EVALUATION OF PROCEDURES USED TO PREDICT MOISTURE DAMAGE IN ASPHALT MIXTURES: EXECUTIVE SUMMARY

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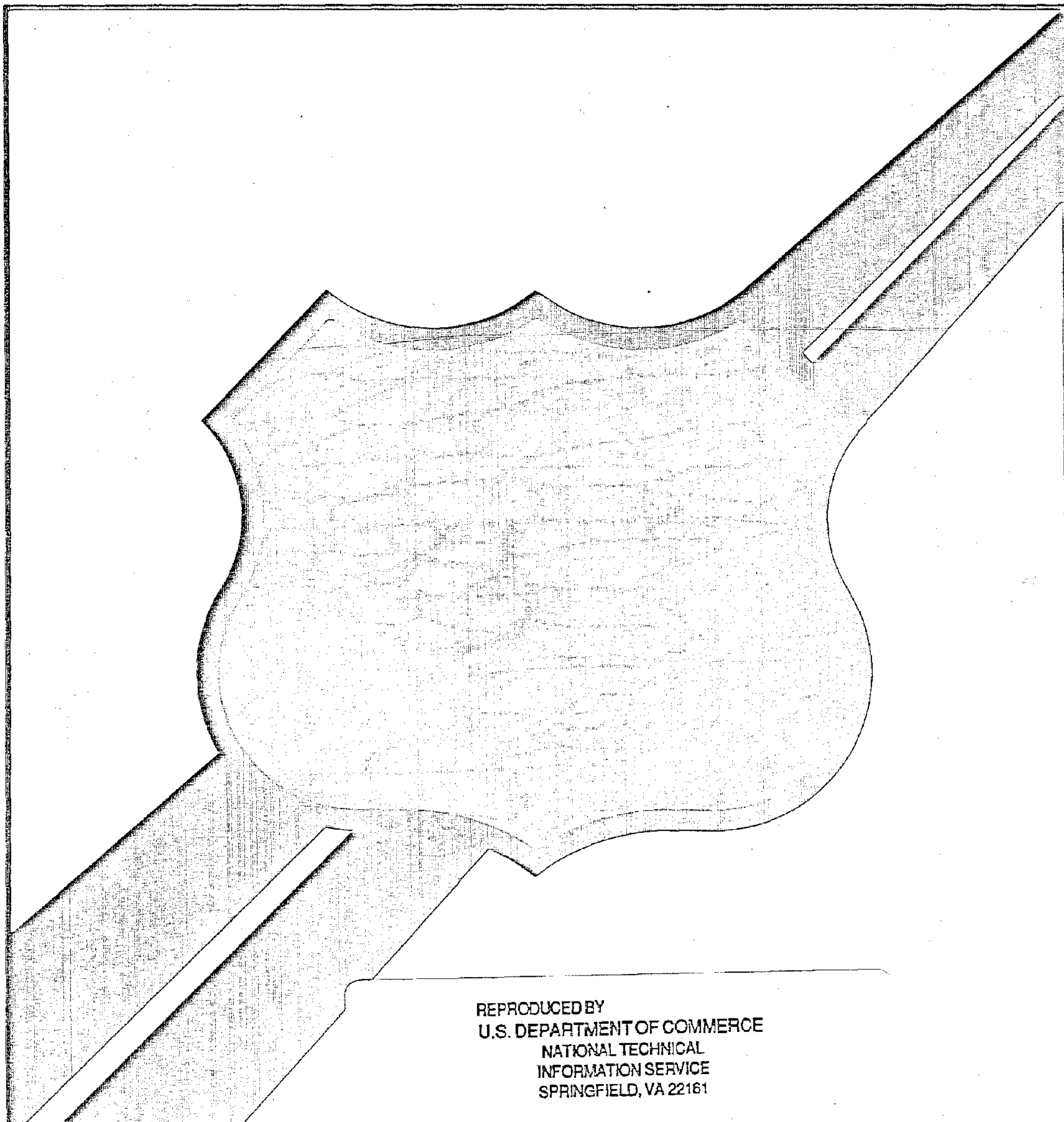
September 1986



FOREWORD

This summary report presents the results of research conducted to compare several procedures used to evaluate the moisture susceptibility of asphalt mixtures. Numerous procedures are currently available, and new or modified procedures are continually being developed. This research was performed to assist State highway officials who must choose or develop a procedure for their use.

The contributions of the four State transportation agencies, namely Georgia, Mississippi, Utah, and Maryland, which provided materials and mixture design information are gratefully acknowledged.

This report is being widely distributed. Copies for State highway agencies are disseminated through the division offices. Additional copies for the public are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. A Final Report, FHWA/RD-86/091, which presents a detailed account of the study, is also available through the National Technical Information Service (NTIS).

Richard E. Hay, Director
Office of Engineering and
Highway Operations
Research and Development

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15. Supplementary Notes

Performed by the Pavements Division (HNR-20) in response to concerns expressed by State highway officials at a conference on asphalt stripping held in Atlanta, Georgia in 1982. Project staff included H. J. Lentz and R. N. Jester.

16. Abstract

Procedures for evaluating the moisture susceptibility of asphalt mixtures were compared by performing them on mixtures having a known history of susceptibility. Data included the retained ratios, visual stripping, mechanical values (tensile strength, stability, etc.), saturation, and swell. The most promising procedures appeared to be the NCHRP 246 and NCHRP 274. Moisture susceptibility was not effectively predicted by the 1-Minute Boiling Water, 10-Minute Boiling Water, Immersion-Compression, Marshall-Immersion, and Dynamic Tumbling procedures. The NCHRP 246 procedure (often referred to as the Lottman procedure) contained two parts: one for short-term pavement performance, and one for long-term pavement performance. The short-term part was not found to be useful with regards to predicting performance. An 80-percent pass/fail criterion was chosen for both tensile strength ratios in the NCHRP 246 and NCHRP 274 procedures, and 70 percent for the M_r test. Ten percent or greater visual stripping generally indicated unacceptable damage in all procedures performed on compacted mixtures.

The data indicated that a freezing period, or higher air void levels, can be beneficial for evaluating moisture susceptibility. The degree of saturation was found to be important in that sufficient water must enter a specimen; however, saturation was not found to be the dominant factor affecting moisture damage. The effects of saturation were masked by other mechanisms such as the type of mechanical test, air void levels, and freezing. There was no conclusive evidence that high saturations or oversaturation due to vacuum conditioning adversely affected the test results.

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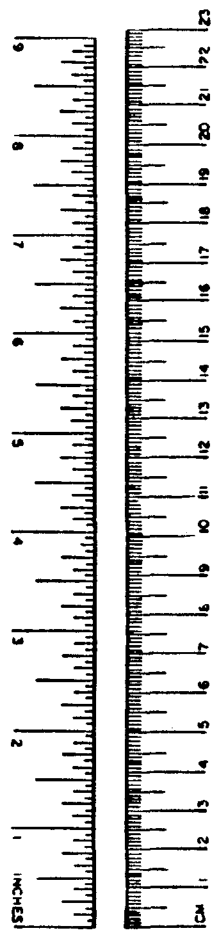
METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

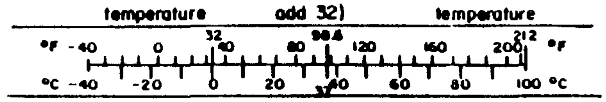


TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Numerous procedures for predicting whether an asphalt pavement will be susceptible to moisture damage have been developed over the past 50 years, and they are continually evolving. Most present procedures evaluate the actual mixture that will be used in the pavement, usually in a compacted state, but they generally employ different methods for fabricating, curing, conditioning, and testing the specimens.

This study was initiated in 1983 to compare several new procedures with each other and with certain traditional procedures which have been used by State highway agencies. Several States were contacted to supply aggregates, asphalts, and antistripping additives. Mixtures were limited to hot-mixed, dense-graded types meeting the following requirements: (1) a known history of performance must be available, (2) design information must be available so that the mixture could be duplicated, and (3) damage must be shown by the visual stripping of the pavement and be related primarily to the type of aggregate. Although the procedures may be applicable to forms of moisture damage other than the usual type, where water strips the asphalt from the aggregate, it was intended in this study to eliminate uncommon forms of moisture damage which could provide unusual data. Also, since the source of an asphalt (supplier or crude) can change from year to year, mixtures where damage was found to be highly influenced by the type of asphalt were not considered good candidates.

