EVALUATION OF SULFUR-ASPHALT BINDER BITUMINOUS PAVING MIXTURES

Progress Report

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

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Evaluation of
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EVALUATION OF SULFUR-ASPHALT BINDER BITUMINOUS PAVING MIXTURES

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Testing and Research Division
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This project was initiated in February 1979 as part of the Michigan Department of Transportation's program to evaluate the effectiveness of sulfur as an additive to bituminous paving mixtures. Potential benefits expected from the use of sulfur are conservation of asphalt cement, reduction in mixture cost, and extended pavement life.

In a previous study, four quarter-mile sulfur-asphalt test sections were constructed on M 18 in Gladwin County (1). These test sections were paved in 1977 as an overlay over an existing jointed, reinforced concrete pavement and are being evaluated with regard to rutting and reflective cracking.

PROJECT DESCRIPTION

This project involved the paving of test sections on M 99 in Hillsdale and Calhoun Counties, Project Mb 30033-15321A (Fig. 1). Four test sections and two control sections will be evaluated for fatigue life, thermal

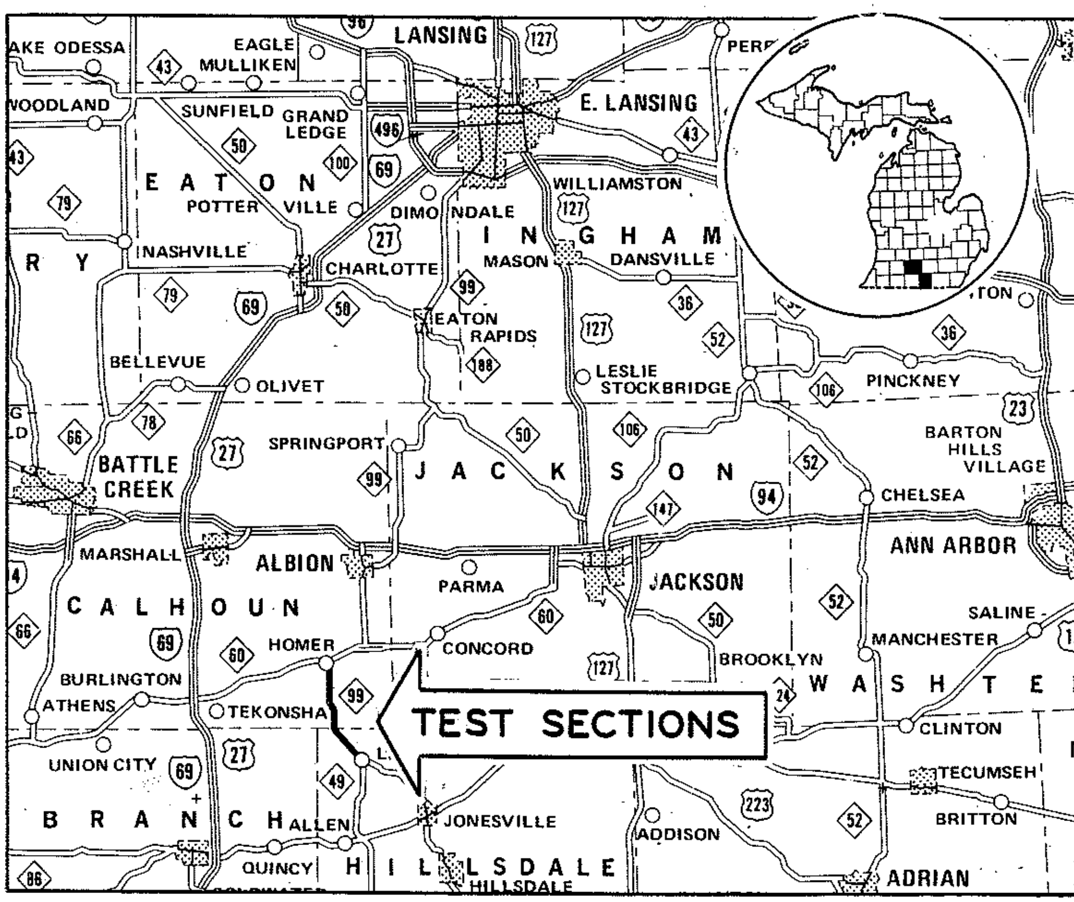


Figure 1. Location of experimental sulfur-asphalt test sections on M 99 in Calhoun and Hillsdale Counties.

Pavement layers on M 99 experimental S/A test sections.

