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16. Abstract

This report contains a description of the development and use of the Wet-Dry Indirect Tensile Test to evaluate stripping or moisture susceptibility of asphalt mixtures.

Tests were performed on eight mixtures of which five had stripped in the field and three had not. Each mixture was tested to determine whether the results could be used to differentiate between stripping and nonstripping mixtures. Based on these tests and other field testing it was tentatively concluded that mixtures with less than 70 percent retained strength are moisture susceptible and require treatment.

Test results indicate the valuable information is provided by the Wet-Dry Indirect Tensile Test. The test can be performed either in the laboratory during mixture design or on the field-mixed materials. In general, the Wet-Dry Indirect Tensile Test offers good potential for use in detecting moisture susceptible mixtures before they are placed in the field.

17. Key Words
stripping, water damage, asphalt mixtures, stripping aggregates, stripping mixtures, indirect tensile test

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WET-DRY INDIRECT TENSILE TEST FOR EVALUATING MOISTURE SUSCEPTIBILITY OF ASPHALT MIXTURES

by

Thomas W. Kennedy
James N. Anagnos

Research Report Number 253-8

Moisture Effects on Asphalt Mixtures
Research Project 3-9-79-253

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

November 1984

PREFACE

This is the eighth report dealing with the findings of a research project concerned with moisture effects on asphalt mixtures. This report describes the Wet-Dry Indirect Tensile Test and includes a description of the procedure. The objectives of the study were to define and evaluate the test procedure, adapt it for use by a highway agency, and evaluate the test results to determine if the results can be used to differentiate between stripping and nonstripping asphalt mixtures and to evaluate proposed antistripping additives.

The work required to develop this report was provided by many people. Special appreciation is extended to Messrs. Pat Hardeman and Eugene Betts for their assistance in the testing program and to Drs. F. L. Roberts and K. W. Lee. In addition, the authors would like to express their appreciation to Messrs. Paul E. Krugler and Billy R. Neeley of the Texas State Department of Highways and Public Transportation for their suggestions, encouragement, and assistance in this research effort and to other personnel who provided the asphalt cements, their physical properties, and the various aggregates used in the testing program. Appreciation is also extended to the Center for Transportation Research staff who assisted in the preparation of the manuscript. The support of the Federal Highway Administration, Department of Transportation, is acknowledged.

Thomas W. Kennedy
James N. Anagnos

December 1984

LIST OF REPORTS

Report No. 253-1, "Stripping and Moisture Damage in Asphalt Mixtures," by Robert B. McGennis, Randy B. Machemehl, and Thomas W. Kennedy, summarizes a study to determine the extent, nature, and severity of moisture related damage to asphalt mixtures used in pavements in Texas.

Report No. 253-2, "An Evaluation of the Asphaltene Settling Test," by Thomas W. Kennedy and Chee-Chong Lin, summarizes a testing program designed to evaluate the Asphaltene Settling Test, the test procedure, factors affecting the test results, and relationships between settling time and asphalt characteristics.

Report No. 253-3, "Texas Freeze-Thaw Pedestal Test for Evaluating Moisture Susceptibility for Asphalt Mixtures," by Thomas W. Kennedy, Freddy L. Roberts, Kang W. Lee, and James N. Anagnos, includes a detailed description of the Texas Freeze-Thaw Pedestal Test and describes how it can be used to distinguish between stripping and nonstripping asphalt concrete mixtures or individual aggregates.

Report No. 253-4, "Lime Treatment of Asphalt Mixtures," by Thomas W. Kennedy and James N. Anagnos, summarizes information related to stripping of asphalt mixtures and the use of hydrated lime as an antistripping agent and makes recommendations concerning the construction techniques for adding lime.

Report No. 253-5, "Texas Boiling Test for Evaluating Moisture Susceptibility of Asphalt Mixtures," by Thomas W. Kennedy, Freddy L. Roberts, and James N. Anagnos, includes a detailed description and evaluation of the Texas Boiling Test Method and also describes how it can be used to distinguish between stripping and nonstripping asphalt concrete mixtures or individual aggregates.

Report No. 253-6, "A Field Evaluation of Techniques for Treating Asphalt Mixtures with Lime," by Thomas W. Kennedy and James N. Anagnos details a field study to evaluate the use of dry lime and lime slurry in asphalt mixtures.

Report No. 253-7, "Modified Test Procedure for Texas Freeze-Thaw Pedestal Test," by Thomas W. Kennedy and James N. Anagnos updates and alters the test procedures contained in a previously published report, Report No. 253-3, on conducting the Texas freeze-thaw pedestal test.

Report No. 253-8, "Wet-Dry Indirect Tensile Test for Evaluating Moisture Susceptibility of Asphalt Mixtures," by Thomas W. Kennedy and James N. Anagnos includes a detailed description of the wet-dry indirct tensile test for moisture susceptibility and describes its use to distinguish between stripping and nonstripping asphalt mixtures.

ABSTRACT

This report contains a description of the development and use of the Wet-Dry Indirect Tensile Test to evaluate stripping or moisture susceptibility of asphalt mixtures.

Tests were performed on eight mixtures of which five had stripped in the field and three had not. Each mixture was tested to determine whether the results could be used to differentiate between stripping and nonstripping mixtures. Based on these tests and other field testing it was tentatively concluded that mixtures with less than 70 percent retained strength are moisture susceptible and require treatment.

Test results indicate that valuable information is provided by the Wet-Dry Indirect Tensile Test. The test can be performed either in the laboratory during mixture design or on the field-mixed materials. In general, the Wet-Dry Indirect Tensile Test offers good potential for use in detecting moisture susceptible mixtures before they are placed in the field.

KEY WORDS: stripping, water damage, asphalt mixtures, stripping aggregates, stripping mixtures, indirect tensile test

SUMMARY

The Wet-Dry Indirect Tensile Test was developed as a laboratory test that could be used to determine if a proposed asphalt-aggregate mixture is prone to stripping. The procedure tests the moisture susceptibility by determining the retained strength of mixtures after being subjected to water conditioning. The retained strength is determined by comparing the dry tensile strength to the wet or conditioned tensile strength.

The purpose of this research was to evaluate a laboratory test procedure that could be used to determine the water susceptibility of asphalt paving mixtures and the effectiveness of antistripping additives.

Using the Wet-Dry Indirect Tensile Test, a series of tests was performed using five stripping and three nonstripping mixtures. The results demonstrate an ability to distinguish between stripping and nonstripping aggregate-asphalt mixtures.

IMPLEMENTATION STATEMENT

Tentative evaluations indicate that the Wet-Dry Indirect Tensile Test can be used to determine whether a mixture is prone to stripping. Therefore, it is recommended that the Districts of the Texas State Department of Highways and Public Transportation use the test procedure, on a trial basis, to evaluate mixtures selected for use in construction projects. As a result of this trial use, needed modifications and improvements can be made to improve the ability of the test to detect mixtures which are susceptible to moisture damage and to evaluate antistripping agents.

If the test is as successful in detecting stripping aggregates as preliminary laboratory results suggest, significant savings in construction and maintenance costs and improved pavement performance can be achieved.

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CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 1. INTRODUCTION

Water-induced damage of asphalt mixtures has produced serious distress, reduced performance, and increased maintenance for pavements in Texas, as well as in other areas of the United States. This damage occurs due to stripping of asphalt from aggregate and in some cases possibly due to softening of the asphalt matrix. Moisture-induced damage produces several forms of distress including localized bleeding, rutting, shoving, and ultimately complete failure due to permanent deformations and cracking. The two basic forms of moisture-related distress are stripping and softening.

Stripping, which is of primary concern, is the physical separation of the asphalt cement and aggregate produced by the loss of adhesion between the asphalt cement and the aggregate surface primarily due to the action of water or water vapor. Stripping is accentuated by the presence of aggregate surface coatings and by smooth surface textured aggregates. Softening is a general loss of stability of a mixture that is caused by a reduction in cohesion due to the action of moisture within the asphalt matrix.

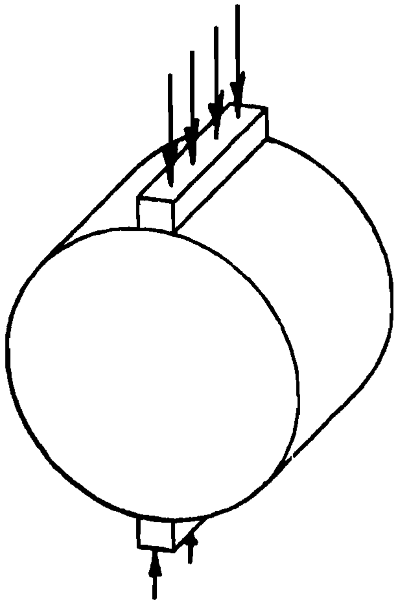
Field and laboratory experience to date (Refs 1-5) indicates that stripping is primarily an aggregate problem but that the type of asphalt is also important. Thus, it is important to evaluate both the asphalt and the aggregate which is proposed for use. In addition, attempts to reduce the magnitude of the problem often have centered on introducing various antistripping additives to asphalt mixtures. Unfortunately, there has been no generally accepted, reliable way to evaluate proposed aggregate-asphalt combinations to determine their water susceptibility.

In response to the above problem, the Center for Transportation Research (CTR) and the Texas Department of Highways and Public Transportation (DHT), through their cooperative research program, initiated a research project to study water-induced damage to asphalt mixtures in Texas.

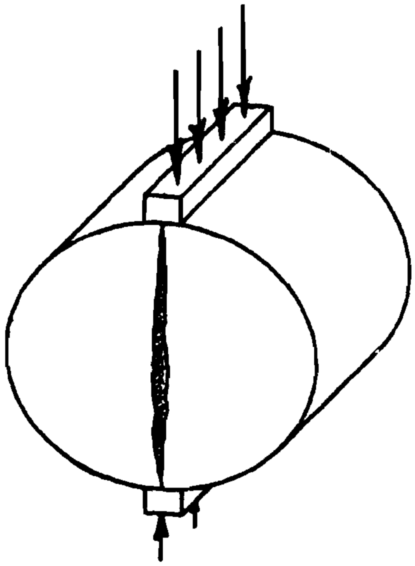
Prior to and during this project, an extensive study was conducted by Lottman (Ref 6) which led to a laboratory test to predict moisture damage in asphalt mixtures. This procedure includes a conditioning procedure for the specimens after which the specimens are tested using the static or repeated-load indirect tensile test (Refs 7, 8, and 9). Schmidt (Ref 10) also used the repeated-load indirect tensile test to evaluate the effects of moisture. Kennedy et al (Refs 11 and 12) investigated the effects of moisture on blackbase mixtures using the same test method.

