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SAND-ASPHALT-SULFUR PAVEMENT EXPERIMENTAL PROJECT

HIGHWAY U.S. 77, KENEDY COUNTY, TEXAS

A CONSTRUCTION REPORT

TEXAS TRANSPORTATION INSTITUTE

Texas A&M University
College Station, Texas

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by

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April 1977

Texas Transportation Institute

College Station, Texas

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SAND-ASPHALT-SULFUR PAVEMENT EXPERIMENTAL PROJECT

HIGHWAY U.S. 77, KENEDY COUNTY, TEXAS

Sponsored By

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

and

THE FEDERAL HIGHWAY ADMINISTRATION, OFFICE OF DEVELOPMENT

in cooperation with

U.S. BUREAU OF MINES

and

THE SULPHUR INSTITUTE

Other Participants Include:

Barber-Greene Company

Foremost Paving, Inc.

Motheral Contractors, Inc.

Shell Canada Limited

Texas Air Control Board

Texasgulf, Inc.

Texas Transportation Institute

For additional information on sand-asphalt-sulfur paving materials, please contact:

THE SULPHUR INSTITUTE
1725 K Street, N.W.
Washington, D.C. 20006

Or other participants.

ABSTRACT

The use of sulfur as a means of upgrading poorly graded mineral aggregates for use in asphaltic concrete mixes has been under study by Shell Canada under the trade name of Thermopave® for approximately fifteen years. Laboratory work has been extensive and numerous field trials have been completed in Canada. The Texas Transportation Institute under the co-sponsorship of The Sulphur Institute, and The Bureau of Mines instituted a program to introduce this concept to the United States. Following a 4-year laboratory effort a 3,000 lineal foot, sand-asphalt-sulfur experimental test section was placed along a portion of U.S. 77 in Kenedy County, Texas. This was the first demonstration of the Shell concept on a Federal Highway in this country.

The 3,000-foot section was divided into six subsections of various thicknesses with two sections purposely underdesigned to show distress in two to three years.

In conjunction with the construction activity, measurement of polutants, namely H_2S, SO_2 and particulate sulfur were generated at various locations throughout the construction site were made by the Texas Air Control Board, The Bureau of Mines and TTI personnel.

This report deals with pavement mixture designs, the construction operation and equipment used in the project. The sulfur content of the pavement mixture varied from about 10 to 20 weight percent, (w/o), of the total mix. Similarly the asphalt content ranged from 4 to 8 w/o. The mineral aggregate was a 65/35 w/o coarse to fine sand. The

latter was taken from a source local to the construction site. Construction operations and equipment are detailed with photographs where possible.

INTRODUCTION

1.0 Introduction

Sulfur is unique among our nation's mineral resources in that it is one of the few materials which will be in abundant supply in the future. Current projections indicate that by the year 1978 the supply of sulfur will begin to exceed the demand. For this reason, various industry, government and university groups have initiated efforts to develop new uses for sulfur.

One of the most promising outlets for sulfur is highway construction in which interest is currently being stimulated by two factors: (a) the decreasing availability or total absence of quality aggregates in a number of regions around the country and (b) the current increase in cost and projected demands for asphalt. Sulfur's unique properties permit it to be utilized either as a structuring agent (i.e. playing the role of the aggregate) or as an integral part of the binder or both.

The project described in this report addresses itself specifically to the use of sulfur in sand-asphalt-sulfur paving mixtures. This concept was developed and patented by Shell Canada, Ltd. and involves the use of sulfur as a structuring agent with poorly grades of sands as found in many areas of the United States and specifically along the beaches and inland regions of the Gulf Coast States. Through efforts initiated by The Sulphur Institute and co-sponsored by the U. S. Bureau of Mines, the Texas Transportation Institute has, during the past four years done considerable laboratory verification studies of the sand-asphalt-sulfur technology developed in Canada. One of the prime objectives of this effort was to introduce to the United States and adapt to her conditions the utilization of sulfur in asphaltic concrete mixes for bases.

This program culminated during April, 1977, with successful placement of a 3,000 lineal foot sand-asphalt-sulfur test section on U.S. 77 in Kenedy County, Texas. Construction details including materials, mix designs, equipment, materials handling, quality control and evolved gas emissions analyses will be discussed along with descriptions of non-conventional operations.

1.1 Location and Scope

The geographical location of the project is shown on the vicinity map, Figure 1. The location is further described as a portion of Highway U.S. 77, 5 miles south of Sarita and 46 miles north of Raymondville in Kenedy County, Texas. This area is under the jurisdiction of District 21 of the Texas State Department of Highways and Public Transportation.

The beginning and the end, respectively, of the experimental section are designated by markers on the east right-of-way; i.e.

BEGINNING (END)
SAND-ASPHALT-SULFUR
DEMONSTRATION

The sand-asphalt-sulfur experimental pavement base was placed on the two right N-S lanes between station 1985+00 and 2015+00, Highway Project TQF 913(13) Kenedy County, Texas, District 21.

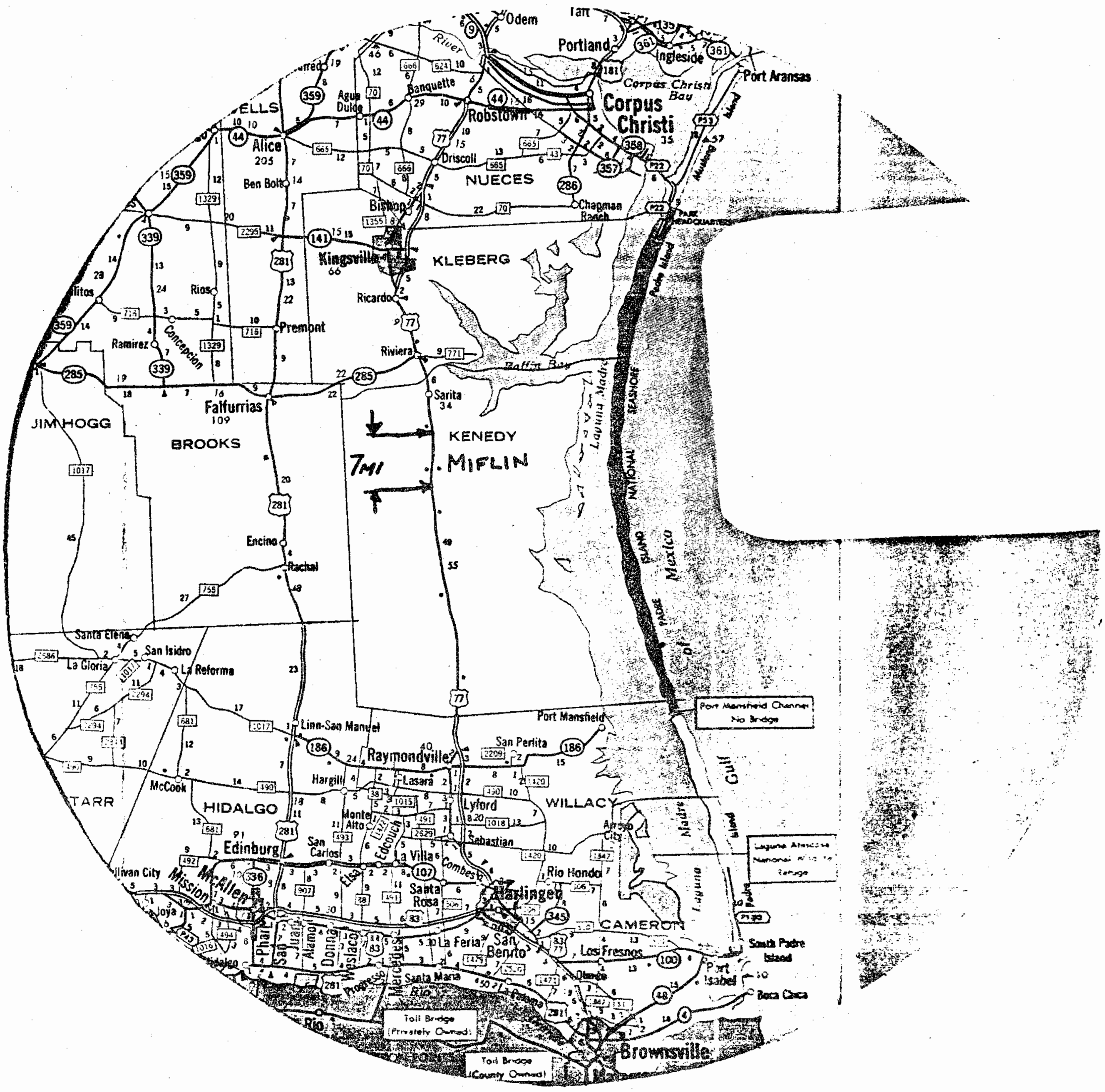


Figure 1. Vicinity map showing location of sand-asphalt-sulfur experimental project on Highway U.S. 77, Kenedy County, Texas.

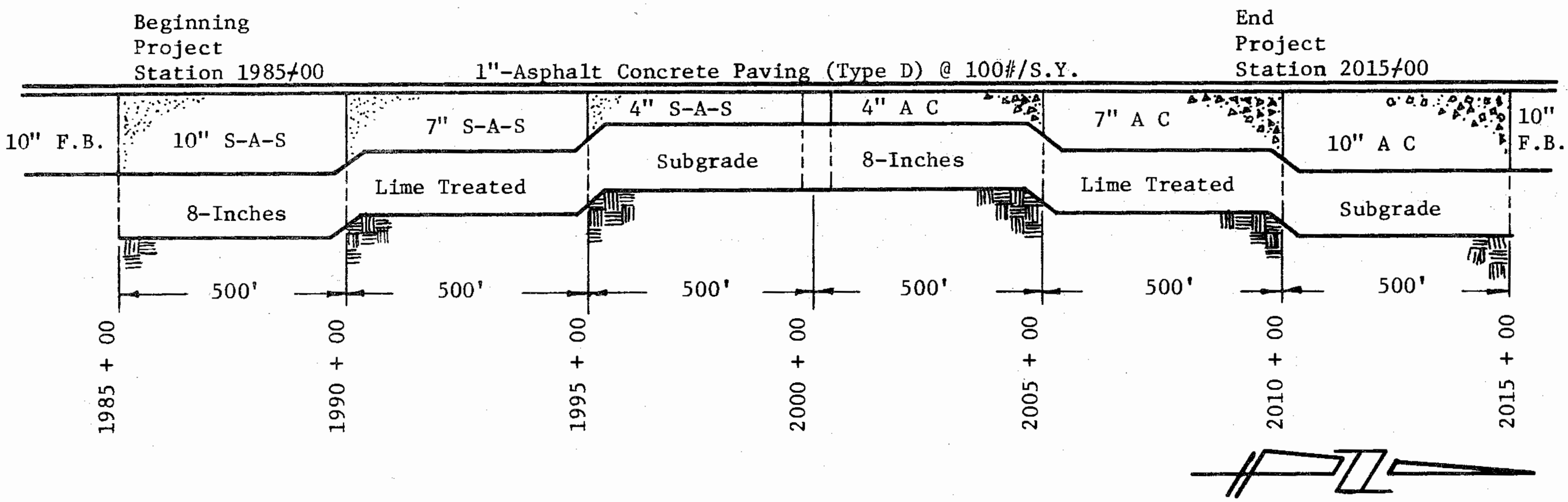
The experimental section as shown in Figure 2 is two traffic lanes wide (26 ft.) and contains six test items, each 500 ft. in length. From south to north there are three subsections of sand-asphalt-sulfur base in thicknesses of 10, 7 and 4-in., respectively. These are followed by three test items of asphalt concrete base in thicknesses, respectively, of 4, 7 and 10-in. The arrangement of the subsections together with a basic X-section is shown in Figure 2.

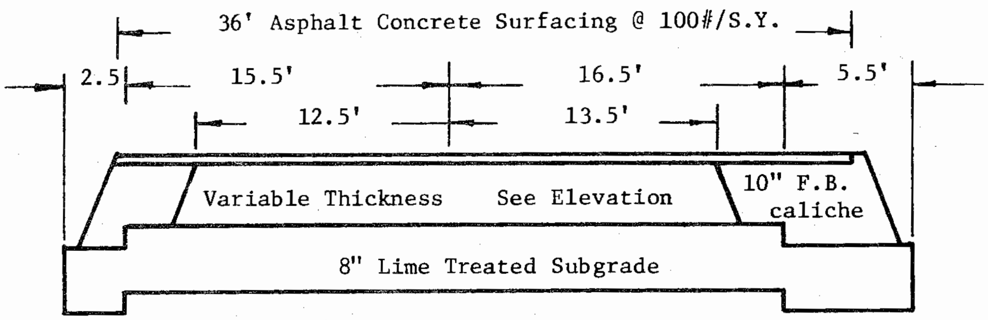
The test items were designed by Texas Transportation Institute, College Station, Texas, to "...give a fair comparison of the relative performance of sand-asphalt-sulfur pavement and a deep asphalt concrete pavement".

1.2 Construction Contract

The mineral aggregate-asphalt-sulfur experimental project was organized as an integral part of the Texas State Department of Highways and Public Transportation (SDHPT) Project TQF 913(13), U.S. Highway 77. The project as designed by District 21 and submitted to competitive bidding encompassed grading, structures, flexible base and asphaltic pavement on U.S. Highway 77 from a location 3.6 miles south to 3.4 miles north of Mifflin, Texas, for a net length of 7.0 miles, Items also included in the bid package were: (a) Typical Cross Sections and Elevations (b) Special Specification - item 'Mineral Aggregate-Asphalt-Sulfur Base and plan sheet' Suggested Sand-Asphalt-Sulfur Equipment, for construction of the experimental section.

Bids were opened at Austin, Texas, August 18, 1976. Of the four contractors who responded to the bid request, Motheral Contractors, Inc.,





Cross-Section
N-S Right Lanes

Notes:

S-A-S Sulfur-Asphalt-Sand Paving Material

AC Asphalt Concrete

F.B. Flexible Base (caliche)

Schematic Is Not Down To Scale

Figure 2. Schematic Showing Arrangement of Subsections and Construction of Mineral Aggregate-Asphalt-Sulfur Experimental Project

Weslaco, Texas, submitted the lowest cost ($1,394,110.52), was therefore awarded the contract on September 17, 1976. In turn, Motheral entered into a sub-contract with Foremost Paving, Inc., Weslaco, Texas, for the construction of asphalt concrete and the sand-asphalt-sulfur test items. The project was awarded to the low bidder, Motheral Contractors, Inc., on September 15, 1976.

1.3 Participants

The mineral aggregate-asphalt-sulfur experimental project was made possible through the participation of many groups:

Texas State Department of Highways and Public Transportation, Austin and District 21, Pharr, Texas.

The Federal Highway Administration, Implementation Division, Washington, D.C. and the Regional Offices, Fort Worth, and Austin, Texas.

The U. S. Bureau of Mines, Washington, D.C. and Boulder City Metallurgy Engineering Laboratory, Nevada.

The Sulphur Institute, Washington, D.C.

Shell Canada Limited, Oakville Research Centre, Oakville and Products Application, Toronto.

Texasgulf, Inc., Houston and Newgulf, Texas.

Barber-Greene Company, Inc., Aurora, Illinois.

Motheral Contractors, Inc., Weslaco, Texas.

Foremost Paving, Inc., Weslaco, Texas.

New Paving Contracting, Inc., Seguin, Texas.

Texas Air Control Board, Austin, Texas.

Texas Transportation Institute, College Station, Texas.

The engineering construction of the experimental project was under the immediate supervision of G. J. (Lupe) Camargo, Supervising Resident Engineer, State Department of Highways and Public Transportation, Raymondville, Texas. G. G. Garcia, District Engineer, Wade D. Barnes, Assistant District Engineer and Jack T. Trammell, Senior Laboratory Engineer, provided assistance and supervision in their respective fields.

The contractor's operations were under the supervision of Eddie F. Forshage, Owner, Foremost Paving, Inc. He was assisted by Parker New, Plant Superintendent and Pete Leal, Paving Foreman.

Shell Canada Limited, Oakville Research Centre, provided three engineering consultants: Imants Deme at the paver and at the hot-mix plant, Carl Mohammed at the hot-mix plant and Charles E. Spurr on heated dumpbody trucks.

Texas Transportation Institute was represented by B. M. Gallaway and Don Saylak co-principle investigators of the over-all study and technicians R. Barnett, N. Little and E. Ellis.

Texas Air Control Board monitored the project for possible air contaminants.

W. H. Richardson, Texasgulf, Inc., supervised the design and operation of the sulfur system at the hot-mix plant.

Kenneth J. Rudolph, Barber-Greene Company, supervised the modifications of the B-G paver.

Wm. C. McBee, Bureau of Mines, provided instrumentation for measuring sulfur gases and assisted D. Saylak with the measurements.

1.4 Sand-Asphalt-Sulfur Pavement Material

A sand-asphalt-sulfur (S-A-S) pavement material is composed of mineral aggregate (sand), elemental sulfur and asphalt in which by weight, the amount of sulfur is equal to or exceeds that of the asphalt. The sulfur content in the sand-asphalt-sulfur pavement mixture varied from about 10 to 20 percent by weight, the asphalt content from about 4 to 8 percent by weight and the sand from 72 to 86 percent by weight accordingly.

The sand-asphalt-sulfur pavement concept was developed by Shell Canada Limited, Oakville Research Centre. Shell with assistance from Blaw-Knox and Barber-Greene developed the construction equipment and construction procedures which were used for preparing and placing the pavement mixture.

1.5 The Need

In many of the "severe problem aggregate areas" of the United States, sand is found in abundance while coarse aggregates are being depleted at an alarming rate. At the same time, the Clean Air Acts of 1963 and 1970-73 required the removal of sulfur from fossil fuels to the extent of an anticipated sulfur surplus. Sulfur and sand can replace coarse aggregate, a potentially scarce product.

A comparison of the unit weight and volumes of S-A-S components with those found in conventional asphalt pavement is given below:

Component of the Mix	wt./cu.ft. mixture		vol./cu.ft. mixture
Conventional asphalt:			
Asphalt Cement	8 lbs.		0.127 cu.ft.
Quality Aggregates	135 lbs.		0.813 cu.ft.
	143	air voids	0.060 cu.ft.
			1.000 cu.ft.
Sand-Asphalt-Sulfur:			
Asphalt Cement	8 lbs.		0.127 cu.ft.
Sulfur	17 lbs.		0.136 cu.ft.
Sand, natural or blended	105 lbs.		0.642 cu.ft.
	130	air voids	0.090 cu.ft.
			1.000 cu.ft.

In this example, 17 pounds of sulfur and 105 pounds of sand replace 135 pounds of quality aggregates.

The sulfur acts as a structuring agent in the properly prepared and cured mixture. It hardens within the voids in the asphalt coated aggregate producing a mechanical interlock (see Figure 3) to provide a strong pavement with remarkable elastic properties.

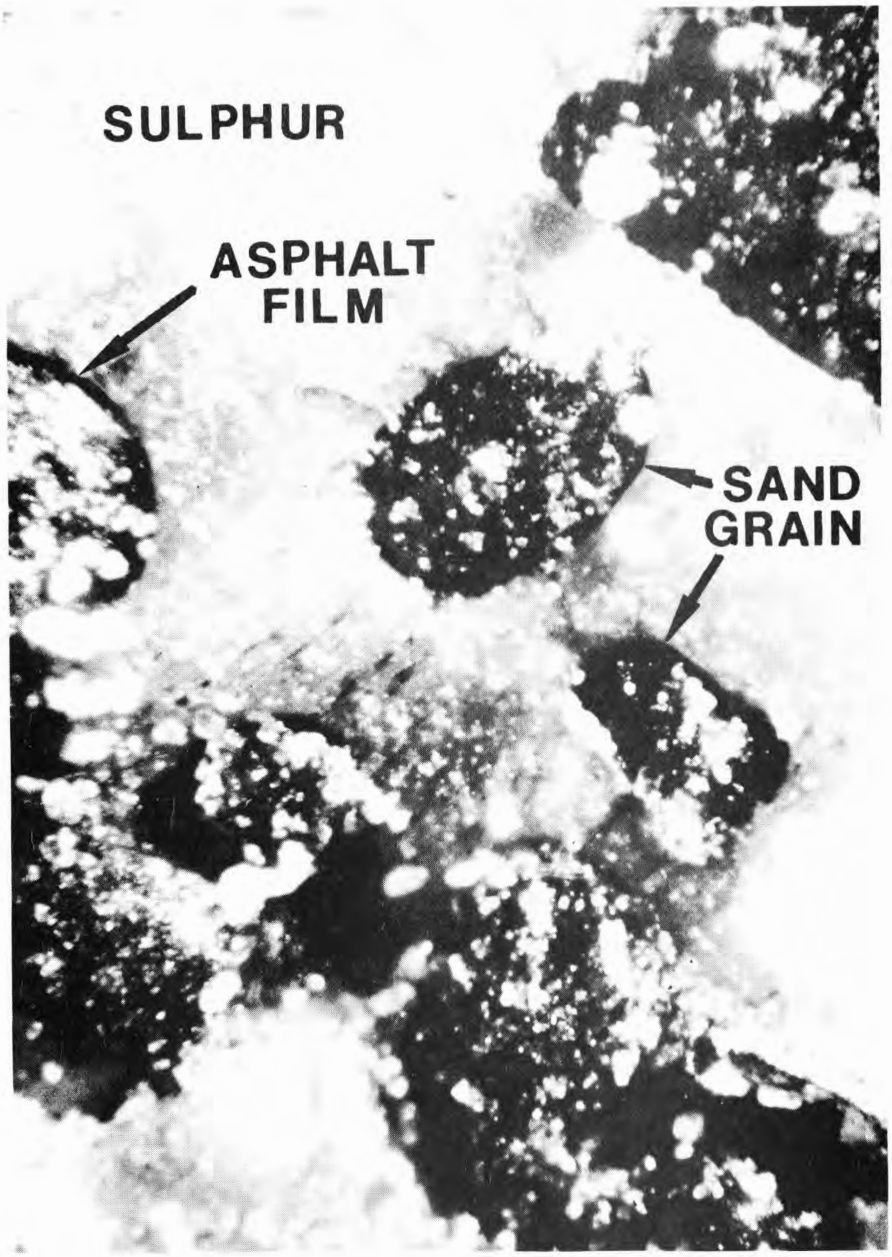


FIG.3 —Photomicrograph of sand-asphalt-sulphur matrix showing the mechanical interlock of sand particles provided by the sulphur. Mag: 120X.

