DEPARTMENT OF SOILS, GEOLOGY AND FOUNDATIONS

Use of Foamed Asphalt in Soil Stabilization

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• THE VAST NETWORK of 2½ million miles of secondary and local roads in the U.S. carries only about 15 percent of the total traffic. Yet there is a definite need for these roads and an ever present clamor for their improvement. Their low usage, however, does not justify a high per mile construction expenditure. Thus, a large proportion of this mileage consists of a grade at minimum standards covered with a thin layer of gravel or crushed stone.

The maintenance and renewal of this surface material is a costly operation. Recognizing this and the constant depletion of available aggregate sources, many agencies have embarked upon programs of research and development of methods to stabilize soils for road construction.

The concept of soil stabilization involves the improvement of the physical properties of the local soil by some means so that the resulting layer can withstand the action of weather and traffic. Many materials have been tried to accomplish this result, and many miles of sound, durable bases have been built. Because of their waterproofing and binding properties and ready availability in most areas of the U.S., bituminous materials constitute one group of materials widely used in soil stabilization.

These bituminous materials include cutback asphalts and asphalt emulsions, which have been applied to soil stabilization because of their low viscosities and their wetting ability, sometimes in conjunction with wetting agents, when applied to cold, damp soil materials and aggregates. Asphalt cements have been practically excluded. When cutbacks and emulsions have been properly handled, excellent stabilized layers have been built with some soils. However, certain types of soils lend themselves to bituminous treatment using available techniques much more readily than do others.

Generally, granular soils having low clay contents have produced the best results. Attempts to stabilize fine-grained soils of high clay contents, which abound in many regions, have been attended by serious difficulties. One of these is securing a uniform distribution of the asphaltic material, even when the lightest cutbacks and thinest emulsions have been tried. But the most serious problem has been the proper control of aeration and compaction of the mixtures. The detrimental effects of trapping excess amounts of solvent or moisture in the compacted layer need no explanation. The difficulties of aerating or "farming" a layer in inclement weather are obvious. Proper compaction cannot be attained under these conditions.

A method of bituminous soil stabilization which could be applied to fine-grained soils and which could overcome the difficulties noted above, would find wide application. The binder must have low viscosity to permit thorough mixing, yet must have no undesirable residual moisture or solvent after mixing. These properties would also allow immediate compaction after mixing. A method of applying asphalt cement in the form of a foam to local aggregates and in soil stabilization was developed by Csanyi (*1*).

The properties of a foamed asphalt cement include low viscosity and appropriate surface tension, which are necessary for coating fine grained soils. Very little moisture is required to produce a foamed asphalt .When the foam bubble collapses in coating a mineral particle, the entrapped moisture vapor escapes and the residual asphalt cement rapidly regains its original properties. Compaction can then be carried out immediately after mixing and spreading. In the early stabilization work reported by Csanyi (*1*), the results of small test sections of stabilized soil bases constructed using the foam process showed considerable promise. These early sections have withstood a year and a half of Iowa weather and traffic comparable to a secondary road.

The success of the early work led to continuation of a project to carry forward this phase of the application of the foamed asphalt process. The project, conducted by the Bituminous Research Laboratory of Iowa State College under Project Number 347-S, was sponsored by the Iowa Highway Research Board. The project included provisions for larger field test sections and complete testing of field-produced stabilized soil mixtures.

The field test sections were constructed on a typical county road running along the north edge of Ames, Iowa (Fig. 1). This project runs approximately ½ mi from US 69 west to another county road parallel to US 69. Actual operations were carried out from the west right-of-way line of US 69 to the east right-of-way line of the county road, a distance of 2,541 ft.

This road runs along the edge of a rapidly expanding area of Ames. The area on the north side of the road is to be annexed to the city at an early date. Considerable traffic bound for Iowa State College from the north uses this road. The traffic count is approximately 160 vehicles per day.

The cross-section of this road is typical of many miles of secondary and local roads (Fig. 1). The top is about 22 ft wide. Ditches vary from 4 to 6 ft in depth and are roughly flat-bottomed. The fairly steep side slopes and back slopes com-

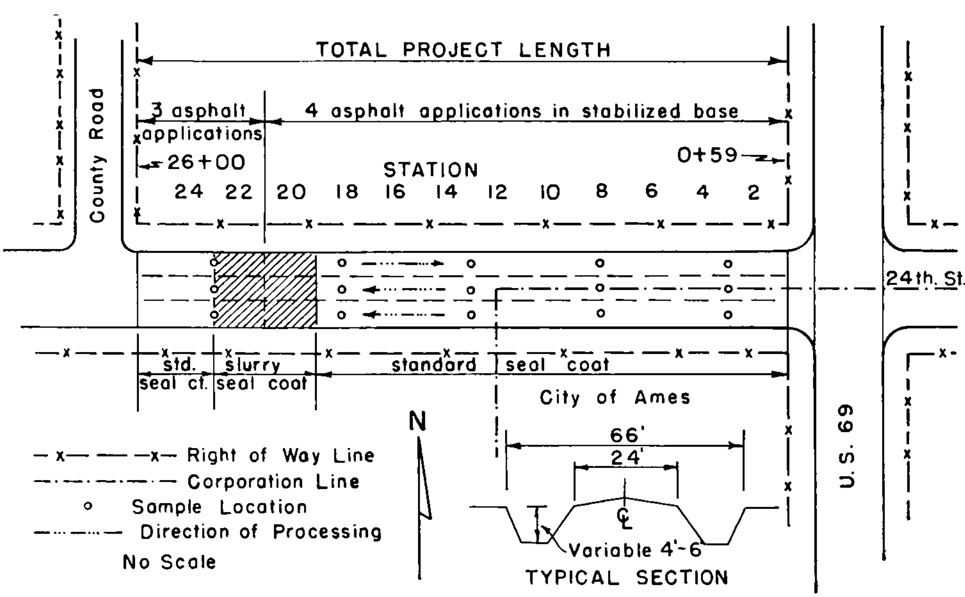

Figure 1. Location of test road, showing sample locations, processing lanes, direction of operations, and types of seal coats.

plete the section to a total width of 66 ft from right-of-way to right-of-way line.