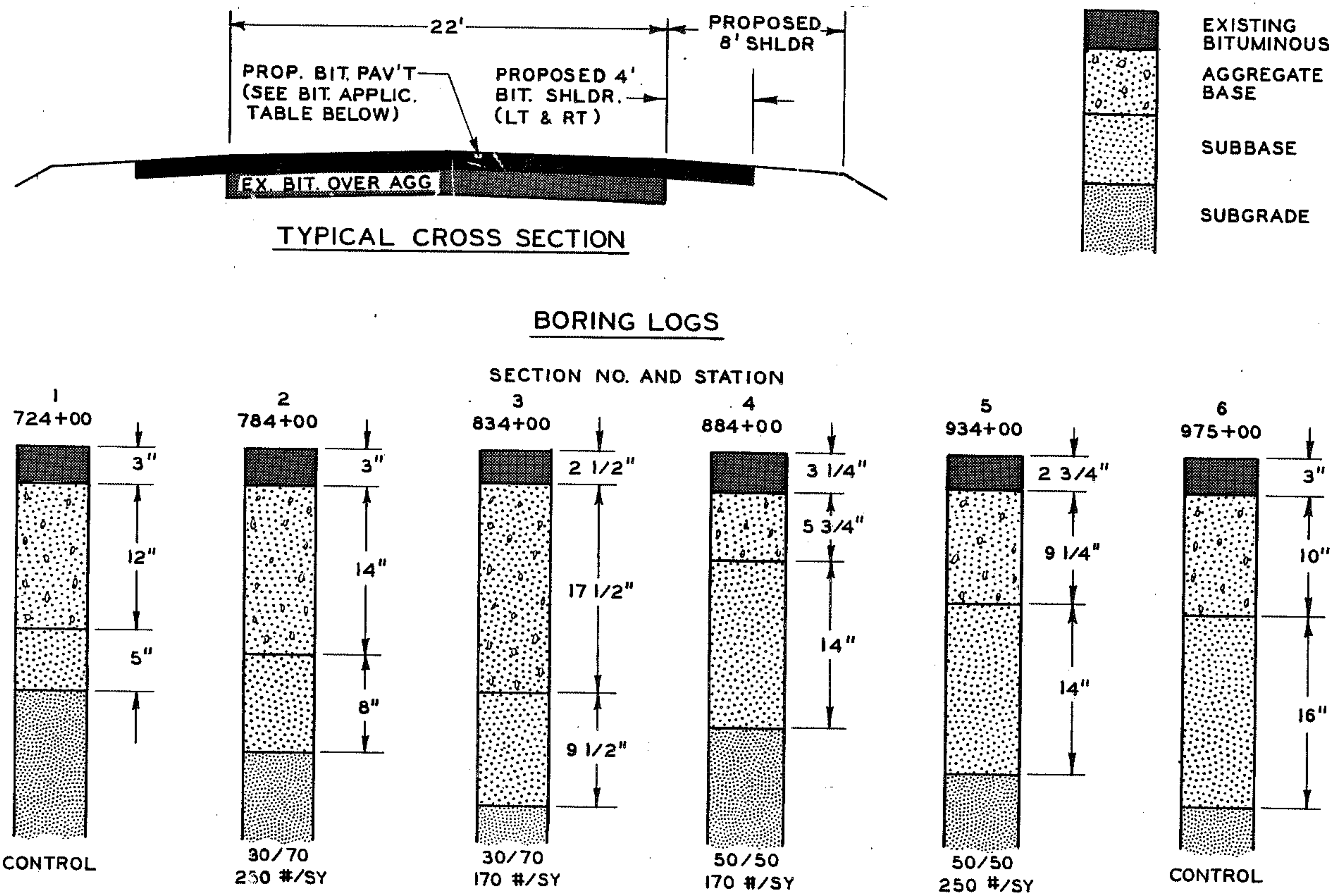


Figure 2. Pavement cross-section and boring logs for sulfur-extended-asphalt test sections.

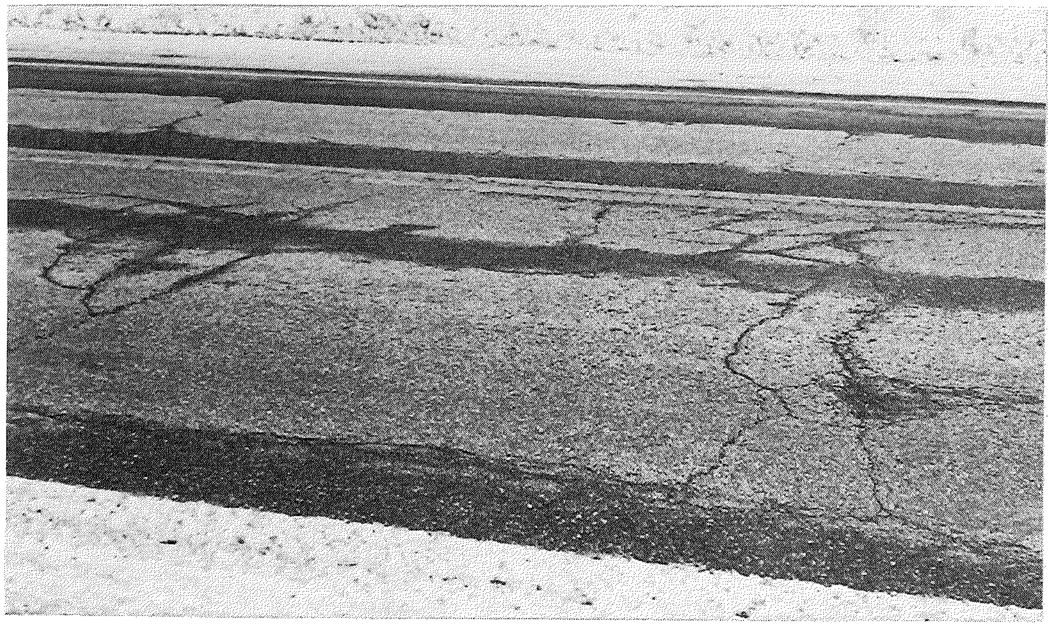
cracking, and rutting. Each section is 5,000 ft long and consists of an overlayment of an existing flexible pavement. The experimental sections are located in a rural area of M 99 which carries about 2,000 vehicles per day, 14 percent of which is commercial traffic. The pavement cross-section and boring logs for each test section are shown in Figure 2. The surface of the road was badly cracked (Fig. 3), with Cracking Index values ranging from 18 to 46 (Table 1). In a previous survey (2) of 34 flexible pavements in Michigan, Cracking Index[1] values were found to range from 1.5 to 21.2 for 12-year old pavements. Values of 0 to 3.4 were observed for pavements less than 11 years old. Also given in Table 1 are dynamic resilient modulus and tensile strength values obtained by testing cores from the old pavement. These measurements along with deflection measurements will be used to assess the structural characteristics of the existing road which will provide the basis for comparing the several test sections for design life. Benkelman beam deflection measurements were made in each test section prior to resurfacing. Deflection basins are shown in Figure 4.