MATERIALS AND MIXTURE DESIGNS

Nine aggregates and the companion asphalts were provided by four State highway agencies. Mixture designations were based on the State which provided the materials, followed by the location or name of the contractor which supplied the aggregate:

1. Georgia-Grayson (hydrated lime)
2. Georgia-Kennesaw (hydrated lime)

3. Utah-Staker (Pave Bond AP Special)
4. Georgia-Norcross (hydrated lime)
5. Georgia-Rome (Pave Bond LP)
6. Mississippi-Hattiesburg #1
7. Mississippi-Hattiesburg #2 (Pave Bond Special)
8. Maryland-Julian (Acra 500)
9. Maryland-Genstar

Antistripping additives, also listed above, were provided except for the Mississippi-Hattiesburg #1 and Maryland-Genstar mixtures. Thus a total of 16 mixtures were used to evaluate the moisture damage procedures.

State highway agency job mixture formulas were duplicated as closely as possible. Optimal asphalt contents were based on obtaining a 4-percent air void level using the 50-blow Marshall method of compaction. Standardized AASHTO(1) methods for sampling and testing were used during the mixture designs.

MOISTURE DAMAGE PROCEDURES

Six procedures were chosen for comparison in this study:

1. NCHRP 246 (tensile strength and resilient modulus M_r)(2) (Lottman procedure)
   a. Short-Term
   b. Long-Term
2. NCHRP 274 (tensile strength)(3)
3. AASHTO T 165-82 Immersion-Compression(1)
4. Marshall-Immersion (stability and flow)
   a. Dry Evacuation
   b. Wet Evacuation (modified procedure)
5. Dynamic Tumbling (tensile strength and weight loss)

6. ASTM D 3625-77 Boiling Water[4]
    a. 1-Minute Boiling
    b. 10-Minute Boiling (modified procedure)

The NCHRP 246 procedure contained a long-term and a short-term part, the Marshall-Immersion procedure was modified so that two methods of vacuum saturation were evaluated, and the Boiling Water procedure was modified so that both a 1-minute and a 10-minute time of boiling were evaluated. Each of these was treated as a separate procedure, giving a total of nine procedures. All mixtures were not tested under the Short-Term NCHRP 246 procedure because the initial results were not promising. The procedures were performed as outlined in table 1. Modifications could lead to different relationships and conclusions.

The Marshall-Immersion and Dynamic Tumbling procedures have not been published. The Marshall-Immersion procedure was proposed for standardization to the American Society for Testing and Materials (ASTM) Committee D04 on Road and Paving Materials in 1982. The vacuum conditioning method for this procedure was termed "dry evacuation" under this study. A second approach, which was termed "wet evacuation" under this study, was also evaluated because it was easier to perform.

The Dynamic Tumbling procedure, provided by the Nevada Department of Transportation, was evaluated on a limited basis. Moisture susceptibility is based on the percent loss of specimen weight after dynamic action. Mixtures with losses greater than 25 percent are considered to be moisture-susceptible. The indirect tensile strength test was included in this procedure as an additional measurement of damage.

Retained ratios were computed as the wet (moisture conditioned) mechanical value divided by the dry (unconditioned) mechanical value except for Marshall-Immersion flow ratios. Because flow increased with damage, the ratios were calculated as the dry value divided by the wet value.

Table 1. Summary of moisture damage procedures evaluated.

	NCHRP 246 Long-Term	NCHRP 246 Short-Term	NCHRP 274	AASHTO T 165-82 Immersion-Compression
Specimen Size height x diameter	2.5 in x 4 in (63.5 mm x 102 mm)		2.5 in x 4 in (63.5 mm x 102 mm)	4 in x 4 in (102 mm x 102 mm)
Number of Specimens	3 Dry 3 Wet	3 Wet	3 Dry 3 Wet	3 Dry 3 Wet
Compaction (Moisture Damage Test)	Marshall, 50 blows		Marshall, variable blows (to meet void range)	Double Plunger, variable level (to meet void range)
Air Void Range	3 to 5		6 to 8	5 to 7
Vacuum Conditioning (wet specimens)	26 in (660 mm) Hg for 30 min, remove vacumm and keep specimens submerged for another 30 min		20 in (508 mm) Hg for 1 to 5 min to obtain a saturation level of 55 to 80 % based on void volume	None
Moisture Conditioning (wet specimens)	15 h freezing at -0.4 °F (-18 °C), 24 h static soak at 140 °F (60 °C), 3 h static soak at 77 °F (25 °C)	3 h static soak at 77 °F (25 °C)	24 h static soak at 140 °F (60 °C), 1 hr static soak at 77 °F (25 °C)	24 h static soak at 140 °F (60 °C), 2 h static soak at 77 °F (25 °C)
Measurements of Damage	Visual, Mr (Resilient Modulus) at 77 °F (25 °C), Tensile Strength at 77 °F (25 °C) and 2 in/min (50.8 mm/min)		Visual, Tensile Strength at 77 °F (25 °C) and 2 in/min (50.8 mm/min)	Visual, Unconfined Compression at 77 °F (25 °C) and 0.2 in/min (5.1 mm/min)

Table 1. Summary of moisture damage procedures evaluated (continued).

	Marshall-Immersion: Dry Evacuation	Marshall-Immersion: Wet Evacuation	Dynamic Tumbling	ASTM D 3625-77 (and modified) Boiling Water
Specimen Size height x diameter	2.5 in x 4 in (63.5 mm x 102 mm)		2.5 in x 4 in (63.5 mm x 102 mm)	Uncompacted Mixture
Number of Specimens	3 Dry 3 Wet	3 Wet	3 Dry 3 Wet	1
Compaction (Moisture Damage Test)	Marshall, 50 blows		Marshall, 50 blows	-
Air Void Range	3 to 5		3 to 5	-
Vacuum Conditioning (wet specimens)	1.18 in (30 mm) Hg residual pressure applied to specimens for 1 h then water at 140 °F (60 °C) added	1.18 in (30 mm) Hg residual pressure applied to submerged specimens for 1 h at 77 °F (25 °C)	none	-
Moisture Conditioning (wet specimens)	24 h soak at 140 °F (60 °C) (Note: Dry specimens were conditioned at 140 °F (60 °C) for 35 min according to Marshall procedure AASHTO T 245-82)		144 h (6 days) static soak at 120 °F (49 °C), 1 h ice water soak at 41 °F (5 °C), Dynamic Tumbling for 1000 revolutions at 30 r/min	1 min boiling or 10 min boiling (modified)
Measurements of Damage	Visual, Stability and Flow at 140 °F (60 °C) and 2 in/min (50.8 mm/min)		Visual, Percent Weight Loss, Tensile Strength at 77 °F (25 °C) and 2 in/min (50.8 mm/min)	Visual only

Visual stripping was estimated in all procedures. Estimating visual stripping was often difficult, especially when stripping was high or when a greater percentage of the stripping occurred in the fine aggregate.

The percent saturation and swell were measured both after vacuum conditioning and after moisture conditioning.

RANK ORDER OF RETAINED RATIOS AND VISUAL STRIPPING

The percent retained ratios and percent visual stripping were grouped, as shown in tables 2 and 3, according to the degree of moisture damage experienced in the States. Field-reported damages could not be quantified, and thus the mixtures were placed into four qualitative categories describing the degree of damage: (1) "moderate to severe," (2) "slight," (3) "good" for non-moisture-susceptible mixtures, and (4) "unknown" for mixtures with no past performance records. After testing had started, it was found that the treated Utah-Staker and the Maryland-Genstar mixtures had no performance histories. These two mixtures could not be used when comparing the test results to field performance, but could be used when comparing one test to another.

Eight sets of retained ratios from five procedures were chosen for analysis: (1) Long-Term NCHRP 246 M_r and tensile strength, (2) NCHRP 274 tensile strength, (3) AASHTO T 165 Immersion-Compression, (4) Marshall-Immersion stability and flow using dry evacuation, and (5) Marshall-Immersion stability and flow using wet evacuation. This provided five sets of visual stripping evaluations. Both the retained ratios and visual stripping were examined to develop pass/fail criteria and to determine discrepancies with field performance. The results of the Short-Term NCHRP 246, Dynamic Tumbling, and Boiling Water procedures did not appear promising and were excluded from the analyses.

