EVALUATION OF MOISTURE SENSITIVITY PROPERTIES OF ADOT MIXTURES ON US 93

Final Report 402

Prepared by:
Peter E. Sebaaly
Zein Eid
Jon A. Epps
Department of Civil Engineering
University of Nevada
Reno, Nevada 89557

NOVEMBER 2001

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No. FHWA – AZ98-402-01	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Moisture Sensitivity Properties of ADOT Mixtures on US 93 Volume I – Final Report		5. Report Date November 2001
		6. Performing Organization Code
7. Author Peter E. Sebaaly, Zein Eid, and Jon A. Epps		8. Performing Organization Report No.
9. Performing Organization Name and Address Pavements/Materials Program / Department of Civil Engineering College of Engineering / University of Nevada Reno, Nevada 89557		10. Work Unit No.
		11. Contract or Grant No. SPR-PL-1-(47)402
12. Sponsoring Agency Name and Address **ARIZONA DEPARTMENT OF TRANSPORTATION** **206 S. 17TH AVENUE** **PHOENIX, ARIZONA 85007** Project Manager: Larry Scofield		13.Type of Report & Period Covered Final
		14. Sponsoring Agency Code

15. Supplementary Notes
Volume I: Final Report
Reviewed By Gene Morris, P.E. Volume II: Appendices

16. Abstract

In 1993, the Arizona Department of Transportation (ADOT) constructed pavement test sections as part of the Long Term Pavement Performance (LTPP) Specific Pavement Studies (SPS). The test sections are located on US 93 north of Kingman, Arizona, and consist of both SPS-1 and SPS-9 experiments constructed at the same location. As early as 1996 it was reported that fatigue cracking was occurring in the SPS-9 Superpave sections. A field visit in 1998 by personnel from ADOT, LTPP, and the FHWA revealed that the SPS-9 Superpave test sections were experiencing premature fatigue cracking while the SPS-1 test sections which used Marshall Mix designs had not experienced any distress. The survey team concluded that moisture sensitivity may be the primary cause of the premature fatigue of the Superpave designed HMA mixtures. An investigation into this premature failure was subsequently initiated.

This report describes the performance of the SPS-9 sections and documents the laboratory evaluation of mixtures and cores from the three sections in an effort to assess the appropriateness of the Superpave moisture damage requirements. The three evaluated sections included: a Superpave designed section with 1” nominal maximum size, a Superpave designed section with 3/4” nominal maximum size, and an ADOT Marshall designed section with 3/4” nominal maximum size. The two Superpave sections did not include anti-stripping additive based on the results of the Superpave moisture sensitivity testing. The ADOT section included 2% Portland Cement (PC) based on the results of the ADOT immersion compression test.

This research project evaluated the moisture sensitivity of the HMA mixtures used on all three sections using a modified AASHTO T-283 procedure and a modified ADOT immersion compression test procedure. Laboratory mixtures and field cores were tested by the modified AASHTO T-283 method using both the freeze/thaw and no freeze/thaw conditioning methods. Three methods of compaction were used (gyratory 4- and 6-inch and Marshall 4-inch).

The analysis of the data generated in this study led to the following conclusions: The moisture conditioning (freeze/thaw and no freeze/thaw) did not significantly impact the retained strength ratios of HMA mixtures as measured by the resilient modulus (Mr) and Indirect Tensile Strength (ITS) test procedures. The impact of compaction method on retained strength of HMA mixtures is affected by other factors such as: type of mixture and the addition of PC. The impact of adding PC to HMA mixtures showed mixed results depending on compaction method. The ability of the modified AASHTO T-283 method in assessing moisture sensitivity of HMA mixtures, with either the gyratory or the Marshall compaction methods, is questionable. Similarly, ADOT immersion compression test results provided questionable value in discriminating between acceptable and unacceptable mixes.

In addition to the testing conducted for the University of Nevada-Reno (UNR) research, previous research conducted on these test sections is also summarized in this report to enhance the UNR work.

17. Key Words Long term pavement performance Specific Pavment Studies (US93)		18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161		23. Registrant's Seal
19. Security Classification Unclassified	20. Security Classification Unclassified	21. No. of Pages 55	22. Price	

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	Inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	Feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	Yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	Miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	Acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	Gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	Ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	Pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	Poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

TABLE OF CONTENTS

Volume 2 – Appendixes

The appendixes are unpublished
but are available for viewing at the Arizona Transportation Research Center

Appendix 1 : Asphalt Institute Mix Design for 19mm
Appendix 2 : Asphalt Institute Mix Design for 25mm
Appendix 3: Koch Materials Hamburg Wheel Tracking Test Results
Appendix 4: Mix Designs for ADOT Mixtures
Appendix 5: Repeated Simple Shear at Constant Height Test Results
Appendix 6: Forensic Analysis of Arizona's US93 Superpave Section
Appendix 7: Core Extraction Report
Appendix 8: Nichols Construction Report
Appendix 9 UNR Research Workplan

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF PHOTOS

Page

EXECUTIVE SUMMARY

In 1993, the Arizona Department of Transportation (ADOT) constructed pavement test sections as part of the Long Term Pavement Performance (LTPP) Specific Pavement Studies (SPS). The test sections are located on US 93 north of Kingman, Arizona and consist of both the SPS-1 and SPS-9 experiments. Both experiments were constructed at the same location on the same project. The SPS-9 test sections, which used the Superpave mix design procedures, experienced premature fatigue cracking, while the SPS-1 test sections, that used ADOT's Marshall mix design procedures, did not experience premature distress.

The research program documented in this report evaluated three test sections in an effort to assess the appropriateness of the Superpave moisture damage requirements. The three evaluated sections included: a Superpave designed section with 1" nominal maximum size (1" SP mix), a Superpave designed section with 3/4" nominal maximum size (3/4" SP mix), and an ADOT designed section with 3/4" nominal maximum size (3/4" ADOT mix). The 3/4" ADOT mix was designed using the Marshall mix design method. The two Superpave test sections represented two of the four SPS-9 test sections and the ADOT ¾" mix represented one of the SPS-1 test sections.

During the design phase of the SPS-9 project, the Superpave volumetric mix design method was used by the Asphalt Institute to conduct the mix design. This procedure used the AASHTO T-283 test method to evaluate moisture sensitivity of the hot mixed asphalt (HMA) mixtures. Based on the results of the AASHTO T-283 measurements during the mix design stage, the Superpave mixtures did not include an anti-stripping additive. The ADOT mixture, however, incorporated 2% Portland Cement (PC) additive based on results from immersion compression testing. This test is used by ADOT to assess the moisture sensitivity of HMA mixtures.

The objective of this research was to compare the efficacy of the AASHTO T-283 and ADOT Immersion Compression test criteria in predicting actual field performance of Superpave Mixtures. The specific objectives can be summarized as follows:

- To evaluate the effectiveness of the AASHTO T-283 and the ADOT immersion compression tests in evaluating the moisture sensitivity of HMA mixtures.
- To compare the moisture sensitivity, as determined by AASHTO T-283, of 6-inch and 4-inch diameter samples prepared by the gyratory compactor and the 4-inch diameter samples prepared by the Marshall compactor.
- To compare the moisture sensitivity, as determined by AASHTO T-283 of 6- and 4-inch core samples.
- To compare the laboratory test results to actual field performance.

Laboratory mixed and compacted specimens (LMLC) and field cores were tested using modified AASHTO T-283 procedures. Both the freeze-thaw and no freeze-thaw conditioning methods were evaluated. Three methods of compaction were used to assess the impact of compaction methods on moisture sensitivity: 6-inch gyratory specimens, 4-inch gyratory specimens, and 4-inch Marshall specimens. The impact of using cement as an anti-stripping agent was also evaluated. ADOT Immersion Compression testing was conducted on LMLC specimens only.

The results of this research are:

- The moisture conditioning method (freeze-thaw and no freeze-thaw) did not significantly impact the retained strength ratios of HMA mixtures as measured by the Resilient Modulus test and Indirect Tensile Test. This observation agrees very well with the findings of the NCHRP 9-13 project.

- The impact of the compaction method on the retained strength ratios of HMA mixtures is affected by other factors such as type of mixture and addition of PC.

- The impact of adding PC to the HMA mixture showed inconclusive results.

- The ability of the modified AASHTO T-283 method to assess moisture sensitivity of HMA mixtures, with either the gyratory or the Marshall compaction methods, is questionable. This observation agrees very well with the findings of the NCHRP 9-13 project.

- The modified ADOT immersion compression procedure also produced results that did not completely define the moisture susceptibility of the mixes.

At the time this research began, the research team was also conducting Project 9-13 "Evaluation of Water Sensitivity Tests" for the National Cooperative Highway Research Program (NCHRP). Since the original plan was to piggyback the ADOT research onto the ongoing NCHRP 9-13 research, some of the conclusions of the NCHRP research are noteworthy. They are as follows:

- The freeze-thaw tensile strength was the same as the no freeze tensile strength in 56 of 68 possible comparisons.

- In general, the tensile strength ratios of the Superpave gyratory 6-inch diameter samples were larger than the Superpave gyratory 4-inch diameter samples.

- The tensile strength ratios obtained from the Marshall 4-inch samples were similar to the tensile strength ratios obtained from the Superpave gyratory 6-inch samples.

- Results obtained from the NCHRP 9-13 study indicate that the water sensitivity of the HMA mixtures as described by the states did not satisfactorily match the observed behavior of the mixtures in the AASHTO T-283 laboratory method.

- Public agencies presently using samples compacted with the Marshall 4-inch diameter compactor to determine the water sensitivity of HMA mixtures by AASHTO T-283 are encouraged to perform a structured laboratory testing program to determine the comparative behavior of their mixtures before switching to the Superpave gyratory 6-inch diameter compactor.

- Public agencies presently using samples compacted with the Superpave gyratory 4-inch diameter compactor to determine the water sensitivity of HMA mixtures by AASHTO T-283 should not switch to the Superpave 6-inch diameter gyratory compactor without performing a structured laboratory testing program to determine the comparative behavior of their mixtures.

In addition to documenting the UNR research previously described, this report also summarizes the previous research that occurred on these test sections in an attempt to enhance the UNR research findings.

This page left blank

INTRODUCTION

BACKGROUND

Design and Construction

In the summer of 1993, the Arizona Department of Transporation (ADOT) constructed four test sections to evaluate the newly developed Superpave Mix design procedures. These were the first Superpave test sections placed in Arizona. They were constructed on US 93 north of Kingman, Arizona.

The four SPS-9 Superpave test sections were constructed in conjunction with the SPS-1 test sections that were already part of the existing construction. The four Superpave test sections were added to the project by change order. Two of the test sections were constructed with a one-inch nominal size aggregate and two with a ¾ inch nominal size aggregate. By including these sections with the SPS-1 test sections, comparisons could be made between the various design strategies. The layout of the SPS-1 and SPS-9 test sections is shown in Figure 1. One ¾" and one 1" inch test section was placed on each end of the SPS-1 experiment to provide for replication. The SHRP SPS-1 sections are identified in the center of the figure. The sections identified as AZ are Arizona supplemental sections on the SPS-1 experiment. Each of the different colors represents a different structural layer type as identified in the legend.

