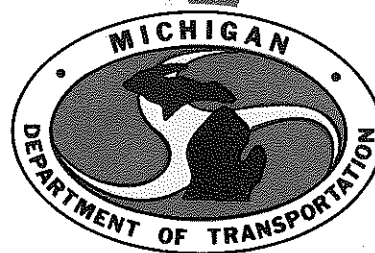


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EVALUATION OF SULFUR-ASPHALT BINDER
FOR BITUMINOUS RESURFACING MIXTURES



**TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION**

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EVALUATION OF SULFUR-ASPHALT BINDER
FOR BITUMINOUS RESURFACING MIXTURES

J. H. DeFoe

Research Laboratory Section
Testing and Research Division
Research Project 74 D-29
Research Report No. R-1220

Michigan Transportation Commission
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Lansing, May 1983

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This research project was initiated in 1974, at the request of the Engineer of Testing and Research, for the purpose of evaluating sulfur-asphalt binders as used in bituminous paving mixtures, and was conducted in cooperation with Gulf Oil of Canada, Ltd. For this operation, molten sulfur was blended with hot asphalt cement in specific and carefully controlled proportions, to form a sulfur-asphalt binder which was then mixed with aggregate, sand, and mineral filler in the usual manner to form a sulfur-asphalt paving mixture.

Benefits to be expected from the use of sulfur have been reported elsewhere and include: 1) use of less asphalt than is normally required for comparable conventional mixes; 2) lower mixing and placing temperatures; 3) longer fatigue life compared with conventional mixes; and, 4) reduced rutting (1, 2, 3).

Four, one-quarter mile experimental sulfur-asphalt test sections were constructed in 1977 as part of a resurfacing project (Control Section 26011, Job No. 11032A) on M 18 in Gladwin County (Fig. 1). In addition to the four sulfur-asphalt test sections, two adjacent sections using conventional mixes, and located on either end of the test sections, were included as control sections in this study. A progress report describing the construction was published in 1978 (4).

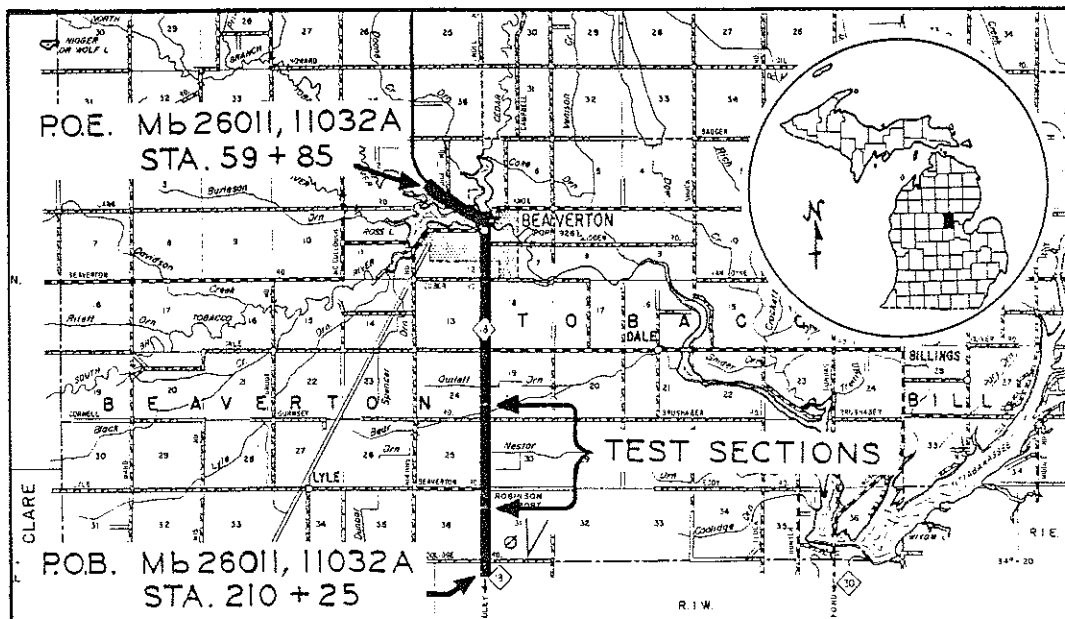


Figure 1. Location of experimental sulfur-asphalt test sections on M 18 in Gladwin County.

