2.8274207	4.5131059
4011	3.189024	2.8552895	0	2.7143784	2.6031342	4011	3.0973663	2.8432999	0	2.6863766	2.6975861	4011	4.1016407	3.8527203	0	4.81497	5.1604881	59	59	4011	2.8404565	2.8311572	4.4824548
4012	3.189024	2.8552895	0	2.7106705	2.6031342	4012	3.0973663	2.8432999	0	2.6863766	2.6975861	4012	4.1016407	3.8527203	0	4.7629566	5.1604881	59	59	4012	2.8395295	2.8311572	4.4694514
4013	3.189024	2.8552895	0	2.7106705	2.5994263	4013	3.0973663	2.8432999	0	2.6863766	2.667696	4013	4.1016407	3.8527203	0	4.7629566	5.271946	59	59	4013	2.8386025	2.8236847	4.4973159
4014	3.189024	2.8552895	0	2.6995468	2.5994263	4014	3.0973663	2.8432999	0	2.7125301	2.667696	4014	4.1016407	3.8527203	0	4.7146587	5.271946	59	59	4014	2.8358216	2.8302231	4.4852414
4015	3.189024	2.8552895	0	2.7069626	2.606842	4015	3.0973663	2.8432999	0	2.7050591	2.6639595	4015	4.1016407	3.8527203	0	4.7480965	5.2645168	59	59	4015	2.8395295	2.8274212	4.4917436
7980	3.9269505	3.4856777	0	3.4115143	3.2780209	7980	4.0949497	3.2542896	0	3.15341	3.1160469	7980	5.1344814	5.2273636	0	6.6986046	6.3902378	59	59	7980	3.5255408	3.4046741	5.8626719
7981	3.9269505	3.4856777	0	3.4115143	3.2780209	7981	4.0949497	3.2542896	0	3.15341	3.1160469	7981	5.1344814	5.2273636	0	6.6986046	6.3902378	59	59	7981	3.5255408	3.4046741	5.8626719
7982	3.9269505	3.4856777	0	3.4115143	3.2780209	7982	4.0949497	3.2542896	0	3.15341	3.1160469	7982	5.1344814	5.2273636	0	6.6986046	6.3902378	59	59	7982	3.5255408	3.4046741	5.8626719
7983	3.9269505	3.4856777	0	3.4115143	3.2780209	7983	4.0949497	3.2542896	0	3.15341	3.1160469	7983	5.1344814	5.2273636	0	6.6986046	6.3902378	59	59	7983	3.5255408	3.4046741	5.8626719
7984	3.9269505	3.4856777	0	3.4115143	3.2780209	7984	4.0949497	3.2542896	0	3.15341	3.1160469	7984	5.1344814	5.2273636	0	6.6986046	6.3902378	59	59	7984	3.5255408	3.4046741	5.8626719
7985	3.9269505	3.4448891	0	3.4115143	3.2780209	7985	4.0949497	3.7400036	0	3.15341	3.1160469	7985	5.1344814	5.0267391	0	6.6986046	6.3902378	59	59	7985	3.5153437	3.5261025	5.8125157
7986	3.9269505	3.4448891	0	3.4115143	3.2780209	7986	4.0949497	3.7400036	0	3.15341	3.1160469	7986	5.1344814	5.0267391	0	6.6986046	6.3902378	59	59	7986	3.5153437	3.5261025	5.8125157
7987	3.9269505	3.4448891	0	3.4115143	3.3113937	7987	4.0949497	3.7400036	0	3.15341	3.1272564	7987	5.1344814	5.0267391	0	6.6986046	6.4088135	59	59	7987	3.5236869	3.5289049	5.8171597
7988	3.9269505	3.4448891	0	3.3744335	3.3113937	7988	4.0949497	3.7400036	0	3.3663769	3.1272564	7988	5.1344814	5.0267391	0	6.6428757	6.4088135	59	59	7988	3.5144167	3.5821466	5.8032274
7989	3.9269505	3.4448891	0	3.3744335	3.2965622	7989	4.0949497	3.7400036	0	3.3663769	3.1272564	7989	5.1344814	5.0267391	0	6.6428757	6.7246113	59	59	7989	3.5107088	3.5821466	5.8821769
7990	3.9269505	3.4448891	0	3.3670158	3.2965622	7990	4.0949497	3.7400036	0	3.3850594	3.1272564	7990	5.1344814	5.0267391	0	6.2341976	6.7246113	59	59	7990	3.5088544	3.5868173	5.7800074
7991	3.9269505	3.4448891	0	3.3670158	3.2854366	7991	4.0949497	3.7400036	0	3.3850594	3.1272564	7991	5.1344814	5.0267391	0	6.2341976	6.6725979	59	59	7991	3.506073	3.5868173	5.767004
7992	3.8157043	3.4448891	0	3.3670158	3.2854366	7992	3.6690159	3.7400036	0	3.3850594	3.1272564	7992	5.1790657	5.0267391	0	6.2341976	6.6725979	59	59	7992	3.4782615	3.4803338	5.7781501
7993	3.8157043	3.4448891	0	3.3670158	3.2854366	7993	3.6690159	3.7400036	0	3.3850594	3.1272564	7993	5.1790657	5.0267391	0	6.2341976	6.6725979	59	59	7993	3.4782615	3.4803338	5.7781501
7994	3.8268299	3.4448891	0	3.3855572	3.2854366	7994	3.6615429	3.7400036	0	3.1608829	3.1272564	7994	5.1864948	5.0267391	0	6.743187	6.6725979	59	59	7994	3.4856782	3.4224215	5.9072547
7995	3.941782	3.4448891	0	3.3855572	3.2854366	7995	4.0575867	3.7400036	0	3.1608829	3.1272564	7995	5.1976414	5.0267391	0	6.743187	6.6725979	59	59	7995	3.5144162	3.5214324	5.9100413
7996	3.8268299	3.4448891	0	3.3855572	3.2854366	7996	3.7885761	3.7400036	0	3.1608829	3.1272564	7996	5.1790657	5.0267391	0	6.743187	6.6725979	59	59	7996	3.4856782	3.4541798	5.9053974
7997	3.9491997	3.4448891	0	3.3855572	3.2557716	7997	4.0463791	3.7400036	0	3.1608829	3.1571465	7997	5.2013569	5.0267391	0	6.743187	6.4571133	59	59	7997	3.5088544	3.526103	5.8570991
7998	3.8268299	3.4448891	0	3.3855572	3.2557716	7998	3.7736301	3.7400036	0	3.1683559	3.1571465	7998	5.1716347	5.0267391	0	6.7952003	6.4571133	59	59	7998	3.4782619	3.459784	5.8626719
7999	3.8268299	3.4448891	0	3.3855572	3.2631874	7999	3.7736301	3.7400036	0	3.1683559	3.1085758	7999	5.1716347	5.0267391	0	6.7952003	6.5351334	59	59	7999	3.4801159	3.4476414	5.8821769
8000	3.8268299	3.4448891	0	3.3855572	3.2631874	8000	3.7250595	3.7400036	0	3.1683559	3.1085758	8000	5.1827812	5.0267391	0	6.7952003	6.5351334	59	59	8000	3.4801159	3.4354987	5.8849635
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59	59	0	0	0	0