The Superpave sections were constructed of seven inches of Hot Mix Asphalt (HMA) placed upon 4 inches of dense graded base. The seven inches of HMA was placed in lifts of 2.5 inches, 2 inches, and 2.5 inches. The asphalt binder was an AC-30 that met the specifications of a PG 64-16 required by the Superpave mix design procedures.

The mix designs for the ¾" and 1" Superpave test sections were performed by the Asphalt Institute as shown in Appendices 1 and 2. The gradations for these mix designs are shown in Figures 2 and 3. Aggregates for the 1" mix had 98% fractured faces while the ¾" mix had 72% fractured faces.

The Superpave design required 4% air voids and this resulted in a binder content of 4.9 % for the 1" mix and 5.2% for the ¾" mix. These were considerably higher binder contents than for mixtures designed by the Marshall mix design method. Marshall testing indicated void levels of 2 % - 3% at these binder contents.

The Asphalt Institute (AI) attempted to evaluate the moisture damage sensitivity using AASHTO T-283. The results of this testing, along with other mix properties are indicated in Table 1. It should be noted that there is no T-283 test result for the ¾" mixture. This was a result of a change to a different compaction device during the mix design phase. The new device compacted the specimens to an actual void level of 5.5% instead of the required 7%. This is outside the requirements of the test method and therefore could not be used. Unfortunately, there was a shortage of aggregate and additional testing could not occur before commencement of actual test section construction.

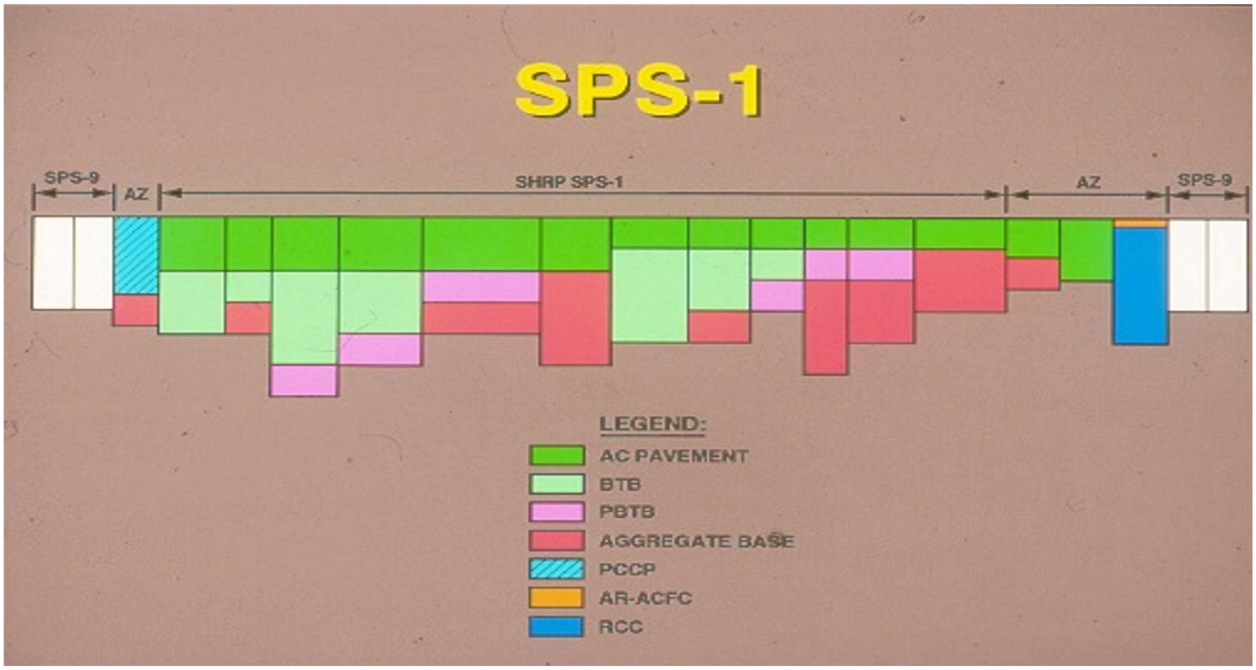

Figure 1. Layout of SPS-1 and SPS-9 Test Sections.

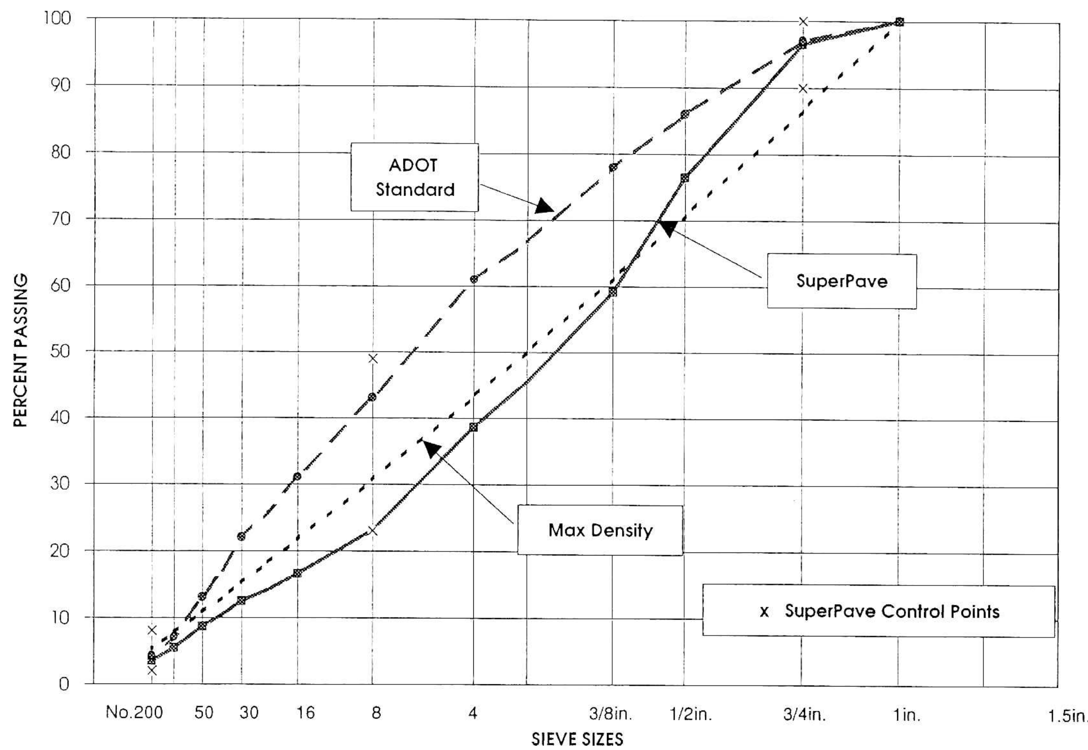

Figure 2. Gradation for ¾" Superpave Mix Design

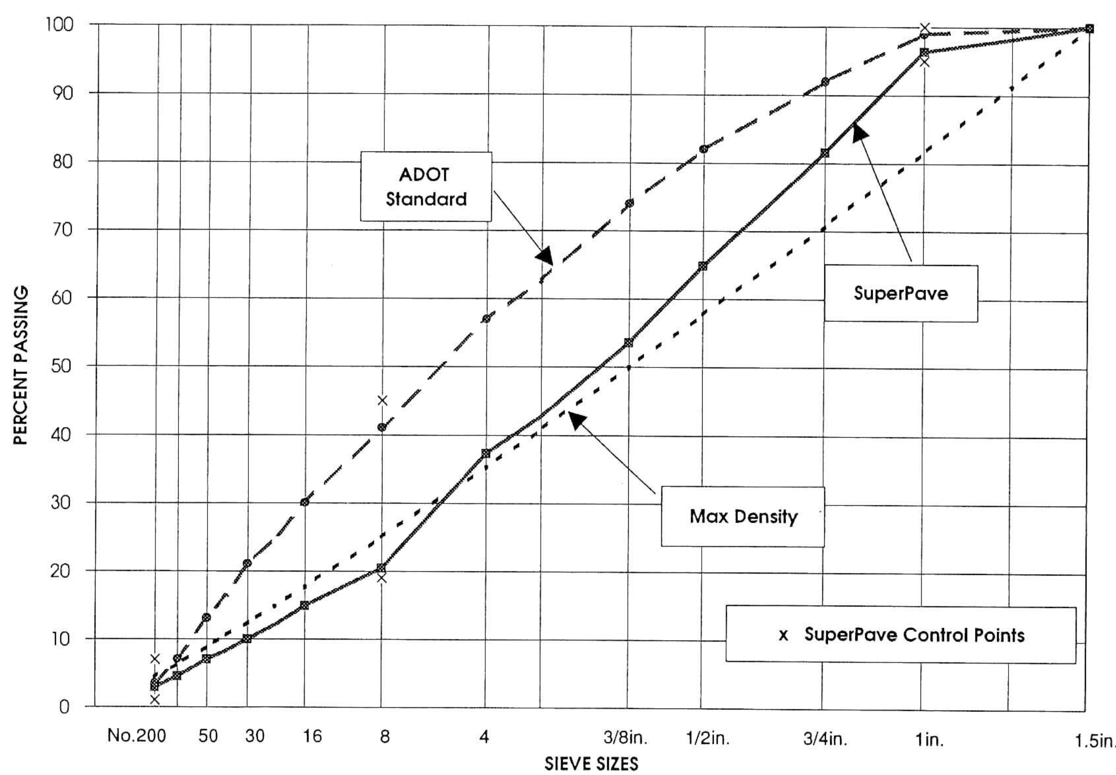

Figure 3. Gradation for 1" Superpave Mix Design

Table 1. ASPHALT INSTITUTE MIX DESIGN RESULTS

	19 mm Mix	25 mm Mix
% AC	5.2	4.9
Air Voids	4.1	4.0
Voids in Mineral Aggregate	14.6	14.2
Tensile Strength Ratio	----	82.6%

mm=millimeters

During construction of the test sections considerable segregation of the mix occurred due to its coarseness and a paver problem. However, density attainment was good with final mat densities ranging from 92% to 94% of maximum theoretical density. Plate samples were taken from the grade every 500 tons. Results of this testing indicated that both the ¾ inch and 1 inch mixtures were placed at 5% binder content.

Additional Testing Subsequent to Construction

Hamburg Wheel Tracking Tests

In August of 1994, Koch Materials, at their Terre Haute laboratory, conducted Hamburg Wheel Track testing on ten inch core samples provided by the Department. The results of this testing are included in Appendix 3 and summarized in Table 2. The percentile score indicated for each test represents the percentage of mixes that have scored at that value or worse for all materials tested by Koch. The Colorado DOT's Eurolab has also attempted to correlate the Hamburg Wheel Track Test results to field performance. They have assigned descriptive attributes such as high maintenance, etc. based on their studies. These descriptions are included with the percentile scores in Table 2.

In Table 2, reference is also made to an ADOT 1" base mix. This refers to a state-supplemental section that was constructed as part of the SPS-1 experiment (040159). It should be noted that this supplemental section is different than the one referenced in the University of Nevada – Reno (UNR) research. This section included an open graded friction course that was removed prior to wheel track testing. The mix design is included in Appendix 4. The binder content for this mix was 4.1% and the gradation plots above the maximum density curve, whereas the Superpave mixes plot below the maximum density curve. This mix design was used to construct this project except for the SPS-1 test sections that did not receive an asphalt concrete friction course (ACFC) and therefore used a different mix design. Both mix designs are included in Appendix 4. All the SPS-1 test sections as well as the State supplemental test sections used the 406 mix design that required 4.6% binder content.