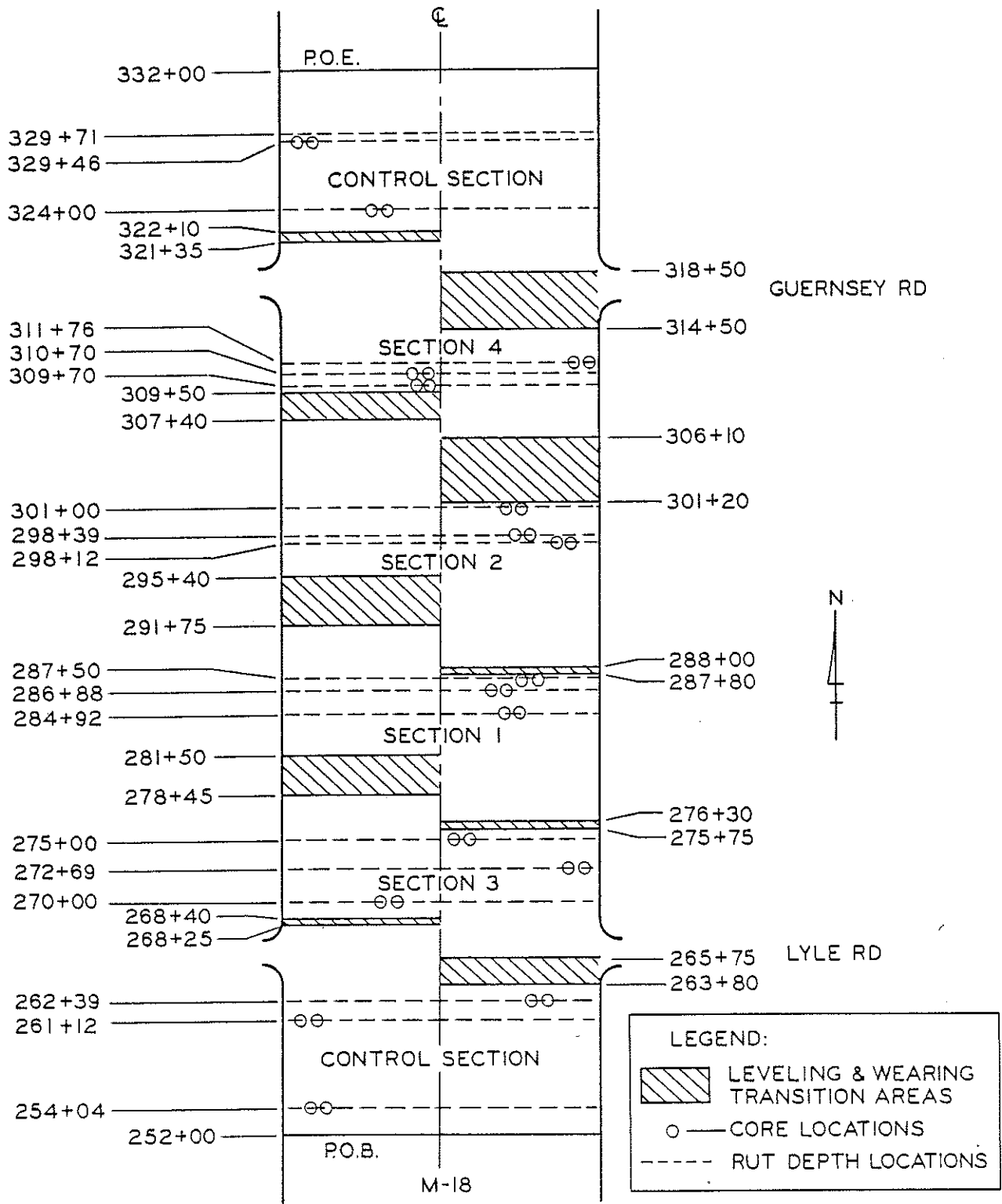


Figure 2. Experimental sulfur-asphalt test sections.

The four test sections consist of mixes made with two different ratios of sulfur-to-asphalt binder. Two test sections were made with each of the two sulfur-to-asphalt ratios at two different percentages of binder as shown in Table 1 and in Figure 2.

TABLE 1
COMPOSITION OF SULFUR-ASPHALT MIXTURES AS
PROPOSED FOR THE FOUR TEST SECTIONS

Test Section	Sulfur-to-Asphalt Ratio in Binder, percent by weight	Sulfur-Asphalt Binder in Mixture, percent	
		Leveling Course	Wearing Course
1	30:70	5	5.5
2	30:70	5.5	6
3	50:50	5	5.5
4	50:50	5.5	6

The experimental sections were paved in accordance with the 1976 Departmental Specifications for Bituminous Concrete Pavement (4.12) involving 1-1/2 in. of leveling course (25A) and 1 in. of Type C wearing course. Asphalt cement, 85 to 100 penetration, was used to make the sulfur-asphalt binder. Materials and experimental features unique to the project were covered in a Special Provision for Sulphur-Bituminous Concrete Pavement which was included in the project proposal, and was included as an Appendix to the progress report (4).

Prior to construction, crack surveys and rut depth measurements were made on the four test sections and on the two control sections. These measurements form the basis for future performance evaluation. Locations of rut depth measurements are shown in Figure 2 along with points where cores were taken from the experimental and control mixtures. Construction utilizing the experimental sulfur-asphalt mixtures involved preliminary mix design, plant set-up, plant sampling, transportation of the mix, and paving. Several weeks before the job was to start, samples of aggregate and asphalt were sent to the Gulf Laboratory and to the Department's Testing Laboratory for mix design testing.

A conventional stationary batch plant, owned by the contractor and located in Midland, produced the mixtures. A special set-up by Gulf, prior to mixing the sulfur-asphalt materials, required connection of a specially

designed sulfur-asphalt blending module (SAM) between the regular asphalt storage tank and the plant, with a control unit in the plant operations trailer. Figure 3 is a schematic diagram showing the extra units involved; all of which were supplied, connected, and operated by Gulf personnel.

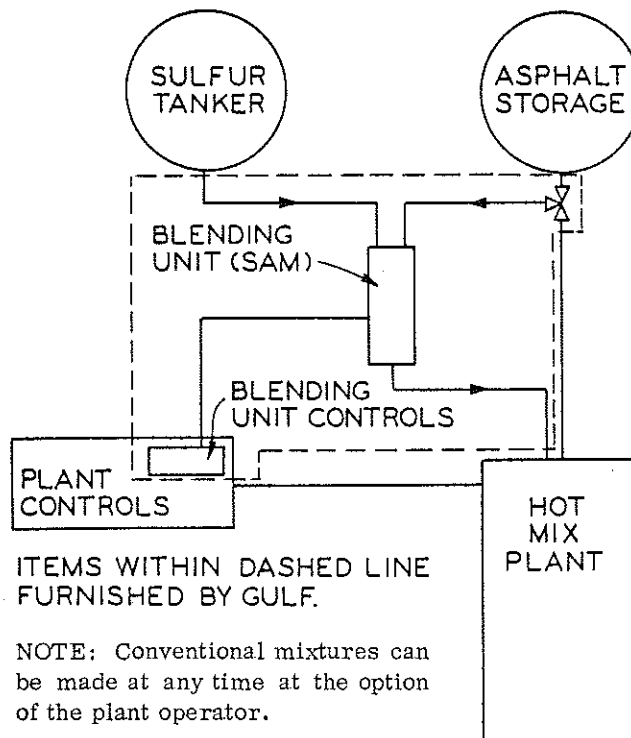


Figure 3. Schematic diagram of plant set-up to make sulfur-asphalt paving mixtures.

During production, samples of the sulfur-asphalt binder were obtained and analyzed for proportion of sulfur. Mixtures were also sampled from the trucks before leaving the plant, tested for binder level, and then formed into specimens for later laboratory testing of physical properties. The material was transported to the job site, about 25 miles, with each truck hauling approximately 40 tons. Paving consisted of two courses, leveling and wearing, meeting requirements for Bituminous Concrete Pavement, Section 4.12 of the MDSHT Standard Specifications for Highway Construction.

Except for the addition of sulfur, the project involved standard construction methods. The presence of sulfur in the mix was accompanied by a strong and distinct odor. Previous studies by Gulf have shown sulfur

emissions to be well within current clean air standards, provided the temperature of the sulfur does not exceed 300 F throughout the process. The formation of hydrogen sulfide is prevented when temperatures remain below 300 F. To provide further assurance regarding personnel and environmental health conditions, Gulf maintained a mobile laboratory on the job to measure levels of hydrogen sulfide (H₂S), sulfur dioxide (SO₂), elemental sulfur, hydrocarbons, and particulates. Portable monitors were also used to measure sulfur emission levels on the paver, especially at the operator's station.

