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16. Abstract

Important experience has been gained in the successful use of sulphur-extended-asphalt (SEA) binder in an open graded friction course (OGFC) in field trials conducted on Loop 495 in Nacogdoches, Texas on August 7 and 8, 1980. This project was the first whereby the State Department of Highways and Public Transportation (SDHPT) has used SEA in an OGFC pavement and also marks the first time that separate streams of sulphur and asphalt have been added directly to the aggregate in a dryer drum.

As a result of the above project, experience in the use of SEA in an OGFC has been gained in the areas of preliminary laboratory design, plant modification and operation, roadway operations, emission measurements and post construction testing and pavement performance.

Research to date has indicated that the SEA binder OGFC pavement is performing as well as the conventional OGFC pavement. Problems encountered with the SEA include the need for additional facilities to handle the sulphur and some irritation to workers from emissions.

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FIELD TRIALS OF SULPHUR-EXTENDED-ASPHALT BINDER IN OPEN GRADED FRICTION COURSE LOOP 495, NACOGDOCHES, TEXAS

A Detailed Construction Report

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for

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Federal Highway Administration

Texas State Department of Highways and Public Transportation

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January, 1981

PREFACE

The information presented in this initial or construction report was developed in Demonstration Study 1-11D-80-547 titled "Use of Sulfur Extended Asphalt with an Open Graded Friction Course", a cooperative study with the Texas State Department of Highways and Public Transportation (SDHPT), the Federal Highway Administration (FHWA) and The Sulphur Institute.

The principal objectives of this study were (1) to gain experience in Texas with the use of a sulphur-extended-asphalt (SEA) binder in an open graded friction course (OGFC) produced in a dryer-drum plant and (2) to assess the design, plant modifications, construction methods and roadway performance that would characterize utilization of an SEA binder OGFC paving mixture.

The above objectives are being achieved through (1) the experience that has been gained from the construction phase of the Demonstration Study which was completed in August 1980 and (2) the knowledge being gained from evaluation of test data obtained both during and shortly after construction. This initial report describes this experience and knowledge achieved to date.

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.

ACKNOWLEDGEMENTS

The assistance and cooperation of personnel from several organizations as presented below is gratefully acknowledged.

Thanks are due to Messrs. J. L. Beaird, Lynn S. Hill, W. E. Rudd, Kenneth W. Fults, Morgan Prince, Bob Walker and Jay Wingate of District 11 of the Texas SDHPT for providing information, planning and testing concerning the highway project from which this report is derived. Also, thanks are due to Messrs. Kenneth Hankins and John F. Nixon, SDHPT Division - 10, and Messrs. Don O'Connor and Robert F. Kriegel, SDHPT Division D-9, who helped provide for planning, coordinating and testing involved on the project.

Thanks are due to Mr. William Bell at Texasgulf, Incorporated, for the provision of sulphur handling facilities at the hot mix plant. Mr. Harold Fike of The Sulphur Institute is to be thanked for providing for project planning and the supply of sulphur. Messrs. Julian Nunnaly and W. W. Wiand of Texaco, Incorporated are to be thanked for their participation in the project planning.

Finally, appreciation is due for the helpful cooperation in the contractor's project planning and prosecution as given by Messrs. Raymond Moore and Thomas Moore of Moore Brothers Construction Company and Charlie Foster and Gene Carrier of East Texas Asphalt.

KEY WORDS

ASPHALT, BITUMINOUS MIXTURES, OPEN GRADED FRICTION COURSE, PERMEABILITY, SKID RESISTANCE, SULPHUR, SULPHUR EXTENDED ASPHALT, SURFACE COURSE

SUMMARY

Successful field trials have been conducted in which a sulphur-extended-asphalt (SEA) pavement binder was used in an open graded friction course (OGFC) pavement in a demonstration project constructed on Loop 495 at Nacogdoches, Texas on August 7 and 8, 1980, by District 11 of the Texas State Department of Highways and Public Transportation (SDHPT) under the general direction of Texas Transportation Institute (TTI). The Nacogdoches field trials represent the twelfth sulphur-asphalt binder demonstration project that TTI has participated in since TTI began sulphur-asphalt research in 1973. Previously, under a number of projects funded by the Federal Highway Administration, researchers from organizations such as the Texas SDHPT, the U. S. Bureau of Mines, The Sulphur Institute and TTI have cooperated in important studies aimed at gaining increased benefits from the use of sulphur in asphalt concrete pavements.

The Nacogdoches field trials are significant for several reasons. They represent Texas' first use of SEA in an open graded friction course pavement, and they represent the first time that separate streams of liquid sulphur and asphalt cement have been added to aggregate in a dryer-drum plant. In all but one of the previous SEA field trials involving TTI research efforts, weigh-batch plants have been used to produce the hot mix, and the liquid sulphur was combined with the asphalt cement in colloid mills or static mixers. The one exception was the Brazos County (Texas) SEA Field Trials on MH 153 where liquid asphalt and molten sulphur were co-mingled in a by-pass line around the colloid mill before being introduced into the pugmill with the aggregate.

For the Nacogdoches SEA binder OGFC field trials, a 35 weight percent of sulphur and a 65 weight percent of asphalt were chosen for the SEA binder. The procedure used in the design of the SEA-OGFC mix involved substituting an equal volume of SEA binder for the pure asphalt binder in the conventional mixture, with the actual proportions of sulphur and asphalt in the SEA binder being based on a weight percentage of the total SEA binder. The above procedure was based on a widely used procedure developed by the FHWA for optimizing the binder content of an OGFC.

Preliminary laboratory tests for mixture design were performed by TTI to examine the properties of SEA binder OGFC mixtures which duplicated proportions of binders and aggregate in use on the job where the SEA was to be substituted for pure asphalt. These tests revealed no anticipated problems.

Modifications to the contractor's dryer-drum plant to accomodate the SEA binder OGFC were minimal except that (1) a trailer mounted unit was provided by Texasgulf, Incorporated to handle temporary storage, pumping and metering of the liquid sulphur and (2) insulated piping had to be erected between the trailer mounted sulphur handling unit and the dryer drum. Operations of the dryer-drum plant were modified in that(1) some emissions from the use of sulphur resulted and (2) the dryer drum was operated at a higher temperature for the

SEA binder OGFC than for the conventional binder OGFC.

Field placement and compaction conditions for the SEA binder OGFC were essentially no different than those of the conventional binder OGFC with the exception of higher laydown temperatures and some sulphur emissions for the SEA mixture.

Immediately upon completion of the construction of the field trials, data gathering for a four-year post construction evaluation program was begun. Initial measurements made included Dynaflect, Mays Ride Meter, visual evaluation, skid resistance, surface texture and permeability. The data gathering included cores for selected laboratory tests, including void contents and specific gravities. Measurements for sulphur emissions were made during construction.

The performance of the SEA binder OGFC field trials to date can be described as "at least equal" to that of the conventional binder OGFC and as "entirely satisfactory". The results of the different measurements made on the SEA binder OGFC and the conventional OGFC show the two pavements to have essentially the same characteristics except for the SEA pavement having higher initial permeability.

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LOOP 495, NACOGDOCHES, TEXAS

I. INTRODUCTION

A sulphur-extended-asphalt (SEA) pavement binder was used in an open graded friction course (OGFC) pavement in a demonstration project constructed at Nacogdoches, Texas on August 7 and 8, 1980, by District 11 of the Texas State Department of Highways and Public Transportation (SDHPT).

The sulphur in sulphur-extended-asphalt binders is substituted for a portion of the asphalt. There is evidence, supported by increased experience with sulphur-extended-asphalt binders, that the sulphur enhances the stiffness and strength characteristics of asphalt pavements and can, therefore, be used for the upgrading of marginal aggregates.

Specific Objectives of Nacogdoches Field Trials

There were four principal objectives of these field trials: (1) to employ the SEA binder for the first time in an open graded friction course in Texas; (2) to use and evaluate the use of SEA binder in a dryer-drum plant without preblending, as all previous uses had been in weigh-batch plants; (3) to ascertain different properties of designs using SEA binder open graded friction courses versus normal asphalt binder open graded friction courses as relating to laydown, compaction and performance under traffic and (4) to continue to evaluate construction associated emissions that may evolve from the use of SEA binders.

Significance

Research to increase the use of sulphur-extended-asphalt can have far reaching consequences. It is worthy to note that approximately 90 percent of all pavements in the United States contain asphalt cement as a construction material and that other countries have a similarly high percentage of pavements constructed with asphalt. G. D. Love, Associate Administrator for Research and Development, Federal Highway Administration, notes that the United States use of asphalt cement is currently about 30 million tons (2.72×10^{10} kg) annually including the maintenance use of some 1.6 million tons (1.45×10^9 kg) of asphalt cement annually (1). This use of petroleum residuum will become more and more expensive as the price of crude oil is increasing sharply each year from declining domestic production and increasing pricing pressures from the organizations of producing and exporting countries. Possible compounding of the increasing expense of asphalt cement usage could come from unforecasted shortages, cut offs of foreign oil from political and military emergencies and the eventual decline of world petroleum reserves.

The use of sulphur as a partial substitute for the amount of asphalt binder is seen to have significant potential for reducing the United States usage of asphalt cement and thus for extending our supply of this versatile material. Significantly increased use of sulphur in place of asphalt cement would allow the increased production of heavy fuel oil and other petroleum products from the cracking of asphalt cement thus diverted.

Sulphur is in plentiful supply in the United States and is less expensive than asphalt cement in many areas of the country, with the cost of transportation being the deciding cost factor in many cases. (2) The availability of the supply of sulphur is increasing in this country, with one major reason being the Clean Air Acts which have required more nearly complete removal of sulphur from fossil fuels with the consequent increase in sulphur as a by-product. Concerning future sulphur supply, G. D. Love estimates that the annual United States production of sulphur will be 100 million tons(9.07×10^{10}kg) by the year 2000 (1).

Background and Significance

The Nacogdoches Field Trials represent the twelfth sulphur-asphalt binder demonstration project that the Texas Transportation Institute (TTI) has participated in since TTI began sulphur-asphalt research in 1973. Previously, under a number of projects funded by the Federal Highway Administration, researchers from such organizations as the Texas SDHPT, the U. S. Bureau of Mines, The Sulphur Institute and TTI have cooperated in carrying out important studies aimed at gaining increased benefits from the use of sulphur in asphalt concrete pavements. Other organizations which have played major roles in SEA and other sulphur usage in pavements research include the French Societe Nationale Elf Aquitaine (SNEA), the Sulphur Development Institute of Canada, Shell Canada Limited and Gulf Oil Limited of Canada.

The Nacogdoches Field Trials are significant for several reasons. They represent the first use of SEA in an open graded friction course pavement, and they represent the first time that separate stream addition of liquid sulphur and asphalt cement to aggregate in a dryer-drum plant has been utilized. In all but one of the previous SEA field trials involving TTI research efforts, weigh-batch plants have been used for the manufacture of hot mix, and the liquid sulphur was combined with the asphalt cement in colloid mills or static mixers with the resultant dispersion added to the aggregate for mixing in the pugmills. The one exception was the Brazos County SEA Field Trials on MH153 (3) whereby the liquid asphalt and the molten sulphur were co-mingled in a by-pass line around the colloid mill before being introduced into the pugmill with the aggregate.

Original Scope

The original state contract on the Loop 495 project in Nacogdoches called for placing a one-course surface treatment on the 39,350 yd^2(32,897 m^2) of travel lanes and shoulders as called for under SDHPT Specification Items 320(506) and 320(571), with the planned rate of application for the asphaltic material specified as 0.3 gal/yd^2(1.4 liters/m^2) and for the aggregate, a cover rate of 1 cubic yard (0.76 cubic meters) per 100 square yards (83.6 square meters). The purpose of the surface treatment was to provide a water resistant surface for the existing pavement surface for the subsequent application of an OGFC, Specification Item 3022.

The OGFC called for under Item 3022 would then be applied on the same 39,350 square yards (32,897 square meters) of previously placed surface treatment in accordance with the special specifications of Item 3022, Plant Mix Seal, to provide a permeable, free draining, skid resistant surface approximately 3/4-inch(19.1 mm) in thickness. The project plans indicated an aggregate rate of 1 cubic yard (0.76 m^3) of aggregate per 49 square yards(41.0 square meters) of pavement and an asphaltic material binder rate of 180 pounds/cubic yard (106.7 kilograms/cubic meter) of aggregate. The aggregate was intended to be uniformly graded as called for in the Grade 3 grading requirements specified in the SDHPT Item 3022.

Sponsors and Location

The sulphur-extended-asphalt (SEA) open graded friction course field trials were made possible by a "Field Change" in the contract between the State Department of Highways and Public Transportation and Moore Brothers Construction of Lufkin, Texas on SDHPT Project CSB 138-6-26 etc. for Loop 495 in Nacogdoches, Texas. Under a separate verbal agreement between Moore Brothers and The Sulphur Institute, Moore Brothers would be reimbursed for any additional costs required for placing the conventional pavement.

The SEA-OGFC field trial sections were located in a 9600-foot (2928-meter) section of project CSB 138-6-26 etc. between the project station numbers 89+00 to 185+00 and comprised the two northbound lanes of Loop 495. This location is indicated on the vicinity map, Figure 1, together with the location of the East Texas Asphalt dryer-drum plant.

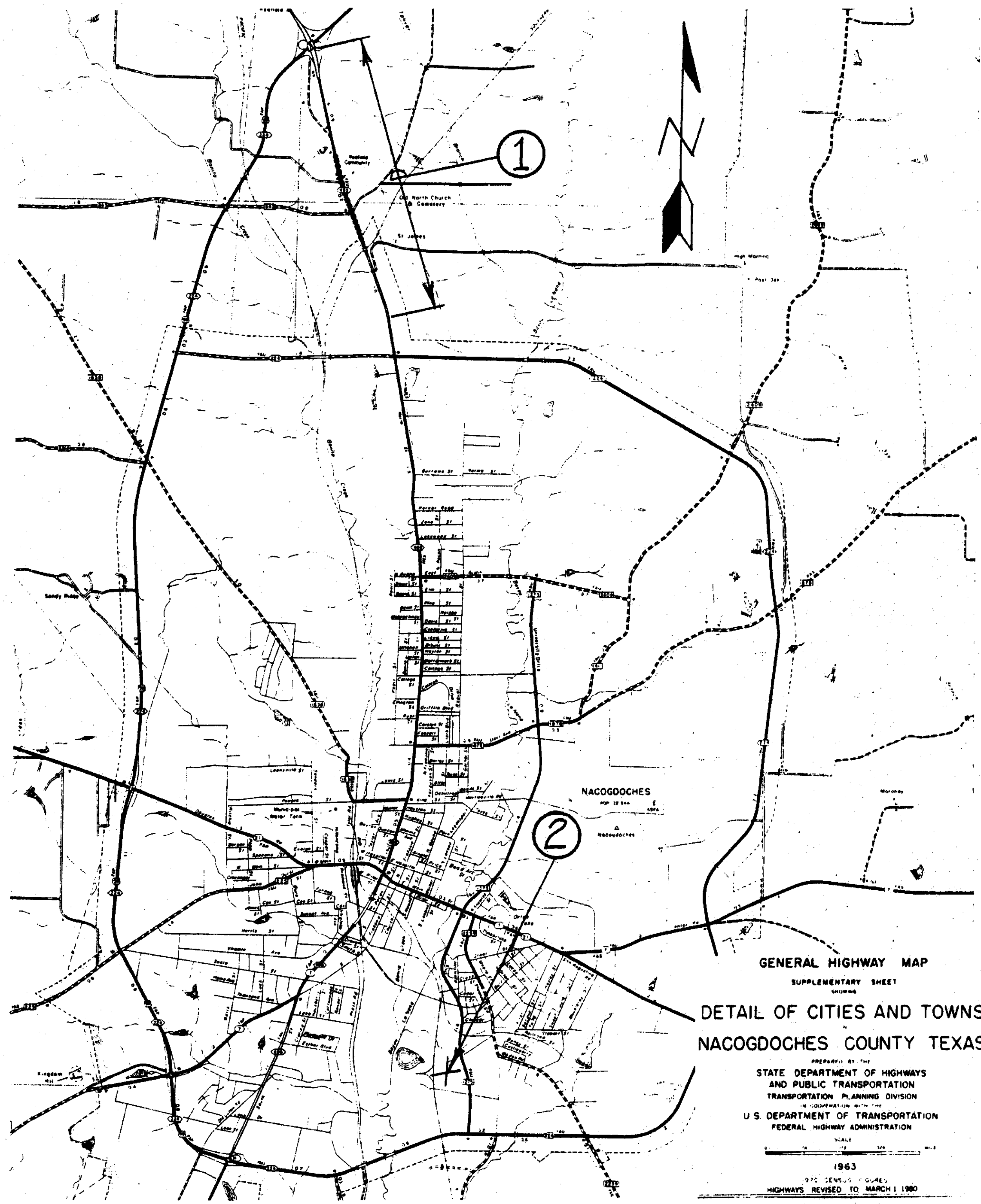
The typical cross sections for both the SEA-OGFC field trials and the conventional OGFC sections are shown in Figures 2 and 3. It is noted that both the SEA-OGFC and OGFC pavement layers were placed on a 3-inch(76.2-mm) dense-graded hot mix asphaltic concrete pavement layer. The new one course surface treatment placed under SDHPT Specification Item 320 is shown as covering the existing hot mix paving layer in the typical sections and is expected to provide the desired water-proofing for the structure underlying the new OGFC.