The indirect tensile test subjects a cylindrical specimen to compressive loads, distributed along two opposite generators, which create a relatively uniform tensile stress perpendicular to and along the diametral plane which contains the applied load and causes a splitting failure (Fig 1). Estimates of the tensile strength, modulus of elasticity, and Poisson's ratio can be calculated from the applied load and corresponding vertical and horizontal deformations.

This report summarizes the development of the Wet-Dry Indirect Tensile Test and the findings of the study to evaluate its effectiveness. Chapter 2 contains the experimental program, Chapter 3 presents the test results, and Chapter 4 summarizes the conclusions and recommendations.



(a) Compressive load being applied.



(b) Specimen failing in tension.

Fig 1. Indirect tensile test loading and failure.

CHAPTER 2. EXPERIMENTAL PROGRAM

The objective of this study was to evaluate the use of the indirect tensile test on dry and wet cylindrical specimens for measuring the water susceptibility of asphalt mixtures and evaluating the effectiveness of various antistripping additives used in asphalt mixtures. To meet the objective, an experimental program was developed. The materials, specimen-preparation techniques, test equipment, experimental design, and testing procedures selected for study are described in this chapter.

MATERIALS

Eight project mixtures from seven Texas highway department districts were selected for use in this study (Fig 2). Of these eight projects, four previously exhibited stripping in the field and four did not. The stripping mixtures were from the Waco, Lufkin, Yoakum, and Houston (Harris County) districts. The major components of these stripping mixtures were siliceous river gravel and sand. The nonstripping mixtures were from the Lubbock, Houston (Galveston County), Austin, and Atlanta districts. The major components of these nonstripping mixtures were crushed limestone, caliche, or slag. The composition of each mixture by aggregate type and percentage is shown in Table 1.

The asphalt cements included in the testing program were the same as those used in previous pavement constructions. The asphalt properties, as determined by the Materials and Tests Division (D-9) of the Texas State Department of Highways and Public Transportation (DHT) are summarized in Table 2.

AGGREGATE GRADATION

The gradations for materials used to prepare specimens for the indirect tensile test and the boiling test are the same as those used in construction. The Yoakum and Lubbock materials met the requirements of Grade 1 flexible base Item 238 (processed gravel) and Item 232 (caliche), respectively

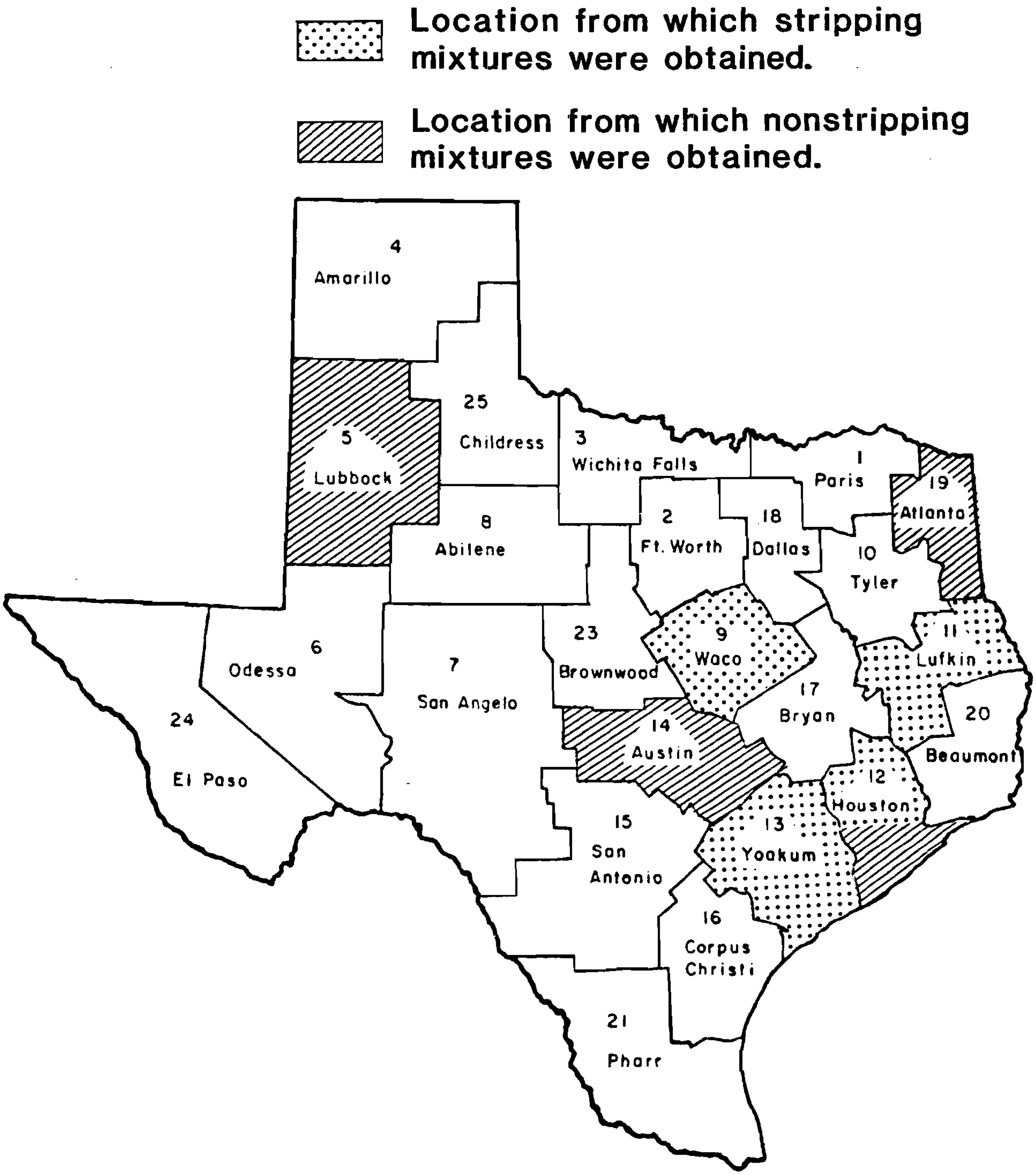


Fig 2. Texas Highway Department districts and location from which the mixtures were obtained.

TABLE 1. LOCATION AND DESCRIPTION OF AGGREGATE MIXTURES

A. STRIPPING

District	Aggregate Type	Producer and/or Source	Aggregate Proportion %
Dist. 9 Waco	Coarse gravel	Waco Sand & Gravel Co.	65.0
	Washed sand	Waco Sand & Gravel Co.	21.0
	Field sand	Pendeley River Sand, Inc.	14.0
Dist. 11 Lufkin	Crushed limestone	Gifford-Hill	27.0
	Pea gravel	Crocket Sand & Gravel Co.	15.0
	Coarse sand	Midway Material Co.	15.0
	Local fine sand	Dickerson pit	43.0
Dist. 12 Houston (Harris Co.)	Gravel screenings	Lone Star, Eagle Lake	63.3
	Crushed limestone	Texas Crushed Stone Co. (Harris Co.)	10.3
	Local field sand		26.4
Dist. 13 Yoakum	Lone Star coarse agg.	Lone Star, Eagle Lake	43.0
	Lone Star Gem sand	Lone Star, Eagle Lake	12.2
	Styles coarse sand	Styles	13.3
	Tanner Walker sand	Tanner Walker	31.5

B. NONSTRIPPING

District	Aggregate Type	Producer and/or Source	Aggregate Proportion %
Dist. 5 Lubbock	Crushed caliche	Lubbock (Long pit)	100.0
Dist. 12 Houston (Galveston Co.)	Crushed limestone	Texas Crushed Stone Co.	55.0
	Limestone screenings	Texas Crushed Stone Co.	20.0
	Field sand	Alvin (Flora pit)	25.0
Dist. 14 Austin	Crushed limestone	Southwest Materials Co.	61.0
	Limestone screenings	Texas Crushed Stone Co.	22.0
	Local sand	Centex Materials (Sheppard pit)	17.0
Dist. 19 Atlanta	Coarse slag	Gifford-Hill	60.0
	Slag screenings	Gifford-Hill	15.0
	Local sand	Panola County	12.0
	Wilson red sand	Shelby County	13.0

TABLE 2. PROPERTIES OF ASPHALT CEMENT AS DETERMINED BY TEXAS DHT

	Yoakum	Houston (Harris County)	Lufkin	Waco	Lubbock	Atlanta	Austin	Houston (Galveston County)
Asphalt Type	AC-20	AC-10	AC-20	AC-20	AC-10	AC-20	AC-10	AC-10
Producer	Exxon	Exxon	-	Vickers	Cosden Oil	Texaco	Exxon	Exxon
Water, percent	Nil	-	-	-	Nil	-	-	-
Viscosity at 135°C (275°F), Stokes	3.3	-	-	-	2.5	-	-	-
Viscosity at 60°C (140°F), Stokes	2,093	-	-	-	912	1,926	1,052	-
Solubility in CCl_4, percent	99.7	-	-	-	99.7	-	-	-
Flash Point, C.O.C., °C (°F)	>315 >(600)	-	-	-	>315 >(600)	>315 >(600)	-	-
Ductility at 25°C (77°F), 100 g, 5 sec	56	-	-	-	86	90	100	-
Specific Gravity at 25°C (77°F)	1.020	1.026	1.020	1.003	1.026	1.030	1.022	1.026
Tests on Residues from Thin Film Oven Tests								
Viscosity at 60°C (140°F), Stokes	3,574	-	-	-	2,172	-	-	-
Ductility at 25°C (77°F), 5 cm/min, cm	>141	-	-	-	>141	-	-	-
Spot Test	Neg	-	-	-	Neg	-	-	-

(Ref 13). To prepare specimens with 4 inch diameters, the aggregate particles retained on the 7/8 inch sieve were removed. Gradations of the other six materials met the requirements of Type D surface course paving mixtures and could be used without modification. The final gradations for the stripping and nonstripping mixtures are shown in Figures 3a and 3b, respectively.