2.0 Construction Materials

2.1 Sulfur

Sulfur is one of the basic elements, with an atomic number of 16 and atomic weight of 32.06. The specific gravity of solid sulfur is about 2.00, or twice as heavy as asphalt, at ambient temperatures and 1.80 at 275F.

Sulfur is not considered a hazardous material in commerce. About 90% of the elemental sulfur 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. Practices for hauling, heating, storage and safety are well established in the trade.

Sulfur melts at about 240F. The working range for molten sulfur corresponds quite well to the working range for paving grade asphalt; i.e. 255 to 300F. A temperature-viscosity curve for sulfur is shown in Figure 4. At higher temperatures, the molten sulfur becomes very viscous.

When heated, the concentrations of toxic gases formed are low or nonexistent in the temperature range of 250 to 300F but increase rapidly as the temperature rises above this range. Sulfur dust and fumes from molten sulfur can exist within the working temperature range and can cause eye irritation.

Briefly, liquid sulfur is hot and poses the same dangers in this respect as hot asphalt or any other hot liquid. Molten sulfur at 300F will burn in air if ignited and sulfur fumes and hudrogen sulphide

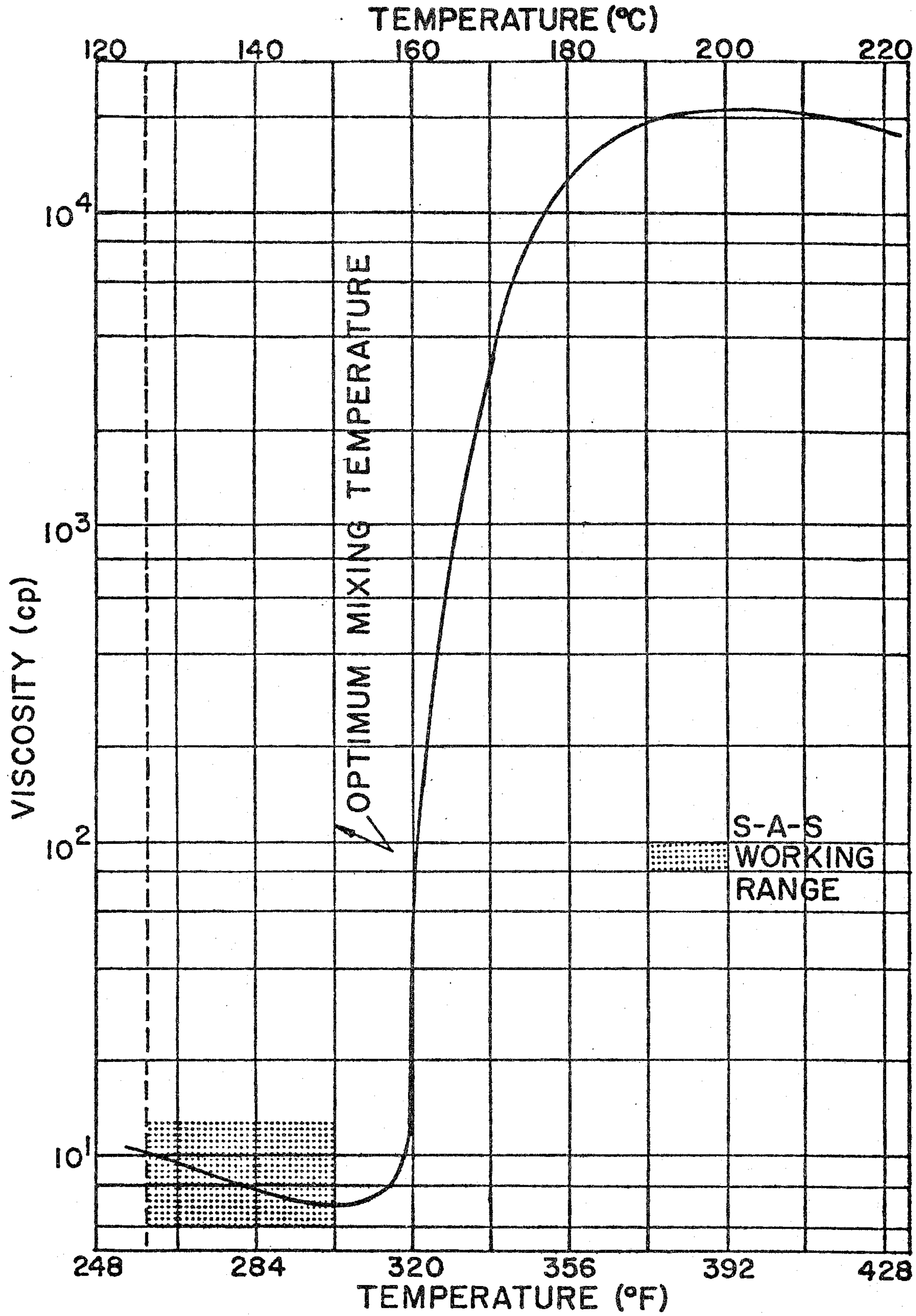


FIG. 4—Viscosity-temperature curve for liquid sulphur.

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 sulfur.

Safety precautions are well established in the trade. These include attention to temperature control and measuring and monitoring the H_2S content of the air in the work place during paving operations. Methods and equipment for these purposes have been developed and measurements of emissions both in the laboratory and in the fields have been monitored by Shell Canada, The U. S. Bureau of Mines and TTI. The results of these measurements taken during the U.S. 77 S-A-S field trials will be discussed later in this report.

The sulfur was supplied form two sources:

1. Warren Petroleum, A Division of Gulf Oil, ex. Fashing, Texas

2. Texasgulf, Inc., ex. Newgulf, Texas

The sulfur was delivered from both sources by the same two haulers:

1. Oil Transport Company, Abilene, Texas

2. Robertson Tank Lines, Houston, Texas

Sulfur transports were tractor-trailer units (18 wheelers) of about 3,400 gallon capacities (ca. 22.5 long tons @ 14.91 lbs. per gallon at 280F). Each unit was equipped with heating coils and steam jacketed discharge valves.

Typical Characteristics

Test Property	Warren Petroleum % wt.	Texasgulf, Inc. % wt.
Purity, dry basis,	99.95	99.97
Ash	.003	.003
Carbon Content	.005	.03
Specific Gravity, 60/60	2.03	
Source:	'Recovered Sulfur'	'Frasch'
Color:	Bright yellow	Bright yellow

2.2 Asphalt

The asphalt was supplied from Gulf States Asphalt Company, Houston, Texas. Two carriers were noted at the job site: 1) Mission Petroleum Carriers, Inc., San Antonio-Houston, Texas and 2) The Transport Company of Texas, Houston, Texas.

Characteristics

The asphalt was a paving grade complying with the Texas State Department of Highways and Public Transportation for Viscosity Grade AC-20. The test data for Gulf States Asphalt AC-20 together with test values on a representative sample; State Sample No. C 7737 05 56 are given below:

Test	AC-20	State Sample No.* 05 56
Viscosity, 140F, stokes	2000-400	1907
Viscosity at 275F, stokes (min)	2.5	3.41
Penetration at 77F, 100g, 5 sec. (min)	55	56
Flash Point, COC, F (min)	450	600
Solubility in Trichlorethylene, percent (min)	99.0	-
Tests on Residue from Thin Film Oven Test		
Viscosity, 140F, stokes (max)	6000	3878
Ductility, 77F, 5 cm. per min.,cm. (min)	50	141+
Spot Test	negative	negative
Penetration, 77F, 100g, 5 sec.		36

*Values were provided by the State Department of Highways and Public Works, Division of Materials and Tests, Camp Hubbard, Austin, Texas.

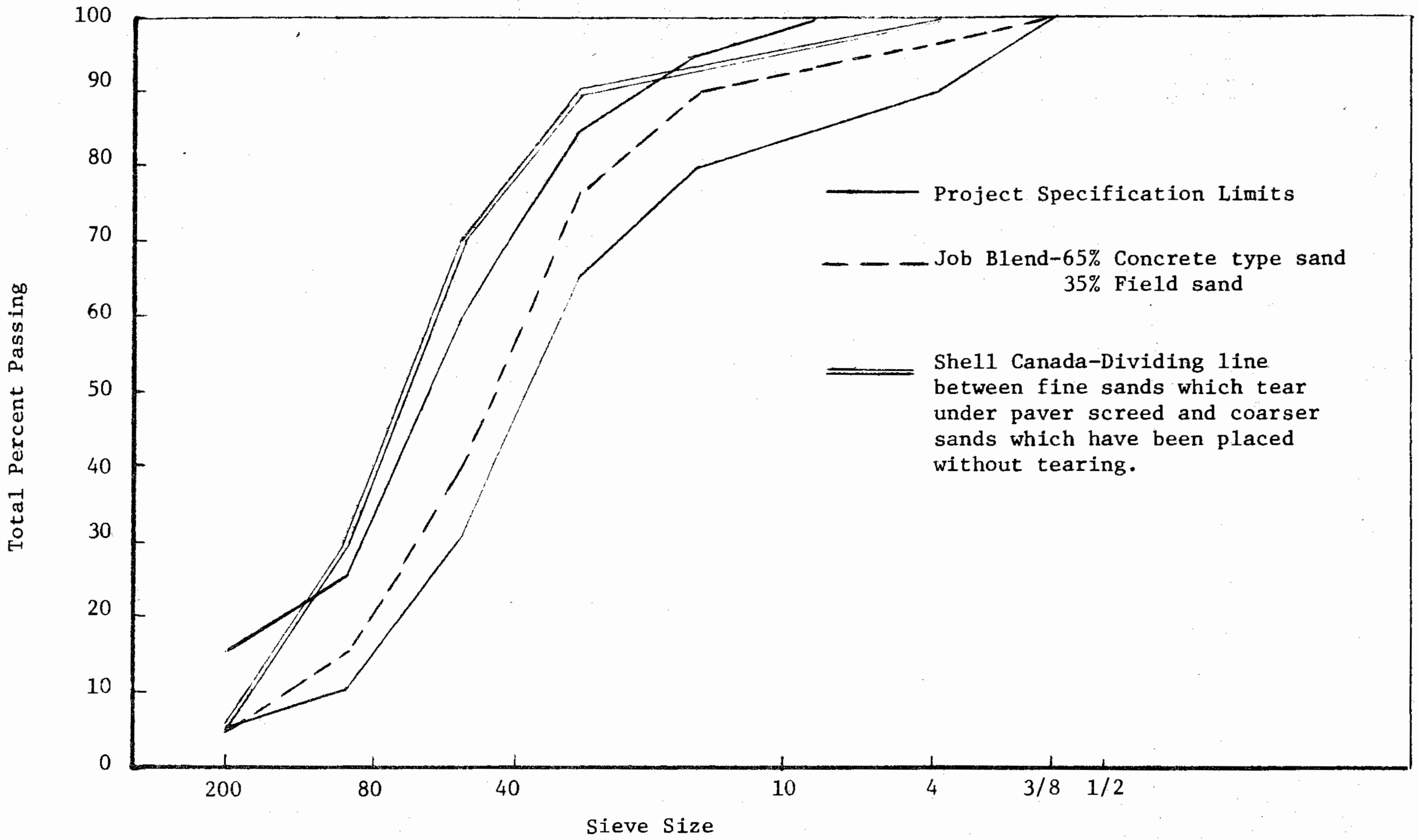
2.3 Mineral Aggregates

The aggregate requirements for the project were based on recommendations from Shell Canada Limited, Oakville Research Centre. The project specifications were prepared to describe sands which Shell Canada had successfully placed without appreciable imperfections in the mat. In their experiences, fine sands of near single-size have been difficult, if not impossible, to place without 'tearing' under the paver screed. Most of the sands in the vicinity of the project were either dune sands of near single-size or silty sands with appreciable plasticity. At the same time, the project sponsors, with favorable economics in mind, were interested in using as much local sand as possible. Further mention will be made of this idea later in the report.

Shell Canada's recommendation on gradation together with the grading limits selected for the project are shown in Figure 5.

The mineral aggregate selected by the contractor, Foremost Paving, Inc., consisted of a blend of two sands; 1) a concrete type sand from Wright Materials Co., 'Bluntzer' Pit on the Nueces River near Corpus Christi, approximately 55 miles north of the project and 2) a field sand located about 500 ft. east of the project right-of-way at the hot-mix plant site, station 2030.

Gradations of 1) preliminary sand samples, 2) the job blend of 65-35% wt. coarse to fine sand and the project gradation limits are shown in Table 1.



U. S. Standard Sieves - ASTM Designation E 11-39

Figure 5. Master Gradation Chart Showing U.S. 77 Job Blend Relative to Specified and Recommended Limits

Table I. Individual Sieve Analyses of Sands and Blends Used

On U.S. 77 S-A-S Field Demonstration Project

Sieve Size	'Bluntzer' Concrete Sand Percent wt. Passing	Field Sand Percent wt. Passing	65% wt. 'Bluntzer' 35% wt. Field Sand Percent wt. Passing	Project Specifications Percent wt. Passing
3/8"	100		100	100
No. 4	96		97	90-100
No. 8	91		94	85-100
No. 16	85		90	80-95
No. 30	65	100	77	65-85
No. 50	21	70	39	30-60
No. 100	2	38	14	10-25
No. 200	1	10	4	5-15
Plasticity Index				6 max.
Liquid Limit				25 max.

3.0 Contractor Equipment

3.1 General

The sand-asphalt-sulfur pavement mixtures were prepared in a conventional stack-up type hot-mix batch plant which was equipped with auxiliary stystems for handling the molten sulfur. The hot asphalt and molten sulfur are transferred from separate storage by approved pumps into the weigh bucket. The dried and heated mineral aggregate (sand) is weighed into the pug-mixer. The required amount of hot asphalt and the required amount of molten sulfur for each batch are introduced into the mixer in that sequence and mixing continued as required to prepare a uniform paving material. The mix is loaded into trucks with heated dump bodies to maintain the temperature within the working range. Pavers must be altered to permit the screed to be fully supported for strike-off smoothing and consolidation of the comparatively soft paving mixture. Placement is carried out in lifts of 3 inches maximum thickness without rolling or subsequent compaction. Details of each phase of the operation are given below.

3.2 The Hot-Mix Plant

The hot-mix plant used for the preparation of sand-asphalt-sulfur pavement mixture was a Standard, portable, 2,000 lb., batch stack-up type with a 3,000 lb. mixer; Serial Number 2045 (or 2046). The plant was manufactured by Standard Steel Corporation, now widely known as Stan Steel, a division of Allis Chalmers, 5001 South Boyle, Los Angeles, California. It consisted of the basic units only; a cold feed elevator, 5 ft. diameter x 24 ft. long dryer, hot elevator, screens, bins, aggregate weight hopper, asphalt weight bucket and mixer. The plant was manually operated.

This hot-mix plant was manufactured and sold to the original owner in 1951. It was leased for the project by the sub-contractor, Foremost Paving, Inc., from New Paving Contracting, Inc., Seguin, Texas.

The hot-mix plant was dismantled from a project near Fort Worth, Texas and truck-hauled (one or more parts per load) to the project site 25 miles South of Kingsville, Texas. It was reassembled for use on a lot east and immediately adjacent the project right-of-way at station 2030. The erection and operation of the plant were supervised by Mr. Parker New, co-owner of New Paving Contracting, Inc.

3.2.1. Emission Control

The emission control system consisted of an 8 ft. diameter cone precipitator, part of the original equipment, and a wet washer supplement. Water for the scrubber (washer) was truck-hauled to the site and discharged into a membrane lined pond. The pond doubled for sludge disposal and water storage. A small pump returned water from the surface of the pond to the washer in a continuous circulating system.

The emission control system is shown schematically in Figure 6.

3.2.2. Cold Aggregate Feed

The coarse sand and the fine sand were stored in separate stockpiles on the site. A caterpillar front-end loader was used to transfer the sands to a twin, 2-compartment (four compartments total) portable steel bin. One-half was used for coarse and one-half for fine sand. The

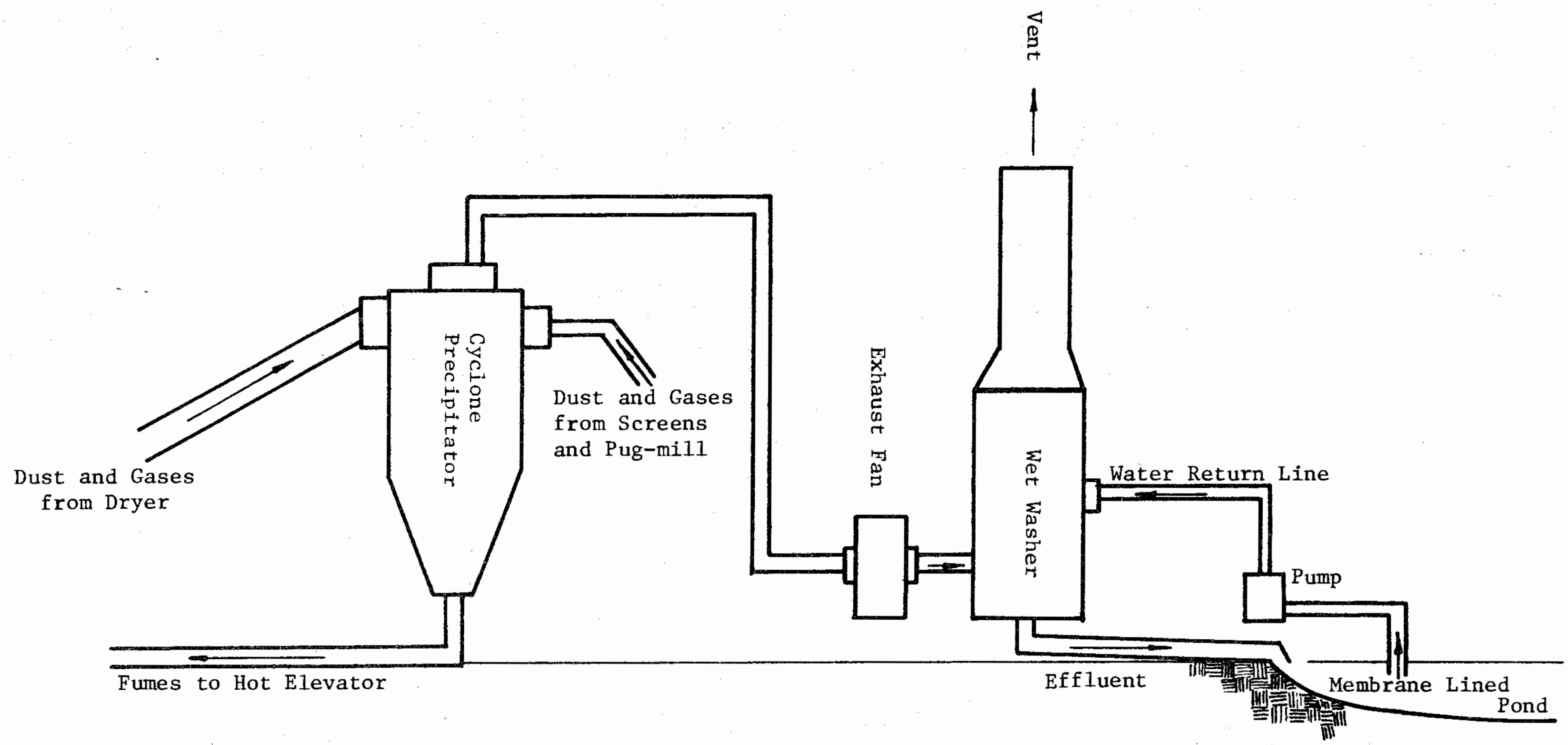


Figure 6. Schematic Emission Control System (New Paving Contracting, Inc. Hot-Mix Plant)

aggregate feeder system consisted of manual gates with reciprocating feeders and an continuous belt conveyor to the cold feed bucket line. Vibrators were attached to the side of each sand bin. The cold feed elevator discharged into a funnel leading to the dryer.

3.2.3. Electric Power

Electric power for the hot-mix plant was provided by portable generators. One was a Caterpiller diesel, 210 kw., 60 cycle unit.

3.2.4. Asphalt System

Asphalt was stored in a salvaged horizontal railroad tanker with a rated capacity of 8,145 gallons. It was equipped with the usual heating coils and a recording thermometer.

