PERFORMANCE EVALUATION OF MIXED-IN-PLACE BITUMINOUS STABILIZED SHOULDER GRAVEL

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INTRODUCTION

The Problem

Economical maintenance of gravel shoulders is a common problem facing highway agencies. On highways carrying high-speed traffic, substandard shoulders are a hazard and, therefore, efforts are continually being made to upgrade them.

One method of improving substandard shoulders is to remove the existing material, where it is marginal or poor, and replace it with a high quality soil-aggregate surfaced with a bituminous mat or seal. A more economical solution was proposed whereby existing gravel would be mixed-in-place, stabilized with asphalt and surfaced with a bituminous shoulder mixture. If the resulting bituminous mix is properly stabilized, it should be more durable than conventional paved shoulders, as well as being more economical.

Background

In 1968, the Department began investigating the feasibility of upgrading existing shoulders along I 75 near Flint. Soil samples taken at 500-ft intervals along the existing shoulders were analyzed for both grain size and plasticity. After reviewing soil sample data, the Engineer of Soils agreed that bituminous stabilization was feasible provided certain areas were reconstructed (where only a thin layer of granular material lay over clay) and also, granular material in the shoulder base having a plasticity index was to be replaced. In a letter to R. L. Greenman (August 21, 1968), Paul J. Serafin, Bituminous Engineer, recommended that the shoulder be bituminous stabilized to a depth of 4 in. and capped with 130 lb per sq yd of bituminous shoulder mixture meeting 1967 Standard Specifications (Section 6.28). This was later changed by the Pavement Selection Committee to a 170-lb mat. Mr. Serafin further recommended that the area be divided into five equal sections, with each section being stabilized with one of the following:

1) Tar, RT-6 (for construction July 1 to September 15), and tar, RT-4 for the balance of the construction season.
2) Asphalt Emulsion, AE-1S
3) Cationic Asphalt Emulsion, CSS-1

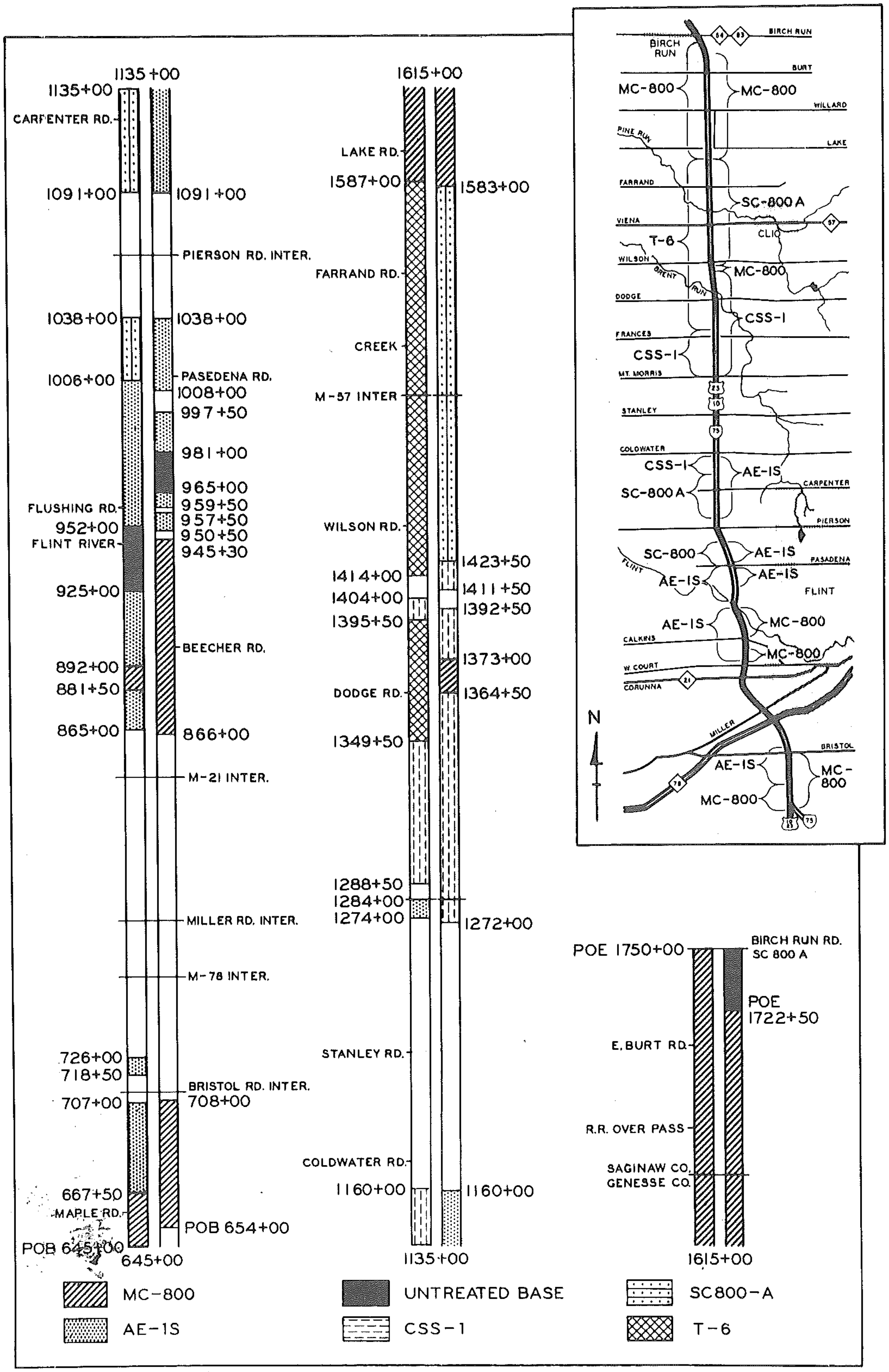

Figure 1. Schematic drawing showing relative locations of shoulder areas treated with P & H Stabilizer.