D-4 APA Rutting Test Chart for a Wet Test (25,000 Cycles)



D-5 APA Data Sheet for a Wet Rutting Test (25,000 Cycles)

MOISTURE TEST DATA SHEET

Project No.	NDDOT Phase I	**Test No.**		**Temperature**	58 oC
Mix ID No.	HK Confirm Block 2	**Test Date**		**Wheel Load**	100 psi
Mix Type	Superpave 7% air	**Data File**		**Hose Pressure**	100 psi
Mold Type	75 mm	**Operator**	Suleiman	**Lab ID**	UND

Left Sample ID	C1, C2	Bulk S Gravity		% Air Void						
	Temperature		Depth Gauge Reading							
STROKE COUNT	**F**	**C**	**1**	**2**	**3**	**4**	**5**	**Man Average Depth**	**APA Average**	**Percent Change**
0	32	0						0		
1	136.4	58	0.085338593	-0.137285233	0	-0.515750885	-0.474935532		-0.260658264	
25000	136.4	58	6.882862091	6.675077438	0	6.949649811	6.292901993		6.700122833	103.89%
25000	136.4	58	6.882862091	6.463582993	0	6.949649811	6.292901993		6.647249222	-0.80%
25000	32	0						0		

Center Sample ID	H1, H2	Bulk S Gravity		% Air Void						
	Temperature		Depth Gauge Reading							
STROKE COUNT	**F**	**C**	**1**	**2**	**3**	**4**	**5**	**Man Average Depth**	**APA Average**	**Percent Change**
0	32							0		
1	136.4	58	0.070978165	-0.138221741	0	-0.564094543	-0.339950562		-0.24282217	
25000	136.4	58	7.98324585	8.775220871	0	8.741598129	8.274633408		8.443674564	102.88%
25000	136.4	58	7.98324585	8.244747162	0	8.741598129	8.274633408		8.311056137	-1.60%
25000	32							0		

Right Sample ID	K1, K2	Bulk S Gravity		% Air Void						
	Temperature		Depth Gauge Reading							
STROKE COUNT	**F**	**C**	**1**	**2**	**3**	**4**	**5**	**Man Average Depth**	**APA Average**	**Percent Change**
0	32							0		
1	136.4	58	0.13007164	-0.349334717	0	-0.386497498	-0.237844467		-0.21090126	
25000	136.4	58	6.663373947	6.626211166	0	6.711685181	6.603912354		6.651295662	103.17%
25000	136.4	58	6.663373947	6.529584885	0	6.711685181	6.603912354		6.627139091	-0.36%
25000	32							0		

D-6 APA Raw Data for a Wet Rutting Test (25,000 Cycles)