TABLE 1
CHARACTERISTICS OF EXISTING PAVEMENT

Section Number	Cracking Index	Dynamic Resilient Modulus, M_r, psi	Tensile Strength, S_T, psi
1	18.7	422	115
2	30.0	276	148
3	18.3	439	97
4	26.3	292	140
5	36.0	430	142
6	46.3	351	144

In addition to exploring the use of sulfur to reduce the amount of asphalt required, the project was designed to evaluate the ability of sulfur to improve the fatigue life and temperature characteristics of bituminous mixtures. The use of sulfur blended with a soft asphalt such as a 200/250

[1] The Cracking Index is sometimes used as a measure of the pavement condition and is equal to the number of cracks extending completely across both lanes plus one half the number of cracks which extend only half way across the pavement. The method is more fully explained in Ref. (3).



Area of predominately transverse cracking.

Alligator cracking.

Area with both transverse and longitudinal cracking.

Figure 3. Condition of the surface on M 99 prior to resurfacing with sulfur-asphalt paving.

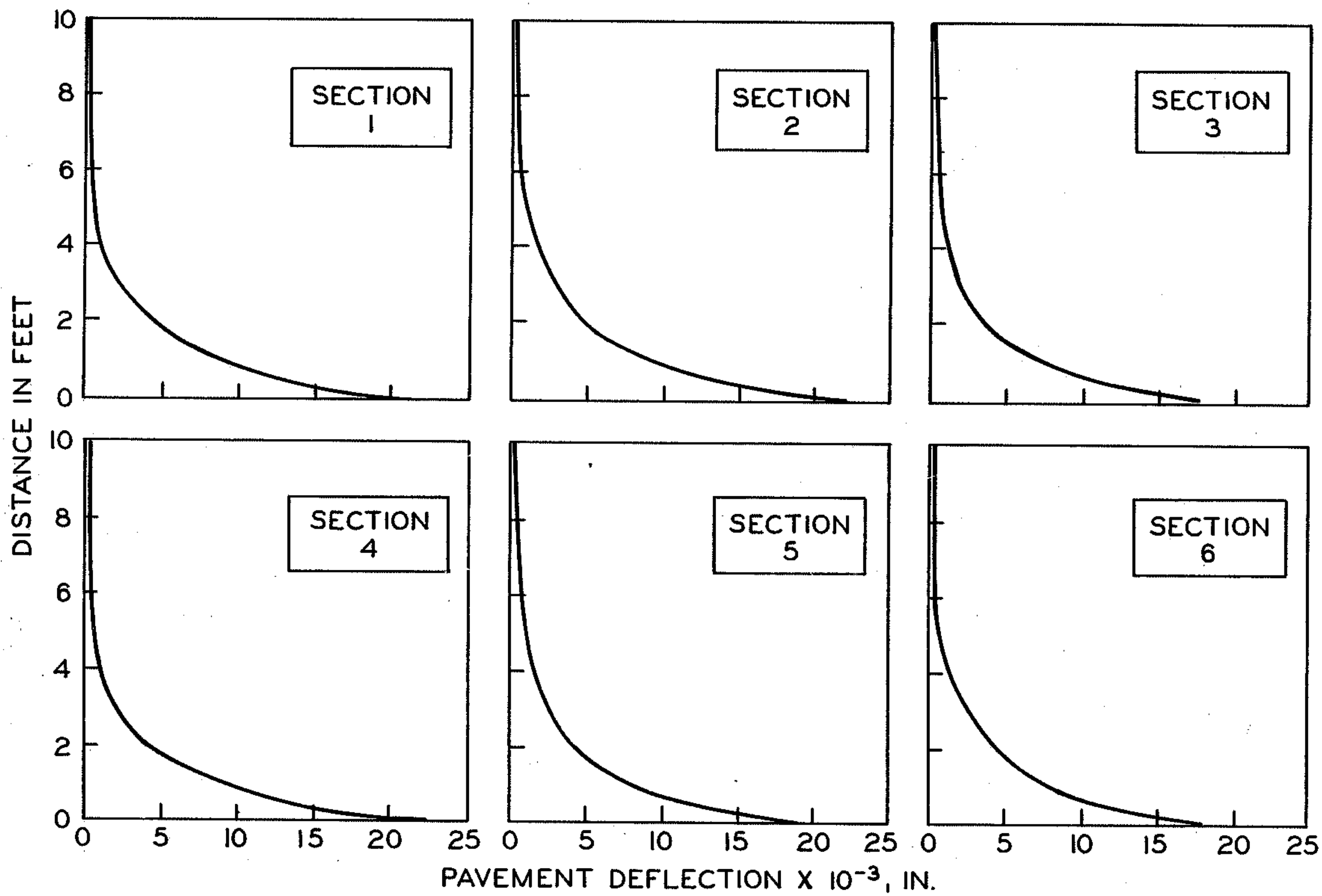
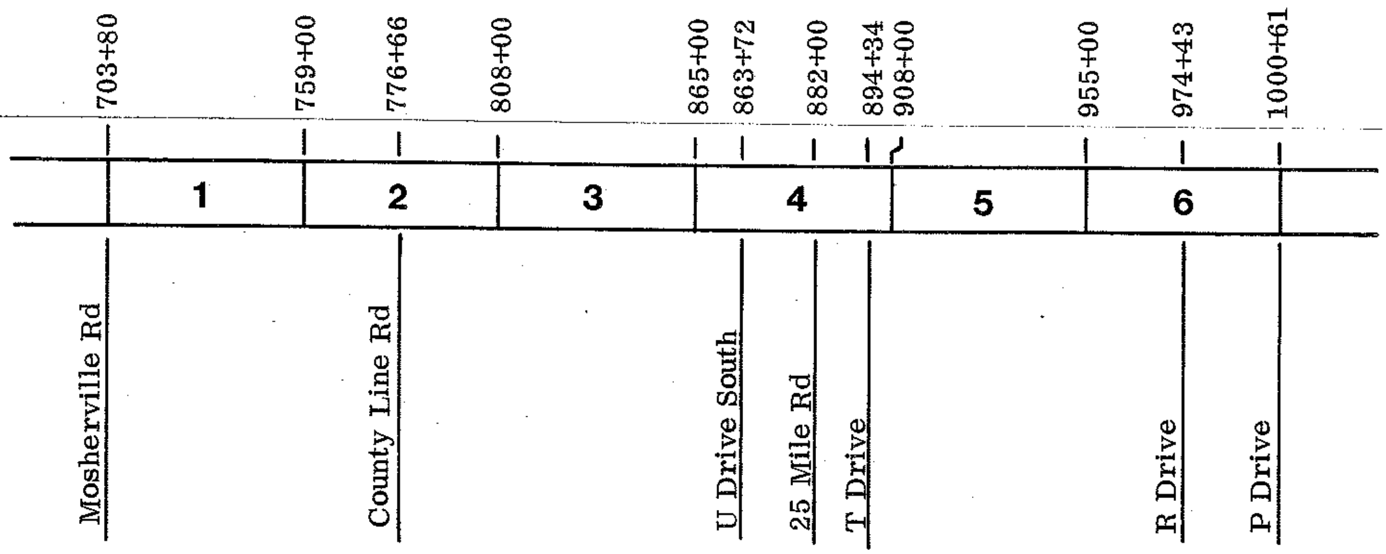