4) Liquid Asphalt, SC-800A
5) Liquid Asphalt, MC-800.

Residual bitumen content was to be from 3 to 5 percent.

A research proposal prepared by the Research Laboratory was approved by the Federal Highway Administration in a letter dated December 3, 1969. On May 15, 1970, work was begun on the shoulders by Reith-Riley Construction Co., Inc.

Research Procedure

Shoulders for this project are a part of I 75, a pavement constructed in 1957-58, about 21 miles long, and lying in Genesee and Saginaw Counties. The 1967 ADT for this highway ranges from 35,600 on the south end of the project to 25,700 on the north end. Existing soil-aggregate is well drained with a gravelly sand having a low stability.

Five test areas, equal in net length, were to be constructed along each roadway (northbound and southbound) as shown in Figure 1. Areas containing curb and gutter, and areas where existing shoulders had no sand subbase (on the outside of superelevated pavements), were to be excavated and reconstructed as conventional paved shoulders. The lengths of conventional shoulder were to be subtracted from the gross shoulder length in determining net length of experimental shoulder.

Condition surveys and riding quality measurements are to be made at least annually after completion of construction. Cost data for each of the five stabilized areas were obtained by the Construction Division. This interim report has been prepared to describe construction and initial performance; subsequent reports will be written as required.

CONSTRUCTION

Special Equipment

The majority of stabilization was carried out using a P & H Single-Pass Stabilizer. This machine appeared very efficient in road-mixing soils but, because of its width, could not be used under bridges or where guard rail was located close to the pavement edge. Only one pass was made over the shoulder wherever the P & H mixer was used.

Figure 2. P & H Single-Pass Stabilizer. Lower photo shows underside of processing chamber.

The P & H Single-Pass Stabilizer (Fig. 2) is a self-propelled machine, consisting of a power unit which is mounted on tractor-type crawler treads, and a processing unit suspended from the rear of the power unit. It performs, in a single pass, all of the necessary operations for complete in-place processing of road materials, leaving them in position for immediate compaction where aeration is not required.

The power unit provides the means of propelling the entire machine and carries the processing chamber and the necessary liquid systems. It is mounted on crawler treads to provide low ground bearing pressure for ease in operation on loose sand as well as on a firm soil. A diesel engine provides the power to propel the entire machine and operate the liquid systems and processing units. The system for application of bituminous liquids is equipped with a positive displacement type pump and the necessary control valves, gages, meters, and thermometer. Liquids are supplied to the machine by a tank truck which is coupled to, and pushed by the Stabilizer. Small liquid tanks are built into the frame of the power unit and have sufficient capacity to keep the machine in operation while the supply trucks are being changed.

The entire unit is operated by one man with a helper on the ground to connect and disconnect liquid supply trucks. The processing chamber, which is suspended from the rear of the power unit, is composed of a chamber that houses all the mixing elements. The operator can raise and lower the entire processing chamber and regulate the depth of cut, as well as position the rear of the processing chamber to keep it parallel to the grade.

As shown in Figure 3, the processing chamber is equipped with four rotors. The first rotor to contact the material being processed is the high speed "cutting rotor." This rotor, cutting downward into the soil, cuts and pulverizes as the machine moves forward. The amount of cut necessary to obtain the required degree of pulverization is regulated by the forward travel speed of the machine.

The second, or blending rotor, rotates in a direction opposite to the cutting rotor, and at a much slower speed. It is equipped with curved blades, set in a staggered pattern. This rotor stops the velocity of material moved by the cutting rotor; moves material back toward the cutting rotor for thorough blending; trims the subgrade to a smooth plane; picks up all material from the subgrade, and casts it in a thin layer into the pugmill.

Liquids are applied as the material is in the air while being cast from the blending rotor to the pugmill. This permits a continuous combination of liquids and soils such that the liquids are dispersed throughout the entire