Traffic

The average daily traffic, ADT, for the project completion date in 1980 was estimated to be 15,620 vehicles per day of which 10 percent would be trucks. The pavement surface is designed for a 10-year life during which it would be subjected to traffic with about five million 18-kip(8172 kg) equivalent axle loads.

Layout of Field Trial Sections

Figure 4 is a schematic showing the layout for the SEA binder OGFC field trial sections on the Loop 495 northbound lanes from station number 89+00 to 185+00 and for the reference section of conventional OGFC on the Loop 495 southbound lanes between the same station number limits. Loop 495 is a four-lane divided, full access facility.

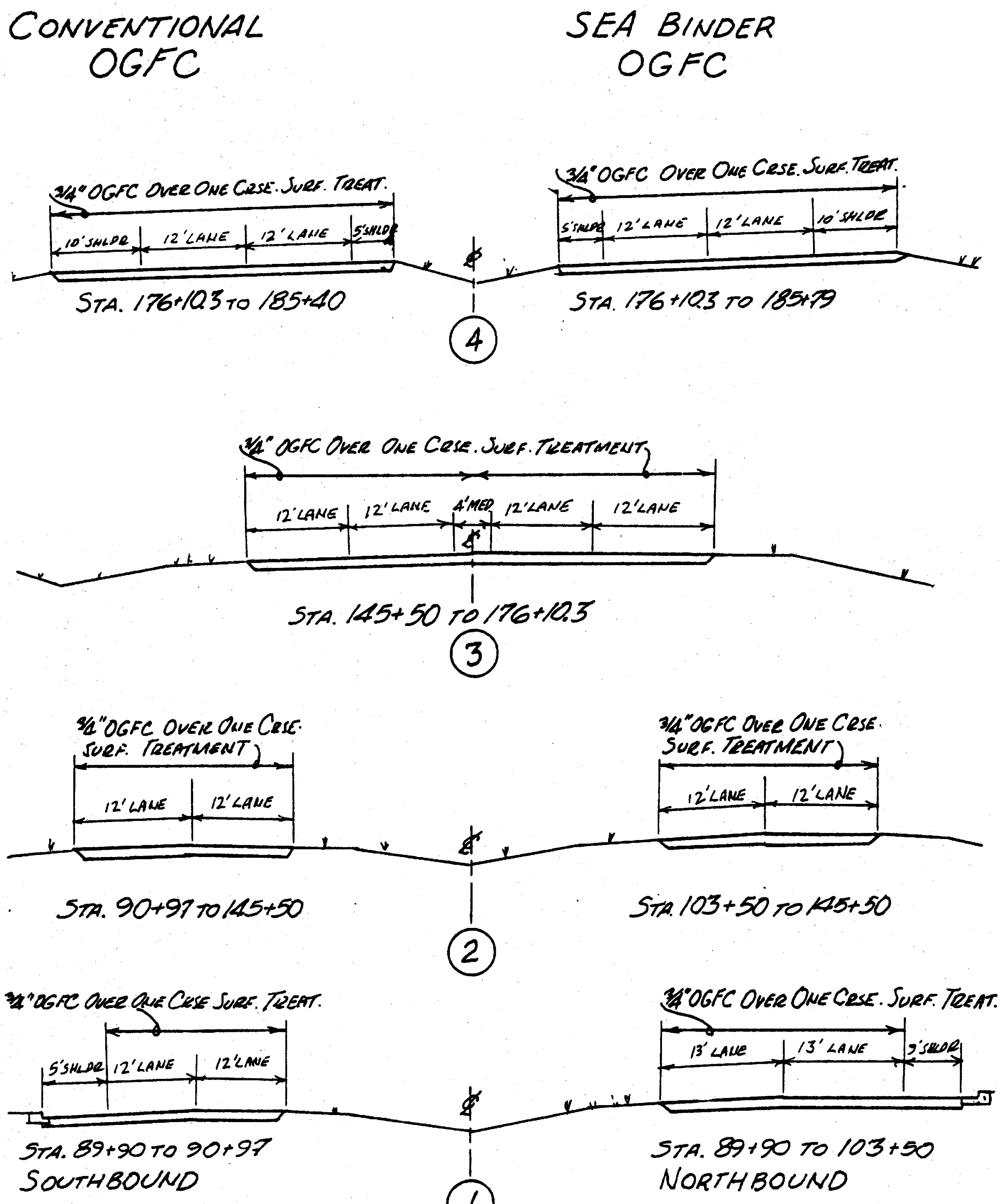


1 mi equals 1.609 km

① SEA Binder OGFC Field Trials Site

② Hot Mix Plant

Figure 1 Vicinity map of Nacogdoches, Texas Loop 495 field trials of sulphur extended asphalt in open graded friction course



Metric Conversion: 1 in = 25.4 mm
1 ft = 0.305 m

Figure 2 Typical roadway sections for Loop 495 field trials

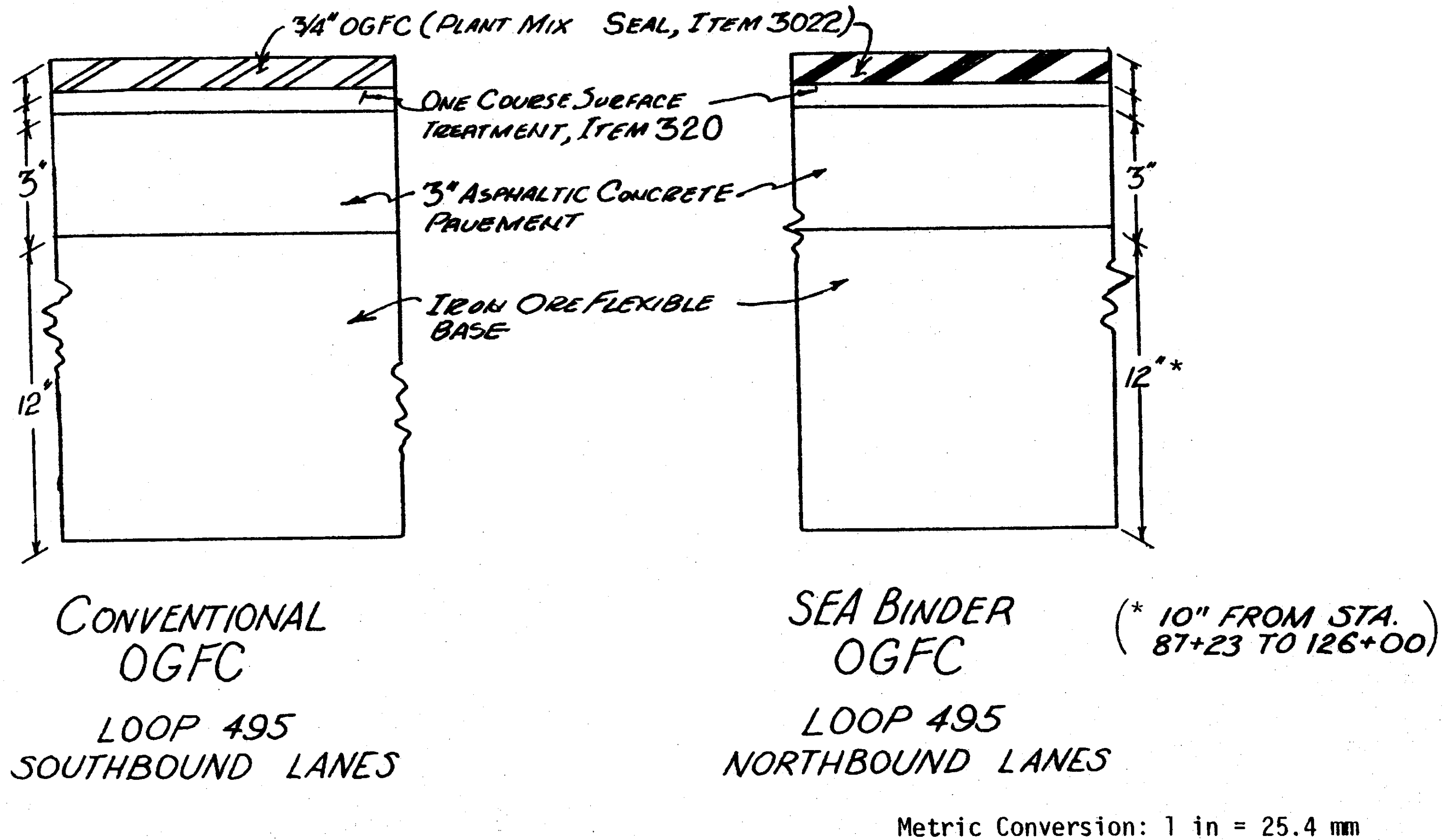


Figure 3 Typical pavement structural sections for Loop 495 field trials

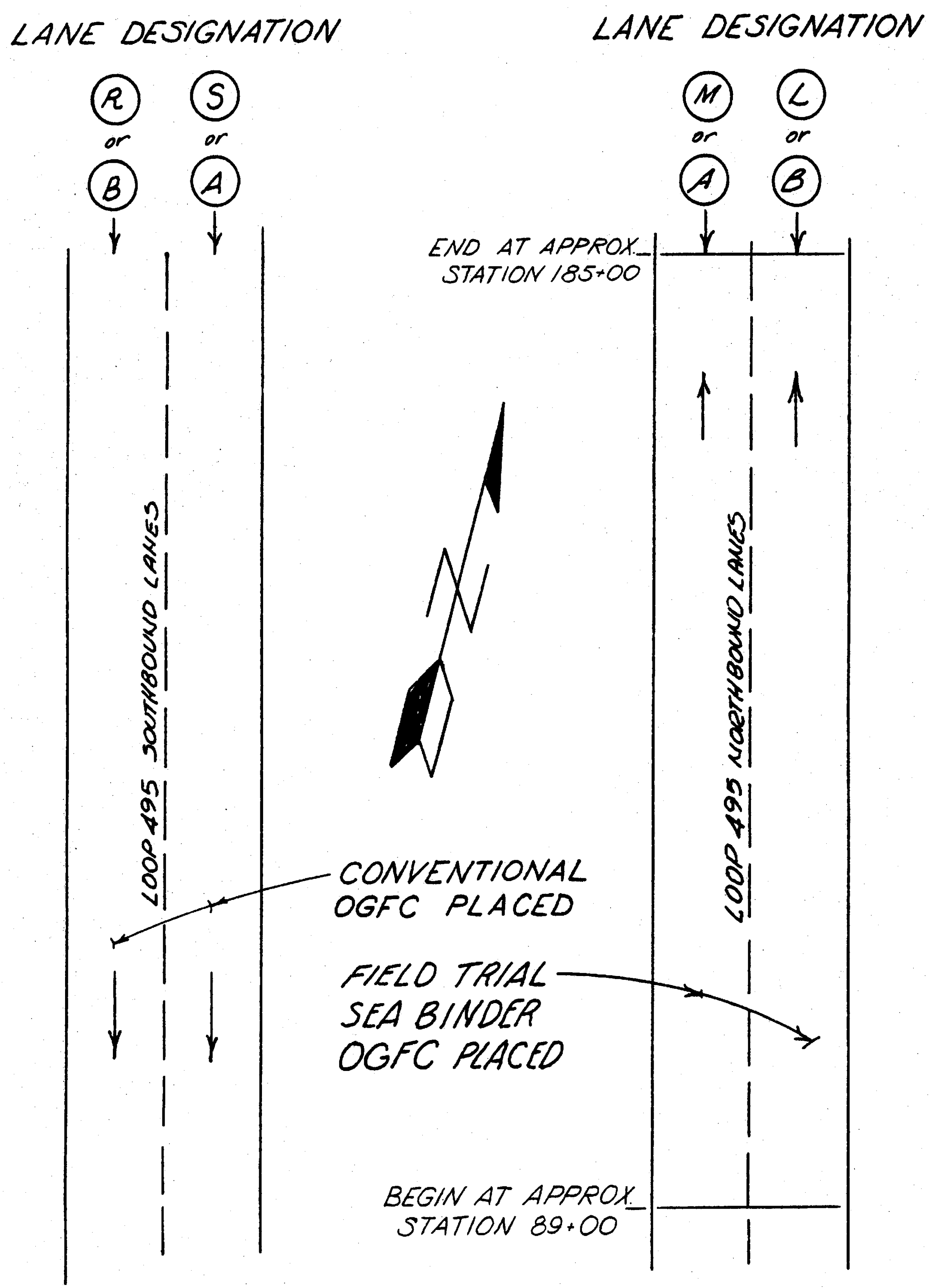


Figure 4 Schematic plan layout of Loop 495 travel lanes for field trials

Evaluation of Field Trial Sections

The post construction evaluation of the field trial sections has been and will continue to be made by the TTI in close cooperation with the SDHPT and with the Federal Highway Administration. The initial evaluation period has been set for four years following the completion date of August 8, 1980.

Participants

The field trials on Loop 495 in Nacogdoches were made possible through the close participation of several organizations. These organizations included the following:

> The U. S. Department of Transportation, Federal Highway Administration, Washington, D. C. and Regional Offices, Ft. Worth, Texas
>
> Texas State Department of Highways and Public Transportation, Austin, Texas and District 11, Lufkin, Texas.
>
> Texasgulf, Inc., Houston and Newgulf, Texas
>
> The Sulphur Institute, Washington, D. C.
>
> Texaco, Inc., Houston, Texas
>
> Moore Brothers Construction Company, Lufkin, Texas
>
> Texas Transportation Institute, College Station, Texas

Construction of the field trials was under the general supervision of Mr. J. L. Beaird, P. E., District Engineer for the State Department of Highways and Public Transportation, District 11, Lufkin, Texas. Mr. Jay M. Wingate, P. E., Supervising Resident Engineer for Nacogdoches County was in direct charge of the project. He was assisted by Mr. Chester R. Still, Senior Resident Engineer and Robert W. Parker, Associate Resident Engineer. The project inspector was James R. Parrish. William E. Ford supervised the laboratory control testing.

The contractor's operations were under the immediate supervision of Mr. Thomas Moore and Mr. Charles Foster of Moore Brothers Construction Company.

Mr. Harold Fike represented The Sulphur Institute who provided for the supply of sulphur for the project. The sulphur was purchased from the International Chemical Company of Mt. Pleasant, Texas whose President is Mr. Ted Brown.

Texasgulf Inc. of Newgulf, Texas installed sulphur handling equipment for the Moore Brothers dryer-drum plant and provided for the delivery of the molten sulphur in tank trucks. Mr. William M. Bell of Texasgulf supervised the construction and operation of the sulphur handling system at the Moore Brothers plant during construction.

Texas Transportation Institute was represented by Bob M. Gallaway, principal investigator for the overall study, and by a crew of technicians with primary functions as follows:

> Obtaining preliminary laboratory binder and mix temperature control and field emission measurements - Mr. Ed Ellis and Mr. K. K. Ho
>
> Sampling of mixes, laboratory testing of mixes, binder specific gravity, etc. - Mr. Ed Ellis and Mr. Sidney Greer.

The post construction testing and data gathering was under the supervision of Mr. Jay Wingate of the SDHPT, Nacogdoches, Texas.

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 an 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 (20,317 to 22,348 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 5. At temperatures above about 315°F(157°C) molten sulphur becomes very viscous.

When heated, the concentrations of toxic gases formed are low or non-existent in the temperature range of 250°F to 300°F(121°C to 149°C) but increase rapidly as the temperature rises above 300°F (149°C). Particulate sulphur and some forms of 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 sulfide 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 during the sulphur-extended-asphalt binder open graded friction course operations. The results are discussed under Section VII "Evolved Gas Measurements".