Figure 4. Benkelman beam deflection measurements for each of the test sections prior to resurfacing.



Test Section	Ratio of Sulfur to Asphalt, S/A, in Binder by Weight	Asphalt Cement Penetration Grade	Design Thickness, in. (lb/sq yd)
1	Control	120/150	1.5(170)
2	30/70	200/250	2.5(270)
3	30/70	200/250	1.5(170)
4	50/50	200/250	1.5(170)
5	50/50	200/250	2.5(270)
6	Control	120/150	1.5(170)

Figure 5. Sulfur-extended-asphalt test section layout, M 99.

penetration grade (AC-2.5), is expected to result in a more durable material than can be achieved with a 120/150 (AC-5) asphalt which normally would have been used on this job. In order to compare a mixture of soft asphalt and sulfur with a conventional paving mixture, six experimental test sections were constructed, four with sulfur-asphalt binders using 200/250 grade asphalt cement, and two for use as control sections, using a conventional bituminous paving mixture with a 120/150 asphalt cement. Two thicknesses were used for the experimental sulfur-asphalt sections, 170 lb/sq yd and 270 lb/sq yd, each with sulfur-to-asphalt cement ratios of 30 percent sulfur:70 percent asphalt, and 50 percent sulfur:50 percent asphalt. The arrangement of the individual test sections is shown in Figure 5.

MATERIALS

Paving mixtures for this project were proportioned by the Department's Testing Laboratory and by Gulf Oil Canada. The conventional design for this project required a bituminous aggregate mixture of a 20A aggregate and a 120/150 penetration grade asphalt cement. The experimental sections required the same 20A aggregate but mixed with a 200/250 penetration grade asphalt blended with sulfur. Material proportions and mixture designs as developed by Gulf Oil Canada are shown in Table 2. These include the conventional mix, using 120/150 grade asphalt, as well as sulfur-asphalt mixtures having sulfur-to-asphalt ratios of 0:100, 30:70, 40:60, and 50:50 with 200/250 grade asphalt.