As evident in Table 2 the test results for the between-wheelpath location are significantly different than the wheelpath locations. It should also be noted that at one location for the 1" Superpave mix, both the between and wheelpath test results indicate good performance.

Table 2. RESULTS OF HAMBURG WHEEL TRACKING TEST

Test Section	Core Location	Koch Percentile Score	Colorado DOT Classification
1" ADOT Base Mix	Between Wheelpath	50%	High Maintenance
	Right Wheelpath	70%	Fair
¾" Superpave Sample 1	Between Wheelpath	35%	High Maintenance
	Right Wheelpath	70%	Fair
1" Superpave Sample 1	Between Wheelpath	60%	Fair
	Right Wheelpath	70%	Fair
1" Superpave Sample 2	Between Wheelpath	90%	Good
	Right Wheelpath	90%	Good
¾"Superpave Sample 2	Between Wheelpath	50%	High Maintenance
	Right Wheelpath	70%	Fair

Repeated Simple Shear at Constant Height Test (RSCH)

Between June of 1995 and March of 1996 cores were retrieved by ADOT for testing conducted by Dr. Souza using RSCH equipment. This equipment was developed as part of the SHRP program. The RSCH test information is presented in terms of the predicted rut life in equivalent single axle loads (ESALs) and the permanent shear strain at a given number of cycles. The predicted rut life is often a projection, because the 5% shear strain criteria which is normally used to estimate rut life, is often not obtained within the 5099 cycles normally used for the test. The number of shear cycles related to traffic is estimated using the following equation which was developed during the SHRP research:

$$\text{Log(cycles)} = -4.36 + 1.240 * \log(\text{ESAL})$$

The number of cycles in RSCH necessary to obtain a strain in percent equal to 1/11 of the observed rut depth in inches was developed during the SHRP effort. Using the results of the above equation and the 1/11 relationship, rut depth can be estimated. Using these prediction techniques, the rut life (expressed in traffic loading) and measured strain at 5099 cycles are shown in Table 3 for all the Superpave mixes and the ADOT base mix.

The testing was conducted on cores obtained at 1.8 and 2.5 years after construction. Cores were retrieved in both the wheel path and between wheelpath locations. The between wheelpath locations represent light traffic. The results suggest that all the mixes should perform satisfactorily. However, the report, shown in Appendix 5, indicates that the 1" Superpave results could be questionable due to the amount of larger size aggregate observed in these cores compared to the two inch height of the specimen tested in the RSCH. With the larger aggregate it is possible for the large aggregate glued to the bottom platen to interfere with the large aggregate glued to the top platten causing erroneously high values.

Table 3. RESULTS OF REPEATED SIMPLE SHEAR AT CONSTANT HEIGHT TEST (RSCH)

Date of Core Retrieval	Test Section	Location	Rut Life (Million ESALs)	Strain at 5099 Cycles (%)
6/30/95	ADOT Base Mix #1	Non Wheelpath	9.55	3.05
6/30/95	ADOT Base Mix #2	Non Wheelpath	5.31	4.35
6/30/95	ADOT Base Mix #3	Wheelpath	38.3	1.31
6/30/95	ADOT Base Mix #4	Wheelpath	28.1	1.58
6/30/95	¾" Superpave #1	Non Wheelpath	7.3	3.59
8/23/95	¾" Superpave #2	Non Wheelpath	10.5	2.88
6/30/95	¾" Superpave #3	Wheelpath	18.8	2.02
8/23/95	¾" Superpave #4	Wheelpath	28.6	1.57
3/30/96	ADOT Base Mix #5	Wheelpath	85.0	0.53
3/20/96	ADOT Base Mix #6	Wheelpath	105	0.59
3/30/96	¾" Superpave #5	Wheelpath	61.3	0.79
3/30/96	¾" Superpave #6	Wheelpath	60.9	0.68
3/20/96	¾" Superpave #7	Wheelpath	71.4	0.61
3/20/96	¾" Superpave #8	Wheelpath	35.5	1.47
3/20/96	1" Superpave #1	Wheelpath	243	0.49
3/20/96	1" Superpave #2	Wheelpath	758	0.23

ESALs denotes Equivalent Single Axle Loads

FHWA Forensic Investigation

During the January 1998 site review, approximately 8 cores were retrieved from the three test sections: ¾" SP(040902), 1" SP(04A902), and ¾" ADOT(040162). These cores were provided to the FHWA to conduct additional testing. This testing consisted of rheology testing of the extracted binder, determination of volumetric properties, repeated shear testing at constant height, and X-ray Computed Tomography (XCT). In addition, the Asphalt Institute had some plant produced material from the original construction (i.e. 4.5 years earlier) that was used to conduct moisture sensitivity analysis on plant produced material. The results of this testing are contained in Appendix 6.

Binder Rheology Testing

The binder was extracted from each of the cores and tested to see if differences existed between test sections. It was noted that after 4.5 years the binder had aged from 64-16 at the time of construction to 82-10 for the ¾" SP and ¾" ADOT and to an 82 – 4 for the 1" SP. It was also noted that the low temperature stiffness of the ¾" ADOT mix was significantly higher than for the Superpave mixtures (approximately 25%). The m-value of binders for the ¾" ADOT is also approximately 25% higher than for the Superpave mixtures. Table 4 contains selected test results.

Table 4. SELECTED BINDER PROPERTIES FROM EXTRACTED ASPHALT

Property	ADOT ¾"	Superpave ¾"	Superpave 1"
S_{60} (MPa)	25.6	20.5	19.03
M_{60}	0.375	0.300	0.287

S_{60}=creep stiffness at 60 seconds. M_{60}=slope of log stiffness vs. log time curve at 60 seconds

Volumetric Properties

Volumetrics were determined on the cores using four techniques: dimensional analysis, saturated surface dried (SSD, parafilm procedures, and image analysis. The test results are shown in Table 5. These results are for the "as is" condition reported in reference 3. The study reported that the difference between the SSD voids and the parafilm void levels provides an indication of the amount of interconnected voids. This difference is 0.6% for the ADOT mix and 1.2% and 1.6% for the ¾" SP and 1" SP, respectively. This suggests that there may be more interconnected voids in the Superpave mixtures.

At the time of the January field evaluation there was concern that the as constructed voids were excessive. These results confirm the construction test results, and, that proper compaction had been achieved and high in place voids were not the cause for rutting.

Table 5. AIR VOID DETERMINATION

Procedure	ADOT ¾"	Superpave ¾"	Superpave 1"
Saturated Surface Dry	5.8%	4.5%	5.4%
Parafilm Method	6.4%	5.7%	7.0%
Geometric Analysis	7.2%	6.8%	7.9%
Image Analysis	1.2%	5.6%	4.8%

SHRP Shear Testing

The following SHRP shear testing was conducted on the retrieved cores: frequency sweep test (FSCH), simple shear (SSCH) and the repetitive shear (RSCH). The results of this testing is indicated in Table 6. The frequency sweep results were conducted at 40 degrees C.

RSCH testing indicated that both Superpave mixtures should be more rut resistant than the ADOT ¾' mix at 5,000 cycles of strain.

Table 6. RESULTS OF SHRP SHEAR TESTING

Test Type	ADOT ¾"	Superpave ¾"	Superpave 1"
FSCH (G*@10hz kpa)	937216	490035	787183
SSCH (Elastic Recover %)	80%	66%	68%
RSCH (Strain @5,000)	2.48%	1.25%	1.19%

FSCH = Frequency Sweep at Constant Height; SSCH = Simple Shear at Constant Height; RSCH = Repetitive Shear at Constant Height

X-Ray Computed Tomography (XCT)

The X-ray Computed Tomography was conducted to evaluate the void structure of the cores. The results of the image analysis on air voids are shown in Table 5. It should be noted that the size of the air voids can be measured using the XCT, and that only voids larger than a certain threshold are measured. This may be why the void determination for the ADOT ¾" mix is so low. It further indicates that the void structure in the dense graded mixture is smaller than in the Superpave mixes. The XCT also indicated that the Superpave mixes had interconnected void structures.

AASHTO T-283 Testing on Plant Produced Material

The Asphalt Institute had obtained field produced mix samples at the time of SPS-9 test section construction. This material was retrieved and AASHTO T-283 testing was conducted on specimens prepared with these materials. The tensile strength ratios are shown in Table 7. It should be noted that these mixtures had been stored for approximately 4.5 years before specimen preparation and testing. It is very common for mixtures stored for considerable time to exhibit very high TSR values as occurred here. It is generally considered that these values do not relate to field performance.

Table 7. AASHTO T-283 TESTING ON PLANT MIX

Mix Type	Tensile Strength Ratio (%)
Superpave ¾"	87.6%
Superpave 1"	95.7%

Field Distress Observations

Rut Depth Observations

As indicated in Table 8, rutting was not significant before 1996. Even in 1996 it was only just beginning to become of concern.

Fatigue Cracking Observations

The first noted observation of cracking in the Superpave test sections was reported by the Regional LTPP contractor in 1997. A subsequent visit by ATRC staff in the fall of 1997 indicated that significant fatigue cracking was occurring in the Superpave test sections. The ADOT base mix was not experiencing these problems.

As a result of this distress, a preliminary site review was made on January 22, 1998, by ADOT, FHWA, and LTPP personnel to determine if significant problems were occurring. Fatigue cracking was observed as evident in Photo No. 1. This cracking was observed in all four SPS-9 Superpave sections. Photo No. 2 indicates the rutting that was occurring. This was also typical of all four SPS-9 test sections.

Table 8. RUT DEPTH MEASUREMENTS

Date	Test Section	Location[1]	Rut Depth (inches)
9/12/95	¾" Superpave(040903)	North ¾" (MP47.01)	0.21
9/12/95	¾" Superpave(040902)	South ¾"(MP53.19)	0.06
9/12/95	1" Superpave(04A902)	North 1"(MP53.4)	0.11
9/12/95	1" Superpave(04A903)	South 1"(MP46.8)	0.15
6/25/96	¾" Superpave(040903)	North ¾" (MP47.01)	0.1
6/25/96	¾" Superpave(040902)	South ¾"(MP53.19)	0.2
6/25/96	1" Superpave(04A902)	North 1"(MP53.4)	0.2
6/25/96	1" Superpave(04A903)	South 1"(MP46.8)	0.1
6/25/96	ADOT Base Mix	(MP50.1)	0.05

1 – MP denotes milepost

Cores were retrieved from several of the sections to determine if moisture damage was occurring as suspected. Photo No. 3 shows the remains of a core attempt in the 3/4" Superpave test section (040902). Photo No. 4 is an example of a core retrieved from the ADOT base mix (040162). It was evident that the standard ADOT base mix that used cement as an anti-stripping agent was outperforming the Superpave mixtures. Photo No. 5 displays the segregation that was evident in the Superpave sections and Photo No. 6 displays the severe stripping of some of the cores retrieved. Note the lack of asphalt on some aggregate particles.

The cores retrieved during this review were provided to the FHWA (approximately 7 cores) to conduct additional bulk gravity testing and 3D tomography testing. The FHWA at this time felt that the Superpave mixes may have been compacted to unacceptably high air void contents and that the reported densities may in fact be in error.