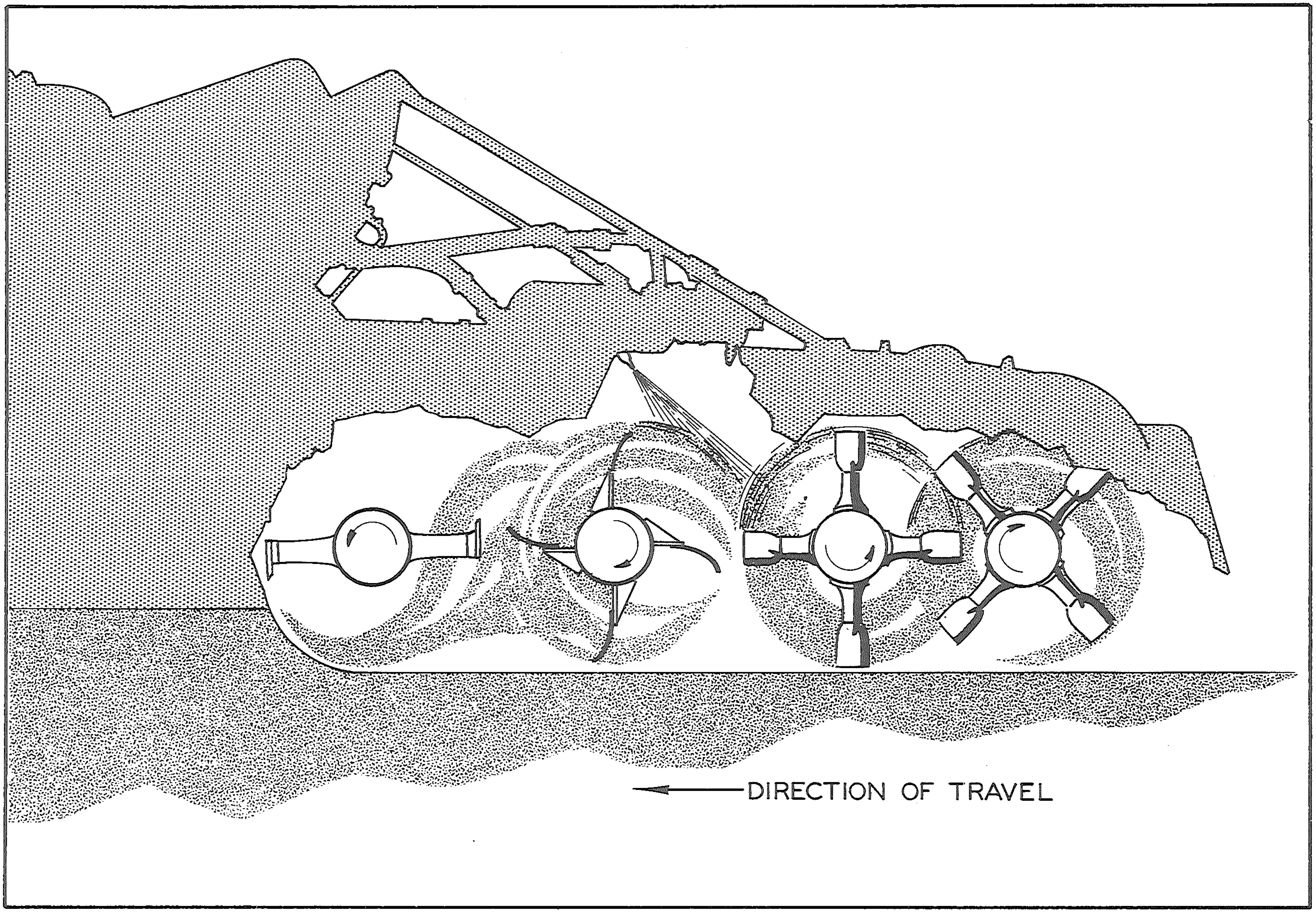

Figure 3. Schematic Diagram of Processing Chamber: P & H Single Pass Stabilizer

soil mass before it is fed to the pugmill for final mixing. Spray bars extend the full width of the processing chamber and are equipped with nozzles to give a fan-shaped spray pattern, providing a uniform liquid application throughout the full width of the processing chamber.

The last two rotors provide a twin transverse pugmill. The pugmill rotors are equipped with wide-face paddles set in opposing positions with the drums rotating in opposite directions. The rear end of the processing chamber is enclosed by an adjustable tail gate. This gate is adjustable to a variable processing depth and to regulate the volumes of material held in the pugmill.

This tail gate also acts as a strike-off to spread the mixed material to a uniform loose density the full width of the processing chamber. Immediate compaction may be accomplished on any mixture which does not require aeration.

Thus, the essential basic requirements of proportioning of materials; complete pulverization; uniform blending; applying and dispersing an accurately controlled volume of liquid; thorough mixing; and uniform spreading of material, are accomplished in a single pass at a high rate of production.

In areas where the P & H stabilizer could not be used, mixing was done with a smaller Rex single-shaft mixer with tooth-like scarifier tines. This smaller machine was quite ineffective as a mixer; probably, because it had no mixing tines or paddles. With the small unit, even after several passes, the mix was not always uniform.

Table 1 lists areas where mixing was done with the smaller unit. The Table also lists areas where existing soil was removed and replaced with conventional shoulders.

Construction Problems

Generally, even though carried out under conditions of heavy traffic, construction went quite smoothly with few major problems. Traffic was prohibited from one lane only in the area where the mixing and compacting of shoulder material was taking place.