Asphalt was pumped to the weigh bucket in a full circulating system. It included a 3-inch hot oil jacketed Viking gear pump and manually operated 3-way valve at the weigh bucket. A 3-inch flexible hose (some segments were Teflon stainless steel) without heat or insulation was used on the suction and return lines.

Hot oil was provided by a Childress Oil Heater rated at 1500 BTU/Hr. A 3 Hp. electric driven centrifugal pump was used for circulating the oil. The oil temperature was maintained at about 400F which kept the asphalt in storage at 290-300F.

3.3 The Sulfur System

The sulfur system was designed by Mr. W. H. Richardson, Sr. Engineer, Texasgulf Inc., Newgulf, Texas. It was constructed by Mr. Parker New, Superintendent, with assistance from Mr. Richardson.

Texasgulf provided much of the basic sulfur handling equipment and transported it to the construction site in a U-Haul trailer. Items provided by Texasgulf included:

1. A 1 1/2 x 7 inch United In-Line Pump, 120 gpm, 75 ft. head with 10 Hp. 220 volt electric motor,
2. Two 3-inch steam jacketed plug valves,
3. One 4-inch Mission check valve and
4. All steam jacketed pipe and fittings on pump unit.

Items provided by the contractor included:

1. Sulfur storage tank
2. 3 way valve at weight bucket
3. Approximately 100 lineal feet of 3 by 4-inch jacketed pipe for suction and return lines
4. Foil backed 4-inch insulation mats

The sulfur storage facility consisted of a used, horizontal 10 ft. diameter by 30 ft. long insulated tank with a calculated capacity of 17,6000 gallons. The storage tank was heated with hot oil.

The sulfur pump, attached pipe valves, and fittings, receiving hopper and sulfur transports (as needed) were steam heated. Steam was generated by a skid mounted oil-fired boiler rated at 25 Hp. It was manufactured by Murray Iron Works, "Turbines and Boilers", Burlington, Iowa.

A schematic of the sulfur system is shown in Figure 7.

3.4 Special Heated Truck Bodies

The sand-asphalt-sulfur pavement material was hauled in heated dump truck bodies to prevent the formation of cold lumps.

The sand-asphalt-sulfur pavement material was transported, an average distance of about 3/4 miles, from the hot-plant located east and adjacent the project right-of-way at station 2030 to the roadway on U.S. 77, in four trucks equipped with special heated bodies constructed of aluminum. This

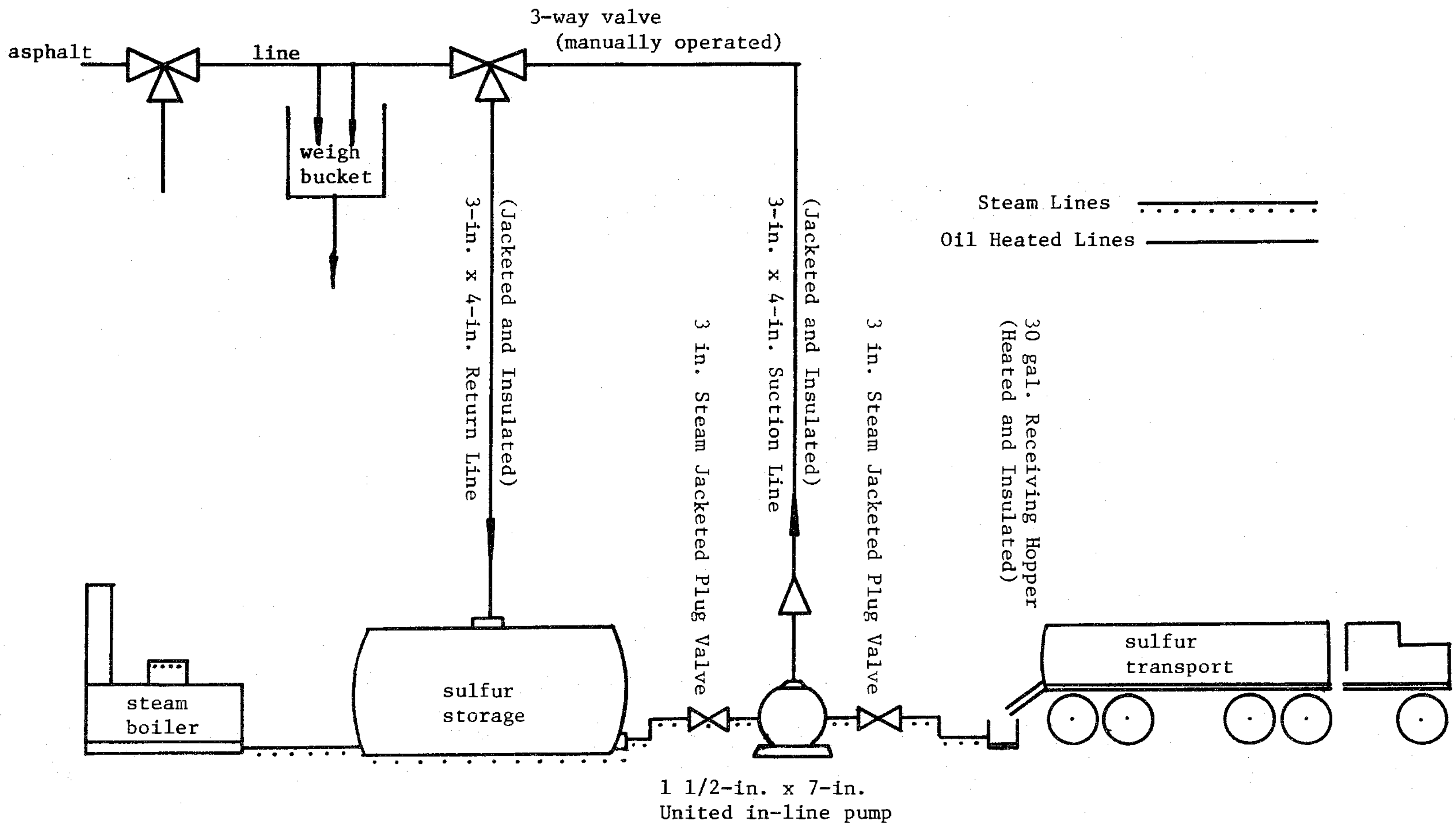


Figure 7. Schematic Sulfur System (New Paving Contracting, Inc. Hot-Mix Plant)

requirement was brought about by the need to keep the mix temperatures within the working temperature range (250-300F). Premature solidification of the sulfur can cause the formation of cold lumps which may produce regions of weakness within the finished pavement.

The special heated bodies were developed by Shell Canada Limited, Oakville Research Centre. They were loaned to The Sulphur Institute for use on a sand-asphalt-sulfur project constructed at Sulphur, Louisiana, January 1977 and for use on the Kenedy County, Texas Project. They were shipped by truck freight from Saskatchewan to Westlake, Louisiana in September 1976 consigned for use to the contractor, R. E. Heidt Construction Company, Inc., for the Sulphur, Louisiana project. A search for suitable trucks lead to Rebel Ford Truck Sales, Inc., Jackson, Mississippi with whom R. E. Heidt made arrangements to supply the trucks and attach the special heated bodies. In turn, Rebel Ford engaged OK Welding Co., Brookhaven, Mississippi to mount the special beds. Following the completion of the Sulphur, Louisiana project, the trucks with special beds attached were leased to Foremost Paving Inc., for use in Texas.

3.4.1. Basic Features

The basic features of the heated dump truck bodies are shown in Figure 8. The body has a tub-shaped inner shell and an outer shell which is insulated on the inside. The body is heated with propane burners, one on each side at the front end. Cold air is force into pipes above the flames by means of a fan. The mixture of hot burner exhaust gas and cold air is lead by ducts and baffles through the body and tail gate then above the mix. The burners and fan are electrically operated from the truck batteries and controlled by on-off switches in the control panel on driver's side of the cab.

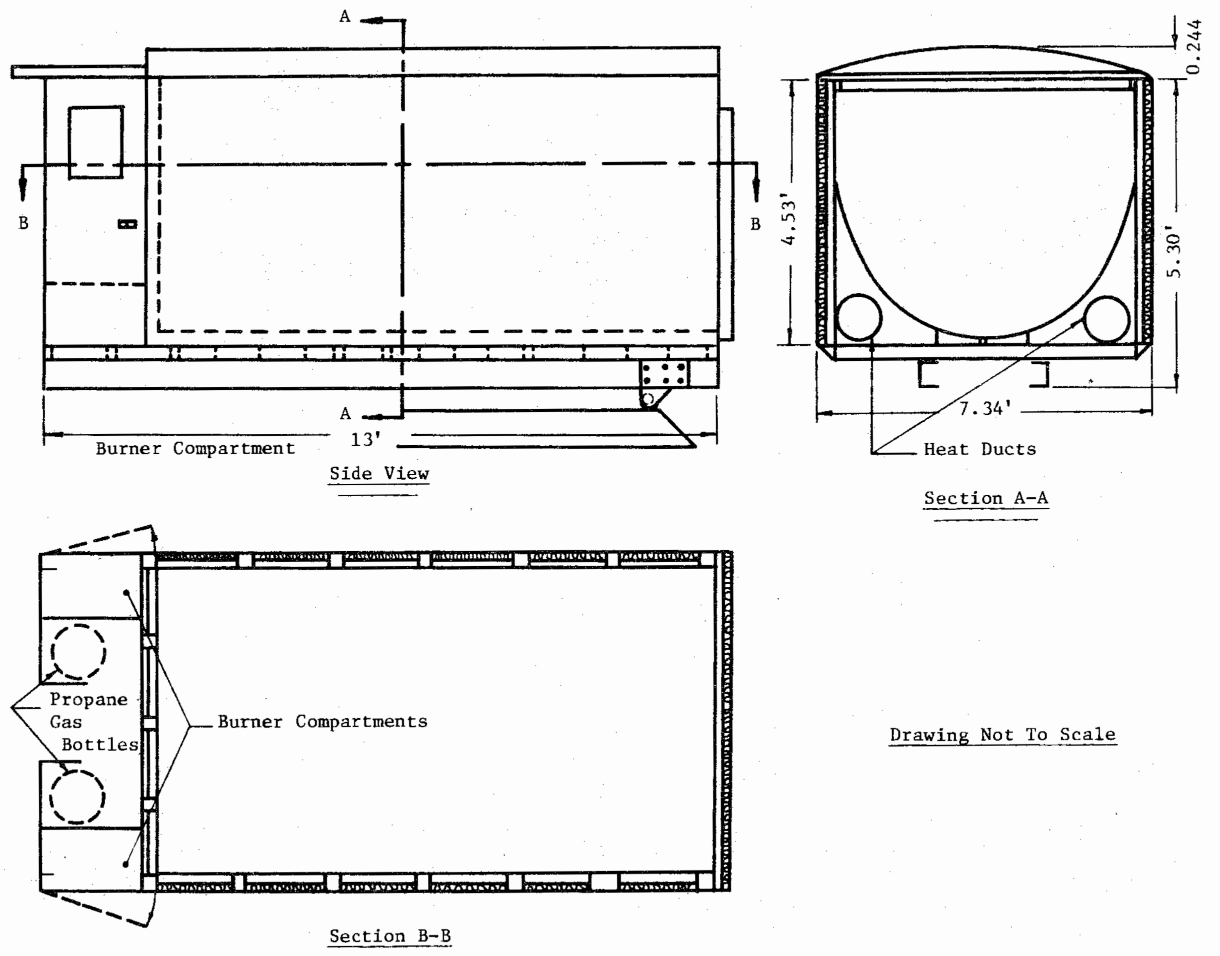


Figure 8. Heated Truck Bodies As Developed By Shell Canada Limited, Oakville Research Centre.

The body is equipped with a removal cover which has flaps for loading purposes. The aluminum body weighs 3,800 lbs. Capacity loads are 14-15 tons of sand-asphalt-sulfur pavement mixture.

3.4.2. Truck Mounting

The special heated truck bodies, as constructed, can be mounted on tandem-axle asphalt dump trucks having 14 ft. dump bodies and equipped with front mount hoists of the Edbro type or equipped with underbody hoists. They will not work with the tandem-axle asphalt dump trucks commonly used in the Louisiana-Texas areas which have 13-13.5 ft. dump bodies and telescopic hoists attached to the top front of the body requiring body recesses known locally as "dog boxes".

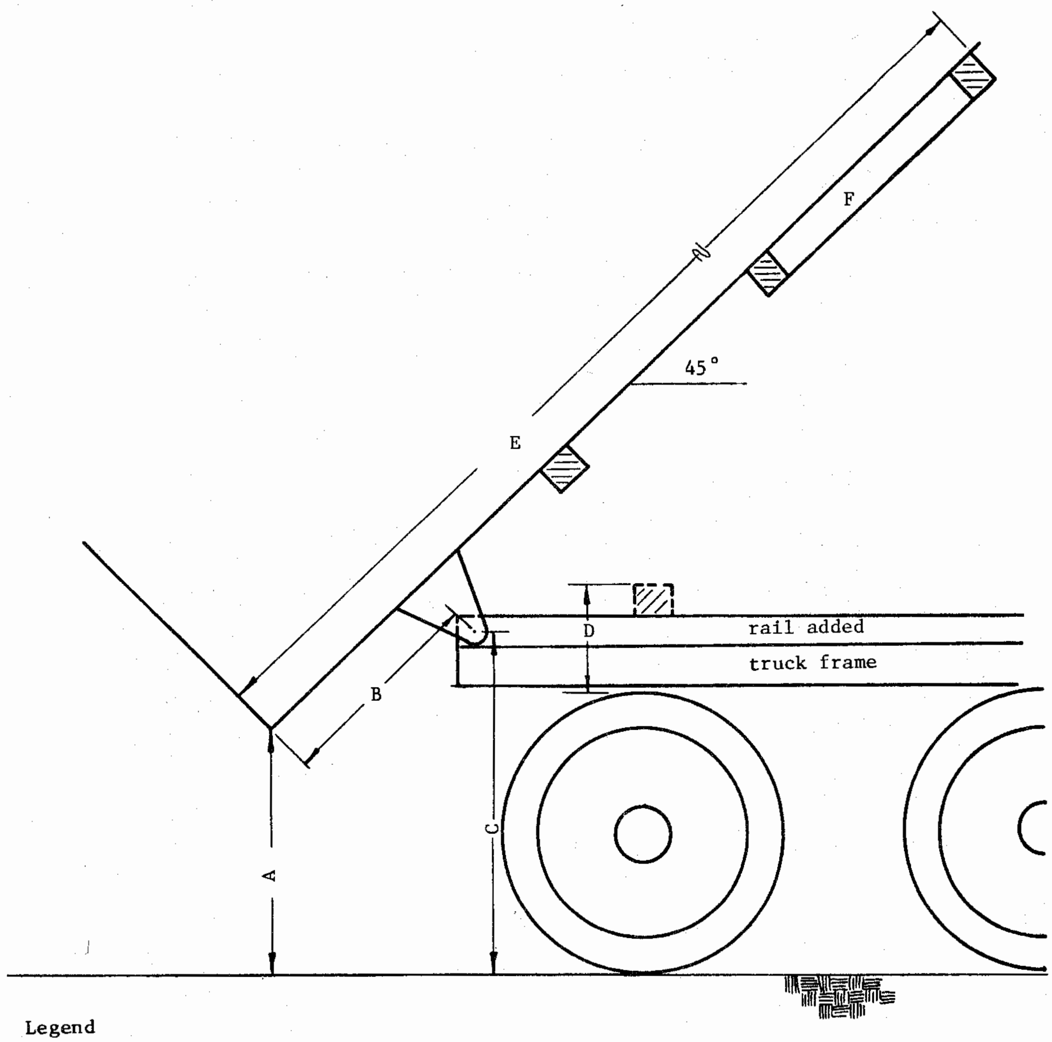
Figure 9 shows schematically some dimensions to be used as a guide for matching the trucks and the special beds for use with a paver.

3.4.3. Hoists

The hoists selected by OK Welding were underbody type "Twin Telescopic" hoists Model 498, 102-inch truck cab to axle (cab to midpoint between rear axles), manufactured by Perfection-Cobey Company, Galion, Ohio and sold and distributed by OK Welding. These hoists are designed for outside frame mounting or inside frame mounting an unique feature which accommodates many space restrictions.

3.4.4. Trucks

Rebel Ford provided re-built trucks of the following makes and types. Shown also are Shell Canada's designations for the special



Legend

A - ca. 27" min. ground to bed required to clear apron on paver

B - ca. 19-22" body overhang to properly deposit mix in paver hopper

C - ca. 41" ground to center line of hinge tangent to tire at no load

D - 10" min. clearance top of cross-frame to top of tire at no load

E - The body lengths of the special beds varied from 166 1/2 to 168"

F - Frame was reinforced to support thrust from hoist

Figure 9. Schematic For Matching Truck With Special Bed For Use With Paver

heated bodies.

Manufacturer	Description	Special Bed
Ford 9000	Tandem-axle diesel	HTB 2-A (aluminum)
Chevrolet C65	Tandem-axle gasoline	HTB 3-A "
Ford 880	Tandem-axle diesel	HTB 4-A "
Ford 880	Tandem-axle gasoline	HTB 5-A "

OK Welding modified the trucks as necessary for mounting the special heated beds. The Chevrolet C65 has a 13.5 ft. dump body and the chasis was not suitable. The ladder on the front of the special bed had to be removed to make room between the front end of the body and the cab. The Ford 880, gasoline, had a 13.0 ft. dump body. It was "stretched" by cutting and welding inserts into the frame and replacing the driveshaft. OK Welding increased the height of the truck rails when required and reinforced the under body frames; Figure 9 see Dimensions D and F, respectively.

OK Welding is affiliated with Perfection-Cobey Co., which operates a new truck body factory nearby. Perfection-Cobey provide, a computer analyses of the truck-body-hoist system. Measurements for each truck were so analyzed.

3.4.5. Transportation

The trucks with the special bodies were picked up at Brookhaven and delivered by R. E. Heidt Construction Company to the Sulphur, Louisiana project, January 1977. There each of the truck beds were fitted with two 100 lb. capacity propane bottles. Upon completion of the Louisiana project the trucks were made available to Foremost Paving Inc., who picked them up at Westlake, Louisiana and drove them to the Kenedy County project in late March 1977. Upon completion of the project, April 1977, the trucks were picked up by Rebel Ford and returned to OK Welding for detachment of the special beds for return to Canada.

3.5 Paver - Modifications

The hot sand-asphalt-sulfur pavement mixtures are soft and plastic at the time of placement. They will not usually support the weight of the floating screed assembly on the conventional paver. The screed must be fully supported for strike-off, smoothing and consolidation. No supplemental rolling of the mixture is required for compaction.

3.5.1. Modification Kit

Barber-Green Company, Aurora, Illinois, in cooperation with Shell Canada Limited, Oakville Research Centre, have developed a modification kit suitable for use with Barber-Greene Model Series 100 "Matmakers". Basically, it consists of double-acting rams mounted at the rear end of the paver frame and to the levelling arms using specially designed brackets. The rams and, in turn, the screed, are controlled by a slightly modified automatic system. In this way, upward lift and downward pressure are balanced for the designed layer thicknesses. The Grad-Line, Inc., Woodinville, Va., was used to control the grade and slope during paving. The system included a summing circuit, and electronic control component, developed in cooperation with Shell Canada Limited. The slope controller and grade controller were moved to the trailing edge of the screed.

3.5.2. Paver Characteristics

The paver provided by the contractor, Foremost Paving, Inc., was a Barber-Greene "Matmaker" Model SB-170, Rubber-Tired Interstate Finisher equipped with automatic grade and slope controls. This paver has a standard paving width of 10 ft. With cut-off shoes and extensions, the width can be changed for a range of widths from 8 to 28 ft. The Traveling Grade Reference Unit consisted of pin connected random length aluminum beams, mounted on eight dual runner sleds, attached to three 10'-0" length beams with string line support posts and line.

Modifications: Barber-Greene furnished their modification kit to the contractor. The mechanism was installed by the contractor under the supervision of Barber-Greene and Shell Canada Engineers. Other modifications necessary for the handling of the soft, sand-asphalt-sulfur mixture were also made.

A front endgate was provided to keep the soft mixture from flowing forward out of the hopper. It consisted of heavy composition belting supported vertically with heavy flexible cable loops the ends of which were attached to the leading edges of the hopper and wings in such a way that movement of the wings was not restricted.

Two main frame extensions consisting of two one-foot segments each were constructed by the contractor under the supervision of the Barber-Greene engineer. These became a part of the modification kit.

The auger chamber was enclosed by extending the main frames for the screed extensions on either side. The feeder switches were relocated between the main frame extensions and turned to work in the direction of paving. A larger paddle was used in order to float on the soft mixture.

Side plates were used on the free ends of the screed to prevent "dribbling" of the soft mixture to the side. The plates sloped inward to provide some edge consolidation.

The hopper and wings were lined with 3/4" plywood in an effort to insulate the hopper and reduce cooling and formation of lumps.