Table 2. Percent retained ratios.

Damage Rating	Mixture	Long-Term NCHRP 246 M_rR	Long-Term NCHRP 246 TSR	NCHRP 274 TSR	AASHTO T 165 I-C	Marshall-Immersion Dry Evac. Stb. Ratio	Marshall-Immersion Dry Evac. Flow Ratio	Marshall-Immersion Wet Evac. Stb. Ratio	Marshall-Immersion Wet Evac. Flow Ratio	Short-Term NCHRP 246 M_rR	Short-Term NCHRP 246 TSR	Dynamic Tumbling % wt. loss	Dynamic Tumbling TSR
Moderate to Severe	GA-Grayson	4.8	6.5	4.8	16.4	8.6	51.2	2.9	47.7	120.6	97.8	18.2	2.7
	GA-Kennesaw	15.3	25.4	22.9	59.9	35.5	67.6	35.4	69.7	81.8	90.5	3.0	57.6
	UT-Staker	60.8	77.2	55.4	55.7	85.8(P)	80.8(P)	86.6(P)	75.0	106.9	110.9		
	GA-Norcross	24.9	35.8	40.6	69.5	49.9	65.6	43.3	67.7	101.1	100.7	2.7	63.3
Slight	GA-Rome	59.0	75.2	76.8	84.6(P)	81.3(P)	66.7	81.9(P)	64.9	86.2	99.1	0.7	86.9
	MS-Hattiesburg #1	56.2	86.9(P)	81.7(P)	97.7(P)	78.7	61.9	73.3	65.0	86.7	107.1	5.6	102.3
	MS-Hattiesburg #2	68.7	84.8(P)	75.9	92.6(P)	65.5	61.9	65.5	59.1				
	MD-Julian	48.8	59.7	61.6	90.2(P)	78.7	81.8(P)	77.9	78.3	80.5	100.0		
Good	GA-Grayson + A	92.1	92.9	92.7	96.8	87.1	80.0	83.3	80.0			1.5	92.2
	GA-Kennesaw + A	74.4	89.9	74.7(F)	95.4	73.0(F)	82.1	76.5(F)	76.7(F)			1.5	89.8
	GA-Norcross + A	78.7	86.9	89.4	90.9	76.6(F)	81.5	72.9(F)	81.5			1.5	94.2
	GA-Rome + A	76.3	88.0	83.8	83.7	93.2	71.0(F)	87.0	68.8(F)			0.4	92.7
	MS-Hattiesburg #2 + A	60.0(F)	83.7	90.9	99.4	79.9(F)	63.2(F)	88.7	60.0(F)				
	MD-Julian + A	74.6	97.0	94.3	99.2	84.4	85.7	85.3	81.8				
Unknown	UT-Staker + A	63.5	79.1	58.0	87.3	88.8	70.4	86.6	79.2	103.4	98.6		
	MD-Genstar	33.1	54.7	62.3	62.7	53.6	60.7	49.8	60.7	44.2	74.8		
	Average	55.7	70.2	66.6	80.1	70.0	70.8	68.6	69.9				
	(Std. Dev.)	(24.5)	(26.6)	(25.8)	(22.4)	(22.7)	(10.1)	(24.0)	(9.7)				

Note:
A = Mixtures treated with additive.
P = Passes suggested criteria.
F = Fails suggested criteria.

Table 3. Percent visual stripping.

Damage Rating	Mixture	Long-Term NCHRP 246	NCHRP 274	AASHTO T 165 I-C	Marshall-Immersion Dry Evac.	Marshall-Immersion Wet Evac.	Short-Term NCHRP 246	Dynamic Tumbling	Boiling Water 1 min	Boiling Water 10 min
Moderate to Severe	GA-Grayson	50	50	50	50	50	0	80	65	85
	GA-Kennesaw	50	50	45	40	40	0	25	2.5	15
	UT-Staker	65	75	65	15	15	0		2.5	2.5
	GA-Norcross	60	60	40	30	30	0	35	2.5	15
Slight	GA-Rome	25	20	7.5(P)	10	10	0	5	2.5	5
	MS-Hattiesburg #1	10	10	10	10	10	0	2.5	5	15
	MS-Hattiesburg #2	15	15	15	15	15			7.5	15
	MD-Julian	65	65	35	12.5	17.5	0		2.5	7.5
Good	GA-Grayson + A	2.5	2.5	2.5	7.5	7.5		2.5		12.5
	GA-Kennesaw + A	2.5	2.5	2.5	7.5	7.5		2.5		15
	GA-Norcross + A	2.5	2.5	2.5	7.5	7.5		2.5		7.5
	GA-Rome + A	2.5	2.5	2.5	2.5	2.5		2.5	2.5	2.5
	MS-Hattiesburg #2 + A	15 (F)	10 (F)	2.5	2.5	2.5			2.5	15
	MD-Julian + A	12.5(F)	7.5	7.5	7.5	7.5			2.5	2.5
Unknown	UT-Staker + A	65	75	25	10	10	0		2.5	2.5
	MD-Genstar	17.5	7.5	12.5	7.5	7.5	0		2.5	2.5
	Average (Std. Dev.)	28.8 (25.4)	28.4 (28.4)	20.3 (20.4)	14.7 (13.5)	15.0 (13.5)				

Note:
A = Mixtures treated with additive.
P = Passes suggested criteria.
F = Fails suggested criteria.

Retained Ratios

A perfect pass/fail criterion, where all moisture-susceptible mixtures fail and all non-moisture-susceptible mixtures pass, could not be developed for any of the eight sets of retained ratios. The best criterion for each test appeared to be 80 percent, except for the Long-Term NCHRP 246 M_r, where a criterion of 70 percent was used. Discrepancies between these pass/fail criteria and field performance are shown in table 2.

A valid pass/fail criterion could not be chosen for the Immersion-Compression procedure because all mixtures rated as "slight" had high ratios, indicating that the severity of this test was insufficient.

It was also difficult to assign pass/fail criteria to the stability ratios provided by both Marshall-Immersion procedures since the Utah-Staker mixture, rated as "moderate to severe," produced high ratios relative to the other mixtures. To prevent premature pavement failure, a moisture damage procedure must always fail mixtures which will lead to moderate or severe problems; otherwise, it is not fulfilling its purpose. Based on the suggested 80-percent pass/fail criterion, the Utah-Staker mixture passed both Marshall-Immersion procedures. The flow ratios did not provide better results and were overall less sensitive to damage than the stability ratios. The Long-Term NCHRP 246 tensile strength test also produced a relatively high ratio for the Utah-Staker mixture, which did not match the high degree of visual damage, but the mixture failed the suggested criterion in this case.

Establishing valid pass/fail criteria for the Marshall-Immersion procedures was also difficult because there were more borderline mixtures --for example, one having retained ratios within two percent of the criterion--and little apparent difference between the retained ratios produced by mixtures rated as "slight" and those rated as "good."

Considering the limited number of mixtures evaluated, a choice between the two NCHRP procedures could not be made based on the retained ratios alone. Possibly, a slight edge could be given to the NCHRP 274 and Long-Term NCHRP 246 M_r tests over the Long-Term NCHRP 246 tensile strength test. Based on the ease of performing the tests and the required equipment, the NCHRP 274 procedure would be preferred.

Visual Stripping

A criterion for acceptability based on the results of the five sets of visual evaluations appeared to be 10 percent, with 10 percent or greater visual stripping indicating an unacceptable level of damage. Discrepancies between this criterion and field performance are shown in table 2. Although visual stripping was difficult to accurately determine and some discrepancies between mixtures rated as "slight" and "good" were noted, the visual values were at least as good as the retained ratios in matching pavement performance. The Marshall-Immersion procedures provided no discrepancies, but the differences between mixtures rated as "slight" and "good" were small.

STATISTICAL ANALYSES OF RETAINED RATIOS AND VISUAL STRIPPING

Data were analyzed using one- and two-way analyses of variance and regression analyses. A 95-percent confidence level was used in all analyses of variance. When an analysis of variance indicated a significant difference between the moisture damage tests, Duncan's multiple range analysis was used to determine which tests caused the difference.

Analyses of the two Marshall-Immersion procedures indicated that they provided the same retained ratios and visual damages for a given mixture. Statistical differences were only found for the levels of vacuum saturation. To eliminate any bias which could result from including both procedures in subsequent statistical analyses, only the data from the dry evacuation procedure was used, except for analyses performed on saturations.