Left Stroke Count	Left Depth Value 1	Left Depth Value 2	Left Depth Value 3	Left Depth Value 4	Left Depth Value 5	Center Stroke Count	Center Depth Value 1	Center Depth Value 2	Center Depth Value 3	Center Depth Value 4	Center Depth Value 5	Right Stroke Count	Right Depth Value 1	Right Depth Value 2	Right Depth Value 3	Right Depth Value 4	Right Depth Value 5	Cabin Temp	Water Temp	Add Stroke	L Avg	C Avg	R Avg
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	59	59	0	0	0	0
1	0.0853386	-0.1372852	0	-0.5157509	-0.4749355	1	0.0709782	-0.1382217	0	-0.5640945	-0.3399506	1	0.1300716	-0.3493347	0	-0.3864975	-0.2378445	58	58	1	-0.2606583	-0.2428222	-0.2109013
2	0.063076	-0.1372852	0	-0.5157509	-0.9461632	2	0.336216	-0.1382217	0	-0.5640945	-0.7508812	2	0.3939304	-0.3493347	0	-0.3864975	-0.5425835	58	59	2	-0.3840308	-0.2792454	-0.2211213
3	0.063076	-0.1261559	0	-0.5157509	-0.9461632	3	0.336216	-0.1382217	0	-0.5640945	-0.7508812	3	0.3939304	-0.3790646	0	-0.3864975	-0.5425835	58	58	3	-0.3812485	-0.2792454	-0.2285538
4	0.063076	-0.1261559	0	-0.5157509	-0.9461632	4	0.336216	-0.1382217	0	-0.5640945	-0.7508812	4	0.3939304	-0.3790646	0	-0.3864975	-0.5425835	58	58	4	-0.3812485	-0.2792454	-0.2285538
5	0.063076	-0.3784657	0	-0.5380135	-0.9461632	5	0.336216	0.0298862	0	-0.5715656	-0.7508812	5	0.3939304	-0.1709499	0	-0.4422417	-0.5425835	58	58	5	-0.4498916	-0.2390862	-0.1904612
6	0.063076	-0.3784657	0	-0.5380135	-0.9461632	6	0.336216	0.0298862	0	-0.5715656	-0.7508812	6	0.3939304	-0.1709499	0	-0.4422417	-0.5425835	58	58	6	-0.4498916	-0.2390862	-0.1904612
7	0.0964699	-0.3784657	0	-0.5380135	-0.5862503	7	0.4221363	0.0298862	0	-0.5715656	-0.4408169	7	0.4794064	-0.1709499	0	-0.4422417	-0.3381844	58	58	7	-0.3515649	-0.14009	-0.1179924
8	0.1669693	-0.3784657	0	-0.1929436	-0.5862503	8	0.3885155	0.0298862	0	-0.4445515	-0.4408169	8	0.1449375	-0.1709499	0	-0.3790646	-0.3381844	58	58	8	-0.2476726	-0.1167417	-0.1858153
9	0.1669693	-0.3784657	0	-0.1929436	-0.8645325	9	0.3885155	0.0298862	0	-0.4445515	-0.7023163	9	0.1449375	-0.1709499	0	-0.3790646	-0.4459591	58	58	9	-0.3172431	-0.1821165	-0.212759
10	0.1669693	-0.3784657	0	-0.1929436	-0.8645325	10	0.3885155	0.0298862	0	-0.4445515	-0.7023163	10	0.1449375	-0.1709499	0	-0.3790646	-0.4459591	58	58	10	-0.3172431	-0.1821165	-0.212759
11	0.1669693	-0.3784657	0	-0.1929436	-0.8645325	11	0.3885155	0.0298862	0	-0.4445515	-0.7023163	11	0.1449375	-0.1709499	0	-0.3790646	-0.4459591	58	58	11	-0.3172431	-0.1821165	-0.212759
12	0.1669693	-0.3784657	0	-0.1929436	-0.8645325	12	0.3885155	0.0298862	0	-0.4445515	-0.7023163	12	0.1449375	-0.1709499	0	-0.3790646	-0.4459591	58	58	12	-0.3172431	-0.1821165	-0.212759
13	0.1669693	-0.3784657	0	-0.5046196	-0.8645325	13	0.3885155	0.0298862	0	-0.4669666	-0.7023163	13	0.1449375	-0.1709499	0	-0.3456173	-0.4459591	58	58	13	-0.3951621	-0.1877203	-0.2043972
14	0.204073	-0.3784657	0	-0.5046196	-0.8645325	14	0.5865078	0.0298862	0	-0.4669666	-0.7023163	14	0.6726551	-0.1709499	0	-0.3456173	-0.4459591	58	58	14	-0.3858862	-0.1382222	-0.0724678
15	0.204073	0	0	-0.5046196	-0.8645325	15	0.5865078	0.0635071	0	-0.4669666	-0.7023163	15	0.6726551	-0.2452774	0	-0.3456173	-0.4459591	58	58	15	-0.2912698	-0.129817	-0.0910497
12000	5.6769695	5.5322628	0	5.5025787	5.2131653	12000	6.5599346	6.8587933	0	7.4976025	6.3694134	12000	5.8940945	5.749157	0	5.7305756	5.7454414	59	58	12000	5.4812441	6.8214359	5.7798171
12001	5.6769695	5.5322628	0	5.5025787	5.2131653	12001	6.5599346	6.8587933	0	7.4976025	6.3694134	12001	5.8940945	5.749157	0	5.7305756	5.7454414	59	58	12001	5.4812441	6.8214359	5.7798171
12002	5.6769695	5.5322628	0	5.5025787	5.2131653	12002	6.5599346	6.8587933	0	7.4976025	6.3694134	12002	5.8940945	5.749157	0	5.7305756	5.7454414	59	58	12002	5.4812441	6.8214359	5.7798171
12003	5.6769695	5.5322628	0	5.5025787	5.2131653	12003	6.5599346	6.8587933	0	7.4976025	6.3694134	12003	5.8940945	5.749157	0	5.7305756	5.7454414	59	59	12003	5.4812441	6.8214359	5.7798171
12004	5.6769695	5.5322628	0	5.5025787	5.2131653	12004	6.5599346	6.8587933	0	7.4976025	6.3694134	12004	5.8940945	5.749157	0	5.7305756	5.7454414	59	58	12004	5.4812441	6.8214359	5.7798171
12005	5.6769695	5.5322628	0	5.5025787	5.2131653	12005	6.5599346	6.8587933	0	7.4976025	6.3694134	12005	5.8940945	5.749157	0	5.7305756	5.7454414	59	58	12005	5.4812441	6.8214359	5.7798171
12006	5.6769695	5.528553	0	5.5025787	5.2131653	12006	6.5599346	6.9297714	0	7.4976025	6.3694134	12006	5.8940945	5.7194271	0	5.7305756	5.7454414	59	58	12006	5.4803166	6.8391805	5.7723846
12007	5.6769695	5.528553	0	5.5025787	5.2131653	12007	6.5599346	6.9297714	0	7.4976025	6.3694134	12007	5.8940945	5.7194271	0	5.7305756	5.7454414	59	58	12007	5.4803166	6.8391805	5.7723846
12008	5.6769695	5.5211315	0	5.5025787	5.2131653	12008	6.5599346	6.8774719	0	7.4976025	6.3694134	12008	5.8940945	5.7565899	0	5.7305756	5.7454414	59	58	12008	5.4784613	6.8261056	5.7816753
12009	5.6769695	5.5211315	0	5.5025787	5.2131653	12009	6.5599346	6.8774719	0	7.4976025	6.3694134	12009	5.8940945	5.7565899	0	5.7305756	5.7454414	59	58	12009	5.4784613	6.8261056	5.7816753
12010	5.6769695	5.5211315	0	5.5025787	5.2131653	12010	6.5599346	6.8774719	0	7.4976025	6.3694134	12010	5.8940945	5.7565899	0	5.7305756	5.7454414	59	58	12010	5.4784613	6.8261056	5.7816753
12011	5.6769695	5.5322628	0	5.5025787	5.2131653	12011	6.5599346	7.0829372	0	7.4976025	6.3694134	12011	5.8940945	5.749157	0	5.7305756	5.7454414	59	59	12011	5.4812441	6.8774719	5.7798171