Sulphur Supplier

The sulphur was supplied by the International Chemical Company as a by-product of petroleum production from Mt. Pleasant, Texas about

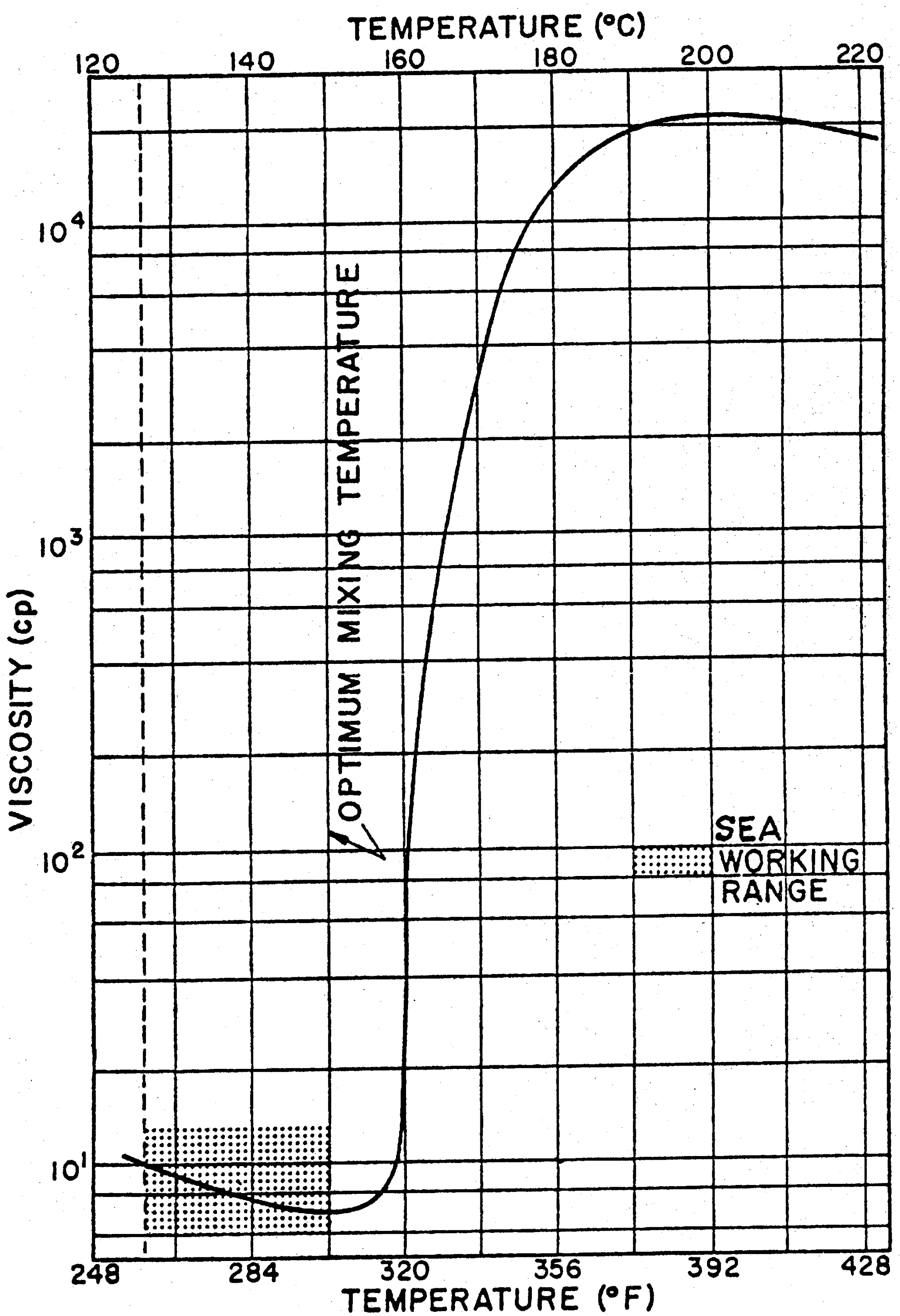


Figure 5 Temperature-viscosity chart for liquid sulphur

122 miles (196 km) north of the project. It was delivered to the job site in liquid form.

Typical Characteristics of Sulphur	
Purity, Dry Basis, pct wt	99.97
Ash, pct wt	0.002
Carbon Content, pct wt	0.03
Specific Gravity at 275°F (135°C)	1.79
Specific Gravity at Ambient	2.00
Source Process	Frasch or petroleum by-product
Color	Bright yellow

Asphalt

The asphalt was supplied from Texaco at Port Neches, Texas about 145 miles (233 km) south of the project. It was delivered hot in tanker trucks.

Test Characteristics of Asphalt

The asphalt was Viscosity Grade AC-20, conforming to asphalt cement of SDHPT Specification Item 300, Asphalts, Oils and Emulsions. The asphalt used on the project was represented by the SDHPT Laboratory No's. C80374076 and C80372754. Specification limits together with key test results supplied by the SDHPT Materials Division, D-9, Austin, Texas are shown in Table 1.

Mineral Aggregate

An objective of the field trials using the sulphur-extended-asphalt binder in the open graded friction course was to compare the SEA binder with pure asphalt used on the balance of the paving project. Therefore, the aggregate chosen for use should be from one source and should exhibit approximately the same gradation for the entire project. The aggregate gradation and other characteristics was governed by the requirements set forth in the Special Specification Item 3022 Plant Mix Seal under the master grading for Grade 3 mineral aggregate.

It was concluded among TTI and SDHPT personnel that for optimum results, the mineral aggregate as mixed and combined with the SEA binder should contain approximately 10 percent of material passing the No. 10 (2.00 mm) sieve and from 2 to 3 percent of mineral filler or material passing the No. 200 (75 μm) sieve. As extraction results will subsequently show, the amounts of finer material were achieved by means of natural degradation of the mineral aggregate during mixing, transporting and compaction operations. The aggregate called for by the Grade 3 master grading was essentially a uniformly graded aggregate with the exception of the minus No. 10 (2.00 mm) material.

Crushed Rhyolite Stone (Gifford-Hill)

The crushed rhyolite stone came from Gifford-Hill's Alamoore Pit located near Van Horn, Texas. Rhyolite is a stone of volcanic origin which contains a substantial amount of silica and resembles granite in composition but also has a texture which shows flow. Tests run on

Table 1   Properties of asphalt, AC-20 from Texaco

Test	Specification Limits		State Samples	
			SEA-OGFC	Conventional OGFC
	Min	Max	C80374076 Tank No. 260 Seal No. 04489	C80372754 Tank No. 5633 Seal No. 04358
Visc, 60°C, stokes	1600	2400	1918	1886
Visc, 135°C, stokes	2.5		---	4.0
Pen @ 25°C, 100g, 5 sec	55		80	85
Flash, COC, °C	232		316+	316+
Solubility in Trichloroethylene, pct	99		---	---
Specific Gravity, 25°C			1.030	1.028
Residue from Thin Film Test				
Visc, 60°C, stokes		6000	---	3534
Ductility @ 25°C, cm	50		---	141
Spot Test	Negative		---	
Specific Gravity @ 25°C	---	---	---	1.030
Specific Gravity @ 20°C	---	---	---	1.034
Pen @ 25°C, 100g, 5 sec	---	---	---	55

this material for the SEA-OGFC trial sections showed it to have an oven-dry loose unit weight of 88 pcf (1408.9 kg/m^3) and a bulk specific gravity of 2.59.

Some initial consideration was given to using 5 to 10 percent by weight of a local field sand in the rhyolite stone to provide minus No. 10 (2.00 mm) and minus No. 200 (75 μm) material, the objective being to provide fine material which would act to hold the asphalt film on the rhyolite particles during construction. However, the addition of field sand was unnecessary due to degradation of the rhyolite during mixture, laydown and compaction.

Sieve Analyses

The preliminary sieve analysis of the crushed rhyolite aggregate is shown in Table 2. Also shown is the average sieve analysis of the rhyolite based results of four extractions, three taken from the SEA-OGFC mix produced on August 7, 1980 and one for August 8, 1980. Also shown is the Grade 3 master grading specifications required for Specification Item 3022. Figure 6 also illustrates the above data. In the second part of Table 2 is a breakdown of a cold bin analysis and an extraction for August 8, 1980 including the entire grading data.

Sulphur-Extended Asphalt SEA (OGFC) Pavement Binder

In the sulphur-extended-asphalt pavement binder some volume or weight percent of asphalt cement is replaced by the addition of molten sulphur and thus the effective use of the asphalt can be said to be "extended" by the addition of the sulphur. The sulphur-asphalt binder thus produced consists of sulphur in solution with the asphalt plus a fine dispersion of the sulphur in the asphalt.

The sulphur and asphalt may be introduced together in the presence of sufficient shearing forces to assure the dispersion of the sulphur. Previous projects involving TTI research have provided for the dispersion of the liquid sulphur by means of a colloid mill or an in-line blender and in one case by co-mingling asphalt and sulphur in the colloid mill by-pass line.

In the SEA-OGFC field trials in Nacogdoches, the shearing forces and the dispersion of the sulphur were provided for by introducing the liquid sulphur into the tumbling mass of the aggregates and asphalt in the dryer drum.

SEA binder can be prepared in a wide range of sulphur contents, varying from 10 to 50 percent by weight of the total binder, and previous research projects have included 30 percent weight of sulphur (30/70) and 40 percent weight of sulphur (40/60). For the Nacogdoches SEA-OGFC field trials, a 35 percent weight of sulphur was chosen (35/65) for the SEA binder as a reasonable value for the sulphur-asphalt binder in order to expedite planning and preparation to use SEA binder for the first time in an open graded friction course.

Design of the SEA Binder OGFC Mix

The procedure to design the sulphur-extended-asphalt binder for the open graded friction course mix involves substituting an equal volume

Table 2 Item 3022 specifications and sieve analyses

Rhyolite Crushed Stone

Sieve Size	A. Preliminary Analysis Laboratory Tests (percent passing)	B. 4 Extraction Analyses August 7 & 8, 1980 (percent passing)	C. Item 3022 Specifications (pct passing)	(pct retained)
15.9 mm (5/8")	100	100	100	0
12.7 mm (1/2")	97	98	95-100	0-5
9.5 mm (3/8")	78	65	50-80	20-50
4.75 mm (No. 4)	18	18	0-12	88-100
2.00 mm (No. 10)	10	10	0-8	92-100

Sieve Analyses Showing Break Down of
Minus No. 10(2.00 mm) Material Taken on August 8, 1980
(expressed in percent passing)

Sieve Size	Cold Bin Analysis	Extraction Analysis
15.9 mm (5/8")	100	100
12.7 mm (1/2")	97	97
9.5 mm (3/8")	64	69
4.75 mm (No. 4)	17	20
2.00 mm (No. 10)	8	11
0.42 mm (No. 40)	5	7
0.18 mm (No. 80)	3	5
75 μm (No. 200)	2	3

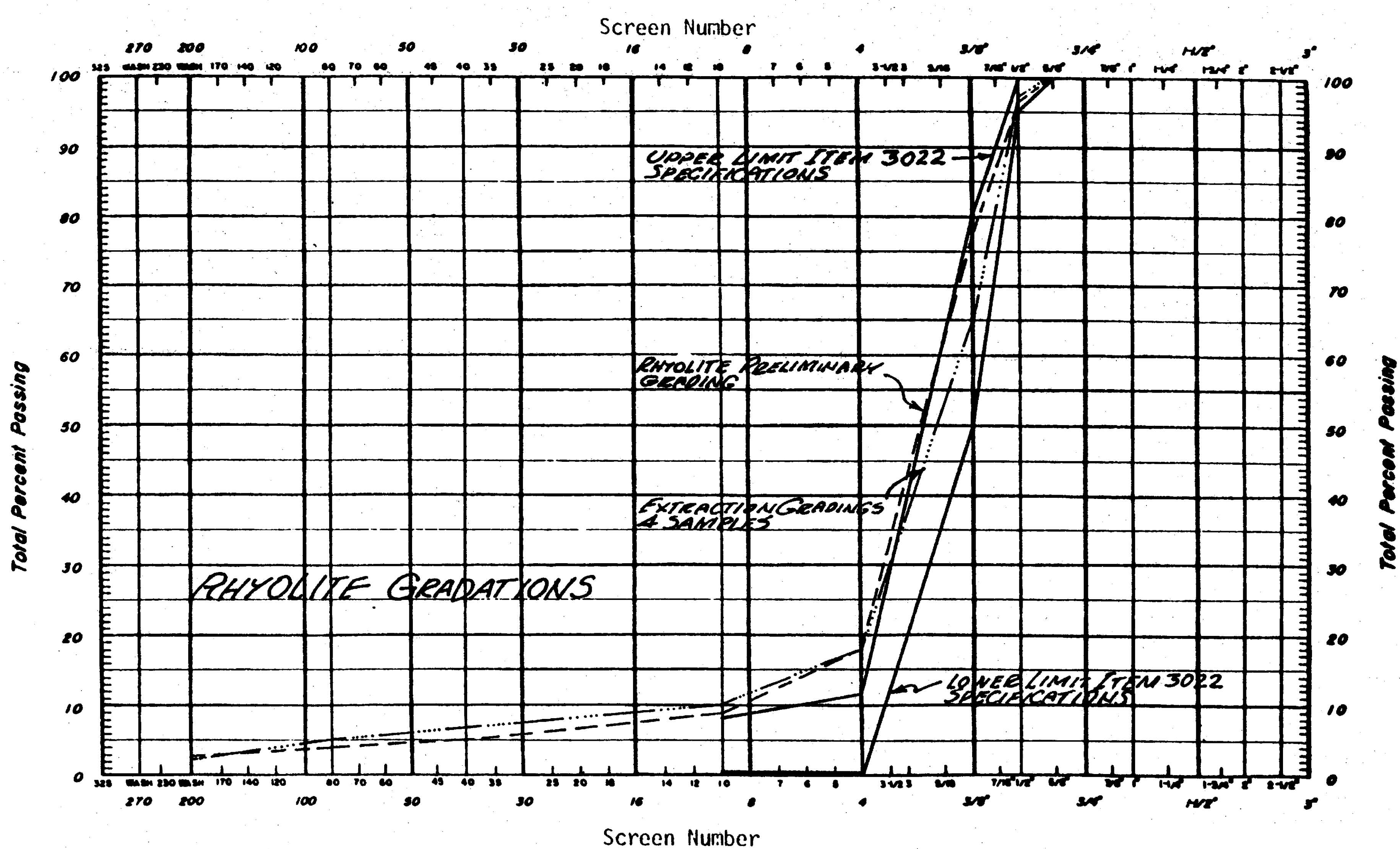


Figure 6 Sieve analyses of rhyolite aggregate used in Nacogdoches field trials

Metric Conversion: 1 in = 25.4 mm

of SEA binder for the asphalt binder in the conventional mixture, with the actual proportions of sulphur and asphalt in the SEA binder being based on a weight percentage of the total SEA binder weight. Thus, if 14 percent by volume of the conventional paving mixture were pure asphalt, then the percentage by volume of the SEA binder would still represent 14 percent by volume of the paving mixture. Sample calculations for determining the proportions of sulphur and asphalt in a given SEA binder are outlined below. These calculations are for an equal volume substitution of SEA binder for asphalt in a paving mixture having 7.3 weight percent pure asphalt binder.

Given: 100 grams conventional OGFC mix

7.3% asphalt cement binder by weight of total mix

Aggregate specific gravity = 2.45

Asphalt cement specific gravity = 1.03

Sulphur specific gravity = 2.00 (at ambient temperature)

SEA composition = 35/65 weight ratio

Required: Convert 7.3 weight percent pure asphalt to equal volume percent of 35/65 SEA binder.