4.0 Construction Features

4.1 Sulfur Handling

4.1.1. Asphalt Contamination

The sulfur tank was gauged prior to use and found to contain a depth of 22 inches of paving grade asphalt which calculated to be 2,200 gallons. It could not be drained readily since heating failed to liquify the material below the heating coils. The hot liquid asphalt in the top layers was pumped out as much as possible using an asphalt distributor (pump and tank) with the suction line placed overhead into the dome of the tank. A gauged 1,150 gallons, 14-inches still remained after pumping and was left in the tank. There was some reasoning that after additions of the hot molten sulfur (Specific Gravity - 2.0) the residual asphalt (Specific Gravity - 1.0) would rise to the surface and that contamination from any turbulent mixing in the tank would be minimal. The pavement mix design required 6.2% weight percent (w/o) asphalt and 13 w/o of sulfur.

During construction, attempts were made to check on the amounts of asphalt contamination. On April 13th., with the gauged sulfur depth at 30 in. (3,440 gallons) in the tank, a sample was taken from the outlet, cooled and weighed in air and in water. The composition, as calculated, was 80 w/o sulfur and 20 w/o asphalt. This high asphalt content was questioned due to the probability of discrete air voids in the sample. A concurrent sample of the pavement mixture, analyzed in the field laboratory, showed an asphalt content of 6.8 w/o versus a designed content of 6.2 w/o.

4.1.2. Steam Boiler

Start-up of the sand-asphalt-sulfur paving operations was delayed one day, April 5th., largely due to problems with the steam boiler. It was fired up late in the afternoon on 4 April with a targeted pressure of 60 psig. Pressures varied out-of-control from an observed 0 to 125 psig during which the boiler "popped-off" at 150 psig. The condensate from the steam shorted out the electric motor on the nearby oil heater. The boiler developed a leak due to the melting of a soft plug; or so it was reasoned. The electric motor was replaced and the boiler repaired and operation resumed late the next day (5 April).

Boiler operation was erratic throughout the project. Gauge pressures fluctuated from an observed 40 to 120 psig. The oil burner was not easily regulated and this accounted for the erratic operation. Despite this irregular operation, the steam supply, after start-up April 6th., was adequate to keep the sulfur pump, pipe and auxiliary equipment operative and provide steam for the sulfur transports, as required.

4.1.3. Sulfur Tank Capacity

There was some question about the structural integrity of the sulfur tank which had been used solely for asphalt service. There was some concern that the tank might rupture if filled with sulfur whose weight per unit volume is double that of asphalt. It was described that the amount of sulfur in the tank at any one time would be limited to one-half tank capacity and sulfur deliveries scheduled accordingly. No problems were encountered.

4.1.4. Transport Handling

The first sulfur transport, ex Warren Petroleum, and 18 wheeler with a Mack tractor, arrived about noon on 4 April, with an invoiced load of 47,800 lbs. (3,200 Gals.). The temperature was measured at 272F. It could not be unloaded at that time due to problems with the steam boiler discussed above. At 5:45 pm., it was returned to Warren Petroleum for steaming. It was reasoned that the temperature of the sulfur would fall an estimated 1/2 degree hr., perhaps to the solidification point before unloading would be completed.

The above transport returned the next day (5 April) about 5:00 pm. The temperature of the sulfur was 276F. The transport was positioned and put on steam for about an hour. The temperature rose to 292F. The transport was unloaded by gravity flow into the receiving hopper thence by pumping through the system into the dome of the sulfur storage tank. Sulfur unloading took 24 minutes and was accomplished without problems. The liquid level in the storage tank was depth gauged at 34 inches for a calculated 4,100 gallons. The total gallons of sulfur unloaded by difference (4,100 minus the 1,150 gallons of asphalt) was 2,950 gallons. The difference of 250 gallons between the amount invoiced and the amount gauged in the storage tank was attributed to clingage in the transport and to possible inaccuracies in gauging since the tank has not been calibrated to correct for volume occupied by heating coils.

There were no appreciable problems experienced with the sulfur transports. The earth ramp to the receiving hopper had to be adjusted once for height.

4.1.5. Operating of Sulfur System

There were some problems encountered in the operation of the sulfur system. The 3-way valve at the pug-mill was not insulated or hot oil traced, initially, in deference to the contractor's experience in handling asphalts. During most of the first day of pavement mix production this 3-way valve froze repeatedly and had to be unclogged with sledge hammer blows. Eventually, Texasgulf engineers removed and cleaned the valve, tapered the cylinder and adjusted the clearance. The valve was circled with a hot oil line and insulated. The additions of the oil tracing, insulation and other adjustments proved to be the solution for this problem.

The return line was extended well below the center of the sulfur storage tank in an effort to reduce trubulence. Following the week end of 9-11 April, the sulfur system was found to be plugged up due to low heating oil temperatures. An inspection revealed that the lower end of this return pipe had been clogged with cold asphalt and sulfur presumably near the liquid surface. A 3.5-ft. segment of the return line was removed solving the problem.

4.1.6. Sulfur Pump

In the preliminary engineering of the sulfur system, Texasgulf engineers proposed the use of the 1.5 inch in-line pump. An estimated 390 lbs. (ca. 24.5 gals.) of sulfur would be required for each 3,000 lb. batch of pavement mix. The sand-asphalt mixing cycle during which the weigh bucket would be filled with sulfur was set at 20 seconds by project specifications. It was reasoned that the pump would deliver this amount in about 12 seconds. The actual time required to pump 325 lbs. of sulfur (2,500 lb/batch) was measured repeatedly on 7 April at 8 to 10 seconds.

4.1.7. Conclusion of Sulfur Operations

At the end of the sand-asphalt-sulfur portion of the project, 14 April, the sulfur tank was depth gauged at 22.5 in. for a calculated residual of 2,290 gallons. When offset for the 1,150 gallons of asphalt known to have been in the tank initially, the sulfur content was 1,140 gallons or 17,000 pounds.

This material was drained into a pit which was excavated alongside the sulfur tank. After hardening, it may either be removed with the front end loader and hauled away or covered up and left in place.

4.2 Sulfur Balance

A log of the sulfur delivered to the project as obtained from State Engineer's field records is as follows:

Date	Transport Number	Supplier	Invoice Amount, Lbs.	Temperature on Arrival, °F
5 April	1	Warren Petroleum	47,800	276
6 April	2	Warren Petroleum	47,830	273
6 April	3	Warren Petroleum	51,360	-
7 April	4	Warren Petroleum	47,600	272
8 April	5	Warren Petroleum	47,640	273
8 April	6	Warren Petroleum	50,970	272
11 April	7	Warren Petroleum	50,730	268
12 April	8	Warren Petroleum	51,110	268
13 April	9	Texasgulf, Inc.	47,860	268
13 April	10	Texasgulf, Inc.	50,960	268
		Total amount invoiced:	493,860 Lbs.	

A log of the tonnage of sand-asphalt-sulfur mix delivered to the roadway according to State Engineer's records together with an estimate of mixture wasted at the hot-mix plant follows:

Date	Regular Mix @ 13 w/o Sulfur - to Roadway, tons	Special Mix @ 15 w/o Sulfur Prepared, tons	Regular Mix @ 13 w/o Sulfur Wasted at Hot-Plant, tons
6 April	89		
7 April	311		
8 April	336		12, mix too hot
11 April	130		
12 April	357		12, mix too hot
13 April	335	13	8, too much sulfur 8, sulfur valve stuck
14 April		24	
Totals	1,558	37	40

Sulfur in sand-asphalt-sulfur mix:

1,558 tons @ 0.13/ton	................202.54	tons sulfur
37 tons @ 0.15/ton	.... 5.55	tons sulfur
40 tons @ 0.13/ton	.... 5.20	tons sulfur
Total short tons	..........213.29	
Total lbs.	426,580	

Summary:

Total weight of sulfur delivered, per invoices	493,860 lbs.
Sulfur left in tank at end of project	17,000 lbs.
Total sulfur, invoiced minus residual in tank	476,860 lbs.
Sulfur used in mixes per hot-plant records	426,580 lbs.
Difference	50,280 lbs.

A total of 50,280 lbs. (25.14 short tons) of sulfur invoiced to the project was unaccounted for by hot-plant mix records. This amounts to 10.54 percent.

4.3 Summary of Sulfur Handling

It was the sense of the contractors, engineers and visitors who observed the construction operations that sulfur handling was a safe practical construction operation.

4.4 Subgrade - 8" Lime Treated Soil

The 8" lime-treated soil subgrade for all test items was constructed according to plans. In order to preserve the grade lines during construction traffic, the subgrade was covered with several inches of F. B. (flexible base) caliche. This cover was removed before placement of the pavement mixtures and the exposed surface was tacked with emulsified asphalt; type EA-11M diluted with several volumes of water. The tack was entirely inadequate, effecting little or no bond of the paving mixture to the subbase.

There were some irregularitites in the subgrade profile. One was located in the 10-inch sand-asphalt-sulfur section near station 1988 where the subgrade was several inches low.

The subgrade was swept with a power broom each day, as required, before placing the pavement mixture to remove all loose material.

4.5 Preparation and Placement of the Sand-Asphalt-Sulfur Mix

Construction of the sand-asphalt-sulfur pavement was not a smooth operation. Some pavement layers, one lane wide and hundreds of feet in length, were placed true to line and grade and without noticable imperfections. Some segments were ragged with widespread imperfections of checks and tears, some skillfully patched and some not. There were two general types of tearing and combinations of the two; one possibly due to an excess of No. 50 to No. 100 mesh sand in the mixture, the other caused by lumps of cold material passing under the screed. In some stretches, the grade was undulating caused by a "galloping screed". Two small segments the first 2-inch layer, right lane of the 4-inch section, station 1997/60 to 1998/20 and the 2-inch layer, third lift, left land of the 10-inch section station 1985/00 to 1985/50 were rejected by the engineers and removed with a blade grader.

Good and poor pavement stretches were placed intermittently throughout the project. At the same time, it is a desirable characteristic of the soft (7-inch slump) hot sand-asphalt-sulfur mixture that it is squeezed under the paver screed and into the surface imperfections of the underlying layer.

There was considerable speculation among the engineers and consultants as to the cause or causes of the construction problems. Some of these are examined as follows:

4.5.1. Mixing

Hot-plant mixing was widely judged from visual inspection to be non-uniform. The non-uniformity was manifested by color and texture differences seen at the paver. Usually the dividing line was at or near the center of the paver as the mixture passed through the hopper suggesting that proportioning and/or mixing were different at opposite ends of the pug-mill.

Mixing time, in general, followed the specifications which called for 5 seconds dry mixing, 20 seconds sand-asphalt mixing and 25 seconds sand-asphalt-sulfur mixing. Total batching time were checked on different days and showed a range to 60 to 80 seconds.

Some adjustments were made in the spray bar in the pug-mill. Nozzles were closed on one end where the mix visually appeared to be the richest in binder. The color and texture differences then seemed to shift from that side to the other side accordingly, but were not eliminated.

There is little, if anything, to suggest a maldistribution of asphalt in the mixture from studying the field laboratory determinations. Sulfur distribution may be suspect from studies of the field tests but so, also, was the precision of the test methods used. See Quality Control, Section 5.0 page 81.

Some material was observed to ride atop the paddles when the batch weights were initially set to total 3,000 lbs. This was stopped by reducing the batch sizes first to 2,500 lbs. and then to 2,000 lbs.

There was some contention that mix temperatures contributed to variability in mix consistencies. There is little, if any, support for this, except for a few loads, to be found in the field measurements of temperatures at the hot-plant and checked in the field. See Quality Control, Section 5.0 page 81.

There was a build-up of hard materials in the pug-mill especially during the first two days. On 7 April the pug-mill was cleaned by chopping out the hard mix, mixing with clean sand and flushing with fuel oil. Adjustments were made in the heating and insulation of the pug-mill but the problem did not disappear.

The one source of known wide variability throughout the project was in the sand gradings, a variability which in conventional asphalt concrete pavement construction can produce "lean" and "rich", "tough" and "workable" mixtures and with obvious color and texture differences.

In summary, hot-mix plant mixing efficiency was suspect and as it turned out there was a basic mechanical problem. This may very well be an explanation for some of the aggregate grading variations reported. Purportedly, the paddle arrangement in the pug-mill was changed prior to receiving the coventional asphalt concrete mixture to push the material into what is known in the trade as a "figure-eight" or a 3-dimensional figure-eight. No nonuniform mixing was encountered following this operation.

4.5.2. Hauling

The four haul trucks with the special heated beds were used to transport the sand-asphalt-sulfur mixture from the hot-plant to the roadway. The center of the test project was about 3,500 feet from the hot-plant but the circuitous route elected extended the haul distance to about 1 1/2 miles. Excellent weather prevailed throughout the project.

Only two mechanical problems were noted in the truck operation. The transmission on one truck malfunctioned leaving only one forward speed. On another truck a fire broke out in the wiring system, battery to burner on the bed. It was extinguished without appreciable damage. Propane bottles, two per truck, were filled as required by drivers from storage at the hot-plant site. A Shell Canada engineer tended the trucks at all times and assisted with the burners and cleaning of the beds.

Before each shift each truck bed was thoroughly cleaned and coated inside with fuel oil. During use there was some formation of cold lumps of materials in all truck bodies usually more pronounced in the front bottom corners and about the rear end gate. It was routine throughout the project for the drivers to return the empty trucks to a waste pile near the hot-plant, raise the bed and remove the hard attached mix by chopping and scraping. In at least one instance neat sulfur (i.e. unassociated with sand and asphalt), was evident at the metal to mixture interface.

4.5.3. Placing

There were two intermittent problems at the paver; tearing under the screed and "galloping of the screed" to create transverse waves. The tearing was of two types and combinations of the two; tearing apparently caused by a lack of cohesion in the mixture possibly attributable to an excess of one-size particles of sand and the other by lumps of cold mix dragging under the screed.

When the temperature of the sand-asphalt-sulfur mixture cools much below the melting point of sulfur (ca. 250F), the mixture becomes stiff. It is therefore basic that the material not be permitted to cool below 250F anywhere in-route from the hot-mix plant to the roadway. This requirement is reflected in the project specifications which states in part: "The entire system, hopper to screed, shall be of such design and operation as to assure uniform flow of the mixture and prevent material from collecting and cooling in the spreader".

Continuous operation of the paver was impracticable. Plant production rarely exceeded 50 tons per hour. For continuous operation, the paver would have to be slowed to about 6 ft./min. on the 2-inch layer from a normal speed of 20 ft./min. or more. Two procedures were tried. In one, the four haul trucks were loaded and grouped at the paver. Paving was continuous until the four loads were placed at which point the paver was run-out. The crew was then required to clean and scrape the hopper to remove solidified material. In the other, the paver speed was slowed to match hot-plant production. The latter was preferred by the crew since it eliminated the need for periodic clean-up of the paver. However, build up of solid material in the hopper was produced in this method as well and require cleaning and scraping for removal.

A string line on one side of the paver was usually used as a grade reference for the initial layers in each test item. A skid reference unit (joint matcher) was used, generally, on subsequent paver courses although from time to time changes were made from the one skid reference unit to a travelling string line.

There were stretches where transverse waves were left in the pavement after passage of the screed. The automatic screed control may have malfunctioned. This was a recurrent problem possibly attributable to variability in the consistency of the mixture which precluded a fixed attack angle for the screed.

4.5.4. Summary of Mixing and Placing

From field observations and inspection of the field laboratory test data, the quality of the pavement, as placed, seems to relate to the time of day and the clean-up of all equipment. In general the best quality pavement was that placed earliest in the day and following the previous night equipment clean-up. Two examples can be cited. On 7 April paving began at 9:15 am. From 2:25 to 3:20 pm., the first 3-inch layer, right lane, 7-inch section, station 1990 to 1995 was paved with quality of the pavement decreasing with time. The paver then moved to station 1990 for paving back to station 1985. The second 3-inch layer in the right lane of the 10-inch section was a near continuous mass of transverse waves, checks and tears and poor patching. A complete clean-up of all equipment was made that evening. On 8 April paving started at station 1985, left lane, second 3-inch layer at 10:27 am. The next 6 or 8 hundred lineal feet, reaching into the 7-inch section was placed with near perfection. Also on 12 April, following the rejection of some pavement placed on previous day and general clean-up that night, near perfect pavement was placed for hundreds of lineal feet of the first 2-inch layer, right lane ahead of station 1985. There were other examples which tend to support this hypothesis. The advantage of the learning process should not be overlooked as an input to an important operation.

It was the sense of the engineers and crews that the mixtures should be uniform and perhaps the automatic controls on the paver should have been fine tuned to eliminate the waves in the surface. Also, the formation of lumps must be eliminated or substantially reduced to relieve the burdens of continuous clean-up of the pug-mill, the trucks and the paver.

At the conclusion of the planned project some 35 tons of S-A-S was prepared and placed using local field sand as the only aggregate. Observations by SDHPT personnel in the field laboratory and on the placing site indicated that this mixture produces a pavement equal in quality to that consisting of the blended sands. This was no surprise to many of those who observed the operation, since it was consistent with TTI's laboratory findings. In fact, virtually all of TTI's effort from the outset of this program has been associated with unblended, poorly-graded, beach sands. The major obstacle to the utilization of significantly higher fractions of local sands on this project was the current state of development of the paver. Paver modification utilizing another mode of screed motion is now under study by Shell which could provide a solution to this problem.

4.5.5. Joints

Paving widths were 14 ft. and 13 ft. as shown in Figure 10 with the centerline joints offset either 3 or 6-inches. In all cases where a layer abutted another layer, the face against which the layer was placed was first painted with a heavy coat of emulsified asphalt, Type EA-11M, applied with a hand hose attached to the asphalt distributor.

Transverse joints were constructed where operations were markedly delayed. The leading edge of the layer was cut back to a near straight line with a vertical face. The surplus material was removed by transverse blading with a road grader. The vertical face of the joint was given a heavy coat of emulsion also applied from the asphalt distributor.

4.5.6. Patching

Patching, not always done well, consisted of tamping the small checks and tears with the flat side of a lute or shovel to close the surface and provide a continuous although thinner layer over the spot. Larger imperfections were filled with hot mixture from the hopper or from in front of the screed and tamped to grade.

Note: Layer 1 - Station 1985 to 1990
Layer 2 - Station 1985 to 1995
Layers 3 and 4 Station 1985 to 2000

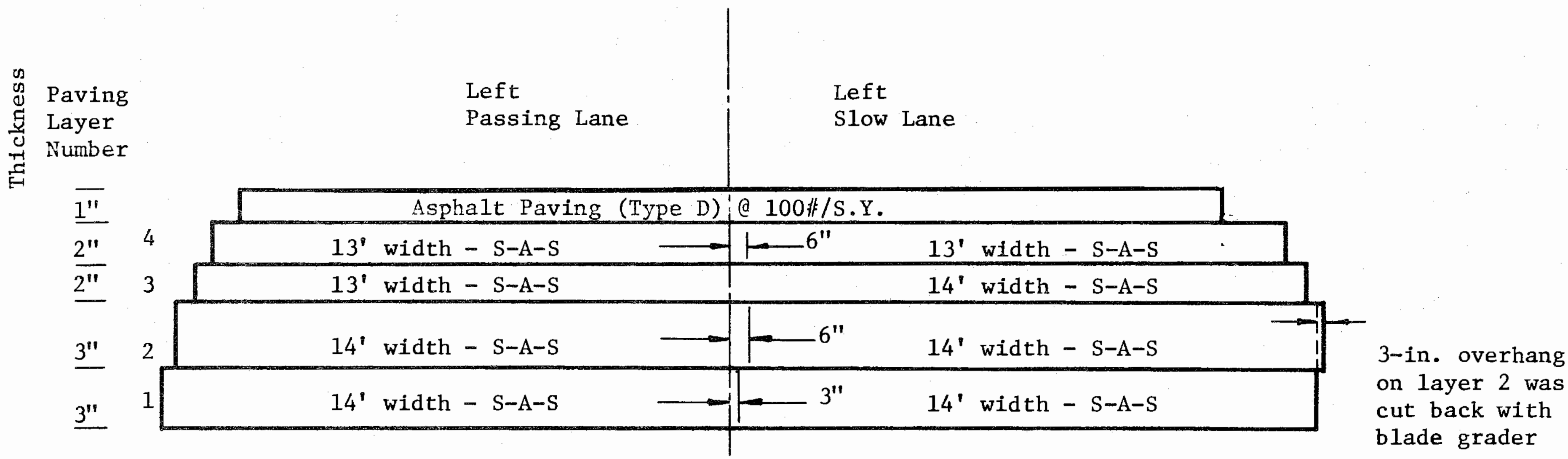


Figure 10. Schematic Cross-Section Showing Longitudinal Joint Offsets

4.5.7. Smoothing the Pavement Surfaces

In areas such as that described above, and in particular the second 3-inch layer lift in the right lane of the 10-inch section placed 7 April tight blading with a road grader was used in an attempt to improve surface smoothness. The sand-asphalt-sulfur at or less than one day old "cut like cheese". After several days, it was too hard. The blade would grind over the surface producing sparks and some smoke and an odor of sulfur. After completion of the sand-asphalt-sulfur test items and before placing the 100 lbs/per S.Y. surfacing, fine graded asphalt hot-mix was bladed over the roughest areas in preparation for the final riding surface.