In applying the liquid tar, operating personnel suffered skin irritation as a result of vapors from the tar. As a result, operators refused to apply tar in the second (NB) test area of that project, and the shoulder was stabilized using one of the other bituminous materials. Also, people in vehicles

TABLE 1
LIST OF LOCATIONS WITH CONVENTIONAL PAVED SHOULDERS AND THOSE STABILIZED WITH THE SMALL MIXING UNIT

(Asterisk designates those mixed with the small unit)

NORTHBOUND SHOULDER		SOUTHBOUND SHOULDER	
Start: Sta. 654+15		1764+00-1750+20	M 83 and ramp
*658+80-660+70	Maple Rd.	*1707+80-1705+50	Burt Rd
697+20-701+58	Ramp	*1689+20-1661+00	C & O RR Overpass
708+20-866+00	Ramps, conventional shoulder	*1636+20-1632+70	Guard rail
877+00-906+00	Conventional shoulder	*1600+50-1598+00	Lake Rd
*945+10-981+50	Flint River	*1547+70-1545+50	Farrand Rd
996+00-1007+80	Conventional shoulder	*1516+00-1509+00	Pine Run Creek
*1007+80-1009+30	Pasadena Ave	1505+00-1501+40	Ramp
1037+90-1091+00	Conventional shoulder	*1496+20-1492+50	Vienna Rd
*1118+10-1120+00	Carpenter Rd	1489+50-1481+00	Ramp
1160+15-1272+10	Conventional shoulder	*1476+20-1469+00	Guard rail
*1277+90-1279+25	Mt. Morris Rd	*1441+80-1440+00	Wilson Rd
1282+60-1291+00	Ramp	1439+30-1435+60	Rest Area ramp
*1364+30-1372+70	Guard rail	1413+50-1403+80	Rest Area ramp
*1384+60-1386+10	Dodge Rd	*1403+80-1398+00	Guard rail
1392+50-1411+40	Brent Run Bridge/conventional shoulder	1398+00-1395+80	Brent Run Bridge
*1439+20-1441+00	Wilson Rd	*1387+00-1385+00	Dodge Rd
*1471+00-1474+20	Guard rail	*1367+80-1365+00	Guard rail
1483+80-1487+40	Ramp	*1363+20-1360+50	Guard rail
*1492+30-1494+50	Vienna Rd	*1340+80-1339+50	Guard rail
1499+00-1507+50	Ramp	1289+80-1284+00	Ramp
*1510+00-1517+00	Pine Run creek	*1279+80-1277+80	Mt. Morris Rd
*1537+30-1538+20	Guard rail	1273+75-1265+80	Ramp
*1545+00-1548+00	Farrand Rd	1265+80-1159+20	Conventional shoulder
*1598+00-1600+00	Lake Rd	*1125+50-1124+50	Guard rail
*1630+80-1636+30	Guard rail	*1120+30-1118+50	Carpenter Rd
*1659+50-1688+00	C & O RR Overpass	1090+72-1038+00	Conventional shoulder
*1697+00-1698+00	Guard rail	*1010+20-1008+60	Pasadena Ave
*1705+40-1707+60	Burt Rd	*971+25-952+60	Guard rail
1721+50-1763+00	Conventional shoulder	952+60-925+00	Conventional shoulder
End at 1763+00 (M-83)		*900+60-898+50	Beecher Rd
		*892+25-881+40	Guard rail
		865+20-728+20	Ramps/conventional shoulder
		718+60-706+50	Ramp
		700+20-698+80	Ramp
		*661+20-659+00	Maple Rd
		End at: 645+00	

which were temporarily stopped during construction complained of the fumes from the tar.

Some problems were encountered because of waste concrete dumped into the shoulder base during construction of the pavement. These chunks of waste concrete, which were buried in the existing shoulder, broke several paddles on the P & H mixer, causing operational delays.

Probably the greatest problem was obtaining sufficient aeration after the bitumen and soil aggregate were mixed. Specifications called for "... a minimum of 2 mixing passes and as many more as required to thoroughly mix the bituminous material with the aggregate." Therefore, one pass with the P & H machine with its double-shafted pugmill was interpreted as two mixing passes, and there was little question that the bituminous material had been thoroughly mixed with the aggregate. However, specifications did not provide for aerating to evaporate the volatiles and obtain moisture content before the material was compacted. Thus, material was sometimes compacted when moisture was much higher than optimum.

SAMPLING AND TESTING

After mixing the admixtures into the soil, but before compaction, 150 small samples (about 250 gm each) were taken over the length of the project. At each test site along the project length, three samples were taken for bitumen extraction tests. The three samples were spaced transversely across the shoulder; one near the inside of the shoulder, one in the center, and one on the outside.

Results of extraction tests taken in areas where the P & H Stabilizer was used are shown in Tables 2 and 3. Bituminous residual averaged about 3.5 percent over the entire project. In order to evaluate the uniformity of mix, transversely across the shoulders, ratios of the three samples' values taken at each longitudinal location were computed. For these ratios, the value of residual bitumen content measured closest to the pavement at each site was used as the denominator and the measurements taken in the center and outside edge were each a numerator.

For example, at a given test site, the ratio of the center sample extraction value to the inside (nearest the pavement) sample extraction value was computed. That value was subtracted from one and where the mix was uniform the difference was near or equal to zero. These computations were made for each longitudinal location where the mix was sampled and statistical parameters computed as listed in Table 3. The uniformity of mix within each test section, as indicated by standard deviations, was least uniform for the SC-800A and most uniform for the MC-800. Table 3 further shows that transverse mixing was very good for all test areas. Large variations in the SC-800A concentration were found longitudinally along the shoulders rather than transversely. This indicates that the mixing action of the P & H unit was very good, but that the rate at which the admixture was applied varied quite a bit over the length of the project.

