Sulphur-Extended-Asphalt Field Trials

MH 153 Brazos County, Texas

A Detailed Construction Report

Prepared by

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for

The Sulphur Institute

Federal Highway Administration

Texas State Department of Highways and Public Transportation

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I. INTRODUCTION

A sulphur-extended-asphalt pavement binder was used in a demonstration project constructed at Bryan, Texas in June 1978 by the State Department of Highways and Public Transportation.

The sulphur in sulphur-extended-asphalt binders replaces a part of the asphalt used in conventional asphalt paving. There is evidence, also, that the sulphur enhances the strength and fatigue characteristics of the asphalt pavements mix and can, therefore, be used for the beneficiation of mineral aggregates.

The use of sulphur is both energy-related and environment-related. The energy crisis of late 1973 markedly increased the cost and, in time, may restrict the availability of asphalt. The Clean Air Acts which require more complete desulphurization of fossil fuels will substantially increase the supply of by-product sulphur in the future.

The sulphur-extended-asphalt binder, therefore, may enable filling part of our country's needs for asphalt and extending our supplies of aggregates.

Specific Objectives of the Tests

There were three principal objectives of these field trials: (1) to compare the benefits of sulphur-asphalt binder prepared in a mill as an emulsion with sulphur-asphalt binder prepared by by-passing the mill and comingling the molten sulphur and the hot asphalt in the pipeline leading directly to the pug-mill, (2) to beneficiate local marginal aggregates, (3) to compare SEA binders with different sulphur/asphalt ratios and to present laboratory mixture designs for the study, (See Appendices A and B).

Sponsors and Location

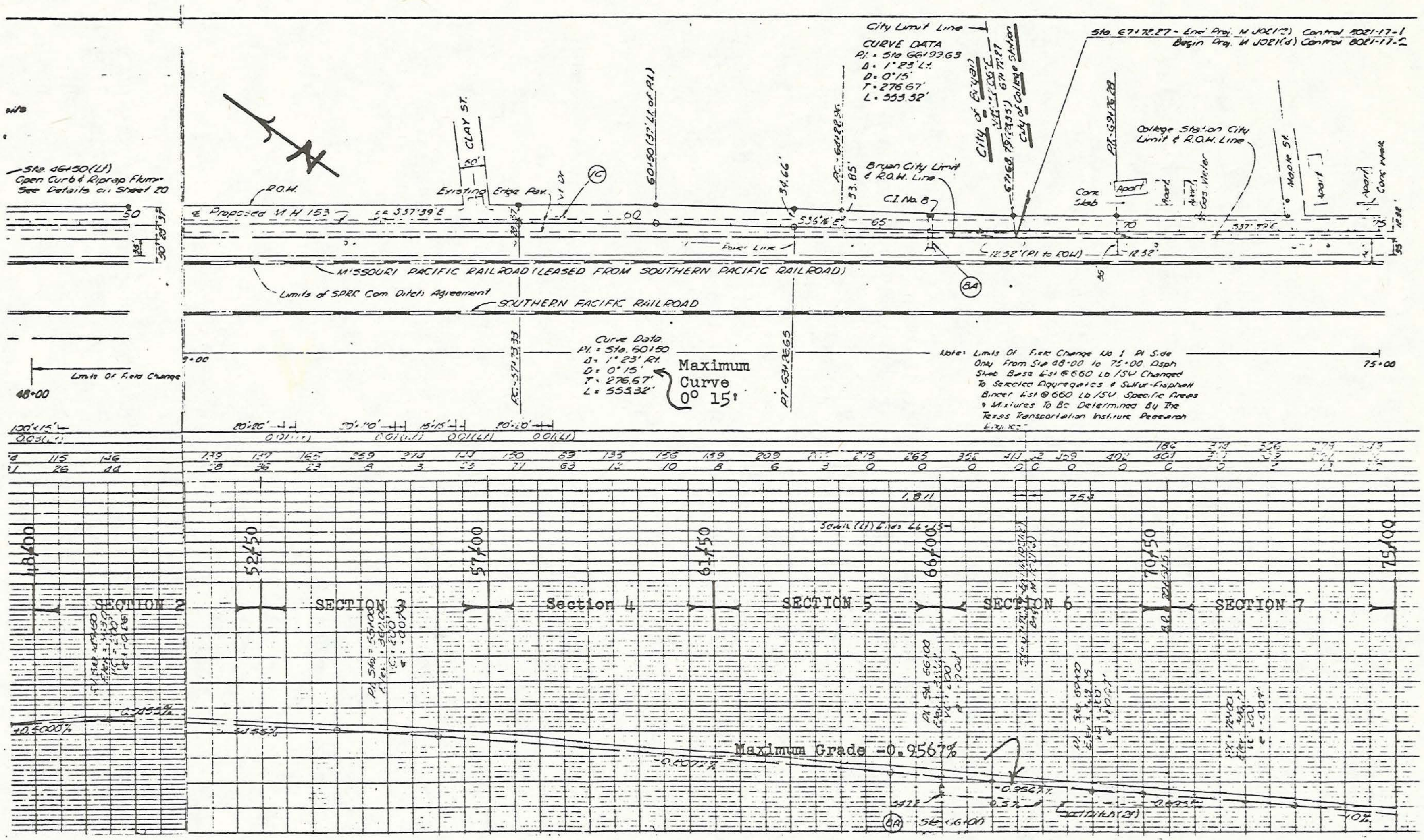
The sulphur-extended-asphalt binder highway test project was made possible by a "Field Change" in the contract between the State Department of Highways and Public Transportation and Young Brothers, Contractors, Waco, Texas on Project MJ021 (4), Control No. 8021-17-2, on MH 153 in Brazos County, Texas, which permitted the construction of the test section as part of an on-going contract; and by a separate agreement between The Sulphur Insititute and Young Brothers, Contractors, whereby The Sulphur Institute would pay Young Brothers for any costs additional to the reimbursements from the State for the conventional pavement which the test pavement replaced.

The test was located at the southeast end of the project on the westerly, southbound traffic lanes between engineer stations 48+00 and 75+00. This is locally designated as MH 153 and may be considered an extension of Farm Road 2154. The location has been marked on the vicinity map, Figure 1, together with the location of the contractor's hot-mix plant and the three aggregate sources. The highway alignment and grades at the test site are shown on Figure 2 (for details see Figure 4).

Scale: 1/2 in equals 1 mi (approx)
1 mi equals 1.609 km

(1) Sulphur-extended Asphalt Test Site
(2) Concrete Sand Production (Gifford-Hill)
(3) Bank-Run Gravel Deposits (Scarmardo)
(4) Hot-Mix Plant (Young Brothers)
(5) Field Sand Pit (Young Brothers)

Figure 1 Brazos County sulphur-extended-asphalt field trial, vicinity map



Metric Conversion: 1 ft = 0.3 m

Figure 2 Brazos County sulphur-extended-asphalt field trial highway alignments and grade

The typical cross section of the test section, showing also the cross section of the adjoining conventional asphalt pavement, is shown in Figure 3.

Traffic

The Average Daily Traffic, ADT, for the job completion date (1978) was estimated to be 8,100 vehicles per day of which 6.1 pct would be trucks. The pavement is designed for a 20-year life during which it would be subjected to traffic with an equivalency of about 50,000 18-kip (8172 kg) axle loads.

Layout of Field Test

This construction report is intended to record 'what was done' and 'how it was done' in the construction of the sulphur-asphalt pavement test with the expectations that it will be useful in the post construction evaluation of the test sections and in the planning and construction of other sulphur-asphalt pavement projects.

A general layout of the six field test sections is shown in Figure 4. Sections 4 and 5 are companion sections except that the binder in Section 4 was prepared as an emulsion in the mill, and the binder in Section 5 was prepared by bypassing the mill and comingling the sulphur and asphalt in the pipeline. See general view of job site in Figure 5.

Evaluation of the Test Sections

The post construction evaluation of the test sections will be made by Texas Transportation Institute in cooperation with the State Department of Highways and Public Transportation and the Federal Highway Administration. The initial evaluation period has been set for three years.

Participants

The sulphur-extended-asphalt field trials on MH 153 were made possible through the participation of many groups. Among these were:

The U. S. Department of Transportation, Federal Highway Administration, Washington, D. C. and Regional Offices, Fort Worth, Texas

Texas State Department of Highways and Public Transportation, Austin and District 17, Bryan, Texas

The Sulphur Institute, Washington, D. C.

U. S. Bureau of Mines, Boulder City, Nevada

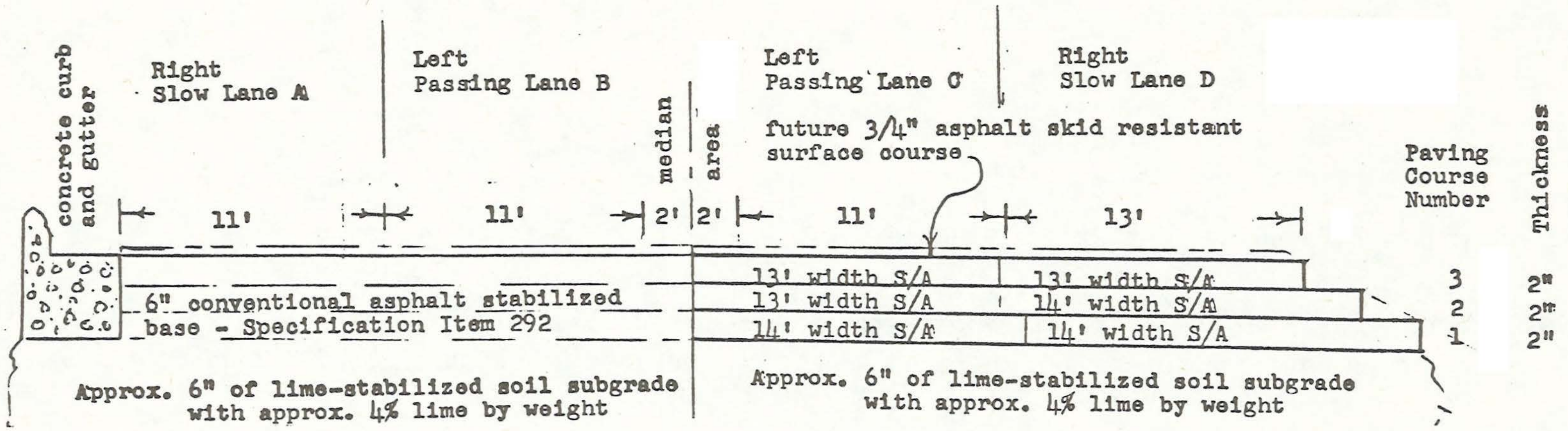
Texasgulf, Inc., Houston and Newgulf, Texas

Slurry Seal Incorporated, Waco, Texas

Young Brothers, Contractors, Bryan and Waco, Texas

Texas Transportation Institute, College Station, Texas

Construction of the field trials was under the general supervision of the State Department of Highways and Public Transportation, District 17, Bryan, Texas. Carol D. Zeigler, P.E., is District Engineer for 10 counties including Brazos. B. G. Bockman, P.E., Supervising Resident Engineer



Schematic does not scale.

Schematic Cross Section of 4-Lane Highway: Showing Conventional Asphalt Stabilized Base on Northbound Traffic Lanes Left, and Sulphur-Asphalt Pavement on Southbound Traffic Lanes Right also, Paving Widths and Longitudinal Joint Offset on Sulphur-Asphalt Pavement

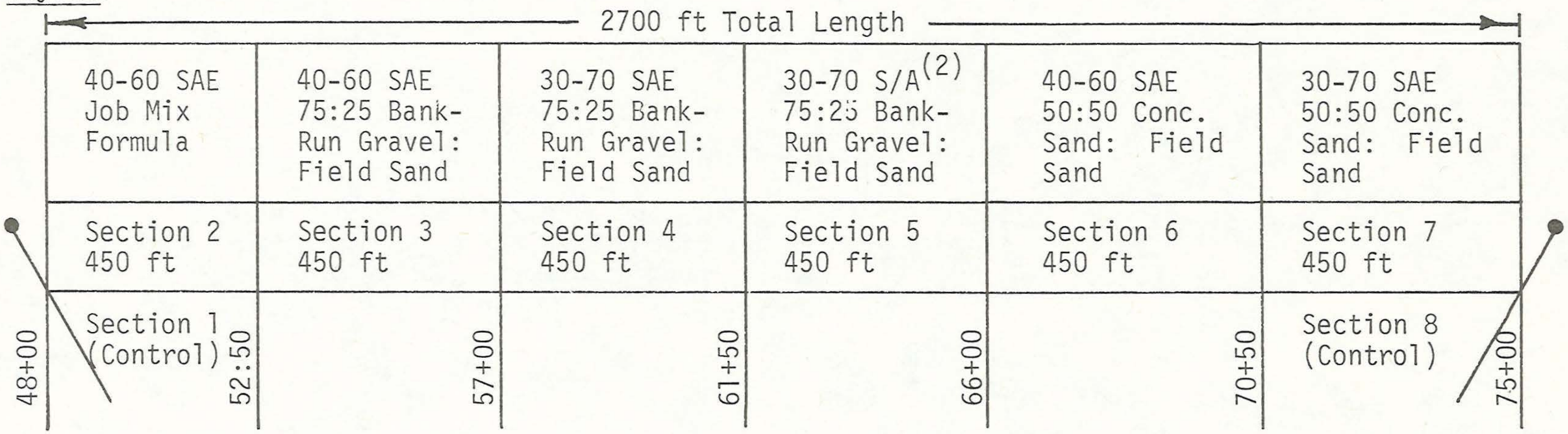
Metric Conversions: 1 ft = 0.3 m
1 in = 25.4 mm

Figure 3 Brazos County sulphur-extended-asphalt field trials on MH 153

Estimated Tons of Paving Mix Required:

Pavement: Finished width, 26 ft; length, 2700 ft; area, 7,800 sq yds
Mix: Quantity of mix/sq yd estimated at 660 lbs; total tons, 2,574

Layout:



Notes: 1) Sulphur-asphalt binder was optimized on a volume substitution basis.
2) Sulphur-asphalt binder for Section 5 to be prepared by by-passing emulsion mill.

Nomenclature: Job Mix Formula: 55:30:15 Bank-Run Gravel:Pea Gravel:Field Sand with 5 pct wt binder. (Mix used for conventional asphalt in Section 1, etc.)

SAE: Sulphur-asphalt-emulsion: 30-70 and 40-60 are ratios of sulphur to asphalt by weight.

Metric Conversions: 1 ft = 0.3 m
1 sq yd = 0.84 m^2
1 lb = 0.45 kg

Figure 4 General layout of field test sections, MH 153 Brazos County, Texas (southbound lanes)

Figure 5. Two northbound lanes were under traffic while test section (two left lanes) was being constructed. Current traffic exceeds 8000 VPD with about 10 percent trucks.

for Brazos and Burleson counties was in direct charge of the project. He was assisted by Robert R. Odstrcil, P.E., Senior Resident Engineer. The Project Inspector was Joe E. Smith. Jimmy Anderson and Bobby Wade supervised the control laboratory testing. Danny Loehr was field inspector.

The contractor's operations were under the immediate supervision of A. P. Boyd, General Manager, Bryan Division of Young Brothers. He was assisted by Fred Rocky, plant superintendent, and Bud Smith, field superintendent.

Texasgulf, Inc., supplied the sulphur and provided the sulphur-asphalt colloid mill. Wm. M. Bell, Texasgulf, supervised the construction and operation of the sulphur handling system. He was assisted by Robert Province, Slurry Seal Incorporated of Waco, Texas.

Texas Transportation Institute was represented by Bob M. Gallaway and Don Saylak, co-principal investigators of the overall study, and by a crew of twelve technicians with principal functions as follows:

> Bill Vajdak, David Teague, Mike Byrd and Joe Lavoie - pavement coring and Dynaflect measurements;
>
> Edward Conger, Carolyn Jacobs, David Newcomb, Ed Shackelford and John Tenison - field binder control, mix temperatures and sulphur emission measurements; and
>
> Ed Ellis, Sidney Greer, Gene Schlieker - sampling of mixes, laboratory testing of mixes, binder specific gravity, etc.

II. CONSTRUCTION MATERIALS AND MIXTURE PROPERTIES

Sulphur

At standard conditions of temperature and pressure, ordinary sulphur is an odorless and tasteless yellow solid. Its specific gravity is 2.07 and its melting point is 238°F (114°C). It is one of the basic elements, with an atomic number of 16 and atomic weight of 32.06.

Sulphur is not considered a hazardous material in commerce. About 90 percent of the elemental sulphur used in the U. S. is shipped in the liquid state. Truck transports are widely used with a typical truck hauling a load of 20 to 22 long tons (20,320 to 22,352 kg). Practices for hauling, heating, storage and safety are well established in the trade.

The working range for molten sulphur corresponds quite well to the working range for paving grade asphalt, i.e., 255°F to 300°F (124°C to 149°C). A temperature-viscosity curve for sulphur is shown in Figure 6. At temperatures above about 315°F (157°C) molten sulphur becomes very viscous.

When heated, the concentrations of toxic gases formed are low or nonexistent in the temperature range of 250°F to 300°F (121°C to 149°C) but increase rapidly as the temperature rises above this range. Particulate sulphur and some fumes from molten sulphur can exist within the working temperature range and may cause eye irritation.

Briefly, liquid sulphur is hot and poses the same dangers in this respect as hot asphalt or any other hot liquid. Molten sulphur at 300°F (149°C) will burn in air if ignited, and sulphur vapor and hydrogen

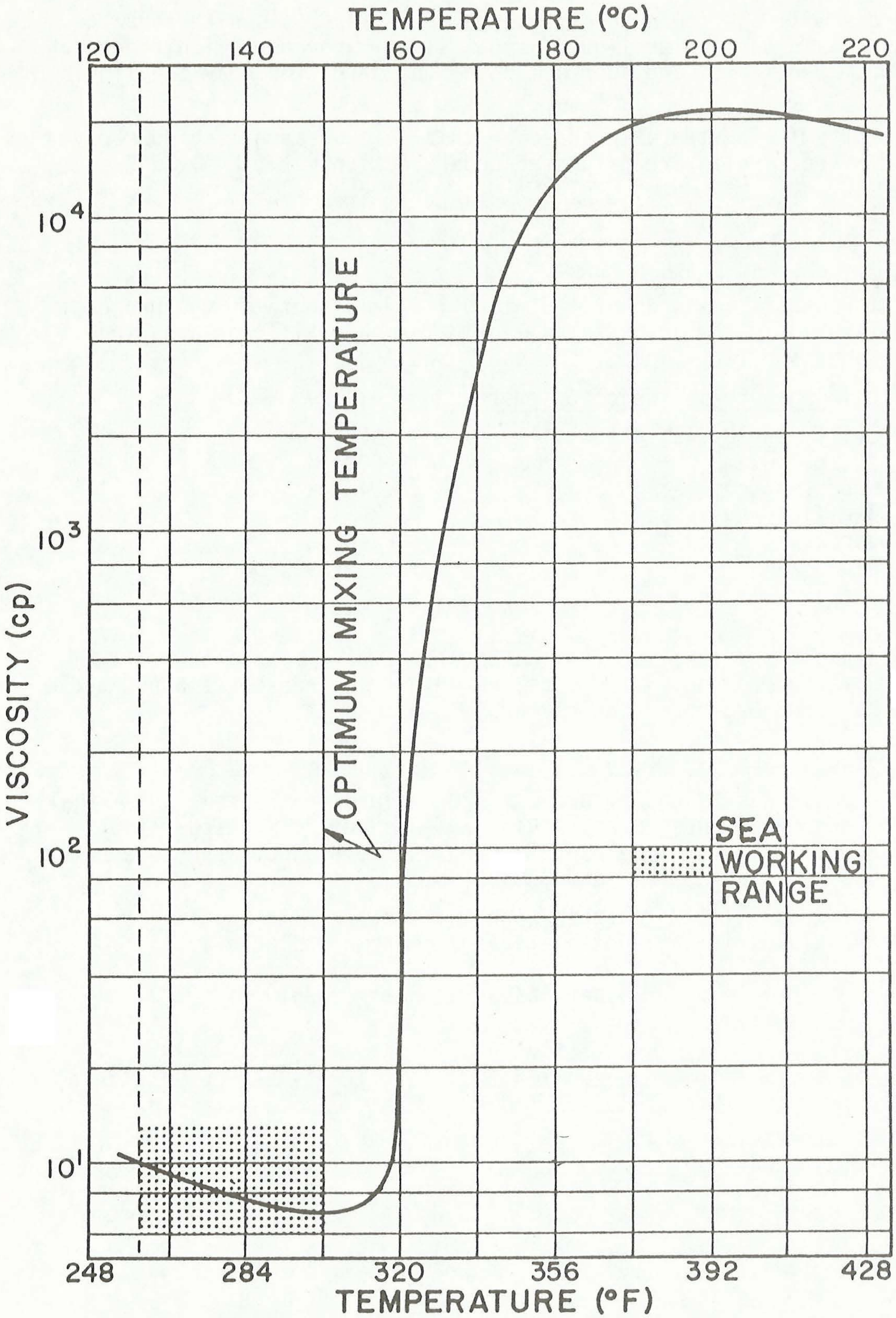


Figure 6   Temperature-viscosity chart for liquid sulphur

sulphide gas will also burn under extreme conditions. As with asphalt handling and, in particular liquid asphalts, all sources of ignition such as smoking, open flames and sparks must not be permitted near the liquid sulphur.

Sulphur emissions were measured on this sulphur-asphalt binder pavement test. The results are discussed under Section VII, "Evolved Gas Analyses".

Supplier

The sulphur was supplied by Texasgulf, Inc., from their Frasch production at Newgulf, Texas about 110 miles (177 km) south of the project. It was delivered to the job site in liquid form by DSI Transport, Inc., formerly Robertson Tank Lines, Houston, Texas.

Typical Characteristics of Sulphur

Purity, Dry Basis, pct wt	99.97
Ash, pct wt	0.002
Carbon Content	0.04
Specific Gravity at 275°F	1.79
Source	Frasch
Color	Bright yellow

Asphalt

The asphalt was supplied from EXXON at Baytown, Texas about 241 km southeast of the project. It was delivered hot in transports owned and operated by Young Brothers, Contractors.