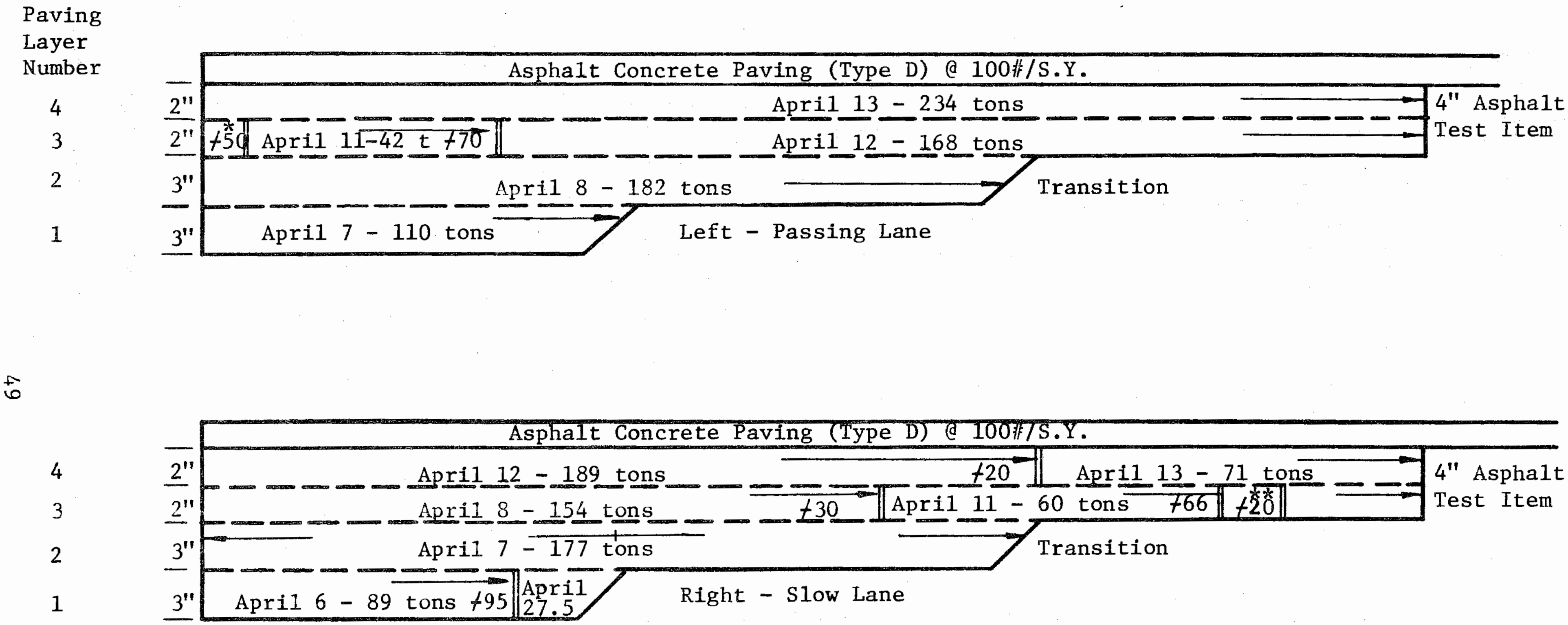
4.5.8. Log of Field Construction - Sand-Asphalt-Sulfur Test Items

Details of S-A-S experimental pavement construction showing tons of sand-asphalt-sulfur pavement mixture placed by dates, quantities, pavement layer, traffic lane and engineer station, is depicted in Figure 11.

A log of Field Construction is contained in Appendix A. It includes by date and station, the load number, section, layer and layer thickness where placed together with time and mix temperature as recorded by the State Engineers.

4.5.9. Weather

The two weather services closest to the construction site were located at Brownsville and at Corpus Christi. The following weather information was provided by the U.S. Weather Service, Corpus Christi,



Notes: *April 11 - 16 tons placed and rejected; replaced April 13
**April 11 - 10 tons placed and rejected; replaced April 13
End of Day's run or Rejected and Patched
Direction of Paver

Figure 11. Details of S-A-S Experimental Pavement Sections As Constructed

Texas for the duration of the project.

Date	Temp. Max.	F Min.	Wind Velocity Average, MPH	Rainfall Inches
5 April	77	44	10.6	0.00
6 April	81	45	9.9	0.00
7 April	81	52	13.2	0.00
8 April	81	55	10.2	0.00
9 April	78	57	11.5	0.00
10 April	82	59	12.7	0.00
11 April	83	63	17.3	0.00
12 April	82	64	16.1	trace
13 April	82	66	16.1	trace
14 April	82	69	19.3	0.04
15 April	79	72	20.0	1.74

The sand-asphalt-sulfur test items were constructed in the period of 6-14 April, 1977.

The weather at the construction site was quite similar to that reported by the U.S.Weather Service at Corpus Christi, Texas.

4.6 Asphalt Concrete Pavement Test Items

The experimental section contains six test items, each 500 ft. in length. From South to North there are three test items of sand-asphalt-sulfur base in thicknesses respectively, of 10, 7 and 4-in. These items are followed by three test items of asphaltic concrete base in thicknesses respectively of 4, 7 and 10-in. See Figure 2.

The test items were designed by the Texas Trasnportation Institute to "...give a fair comparison of the relative performance of sand-asphalt-sulfur pavements and deep asphalt concrete pavements".

4.6.1. Specifications

The asphalt concrete test items were constructed in accordance with Texas State Department of Highways and Public Transportation, Standard Speicifications; Item 340, "Hot-Mix Asphaltic Concrete Pavement," 340.3 Paving Mixtures, Type "D" (Fine Graded Surface Course).

4.6.2. Pavement Mixture Requirements

Aggregate Gradings: The specifications required aggregate gradings for the Type "D" to conform with the following:

Passing 1/2" sieve	100	percent
Passing 3/8" sieve	90-100	"
Passing 3/8", retained on No. 4 sieve	20-50	"
Passing No. 4, retained on No. 10 sieve	10-30	"
Total Retained on No. 10 Sieve	50-70	"
Passing No. 10, retained on No. 40 sieve	0-30	"
Passing No. 40, retained on No. 80 sieve	4-25	"
Passing No. 80 sieve, retained on No. 200 sieve	3-25	"
Passing No. 200 sieve	0-6	"

Asphalt Content: "The asphalt material shall be from 4.0 to 8.0 percent of the mixture by weight....".

Control Tests (Field): "It is the intent of this specification to produce a mixture which when designed and tested in accordance with these specifications and methods outlined in THD Bulletin C-14, will have the following laboratory density and stability:

Density, Percent			Stability, Percent*
Min.	Max.	Optimum	
93	96	95	Not less than 30 unless otherwise shown on the plans
95	99	97	

Stability and density tests are control tests.

*Hveem methods

4.6.3. Materials

Mineral Aggregates: The mineral aggregates selected by the Contractor, Foremost Paving, Inc., for the Type "D" asphalt concrete was a blend of four materials as follows:

Aggregate Size Designation	Source of Aggregate
7/16"	Fordyce Gravel Company, Sullivan City, Texas
1/4"	Same Source as 7/16"
Sand	"Hawkins Sand", Valley Caliche Products, Texas
Field Sand	Pit, 500 ft. east of Project ROW, Engineer's Station 2030 (See Construction Materials, S-A-S, page 13).

Aggregate Blend:

35% wt. Fordyce 7/16"

25% wt. Fordyce 1/4"

20% wt. Hawkins Sand

20% wt. Kenedy Field Sand

Asphalt: The asphalt for the asphalt concrete test items came from the same source as the asphalt for the sand-asphalt-sulfur test items; Gulf States Asphalt, Corpus Christi.

4.6.4. Characteristics

The asphalt was a Viscosity Grade AC-20 paving asphalt cement. The test requirements for this material together with the test values of a representative sample follow:

Viscosity Grade

Test	AC-20	State Sample No.* 05 56
Viscosity, 140F, stokes	2000 + 400	1731
Viscosity at 275F, stokes (min)	2.5	3.61
Penetration at 77F, 100g 5 sec. (min)	55	73
Flash Point, COC, F (min)	450	590
Solubility in Trichlorethylene, percent (min)	99.0	
Tests on Residue from Thin Film Oven Test		
Viscosity, 140F, stokes (max)	6000	4039
Ductility, 77F, 5 cm. per min., cms., (min)	50	141+
Spot Test	negative	negative
Penetration, 77F, 100g, 5 sec.	-	50

Complete analyses are not run by the State of Texas on all field samples of asphalt.

Test numbers for the field sample, C 7737 05 85, were provided by the State Department of Highways and Public Works, Division of Materials and Tests, Camp Hubbard, Austin, Texas.

4.6.5. Asphalt Concrete Mix Design

The aggregates were proportioned to give 60 percent weight retained on the No. 10 sieve. The asphalt content was set at 5.8 percent of total mixture by weight (ca. 6.1 percent weight ratio of asphalt to aggregate). The mix design was not changed during the construction of the asphalt concrete test items.

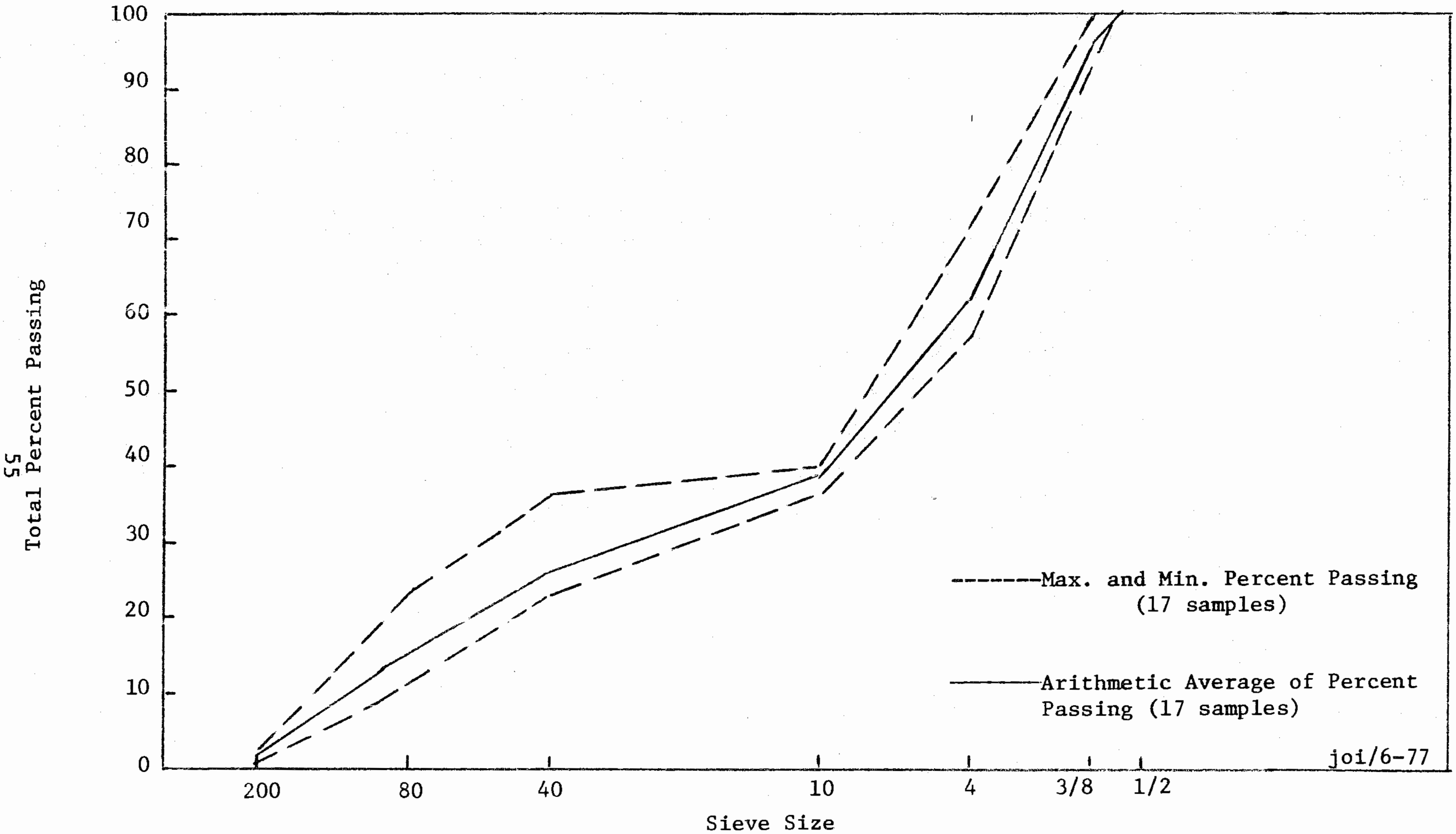
4.6.6. Quality Control

Aggregate - Dry Sieve Analyses: The daily aggregate sieve analyses, totaling 17 samples, are reported by the State in terms of "Percent Passing and Retained" as required by the specifications. These gradings were recalculated on the basis of "Percent wt. Passing". The minimum and maximum values for each specification sieve together with the arithmetic average for the job have been plotted. See Figure 12.

This type of aggregate grading is known in the industry as "gap-graded" as distinguished from "well graded".

Densities and Stabilities: The densities and stabilities of the pavement mixture as determined in the field by the State Engineers follow:

Date	Laboratory Density	Stability (Hveem)
April 15	97.6	34, 31, 32
April 18	-	29
April 19	-	28
April 25	96.7	26, 38, 38
April 29	96.8	31, 31, 33
May 2	96.4	36, 33, 37



U.S. Standard Sieves - ASTM Designation E 11-39

Figure 12. Daily Aggregate Sieve Analyses Showing Maximum, Minimum and Mean Values for Seventeen (17) Samplings

Extractions and Gradations

Date	Specification Sieve Sizes	Field Sample	Asphalt Percent in Mix
April 15	1/2" to 3/8"	2.8	5.8
	3/8" to No. 4	28.0	
	No. 4 to No. 10	30.5	
	Plus No. 10	61.3	
	No. 10 to No. 40	1.9	
	No. 40 to No. 80	12.7	
	No. 80 to No. 200	16.8	
	Passing No. 200	1.5	
April 18	1/2" to 3/8"	3.2	5.9
	3/8" to No. 4	27.6	
	No. 4 to No. 10	31.5	
	Plus No. 10	62.3	
	No. 10 to No. 40	1.9	
	No. 40 to No. 80	12.4	
	No. 80 to No. 200	16.0	
	Passing No. 200	1.5	
April 29	1/2" to 3/8"	3.8	5.8
	3/8" to No. 4	34.7	
	No. 4 to No. 10	18.4	
	Plus No. 10	56.9	
	No. 10 to No. 40	2.9	
	No. 40 to No. 80	16.1	
	No. 80 to No. 200	16.5	
	Passing No. 200	1.8	
May 2	1/2" to 3/8"	5.2	5.8
	3/8" to No. 4	34.0	
	No. 4 to No. 10	20.5	
	Plus No. 10	59.8	
	No. 10 to No. 40	1.8	
	No. 40 to No. 80	16.6	
	No. 80 to No. 200	14.3	
	Passing No. 200	1.9	

Extraction tests were not recorded for April 19, 25 and 30.

Temperatures of the Paving Mixture - Tonnage

Date	Temperature, °F Max.	Min.	Avg.	Tonnage of Mix
April 15	280	-	-	214
April 18	280	-	-	243
April 19	-	-	-	216
April 25	295	285	290	159
April 29	285	280	284	495
April 30	280	-	-	120
May 2	280	275	279	465
				1,912

4.6.7. Construction

A "Schematic of Construction" showing the tonnages placed by date, engineer's station, pavement layer and traffic lane is shown in Figure 11.

4.7 Evolved Gas Analysis

General: Throughout the development of the sulfur/asphalt concept one of the major concerns of the industry has been the potential hazards created at the construction site due to the evolution of toxic gases (H_2S and SO_2) and particulate sulfur. Over the years Shell Canada has monitored these pollutants both in the laboratory as well as in conjunction with their Thermopaver field trials. As yet, none of their data has been reported in the open literature. However, Shell has stated that as long as the temperature of the mix is maintained below 300°F the concentrations of H_2S and SO_2 produced are well below the maximum allowable concentrations (MAC) as suggested by the American Conference of Governmental Industrial Hygienists (ACGIH) [1]*. Similar studies at TTI and the Bureau of Mines support this claim [2, 3]. Because of its importance to the general acceptability of the sand-asphalt-sulfur concept an emissions monitoring activity was incorporated into this project.

4.7.1. Equipment

The responsibility for collecting these data was shared by three agencies; TTI, The Bureau of Mines and The Texas Air Control Board (TACB). The latter is charged with the responsibility of assessing the environmental impact of various types of industrial pollutants for the state of Texas. A meeting was held at the TACB facility in Austin, Texas on November 28, 1976. In addition to the three participating agencies mentioned above, Mr. William Gaw of Shell Canada was also present. A breakdown of the responsibilities and the specific monitoring equipment

*Numbers in brackets are references which are listed on page at the end of this section.

which was to be furnished by each agency was resolved at that meeting and is shown in Table II.

Although TACB had the responsibility for monitoring particulate sulfur these data were not generated on this project. Except for specific monitoring equipment used, all other responsibilities as shown in Table II were fulfilled. The evolved gas measurements were taken during the construction period 5 - 7 April, 1977 which corresponds to the dates during which the sand-asphalt-sulfur pavement was being placed. TACB data were obtained using a mobile sampling van (see Figure 13) equipped with a Meloy SA1655 total sulfur analyzer, a Houston Atlas H_2S tape sampler and an Interscan Model 1176 H_2S analyzer. An Omniscible Model 5213-15 dual pen chart recorder was used to record signals from the Meloy and Interscan instruments and a Weather Measure Corporation electronic polyrecorder Model EPR - 200A was used to record signals from the Houston Atlas unit.

The mobile van moved about the various sampling sites at the discretion of TACB personnel. Specifically, measurements were taken at the following locations: sulfur storage tank, hot-mix plant mixing chamber and the paver hopper and auger. Additional measurements were taken downwind of the plant and paver so as to establish dissipation factors. Locations of the various sampling sites monitored by TACB are shown in Figures 14 to 16.

Except for downwind samplings, most of the emissions readings generated by TACB were considered to be source type data; that is measurements were taken directly over the mixture. This was accomplished using a Midget Impinger Gaseous Air Sampling Train (MIGAST). MIGAST samples were taken using Bendix Telematic 150A automatic air samplers with a cadmium hydroxide absorbing solution. Samples were collected with a 5-ft. length probe of 3/8 in. O.D. stainless steel tubing. Gases were sucked back to the analyzer

Table II.

ARRANGEMENTS FOR INSTRUMENTATION

Location During Project Construction	Pollutant	Instrument	Number	Supplier
I. Hot-Mix Plant:				
a) Workman platform near pug-mill	H_2S	HOUSTON ATLAS Hydrogen Gas Analyzer	1 Complete with remote sampler and recorder	Bumines
b) Other workman areas of interest	H_2S	COLORTEC Hyrdogen Sulfide Detector	100 total	TTI
c) Ambient air	Particulate sulphur	HI-VOL Air Sampler	2	TACB
II. Haul Trucks:				
a) Cab	H_2S	COLORTEC Hydrogen Sulfide Detector	see item I. b)	TTI
b) Inside top of truck bodies	H_2S	DRAGER Multi-Gas Detector	50 tubes plus bellows pump	TTI
III. Asphalt Paver:				
a) Operator area	H_2S	INTERSCAN Hydrogen Sulfide Recorder or equivalent	1	TTI
b) Ambient air	H_2S	COLORTEC Hydrogen sulfide Detector	see item I. b)	TTI

cont'd next page

Table II. cont'd

ARRANGEMENTS FOR INSTRUMENTATION

Location During Project Construction	Pollutant	Instrument	Number	Supplier
IV. TACB Moving Van:				
a) On highway and at paving site	H_2S	HOUSTON ATLAS Hydrogen Gas Analyzer	1	TACB
b) ditto	H_2S	SENTOX System	1	TACB
V. Areas Surrounding Plant and Paver	Particulate matter	Bubbler - Gas/ Particualte samplers	2	TACB
ditto	Particulate matter	HI-VOL Air Sampler	see item I. c)	TACB

NOTE: Other instrumentation, such as safety alarm devices, was considered favorably.