12012	5.6769695	5.5322628	0	5.5025787	5.2131653	12012	6.5599346	7.0829372	0	7.4976025	6.3694134	12012	5.8940945	5.749157	0	5.7305756	5.7454414	59	59	12012	5.4812441	6.8774719	5.7798171
12013	5.6769695	5.5322628	0	5.5025787	5.2131653	12013	6.5599346	7.0829372	0	7.4976025	6.3694134	12013	5.8940945	5.749157	0	5.7305756	5.7454414	59	58	12013	5.4812441	6.8774719	5.7798171
12014	5.6769695	5.5322628	0	5.5025787	5.2131653	12014	6.5599346	7.0829372	0	7.4976025	6.3694134	12014	5.8940945	5.749157	0	5.7305756	5.7454414	59	59	12014	5.4812441	6.8774719	5.7798171
12015	5.6769695	5.5322628	0	5.5025787	5.2131653	12015	6.5599346	7.0829372	0	7.4976025	6.3694134	12015	5.8940945	5.749157	0	5.7305756	5.7454414	59	58	12015	5.4812441	6.8774719	5.7798171
24975	6.8939934	6.6528149	0	6.9422283	6.2966137	24975	7.9122677	8.726656	0	8.8275204	8.3456116	24975	6.6447926	6.6187782	0	6.7042522	6.6410751	59	59	24975	6.6964126	8.4530139	6.6522245
24976	6.8939934	6.6528149	0	6.9422283	6.2966137	24976	7.9122677	8.726656	0	8.8275204	8.3456116	24976	6.6447926	6.6187782	0	6.7042522	6.6410751	59	59	24976	6.6964126	8.4530139	6.6522245
24977	6.8939934	6.463583	0	6.9422283	6.2966137	24977	7.9122677	8.1999187	0	8.8275204	8.3456116	24977	6.6447926	6.5035706	0	6.7042522	6.6410751	59	59	24977	6.6491046	8.3213296	6.6234226
24978	6.8939934	6.463583	0	6.9422283	6.2966137	24978	7.9122677	8.1999187	0	8.8275204	8.3456116	24978	6.6447926	6.5035706	0	6.7042522	6.6410751	59	59	24978	6.6491046	8.3213296	6.6234226
24979	6.8939934	6.463583	0	6.9422283	6.2966137	24979	7.9122677	8.1999187	0	8.8275204	8.3456116	24979	6.6447926	6.5035706	0	6.7042522	6.6410751	58	59	24979	6.6491046	8.3213296	6.6234226
24980	6.8939934	6.4747143	0	6.9422283	6.2966137	24980	7.9122677	8.2596893	0	8.8275204	8.3456116	24980	6.6447926	6.5184364	0	6.7042522	6.6410751	59	59	24980	6.6518874	8.3362722	6.6271391
24981	6.8939934	6.463583	0	6.9422283	6.2966137	24981	7.9122677	8.2447472	0	8.8275204	8.3456116	24981	6.6447926	6.5295849	0	6.7042522	6.6410751	59	59	24981	6.6491046	8.3325367	6.6299262
24982	6.8939934	6.463583	0	6.6528149	6.2966137	24982	7.9122677	8.2447472	0	8.6892986	8.3456116	24982	6.6447926	6.5295849	0	6.6150608	6.6410751	58	59	24982	6.5767512	8.2979813	6.6076283
24983	6.8939934	6.463583	0	6.6491051	6.4413204	24983	7.9122677	8.2447472	0	8.6743565	7.949625	24983	6.6447926	6.5295849	0	6.577898	6.5667496	58	59	24983	6.6120005	8.1952491	6.5797563
24984	6.8939934	6.463583	0	6.6491051	6.4413204	24984	7.9122677	8.2447472	0	8.6743565	7.949625	24984	6.6447926	6.5295849	0	6.577898	6.5667496	58	59	24984	6.6120005	8.1952491	6.5797563
24985	6.8939934	6.463583	0	6.6491051	6.4376087	24985	7.9122677	8.2447472	0	8.6743565	7.8973255	24985	6.6447926	6.5295849	0	6.577898	6.6039124	58	59	24985	6.6110725	8.1821742	6.589047
24986	6.8939934	6.463583	0	6.6602364	6.4376087	24986	7.9122677	8.2447472	0	8.6631489	7.8973255	24986	6.6447926	6.5295849	0	6.585331	6.6039124	58	59	24986	6.6138554	8.1793723	6.5909052
24987	6.8939934	6.463583	0	6.6602364	6.4301891	24987	7.9122677	8.2447472	0	8.6631489	7.893589	24987	6.6447926	6.5295849	0	6.585331	6.6076279	58	59	24987	6.6120005	8.1784382	6.5918341
24988	6.8939934	6.463583	0	6.6379738	6.4301891	24988	7.9122677	8.2447472	0	8.6668835	7.893589	24988	6.6447926	6.5295849	0	6.5593166	6.6076279	58	59	24988	6.6064348	8.1793718	6.5853305
24989	6.8939934	6.463583	0	6.5340805	6.4190578	24989	7.9122677	8.2447472	0	8.6071129	8.0318108	24989	6.6447926	6.5295849	0	6.5741825	6.6039124	58	59	24989	6.5776787	8.1989846	6.5881181
24990	6.8939934	6.463583	0	6.6379738	6.4190578	24990	7.9122677	8.2447472	0	8.67062	8.0318108	24990	6.6447926	6.5295849	0	6.5741825	6.6039124	58	59	24990	6.603652	8.2148614	6.5881181
24991	6.8939934	6.463583	0	6.6379738	6.4227676	24991	7.9122677	8.2447472	0	8.67062	7.9832458	24991	6.6447926	6.5295849	0	6.5741825	6.5667496	58	59	24991	6.6045794	8.2027202	6.5788274
24992	6.8939934	6.463583	0	6.6639462	6.4227676	24992	7.9122677	8.2447472	0	8.6818275	7.9832458	24992	6.6447926	6.5295849	0	6.5258694	6.5667496	58	59	24992	6.6110725	8.2055221	6.5667491
24993	6.8939934	6.463583	0	6.6639462	6.4190578	24993	7.9122677	8.2447472	0	8.6818275	7.8898525	24993	6.6447926	6.5295849	0	6.5258694	6.5704651	58	59	24993	6.6101451	8.1821737	6.567678
24994	6.868021	6.463583	0	6.6639462	6.4190578	24994	8.3792343	8.2447472	0	8.6818275	7.8898525	24994	6.655941	6.5295849	0	6.5258694	6.5704651	58	59	24994	6.603652	8.2989154	6.5704651
24995	6.8828621	6.463583	0	6.6639462	6.4190578	24995	7.9832458	8.2447472	0	8.6818275	7.8898525	24995	6.6633739	6.5295849	0	6.5258694	6.5704651	58	59	24995	6.6073623	8.1999183	6.5723233
24996	6.8828621	6.463583	0	6.9496498	6.4190578	24996	7.9832458	8.2447472	0	8.7415981	7.8898525	24996	6.6633739	6.5295849	0	6.7116852	6.5704651	58	59	24996	6.6787882	8.2148609	6.6187773
24997	6.8828621	6.463583	0	6.9496498	6.292902	24997	7.9832458	8.2447472	0	8.7415981	8.2746334	24997	6.6633739	6.5295849	0	6.7116852	6.6039124	58	58	24997	6.6472492	8.3110561	6.6271391
24998	6.8828621	6.463583	0	6.9496498	6.292902	24998	7.9832458	8.2447472	0	8.7415981	8.2746334	24998	6.6633739	6.5295849	0	6.7116852	6.6039124	58	59	24998	6.6472492	8.3110561	6.6271391
24999	6.8828621	6.463583	0	6.9496498	6.292902	24999	7.9832458	8.2447472	0	8.7415981	8.2746334	24999	6.6633739	6.5295849	0	6.7116852	6.6039124	58	59	24999	6.6472492	8.3110561	6.6271391
25000	6.8828621	6.6750774	0	6.9496498	6.292902	25000	7.9832458	8.7752209	0	8.7415981	8.2746334	25000	6.6633739	6.6262112	0	6.7116852	6.6039124	58	59	25000	6.7001228	8.4436746	6.6512957
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	59	0	0	0	0