Material proportions and mixture design data were also developed by the Bituminous Technical Service Unit of the Testing Laboratory and are shown in Table 3. This basic design was modified for the experimental sections by adjusting the sulfur-asphalt binder contents to achieve equivalent binder levels by volume. A chart published by the National Asphalt Pavement Association (4), used in the binder content conversion, is reproduced as Table 4.

Although it was intended that Gulf's recommendations be followed throughout the project, it seemed advisable to develop our own designs as a check. Since the Department was ultimately responsible for the overall quality of the road, the Department's mix design was developed to provide a basis for any field changes that might be needed if problems occurred. Table 5 compares the sulfur-to-asphalt proportions selected for this project by the two organizations.

TABLE 2
EXPERIMENTAL MIXTURE DESIGNS
DEVELOPED BY GULF CANADA

Aggregate Gradation
Cumulative Percent Passing

Sieve Size	Percent Passing
1-in.	100.0
3/4-in.	100.0
5/8-in.	97.6
1/2-in.	87.7
3/8-in.	71.9
No. 4	51.9
No. 8	43.4
No. 16	33.9
No. 30	24.6
No. 50	12.7
No. 100	6.5
No. 200	4.4

Marshall Test Results

	S/A Ratio				Conventional 120/150 Asphalt Cement Mixture
	0:100	30:70	40:60	50:50	
Total Binder, percent	5.90	6.42	6.64	6.90	5.90
Sulfur, percent	0.00	1.93	2.66	3.45	0.00
200/250 Asphalt, percent	5.9	4.5	4.0	3.5	--
Bulk, specific gravity	2.393	2.412	2.393	2.396	2.384
Max., specific gravity	2.433	2.474	2.495	2.494	2.450
Air Voids, percent	1.70	2.50	4.10	3.90	2.99
V.M.A., percent	15.50	15.70	16.90	16.30	16.60
Marshall Flow	12.6	9.7	8.0	7.5	10.5
Marshall Stability	1197.0	1533.0	2003.0	2751.0	1558.0

TABLE 3
CONVENTIONAL MIXTURE DESIGN DEVELOPED
IN THE TESTING LABORATORY, MDOT

Aggregate Gradation
Cumulative Percent Passing

Sieve Size	Coarse Aggregate	Extracted Aggregate
1-in.	100.0	100.0
3/4-in.	100.0	100.0
1/2-in.	88.5	88.8
3/8-in.	75.4	76.0
No. 4	59.7	60.8
No. 8	49.5	50.8
No. 16	39.3	40.9
No. 30	27.6	29.5
No. 50	14.5	16.8
No. 100	5.9	8.4
No. 200	3.5	5.7

Mix Design

Optimum Asphalt Content, percent	5.85
Bulk, specific gravity	2.384
Air Voids, percent	2.99
V.M.A., percent	16.64
Marshall Flow	10.54
Marshall Stability	1558.0
Voids Filled with Asphalt	81.99
Density, lb/cu ft	148.7

TABLE 4
EQUIVALENT SULPHUR-ASPHALT BINDER BY WEIGHT OF MIX (PERCENT)

Conventional Asphalt Content by Weight of Mix, percent	Desired Sulphur-Asphalt Ratio (S/A)				
	10:90	20:80	30:70	40:60	50:50
4.00	4.202	4.425	4.673	4.950	5.263
4.50	4.726	4.975	5.252	5.562	5.911
5.00	5.249	5.525	5.831	6.173	6.557
5.50	5.772	6.074	6.408	6.782	7.201
6.00	6.296	6.622	6.985	7.389	7.843
6.50	6.818	7.170	7.560	7.995	8.483
7.00	7.341	7.718	8.135	8.600	9.120
7.50	7.863	8.264	8.708	9.202	9.756
Specific Gravity of S/A Binder Using 1.00 for Asphalt and 2.00 for Sulphur	1.0526	1.1111	1.1765	1.2500	1.3333

For anyone requiring information not shown in the above table, the following formula can be used to compute any other conditions desired:

$$\% BC_2 = \frac{(SG_2/SG_1)\ (\% BC_1)\ (100)}{(SG_2/SG_1)\ (\% BC) + (100 - \% BC_1)}$$

Where BC_2 (%) is the unknown percentage binder content of a binder having a specific gravity of SG_2,

BC_1 (%) is the known percentage binder content of a binder having a specific gravity of SG_1,

Where also the volume of $BC_2 = BC_1$.

TABLE 5
COMPARISON OF SULFUR AND ASPHALT BINDER PROPORTIONS AS DETERMINED BY MDOT AND GULF LABORATORIES FOR THE TEST SECTIONS

Test Sections	Total Binder, percent		Sulfur, percent		Asphalt, percent	
	MDOT	Gulf	MDOT	Gulf	MDOT	Gulf
1 and 6 (control) S/A, 0:100	5.9	5.9	---	---	5.9	5.9
2 and 3 S/A, 30:70	6.8	6.4	2.0	1.9	4.8	4.5
4 and 5 S/A, 50:50	7.7	6.9	3.8	3.4	3.8	3.4

CONSTRUCTION

Paving of the experimental sulfur-extended-asphalt (SEA) sections began on June 28, 1979 with the 50:50 sections near the north end of the project. Prior to beginning paving, Gulf Oil Canada delivered, set-up, and adjusted the sulfur-blending equipment, SAM (Sulfur Asphalt Module), Figure 6. A schematic diagram (Fig. 7) shows how the blending unit is connected to the plant and the asphalt and sulfur binder supplies. The plant, a Barber-Greene drum mixer, was located in Jackson about 30 miles from the job site. Except for the addition of sulfur, the project was constructed using regular construction methods for bituminous aggregate pavement, Section 4.11 of MDOT Standard Specifications for Highway Construction, 1976. A Special Provision specifying the means of adding sulfur was included in the contract proposal and is reproduced as an appendix to this report.