MANPOWER SUPPLY:

Texas Air Control Board	3
Bureau of Mines	1
Texas Transportation Institute	3-4

Figure 13

TACB Mobile Sampling Van

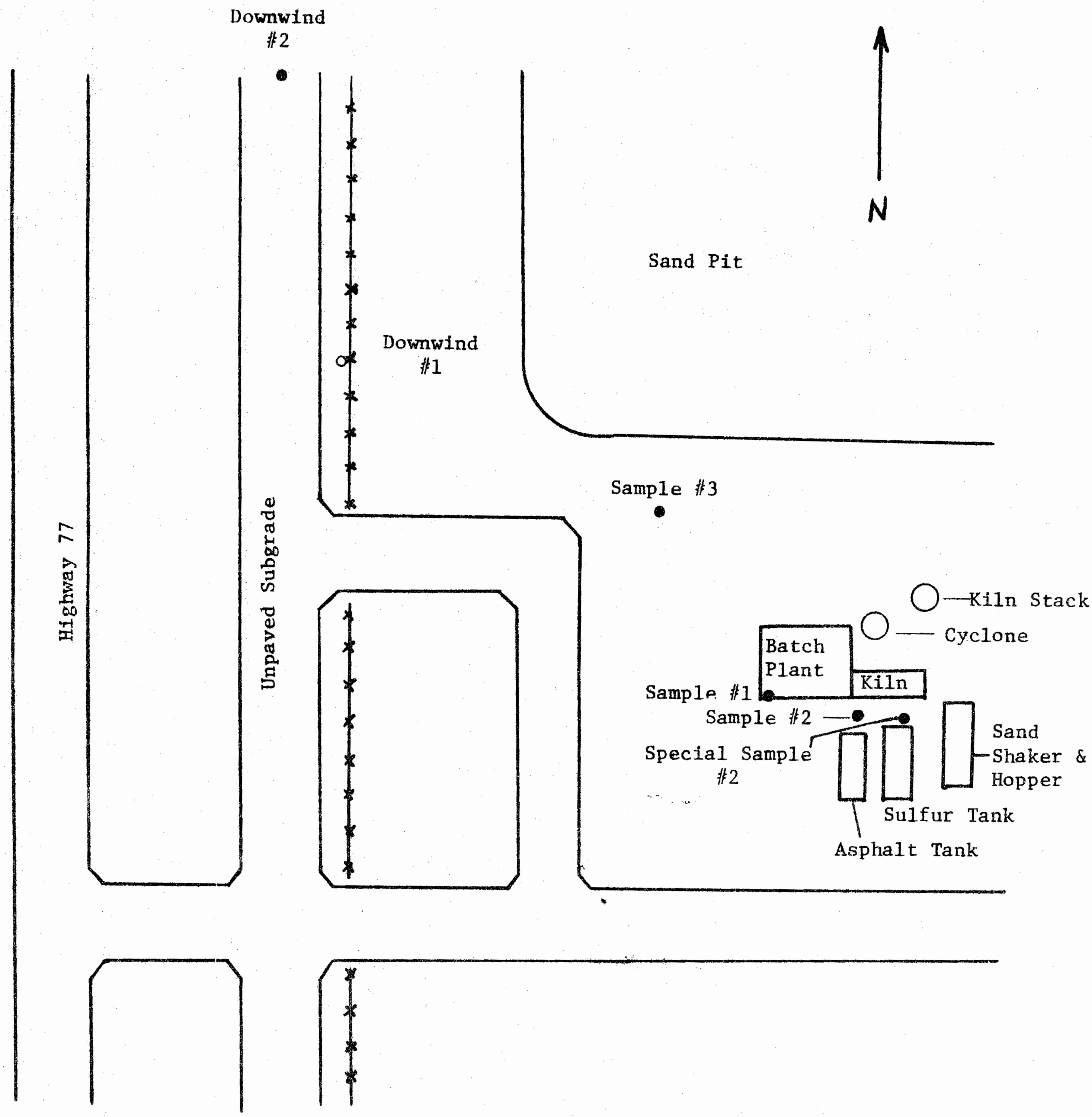


Figure 14

Batch Plant Sample Sites

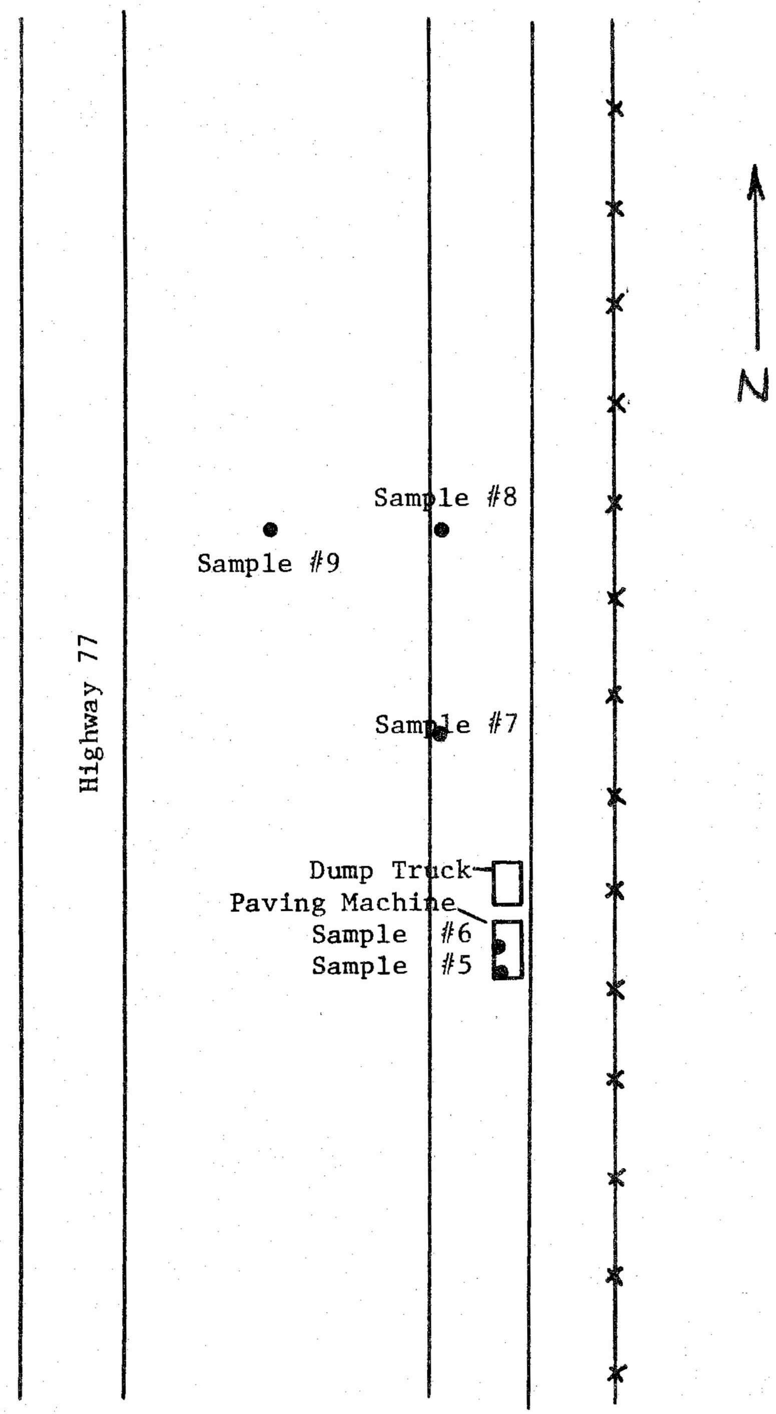


Figure 15

Paving Site Sample Locations

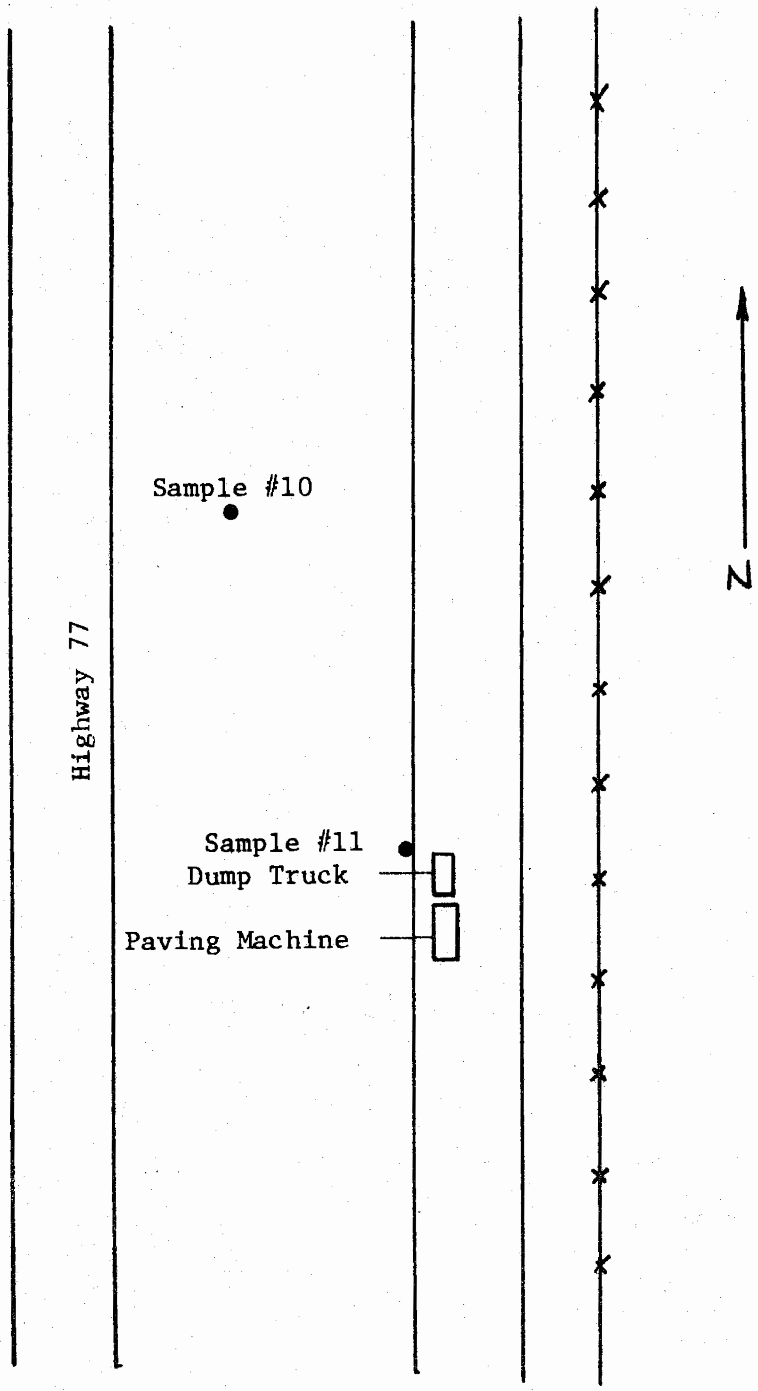


Figure 16

Paving Site Sample Locations

through a 1/4 in. polyethylene tube by a Metal Bellows Company, Model MB-41 pump. Samples were collected by placing the probe tip at distances which ranged from 1 to 12 inches from the surface of the material from which the gases were being evolved. These distances are much less than that normally occupied by personnel (normally 3 to 6 ft.) hence the designation "source data" were assigned to these samplings. As a backup to the source data collected by TACB, both TTI and The Bureau of Mines samplings were obtained at locations more representative of those which might be expected to be occupied by personnel.

One such area was on the platform of the hot-mix plant where the various mix ingredients were introduced into the pug mill. Continuous samplings over a 24-hour period were taken in the vicinity of the manually operated feed controls at a height equal to nose level of the operator. Additional 24-hour continuous samplings were taken at a point under the pug mill and just over the dump bodies of the trucks. Both of these points were monitored using a Houston Atlas Sampler of the type mentioned above. This unit was furnished by The Bureau of Mines Metallurgy Research Laboratory of Boulder City, Nevada.

TTI personnel took samplings for both H_2S and SO_2 using two types of portable sensing instruments. A Metronics Model 721 "Rotorod" Gas Sampler (Figure 17) which is designed for monitoring only H_2S emissions was used to collect data in the vicinity of the plant, within the quality content testing laboratory, inside the cab of hauling trucks, at the paver operator's seat, alongside the paver at the hopper and at the auger and in the vicinity of the sulfur storage tanks.

The Rotorod Gas Sampler spins a disc on which is mounted a lead acetate treated pad. Upon exposure to H_2S the pad changes color which can be compared with 5 standards located around the perimeter of the treated pad. The color

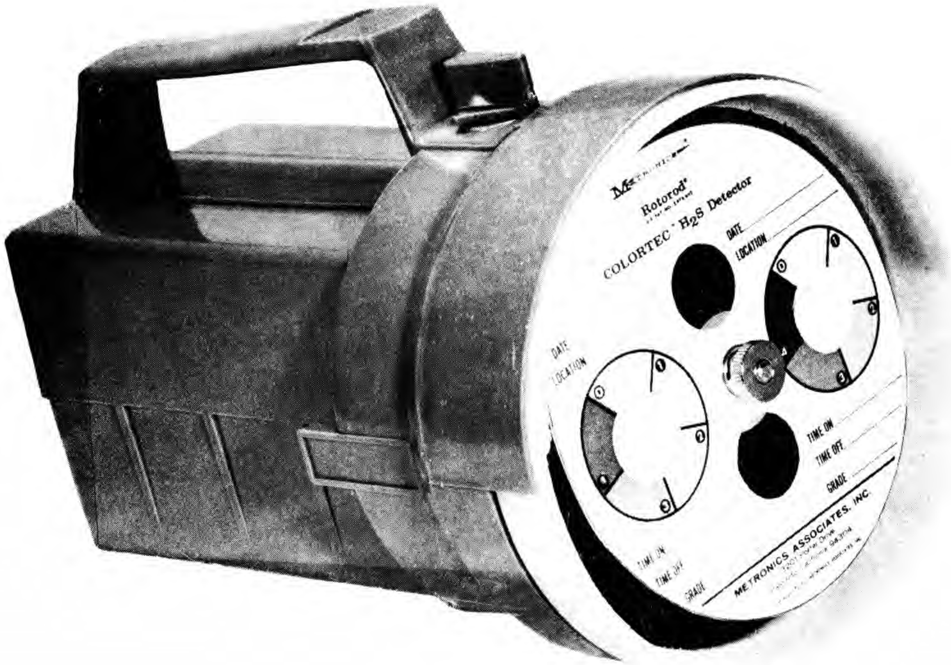


Figure 17. Metronics Model 721 "Rotorod" Gas Sampler

grade number of the stain produced on the pad and the duration of the sampling time are then converted to H_2S concentrations using the chart shown in Figure 18. Colortek cards as shown in Figure 19 were also used. These were mounted on walls and other locations where sampling duration times were greater than 30 minutes.

The other portable sampler employed was a Drager Tube Sampler with a manually operated bellows. Appropriate callibrated tubes for monitoring both H_2S and SO_2 were used with this device.

Samplings were taken at essentially the same locations monitored by the Metronics Rotorod Sampler. Drager tube measurements of H_2S concentrations thus provided a back up to those taken with the Rotorod Sampler.

4.7.2. Hydrogen Sulfide

4.7.2.1. Relative Toxicity of H_2S

Hydrogen Sulfide is known for its characteristic "rotten egg" odor. Although this odor is noticeable at concentrations as low as 0.02 ppm [1], odor is not a good indicator of concentration level. Hydrogen sulfide can have a paralyzing effect on the sense of smell [2]. Therefore, high concentrations of H_2S can escape recognition.

The basis used for establishing the relative toxicity of emissions data generated during this project were the relationships between H_2S concentrations and human effects as specified by ACGIH [1, 3]. These relationships are shown below:

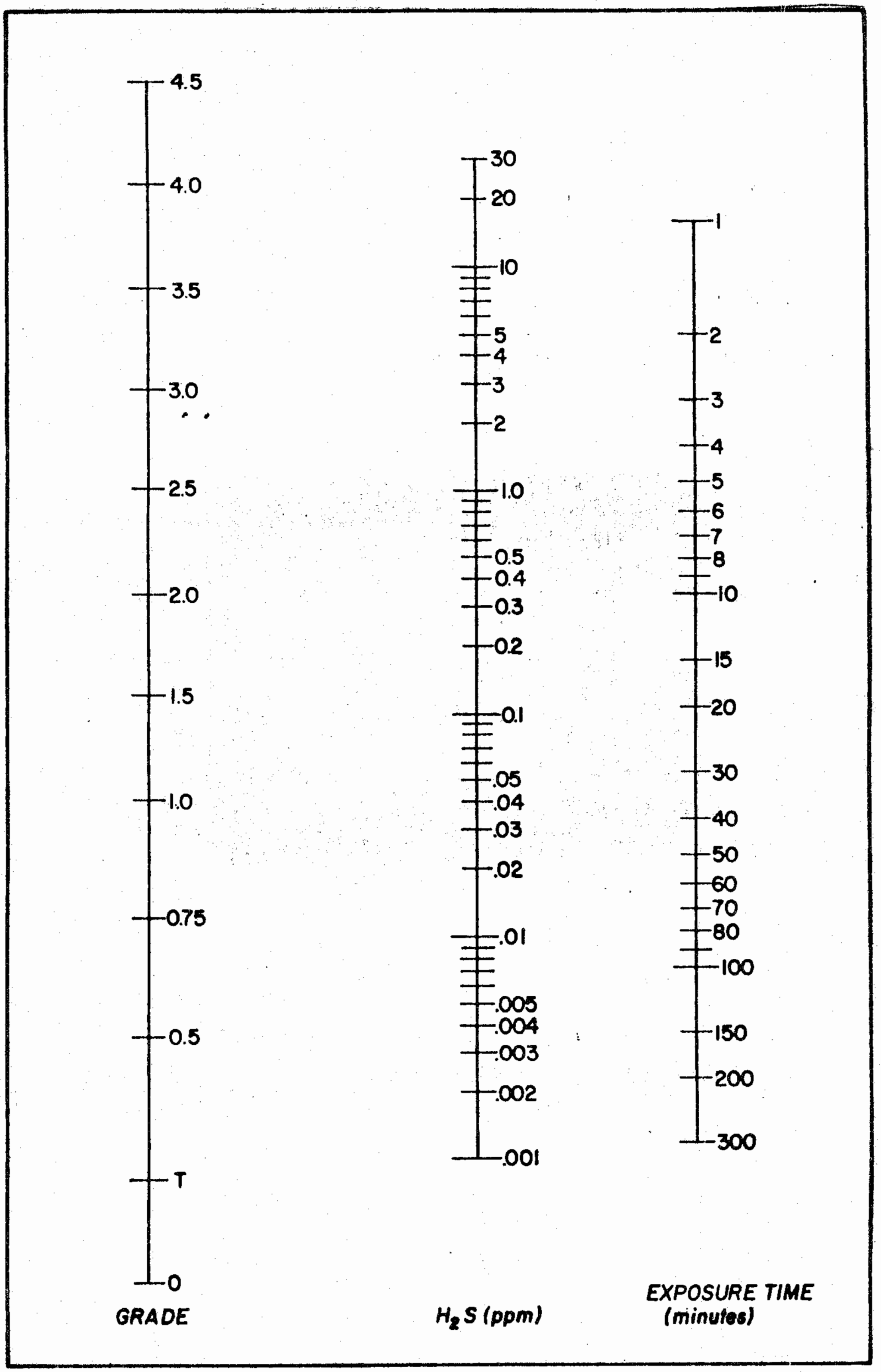


Figure 18. Conversion of Color Grade to Mean H_2S Concentrations

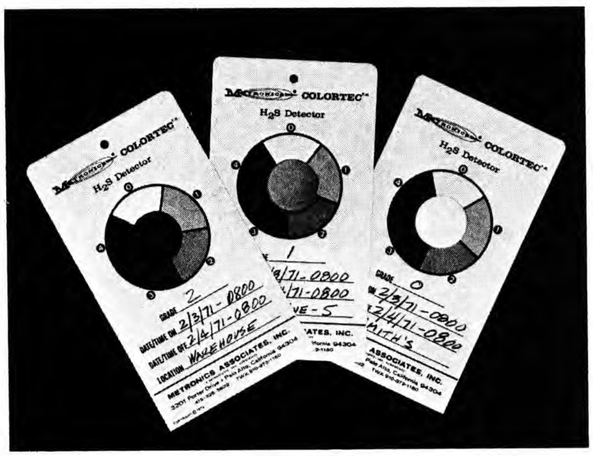


Figure 19. Colortek H_2S Detector Cards

Toxicity of Hydrogen Sulfide [3]

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

On the basis of these effects a MAC value of 5 ppm was specified as the upper threshold limit for continuous exposure to H_2S emissions in areas normally expected to be occupied by construction or plant personnel.

4.7.2.2. Test Results

The results of the measurements taken of H_2S concentrations at various locations of the construction site and plant given in Tables III to V. Table III includes data taken at and in the vicinity of the hot mix plant and sulfur storage area. Table IV contains emissions monitored in the vicinity of the paving operation. Table V includes all other areas monitored. Data are presented in a manner to reflect location, sampling agency (TACB, TTI or both), sampling equipment, average concentration and supporting remarks.