Test Characteristics of Asphalt

The asphalt was Viscosity Grade AC-20 conforming to Item 300, Asphalt Cement, of the State Department of Highways and Public Transportation Standard Specifications. The asphalt used on the project was represented by State Lab. No's. C78372512 and C78372106.

Specification limits together with key test results supplied by the State, Materials Division, Austin, Texas are shown in Table 1.

Table 1 Properties of asphalt cement

Test	Specification Limits		State Samples	
	Min	Max	C78372412	C78372106
Visc, 60°C, stokes	1600	2400	1709	1659
Visc, 135°C, stokes	2.5		3.3	3.4
Pen @ 25°C, 100g, 5 sec	55		68	72
Flash, COC, °C	232			
Solubility in Trichlorethylene, pct	99.0			

Table 1 Properties of asphalt cement (continued)

Residue from Thin Film Test

Test	Specification Limits Min	Specification Limits Max	State Samples C78372412	State Samples C78372106
Visc, 60°C, stokes		6000		
Ductility @ 25°C, cm	50			
Spot Test	Negative			
Specific Gravity @ 25°C	--	--	1.032	1.035
Specific Gravity @ 20°C	--	--	1.036	1.039

Note: The State does not run complete analyses on all samples.

Mineral Aggregate

An objective of the sulphur-asphalt binder test was to study the benefits of the binder for upgrading marginal aggregates to produce a pavement with better performance properties than the same aggregates with asphalt. Three aggregate blends were selected: (1) a 75-25 weight percent blend of bank-run gravel and field sand, (2) a 50-50 weight percent blend of concrete sand and field sand, and (3) a 55-30-15 weight percent blend of bank-run gravel, pea gravel and field sand. Blend 3 was used in the preparation of the conventional asphalt stabilized base adjoining the field test and in Section 2.

Bank-Run Gravel -- Scarmardo Pit

Source: The bank-run gravel came from the Scarmardo gravel pits which are located westerly and adjacent the Brazos River about 12 miles (19 km) by haul road from the contractor's hot-plant. See Figure 1. The deposit consists of nonuniform strata and pockets of minus 2-inch (51 mm) gravel and sand overlaid with sandy-silty soils. Plastic (clayey) fines are present. The plasticity index of the material averages about 8. (The plasticity drops when mixed with nonplastic sands.) Excavation and loading are done by dragline operating at depths of up to 30 feet (9.2 m). The Scarmardo people are now exploring a large area by test coring.

Concrete Sand and Pea Gravel

Source: The concrete sand and pea gravel are produced by washing and screening by Gifford-Hill, Contractors, at a plant located on the Brazos River at the westerly end of Leonard Road in College Station. See Figure 1.

The Field Sand

Source: The field sand is produced by Young Brothers from a bank-run source near the hot-mix plant. See Figure 1.

Preliminary Sieve Analyses

The preliminary sieve analyses of the aggregates together with the calculated combined analyses for the aggregate blends are shown in Table 2. Gradation curves are shown in Figure 7.

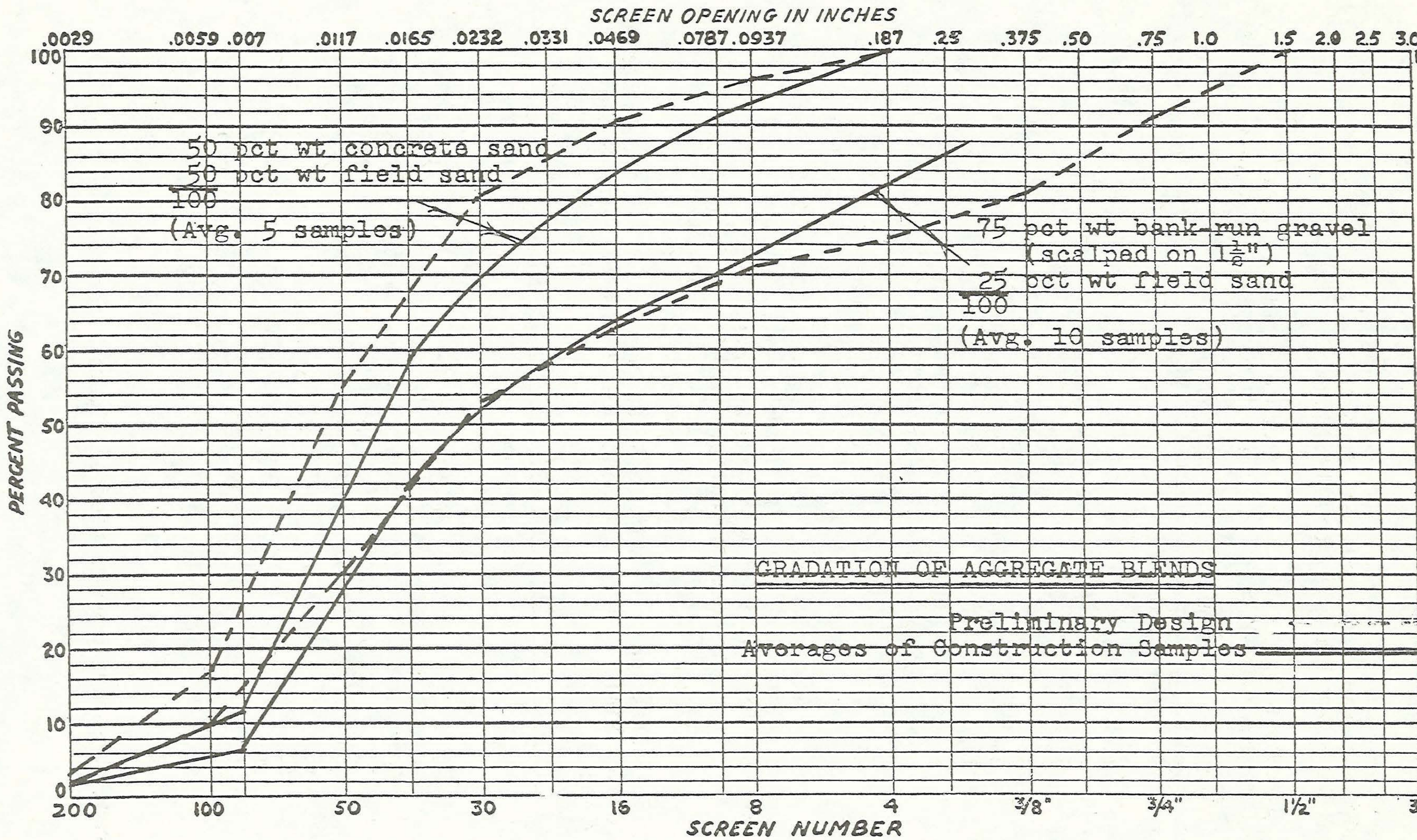
Table 2 Aggregate Specification and Sieve Analyses
(Laboratory Tests, Percent Passing)

Type:	Scarmardo Pit, Bank-run Gravel		Concrete Sand	Field Sand	Pea Gravel
Sieve Size	Pit Run	Minus 1 1/2 Inch			
38 mm	90	100			
19 mm	78	87			100
9.5 mm	68	75			90
4.75 mm	60	67	100		60
2.36 mm	55	61	92		5
1.18 mm	46	51	82	100	
600 µ mm	35	39	68	95	
300 µ mm	11	12	24	85	
150 µ mm	2	2	4	30	
75 µ mm	-	-	1	5	
P. I.	8		NP	NP	

Preliminary Combined Aggregate Analyses
(Percent Passing, Calculated)

Aggregate Blend:	75:25 Bank-Run Gravel Field Sand	50:50 Concrete Sand Field Sand	55:30:15 Bank-run Gravel Pea Gravel Field Sand
Sieve Size			
38 mm	100		100
19 mm	91		93
9.5 mm	81		83
4.75 mm	75	100	70
2.36 mm	71	96	50
1.18 mm	63	91	43
600 µ mm	53	81	36
300 µ mm	30	55	20
150 µ mm	10	17	6
75 µ mm	2	3	2
P. I.	4±		4±

These gradations have been charted on Figure 7 for ready reference.



Metric Conversion: 1 = 25.0 mm

Figure 7 Gradation of aggregate blends used in Brazos County field tests

Sulphur-Asphalt Pavement Binder

The sulphur-asphalt pavement binder consists primarily of a very fine dispersion of sulphur in asphalt with asphalt as the continuous phase. The dispersion can be made in a colloid mill using molten sulphur and hot asphalt.

When hot asphalt and molten sulphur are intimately mixed using high shearing action, some of the sulphur, about 20 percent by weight of the asphalt, will dissolve in the asphalt. The remainder of the sulphur forms a dispersion of sulphur in asphalt. Both the dissolved and the dispersed sulphur modify the properties of the asphalt.

The binder can be prepared in a wide range of sulphur contents, from 10 weight percent to 50 weight percent of total binder. Two binder compositions were used on the sulphur-asphalt pavement test. One contained 30 weight percent of sulphur (30-70) and the other contained 40 weight percent sulphur (40-60).

The targeted Specification for the binder required 85 percent of the sulphur portion to have a particle size distribution of five microns or less. Check tests made using an electron microscope indicated 85 percent or more particles were three microns or less.

Specific Gravities

The specific gravities for sulphur and for the EXXON AC-20 asphalt used on the project at temperatures of interest were as follows:

	Temperature, ^{o}C					
	20	25	121	135	149	163
Sulphur	2.07	2.07	1.80	1.79	1.78	1.77
Asphalt	1.04	1.03	0.97	0.96	0.95	0.94

The specific gravity of the sulphur at all temperatures was taken from 'STAUFFER SULFURS', a publication of Stauffer Chemical Company. The values at 20^{o}C and 25^{o}C are for the 'rhombic allotrope' which 'is the stable form of sulphur below 96^{o}C'.

The specific gravities for the asphalt at 20^{o}C and 25^{o}C were measured by the State Department of Highways and Public Transportation, Materials Division, Austin, and are the averages of two measurements. The specific gravities for the high temperatures were back-calculated from Table IV-1, Temperature-Volume Corrections for Asphalt Materials, ASPHALT POCKETBOOK USEFUL INFORMATION, The Asphalt Institute (1974).

Unit Weights

Some unit weights for the 30-70 and the 40-60 sulphur-asphalt blends, based on the above table, are shown for ready reference:

	Binder Composition		
	Asphalt (AD-20)	30-70-S/A wt	40-60 S/A wt
wt pct Sulphur in Binder	0.00	30.0	40.0
Specific Gravity @ 20°C	1.04	1.21	1.28
Specific Gravity @ 135°C	0.96	1.12	1.18
kg/l @ 135°C	0.96	1.12	1.18

Manufacture

The sulphur-asphalt binder for test Sections 2, 3, 4, 6 and 7 was prepared by passing the molten sulphur and hot asphalt through the colloid mill on the binder plant. The sulphur-asphalt binder for test Section 5 was prepared by by-passing the colloid mill and comingling the molten sulphur and hot asphalt in the pipelines leading to the pug-mill.

Silicone

Silicone was added to the hot asphalt in the contractor's storage tank prior to preparing the sulphur-asphalt emulsion. The silicone was Dow Corning 200 fluid at 100 centistokes viscosity. It was added in the estimated amount of 1 ppm.

There is some evidence that silicone makes the sulphur-asphalt emulsion more stable and the sulphur-asphalt pavement mixtures easier to work. Normally, 2 ppm added to the hot asphalt in the storage tank will improve moisture release from hot mix and reduce pulling and tearing at the screed of the laydown machine.

III. CONTRACTOR'S EQUIPMENT

Hot-Mix Plant

The hot-mix plant used for the preparation of the sulphur-asphalt binder pavement mixtures was a STANDARD, model RM, 3-ton (2721 kg) batch stack-up type. The plant, basics only, was manufactured in 1962 by Standard Steel Corporation, a Division of Allis Chalmers, 5001 South Boyle Avenue, Los Angeles, California. Normal operating capacity is 175 tons per hour (158,725 kg/h). Twin silos, STANDARD HAVENS, are used for intermittent storage of asphalt paving mixtures.

Asphalt Meter

Asphalt binder is metered, as opposed to being weighed, into the pug-mill by means of a FLUIDOMETER SYSTEM. It was manufactured by Hetherington & Berner, Inc., a company since sold to American Hoist and, in turn, to Midwest Tank Co., Indianapolis, Indiana.

The Fluidometer system consists essentially of a positive displacement meter, an automatic resetting control head and a shut-off valve. The installation is located in the asphalt line about midway between the asphalt pump and the pug-mill with the dial on the control head in full view of the operator. The asphalt pump is equipped with a by-pass and flow is direct, as opposed to full circulating, to the meter. During operating conditions, the indicator on the control head is set for the desired quantity of asphalt. The meter drives the control head which, in turn, energizes the shut-off valve which opens and closes to deliver the required amount of asphalt for each batch. It can be manually operated by push button or set for automatic cycling on the control panel.

Emission Control

The emission control equipment, also manufactured by Standard Steel, consists of twin 100-inch (2.54 m) cyclones, a No. 737 materials handling fan with a capacity of 40,000 cfm (1132 m^3/min) and a wet washer system of two chambers one on top of the other. The sludge passes through a clean-out and vent enroute to the settling area.

The emission control system is shown schematically in Figure 8.

Cold Aggregate Feed

The cold aggregate feed tunnel contains five aggregate chutes. Three of the chutes are equipped with VIBRA-FLOW FEEDERS, a vibrating plate arrangement manufactured by Syntron Co., Homer. Pennsylvania.

It is worthy of note that the other two chutes are equipped with variable speed belt feeders about 8 feet (2.44 m) long, developed by the contractors to improve the flow of damp sandy materials. Generally, sand must be proportioned at the cold feed, since they cannot be separated and recombined in the hot-plant.

The two chutes with the belt feeders were used throughout the project for preparing the 75:25 blend of bank-run gravel and field sand and the 50:50 blend of concrete sand and field sand. One chute was used alternately for the gravel and concrete sand. Aggregates are weighed with HARDY SCALES equipment. The dial is visible to the plant operator.

Plant Control System

The hot-plant is equipped with an automatic burner control system, GENCONTROL II, manufactured by MECHTRON International Corporation, Orlando, Florida. Aggregate temperature at the hot elevator is continuously recorded in the control house. Batching is semiautomatic with the operator's console located in the control house in view of the asphalt meter and the aggregate scales.

Haul Trucks

A wide variety of haul trucks was used for transportation of the sulphur-aggregate hot-mix to the job site. Several were FLOW-BOY hot-mix asphalt semitrailers of 23 tons (20,861 kg) capacity. The asphalt mixture is pulled from the unit by a 'chain-veyor' system in the floor of the bed. One truck was a HOBBS frameless dump truck of about 21-ton (19,047 kg) capacity. One was a CLEMENTS dump trailer with GMC tractor. Another was a steel bed with a MACK tractor having three power driven rear axles. These axles were noted to scuff the pavement when turning. There were, also, the more conventional twin-axle tandems.

Truck beds were sprayed lightly with diesel oil as a parting compound.

Truck beds were not covered during transportation of hot sulphur-asphalt mixes to the job site.

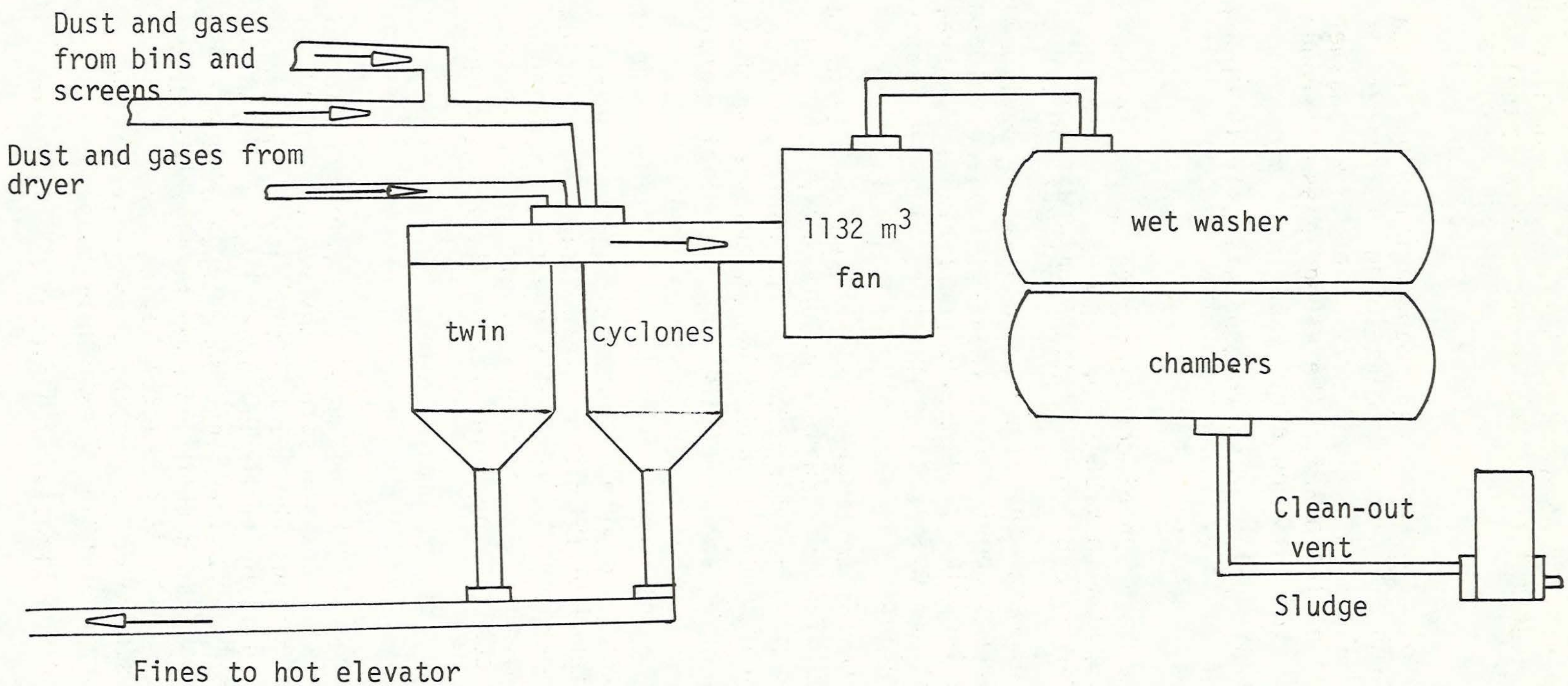


Figure 8 Schematic: Emission control system (Young Brothers Hot-Mix Plant)

The Paver

The paver was a Barber-Greene SB 50 rubber-tired finisher. The model number SB 50 was changed to SB 170 when Barber-Greene introduced the 100 Series Hydrostatic line. The basic machine did not change with the model number change. See Figure 9.

The machine paves in widths from 8 to 28 feet (2.44 to 8.54 m) with thickness up to 5 inches (127 mm) or more and with variable speeds up to 217 ft per min (66 m/min). A vibratory screed provides the initial compaction of the asphalt mat.

The SB 50 was equipped with a 40-foot (12.2 m) mobile string line grade reference. It was attached to the paver and supported at either end with a single 12-inch (305 mm) diameter wheel.

Rollers

Most of the compacting of the sulphur-asphalt pavement mix was done with a REX 900, model SPVIB roller, manufactured by Rexnord, Milwaukee, Wisconsin. It has an 2.14 m steel roller fore and two rubber tired wheels aft. The steel roller weighs 10,300 lbs (4676 kg). It can be vibrated in a range of frequencies from about 1200 to 2000 cycles per min. At 1200 the total force on the pavement is 12,110 lbs (54 kN); at 1500 it is 18,900 lbs (84 kN) and at 2000 it reaches 33,600 lbs (149 kN). The rubber tires are inflated with air to about 25 (172 kPa) psig providing pavement contact pressures slightly higher than the inflation pressure. Diesel is used periodically on the rubber tires to lessen sticking and pickup of the mat.

Supplemental compacting and smoothing on part of the project was done with an INGRAM 5-4 (SPR 14) 25-ton (22,675 kg) rubber tired roller. An INGRAM tandem steel wheel roller was used during a period when the REX was broken down.

IV. SPECIAL EQUIPMENT

Sulphur-Asphalt Emulsion Plants

Mills for the preparation of sulphur-asphalt binder have been developed by Society Nationale Elf Aquitaine, Paris, France and by Gulf Oil Canada Limited. In principle, the sulphur is finely dispersed in the asphalt by high-shear mixing devices prior to being added to the aggregate in the hot-plant pug-mill.

The Bureau of Mines, Boulder City, Nevada has prepared the sulphur-asphalt binder by charging the hot asphalt and molten sulphur directly into the pug-mill where a satisfactory dispersion of sulphur in the asphalt was achieved during normal mixing with the hot aggregates.

The Young SAE-15 Emulsion Plant

The plant used for the preparation of sulphur-asphalt binder on the MH 153 highway test was developed by Slurry Seal International, Inc., Waco, Texas. The plant has been identified as the Young Sulphur-Asphalt Emulsification Unit, 'Young SAE-15 Emulsion Plant'.