Paving of the experimental sections was completed on July 9, 1979.

CONSTRUCTION PROBLEMS

Problems began on this project when the first loads of sulfur were delivered late and cold to the plant site. The first load arrived three hours late with sulfur at a temperature of 237 F and the outlet valve 'frozen' within a solid block of sulfur; specifications required the sulfur to be 280 to 300 F on delivery. This load was rejected as there was about 1 ft of solid sulfur

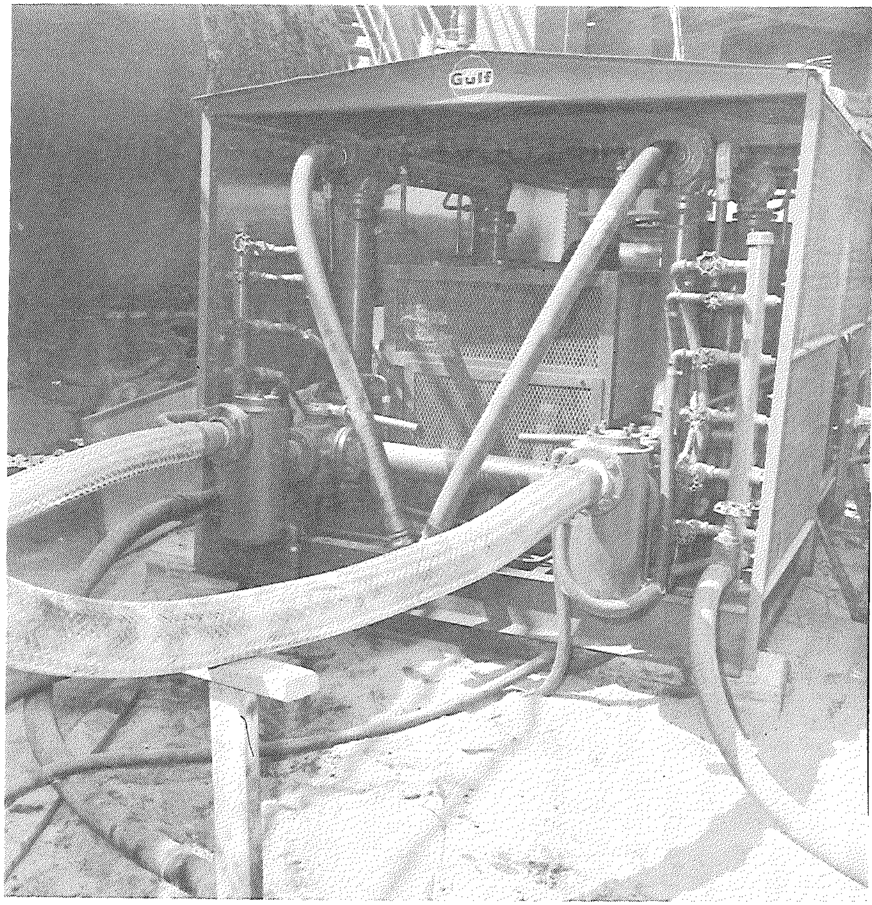
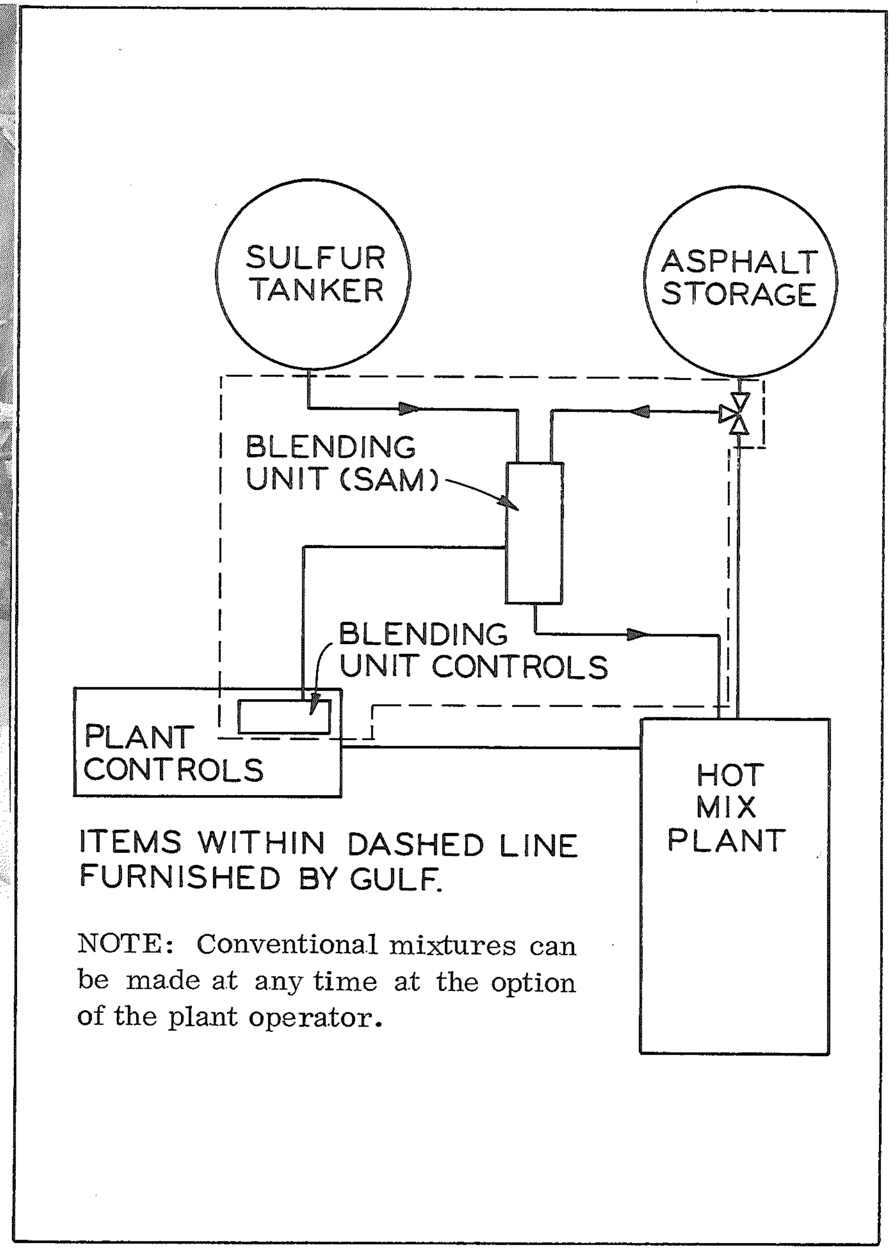