Solution:

(1) 100 grams of OGFC mix - 7.3 grams of asphalt = 92.7 grams of aggregate

(2) Volume of aggregate = $\frac{92.7 \text{ grams}}{2.45 \text{ grams/cc}}$ = 37.83 cc

(3) Volume of asphalt = $\frac{7.3 \text{ grams}}{1.03 \text{ grams/cc}}$ = 7.08 cc

(4) Total volume of aggregate plus asphalt = 44.91 cc

(5) Percent volume of asphalt = $\frac{7.08 \text{ cc}}{44.91 \text{ cc}}$ (100%) = 15.76%

(6) Volume of SEA = Volume of asphalt = 7.08 cc

(7) Weight of 7.80 cc volume of 35/65 SEA binder = X

and $\frac{0.35X}{2.00 \text{ grams/cc}} + \frac{0.65\ X}{1.03 \text{ grams/cc}} = 7.08 \text{ cc}$

$0.175X + 0.631X = 7.08 \text{ cc X grams/cc}$

$0.806X = 7.08 \text{ grams}$

$X = 8.78 \text{ grams}$

(8) Weight of aggregate plus SEA binder = 92.7 grams + 8.78 grams = 101.48 grams

(9) Aggregate percent weight = $\frac{92.7 \text{ grams}}{101.48 \text{ grams}}$ (100%) = 91.3%

(10) Weight percent of 35/65 SEA binder = 100% - 91.3% = 8.7%

(11) Weight of 35 percent sulphur in 35/65 SEA binder =

0.35 (8.78 grams) = 3.07 grams

(12) Weight of 65 percent asphalt in 35/65 binder =

0.65 (8.78 grams) = 5.71 grams

(13) Volume of 35/65 SEA binder =

$$\frac{3.07 \text{ grams}}{2.00 \text{ grams/cc}} + \frac{5.71 \text{ grams}}{1.03 \text{ grams/cc}}$$

Volume = 1.535 cc + 5.544 cc = 7.08 cc

Mix Design Procedures

Conventional OGFC Mixture: The SDHPT District 11 laboratory personnel designed the open graded friction courses to arrive at the optimum amount of pure asphalt cement by weight and volume and the desired production and construction temperature range to preclude excessive binder rundown.

In the laboratory procedure, the weight of a known loose volume of aggregate is determined, such as a one cubic foot volume, and as a point of beginning, to this volume is added 10 percent by volume of asphalt cement. Both aggregates and asphalt are introduced and mixed thoroughly at a selected temperature. Mixing is considered complete when the aggregate is well coated. The mixture is then placed on a brown paper surface, and the amount of asphalt cement binder that drains off the aggregates where they contact the paper, called "drain down", is then subjectively evaluated. If the amount of drainage at the aggregate-paper contact points could be termed a "slight puddle", then the grade and amount of asphalt and the production temperature may be called acceptable.

District 11 has found from experience that about 10 percent of asphalt cement by volume (based on the loose volume of aggregate) constitutes a point close to being optimum for many aggregates used in OGFC. The production temperature for OGFC has been found to be in the general range of 190°F to 240°F (88°C to 116°C) for an AC-20 grade of pure asphalt.

An example of the calculations used to determine asphalt cement binder percent by weight and volume for one trial at a selected temperature is given below in English Units. Metric conversions are given below.*

Given: One cubic foot loose volume of aggregate weighing 88.0 pounds

Asphalt cement, AC-20, with a specific gravity of 1.03

Aggregate specific gravity of 2.45

Required: Find the weight and volume percent of asphalt cement in relation to the aggregate (based on the total mixture).

---

*Metric Conversion: 1 ft = 0.305 m
1 ft^3 = 0.028 m^3
1 lb = 0.454 kg

Solution: (1) Assume volume of asphalt cement, as a starting point, to equal one-tenth of volume of loose aggregate; therefore volume of asphalt =

0.1 cubic foot and volume percent = 10.0.

(2) Weight of asphalt =

$$0.1 \text{ cubic ft} \times \frac{62.4 \text{ lb}}{\text{cubic ft}} \times 1.03$$

Weight of asphalt = 6.43 pounds

(3) Weight percent of asphalt cement =

$$\frac{6.43 \text{ pounds}}{88.0 \text{ pounds}} \times 100\%$$

Weight percent of aggregate = 7.3%

(4) Weight percent of asphalt cement to total mixture =

$$\frac{6.43 \text{ pounds}}{88.0 \text{ pounds} + 6.43 \text{ pounds}} \times 100\%$$

Weight percent of total mixture = 6.8%

(5) Volume of aggregate =

$$\frac{88 \text{ pounds}}{62.4 \text{ pounds/cubic foot}} \times \left(\frac{1}{2.45}\right) = 0.575 \text{ cubic ft}$$

(6) Volume of aggregate and asphalt =

0.575 + 0.10 cubic ft = 0.675 cubic ft

(7) Volume percent of asphalt to volume total mixture

$$= \frac{0.1 \text{ cubic ft}}{0.675 \text{ cubic ft}} \times 100\% = 14.8\%$$

SEA-OGFC Mixture: Texas Transportation Institute laboratory personnel tested six different mix designs (a) containing varying combinations of Gifford-Hill rhyolite coarse aggregate and local sand from the Dickerson Pit near Nacogdoches and (b) containing varying combinations of asphalt cement binder and sulphur extended binders to arrive at a probable choice of SEA binder mix design to employ in the Nacogdoches field trials. These tests were in accordance with the procedures listed under "Optimum Mixing Temperature" of the Appendix A of NCHRP 49 (4) which appendix describes an updated Federal Highway Administration design procedure for open-graded friction courses using pure asphalt cement and selected aggregates. Table 3 summarizes these tests.

The following footnotes apply to Table 3:

(1) The amount of rhyolite used in all tests was 1000 grams with a bulk specific gravity of 2.59 giving a bulk volume of 386.1 cubic centimeters.

(2) For SEA binders, the asphalt cement was mixed with the aggregates first, then the sulphur at 270°F(132°C) to 290°F(143°C) was added and mixed.

Table 3 TTI laboratory test mixes for OGFC design

Test Mix Number	Aggregates	Binder Contents (By volume of aggregate + binder)	Testing Temperature	Drainage Observations
1	Rhyolite coarse aggregate	10% AC-20	$240^oF (116^oC)$	15 minutes = slight 60 minutes = slight
Observation after mixing	Looks relatively wet and good coating			
2	Rhyolite coarse aggregate	10% SEA (35/65)	$240^oF (116^oC)$	15 minutes = good 60 minutes = good
Observation after mixing	Looks relatively wet and good coating			
3	Rhyolite coarse aggregate + 5% (by weight) field sand	10% SEA (35/65)	$240^oF (116^oC)$	15 minutes = slight 60 minutes = slight
Observation after mixing	Relatively dry surface on aggregates			
4	Rhyolite coarse aggregate + 10% (by weight) field sand	10% SEA (35/65)	$240^oF (116^oC)$	15 minutes = no drainage 60 minutes = very slight
Observation after mixing	Aggregate not coated completely			
5	Rhyolite coarse aggregate + 5% (by weight) field sand	12% SEA (35/65)	$240^oF (116^oC)$	Not tested
Observation after mixing	Looks relatively wet on aggregate surface and good coating			
6	Rhyolite coarse aggregate + 5% (by weight) field sand	15% SEA (35/65)	$240^oF (116^oC)$	15 minutes = good 60 minutes = good
Observation after mixing	Looks relatively wet on aggregate surface and good coating			

(3) The specific gravity of the field sand was 2.60.

(4) The asphalt cement was added to the aggregate at 250-255°F (121-124°C).

(5) The amount of AC-20 binder in Text Mix Number 1 to give 10% volume of aggregate was 38 grams at a specific gravity of 1.03.

(6) The testing temperature of 240°F(116°C) was considered to be representative of the production temperatures that would be obtained in the field and was not varied.

In each of the above test mixtures, the aggregates and binder were mixed in the proportions shown. The asphalt cement was heated to 250-255°F(121-124°C) and added to the aggregate first and thoroughly mixed. Then the sulphur at a temperature between 270-290°F(132-143°C) was added to the aggregate and asphalt, and this combination was thoroughly mixed. The resultant mixture of SEA binder and aggregate was then placed on a pyrex plate, returned to an oven at a temperature of 240°F (116°C) and observed at 15 and 60 minutes to determine the amount of drainage at the aggregate contact points, in accordance with the FHWA procedure in NCHRP Report 49 (4).

From the results of the six trial mix designs above, it was decided to proceed on the combination of aggregates, SEA binder and mixing temperature obtained in Test Mix Number 6. For this mixture the following proportions of materials would hold:

1. Weight of rhyolite = 1000 grams
2. Weight of field sand = 50 grams
3. Volume of rhyolite and field sands

   $$= \frac{1000 \text{ gm}}{2.59 \text{ gm/cc}} + \frac{50 \text{ gm}}{2.60 \text{ gm/cc}}$$

   Volume of rhyolite plus field

   = 386.1 cc + 19.2 cc = 405.3 cc
4. Volume of 15% SEA(35/65) = 15% of 405.3 cc = 6.08 cc
5. Weight of SEA binder = X gm;

   $$\frac{0.35X}{2.00 \text{ gm/cc}} + \frac{0.65X}{1.03 \text{ gm/cc}} = 60.8 \text{ cc};$$

   $$0.806X = 60.8 \text{ cc(gm/cc)}$$

   $$X = 75.4 \text{ gm}$$
6. Weight of sulphur = 0.35 (75.4) = 26.4 gm.
7. Weight of asphalt = 0.65 (75.4) = 49.0 gm.
8. Weight percent of SEA binder total mixture

   $$= \frac{75.4 \text{ gm}}{1050 \text{ gm} + 75.4 \text{ gm}} (100\%);$$

   Weight percent = 6.7%

Final Selection of SEA Binder OGFC Mix Design

The sulphur-extended-asphalt binder open graded friction course mixture design finally selected for the Nacogdoches field trials consisted of the following:

(1) Aggregate = 100 percent Gifford-Hill rhyolite

(2) Binder = 15 percent by volume of aggregate of SEA (35/65)

(3) Production Temperature = Approximately 240°F(116°C)

It was decided to eliminate the field sand because construction degradation of the rhyolite occurring between the dryer-drum plant mixing and final compaction on Loop 495 would achieve the desired 10 percent of aggregate passing the No. 10(2.00 mm) sieve. Under the above design the weight percent of the 15 percent by volume of the SEA (35/65) binder is 6.7%, and the weight percent of pure asphalt cement would be 5.6%.

Specific Gravities

The specific gravities for the sulphur and the Texaco AC-20 asphalt cement used on the project were determined to be 2.00 and 1.03 respectively, with the specific gravity for the asphalt cement measured by the Materials and Tests Division, D-9, of the State Department of Highways and Public Transportation.

Manufacture of SEA Binder

The SEA (35/65) binder for the Nacogdoches SEA-OGFC field trials on Loop 495 was produced by the shearing action of the aggregates in concert with the asphalt and sulphur in the dryer drum. The hot asphalt at 280°F to 300°F(138°C to 149°C) was first introduced into the aggregates in the dryer drum at a fixed point 14 feet (4.3 meters) down from the inlet end of the dryer drum. The liquid sulphur at a temperature of 280°F (138°C) was introduced into the already partially mixed asphalt cement and aggregate at a point from 5 to 9 feet (1.5 to 2.7 meters) downstream from the liquid asphalt entry point in the dryer drum.

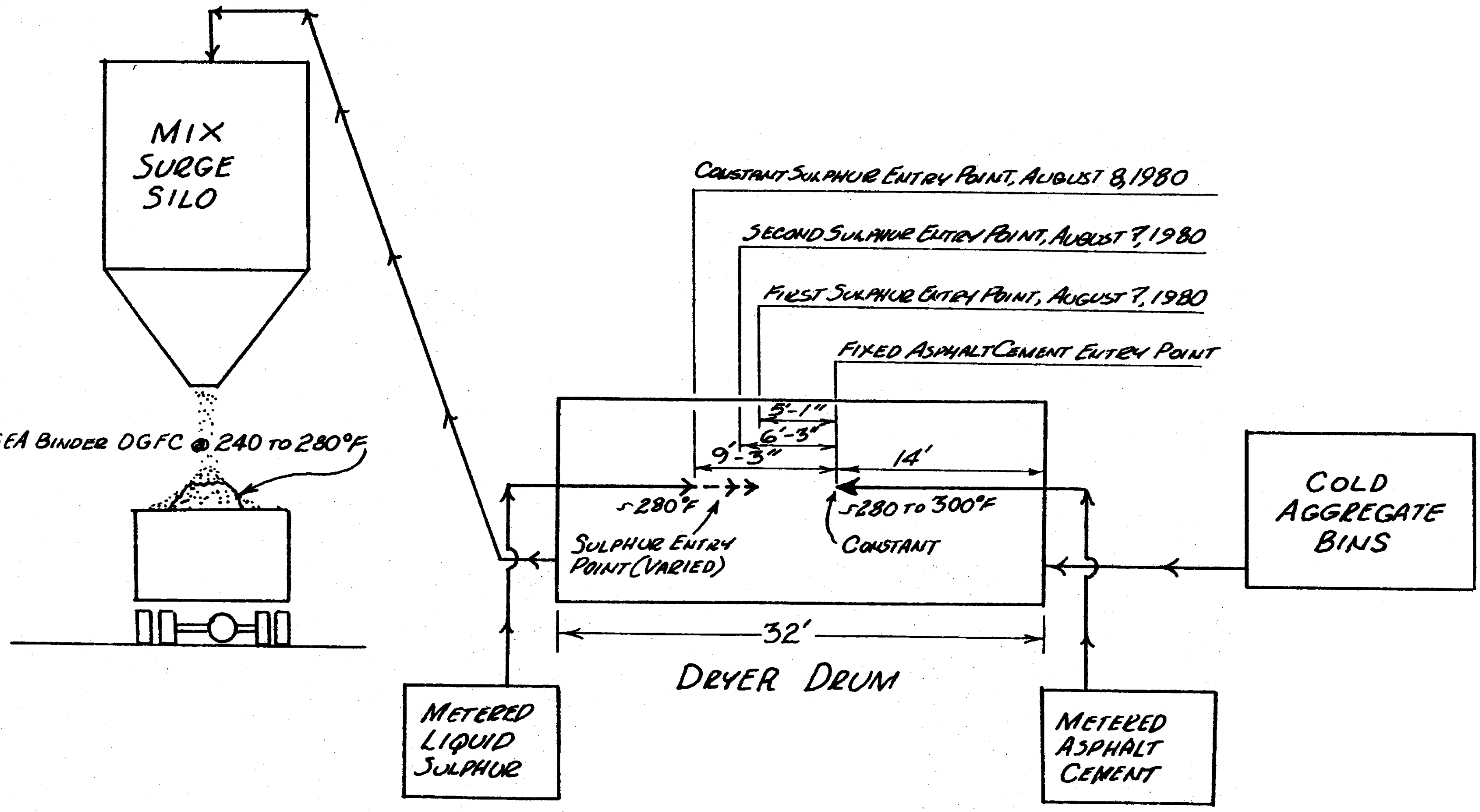
The point of entry of the sulphur was started at 13 feet(4.0 meters) from the outlet end of the drum on August 7 and then changed to 12 (3.7) and finally 9 feet (2.7 meters) on August 8. These sulphur entry locations provided from 5 to 9-foot (1.5 to 2.7 meter) distances between asphalt and sulphur entry points in the dryer drum for the dates of August 7 and August 8. The 9-foot (2.7-meter) distance seemed adequate for the desired production of the SEA binder. The schematic showing the points of entry for the asphalt and sulphur into the dryer drum is shown in Figure 7. Figures 8 and 9 show the sulphur handling tanks and the insulated lines carrying the sulphur into the dryer drum.

Additives

Silicone at a rate of 40 parts per million by weight was added to the hot asphalt cement in the Moore Brothers storage tank prior to its use in the dryer drum. This material was Dow Corning 2000 silicone.

The silicone fluid acts as a construction aid during production and laydown of the SEA-OGFC paving mix, serving to improve moisture release and to reduce pulling and tearing of the mix.

Anti-stripping agent was not used on the project.



