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# SULPHUR/ASPHALT MIXTURE DESIGN AND CONSTRUCTION DETAILS - LUFKIN FIELD TRIALS

Interim Report 512-1

Study No. 1-10-75-512

For

Texas State Department of Highways
and Public Transportation
Transportation Planning Division
P. O. Box 5051
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TEXAS TRANSPORTATION INSTITUTE

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16. Abstract

The introduction of elemental sulphur as a binder in paving mixtures has been under study for several years in Canada and Europe. The use of elemental sulphur in flexible pavements of the United States is a recent affair sponsored initially by the Sulphur Institute and the U.S. Bureau of Mines.

This report deals with pavement mixture designs and construction operations of field trials on U.S. 69 north of Lufkin, Texas. The binders used in this field trial consisted of pure asphalt cement for the control sections and 30/70 weight percent of sulphur/asphalt emulsion as the test binder. All elements of the structural (thickness) design were produced in pairs for comparison purposes with the exception of two thinner sections selected to possibly show distress in two to three years. Otherwise, the thickness designs used in the test sections were those specified by the State Department of Highways and Public Transportation in the conventional section of this highway.

Preconstruction laboratory evaluations of mixture properties and field laboratory control measurements are included as a part of this report. Construction operations are detailed by photographs and verbal descriptions.

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# Sulphur/Asphalt Mixture Design and Construction Details
# Lufkin Field Trials

by

Bob M. Gallaway and Donald Saylak

Research Report 512-1

Research Project 1-10-75-512

Sponsored by

State Department of Highways and Public Transportation

In Cooperation with the

U. S. Department of Transportation

Federal Highway Administration

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TEXAS TRANSPORTATION INSTITUTE

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College Station, Texas 77843

FRANK D. GALLAWAY

# DEDICATION

This report is dedicated to Frank D. Gallaway, District Engineer, State Department of Highways and Public Transportation, District 11 Lufkin, Texas in recognition of his many years of outstanding service in the field of highway engineering and public service.

Frank D. Gallaway was born in Laneville, Texas October 5, 1917. He graduated from Texas A&M University in 1941 with a B.S. degree in Civil Engineering. Frank had a total of 29 years of service with the State Department of Highways and Public Transportation, having begun his professional career in Houston County as Residency Field Engineer in 1946. He was promoted to Assistant Resident Engineer in Angelina County in 1948 and through the ranks to Supervising Engineer in Polk County in the period 1949 to 1971. In recognition of his talents as an administrator he was promoted to District Administrative Engineer at the District Office in Lufkin in 1971. In 1973 Frank was appointed District Engineer of District 11 in Lufkin where he served until his death on December 10, 1975.

Not only was Frank Gallaway a fine Civil Engineer, loved and respected by his peers in his chosen professional area, but he was also a dedicated worker in the community. He is remembered as one who placed service to his fellow man before self, having served variously over the years as Sunday school teacher, Sunday school superintendent, and deacon of the Baptist Church, President of Rotary, President of the Chamber of Commerce, Chairman of March of Dimes, a leader of Troop 97 Boy Scouts of America and President of Band Boosters among other civic activities.

Mr. Gallaway's civic and professional efforts endeared him to all with whom he worked as he practiced the Professional Engineer's Creed which states in part:

> "----To place service before profit, the honor and standing of the profession before personal advantage, and the public welfare above all other considerations."

## PREFACE

The information contained herein was developed on Texas A&M Research Foundation Project 3146, a project which was cosponsored by the Sulphur Institute of Washington, D.C. and Societe Nationale des Petroles d'Aquitaine (SNPA), a French petroleum company with home offices in Paris, France.

This report was prepared as a part of a subcontract between the Texas Transportation Institute and the State Department of Highways and Public Transportation, and it constitutes a descriptive accounting of the sulphur/asphalt mixture design and the construction details of the Lufkin field trials carried out on a 3,650-foot section of U.S. 69 north of Lufkin, Texas. Specifically the report is intended to satisfy Item 1d as found in W. O. Hamm's Technical Memorandum dated July 30, 1975.

## DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

## ACKNOWLEDGMENTS

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The sponsors, The Sulphur Institute and SNPA, are due special thanks. Among those who were most helpful are Russell Coleman, Harold Fike, J. O. Izatt, Pierre Vincent and Claude Garrigues.

Contributions were also made by Thomas A. Sullivan and William McBee of the U. S. Bureau of Mines and the authors appreciate their assistance.

# ABSTRACT

The introduction of elemental sulphur as a binder in paving mixtures has been under study for several years in Canada and Europe. Laboratory work has been extensive and numerous field trials have been completed and these are serving satisfactorily. The use of elemental sulphur in flexible pavements of the United State is a recent affair sponsored initially by the Sulphur Institute and the U.S. Bureau of Mines. The first U.S. effort has dealt with the Thermopave® concept developed by Shell Canada Limited, which concept involves the use of sulphur as a structuring agent in poorly graded sands that have been processed in a conventional hot mix plant including coating the sand with asphalt cement.

This report deals with pavement mixture designs and construction operation of field trials on U.S. 69 north of Lufkin, Texas. The binders used in this field trial consisted of pure asphalt cement for the control sections and 30/70 weight percent of a sulphur/asphalt emulsion as the test binder. All elements of the structural (thickness) design were produced in pairs for comparison purposes with the exception of two thinner sections selected to possibly show distress in two or three years. Otherwise, the thickness designs used in the test sections were those specified by the State Department of Highways and Public Transportation in the conventional section of this highway.

Preconstruction laboratory evaluations of mixture properties and field laboratory control measurements are included as a part of this report. Construction operations are detailed by photographs and verbal descriptions.

## 1.0 Introduction

The need for substitute binders in the paving field has been intensified in recent years as a result of the increased need for conservation of our petroleum resources, particularly asphalt cement, which is currently being used for paving purposes at an annual rate exceeding 20 million tons.

The conservation of petroleum resources in the highway paving area must include the associated operations of the industry among which may be listed aggregate production and transportation activities related to paving operations.

A suitable substitute binder must be effective and economically available in large quantities to meet the demands of the paving industry. Based on current industrial trends, sociological demands and reasonably firm data gathered by the sulphur industry, elemental sulphur will, in the very near future, meet the duel requirements of economic availibility ( 1 ). General proof of the useful effectiveness of sulphur as as partial substitute for asphalt cement has been extensively published ( 2 ) ( 3 ) ( 4 ) ( 5 ) ( 6 ). Until recently, the laboratory and field data related to the use of elemental sulphur as a part of the binder in mixtures of asphalt and aggregate have been restricted to countries other than the United States.

Leaders in the use of sulphur in the paving field include Shell Limited and Gulf Oil Limited of Canada and Societe Nationale de Petroles d'Aquitaine (SNPA) of France. Through efforts initiated by the Sulphur Institute and cosponsored by the U.S. Bureau of Mines, the Texas Transportation Institute has, during the past two years, done considerable laboratory verification work confirming the findings of these foreign researchers (4) (6).

During September of 1975, through the cooperative efforts of District Personnel of District 11 of the State Department of Highways and Public Transportation, the Austin Office of the SDHPT, FHWA, SNPA, the Bureau of Mines, Texas Gulf and Moore Brothers Construction Company, a 3,650-foot, 2-lane test section on U.S. 69 in Angelina County was successfully completed. This was the culmination of planning which began in March of 1975.

The binder system used in the various subsections of the field trial was either pure asphalt cement or a 30/70 weight percent blend of sulphur and asphalt cement which blend was produced on site at the hot mix plant in special equipment furnished and operated by SNPA.

Because the construction of the field trials came about on rather short notice and because the original research planned between the sponsors and TTI did not include field trials, rather radical changes had to be made in all categories of the research. As a result of these changes and due to limitations of time, extensive data were not collected in the laboratory on the materials used in the field sections. The reader is therefore being made aware of this and is cautioned against attempting to extrapolate data.

## 2.0 Materials

### 2.1 Binders

The early sulphur/asphalt binders were prepared using an Exxon AC-10 asphalt from Baytown, Texas. Texaco AC-20 from the Port Neches refinery was then selected to duplicate that which would be available for the Lufkin test sections.

The elemental sulphur used was a commercial grade (99.8% purity) which was used throughout the investigation. The sulphur was furnished by Texas Gulf Sulphur from their Freeport, Texas plant.

Physical properties of a number of sulphur-asphalt blends prepared at 140°C (284°F) are shown in Table 1. As expected the specific gravity increased with sulphur content; whereas, the softening point and penetration remained relatively constant for the blends tested. The dual values for the specific gravity of pure sulphur are representative of those reported in the literature for the monoclinic (1.96) and rhombic states (2.07), respectively ( 1 ).

The viscosity-temperature characteristic for the same sulphur-asphalt blends are given in Table 2. At 25°C (77°F) the absolute viscosity of all the blends increases with sulphur content. The change in viscosity (with temperature) of the four sulphur/asphalt blends is an initial large decrease when the temperature is increased from 25°C (77°F) to 60°C (140°F). Another sizeable reduction occurs when the temperature is increased from 60°C (140°F) to 120°C (248°F). The viscosity changes occurring with temperature increases up to 150°C (302°F) are rather insignificant but quite similar to the viscosity changes for pure asphalt cement in the same temperature range.

Table 1. PHYSICAL PROPERTIES[a] OF SULPHUR ASPHALT BINDERS

| | Composition, % By Weight | | | | | |
|---|---|---|---|---|---|---|
| Blend of | | | | | | |
| Asphalt[b] | 100 | 75 | 70 | 60 | 50 | |
| Elemental Sulphur | | 25 | 30 | 40 | 50 | 100 |
| Specific Gravity, 16°C (60°F) | 1.0172 | 1.16 | 1.19 | 1.27 | 1.35 | (1.96-2.07) |
| Softening Point, °C (°F) | 46 (115) | 51 (124) | 48 (118) | 53 (128) | 50 (123) | |
| Penetration, | | | | | | |
| 25°C (77°F) 100g, 5s | 83 | 81 | 76 | 76 | 80 | |
| 4°C (39.2°F) | 17 | 20 | | 12 | 15 | |
| Actinic Light (poise) | $5.5 \times 10^6$ | | | | | |
| Hardening Index | 5.3 | | | | | |

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[a] Tests run in accordance with AASHTO M 226-73 (7)

[b] Texaco AC-20, Port Neches, Texas

## Table 2. VISCOSITIES OF SULPHUR ASPHALT BINDERS
(Poise)

| Blend Percent (By Weight) | | Temperature | | | | |
|---|---|---|---|---|---|---|
| Asphalt | Sulphur | °C 25<br>(°F) (77) | 60<br>(140) | 120<br>(248) | 135<br>(275) | 150<br>(302) |
| 100 | | 960,000 | 1280 | 4.98 | 2.64 | 1.73 |
| 75 | 25 | 1,300,000 | 1200± | 3.01 | 1.39 | 0.84 |
| 70 | 30 | 1,840,000 | 962 | 2.92 | 1.55 | 0.80 |
| 60 | 40 | 3,100,000 | 1330 | 3.40 | 1.50 | 1.21 |
| 50 | 50 | 16,800,000 | 1690 | 4.30 | 1.90 | 1.02 |
| | 100 | -------- | -- | 0.11 | 0.08 | 0.07 |

## 2.2. Aggregates

In the original test matrix two aggregate types were to be evaluated; a crushed limestone (calcareous) and a rounded river gravel (siliceous). The size distribution in these aggregates was consistent with that for an Asphalt Institute Type IV b paving mixture (8) as given in Table 3 below.

Table 3: Gradation Specifications of Crushed Limestone and River Gravel

| Sieve Size, mm (in. or No.) | Weight Percent Passing |
|---|---|
| 20, (3/4) | 100 |
| 13, (1/2) | 80-100 |
| 10, (3/8) | 70-90 |
| 4.75 (No. 4) | 50-70 |
| 2.36 (No. 8) | 35-50 |
| 0.6 (No. 30) | 18-29 |
| 0.3 (No. 50) | 13-23 |
| 0.15 (No. 100) | 8-16 |
| 0.075 (No. 200) | 4-10 |

Early revamping of the testing program resulted in the gravel being eliminated entirely from the program and replaced by a beach sand, concrete sand and a 50/50 blend of these two sands. The size distributions for these sand systems are given in Table 4 .

Table 4 : Average Gradations of Sands Used in the Laboratory Studies

| Sieve Size, mm(No.) | Percent Passing<br>Beach Sand | Concrete Sand | 50/50 Blend |
|---|---|---|---|
| 4.75 (No. 4) | 100 | 100 | 100 |
| 2.36 (No. 8) | 100 | 87 | 94 |
| 1.18 (No. 16) | 100 | 76 | 88 |
| 0.6 (No. 30) | 99 | 62 | 80 |
| 0.3 (No. 50) | 98 | 14 | 56 |
| 0.15 (No. 100) | 4 | 1 | 2 |
| 0.075 (No. 200) | 1 | 0 | 0.5 |
| Voids in Mineral Aggregates (VMA) | 37.6 | 33.1 | 35.0 |
| Specific | 2.65 | 2.66 | 2.65 |
| Unit Weight kg/m$^3$ | 1669 | 1798 | 1733 |
| lb/ft.$^3$ | 103 | 111 | 107 |

Upon the initiation of the Lufkin field demonstration, new aggregates were introduced into the testing sequence. These included a local sand, originating from the Seal Pit, a source near the demonstration site and a 60/40 mix (by weight) of an imported Gifford-Hill river gravel and the Seal Pit sand. The size distributions of these aggregates are reflected in Figure 1 which also shows that the 60/40 mix results in an aggregate with a size distribution falling within the envelope designated by a Texas Highway Department Type "D" gradation.