Figure 6. Sulfur-asphalt blending unit, SAM, connected to the hot sulfur and asphalt supply tanks.

Figure 7. Schematic diagram of plant set-up to make sulfur-asphalt paving mixtures.



in the bottom of the tank. The next load was warmer but the hot oil circulation valves were broken so that hot oil could not be used to achieve flow of sulfur from the outlet valve. Because of these problems the first sulfur asphalt mixture was not produced until around noon instead of 7:00 a.m. as planned.

The next and most significant problem concerned the sulfur-asphalt mixture itself and became apparent when the first load was dropped from the silo to the hauling truck. The mixture appeared to be very dry and 'dead' with many uncoated stones on the surface. Gulf technicians assured us that obtaining uncoated stones in the first loads from a drum mixer was normal as was the dry appearance for a 50:50 sulfur to asphalt ratio. The brownish color of the mix had been observed on a previous sulfur asphalt job and is not a problem. A few uncoated stones were visible after the mix had been placed by the paver. There were, however, many stones with a very thin layer of asphalt, sufficient only to impart a dark, but dry appearance to the stone surfaces.

The third problem was actually a continuation or result of the second problem, and concerned the workability of the 50:50 mixture during rolling and the resulting riding quality and integrity of the finished surface.

The mixture was dry and friable so that much tearing and shoving occurred under the roller. Gulf engineers assured us that the dry, dead appearance was normal and that the tearing would 'heal up' under traffic. They also recommended that the initial or breakdown roller not be used until the mix was cooler and that a pneumatic roller be used as an intermediate step. These changes, however, were not completely effective in solving the problem. A mile-long lane of 50:50 mixture was placed before the changes could be made and it was rough, with extensive tearing and bumps created by the shoved material. Rather than blade-off and waste this first material, it was decided that the section could be changed to a two-course test section which had originally been planned for the next mile.

Even though the greatest problems of the project were encountered during construction of the first section, the remainder of the 50:50 mixture was also difficult to apply. By increasing the binder content to 7.7 percent (the Department's design value), keeping the initial or breakdown roller well behind the paver to let the mat cool, and by reducing roller passes to one or two, the rest of the job was paved. The 30:70 mixture went down with minimal difficulty. Overall, the riding quality of the surface was rougher than normal with many roller marks and rough areas in the 50:50 sections.

Throughout the rolling process, mat temperatures were measured to determine their appropriate ranges for proper compaction in order to eliminate shoving and tearing problems. As a result of these measurements, the temperatures in Table 6 are recommended for future sulfur-asphalt paving projects. The values are to be considered as a guide only, with modification as experience dictates. It is recommended that the mix formula be adjusted rather than relying on a pneumatic intermediate roller to correct for cracks and tearing.

TABLE 6
RECOMMENDED TEMPERATURES FOR SULFUR-ASPHALT MIXTURES DURING CONSTRUCTION

Delivered to Paver	260 - 270 F
Breakdown Rolling	220 - 250 F
Intermediate (Pneumatic) Rolling	*
Finish Rolling	170 - 200 F

* A rubber-tired intermediate roller was used in some areas to knead out cracks and tears on the recommendation of Gulf.

CONCLUSIONS

Only after a long-term performance evaluation, five or more years, can the merits of this experimental paving be fully judged. From a construction viewpoint, the material was less than successful. As a research project, however, the project was more successful in that the material was placed in service and can thus be measured for long-term structural performance regarding fatigue life, thermal cracking, rutting, and overall durability.