PERFORMANCE MEASUREMENTS

Performance of the test and control sections was measured over a five-year period in order to compare rutting, reflection cracking, and friction levels.

Rut depths were measured six months after construction and then at yearly intervals during the five-year evaluation period. Rutting of the old pavement surface was also measured because it was thought that the depth of existing ruts might influence the depth of rutting in the new overlay.

The ability to inhibit reflective cracking was compared for the sulfur-asphalt and conventional asphalts on the basis of annual crack surveys. The length of all transverse cracks at the pavement joints were measured prior to resurfacing and each year after resurfacing. The percentage of reflected cracking was determined for each section.

Friction level measurements were made annually using the Department's Pavement Friction Tester, which complies with ASTM Specification E-17.

PHYSICAL PROPERTIES

Physical properties of the experimental mixtures were measured in the laboratory in order to relate to performance and to assess the potential use on future projects. The physical properties which were measured included resilient modulus, stiffness modulus, tensile strength, unit weight, thermal contraction coefficient, binder content, and layer thickness. Samples cored from the pavement surface were used for these tests. Unit weight and thicknesses were measured for each core specimen as part of the testing program.

Strength and modulus properties of core samples were measured in the laboratory using procedures based on the Indirect Tensile Test (5). Figure 4 illustrates the sample loading and measurement configuration used for the Indirect Tensile Test. A compressive load is applied across the vertical diametral plane of the sample which creates a tensile stress acting perpendicular to that plane. The load, P , also causes a horizontal deformation, ΔH , as well as a vertical deformation, ΔV . By measuring P and ΔH during the test, the stiffness modulus, E , tensile stress and tensile strain are determined. Poisson's ratio can also be computed if ΔV is measured.

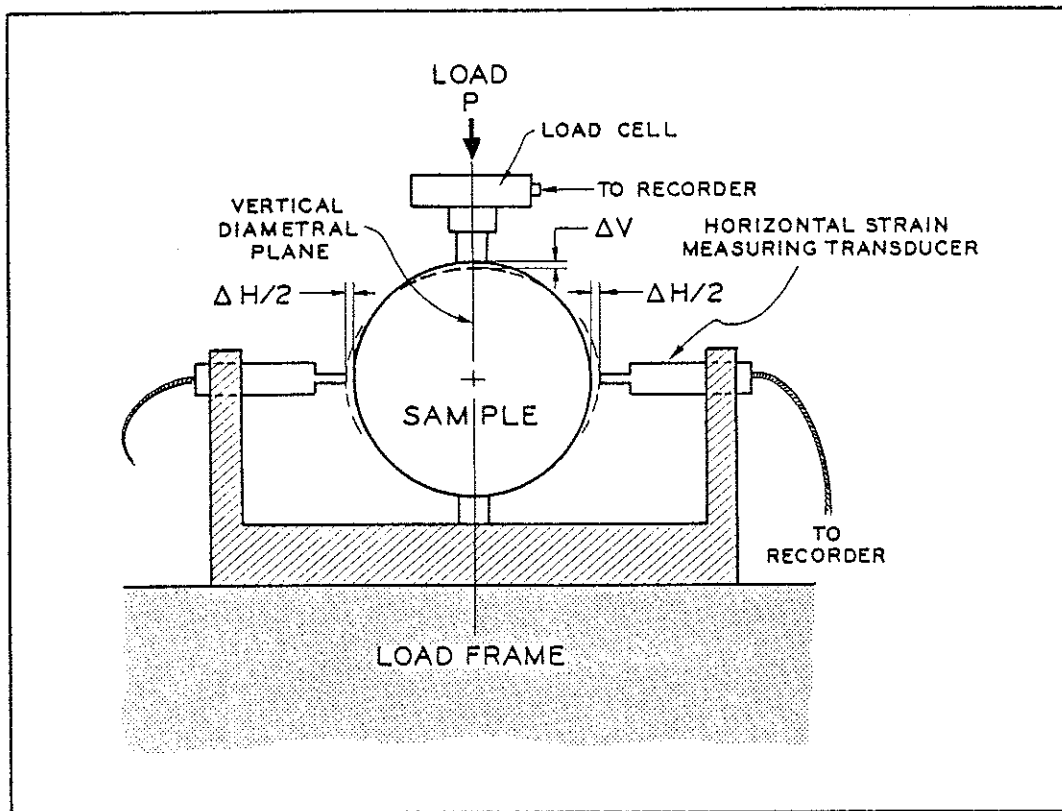
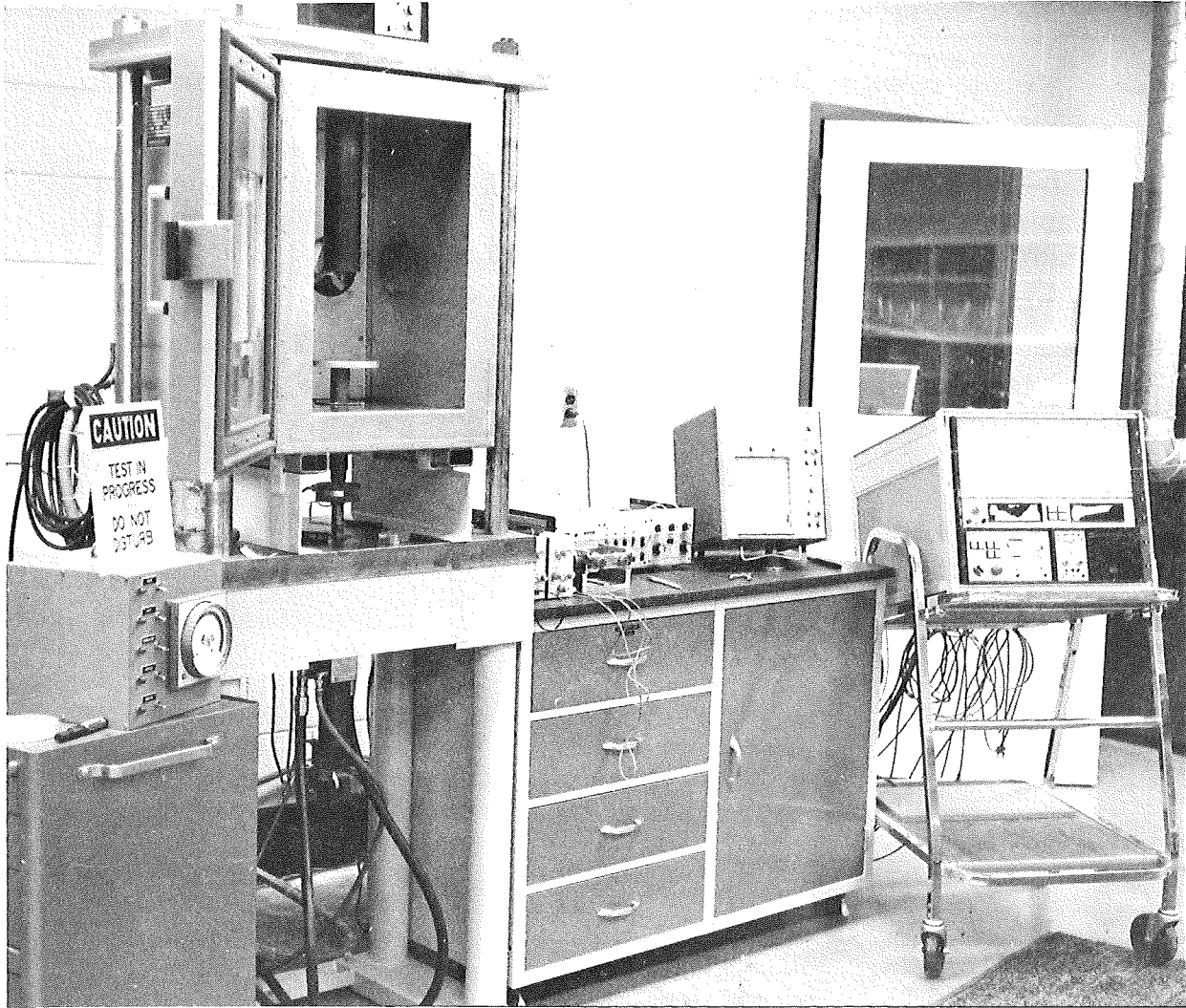
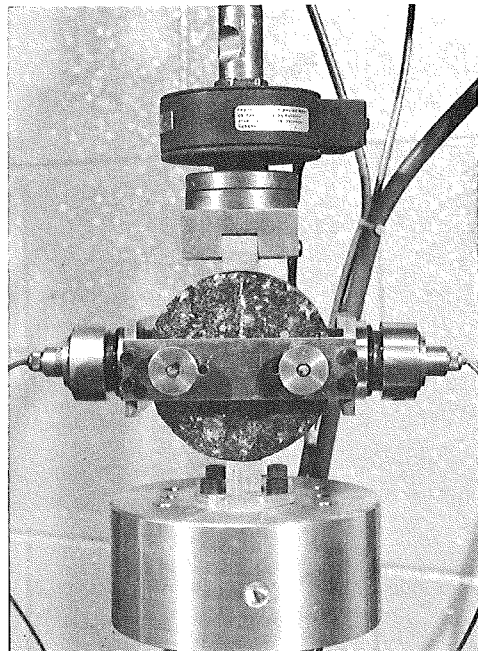