As a result of the January 22 preliminary evaluation, it was felt that the Superpave test sections were experiencing moisture induced distress. Since the original Asphalt Institute design indicated that this should not be a problem, the efficacy of the AASHTO T-283 moisture damage test became suspect. It was also of concern to the Department that the standard mixes were performing satisfactorily while the Superpave mixes had essentially failed within four years after construction.

The Department then contracted with the University of Nevada – Reno to study this problem. The University was already performing NCHRP project 9-13 "Evaluation of Water Sensitivity Tests" that was investigating this same issue. An attempt was made to pattern the ADOT study after the 9-13 project to leverage available research. Even though the NCHRP project covered a wider range of materials and sample preparation methods, a few similarities existed between NCHRP 9-13 and the ADOT project. Both projects attempted to compare the performance of gyratory prepared 6-inch and 4-inch samples with 4-inch Marshall samples using the AASHTO T-283 test method. Also, both projects attempted to evaluate the effectiveness of the AASHTO T-283 method in measuring the moisture sensitivity of HMA mixtures.

Photo No. 1 Fatigue Cracking in 1" Superpave Section (04A902)

Photo No. 2 Rutting on ¾" Superpave Section (040902)

Photo No. 3 Remains of Core Attempt of ¾" Superpave Section (040902)

Photo No. 4 Intact Core of ADOT Base Mix Retrieved (040162)

Photo No. 5 Segregation Evident in Superpave Sections

Photo No. 6 Severe Stripping Evident in Core Retrieval Remains

In support of the UNR study, the Department obtained four and six inch core samples from two of the SPS-9 test sections (04A903 & 040903) and one SPS-1 test section (040162) on September 16-17, 1998. The cores from the 1” Superpave (SP) section and the 3/4” ADOT mix sections were retrieved from the right most wheel path of the travel lane. For the 3/4” SP mix section, the majority of the six inch cores separated at the lift interface and the four inch cores disintegrated during extraction. Attempts were made to obtain cores from the wheel path locations, the between wheel path locations, and from the shoulder but none were successful. No apparent advantage was noted for any of these locations. Intact core retrieval was an issue at all locations. As a result of these attempts, only a few six inch cores from the 3/4” SP mix section were available for testing. The core extraction report is included in Appendix 7.

This page left blank

UNR TEST PROGRAM

The test program completed in this research consisted of testing laboratory-mixed – laboratory-compacted samples and field cores. Both types of samples were tested using a modified AASHTO T-283 moisture sensitivity test method with and without the freeze/thaw option. The ADOT immersion compression test was also used to evaluate the moisture sensitivity of the 1" and 3/4" SP laboratory-mixed, laboratory-compacted (LMLC) mixtures. Table 9 shows the laboratory-testing program completed on the LMLC materials. It should be noted that the ADOT immersion compression test was conducted on the 3/4" ADOT mix at the mix design stage which prompted the use of 2% PC in the 3/4" ADOT mix.

The resilient modulus (Mr) and Indirect Tensile Strength (ITS) properties, measured using ASTM D4123 test method, were selected as measures of the mixture's strength for the modified AASHTO T-283 test. The unconfined compressive strength (fc) was used for the ADOT method.

The Mr test is a nondestructive test which can be conducted on the same sample before and after moisture conditioning. The ITS and fc tests are destructive tests and require different sets of samples under the dry and moisture conditioned stages. The immersion compression tests were conducted at the ADOT central laboratory in Phoenix. All other tests were conducted in the Pavements/Materials Laboratory of the University of Nevada, Reno.

The retained strength ratios are calculated based on the Mr, ITS, and fc properties as follow:

Mr ratio: $$\frac{\text{Mr of conditioned sample}}{\text{Mr of unconditioned sample}} \times 100$$

TS ratio: $$\frac{\text{TS of conditioned sample}}{\text{TS of unconditioned sample}} \times 100$$

fc ratio: $$\frac{\text{fc of conditioned sample}}{\text{fc of unconditioned sample}} \times 100$$

Table 9. EXPERIMENTAL PROGRAM FOR THE LMLC MIXTURES

Mix	% PC	AASHTO T-283			ADOT Immersion Compression 4” diameter Specimens.
		Gyratory 6” diam.	Gyratory 4” diam.	Marshall 4” diam.	
1” SP Mix	0	X		X	Y
	2				Y
3/4” SP Mix	0	X	X	X	Y
	2	X	X	X	Y
3/4”ADOT Mix	0	X	X	X	
	2	X	X	X	

Note: (1) Each X represents nine samples to be used to conduct the moisture sensitivity testing with and without freeze/thaw cycle.
(2) Each Y represents six samples to be used to conduct the moisture sensitivity testing.

The higher the retained strength ratio, the more resistant the HMA mix is to moisture damage.

The following conditions were used in the modified AASHTO T-283 test:

- 6-8% air voids
- 75% saturation
- 4 hours loose mix aging at 135^{o}C
- 96 hours compacted mix aging at room temperature

During the NCHRP 9-13 testing it was found that the above procedures could be used as a substitute for the current AASHTO T-283 procedures without any loss of accuracy. So these procedures were used for this research. However, the test method is referred to as the modified AASHTO T-283 to denote that the procedures were different.

Similarly, the ADOT immersion compression test procedures require that the specimens be prepared to 95%-97% of Marshall density. At the time the specimens were prepared, insufficient material remained to prepare the Marshall Specimens so this could not be verified. For this reason, the term modified has also been included with any reference to the ADOT immersion compression testing.

MATERIALS

The aggregates and binders used in this research were supplied by the FHWA Materials Reference Library (MRL) (Reno, NV) from samples obtained during the construction of the test sections. Two fifty-five gallon barrels of aggregates and one five gallon bucket of asphalt binder were obtained from MRL. The MRL aggregate samples were obtained from cold feed belts during asphalt concrete production for the SPS-1 and SPS-9 construction. The binder is an AC-30 (PG64-16) sampled during construction.

Core samples were obtained by ADOT personnel in September of 1998 and shipped to the Pavements/Materials Laboratory at the University of Nevada, Reno. Several unsuccessful attempts were made to obtain 4” and 6” cores from the ¾” SP mix section. On the other hand both 4” and 6” cores were successfully obtained from the 1” SP mix and the ¾” ADOT mix sections.

MIX DESIGNS

This research program evaluated HMA mixtures: 1" SP mix, ¾" SP mix, and ¾" ADOT mix. This project did not conduct the mix designs for these mixtures. The mix designs for the ¾" and 1" SP mixes were conducted by the Asphalt Institute (AI) as shown in Appendices 1 & 2. The mix design for the ¾" ADOT mix was conducted by Coronado Engineering & Consulting as shown in Appendix 4.

Because the aggregate used in this study was sampled from the cold feed, it was decided to use the field extraction gradations for the 1" SP and ¾" SP mixtures (2). In the case of the ¾" ADOT mix, field extraction data were not available which necessitated the use of the mix design gradation. It should be noted, however, that the mix design gradation for the ¾" ADOT mix compared very well with the gradations of the cold feed samples collected during construction. Table 10 summarizes the gradations and binder contents used for all three mixtures.

DATA ANALYSIS

As previously stated, the overall objective of this research was to evaluate the effectiveness of the modified AASHTO T-283 and the ADOT modified immersion compression methods in identifying the moisture sensitivity of the HMA mixtures used on the ADOT US 93 experiment. A nine sample test plan was used in the AASHTO T-283 testing: three samples were tested dry (dry set), three samples were tested after one cycle of freeze-thaw (F-T set), and three samples were tested after moisture saturation without freezing (NF-T set).

The factorial experimental plan summarized in Table 9 shows that the 1" SP mixtures were subjected to a partial factorial experiment, while the ¾" SP and ¾" ADOT mixtures were subjected to a full factorial experiment. The term LMLC refers to mixtures that have been prepared in the laboratory using aggregates and binders sampled during the construction of the project. In addition to the evaluation of the LMLC mixtures, cores were obtained from the pavement sections and tested in the laboratory using the modified AASHTO T-283 method. The following sections present the analysis of the data generated from this research effort.

The statistical analysis consisted of using the Analysis of Variance (ANOVA) program of the SAS Institute, Inc. The statistical difference in data was established using a P-value at an alpha of 5%, calculated using the Tuckey Method. This approach is a general linear model procedure least square means adjustment for multiple comparisons.

EVALUATION OF THE 1" SP MIXTURES

Results of the Modified AASHTO T-283 Method

The 1" SP mixtures were evaluated through a partial factorial experiment which included the gyratory 6" diameter samples and the Marshall 4" diameter samples without any additive (Table 9). Nine samples were prepared for each of the compaction methods and tested using the modified AASHTO T-283 method with and without freeze-thaw cycling. In addition, 4" and 6" cores were evaluated. The Mr and TS properties of the mixtures were evaluated at both the conditioned and unconditioned stages.

Table 10. AGGREGATE GRADATIONS AND BINDER CONTENTS USED FOR ALL THREE MIXTURES

Sieve Size	1” SP Mix Binder Content: 4.9%	3/4” SP Mix Binder Content: 4.2%	3/4” ADOT Mix Binder Content: 4.6%
	% Passing	% Passing	% Passing
1-1/2”	100	100	100
1.0”	95	100	100
3/4”	88	96	97
1/2”	74	69	86
3/8”	65	54	78
1/4”			67
#4	46	35	61
#8			43
#10	24	19	39
#16			31
#30			22
#40	11	10	17
#50			13
#80	6	6	
#100			7
#200	4.0	3.6	4.2

Tables 11, 12, and 13 summarize the moisture sensitivity data of the 1” SP mix using the modified AASHTO T-283 test. Figures 4 and 5 show the retained strength ratios of the 1” SP mix. The data in these figures indicate that there is no significant difference between the freeze-thaw and no freeze-thaw conditioning. In the majority of cases, the gyratory 6” samples showed significantly higher ratios than the Marshall 4” samples. The 4” cores showed higher ratios than the 6” cores. Using the modified AASHTO T-283 method, the 1” SP mix fails the retained strength ratio criterion of 80% in all cases except for the 4” cores.