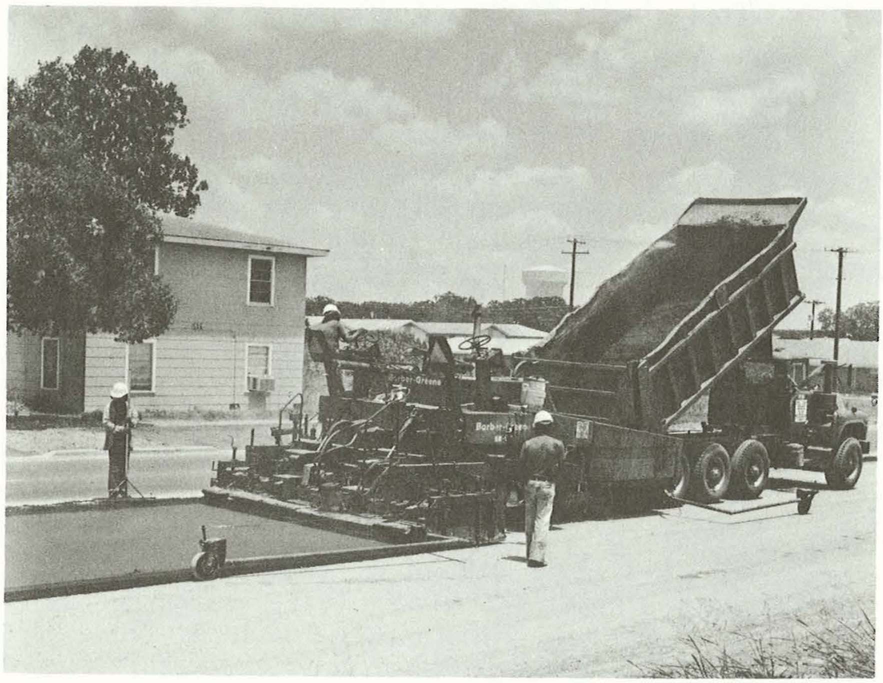


Figure 9 Placing first lift of sulphur-extended-asphalt base material on lime stabilized subgrade

Slurry Seal International since 1960 have been manufacturers and world wide marketers of asphalt emulsion plants which provides a rather considerable knowledge and an operating base for the development of sulphur-asphalt plants. The Young SAE-15 is an adaptation of the Young SS 5-15 Asphalt Emulsion Plant. See Figure 10.

The Young SAE-15 Emulsion Plant was developed by Slurry Seal under an agreement with The Sulphur Institute and Texasgulf, Inc. The mill was purchased by Texasgulf and loaned to Young Brothers, Contractors, for the highway test.

Description

The plant, mounted on a structural steel base, includes the following equipment: (as taken from Slurry Seal Inc. brochure)

"1. Individual 50 gpm (1891 l/min), hot oil heated, variable volume, asphalt and sulphur feed pumps powered by 7.5 hp (5593 W) electric motors.

2. Provisions within the asphalt and sulphur feed systems to maintain specified temperature throughout; recirculate each product as required, instrumentation to measure total accumulated flow for each product, and the rate-of-flow for asphalt.

3. A standard Young 15-ton per hour (13,605 kg/h) capacity, hot oil heated Colloid Mill, driven by a 25 hp (18,643 W) electric motor.

4. A 500 gal (1893 l) capacity product surge tank which is heated by hot oil coils and a 200 gpm (756 l/min) product transfer pump driven by a 15 hp (11,186 W) electric motor for recirculating the product in the surge tank.

5. A hot oil heating system comprising a 12 kw electric hot oil heater, a 1-inch (25.4 mm) hot oil pump feeding the entire hot oil circulation system of the facility from a 20 gal (75.6 l) hot oil storage tank -- including all lines, valves, instrumentation, insulation, and safety provisions required to maintain asphalt and sulphur at delivered temperatures, and the product to storage at Colloid Mill exit temperatures. Capacity sufficient to heat entire system with maximum 250 gal (945 l) of product in surge tank in less than one hour form cold startup.

6. Instrumentation and controls assure accurate temperature-controlled flow of materials and finished product at the specified values -- including automatic level controls on surge tank to prevent overfilling in event of transfer pump failure or blockage of product lines."

The mill is capable of producing product at the rate of 15 short tons per hour (13,605 kg/h) of up to a 50-50 weight percent sulphur to asphalt and with 85 weight percent of the sulphur portion having a particle size of 5 microns or smaller.

Figure 11 is a layout of the SAE-15 plant. Note the by-pass line which enables comingling of the molten sulphur with the hot asphalt without passing these components through the mill. Also, the sulphur system

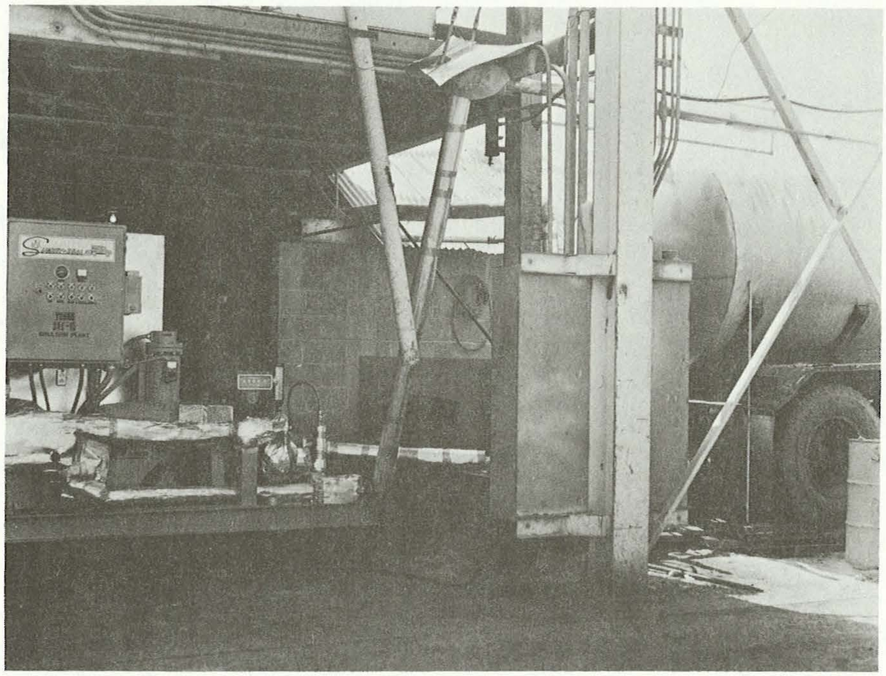


Figure 10 Sulphur-asphalt colloid mill and portable hot storage for sulphur

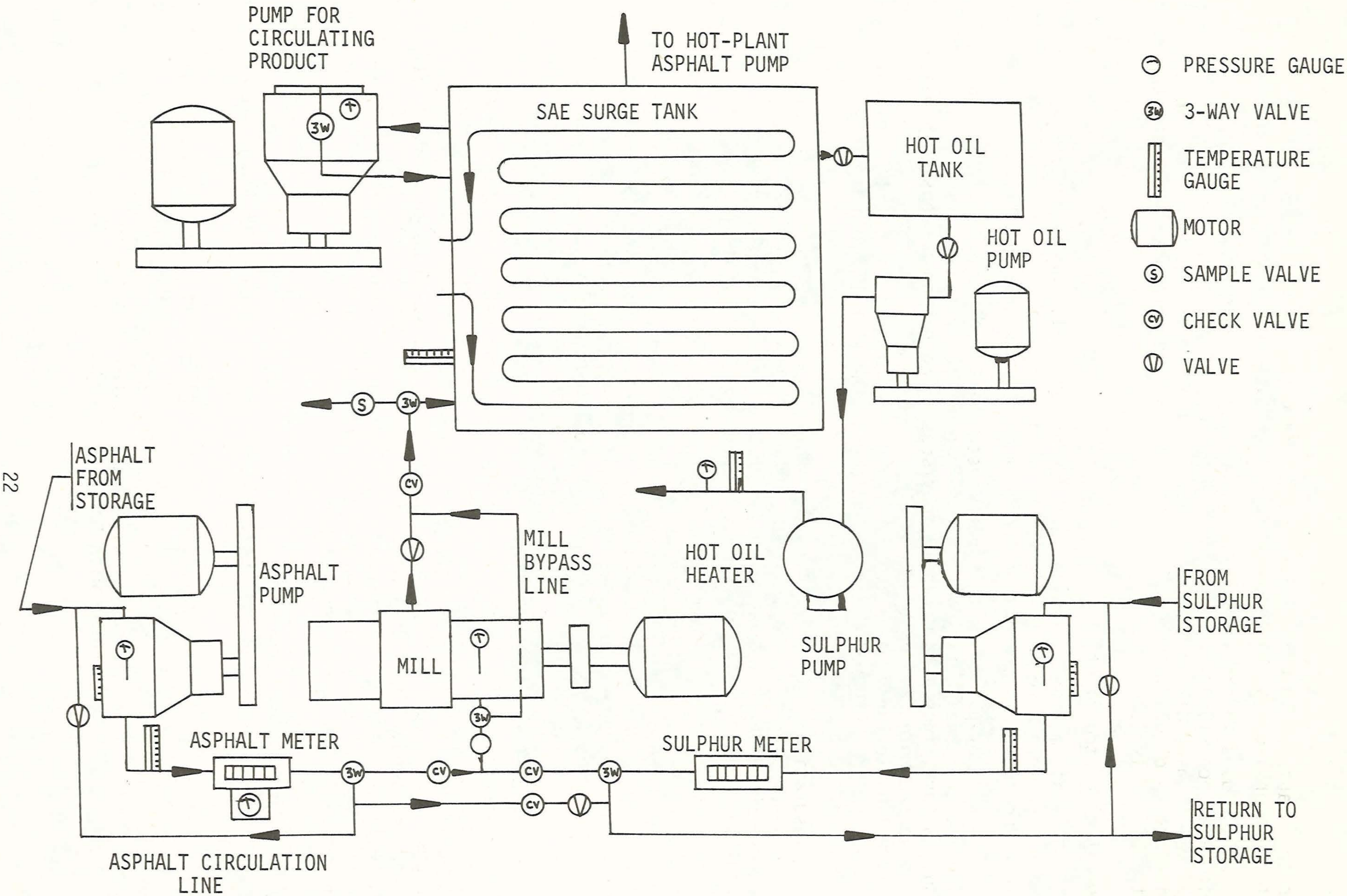


Figure 11 Layout of Young SAE-15 plant

on the plant (exclusive of the suction and return lines to the sulphur storage tank) can be purged of sulphur by flushing with hot asphalt.

Pipe used in the sulphur and asphalt systems was 2-inch (51 mm) ID with 1/2-inch (13 mm) ID "gut line" (inside) hot oil pipe. A 3-inch (76 mm) ID pipe with a 1/2-inch (13 mm) hot oil "gut line" was used on the discharge, hot plant to asphalt pump. Hot oil temperatures were targeted at 340^{o}F (171^{o}C).

Operation of the Plant

Several improvements were made during the early operation of the plant, and more have been effected by Texasgulf personnel based upon the experiences on this project including mounting the unit on wheels.

Sulphur by-passed in the short system around the sulphur pump, see Figure 11, increased markedly in temperature from friction in the system and, in turn, increased markedly in viscosity to put an increasingly heavy load on the motor and pump. This was corrected with the installation of a return line to the sulphur storage tank and including it in a full circulating system. Figure 12 is a schematic of the asphalt, sulphur, and sulphur-asphalt "emulsion" system.

Insulation, which initially surrounded the sulphur part of the plant, was gradually increased by wrapping with foil backed insulation mats to include the asphalt and hot oil systems. Texasgulf now plan to fully insulate the entire operating system of pumps, valves, and pipe.

The Colloid Mill, machined to close tolerances, has adjustable clearance between the rotor and stator. In the preparation of the asphalt "emulsion", this clearance was about 0.015 inches (0.38 mm). At this setting, when preparing the sulphur-asphalt binder, the load on the mill was excessive. The mill clearance was increased, accordingly, in steps up to 0.08 inches (2 mm) and then reduced to 0.057 inches (1.4 mm) where performance was satisfactory.

Preparing the Sulphur-Asphalt Binder

In preparing the binder the asphalt pump was set for a constant flow rate, and the sulphur pump was adjusted to prepare the different binder compositions. Normal production rates were about 15 gpm (56.7 l/min) of sulphur and 40 gpm (151 l/min) of asphalt for the 40-60 weight percent SEA blend and about 9 gpm (34 l/min) of sulphur and 40 gpm (151 l/min) of asphalt for the 30-7- weight percent SEA blend. Fixing the setting of the asphalt pump at a constant rate of discharge was a most significant factor in the control of the binder compositions.

The Sulphur Handling System

The sulphur system was designed by Texasgulf around the Young SAE-15 Emulsion Plant.

The sulphur storage consisted of an insulated and coil heated semi-trailer tank. It was rented and installed by the contractor near the emulsion plant. The tank was approximately 6 feet (1.83 m) in diameter by 35 feet (10.7 m) in length with an estimated capacity of 50,800 kg of sulphur. It was heated with hot oil at around 350^{o}F (177^{o}C). Sulphur

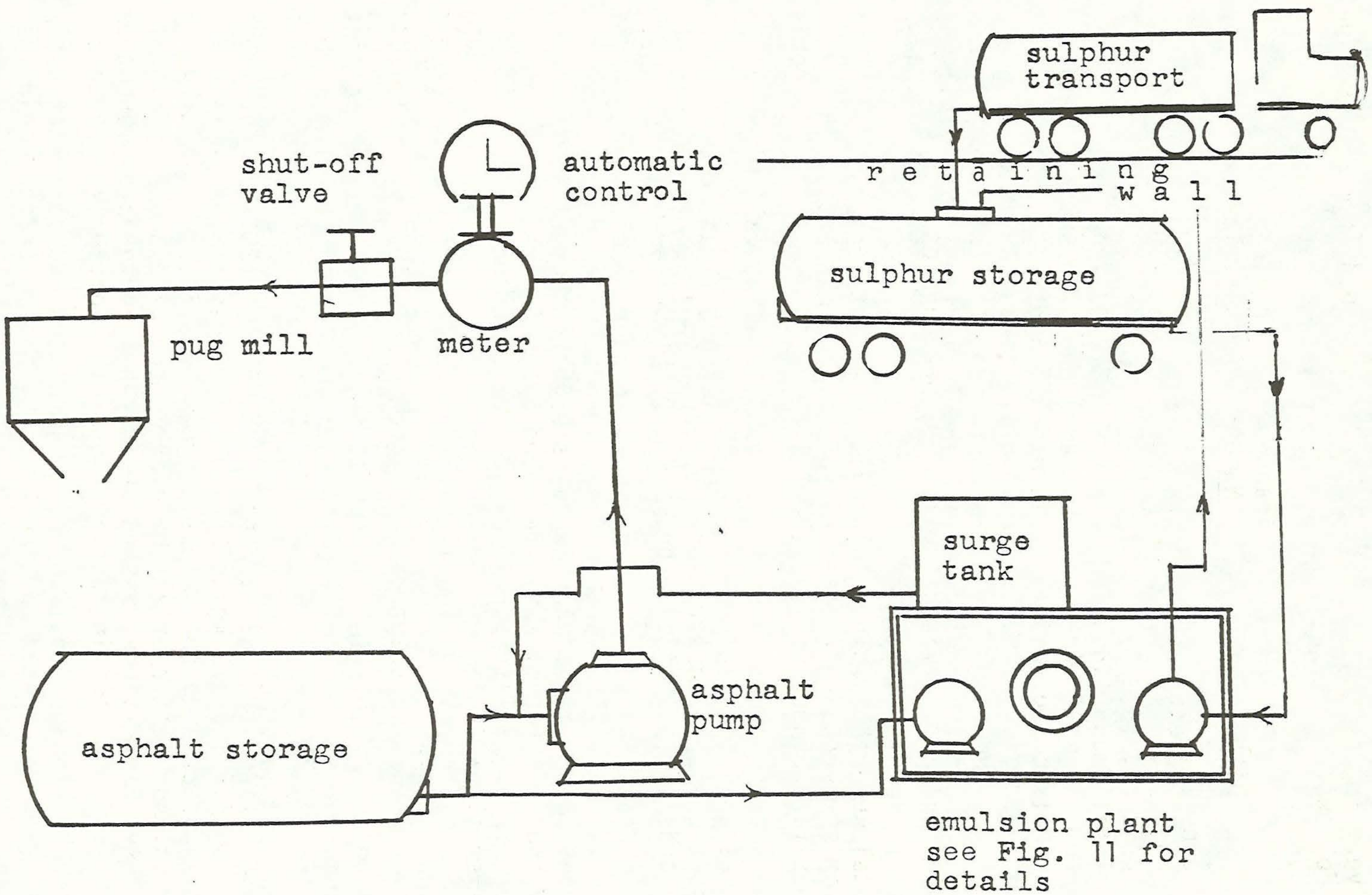


Figure 12 Asphalt mix plant, schematic flow diagram for asphalt, sulphur and sulphur-asphalt emulsion

transports backed up to the top of an adjacent 12-foot (3.66 m) retaining wall above the sulphur storage and unloaded by gravity.

Delivered Sulphur

A delivery log of the molten sulphur as obtained from the Texasgulf engineers, follows:

Date	Transport Number	Invoice Amount, lbs
June 12, 1978	1	50,700
June 20, 1978	2	50,700
June 22, 1978	3	51,720
Total amount invoiced		153,120

(Metric Conversion: 1 lb = 0.454 kg)

Summary

1.	Total weight of sulphur delivered, per invoice, lbs	153,120 (69,516 kg)
2.	Total weight of sulphur placed on the test sections, from state engineer's records of tons of mix and specified binder compositions, lbs	124,849 (56,681 kg)
3.	Total weight of sulphur placed on the roadway for short course demonstration from state engineer's records of tons of mix and specified binder composition, lbs	13,614 (6,181 kg)
4.	Total weight of sulphur in mixes prepared for start-up and clean-up of mill, rejected by engineers for noncompliance with specifications or disposed at paver site, lbs	8,976 (4,075 kg)
	Total weight of sulphur in prepared mixes, lbs	147,439 (66,937 kg)

Item 1 minus items 2, 3, and 4 = 5,681 lbs (2579 kg) giving a total of 5,681 (2579 kg) of sulphur invoiced to the project that was unaccounted for. This amounts to 3.7 pct wt. There was no sulphur left over at the plant site. A discussion of the binder compositions, as measured by hydrometer and pycnometer methods, is contained in "Quality Control", Section VI, of this report.

V. CONSTRUCTION OPERATIONS

Introduction

The sulphur-asphalt field test was located in an excavation section on the site of the old road. The subgrade soil was variable due in part to incorporation of some cohesionless material from the old road base. Otherwise the soil was a silty clay with a measured plasticity index of 21. It was stabilized to a depth of 6 inches (152 mm) with hydrated lime in the amount of about 4 percent by weight and in accordance with the State Standard Specifications, Item 260. The required density of 95 percent by weight of optimum (test Tex 114-E) was difficult to achieve in spots. Some of these soft spots were removed immediately ahead of the paver and were filled to grade as the paver passed with sulphur-asphalt pavement mixture. One of these, on the left side of lane C between Stations 53+50 and 54+00, was five inches (127 mm) low at the left side and tapered to grade at the centerline.

The surface of the lime stabilized base was kept damp by periodic spraying with water until covered with pavement mixture. See Figure 13 for field mixing operations.

Production of Sulphur-Asphalt Pavement Mixtures

The asphalt stabilized base on the traffic lanes A and B of the four-lane highway and adjacent to the test section was constructed in accordance with Item 292 of the 1972 Standard Specifications of the State. The same Specifications, modified to provide for the use of special aggregate blends, sulphur-asphalt binder and special handling, were used for the construction of the test sections, traffic lanes C and D.

Production of the sulphur-asphalt pavement mixture began at 10:45 a.m., June 16, with the preparation of some trial batches which contained binder of uncertain composition that had been prepared while calibrating the mill. The aggregate was the same as for the conventional asphalt mixtures; 55 percent of Scarmardo bank-run gravel, 30 percent pea gravel, and 15 percent field sand. Binder content was 38 gals (144 l) per 6,000 lb (2724 kg). Approximately 27 tons (24,489 kg) of the mix were placed about 2 inches (51 mm) in thickness in a parking area adjacent to the Young Brothers office using a LAY-MOR vibrating screed and a GALLION tandem roller. The first batch looked dry. The balance of the mix looked good. It was tender under the roller but compacted without appreciable delay for cooling. The odor of sulphur was quite apparent to the paving crew.

Production of paving mixtures for the test sections began at 2:30 p.m., June 16, 1978. The aggregate composition was 75:25 bank-run gravel and field sand, respectively. The targeted binder composition was 40:60 percent by weight of sulphur and asphalt, respectively. Binder content was set at 7-1/2 percent by weight of total mix. There followed a period in which field tests of the binder, using hydrometer analyses, were used as guides to calibrate the "emulsion" plant. Some early test results were 44-56 S/A and, in turn, 42-58 S/A. There were obvious anomalies. For further details on sulphur-asphalt binder testing see Section VI, "Quality Control".

There were no problems with the hot-plant production of the sulphur-asphalt paving mixtures. A total of 2,571 tons (2332 metric tons) of

Figure 13 Mixing hydrated lime in subgrade soil of sulphur-asphalt test section

mixture was placed on the test sections. The engineer's estimate was 2,574 tons (2,335 metric tons). This attests to excellent grade and pavement thickness control as well as plant control of quantities.

On June 20, as part of a Texas Transportation Institute short course on "Sulphur Utilization and Asphalt Conservation", the top 2-inch course (51 mm) in traffic lane A between stations 26+00 and 34+54 was paved with a mixture containing a 50-50 percent by weight blend of concrete sand and field sand with 8-1/2 percent binder of 40-60 composition. The operation was observed by over 75 highway engineers and contractors from all over the United States.

Table 3 shows production of the sulphur-asphalt paving mixture by dates together with temperatures of the various batches at the hot-plant for mixtures placed on the test sections, on the TTI short course demonstration site and for that rejected or discarded.

			Metric tons
Summary:	Tons of mix on test sections	2,571	(2,330)
	Tons of mix on TTI demonstration	132	(120)
	Tons of mix rejected and discarded	228	(210)
	Total	2,931	(2,660)

Some of the sulphur-asphalt mix rejected or discarded was used by the contractor to pave a parking area near his office and to cover a nearby area designated as a future heliport.

Pavement Structural Design

Thickness design of the pavement was fixed by the State Department of Highways and Public Transportation as shown in Figure 3. The sulphur-asphalt test sections were placed at the same thickness, 6 inches (152 mm), as the control sections. The only changes made in the field trial sections involved aggregate grading, binder type and quantity of binder. These changes have been fully described.

Temperature Control of the Sulphur-Asphalt Pavement Mix

On June 16, the temperature range for the sulphur-asphalt paving mixture was set by Texas Transportation Institute at 225^{o}F (107^{o}C) to 295^{o}F (146^{o}C) with instructions to reject mix outside this range. Following observations on June 16, TTI changed the range to 235^{o}F to 300^{o}F (113^{o}C to 149^{o}C) where it remained for the remainder of the project.