INDIRECT TENSILE TEST ON DRY AND WET SPECIMENS

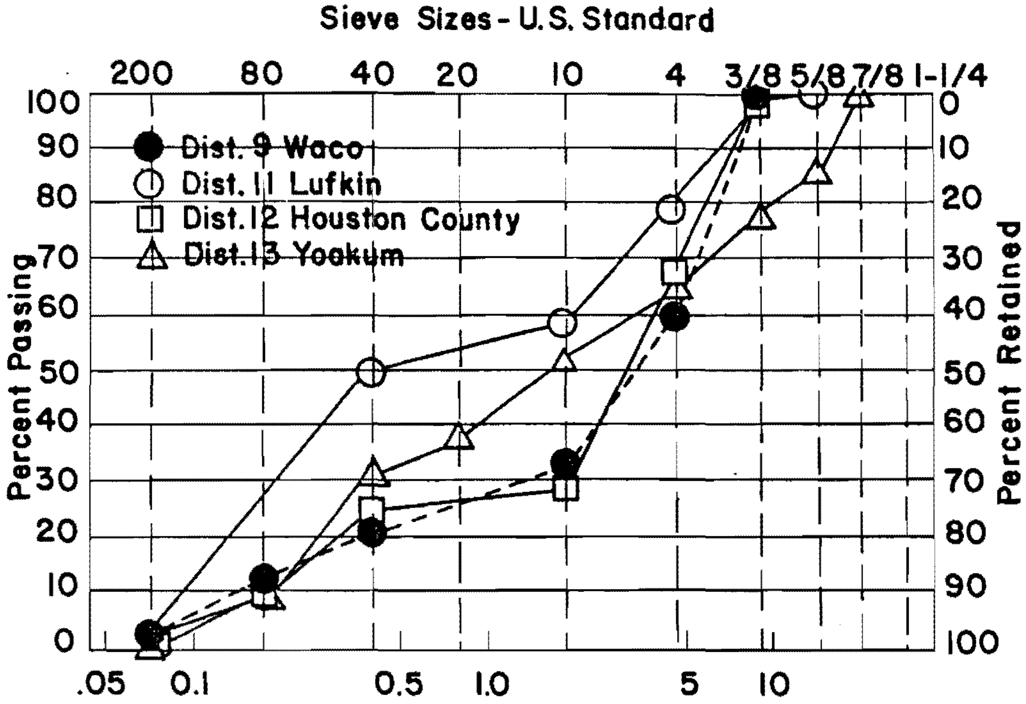
Some specimens were tested in a dry condition and others after moisture conditioning using the indirect tensile test. Estimates of the tensile strength, modulus of elasticity, and Poisson's ratio were calculated from the applied load and corresponding vertical and horizontal deformations. Formulas used to calculate these properties are included in Appendix A.

Specimen Preparation

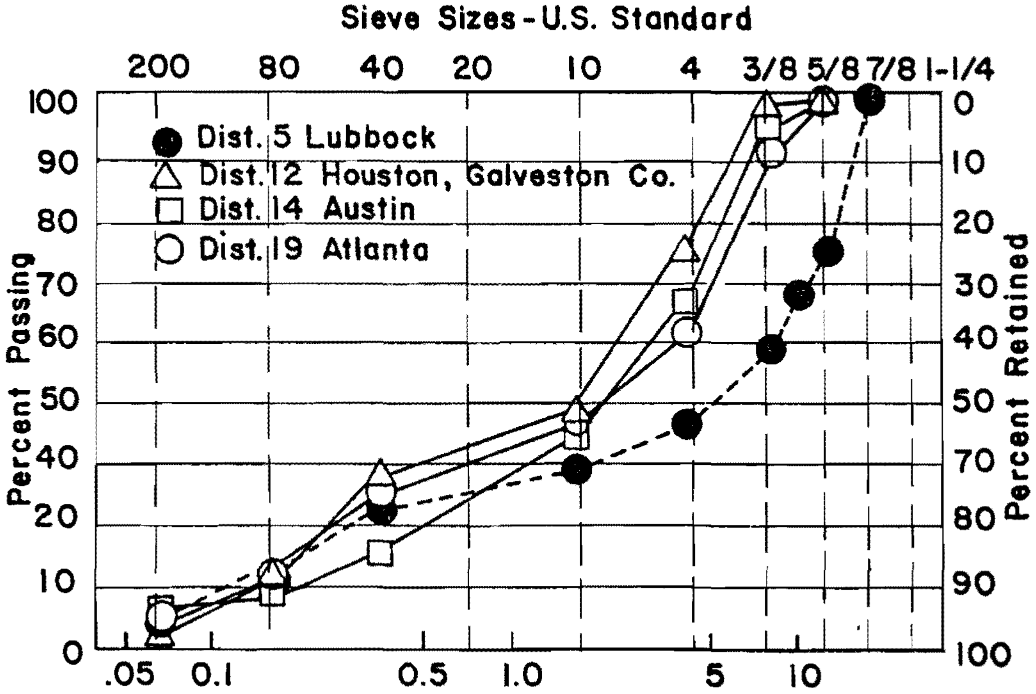
All specimens consisted of 900 g of aggregate and were batched by dry weight using the field job mix formula for each mixture. Cylindrical specimens with a 4.0 inch diameter and approximately a 2.0 inch height were compacted according to Texas Test Method Tex-206-F (Ref 14). The aggregate and asphalt were heated to 275°F, mixed at 275°F, and compacted at 250°F using the Texas-Gyratory shear compactor. However, different compaction efforts were applied to each mixture to produce air voids ranging from 6 to 8 percent so that water could penetrate easily. To produce specimens with this air void range, the Texas standard gyratory compaction procedure was modified as shown in Table 3. Only the Lufkin sand-asphalt mixture was compacted using the standard compaction effort since the air voids under standard compaction effort exceeded 10 percent.

Specimen Conditioning

In order to evaluate the changes in engineering properties of asphalt concrete mixtures when subjected to the effects of water, specimens were tested after either dry or wet conditioning. The dry conditioning consisted of curing the specimen at room temperature for 2 days prior to testing. The wet conditioning involved immersing the specimen in distilled water at room temperature, applying a vacuum, and then subjecting the specimen to various



a. Mixtures Experiencing Stripping in the Field



b. Mixtures not Experiencing Stripping in the Field

Fig 3. Gradation of asphalt mixtures in this study.

TABLE 3. SUMMARY OF COMPACTION EFFORT

	Mixture							
Compaction Effort	Dist. 5 Lubbock	Dist. 9 Waco	Dist. 11 Lufkin	Dist. 12 Houston (Harris Co.)	Dist. 12 Houston (Galveston Co.)	Dist. 13 Yoakum	Dist. 14 Austin	Dist. 19 Atlanta
Initial Pressure, psi	50	40	50	50	50	10	50	50
Number of Cycles at Initial Pressure Before Leveling-Up	4	2	continue until reaching 150 psi	5	3	2	2	2
Level-Up Pressure, psi	500	700	2500	1000	1700	275	1000	500
Remarks			Texas Standard Procedure, Tex-205-F					

other types of conditioning (Refs 6 and 15) as summarized in Table 4. Three levels of vacuum were used: 4-, 15-, and 26-inches of mercury. Lottman used 26-inch for his NCHRP study, but since it is difficult to obtain a 26-inch vacuum without a high quality pump, two lower levels, i.e., 4- and 15-inch, were also evaluated. Details of each conditioning procedure are included in Appendix B.

Test Procedure

The test equipment was the same as that used in previous studies at the Center for Transportation Research and included a loading frame, loading head, and MTS closed-loop electrohydraulic system to apply load and to control deformation rate (Refs 7 and 8). For the static test the vertical deformations were monitored by a DC linear variable differential transducer (LVDT) positioned on the upper platen. Horizontal deformations were measured using a device consisting of two cantilevered arms with strain gauges attached (Ref 8). A loading rate of 2 inches per minute was applied at a test temperature of 75°F. The loads and deformations were recorded by a pair of X-Y plotters, Hewlett Packard Models 7000A, one recording load and horizontal deformation and the other recording load and vertical deformation.

Engineering Properties Analyzed

The properties analyzed were tensile strength, modulus of elasticity, and Poisson's ratio. Equations used to calculate each property are included in the sections that follow.

Tensile Strength. Tensile strength is the maximum tensile stress which the specimen can withstand and is related to thermal or shrinkage cracking resistance. For 4-inch diameter specimens and the load-deformation information obtained from the static test, tensile strength can be calculated from the following relationship:

$$S_T = \frac{0.156P}{t} \qquad \text{(Eq 1)}$$

TABLE 4. SUMMARY OF CONDITIONING PROCEDURE FOR DRY AND WET SPECIMENS

Conditioning Abbreviation	Vacuum Height (inch)	Vacuum Time	Soaking Time After Vacuum	Temperature & Time at Cycle Freeze	Temperature & Time at Cycle Thaw	Number of Cycles	Remarks
Dry	--	--	--	--	--	--	2 days at 75°F
4VS	4	30 mins	30 mins	--	--	--	--
4F/TH	4	30 mins	30 mins	0°F (15 hrs)	140°F (24 hrs)	1	Plastic bag for freezing period
4VS+SOAK(7)	4	2 hrs	7 days	--	--	--	--
15F/TH	15	30 mins	30 mins	0°F (15 hrs)	140°F (24 hrs)	1	Plastic bag for freezing period
15TC	15	30 mins	30 mins	0°F (4 hrs)	120°F (4 hrs)	18	After thermal cycle 54°F water bath for 3 hrs
15VS+SOAK(7)	15	2 hrs	7 days	--	--	--	--
26VS	26	30 mins	30 mins	--	--	--	--
26F/TH	26	30 mins	30 mins	0°F (15 hrs)	140°F (24 hrs)	1	Plastic bag for freezing period
26TC	26	30 mins	30 mins	0°F (4 hrs)	120°F (4 hrs)	18	After thermal cycles 54°F water bath for 3 hrs
26VS+SOAK(7)	26	2 hrs	7 days	--	--	--	--

NOTE: All wet specimens are moisture conditioned after 2 days dry curing at 75°F.

where

S_T = tensile strength, psi,

P = the maximum load carried by the specimen, lb, and

t = thickness or height of the specimen, inch.

Tensile stress at any load can be calculated using the above equation.

Poisson's Ratio. Static Poisson's ratio is determined from an analysis of the load-deformation relationships obtained from the static indirect tensile tests. A regression analysis is performed to establish the equation of the straight line from the origin up to the sharp inflection point in the load-deformation curves, which generally occurs between 60 and 90 percent of the ultimate load. If a sharp break in the curve does not occur, data points up to about midway between the ultimate load and the deviation from linearity are included (Refs 7 and 8). The equation for calculating static Poisson's ratio is:

$$\nu = \frac{3.59}{DR} - 0.27 \qquad \text{(Eq 2)}$$

where

ν = static Poisson's ratio, and

DR = deformation ratio (the slope of the linear regression relationship between vertical and horizontal deformation), inches of vertical deformation per inch of horizontal deformation.

Modulus of Elasticity. The modulus of elasticity of an asphalt mixture is an important parameter that influences the structural design of asphalt pavements because the modulus affects the distribution of stress and strains throughout the structure. Static modulus of elasticity is calculated from the relationship between the vertical and horizontal deformations up to the sharp inflection point in the load-deformation relationship first as for static Poisson's ratio. The equation for calculating the static modulus of elasticity is:

$$E_S = \frac{S_h}{t} (0.27 + \nu) \qquad \text{(Eq 3)}$$

where

E_S = static modulus of elasticity, psi, and

S_h = the slope of the relationship between load and horizontal deformation, lb/inch.