Retained Ratios

Analyses were performed on the retained ratios to determine differences in the severity (average retained ratio) of the tests. The results, shown in table 4, indicated that the Immersion-Compression was less severe and the Long-Term NCHRP 246 M_r more severe than the other tests. The M_r retained ratios were even lower than the tensile strength ratios obtained on the same specimens. This indicated that the type of mechanical test can have a high influence on the retained ratios. The remaining four tests were not significantly different in severity.

Visual Stripping

Analyses were also performed on the visual stripping data. The ranking, shown in table 4, indicated that the Long-Term NCHRP 246 and NCHRP 274 procedures produced more visual stripping than the Marshall-Immersion procedure. The average value for the Immersion-Compression procedure was between these tests, but was not statistically higher than the average for the Marshall-Immersion procedure or lower than the average for the other two procedures.

The ranking based on visual stripping did not match the ranking based on the retained ratios. Overall, visual stripping was less than expected for the Marshall-Immersion procedure and more than expected for the Immersion-Compression procedure. Based on the visual ranking, the ranking according to the retained ratios, and the ability of the retained ratios of each procedure to match field performance, the following were concluded:

1. Although vacuum saturation was not used in the Immersion-Compression procedure, the higher retained ratios produced by this procedure appeared to be primarily related to the inability of compression to measure moisture damage.

Table 4. Statistical analyses of the retained ratios, visual stripping, and saturation.

Ranking of Tests According to Retained Ratios

Test	Rank	Average, percent	Standard Deviation
Long-Term NCHRP 246 M_r	1	55.7	24.5
NCHRP 274 Tensile Strength	2	66.6	25.8
Marshall-Immersion Stability (Dry Evac.)	2	70.0	22.7
Long-Term NCHRP 246 Tensile Strength	2	70.2	26.6
Marshall-Immersion Flow (Dry Evac.)	2	70.8	10.1
Immersion-Compression	3	80.1	22.4

Ranking of Procedures According to Visual Stripping

Procedure	Rank	Average, percent	Standard Deviation
Long-Term NCHRP 246	1	28.8	25.4
NCHRP 274	1	28.4	28.4
Immersion-Compression	2	20.3	20.4
Marshall-Immersion	3	14.7	13.5

Note: Statistically, the average visual stripping of 20.3 percent for the Immersion-Compression procedure is not greater than or less than the averages for the other procedures.

Ranking of Procedures According to Saturation after Moisture Conditioning (based on sample volume)

Procedure	Rank	Average, percent	Standard Deviation
NCHRP 274	1	6.9	3.3
Marshall-Immersion (Wet Evacuation)	2	5.6	3.1
Marshall-Immersion (Dry Evacuation)	3	5.1	2.8
Long-Term NCHRP 246	3	4.9	2.9
Immersion-Compression	4	4.6	2.6

2. The Marshall-Immersion procedure provided a lower average level of visual stripping than the Long-Term NCHRP 246 procedure even though the void and saturation levels in the two procedures were similar. This indicated that the greater visual damage in the Long-Term NCHRP 246 procedure was due to the 15-hour freezing period. The lower level of visual stripping in the Marshall-Immersion procedure was probably a contributing factor to the discrepancies between the retained ratios and field performance for this procedure.

3. Since the average retained tensile strength ratios and average levels of visual stripping for the Long-Term NCHRP 246 and NCHRP 274 procedures were equal, it was inferred from the data that either higher air void levels (6 to 8 percent) or a freezing period could be used to obtain a higher level of damage. Neither high air void levels nor a freezing period was used in the Marshall-Immersion procedure.

4. The higher average level of visual damage for the Immersion-Compression procedure compared to the Marshall-Immersion procedure, even though not statistically significant, again indicated that higher air void levels are beneficial for evaluating moisture susceptibility.

Retained Ratios Versus Visual Stripping

Correlations were performed to determine the dependency of the retained ratios on visual stripping. Overall, the retained ratios were only weakly related to the degree of visual stripping, with the ratios decreasing as visual damage increased. The correlations could have been affected by inaccurate visual values; however, the exact cause of the poor relationships could not be determined from the data. Even with accurate visual data, good correlations may not be obtained because other factors, such as aggregate characteristics, may affect the retained ratios. For example, a 50-percent loss of adhesion may be more critical with a rounded aggregate than with a crushed aggregate, or vice versa. Also, the percentage of stripping in the fine aggregate versus the percentage of stripping in the coarse aggregate may be a factor. These factors could not be evaluated. The Marshall-Immersion stability test produced the only good correlation, but only three mixtures had greater than 20-percent visual stripping and the skewness of the data made the correlation highly questionable.

MECHANICAL VALUES

Wet and dry mechanical values (compressive strength, tensile strength, M_r, stability, and flow) were investigated to determine the following: (1) effect of the additive on the dry values, (2) effect of the additive on the wet values, and (3) pass/fail criteria based on the wet values.

The dry mechanical values were not affected by the addition of the additives in the NCHRP 274 and Marshall-Immersion procedures. The dry values were affected in the NCHRP 246 and Immersion-Compression procedures; however, most changes were less than 10 percent with the M_r providing the greatest changes. Changes in the dry values could affect the retained ratio, and it is conceivable that a borderline mixture could pass a test without any improvement in the quality of the mixture.

The effects of the additives on the wet values were compared to the effects on the retained ratios and visual damages. Overall, the changes in the wet values agreed reasonably well with the changes in the retained ratios, and there was no indication that one was significantly better than the other for evaluating the effects of additives. Comparing the changes in visual stripping to the changes in the wet values or retained ratios was more difficult; however, the comparisons showed that it is possible that visual stripping may decrease without a change in the wet value and/or the retained ratio. The results of these comparisons supported previous conclusions in that the two NCHRP procedures provided better relationships than the Immersion-Compression and the Marshall-Immersion procedures.

The wet mechanical values were a poor indicator of damage, and minimum allowable values based solely on moisture damage could not be determined. Wet mechanical values of some moisture-damaged mixtures were higher than some dry values of other mixtures. The lack of a good relationship was attributed to the ineffectiveness of the tests to adequately predict damage for some mixtures, and the premise that the retained ratio indicates a rate of loss of mechanical value rather than an end point.

SATURATION

The degree of saturation, or percent water in a specimen, was measured both after moisture conditioning and after vacuum conditioning, except for the Immersion-Compression procedure in which no vacuum conditioning was used. Both Marshall-Immersion procedures were included in the analyses since the two vacuum conditioning methods provided different levels of saturation.

Saturation was calculated both as a percent of the void volume and as a percent of the specimen volume. The latter calculation was used when comparing one procedure with another because it accounted for the various air void levels used in the procedures by relating moisture damage to the amount of water in the specimen. The former calculation was used to investigate whether or not oversaturation adversely affected the data.

Analyses were performed on the following saturations to determine if differences existed from procedure to procedure: (1) saturation after vacuum conditioning, (2) saturation after moisture conditioning, and (3) the change in saturation during moisture conditioning (saturation after moisture conditioning minus the saturation after vacuum conditioning). It was concluded from the analyses that the methods of vacuum conditioning and the differences in the levels of saturation were not the only or dominant factors affecting the overall severity (average retained ratio) of the tests. For example, the two Marshall-Immersion procedures provided different levels of saturation but these differences had no effect on the retained ratios or visual stripping, and no damage due to the high level of saturation (average of 106 percent) after vacuum conditioning in the wet procedure was measured. Also, the Long-Term NCHRP 246 M_r retained ratios were overall lower than the retained ratios produced by the other tests even though the degree of saturation was not the highest. The M_r ratios were even lower than the tensile strength ratios obtained on the same specimens. This indicated that the type of mechanical test had a high influence on the ratios, even more influence than the differences in saturation. The ranking of the saturations after moisture conditioning is shown in table 4.

Visual stripping also did not match the degree of saturation. Furthermore, the average saturation after moisture conditioning for the Immersion-Compression procedure was less than that for the Marshall-Immersion procedure even though the average visual damage was not lower. Again, it appeared that mechanisms, such as the type of mechanical test, air voids, and freezing, were more important than saturation. (Air voids not only affect saturation, but also permeability and asphalt film thickness.)