The standard deviation of the mixture temperatures was calculated for June 22 and June 23 and are shown in Table 4. These were the two days during which there were no mix rejections. These were the days also when TTI made measurements of the amount of sulphur dust in the ambient air. Data are presented in Section VII, "Evolved Gas Analyses".

The standard deviations shown for June 22 and June 23 of 17.2 and 17.8, respectively, attest to a significant variability in temperature control. Assuming a normal distribution of the measurements, the hot-plant could be expected to produce mixtures within a temperature range of 225^{o}F to 300^{o}F (107^{o}C to 149^{o}C) ninety-five percent of the time.

Table 3 A log of sulphur-asphalt pavement mix delivered to the roadway as recorded by the state engineers together with an estimate of pavement mix rejected

Date	Section	Course	Mix, tons	Binder Composition Specified	Binder pct wt in Mix	Calculated Sulphur, lb
6/19-21-22	2	1,2,3	454	40-60	5	18,160
6/16-21-23	3	1,2	303	40-60	7.5	18,180
6/16-21-23	3	3	138	40-60	6.8	7,507
6/19-21-23	4	1,2	282	30-70	7.0	11,844
6/19-21-23	4	3	135	30-70	6.3	5,103
6/19-21-23	5	1,2	288	30-70	7.0	12,096
6/19-21-23	5	3	153	30-70	6.3	5,783
6/20-22-23	6	1,2	291	40-60	8.5	19,788
6/20-22-23	6	3	129	40-60	7.9	8,153
6/20-22-23	7	1,2	280	30-70	8.0	13,440
6/20-22-23	7	3	108	30-70	7.4	4,795
	Totals for Test Sections		2,561			124,849
	Short Course Demonstration					
6/20		3	132	40-60	8.5	8,976
	Totals for Roadway		2,693			133,825
	Additional Mix Prepared (not placed on roadway)*					
6/16	startup		27	40-60	5.0	1,080
6/16	rejected; disposed		39	40-60	7.5	2,340
6/19	rejected; disposed		126 (96)	30-70	7.0	5,292
6/20	rejected; disposed		18	40-60	8.5	1,224
6/21	rejected; disposed		42 (21)	40-60	5.0	1,680
6/23	rejected; disposed		18 (0)	30-70	7.4	799
6/23	cleanup of mill		27	30-70	7.4	1,199
			297			13,614
	Summary, Totals		2,990 tons			147,439 lbs

Metric Conversions: 1 lb = 0.454 kg
1 ton = 907 kg

Note: Tonnages shown as not placed on roadway are from plant operator's records as reported by Texasgulf. There was some question as noted by numbers in parentheses. The compositions and weight percent of binder in mixes prepared for startup and cleanup of the mill have been estimated.

Table 4 Production of sulphur-asphalt hot-mix

Date: (June 1978)	16	19	20	21	22	23
Field Test Sections						
Loads	7	22	14	32	25	35
Tons	144	418	276	610	460	663
Temperature, ^{o}F (hot-plant)						
Mean	290	255	255	253	259	255
Max.	300	280	295	270	285	300
Min.	270	235	230	240	240	230
Std. Dev.					17	18
Two Std. Dev.					34	35
Short Course Demonstration						
Loads			7			
Tons			132			
Temperature, ^{o}F (hot-plant)						
Mean			255			
Rejected and Discarded *						
Loads						
Tons	66	96 (126)	1	21 (42)	0 (18)	27

Metric Conversions: $^{o}C = (^{o}F-32)\frac{5}{9}$

1 ton = 907 kg

*Notes:
1) There was some question as noted by numbers in parentheses.
2) June 16: 27 tons disposed at startup, 18 tons too cold at 210°F and 21 tons too hot at 350°F.
3) June 19: 18 tons disposed at paver; 21 tons too hot at 350°F, 18 tons too hot at 340°F, 33 tons too hot at 320°F, and 6 tons too hot at 325°F.
4) June 20: 18 tons too hot at 320°F.
5) June 21: 21 tons disposed at paver.
6) June 23: 27 tons cleanup of plant.

Aggregate Control

Table 5 shows field sieve analyses of the aggregates, from the engineer's records, by date, section, lane, course, engineer station, and aggregate blend. Table 6 is a summary of the sieve analyses.

Figure 7, presented earlier, depicts aggregate gradings as designed vs averages of field samples. The Standard Deviation for percent passing the critical No. 40 sieve for the 75:25 aggregate blend shows considerable variation. A range of about 90:10 to 50:50 bank-run gravel to field sand is evident.

Haul and Placement

Dead haul to the project was 9.0 miles (14.5 km) over surfaced highways and streets. There were no traffic lights or stop signs.

There were no significant problems with hauling and placing. A wide variety of haul trucks were used as indicated in Section III, "Contractor's Equipment". See also Figure 14 for typical field operations.

Joints

The longitudinal joint between the asphalt stabilized base, lane B, and the sulphur-asphalt base, lane C, was tacked with cutback asphalt type RC-2. The cold cutback was applied with a hand swab, and the applications were spotty and discontinuous.

Transverse joints in each lane at the ends of sections were staggered with the lower courses extending several feet beyond the overlay course. This produced transitions between sections of up to 30 feet (9.1 m) or more. Cold transverse joints were tacked with the RC-2 immediately before placing the adjacent course.

Compacting the Mix

In general, the sulphur-asphalt pavement mixture was compacted at the highest practical temperature but with emphasis on densities rather than compaction temperature, since the maximum weight percent of sulphur in the binder was 40 (25 volume percent)*.

The first course, Sections 2 through 6, was compacted using only the REX 900 roller for which Texas Transportation Institute set the following rolling pattern:

1 breakdown pass without vibration,
1 pass with vibration, and
4 passes without vibration.

This pattern was observed to work well in Section 4, Course 1, (30:70 binder and 75:25 bank-run gravel and field sand) with measured temperatures of the mat at 220°F to 230°F (104°C to 110°C) but with evidence (undue lateral displacement of the mat) that 230°F (110°C) was the upper

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*There is evidence that dense mixtures containing binder with more than 25 volume percent sulphur in the binder should be compacted above 250°F (121°C) to optimize structural properties of the pavement.

Table 5 Field sieve analyses of aggregates

Date June	Sect.	Lane	Course	Engr. Station	Agg.* Blend	Weight Percent Passing Sieves 1-1/2" (38.1 mm)	No. 4 (4.75 mm)	No. 10 (2.0 mm)	No. 40 (425 μm)	No. 80 (180 μm)	No. 200 (75 μm)
16	3	C	1	53+50	75:25	95	82	69	36	6	1
19	4	D	1	60+00	75:25	100	83	73	45	8	2
19	5	D	1	63+00	75:25	100	83	70	30	5	3
19	2	C	1	51+25	Job Mix	100	66	55	27	9	4
20	Demonstr.	A	3	28+25	50:50	100	100	91	61	12	3
21	2	D	2	50+00	Job Mix	100	77	47	33	7	2
21	3	C	2	50+00	75:25	100	82	70	42	7	2
21	4	C	2	57+75	75:25	100	80	67	44	7	3
21	5	C	2	64+75	75:25	100	83	74	52	9	2
22	6	D	2	66+05	50:50	100	100	92	60	11	2
22	7	C	2	71+50	50:50	100	100	89	53	9	2
22	3	D	3	52+50	75:25	100	76	52	29	5	1
23	3	D	3	52+75	75:25	100	82	70	45	8	2
23	5	C	3	60+00	75:25	100	82	70	34	6	2
23	5	C	3	63+25	75:25	100	82	70	48	8	2
23	6	C	3	69+25	50:50	100	100	90	58	11	2
23	7	D	3	70+65	50:50	100	100	92	63	14	3

Note: The percent passing and retained were changed to total percent passing by wt for purposes of ready analysis.

*Aggregate blends: 75:25 - 75 pct wt bank-run gravel plus 25 pct wt field sand.
50:50 - 50 pct wt concrete sand plus 50 pct wt field sand.
Job mix - 55 pct wt bank-run gravel plus 30 pct wt pea gravel plus 15 pct wt field sand.

Table 6 Summary of field analyses of aggregates

Aggregate Mix:

1) 75:25 pct wt
Scalped Bank-Run Gravel: Field Sand

Sieve Size	No. 4 (4.75 mm)	No. 10 (2.10 mm)	No. 40 (425 μm)	No. 80 (180 μm)	No. 200 (75 μm)
pct wt passing					
Avg. (10 samples)	82	69	41	7	2
Max.	83	73	52	8	3
Min.	76	52	29	5	1
Std. Dev.			8		
Two Std. Dev.			16		

2) 50:50 pct wt
Concrete Sand: Field Sand

Sieve Size	No. 4 (4.75 mm)	No. 10 (2.10 mm)	No. 40 (425 μm)	No. 80 (180 μm)	No. 200 (75 μm)
pct wt passing					
Avg.	100	91	59	11	2
Max.		92	63	14	3
Min.		89	53	9	2
Std. Dev.			4		
Two Std. Dev.			8		

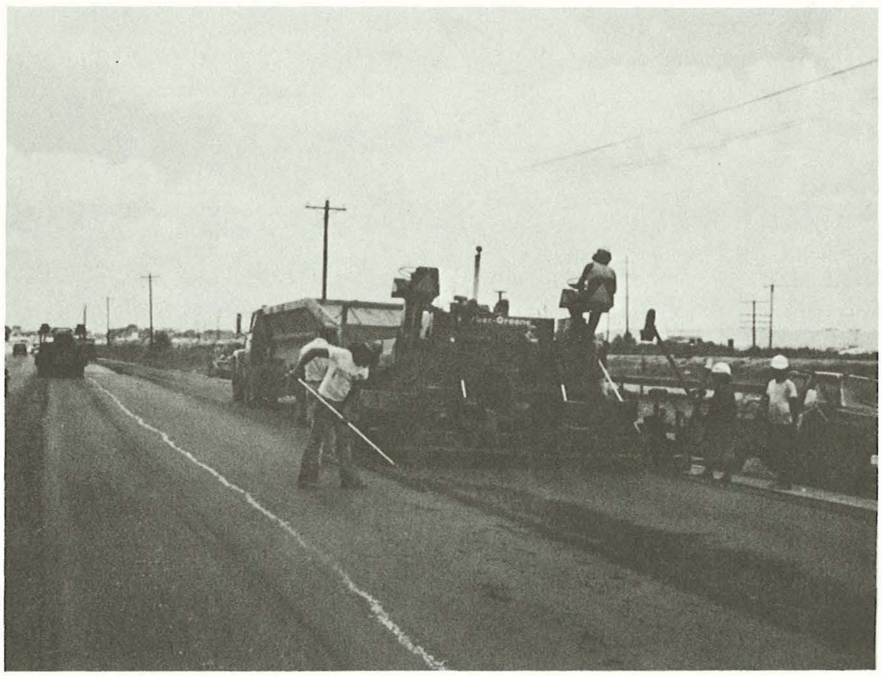

Figure 14 Placing final 2-inch (51 mm) lift of SEA base on MH 153. (Note vibrating roller in left background and flow boy truck used to transport mixture. Paving mixture was easy to rake.)

limit. Observations on the TTI demonstration section (40:60 SEA binder and 50:50 concrete sand and field sand with 8-1/2 percent weight binder in the mix) showed the mix to be too soft for compacting at about 230^{o}F (110^{o}C). Eventually, the time for breakdown rolling was left to the judgment of the roller operator and the inspectors.

Beginning with the first course in Section 7, the REX 900, operating per the above pattern, was supplemented with eight passes of the INGRAM rubber tired roller. This procedure was not changed for the remainder of the project except for the second course, Section 6, where the REX 900 broke down. Part of lane C and all of lane D were left without compaction for over two hours then compacted with the INGRAM tandem followed by the rubber tired roller.

The Contract Specifications, intended for control testing, Item 292, specify the following percent density of laboratory gyratory compaction (test method Tex 126 E):

MIN	MAX	OPTIMUM
92	99	96

The field densities of the pavement as determined with a nuclear density gage are shown in Table 7 by section, course, and roller patterns.

The field densities and percent compaction show substantial comliance with specifications. These data do show an appreciable benefit from the eight passes of the rubber tired roller; however, a detailed treatment of the data will be presented in a separate report. The benefit, not apparent in the tabulated densities, was in removing the surface roller marks of the REX 900.

Course 2, part of lane C and all of lane D in Section 6, where compaction was delayed shows compaction to have been slightly higher than for adjoining courses.

In summary the internal resistance of these sulphur-asphalt mixes was so low that compaction was not critical to temperatures above ambient and below that required to support the rollers. This was due to aggregate grading and particle shape and surface texture and, in part, to very hot weather. See Table 8, "Weather Conditions".

It is thought worthy of note that there are no appreciable differences between the laboratory densities as determined by Texas Transportation Institute using the Marshall method and the State using the gyratory method. The differences are probably within the repeatability limits of each procedure. Again, the low internal friction of these mixtures is offered as the primary reason for this observation. Figure 15 is a layout of the as-constructed test sections showing mixture compositions, date paved, and mixture tonnages.

Dynaflect Measurements

Dynaflect measurements are a scheduled part of the post construction evaluation of all subsections of the field experiment. Data collection is shown in Figure 16. Plotted in Figure 17 are data which show changes in

Table 7 Laboratory and field densities of the sulphur-asphalt pavement

Section:	2			3		
Course:	1	2	3	1	2	3
Date Placed	6/9	6/21	6/22	6/16	6/21	6/23
Date Field Test	6/20	6/21	6/27	6/20	6/21	6/27
Laboratory Density, pcf						
Marshall (TTI)	148	143	146	141	142	136
Gyratory (SDHPT)	148	143	144	140	134	137
Field Density, pcf						
Avg.	141	144	143	127	136	133
Max.	149	149	145	135	140	136
Min.	136	133	140	121	132	130
Percent Compaction:						
Marshall						
Avg.	95	101	98	90	96	93
Max.	100	104	99	96	103	101
Min.	92	96	96	87	95	96
Gyratory						
Avg.	95	101	100	91	98	97
Max.	100	104	101	97	101	100
Min.	92	93	97	91	93	95

Section:	4			5		
Course:	1	2	3	1	2	3
Date Placed	6/19	6/21	6/23	6/19	6/21	6/23
Date Field Test	6/20	6/22	6/27	6/20	6/22	6/27
Laboratory Density, pcf						
Marshall (TTI)	140	133	136		136	134
Gyratory (SDHPT)	140	140	135	143	138	138
Field Density, pcf						
Avg.	130	133	135	131	131	136
Max.	135	138	141	136	132	141
Min.	138	127	132	129	127	133
Percent Compaction:						
Marshall						
Avg.	94	96	100		96	101
Max.	97	99	100		98	103
Min.	92	92			93	99
Gyratory						
Avg.	94	95	100	92	94	98
Max.	96	99	105	95	96	102
Min.	92	92	98	87	92	96

Table 7 Laboratory and field densities of the sulphur-asphalt pavement (continued)

Section:	6			7		
Course:	1	2	3	1	2	3
Date Placed	6/20	6/22	6/23	6/20	6/22	6/23
Date Field Test	6/22	6/22	6/27	6/22	6/22	6/27
Laboratory Density, pcf						
Marshall (TTI)	133	134	133	133	132	133
Gyratory (SDHPT)	135	136	135	136	134	134
Field Density, pcf						
Avg.	134	135	138	133	137	137
Max.	139	143	141	139	141	138
Min.	131	126	135	131	132	133
Percent Compaction:						
Marshall						
Avg.	101	101	104	100	104	103
Max.	104	103	106	105	106	104
Min.	98	94	103	99	99	100
Gyratory						
Avg.	99	99	103	98	101	102
Max.	103	105	104	103	104	103
Min.	98	93	101	97	97	100

Metric Conversion: 1 pcf = 16.01 kg/m^3)

The weather throughout the construction period, June 16-23, inc., 1978, was hot and dry. Table 8 contains a tabulation of weather conditions for the period of June 15-25, 1978 at College Station, Texas.

Table 8 Weather Conditions

Date	Temperature, ^{o}F Max.	Min.	Relative Humidity, pct AM	PM	Rainfall	Avg. Wind Velocity and Direction
15	92	72			0.00	
16	93	75			0.00	
17	92	75			0.00	
18	95	73			0.00	
19	95	73	82max	45min	0.00	12 mph S-SE
20	93	74	84max	42min	0.00	12 mph SE
21	93	71	90max	39min	0.00	10 mph S-SE
22	94	72	87max	33min	0.00	10 mph S-SE
23	96	74	85max	39min	0.00	12 mph S
24	98	75			0.00	
25	97	75			0.00	

Metric Conversions: $^{o}C = (^{o}F - 32)\frac{5}{9}$

1 mph = 1.609 km/h

	Aggregate SEA Binder pct wt Date Paved Tons of Mix	Aggregate SEA Binder pct wt Date Paved Tons of Mix	Aggregate SEA Binder pct wt Date Paved Tons of Mix	Aggregate SEA Binder pct wt Date Paved Tons of Mix	Aggregate SEA Binder pct wt Date Paved Tons of Mix	Aggregate SEA Binder pct wt Date Paved Tons of Mix	Paving Course Number	Thickness
	D e n s e N o n - s k i d S u r f a c e						4	1 in
6 Inches (152 mm) Asphalt Stabilized Base Item 292	Job-Mix 40-60 5 June 22 165	75:25 40-60 6.8 June 23 138	75:25 30-70 6.3 June 23 135	75:25 30-70 6.3 June 23 153	50:50 40-60 7.9 June 23 129	50:50 30-70 8.0 June 23	3	2 in
	Job-Mix 40-60 5 June 21 157	75:25 40-60 7.5 June 21 159	75:25 30-70 7.0 June 21 153	75:25 30-70 7.0 June 21 141	50:50 40-60 8.5 June 22 153	50:50 30-70 8.0 June 22	2	2 in
	Job-Mix 40-60 5 June 19 132	75:25 40-60 7.5 June 16 144	75:25 30-70 7.0 June 19 129	75:25 30-70 7.0 June 19 147	50:50 40-60 8.5 June 20 138	50:50 30-70 8.0 June 20	1	2 in
SECTION 1 (Control)	SECTION 2	SECTION 3	SECTION 4	SECTION 5	SECTION 6	SECTION 7	SECTION 8 (Control)	

Station: 48+00, 52+50, 57+00, 61+50, 66+00, 70+50, 75+00

Metric Conversion: 1 in = 25.4 mm
1 ton = 907 kg

Figure 15 General layout of as-constructed field test sections on MH 153, Brazos County, Texas

Figure 16 Dynaflect utilized to measure stiffness of completed sulphur-extended asphalt pavement

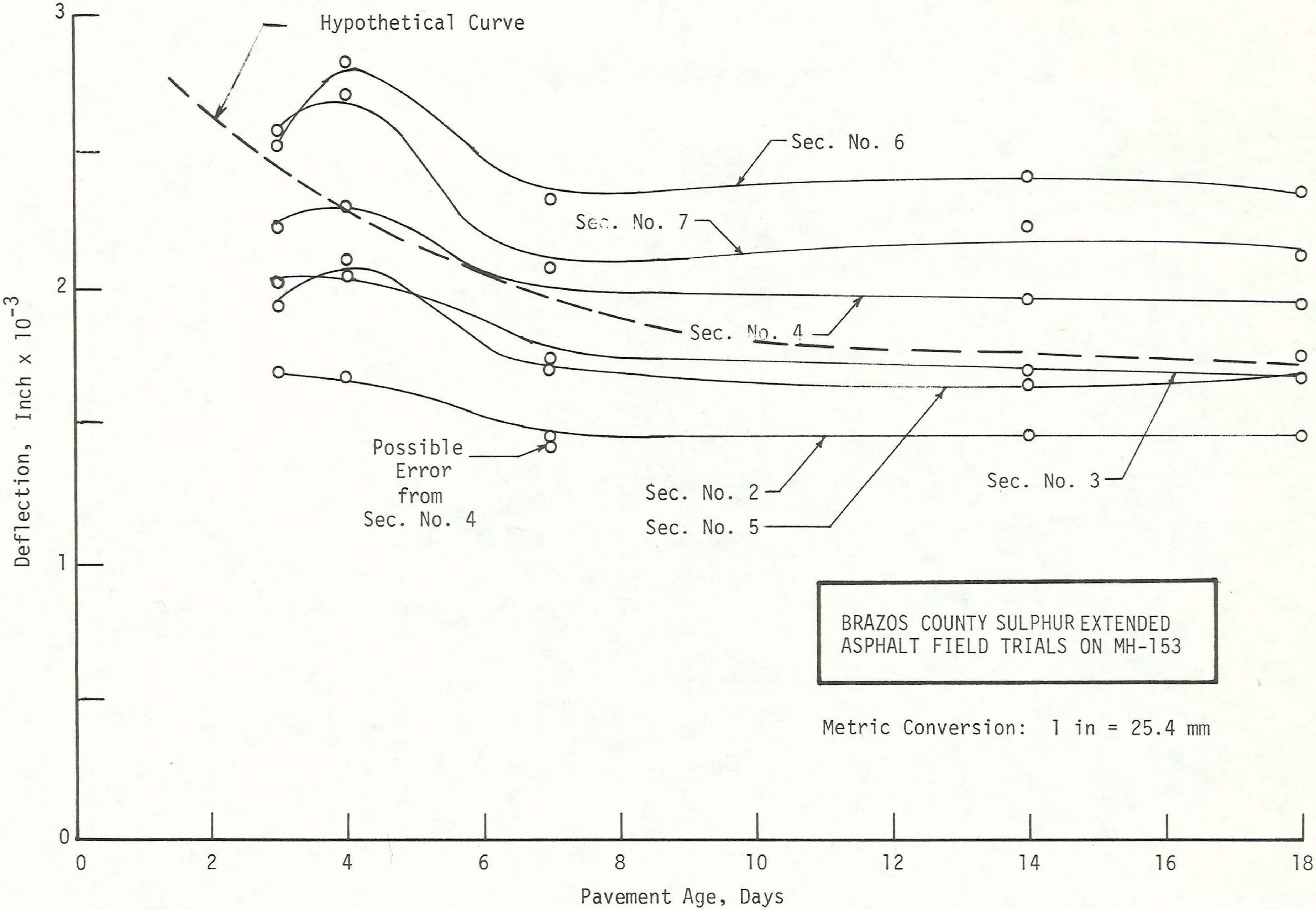

Figure 17 Dynaflect deflections vs. pavement age for sulphur-extended-asphalt binders.

stiffness over the first 18 days of the pavement life. Initial measurements were made at age three days. For tender mixtures such as these, the stiffness would generally be expected to change at a higher rate for the first few days. A hypothetical curve depicting such changes is superimposed on the curves shown in Figure 17. If the assumed shape and position of this hypothetical curve is representative, and it appears to be so, these mixtures improved in stiffness a considerable amount in about seven days.