Metric Conversion: 1 ft = 0.305 m
$^{o}C = 5/9(^{o}F - 32)$

Figure 7 Schematic of dryer-drum plant showing sulphur and asphalt entry points into dryer drum

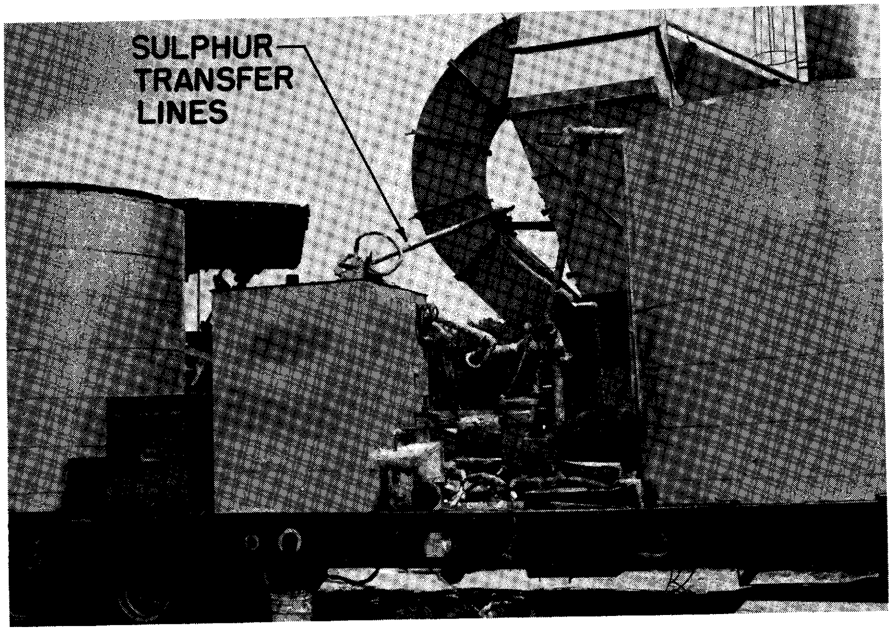


Figure 8 Sulphur storage tanks, pump and insulated line to dryer drum

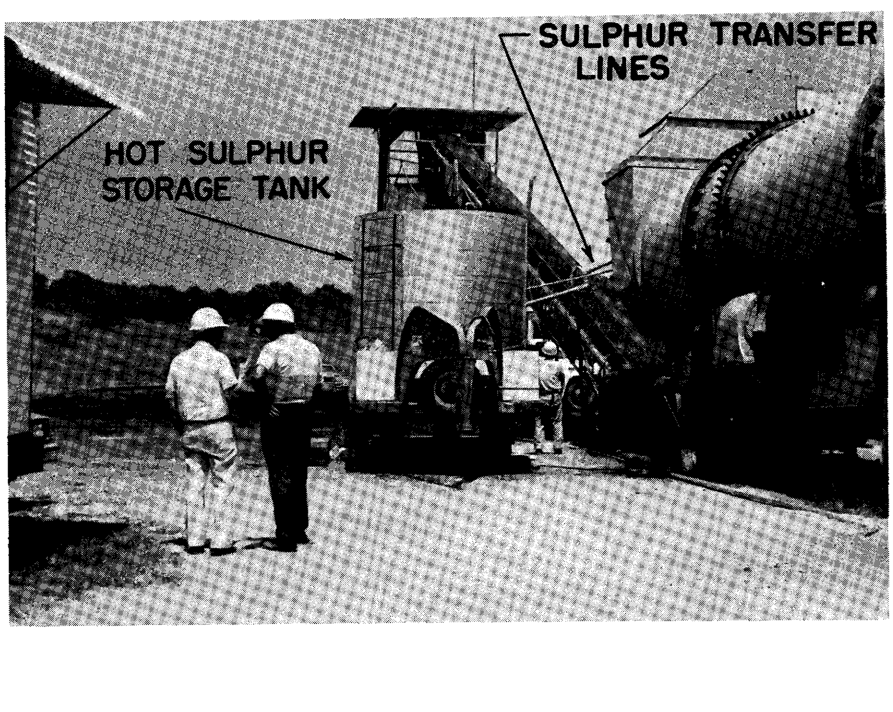


Figure 9 Sulphur storage tank, insulated lines and dryer drum

III. CONTRACTORS EQUIPMENT

Hot-Mix Plant

The hot-mix plant for producing the SEA-OGFC paving mixture is a Cedar-Rapids Dryer Drum Plant, Model 10032 built in 1973. The normal operating capacity of the plant is 650 tons per hour (589,680 kg/hr). The cold aggregate feed utilizes a standard belt feed from the cold bins. The plant control system is automated. Figures 10, 11 and 12 provide views of the plant showing progression of hot mix production from cold feeding of aggregates to the exit of finished mix from the dryer drum to the vertical surge tank.

Intermittent storage of the asphaltic paving mixture was provided for by a 50-ton (45,350 kg) vertical surge tank which is shown in Figure 13.

Emission Control

Control of stack emissions for the Moore Brothers dryer drum plant was provided by passing dust and gases from the production through a wet scrubber. The scrubber water pH was controlled in the approximate range of 9 to 11 by intermittent use of hydrated lime.

Haul Trucks

The haul trucks used to transport the SEA-OGFC paving mixture from the plant to the roadway were standard dump trucks of 14-ton (12,698 kg) net load capacity.

The Paver

The paving machine for the SEA-OGFC paving mixture was a Blaw-Knox, Model PF-180H, built in 1975. The paving speed was about 45 feet per minute (13.7 meters per minute). Figure 14 shows a haul truck unloading SEA binder OGFC mixture into the paver on the outside north-bound lane of Loop 495.

Rollers

The roller used to compact the SEA-OGFC pavement mixture was a 1969 Ferguson Model SP-266 tandem steel wheel roller (See Figure 15), weighing 10 tons (9072 kg). This roller had a vibratory capacity that was not used. A close-up view and a general view of the completed overlay is shown in Figure 16 and 17, respectively.

IV. PLANT MODIFICATIONS & OPERATIONS FOR SEA-OGFC PRODUCTION

Trailer Mounted Sulphur Handling Unit

Sulphur handling capacity for the Moore Brothers plant was provided on a self-contained trailer mounted unit provided by Texasgulf, Incorporated of Newgulf, Texas. The liquid sulphur handling equipment on this unit consisted of (a) two 20-ton (18,140 kg) capacity liquid sulphur storage tanks heated by hot oil, (b) a liquid sulphur pumping unit, (c) a liquid sulphur meter, and (d) insulated liquid sulphur feed and return lines. All of the above equipment was mounted on a single goose-neck trailer and was set up at the Moore Brothers plant site

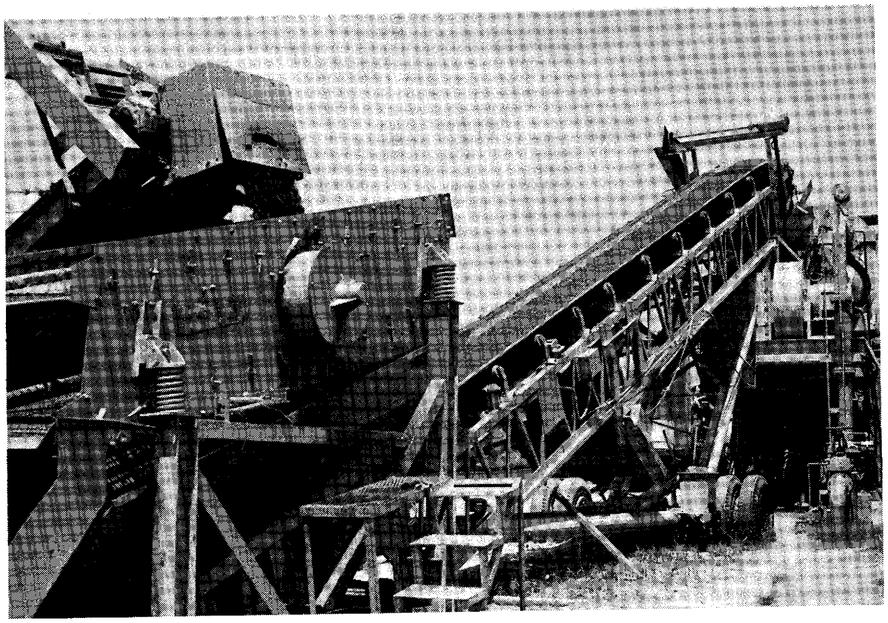


Figure 10 Aggregate from cold feed moving to dryer drum

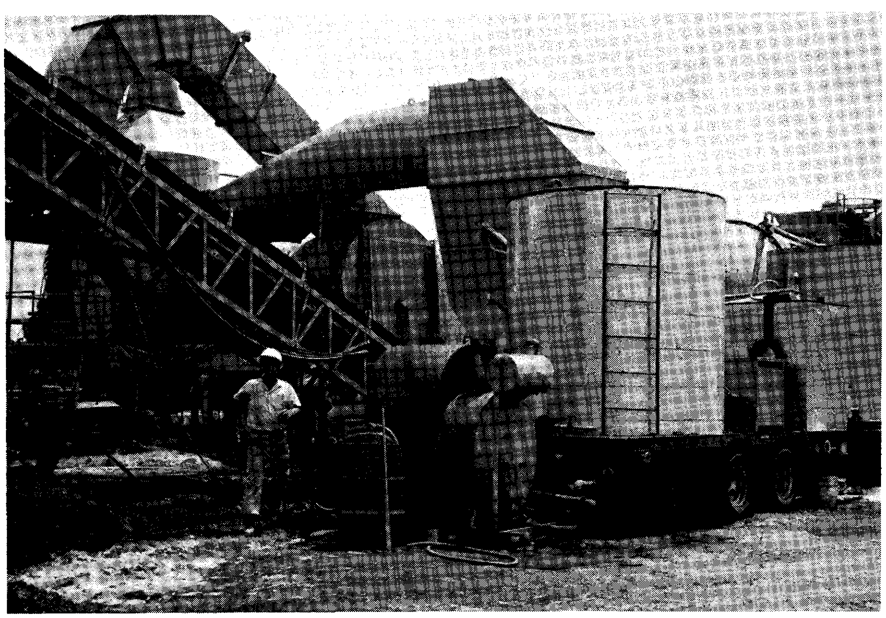


Figure 11 Discharge end of dryer drum, sulphur handling unit and conveyor belt to vertical surge tank

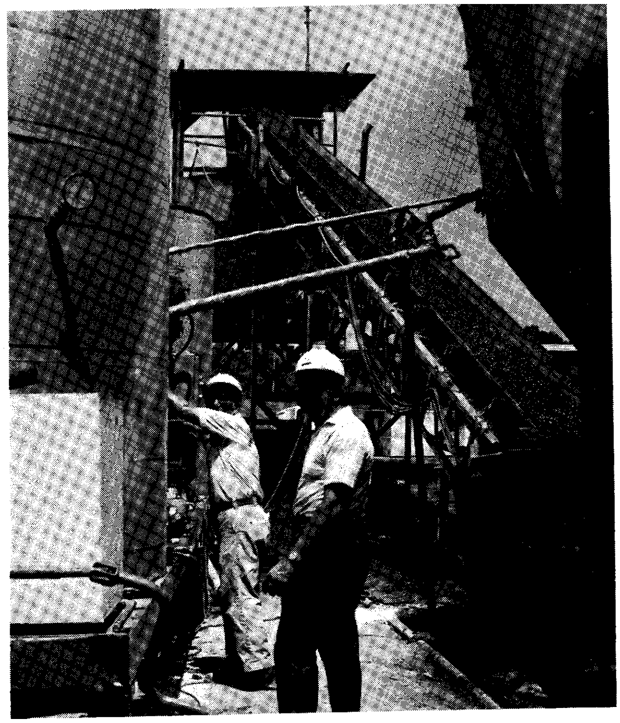


Figure 12 Completed hot mix production moving to vertical surge tank

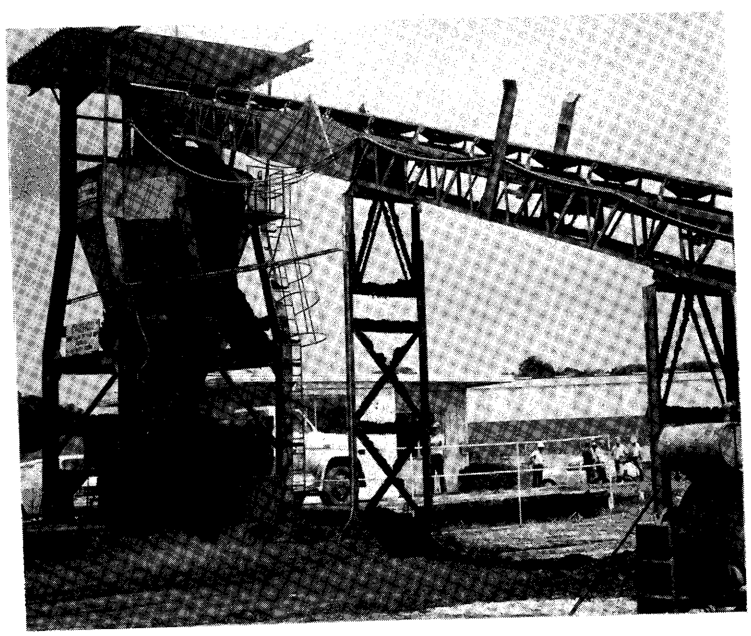


Figure 13 Vertical surge tank discharging hot mix to haul truck

Figure 14 Haul truck and paver laying SEA binder OGFC on Loop 495 northbound lanes

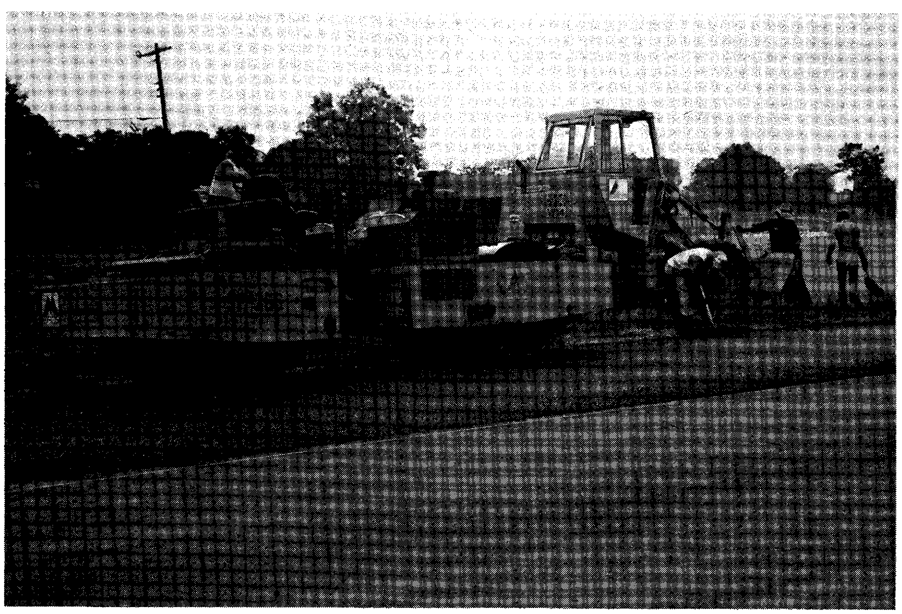


Figure 15 Steel wheel roller (in non-vibratory mode) compacting OGFC mix on Loop 495

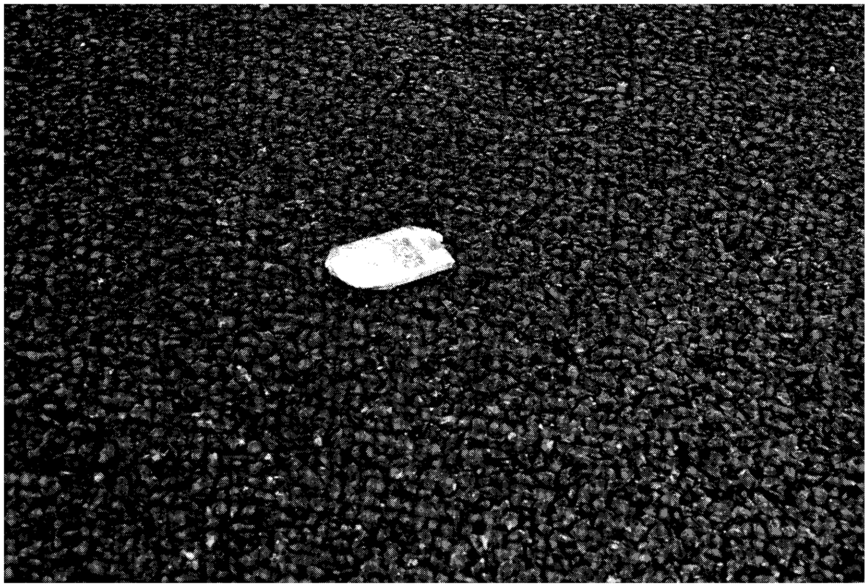


Figure 16 Close-up view of finished SEA binder OGFC paving

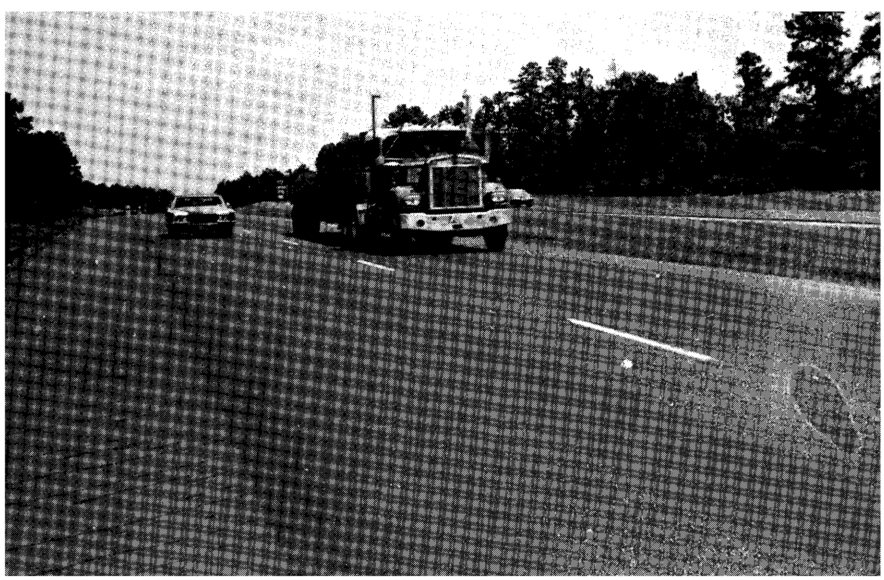


Figure 17 Completed SEA binder OGFC paving on Loop 495 northbound lanes

using 24 man-hours of labor. The Texasgulf handling system was designed to be able to heat liquid sulphur from a storage temperature of 270°F (132°C) to a temperature of 340°F(171°C) by means of hot oil heating.