In order to evaluate the effects of moisture conditioning on the stripping and nonstripping mixtures, three additional parameters were defined in terms of tensile strength and modulus of elasticity of the mixtures. These parameters are tensile strength ratio, static modulus of elasticity ratio, and resilient modulus of elasticity ratio, which are defined as follows:

$$TSR = \frac{S_{T_{wet}}}{S_{T_{dry}}} \qquad \text{(Eq 4)}$$

where

TSR = tensile strength ratio,

$S_{T_{wet}}$ = tensile strength of the wet specimen, psi, and

$S_{T_{dry}}$ = tensile strength of the dry specimen, psi;

and

$$MER = \frac{E_{S_{wet}}}{E_{S_{dry}}} \qquad \text{(Eq 5)}$$

where

MER = static modulus of elasticity ratio,

$E_{S_{wet}}$ = modulus of elasticity of the wet specimen, psi, and

$E_{S_{dry}}$ = modulus of elasticity of the dry specimen, psi.

Experimental Design

The variables included in this study were aggregate type, specimen conditioning before testing (dry and wet), and test methods. Specimens were prepared and tested according to the experimental design outlined in Table 5. All specimens were tested at room temperature, 75°F, after the conditioning sequence was completed.

A limited set of repeated-load indirect tensile tests on dry and wet specimens was also conducted to investigate the use of resilient modulus for detecting water damage in asphalt mixtures. Tests were performed on specimens conditioned using only 4-inch vacuum saturation. These tests are described in Appendix E.

TABLE 5. EXPERIMENTAL DESIGN FOR STATIC INDIRECT TENSILE TEST WITH AND WITHOUT MOISTURE CONDITIONING

	Stripping Mixtures (Field Performance)				Nonstripping Mixtures (Field Performance)			
	Materials (District)				Materials (District)			
Moisture Conditioning	9 Waco	11 Lufkin	12 Houston (Harris Co.)	13 Yoakum	5 Lubbock	12 Houston (Galveston Co.)	14 Austin	19 Atlanta
Dry	5	15	15	15	15	4	5	15
4VS	3	3	3	3	3	3	3	3
4F/TH	3	3	3	3	3	3	3	3
4VS+SOAK(7)	3	3	3	3	3	3	3	3
15F/TH	-	3	3	--	--	3	3	--
15TC	-	3	3	--	--	3	3	--
15VS+SOAK(7)	-	3	3	--	--	3	3	--
26VS	3	3	3	3	3	3	3	3
26F/TH	3	3	3	3	3	3	3	3
26TC	3	3	3	3	3	3	3	3
26VS+SOAK(7)	3	3	3	3	3	3	3	3

NOTE: Number of specimens are indicated in each cell.

CHAPTER 3. ANALYSIS AND DISCUSSION OF TEST RESULTS

The tensile strength ratio, TSR, and modulus of elasticity ratio, MER, are summarized in Table 6 for each of the eight mixtures.

TENSILE STRENGTH RATIO

Values of TSR for the moisture conditioning techniques with a 4-inch vacuum ranged from 0.79 to 1.14 for the stripping mixtures and 0.34 to 1.21 for the nonstripping ones. The range of values using 15 inches vacuum was 0.41 to 0.94 for stripping mixtures and 0.37 to 0.84 for nonstripping ones. TSR values for the various moisture conditioning techniques with a 26-inch vacuum ranged from 0.16 to 0.91 for the stripping mixtures and from 0.10 to 1.25 for the nonstripping mixtures.

TSR values for 4-, 15-, and 26-inch vacuum are plotted in Figs 4, 5, and 6, respectively. Review of these results show that the 4-inch Hg vacuum technique was not able to distinguish between stripping and nonstripping mixtures (Fig 4). Furthermore, some TSR values are over 1.0 which means the gain of strength after moisture conditioning. This probably reflects the variation in specimen strength due to preparation and testing techniques rather than an inability to detect moisture damage. It was also observed that the Lubbock caliche exhibited smaller TSR values for the 4VS+SOAK(7DAYS) and 4F/TH moisture conditioning techniques than did the other materials. For the 15-inch Hg vacuum technique, only four mixtures were tested: two stripping and two nonstripping mixtures. Use of these data did not allow a clear differentiation between stripping and nonstripping mixtures (Fig 5).

Use of the TSR values at 26-inch vacuum provided better differentiation than did values from the 4- or 15-inch vacuum (Fig 6). In general, conditioning with method 26VS appears to produce higher TSR values and is therefore less severe than any other conditioning method, and 26VS+SOAK(7DAYS) was next. But use of data from these techniques did not allow a clear separation between the stripping and nonstripping mixtures. The most severe conditioning techniques were methods 26F/TH and 26TC, and data from these two methods could be used to discriminate between the stripping and nonstripping

TABLE 6. SUMMARY OF STATIC INDIRECT TENSILE TEST RESULTS

A. STRIPPING MIXTURES

District	Conditioning Technique	Air Void Contents,		Moisture Content, %	Tensile Strength, S_T psi	Static Modulus of Elasticity, E_S psi	Wet/Dry Ratio	
		Before Conditioning	After Conditioning				Tensile Strength Ratio, TSR	Modulus of Elasticity Ratio, MER
Dist. 9 Waco	DRY	6.8	--	--	75	38,100	--	--
	4VS	6.9	7.0	1.8	74	31,400	0.99	0.82
	4F/TH	7.0	6.7	2.6	59	24,900	0.79	0.65
	4VS+SOAK(7)	7.2	6.8	1.5	78	42,400	1.04	1.11
	26VS	7.2	7.0	3.0	54	20,700	0.73	0.54
	26F/TH	7.4	8.2	3.9	16	8,800	0.21	0.23
	26TC	7.5	7.8	3.3	15	5,800	0.20	0.15
	26VS+SOAK(7)	7.6	7.3	3.8	42	35,900	0.56	0.94
Dist. 11 Lufkin	DRY	10.9	--	--	49	28,500	--	--
	4VS	10.6	10.6	0.7	51	27,300	1.05	0.96
	4F/TH	10.3	10.5	2.3	46	22,100	0.95	0.77
	4VS+SOAK(7)	10.7	10.8	2.2	55	24,100	1.14	0.85
	15F/TH	11.4	12.6	4.7	21	9,000	0.44	0.32
	15TC	11.4	11.8	3.7	29	14,800	0.60	0.52
	15VS+SOAK(7)	11.3	11.7	4.2	45	34,100	0.94	1.20
	26VS	11.4	11.9	5.4	43	18,300	0.88	0.64
	26F/TH	11.4	13.6	6.5	10	4,800	0.20	0.17
	26TC	11.4	12.0	5.2	15	6,900	0.31	0.24
	26VS+SOAK(7)	11.7	12.1	5.8	41	28,300	0.84	0.99
Dist. 12 Houston (Harris Co.)	DRY	7.1	--	--	50	23,200	--	--
	4VS	7.2	7.2	0.6	55	23,600	1.11	1.02
	4F/TH	7.2	7.1	2.2	44	18,900	0.89	0.82
	4VS+SOAK(7)	6.8	6.8	1.7	49	26,400	0.99	1.14
	15F/TH	7.1	7.3	3.1	24	13,800	0.47	0.59
	15TC	7.3	7.4	2.8	21	11,900	0.41	0.51
	15VS+SOAK(7)	6.7	6.4	2.8	43	29,600	0.87	1.28
	26VS	7.0	6.9	3.8	45	27,100	0.91	1.17
	26F/TH	6.8	7.1	3.8	16	14,800	0.32	0.64
	26TC	6.6	6.9	3.3	12	9,000	0.26	0.39
	26VS+SOAK(7)	6.8	7.1	4.2	26	12,100	0.52	0.52
Dist. 13 Yoakum	DRY	5.8	--	--	101	55,200	--	--
	4VS	--	--	0.3	103	52,600	1.01	0.95
	4F/TH	--	--	1.3	109	58,800	1.07	1.06
	4VS+SOAK(7)	--	--	1.1	100	45,600	0.99	0.83
	26VS	4.7	6.7	2.8	51	13,800	0.51	0.25
	26F/TH	4.6	5.3	2.3	36	18,900	0.36	0.34
	26TC	4.9	5.6	2.0	29	11,500	0.29	0.21
	26VS+SOAK(7)	3.9	5.7	3.3	51	28,000	0.50	0.51

TABLE 6. (Continued)

B. NONSTRIPPING MIXTURES

District	Conditioning Technique	Air Void Contents,		Moisture Content, %	Tensile Strength, S_T psi	Static Modulus of Elasticity, E_S psi	Wet/Dry Ratio	
		Before Conditioning	After Conditioning				Tensile Strength Ratio, TSR	Modulus of Elasticity Ratio, MER
Dist. 5 Lubbock	DRY	7.9	--	--	75	39,800	--	--
	4VS	7.7	--	1.9	88	41,100	1.18	1.03
	4F/TH	8.7	12.5	8.0	25	7,400	0.34	0.19
	4VS+SOAK(7)	8.1	11.9	7.2	27	9,500	0.37	0.24
	26VS	7.6	8.6	6.8	34	9,800	0.46	0.25
	26F/TH	7.1	14.6	10.3	7	2,700	0.10	0.07
	26TC	7.2	13.3	7.8	13	5,500	0.17	0.14
	26VS+SOAK(7)	6.5	11.0	8.5	22	9,000	0.29	0.23
Dist. 12 Houston (Galveston Co.)	DRY	7.9	--	--	66	42,900	--	--
	4VS	7.6	7.8	1.2	70	36,200	1.06	0.84
	4F/TH	7.9	8.5	2.8	49	25,100	0.73	0.58
	4VS+SOAK(7)	7.8	8.2	2.2	70	34,100	1.06	0.79
	15F/TH	6.6	8.7	4.4	24	7,700	0.37	0.18
	15TC	6.6	7.6	3.3	33	13,200	0.51	0.31
	15VS+SOAK(7)	8.4	9.6	4.8	36	26,700	0.54	0.62
	26VS	7.8	8.8	5.0	31	9,900	0.47	0.23
	26F/TH	7.7	10.2	6.3	12	5,300	0.18	0.12
	26TC	7.9	9.8	5.8	13	6,000	0.20	0.14
	26VS+SOAK(7)	8.1	9.5	6.0	30	26,800	0.45	0.63
Dist. 14 Austin	DRY	7.7	--	--	49	20,100	--	--
	4VS	7.5	7.7	1.4	53	28,500	1.09	1.42
	4F/TH	8.2	8.3	3.1	36	16,700	0.73	0.83
	4VS+SOAK(7)	7.7	7.6	2.6	55	23,200	1.13	1.15
	15F/TH	8.4	8.5	4.4	29	13,100	0.60	0.68
	15TC	8.7	9.0	3.1	30	13,700	0.61	0.68
	15VS+SOAK(7)	7.2	7.1	3.6	41	17,100	0.84	0.85
	26VS	6.9	9.0	4.3	61	38,200	1.25	1.90
	26F/TH	6.6	6.6	4.2	34	17,200	0.69	0.86
	26TC	6.6	7.3	3.9	31	15,800	0.64	0.78
	26VS+SOAK(7)	7.1	7.2	5.2	44	22,600	0.91	1.12
Dist. 19 Atlanta	DRY	7.7	--	--	54	22,100	--	--
	4VS	7.1	7.3	1.2	55	22,800	1.02	1.03
	4F/TH	9.8	9.9	3.0	57	18,300	1.07	0.83
	4VS+SOAK(7)	6.7	6.8	2.2	65	25,20	1.21	1.14
	26VS	7.8	10.1	4.1	61	26,000	1.14	1.17
	26F/TH	5.8	6.2	4.0	43	8,500	0.80	0.38
	26TC	7.0	7.1	4.0	35	9,600	0.66	0.44
	26VS+SOAK(7)	8.3	8.2	5.7	41	9,200	0.77	0.41