VI. QUALITY CONTROL

Quality control and inspection of the Brazos County SEA job was a joint effort of State and TTI personnel with assistance from the U. S. Bureau of Mines and Texasgulf. Details of the various operations will follow.

State Inspection

A field laboratory staffed by state personnel and located at the hot-mix plant, was equipped with Hveem (ASTM D1560) molds, a "Motorized Gyratory Press", aggregate sieves, mechanical sieve shaker, asphalt extractor, constant temperature bath, constant temperature oven, scales, thermometers and miscellaneous containers, etc. The schedule of field testing follows:

Prepare Hveem test specimens, three each section, each layer and determine specific gravity and density; forward specimens to Austin for stability measurements.

Run dry sieve analyses on composite samples of aggregates.

Check temperatures of the paving mixtures.

TTI Inspection

TTI provided equipment and personnel for field and laboratory measurements as follows:

Monitor sulphur-asphalt binder compositions by use of a hydrometer at the mill and recheck the results in the TTI laboratory by specific gravity measurements (see Figure 18).

Measure the temperature of each load of pavement mixture.

Sample and test pavement mixtures from each section.

Core finished pavement and run Dynaflect measurements on each section and each course.

Sulphur-Asphalt Binder Compositions

Provisions were not made for laboratory extractions to determine the quantities of asphalt and sulphur in the pavement mixture during construction of the test sections. However, a limited number of tests was made to determine total binder content by sampling the paving mixture in the usual manner and running a Ratorex extraction and then igniting the residue (aggregate sulphur and liquids). In this way total binder content was determined and approximate separate values for sulphur and asphalt

Figure 18 Hydrometer used to monitor composition of sulphur-asphalt binder

were obtained. Acceptable checks with job quantities of sulphur and asphalt were evident from these tests.

Hydrometer and Pycnometer Measurements

Field measurements to determine binder compositions were made by hydrometer methods using ASTM D 3142 as a guide. Hot samples from the mill were transferred to 1000 ml graduate cylinders and near simultaneous readings of temperature and hydrometer were taken. The measurements were referred to a prepared chart showing temperature-specific gravity vs sulphur content. A portion of many of these binder samples was taken to the TTI laboratories for checking the sulphur content by use of pycnometer methods using ASTM D 70 as a guide.

The chart of temperature-specific gravity vs sulphur content used during construction was based on an assumed specific gravity for the asphalt of 1.000 @ 20°C. Test results obtained later from the State laboratory at Austin showed the specific gravity of the asphalt used on the project to be 1.0375 (avg. of two tests) at 20°C.

The calculated temperature-specific gravity vs sulphur content for both specific gravity values, 1.000 and 1.0375 at 20°C, are shown in Figure 19. The importance of accurate specific gravity measurements of the binder components is obvious. For example (see Figure 19), a specific gravity reading of 1.150 @ 135°C would indicate a sulphur content of 35.5 pct wt on the solid line for asphalt of specific gravity 1.000 @ 20°C, a difference of five percentage points.

Table 9 shows, by date and sample number, the weight percent of sulphur in the binder from field hydrometer measurements, based on asphalt of 1.04 specific gravity at 20°C vs the weight percent of sulphur in the binder from laboratory pycnometer measurements. Eliminating sample No's. 1, 6, and 42 as being erratic and assuming a normal distribution of the field test values, statistical analyses show that the field hydrometer tests can be expected to be within two percent (sulphur in total binder) plus or minus of the laboratory pycnometer measurements 95 percent of the time.*

Information on the composition of the binder at any location of interest in the test sections must await laboratory analyses of the asphalt and sulphur contents of field pavement cores.

Particle Size of Dispersed Sulphur

The distribution of the sulphur in the sulphur-asphalt binders was examined by TTI in their laboratories by scanning electron microscopy methods. In all samples examined, the sulphur portion had a particle size distribution such that over 95 percent by weight was 5 microns or smaller.

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* See Section IV of this report for an overall estiamte of binder composition based on mill operations and the amount of sulphur used on the project.

Table 9 Composition of the sulphur-asphalt binder (field hydrometer vs laboratory pycnometer)

Date Sampled	Field Sample	Hydrometer Field Test			Pychnometer Lab. Test		
		Temp ^{o}C	sp gr	pct wt S*	Temp ^{o}C	sp gr	pct wt S
June 16	1	132	1.116	30	25	1.306	43
" 16	2	135	1.140	34	"	1.221	31
" 16	3	131	1.140	34	"	1.245	34
" 16	4	135	1.137	29	"	1.187	27
June 19	5	127	1.098	26	"	1.169	25
" 19	6	121	1.090	24	"	1.249	35
" 19	8	135	1.085	25	"	1.166	24
" 19	9	138	1.185	41	"	1.297	41
" 19	10	138	1.133	33	"	1.223	33
June 20	11	142	1.188	42	"	1.318	42
" 20	17	142	1.126	33	"	1.237	34
" 20	24	138	1.064	23	"	1.162	23
June 21	26	129	1.103	31	"	1.244	34
" 21	30	156	1.048	21	"	1.154	22
June 22	33	151	1.043	20	"	1.156	22
June 23	39	145	1.122	33	"	1.258	36
" 23	42	154	1.045	21	"	1.183	28
" 23	44	151	1.128	34	"	1.213	31

*From chart based on asphalt specific gravity of 1.0375 at 20^{o}C. (See Figure 19.)

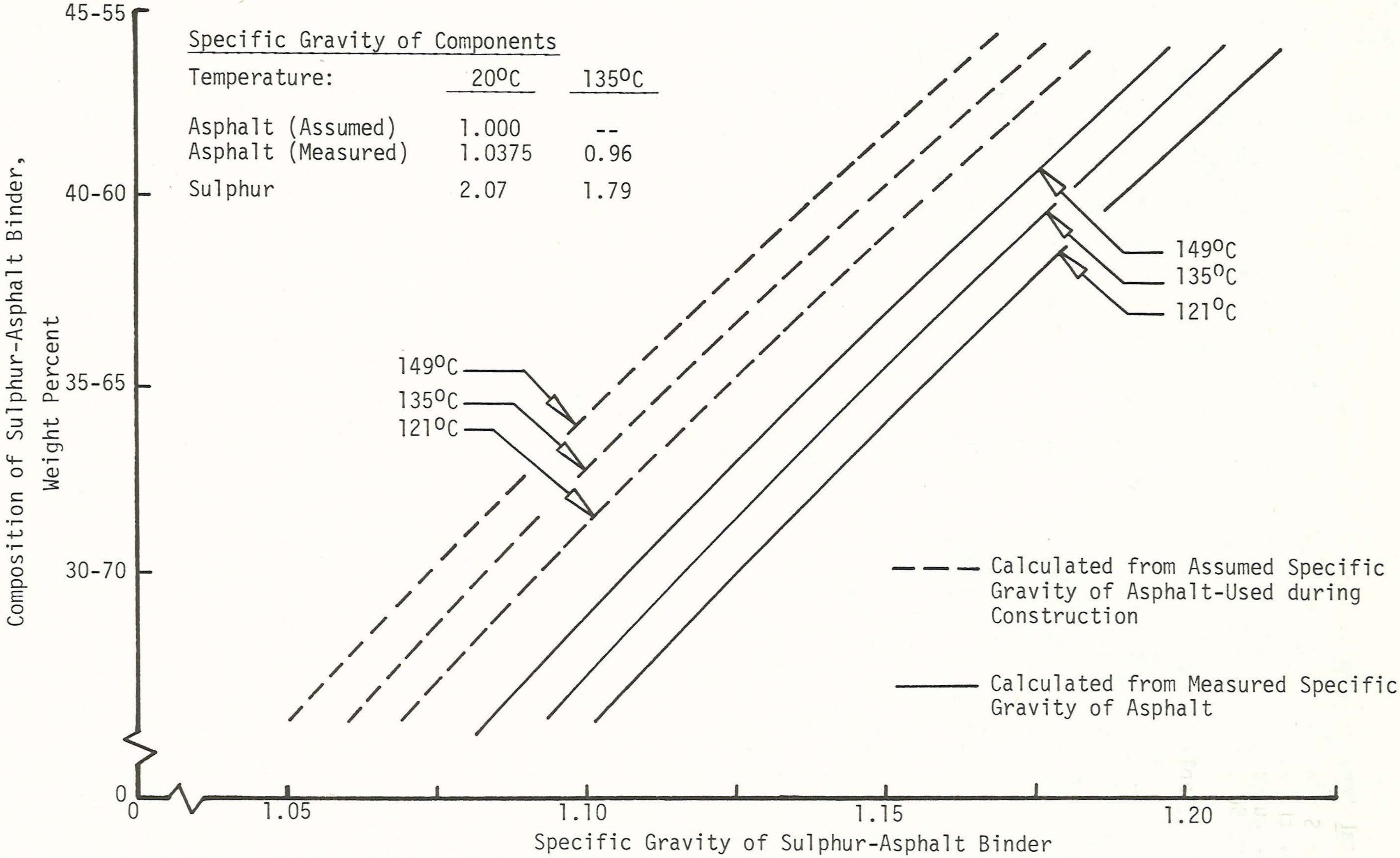

Figure 19 Sulphur-asphalt binder - composition vs specific gravity

Hveem Stabilometer Test Values

The State Specifications, Item 292, require a percent stability measured by the Hveem methods of "not less than 25%". The stability value is used for quality control on construction. Measured values are shown in Table 10. See Appendices A and B for details.

Table 10 Hveem stability values on field samples

Date	Section	Lane	Course	Engr. Sta.	Aggregate Blend	Binder Composition	Binder pct wt	Hveem
June 16	3	C	1	55+50	75-25	40-60	7.5	34
June 19	5	D	1	61+54	75-25	30-70	7.0	32
June 19	5	D	1	63+00	75-25	30-70	7.0	28
June 19	2	C	1	51+25	Job Mix	40-60	5.0	34
June 20		A*	3	34+54	50-50	40-60	8.5	19
June 21	2	D	2	50+50	Job Mix	40-60	5.0	38
June 21	3	C	2	55+50	75-25	40-60	7.5	36
June 21	4	C	2	57+75	75-25	30-70	7.0	35
June 21	5	C	2	64+75	75-25	30-70	7.0	37
June 22	6	D	2	66+05	50-50	40-60	8.5	21
June 22	7	C	2	71+50	50-50	30-70	8.0	19
June 23	3	D	3	52+75	75-25	40-60	6.8	34
June 23	4	C	3	60+00	75-25	30-70	6.3	36
June 23	5	C	3	63+25	75-25	30-70	6.3	30
June 23	6	C	3	69+25	50-50	40-60	7.9	28
June 23	7	D	3	70+65	50-50	30-70	7.4	21

Nomenclature:

Aggregate Blend 75-25; 75 pct wt Bank-Run Gravel
25 pct wt Field Sand

Aggregate Blend 50-50; 50 pct wt Concrete Sand
50 pct wt FieldSand

Aggregate Blend Job Mix; 55 pct wt Bank-Run Gravel
30 pct wt Pea Gravel
15 pct wt Field Sand

*Demonstration section

Sulphur-Asphalt Pavement Mix Design

The mixture designs for the sulphur-asphalt binder paving mixtures were the results of extensive laboratory tests by Texas Transportation Institute. Table 11 contains a summary of the design properties for all mixes used in the test sections.

VII. EVOLVED GAS ANALYSES

Emissions of hydrogen sulphide and sulphur oxides during the preparation and placement of sulphur-asphalt pavement mixtures are usually low or nonexistent at temperatures below 150°C. Above this point gaseous

Table 11 Summary of preliminary laboratory tests on mixture designs

Aggregate Combinations			Binder Composition		Mix	Marshall*	MR	Voids	Hveem*
Pit-run Gravel pct wt	Conc. Sand pct wt	Field Sand pct wt	Sulphur Sand pct wt	Asphalt Content pct wt	Binder in Mix pct wt	Stability lbs	Resilient Modulus $x10^6$ psi	Air Voids in Mix pct vol	Stabilometer Value
75		25		100	5	800	0.670	14	30
					6	1225		12	39
					7	1450	0.730	5	39
					8	1375			41
75		25	30	70	6	1400	0.520	10	36
					7	1650	0.500	8	40
					8	1850	0.660	5	40
75		25	40	60	6	1750	0.510	10	44
					7	2050	0.640	8	42
					8	2300	0.660	5	40
	50	50		100	6	1300	0.490	16	30
					7	1500	0.290	14	28
					8	1650	0.350	9	25
	50	50	30	70	6	550	0.190	13	32
					7	750	0.230	9	32
					8	800	0.225	8	31
	50	50	40	60	6	1000	0.330	13	34
					7.5	1100	0.525	10	31
					8.5	1100	0.315	7	30

* Marshall and Hveem values were taken from data plots. Metric Conversion: 1 lbf = 4.45 N
1 psi = 6.89 kPa

emissions may increase rapidly. Gaseous emissions may be high in the dome of sulphur transports or in the top of improperly ventilated sulphur storage. Since these are points seldom visited by plant personnel, these areas present only minor problems. Additionally, sulphur vapors (finely divided sulphur particles) are evolved at normal operating temperatures.

Texas Transportation Institute provided the instrumentation and made measurements of the sulphur emissions on this project.

Equipment

Three types of portable instruments were used for measuring hydrogen sulphide and sulphur oxides. These were:

1) DRAGER multigas detector with tubes
   National Mine Service Company
   Pittsburgh, Pennsylvania (see Figure 20)

2) COLORTEK, Hydrogen sulphide detector cards
   Metronics Associates, Inc.
   Palo Alto, California (not shown)

3) ROTOROD gas sampler, Model 721
   Metronics Associates, Inc.
   Palo Alto, California (see Figure 21)

High volume type air samplers, each assembled with electric motor, air suction pumps, and cages were used to monitor sulphur dust in the ambient air. Air is drawn into covered housing and through a filter by means of a high flow rate blower at flow rates of 40 to 60 cfm (1.13 to 1.70 m^3/min) that allows suspended particles having diameters of less than 100 microns to pass to the filter surface. Particles with size range of 100 to 0.1 micron diameter are ordinarily collected in glass fiber filters. The mass concentration of the suspended particulates in the ambient air is computed by measuring the mass of collected particulates and the volume of air sampled. See Figure 22 for unit in use.

Locations of High Volume Air Samplers

The high volume air samplers were set up on June 23 at four locations, two on the project test site and two at the hot-plant. The two at the test site were located on the adjoining earth surface about 35 ft (10.7 m) easterly from the median area of the four-lane highway opposite Engineer stations 57+10 and 58+20. These units were powered with portable gas driven POWER GRAD 2.5 kw electric power generators. At the hot-plant, one sampler was located midway between the binder plant (mill) and the hot-mix plant; the other located northerly, downwind, from the hot-plant site.

The prevailing winds were from the south-southwest.

Tables 12 and 13 show details of the hydrogen sulphide measurements. The highest concentrations encountered were at the dome in the sulphur storage tank and at the sample pet cock on the binder surge tank. These are not considered workmen areas and special safety rules apply. All other measurements were well within the safe working limits specified by

Table 12 Hydrogen sulphide emissions in the vicinity of hot-mix plant

Location	Sampling Equipment	Average Concentration, ppm	Remarks NPA-nonpersonnel area PA-personnel area
Sulphur Storage Tank Area			
Top Opening of Tank	DRAGER tube	200*	NPA
Ten feet from Tank Inlet Port (downward)	DRAGER tube	4.5	NPA
Hot-Mix Plant Area			
Operator's Platform	DRAGER tube	trace	PA (1-2 people)
Control House	ROTOROD	0.2	PA (moderate)
	COLORTEC	0.6	PA
Over Loaded Truck	DRAGER tube	1.0	NPA
100 ft Downward of Hot-Mix Plant	DRAGER tube	0.0	PA (light)
Binder Plant (Mill):			
Open Valve	DRAGER tube	60	Open for sampling only
Closed Valve	DRAGER tube	trace	PA

* Source Data; not representative of typical personnel areas

Metric Conversion: 1 ft = 0.305 m

Table 13 Hydrogen sulphide emissions in the vicinity of the paver

Location	Sampling Equipment	Average Concentration, ppm	NPA-nonpersonnel area PA-personnel area
Paver			
Paver Operator's Seat	ROTOROD	0.0	PA (one person)
Paver Hopper	DRAGER tube	trace	NPA
Alongside Paver (at auger) downwind	ROTOROD	0.0-trace	PA (1-2 people)
	DRAGER tube	trace	
Paver Vicinity			
100 ft (30.5 m) downwind	DRAGER tube	0.0-trace	PA (light)
Over Back of Paver			
Two feet (0.6 m) above surface	DRAGER tube	0.0-trace	NPA

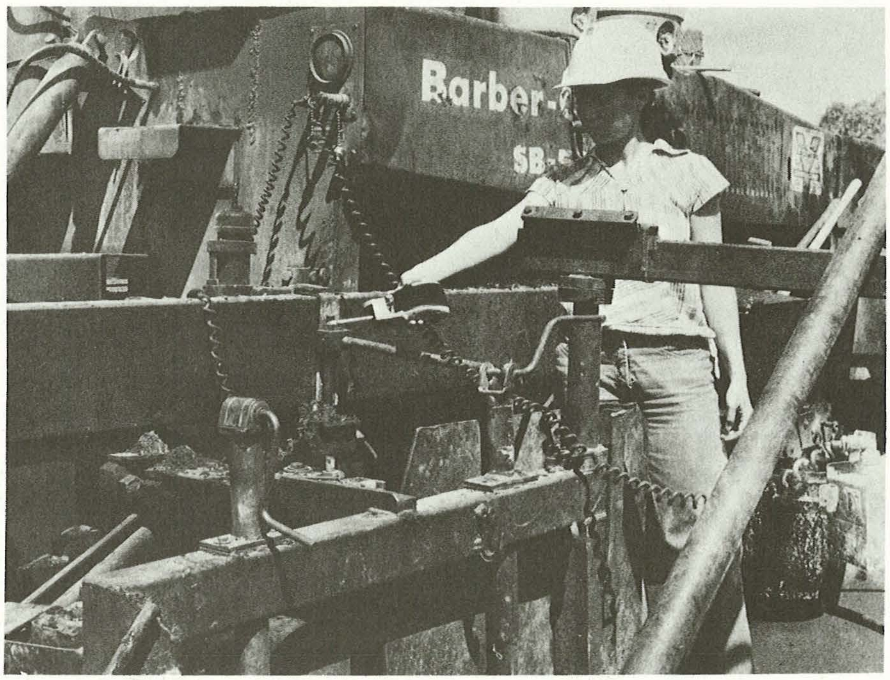

Figure 20   Drager tube used to monitor SO_2 emissions at the paver

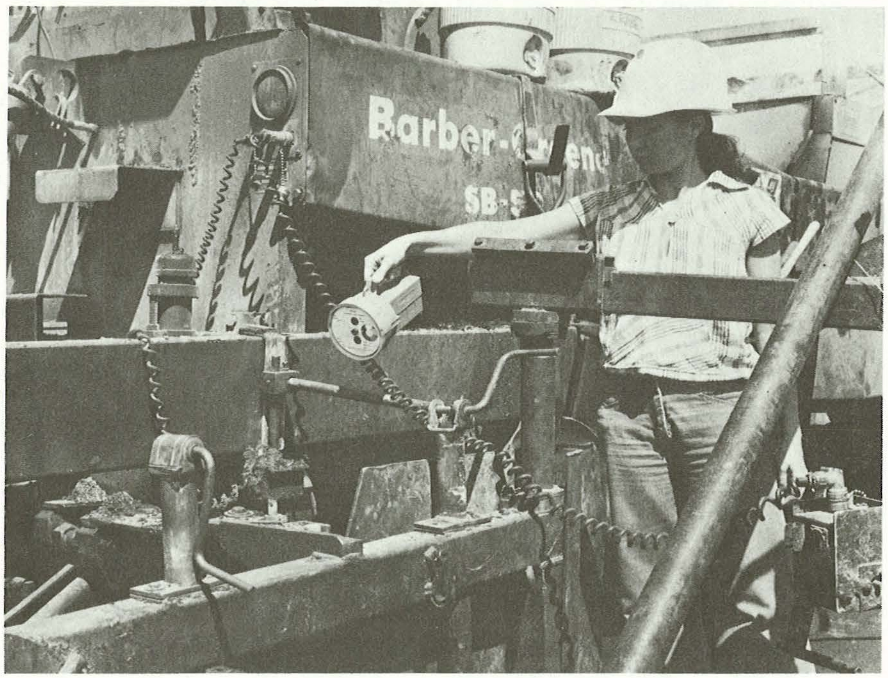

Figure 21 Roto rod H_2S analyzer used to check emissions at the paver

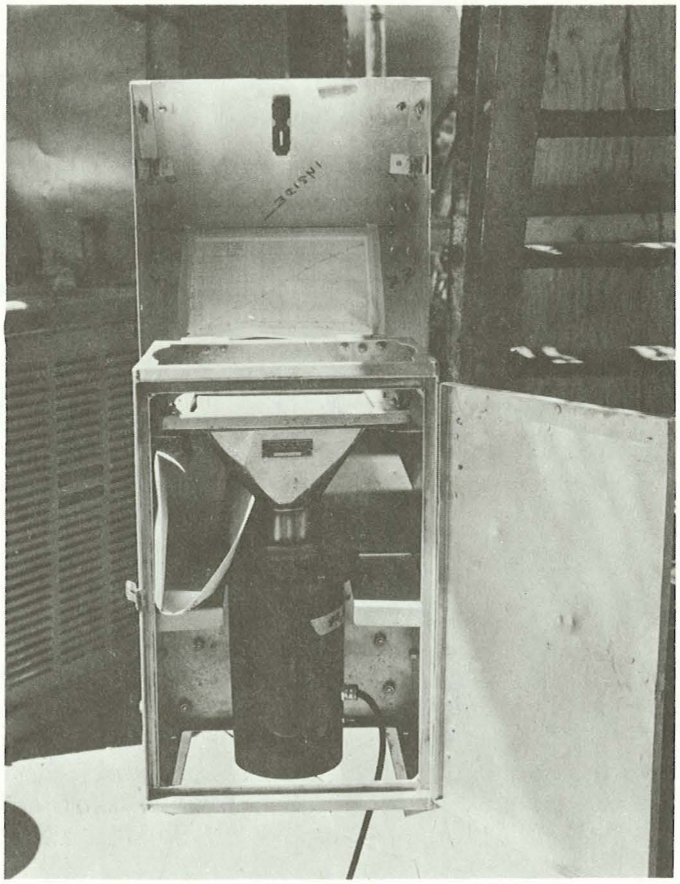

Figure 22 "Hi Vol Dust Collector" utilized for measuring particulate sulphur at the plant and on the job

American Conference of Governmental and Industrial Hygienists and summarized in Tables 14 and 15 and further described in:

1) The Chemistry of Industrial Toxicology, Elkins, H. B., John Wiley and Sons, Inc., New York, pp. 95, 232, 1950; and
2) Hydrogen Sulfide, Chemical Safety Data Sheet DS-36, Manufacturing Chemists Association, Washington, D.C., revised 1968.