Correlations were performed to investigate the effects of saturation on the retained ratios and visual damages within a given procedure. Overall, saturation was a poor indicator of moisture damage, and only general trends of increasing damage with increasing saturation were found. This indicated that within a procedure, saturation was not the only or dominant factor affecting damage. There was also a slight indication that the two Marshall-Immersion procedures were overly dependent on the ability of the air void system to absorb water during the procedure, and that a higher void level or a freezing period is needed in these procedures.

There was no conclusive evidence that oversaturation during vacuum conditioning adversely affected the data. Oversaturated mixtures produced retained ratios which in some cases were low, while in other cases high, compared with pavement performance. Increased vacuum saturation also did not lead to low retained ratios relative to the degree of visual stripping. Possibly, damage was so small that it could not be measured by the tests, or, damage only occasionally affected the results of a test. There was also no conclusive evidence that oversaturation after moisture conditioning adversely affected the results. In general, the discrepancies between the test results and field performance were due to (1) relatively high retained ratios or low visual damages produced by some mixtures which were reportedly susceptible to moisture damage, or (2) the inability of a procedure to measure the effectiveness of an additive.

Saturation is still very important in that sufficient water must enter the specimen. Neither high air voids nor vacuum conditioning was used in the Dynamic Tumbling procedure, and the results indicated that saturation was insufficient. The degree to which the absence of vacuum saturation in the Immersion-Compression procedure contributed to its lack of severity could not be established, since any effects were masked by the inability of compression to measure damage. (A minimum requirement for saturation was not investigated in this study.)

SWELL

The percent swell, or percent change in the volume of a specimen, has been measured by various State highway agencies in the past as an indicator of stripping and to detect the presence of expansive materials such as clays. Swell was measured after moisture conditioning in the Long-Term NCHRP 246, NCHRP 274, and Immersion-Compression procedures. Swell could not be measured during the Marshall-Immersion procedures. Swell after vacuum saturation was measured during the Long-Term NCHRP 246 and NCHRP 274 procedures. Specimens in the Immersion-Compression procedure were not vacuum saturated.

Overall, swell was a poor indicator of stripping, and additional differences between the moisture damage procedures were not provided by measuring swell. Most swells were low and there were no apparent differences in the trends between the data and pavement performance from one procedure to another.

OTHER TESTS

One-Minute Boiling Water (ASTM D 3625)

This procedure produced little or no stripping in most mixtures and thus was not effective. Five out of eight moisture-susceptible mixtures retained more than 95 percent of the coating.

Ten-Minute Boiling Water

Overall, this procedure produced more stripping than the 1-Minute Boiling Water procedure, but could not differentiate between mixtures with good and poor performance records.

Short-Term NCHRP 246 Procedure

The Short-Term NCHRP 246 procedure provided no additional information concerning the moisture susceptibility of the mixtures, and no reason was found for performing this part of the procedure. There were no relationships between the retained ratios and (1) field performance, (2) saturation, or (3) visual stripping. The effect of the conditioning process on the retained ratios varied with the test and with the mixture, and could not be adequately explained by the data.

Dynamic Tumbling

All five moisture-susceptible mixtures passed the recommended maximum allowable loss of weight criterion (25 percent) used by the Nevada

Department of Transportation, and only the Georgia-Grayson mixture produced a high loss of weight. As shown by table 2, the tensile strength ratios were similar to the ratios produced by the Immersion-Compression procedure even though the moisture conditioning process in the Dynamic Tumbling procedure was more severe. This method used neither high air voids nor vacuum conditioning, and the saturations after moisture conditioning and most visual damages were relatively low compared to the other procedures. Damages in this procedure did not match the severity of the moisture conditioning and testing processes, which indicated that saturation was insufficient.

RECOMMENDATIONS

1. The moisture susceptibility of the mixtures could not be effectively predicted by the following procedures, and thus they are not recommended for general use: (1) 1-Minute Boiling Water, (2) Dynamic Tumbling, (3) Immersion-Compression, and (4) both Marshall-Immersion procedures. The short-term part of the NCHRP 246 procedure provided no additional information concerning the moisture susceptibility of the mixtures under this procedure, and thus no reason was found for performing this part of the procedure. The 10-Minute Boiling Water procedure was also not effective and not recommended, except in individual cases where the procedure provides results consistent with those of another procedure which has a better relationship to field performance. Possibly, it could then be used in the field to check for the presence of additive in a mixture.

2. The best procedures appeared to be the NCHRP 274 and Long-Term NCHRP 246. A criterion of 80 percent was chosen for both tensile strength tests and 70 percent for the M_r test. The NCHRP 274 procedure is slightly easier to perform. These procedures are given in appendix A.

3. The effectiveness of an additive should be based on both the retained ratio and the change in visual damage. It is possible with a borderline mixture that an additive may produce a passing mixture without any improvement in the quality of the mixture by decreasing the dry mechanical value and/or increasing the wet mechanical value. However, it is also possible that visual stripping may decrease without a change in the wet value or the retained ratio. Ten-percent or greater visual stripping generally indicated moisture susceptibility.

4. Although no highly expansive materials were encountered in this study, measuring swell may still be useful for detecting these materials in mixtures which do not strip. However, for moisture-susceptible mixtures, it may be difficult to differentiate between expansion due to stripping and expansion due to other mechanisms. Swell is based on the change in the volume of the specimens and is easy to calculate.

5. The voids in the mineral aggregate (VMA) for many of the mixtures were low compared to recommended criteria[5,6]. VMA should be properly considered in the mixture design process. Criteria for this property were developed to insure that the aggregate is adequately coated.

APPENDIX A: Moisture Damage Procedures

This appendix presents the NCHRP 246(2) and NCHRP 274(3) procedures.

NCHRP 246

PREDICTIVE MOISTURE DAMAGE TEST METHOD USED IN NCHRP PROJECT 4-8(3)

EFFECT OF WATER-RELATED CONDITIONING ON INDIRECT TENSILE PROPERTIES OF COMPACTED BITUMINOUS MIXTURES

1. Scope

1.1 This method covers measurement of the change of diametral tensile strength and diametral (tensile) resilient modulus resulting from the effects of saturation and accelerated water conditioning of compacted bituminous mixtures. Internal water pressures in the mixtures are produced by vacuum saturation followed by a freeze and warm-water soaking cycle. Numerical indices of retained indirect tensile properties are obtained by comparing the retained indirect properties of saturated and accelerated water-conditioned laboratory specimens with the similar properties of dry specimens.

2. Apparatus

2.1 Two automatically controlled water baths will be required for immersing the specimens. The baths will be of sufficient size to permit total immersion of the test specimens. They will be so designed and equipped to permit accurate and uniform control of the immersion temperature. One bath is provided for bringing the immersed specimens to the temperature of 140 ± 3.6 F (60 ± 2C) for the warm-water-soak portion of the specimen conditioning. The second bath is provided for bringing the immersed specimens to either the selected test temperature of 55 ± 1.85 F (12.8 ± 1C) or of 73 ± 1.8 F (22.8 ± 1C) for the indirect tensile testing. The baths will be constructed of or lined with stainless steel or other nonreactive material. The water in the baths will be either distilled or otherwise treated to eliminate electrolytes; and the baths will be emptied, cleaned, and refilled with fresh water for each series of tests.

2.2 One automatically controlled freezer will be required for freezing the specimens. The freezer will be of sufficient size to permit total containment of the test specimens. It will be so designed and equipped to permit accurate and uniform control of its air temperature. The freezer is required to bring the specimens to the selected temperature of −0.4 ± 3.6 F (−18 ±2C) for the freeze portion of specimen accelerated conditioning.

2.3 One vacuum pump with capacity to pull at least 26 in. (66 cm) of mercury will be required to water-saturate the test specimens. Accessory equipment will include: Pyrex or equivalent vacuum jars of at least 6 in. (15 cm) diameter and 8 in. (20 cm) high with smooth fired edges, a donut-shaped gasket made of rubber-type sponge, a stiff metal round plate greater than 6 in. (15 cm) diameter with suitable vacuum hose receptacle and hole bored through the plate thickness, vacuum hose attached to receptacle fitting and vacuum pump, and a 6-in. (15-cm) diameter screen-type or highly porous specimen spacer seat approximately 0.25 in. (1 cm) high.