TABLE 2
AVERAGE BITUMEN CONTENT OF STABILIZED SHOULDER BASE

Type of Admixture	Number of Locations[1]	Location of Shoulder Sample			All Samples Combined
		Inside Edge	Center	Outside Edge	
SC-800A	7	3.826	3.536	3.253	3.538
CSS-1	11	4.421	4.047	4.542	4.337
AE-1S	11	3.596	3.241	3.104	3.314
MC-800	19	3.262	3.277	2.975	3.171
Combined	48	3.686	3.483	3.404	3.524

[1] Three samples taken at each location.

TABLE 3
VARIATION IN BITUMEN CONTENT IN STABILIZED SHOULDER BASE

	Type of Admixture				
	SC-800A	CSS-1	AE-1S	MC-800	Combined
Standard deviation among all samples	1.569	0.750	0.610	0.294	0.851
Average variation in ratios of center and inside sample extraction values[1]	0.035	0.056	0.079	-0.027	0.026
Average variation in ratios of center and outside sample extraction values[2]	0.138	-0.065	0.061	0.067	0.046
Standard deviation of ratios of center and inside sample extraction values	0.047	0.041	0.058	0.030	0.041
Standard deviation of ratios of outside and inside sample extraction values	0.074	0.060	0.145	0.020	0.065
Coefficients of variation of all bitumen percentages	44.338	17.286	18.397	9.267	24.143

[1]Variation in ratios of inside and center sample extraction values $= 1 - \frac{\text{center extraction value}}{\text{inside extraction value}}$

[2]Variation in ratios of inside and outside sample extractions values $= 1 - \frac{\text{outside extraction value}}{\text{inside extraction value}}$

Water contents in the mix, measured just before compaction, were found to be high; in many cases 8 to 10 percent. Because of the mixing efficiency of the P & H unit, only one pass was necessary to mix the bituminous material into the soil. But this one pass did not aerate the material sufficiently to remove all the volatiles, including water.

In a few small areas, the small mixer applied excessive bituminous material and, in the worst of such areas, the mix was replaced with compacted 22A aggregate before surfacing. At some locations, material containing excessive bitumen were surfaced, and failure of the bituminous shoulder mat soon occurred (Fig. 4). Those areas were then excavated and replaced with conventional shoulders. Locations of excessive bitumen usually appeared where the small mixer was permitted to stand still.

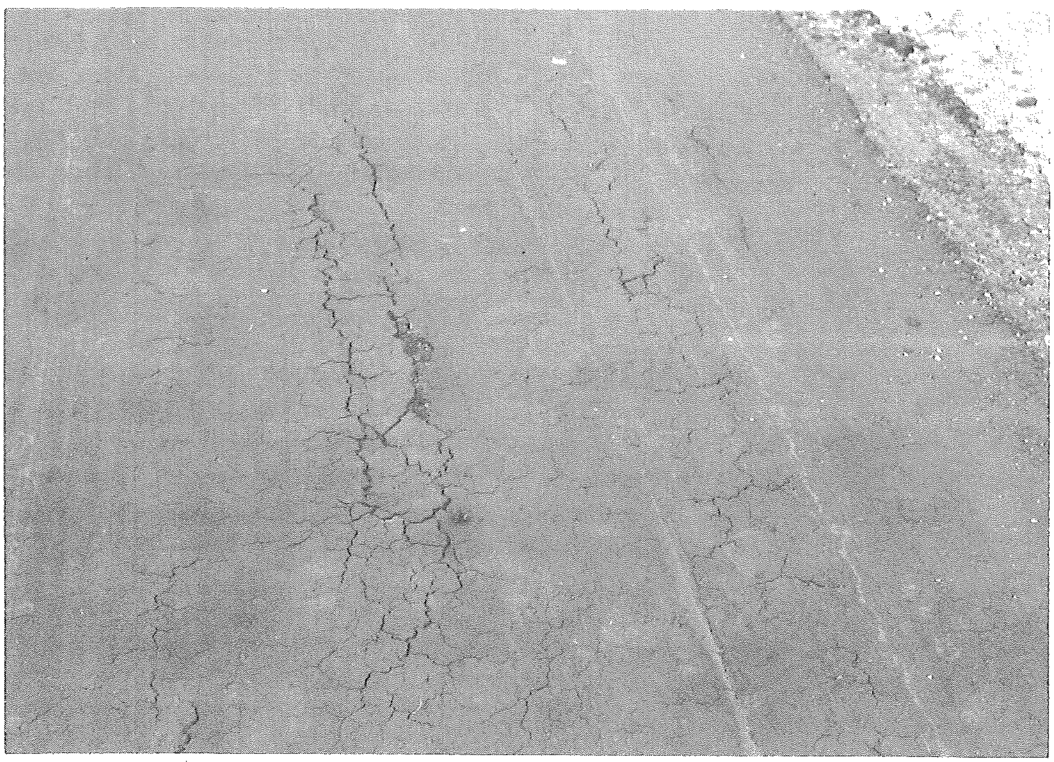

Figure 4. Failure of bituminous aggregate mat over base containing excessive quantity of stabilizing material.

After serving through one winter, some small portions of the shoulders also failed. Inspections indicated that these areas contained excessive bitumen and/or water.