Table 16 shows details of sulphur dioxide field measurements.

Particulate Sulphur -- Occurrence and Toxicity

Vapor given off during the preparation and placement of sulphur-asphalt pavement mixtures contains a certain amount of elemental sulphur. As the vapors come in contact with air and cool, the sulphur vapor crystalizes into small particles which are carried by the wind in a manner similar to dust. Since there is no practical way to eliminate this pollutant, its effect on both environment and personnel needs to be considered.

The principal problem associated with sulphur dust lies in its contact area with the eyes. Sulphur is virtually nontoxic and there is no evidence that systemic poisoning results from the inhalation of sulphur dust. However, sulphur is capable of irritating the inner surfaces of the eyelids. Sulphur dust may also irritate open cuts of the skin. The problem with eye irritation is minimized by wearing goggles in the area where the pollutant is present such as the vicinities of the hot-plant and the paver.

Table 17 shows details of the particulate sulphur measurements.

Summary of Evolved Gas Analyses

Three forms of sulphur pollutants were measured: hydrogen sulphide, sulphur dioxide, and sulphur dust. Except for high values in the top of the sulphur storage tank and at the sampling pet cock on the sulphur emulsion surge tank, the hydrogen sulphide measurements were well below recommended allowable threshold limits. Measurements of sulphur dioxide were well below recommended allowable threshold limits at all locations.

VIII. CLOSURE

The information presented in this detailed construction report is intended as guides for agencies that plan to use sulphur-extended-asphalt as a binder for flexible paving systems.

Much remains to be learned about the benefits to pavement systems by the addition of sulphur to asphalt; however, strong evidence already exists indicating that the use of petroleum products as pavement binders can be reduced via this approach and, further, that where SEA is substituted on an equal volume basis for pure asphalt, satisfactory paving mixtures are easily produced. These SEA mixtures can be produced with commonly used, available hot-mix plants and placed with standard laydown equipment.

Based on laboratory fatigue data collected by the Texas Transportation Institute and on the performance of field test sections, SEA paving mixtures present no problems in this important area.

Table 14 Toxicity of hydrogen sulfide*

Concentration, ppm	Effect
0.02	Odor threshold
0.10	Eye irritation
5-10	Suggested Maximum Allowable Concentration (MAC) for prolonged exposure
70-150	Slight symptoms after exposure of several hours
170-300	Maximum concentration which can be inhaled for 1 hour without serious consequences
400-700	Dangerous after exposure for 1/2 to 1 hour
600	Fatal with 1/2 hour exposure

Table 15 Toxicity of sulphur dioxide*

Concentration, ppm	Effect
0.3-1	Detected by taste
more than 1	Injurious to plant foliage
3	Noticeable odor
5	Maximum Allowable Concentration (MAC) according to ACGIH
6-12	Immediate irritation to nose and throat
20	Irritation to eyes
50-100	MAC for 30-60 minutes exposure
400-500	Immediately dangerous to life

Table 16 shows details of sulphur dioxide measurements. All were within safe working limits as summarized in Table 15.

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* Data from:

1) Hydrogen Sulfide, Chemical Safety Data Sheet D5-36, Manufacturing Chemists Association, Washington, D.C. (Revised 1968)

2) Sulfur-Dioxide, Chemical Safety Data Sheet SD-52, Manufacturing Chemists Association, Washington, D.C. (1959)

Table 16 Sulphur dioxide emissions - vicinities of hot-mix plant and paver

Location	Sampling Equipment	Average Concentration, ppm	Remarks NPA-nonpersonnel area PA-personnel area
Hot-Mix Plant			
Top of Dome of Sulphur Storage Tank	DRAGER tube	25*	NPA
Operator's Platform	DRAGER tube	2.0	PA
Over Loaded Truck	DRAGER tube	1.5-5*	NPA
100 feet (30.5 m) Downwind of Hot Plant	DRAGER tube	0.0	PA
Binder Plant (Mill) Closed Valve	DRAGER tube	10	PA
Paver			
Paver Operator's Seat	DRAGER tube	0.0	PA
Over Loaded Hopper	DRAGER tube	trace	NPA
Alongside Paver (at auger) downwind	DRAGER tube	trace	PA
Over Pavement Surface Back of Paver	DRAGER tube	trace	NPA

* Immediately over one truck load of mix which had a measured temperature of 370°F (188°C) a reading of 120 ppm was obtained.

Table 17 Particulate sulphur measurements

Location	mg Total Sediment	mg Total Sulphur	Sediment Flux $mg/m^3/day$	Sulphur* Flux $mg/m^3/day$
Test site, 35 feet (10.7 m) Easterly from Engineer Station 57+10	120.07	0.654	205.73	1.12
Test Site, 35 feet (10.7 m) Easterly from Engineer Station 58+20	139.5	0.630	249.98	1.13
Hot-Mix Plant, on Ground Between Binder Plant (Mill) and Pug-Mill	1275.96	1.634	3198.40	4.10
same	1008.47	0.595	498.1	2.98
Hot-Mix Plant, Downwind Northerly	199.68	0.011	1126.2	0.06

* Not Particulate Sulphur Exclusively

Note: Measurements of Sediment Flux and Sulphur Flux are 8-hour day basis.

The total matter collected by the "High Volume" units were analyzed by following ASTM Standard E 30-47.

Appendix A

Guidelines for Mixture Design of SEA Paving Materials

General

Most State and Federal agencies across the country use laboratory paving mixture designs procedures that may be considered to fall loosely into one of two different methods, i. e., Marshall or Hveem. Nationwide, the most prevalent is the Marshall Method of Mix Design. Both of these design procedures are fully described in Manual Series No. 2 of the Asphalt Institute(1A).

Associated applicable specifications and test methods include(2A):

Specifications:

ASTM D-3515:	Hot-mix, Hot-laid Bituminous Paving Mixtures
ASTM D-995:	Requirements for Mixing Plant for Bituminous Paving Mixtures
ASTM D-946:	Asphalt Cement in Pavement Construction
ASTM D-692:	Specifications for Coarse Aggregate for Bituminous Paving Mixtures
ASTM D-1073:	Specifications for Fine Aggregate for Bituminous Paving Mixtures
ASTM D-242:	Specifications for Mineral Filler for Bituminous Paving Mixtures

Test Methods:

ASTM D-3497:	Dynamic Modulus of Asphalt Mixtures
ASTM D-3496:	Preparation of Bituminous Mixture Specimens for Dynamic Modulus Testing
ASTM D-1075:	Effect of Water on Cohesion of Compacted Bituminous Mixtures
ASTM D-2950:	Density of Bituminous Concrete in place by Nuclear Method
ASTM D-3203:	Percentage of Air Voids in Compacted Dense and Open Mixtures
ASTM D-1559:	Resistance to Plastic Flow using Marshall Apparatus
ASTM D-979:	Sampling Bituminous Paving Mixtures
ASTM D-75:	Soundness of Aggregates
ASTM D-2041:	Maximum Specific Gravity of Bituminous Paving Mixtures

These listed specifications and test methods are not all inclusive, indeed, TTI researchers also used the tensile splitting test(3A) and the resilient modulus test(4A) to give further insight into the properties of SEA mixtures. In the preliminary evaluation of binder-aggregate systems the Lottman(5A) tests serve as useful tools to measure water susceptibility. The potential of the resilient modulus as an evaluation device for SEA mixtures justifies a limited description of this test; this is given in Appendix B.

Laboratory Mixture Design Considerations

Any agency considering the use of SEA as a binder for paving mixtures should examine their standard materials requirements and use those design and test procedures normally used to produce paving mixtures made with pure asphalt cement, considering the associated effects of traffic and the environment.

Researchers at TTI have chosen the Marshall Method of Mix Design for the laboratory evaluation of SEA paving materials with supplemental data from other tests such as Schmidt's resilient modulus values, tensile tests and Lottman water susceptibility evaluations. Similar acceptable design systems in current use by a given agency wherein pure asphalt is used should serve the intended purpose.

Available materials for producing acceptable bituminous paving mixtures vary widely across the country; however, familiarity with these materials and the demands imposed by traffic and the environment make it possible to design successful paving mixtures by a given agency and the substitution of SEA binders for pure asphalt will not present any particular problems.

Materials

The sulphur-asphalt cement used to produce the SEA binder in the laboratory design of the mixtures used on MH 153 are described on pages 8 through 11 in the body of this report. These materials, with the exception of the sulphur, were obtained from stocks at the contractor's hot mix plant and were considered representative of the materials to be used in the test section.

The SEA binder used in the laboratory was produced in a six-liter capacity Eppenbach colloid mill* just prior to the formation of a given binder-aggregate mixture. The use of other types of high shear mixers for producing the SEA binder should result in satisfactory dispersions of the sulphur in the asphalt, provided the blend is used within about one hour. In those instances where the weight percent of sulphur exceeds about 30 percent and the delay time between production and use of the binder exceeds about 30 minutes the binder should be remixed by vigorous stirring or reprocessed through the mixing device to preclude separation of the two liquids.

The aggregates used in the laboratory mix designs are described on pages 11 through 13 in the body of this report. As may be noted these are locally available aggregates and are primarily silicate gravels and sands deposited in a meander of the Brazos River.

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* Mixtures of sulphur, asphalt and aggregates have been successfully produced by direct and simultaneous entry of the two liquids to the hot aggregate during active mixing.

Mixture Design

Laboratory mixture designs for this project involved three aggregate blends and two SEA binders. Optimum binder contents were determined by use of the Marshall Method.

Aggregate gradings for the three blends are shown in Figure 1A. The "job mix formula" is the 50:30:15 combination. This was considered the most expensive aggregate blend, since the pea gravel was a processed material. The least expensive aggregate was the 50:50 sand blend with the 75:25 bank run gravel-field sand being in between. Only the "job mix formula" met the State's Specifications; hence, the other two aggregate blends were designated "marginal aggregates."

These three aggregate blends were optimized for binder demand by the Marshall Method of Mix Design using 30-70 and 40-60 SEA binders. Summary results are shown in Table 11 on page 48 in the body of the report.

Past experience of TTI research personnel as well as findings of others who have used SEA binders indicate a need to substitute SEA binders for pure asphalt on an equal volume basis. When the laboratory mix designs were taken to the field, this practice was carried out.

The "job mix formula" which utilized pure asphalt was that specified in Texas State Specifications under Item 292 (6A) with some over-ride features designated by local district personnel. A description of these "special" requirements follows:

a) Field density 93 to 99 percent* (96% optimum)

b) Hveem stability ≥ 25 percent

c) Laboratory density 93 to 98 percent (96% optimum)

d) Aggregates:

   1) No. 4 sieve; ≤ 85 percent passing

   2) No. 10 sieve; 40-70 percent passing

   3) Maximum PI of minus No. 40 fraction, ≤ 8

On the experimental portion of this project field density was measured with a portable nuclear device. It should be noted, however, that the State does not impose a field density requirement on the contractor. The general practice is to compact the pavement "to the satisfaction of the Engineer."

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* Percent of laboratory density.

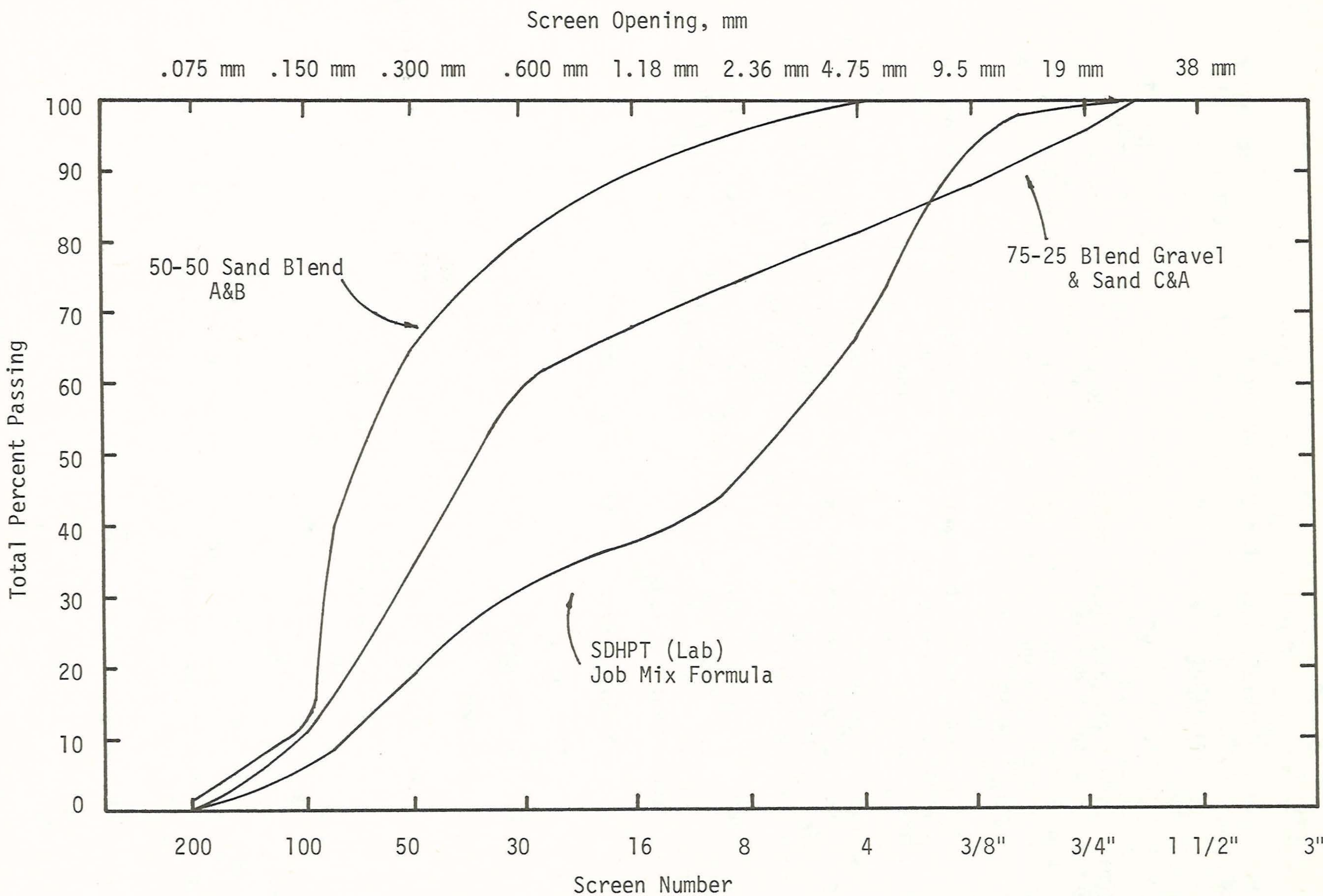


Figure 1A Gradation of Aggregate Blends Used in Brazos County Field Tests

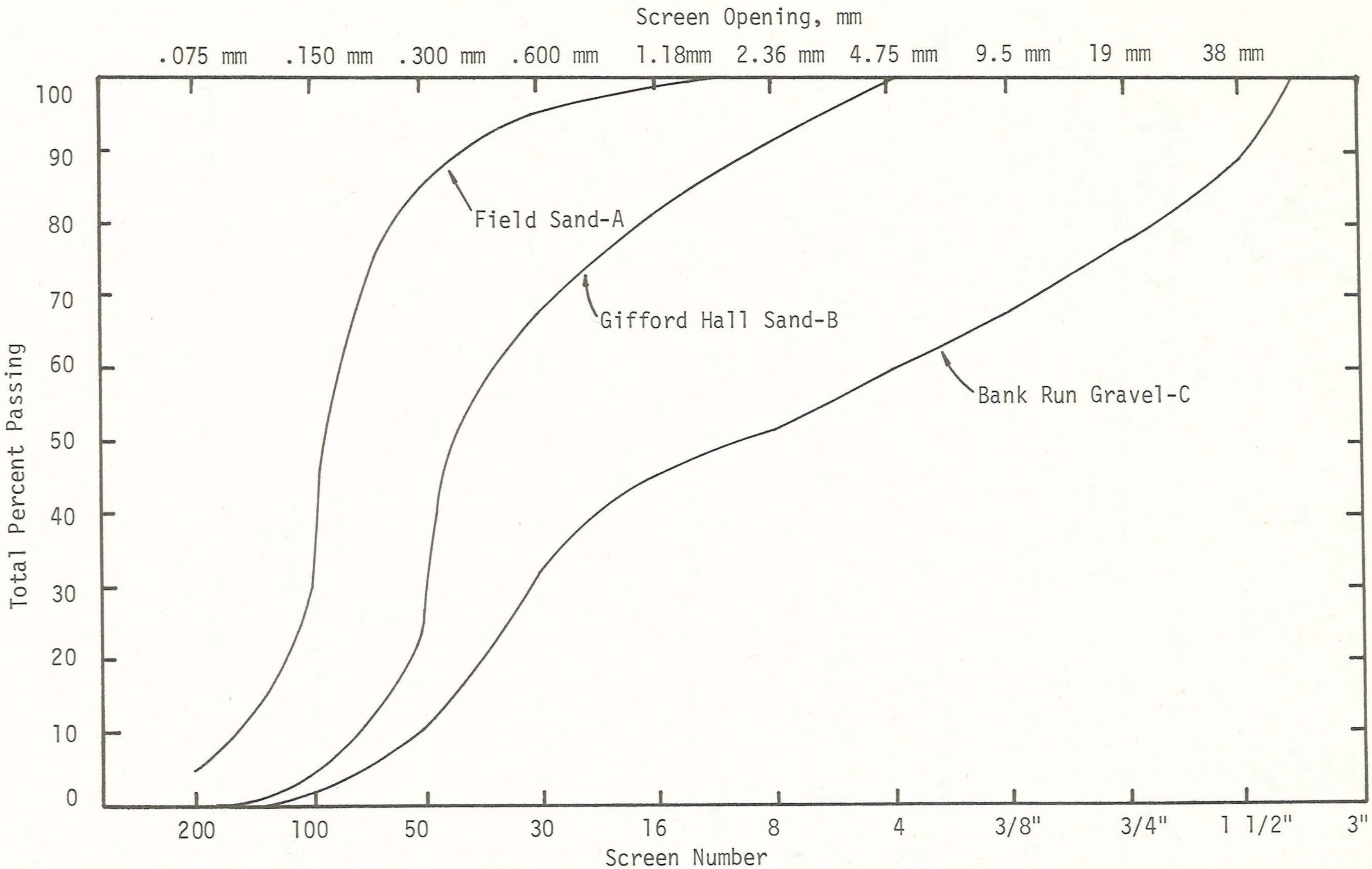


Figure 2A Gradation of Aggregates Used for Field Trial Paving Mixtures

This practice often results in a pavement with 8 to 12 percent voids when the road is opened to traffic. High voids content caused by inadequate compaction result in mixtures with poor test properties.

Properties of the laboratory mixture designs are presented in Figures 3A through 12A.

Figure 3A presents both Marshall and Hveem stabilities as function of the binder content for pure AC-20 asphalt cement and a blend of 75 percent bank run gravel and 25 percent field sand. Also shown on this figure are resilient modulus (M_R) values measured at 68°F (20°C) as well as the TTI Marshall and Hveem stabilities of the "job mix formula" at five percent asphalt cement. The SDHPT value for Hveem stability at their optimum asphalt content of five percent is also shown.

Figure 4A presents similar data wherein AC-20 asphalt was used with the 50:50 concrete sand and field sand. Hveem stabilities are lower than these in Figure 3A; however, Marshall stabilities are about the same. Resilient modulus values are much lower.

In Figure 5A a 30-70 SEA binder has been substituted for pure asphalt. Values of both Marshall and Hveem stability have increased and the M_R values approach those for pure AC-20. Weight percent of SEA is seen to increase.

The Marshall and Hveem stabilities experience further increases in Figure 6A when the sulphur content of the SEA binder is increased to that represented by a 40:60 blend. No noticeable change in M_R is observed.