The work of preparing the Moore Brothers dryer-drum plant also involved running hot liquid sulphur feed lines from the trailer mounted unit to the appropriate position of feeding the liquid sulphur to the hot asphalt cement and aggregate mixture in the dryer drum. This work was done in a manner which allowed the position of discharge of the sulphur inside the drum to be varied.

All of the above work of setting up the sulphur handling system was accomplished gratis by Texasgulf, Incorporated, and the cost of the liquid sulphur delivered to the dryer-drum plant was borne by The Sulphur Institute.

Operation of Plant

It was desired that Moore Brothers plant operate over a range of mixing temperatures from 230°F(110°C) to 300°F(149°C) in producing the sulphur-extended-asphalt binder open graded friction course material to investigate any changes in the properties of the SEA binder OGFC paving materials as the temperature varied. Daily construction reports supplied by the SDHPT show that on August 7, 1980 mixing temperatures in the dryer drum of 265°F(129°C), 280°F(138°C) and 270°F (132°C) were obtained at 9:12 A.M., 11:05 A.M. and 1:40 P.M. On August 8, only one mixing temperature of 250°F(121°C) taken at 8:11 A.M. Mix temperatures measured in the field immediately behind the laydown machine cover the range from 290°F(143°C) to 230°F(110°C).

At the start of operations on August 7, the point of entry of the liquid sulphur into the dryer drum was 13 feet (4.0 m) upstream of the discharge end of the drum. This location gave a 5-foot (1.5 m) distance between the points of entry of the sulphur and the asphalt cement. On the same day, the sulphur entry point was moved to 6 feet (1.8 m) from the fixed asphalt entry point, and on August 8 the sulphur entry point was moved to 9 feet (2.7 m) as shown on Figure 7. The reason for the above changes was to help clear up the excessive plume on the plant exhaust stack shown in Figure 18. The move to 9-foot (2.7 m) location plus a lowering of the dryer drum operating temperature from approximately 270°F(132°C) to 250°F(121°C) succeeded in virtually eliminating the exhaust stack plume (See Figure 19). Also, water was added to the aggregate cold feed on August 8 which is believed to have acted to reduce exhaust particulate matter.

Delivered Sulphur

A delivery schedule of the molten sulphur as obtained from the International Chemical Company was as follows.

Date	Transport Numbers	Invoice Amount, lbs
August 7, 1980	One	51,640 (23,444 kg)
August 8, 1980	None	0 (0 kg)
Total amount invoiced		51,640 (23,444 kg)

(Metric conversion: 1 lb = 0.454 kg)

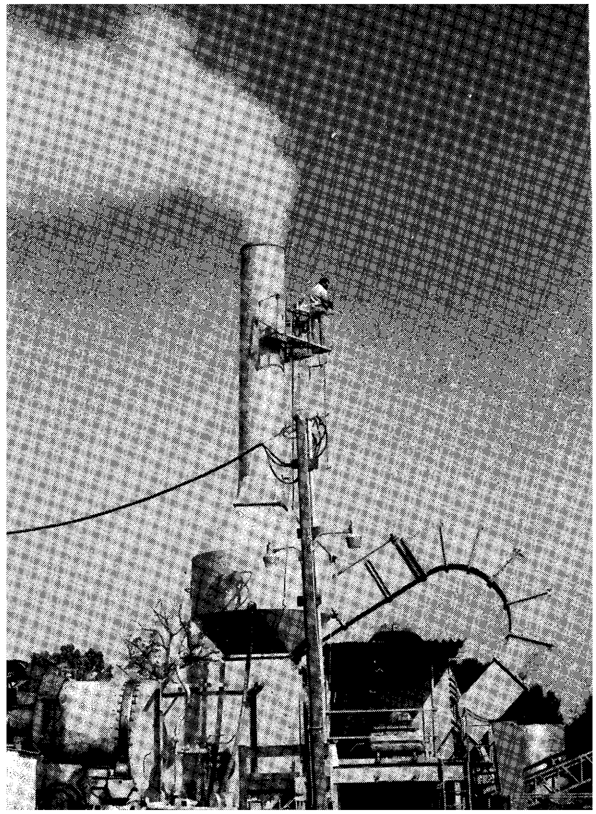


Figure 18 View of dryer-drum plant exhaust stack showing excessive vapor plume

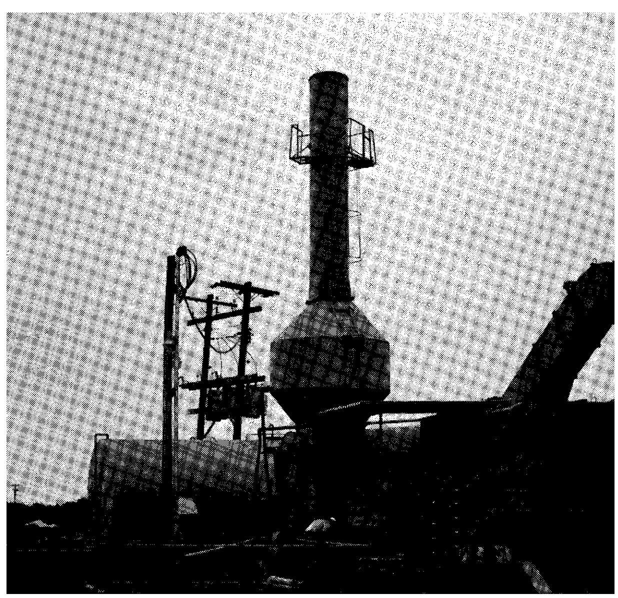


Figure 19 View of dryer-drum plant exhaust stack showing negligible vapor plume

Summary

1. Total weight of sulphur delivered, per invoice, lb = 51,640 (23,444 kg)

2. Total weight of sulphur used in SEA binder OGFC trial sections from the SDHPT engineer's records of tons of mix, asphalt and sulphur placed, lbs = 44,284 (20,105 kg)

Item 1 minus Item 2 = 7356 lbs (3387 kg) giving the total amount of sulphur delivered to the Moore Brothers plant but not used on the roadway in the SEA binder OGFC, which amount of sulphur represents 14 percent of the total amount of sulphur delivered. Most of this sulphur was available for use by the SDHPT for other purposes.

SEA Binder OGFC Production Rates

The total mix production of SEA binder OGFC paving mixture was approximately 429 short tons(389,103 kg) for August 7, 1980 and approximately 361 short tons (327,427 kg) for August 8 according to the summary of haul tickets compiled by the SDHPT engineers. The AC-20 used for those two days was approximately 23 and 20 tons(20,861 and 18,140 kg) respectively, and sulphur tonnages used according to the SDHPT summary were approximately 12 and 10 (10,884 and 9070 kg) respectively. These figures are summarized in Table 4 below.

Table 4 SEA binder OGFC production rates

Date	Total Weight of SEA-OGFC Mix Produced lbs (tons)	Weight of Asphalt Used lbs (tons)	Weight of Sulphur Used lbs (tons)	Weight Ratio of Sulphur to Asphalt
August 7, 1980	858,460(429.23)	46,106(23.05)	24,729(12.36)	35/65
August 8, 1980	721,730(360.89)	40,410(20.21)	19,555(9.78)	33/67
Totals	1,580,240(790.12)	86,516(43.26)	44,284(22.14)	34/66

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

SEA Binder Weight Percentage Obtained

Information contained in the above Table 4 compiled from SDHPT summaries of asphalt and sulphur used on August 7 and 8 may be used to check the weight percentages of sulphur and asphalt obtained in production of the SEA binder. For instance, on August 7, 35.41 total tons (32,117 kg) of sulphur and asphalt cement were used in the SEA binder and the percentages of weight for sulphur and asphalt of this total were 34.9 and 65.1 to yield a (35/65) SEA binder, which was desired. For the combined usage of sulphur and asphalt for August 7 and 8, an SEA binder with a ratio of 34/66 sulphur/asphalt was obtained which was close to the target value.

The volume percent of the SEA binder of the total SEA-OGFC mixture for the two days production may also be checked from the figures in Table 4. With the aggregates being 100 percent rhyolite with a specific gravity of 2.59, and the sulphur and asphalt having specific gravities of 2.00 and 1.03, respectively, the volume percent of SEA binder would be as follows:

Volume Percent SEA

$$= \frac{\frac{22.14 \text{ tons of sulphur}}{2.00} + \frac{43.26 \text{ tons of AC-20}}{1.03}}{\frac{790.12 \text{ tons} - 65.40 \text{ tons}}{2.59} + \frac{22.14 \text{ tons}}{2.00} + \frac{43.26 \text{ tons AC-20}}{1.03}} (100\%);$$

$$\text{Volume Percent SEA} = \frac{11.07 + 42.00}{279.81 + 11.07 + 42.00} (100\%) = \left(\frac{53.07}{332.88}\right)(100\%);$$

$$\text{Volume Percent SEA} = 15.94\%^{*}$$

Metric Conversion 1 ton = 907 kg

V. CONSTRUCTION OPERATIONS

Introduction

Construction operations for placing the sulphur-extended-asphalt binder open graded friction course on the Loop 495 in Nacogdoches were commenced Thursday morning August 7. Operations were completed on the afternoon of Friday, August 8, with the plant operations closing at 5:00 P.M. According to the summary prepared by SDHPT personnel from paving mixture haul records and other records, the northbound inside lane and some shoulder sections of Loop 495 were paved with the SEA binder OGFC mixture on August 7, and the outside lane and some shoulder lengths were paved on August 8. The paving with the SEA binder OGFC was accomplished from Station Number 89+00 to Station Number 185+00 of the controlling State Project.

Production of SEA Binder OGFC Mixture

The production of the SEA binder OGFC mixture was initiated on August 7 and was governed by SDHPT Special Specification 3022 for Plant Mix Seal (Specification 3022.000 adopted 5-74) and by the applicable notes in the "General Notes and Specification Data" for Item 3022. The grading and other requirements established by District 11 for the aggregate utilized on the project which were specified in the General

* This compares to 15.76% by volume design value of pure asphalt in the example presented earlier in this report.

Notes and Specification Data are given below (5).

"Item 3022. Plant Mix Seal

From October 1st through March 31st, no plant mix seal shall be placed without written permission of the Engineer.

If crushed stone is used for the mineral aggregate, it shall be either calcareous sandstone or rhyolite.

For mixtures composed of crushed stone, the asphaltic material shall form from 5.0 to 8.5 percent of the mixture by weight. For mixtures composed of lightweight aggregate, the asphaltic material shall form from 10.5 to 16.0 percent of the mixture by weight.

Tack coat shall be applied at the approximate rate of 0.05 gal/yd^2 [0.23 $liters/m^2$].

The Engineer may require the use of an anti-stripping agent. This work will not be paid for separately but shall be part of the unit bid for this item."

"Master Grading for Grade 3 Mineral Aggregate

	Percent by Weight
Retained on 5/8" [15.9 mm] sieve ----------------------	0
Retained on 1/2" [12.7 mm] sieve ----------------------	0-5
Retained on 3/8" [9.5 mm] sieve -----------------------	20-50
Retained on No. 4 [4.75 mm] sieve----------------------	88-100
Retained on No. 10 [2.00 mm] sieve --------------------	92-100"

The actual production of the SEA binder OGFC paving mixture commenced at 9:04 A.M. on August 7 using 100 percent rhyolite aggregate with a target SEA binder of 35 percent sulphur and 65 percent AC-20 asphalt. As noted earlier, approximately 429 tons (389,100 kg) of SEA binder OGFC mixture was placed on August 7, and plant operations were ceased at 4:01 P.M. Production began on August 8 at 8:02 A.M. and ended at 3:00 P.M. Approximately 361 tons (327,430 kg) of SEA binder OGFC were placed on this date.

Pavement Design

As shown in the pavement section for Loop 495 in Figure 3, approximately 3/4 in (19.1 mm) of SEA binder OGFC was placed as the pavement wearing course. This overlay, as was the conventional OGFC, was intended to enhance the surface riding properties of the pavement by accomplishing the following:

(1) Improved skid resistance and lessened probability of dynamic hydroplaning during high intensity rainfall,

(2) Reduced splash and spray from vehicles during rainy weather,

(3) Improved night visibility during wet weather by break up of the glaring surface,

(4) A smooth riding surface providing a uniform appearance and lower highway noise levels and

(5) Improved visibility and durability of painted traffic markings.

The attainment of the above listed benefits would be achieved by the high surface porosity and high inner permability of the OGFC wearing layer which allows surface water to percolate down and through the OGFC layer minimizing the amount of water carried on the pavement surface. The porous surface and permeable layer also minimize the development of percussion cups thus reducing highway noise. The porous surface serves to break up light reflection from surface water and thus helps reduce the glare surface that occurs on dense graded pavement surfaces.

Also worthy of note from Figure 3 is that SDHPT Item 320, one course surface treatment was placed on Loop 495 prior to the placement of the SEA binder OGFC and the conventional OGFC (SDHPT Item 3022, Plant Mix Seal). The purpose of the one course surface treatment was to seal the existing pavement surface before the OGFC was placed because OGFC pavements require that the old pavement surfaces be waterproof. OGFC pavements tend to retain water for several days, and this water will cause the rapid deterioration of any water susceptible underlying layers that are not sealed. OGFC pavements have caused much damage in such cases where prior sealing was not accomplished.

Temperature Control of SEA Binder OGFC Pavement Mixture

The Daily Construction Reports of the SDHPT indicate that plant temperatures for the production of the SEA binder OGFC mixture ranged from about 250°F(121°C) to 280°F(138°C). At this temperature range, the kinematic viscosity of liquid sulphur runs from approximately 12 to 8 centipoise as shown in Figure 5, with the expected optimum "working range" for SEA binders running from approximately 259°F (126°C) to 302°F(150°C) according to this same figure. The approximate viscosity for AC-20 asphalt used in the SEA binder would run 410 centipoise for the 250°F (121°C) to 280°F (138°C) range.

TTI researchers wanted to investigate laydown temperatures in the range of 230°F(110°C) to 275°F(135°C). Temperatures obtained behind the laydown machine showed minor reductions from the plant values ranging from about 235°F(113°C) to 270°F(132°C). The haul distance for the SEA binder OGFC paving mixture was approximately 8 miles(13 km) (6); therefore, the haul distance was not great enough to appreciably lower the temperature of the heated mixture from the plant even though the haul trucks were not covered. High summer temperatures also served to reduce the drop in mix temperature from the plant to the roadway even though partly cloudy conditions existed on August 7.

Aggregate Control

Table 5 shows the field sieve analyses of the rhyolite as shown on SDHPT daily construction reports for August 7 and 8. Sieve

Table 5 Daily field sieve analyses of rhyolite aggregate

Sieve Analysis Number	August Date	Lane	Weight Percent Passing Sieves 5/8" (15.9 mm)	1/2" (12.7 mm)	3/8" (9.5 mm)	No. 4 (4.75 mm)	No. 10 (2.00 mm)	No. 40 (0.42 mm)	No. 80 (0.18 mm)	No.200 (75 μm)
1*	7	M or A	100	98	63	13	6			
2	7	M or A	100	98	64	16	9			
3	7	M or A	100	99	64	16	9			
4	7	M or A	100	98	63	19	11			
5*	8	L or B	100	97	64	17	8	5	3	2
6	8	L or B	100	97	69	20	11	7	5	3

Note: The percent passing and percent retained figures from the SDHPT Construction Reports were changed to total percent passing by weight for purposes of ready analysis.