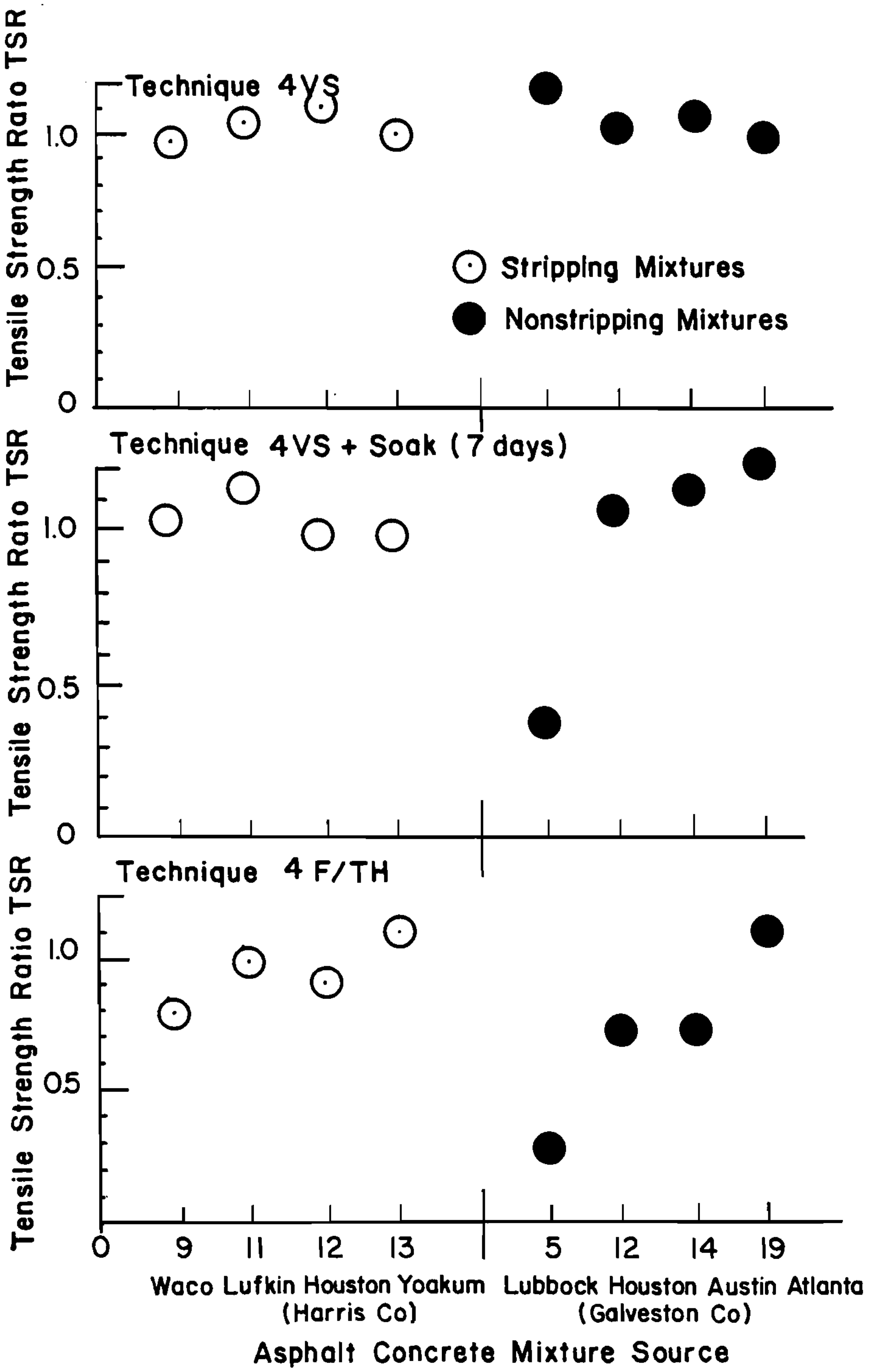


Fig 4. Tensile strength ratio, TSR, for various moisture conditioning techniques with 4-inch vacuum.

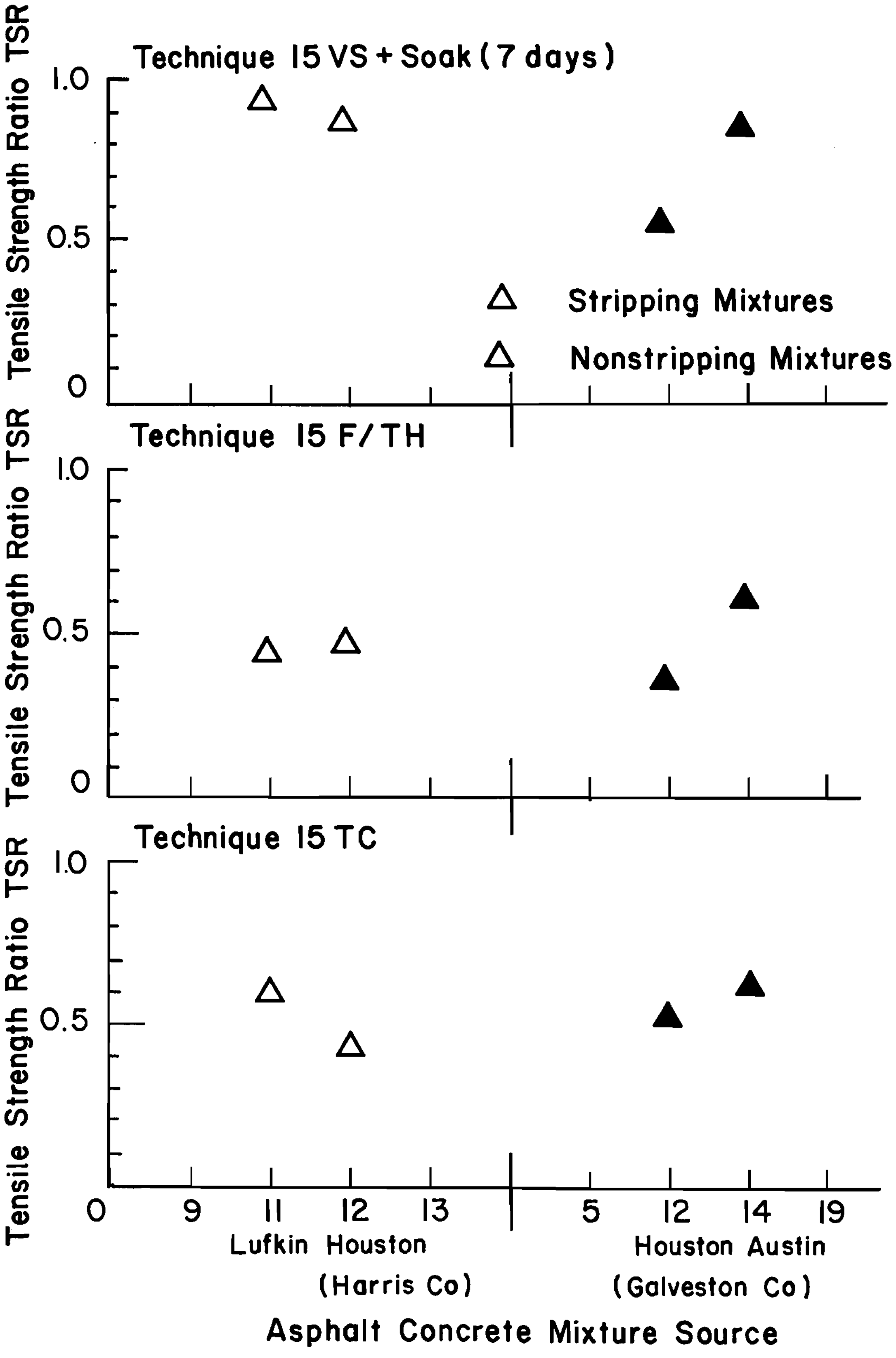


Fig 5. Tensile strength ratio, TSR, for various moisture conditioning techniques with 15-inch vacuum.