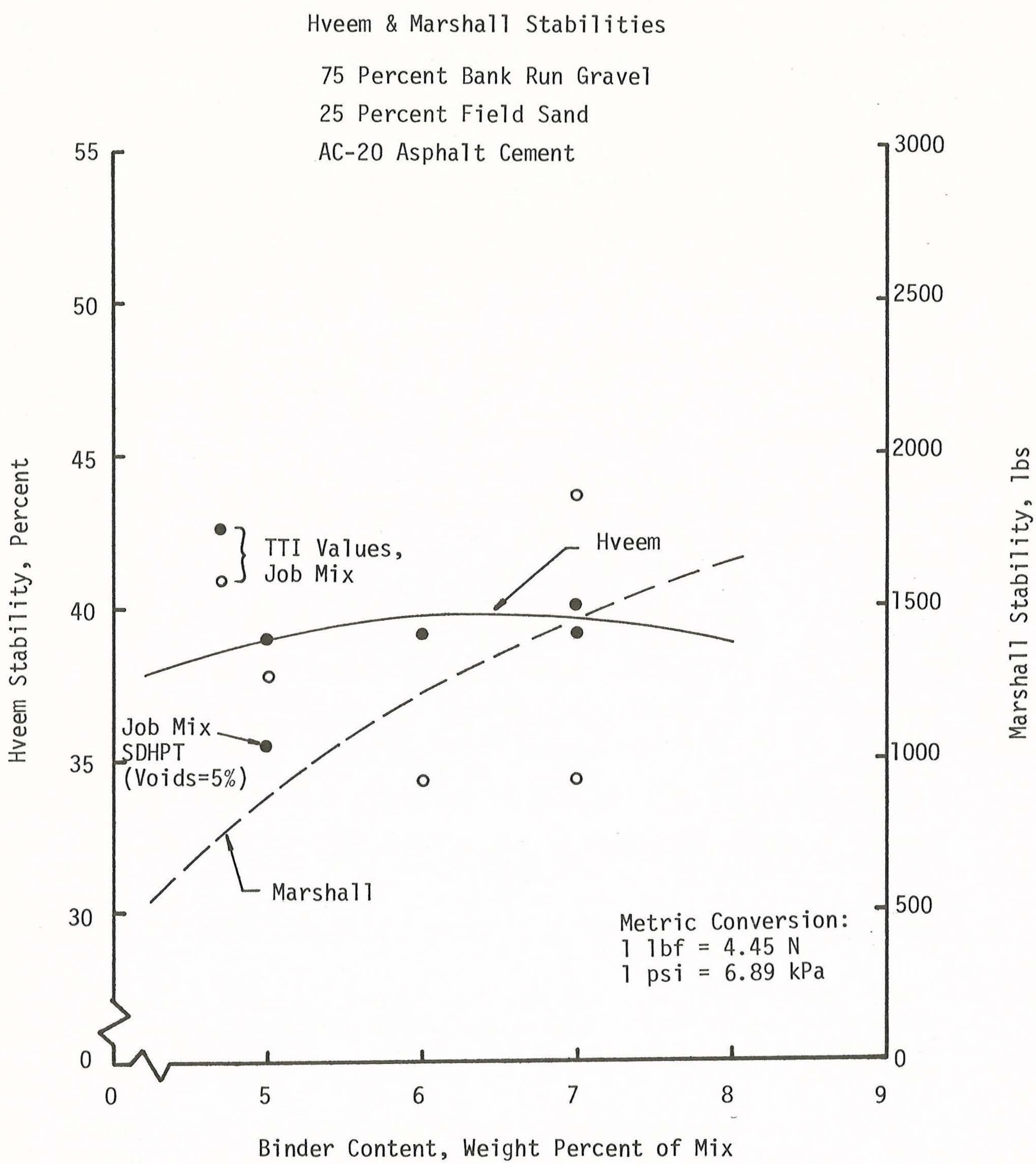
In Figure 7A laboratory mix design data are presented wherein 50:50 SEA binder is mixed with the 75:25 blend of bank run gravel and field sand. As the binder content was increased from six to ten percent the stability values became erratic with Marshall values increasing significantly.

Figure 8A presents Marshall and Hveem values for a 50:50 blend of coarse and fine sands and a 30:70 SEA binder. Test values drop significantly from those in Figure 7A. Values of M_R are somewhat lower than those for a similar mix design utilizing pure asphalt. These mixtures are relatively insensitive to binder content.

With a change to 40:60 SEA binder the Marshall stability increases as shown in Figure 9A and the M_R values are almost doubled. Again as the percent sulphur is increased in the SEA binder the total weight percent of binder increased.

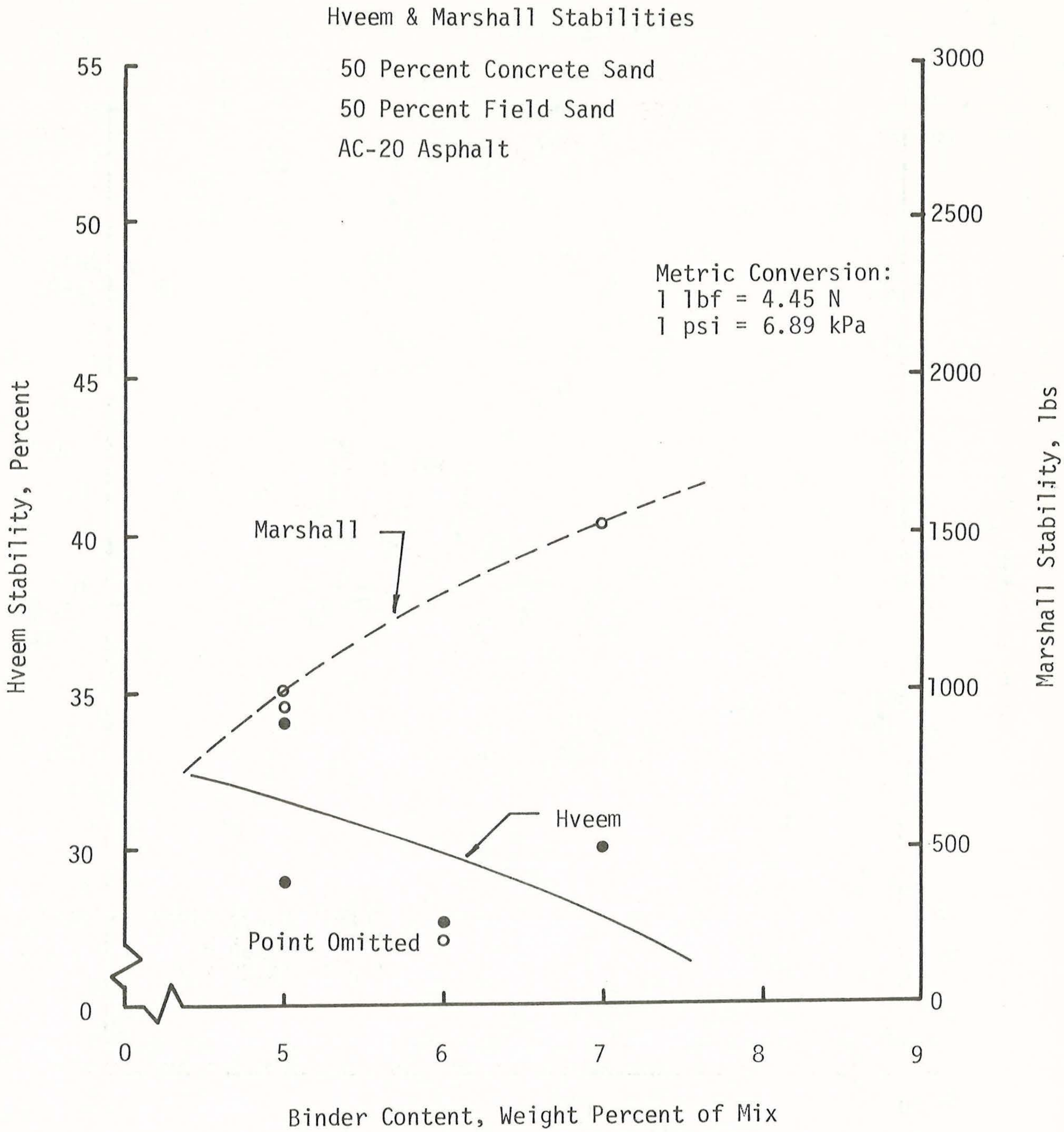
Figure 10A presents data for 50:50 SEA binder used in an "all sand" mixture. Both Marshall and Hveem values are highly scattered as binder contents were increased from six to more than nine percent.

Figures 11A and 12A present data on the air void content of the laboratory compacted mixtures that were evaluated on this project.



M_R, psi 670,000 700,000 730,000

Figure 3A Hveem & Marshall Stabilities, 75 Percent Bank Run Gravel, 25 Percent Field Sand, AD-20 Asphalt Cement



M_R, psi 190,000 290,000 350,000

Figure 4A Hveem & Marshall Stabilities, 50 Percent Concrete Sand, 50 Percent Field Sand, AC-20 Asphalt

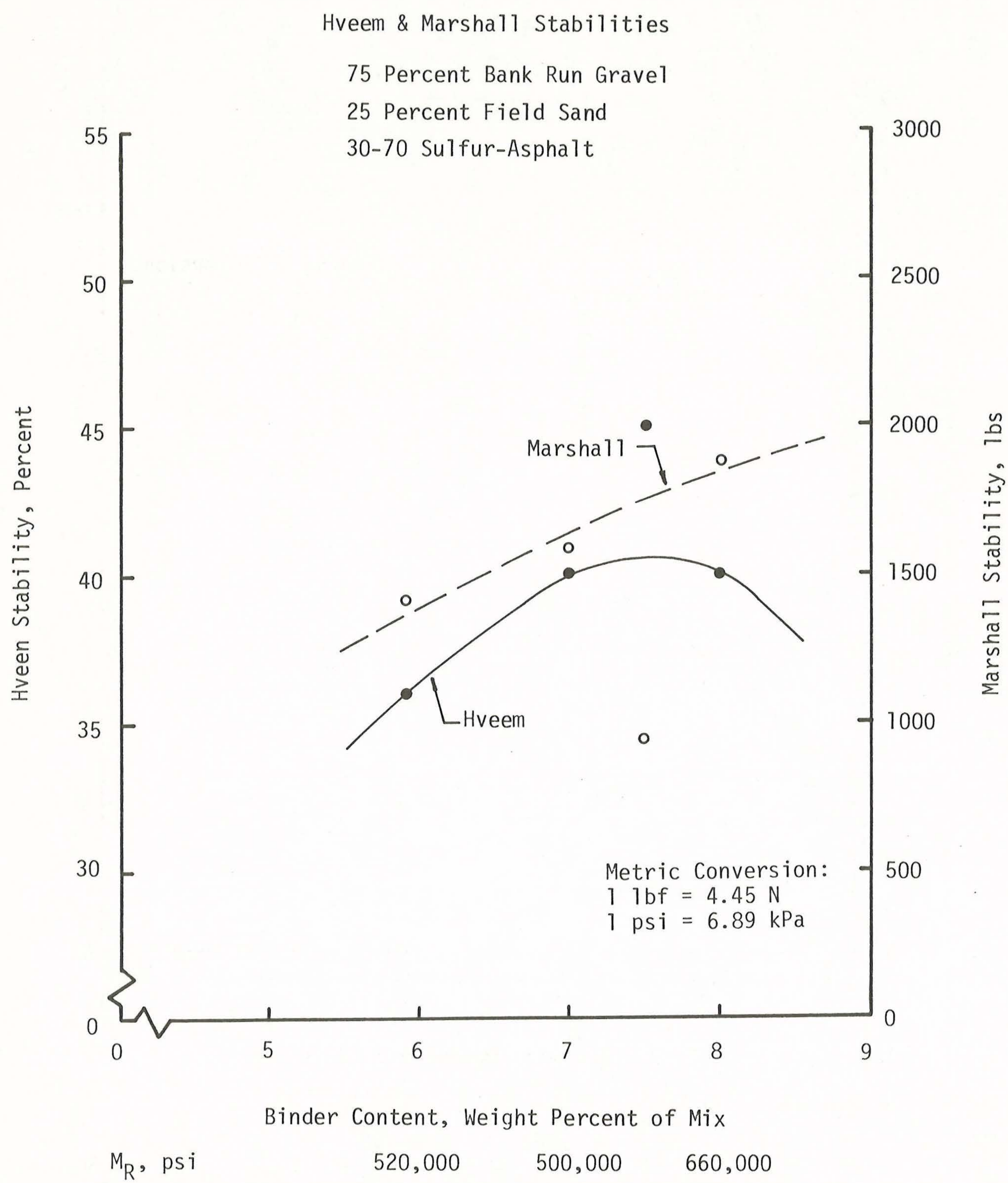
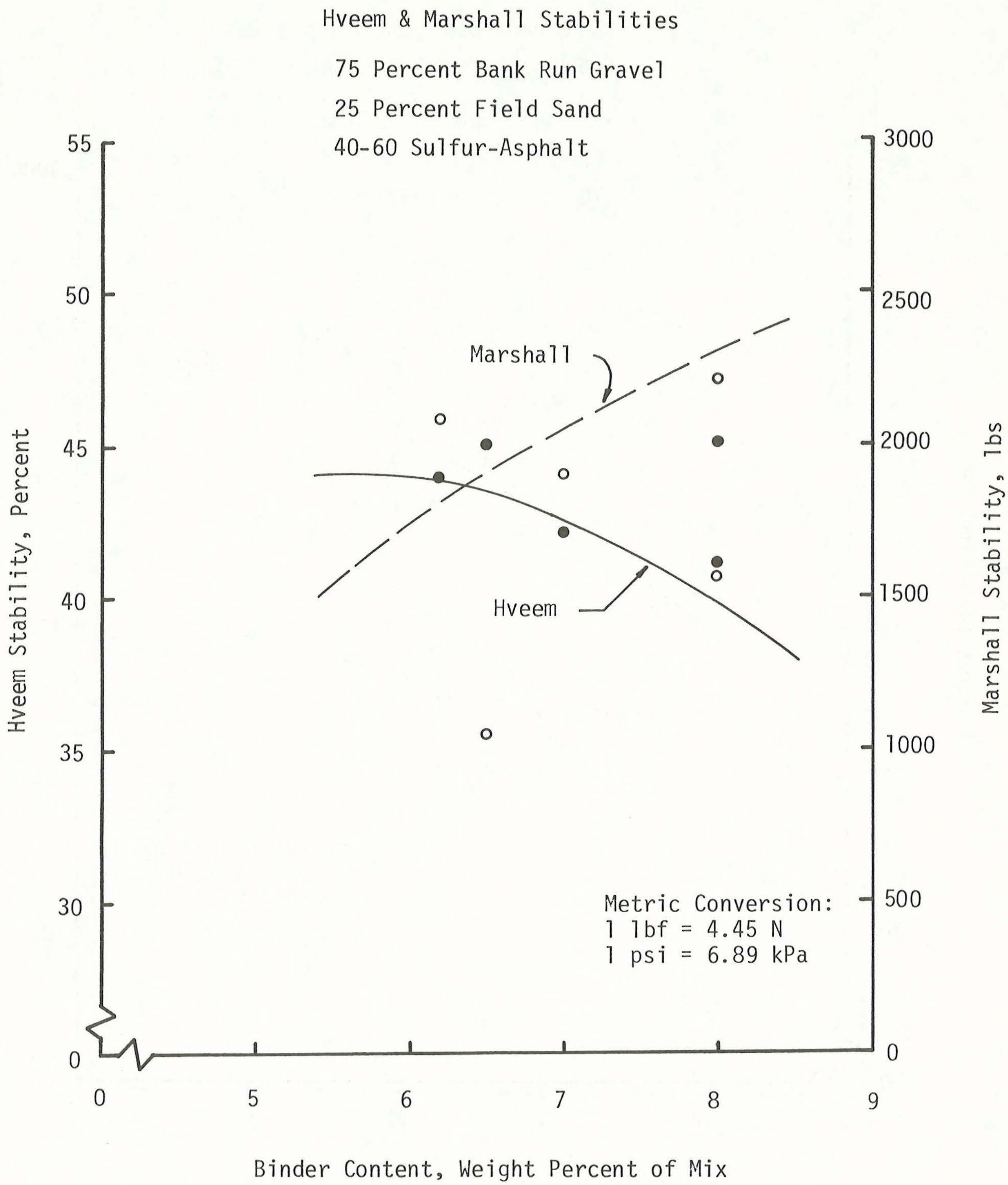


Figure 5A Hveem & Marshall Stabilities, 75 Percent Bank Run Gravel, 25 Percent Field Sand, 30-70 Sulfur-Asphalt



M_R, psi	510,000	640,000	630,000

Figure 6A Hveem & Marshall Stabilities, 75 Percent Bank Run Gravel, 25 Percent Field Sand, 40-60 Sulfur-Asphalt

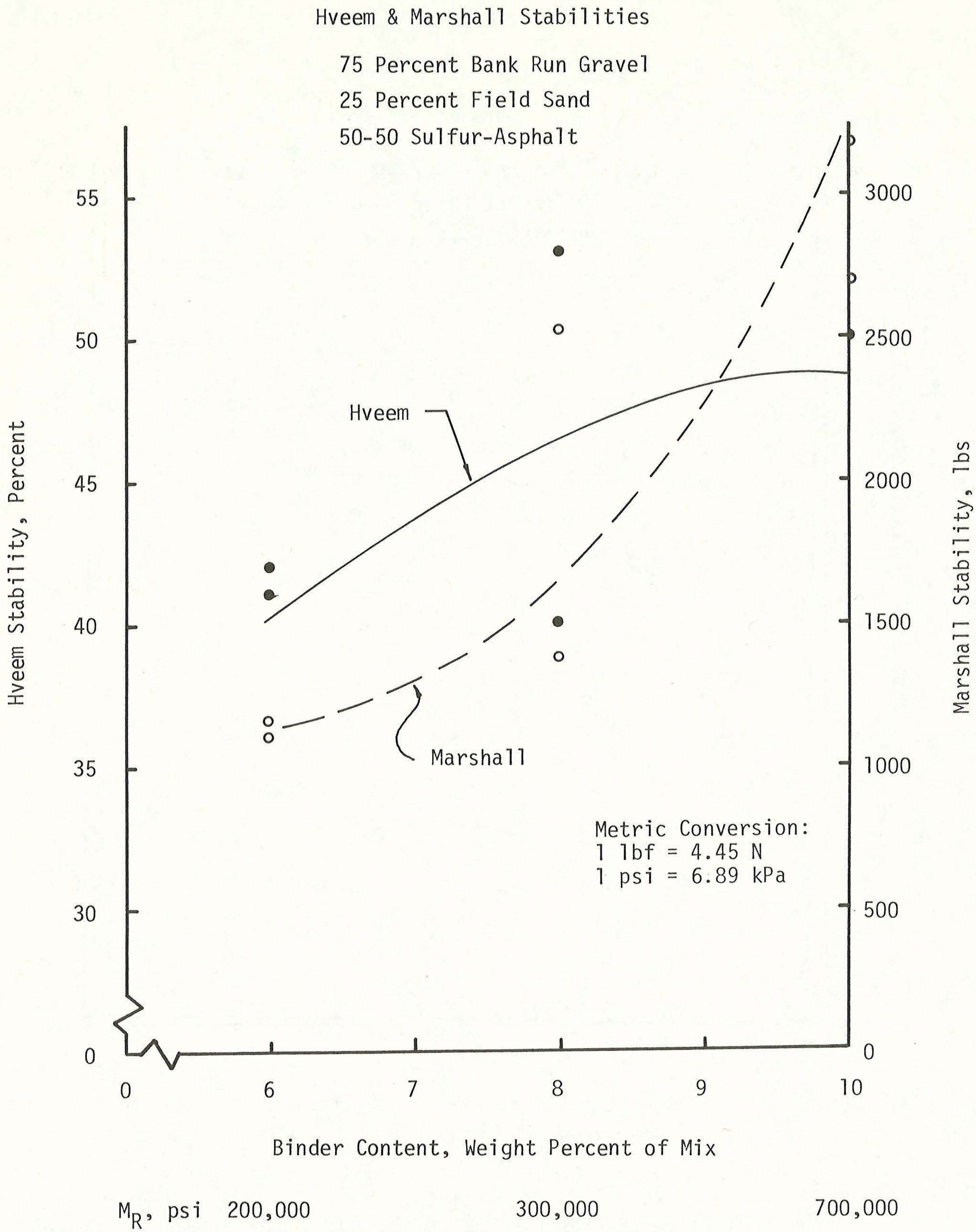


Figure 7A Hveem & Marshall Stabilities, 75 Percent Bank Run Gravel, 25 Percent Field Sand, 50-50 Sulfur-Asphalt