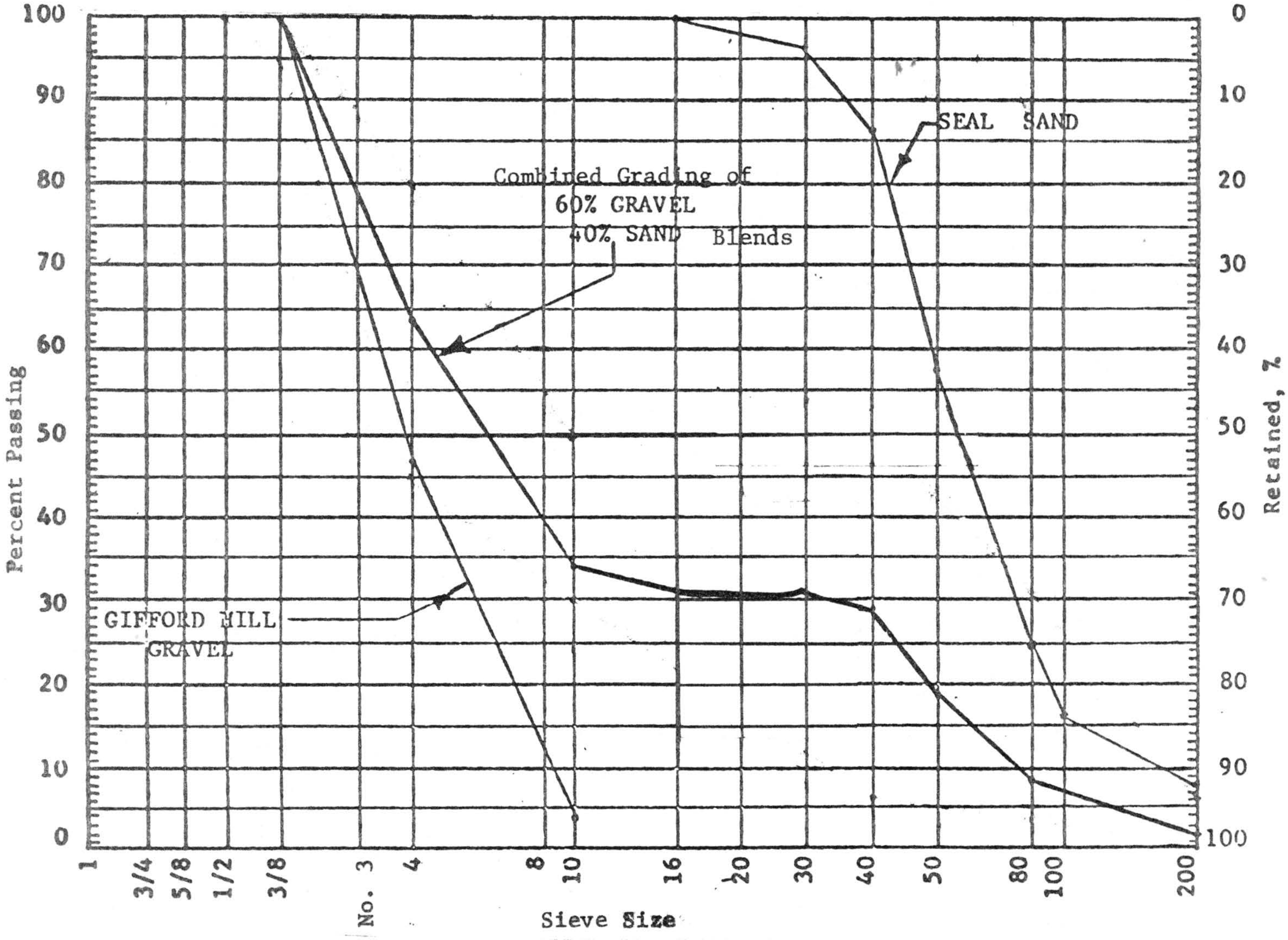

Figure 1: AGGREGATE GRADATIONS FOR LUFKIN FIELD TRIALS

Specific Gravity of:

Gifford-Hill Gravel

Retained on No. 4 sieve: 2.556
Passing on No. 4 sieve: 2.564

Combined: 2.560

Seal Sand

Retained on No. 80 sieve: 2.533
Passing on No. 80 sieve: 2.582

Combined: 2.560

## 2.3 Laboratory Evaluations

Mix and material properties tests of a variety of sulphur-asphalt mixtures were performed in accordance with the above mentioned test matrices, as revised. Except for one series of tests which was performed on samples prepared with a 20/80 sulphur-asphalt binder all mixes were prepared using 30/70 sulphur-asphalt binders. Binder contents ranged from 4 to 8 weight percent. For comparison purposes a series of tests was run on samples prepared with pure asphalt binder. Specific tests which were performed include:

| | |
|---|---|
| 1. Marshall Stability and Flow | |
| Standard | ASTM D-1559 ( 9) |
| Immersion | ASTM D-1075-54( 9) |
| Vacuum Saturated | As by Schmidt (10) |
| 2. Hveem Stability | ASTM D-1560-71( 9) |
| 3. Dynamic Modulus | As by Schmidt |
| 4. Compression | |
| Standard | ASTM D-1074-74 (10) |
| Immersion | ASTM D-1075-54 ( 9) |
| Splitting Tensile Test | ASTM C-496-71 (11) |
| 5. Percent Air Voids | Asphalt Institute Method (12) |
| 6. Unit Weight | Texas Highway Dept. Test Method Tex 207-F (Revised 1 Jan., 1972) (13) |

The criteria used for evaluating the results of the tests listed above are those recommended by the Asphalt Institute (12) in conventional asphalt concrete mixes under heavy, moderate and light traffic loads. These suggested values are listed below:

| Design Method [a] | Traffic Loading<br>Heavy | <br>Moderate | <br>Light |
|---|---|---|---|
| 1. Marshall Stability, kg (min) | 340 | 227 | 227 |
| lb (min) | 750 | 500 | 500 |
| 2. Marshall Flow, 1/100 inch | 8-16 | 8-18 | 8-20 |
| 3. Hveem Stability, percent | 37 | 35 | 30 |
| 4. Air Voids, percent | 3-5 | 3-5 | 3-5 |

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[a] See also, Asphalt Institute, Manual Series No. L (MS-1), Thickness Design, Asphalt Pavement Structure for Highway and Streets, for details of traffic classification.

### 2.3.1 Test Descriptions

#### 2.3.1.1 Marshall Stability and Flow

The Marshall test (ASTM 1559-73) (9) is used by the asphalt paving industry to establish proper proportions and performance characteristics of asphalt-aggregate mixtures. The results are used for laboratory design and field control of binder-aggregate mixtures. Marshall stability and flow numbers are used as qualitative measures of a pavement's ability to withstand traffic loads and permanent deformation, respectively.

In conjunction with the standard Marshall tests, the effect of water on Marshall stability was also determined using test samples which had been moisturized by simple immersion (ASTM D 1075) and vacuum saturation ( 9). The former was achieved by soaking samples at 60°C (140°F) 24 hours whereas in the latter, water was forced into the sample under vacuum.

#### 2.3.1.2 Hveem Stability

In Texas, the Hveem method (ASTM D-1560-65), (9) with some modifications, is used instead of the Marshall test. This test uses a Hveem stabilometer which subjects the specimen to a triaxial stress in which vertical loads are applied and resulting lateral pressures read at several loading increments. The Hveem stability is calculated by an established formula and represents the resistance to lateral deformation due to a 5000-pound vertical load. The same specimen used in the Hveem method was also used in the Marshall test since the Hveem stability test is considered non-destructive.

### 2.3.1.3 Dynamic Modulus

Under short-duration, dynamic loads on a viscoelastic material yield an apparent Young's modulus, or stiffness, E, which is frequently defined as the dynamic or resilient modulus, $M_R$. This parameter is used in conjunction with layered-elastic or finite element design methods for determining pavement thickness and fatigue life. The test procedures and equipment used in this series of tests were similar to those developed by Schmidt (10).

A light pulsating load of 0.1 second-duration was applied every 3 seconds through a load cell across the vertical axis of a 102 mm (4 in.) diameter by 63.6 mm (2 1/2 in.) thick specimen. This load produced an elastic deformation across the specimen's horizontal diameter. This deflection was monitored by a pair of compensating, highly sensitive Schaevits transducers 0.126 mm (0.005 in.) full-scale deflection. Air pulses were supplied to a Bellafram pneumatic cylinder from a MAC, electrically-activated solenoid valve. Pulse width was controlled by a Sizer timer and load magnitude by a Kendall Model 10 pressure regulator.

The Specimen was mounted in a yoke using a hold assemble, (as shown in Figure 2) by a pair of clamping screws. A locking nut was provided in the yoke to position and adjust the contact pressure of Schaevitz transducers after which the sample is removed from the holder and placed in the tester.

A typical loading pattern is shown in Figure 3 which indicates the dynamic load, P, and the total deformation, Δ. The resilient modulus for a sample of thickness, t, was computed form the following relation (10):

$$M_R = \frac{P(\nu + 0.2734)}{t\Delta} \times 6.89 \times 10_3$$

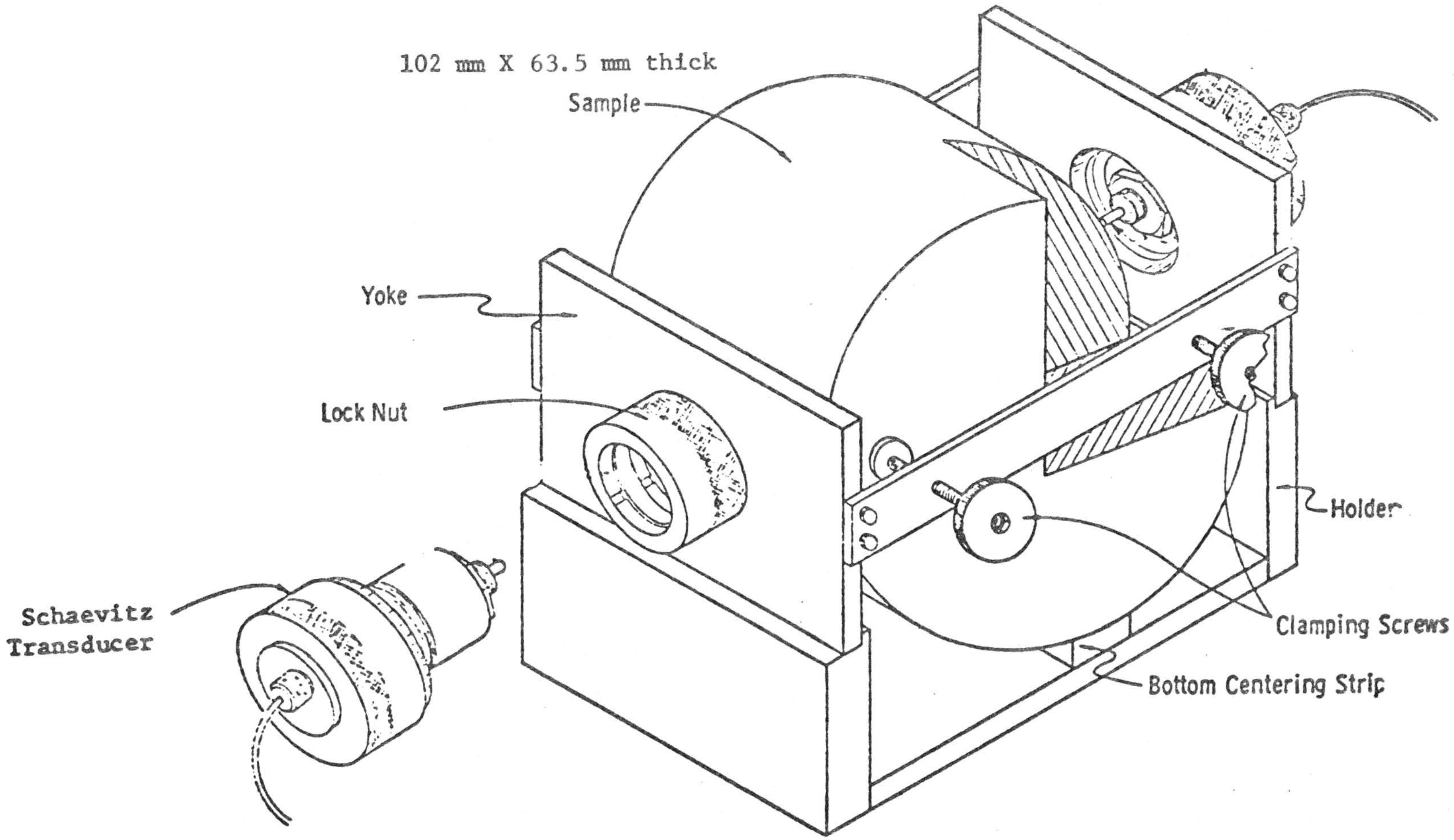


FIGURE 2. Diametral resilient modulus device yoke and holder assembly.

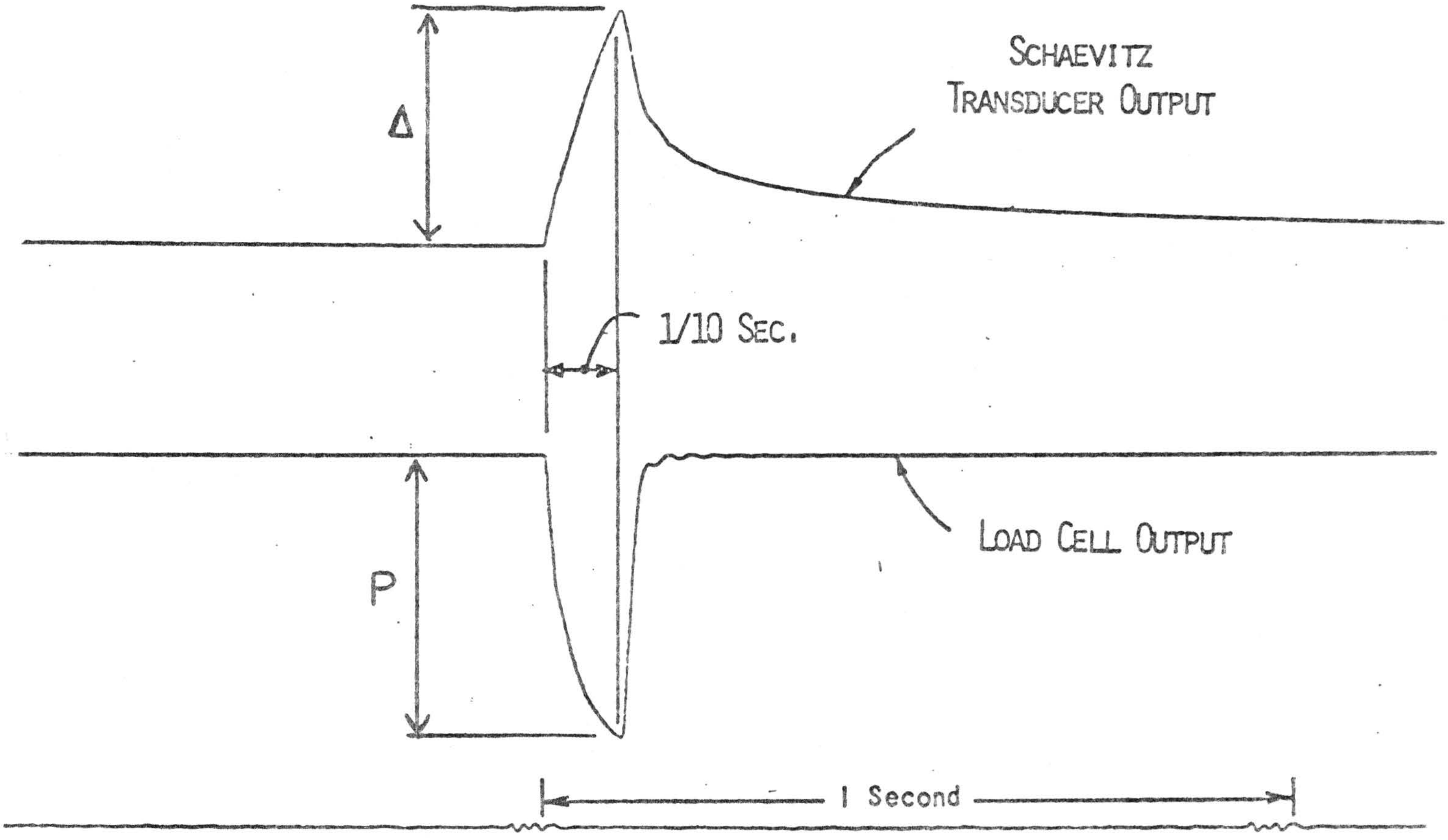


FIGURE 3. Typical trace diametral measurement of resilient modulus.