Table 11. MOISTURE SENSITIVITY PROPERTIES OF 1" SP MIX WITHOUT PC ON THE GYRATORY 6" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.3	7.5	7.5	6.6	7.9	7.6	7.6	7.6	7.0
Mean Air Voids (%)	7.4			7.4			7.4		
Unconditioned Mr at 77°F (ksi)	615	515	584	500	NA	505	615	611	NA
Conditioned Mr at 77°F (ksi)				336	NA	363	477	455	NA
Mr ratio (%)				67	NA	72	78	74	NA
Mean Mr ratio (%)				70			76		
TS at 77°F (psi)	95	102	100	76	NA	78	57	71	NA
TS Ratio (%)				78			65		

1: psi = pounds per square inch; ksi = kips per square inch

Table 12. MOISTURE SENSITIVITY PROPERTIES OF 1" SP MIX WITHOUT PC ON THE MARSHALL 4" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.3	6.0	6.1	6.4	6.5	6.7	6.1	6.2	7.2
Mean Air Voids (%)	6.5			6.5			6.5		
Unconditioned Mr at 77°F (ksi)	694	953	831	954	907	916	889	911	793
Conditioned Mr at 77°F (ksi)				646	478	639	570	590	505
Mr ratio (%)				68	53	70	64	65	64
Mean Mr ratio (%)				64			64		
TS at 77°F (psi)	144	177	184	97	91	86	93	92	79
TS Ratio (%)				54			52		

1: psi = pounds per square inch; ksi = kips per square inch

Table 13. MOISTURE SENSITIVITY PROPERTIES OF THE CORES OBTAINED FROM THE 1" SP MIX SECTION USING THE AASHTO T-283 TEST

4-inch cores	Air Voids (%)	4.0	3.4	2.7	3.9	4.1	1.9	2.5	2.5	2.9
	Unconditioned Mr at 77°F (ksi)[1]	773	810	823	821	779	800	717	856	785
	Conditioned Mr at 77°F (ksi)	616	681	746	572	592	708	687	777	623
	Mr ratio (%)	80	84	91	70	76	89	96	91	79
	Mean Mr Ratio (%)	84								
6-inch cores	Air Voids (%)	4.2	3.3	3.8	3.4	3.9	3.5			
	Unconditioned Mr at 77°F (ksi)	654	855	782	814	775	826			
	Conditioned Mr at 77°F (ksi)	392	473	526	357	389	534			
	Mr Ratio (%)	60	55	67	44	50	65			
	Mean Mr Ratio (%)	57								

1: ksi = kips per square inch

Results of the Modified ADOT Immersion Compression Test

Table 14 summarizes the results of the ADOT immersion compression test on the 1" SP mix. The ADOT test was conducted on the untreated 1" SP mix and on the 1" SP mix treated with 2% PC. The measured fc ratios were 64% and 73% for the untreated and treated mixtures, respectively. Using the ADOT immersion compression test, both the untreated and treated 1" SP mixtures pass the retained strength ratio criterion of 50%.

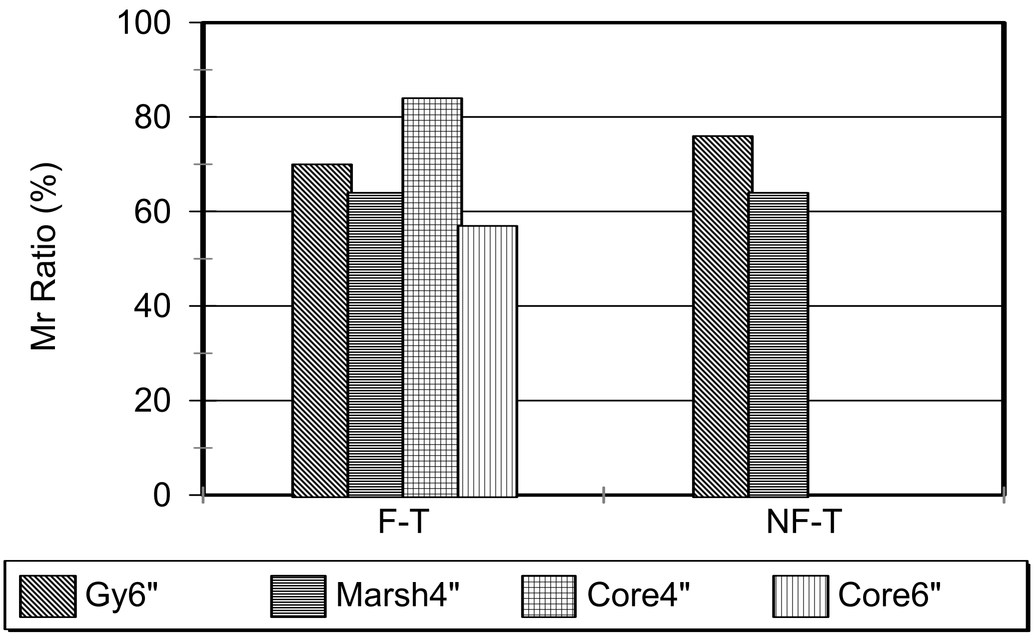

Figure 4. Mr ratios of the 1” SP mix

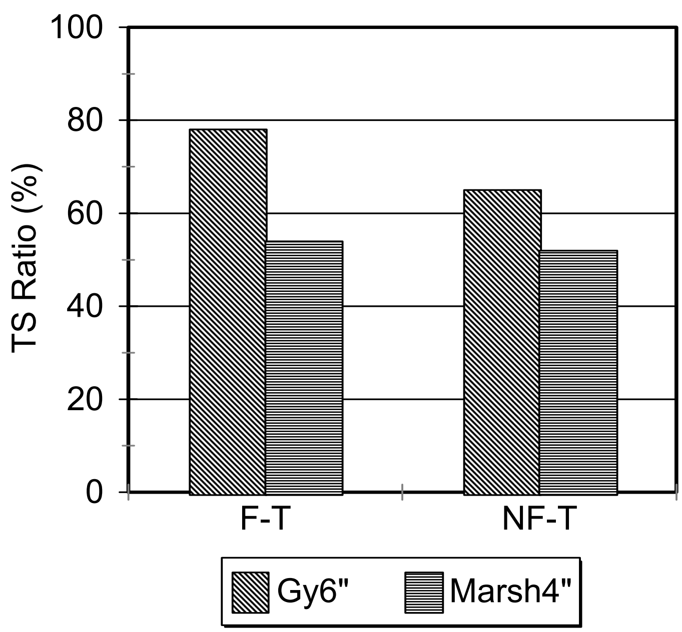

Figure 5. TS ratios for the 1” SP mix

Table 14. MOISTURE SENSITIVITY PROPERTIES OF 1" SP MIX ON MARSHALL 4" DIAMETER SAMPLES USING THE ADOT IMMERSION COMPRESSION TEST

Additive	Property[1]	Dry Set			Wet Set		
		1	2	3	4	5	6
None	Comp. Strength, fc (psi)	392	445	411	259	257	286
	Mean fc (psi)	416			267		
	fc ratio (%)	64					
2% PC	Comp. Strength, fc (psi)	433	474	474	338	342	331
	Mean fc (psi)	460			337		
	fc ratio (%)	73					

1: psi = pounds per square inch

EVALUATION OF THE 3/4" SP MIXTURES

Results of the Modified AASHTO T-283 Method

The 3/4" SP mix was subjected to a full factorial experiment as shown in Table 9. The full experiment allows the comparison of conditioning methods, comparison of compaction methods, and the evaluation of the impact of adding PC. Tables 15 through 21 summarize the data generated from the evaluation of the 3/4" SP mixtures. It should be noted that in all of the following comparisons, the retained strength ratios are used as the indicator.

Table 15. MOISTURE SENSITIVITY PROPERTIES OF 3/4" SP MIX WITHOUT PC ON THE GYRATORY 6" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.3	7.3	6.0	6.9	6.9	6.7	6.6	6.8	7.1
Mean Air Voids (%)	6.9			6.8			6.8		
Unconditioned Mr at 77°F (ksi)	850	1002	666	893	971	1138	1020	NA	778
Conditioned Mr at 77°F (ksi)				712	620	938	756	NA	682
Mr ratio (%)				80	64	82	74	NA	88
Mean Mr ratio (%)				75			81		
TS at 77°F (psi)	126	125	127	89	70	90	97	NA	91
TS Ratio (%)				66			75		

1. psi = pounds per square inch; ksi = kips per square inch

Table 16 MOISTURE SENSITIVITY PROPERTIES OF THE 3/4" SP MIX WITH PC ON THE GYRATORY 6" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	6.3	7.0	6.7	6.9	6.7	6.6	6.9	6.8	6.4
Mean Air Voids (%)	6.7			6.7			6.7		
Unconditioned Mr at 77°F (ksi)	741	865	850	780	826	757	938	781	885
Conditioned Mr at 77°F (ksi)				680	709	659	741	745	728
Mr ratio (%)				87	86	87	79	95	82
Mean Mr ratio (%)				87			85		
TS at 77°F (psi)	111	136	128	86	107	101	99	99	101
TS Ratio (%)				78			80		

1. psi = pounds per square inch; ksi = kips per square inch

Table 17. MOISTURE SENSITIVITY PROPERTIES OF 3/4" SP MIX WITHOUT PC ON THE GYRATORY 4" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	6.6	6.5	6.1	6.4	6.5	6.4	6.3	6.5	6.5
Mean Air Voids (%)	6.4			6.4			6.4		
Unconditioned Mr at 77°F (ksi)	881	1066	873	1006	1283	1189	768	857	833
Conditioned Mr at 77°F (ksi)				519	627	546	678	749	744
Mr ratio (%)				52	49	46	88	87	89
Mean Mr ratio (%)				49			88		
TS at 77°F (psi)	171	163	151	91	88	89	92	104	91
TS Ratio (%)				55			59		

1. psi = pounds per square inch; ksi = kips per square inch

Table 18. MOISTURE SENSITIVITY PROPERTIES OF THE 3/4" SP MIX WITH PC ON THE GYRATORY 4" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	6.1	6.4	6.6	6.3	6.6	6.1	6.3	6.5	6.2
Mean Air Voids (%)	6.4			6.3			6.3		
Unconditioned Mr at 77°F (ksi)	736	777	631	684	673	789	638	676	588
Conditioned Mr at 77°F (ksi)				576	540	525	593	596	582
Mr ratio (%)				84	80	67	93	88	99
Mean Mr ratio (%)				77			93		
TS at 77°F (psi)	122	137	143	112	114	101	107	110	106
TS Ratio (%)				81			80		

1. psi = pounds per square inch; ksi = kips per square inch

Table 19. MOISTURE SENSITIVITY PROPERTIES OF THE 3/4" SP MIX WITHOUT PC ON THE MARSHALL 4" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.7	6.4	7.9	7.2	7.6	7.3	7.2	7.3	7.5
Mean Air Voids (%)	7.3			7.4			7.3		
Unconditioned Mr at 77°F (ksi)	696	896	677	811	811	981	NA	677	877
Conditioned Mr at 77°F (ksi)				757	572	637	NA	423	632
Mr ratio (%)				93	71	65	NA	62	72
Mean Mr ratio (%)				76			67		
TS at 77°F (psi)	127	NA	122	101	104	104	99	92	85
TS Ratio (%)				82			74		

1. psi = pounds per square inch; ksi = kips per square inch

Table 20. MOISTURE SENSITIVITY PROPERTIES OF THE 3/4" SP MIX WITH PC ON THE MARSHALL 4" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	6.9	7.8	6.3	6.8	7.1	7.1	7.6	7.0	6.6
Mean Air Voids (%)	7.0			7.0			7.1		
Unconditioned Mr at 77°F (ksi)	896	856	1081	840	930	734	925	719	917
Conditioned Mr at 77°F (ksi)				694	692	694	702	697	685
Mr ratio (%)				83	74	95	76	97	75
Mean Mr ratio (%)				84			83		
TS at 77°F (psi)	138	141	141	120	110	117	111	103	99
TS Ratio (%)				83			75		

1. psi = pounds per square inch; ksi = kips per square inch

Table 21. MOISTURE SENSITIVITY PROPERTIES OF THE CORES OBTAINED FROM THE 3/4" SP MIX SECTION USING THE AASHTO T-283 TEST

Property	Dry Set		Freeze-Thaw (F-T) Set	
Air Voids (%)	4.4	4.8	5.2	8.4
Mean Air Voids (%)	4.6		6.8	
Unconditioned Mr at 77°F (ksi)	695	730	643	731
Conditioned Mr at 77°F (ksi)			324	257
Mr ratio (%)			50	35
Mean Mr ratio (%)			43	
TS at 77°F (psi)	166	168	93	76
TS ratio (%)			51	

1. psi = pounds per square inch; ksi = kips per square inch

Comparison of Conditioning Methods

The data presented in Figures 6 and 7 show that in 9 out of 12 cases the freeze-thaw and no freeze-thaw conditioning methods showed very similar retained strength ratios. In the three cases where some differences were present, in only one case was the difference significant

(Figure 6: Mr ratios of 49 and 88 for the gyratory 4" diameter samples). Based on this data, it can be concluded that both the F-T and NF-T conditioning methods generated the same retained strength ratios. This observation agrees very well with the findings of the NCHRP 9-13 project.