Figure 4. Indirect Tensile Test configuration for loading and measurement of deformation.

The Indirect Tensile Test was selected because the method is applied directly to cores from pavements of any thickness over about 1 in. and because the procedure can be used, with slight modifications, to determine both of the stiffness parameters as well as the tensile strength as required for this study. Figure 5 shows the complete test set-up for the indirect tensile resilient modulus test including load frame, load controller, and temperature chamber.



Resilient modulus testing apparatus including load controller, environmental chamber and recording equipment.



Sample loading and deflection measurement device used in the resilient modulus test.

Figure 5. Test apparatus for performing the repeated loading resilient modulus test using the Indirect Tensile Test sample configuration.

Tensile Strength

Tensile strength of the materials was measured by using the Indirect Tensile Test, as it was first used for bituminous mixtures (5). The test was selected because previous investigations have shown reasonable agreement between Indirect Tensile Test results, asphalt performance, and pavement thermal cracking (6, 7). In addition to tensile strength, the test measures stiffness modulus, E , at the instant of failure.

To measure tensile strength by this test the load, P , is applied at a constant rate of vertical deformation until it reaches a maximum, P_{\max} (Fig. 6), when the sample fractures along the vertical diametral plane. The tensile strength is equal to:

$$\sigma_F = 2P_{\max} \div \pi hd \quad (1)$$

where: h = sample thickness, in.
 d = sample diameter, in.

The stiffness modulus, E , of the sample can be determined from the equation:

$$E = P_{\max} (0.9974\mu + 0.2692) \div h \times \Delta H \quad (2)$$

where: ΔH = horizontal deformation, in., at the selected loading time
 μ = Poisson's ratio (assumed as 0.35 throughout this study).

Poisson's ratio, μ , can be determined by methods discussed in Ref. (5) and involves the measurement of vertical as well as horizontal deflection.