2.4 A compressive testing machine as described in accordance with Method D 1074, but having the controlled deformation rate capability of 0.065 in. per min (0.165 cm per min).

2.5 Mark III or Mark IV Resilient Modulus Apparatus manufactured by Retsina Co., El Cerrito, CA 94530, or equivalent.

2.6 A balance and a room-temperature water bath with suitable accessory equipment will be required for weighing the test specimens in air and in water (saturated specimens only) in order to determine their densities, the amount of absorption, and permeable voids. This apparatus is similar to that required for Method D2762, Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens.

2.7 A supply of plastic film for wrapping and heavy-duty leak-proof plastic bags will be required to wrap and enclose the saturated specimens for preventing moisture loss during handling and freezing. Also, several metal jars of at least 4 in. (10.2 cm) diameter and at least 6 in. (15 cm) high will be required for bringing dry specimens to test temperature without water intrusion into the dry specimens in the water bath.

3. Test Specimens

3.1 At least nine, duplicate 4-in. (102-mm) diameter by 2.5-in. (63.5-mm) high cylindrical test specimens of the same mixture will be made for each test. The procedures described in either Method D1559, Test for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus, or Method D1561, Test for Compaction of Test Specimens of Bituminous Mixtures by Means of California Keading Compactor, or Method D3387, Test for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine, will be followed in preparing the loose mixtures and in molding and curing the test specimens.

4. Grouping, Vacuum Saturation, and Determination of Bulk Density and Permeable Voids of Test Specimens

4.1 Allow each set of nine test specimens to cool at room temperature for at least 24 hours after completion of specimen fabrication described in Methods D1559, D1561, and D3387. Label each specimen with waterproof identification and obtain the dry weight of each specimen to the nearest 0.1 g.

4.2 Randomly select a subset, I, of three specimens from the set of nine test specimens. Maintain subset I specimens in a dry condition. Place subset I specimens in metallic jars and then place the jars in a water bath at the selected mechanical test temperature (refer to section 6 for information on the selection of mechanical test temperature) of 55 ± 1.8 F (12.8 ± 1 C) or 73 ± 1.8 F (22.8 ± 1 C) for 5 hours maintaining the top rim of the jars above the water level of the bath. Place an insulating stuffing in the top of the jars, making contact with the top specimen's surface and with the jar walls, then proceed with the mechanical testing of subset I as described in sections 6–9.

4.3 The six remaining test specimens will be vacuum saturated as follows. Place a porous spacer seat on the bottom of a vacuum jar and then place one or more of the specimens, depending on jar height, flat in the jar using another porous spacer seat between the specimens. Put distilled water, or water treated to eliminate electrolytes, at 73 F (22.8 C) in the jar to about 1 in. (2.5 cm) above the upper specimen's surface. Place a dampened donut gasket and a stiff metallic plate on top of the jar. Attach a vacuum hose from vacuum pump. Apply a vacuum of 26 in. (66 cm) of mercury to the jars for a duration of 30 min., gently agitating the jar wall. Remove the vacuum and leave the six specimens submerged in the jars at atmospheric pressure for 30 minutes.

4.4 Remove each of the six specimens from the vacuum jars, quickly surface dry the specimens by towel blotting, and weigh immediately in air and then weigh submerged in room-temperature water at approximately 73 F (22.8 C). Immediately after weighing each submerged specimen, return the specimens to the water-filled vacuum jars and submerge each specimen temporarily under the water at atmospheric pressure.

4.5 Calculate the bulk density and permeable voids of each of the six vacuum-saturated test specimens as follows:

$$\text{Bulk density} = \frac{AD}{B - C} \qquad \text{(A-1)}$$

$$\text{Permeable voids, \%} = \frac{100\,(B - A)}{B - C} \qquad \text{(A-2)}$$

where:

A = weight of dry specimen in air, g;

B = weight of surface-dry (blotted) vacuum-saturated specimen in air, g;

C = weight of vacuum saturated specimen submerged in water, g; and

D = density of water at 73F (22.8C), g/cc.

4.6 Sort and assign each of the six vacuum-saturated test specimens into subsets, II and III, consisting of three specimens each so that the average permeable voids (or average bulk density) is essentially the same in each subset. Immerse subset II specimens into a water bath at the selected mechanical test temperature of 55 ± 1.8 F (12.8 ± 1 C) or 73 ± 1.8 F (22.8 ± 1 C) for 3 hours and then proceed with the mechanical testing of this subset described in sections 6–9. Condition the subset III specimens by using the procedure described in section 5.

5. Accelerated Conditioning Procedure

5.1 Maintain specimen surface dampness and internal saturation, and wrap tightly each of the three specimens of subset III with two layers of plastic film using masking tape to hold the wrapping if necessary. Place each wrapped specimen into a leak-proof plastic bag containing approximately 3 ml of distilled water, and seal the bag with a tie or tape.

5.2 Immerse each of the three individually wrapped and bagged specimens of subset III into an air bath freezer for 15 hours at −0.4 ± 3.6 F (−18 ± 2 C). (If this step begins at 5 p.m., specimens can be removed from the freezer at 8:00 a.m. the following day).

5.3 Remove the three wrapped and bagged specimens of subset III from the freezer and immerse them immediately into a water bath at 140 ± 3.6 F (60 ± 2 C) for 24 hours. (After 3 min of immersion, when specimen surface thaw takes place, rapidly, but carefully, remove the bag and wrapping from the specimens and rapidly reimmerse the specimens in the water bath).

5.4 Carefully remove the three unwrapped specimens of subset III from the water bath, immerse the specimens in a water bath at the selected mechanical test temperature of 55 ± 1.8 F (12.8 ± 1 C) or 73 ± 1.8 F (22.8 ± 1 C) for 3 hours, and proceed with the mechanical testing of this subset as described in sections 6–9.

6. Selection of Mechanical Test Temperature

6.1 The selection of the mechanical test temperature for the nine specimen set is based on the type of mechanical test desired for measurement of the effects of the water-related conditioning. Diametral (tensile) resilient modulus may be performed at either 55 ± 1.8 F (12.8 ± 1 C) or 73 ±1.8 F (22.8 ± 1 C). Diametral tensile strength is performed at 55 ± 1.8 F (12.8 ± 1 C). If low-to-moderate stresses are applied to the specimens in the diametral (tensile) resilient modulus test, this test can be considered nondestructive and the same specimens can be also tested using the diametral tensile strength test, therefor providing additional mechanical properties data. If this is to be done, specimens must be reimmersed in the water bath at selected test temperature for 1 to 2 hours after diametral (tensile) resilient modulus testing prior to the diametral tensile strength testing.

7. Specimen Handling in the Mechanical Testing Procedures

7.1 Each specimen subset shall be tested rapidly following the completion of their respective test-temperature water-bath soak times as prescribed in section 4.2 for subset I, section 4.6 for subset II, and section 5.4 for subset III.

7.2 Remove a subset specimen from the water bath at the test temperature, surface dry by blotting with a towel (necessary for specimens from subsets II and III), measure and record the specimen height (thickness) and identification, and place the specimen with circular ends vertical (specimen on edge) into the appropriate mechanical loading device. Test one specimen at a time, leaving the remaining untested specimens in the water bath. Proceed with testing as rapidly as possible because the mechanical testing will expose the specimen to air temperature which may be different from the test temperature. Test the specimens by either one or both of the procedures described in sections 8 and 9.

8. Test and Calculation Procedure for Diametral (Tensile) Modulus

8.1 Place the transducers of the Resilient Modulus Apparatus on the specimen at test temperature and proceed rapidly with diametral loading at 0.1-sec load duration time, following the procedures described in the instruction manual provided by the manufacturer. Record load and horizontal deformation. Rotate the specimen 90° and repeat.

8.2 Calculate the specimen's diametral resilient modulus for each of the two 90° rotations as follows:

$$M_R = \frac{P(\nu + 0.2734)}{L\,\Delta} \qquad \text{(A-3)}$$

where:

M_R = diametral resilient modulus, psi (k Pa);
P = load magnitude applied to specimen, lb (N);
ν = Poissons ratio of specimen (use 0.35 unless measured specifically);
0.2734 = dimensionless strain integration constant for 4-in. (10.2-cm) diameter specimens;
L = thickness of specimen, in. (cm); and
Δ = horizontal deformation magnitude of specimen, in. (cm).