APPENDIX E

Moisture Sensitivity Testing
(Modified Lottman)

E-1 Moisture Sensitivity (Modified Lottman) for PM1 Design Case

Moisture Sensitivity AASHTO T-283

Project Number : Lottman - PM1 (30 Blows)
Project Location : UND 5/26/05

		Conditioned Subset			Unconditioned Subset		
Original Volumetrics		**1**	**2**	**3**	**4**	**5**	**6**
Diameter	D	101.6	101.6	101.6	101.6	101.6	101.6
Thickness	t	67.1	66.8	67.3	67.1	66.9	67.1
Dry mass in air	A	1199.2	1198.0	1196.1	1198.7	1196.4	1196.1
SSD mass	B	1206.1	1202.4	1202.4	1204.2	1204.4	1204.8
Mass in Water	C	680.3	676.3	678.7	678.5	680.9	679.7
Volume	E	525.8	526.1	523.7	525.7	523.5	525.1
Bulk Sp Gravity (A/E)	F	2.281	2.277	2.284	2.280	2.285	2.278
Max Sp Gravity	G	2.454	2.454	2.454	2.454	2.454	2.454
% Air Voids (100(G-F)/G)	H	7.06	7.21	6.93	7.08	6.87	7.18
Vol Air Voids (HE/100)	I	37.13	37.92	36.29	37.23	35.97	37.69
Load - N	P				6829.8001	6324.0372	6324.0372

SSD Volumetrics		**1**	**2**	**3**
SSD Mass	B'	1225.7	1224.8	1223.4
Mass in Water	C'	690.7	689.0	689.3
Volume (B'-C')	E'	535.0	535.8	534.1
Vol Abs Water (B'-A)	J'	26.5	26.8	27.3
% Saturation (100J'/I)		71.37	70.68	75.22
% Swell (100(E'-E)/E)		1.72	1.81	1.95

SSD Conditioned		**1**	**2**	**3**
Thickness	t"	67.1	66.8	67.3
SSD mass	B"	1235.3	1234.5	1231.7
Mass in Water	C"	697.3	695.6	696.6
Volume (B"-C")	E"	538.0	538.9	535.1
Vol Abs Water (B"-A)	J"	36.1	36.5	35.6
% Saturation (100J"/I)		97.2	96.3	98.1
% Swell (100(E"-E)/E)		2.3	2.4	2.2
Load - N	P"	4889.041	5345.428	5150.151432

Calculated Strengths		**1**	**2**	**3**	**4**	**5**	**6**
Dry Strength 2P/(tDPi)	Std				637	592	591
Wet Strength 2P"/(t"DPi)	Stm	457	501	480			

Tensile Strength Ratio		**English Units**
Average Dry Strength (kPa)	607	88.0
Average Wet Strength (kPa)	479	69.5
% TSR	79.0%	79.0