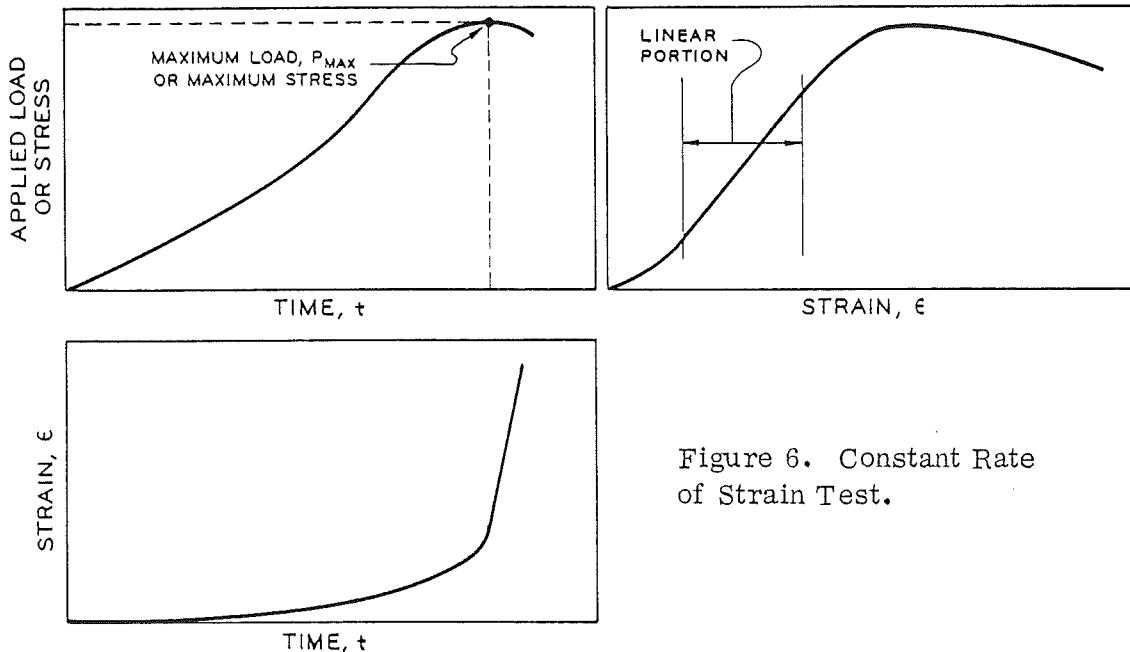


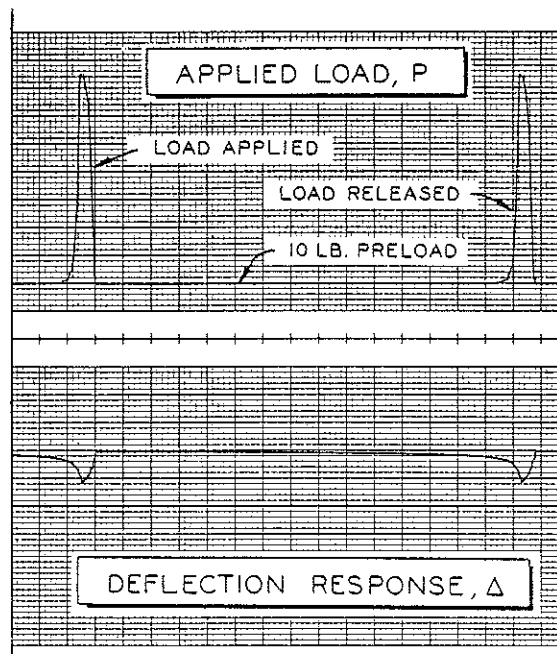
Figure 6. Constant Rate of Strain Test.

Resilient Modulus

The repetitive load resilient modulus test involves the repeated application of a short duration dynamic load, much smaller than that required to cause the sample to fail. The 75-lb peak load used in this study was applied to each sample at controlled durations (loading times) of 0.05, 0.1, and 1.0 seconds with a three-second relaxation interval between loads. The 75-lb load was equivalent to that used by Schmidt in the development and evaluation of the method (8).

Figure 7 shows the strip chart recording of several cycles of loading and horizontal deformation obtained from a typical resilient modulus test. The recovered, or resilient horizontal deformation, ΔH , was measured from the charts and the resilient modulus, M_r , determined from Eq. (2). Load durations of 0.05, 0.1, and 1.0 seconds were selected to represent a range of corresponding vehicle speeds (Fig. 8).

Figure 7. Typical stress-strain-loading time relationships for the test methods used to measure properties of bituminous pavement cores.



Thermal Contraction Coefficient

Thermal contraction coefficient was measured using the device shown in Figure 9. Specimens 1 in. square by 3 in. long were cut from a core sample and placed in the device as shown. Contraction was measured as the specimen and device were cooled from 80 to -10 F. Correction for contraction of the test device was obtained by the use of an Invar steel rod in place of the test specimen. The test method is similar to a procedure described in Ref. (9).

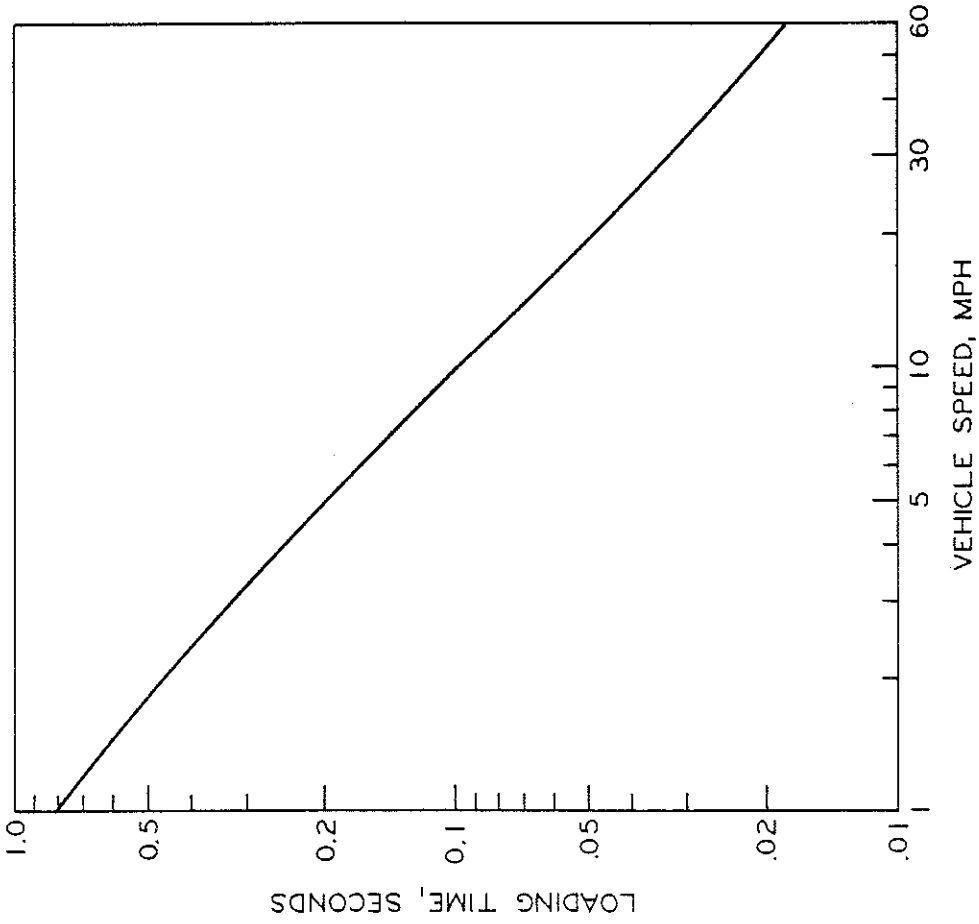
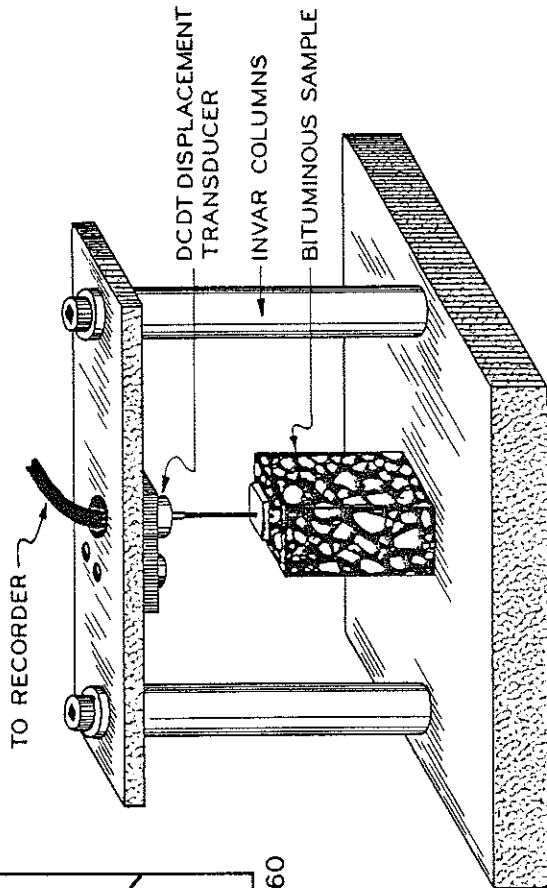