* These sieve analyses were obtained from samples taken from the feeder belt from the cold bins to the dryer drum. The others represent extraction analyses.

analyses No.'s 1 and 5 were taken on the belt from the cold bins to the dryer drum. The sieve analyses for August 7 do not show the breakdown of minus Sieve No. 10(2.00 mm) material as those for August 8 do. Both sets of analyses showed an average of 9 percent by weight passing the No. 10 (2.00 mm) sieve. The analyses for August 8 show from 2 to 3 percent of material passing the No. 200(75 μm) sieve which is considered of advantage for binder film maintenance. Design values for minus No. 10 (2.00 mm)and minus No. 200(75 μm) were 10 and 3 percent, respectively.

Haul and Placement

Dead haul to the project was approximately 8 miles (13 km) over surfaced highways. No significant problems were encountered with the hauling and the placing of SEA binder OGFC paving mixture.

Rolling of the SEA Binder OGFC Mixture

The SEA binder OGFC mixture was compacted by the Ferguson Model SP-266 tandem steel wheel roller, using two coverages in a non-vibrating mode. Approximately 3/4 to one inch (19.1 to 25.4 mm) of the SEA binder OGFC paving mixture was placed, although the figures in the Daily Construction Report of rates of 1 cy/37sy(1 m^3/40.5 m^2) and 1 cy/38sy (1 m^3/41.6 m^2) for August 7 and August 8 respectively indicate that an average of about 1 inch(25.4 mm), a rate of 1 cy/36sy(1 m^3/39.4 m^2), was placed. As noted previously, compaction temperatures of the SEA binder OGFC paving mixture were in the 235°F (113°C) to 270°F (132°C) range which were considered entirely acceptable.

Compaction Requirements

No compaction requirements were set for either the SEA binder OGFC paving mixture or the conventional OGFC paving mixture as those materials are not considered to constitute structural layers. Therefore, no laboratory or field density tests were scheduled or carried out.

Weather Conditions

The weather conditions for the Loop 495 project in Nacogdoches were typical for East Texas in the summer. The weather during placement of the SEA binder OGFC was partly cloudy and hot, with the daily temperatures for August 7 and 8 ranging from lows of 74°F(23°C) to highs of 98°F(37°C). The weather for the adjacent conventional OGFC section had lows of 71°F(22°C) and highs of 93°F(34°C).

VI. PROJECT MONITORING AND INSPECTION

The monitoring and inspection of the Nacogdoches County SEA binder OGFC project was a joint effort of SDHPT and TTI personnel with assistance from personnel of Texasgulf, Inc. Details of the various inspection operations are given below.

State Inspection

Professional inspection of the production and placement of both the SEA binder OGFC and conventional OGFC paving materials was accomplished by SDHPT personnel from District 11 and from Austin, Texas.

At the field laboratory at the Moore Brothers dryer-drum plant, SDHPT personnel conducted the following tests:

a) Screen analyses of the aggregate from both the extractions of the produced OGFC and SEA binder OGFC paving mixtures and from the combined aggregate feed belt from the cold bins to the dryer drum,

(b) Extractions of the produced paving mixtures to determine the amount of both conventional asphaltic cement and SEA binders in the produced mixtures,

(c) Temperature checks of the completed mixture at the plant and at the laydown machine for the SEA mixtures and

(d) Recordkeeping to account for the amounts of asphalt cement and sulphur that went into the paving mixtures on a daily basis.

In the field, SDHPT personnel from District 11 or Austin were responsible for accomplishing a varied array of project inspection and testing of the SEA binder OGFC and conventional OGFC mixtures that were placed on Loop 495. This inspection and testing covered the following:

a) Monitoring and inspecting the hauling, dumping, laydown and compaction of the OGFC paving mixtures,

b) Taking temperature checks of the OGFC paving mixtures at the project site,

c) Running Dynaflect deflection measurements; Mays Ride Meter pavement serviceability index (SI) measurements and skid resistance measurements to determine skid numbers at 40 and 20 mph(64.4 and 32.2 km/h), SN_{40} and SN_{20} for the finished SEA binder OGFC and conventional OGFC pavement surfaces,

d) Performing sand-patch measurements and water flow or outflow meter measurements to determine the surface texture characteristics and permeability characteristics of the SEA binder OGFC and the conventional OGFC pavement layers and

e) Coring the two different OGFC pavement surfaces to obtain samples to use in laboratory determinations of the air voids and densities of the SEA binder OGFC and conventional OGFC paving mixtures.

<u>TTI Inspection</u>

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

a) Monitoring sulphur dioxide, hydrogen sulfide and particulate sulphur emissions at both the dryer-drum plant site and on the Loop 495 roadway,

b) Running laboratory investigations to determine the densities and air void contents of field cores of the SEA binder and conventional OGFC paving mixtures obtained by the SDHPT personnel and

c) Analyzing and compiling the data obtained from the various field measurements on the OGFC and SEA binder OGFC pavement sections.

Sulphur-Asphalt Binder Compositions

Laboratory extractions on the Nacogdoches Loop 495 were used to determine the total amount of SEA binder used in the OGFC paving mixture placed on August 7 and August 8. The three extractions taken on August 7 revealed total binder contents of 6.7, 7.6 and 7.3 percent by weight of the total mixtures yielding an average binder content of 7.2 percent. One extraction for August 8 showed a total binder content of 8.0 percent.

No field or laboratory attempts were made to test for individual amounts of sulphur and asphalt cement in the SEA binder. Based on previously discussed records kept by SDHPT personnel of tonnages of sulphur and asphalt received, it is evident that the desired goal of a 35/65 SEA binder was essentially attained and that a weight percentage of binder to total mixture of 8.3 percent was achieved, thus yielding a volume of SEA binder equal to a volume of asphalt cement comprising 6.9 percent by weight of the total mixture.

Dynaflect Measurements

Dynaflect deflection measurements were taken at 15 test locations each on the four lanes of Loop 495 on September 9, 1980 by a Layne-Wells dynaflect apparatus in order to compare (at some later date) the measured stiffness of the SEA binder OGFC pavement system with the conventional OGFC pavement system. Both 3/4-inch(19.1 mm) OGFC surface courses were underlain by 3 inches(76.2 mm) of hot mix asphaltic concrete and 12 inches(305 mm) of iron ore flexible base. The one exception is that from Station 87+23 to 126+00 of the northbound lanes of Loop 495 (under the SEA binder OGFC pavement surface) the thickness of the iron ore flexible base is 10 inches(254 mm).

Dynaflect measurements were taken in each travel lane in the direction of traffic. The Loop 495 lane designations for testing purposes are shown in Figure 4. The results of the dynaflect testing are shown in Table 6.

Based on the data in Table 6, the SEA binder OGFC pavement system on the northbound lanes "L" and "M" of Loop 495 appears to have slightly higher pavement stiffness. The pavement system of the conventional OGFC surfacing shown under lanes "R" and "S" shows higher average maximum deflection and Surface Curvature Index (SCI). Both pavement systems show almost the same value for average subgrade stiffness.

Mays Ride Meter Measurements

A Mays Ride Meter (MRM) was used on September 8, 1980 to measure the roughness of both the SEA binder OGFC and conventional OGFC pavement sections from station 89+00 to 185+40 for Loop 495. Mays Meter

Table 6 Dynaflect measurements for Nacogdoches Loop 495

	Test Results			
	Pavement Type			
	SEA Binder OGFC		Conventional OGFC	
	Lane L	Lane M	Lane R	Lane S
Pavement Structural Layers:				
OGFC	3/4 inch		3/4 inch	
Asphalt Concrete Pavement	3 inches		3 inches	
Iron Ore Flexible Base	12 inches *		12 inches	
Dynaflect Results:				
Avg. Maximum Deflection, W_1	0.828 inch	0.763 inch	0.893 inch	0.831 inch
Avg. Surface Curvature Index, SCI	0.313 inch	0.264 inch	0.393 inch	0.282 inch
Avg. Pavement Stiffness Coefficient, AP2	0.48	0.51	0.43	0.51
Avg. Subgrade Stiffness Coefficient, AS2	0.30	0.29	0.31	0.29

Metric Conversion: 1 in = 25.4 mm

* Thickness is 10" from Station 87+23 to 126+00 on northbound lanes.

readings are used to determine a Serviceability Index (SI) number for a pavement which number has a possible range from the worst case of extreme roughness, 1, to the best case of 5. Normally, corrective action is deemed necessary for a pavement when its SI drops to 2.5 or lower.

Mays Meter readings were taken on each lane at 50 mph (80.5 km/h) speed over 0.2 mile (0.32 km) intervals on the Loop 495 project. Table 7 below summarizes the results of the Mays Meter tests.

Table 7 Mays Ride Meter results for Nacogdoches Loop 495

Serviceability Index, SI	Test Results			
	SEA Binder OGFC		Conventional OGFC	
	Lane L	Lane M	Lane R	Lane S
Low SI	4.0	*4.1, *4.0	3.4, *3.6	3.7
Average SI	4.2	*4.3, *4.4	3.9, *3.9	4.1
High SI	4.4	*4.6, *4.7	4.3, *4.1	4.4

Note: An * before the number indicates reading was acquired during rainfall.

All of the above results for Serviceability Index indicate that both SEA binder and conventional OGFC pavements surfaces were placed with acceptable to very good riding surfaces. The SI results show that the SEA binder OGFC paving layer attained a smoother, better riding surface. For both the SEA binder OGFC and the conventional OGFC the inside lanes or lanes "M" and "S" obtained a better riding surface than the outside lanes, "L" and "R".

Visual Evaluation

Both northbound and southbound lanes of Loop 495 were evaluated visually on September 8, 1980 by use of the "Flexible Pavement Evaluation" form which provides for a visual rating of such pavement conditions as rutting, raveling, flushing, failures, alligator cracking, longitudinal cracking and transverse cracking. No distress was noted in either the northbound SEA binder OGFC pavement surface or in the southbound conventional OGFC surface.

Skid Resistance Measurements

Although rhyolite is not an optimum OGFC aggregate due to its polishing characteristics, skid resistance measurements of Loop 495 for comparison purposes were taken with a SDHPT standard ASTM E-274 skid trailer on September 3, 1980. Skidding was done at nominal speeds of 40 mph and 20 mph (64.4 km/h and 32.2 km/h) to determine the skid number at these speeds, SN_{40} and SN_{20}. Both the SEA binder and the conventional OGFC surfaces were tested. Table below summarizes the results.

Table 8 Skid resistance measurements for Nacogdoches Loop 495

	SEA Binder OGFC				Conventional OGFC			
Lane	Lane L		Lane M		Lane R		Lane S	
Number of Tests	18	14	17	17	17	17	17	17
	SN_{20}	SN_{40}	SN_{20}	SN_{40}	SN_{20}	SN_{40}	SN_{20}	SN_{40}
Low Skid Number	33	36	42	38	36	30	43	38
Average Skid Number	47	40	48	41	46	39	51	43
High Skid Number	52	44	52	43	54	46	58	49

Based on the results in the above table, it appears that there was no appreciable difference in skidding frictional resistance in September, 1980 between the SEA binder OGFC and the conventional OGFC pavement surfaces as measured by the SDHPT locked wheel skid trailers, either at 40 mph or 20 mph(64.4 km/h or 32.2 km/h). As would be expected, skid numbers at 20 mph(32.2 km/h) were found to be higher than skid numbers at 40 mph (64.4 km/h) for both pavement surfaces.

Texture Measurements

Texture measurements were taken at 15 locations on each of the northbound lanes "L" and "M" and on each of the southbound lanes, lanes "R" and "S" on September 9, 1980 in order to compare the SEA binder and conventional OGFC surfaces. These tests were run according to the requirements in SDHPT Test Method TEX-436-A, Measurements of Texture Depth by the Sand-Patch Method, using natural sand from Ottawa, Illinois. The results of these tests are given in Table 9.

Based on the results expressed in Table 9, it appears that approximately equivalent average surface textures were obtained for both the SEA binder and conventional OGFC paving mixtures. For the outer lanes, "L" and "R", the conventional OGFC paving mixture provides more texture according to the sand patch method and for the inner lanes, "M" and "S", the SEA binder OGFC pavement has somewhat more texture; however, the difference is not significant.

Table 9 Pavement texture measurements for Loop 495 in Nacogdoches

	SEA Binder OGFC		Conventional OGFC	
	Lane		Lane	
	L	M	R	S
Low Texture Measurement, inches	0.080	0.071	0.080	0.077
Average Texture Measurements, inches	0.093	0.103	0.095	0.091
High Texture Measurement, inches	0.113	0.137	0.119	0.108

Metric Conversion: 1 in = 25.4 mm

OGFC Permeability Measurements

Permeability measurements were taken on September 9, 1980 with a water outflow device at 15 locations on each of the two northbound lanes of Loop 495 surfaced with the SEA binder OGFC material and on each of the two southbound lanes surfaced with the conventional OGFC paving material. The results of the permeabilities attained for both the northbound and southbound lanes are summarized in Table 10 below.

Table 10 OGFC pavement permeability measurements for Loop 495 in Nacogdoches

	SEA Binder OGFC		Conventional OGFC	
	Lane		Lane	
	L	M	R	S
Low Permeability Measurement, K_v, cm/sec	0.383	0.288	0.209	0.266
Average of Permeability Measurements, K_v, cm/sec	0.525	0.533	0.467	0.432
High Permeability Measurement, K_v, cm/sec	0.737	0.800	0.636	0.564

Permeabilities indicated above show significant differences between the SEA binder OGFC surface layer and the conventional OGFC surface layer. The overall average of permeability measurements for the two northbound lanes "L" and "M" is 0.529 cm/sec which is 18 percent higher than the 0.450 cm/sec overall permeability for the conventional OGFC in lanes "R" and "S".

The apparatus for measuring the permeabilities was a variable head permeameter designed by S. C. Britton et al (7) and adapted for field usage. Figure 20 shows a schematic of the permeameter and the equation for computing permeability.

Void Content Measurements

The summary of the void content determinations made on 4-in(101.6-mm) cores obtained by the SDHPT from both the SEA binder OGFC field trials and the adjacent conventional OGFC pavement on Loop 495 is given in Table 11. The laboratory test sequence for pavement cores is shown in Figure 21.