4.7.2.3. Discussion of Results of H_2S Evolved Gas Analysis

As has been reported; as long as the temperature of sulfur/asphalt systems are maintained below a maximum of 300°F H_2S emissions were found to be well below suggested MAC values [4, 5]. Except for several occassions when screed temperature content was lost H_2S concentrations as measured in locations normally frequented by construction personnel were found to be

Table III

H_2S Emissions At And In The Vicinity Of The Hot Mix Plant

Location	Sampling Agency	Sampling Equipment	Average Concentration (ppm)	Remarks NPA - non personnel area PA - Personnel area
<u>Sulfur Storage Tank Area</u>				
a) Tank Inlet Port	TACB	Telematic	2939	NPA
b) 5 ft. from Tank Inlet Port	TACB	Telematic	23	NPA
c) On the ground at the base of the sulfur storage tank	TTI	Rotorod	0.9	PA (moderate)
d) Ground level between sulfur tank and Hot Mix Plant Kiln	TACB	Telematic	0.02	PA (moderate to dense)
<u>Hot Mix Plant Area</u>				
a) Operator Platform	TACB	Telematic	>0.007	PA (1-2 people)
	BOM	Houston-Atlas	0.5 to 2.0	PA (1-2 people)
	TTI	Rotorod	Trace	PA (1-2 people)
	TTI	Drager Tube	Trace	PA (1-2 people)
b) Base of Platform	TTI	Rotorod	Trace	PA (light)
Stairwell	TTI	Drager Tube	Trace	PA (light)
c) At Pugmill Discharge and Over Dump Body	BOM	Houston-Atlas	0.5 to 0.6	NPA
d) 125 ft. downwind of Hot Mix Plant	TACB	Telematic	0.01	PA (light)
	TTI	Rotorod	Trace	PA (light)

Table IV

H_2S Emissions At And In the Vicinity of the Paver

Location	Sampling Agency	Sampling Equipment	Average Concentration (ppm)	Remarks NPA - non personnel area PA - personnel area
Paver				
a) Floor at Paver Operator's Feet	TACB	Telematic	1.4	PA (1 person)
b) In Paver Operator's Chair	TTI	Rotorod	Trace	PA (1 person)
	TTI	Drager Tube	Trace	PA (1 person)
c) Paver Hopper	TACB	Telematic	4.3	NPA
	BOM/TTI	Drager Tube	2-5	NPA
d) Alongside Paver (at Auger) Downwind	BOM/TTI	Drager Tube	0-20*	PA (1-2 people)
e) Over Paver Auger	BOM/TTI	Drager Tube	20-80*	NPA
Paver Vicinity				
a) 300 ft. Upwind	TACB	Telematic	0	PA (light)
b) 25 ft. Downwind	BOM/TTI	Drager Tube	0	PA (light)
c) 100 ft. Downwind	TACB	Telematic	0.2	PA (light)
d) 200 ft. Downwind	TACB	Telematic	0	NPA
Over Pavement Behind Paver				
a) 6 in. over surface	TACB	Telematic	1.3	NPA
b) 2 ft. over surface	BOM/TTI	Drager Tube	Trace	NPA

* Highest concentrations were encountered during a period when temperature control of the screed was lost causing mix temperature to exceed 320°F. When temperature was reduced below 300°F concentrations were reduced to near minimum values.

Table V

H_2S Emissions at Miscellaneous Locations

Location	Sampling Agency	Sampling Equipment	Average Concentration (ppm)	Remarks
Dump Trucks				
a) Inside Cab at Hot Mix Plant	TTI	Rotorod	>0.1	PA (1 person)
b) Inside Cab at Paver During Dump	TTI	Rotorod	0	PA (1 person)
c) Over Inlet to Dump Body	TTI	Rotorod	0.2	NPA
d) Inside Dump Body During Cleaning Operation	TTI	Rotorod	0.3	PA (1-2 persons)
Hot Mix Plant Quality Central Test Laboratory	TTI	Rotorod	Trace	PA (2-3 persons)
Hot Mix Plant Parking Area	TTI	Rotorod	0	PA (light)
At Sulfur Truck During Transfer to Storage Tank	TTI	Rotorod	0.4	PA (1-2 persons)

significally less than 5 ppm. The fact that no complaints were registered during the entire sulfur/asphalt construction period supports this conclusion. In some cases "source type" emissions; that is samplings taken directly over the mix material, appeared to be excessively high. However in an open-air environment these concentrations are rapidly reduced with distance.

The highest concentrations encountered were at or near the loading part of the sulfur storage tank and inside the pug mill. Since these are not considered to be personnel areas their impact on worker safety is considered to be minimal.

4.7.3. Sulfur Dioxide

4.7.3.1. Relative Toxicity of SO_2

Sulfur Dioxide (SO_2) is a colorless gas with a pungent odor which unlike H_2S gives ample warning of its presence. The principle health hazard from SO_2 comes from inhalation of excessive quantities above its MAC. The basis for establishing the relative toxicity of emissions data generated during this project were the relationships between SO_2 concentrations and human effects as specified by the National Institute for Occupational Safety by Health and The Manufacturing Chemists Association [6, 7] and shown in the following table.

Toxicity of Sulfur Dioxide [VI]

Concentration (ppm)	Effect
0.3 - 1	Detected by taste
<1	Injurious to plant foliage
3	Noticeable odor
5	MAC (ACGIH)
6 - 12	Immediate irritation of nose and throat
20	Irritation to eyes
50 - 100	MAC for 30 - 60 min. exposures
400 - 500	Immediately dangerous to life

The present Federal standard for SO_2 is an 8-hour time weighted average of 5 ppm (see 29CFR 1910,93 published in the Federal Register, Volume 37, p. 22139 (October 18, 1972)) [6]. This is the MAC specified as the upper threshold limit concentration for SO_2 emissions in areas normally expected to be occupied by construction or plant personnel.

4.7.3.2. Sulfur Dioxide Test Results

All measurements of SO_2 concentrations were monitored by TTI using the Drager Tube. The data given below show the ranges of SO_2 concentrations measured at various locations at the paving site.

Location	Range
Above paving hopper	0 - 0.5
Alongside paver (downwind)	0.5 - 20
Behind paver	0
Paver operator seat	0
Hot mix plant platform	Trace
Inside truck cab	Trace
Vicinity of sulfur storage tank	3 - 12
Alongside paver (over the auger)	3 - 50
Directly over paved surface	0

4.7.3.3. Discussion of Results of SO_2 Evolved Gas Analysis

As indicated, the values varied considerably with some concentration levels exceeding the MAC value recommended by the ACGIH. These values were obtained primarily in areas of minimal worker exposure such as the vicinity of the sulfur storage tank and very close to the material in the paver. The latter were attributed to the overheating of the paver screed a temporary event which occurred on 7 April. After these readings were taken the screed temperature was reduced and the concentrations subsequently were reduced to the lower values indicated above.

The paver screed without suitable temperature controls, would appear to be the main source of potentially high H_2S and SO_2 emissions. At the operator and workmen levels on the paver and at the hot mix plant platform gas toxicity were negligible. As in the case with H_2S, gas evolution stayed well below established MAC limits when mix and paving temperatures were maintained under 300°F.

4.7.4. Particulate Sulfur

4.7.4.1. Occurrence and Toxicity

Vapor given off during mixing and dumping operations contain a certain amount of undissolved and unreacted sulfur. As the vapors come in contact with air and cool, the sulfur vapor crystallized into small particles which are carried by the wind in a manner similar to dust and fine sands. Since there is no practical way to eliminate this pollutant its effect on both environment and personnel need to be considered.

As mentioned above TACB had accepted the responsibility for collecting these data during construction of the sulfur/asphalt pavement. However, particulate sulfur samplings were not taken. This section will be devoted to a discussion of the relative hazards associated with sulfur dust on construction personnel as specified by the Manufacturing Chemists Association [7, 8]. Assessments of the environmental impact of this pollutant is considered to be beyond the scope of this task.

The principal problems associated with sulfur dust lie in its contact with eyes. Sulfur is virtually nontoxic and there is no evidence that systemic poisoning results from the inhalation of sulfur dust. However, sulfur is capable of irritating the inner surfaces of the eyelids. Sulfur dust may rarely irritate the skin. This problem is minimized by the requirement that goggles be worn in areas subject to this pollutant such as at the hot mix plant and in the vicinity of the paver.

The primary hazard in handling solid sulfur results from the fact that sulfur dust suspended in air may be ignited. This problem is almost always limited to enclosures and unventilated areas. Since this is not typical of the hot mix plant or the paving area this particular hazard is not a major concern.

To minimize possible irritation, unnecessary contact with skin and eyes should be avoided. Following the work period, sulfur dust should be removed with mild soap and water. For relief of eye irritation, eyes should be thoroughly flushed with large quantities of plain water of physiological saline. Inadequate amounts of water may actually increase eye irritation.

4.7.5. Summary of Evolved Gas Analysis

Three forms of sulfur pollutants were discussed; H_2S, SO_2 and sulfur dust. Except for a time interval during which the temperature of the pave screed was allowed to exceed 300°F concentrations of the two gaseous pollutants remained below recommended allowable threshold limit. This condition indicates the need to provide positive temperature controls at both the hot mix plant and the paver.

Although the amounts of sulfur dust generated during construction were not monitored as planned, experience dictates that the only major hazard to personnel lies in irritation to eyes. Safety goggles are recommended to offset this problem. No data taken as yet would indicate that sulfur dust is present in sufficient quantities to create a health hazard. It is recommended that data on sulfur dust be generated on any future sulfur-asphalt field trials.

The location where highest concentrations of H_2S and SO_2 were present was in the sulfur storage area; more specifically near the loading ports of the storage tank. This is not considered a personnel area. Furthermore, the concentrations of the pollutants decrease rapidly with distance thus eliminating this area as a potential safety hazard to plant workmen. Normally accepted safety practices should be employed during transfer of hot sulfur from delivery trucks to the storage tanks.

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5.0 Quality Control

5.1 Field Laboratory Personnel and Equipment

The State Department of Highways and Public Transportation, District 21, as usual for field control of pavement construction, provided a mobile laboratory.

The laboratory and hot-mix plant inspection were under the immediate supervision of Sim Giles, Engineering Technician. He was assisted by George Barrera, Engineering Technician, F. J. Gonzales, Engineering Aide and Ed Ellis, Laboratory Assistant from Texas Transportation Institute.

The equipment available for field testing included:

1. A TROXLER Nuclear Asphalt Gauge, Model 2226, TROXLER Laboratories, Raleigh, North Carolina,
2. Marshall Apparatus complete with automatic compaction hammer, special molds, breaking head and compression testing machine (provided by TTI),
3. Rotary type extractor,
4. A mechanical seive shaker with electric motor drive,
5. An 18-in. x 24-in. x 30-in. oven,
6. A muffle furnace, BLUE M (2000F Max.),
7. A gyratory compactor for Hveem specimens and
8. An improvised 'blast Furnace'.

Also miscellaneous scales, thermometers, sample containers, etc.

5.2 Schedule of Testing

The following schedule was used by the field laboratory personnel as a guide:

1. Check temperature of each truck load of mix and record,

2. Make slump tests as required to monitor consistency of the mixtures,

3. Determine binder content of mixtures - asphalt and sulfur,

4. Make set of 9 Marshall test specimen at least twice daily; three specimen to be tested in field at 24 hrs., six specimen to be taken for TTI,

5. Take 40 lbs. of mixture each 1/2 day of operation and place in containers for TTI and

6. When plant is lined out take one 200 lb. sample of mixture for study by TTI.

5.3 Mix Design

The mix design for the sand-asphalt-sulfur pavement mixture was a result of extensive laboratory tests by Texas Transportation Institute some weeks prior to beginning the job. These data are presented in Table VI.

The mix design data reviewed by Shell Canada, were based on the blend of 65/35 w/o of the 'Bluntzer' concrete type sand and the field sand, respectively. See Mineral Aggregates Section 2.3. Shell's confirmatory mix design information is shown in Table VII.

The mix design selected was as follows:

Asphalt, AC-20 ----------------------6.2 w/o of Mix

Sulfur -----------------------------13.0 w/o of Mix

65/35 w/o sand blend --------------80, 8 w/o of Mix

This design, once selected, was not changed for the duration of the project. Selection was based on a minimum Marshall Stability of 2,000 lbs. of ASTM C143-74 and a slump of 2 to 6 inches. Shell Canada's

Table VI. Summary of Preliminary Laboratory Tests

Aggregate Composition		Mix Composition, w/o			Bulk Specific Gravity	Unit Weight, pcf	Hveem Stability	Marshall Stability, lbs.	Marshall Flow 1/100-in.	Air Voids %	VMA %	M_R Resilient Modulus, psi x 10^6
Concrete Sand, w/o Bluntzer Pit	Local Field Sand, w/o	Aggregate	Asphalt	Sulfur								
65	35	80.5	6.5	13.0	2.096	130.8	44	3135	5	8.8	36	0.507
35	65	80.5	6.5	13.0	2.069	129.1	42	3535	5	10.0	37	0.600
35	65	79.0	7.0	14.0	2.040	127.9	43	3358	7	9.6	39	0.571
60	40	78.0	7.0	15.0	2.117	132.0	48	3523	8	5.9	38	0.584

Table VII. Mix Design Properties 65% Coarse Sand; 35% Fine Sand Blend

Mix Composition % wt.			Flexure @ 10°C Rate of Strain @ 10°C				Marshall Properties			
AC	S	Workability (Slump) inch	Density g/cc	Stress kg/cm^2	Strain cm/cm	Eff. Air Voids % vol	Density g/cc	Stability lbs.	Flow 1/100 in.	Eff. Air Voids % vol
6	13	3 1/2	2.040	35.6	0.0033	11.7	2.059	2498	5.4	
				34.9	0.0032		2.066	2729	6.4	
		Mean:	2.040	35.3	0.0033	11.7	2.082	2531	6.0	10.2
6.5	13	5	2.015	31.4	0.0043	12.0	2.036	1695	5.6	11.2
				31.5	0.0043		2.029	1728	5.4	
		Mean:	2.015	31.5	0.0042	12.0	2.034	1541	5.5	11.2

recommended flexural strain at failure is 0.0035 in./in. (See Table VII).

5.4 Mineral Aggregate - Gradations

The mineral aggregate approved for the project consisted of a 65/35% wt. blend of 'Bluntzer' concrete type sand and field sand, respectively, See Construction Materials - Section 2.3. These proportions were set up at the beginning of the construction of the sand-asphalt-sulfur test items and no engineering changes were made during this part of the project.

Complete (all sieves) dry seive analyses of hot bin samples were made in the field laboratory each day. Two wash analyses on the minus No. 30 portions were made, on the 6th of April and the 8th of April. These showed little difference between dry and wet analyses.

There follows a tabulation (Table VIII and IX) showing the variability of the percent passing the No. 50 and No. 100 sieves. Paving mixtures made with high percentages passing these sieves have been found by Shell Canada to be difficult to place without tearing.

Assuming the above test numbers to have a normal distribution, the percent passing the No. 50 sieve would be within 27 to 75 and the percent passing the No. 100 sieve would be within 5 and 27 ninety-five percent of the time. This analyses attests to a rather considerable variability in the sand gradations.

The variability corresponds approximately to a range in the sand blends of 90/100 w/o concrete type sand to field sand respectively, and a 35/65 w/o concrete sand to field sand.

Considerable variability in the selection of the sand blend is

Table VIII. Sand-Aggregate Variability

Date:	April 6		April 7		April 8	
Number of Samples:	2		4		3	
Sieve Size:	50	100	50	100	50	100
Percent wt. Passing:						
Max.	53	16	62	29	61	21
Min.	45	13	33	10	26	7
Avg.	49	14	49	17	45	15
Standard Deviation	5.6	1.6	13.2	8.7	17.8	6.5

Date:	April 11		April 12		April 13	
Number of Samples:	2		4		2	
Sieve Size:	50	100	50	100	50	100
Percent wt. Passing:						
Max.	67	25	64	18	56	19
Min.	45	15	44	12	56	17
Avg.	56	20	56	16	56	18
Standard Deviation	16.5	7.1	13.0	1.6	0	1.4

Table IX. Job Variability

Dates:	April 6-13 inc., 1977	
Number of Samples:	17	
Sieve Size:	50	100
Percent wt. Passing:		
Max.	67	29
Min.	26	7
Avg.	51	16.2
Standard Deviation	11.8	5.4
Two Standard Deviations	23.6	10.8

permitted by the project specification brackets. See Figure 5. At the same time the specification, Item 2029, also provide that, "The proportioning device (cold bin feed, etc.) shall be such as will provide a uniform and continuous flow of aggregates in the desired proportions to the dryer".

Needless to say, variation is the norm on most jobs and more particularly so on projects such as this one. It should be pointed out that the variations shown by the above analysis includes the entire parade of events and further it should be stated that in general the operation was such as to result in a fairly uniform product. Core analyses, yet to be made, will most likely verify this contention.

5.5 Temperature Control of the Mixture

The oil burner on the dryer was manually operated by the plant superintendent. He was guided by an automatic temperature recorder on the hot-elevator and by his skill and long experience in regulating the unit. Temperature control of the S-A-S mixtures was generally good.

As a further aid in temperature control, Shell Canada engineers installed a thermocouple in the No. 1, sand, bin and attached it to a recorder with an alarm set at 300F.

Table X contains a summary of the temperatures of the sand-asphalt-sulfur pavement mixtures as recorded by the State Engineers at the hot-mix plant and in the field.

Table X. Variability of Mix Temperatures

Date:	April 6		April 7		April 8	
Location:	Hot-plant	Field	Hot-plant	Field	Hot-plant	Field
Number of: Measurements:	7	7	16	22	24	20
Max. °F	310	290	300	305	305*	290
Min. °F	240	255	265	255	275	265
Avg.	282	278	289	289	286	277
Standard Deviation:						

*Does not include one load at 325°F which was wasted.

Date:	April 11		April 12		April 13	
Location:	Hot-plant	Field	Hot-plant	Field	Hot-plant	Field
Number of: Measurements:	11	8	26	24	24	25
Max. °F	305	285	300	295	300	290
Min. °F	275	275	265	265	265	255
Avg.	287	280	285	279	283	279
Standard Deviation:			6.7	6.3		
Two Standard Deviations:			13.4	12.6		

The variability, as determined by the Standard Deviation, has been calculated for one day only, April 12. Assuming the test numbers to have a normal distribution, the temperature of the sand-asphalt-sulfur pavement mixture at the hot-plant would be with a range of 272 to 298F ninety-five percent of the time. In the field the range would be 266 to 292F. These temperatures correspond to the working range considered to be acceptable for S-A-S systems.

Temperatures were measured in the top of the loaded truck at the hot-plant and in the paver hopper in the field. Between these two points a rather consistent loss of about 6F was experienced.

5.6 Sulfur-Asphalt Contents

Shell Canada engineers provided a 'Tentative Test Method for the Determination of Bitument Content and Sulfur Content in THERMOPAVE (sand-asphalt-sulfur) Mix' (see Appendix B). Copies are on file with Texas Transportation Institute. The basics of the procedure were used by the State engineers. They follow:

1. The asphalt content is determined using a TROXLER Nuclear Asphalt Density Gauge.
2. The asphalt and some sulfur are extracted using a rotary extractor.
3. A representative portion or the entire sample from Step 2. is heated in a crucible to burn off the remaining sulfur.
4. The sulfur content is determined by subtracting the asphalt, Step 1. from total asphalt plus sulfur, Steps 2. and 3.

There follows (See Table XI) a tabulation, from the State engineers field laboratory records, showing the date, load number for that date, percent wt. asphalt and percent wt. sulfur:

For easy reference, the mix design was 6.2 w/o asphalt, 13 w/o sulfur and 80.8 w/o sand.

Table XI Both Samplings of Sulfur and Asphalt Contents

Date	Load Number	Asphalt, w/o	Sulfur, w/o
April 6	1	6.2	-
April 6	5	5.8	12.2
April 7	1	6.3	12.2
April 7	9	6.4	11.1
April 8	6	6.25	11.75
April 8	11	6.175	14.83
April 11	1	6.25	13.75
April 12	1	6.15	12.85
April 12	14	6.20	12.80
April 13	6	6.9	-
April 13	11	6.2	-

The percentage limits for variations in asphalt and sulfur contents were set by the specifications, Item 2025, as follows:

6.2 w/o Asphalt, plus or minus, 0.3 (percent of total mix)

13 w/o Sulfur, plus or minus, 0.4 (percent of total mix)

The precision for the ASTM D 2172, Method A, test used for determination of asphalt has not been determined by ASTM. From inspection, only one measurement, April 13 - load 6, of 6.9 would be suspect or indicate a variation from specifications for asphalt content.

5.7 Consistency of Sand-Asphalt-Sulfur Mix

Shell Canada engineers provided a 'Tentative Method of Test for slump of Thermopave (sand-asphalt-sulfur) Mix' see Appendix C. The slump cone similiar to that described in ASTM C 143-74, is used to measure the consistency of the hot plastic mixture. There follows (see Table XII) a tabulation of slump measurements form the State Engineers field laboratory records:

Table XII. Batch Samplings of Slump Measurements

Date: (April)	7	7	8	8	11	12	12	13	13
Load Number for that Date:	7	11	3	13	6	5	17	2	17
Slump, inches	8	7	6	7		6.5	7	7	7

These measurements attest to excellent uniformity in consistency.

5.8 Marshall Stability and Flow Properties

Specimens for Marshall testing were made in sets of nine. Three were tested in the field laboratory at approximately 24 hours. Six were carried by truck to Texas Transportation Institute for testing at 7 days or as required. Samples were taken from the trucks, weighted and placed in a 300F oven for equalizing temperatures. The hot mixture was placed into the molds with a small scoop and the specimen compacted with two blows only from a Marshall hammer on one side. Stability test results were adjusted for variations from the 2 1/2-inch thickness of test specimens.

Shell Canada engineers provided a Tenative Method for Preparation of Thermopave (sand-asphalt-sulfur) specimens for Marshall Testing (see Appendix D). Copies are on file with Texas Transportation Institute.

A tabulation of the Marshall test results from the State engineers field laboratory records is shown in Table XIII.

Table XIII. Daily Batch Samplings of Marshall Stability and Flow

Date April 1977	Stability, Lbs.	Stability, Lbs Avg. of Three	Flow 0.01 inches
6	2253	2354	5
	2370	2354	9
	2411		5
7 am	2565		13
	2990	2761	12
	2727		10
	3063		3
7 pm	1767	2618	5
	3063		13
8 am	3113		17
	2071	2724	15
	2989		15
8 pm	3099		15
	2267	2567	15
	2336		21
11	3036		5
	2727	2822	7
	2675		14
12 am	2443		9
	2681	2461	10
	2290		11
12 pm	1810		16
	2381	2065	15
	2005		16
13 am	2028		12
	1820	1990	10
	2122		11
13 pm	2378		16
	3529	2920	15
	2856		16

6.0 Conclusions

The overall objective of this experimental construction project was to evaluate the potential of using sulfur as a means of producing a quality sand-asphalt-sulfur paving mixture using a poorly graded dune sand as an aggregate. The techniques used in the field were basically those developed by Shell Canada and verified by the Texas Transportation Institute in the laboratory. These techniques were subsequently demonstrated in the successful construction of the full scale field sections discussed in this report.