The road was graded by county forces in 1951. Grading operations consisted of moving material from ditches to roadbed in such a manner that very little if any, longitudinal distribution of the soil materials resulted. This was apparent from the appearance of the road before stabilization operations. The material appeared quite black in some areas, and yellow in others. There was some evidence of sandy lenses in other areas. Compaction during construction was that attained under construction equipment and sheeps foot rolling. When sufficient ditch material had been deposited on the roadbed, it was shaped with approximately a 4-in. crown. The surface was covered with a 2½-in. layer of gravel which was maintained periodically and redressed with additional gravel as required. When the present job was started in late July 1957, bare dirt was in evidence in the wheel tracks and some gravel had been windrowed by traffic action between the wheel tracks and along the edges. A motor grader was used to distribute this existing gravel uniformly over the surface. The resulting layer was about ¾ in. thick.

The principal piece of equipment used to process this test road was a Seaman-Andwall Pulvi-Mixer (Figs. 2 and 3). The machine was a standard model with an 8-ft wide mixing hood. It was equipped with attachments for applying foamed asphalt as described (*1*) with modifications.

A foamed asphalt spray bar was attached to the machine. In this test 12 nozzles were used on the spray bar. This

Figure 2. Foamed asphalt spray bar and steam and asphalt connections on mixer.

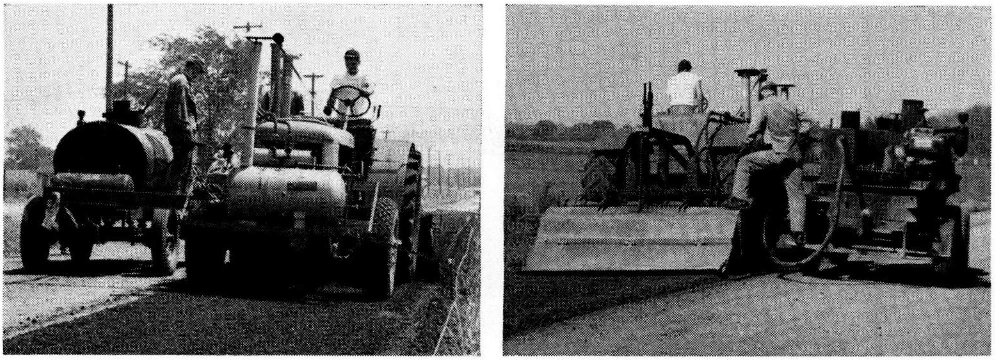

Figure 3. Mixer operating on foamed asphalt soil stabilization.

nozzle arrangement, at a height of 17 in. gave a uniform coverage of foamed asphalt over the road surface. The spray bar was positioned above and ahead of the rotor of the mixer. Due to limited space and the character of the spray bar, only 12 nozzles could be used, thus limiting the capacity of the machine.

Each nozzle was individually calibrated for both capacity and coverage area at different heights operating at different back pressures. An operating pressure of 20 to 25 lb asphalt and 40 lb saturated steam gave about a 7-in. diameter spread at a 17 in. height. The capacity of the nozzles operating under these conditions averages 3 gal per min. The spray bar was also equipped with an asphalt pressure gage.

A 60-gal portable oil-fired steam boiler was mounted on the front of the mixer for generating the necessary steam. One steam line led from the boiler to a manifold supplying steam to the spray bar jackets for heating purposes. A second steam line was connected to another manifold supplying steam to each of the foam nozzles (Fig. 2). Separate controls were provided at the operator's platform. The burner, fuel pump, and blower on the boiler were powered by a small electric generator set mounted on the running board.

An asphalt supply kettle was towed along side the mixer by means of an outrigger (Fig. 3). The kettle was a Littleford 450-gal elliptical tank, mounted on a 4-wheel heavy duty running gear. The kettle and pump were heated by 2 kerosene torches. The pump was equipped with a headtype relief valve which could be adjusted for any pressure up to 50 lb. The pump discharge was controlled by a cock valve for either circulation or application through a 2-in. flexible steel hose to the spray bar on the mixer.

Prior to the start of construction operations, the kettle was accurately calibrated and a graduated dipstick was provided for measuring the asphalt. The kettle was also provided with a 3-in. dial thermometer mounted so that the operator could read the temperature and quantity of the asphalt being applied at any time.

The other major item of equipment used on the project was a roller. A Duopactor for compacting the processed material and for rolling the surface was ballasted with about 8 tons of sand. The ballast tank is supported by a row of pneumatic rubber tires. The unit is also provided with a steel drum roll which is so mounted that it can be adjusted vertically from the driver's seat. Thus, all, part of, or none of the total weight can be carried by either pneumatic tires or a steel drum. The unit is powered by a 2-wheel prime mover (Fig. 4).

The other large items of equipment included a motor grader with scarifier loaned by the city and a motor grader loaned by the county.

The problem of handling materials was comparatively simple. Because of the promise shown in the earlier work, it was

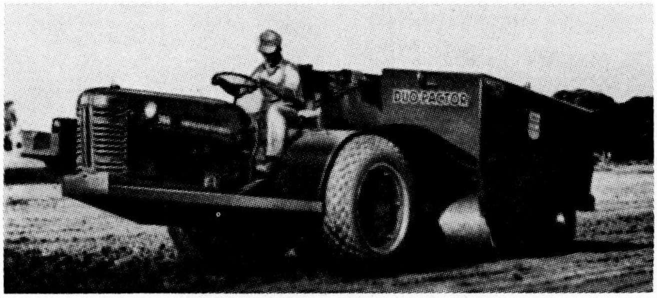

Figure 4. Roller used for compacting.

decided to add no mineral aggregate material of any type to this test section. Stabilization would be performed on the existing materials in the road. Therefore, only asphalt cement had to be procured, stored, and handled. The asphalt used was 100 to 120 penetration grade.

Construction of the test road proceeded with no difficulty. Due to the width of the machine, the ½-mi was divided into 3 processing lanes. Each lane was divided into 700-ft sections to meet the capacity of the asphalt kettle, forward operating speed of the mixer, and the asphalt content desired.