Poisson's ration, $\nu$, can be assumed over a wide range of values without introducing excessive error into the computed $M_R$.

Resilient moduli were measured at temperatures of 20°C (68°F) on all mixture designs. In addition, $M_R$ values of dry specimens were compared with those for samples which had been vacuum saturated (14). The $M_R$ values for S/A mixtures were compared with those for asphaltic concrete used as a control and measured under similar test conditions.

#### 2.3.1.4 Compression Tests

These tests (ASTM D 1074 and 1075) were conducted to provide a measure of the compressive strength of paving mixtures under dry and water saturated conditions, respectively. The test samples consisted of cylinders 102 mm ( 4 in.) in diameter by 102 mm (4 in.) long which were axially compressed at a deformation rate of 1.3 mm/min ( 0.05 in/min.). No lateral support to the sample was provided. The maximum measured vertical load divided by the original cross-sectional area was recorded as the compressive strength. In the immersion tests, samples were soaked in water at 60°C (140°F) for 24 hours before the compression tests were performed.

#### 2.3.1.5 Indirect (Splitting Tensile Test)

Available evidence seems to dictate that the tensile and cohesive characteristics of the subbase has a significant effect on the performance of the pavement. One of the suggested uses of S-A-S materials is as a subbase layer with an A/C surface layer. The splitting tensile test (or indirect tensile test as it is more commonly referred to in the flexible pavement field) has generally been used on concrete and mortar specimens. More recently the test has been modified for use on asphalt-treated materials

(15). This test was incorporated into the program to compare the tensile properties of S-A-S with a conventional A/C system. The tests were run at a temperature of 20°C (68°F) at a deformation rate 5.0 cm/min. (2.0 in/min.) to compare the two systems on the basis of their viscoelastic behavior.

The test involves loading a cylindrical specimen in a diametrical fashion. This condition results in a fairly uniform tensile stress perpendicular to and along the diametrical plane containing the applied load. At the center of the specimen, the ratio of tensile stress, $\sigma_T$, and compressive stress, $\sigma_Y$, is three-to-one. Failure will, therefore, usually occur by splitting along this plane.

### 2.3.1.6 Air Void Content and Unit Weight

The air void content in the compacted specimens was determined by methods prescribed by the Asphalt Institute ( 8 ) which is essentially a gravimetric technique. The unit weight was obtained by first measuring the bulk specific gravity of the specimen and then multiplying by the density of water.

## 2.4 Discussion of Results

### 2.4.1 Marshall Stability, Flow and Air Voids

The Marshall test results generated in the original laboratory effort are shown in Table 5 and Figures 4 through 6. Test results obtained in support of the Lufkin field trials are given in Table 6. Mixtures prepared with crushed stone reflect comparatively high stabilities relative to Asphalt Institute criteria (12). Up to 4 weight percent binder, S/A and pure asphalt stabilities are relatively equal. However, as indicated by Figure 4 , beyond 4 percent binder content stability increases with sulphur/asphalt ratio, shifting the optimum binder content to the right (i.e. higher values). Over the range of binder contents studied the stabilities of the S/A and pure asphalt mixtures present curves of similar shape with S/A being shifted to the right and positioned hihger on the stability scale.

As expected, sand mixtures generated lower stabilities than those prepared with crushed stone with the lowest values occurring in the poorly graded beach sand mixtures. Of the three sands studied in this series of tests the concrete sand gave the highest Marshall stability followed by the 50/50 blend (by weight) and the beach sand.

Water susceptability was more pronounced in the vacuum saturated samples than in the immersed samples with the least effect being exhibited by 30/70 mixes prepared with the limestone. As binder content increased, the reduction in stability became less pronounced indicating that, as in the case of conventional mixes, the primary resistance to moisture is directly related to the amount of asphalt present.

Table 5 and Figure 5 show that Marshall flow tends to decrease with sulphur content in the binder. Mixtures prepared with the three sands had flow values equal to or lower than those prepared with crushed stone. Based on the results with 50/50 blended sand mixtures, the flow was affected to a lesser extent in the sand mixes.

Table 5 and Figure 6 indicate the effect of sulphur content in the binder on air voids. As was the case of water susceptibility, air void content for a fixed compactive effort, is directly related to the amount of asphalt present in the mix. Because of their inherent higher VMA, the void content of the sand mixtures were consistently greater than those in the stone mixes. This might adversely affect consideration of sulphur/asphalt hot sand mixes for use in surface or wearing courses; however, it is a well known fact that hot mixed sand/asphalt mixtures perform well with final void contents in the range of 14 to 18 percent. These voids are usually considered disconnected and therefore have little or no effect on water penetration. On the other hand, as will be shown later, their inherent strength and stability make them well suited for base courses and working platforms over weak subgrades where moisture is present.

Table 6 shows similar data taken on mixtures prepared with aggregates used in the Lufkin field trials. Comparisons of Marshall properties are made between mixtures prepared with 30/70 and pure asphalt binders. Consistent with the above discussions, Marshall stability tends to increase with sulphur content, at least up to 30 weight percent, in the binder. The Lufkin Type D river gravel mixes gave higher values than the sand mixes and both water susceptability and air void contents were directly related to the amount of asphalt present in the binder. Air void contents were higher in the sand mixes because of their greater VMA and inherent resistance to densification.

Table 5. Marshall Data Based on Pre-Lufkin Test Matrix

| Type of Binder | Type of Aggregate | Binder Content % | * Marshall (lb.) | | | ** Flow (0.01 in.) | | | Air Voids % |
|---|---|---|---|---|---|---|---|---|---|
| | | | Standard | Immersion | Vacuum Standard | Standard | Immersion | Vacuum Saturated | |
| Asphalt 0/100 | Limestone | * 4 1/2 | 4720 | 4660 | 4465 | 13 | | | 7.5 |
| | | 5 | 4383 | 4190 | 4080 | 13 | 13 | 12 | 6 |
| | | 6 | 3372 | 3210 | 3060 | 19 | 20 | 23 | 3 |
| | | 7 | 2140 | 2040 | 1900 | 31 | 35 | 35 | 1 |
| | | 8 | 1150 | | | 39 | | | 0.5 |
| Sulphur/ Asphalt 30/70 | Limestone | 4 | 4850 | | | 10 | 18 | 19 | 16 |
| | | 5 | 6182 | 4394 | 2285 | 10 | 20 | 30 | 13.5 |
| | | *6 | 6750 | 4942 | 3466 | 10 | 21 | 26 | 11 |
| | | 7 | 5060 | 4188 | 3410 | 12 | 23 | 25 | 9 |
| | | 8 | 2010 | | | 22 | | | 7 |
| | 50/50 Sand Blend | 4 | 1170 | | | 16 | | | 16 |
| | | 4 1/2 | 1230 | 1250 | | 9 | | | 15 |
| | | 5 | 950 | 1230 | 850 | 11 | 11 | 12 | 14 |
| | | 5 1/2 | 1010 | 1100 | 830 | 8 | 11 | 13 | 12 |
| | | 6 | 925 | 1325 | 780 | 10 | 14 | 17 | 11 |
| | | 6 1/2 | 810 | 920 | | 9 | | | 9 |
| | Concrete Sand | 5 | 1900 | 1870 | | 13 | | | 20 |
| | | 5 1/2 | 2480 | 1980 | | 14 | | | 19 |
| | | 6 | 1920 | 1950 | | 14 | | | 17 |
| | Beach Sand | 5 | 880 | 790 | | 14 | | | 26 |
| | | 5 1/2 | 660 | 530 | | 13 | | | 25 |
| | | 6 | 410 | 620 | | 13 | | | 23 |
| Sulphur/ Asphalt 20/80 | Limestone | 5 | | | | | | | 10 |
| | | 6 | 4760 | 4580 | | 14 | 21 | | 8 |
| | | 7 | 3380 | | | 23 | | | 6 |

* 1 LB. = 4.48 N

** 0.01 in. = 0.25 mm

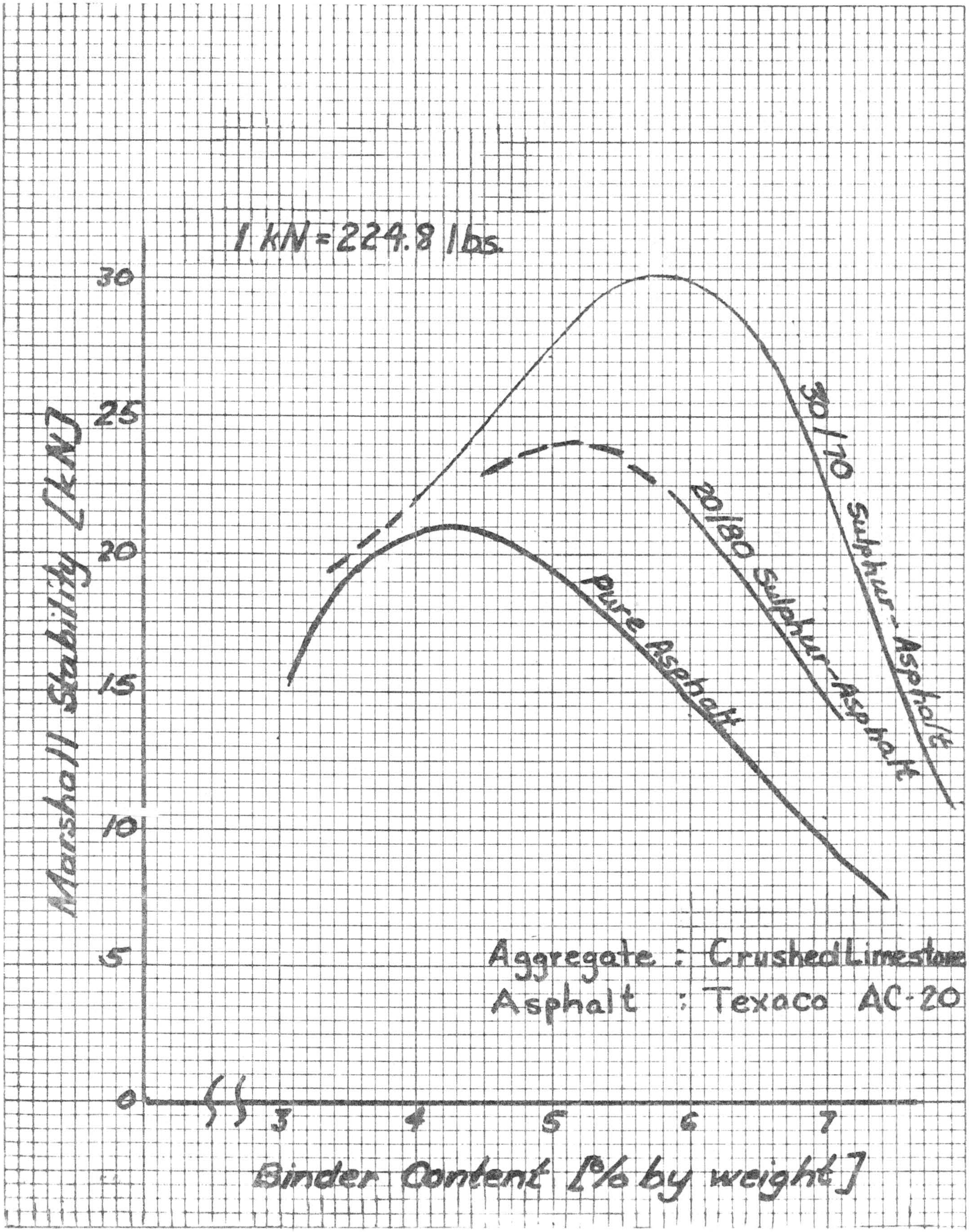


Figure 4. Marshall Stability versus binder content showing effect of sulphur/asphalt ratio.

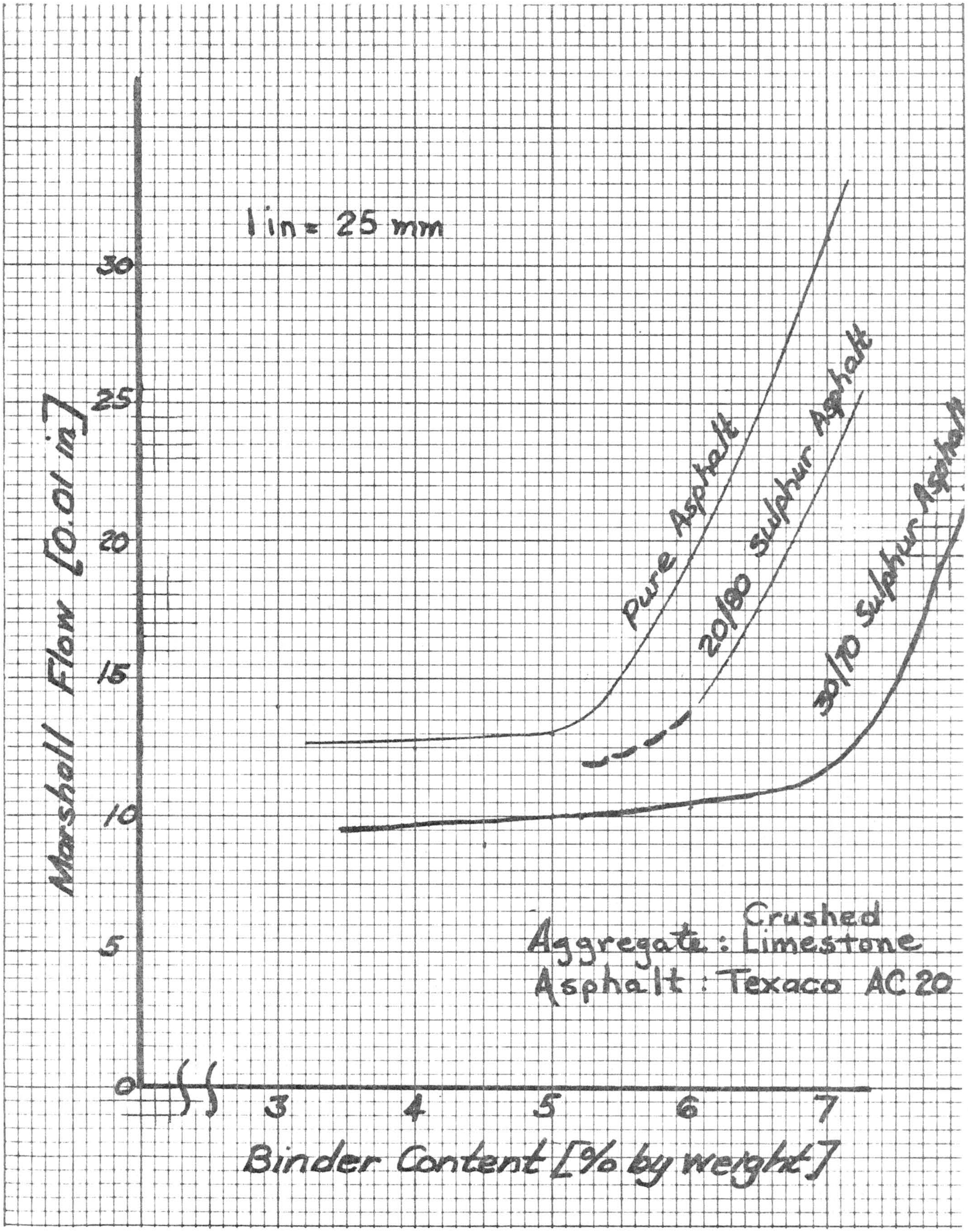


Figure 5 . Marshall flow versus binder content showing effect of sulphur/asphalt ratio.