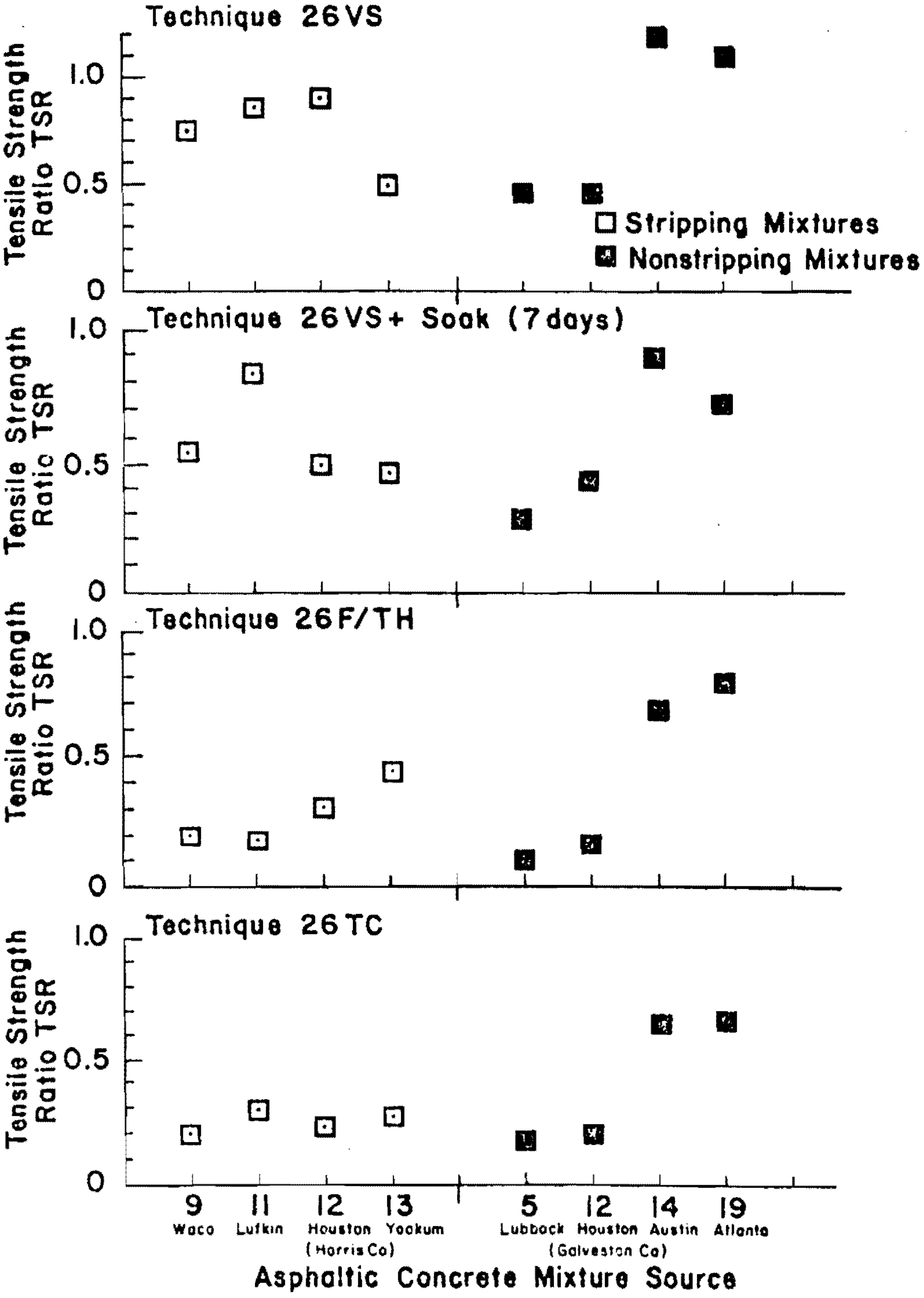


Fig 6. Tensile strength ratio, TSR, for various moisture conditioning techniques with 26-inch vacuum.

mixtures. Evaluation of test results from these two conditioning techniques will be included in a later section.

In overall reviewing of the test data it was not possible to select a single value of TSR using any of the moisture conditioning techniques that will consistently differentiate between the stripping and nonstripping mixtures because of the overlap of data shown in Figs 4, 5, and 6. This result is contrary to those reported by both Lottman (Ref 6) and Epps, et al (Ref 15), but this overlap was consistent for most materials tested in this investigation.

The ranges of these TSR values are slightly wider than those for the mixtures (0.14 to 1.04) reported by Lottman (Ref 6). Maupin reported TSR values ranging from 0.26 to 1.17 for specimens subjected to similar freeze-thaw conditioning (Ref 16). Overall, the ranges reported are very similar and the differences could be produced by the wide range of air void contents included in these data.

Modulus of Elasticity Ratio

Values of MER for the moisture conditioning techniques with a 4-inch vacuum ranged from 0.65 to 1.14 for the stripping mixtures and 0.19 to 1.42 for the nonstripping ones. The range of values using 15-inch vacuum was 0.32 to 1.28 for stripping mixtures and 0.18 to 0.85 for nonstripping ones. Values of MER from tests run with 26 inches of vacuum ranged from 0.15 to 1.17 for stripping mixtures and 0.07 to 1.90 for nonstripping ones. The range of the MER values is a little wider than the values for TSR, but generally are very similar. As with the TSR, the MER results for the stripping and nonstripping materials overlap for the various conditioning techniques with the result that no one method could be identified that could consistently differentiate between stripping and nonstripping mixtures. Figure 7 shows the relationship between TSR and MER for the same specimens and illustrates that there is a fairly well-defined relationship that explains about 75 percent of the variations in the data.

Evaluation of Mixtures

Indirect tensile test results indicated that the stripping mixtures, which are mainly composed of siliceous river gravel and sand, have very low

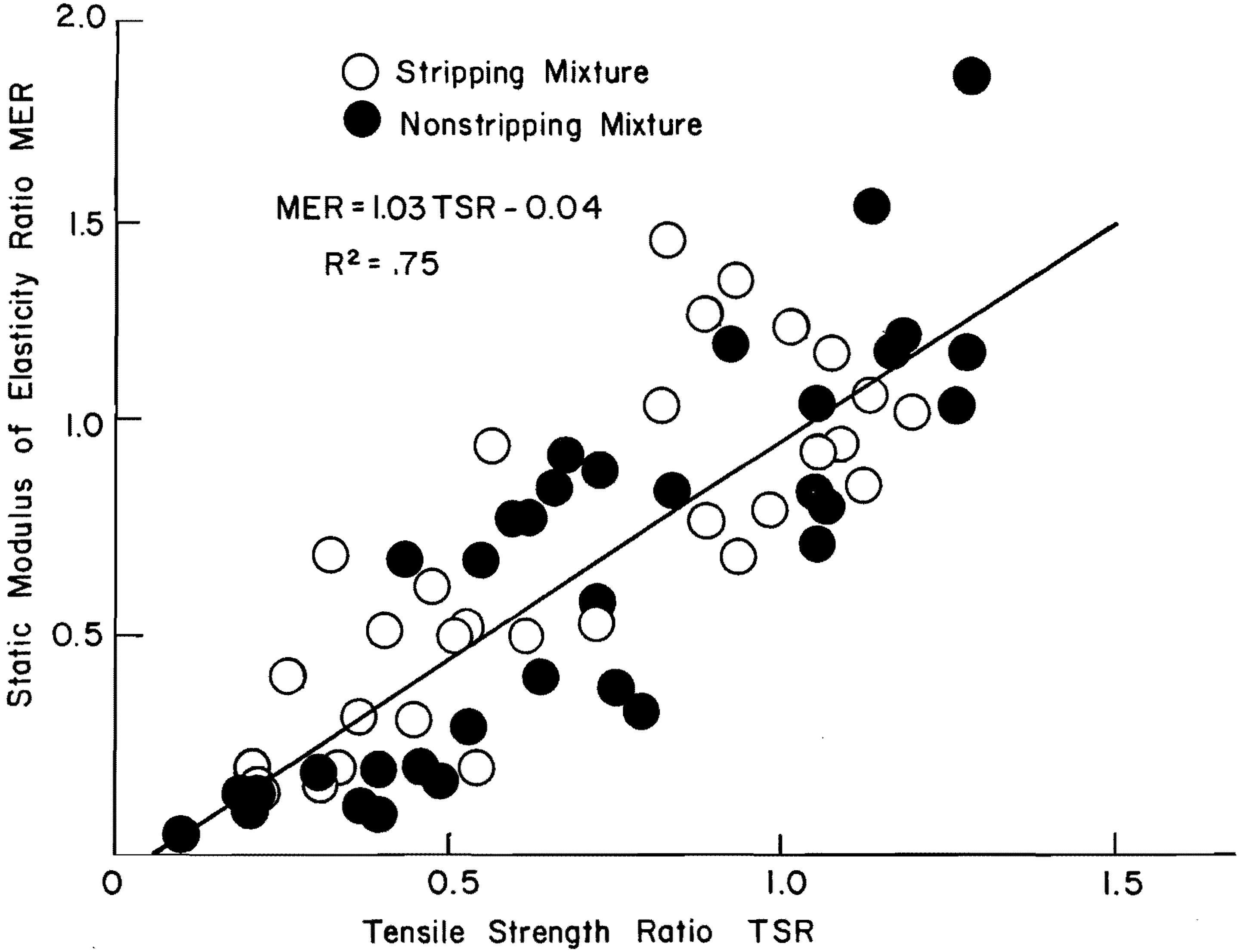


Fig 7. Relationship between tensile strength ratio and static modulus of elasticity ratio.

TSR values using conditioning techniques 26F/TH and 26TC. Two of the nonstripping mixtures, which are mainly composed of caliche or limestone, also exhibited very low values (Fig 6). The values exhibited by these two nonstripping aggregates produced the major difficulty in using these moisture conditioning techniques to discriminate between the stripping-prone and nonstripping mixtures. Therefore, the characteristics of these two nonstripping mixtures will be discussed further.

The Lubbock caliche mixture was much more susceptible to deterioration under water action than any of the other aggregates. Similar observations were reported in two previous studies (Refs 11 and 12) where this caliche was used. As shown in Figs 4, 5, and 6, the TSR values for the caliche mixtures were consistently the smallest for all conditioning methods. In examining Table 7, it was also observed that the caliche mixture had a higher degree of saturation than did the others. The air void contents for the dry caliche specimens ranged from 6.8 to 9.3 percent; however, after moisture conditioning, the air voids content range had increased to 8.2 to 14.9 percent. Figure 8 shows the significance of this change in air void content between before and after moisture conditioning. Because of this large volume change after conditioning, it would appear reasonable to expect the caliche mixtures to exhibit a greater loss in strength, or lower TSR.

The material from Houston district (Galveston County) consisted of 75 percent limestone and 25 percent field sand. Even though there is no stripping problem in the field, the TSR values were lower than those of the stripping mixtures (Figs 4 and 5). On the other hand, the material from the Austin district, which is composed of 83 percent limestone and 17 percent field sand, has the highest TSR values. In comparing the above two limestone mixtures, two differences were observed. First, the Galveston mixture had a deficiency of the size passing the No. 10 sieve and retained on the No. 40 sieve that the Austin mixture did not. According to Goode and Lufsey (Ref 17), mixtures with a deficiency on the above sizes are not well-graded ones, and have experienced considerable difficulty with moisture problems. Secondly, the two mixtures contained different field sands. To check the effect of the sands, the Austin limestone was mixed with the Galveston field sand, compacted, dry cured and 26F/TH moisture conditioned, and tested using the static indirect tensile test. The TSR values dropped from 0.69 of the Austin mixture to 0.28 for the mixture of Austin limestone and Galveston

TABLE 7. SUMMARY OF DEGREE OF SATURATION

	Stripping				Nonstripping			
	Material (District)				Material (District)			
Moisture Conditioning	9 Waco	11 Lufkin	12 Houston (Harris Co.)	13 Yoakum	5 Lubbock	12 Houston (Galveston Co.)	14 Austin	19 Atlanta
4VS (30 min)	59	14	18	--	--	34	40	35
4F/TH	89	48	72	--	122	71	81	66
4VS+SOAK(7)	58	44	56	--	117	57	76	73
15F/TH	--	79	94	--	--	108	110	--
15TC	--	67	83	--	--	96	74	--
15VS+SOAK(7)	--	78	98	--	--	106	111	--
26VS	96	97	120	91	160	121	104	86
26F/TH	107	101	120	94	133	128	137	144
26TC	96	93	107	79	111	125	117	125
26VS+SOAK(7)	119	104	132	128	151	134	158	149