The entire surface was initially dressed with a motor grader to distribute uniformly whatever gravel remained on the road. The 700-ft section in the lane to be processed was then scarified. Several sections were scarified in advance of the processing operations.

Next, a pass was made for the addition of moisture. Only enough moisture was added to assist in breaking up clay lumps and to permit the foamed asphalt to penetrate the lumps. Because the character of the soil materials varied considerably from section to section, moisture was added as deemed necessary by observation. The equipment used to add moisture was a street flushing truck. On some sections containing sufficient moisture, none was added. On others, depending upon the moisture contained, about 2 to 3 percent was added. In all cases, the total moisture of the soil material was at or below optimum (Table 1).

TABLE 1

PHYSICAL PROPERTIES OF SOIL MATERIALS, LOOSE, BLENDED, DEPTH 6 INCHES IN BASE PRIOR TO ADDITION OF FOAMED ASPHALT

Sample Station	Lane[1]	Gradation (% passing) 4	10	40	80	200	5μ	1μ	Atterberg Limits LL	PL	PI	Proctor Test Max Density Dry	Opt Moisture	BPR Class.	Field Moisture	Specific Gravity
3 + 00	S	83	75	66	56	48	25	21	33	17	16	112	13	A-6(5)	13	2.51
	C	82	77	69	58	49	—	—	35	19	16	114	15	A-6(5)	14	2.50
	N	83	77	66	52	41	—	—	27	17	10	125	11	A-4(1)	8	2.55
8 + 00	S	92	89	78	63	49	—	—	23	17	6	117	11	A-4(3)	10	2.55
	C	92	88	78	63	48	—	—	24	15	9	114	15	A-4(3)	12	2.55
	N	89	87	79	65	55	26	17	34	23	11	111	15	A-6(5)	13	2.53
13 + 00	S	93	91	86	77	69	38	25	39	24	15	97	21	A-6(9)	17	2.42
	C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N	89	85	68	54	43	—	—	27	17	10	105	18	A-4(2)	8	2.53
18 + 00	S	91	88	77	61	48	—	—	30	17	13	114	12	A-6(4)	9	2.53
	C	74	68	58	46	37	17	12	28	21	7	119	12	A-4(1)	11	2.51
	N	98	95	85	68	56	—	—	31	18	13	105	17	A-6(5)	15	2.46
23 + 00	S	89	86	74	58	45	—	—	25	17	8	122	12	A-4(2)	12	2.58
	C	69	56	42	31	23	11	9	22	16	6	131	8	A-2-4(0)	8	2.65
	N	93	90	81	66	55	—	—	31	20	11	106	17	A-6(5)	12	2.50

[1] S = south lane; C = center lane; and N = north lane.

The next pass involved blending the scarified wetted material with the mixer. No asphalt was applied during this operation. The blending pass served to break up any lumps with the assistance of moisture and to distribute the existing gravel through the loose layer. Since a 4-in. compacted thickness was to be built, the depth of the blended loose material was about 6 in.

The next operation in the sequence was the actual addition of foamed asphalt. Since the slowest operating speed of the mixer was about 80 ft per min, and because of the number of nozzles and their capacity, 4 passes were required to add the desired quantity of foamed asphalt. Each pass was made over a 700 ft section followed immediately by successive passes until the desired quantity of asphalt had been added.

Since it was necessary to add the asphalt in 4 increments, some unevenness of the surface developed. To overcome this, the loose layer was dressed with a motor grader and a final blending pass was made with the mixer, followed immediately by rolling.

The rolling sequence started with 1 pass of the rubber tire roller. The next 2 to 3 passes were made using rubber and steel together. Weight distribution between the tires and the drum was adjusted by the operator to meet the changing degree of compaction. A final coverage on rubber tires alone completed the rolling sequence. Rolling completed the construction of a section.

Processing of a section proceeded while the previously processed section was being compacted. Traffic was maintained during these operations.

The first lane completed was on the south side. Work continued on the center lane and the north lane, completing the 21-ft width from station 0 + 59 to station 21 + 00.

Since the section from station 21 + 00 to station 26 + 00 was short (500-ft), it was decided to complete all the other sections and do this section last. As construction of the other sections of the road proceeded, the effects of construction operations and other traffic were observed on the completed base. The amount of foamed asphalt applied in 3 passes to the remaining 500-ft section was about 4 percent. All other operations on this section were carried out as previously described.

When processing of the entire ½ mile had been completed, some roughness of the surface due to the manner of construction, was noted. To overcome this, the entire surface was loosened with the mixer to a depth of about 1 in. This loose material was drifted over the surface with a motor grader and the surface was rerolled. Under full scale operations which permit the desired quantity of foamed asphalt to be introduced in a single pass, this surface dressing will not be necessary.

The finished stabilized base was then opened and the effects of weather and traffic on the unsealed surface were observed. Although showers fell and 160 vehicles per day used the road, no softening or base weaknesses were noted. Some scuffing of the surface was observed. This was not serious, but it was advisable to apply a seal coat to prevent excessive wear.

Two types of seals were used on this road. A cold bituminous slurry, manufactured under the Schlämme process (*2*) was laid from station 19 + 00 to 23 + 00. This slurry was plant mixed and hauled to the site. The consistency was adjusted and the slurry laid in 2 lifts totaling ¼ in. in thickness. The remaining surface of the entire test road was sealed with 0.2 gal. per sq yd of 100 to 120 penetration grade asphalt cement and about 20 lb per sq yd of a buckshot gravel, ⅛-in. maximum size. A local contractor furnished and applied the standard seal coat materials. The seal coat was rolled. Four different combinations of base and seal were thus constructed (Fig. 1).

A detailed program of sampling and testing was included in this project. Five sampling stations were selected prior to construction on the basis of preliminary checks and visual inspection of the existing roadway. These were located at stations 3+00, 8+00, 13+00, 18+00, and 23+00 (Fig. 1). These locations were representative of the soil materials encountered in the various construction sections.

Samples were taken in each of the 3 processing lanes at the stations noted. Samples of the loose blended soil were taken before the addition of foamed asphalt. Also at this time, samples of the layer immediately below that being processed, designated "subbase," were secured in order to study the properties of the material upon which the stabilized layer rests.