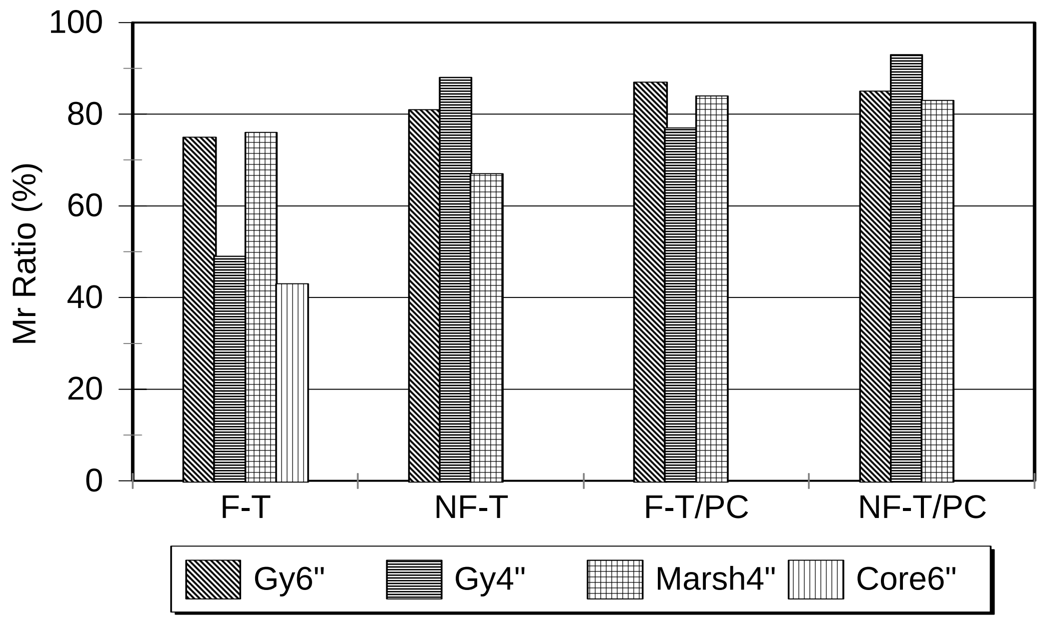

Figure 6. Mr ratios of the ¾" SP mix

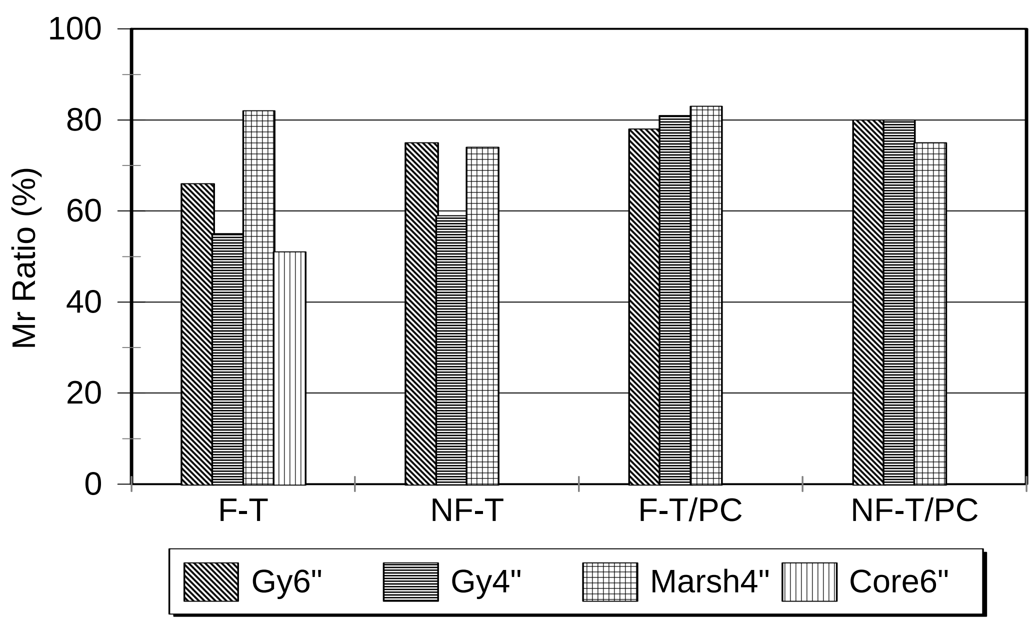

Figure 7. TS ratios of the ¾" SP mix

Comparison of Compaction Methods

Using the data presented in Figures 6 and 7, the methods of compaction can be compared on mixtures with and without PC. It can be seen that there is a better agreement between the gyratory 6" samples and the Marshall 4" samples than with the gyratory 4" samples. Except for the Mr ratio from the NF-T set, the gyratory 4" samples showed lower retained strength ratios than both the gyratory 6" and Marshall 4" samples. This observation agrees very well with the findings of the NCHRP 9-13 project. It can be seen that with the addition of PC, all compaction methods showed very similar retained strength ratios.

Impact of Adding Portland Cement

The impact of adding PC was evaluated at each of the compaction methods. The addition of PC moderately improved the retained strength ratios of the gyratory 6" samples. The addition of PC significantly improved the retained strength ratios of the gyratory 4" samples. The addition of PC slightly improved the retained strength ratios of the Marshall 4" samples.

Moisture Sensitivity of Cores

Figures 6 and 7 also present the moisture sensitivity properties of the 6" cores obtained from the 3/4" SP mix section. It should be noted that several cores were obtained from this section but only four cores were intact and were able to be tested. The Mr and TS of the cores were measured before and after freeze-thaw conditioning. Figures 6 and 7 show that the retained strength ratios of the cores are well below the retained strength ratios of the LMLC mixtures of the 3/4" SP mix. This would indicate that the cores have been subjected to prior field damage and the freeze-thaw conditioning has significantly accelerated their loss of strength. This observation may lead to the conclusion that a laboratory-based moisture sensitivity test would have to incorporate multiple freeze-thaw cycles to better simulate field conditions.

In summary, the modified AASHTO T-283 test results indicate that the 3/4" SP mix without PC fails the retained strength ratio criterion of 80% while the 3/4" SP mix with 2% PC passes the retained strength ratio criterion of 80% in the majority of the cases.

Results of the ADOT Immersion Compression Test

Table 22 summarizes the results of the ADOT immersion compression testing on the 3/4" SP mix. The ADOT test was conducted on the untreated 3/4" SP mix and on the 3/4" SP mix treated with 2% PC. The measured fc ratios were 53% and 71% for the untreated and treated mixtures, respectively. Using the ADOT immersion compression test, both the untreated and treated 3/4" SP mixtures pass the retained strength ratio criterion of 50%. However, the ADOT immersion compression test showed a significant improvement in the retained strength ratio with the addition of 2% PC.

Table 22. MOISTURE SENSITIVITY PROPERTIES OF 3/4" SP MIX ON MARSHALL 4" DIAMETER SAMPLES USING THE ADOT IMMERSION COMPRESSION TEST

Additive	Property[1]	Dry Set			Wet Set		
		1	2	3	4	5	6
None	Comp. Strength, fc (psi)	310	325	278	176	146	161
	Mean fc (psi)	304			161		
	fc ratio (%)	53					
2% PC	Comp. Strength, fc (psi)	301	379	249	230	257	230
	Mean fc (psi)	310			239		
	fc ratio (%)	71					

1. psi = pounds per square inch

EVALUATION OF THE 3/4" ADOT MIXTURES

Results of the Modified AASHTO T-283 Method

The 3/4" ADOT mix was subjected to a full factorial experiment as shown in Table 9. The full experiment allows comparison of conditioning methods, comparison of compaction methods, and evaluation of the impact of adding PC. Tables 23 through 29 summarize the data generated from the evaluation of the 3/4" ADOT mixtures. It should be noted that in all of the following comparisons, the retained strength ratios were used as the indicator.

Table 23. MOISTURE SENSITIVITY PROPERTIES OF 3/4" ADOT MIX WITHOUT PC ON GYRATORY 6" DIAMETER SAMPLES USING AASHTO T-283 TEST

Property	Dry Set			Freeze-Thaw F-T Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.5	6.8	6.8	7.1	7.3	6.7	7.1	7.0	7.0
Mean Air Voids (%)	7.0			7.0			7.0		
Unconditioned Mr at 77°F (ksi)	847	1064	1229	931	954	973	1091	1001	996
Conditioned Mr at 77°F (ksi)				NA	328	610	NA	365	380
Mr ratio (%)				NA	34	63	NA	36	38
Mean Mr ratio (%)				49			37		
TS at 77°F (psi)	105	133	151	42	45	53	30	29	32
TS Ratio (%)				36			23		

1. psi = pounds per square inch; ksi = kips per square inch

Table 24. MOISTURE SENSITIVITY PROPERTIES OF 3/4" ADOT MIX WITH PC ON THE GYRATORY 6" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.1	6.7	6.7	7.0	6.8	6.8	6.9	6.9	6.7
Mean Air Voids (%)	6.8			6.9			6.8		
Unconditioned Mr at 77°F (ksi)	1153	973	879	890	823	1030	1056	983	1069
Conditioned Mr at 77°F (ksi)				764	711	813	704	780	885
Mr ratio (%)				86	86	79	67	79	83
Mean Mr ratio (%)				84			76		
TS at 77°F (psi)	136	139	142	70	71	75	71	65	81
TS Ratio (%)				52			52		

1. psi = pounds per square inch; ksi = kips per square inch

Table 25. MOISTURE SENSITIVITY PROPERTIES OF 3/4" ADOT MIX WITHOUT PC ON GYRATORY 4" DIAMETER SAMPLES USING AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.6	7.1	7.0	7.1	7.2	7.4	7.1	7.4	7.2
Mean Air Voids (%)	7.2			7.2			7.2		
Unconditioned Mr at 77°F (ksi)	1155	967	965	946	1004	985	941	NA	968
Conditioned Mr at 77°F (ksi)				437	496	319	376	NA	453
Mr ratio (%)				46	49	32	40	NA	47
Mean Mr ratio (%)				42			44		
TS at 77°F (psi)	138	151	153	43	45	46	49	NA	55
TS Ratio (%)				30			35		

1. psi = pounds per square inch; ksi = kips per square inch

Table 26. MOISTURE SENSITIVITY PROPERTIES OF 3/4" ADOT MIX WITH PC ON GYRATORY 4" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	7.1	7.1	7.2	7.3	6.7	7.2	7.2	6.6	7.3
Mean Air Voids (%)	7.1			7.1			7.0		
Unconditioned Mr at 77°F (ksi)	1048	1144	1082	1017	939	NA	974	994	NA
Conditioned Mr at 77°F (ksi)				469	445	NA	628	670	NA
Mr ratio (%)				46	47	NA	64	67	NA
Mean Mr ratio (%)				47			67		
TS at 77°F (psi)	143	158	146	63	68	NA	59	70	NA
TS Ratio (%)				44			43		