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

1. A sand-asphalt-sulfur paving mixture with respective weight percent ratios of 80.8-6.2 and 13.0 of the total mix was successfully placed using techniques developed by Shell Canada.

2. Limitations in the design of the paver required that a 65/35 weight percent ratio of coarse to fine (local) sand be used to prevent tearing. At one point 100 percent local sand was placed with acceptable surface quality.

3. Because of the age and efficiency of the hot-mix plant used in the project, batch-to-batch variability was not as good as would be expected in a more modern plant. Part of the problem in maintaining a consistent quality paved surface can be attributed to variables in the hot-mix plant operations.

4. The heated dump bodies furnished by Shell performed well throughout the project. This job reconfirmed the need for heated dump

bodies as an input to the success of this type of operation.

5. The need for good temperature control of the mix at the hot-mix plant and at the paver was demonstrated. At one point excessive temperature at the paver screed produced high emissions of H_2S and SO_2. When the temperature was reduced, the emissions dropped to their normal, safe levels.

6. Cores taken from the finished pavement showed excellent bond strength between successive layers of the S-A-S base.

Appendix

Appendix A - Log of Field Construction Sand-Asphalt-Sulfur Experimental Project

Appendix B - Tentative Test Method for the Determination of Bitumen Content and Sulfur Content in Thermopave Mix

Appendix C - Tentative Method of Test for Slump of Thermopave Mix

Appendix D - Tentative Method for Preparation of Thermopave Specimens for Marshall Testing

Appendix A

Log of Field Construction

Sand-Asphalt-Sulfur Experimental Project

April 6, 1977

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
1	10"	1	3"	Right	85+00 to 85+45		255
2	10"	1	3"	Right	85+45 to 86+00		280
3	10"	1	3"	Right	86+00 to 86+60		280
4	10"	1	3"	Right	86+60 to 87+50		290
5	10"	1	3"	Right	87+50 to 88+00		290
6	10"	1	3"	Right	88+00 to 88+60		280
7	10"	1	3"	Right	88+60 to 88+95		280
					Total Tons of Mix:		89

April 7, 1977

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
1	10"	1	3"	Right	88+95 to 89+50	9:15	285
2	10"	1	3"	Right	89+50 to 90+10	9:30	280
					Total Tons of Mix:		27.5

3	10"	1	3"	Left	85+00 to 85+60	10:40	275
4	10"	1	3"	Left	85+60 to 86+10	10:55	280
5	10"	1	3"	Left	86+10 to 86+80	11:00	305
6	10"	1	3"	Left	86+80 to 87+80	11:07	300
7	10"	1	3"	Left	87+80 to 88+30	11:20	290
8	10"	1	3"	Left	88+30 to 89+15	11:50	290
9	10"	1	3"	Left	89+15 to 89+60	1:20	300
10	10"	1	3"	Left	89+60 to 90+10	1:45	280
					Total Tons of Mix:		106.56

LOG OF FIELD CONSTRUCTION CONT'D.

April 7, 1977 Cont'd.

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
11	7"	1	3"	Right	90+10 to 90+50	2:25	300
12	7"	1	3"	Right	90+50 to 91+35	2:28	290
13	7"	1	3"	Right	91+35 to 91+90	2:35	285
14	7"	1	3"	Right	91+90 to 92+60	2:45	295
15	7"	1	3"	Right	92+60 to 93+35	3:05	300
16	7"	1	3"	Right	93+35 to 94+05	3:20	280
17	7"	1	3"	Right	94+05 to 94+75	-	-
18	7"	1	3"	Right	94+75 to 95+20	-	-
					Total Tons of Mix:		101.25
19	10"	2	3"	Right	90+10 to 89+40	5:00	290
20	10"	2	3"	Right	89+40 to 88+50	5:15	300
21	10"	2	3"	Right	88+50 to 87+60	5:30	290
22	10"	2	3"	Right	87+60 to 86+60	5:45	255
23	10"	2	3"	Right	86+60 to 85+50	-	-
24	10"	2	3"	Right	85+50 to 85+15	-	-
					Total Tons of Mix:		75.75

April 8, 1977

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
1	10"	2	3"	Left	85+00 to 85+75	10:27	285
2	10"	2	3"	Left	85+75 to 86+60	-	-
3	10"	2	3"	Left	86+60 to 87+40	10:50	265
4	10"	2	3"	Left	87+40 to 88+70	11:00	290
5	10"	2	3"	Left	88+70 to 89+25	11:40	275
6	10"	2	3"	Left	89+25 to 90+00	12:00	290
					Total Tons of Mix:		84.0

LOG OF FIELD CONSTRUCTION CONT'D.

April 8, 1977

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.

7	7"	1	3"	Left	90+00 to 90+80	12:15	270
8	7"	1	3"	Left	90+80 to 91+70	12:35	270
9	7"	1	3"	Left	91+70 to 92+60	-	-
10	7"	1	3"	Left	92+60 to 93+10	1:08	275
11	7"	1	3"	Left	93+10 to 93+85	1:22	275
12	7"	1	3"	Left	93+85 to 94+50	1:47	290
13	7"	1	3"	Left	94+50 to 95+20	1:58	280
					Total Tons of Mix:		98.0

14	10"	3	2"	Right	85+00 to 85+60	2:55	275
15	10"	3	2"	Right	85+60 to 86+40	-	-
16	10"	3	2"	Right	86+40 to 87+00	3:15	280
17	10"	3	2"	Right	87+00 to 87+70	3:20	275
18	10"	3	2"	Right	87+70 to 88+50	3:35	280
19	10"	3	2"	Right	88+50 to 89+15	3:45	270
20	10"	3	2"	Right	89+15 to 90+00	4:15	275
					Total Tons of Mix:		98.0

21	7"	2	2"	Right	90+00 to 90+85	4:30	270
22	7"	2	2"	Right	90+85 to 91+60	-	-
23	7"	2	2"	Right	91+60 to 92+30	5:00	275
24	7"	2	2"	Right	92+30 to 93+30	5:15	280
					Total Tons of Mix:		56.0

LOG OF FIELD CONSTRUCTION CONT'D.

<u>April 11, 1977</u>

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
1	7"	2	2"	Right	93+30 to 94+00	1:25	285
2	7"	2	2"	Right	94+00 -	1:40	285
					Total Tons of Mix:		28
2	4"	1	2"	Right	- 1995+50		
3	4"	1	2"	Right	95+50 to 96+50	2:00	285
4	4"	1	2"	Right	96+50 to 97+50	2:35	280
5	4"	1	2"	Right	97+50 to 97+66	-	-

NOTE; This 2" layer, Sta. 97+66 to 97+20 was rejected by the State and removed from the roadway with a blade grader. See April 13 for patching.

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
6	4"	1	2"	Right	97+20 to 99+10	2:53	280
7	4"	1	2"	Right	97+10 to 00+00	3:10	275
					Total Tons of Mix;		60

NOTE; 10" Section, third layer, 2" thickness, Sta. 85+00 to 85+50 was placed but rejected by the State and removed from the roadway with a blade grader. It was replaced April 13. (Left traffic lane).

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
8	10"	3	2"	Left	85+50 to 86+50	-	276
9	10"	3	2"	Left	86+50 to 87+50	-	-
10	10"	3	2"	Left	87+50 to 88+70	-	275
					Total Tons of Mix:		42

<u>April 12, 1977</u>

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
1	10"	3	2"	Left	88+70 to 89+50	9:43	280
2	10"	3	2"	Left	98+50	9:54	275
					Total Tons of Mix:		24

April 12, 1977 Cont'd.

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
2	7"	2	2"	Left	90+50		
3	7"	2	2"	Left	90+50 to 91+50	10:12	275
4	7"	2	2"	Left	91+50 to 92+50	10;22	285
5	7"	2	2"	Left	92+50 to 93+50	10:34	280
6	7"	2	2"	Left	93+50 to 94+50	10:43	280
7	7"	2	2"	Left	94+50 to 95+20	11:05	280
					Total Tons of Mix:		70
7	4"	1	2"	Left	95+20 to 95+50		
8	4"	1	2"	Left	95+50 to 96+40	11:24	285
9	4"	1	2"	Left	96+40 to 97+40	11:42	285
10	4"	1	2"	Left	97+40 to 98+50	12:00	280
11	4"	1	2"	Left	98+50 to 99+50	12:30	280
12	4"	1	2"	Left	- -	12:45	
13	4"	1	2"	Left	99+60 to 00+00	1:05	280
					Total Tons of Mix:		74
14	10"	4	2"	Right	85+00 to 85+50	2:00	280
13	10"	4	2"	Right	85+50 to 85+75	-	-
15	10"	4	2"	Right	85+75 to 86+50	-	-
16	10"	4	2"	Right	86+50 to 87+20	2:17	275
17	10"	4	2"	Right	87+20 to 87+75	3:00	275
18	10"	4	2"	Right	87+75 to 88+50	3:07	280
19	10"	4	2"	Right	88+50 to 89+20	3:20	295
20	10"	4	2"	Right	89+20 to 89+80	4:05	265
21	10	4	2"	Right	89+80 to 90+20	4:10	275
					Total Tons of Mix:		114

LOG OF FIELD CONSTRUCTION CONT'D.

April 12, 1977 Continued

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
21	7"	3	2"	Right	90+20 to 90+40		
22	7"	3	2"	Right	90+40 to 91+40	4:20	290
23	7"	3	2"	Right	91+40 to 92+75	4:30	285
24	7"	3	2"	Right	92+75 to 93+50	4:50	270
25	7"	3	2"	Right	93+50 to 94+25	5:15	285
26	7"	3	2"	Right	94+25 to 95+20	5:30	265
					Total Tons of Mix:		75.0

April 13, 1977

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
1	4"	2	2"	Right	95+20 to 95+70	8:50	280
2	4"	2	2"	Right	95+70 to 96+80	9:00	-
3	4"	2	2"	Right	96+50 to 97+80	9:15	290
4	4"	2	2"	Right	97+80 to 98+50	9:30	280
5	4"	2	2"	Right	98+50 to 99+00	9:45	290
6	4"	2	2"	Right	99+00 to 99+90	10:05	280
					Total Tons of Mix:		71.0

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
7	10"	4	2"	Left	85+00 to 85+25	12:00	275
8	10"	4	2"	Left	85+25 to 85+65	12:05	280

NOTE; Loads 7 and 8 were placed in an approximately 4" layer to bring Sta. 85+00 to 85+50 to grade since layer 3 had been rejected and removed in this segment.

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp. F.
9	10"	4	2"	Left	85+65 to 86+25	12:15	280
10	10"	4	2"	Left	86+25 to 86+90	12:31	265

April 13, 1977 cont'd.

Load No.	Section Thickness	Layer No.	Layer Thickness	Traffic Lane	Approximate Sta. to Sta.	Time	Temp, F.
11	10"	4	2"	Left	86+90 to 87+65	12:55	285
12	10"	4	2"	Left	87+65 to 88+15	1:15	270
13	10"	4	2"	Left	88+15 to 88+70	2:00	280
14	10"	4	2"	Left	88+70 to 89+45	2:03	280
15	10"	4	2"	Left	89+45 to 90+20	2:15	280
				----------	Total Tons of Mix:		106.0
15	7"	3	2"	Left	90+20 to 90+45	-	
16	7"	3	2"	Left	90+45 to 91+40	2:25	280
17	7"	3	2"	Left	91+40 to 92+40	4:05	280
18	7"	3	2"	Left	92+40 to 93+40	4:15	280
19	7"	3	2"	Left	93+40 to 94+15	4:25	280
20	7"	3	2"	Left	94+15 to 95+20	4:35	275
				----------	Total Tons of Mix:		68.0
21	4"	2	2"	Left	95+20 to 96+80	4:52	280
22	4"	2	2"	Left	96+80 to 97+60	5:10	285
23	4"	2	2"	Left	97+60 to 99+00	5:30	280
24	4"	2	2"	Left	99+00 to 00+00	5:45	275
				----------	Total Tons of Mix:		56.0
25 (5 tons)	Patching			Right	85+00 to 84+10	6:35	255
26	Special Mix, variable thickness,			Left	84+90 to 83+75	6:45	285

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1 Special Mix, variable thickness, Right 85+00 back on stationing

Appendix B

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Tentative Test Method For the Determination of Bitumen Content and Sulfur Content In Thermopave® Mix

SCOPE

This method covers the determination of bitumen content using a nuclear asphalt content gauge and determination of the total of bitumen plus sulphur content using a rotary extractor and a sulphur burn-off procedure.

SUMMARY OF METHOD

This method consists of the following steps:

1. The bitumen content of the mix is determined using the Troxler Nuclear Asphalt Content Gauge
2. The bitumen and some sulphur are extracted from the mix using a rotary extractor, in accordance with ASTM Test Method D 2172 Method A.
3. Either a representative portion or the entire sample from Step 2 is then heated in a crucible to burn off the sulphur remaining with the aggregate.
4. The sulphur content is determined indirectly by subtracting the bitumen content (Step 1) from the total of bitumen plus sulphur (Steps 2 + 3). Steps 1 and 2 may be performed simulataneously.

APPARATUS

The equipment requirements for performing the above steps are as follows:

1. Troxler Nuclear Asphalt Content Gauge, Model No. 2226.
2. Rotary extractor, oven and auxillary equipment as described in ASTM Test Method D 2172, Method A.
3. One 300 ml. crucible, Bunsen burner, weigh scale (0.1 g. accuracy), tripod, asbestos/wire gauze pad.

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PROCEDURE

Select a 20 lb. representative sample of hot Thermopave. Place 500 to 800 g. mix into the extractor bowl and proceed as described in ASTM D 2172 Method A. Simultaneously determine the bitumen content of the remaining portion of the sample using the nuclear asphalt content gauge.

Some of the sulphur will be removed by the solvent during the extraction of the bitumen. The remaining sulphur will be left with the aggregate in the extractor bowl. Dry this material in an oven at a temperature of 210 to 220°F. Care should be taken to prevent heating above 235°F to avoid melting the sulphur. After cooling the bowl and contents to room temperature, weigh and determine weight of extracted bitumen and sulphur.

Mix the dried material thoroughly and select a representative sample of 100 to 500 g. and place into a preweighed crucible. Set crucible on stand located in a fumehood or outdoors.* Heat slowly until the sulphur ignites. Increase the heat as the sulphur is burned off. Stir the material in the crucible to ensure that all of the sulphur is completely burned off. Cool the crucible to room temperature, and weigh the sulphur burned off.

Determine the total content of sulphur plus bitumen by adding the weight of extracted bitumen and sulphur to the weight of sulphur burned off as shown in the example below. Express this as percent of total sample. Subtract the percent bitumen (determined with the nuclear gauge) to obtain the sulphur content.

EXAMPLE CALCULATION

1. Bitumen content by nuclear method = 6.0% w (total mix basis)

2. Calculation of total bitumen plus sulphur:

   (i) Extraction

Weight of mix sample in extractor	= 500 g
Dry weight of aggregate/sulphur material after extraction	= 464 g
Extracted bitumen and sulphur	36 g

Percent extracted bitumen and sulphur = $\frac{36}{500} \times 100\%$ =

7.2% (total mix weight basis) (a)

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* Precaution: Burning sulphur emits highly toxic fumes and care must be taken to insure proper ventilation and to avoid breathing fumes.

(ii) Burning off sulphur

Weight of aggregate/sulphur sample in crucible = 250 g

This is representative of = $\frac{250}{(100\% - 7.2\%)}$ x 100% = 269.4 g of total mix.

Weight of aggregate after burning off sulphur = 223 g

Weight of sulphur burned off = (250-223) = 27 g

Percent sulphur burned off = $\frac{27}{269.4}$ x 100% = 10.0% (total mix weight basis) (b)

Total bitumen plus sulphur content - a+ b = 7.2% + 10.0% = 17.2%

3. Sulphur Content = Step 2 - Step 1 = 17.2% - 6.0% = 11.2% (total mix weight basis)

Figure B1. Ignition of S-A-S Mixture To Determine Binder Content

Appendix C

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TENTATIVE METHOD OF TEST FOR SLUMP OF THERMOPAVE® MIX

SCOPE

This test method outlines the procedure to be used for determining the slump of Thermopave mix. It is a modified version of ASTM Test Method C 143-69.

APPARATUS

In addition to apparatus specified by ASTM C 143-69, the following equipment is required: oven with capacity to 350°F, high temperature resistant grease (eg. Dow Corning Silicone Grease No. 970 V), thermometer (200 to 350°F range), metal scoop.

PROCEDURE

Preheat the oven to 300°F ± 5°F. Clean and grease thoroughly the interior of the slump mold. The thickness of the grease film should not exceed 0.5 mm. Heat the mold, tamping rod and scoop in the oven for at least one-half hour before the test.

Obtain a 40 lb. sample of hot(270 to 300°F) Thermopave mix. Remove the mold from the oven, place it on a firm surface and hold it firmly while filling by standing on the two foot rests. Fill the mold completely using the hot scoop, heaping the mix above the top of the mould. Rod the mix rapidly 25 times to the full depth of the mold using the hot tamping rod and distributing the strokes uniformly across the surface of the mold. Strike off the excess mix with a stroking and rolling motion of the tamping rod. Separate the mold from the mix by raising the mold carefully in a vertical direction. Measure the slump to the nearest 0.5 inch. Measure the temperature at the centre of the specimen as quickly as possible.

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Appendix D

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TENTATIVE METHOD FOR PREPARATION OF THERMOPAVE® SPECIMENS FOR MARSHALL TESTING

Scope: This method entails the fabrication of specimens, using sand, asphalt and sulphur. A mixture of sand and asphalt is first made, and then hot, molten sulphur is added to this mix.

Equipment:

(a) Mechanical mixer (variable speed) 4 qt. capacity.

(b) Marshall Mould Assembly as per diagram.

(c) 1 small and 1 large scoop.

(d) 2 large spatulas.

(e) Thermometer dial type +50 to 450°F metal stem.

(f) Oven for heating sand, moulds, mixing bowl, stirrer and asphalt.

(g) Hot plate for heating Marshall hammer and spatula.

(h) Deep fryer for melting flour sulphur.

(i) Marshall hammer.

(j) Balance 5 kgs. capacity sensitive to 1 grm.

(k) Gloves for handling hot equipment.

(l) Ventilation system.

(m) Flour sulphur.

(n) High temperature grease, or some suitable release agent.

Preparations:

Sand: Dry sand and keep in oven at 300°F ± 5°F. Avoid lumps of material due to drying of wet sand.

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Asphalt: Keep one gallon of asphalt in an oven at 300°F ± 5°F.

Sulphur: Weigh out quantity of sulphur to be used in mix design and put in deep fryer, heat to 275-290°F. Viscosity of sulphur would undergo changes if overheated.

Mould Assembly, Marshall Hammer, Mixing Bowl and Stirrer

Thoroughly clean, place mould assembly, mixing bowl and stirrer in oven at 300°F for at least one hour prior to moulding specimens. Clean Marshall hammer, can be heated on a hot plate, or any suitable heat source.

Number of Specimens

If only Marshall stability is required, at least four and preferably six specimens should be made.

Mix Preparation

Weigh predetermined quantity of sand, calculated on batch size and mix design. (1100 grms. per specimen). Sand temperature should be 300°F ± 5°F. Put weighed sand into heated mixing bowl and stir at lowest speed for about 3-5 secs. Form a crater in the sand and weigh the required amount of asphalt cement into the sand. Using the lowest speed on the mixer, switch on and off in quick successions to allow some dispersion of asphalt into the sand. This prevents spilling of asphalt from bowl, when higher speed is being employed. This procedure should take about 5 secs. Select a suitable higher mixer speed and mix thoroughly to yield a mixture having a uniform distribution of asphalt throughout. This should be accomplished in 30-35 secs. of mixing. Pour in molten sulphur 275-290°F and repeat mixing procedure as for sand and asphalt, total mixing time should not exceed 65 secs. Measure and record mix temperature.

Moulding and Compaction Procedure:

Put a very thin film of grease or suitable release agent in hot moulds. Half fill mould with hot mix, and using small scoop, press vigorously around the perimeter and in the centre, repeat until mould is filled to 1/8" below the top of mould collar. Slightly grease the heated face of the Marshall hammer, and apply two blows to each specimen on one side only, remove collar, trim and smooth off with hot spatula.

Recommendations and Precautions:

Sulphur must not be overheated, 275-290°F and sand temperature should not exceed 310°F. This may cause the evolution of harmful fumes. Mixing should be done in a well-ventilated area, preferably with some expel air system. Initially, two people should be available in the mould procedure, until the method is perfectly understood.

All equipment used in moulding samples must be hot, and thoroughly cleaned before reheating. Avoid putting cooled mix (crusted) into mould; mix should not be reheated, but if it becomes necessary to keep mix hot during mixing and moulding specimens, a heating mantle can be employed.