In planning the sampling program, it was recognized that several successive applications of foamed asphalt would be required because of equipment limitations. This proved to be advantageous, however, since the effects of successive applications of asphalt could be studied and since samples could be secured after each application. In summary, samples were taken in each lane at each station after each of 4 processing passes, as well as samples of the loose, blended material and the subbase material. The exception is station 23+00 where only 3 applications of foamed asphalt were used.

All samples were placed into sealed air-tight containers and taken to the laboratory where moisture contents were immediately determined. Other tests were delayed about 2 weeks due to other work being carried on in the laboratory. This delay was not serious, since the samples were in sealed containers.

Test results of the loose blended soil material before the addition of foamed asphalt are shown in Table 1. Generally, the materials are fine grained and fall mainly in the Bureau of Public Roads class of A-4 and A-6, with the exceptions shown. Some variations of test results are noted for the 3 samples secured across a given sample station. This lateral variation is partially due to the original construction techniques used to build the grade. Since material was moved laterally from the ditches to the road bed, these variations are logical. Also, traffic over the years may have contributed to these differences. On roads of this type, drivers tend to operate their vehicles in the center portion, swinging to the right only for oncoming traffic. This produces more degradation of particles in the center of the roadway.

The particle size distribution down to the No. 200 sieve (Table 1) represents a washed sieve analysis, while the clay fractions, 5 microns (μ) and 1 μ, represent the results of the hydrometer method. Because of the large number of samples, hydrometer analyses were run only on one sample from each station as indicated. The Atterberg limits were run on all samples as indicated and the plasticity indexes varied from 6 to 16. Most of the soil materials had a PI above 10.

The Proctor density tests were run on all samples (Table 1). Field moisture contents, determined immediately after sampling, are given, and represent the moisture content of the section immediately before processing. The specific gravities of the soils are indicative of their character. Low gravities are due primarily to organic materials present in the soils, and the presence of organics may be explained again by the original grading operations. No attempt was made to remove top soil or to strip organic materials. All materials were removed from ditches and placed onto the roadbed, hence the organic material.

Test results of the subbase material are shown in Table 2. Sufficient tests were run to classify these materials and to evaluate their bearing capacity by CBR. It will be noted that the texture of these materials is somewhat finer than that of the loose, blended material overlaying the subbase. This is due to the lack of any granular material, used as the original surface layer, in the subbase layer.

The physical properties of the asphalt cement used on this project are shown in Table 3. The values in the table represent the results of tests performed in the Bituminous Research Laboratory and are in agreement with copies of the certified analysis of the material furnished with each load by the supplier.

TABLE 2
PHYSICAL PROPERTIES OF SOIL MATERIALS, SUBBASE

Sample Station	Lane	Gradation (% passing)							Atterberg Limits			Proctor Test		BPR Class.
		4	10	40	80	200	5μ	1μ	LL	PL	PI	Max Density	Opt Moisture	
3 + 00	S	100	99	94	84	75	—	—	31	17	14	100	20	A-6(10)
	C	98	97	89	77	67	31	24	33	18	15	106	19	A-6(8)
	N	98	95	86	72	60	—	—	31	15	16	109	14	A-6(7)
8 + 00	S	97	93	81	64	49	26	15	24	15	9	117	13	A-4(3)
	C	100	99	91	76	65	—	—	36	24	12	99	19	A-6(7)
	N	100	99	92	79	70	—	—	35	23	12	98	22	A-6(8)
13 + 00	S	100	99	94	86	79	43	32	47	22	24	94	26	A-7-6(15)
	C	—	—	—	—	—	—	—	—	—	—	—	—	—
	N	100	100	95	84	74	—	—	40	24	16	88	23	A-6(10)
18 + 00	S	93	92	83	65	51	—	—	29	17	12	112	11	A-6(4)
	C	99	98	91	74	59	—	—	33	22	11	104	18	A-6(5)
	N	100	99	91	75	61	31	18	32	19	13	101	21	A-6(6)
23 + 00	S	96	91	80	64	51	—	—	25	18	7	119	12	A-4(3)
	C	93	91	82	67	56	—	—	28	19	9	112	15	A-4(4)
	N	100	99	90	72	61	—	—	24	16	8	101	21	A-4(5)

Results of tests on soil materials containing various percentages of foamed asphalt are shown in Table 4. The percents of asphalt as shown were calculated from the length, width, depth, and maximum dry density of the soil being processed in the section noted. Other factors used in these calculations were the measured volume, in gallons, of the asphalt applied at the temperature noted on the section being processed. Observed volumes were corrected for temperature and transposed to weights. The reported percentages of asphalt are based on the dry weight of soil being processed.

The field moisture contents were determined on samples secured immediately after each application of asphalt. The moisture content of the last application also represents the moisture content at which the processed soil material was compacted.

Table 4 shows the results of the Hveem tests performed on samples from various locations. In addition to the Hveem tests, Marshall tests and CBR tests were run on all samples. Although the Marshall test and CBR test results were not conclusive, they were indicative of the effects of adding foamed asphalt to these soil materials.

TABLE 3
PHYSICAL PROPERTIES OF ASPHALT CEMENT

Softening point, F	113
Penetration, 100 g, 5 sec, 77 F	126
Specific gravity, 60 F	1.015
Soluble in CCl_4, %	99.96
Flash point, F	590

Marshall specimens were prepared with a dynamic compactive effort applied through 50 blows of a 10-lb hammer falling 18 in. onto each side of the specimen. Moisture contents at the time of specimen preparation were the same as field moisture contents reported in Table 4. The specimens were stored at room temperature for 24 hr, then submerged in a water bath at a temperature of 140 F. Then the stability test was performed. Some of the specimens prepared from material which received 4 applications of foamed asphalt exhibited Marshall stability values up to 420 lb, with most results in the 350- to 400-lb range. Specimens which withstood the submersion for one hour at 140 F were generally made from samples of material secured after the final application of foamed asphalt, although a few specimens containing less asphalt were tested. Usually, however, Marshall specimens made from material containing lesser amounts of asphalt showed considerable distress during submersion and could not be tested.