REFERENCES

1. DeFoe, J. H., "Evaluation of Sulfur-Asphalt Binder for Bituminous Resurfacing Mixtures," Michigan Department of Transportation, Research Report No. R-1078, 1978.

2. Novak, E. C., Jr., "Evaluation of a Model for Predicting Transverse Cracking of Flexible Pavement," Michigan Department of Transportation, Research Report No. R-975, 1976.

3. Fromm, H. J. and Phang, W. A., "A Study of Transverse Cracking of Bituminous Pavements," Proceedings, Association of Asphalt Paving Technologists, V. 41, p 390, 1972.

4. Smith, R. W., "An Update on Sulphur-Based Flexible Pavement Construction," National Asphalt Pavement Association, Paving Forum, Spring 1979.

APPENDIX

SPECIAL PROVISION
FOR
SULPHUR-EXTENDED-ASPHALT
BITUMINOUS AGGREGATE PAVEMENT

A. Description - This work shall consist of furnishing, preparing and placing a bituminous bond coat and a sulphur-extended-asphalt bituminous mixture on a prepared base in accordance with the requirements specified under Bituminous Aggregate Pavement, 4.11, and Bituminous Mixtures--Plant Mixed, 7.10, of the 1976 Standard Specifications, and as specified herein. The various sulphur-extended-asphalt bituminous mixtures shall be placed at the locations designated on the plans or in the proposal.

B. Materials

1. Aggregates - The aggregate used in the mixture shall be Coarse Aggregate 20A.

2. Bituminous Material - The bituminous material for the sulphur-extended-asphalt mixture shall be Asphalt Cement, penetration grade 200/250. Sections without sulphur will require 120/150 as in the remainder of this project.

3. Sulphur - The sulphur compounds to be blended with the bituminous material shall be elemental sulphur in the free state conforming to the following requirements:

Characteristic	Value
Purity, % dry basis	97.5 min.
Moisture, %	1.0 max.
Ash, %	1.0 max.
Carbon content, %	1.0 max.
Acidity (as H_2SO_4), %	0.05 max.

Elemental sulphur will be accepted based upon certification from the supplier.

The sulphur shall be delivered in molten form (280° to 300° F) to the job site in an insulated truck transport. The transport shall have internal coils and a jacketed discharge arrangement so that hot oil or steam can be circulated to maintain the proper temperature of the sulphur at the job site.

Mb 30033

C. Composition of Sulphur-Extended-Asphalt Bituminous Aggregate Mixture - The mixture shall be proportioned in accordance with Section 7.10 of the 1976 Standard Specifications except that the specified sulphur compound shall be blended with the asphalt cement as follows:

Test Section	Ratio of Sulphur to Asphalt, S/A, in Binder by Wt.	Asphalt Cement Penetration Grade	Design Thickness, in. (lb/sq yd)
1	30/70	200/250	1.5 (170)
2	30/70	200/250	2.5 (270)
3	50/50	200/250	2.5 (270)
4	50/50	200/250	1.5 (170)

D. Sulphur Blending Equipment - A portable sulphur-asphalt blending unit shall be used for mixing the sulphur and the asphalt cement. The sulphur-asphalt blending unit shall have two pumps with meters for feeding and controlling automatically on demand of the mix plant streams of molten sulphur and asphalt cement to a mixer for mixing the sulphur with the asphalt cement. The blending unit shall be capable of regulating the temperature of the sulphur and the asphalt cement within the required range.

The blending unit shall be one designed by the manufacturer specifically for mixing hot liquid sulphur with asphalt cement. An acceptable blending unit can be obtained from:

GULF OIL CANADA LIMITED
2489 North Sheridan Way, Sheridan Park
Mississauga, Ontario L5K 1A8
(416) 822-6770

The contractor will be responsible for negotiating a rental-operating agreement and set-up schedule with the supplier of the blending unit.

E. Preparation and Mixing - The bituminous material shall be pumped from the bituminous storage tank to the sulphur module. The sulphur shall be fed in molten form from an insulated truck transport to the sulphur module for blending with the bituminous material. The sulphur-bituminous blend shall be pumped to the bituminous weight hopper of batch plants or under automatic binder control to continuous or drum mixer plants.

The temperature of the sulphur-bituminous mixture shall be maintained within the temperature range of 240° to 290° F at the temperature designated by the Engineer. Aggregates shall be delivered to the pugmill at temperatures not to exceed 300° F.

F. Time Limitation - The sulphur-extended-asphalt Bituminous Aggregate Pavement must be placed before July 22, 1979, to ensure the availability of the sulphur-asphalt blending unit.

G. Method of Measure - Sulphur-extended-asphalt Bituminous Aggregate Pavement will be measured by weight in tons. When blast furnace slag is used in the sulphur-bituminous mixture, the pay weight in tons will be determined by dividing the actual tons measured by a factor of 0.95.

H. Basis of Payment - The completed work as measured for SULPHUR-EXTENDED-ASPHALT BITUMINOUS AGGREGATE PAVEMENT will be paid for at the contract unit prices for the following contract items (pay items).

Pay Item	Pay Unit
Sulphur-Extended-Asphalt Bituminous Aggregate Pavement	Ton

Bituminous bond coat will not be paid for separately.