HELPFUL HINTS SECTION

Grouping Wet Vs Dry Subsets

1	7.061	4	7.082
2	7.207	5	6.871
3	6.930	6	7.178
Ave.	7.066		7.044

Change the sample numbers to min. Ave. Diff

Degree of Saturation

1	2	3	
37.13	37.92	36.29	Vol of Air Voids
26.0	26.5	25.4	H_2O Wt. Gain needed to achieve 70% Saturation
1225.2	1224.5	1221.5	Saturated specimen wt at 70% Saturation
29.7	30.3	29.0	H_2O Wt. Gain needed to achieve 80% Saturation
1228.9	1228.3	1225.1	Saturated specimen wt at 80% Saturation

E-2 Moisture Sensitivity (Modified Lottman) for PM1-L Design Case

Moisture Sensitivity AASHTO T-283

Project Number : Lottman - PM1-L with Lime (27 Blows)
Project Location : UND 6/8/05

		Conditioned Subset			Unconditioned Subset		
Original Volumetrics		**1**	**2**	**3**	**4**	**5**	**6**
Diameter	D	101.6	101.6	101.6	101.6	101.6	101.6
Thickness	t	64.2	64.4	65.3	64.4	65.1	64.2
Dry mass in air	A	1143.4	1146.0	1148.0	1146.3	1147.7	1149.1
SSD mass	B	1149.0	1151.0	1157.2	1151.0	1152.8	1153.4
Mass in Water	C	643.1	642.6	642.3	639.5	639.7	645.6
Volume	E	505.9	508.4	514.9	511.5	513.1	507.8
Bulk Sp Gravity (A/E)	F	2.260	2.254	2.230	2.241	2.237	2.263
Max Sp Gravity	G	2.437	2.437	2.437	2.437	2.437	2.437
% Air Voids (100(G-F)/G)	H	7.26	7.50	8.51	8.04	8.22	7.14
Vol Air Voids (HE/100)	I	36.72	38.15	43.83	41.13	42.15	36.28
Load - N	P				6062.9266	5997.9825	6128.3154

SSD Volumetrics		**1**	**2**	**3**
SSD Mass	B'	1169.8	1172.9	1179.0
Mass in Water	C'	659.5	660.3	662.9
Volume (B'-C')	E'	510.3	512.6	516.1
Vol Abs Water (B'-A)	J'	26.4	26.9	31.0
% Saturation (100J'/I)		71.90	70.51	70.73
% Swell (100(E'-E)/E)		0.86	0.82	0.23

SSD Conditioned		**1**	**2**	**3**
Thickness	t"	64.2	64.4	65.3
SSD mass	B"	1178.2	1182.4	1189.5
Mass in Water	C"	667.7	668.7	669.2
Volume (B"-C")	E"	510.5	513.7	520.3
Vol Abs Water (B"-A)	J"	34.8	36.4	41.5
% Saturation (100J"/I)		94.8	95.4	94.7
% Swell (100(E"-E)/E)		0.9	1.0	1.0
Load - N	P"	5541.15	5606.539	4889.0408

Calculated Strengths		**1**	**2**	**3**	**4**	**5**	**6**
Dry Strength 2P/(tDPi)	Std				590	578	598
Wet Strength 2P"/(t"DPi)	Stm	541	545	469			

Tensile Strength Ratio	
Average Dry Strength (kPa)	588
Average Wet Strength (kPa)	518
% TSR	88.1%

English Units
85.4
75.2
88.1

HELPFUL HINTS SECTION

Grouping Wet Vs Dry Subsets

1	7.258	4	8.040
2	7.504	5	8.215
3	8.512	6	7.144
Ave.	7.758		7.800

Change the sample numbers to min. Ave. Diff

Degree of Saturation

1	2	3	
36.72	38.15	43.83	Vol of Air Voids
25.7	26.7	30.7	H_2O Wt. Gain needed to achieve 70% Saturation
1169.1	1172.7	1178.7	Saturated specimen wt at 70% Saturation
29.4	30.5	35.1	H_2O Wt. Gain needed to achieve 80% Saturation
1172.8	1176.5	1183.1	Saturated specimen wt at 80% Saturation

E-3 Moisture Sensitivity (Modified Lottman) for PM2 Design Case

Moisture Sensitivity AASHTO T-283

Project Number : Lottman - PM2 (29 Blows)
Project Location : UND 5/30/05

		Conditioned Subset			Unconditioned Subset		
Original Volumetrics		**1**	**2**	**3**	**4**	**5**	**6**
Diameter	D	101.6	101.6	101.6	101.6	101.6	101.6
Thickness	t	66.2	65.9	66.3	65.9	66.0	66.2
Dry mass in air	A	1188.5	1185.5	1188.9	1187.4	1186.5	1189.7
SSD mass	B	1190.6	1188.0	1191.9	1189.6	1187.9	1193.2
Mass in Water	C	666.4	667.5	667.8	667.8	663.2	671.0
Volume	E	524.2	520.5	524.1	521.8	524.7	522.2
Bulk Sp Gravity (A/E)	F	2.267	2.278	2.268	2.276	2.261	2.278
Max Sp Gravity	G	2.432	2.432	2.432	2.432	2.432	2.432
% Air Voids (100(G-F)/G)	H	6.77	6.35	6.72	6.43	7.02	6.32
Vol Air Voids (HE/100)	I	35.51	33.04	35.24	33.56	36.83	33.01
Load - N	P				4367.2644	4628.375	4628.375

SSD Volumetrics		**1**	**2**	**3**
SSD Mass	B'	1214.4	1209.9	1214.2
Mass in Water	C'	688.8	688.5	686.7
Volume (B'-C')	E'	525.6	521.4	527.5
Vol Abs Water (B'-A)	J'	25.9	24.4	25.3
% Saturation (100J'/I)		72.94	73.85	71.79
% Swell (100(E'-E)/E)		0.27	0.17	0.64