CBR test results, while not conclusive, also indicated a trend in the effect of adding foamed asphalt to these soil materials. CBR specimens made from the material prior to processing showed CBR test results varying in the range of 1 to 5.

TABLE 4

PROPERTIES OF SOIL MATERIALS AFTER ADDITION OF FOAMED ASPHALT

Sample Station	Lane	Asphalt (% by stick meas.)	Field Moisture Content	Hveem Test Results: Stabilometer R Value	Hveem Test Results: Cohesiometer C Value
3 + 00	S	0.0	13.1	95	566
		1.6	14.0	90	479
		3.0	13.8	84	588
		4.5	11.3	92	523
		5.9	10.9	92	515
3 + 00	C	0.0	13.6	81	622
		1.3	13.6	—	—
		2.5	11.6	—	—
		3.8	13.5	—	—
		5.0	12.4	—	—
3 + 00	N	0.0	7.6	93	495
		1.1	8.0	90	391
		2.2	8.7	56	443
		3.4	8.7	74	267
		4.6	7.9	83	355
8 + 00	S	0.0	10.0	77	627
		1.6	11.6	90	405
		3.1	9.7	92	203
		4.5	10.2	88	391
		5.9	8.4	91	400
8 + 00	C	0.0	12.4	90	558
		1.1	10.0	—	—
		2.1	10.7	79	440
		3.5	9.3	89	—
		4.6	9.8	91	383
8 + 00	N	0.0	12.6	48	553
		1.3	10.1	81	334
		2.6	10.0	80	330
		3.9	9.5	74	367
		5.2	8.5	55	260
13 + 00	S	0.0	16.8	53	408
		1.6	15.7	92	455
		3.3	15.6	44	299
		4.9	13.9	88	424
		6.4	15.4	82	358
13 + 00	C	—	—	—	—
13 + 00	N	0.0	7.9	93	487
		1.4	10.8	71	367
		2.8	9.4	75	432
		4.2	9.0	81	404
		5.4	8.3	83	454
18 + 00	S	0.0	8.9	94	587
		1.4	7.1	93	630
		2.7	7.6	94	543
		4.0	7.3	93	252
		5.2	7.6	—	—
18 + 00	C	0.0	11.0	71	481
		1.4	10.7	64	—
		2.6	9.2	91	—
		3.9	8.6	89	493
		5.3	8.6	—	—
18 + 00	N	0.0	15.0	78	482
		1.7	13.7	—	—
		3.0	13.7	—	—
		4.5	13.5	—	—
		5.7	12.0	—	—
23 + 00	S	0.0	12.4	56	531
		1.3	11.6	—	—
		2.2	11.5	—	—
		3.4	12.4	—	—
23 + 00	C	0.0	7.6	89	513
		1.1	8.7	—	—
		2.3	7.6	88	—
		3.4	7.7	92	—
23 + 00	N	0.0	11.5	92	450
		1.2	13.6	73	307
		2.5	14.3	—	—
		3.7	15.0	—	—

CBR tests of specimens containing increasing amounts of foamed asphalt varied generally from 8 to 15 with a number of specimens exhibiting results as high as 20 to 23.

There was, for a given set of samples, a slight decrease of CBR as the asphalt content increased, although the CBR at all percents of asphalt was much improved over the unprocessed soil. The decrease is due primarily to the distribution of asphalt obtained by the processing sequence used. As mentioned previously, the desired asphalt content was secured by several successive applications. During the first application, a single given soil particle may be coated by the foamed asphalt. However, due to the low rate of application, many particles remained uncoated after the first pass. Then during the second pass, more particles were coated, but there was also a strong possibility of previously coated particles receiving a second coat. Thus in 4 successive applications, a single particle might receive 4 coatings of asphalt, whereas another particle might remain uncoated. This effect was observed during construction; occasional lumps appeared to contain excess asphalt, but there was some uncoated material. In the CBR specimens, the adjacent uncoated particles formed avenues through which moisture could penetrate into the specimen, causing the observed decrease in CBR value. The distress shown by submerged Marshall specimens was also due to these moisture avenues. This condition can be overcome by adding the desired quantity of foamed asphalt in a single application. In a single processing pass many more particles would receive a single coat, and the possibility of any particle receiving more than one coat would be very slight.

Hveem stabilometer tests (*3*) were performed and the results are shown in Table 4 and in Figures 5, 6, and 7. The reported stabilometer R values were calculated by the following formula:

$$R = 100 - \frac{100}{\frac{2.5}{D}\left(\frac{Pv}{Ph} - 1\right) + 1}$$

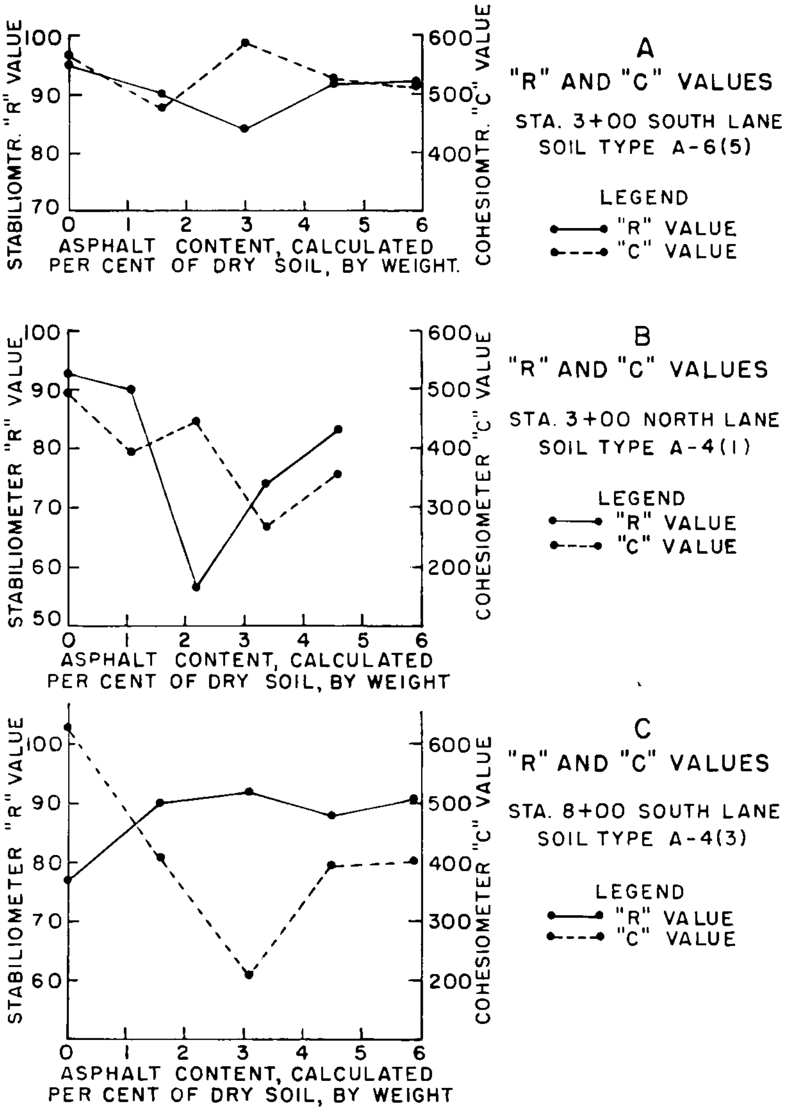

Figure 5.

in which

Pv = 160 psi;
Ph = observed lateral pressure at Pv = 160 psi; and
D = turns displacement.

Hveem specimens prepared from material containing various amounts of foamed asphalt were compacted at the field moisture contents shown. Specimens made from soil materials before the addition of foamed asphalt were also compacted at field moisture contents.

Low Hveem R values could be expected for the unprocessed soil, since it is recommended that the Hveem test be run on soil near saturation. However, the processed materials were compacted in the road at the moisture contents shown and then sealed with a thin seal. Thus the

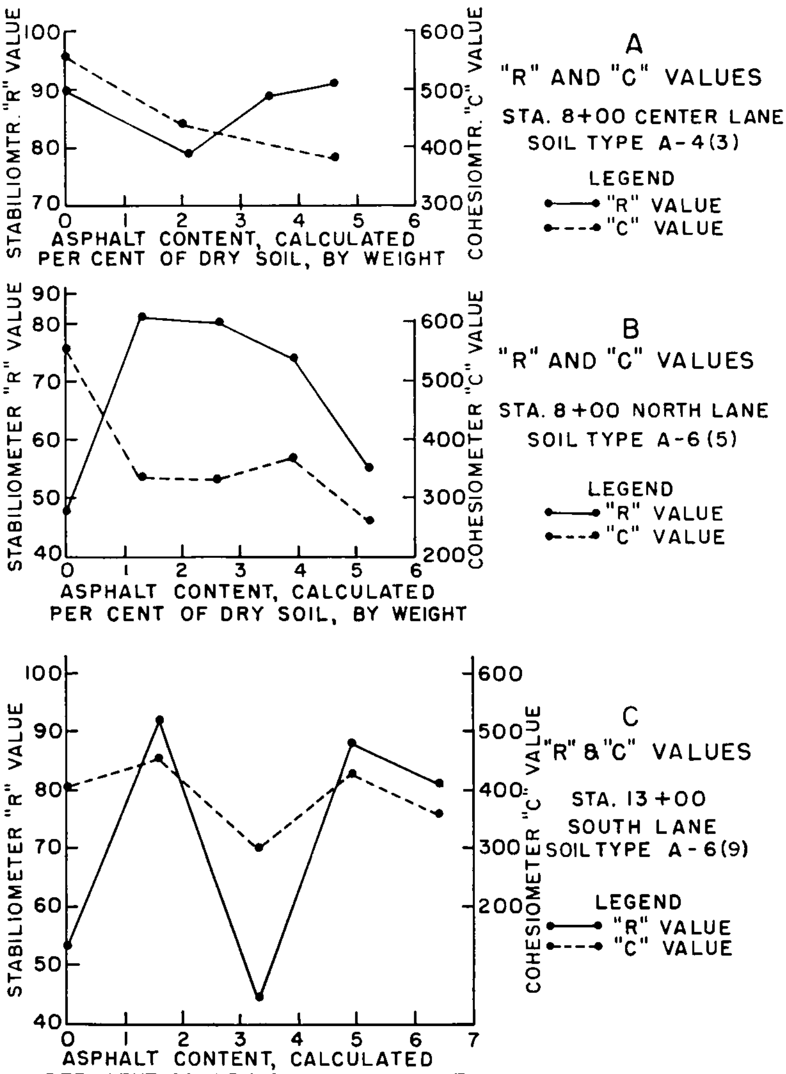

Figure 6.

material as compacted must support traffic loads. Field moisture content, therefore, was the logical and uniform basis for evaluating the test results. All Hveem specimens were prepared at field moisture content in a kneading compactor according to the California method.

The curves (Figs. 5, 6, and 7) generally show an improvement in Hveem stabilometer R values at asphalt contents above 2 percent. The exceptions are Figures 6B and 6C. Figure 6B shows a drop in R value for the final increment of asphalt. This may be largely due to the known presence of uncoated particles. Also, the field samples were placed into sealed containers, but there was a delay between sampling and testing. To be absolutely certain that field moisture contents were maintained during the testing sequence, the moisture content of each sample was again determined immediately before preparation of Hveem specimens. In most cases moisture contents were within 1 percent of that determined after processing. However, some samples lost moisture due to ruptured seals or other causes. Those samples were restored to original field moisture by adding a calculated amount of moisture to the sample. The particular sample represented as the point for the last increment of asphalt (Fig. 6B) showed a moisture loss of 2.5 percent. Thus the amount of moisture added back to this sample was greater than the usual amount, since the few samples which did show a moisture loss were only 1 to 1½ percent below field moisture. Any coarser aggregate in the moisture sample would reflect a lower moisture content. If such an unknown error is present, and the calculated amount of moisture is added to the sample, then the final moisture content of the resulting stabilometer specimens would be higher than the moisture content of the field sample. This combination of excess moisture and the presence of uncoated particles in the test specimen would result in a low R value for the specimen.