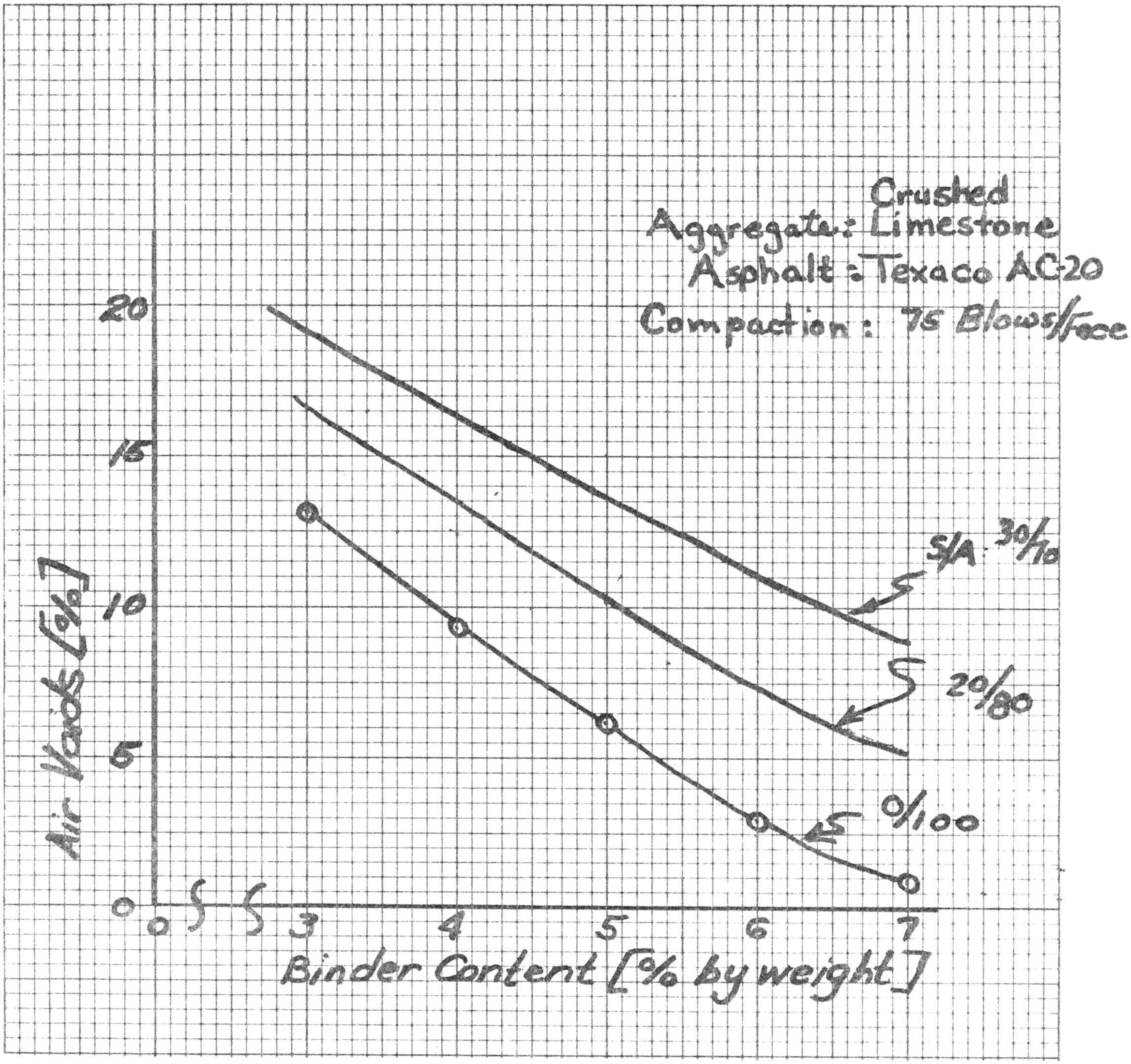


Figure 6. Effect of Sulphur/Asphalt ratio on air voids at various binder contents.

Table 6. Marshall data from tests run in support of Lufkin field trials.

| Type of Binder | Type of Aggregate | Binder Content % | Marshall* | | | Flow (0.01 in.)** | | | Air Voids % |
|---|---|---|---|---|---|---|---|---|---|
| | | | Standard | Immersion | Vacuum Saturated | Standard | Immersion | Vacuum Saturation | |
| Sulphur/ Asphalt 30/70 | Lufkin Sand | 5 | 1280 | | | 12 | | | 17 |
| | | 5 1/2 | 2080 | | | 12 | | | 16 |
| | | 6 | 2670 | | | 10 | | | 13 |
| | | 7 | 1650 | 1790 | | 10 | 18 | 23 | 12 |
| | | 8 | 1790 | 1140 | 970 | 9 | 15 | 19 | 10 |
| | Lufkin Type D | 5 | 2250 | | | 10 | | | 8 |
| | | 5.4 | 2600 | 1870 | 1530 | 12 | 8 | 12 | 6 |
| | | 6 | 2250 | 1320 | 990 | 11 | 14 | 14 | 4 |
| | | 7 | 2270 | 2270 | | 6 | | | 2 |
| | | 8 | 1750 | 1140 | | 13 | | | 1 |
| Asphalt 0/100 | Lufkin Type D | 3 | 920 | | | 14 | | | 13 |
| | | 4.5 | 1680 | 1830 | 1470 | 9 | 17 | 15 | 8 |
| | | 5 | 1740 | | | 10 | | | 6 |
| | Lufkin Sand | 5.4 | 1460 | | | 7 | | | 14 |
| | | 5.5 | 1540 | | | 13 | | | 16 |

* 1 lb. = 4.40 N

** 0.01 in. = 0.25 mm

Table 7. Hveem Stability test results.

| Sulphur/Asphalt Ratio | Aggregate | Binder Content (weight percent) | Hveem Stability (percent) | |
|---|---|---|---|---|
| | | | Laboratory | Field Data |
| 0/100 | Limestone | 4 | 57 | |
| | | 5 | 46 | |
| | | 6 | 26 | |
| 20/80 | Limestone | 6 | 40 | |
| 30/70 | Limestone | 5 | 44 | |
| | | 6 | 37 | |
| | | 7 | 30 | |
| | Lufkin Sand | 5 | 30 | |
| | | 5.3 | | 34 |
| | | 5 1/2 | 33 | |
| | | 6 | 31 | 34 |
| | | 6.2 | | 32 |
| | | 7 | 29 | 29 |
| | | 7.5 | | 30 |
| | | 8 | 31 | |
| | Lufkin Type D | 4.8 | | 40 |
| | | 5 | 44 | |
| | | 5.3 | | 39 |
| | | 5 1/2 | 43 | |
| | | 5.65 | | 44 |
| | | 6 | 37 | 37 |
| | | 6.2 | | 36 |
| | | 6.5 | | 38 |
| | | 7 | 37 | |
| | | 8 | 37 | |

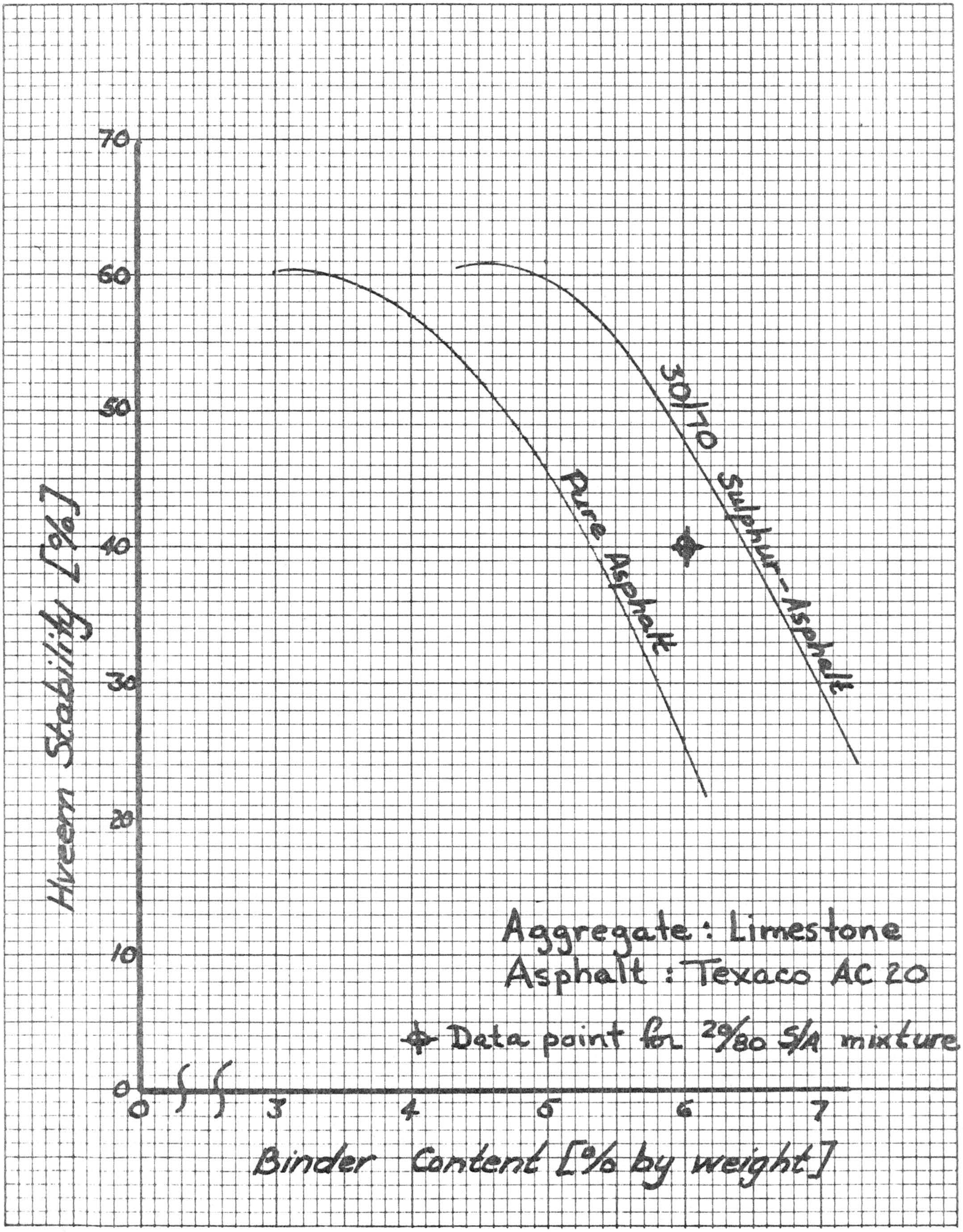


Figure 7. Comparison of Hveem Stability of mixtures prepared with pure asphalt and 30/70 S/A binder.

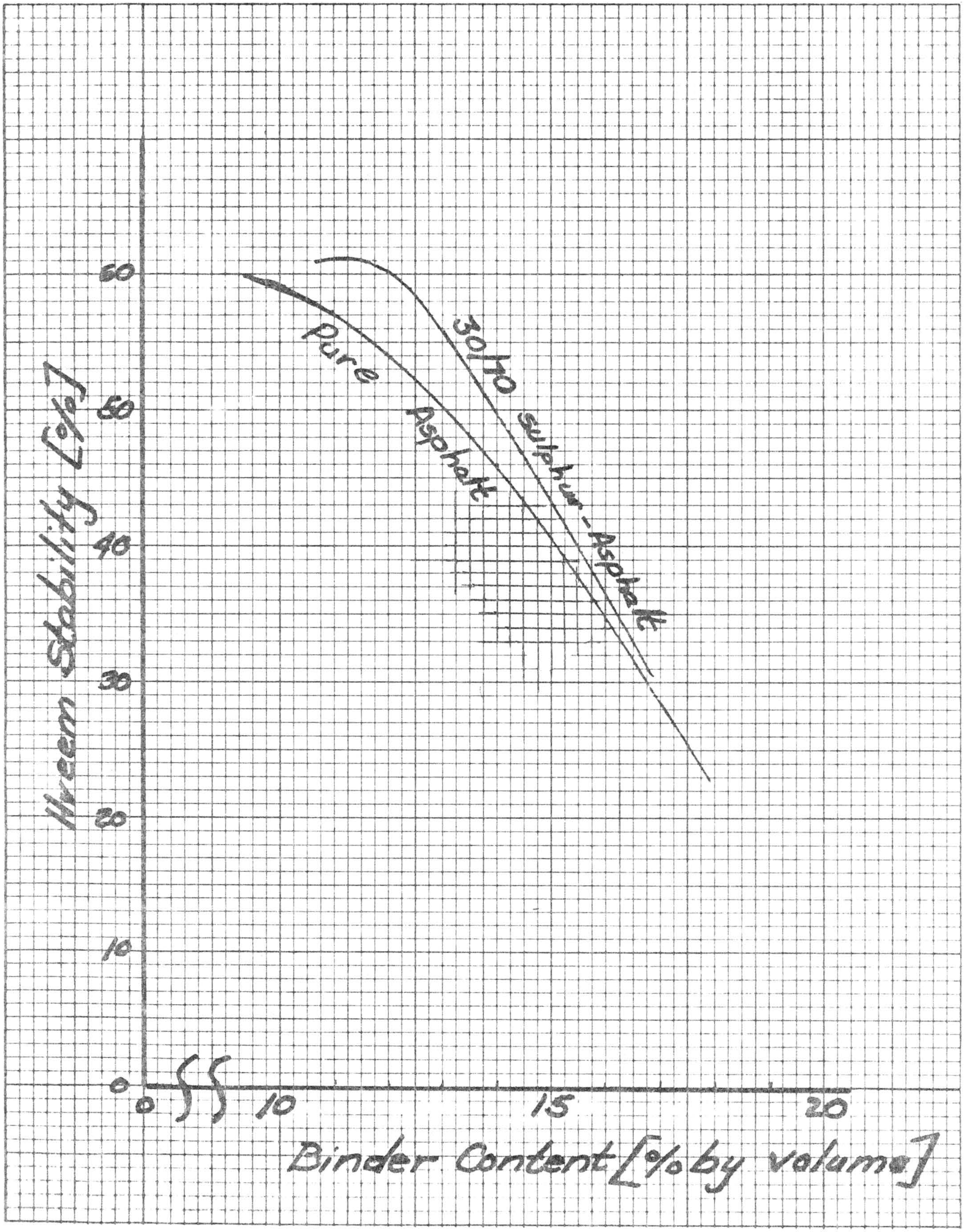


Figure 8. Comparison of Hveem Stability of mixtures prepared with pure asphalt and 30/70 Sulphur/Asphalt on an equal binder volume basis.