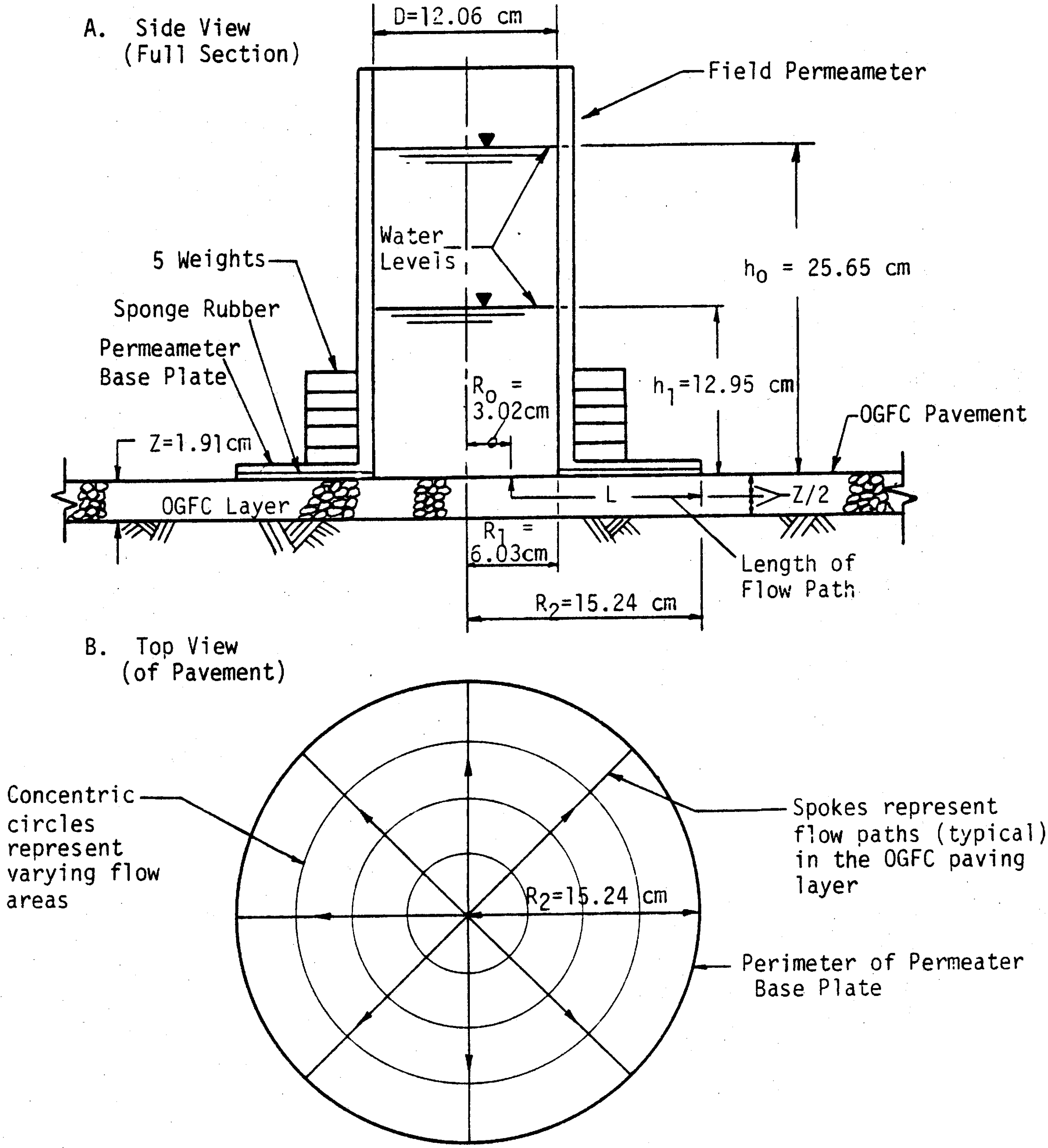
Table 11 Percent voids determinations, bulk specific gravities and maximum specific gravities of conventional and SEA binder OGFC field cores from Loop 495

	Lanes			
	Conventional OGFC (Southbound Lanes)		SEA Binder OGFC (Northbound Lanes)	
	Lane R or B	Lane S or A	Lane L or B	Lane M or A
Number of Core Samples Tested	14	7	13	15
Low Value, % Voids	18.7	24.1	17.4	24.6
Average Value, % Voids (Sawed Samples)	32.8 (5=26.4)	31.2 (1=24.1)	34.3 (1=24.6)	30.2 (3=34.3)
High Value, % Voids	40.3	34.5	42.6	36.9
Average Value, Bulk Specific Gravity	2.129	2.142	2.194	2.299
Average Value, Maximum Specific Gravity	2.263*	2.240*	2.359*	2.333**

* Represents average of 3 core samples
** Represents average of 2 core samples

The results in the above table indicate an average void content of approximately 32 percent for both pavement layers, thus showing no difference between the northbound and southbound lanes. Void contents ranged from lows of 17 to 18 percent to highs of 40 to 43 percent.

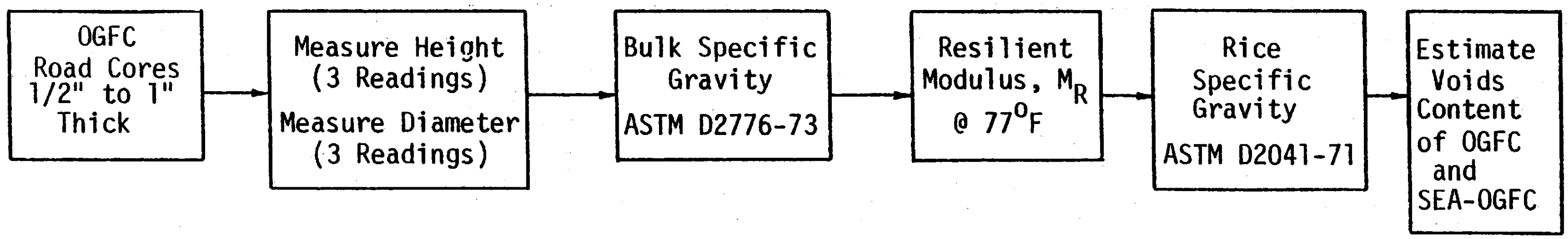
Void contents were estimated using the following relation:



$$K_v = \text{Permeability} = 2.3\ \frac{a}{t}\ \left(\frac{L}{A}\ \text{avg}\right)\ \log_{10} \frac{h_o}{h_1} \quad (\underline{7})$$

where: a = cross sectional area of permeameter standpipe, cm^2
L/A avg = average ratio of flow length to area, 1/cm
h_o, h_1 = the heads between which permeability is determined
L = length of flow path, cm
A = area perpendicular to flow path, cm^2
t = time for water level to fall from h_o to h_1, seconds

Figure 20 (A) Schematic of variable head field permeameter (B) Equation and variables for computing permeability, K_v.



Metric Conversion: 1 in = 25.4 mm
°C = 5/9(°F - 32)

Figure 21 Laboratory test sequence for Loop 495 SEA and conventional binder OGFC cores

$$\text{Air Voids}(\%) = 100 - 100\left(\frac{1}{\text{Max. Sp. Gr.}}\right)\frac{1}{\sigma_W}\frac{W_C}{V_C}$$

where:

Max. Sp. Gr. = the maximum specific gravity of the core material determined by the AASHTO Designation: T209-74 (1978)(ASTM D2041-71)

σ_W = unit weight of water, 1.0 gm/cc

W_c = weight of the OGFC core in air, gm

V_c = volume (gross) of OGFC core, cm^3

$V_c = \pi(\frac{D}{2})^2\ t$

D = average core diameter, cm

t = OGFC layer thickness, cm

The air voids estimated for this project on the basis of the above relation are subject to considerable error, on the high side, since practical difficulties precluded measurement for these pavement cores by more reliable methods. The main source of error lies in the measurement of the core thickness, t, from which the gross volume V_c is calculated. The rough surfaces of both the core sample top (the macrotexture) and the bottom (the imprint of the macrotexture of the underlying Item 302, one course surface treatment) contribute, in addition to the internal voids of the core, to the total volume V_c and to the amount of the apparently measured voids.

The surface of the bottom of the cores was created by carefully heating the total core sample and separating the OGFC layer from the underlying one course surface treatment and asphaltic concrete pavement material by a spatula. Where total cores were large enough, the OGFC layers were sawed from the total core, and the average void content for all the sawed samples (a total of 10 including both conventional OGFC and SEA binder OGFC) was found to be 28 percent. In one case, the three sawed cores for the SEA binder OGFC in the northbound outside lane averaged 34.3 percent or slightly higher than the average of all OGFC samples.

Specific Gravities

The results shown in Table 11 indicate average bulk specific gravities ranging from 2.129 to 2.142 for the conventional OGFC pavement cores to 2.194 to 2.299 or about five percent higher for the SEA binder OGFC pavement cores. These specific gravities were obtained according to the procedure under "Standard Method of Test for Bulk Specific Gravity of Compacted Bituminous Mixtures", AASHTO Designation: T166-78.

Results for the average value of maximum specific gravity are also shown in Table 11. These specific gravities of the loose material from the pavement cores range from 2.240 to 2.263 for the conventional OGFC cores to values of 2.333 to 2.359 or about four percent higher for the SEA binder OGFC pavement cores. These specific gravities were obtained according to the procedure under "Standard Method of Test for Maximum Specific Gravity of Bituminous Paving Mixtures", AASHTO Designation: T209-74 (1978).

Resilient Modulus, M_R, Values

A total of seven acceptable pavement core samples were subjected to the resilient modulus, M_R, test in accordance with the procedure in Appendix A, and results are shown in Table 12.

Table 12 Resilient modulus, M_R, values, 10^6 psi, for conventional and SEA binder OGFC surface layer for Nacogdoches Loop 495 field trials

		Lanes			
		Conventional OGFC Southbound Lanes		SEA Binder OGFC Northbound Lanes	
Sample Number	Thickness, t, inches	Lane R or B	Lane S or A	Lane M or A	Lane L or B
4	0.995			0.0596	
6	0.961			0.0303	
8	1.044			0.0663	
10	1.049			0.0588	
4	0.517				0.0799
14	0.848				0.0443
14	1.189	0.0552			
			Average =	0.0538	0.0621

Metric Conversion: 1 psi = 6.89 kPa
1 in = 25.4 mm

M_R values ranged from 0.0303×10^6 to 0.0799×10^6 psi (208,770 to 550,510 kPa). Six samples came from the SEA binder OGFC pavement cores from the Loop 495 northbound lanes, and only one came from the conventional OGFC cores of the southbound lanes. It was difficult to find sample cores of sufficient thickness or sufficient constancy of diameter or of necessary soundness in order to run the resilient modulus test. Most of the cores had one or more defects that precluded suitability for testing, with the cores from the conventional OGFC paving showing almost complete distress from a testing suitability standpoint.

VII. EVOLVED GAS MEASUREMENTS

When sulphur is used to extend asphalt cement in SEA binder some hydrogen sulfide and sulphur dioxide gases may be given off during the preparation and placement of the pavement mixtures. Usually emissions of the above gases are low or nonexistent as long as production and placement temperatures are below 300°F(149°C). Above this temperature, gaseous emissions may increase rapidly. Another problem that may be encountered with the use of sulphur is that of irritation from sulphur dust.

In order to measure the levels of evolved sulphur gases, Texas Transportation Institute provided the personnel and metering equipment necessary. The measuring instruments used are described below.

Equipment

The two pieces of measuring equipment used on the project to determine evolved gas concentrations were:

(1) The Drager multigas detector with tubes manufactured by the National Mine Service Company, Pittsburg, Pennsylvania and

(2) The Rotorod Model 721 gas sampler, produced by Metronics Associates, Inc., Palo Alto, California.

The Drager instrument was used to detect sulphur dioxide gas emissions,and the Rotorod was used to detect both evolved sulphur dioxide and hydrogen sulfide gases.

Standards for safe working limits for both hydrogen sulfide and sulphur dioxide gases have been developed by the Manufacturing Chemists Association, and these standards are summarized in Table 13 (8) and Table 14 (9).

Table 13 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 14 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

Evolved Gas Measurements Obtained

Measurements for hydrogen sulfide and sulphur dioxide gas concentrations at both the dryer-drum plant and on the site of the paving mixture laydown operations on Loop 495 were taken on both August 7 and August 8, 1980, the two days of the SEA binder OGFC production. The measurements made are summarized in Tables 15 and 16.

The results in Table 15 for the hydrogen sulfide gas measurements as compared to the standards for safe working limits in Table 13 indicate that concentrations of hydrogen sulfide dwelled at levels somewhat above 0.10 parts per million (ppm) which is at the point at which eye irritation begins. No measurements attained concentrations of hydrogen sulfide near the suggested maximum allowable concentration (MAC)(8) of 5 to 10 ppm. The highest measurement was 1.5 ppm at the top of the dryer-drum plant exhaust stack.

Table 16 shows details of sulphur dioxide measurements. These measurements compared to the Manufacturing Chemists Association recommended standards in Table 14 indicate that sulphur dioxide was not detected in appreciable concentrations except at the top of the dryer-drum plant exhaust stack. At this location, an 8 ppm concentration was measured which exceeded the suggested MAC of 5 ppm.

Although emission concentrations of hydrogen sulfide and sulphur dioxide were found to be the highest at the top of the plant exhaust stack, it is probable that atmospheric mixing of these gases above the plant site adequately serves to reduce these concentrations below the MAC before they reach the ground level. This phenomenon was confirmed by other readings around the plant site.

It is in the area of the laydown machine at the project construction site where concentrations of gaseous emissions from the use of SEA binder, especially hydrogen sulfide and some particulate or dust sulphur, may present a problem to construction personnel. In the laydown machine vicinity, concentrations of hydrogen sulfide were measured from 0.15 to 0.9 ppm, and construction workers did experience temporary irritation of the nose and eyes.

Table 15 Hydrogen sulfide gas measurements

Location	Date and Time	Concentration, parts per million(ppm)	Measuring Instrument
E1, Dryer drum mixer outlet	August 7, 1980, 11:02 A.M. August 8, 1980, 8:16 A.M. August 8, 1980, 10:11 A.M. August 8, 1980, 10:35 A.M.	0.4 0.25 0.25 None	Rotorod Rotorod Rotorod Drager
E2, Conveyor from dryer drum to mix surge silo	August 7, 1980, 11:05 A.M. August 8, 1980, 8:20 A.M. August 8, 1980, 10:15 A.M. August 8, 1980, 10:40 A.M.	0.3 0.25 0.15 None	Rotorod Rotorod Rotorod Drager
E3, Top of mix surge silo	No reading taken	-	-
E4, Top of mix dumped into truck	August 7, 1980, 11:31 A.M. August 8, 1980, 8:26 A.M. August 8, 1980, 10:26 A.M. August 8, 1980, 10:50 A.M.	None 0.7 0.25 None	Rotorod Rotorod Rotorod Drager
E5, Laydown machine	August 7, 1980, 1:01 P.M. August 8, 1980, 8:55 A.M. August 8, 1980, 11:16 A.M. August 8, 1980, 11:15 A.M. August 8, 1980, August 8, 1980,	0.9 0.15 0.15 None 0.15 0.15	Rotorod Rotorod Rotorod Drager Rotorod Rotorod
E6, Mat	August 7, 1980, 1:05 P.M. August 8, 1980, 8:59 A.M. August 8, 1980, 11:21 A.M. August 8, 1980, 11:20 A.M. August 8, 1980, August 8, 1980,	None None None None 0.15 0.15	Rotorod Rotorod Rotorod Drager Rotorod Rotorod
E7, Top of plant exhaust stack	August 7, 1980, 12:30 P.M.	1.5	Rotorod

Table 16 Sulphur dioxide gas measurements

Location	Date and Time	Concentration, parts per million(ppm)	Measuring Instrument
E1, Dryer drum mixer outlet	August 7, 1980, 11:05 A.M. August 8, 1980, 8:15 A.M. August 8, 1980, 10:20 A.M.	Trace Trace None	Drager Drager Drager
E2, Conveyor from dryer drum to mix surge silo	August 7, 1980, 11:08 A.M. August 8, 1980, 8:20 A.M. August 8, 1980, 10:23 A.M.	None None None	Drager Drager Drager
E3, Top of mix surge silo	No reading taken	-	-
E4, Top of mix dumped into truck	August 7, 1980, 11:35 A.M. August 8, 1980, 8:30 A.M. August 8, 1980, 10:30 A.M.	None None Trace	Drager Drager Drager
E5, Laydown Machine	August 7, 1980, 1:01 P.M. August 8, 1980, 8:53 A.M. August 8, 1980, 11:25 A.M.	Trace None None	Drager Drager Drager
E6, Mat behind lay-down machine	August 7, 1980, 1:06 P.M. August 8, 1980, 8:58 A.M. August 8, 1980, 11:30 A.M.	None None None	Drager Drager Drager
E7, Top of plant exhaust stack	August 7, 1980, 12:30 A.M.	8.0	Drager

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Appendix A

The Resilient Modulus Test

Some nominal 4-inch(101.6mm)size field cores from both the SEA binder OGFC and conventional OGFC paving surfaces were subjected to the resilient modulus (M_R) test as part of the laboratory testing on field taken specimens to determine possible significant differences between the two OGFC pavement materials. Although the use of the M_R test was not mandatory in the project testing, the test can be a useful tool in the design stage and it may be used to measure water susceptibility, changes in stiffness of paving materials and possible differences among different types of paving materials according to Schmidt (10).

A brief description of the resilient modulus test theory (10) and test procedure is given below.

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, but the duration of the loading and other conditions of the test must be defined because short loading periods can give much higher modulus values than long loading periods. This is because in viscoelastic materials such as hot mixes, etc. more time allows more flow to occur. Moduli that are time-dependent are referred to as resilient modului or as stiffness moduli. Frequently, moduli determined at very long loading times are referred to as creep moduli.

Operating Principle

Resilient modulus (M_R) instruments function by applying a 0.1-second load pulse once every three seconds across the vertical diameter (or vertical diametral plane) 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 to 4 inches (88.9 to 101.6 mm) and a thickness from 1 to 3 inches (25.4 to 76.2 mm). Optimum specimen diameter is 4 inches(101.6 mm) and optimum thickness is 2 3/4 inches(69.9 mm). Loads may range from 10 to 75 lb.(4.54 to 34.05 kg). Specimen deformation ranges from 1 to 2000 micro-inches(2.54×10^{-5} to 5.08×10^{-2}mm).

Diametral load (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), Poisson's ratio (ν), and specimen thickness (t) as follows:

$$M_R = \frac{p(\Delta + 0.2732)}{t\nu}$$

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 mm, then M_R will be in kg/mm^2 which equals 9807 kPa.

Uses of the Resilient Modulus

The instrument permits rapid nondestructive measurement of the resilient modulus of asphalt-aggregate mixtures. This value is of direct use in:

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