Figure 8. Relationship between vehicle speed and loading times used in repetitive load resilient modulus tests.

Figure 9. Device for measuring thermal contraction coefficients.



Mixture Composition

The experimental sections were paved in accordance with the 1976 Departmental Specifications for Bituminous Concrete Pavement (4.12) involving a leveling course (25A) and a Type C wearing course. Asphalt cement, 85 to 150 penetration, was used to make the sulfur-asphalt binder.

Mixture proportions for the control sections were established in the Department's Bituminous Laboratory using Marshall mix design methods. The control mix proportions, for leveling and wearing courses, were also used for the sulfur-asphalt sections; the asphalt cement in the conventional mixes was replaced with the sulfur-asphalt binder on an equal volume basis. Control mix proportions and Marshall design values are given in Table 2.

TABLE 2
CONTROL SECTION MIXTURE CHARACTERISTICS
Aggregate Gradation - Cumulative Percent Passing

Sieve Size	Leveling Course	Wearing Course
1-in.	100.0	100.0
3/4-in.	100.0	100.0
1/2-in.	99.0	99.0
3/8-in.	89.0	88.0
No. 4	51.0	66.0
No. 8	32.0	52.0
No. 16	25.0	43.0
No. 30	19.0	34.0
No. 50	6.2	15.0
No. 100	1.0	7.0
No. 200	1.0	6.0
Marshall Mix Design		
Optimum asphalt content, percent	4.8	5.8
Bulk, specific gravity	2.324	2.358
Air voids, percent	6.39	2.49
Marshall flow	7.76	9.65
Marshall stability	900.0	1732.0
Voids filled with asphalt	63.0	84.2
Density, lb/cu ft	145.0	147.2

Results

Rut depths measured prior to overlaying as well as values obtained one year and five years after overlaying are shown in Figure 10. The results indicate no great differences in performance either between the two sulfur-asphalt blends or between sulfur-asphalt and the control mixtures. Figure 11 shows the progress of rutting over the five-year evaluation period. The