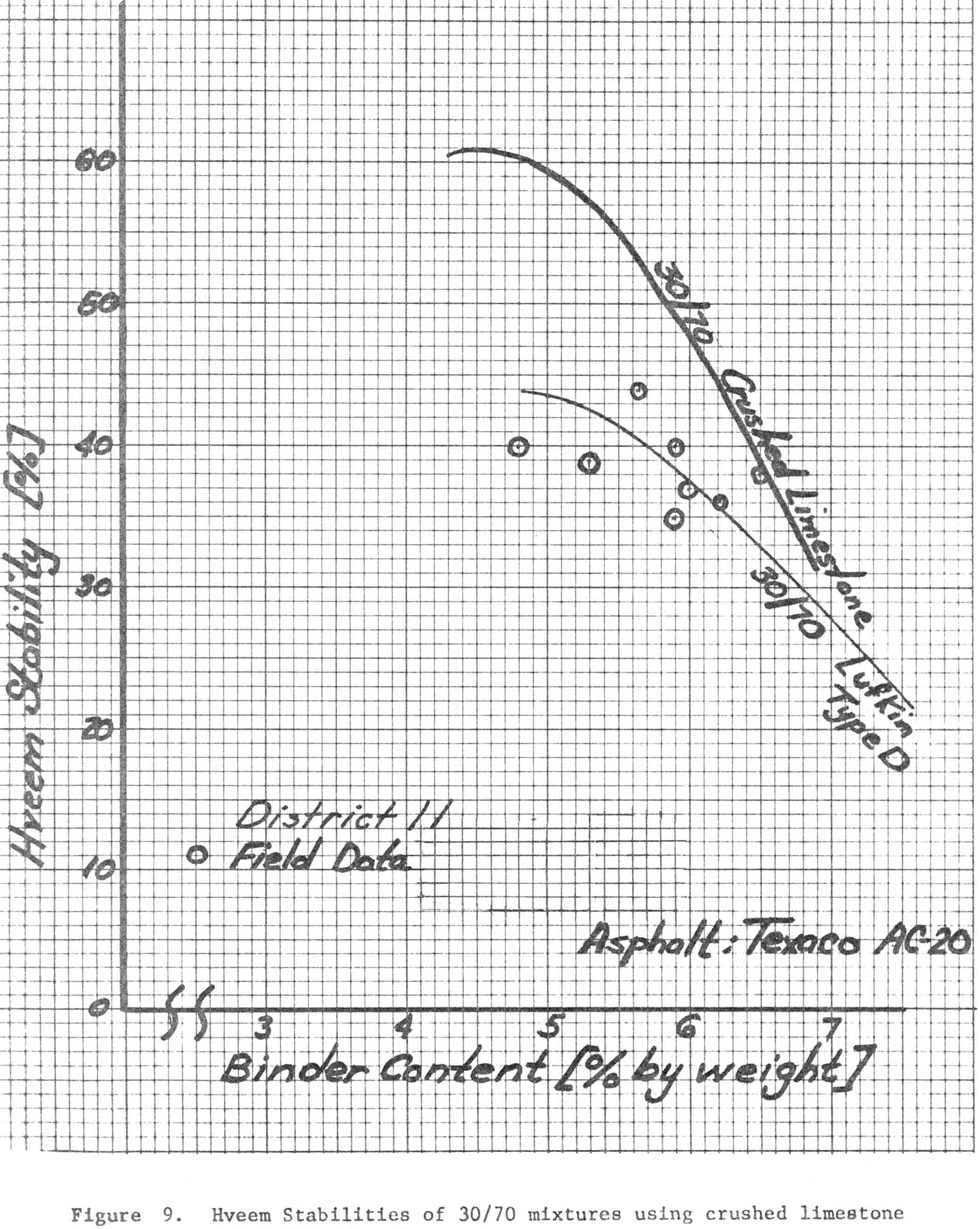


Figure 9. Hveem Stabilities of 30/70 mixtures using crushed limestone and Lufkin Type D aggregates.

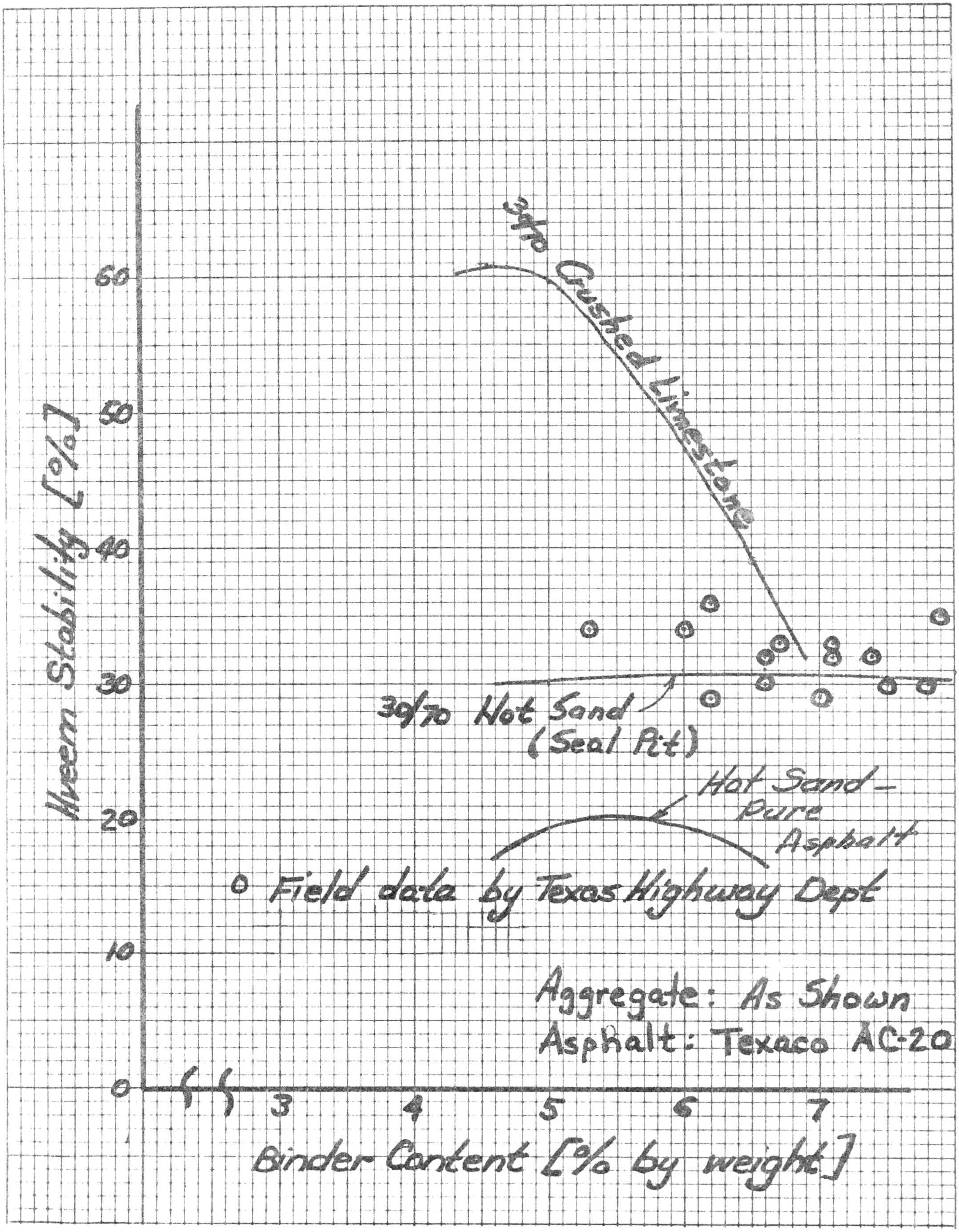


Figure 10. Comparison of laboratory and field data for Hot Sand base mixtures.

### 2.4.2 Hveem Stability

The state of Texas uses Hveem rather than Marshall stability tests to optimize mixture designs. Table 7 and Figures 7, 8, 9 and 10 show the results of Hveem tests run on crushed stone, Lufkin (Seal Pit) sand and Type D aggregates. Samples prepared from material collected at the pugmill during construction of the field sections are also provided for comparison.

Figures 7 and 8 show the effect of sulphur content on Hveem stability of mixtures prepared with crushed stone versus weight percent and volume percent of binder, respectively. On a weight basis, the presence of sulphur tends to increase the stability by 35 to 45 percent at the S/A optimum binder content. The optimum mixture is shifted to higher binder contents as more sulphur is incorporated into the emulsion as was also demonstrated in the Marshall tests. When the same data are plotted against volume percent binder, the improvement in stability is less pronounced.

Figure 9 shows a comparison of the Hveem stabilities of 30/70 sulphur/asphalt mixtures prepared with crushed limestone and Lufkin Type D aggregates. The optimum binder content for these mixtures is in the vicinity of 5 weight percent at which the crushed stone achieved a stability 40 percent higher than the river gravel mixes. Figure 10 also shows excellent agreement with field data taken during construction of the field sections.

Similar comparisons are shown in Figure 10 for 30/70 hot sand and crushed limestone mixtures. The stability of the hot sand mixes (in the normal range of binder contents) appears to be relatively unaffected by the amount of binder. At a binder content of 5 percent, which is the optimum for the crushed stone mixes, the Hveem stability is twice that of the hot sand mixtures. The stability values of the crushed limestone approach that of the hot sand mixtures at a binder content of 7 percent. Again, excellent aggreement with field data is shown. Stabilities of both Lufkin Type D and hot sand mixtures satisfy the criteria for heavy traffic loads as suggested by the Asphalt Institute (12). The SDHPT usually suggests 30 as the minimum Hveem stability for surface courses. Higher values are used for heavy urban traffic and lower values for black base. Hot sand mixtures with pure asphalt gave 30% lower values.

### 2.4.3 Dynamic (Resilient) Modulus

Dynamic (resilient) modulus values for a number of S/A mixtures prepared with the two aggregates used in the Lufkin field sections are compared with crushed limestone mixtures in Table 8. Moduli of the S/A limestone mixes show better than 100 percent increase over the range of sulphur/asphalt ratios studied (i.e. 0/100 - 30/70). The moduli of all mixtures were increased with the addition of sulphur in the binder system. This improvement in dynamic modulus should be considered in thickness design. Thickness reductions in the 25 per cent range seem reasonable for design systems which utilize the dynamic modulus as a primary input.

Table 8. Dynamic (Resilient) Modulus Values for Mixtures Designs of Various Sulphur/Asphalt Ratios.

| Aggregate System | Sulphur/Asphalt Ratio | Weight Percent Binder | Resilient Modulus kN/m$^2$ | (psi) |
|---|---|---|---|---|
| Crushed Limestone | 0/100 | 5 | 2,790,000 | 405,000 |
| | 0/100 | 6 | 2,653,000 | 385,000 |
| | 0/100 | 7 | 1,447,000 | 210,000 |
| Crushed Limestone | 20/80 | 6 | 3,169,000 | 460,000 |
| | 30/70 | 4.5 | 3,541,000 | 514,000 |
| | 30/70 | 6 | 6,201,000 | 900,000 |
| | 30/70 | 7 | 5,719,000 | 830,000 |
| Lufkin - Type D | 30/70 | 5.5 | 4,134,000 | 600,000 |
| Lufkin Sand | 30/70 | 8 | 723,000 | 105,000 |

### 2.4.4 Compressive Strengths

Table 9 shows the results of compression tests run on limestone, 50/50 sand blend, Lufkin Type D and sand mixtures at various S/A ratios. Compressive strengths of both wet and dry samples were evaluated. The compressive strengths of the limestone and sand blend mixtures were improved with increase in S/A ratio. Although no data were taken which permitted the comparison to be made, it is assumed that these trends are also exhibited in Lufkin aggregate mixes, as well.

Except for the 30/70 mixture with 5 weight percent binder, the limestone mixtures were unaffected by immersion in water. Similar compressive strength retention was not exhibited in the one Lufkin sand mix. The compressive strengths of the mix prepared with Lufkin Type D aggregate experienced a significant increase. The reason for this increase can not be explained at this time.

### 2.4.5 Indirect (Splitting) Tension Tests

Mixes prepared with the same aggregates studied in the compressive strengths tests (Section 2.4.4) were also evaluated under tensile loads. The tensile strengths of these mixes as determined by means of the Indirect (Splitting) Tensile Test (10) are given in Table 10. Tensile strengths were increased by the addition of sulphur to the binder and their magnitudes were indirect in relation to the quality of the aggregate. That is, the highest strengths were achieved in the crushed limestone mixes and the lowest with the poorly graded Lufkin dune sand.

Table 9. Compressive Strength Properties of Dry and Immersed Mixture Designs with Various Sulphur/Asphalt Contents.

| Aggregate System | Sulphur/Asphalt Ratio | Weight Percent Binder | Compressive Strength kN/m$^2$, (psi) | | % Retained Strength |
|---|---|---|---|---|---|
| | | | Dry | Immersed | |
| Limestone | 0/100 | 5 | 3307<br>(480) | 3376<br>(490) | 102 |
| | 0/100 | 6 | 3169<br>(460) | 3378<br>(483) | 105 |
| | 30/70 | 5 | 5340<br>(775) | 3514<br>(510) | 66 |
| | 30/70 | 6 | 5519<br>(801) | 5581<br>(810) | 101 |
| 50/50 Sand Blend | 30/70 | 5 * | 1860<br>(270) | 930<br>(135) | 50 |
| | 30/70 | 5 1/2 * | 4341<br>(630) | 2790<br>(405) | 65 |
| | 30/70 | 6 * | 2997<br>(435) | 1791<br>(260) | 60 |
| Lufkin - Type D | 30/70 | 5.5 * | 1447<br>(210) | 2480<br>(360) | 171 |
| Lufkin Sand | 30/70 | 8 * | 2274<br>(330) | 930<br>(135) | 41 |

*Mixtures Used Texaco AC-20. All Others Used Exxon AC-10.

TABLE 10. Indirect (Splitting) Tensile Test Results.
Deformation rate = 50 mm/min. (2 in./min.)
Temperature = 20°C (68°F)

| Sulphur/Asphalt | Type of Aggregate | Binder Content (weight %) | Indirect Tensile (Splitting) Strength $kN/m^2$ (psi) |
|---|---|---|---|
| 0/100 | Limestone | 5 | 710 (103) |
| | | 6 | 482 (70) |
| | | 7 | 413 (60) |
| 20/80 | Limestone | 6 | 586 (85) |
| 30/70 | | 5 | 586 (85) |
| | | 6 | 723 (105) |
| | | 7 | 661 (96) |
| 30/70 | 50/50 Sand Blend | 5 | 379 (55) |
| | | 5 1/2 | 503 (73) |
| | | 6 | 427 (62) |
| 30/70 | Lufkin Sand | 8 | 255 (37) |
| 30/70 | Lufkin Type D | 5 1/2 | 379 (55) |

## 3.0 LUFKIN SULPHUR-ASPHALT PAVEMENT FIELD TRIALS ON U.S. 69

### 3.1 Background

In an article by Noel F. Busch in the October 1975 issue of Reader's Digest, the author remarked that---"Serendipity is the satisfaction of finding, while looking for something good, something even better."---

Such was the situation on 17 April 1975 when a planning meeting was held at the district office of the State Department of Highways and Public Transportation at Lufkin, Texas. At this meeting, attended by representatives of the Sulphur Institute, the Bureau of Mines, the Federal Highway Administration, the SDHPT, Moore Bros. Contractors and Texas Transportation Institute, a decision was made to begin plans immediately for the construction of a field demonstration section on U.S. 69 north of Lufkin wherein sulphur would be used as part of the binder in the paving material.