The average of the two 90° resilient modulus values is calculated for this specimen and test temperature. Return specimen to water bath if a diametral tensile strength test is also to be performed on the same specimen.

8.3 Repeat by testing the two remaining specimens in the subset, and calculate the overall average diametral resilient modulus for the subset of three specimens.

8.4 Repeat procedure and calculations described in sections 8.1–8.4 for the remaining two subsets of three specimens each.

8.5 Proceed to section 10, Calculation.

9. Test and Calculation Procedure for Diametral Tensile Strength

9.1 Place and center a subset specimen at test temperature under the flat loading head of the compression test machine, and proceed quickly with diametral loading at a vertical deformation rate of 0.065 in. per min (0.165 cm per min). The specimen is placed on its edge without support blocks or loading strips). Record the maximum compressive load. Immediately decrease load to zero, remove specimen and measure specimen edge or side flattening to nearest 0.1 in. (0.25 cm). This can be accomplished easily by stroking the top flattened edge (side) with a piece of chalk held lengthwise to delineate the flattened width and then using a scale to measure the average maximum width of the flattened edge. Record this width.

9.2 Replace the specimen in the compression test machine with its original orientation (flattened edges top and bottom) and redeform the specimen at 0.065 in. per min (0.165 cm per min) until a definitive vertical crack appears and opens. Decrease load to zero, remove specimen, and slowly pull apart the two sides of the specimen at the crack. The internal surface may then be observed for stripping and recorded qualitatively.

9.3 Calculate the specimen's diametral tensile strength as follows:

$$S_t = \frac{S_{10} P}{10{,}000\, L} \qquad \text{(A-4)}$$

where:

S_t = diametral tensile strength, psi (k Pa);
S_{10} = maximum tensile stress, psi (k Pa), obtained by calculating: $1591 + 437a - 1889a^2 + 2854a^3 - 2474a^4 + 885a^5$, where a = flattening width, in., based on a 4 in. (10.2 cm) diameter solid cylinder loaded at 10,000 lb (22 kg) per inch (cm) thickness (note: to calculate S_{10} in SI units, first calculate S_{10} in U.S. customary units of psi using the polynomial constants as shown, with a in inches, then convert psi to k Pa using 1 psi = 6.895 k Pa);
P = maximum compressive load on specimen, lb (N);
10,000 = load constant: 10,000 lb per in. of thickness (17,512 N per cm of thickness); and
L = thickness of specimen, in. (cm).

9.4 Repeat by testing the two remaining specimens in the subset, and calculate the overall average diametral tensile strength for the subset of three specimens.

9.5 Repeat procedure and calculations described in sections 9.1–9.4 for the remaining two subsets of three specimens each.

9.6 Proceed to section 10, Calculation.

10. Calculation

10.1 Calculate the numerical indices of the effects of vacuum saturation and accelerated conditioning as the ratios of the mechanical properties of subsets II and III to the mechanical properties of subset I for the specified test temperature as follows:

$$M_R R_1 = \frac{M_R\,(II)}{M_R\,(I)} \quad \text{and} \quad M_R R_2 = \frac{M_R\,(III)}{M_R\,(I)} \qquad \text{(A-5)}$$

where:

$M_R R_1$ = diametral resilient modulus ratio of saturation;
$M_R R_2$ = diametral resilient modulus ratio of accelerated conditioning;

M_R (I) = average diametral resilient modulus of specimen subset I, psi (k Pa);
M_R (II) = average diametral resilient modulus of specimen subset II, psi (k Pa); and
M_R (III) = average diametral resilient modulus of specimen subset III, psi (k Pa).

$$TSR_1 = \frac{S_t\,(II)}{S_t\,(I)} \text{ and } TSR_2 = \frac{S_t\,(III)}{S_t\,(I)} \qquad (A\text{-}6)$$

where:

TSR_1 = diametral tensile strength ratio of saturation;
TSR_2 = diametral tensile strength ratio of accelerated conditioning;
S_t (I) = average diametral tensile strength of specimen subset I, psi (k Pa);
S_t (II) = average diametral tensile strength of specimen subset II, psi (k Pa); and
S_t (III) = average diametral tensile strength of specimen subset III, psi (k Pa).

Ratios will be reported to the nearest hundredth.

10.2 Ratios may be interpreted as follows. $M_R R_1$ and TSR_1 are related to short-term pavement performance (e.g., 2–4 yr), and $M_R R_2$ and TSR_2 are related to long-term pavement performance (e.g., 4 yr or more). Low ratios are associated with the mixture's inability to resist moisture effects.

11. Single-Operator Precision

11.1 The single operator standard deviation has been found to be 14 percent for $M_R R$ and 10 percent for TSR. (These numbers represent, respectively, the (IS) and (D2S) limits as described in ASTM Recommended Practice C 670, for Preparing Precision Statements for Test Methods for Construction Materials.) Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 40 percent for $M_R R$ and 28 percent for TSR.

NCHRP 274

METHOD OF TEST FOR DETERMINING THE EFFECT OF MOISTURE AND ANTISTRIPPING ADDITIVES ON ASPHALT CONCRETE PAVING MIXTURES

1. Scope

This method contains procedures for preparing and testing specimens of asphaltic concrete for purposes of measuring the effect of water, or the effectiveness of antistripping additives on the tensile strength of the paving mixture. The method is applicable to dense mixtures such as those appearing in the upper half of Table 3, ASTM Specification D 3515. The method can evaluate the effect of moisture with or without additives, the effect of liquid antistripping additives which are added to the asphalt cement, or pulverulent solids such as hydrated lime or portland cement which are added to the mineral aggregate.

2. Applicable Documents

2.1. ASTM Standards

- D 979 Method for Sampling Bituminous Paving Mixtures
- D 1559 Test for Resistance to Plastic Flow of Bituminous Mixtures by Marshall Apparatus
- D 2041 Test for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
- D 2726 Test for Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
- D 3203 Test for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
- D 3515 Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures
- D 3549 Test for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D 3665 Practice for Random Sampling of Construction Materials
- D 4123 Method of Indirect Tensile Test for Resilient Modulus of Bituminous Mixtures

3. Significance and Use

This method can be used to test asphaltic concrete mixtures in conjunction with mixture design testing to determine whether or not moisture damage is severe enough so that an additive should be considered, and if it is severe enough, to determine whether or not an antistripping additive is effective and what dose of additive is most effective. It can also be used to test mixtures produced at plants to determine the severity of moisture damage and the effectiveness of additives under conditions imposed by construction in the field. Finally, it can be used to test cores from completed pavements of any age to determine the severity of moisture damage and the effectiveness of additives under conditions of exposure and service in the field.

4. Summary of Method

4.1. To determine the severity of moisture damage and decide whether or not an additive should be considered, a set of laboratory-compacted specimens conforming to the job-mix formula without additive is prepared. The specimens are compacted to a void content corresponding to void levels expected in the field, usually in the 6 to 8 percent range. The set is divided into two subsets of approximately equal void content, and one subset is maintained dry, while the other subset is saturated with water and moisture conditioned. The tensile strength of each subset is determined by the tensile splitting test. The severity of moisture damage is indicated by the ratio of the tensile strength of the wet subset to that of the dry subset.

4.2. To determine the effectiveness of an antistripping additive a set of specimens containing additive but otherwise the same as the set in Section 4.1 is prepared and tested, and the severity of the moisture damage is determined in the manner described in Section 4.1. The effectiveness of the additive is indicated by the improvement in the wet-to-dry ratio of the set containing additive compared to the set without additive. The effect of additive dosage may be estimated by repeating the set with different additive dosages.

4.3. To determine the severity of moisture damage or the effectiveness of an additive in mixture produced in an asphalt plant in the field, specimens are laboratory compacted to field level void content, divided into wet and dry subsets, and the severity of moisture damage or the effectiveness of the additive is determined as in Section 4.2.

4.4 To determine the severity of moisture damage or the effectiveness of an additive in specimens cored from a pavement, cores are maintained at in-place moisture content until tensile strength is measured. This strength may be compared to the tensile strength determined previously before moisture damage occurred.

5. Apparatus

5.1. Equipment for preparing and compacting specimens from Method D 4123.

5.2. Vacuum pump or water aspirator, manometer or vacuum gauge, and container, preferably Type D, from Method D 2041.

5.3. Balance and water bath from Method D 2726.

5.4. Water bath or oven capable of maintaining a temperature of 140 F for 24 hours.

5.5. Loading jack and ring dynamometer from Method D 1559, or a mechanical or hydraulic testing machine capable of maintaining the required strain rate and measuring load with suitable precision.