1. psi = pounds per square inch; ksi = kips per square inch

Table 27. MOISTURE SENSITIVITY PROPERTIES OF 3/4" ADOT MIX WITHOUT PC ON MARSHALL 4" DIAMETER SAMPLES USING AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	8.0	6.7	8.0	7.8	7.8	7.6	7.7	7.5	7.7
Mean Air Voids (%)	7.6			7.7			7.6		
Unconditioned Mr at 77°F (ksi)	695	777	710	751	773	645	732	765	753
Conditioned Mr at 77°F (ksi)				195	263	240	170	209	235
Mr ratio (%)				26	34	37	23	27	31
Mean Mr ratio (%)				32			27		
TS at 77°F (psi)	164	179	180	35	43	42	38	48	47
TS Ratio (%)				23			25		

1. psi = pounds per square inch; ksi = kips per square inch

Table 28. MOISTURE SENSITIVITY PROPERTIES OF 3/4" ADOT MIX WITH PC ON MARSHALL 4" DIAMETER SAMPLES USING THE AASHTO T-283 TEST

Property[1]	Dry Set			Freeze-Thaw (F-T) Set			Non–Freeze-Thaw (NF-T) Set		
Air Voids (%)	6.1	7.1	7.1	7.0	6.8	6.5	6.7	6.9	6.6
Mean Air Voids (%)	6.8			6.8			6.7		
Unconditioned Mr at 77°F (ksi)	NA	757	721	829	1016	959	847	861	669
Conditioned Mr at 77°F (ksi)				369	359	363	269	258	327
Mr ratio (%)				45	35	38	32	30	49
Mean Mr ratio (%)				39			37		
TS at 77°F (psi)	NA	179	188	71	58	59	68	51	67
TS Ratio (%)				34			34		

1. psi = pounds per square inch; ksi = kips per square inch

Table 29. MOISTURE SENSITIVITY PROPERTIES OF THE CORES OBTAINED FROM THE 3/4" ADOT MIX SECTION USING THE AASHTO T-283 TEST

4-inch cores	Air Voids (%)	5.8	6.7	5.7	6.5	7.0	6.4	6.7	6.6
	Unconditioned Mr at 77°F (ksi)	684	599	646	589	581	595	674	591
	Conditioned Mr at 77°F (ksi)	440	467	520	476	413	445	493	559
	Mr ratio (%)	64	78	80	81	71	75	73	95
	Mean Mr Ratio (%)	77							
6-inch cores	Air Voids (%)	6.7	6.4	6.3	6.2	5.8	6.2	5.9	
	Unconditioned Mr at 77oF (ksi)	536	543	649	593	596	529	491	
	Conditioned Mr at 77oF (ksi)	444	452	503	463	545	499	465	
	Mr Ratio (%)	83	83	78	78	91	94	95	
	Mean Mr Ratio (%)	86							

1. psi = pounds per square inch; ksi = kips per square inch

Comparison of Conditioning Methods

The data in Figures 8 and 9 show that in 11 out of 12 cases the freeze-thaw and no freeze-thaw conditioning methods showed very similar retained strength ratios. In one case the Mr ratio was increased from 47% to 67% as the method of conditioning changed from F-T to NF-T (Figure 8: Mr ratio of the gyratory 4" sample). Based on this data, it can be concluded that both the F-T and NF-T conditioning methods generated the same retained strength ratios. This observation agrees very well with the findings of the NCHRP 9-13 project.

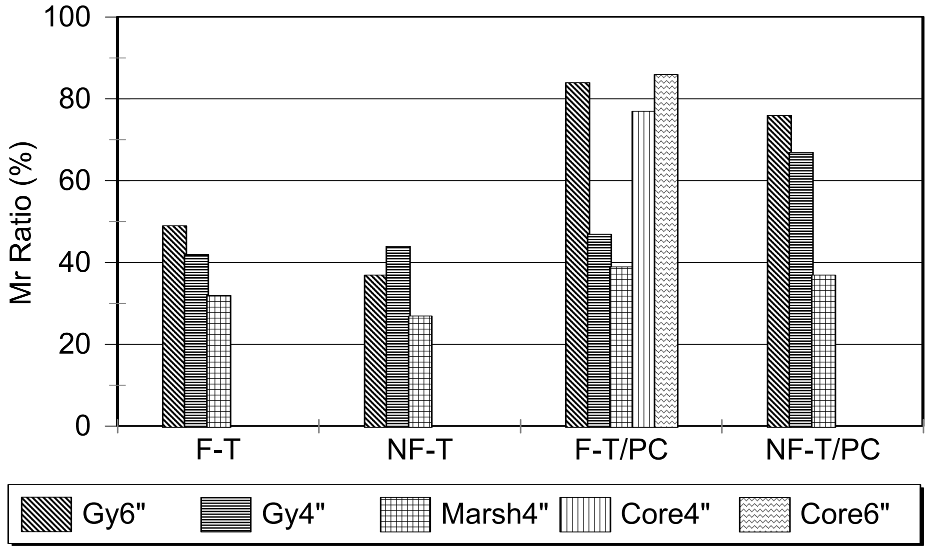

Figure 8. Mr ratios of the ¾" ADOT mix

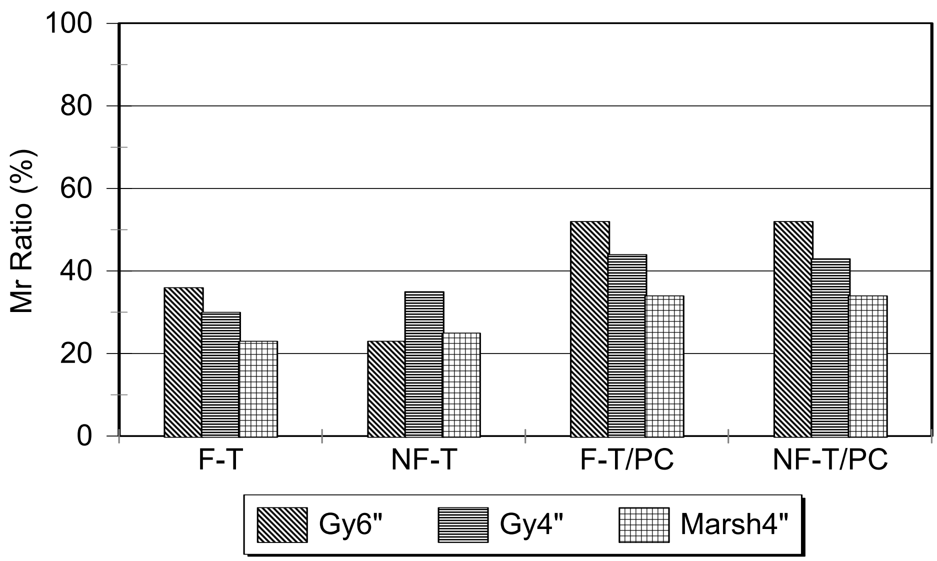

Figure 9. TS ratios of the ¾" ADOT mix

Comparison of Compaction Methods

Using the data presented in Figures 8 and 9, the methods of compaction can be compared on mixtures with and without PC. For the mixtures without PC, it can be seen that there is good agreement among the retained strength ratios generated by all three types of compaction methods. This observation does not agree with the findings of the NCHRP 9-13 project.

The addition of PC has caused some differences among the retained strength ratios generated by all three compaction methods. The gyratory 6" samples showed the highest retained strength ratios followed by the gyratory 4" samples, followed by the Marshall 4" samples. The poor performance of the Marshall 4" samples with PC has contradicted the observations made in the evaluation of the 3/4" SP mixtures, the evaluation of the field cores and the field performance of the 3/4" ADOT mix section. This prompted the researchers to duplicate the experiment of the Marshall 4" samples on the 3/4" ADOT mix with PC. The results of the second trial confirmed the findings of the first trial.

Impact of Adding Portland Cement

The impact of adding PC was evaluated at each of the compaction methods. The addition of PC significantly improved the retained strength ratios of the gyratory 6" samples while the addition of PC slightly improved the retained strength ratios of the gyratory 4" and Marshall 4" samples.

Moisture Sensitivity of Cores

Figure 8 also presents the moisture sensitivity properties of the 6" and 4" cores obtained from the 3/4"ADOT mix section. The Mr of the cores were measured before and after freeze-thaw conditioning. Figure 8 shows that the retained strength ratios of the cores are well above the retained strength ratios of the LMLC mixtures of the 3/4" ADOT mix prepared with the gyratory 4" and Marshall 4" samples. In the meantime, the retained strength ratios of the cores coincide well with the retained strength ratios generated by the gyratory 6" samples.

In summary, the modified AASHTO T-283 test showed that the 3/4" ADOT mixtures with and without PC fail the retained strength ratio criterion of 80%. However, using the gyratory 6" samples and 6" field cores, the modified AASHTO T-283 showed that the 3/4" ADOT mix with 2% PC passes the retained strength ratio criterion of 80%.

This page left blank

COMPARISON OF VARIOUS MIXTURES

Based on the analysis of the data generated from the modified AASHTO T-283 test, some comparisons of the various mixtures can be done. Figures 10 through 13 show a graphical comparison of the various mixtures. It should be noted that the Mr and ITS ratios have shown consistent results in the majority of the cases. Figures 10 and 11 compare the various mixtures without PC using the Mr and TS ratios, respectively. The data in these figures indicate that the 1” and 3/4” SP mixtures have better resistance to moisture damage than the 3/4” ADOT mix. In the majority of the cases, the 3/4” SP mix showed better moisture resistance than the other two mixes.