This highly significant and successful meeting was the direct result of a question raised at a previous meeting in March of 1975 by Dr. Russell Coleman, President of the Sulphur Institute, to the effect that it would be very beneficial to all concerned if a field demonstration of the utility of the sulphur-asphalt binder could be effected during the 1975 construction season.

As a follow-up, the researchers of TTI contacted by Mr. F. D. Gallaway, the District Engineer of SDHPT in Lufkin and obtained his consent to discuss the possibility of a field demonstration with the contractor, Mr. Chester Moore of Moore Bros. Construction Co. of Lufkin. At that time Moore Bros. had an active contract with SDHPT involving the addition of two new lanes to U.S. 69 north of Lufkin to convert several miles of a two-lane facility to a four-lane highway. Traffic volume on this road averages about 6,000 vehicles per day, 15 percent of which are 18 KIP axle-load trucks.

Agreement was obtained from the contractor to consider the use of a sulphur/asphalt binder in a portion of this project and the aforementioned meeting of 17 April 1975 was scheduled and held as planned. The agenda included a review of the laboratory results generated by TTI which were obtained from a study of materials and mixture designs similar to those currently being used in the Lufkin area.

As a result of this meeting, it was agreed that TTI would submit, in cooperation with SDHPT, a plan for the field demonstration section. The Sulphur Institute and Societe Nationale Des Petroles D'Aquitaine (SNPA) agreed to defray any extra costs to the contractor resulting from the inclusion of the field demonstration section in the existing contract job. The Federal Highway Administration agreed to fund the post-construction evaluation of the demonstration section through an arrangement with SDHPT and TTI. This post-construction evaluation is scheduled to cover a two-year period of time with SDHPT doing most of the field data collection and TTI doing laboratory evaluations, data analysis and report preparation.

During the summer of 1975 researchers at TTI worked with specific materials being selected for the U.S. 69 job to more completely evaluate proposed sulphur/asphalt binder and to arrive at suitable mixture designs to be used in the several sub-sections of the demonstration section.

Out on the road where the field section was to be built, preparations were under way to minimize delays from the weather. The job was ideal for a demonstration project of this type. Normal construction provided for a 24 ft. surface with 10 ft. and 4 ft. paved shoulders. The pavement section and shoulders were constructed on 6 inches of "Hot Sand" (Hot-mix Sand Asphalt) base 3 inches of Item 340 Class A Type D hot mix asphalt concrete pavement, (ACP), (16) with a 1 inch Class A Type L HMAC (Lightweight Aggregate) high friction wearing course. The shoulder structure is 10 inches of hot-mix sand asphalt base on a lime treated subgrade. A typical standard section is shown in Figure 11.

Typical sections for the sulphur-asphalt test sections are shown in Figure 12. Figure 13a is a representation of an excavated (cut) section and Figure 13b is a representation of a fill section. Two inches of "Hot Sand" base was placed in the treated subgrade to act as a working platform.

In the meantime SNPA, working with TTI researchers, made the necessary adjustments in their equipment which was to be shipped from Paris, France to Lufkin, Texas for use on this job. SNPA had agreed to furnish the specialized equipment required to produce the sulphur-asphalt emulsion binder to be used on this job. Surprising as it may seem, all aspects of the total plan were fitting together and all efforts were flowing smoothly toward the goal of a completed demonstration section in 1975!

During July 1975 arrangements were made with Texas Gulf and Richardson Tank Lines for supplying and delivering hot liquid sulphur to the job. Preparations at the contractor's hot-mix plant in Lufkin included the construction of heat traced lines, valves and storage to handle the emulsion which would be manufactured on-site and pumped directly to the weigh bucket at the pug mill.

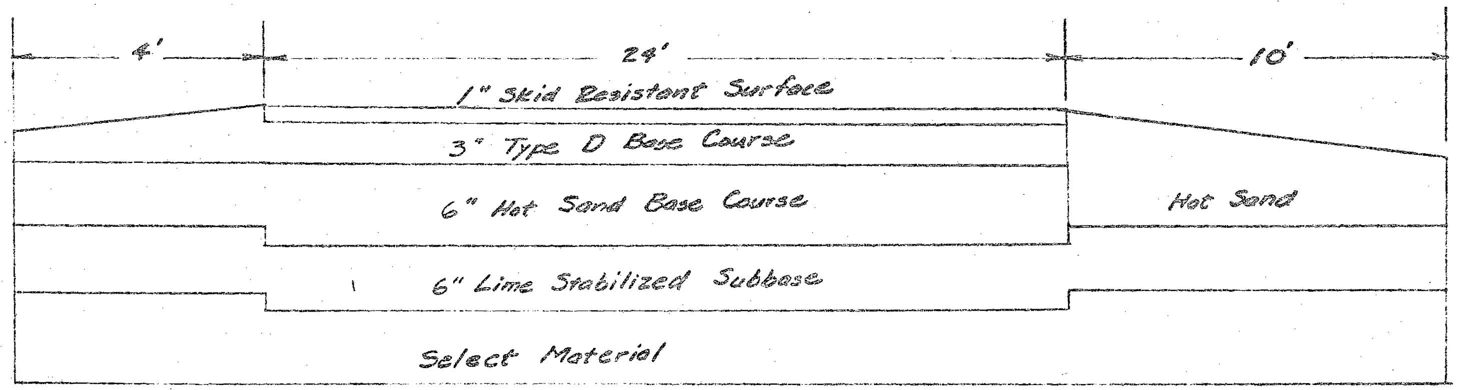
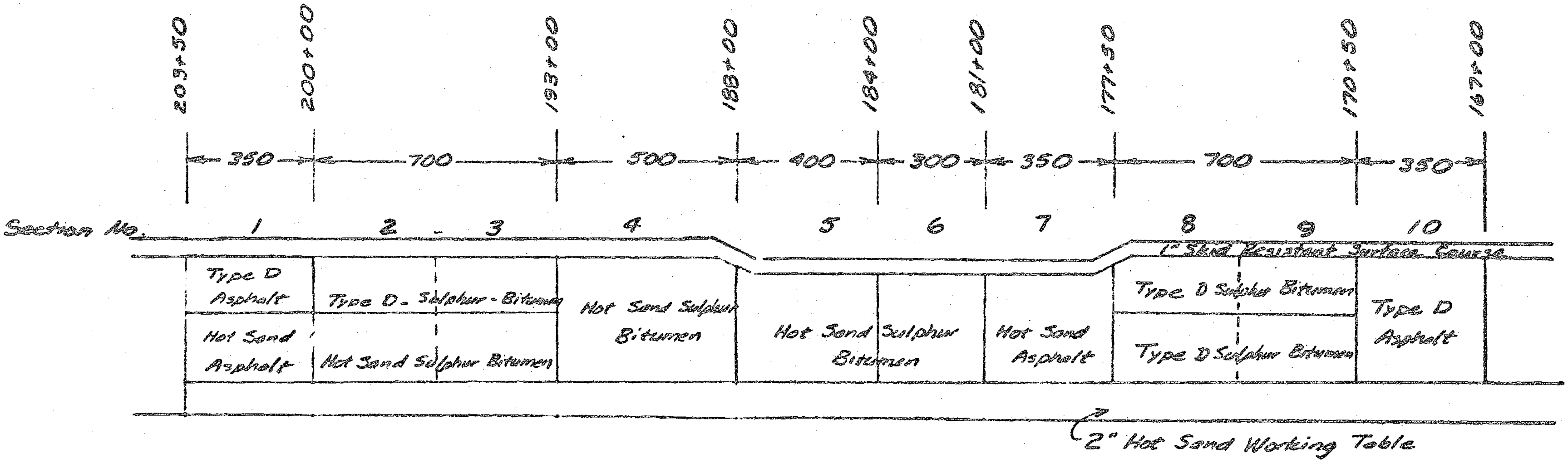


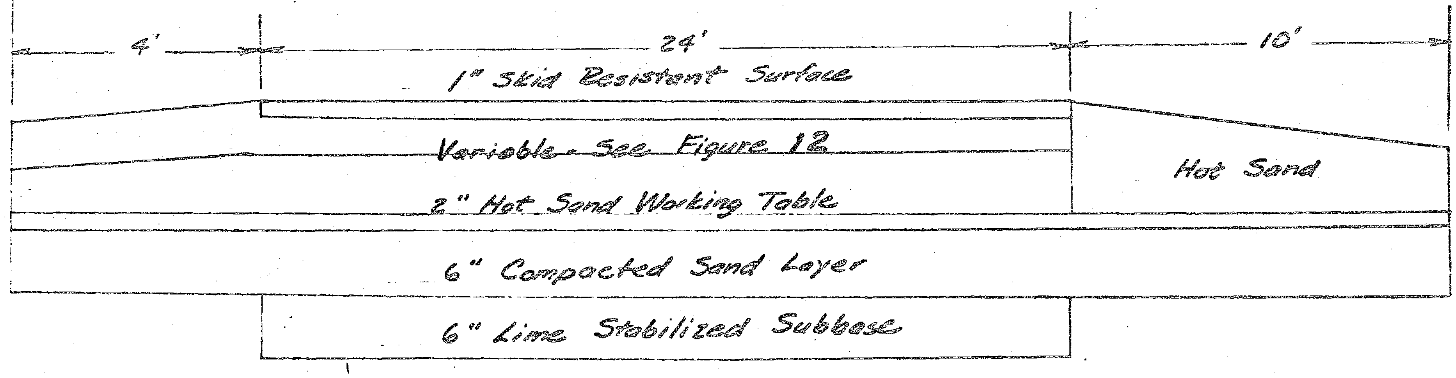
Fig. 11. Standard Fill Cross Section



| Section | Material | Layer Thickness, in. | Binder Content, percent |
|---|---|---|---|
| 1 | Type D Asphalt Base | 3 | 4.8 |
| | Hot Sand Asphalt Base | 4 | 5.4 |
| 2,3 | Type D Sulphur - Bitumen | 3 | 5.65 |
| | Hot Sand Sulphur-Bitumen | 4 | 6.0 |
| 4 | Hot Sand Sulphur-Bitumen | 7 | 7.1 |
| 5 | Hot Sand Sulphur - Bitumen | 5 | 6.35 |
| 6 | Hot Sand Sulphur Bitumen | 5 | 6.0 |
| 7 | Hot Sand Asphalt Base | 5 | 5.4 |
| 8,9 | Type D Sulphur Bitumen | 3 | 5.65 |
| | Type D Sulphur Bitumen | 4 | 4.8 |
| 10 | Type D Asphalt Base | 7 | 4.8 |

Fig. 12. Layout of SNPA Sulphur Bitumen Binder Pavement Test
US Highway 69 Lufkin, Texas

(a) Cut Section



(b) Fill Section

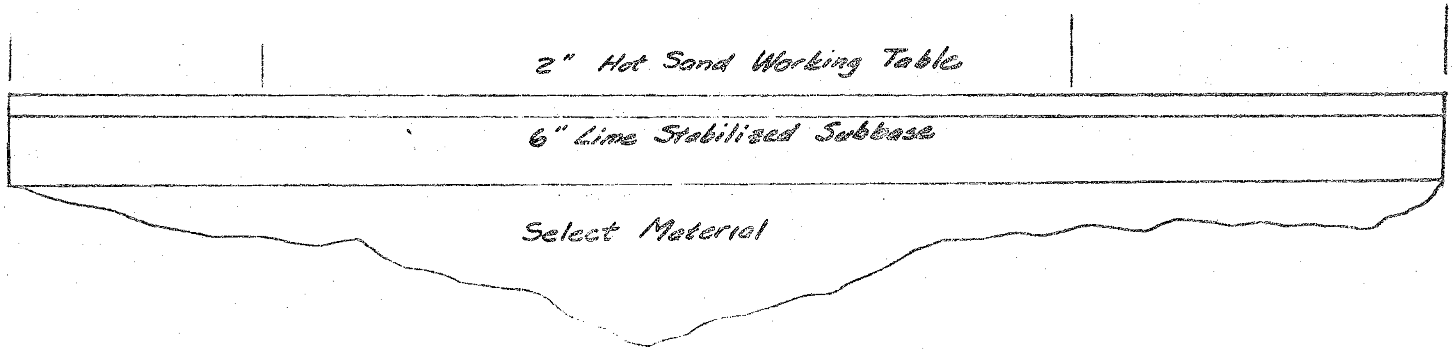


Figure 13. Typical Sulphur-Bitumen Test Section Cross Sections

SNPA delivered their equipment in July of 1975 and set it up at Moore Bros. hot-mix plant in Lufkin. It was ready for use August 1, 1975. Actual construction of the test sections began 2 September 1975 just six short months after the original idea was seeded. Construction of the demonstration section required about ten working days involving some 3650 feet of two-lane highway made up of ten different subsections.

All important aspects of the construction of the test sections were recorded in motion photography. This film was assembled into a 12-minute documentary film entitled "Paving with Sulphur." In addition, still photos have been processed into slides for presentation at highway short courses such as those to held at Texas A&M University during December 1975.

Post-construction evaluation data collection began during construction and included, among other information, deflection and stiffness measurements at various stages of the job. The former was obtained using the Benkelman Beam and the latter using the Texas Highway Department Dynaflect. These two test devices are shown in Figures 14 and 15 respectively. This information will be used in later analyses of the structural benefits derived from use of the special sulphur-asphalt binder.

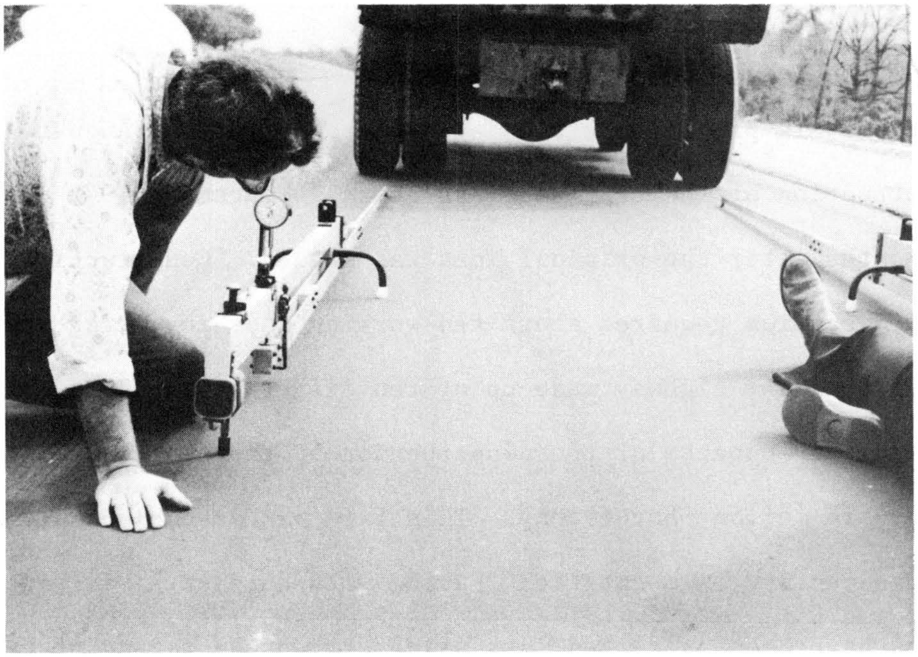


Figure 14. Benkelman Beam rebound deflection measurements being taken on section of Sulphur-Asphalt base course.