In addition to the 250 gm samples discussed earlier, larger samples of the soil-aggregate-bituminous mixture were taken during construction and after one winter. Marshall tests, extraction tests, penetration tests, and gradation analyses were made on the samples and results are listed in Tables 4 through 7. Results of those tests, together with field observations, are summarized for each admixture in the following paragraphs.

TABLE 4
MARSHALL TEST RESULTS ON
STABILIZED SHOULDER BASE MATERIAL

	Type of Admixture									
	SC-800A		MC-800		RT-6		CSS-1		AE-1S	
Number of tests	4	4	4	4	4	4	4	4	4	4
Actual specific gravity	2.267	2.433	2.274	2.349	*	2.294	2.370	2.399	2.281	2.357
Air voids, percent	10.9	2.3	11.5	7.4	*	11.6	5.9	4.2	10.4	5.1
Stability, lb[1]	510	980	1020	1510	*	1070	2060	2140	620	1300
Flow, 0.01 in.	9	10	11	10	*	13	14	11	8	15
Bitumen, percent	3.1	4.9	2.7	3.5	2.2	2.3	4.2	4.4	2.5	3.6

* Samples disintegrated, no tests run.
[1] When comparing stability values, caution should be exercised because of the variation in bitumen residue, since the quantity of residue affects stability. The penetration of the asphalt also directly affects stability.

SC-800A

This material coated the soil-aggregate uniformly but stripped shortly afterwards because of high moisture content. The combination of high moisture content and slow curing of the SC-800A caused the base to remain unstable after rolling. Marshall tests (Table 4) show reasonably good stability when the moisture was reduced to a negligible amount. Table 5 shows that the bitumen did not harden during the nine months the sample was in the laboratory at room temperature. Table 6 shows that the SC-800A apparently penetrated the mat and softened the bituminous shoulder surface mixture appreciably.

MC-800

The MC-800 coated the stone uniformly, could be compacted shortly after being stabilized, and was easily shaped by the motor grader. Marshall test results (Table 4) show the stability to be almost double that of the SC-800A admixture. Table 5 shows that within nine months the bitumen had evolved into a penetration grade, probably as a result of evaporation of diluents and oxidation of the residue. Table 6 shows that the MC-800 did not soften the bituminous surface mixture.

RT-6

The tar coated the soil-aggregate uniformly, the mix was shaped easily with a motor grader, and the finished product appeared stable. Marshall test results (Table 4) show the mixture at 2.3 percent bitumen to be near a critical point. Marshall specimens from one sample could not be molded because of low cohesion whereas Marshall specimens from the other sample had a stability of 1,070 lb. Table 5 shows the tar to be very liquid at 140 F even after nine months at room temperature. Table 6 shows that the tar did not soften the bituminous shoulder surface.

TABLE 5
BITUMEN CONTENT AND PENETRATION RESULTS ON THE RECOVERED BITUMEN OF THE STABILIZED SHOULDER BASE BY THE CURRENT MICHIGAN METHOD

Sampling and Testing Sequence	Type of Admixture	Number of Samples	Avg. Residual Bitumen, percent	Recovered Penetration
Sampled and tested at time of construction.	SC-800A	5	2.8	*
	MC-800	8	3.1	*
	RT-6	4	3.8	*
	CSS-1	4	3.4	114
	AE-1S	5	3.2	*
Sampled at time of construction; tested 7 months later. [1]	SC-800A	2	4.9	3550[a]
	MC-800	2	4.6	95
	RT-6	2	2.2	470[a]
	CSS-1	2	4.3	74
	AE-1S	2	3.0	201
Sampled and tested 9 months after construction.	SC-800A	2	3.0	3390[a]
	MC-800	2	3.0	100
	RT-6	2	2.0	464[a]
	CSS-1	2	3.6	90
	AE-1S	2	2.6	252

* Too soft to make penetration test.
[1] Samples were stored in canvas bags.
[a] Recovered asphalt too soft for penetration test. Results reported here are kinematic viscosities at 140 F in Centistokes.

CSS-1

This material coated the soil-aggregate uniformly but the easily compacted material cured so rapidly that it could not be properly reshaped with a motor grader. Further, after grading, loose material would not be recompacted. This behavior indicated that the admixture had cured almost immediately after mixing. The material plugged the spray nozzles which were later removed. This clogging was probably caused when the emulsion encountered an incompatible material which had not been cleaned from the nozzles. Removal of the spray nozzles caused some streaking in the material. Marshall test results (Table 4) show the material has excellent stability with low air voids. Table 5 shows the bitumen was of penetration grade shortly after mixing. Table 6 suggests that the CSS-1 softened the bituminous shoulder mixture. This is difficult to explain since CSS-1 does not contain solvents which would soften bituminous materials.