5.6. Loading strips from Method D 4123.

6. Preparation of Laboratory Test Specimens

6.1. At least six specimens shall be made for each test, three to be tested dry and three to be tested after saturation and moisture conditioning.

6.2. Specimens 4 in. in diameter and 2.5 in. thick are usually used. Specimens of other dimensions may be used if desired and should be used if aggregate larger than 1 in. is present.

6.3. When 4-in. × 2.5-in. specimens are used, mixtures shall be prepared in batches large enough to make at least 3 specimens. When larger specimens are used, batches may be prepared for each specimen. If theoretical maximum specific gravity is to be determined, the batch should be large enough to provide the specimen for that purpose also.

6.4. When a liquid antistripping additive is used, the asphalt cement in sufficient quantity for one batch shall be heated to 300 F in a closed one quart can in an oven. The required quantity of additive shall be added. Immediately lower a mechanical strirrer to within 1 in. of the bottom of the container, and mix the contents for 2 min. Maintain the treated asphalt cement at 300 F in the closed can until it is used. If the treated asphalt cement is not used on the same day in which it is prepared, or if it is allowed to cool so that it would require reheating, it shall be discarded.

6.5. When a pulverulent solid antistripping additive is used, the batch of mineral aggregate shall be dried, composited, and heated to 300 F. The required quantity of additive shall be added to the aggregate, and the entire mass shall be thoroughly mixed until a uniform distribution of additive has been achieved. Care shall be taken to minimize loss of additive to the atmosphere in the form of dust. After mixing, maintain the treated aggregate at the temperature required for mixing until it is used.

6.6. Proportion, mix, and compact specimens in accordance with Method D 4123 and Sections 6.6.1 and 6.6.2.

6.6.1. After mixing, stabilize mixture temperature at the required compaction temperature in a closed container in an oven for from 1 to 2 hours.

6.6.2. Compact specimens to 7 ± 1 percent air voids, or a void level expected in the field. This level of voids can be obtained by adjusting the static load in double plunger compaction; the number of blows in Marshall hammer compaction; the foot pressure, number of tamps, leveling load, or some combination in kneading compaction; or the number of revolutions in gyratory compaction. The exact procedure must be determined by trial for each mixture.

6.6.3. Cool specimens to room temperature as rapidly as possible in a stream of moving air, extract from molds, and proceed with Section 9 immediately if possible, but within 24 hours at most.

7. Preparation of Field Specimens

7.1. Select a truck to be sampled in accordance with Practice D 3665.

7.2. Secure a sample from the truck at the plant in accordance with Method D 979.

7.3. Stabilize mixture temperature to approximately the temperature found in the field when rolling begins. Maintain this temperature in a closed container, in an oven if necessary, for approximately the time lapse between mixing and the start of actual rolling.

7.4. Compact specimens in accordance with Section 6.6.2. and cool and extract from molds in accordance with Section 6.6.3.

7.5. If specimens are not to be compacted in the field laboratory, place the samples in a sealed container, transport to the laboratory, and reheat to the temperature required in Section 7.3. Then proceed with Section 7.4.

8. Preparation of Core Test Specimens.

8.1. Select locations to be sampled on the completed pavement or pavement layer in accordance with Practice D 3665.

8.2. Core at the selected locations in accordance with Method D 979. A wet coring process should be used, and the periphery of the core should be blotted dry immediately after it is taken. Wrap the core in plastic wrap or otherwise protect it to maintain field moisture content until the test layer of the core is separated.

8.3. Separate core layers as necessary by sawing or other suitable means. A wet sawing process is preferred, and the periphery of the test layer of the core should be blotted dry immediately after it is sawn. Wrap the test layer in plastic wrap or otherwise protect it to maintain field moisture content until it is tested.

9. Procedure

9.1. Determine the theoretical maximum specific gravity by Method D 2041.

9.2. Determine specimen thickness by Method D 3549.

9.3. Determine the bulk specific gravity by Method D 2726, and express the volume of the specimen in cubic centimeters. The term (B-C) in Method D 2726 is the volume of the specimen in cubic centimeters.

9.4. Calculate air voids by Method 3203, and express the volume of air in cubic centimeters. The volume of air is the volume of the specimen from Section 9.3 multiplied by the percentage air voids.

9.5. Sort specimens into two subsets so that average air voids of the two subsets are approximately equal. Store the subset to be tested dry at room temperature.

9.6. Saturate the subset to be moisture conditioned with distilled water at room temperature. If it is difficult to reach the minimum degree of saturation of 55 percent required in Section 9.6.3, the water used to saturate may be heated up to 140 F.

9.6.1. Saturate by applying a partial vacuum such as 20 in. Hg for a short time such as 5 min.

Note 1: Experiments with partial vacuum at room temperature indicate that degree of saturation is very sensitive to the magnitude of the vacuum and practically independent of the duration. The level of vacuum needed appears to be different for different mixtures.

9.6.2. Determine bulk specific gravity by Method D 2726. Determine the volume of absorbed water by subtracting the air dry weight of the specimen found in Section 9.3 from the saturated surface dry weight of the saturated specimen found in Section 9.6.2.

9.6.3. Determine the degree of saturation by dividing the volume of absorbed water found in Section 9.6.2 by the volume of air voids found in Section 9.4 and expressing the result as a percentage. If the volume of water is between 55 and 80 percent of the volume of air, proceed to Section 9.7. If the volume of water is less than 55 percent, repeat the procedure beginning with Section 9.6.1 using a slightly higher partial vacuum. If the volume of water is more than 80 percent, the specimen has been damaged and is discarded.

Note 2: If the average air voids of the saturated subset is less than 6.5 percent, saturation of at least 70 percent is recommended.

9.7. Moisture-condition the saturated specimens by soaking in distilled water at 140 F for 24 hours.

9.8. Adjust the temperature of the moisture-conditioned subset by soaking in a water bath for 1 hour at 77 F.

9.9. On moisture-conditioned subset, measure thickness by Method D 3549, and determine bulk specific gravity by Method D 2726.

9.9.1. Determine water absorption and degree of saturation in accordance with Section 9.6.2 and Section 9.6.3. Saturation exceeding 80 percent is acceptable in this step.

9.9.2. Determine swell of saturated specimens by dividing the change in specimen volumes found in Sections 9.6.2 and 9.3 by the specimen volume found in Section 9.3. Determine swell of conditioned specimens by dividing the change in specimen volumes found in Sections 9.9 and 9.3 by the specimen volume found in Section 9.3.

9.10. Adjust temperature of dry subset by soaking in a water bath for 20 min at 77 F.

9.11. Determine tensile strength at 77 F of both subsets.

9.11.1. Apply diametral load in accordance with Method D 4123 at 2.0 in. per minute until the maximum load is reached, and record the maximum load.

9.11.2. Continue loading until specimen fractures. Break open and estimate and record stripping, if any.

9.11.3. Inspect all surfaces, including the failed faces, for evidence of cracked or broken aggregate, and record observations.

10. Calculations

10.1. Tensile Strength

$$S_t = 2P/\pi tD$$

where:

S_t = tensile strength, psi;
P = maximum load, lb;
t = specimen thickness immediately before tensile test, in.; and
D = specimen diameter, in.

10.2. Tensile Strength Ratio

$$TSR = (S_{tm}/S_{td})100$$

where:

TSR = tensile strength ratio, percent;
S_{tm} = average tensile strength of moisture-conditioned subset, psi; and
S_{td} = average tensile strength of dry subset, psi.

11. Report

11.1. Average room temperature at which any measurements are made.

11.2. Number of specimens in each subset.

11.3. Average degree of saturation after saturating and after moisture conditioning.

11.4. Average swell after saturating and after moisture conditioning.

11.5. Tensile strength of each specimen in each subset.

11.6. Tensile strength ratio.

11.7. Results of estimated stripping observed when specimen fractures.

11.8. Results of observations of fractured or crushed aggregate.

12. Precision

12.1. Precision of the method is under study.

12.2. Tests on one moisture-conditioned mixture containing additive in one laboratory indicate that the difference in tensile strength between duplicate specimens should not exceed 25.2 psi.

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