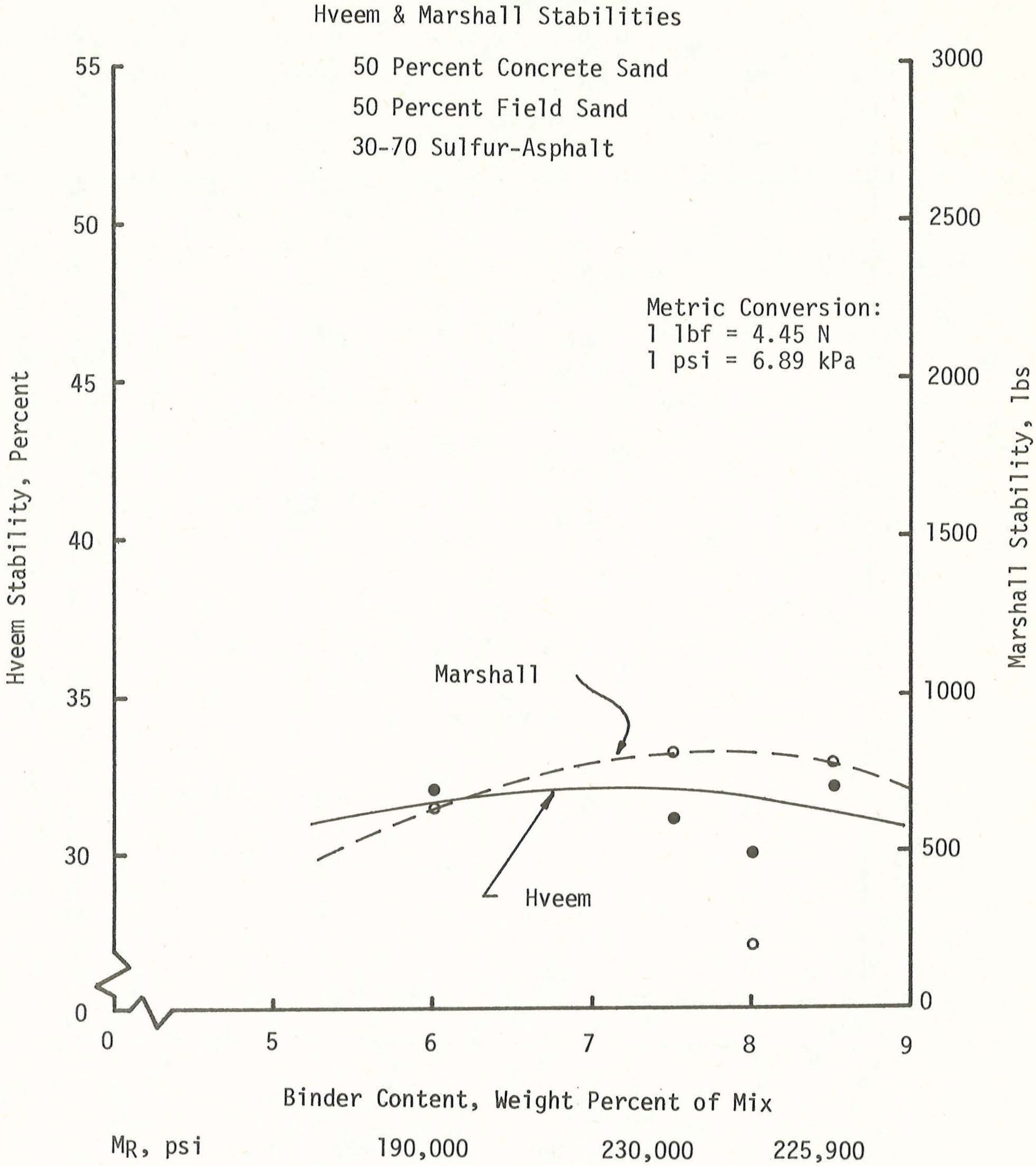
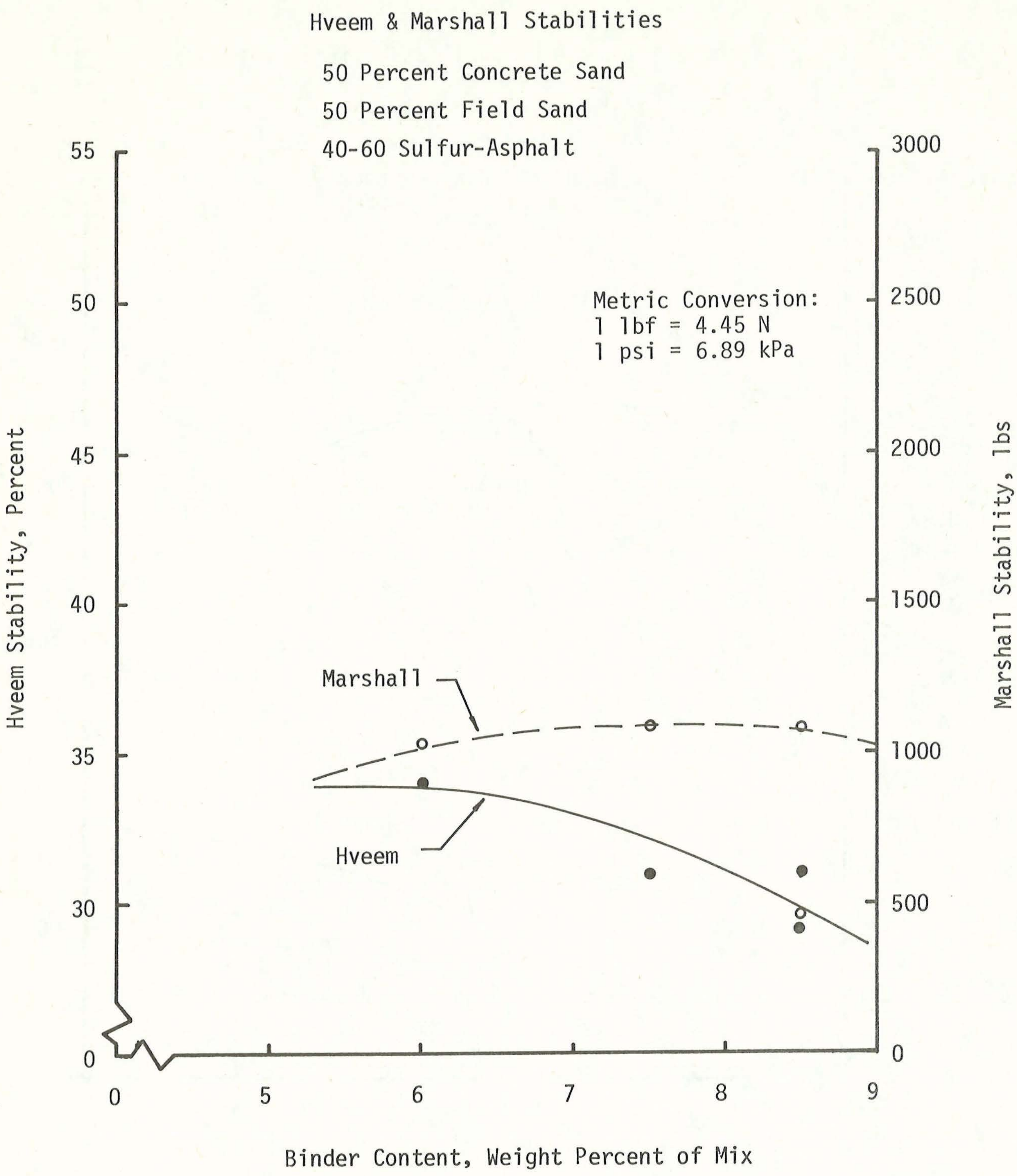


Figure 8A Hveem & Marshall Stabilities, 50 Percent Concrete Sand, 50 Percent Field Sand, 30-70 Sulfur-Asphalt



M_R, psi 330,000 525,000 315,000

Figure 9A Hveem & Marshall Stabilities, 50 Percent Concrete Sand, 50 Percent Field Sand, 40-60 Sulfur-Asphalt

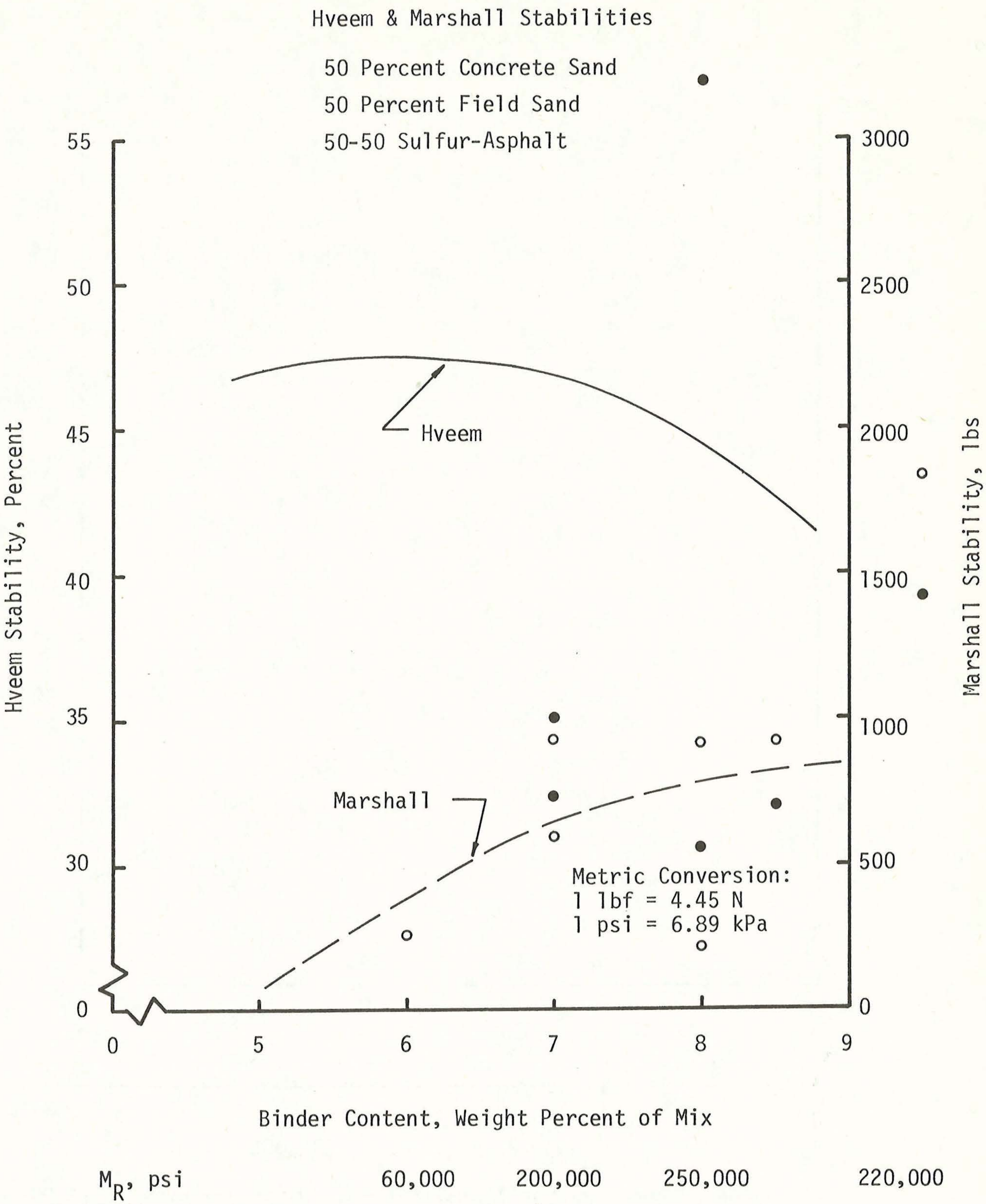


Figure 10A Hveem & Marshall Stabilities, 50 Percent Concrete Sand, 50 Percent Field Sand, 50-50 Sulfur-Asphalt

Air Voids Vs Binder Content

75 Percent Bank Run Gravel

25 Percent Field Sand

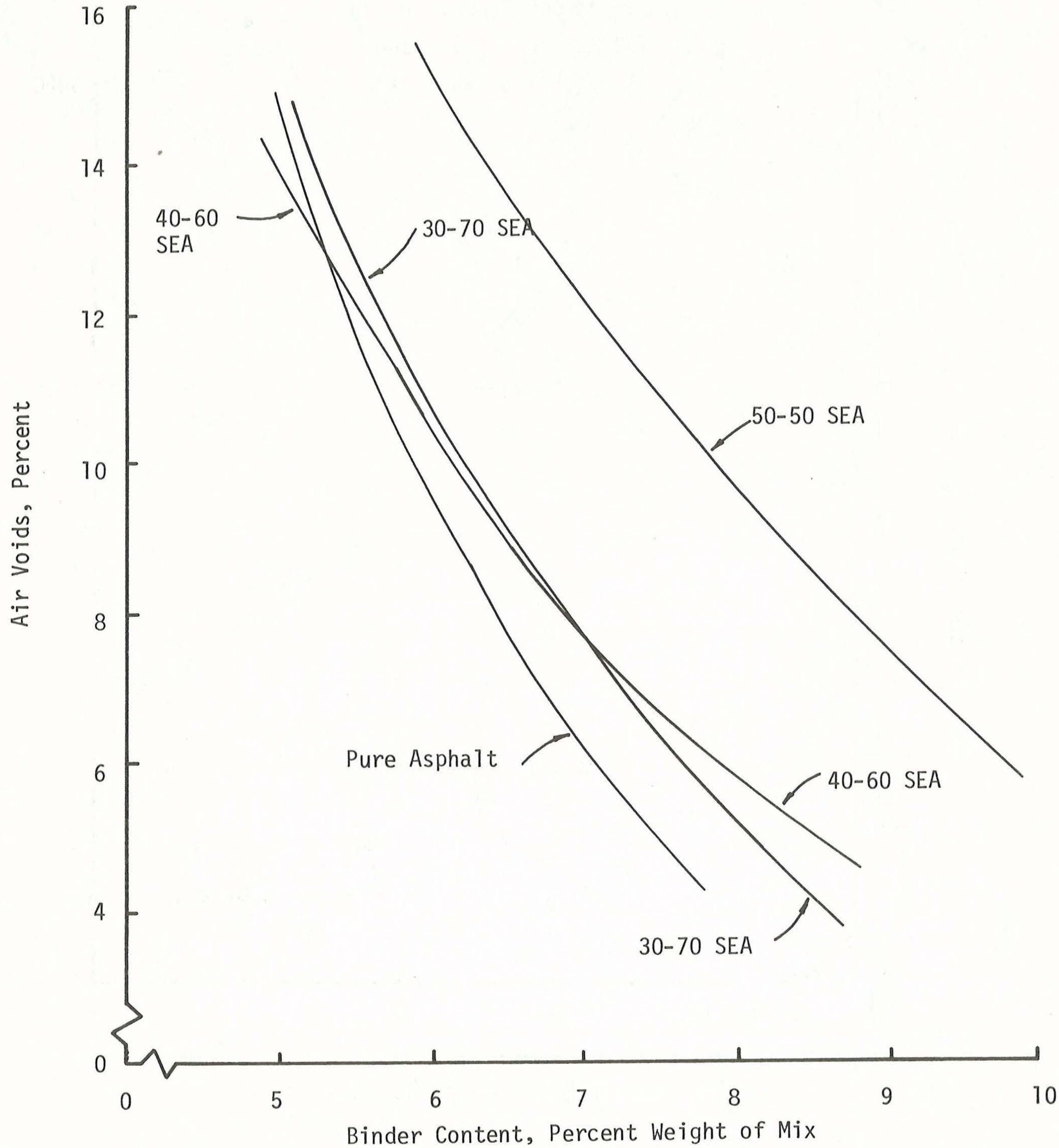


Figure 11A Air Voids Vs Binder Content, 75 Percent Bank Run Gravel, 25 Percent Field Sand

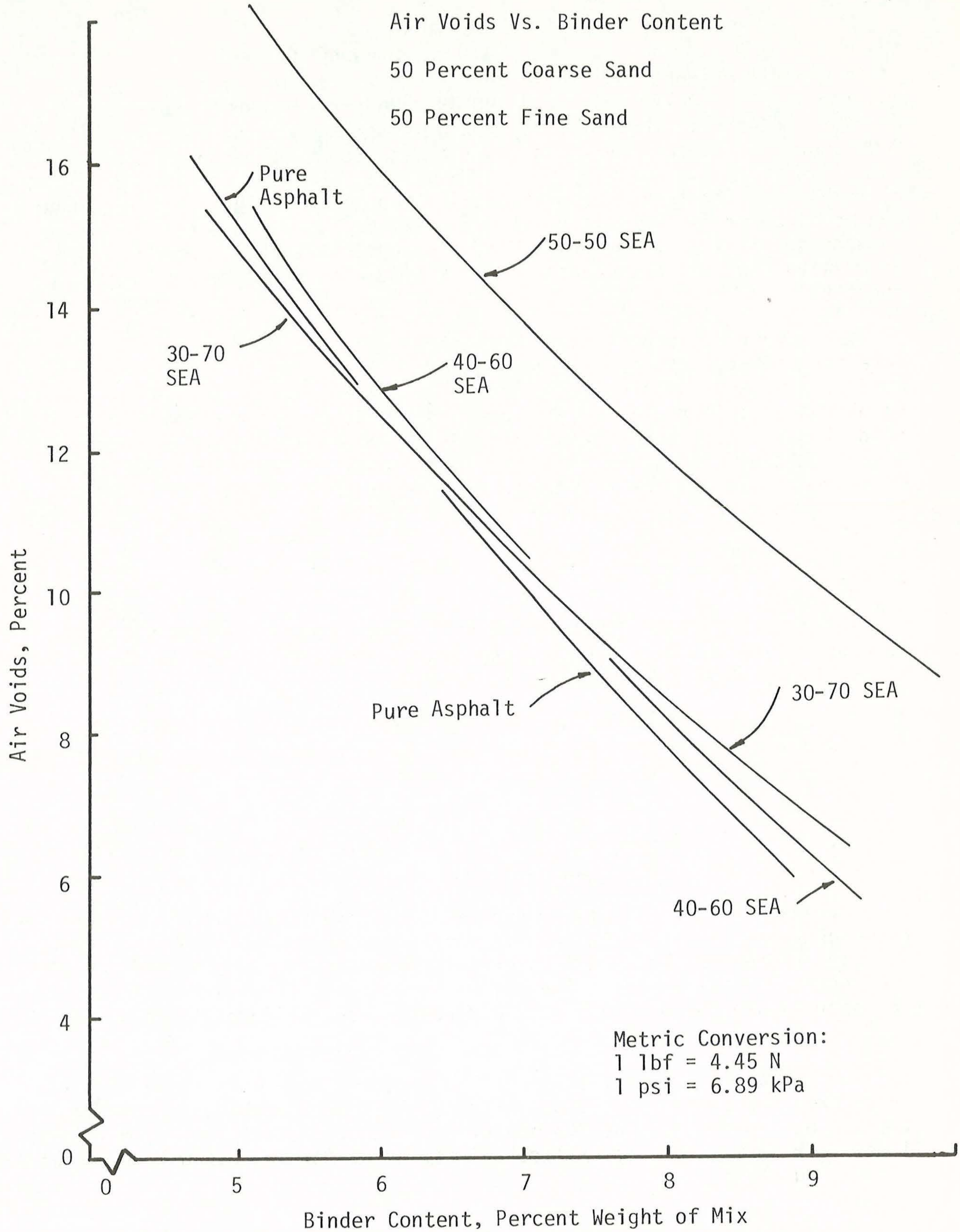


Figure 12A Air Voids Vs. Binder Content, 50 Percent Coarse Sand, 50 Percent Fine Sand

It is clearly evident that these variations are typical for pure asphalt and for both the 30-70 and the 40-60 SEA binders; however, there is a decided increase in the voids for mixtures containing the 50-50 SEA binder. Some suggested reasons for this shift of the voids curve seems appropriate.

Laboratory tests indicate that about twenty weight percent of sulphur may be dispersed in asphalt to form what might be called a fairly stable "pseudo solution." When more sulphur is added to asphalt, separation will occur with the rate of separation increasing with increases in sulphur quantity.

Laboratory mixtures of paving materials which contain SEA binders with more than about forty-five percent sulphur are difficult to compact as evidenced by the shift in the voids curve. Apparently, some of the sulphur acts as fine "aggregate" creating about one percentage point of voids for each two percentage points of sulphur that takes on an aggregate role. In the case under discussion approximately five percentage points of sulphur in acting as fine aggregate give a void increase of about 2.5 percentage points; hence, the shift in the 50-50 SEA voids curves of Figures 11A and 12 A.

Summary

Although any one of several currently used methods of laboratory mixture design may be successfully used to optimize the binder content of SEA mixtures, the Marshall Method is recommended.

The optimum asphalt content of any given paving mixture may be used as the beginning point for optimizing the binder content of the same aggregate similarly graded wherein SEA binder is used.

The optimum SEA binder content will be that weight percent which gives a volume of binder approximately equal to volume of pure asphalt for which the SEA binder has been substituted.

For example, if the optimum asphalt of a given aggregate is five percent by weight of mixture and the equivalent volume percent of this pure asphalt is, say, fifteen percent, this aggregate system would require fifteen volume percent of SEA binder. The weight percent of SEA binder would be in the approximate range of 5.5 to 6.0 depending on the composition of the SEA binder.

The mechanical properties of paving mixtures made with SEA binder will, in general, be superior to those which utilize pure asphalt; however, as the sulphur content of the SEA binder increases, test values are more difficult to repeat. This is particularly true for Marshall stability of binders rich in sulphur.

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Appendix B

The Resilient Modulus Test

Although resilient modulus (M_R) values were obtained for the SEA mixtures in the laboratory design phase of this study, the use of this design and monitoring tool is not mandatory; however, it is a useful tool that assists in the design stage prior to construction and it may also be used to measure water susceptibility and to monitor changes in the stiffness of the paving material during service.

A concise description of the resilient modulus test procedure was recently published in Highway Chemicals News Letter and this version of the test follows.

The term Resilient Modulus is the value obtained by determining the time related stress/strain resiliency or stiffness of asphalt aggregate compacted mixtures which could gain majority acceptance.

Theory

An elastic modulus or Young's modulus of an elastic material is defined as:

$$\text{Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

where the duration of loading does not change the value obtained. In a viscoelastic material the same relationship is used. However, the conditions of the test must be defined because short loading periods can give much higher modulus values than long loading periods. This is because more time allows more flow to occur. Moduli that are time-dependent are referred to as Resilient Moduli or as Stiffness Moduli. Frequently, moduli determined at very long loading times are referred to as Creep Moduli.

Operating Principle

The Mark III Resilient Modulus (M_R) instrument functions by applying a 0.1-second load pulse once every three seconds across the vertical diameter of a cylindrical specimen and sensing the resultant deformation across the horizontal diameter either 0.05 or 0.10 second after the beginning of the specimen deformation. The specimen can have a diameter from 3½ inches to 4-inches and a thickness from 1 to 3 inches. Optimum specimen diameter is 4 inches and optimum thickness is 2 3/4 inches. Loads used vary from 10 lb. to 75 lb. Specimen deformations range from 1 to 2000 microinches.

Diametral loading (application of a load across the vertical diameter of the cylinder) results in a deformation across the horizontal diameter. The vertical load, p, and the horizontal deformation (Δ) are related to the Resilient Modulus (M_R), Poissons ration (v), and specimen thickness (t) as follows:

$$M_R = \frac{p(v+0.2734)}{t\Delta}$$

If p is in pounds and t and Δ are in inches in the above equation, the units of M_R will be psi. If p is kg and t and Δ are in cm, then M_R will be in kg/cm^2.

Thus, by measuring the thickness of the specimen and deformation resulting from a known pulsating load, the Resilient Modulus, or M_R can be calculated. A Poissons ratio of 0.35 has been shown to be a reasonable value to use in this calculation for sound asphalt-treated materials. Higher or lower values may be used for other materials.

Uses of the Resilient Modulus

The instrument permits rapid nondestructive measurement of the resilient modulus of asphalt-treated mixes. This value is directly used in:

1. Design of pavement structures.
2. Design of asphalt mixes.
3. Construction control.
4. Indicating the effect of water or environment on asphalt-treated mixes.
5. Age hardening of asphalt-treated mixes.

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