TABLE 6
CORE TEST RESULTS OF SHOULDER PAVEMENT OVER THE VARIOUS BASES

	Type of Admixture								
	SC-800A	MC-800		RT-6		CSS-1	AE-1S		Untreated
No. of samples	4	4	3	4	3	4	4	2	6
Date sampled	4-15-71	4-15-71	5-12-71	4-15-71	5-12-71	4-15-71	4-15-71	5-12-71	5-12-71
Actual specific gravity	2.378	2.358	2.323	2.338	2.297	2.383	2.338	2.360	2.370
Air voids, percent	3.0	3.8	5.3	4.6	6.3	2.8	4.6	3.8	3.4
Bitumen, percent	6.2	6.0	5.7	6.2	5.8	6.2	6.2	6.0	5.8
Penetration, dmm	164	114	98	131	96	148	136	102	125

TABLE 7
SOIL-AGGREGATE SIEVE ANALYSIS, PERCENT PASSING

Material	No. of Tests	Sieve Size, percent passing										
		1 in.	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200
SC-800A	9	100	98	91	85	72	62	54	45	30	12	5.1
MC-800	12	100	95	84	78	66	56	49	42	30	13	4.9
RT-6	8	100	94	83	78	65	56	49	41	31	18	5.9
CSS-1	8	100	94	81	75	62	52	42	35	23	9.7	5.1
AE-1S	9	100	96	86	79	65	54	45	35	19	9.4	5.5
Grand Average	46	100	95	85	79	66	56	48	40	27	12	5.4

AE-1S

The AE-1S coated the soil-aggregate uniformly, could be compacted shortly after stabilizing, and was shaped with the motor grader easily. It, like CSS-1, also plugged the nozzles on the mixer. Marshall tests (Table 4) show reasonable stabilities. Table 5 shows that the bitumen oxidized to penetration grade within nine months in the pavements. Table 6 shows the AE-1S did not soften the shoulder mixture.

DISCUSSION

Mixed-in-place bituminous stabilization of soil-aggregates is not a new process. Some Michigan counties have successfully used mixed-in-place stabilization for years as an economical means of improving existing roads. Therefore, knowing that bituminous stabilization has proven worthwhile, the objectives of this study are to evaluate the efficiency of each admixture; whether shoulders can be reconstructed economically and with minimal interference of traffic flow; and which construction procedures are important to insure a desirable product.

Reith-Riley, although having extensive experience in many phases of bituminous construction, has done relatively little work with mixed-in-place stabilization. The P & H Stabilizer was not owned by Reith-Riley but was rented, together with operators, for this project. Therefore, without casting disparagement on the capabilities of Reith-Riley it does appear that there would have been fewer problems if the project had been constructed by a contractor with more background using mixed-in-place stabilization. For example, as mentioned earlier, a belt drive assembly on the P & H Stabilizer protruded out too far to permit use of the equipment in areas where guardrail paralleled the pavement or where bridge abutments were close to the pavement edge. According to a contractor who owns such equipment, the belt drive assembly can be transferred to the opposite side of the unit and would then overhang the pavement permitting use of the Stabilizer in areas where the width of the unit was critical.

Some problems can be precluded from future jobs by modifying specifications. Two of the most important modifications involve requiring more mixing of the soil to evaporate volatiles and a requirement that mixing tines or paddles be used on all mixing equipment. On the I 75 project, more restrictive specifications could have resulted in better mixing in areas where the small mixer was used.

Because of its long curing time, it appears that slow-curing asphalt should not be permitted on future shoulder stabilization. Although tar was very unpopular with equipment operators, it was easily mixed into the soil and was easily compacted into a stable mass. Therefore, it should be permitted as an option. Use of the MC-800 presented few problems and should also be considered for future use, except where excessive natural water is likely to be a problem. In such cases, asphalt emulsions should be the choice. If the soil is electropositive (such as limestone), anionic emulsion is preferable while for electronegative soils (such as silicon sand) cationic is preferable (1,2). Probably in the majority of cases, anionic would be the choice because of its lower cost and because most Michigan aggregates contain varying proportions of limestone. One additional benefit of emulsions is their rapid curing time as compared to liquid asphalts (2). Rapid curing time with the related increase in strength appears to be a great advantage for mixed-in-place projects where a mat will be placed shortly after mixing and compacting the aggregate. Also, emulsion can be applied at, or close to ambient temperatures whereas cutback asphalt must be applied hot.

Caution should be exercised in specifying cationic emulsions. Anionic emulsions have been used predominately by Michigan's contractors and their storage tanks probably will not be entirely empty of the material when new bitumen is added. If cationic asphalt would be poured into a tank containing leftover anionic emulsion, the two materials will neutralize each other and the asphalt and water will separate.

As pointed out previously, the emulsions specified for this project were AE-1S (anionic) and CSS-1 (cationic). Since AE-1S contains liquid asphalt and CSS-1 contains penetration grade asphalt, no comparison could be made of the relative effects of particle charge.

On this project, the unit price for shoulder stabilization was $0.20 per sq yd plus the cost of asphalt (or tar). If a 4 percent (residue) is required, cost of asphalt would probably be about $0.60 - 0.90 per sq yd, for a total cost for stabilization of about $0.80 to $1.10 per sq yd. In comparison, the cost based on current unit prices for excavating material and replacing with aggregate for conventionally paved shoulders would be about $0.50 per sq yd for earth excavation and $1.06 per sq yd for replacing and compacting the shoulder base. This is a total of about $1.56 per sq yd for replacing existing aggregate. Thus, replacing shoulder base costs about 1.4 to 2 times as much as to stabilize existing material with bituminous. In addition, traffic hazards are increased by trucks hauling to and from the site as the shoulder base is replaced. Finally, the bituminous stabilized mix should provide a more stable base.