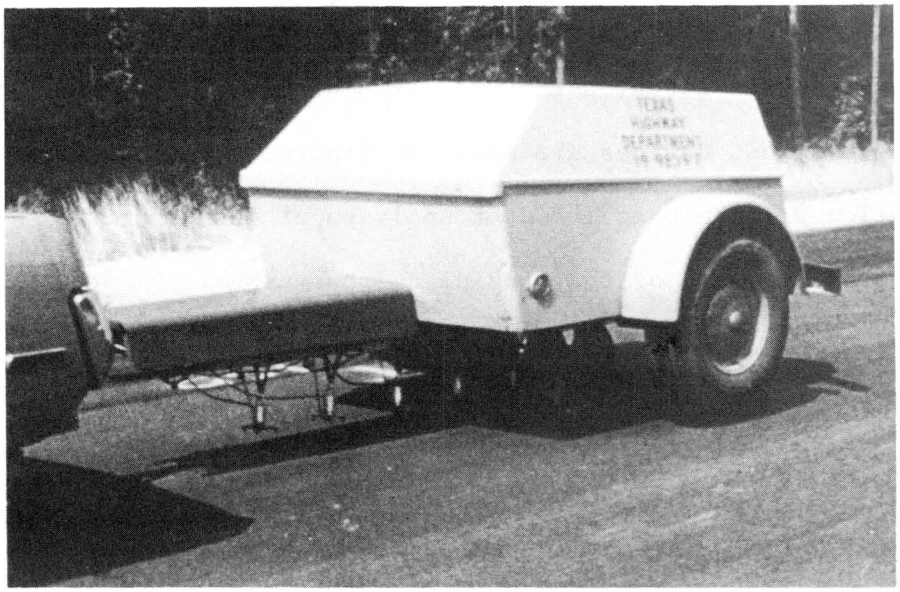


Figure 15. Texas Highway Department "Dynaflect Unit" used to obtain dynamic stiffness measurements.

## 3.2 Test Sections

The test section for the Lufkin field trials is 3,650 feet long and is divided into ten subsections as shown in Figure 12. These subsections were placed over a 6-inch lime-stabilized subgrade and a 2-inch "hot sand" working platform. The conventional pavement section controls have been described above. See Figure 11. All sulphur/asphalt mixtures for the test section were prepared with 30/70 sulphur/asphalt emulsion using a Texaco AC-20 asphalt cement with a penetration of 58 at 77°F, (ASTM D5-73), (9).

The binder content of the 30/70 S/A emulsion mixtures varied from 5.3 to 7.1 weight percent, the equivalent volume percent of pure asphalt corresponding to this range would be 4.5 to 6.0. The binder contents used in each section are shown in Figure 12. The surface course, which at this writing has yet to be placed, will be an Item 340 Class A Type L Asphalt Concrete Pavement designed for high friction.

The aggregate used in the Type D ACP base course consisted of a 60/40 ratio of a pea gravel and a local sand with a gradation as set forth in Texas Highway Department Specifications - Item 340 Class A Type D for fine graded surface courses. The aggregate used in the "Hot Sand" (Hot-mix Sand Asphalt) base course was a dune sand obtained from the Seal Pit in the Lufkin area. An average "as extracted" gradation for each of these aggregate systems is given below.

| Sieve Size | Weight Percent Type D ACP | Seal Pit Sand |
|---|---|---|
| 1/2-3/8 | 1.4 | |
| 3/8-4 | 37.7 | |
| 4-10 | 24.7 | 0 |
| +10 | 63.7 | 0 |
| 10-40 | 4.9 | 12.6 |
| 40-80 | 6.2 | 59.3 |
| 80-200 | 18.1 | 15.8 |
| Pass 200 | 2.0 | 7.7 |

The emulsion was prepared by a technician furnished by SNPA, who was responsible for operating the portable colloid mill shown in Figure 16. The unit was tied directly into the Moore Bros. Construction Company hot asphalt storage tank and into a hot liquid sulphur truck tanker provided by Texas Gulf of Freeport, Texas. A photographic view of the mixing station is shown in Figure 17 and is also shown schematically in Figure 18. After the emulsion was prepared, it was stored for later use in a holding tank (left foreground of Figure 17) from which it was pumped to the pug mill for preparation of the mixes.

The paving mixtures were transported by trucks a distance of approximately 15 miles to the construction site. The materials were placed using a Barber Greene - Series 100 paver and compacted with a Hyster C-615A vibratory steel roller. Break down was effected with vibration and final compaction was effected with the vibrator inactive. A photographic sequence of operations involved in the placing of the S/A mixes is shown in Figures 19 through 24.

During construction a number of direct samplings were taken at the pug mill for Hveem Stability determinations. The results of tests run on these samples are shown in Figure 25 for both HMAC and Hot Sand mixes. These data indicate the stabilitites of the HMAC to be higher than the Hot Sand mixes at the same binder content. Within each system the mixes prepared with the sulphur-asphalt binder achieved stabilities from 35-45 percent higher than those prepared with the pure asphalt. The stability of the conventional HMAC materials was reduced considerably with increased binder content whereas the stability of the mixes prepared with the sulphur-asphalt binder remained relatively constant. This feature appears to exist in the hot sand mixtures as well. The field data shown in Figure 25 agree quite well with that measured in the laboratory as discussed earlier.

The post-construction evaluation which is a part of this contract is in progress at this writing and is proceeding in accordance with the test matrix shown in Table 11. Preliminary data are being obtained from samples taken several weeks after completion of pavement placement and before the pavement is open to traffic. Additional sampling will be made at six-month intervals.

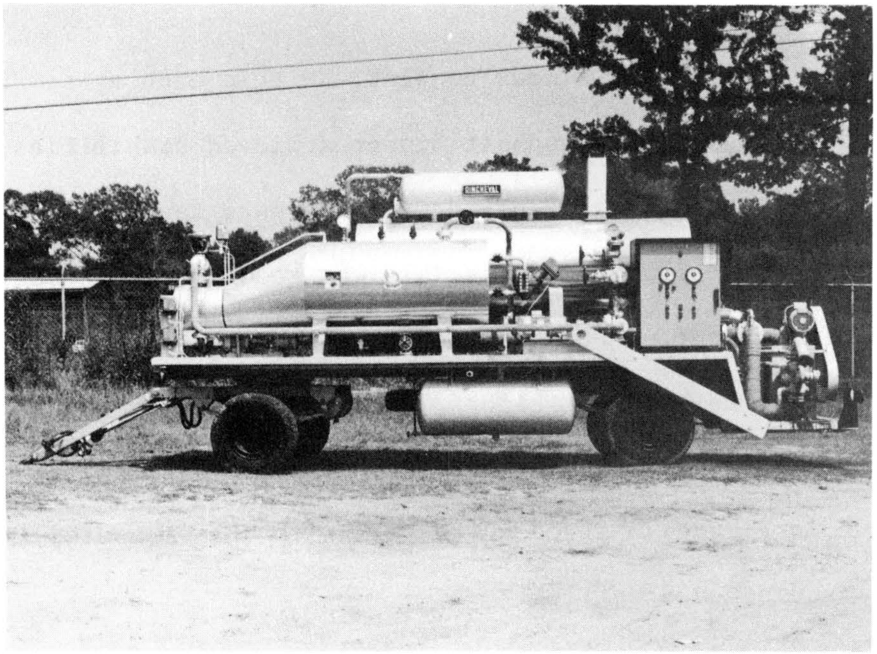


Figure 16. Colloid Mill furnished by SNPA for preparation of Sulphur-Asphalt emulsions.

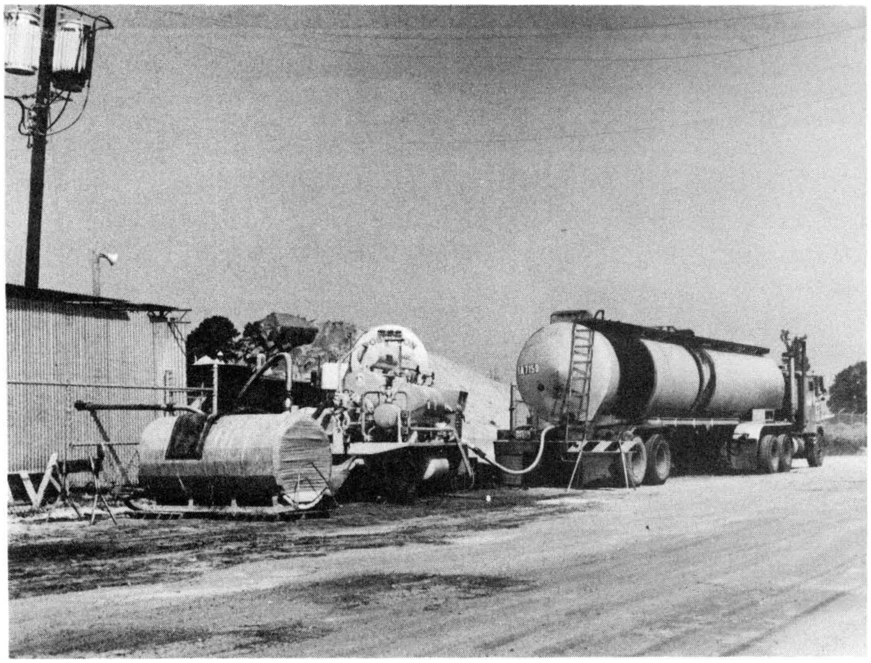


Figure 17. View of Mixing Station showing Sulphur Storage tank, colloid mill and emulsion holding tank.

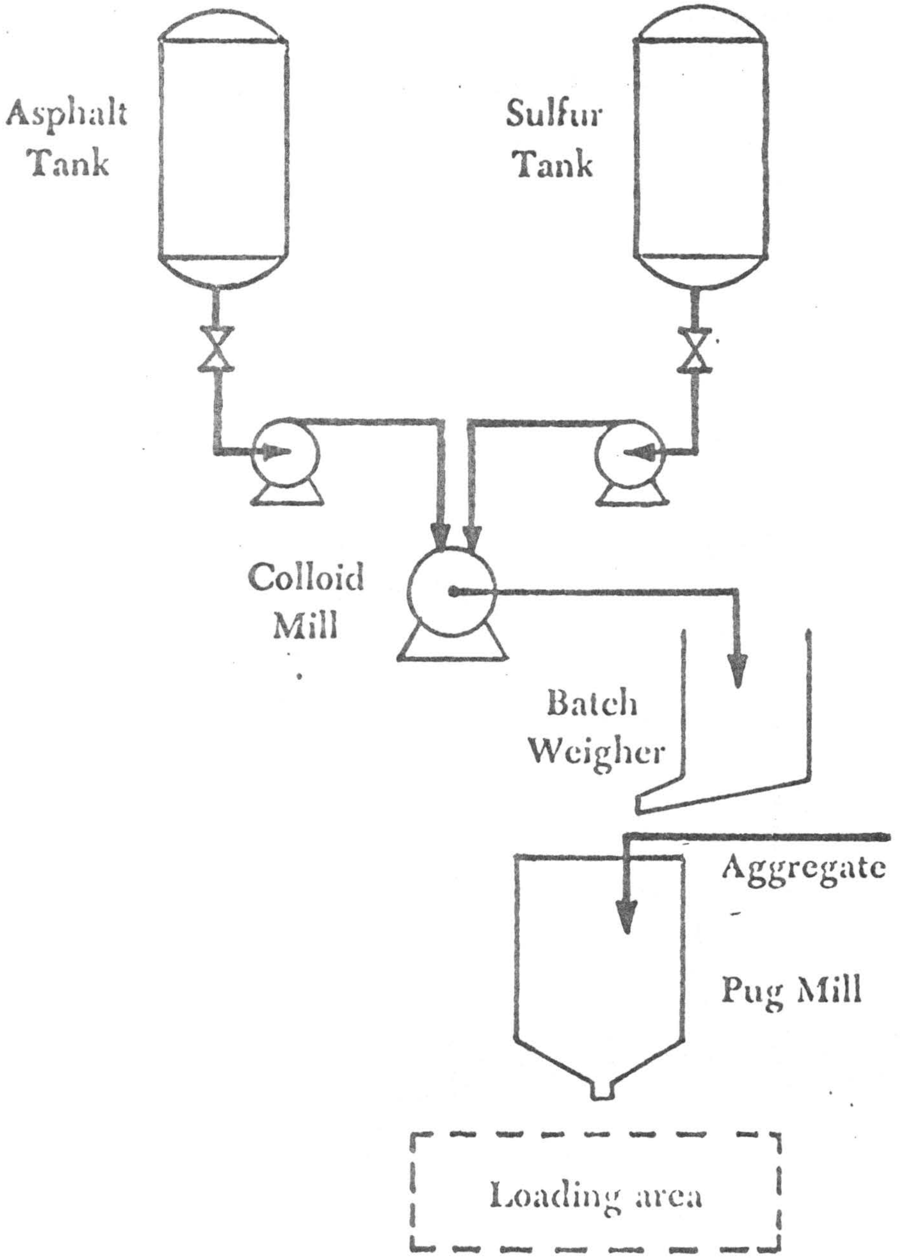


Figure 18. Schematic drawing of Sulphur-Asphalt mixing station

Figure 19. Placing 2-inch thick "Hot Sand" working platform over lime-stabilized subgrade.

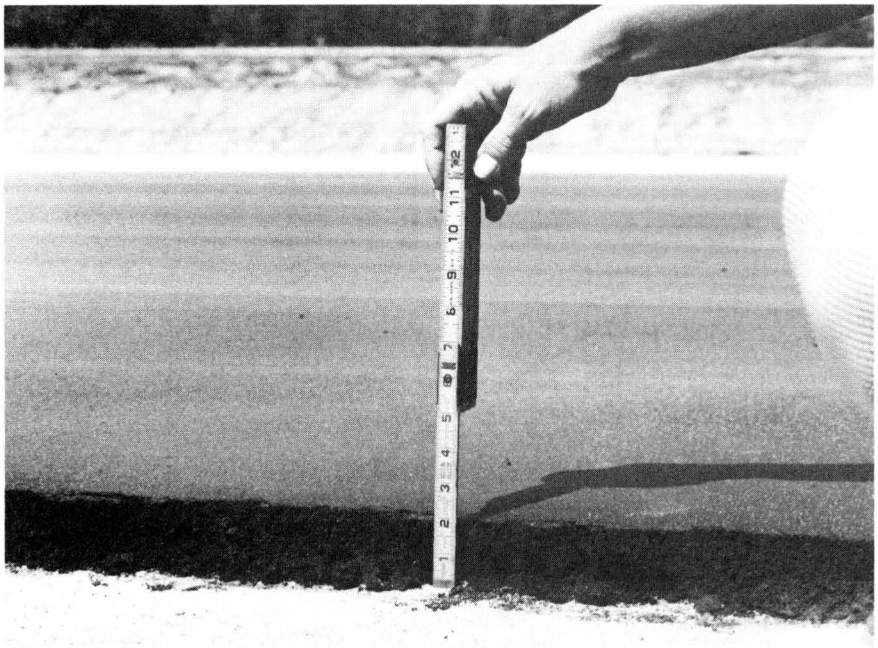


Figure 20. Two-inch "Hot Sand" working platform.