SSD Conditioned		**1**	**2**	**3**
Thickness	t"	66.2	65.9	66.3
SSD mass	B"	1220.9	1212.8	1220.9
Mass in Water	C"	692.5	690.2	692.9
Volume (B"-C")	E"	528.4	522.6	528.0
Vol Abs Water (B"-A)	J"	32.4	27.3	32.0
% Saturation (100J"/I)		91.2	82.6	90.8
% Swell (100(E"-E)/E)		0.8	0.4	0.7
Load - N	P"	3845.488	3975.821	4171.542592

Calculated Strengths		**1**	**2**	**3**	**4**	**5**	**6**
Dry Strength 2P/(tDPi)	Std				415	439	438
Wet Strength 2P"/(t"DPi)	Stm	364	378	394			

Tensile Strength Ratio		**English Units**
Average Dry Strength (kPa)	431	62.5
Average Wet Strength (kPa)	379	55.0
% TSR	87.9%	87.9

HELPFUL HINTS SECTION

Grouping Wet Vs Dry Subsets			
1	6.774	4	6.432
2	6.348	5	7.019
3	6.724	6	6.322
Ave.	6.615		6.591

Change the sample numbers to min. Ave. Diff

Degree of Saturation

1	2	3	
35.51	33.04	35.24	Vol of Air Voids
24.9	23.1	24.7	H_2O Wt. Gain needed to achieve 70% Saturation
1213.4	1208.6	1213.6	Saturated specimen wt at 70% Saturation
28.4	26.4	28.2	H_2O Wt. Gain needed to achieve 80% Saturation
1216.9	1211.9	1217.1	Saturated specimen wt at 80% Saturation

E-4 Moisture Sensitivity (Modified Lottman) for PM2-L Design Case

Moisture Sensitivity AASHTO T-283

Project Number : Lottman - PM2-L with Lime (22 Blows)
Project Location : UND 5/30/05

		Conditioned Subset			Unconditioned Subset		
Original Volumetrics		**1**	**2**	**3**	**4**	**5**	**6**
Diameter	D	101.6	101.6	101.6	101.6	101.6	101.6
Thickness	t	66.5	66.3	66.5	66.3	67.5	67.2
Dry mass in air	A	1186.8	1187.7	1184.9	1186.5	1187.9	1188.5
SSD mass	B	1190.4	1191.2	1189.2	1190.2	1193.4	1196.5
Mass in Water	C	665.2	666.0	663.8	666.2	665.0	669.4
Volume	E	525.2	525.2	525.4	524.0	528.4	527.1
Bulk Sp Gravity (A/E)	F	2.260	2.261	2.255	2.264	2.248	2.255
Max Sp Gravity	G	2.434	2.434	2.434	2.434	2.434	2.434
% Air Voids (100(G-F)/G)	H	7.16	7.09	7.34	6.97	7.64	7.36
Vol Air Voids (HE/100)	I	37.61	37.24	38.59	36.53	40.36	38.81
Load - N	P				4693.319	4236.9315	5019.3737

SSD Volumetrics		**1**	**2**	**3**
SSD Mass	B'	1214.0	1215.1	1212.5
Mass in Water	C'	686.4	687.3	684.5
Volume (B'-C')	E'	527.6	527.8	528.0
Vol Abs Water (B'-A)	J'	27.2	27.4	27.6
% Saturation (100J'/I)		72.33	73.58	71.52
% Swell (100(E'-E)/E)		0.45	0.49	0.49

SSD Conditioned		**1**	**2**	**3**
Thickness	t"	66.5	66.3	66.5
SSD mass	B"	1218.9	1219.3	1216.8
Mass in Water	C"	690.1	689.8	687.3
Volume (B"-C")	E"	528.8	529.5	529.5
Vol Abs Water (B"-A)	J"	32.1	31.6	31.9
% Saturation (100J"/I)		85.4	84.9	82.7
% Swell (100(E"-E)/E)		0.7	0.8	0.8
Load - N	P"	3780.544	4693.319	3975.820824

Calculated Strengths		**1**	**2**	**3**	**4**	**5**	**6**
Dry Strength 2P/(tDPi)	Std				443	393	468
Wet Strength 2P"/(t"DPi)	Stm	356	443	375			

Tensile Strength Ratio		**English Units**
Average Dry Strength (kPa)	435	63.1
Average Wet Strength (kPa)	391	56.8
% TSR	90.0%	90.0

HELPFUL HINTS SECTION

Grouping Wet Vs Dry Subsets

1	7.161	4	6.972
2	7.090	5	7.637
3	7.345	6	7.363
Ave.	7.198		7.324

Change the sample numbers to min. Ave. Diff

Degree of Saturation

1	2	3	
37.61	37.24	38.59	Vol of Air Voids
26.3	26.1	27.0	H_2O Wt. Gain needed to achieve 70% Saturation
1213.1	1213.8	1211.9	Saturated specimen wt at 70% Saturation
30.1	29.8	30.9	H_2O Wt. Gain needed to achieve 80% Saturation
1216.9	1217.5	1215.8	Saturated specimen wt at 80% Saturation

E-5 Moisture Sensitivity (Modified Lottman) for NPM Design Case

Moisture Sensitivity AASHTO T-283

Project Number : Lottman - NPM (37 Blows)
Project Location : UND 6/30/05

		Conditioned Subset			Unconditioned Subset		
Original Volumetrics		**1**	**2**	**3**	**4**	**5**	**6**
Diameter	D	101.6	101.6	101.6	101.6	101.6	101.6
Thickness	t	62.1	64.8	65.1	64.3	64.5	64.2
Dry mass in air	A	1138.0	1148.0	1149.2	1151.3	1149.3	1148.3
SSD mass	B	1140.3	1153.4	1155.6	1157.4	1153.3	1154.7
Mass in Water	C	647.7	639.4	641.2	649.0	640.4	647.0
Volume	E	492.6	514.0	514.4	508.4	512.9	507.7
Bulk Sp Gravity (A/E)	F	2.310	2.233	2.234	2.265	2.241	2.262
Max Sp Gravity	G	2.454	2.454	2.454	2.454	2.454	2.454
% Air Voids (100(G-F)/G)	H	5.86	8.99	8.96	7.72	8.69	7.83
Vol Air Voids (HE/100)	I	28.87	46.19	46.10	39.25	44.56	39.77
Load - N	P				4562.986128	4954.4297	4562.9861