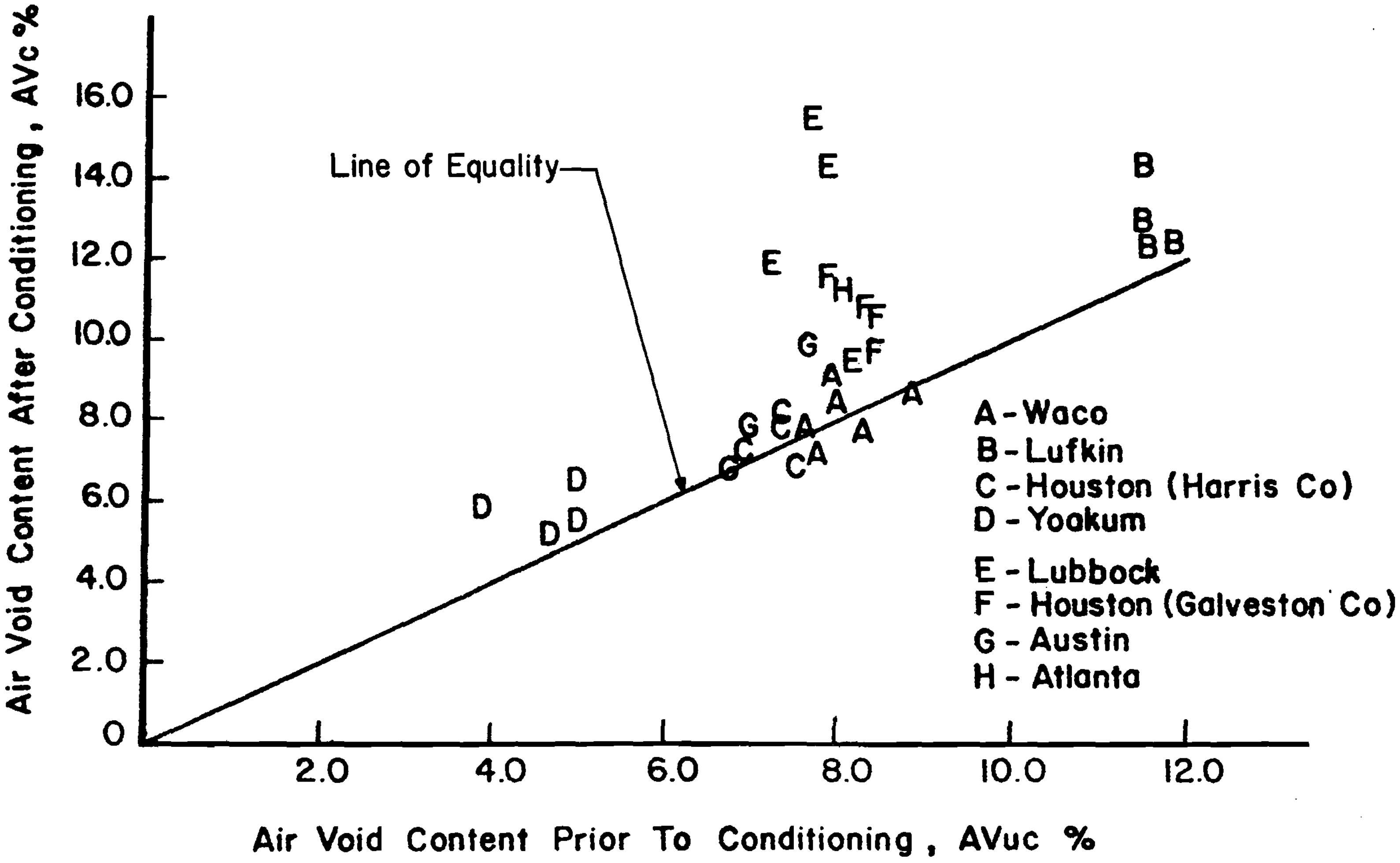


Fig 8. Comparison of air void contents obtained prior to conditioning and the ones obtained after conditioning at 26-inch vacuum.

field sand (Fig 9). This indicates that even with the limestone as the main constituent the Galveston field sand produced a water-susceptible mixture. These two differences help to explain why the Galveston mixture exhibited such a low TSR value even with a stripping resistant limestone.

The moisture contents for four stripping and four nonstripping mixtures were plotted versus TSR results from all moisture conditioning techniques in Fig 10. It was observed that there was considerably more scatter in the data for stripping mixtures than for the nonstripping mixtures. It appears that the water-susceptible aggregates could strip regardless of the amount of water in the voids (Fig 10). On the other hand, the nonstripping mixture had high TSR values at low water content, and low TSR values on high water contents (Fig 10). This observation indicates that even the nonstripping mixtures could lose significant strength at high water contents. Again, the Lubbock caliche and Houston (Galveston County) limestone mixtures exhibited the high strength losses at high water contents.

In general, these data show that the limestone or slag mixtures produce higher TSR values than the siliceous river gravel and sand mixtures. The data also show that the TSR values are affected by several factors including: degree of saturation, gradation, aggregate type, and air void content. Consequently, the TSR values are very helpful in identifying moisture susceptible mixtures, but identification using TSR is not 100 percent reliable.

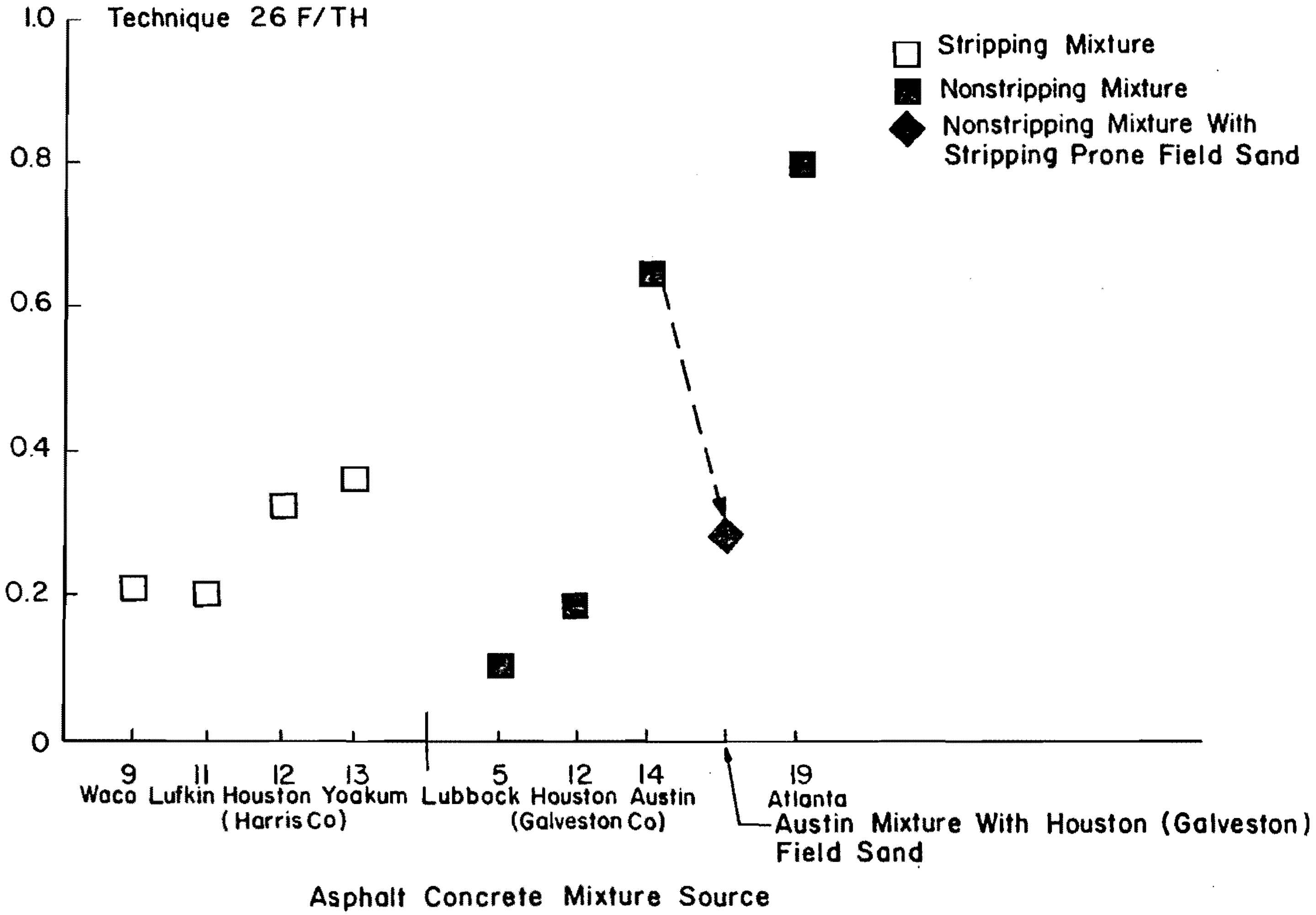


Fig 9. Comparison of two nonstripping mixtures.