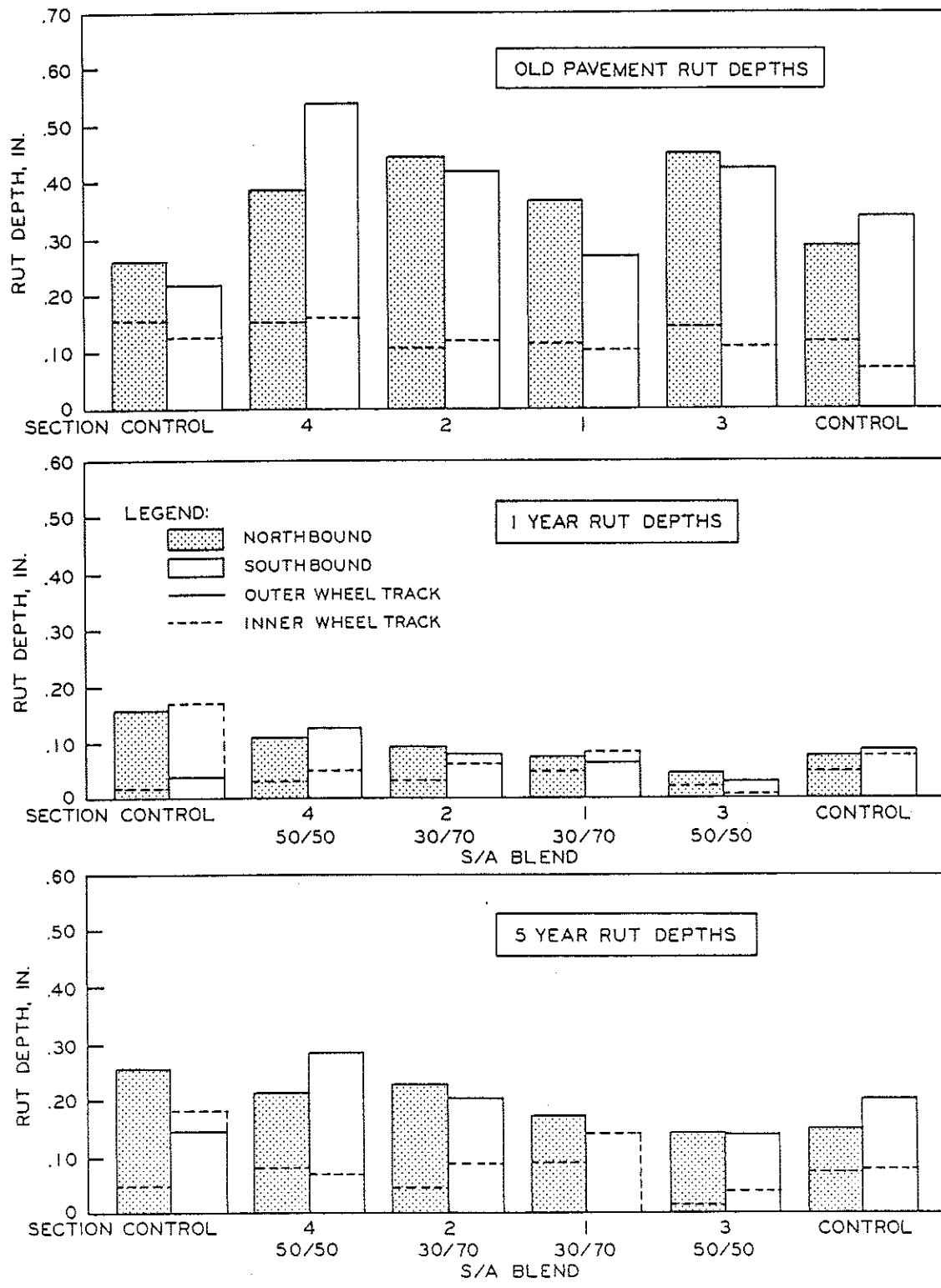


Figure 10. Average rut depths as measured on the old pavement and on the experimental resurfacing after one and five years of service.

data shown in Figure 11 indicate no difference between the two sulfur-asphalt mixtures and only slightly greater rutting at three years as compared with the control sections. Five-year measurements are no different, on the average, for sulfur-asphalt mixtures or the conventional control mixtures.

Reflective Cracking

Reflective cracking in the sulfur-asphalt sections after five years was approximately 17 percent less than the reflective cracking in the control sections (Fig. 12). The 50/50 sulfur sections were slightly better than the 30/70 sections. All sections experienced reflective cracking after one year of service with the two control sections showing 30 and 64 percent reflective cracking and the sulfur sections showing 34 and 46 percent, respectively, for 30/70 and 50/50 blends.

Friction Levels

Pavement friction levels were measured periodically throughout the evaluation beginning three months after resurfacing. These measurements are summarized in Table 3 and show only minor differences between sections.

TABLE 3
AVERAGE WET SLIDING FRICTION NUMBERS
MEASURED DURING THE FIVE-YEAR EVALUATION

Date of Measurement	Control Sections	30/70 S-A Sections	50/50 S-A Sections
October 1977	39	42	41
August 1978	42	42	42
November 1979	43	45	45
August 1980	46	47	46
September 1981	42	43	43
September 1982	47	48	48

Material Properties

Physical and structural properties of the paving mixtures were measured in the laboratory. Results of these tests and measurements are summarized in Table 4 which includes tensile strength and modulus values as well as thickness, unit weight, and binder content of the core specimens. Tensile strength and stiffness values were greater for the sulfur-asphalt mixtures than for the control material (Fig. 13).

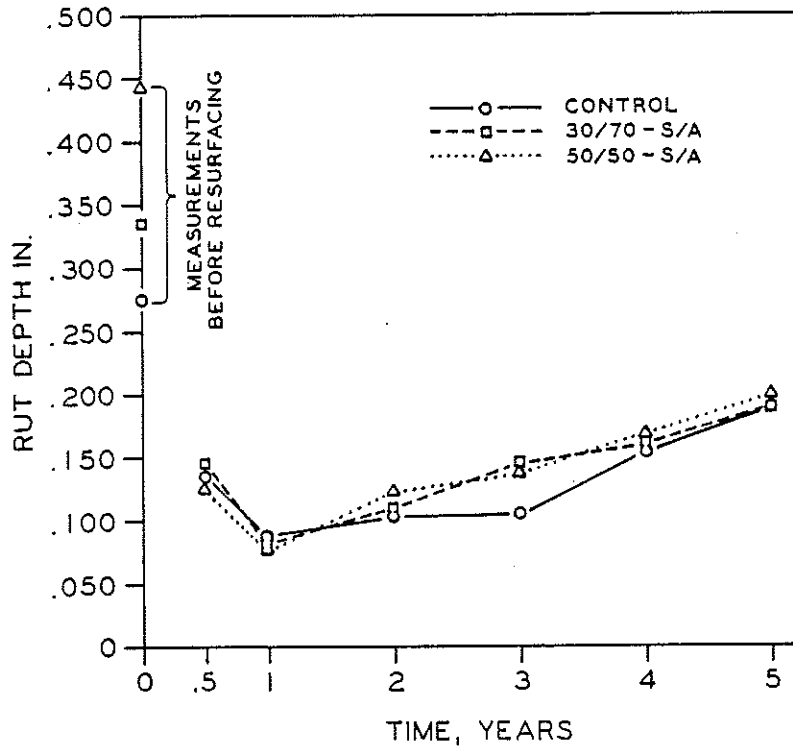


Figure 11. History of average rut depths for each resurfacing mixture.

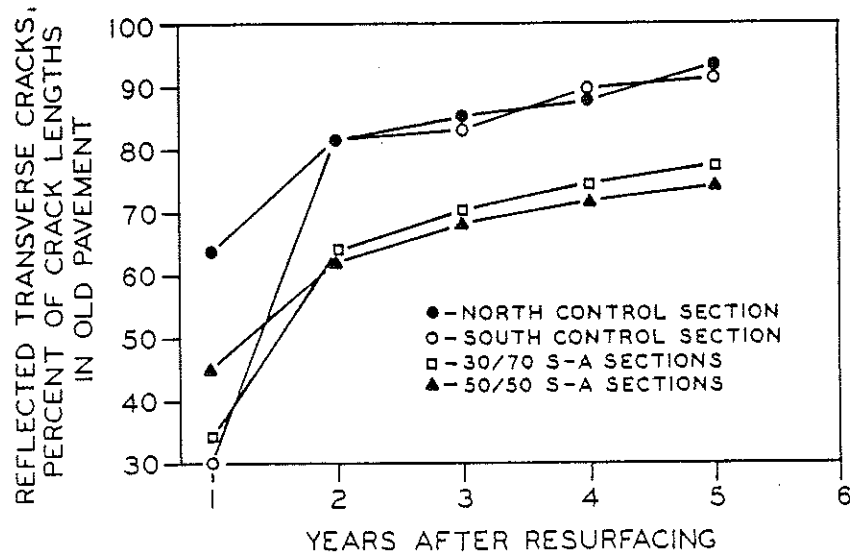


Figure 12. Reflective transverse crack history for the experimental test and control sections.