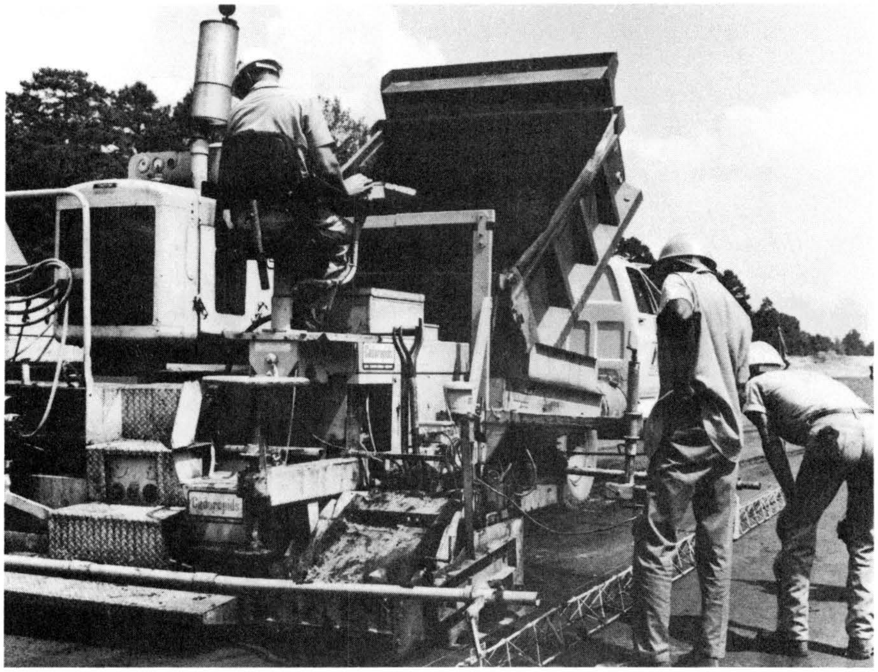


Figure 21. Placing HMAC base course using a Barber-Greene Series 100 paver with automatic screed control.

Figure 22. Hyster vibratory steel roller for initial compaction of base course.

Figure 23. Hyster C-615A steel roller with inactive vibrator for final compaction of base course.

Figure 24. Completed test section prior to laying surface course.

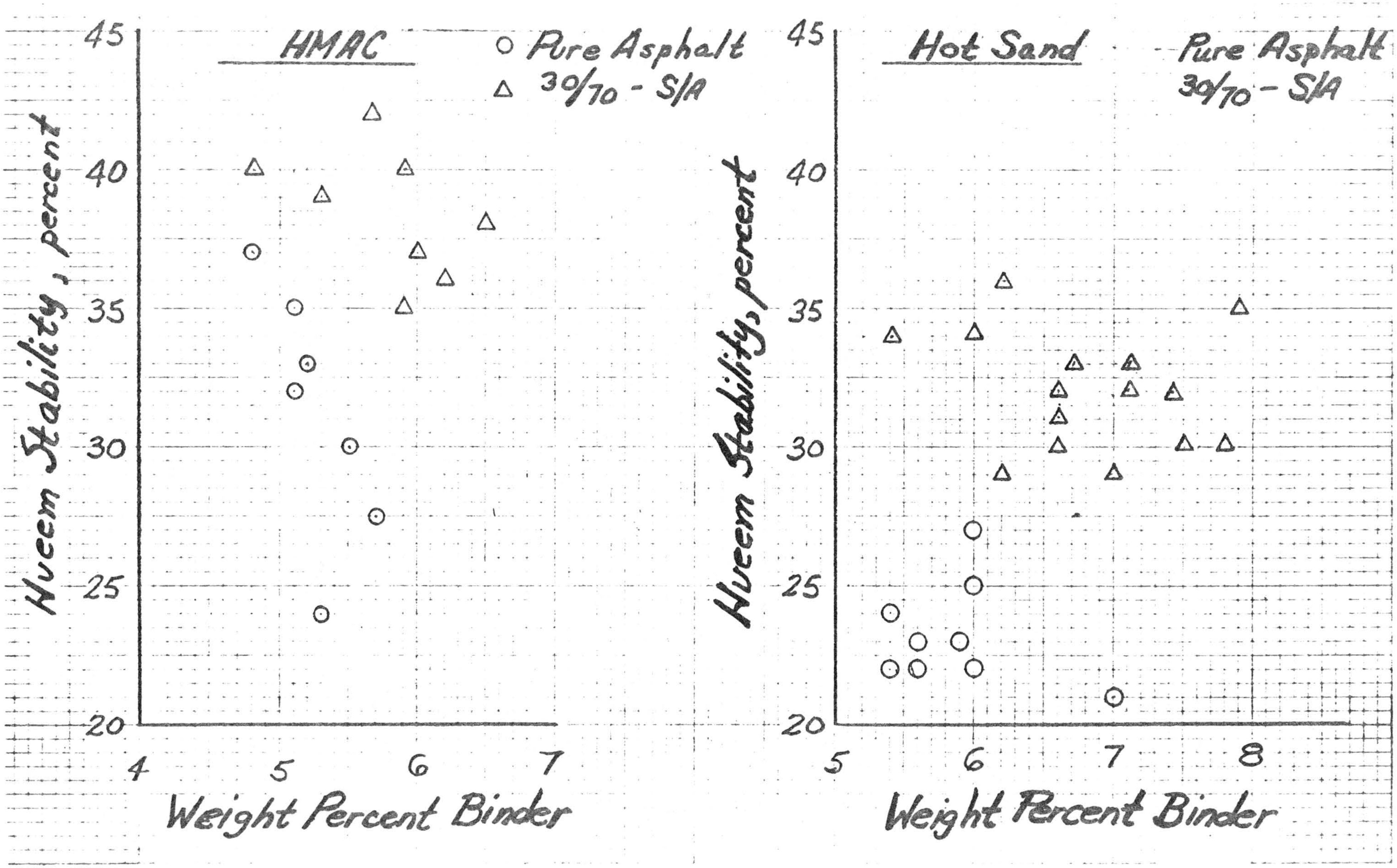


Figure 25. Hveem Stability of HMAC and Hot Sand Mixtures Taken During Construction.

Table 11. Testing Matrix For Post Construction Evaluation

| Test Description | | Preliminary | Initial | Time Intervals | | | |
|---|---|---|---|---|---|---|---|
| | | | | 6 mo. | 12 mo. | 18 mo. | 24 mo. |
| 1. Traffic Analysis | | | | | | | |
| a. Average Daily Traffic Count | | | ← continuous → | | | | |
| b. Truck and Axle Weight Distribution | | | ○ | | | | ○ |
| 2. Visual Evaluation | | △ | △ | △ | △ | △ | △ |
| 3. Mays Meter (PSI) | | △ | △ | △ | △ | △ | △ |
| 4. Benkelman Beam Deflections | | △ | △ | △ | △ | △ | △ |
| 5. Dynaflect Deflections | | △ | △ | △ | △ | △ | △ |
| 6. Cored Samples | | | | | | | |
| a. Density | set of 6 | | | | | | |
| b. Stability, Marshall | cores (min) | | | | | | |
| c. Stability, Hveem | at each test | △ | △ | △ | △ | △ | △ |
| d. Resilient Modulus | section per | | | | | | |
| e. Indirect Tension | sampling period | | | | | | |
| f. Rice Specific Gravity | | ⊥ | | | | | |
| g. Thermal Expansion | | ⊥ | | | | | |
| 7. Skid Resistance | | △ | △ | △ | △ | △ | △ |

○ Loadometer survey, 1-week duration
△ Evaluations on both sulfur-asphalt binder and asphalt binder pavement sections
⊥ Initial evaluation of paving materials

NOTES:
1. Preliminary testing will be performed at completion of pavement placement.
2. Initial testing will be performed one week after pavement is open to traffic.
3. Skid tests will be made on surface with s/a binder on the project but not at site of test section.

## 3.3 Hydrogen Sulfide Emissions Measurements

Hydrogen Sulfide ($H_2S$) emissions evolved during emulsification, mixing at the pug mill and in the vicinity of the paver were monitored during the construction of the field section. Hydrogen sulfide is known for its characteristic "rotten egg" odor. Although this odor is noticeable at concentrations as low as 0.02 ppm, odor is not an effective indicator of concentration level. A number of concentration levels and their associated environmental effects are shown in Table 12 below. Based on the above, a maximum allowable concentration (MAC) suggested by American Conference of Governmental Industrial Hygienist (17) is between 5-10 ppm.

Table 12: Hydrogen Sulfide Concentration Levels

| $H_2S$ Concentration | Environmental Impact |
|---|---|
| .02 ppm | Odor Threshold Value |
| 5-10 ppm | Suggested MAC* |
| 20 ppm | MAC (18) |
| 70-150 ppm | Slight symptoms after exposure of several hours |
| 170-300 ppm | Maximum concentration that can be inhaled for one hour without serious consequences |
| 400-700 ppm | Dangerous after continuous exposure of 30 min - 1 hr |
| 600 ppm | Fatal with exposure greater than 30 min |

* Maximum allowable concentration

Two instruments used to measure these emissions were: (a) Houston-Atlas ambient $H_2S$ Detection System (furnished for use on the project by the U.S. Bureau of Mines) and (b) a portable Metronics "Rotorod Gas Sampler (furnished by TTI) - See Figures 26 and 27. It was found that good agreement was achieved between concentrations indicated by both instruments. The emissions at some of the critical areas of the hot-mix plant and paving site are given below.

| | Location | $H_2S$ Concentration (ppm) |
|---|---|---|
| 1. | Batch Stack | <0.5 |
| 2. | Vicinity of the Colloid Mill | negligible |
| 3. | Inside Opening of S/A Emulsion Storage Tank | 15 ppm |
| 4. | Pug Mill Platform | <1.0 |
| 5. | Over Truck Dump Body | <1.0 |
| 6. | Paver Hopper during Truck Dumping | <1.0 |
| 7. | Paver Hopper during Paving | negligible |

Based on the recommended MAC values, the $H_2S$ concentrations measured in the areas most frequented by construction personnel are well below the critical threshold. The highest $H_2S$ concentration was measured inside the S/A emulsion storage tank, an area normally sealed off during construction activity and as such represents no serious threat.

During the paving operation it was noted that the paver operator experienced a certain amount of eye irritation. It was subsequently established that this was due to sulphur which was being borne by water vapor fumes drifting from the hopper. It is therefore suggested that paver operators be required to wear goggles to eliminate this hazard.

Figure 26. Monitoring $H_2S$ emissions with a Metronics "Rotorod" gas sampler.

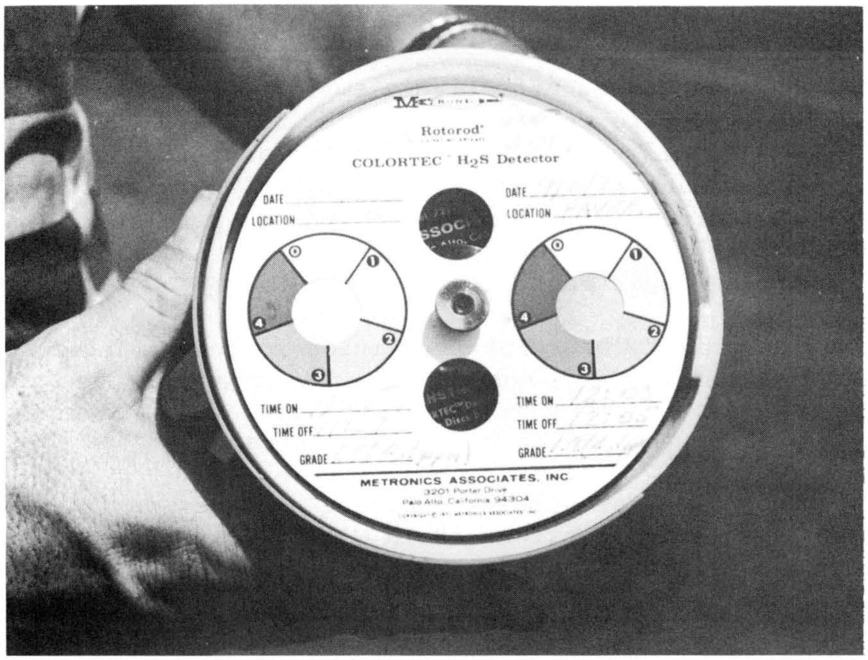


Figure 27. Comparison of exposed and unexposed surfaces on a Rotorod Colortec Card used for detection of $H_2S$ emissions.

# 4.0 CONCLUSIONS

The overall objective of this study was "to evaluate the potential of sulphur/asphalt emulsion binder systems for highway pavement construction". The laboratory study, described in a report to the original sponsors, provided a means of familiarizing TTI and SDHPT personnel with the techniques for preparing relatively stable sulphur/asphalt dispersions in which 15 volume percent of the asphalt in the binder system was replaced by sulphur. These techniques were subsequently demonstrated in the successful construction of the full scale field sections on U.S. 69 north of Lufkin, Texas.

Specific results of the project at this point in time can be summarized as follows:

1. Sulphur can be effectively employed as a binder component to reduce asphalt demand. Although a maximum 15 volume percent of the asphalt was replaced in this study, the potential does exist to increase this limit to 25 volume percent through the use of aggregate blends, and minimizing fines content.

2. The ability of sulphur addition to lower binder viscosity, improved mix workability which, in turn, suggests a wider permissible range of mixing and placing temperatures, was demonstrated.

3. Mechanical properties indicate a higher resistance to shear distortion. Both Marshall and Hveem stabilities of S/A mixtures ranged from 35 to 40 percent higher as compared with the conventional asphaltic concrete systems treated in this study.

4. It is suggested that for best workability and strength, processing of S/A binders should be accomplished over the temperature range $130 \geq T \geq 140^\circ C$ ($265 \geq T \geq 285^\circ F$). The upper limit is established to minimize hydrogen sulfide formation. Virtually all mixtures in this study were prepared at 140°C (285°F).

5. The resilient modulus, compressive strength and splitting tensile strength values not normally obtained by SDHPT indicate that S/A binder was definitely beneficial when used in optimum amounts. Values of these test parameters increased roughly 30 to 100 percent due to the use of 30/70 sulphur asphalt binder.

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