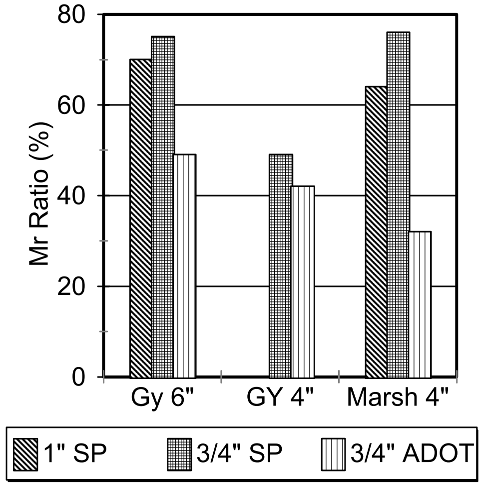

Figure 10. Comparison of Mr ratios of various for mixtures without PC

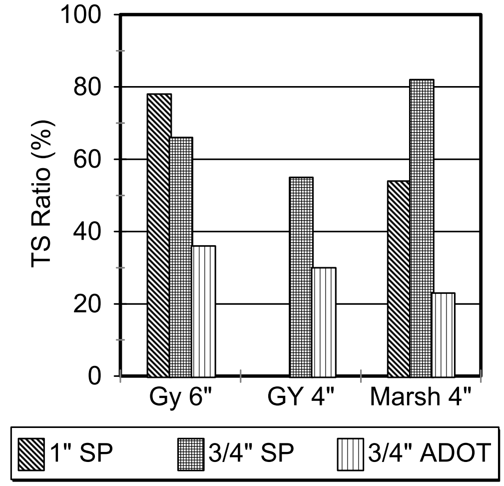

Figure 11. Comparison of TS Ratios Various Mixtures Without PC

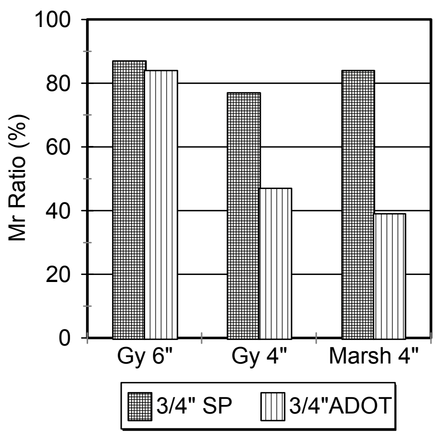

Figure 12. Comparison of Mr Ratios of Various Mixtures with PC

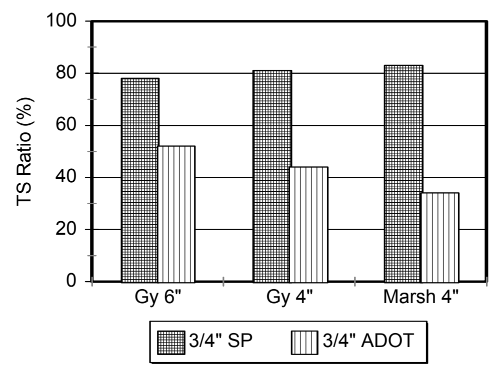

Figure 13. Comparison of TS Ratios of Various Mixtures with PC

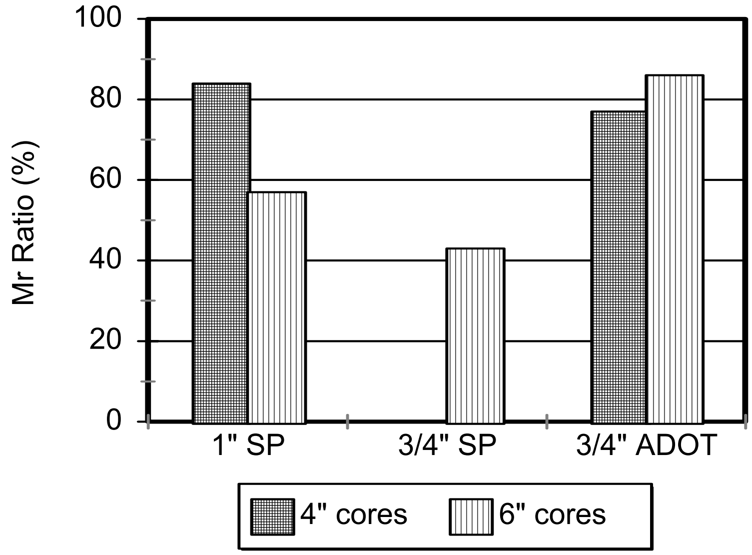

Figure 14. Comparison of the Moisture Sensitivity of Core Samples

Figures 12 and 13 compare the various mixtures with PC using the Mr and ITS ratios, respectively. The data in these figures show that the 3/4" SP mix exhibited very significant improvement in resistance to moisture damage with the addition of PC. On the other hand, the 3/4" ADOT mix only showed improvement with the gyratory 6" samples.

The above comparisons of the various mixtures have been made based on the evaluation of the LMLC mixtures. These observations contradict the findings from the core testing as shown in Figure 14. The moisture sensitivity of the field cores from the three sections indicate that the 3/4" ADOT mix has the best resistance to moisture damage followed by the 1" SP mix and lastly the 3/4" SP mix. It should be noted that the cores from the 3/4" ADOT mix section have a higher air void content than the cores from the 1" SP mix section (6.30% vs 3.33%). In addition, the cores from the 3/4" ADOT mix section have air voids that are closer to the LMLC samples than those of the 1" SP mix section. Considering the closeness in air void content between field cores and LMLC samples of the 3/4" ADOT mix, as compared to the larger difference in the air void contents between SP field cores and LMLC samples, it can only be concluded that the modified AASHTO T-283 has some limitations when predicting field performance of HMA mixtures.

This page left blank

COMPARISON OF LABORATORY TESTS TO FIELD PERFORMANCE

SUBJECTIVE EVALUATION OF LABORATORY TESTS' ABILITY TO PREDICT FIELD PERFORMANCE

Due to the importance of this project to the Department and its uniqueness, an attempt has been made to rate each of the tests that have been conducted to date on these sections, including the testing performed previous to this research. This rating is simply a subjective rating of satisfactory or unsatisfactory based upon perceived relationships to field distress. The results in Table 30 are not separated by 4-inch or 6-inch core size, as the intent is to define the suitability of the procedure itself. As indicated by the results presented in the Table, none of the test methods satisfactorily predicted field performance.

Table 30. RATING OF LABORATORY TESTS' ABILITY TO PREDICT FIELD PERFORMANCE

Test Method	¾" Superpave	1" Superpave	¾ " ADOT
Modified AASHTO T-283	U	U	U
Modified Immersion Compression	U	U	U
Hamburg Wheel Tracking Test	U	U	U
RSCH	U	U	U

Note: S = Satisfactory Prediction
U = Unsatisfactory Prediction

DISCUSSION OF LABORATORY TEST RESULTS AND IMPLICATIONS TO FIELD PERFORMANCE

One of the problems with evaluating the suitability of a particular laboratory test's ability to predict actual field performance after the fact, is determining what binder rate to use for laboratory specimen preparation. For example, Table 31 indicates the various binder contents that were used for the testing conducted in this study and the field binder contents determined in other studies.

Table 31. ASPHALT BINDER CONTENTS FOR LABORATORY TESTING AND FIELD CONDITIONS

Test or Field Record	¾” Superpave	1” Superpave	¾” ADOT Marshall
Asphalt Institute Design	5.2%	4.9%	NA
Consultant Mix Design			4.6%
Modified AASHTO T-283	4.2%	4.9%	NA
Modified Immersion Compression Test	4.2%	4.9%	
LTTP Field Records	4.2%	4.9%	
ADOT Construction Records	5.0%	5.0%	
Hamburg Wheel Tracking	Core	Core	
RSCH	Core	Core	

SUMMARY AND RECOMMENDATIONS

This research effort was carried out to assess the feasibility of using laboratory-based moisture sensitivity test, namely the modified AASHTO T-283 and the modified ADOT immersion compression tests, to predict the performance of the pavement sections on the ADOT US 93 experiment. LMLC and field cores were tested under the modified AASHTO T-283 method using both the freeze-thaw and no freeze-thaw conditioning methods. Three methods of compaction were used to assess the impact of compaction techniques on the measured moisture sensitivity of HMA mixtures. Also the impact of adding PC to the HMA mixtures was assessed through testing mixtures with and without PC. The ADOT immersion compression test was only conducted on the LMLC mixtures of the 1" SP and 3/4" SP sections. Based on the laboratory experiment completed in the study and the data analysis presented in this report, the following recommendations can be made:

- The moisture conditioning method (freeze-thaw and no freeze-thaw) did not significantly impact the retained strength ratios of HMA mixtures as measured by the Mr and ITS properties. This observation agrees very well with the findings of the NCHRP 9-13 project.

- The impact of the compaction method on the retained strength ratios of HMA mixtures is affected by other factors such as: type of mixture and the addition of PC. The data produced in this study showed that the impact of compaction method was significant on the 3/4" SP mix without PC. But when PC was added to the same mix, the impact of compaction method was insignificant (Figure 15). In the case of the 3/4" ADOT mix, the opposite trends were shown, where the impact of compaction method was insignificant in the absence of PC but became significant when PC was added (Figure 16).

- The impact of adding PC to the HMA mixture showed mixed results. The addition of PC was significant in improving the moisture sensitivity of the 3/4" SP mix under all three types of compaction methods (Figure 15) while it was only significant in improving the moisture sensitivity of the 3/4" ADOT mix under the gyratory 6" compaction method (Figure 16).

- The data generated in this experiment indicate that the ability of the modified AASHTO T-283 method to assess moisture sensitivity of HMA mixtures, with either the gyratory or the Marshall compaction methods, is questionable. In the case of the LMLC mixtures, the modified AASHTO T-283 failed to show the impact of adding PC to the 3/4" ADOT mix. On the other hand, the modified AASHTO T-283 testing of the field cores showed results which are consistent with the observed field performance of the pavement sections. This would indicate that the modified AASHTO T-283 method may have some serious limitations which are compounded when used with laboratory fabricated samples. This observation agrees very well with the findings of the NCHRP 9-13 project.

- The limited data generated with the ADOT immersion compression testing showed that this test was not successful at identifying moisture sensitive mixtures on this project. In this study, the ADOT immersion compression test indicated that the 1" SP and 3/4" SP mixtures are prone to moisture damage even after being treated with 2% PC. However, since Superpave test sections employing cement were not constructed, the accuracy of this prediction cannot be confirmed.

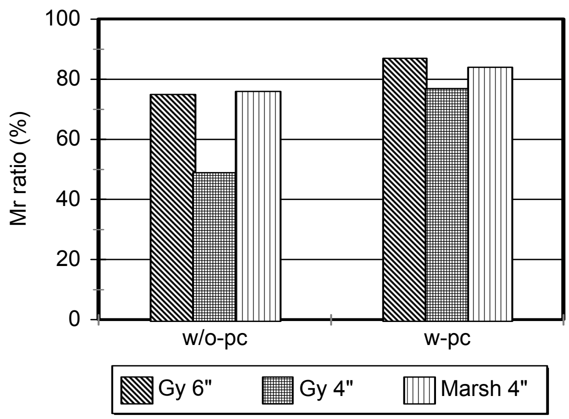

Figure 15. Impact of Compaction Method on Mr Ratios for ¾" Mix

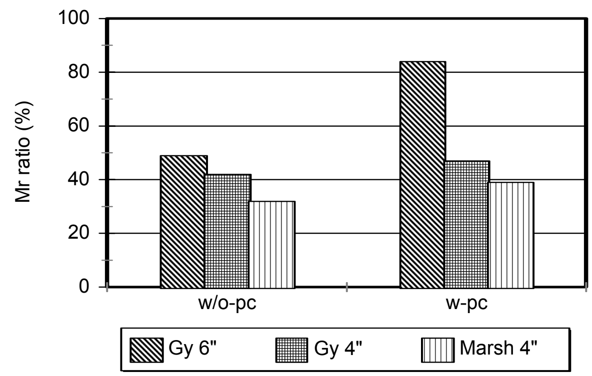

Figure 16. Impact of Compaction Method on Mr Ratios, ¾" ADOT Mix

REFERENCES

1. NCHRP Research Project 9-13, "Evaluation of Water Sensitivity Tests," Research Project Conducted By the University of Nevada, Reno, January 1998 to March1999.

2. FHWA Long Term Pavement Performance Specific Pavement Studies, "Arizona SPS-9P: Construction Report on Site 040900/04A900," Prepared by Western Region Contractor, Nichols Consulting Engineers, Chtd., December 1997.

3. Shashidhar, N., D'Angelo, J., Way, G., Bastian, E., and Harman, T., "Forensic Analysis of Arizona's US-93 Superpave Sections," Draft Report, Federal Highway Administration, Washington, D.C., 1999.