TABLE 4
 PROPERTIES OF EXPERIMENTAL SULFUR-ASPHALT PAVING LAYERS AS
 MEASURED IN THE LABORATORY ON PROJECT CORE SAMPLES

Section	Thickness, in.	Unit Weight, P.C.F.	Binder Content, percent		Tensile Strength, psi			Stiffness Modulus, E, psi	Loading Time, seconds	Resilient Modulus, M _r , psi (0.1 sec. loading)		Contraction Coefficient, in./in./°F x 10 ⁵ , Composite*	
			Wearing	Leveling	Wearing	Leveling	Composite*			72 F	40 F		
Control	2.2	139.8	5.8	---	55	---	10,200	---	39	---	---	---	
			---	4.5	---	35	---	3,800	---	46	---	---	
			---	---	---	---	45	---	7,600	---	40	350,000	1,290,000
30/70 S-A	2.2	139.6	5.6	---	49	---	17,400	---	32	---	---	0.69	
			---	4.9	---	40	---	8,200	---	37	---	---	0.34
			---	---	---	---	61	---	15,600	---	35	410,000	1,880,000
50/50 S-A	2.5	140.6	5.8	---	69	---	30,900	---	24	---	---	0.48	
			---	4.9	---	37	---	10,500	---	26	---	---	0.38
			---	---	---	---	60	---	19,200	---	30	470,000	1,660,000

* Samples consisted of wearing and leveling courses together.

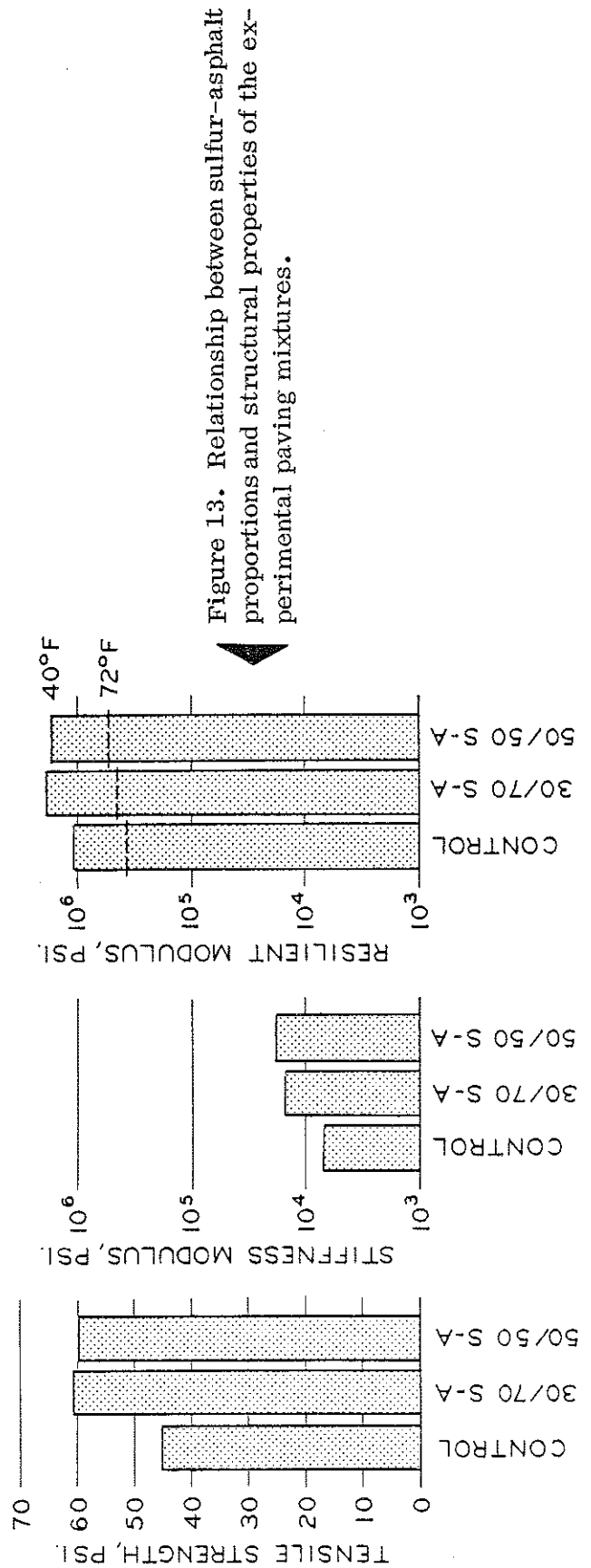


Figure 13. Relationship between sulfur-asphalt proportions and structural properties of the experimental paving mixtures.

Thermal contraction coefficients of the sulfur-asphalt blends were much less than for the control mixtures (Table 4). The combined effects of higher tensile strengths, stiffnesses, and lower thermal contraction coefficients could be expected to reduce the amount of transverse cracking as demonstrated in Figure 12.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This project has demonstrated the technical feasibility of blending hot liquid sulfur and asphalt cement to form a sulfur-asphalt binder for bituminous paving mixtures. Specifically, the sulfur-asphalt mixtures used on this project can be compared with conventional mixtures as follows:

- 1) Rutting of the sulfur-asphalt overlay was the same as for the conventional material.
- 2) Reflective transverse cracking was reduced by 17 percent in the sulfur sections.
- 3) The use of sulfur in the mixtures resulted in increased tensile strengths, increased stiffness values and decreased thermal contraction coefficients.

Recommendations

Although it is technically feasible to use sulfur-asphalt blends for paving mixtures, the current sulfur to asphalt cost ratio must be much less before the concept becomes economically desirable.

Consideration must be given to the effects of the presence of sulfur when recycling paving mixtures before widespread usage should be permitted.

In addition to this resurfacing job, a flexible pavement, M 99 in Calhoun and Hillsdale Counties, was resurfaced with sulfur-asphalt mixtures as part of another research study (10). Construction problems encountered on this project indicated the desirability of limiting sulfur-to-asphalt ratios to something less than the higher 50/50 ratio used, and to the need for limiting the dust or filler content of the mixes. The 30/70 ratio which was also used on M 99 presented no construction problems.

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