In Figure 6C, the R value for the samples containing 3.3 percent asphalt is obviously low. In addition to the factors discussed above, which tend to produce erratic results, the parent soil material at this location exhibited the highest clay content of all soils encountered through-

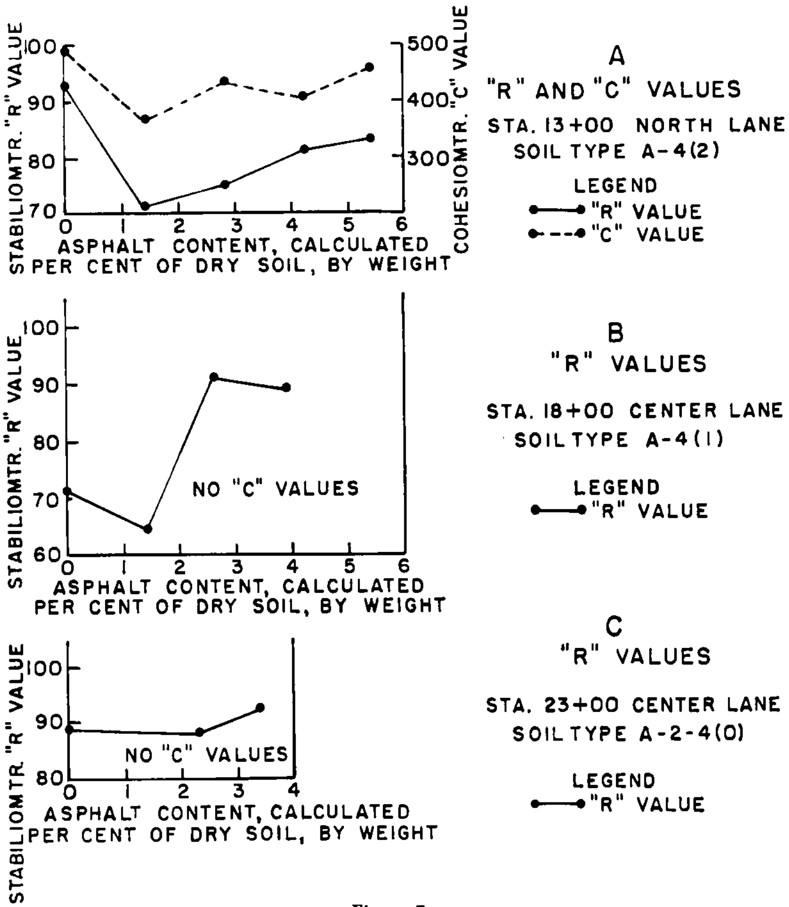

Figure 7.

out the ½-mi project. Thus there was a greater opportunity for uncoated particles and for discrepancies in the test results.

The Hveem R values at 0 percent asphalt, that is, the soil material before processing, were generally high. This was expected since specimens were compacted at field moisture contents. These field moistures were usually in the range of 3 to 6 percent below calculated saturation moisture content. The standard Hveem method (*3*) for soils recommends that the material be tested near saturation. Had this procedure been followed, lower R values for the unprocessed soil would have resulted, since an inverse relationship between R value and moisture content at time of compaction exists for soil materials.

It is felt that the soil-moisture combination controls the system up to asphalt contents of about 2 percent. Generally, at about 2 to 3 percent asphalt, or on this project after 2 passes of the processing equipment, the effects of adding foamed asphalt appear as improvements in R values for increasing amounts of asphalt, with the isolated exceptions noted. The trend in this direction was observed through the Marshall and CBR testing sequence as well as in the field at the time of construction.

R values of specimens prepared from material after 4 processing passes vary in the range of 80 to 92, with the exception noted. This variation is due partly to differences in the soil materials encountered and partly to slight differences in asphalt content because of operating speed and temperature variations. These variations do not appear to be serious since the range is high.

The cohesiometer test results, where available, are also reported in Table 4 and in Figures 5, 6, and 7. These results are C values derived from cohesiometer readings corrected for specimen height. The C values represent a combination of the effects of the cohesive soil and of the asphalt cement added to the system. It is generally confirmed that materials exhibiting high C values in combination with high R values can withstand the pounding of heavy traffic volumes, if these high values can be maintained.

Freeze-thaw tests were conducted on specimens of the compacted materials. Specimens containing no asphalt showed severe distress during the first cycle. Generally, increasing amounts of asphalt resulted in improved resistance to freezing and thawing. Many of the specimens made from samples secured after the final asphalt pass withstood 3 freeze-thaw cycles with no distress. Minor surface scaling, although not detrimental to the over-all structure of the specimen, does introduce errors in freeze-thaw measurements and calculations, due to slight losses of the material. Therefore, when such a condition appears, the test sequence is discontinued. Minor scaling after 3 freeze-thaw cycles indicates fairly good freeze-thaw resistance. It is also apparent that moisture avenues, present because of uncoated particles, will contribute to low freeze-thaw resistance. If more particles were coated uniformly, these materials would demonstrate even better resistance to freeze-thaw action.

The sealed pavement is being observed daily. The pavement has been presently under traffic for a period of 3 months through an unusually wet fall season. Continuing observation is contemplated as well as core sampling when spring weather permits.

Another aspect of this project has been the construction of a farm feed lot. There is a pressing demand for low-cost feed lot pavements in this area. The applicability of the foamed asphalt stabilization process to this type of construction was, therefore, investigated.

The feed lot test section is located on the Iowa State College campus. It is a 21- by 100-ft section situated between a beef cattle barn and a feeding bunker.