In summary, mixed-in-place stabilization appears to be an economical and efficient means of improving existing shoulders and existing bituminous pavements.

The upgrading of existing shoulders or pavements need not be restricted only to those without paved surfaces. Some Michigan counties have inexpensively rebuilt existing bituminous roadways through contracts requiring initial scarifying to a specified depth, pulverizing the existing bituminous surface with a traveling hammer-mill, followed by a mixed-in-place stabilization operation such as used on this shoulder project. The existing bituminous material is re-used as it is mixed in with the underlying base. By that process, lesser quantities of new bitumen must be added than if the existing material consisted only of soil-aggregate. Also, aggregates of lesser quality than those encountered on the I 75 shoulders have successfully been bituminous stabilized to upgrade county roads.

CONCLUSIONS

1. As demonstrated on this project, equipment and methods are available for quickly and economically upgrading existing shoulders through mixed-in-place stabilization using bituminous admixtures.

2. Upgrading shoulder base by excavating existing material and replacing with soil-aggregate base to meet current standards would cost about 1.4 to 2 times as much as mixed-in-place bituminous stabilization.

3. Mixed-in-place bituminous stabilization causes minimal traffic safety hazards since material is not excavated to cause a dangerous drop-off at the pavement edge. Further, if shoulders are upgraded by removing and replacing existing material, the trucks used hauling material to and from the site would create a significant hazard.

4. For ease of construction, asphalt emulsions and MC-800 appear to be the choice. Because of ease of use and versatility, emulsions would probably be a better choice over a broader range of conditions. MC-800 could be used except when excess moisture is present in the aggregate. Tar should be permitted but will probably never be used because of high cost and irritation to the skin of those handling it. In congested areas, it would also irritate the skin of passersby.

5. Because of lower cost, suitability of Michigan aggregates, and because Michigan contractors storage facilities already contain anionic emulsion and would react unfavorably if cationic emulsion were added, the choice between emulsions would probably be weighted in favor of anionic.

6. SC-800A should not be permitted because its cut-back agent which is almost non-volatile extends the curing time too long.

7. No evaluation could be made of the relative benefits of cationic and anionic emulsions since the particular ones used on this project each contained a different type of asphalt base.

8. Specifications should be modified to require sufficient aeration of volatiles.

9. Since it is so economical, mixed-in-place stabilization should be considered for upgrading bituminous pavements.

10. Stabilizing soil-aggregates of lesser quality than those on the I 75 shoulder project has been successfully done in the past on county roads and should be considered on state projects.

11. On the basis of existing knowledge, additional mixed-in-place stabilization projects can be carried out. However, this research study has called attention to certain areas where improved methods could be developed with very little additional research. These areas of suggested research are described in the Appendix.

REFERENCES

1. Merten, E. W. and Wright, J. R., "Cationic Asphalt Emulsions: How They Differ from Conventional Emulsions in Theory and Practice," Highway Research Board Proceedings, Volume 38, 1959.

2. Borgfeldt, M. J. and Ferm, R. L. "Cationic Mixing-Grade Asphalt Emulsions," Highway Research Board Proceedings, Volume 41, 1962.

APPENDIX

Additional Suggested Research

Many problems were encountered in reconstructing the shoulders on the I 75 project because adequate specifications and quantitative guidance were not available. Research Project 69 F-111 was a performance evaluation and, as such, disclosed that additional information must be provided if the Department is to effectively use mixed-in-place bituminous stabilization. Therefore, additional research should be conducted to develop appropriate specifications and quantitative guides for mixed-in-place bituminous stabilization. For efficiency the study should be limited to bituminous admixtures only and specifications should be ready for use in the 1972 construction contracts.

Conventional shoulders should be assumed adequate and our goal should be to approach or exceed their stability using mixed-in-place materials.

The research proposal should include:

1. A survey and summary of current knowledge as determined from existing literature.

2. Rationale for deciding what physical characteristics are critical to shoulder base performance; such as shear strength or ability to resist load deflection, and appropriate laboratory tests should be selected to measure and compare these critical physical characteristics. Also, the physical characteristics should be related, if possible, to such common tests as Marshall Stability or Hveem Stabilometer so they might be made routinely by the Testing Laboratory as operational measurements.

3. Provision for evaluating the effect of bituminous admixtures on the critical physical properties of potential base course material. Also, other contributions of the admixture, such as waterproofing, should be considered.

4. Provision for determining which soils may feasibly be stabilized using the mixed-in-place bituminous method, giving specific limits for influential properties such as gradation and plasticity.

5. Provision for developing methods for operationally determining which bituminous materials are most suitable under the various conditions to be found such as:

a. soil type
b. existing moisture or drainage condition

c. ambient temperature
d. humidity
e. sensitivity to particle charge
f. curing time.

6. Provision for determining optimum bituminous content and how it might be measured routinely.

7. Provision for determining tolerable or desired moisture content.

8. Provision for developing standard specifications.

It may appear that attainment of the long preceding list of goals in a short period of time is not likely. However, mixed-in-place bituminous stabilization has been used by Michigan county road agencies for many years and much research has been carried out internationally. Therefore, by supplementing existing information with tests conducted in accordance with efficient, statistically designed experiments, this study could be completed within the desired time.