SSD Volumetrics		**1**	**2**	**3**
SSD Mass	B'	1160.3	1180.4	1184.9
Mass in Water	C'	667.9	663.7	662.9
Volume (B'-C')	E'	492.4	516.7	522.0
Vol Abs Water (B'-A)	J'	22.3	32.4	35.7
% Saturation (100J'/I)		77.25	70.14	77.43
% Swell (100(E'-E)/E)		-0.04	0.52	1.46

SSD Conditioned		**1**	**2**	**3**
Thickness	t"	62.1	64.8	65.1
SSD mass	B"	1168.8	1192.4	1191.1
Mass in Water	C"	672.4	670.4	671.0
Volume (B"-C")	E"	496.4	522.0	520.1
Vol Abs Water (B"-A)	J"	30.8	44.4	41.9
% Saturation (100J"/I)		106.7	96.1	90.9
% Swell (100(E"-E)/E)		0.8	1.6	1.1
Load - N	P"	5606.539	3845.488	4106.59855

Calculated Strengths		**1**	**2**	**3**	**4**	**5**	**6**
Dry Strength 2P/(tDPi)	Std				445	482	446
Wet Strength 2P"/(t"DPi)	Stm	565	372	395			

Tensile Strength Ratio			English Units	English Units - Modified
Average Dry Strength (kPa)	457	**457.4**	66.4	**66.4**
Average Wet Strength (kPa)	444	**384**	64.5	**55.7**
% TSR	97.1%	**83.9**	97.1	**83.9**

HELPFUL HINTS SECTION

Grouping Wet Vs Dry Subsets

1	5.860	4	7.720
2	8.987	5	8.688
3	8.963	6	7.833
Ave.	7.937		8.081

Change the sample numbers to min. Ave. Diff

Degree of Saturation

1	2	3	
28.87	46.19	46.10	Vol of Air Voids
20.2	32.3	32.3	H_2O Wt. Gain needed to achieve 70% Saturation
1158.2	1180.3	1181.5	Saturated specimen wt at 70% Saturation
23.1	37.0	36.9	H_2O Wt. Gain needed to achieve 80% Saturation
1161.1	1185.0	1186.1	Saturated specimen wt at 80% Saturation

E-6 Moisture Sensitivity (Modified Lottman) for NPM-L Design Case

Moisture Sensitivity AASHTO T-283

Project Number : Lottman - NPM-L with Lime (25 Blows)
Project Location : UND 5/30/05

		Conditioned Subset			Unconditioned Subset		
Original Volumetrics		**1**	**2**	**3**	**4**	**5**	**6**
Diameter	D	101.6	101.6	101.6	101.6	101.6	101.6
Thickness	t	67.0	66.1	66.0	66.3	67.9	67.6
Dry mass in air	A	1187.4	1184.1	1186.0	1186.6	1188.1	1187.8
SSD mass	B	1192.2	1187.0	1188.6	1193.9	1197.8	1194.5
Mass in Water	C	666.9	665.4	668.0	672.1	670.3	667.7
Volume	E	525.3	521.6	520.6	521.8	527.5	526.8
Bulk Sp Gravity (A/E)	F	2.260	2.270	2.278	2.274	2.252	2.255
Max Sp Gravity	G	2.437	2.437	2.437	2.437	2.437	2.437
% Air Voids (100(G-F)/G)	H	7.25	6.85	6.52	6.69	7.58	7.48
Vol Air Voids (HE/100)	I	38.06	35.72	33.94	34.89	39.97	39.40
Load - N	P				5476.2061	4889.0408	5410.8172

SSD Volumetrics		**1**	**2**	**3**
SSD Mass	B'	1218.5	1210.5	1209.7
Mass in Water	C'	688.1	685.9	687.2
Volume (B'-C')	E'	530.4	524.6	522.5
Vol Abs Water (B'-A)	J'	31.1	26.4	23.7
% Saturation (100J'/I)		81.71	73.92	69.84
% Swell (100(E'-E)/E)		0.96	0.57	0.36

SSD Conditioned		**1**	**2**	**3**
Thickness	t"	67.0	66.1	66.0
SSD mass	B"	1221.4	1213.6	1212.5
Mass in Water	C"	690.5	688.6	689.7
Volume (B"-C")	E"	530.9	525.0	522.8
Vol Abs Water (B"-A)	J"	34.0	29.5	26.5
% Saturation (100J"/I)		89.3	82.6	78.1
% Swell (100(E"-E)/E)		1.1	0.7	0.4
Load - N	P"	4841.89	4628.375	4562.986128

Calculated Strengths		**1**	**2**	**3**	**4**	**5**	**6**
Dry Strength 2P/(tDPi)	Std				518	451	502
Wet Strength 2P"/(t"DPi)	Stm	453	439	433			

Tensile Strength Ratio		**English Units**
Average Dry Strength (kPa)	490	71.1
Average Wet Strength (kPa)	442	64.1
% TSR	90.1%	90.1

HELPFUL HINTS SECTION

Grouping Wet Vs Dry Subsets

1	7.246	4	6.686
2	6.847	5	7.578
3	6.519	6	7.479
Ave.	6.871		7.248

Change the sample numbers to min. Ave. Diff

Degree of Saturation

1	2	3	
38.06	35.72	33.94	Vol of Air Voids
26.6	25.0	23.8	H_2O Wt. Gain needed to achieve 70% Saturation
1214.0	1209.1	1209.8	Saturated specimen wt at 70% Saturation
30.4	28.6	27.1	H_2O Wt. Gain needed to achieve 80% Saturation
1217.8	1212.7	1213.1	Saturated specimen wt at 80% Saturation