The soft and poorly drained surface was composed mostly of barnyard refuse. It was badly cut up by hoof action. The surface was dressed with a light layer of power plant cinders to overcome roughness and to adjust surface drainage. This cinder layer was, on the average, 1 to 2

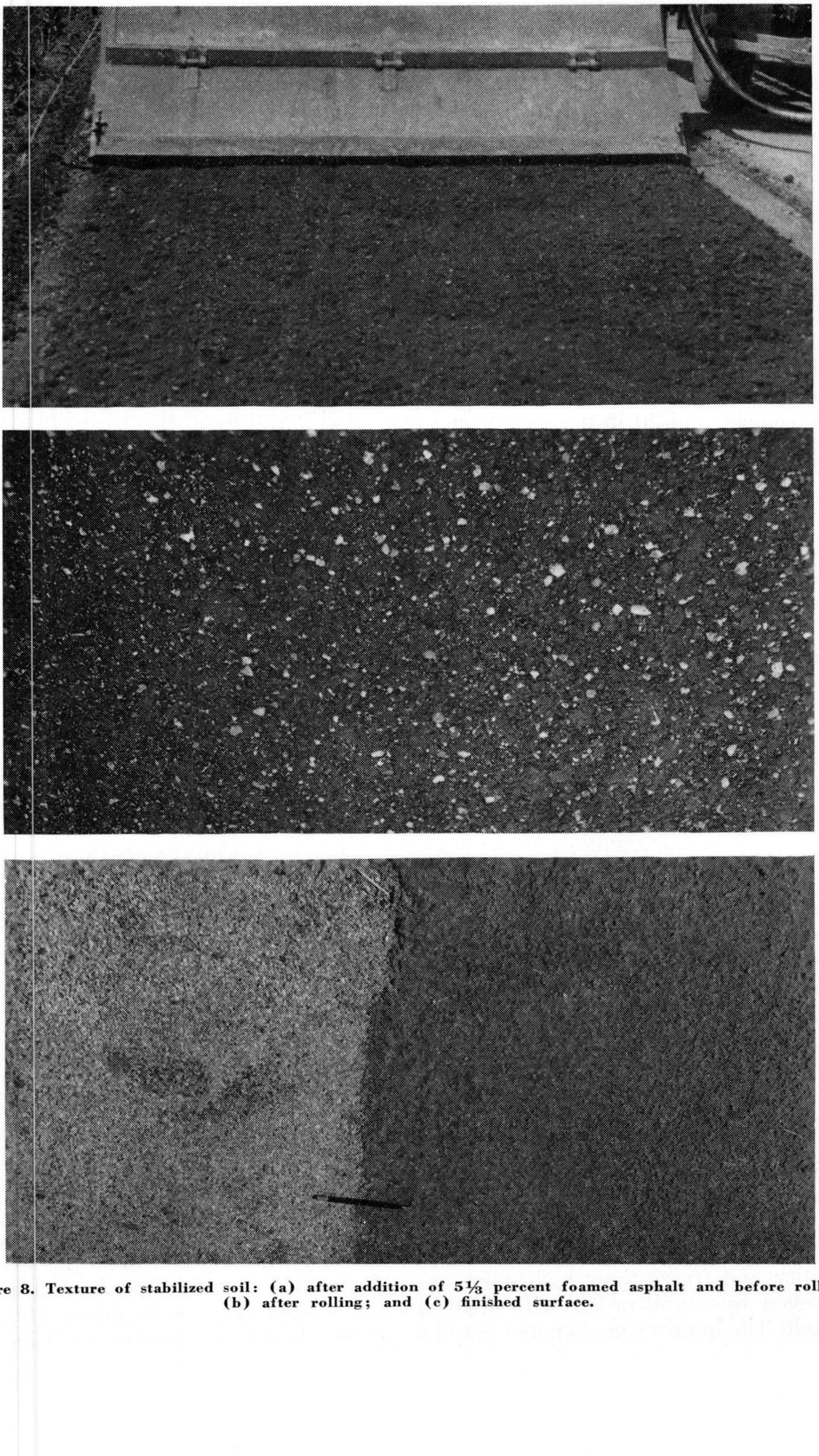

Figure 8. Texture of stabilized soil: (a) after addition of 5⅓ percent foamed asphalt and before rolling; (b) after rolling; and (c) finished surface.

in. thick in a loose condition, but varied to meet the established drainage pattern.

The processing of this section was done in three 7-ft wide lanes. Processing involved a blending pass during which any cinders were blended through the material underneath for a total loose depth of about 6 in. The blending pass was followed by 4 passes during which foamed asphalt was introduced. Rolling followed immediately.

After a final trimming to finished grade, the surface was sealed. One-half the surface was sealed with a standard single layer seal composed of 0.2 gal per sq yd of 150 to 200 penetration grade asphalt cement and 20 lb per sq yd buckshot gravel. The other half was sealed with the cold bituminous slurry manufactured and laid according to the Schlämme process (*2*).

During processing, the animals were prevented from using the area because of the litter problems they created. However, the pavement was opened after sealing, and has been constantly exposed to weather and animal traffic for 2 months. The area is performing satisfactorily at present. Further observation and coring are contemplated for this feed lot pavement.

CONCLUSIONS

1. Through the use of properly designed and controlled equipment, asphalt cement in the form of a foam can coat fine-grained soil particles in a cold, damp condition. Coating can be accomplished on soils varying from A-2-4(0) to A-6(9).

2. When applied as an in-place soil stabilization method of mixing, the moisture content of the soil being processed should be controlled between the amount necessary to assist in breaking up agglomerations of soil particles and permit the foamed asphalt to penetrate lumps of soil, and optimum moisture content.

3. Physical properties of soils such as stability and freeze-thaw resistance, are improved by stabilization with foamed asphalt. The improvements noted may be attained without the addition of granular material or adjustment of particle size distribution.

4. Visual inspection at the time of construction and the test results indicate a desirable asphalt content of 6 percent for soils falling within the range encountered. To secure a uniform distribution of foamed asphalt with single coatings on individual soil particles, the desired quantity of asphalt should be introduced during a single processing pass. Other benefits, such as the prevention of distortion of the roadway shape, better control, and lower processing costs can be realized from a single pass operation.

5. Present methods of thickness design for flexible pavements indicate a 6-in. compacted thickness of stabilized material to be desirable.

6. The foamed asphalt process is commercially applicable, to in-place soil stabilization from aspects of costs, production rate, control of compaction, control of processing, and safety of operation. It was estimated that the cost of such stabilization would be about $1,000 per inch of depth per mile on a 22-ft wide road. Thus a 6-in. stabilization would cost about $6,000 per mi plus about $1,500 for a seal coat or a total of $7,500 per mile.

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