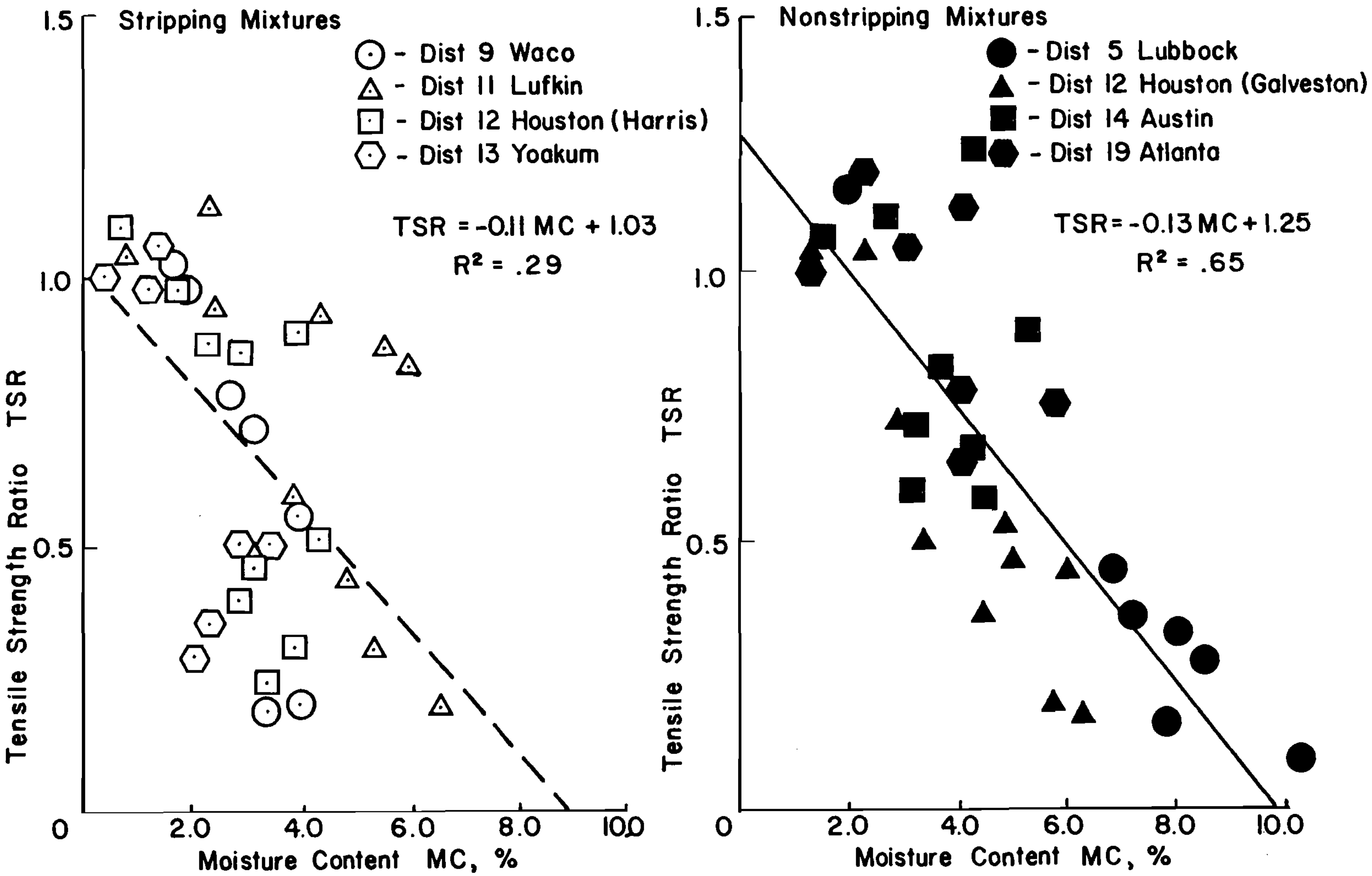


Fig 10. Relationship between moisture content and tensile strength ratio.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

For proper evaluation based on project findings and experience, mixtures should have about 7 percent air voids and it is tentatively recommended that compacted specimens should be conditioned to produce a constant degree of saturation in the range of 60 to 80 percent, rather than by following a specified procedure. Moisture conditioning is provided by subjecting submerged samples to a vacuum equivalent to 26 inches of mercury. Moisture susceptibility is determined by the ratio of tensile strength in a wet condition to the tensile strength in a dry condition, which is called the tensile strength ratio. Currently, it is felt that mixtures with tensile strength ratios less than 70 percent are moisture susceptible and mixtures with ratios greater than 70 percent are relatively resistant to moisture damage. However, mixtures with ratios between 70 and 85 percent would probably benefit by treating the aggregate or asphalt with an effective antistripping additive. In addition, consideration should be given to the absolute values of the retained strength.

INDIRECT TENSILE TEST

(1) Results from tensile testing after subjecting specimens to the different moisture conditioning techniques do not differentiate consistently between the stripping and nonstripping mixtures. In general, the 26F/TH and 26TC techniques do the best job of separating the stripping and nonstripping mixtures.

(2) Values of TSR decreased with increased water contents.

(3) Many mixtures exhibited increases in void contents during moisture conditioning, especially the caliche which had a large change in air voids which helps to explain the very high loss of strength in the moisture conditioned caliche specimens. On the other hand, the gravel mixture showed a small increase in air void content during moisture conditioning.

(4) Potential treatments can also be evaluated using either test; however, each aggregate-asphalt combination should be tested. If

any component of a mixture is changed, the new mixture should also be tested.

LONG TERM

(1) Other aggregate mixtures with known field performance characteristics should be tested and the results evaluated.

(2) Additional tests should be performed using other aggregate and asphalt combinations to determine if other antistripping additives are effective in increasing the moisture resistance of asphalt-aggregate mixtures.

(3) Additional aggregates should be tested with hydrated lime to determine if its effectiveness is limited to a certain class of aggregates.

(4) Long-term performance evaluations should be made on field projects which are designed using the results from these tests. Only with long-term observations can the reliability of the laboratory findings be assessed. These observations are also needed to evaluate the long-term effectiveness of antistripping additives.

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APPENDIX A

PROPERTIES ANALYZED FOR
INDIRECT TENSILE TEST SPECIMENS

APPENDIX A. PROPERTIES ANALYZED FOR INDIRECT TENSILE TEST SPECIMENS

OTHER PROPERTIES REQUIRED FOR ANALYSIS

To assist in the total analysis of test results, several additional mixture properties were required. Each of the following sections describes one of those properties.

Bulk Specific Gravity

The gulk specific gravity is the ratio of the weight of the compacted bituminous mixture specimen to the bulk volume of the specimen (Refs 14 and 19). ASTM Designation D-2726-73 was used to determine the actual specific gravity as follows:

$$G_a = \frac{A}{B - C} \qquad \text{(Eq A.1)}$$

where

G_a = actual specific gravity,

A = weight of the dry specimen in air, g

B = weight of the saturated surface-dry specimen in air, g, and

C = weight of the specimen in water, g.

Theoretical Maximum Specific Gravity

The theoretical maximum specific gravity of a specimen occurs when all the air voids are filled and is calculated as follows:

$$G_t = \frac{100}{\frac{P}{G} + \frac{P_1}{G_1}} \qquad \text{(Eq A.2)}$$

where

G_t = theoretical specific gravity,

P = percent by weight of aggregate in specimen,

P_1 = percent by weight of asphalt in specimen,

G = average bulk specific gravity of the combined aggregate, and

G_1 = specific gravity of the asphalt determined at 77°F.

Percent Air Voids in Dry Specimens

The air voids in a dry specimen are the small air spaces between the individual aggregate particles. This can be determined by the following equation:

$$AV_{dry} = \frac{G_t - G_{a_{dry}}}{G_t} \times 100 \qquad \text{(Eq A.3)}$$

where

AV_{dry} = air voids in a dry specimen, percent, and

$G_{a_{dry}}$ = actual bulk specific gravity of a dry specimen.

Percent Air Voids in Wet Specimens

The air voids in a wet specimen are determined in the same manner as for a dry specimen:

$$AV_{wet} = \frac{G_t - G_{a_{wet}}}{G_t} \times 100 \qquad \text{(Eq A.4)}$$

where

AV_{wet} = air voids in a wet specimen, percent, and

$G_{a_{wet}}$ = actual bulk specific gravity of a wet specimen.

Degree of Saturation

The ratio of the volume of water in a wet specimen to the total volume of voids is the degree of saturation and is calculated as a percentage:

$$S = \frac{V_W}{V_V} \times 100 \qquad \text{(Eq A.5)}$$

where

S = degree of saturation in wet specimen, percent,

V_W = volume of water in a wet specimen, and

V_V = total volume of voids in a wet specimen.

Moisture Content

The ratio of the weight of water in a wet specimen to the weight of a dry specimen is the moisture content and is calculated as a percentage:

$$w = \frac{W_{water}}{W_{dry}} \times 100 \qquad \text{(Eq A.6)}$$

where

w = moisture content of wet specimen, percent,

W_{water} = weight of water in wet specimen, and

W_{dry} = weight of dry specimen.

APPENDIX B

SPECIMEN PREPARATION AND CONDITIONING PROCEDURE FOR THE INDIRECT TENSILE TEST

APPENDIX B. SPECIMEN PREPARATION AND CONDITIONING PROCEDURE FOR THE INDIRECT TENSILE TEST

Wet tensile strength and static and resilient moduli of elasticity were determined for cylindrical specimens using the indirect tensile test method as developed by Anagnos and Kennedy (Refs 11 and 12). For the wet testing, four methods of moisture conditioning were used as follows:

A. Vacuum Saturation (4VS or 26VS)

1. Mix and compact specimens
2. Cure specimen at 75°F for 2 days
3. Submerge the specimen in distilled water at 75°F and vacuum saturate for 30 minutes at 4 or 26 inches of mercury
4. Soak for 30 minutes (no vacuum) at 75°F
5. Remove and immediately test at 75°F at a loading rate of 2 inches per minute.

Mixture age at testing: 2 days, approximately.

B. Vacuum Saturated Freeze-Thaw (4F/TH, 15F/TH, or 26 F/TH)

1. Mix and compact specimens
2. Cure specimens at 75°F for 2 days
3. Submerge the specimen in distilled water at 75°F and vacuum saturate for 30 minutes at 4 or 26 inches of mercury
4. Soak for 30 minutes (no vacuum) at 75°F
5. Place the wet specimen in a plastic bag, and seal; place sealed bag in a second bag containing 10 ml of water and seal
6. Freeze specimen at 0 ± 5°F for 15 hours
7. Remove specimen from both bags, place in 140°F water bath for 24 hours
8. Place specimen in 75°F water bath for 3 hours
9. Remove and immediately test at 75°F at a loading rate of 2 inches per minute

Mixture age at testing: 4 days, approximately.

C. Thermal Cycling (15TC or 26TC)

1. Mix and compact specimen
2. Cure specimen at 75°F for 2 days
3. Submerge the specimen in distilled water at 75°F and vacuum saturate for 30 minutes at 4 or 26 inches of mercury
4. Soak for 30 minutes (no vacuum) at 75°F
5. Place the wet specimen in a plastic bag, and seal; place sealed bag in a second bag containing 10 ml of water and seal
6. Freeze specimen at 0 ± 5°F for 4 hours, and thaw it at 120 ± 5°F for 4 hours. Repeat until 18 cycles of freezing and thawing have been completed. Every other cycle was followed by 8 hours at 75°F.
7. At the end of the last 120°F cycle, unwrap specimen and place in 75°F water bath for 8 hours prior to test time
8. Test at 75°F at a loading rate of 2 inches per minute

Mixture age at testing: 11 days, approximately.

D. Seven-Day Soak (4VS+SOAK, 15VS+SOAK, or 26VS+SOAK)

1. Mix and compact specimen
2. Cure specimen at 75°F for 2 days
3. Submerge the specimen in distilled water at 75°F and vacuum saturate for 30 minutes at 4 or 26 inches of mercury
4. Soak for 7 days (no vacuum) at 75°F
5. Remove and immediately test at 75°F at a loading rate of 2 inches per minute

Mixture age at testing: 9 days, approximately.