TABLE 8
SOIL GROUPS

Type No.	Retained No. 40 sieve	Coarse sand	Fine sand	Silt	Clay	Soil group and plasticity	Optimum moisture	Theoretical maximum density lb. per cu. ft.
	%	%	%	%	%		%	
1	30–40	65–80	6–12	6–14	10–14	A–1 and 2 F and P	14.0	116
2	25–35	65–80	10–16	8–14	14–25	A–2 VP to A–2 and 7 VP	14.5	115
3	30–40	65–80	6–12	3– 9	0–10	A–3 NP, A–1 to A–1 and 2 F	13.0	114
4	25–35	60–75	14–20	12–18	14–25	A–2 and 7 VP	14.5	118
5	40–50	75–80	8–10	6– 9	0– 5	A–1 to A–3 NP	16.5	114
6	40–45	75–80	7– 9	5– 9	6– 9	A–1 and 2 F and P	16.0	118
7	35–45	70–75	6–12	4– 8	10–13	A–1 and 2 P	16.0	119
8	0–15	35–50	25–45	8–12	10–16	A–1 and 2 P	14.5	115

NOTE: "F" Denotes "Friable"
"P" Denotes "Plastic"
"VP" Denotes "Very plastic"
"NP" Denotes "Non-plastic"

SINGLE MACHINE METHODS AND CONTROL OPERATIONS

BY R. R. LITEHISER AND H. E. BROOKS

The Ohio Department of Highways built its first soil-cement road during the summer of 1939. This road was 6 in. in depth, 18 ft. wide, on a 30-ft. roadway. A bituminous surface treatment was included in the contract. The soil-cement pavement was constructed with 8 per cent cement, except for a length of 1,000 ft. with 10 per cent.

The contractor elected to use a roadbuilding machine for the cutting, pulverizing, mixing, and hydrating of the soil and cement, and instead of the plows, cultivators, harrows and discs usually used as separate units for the mixing operation.

PRELIMINARY LABORATORY INVESTIGATION

A preliminary soil survey was made to determine the different soil types which would be encountered. Durability tests were then run to determine the percentage of cement required for each type of soil. Moisture density tests were also made to determine the maximum dry weight and optimum moisture content of soil-cement mixtures for each soil type. Additional samples were taken at intervals of 500 ft. along the center-line from the top 6 in. of the road, to determine the relocation by the grading operations of the various soil types, so that the correct percentage of cement would be used at each location.

PROCESSING

The roadbuilding machine cut, pulverized, mixed, and applied the water in one operation. The sequence of the processing operations was as follows: Scarifying, blading, spreading the cement, mixing and hydrating the soil and cement with the roadbuilding machine, rolling with sheepsfoot rollers, shaping with a

blade grader, smooth rolling, and curing with a moist straw cover.

The roadbuilding machine consisted of a track-type tractor upon which was mounted a box-like steel platform, the rear end containing two rapidly revolving cylinders to which were spirally attached four rows of hardened steel teeth. As the machine advanced these steel teeth cut into the roadway to a depth of six inches,

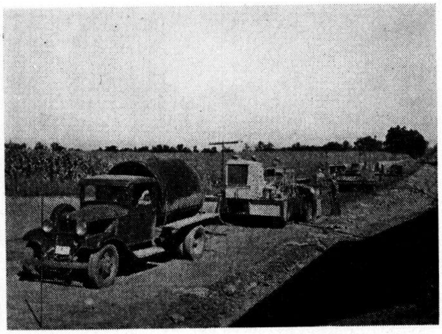

Figure 1. Tank truck supplying water to roadbuilding machine

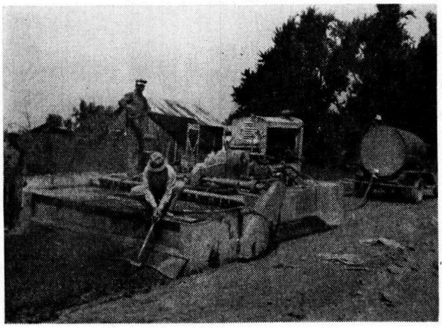

Figure 2. Rear view of roadbuilding machine showing taking of samples of mixture

picked up and pulverized the material, thoroughly mixed it with water and delivered it behind the machine as a level pulverized soil-cement mixture ready for the sheepsfoot roller. The roadbuilding machine processed one-half the width of the pavement at one time. By starting with an initial length of 500 ft., then returning and processing 1,000 ft. on the opposite side, it was possible to continue with staggered sections of 1,000 ft. throughout the day's run. This enabled the finishing operations to be started early and kept about 500 ft. behind the roadbuilding machine.

FIELD LABORATORY CONTROL

A portable field laboratory, mounted on a rebuilt truck chassis, was provided.

Soil samples from the portion of the road to be processed were taken shortly before work started, in order to determine the amount of moisture present and the quantity required to bring the processed soil-cement mixture to optimum moisture content.

With the usual procedure, using cultivators and discs for mixing the soil and cement, and tank trucks for the addition of the water, there is sufficient time to make an intermediate moisture determination, and to calculate the remaining amount of water necessary to obtain the optimum moisture content. However, when using the roadbuilding machine continual attention must be given to the proper addition of water to insure the optimum moisture content, since the very short time required for mixing makes intermediate moisture determinations impossible. It was therefore necessary to devise a method for a quick estimate of the condition of the soil-cement mixture at its optimum moisture content. This was done by vigorously squeezing the moist soil-cement mixture in the hand and noting the consistency. In the field laboratory, moisture determinations on samples of varying moisture content quickly established the proper consistency indicating optimum moisture.

Frequent tests made at the field laboratory for moisture in machine mixed samples, showed the inspector's estimate of optimum moisture content to be very good.

Samples of the machine mix, representative of the day's run, were taken at designated stations so that compaction tests could be made later at the same locations. The moisture content of these samples was determined at the field labo-

ratory and then several density determinations, with varying moisture content, were made on each sample. From these density determinations, partial moisture-density curves were prepared for each sample showing maximum dry weight and optimum moisture content.

Compaction tests of the finished soil-cement pavement were made at intervals of approximately 1,000 ft., at the same stations where the machine mixed samples had been obtained. The compaction tests were usually made the day after laying the pavement since the material was still somewhat soft. To observe the effect of hardening of the soil-cement, other compaction tests were made after seven days' curing and some tests made after two weeks' time. Duplicate tests made at the same locations but after varying lengths of time, showed that difference in the elapsed time before making the compaction tests made no difference in the percentage of compaction.

When the moisture of the soil-cement was 4.4 per cent below optimum, the compaction test on the rolled pavement showed 85 per cent compaction; while with moisture 3.6 per cent below optimum, the compaction test showed 91 per cent compaction. This condition was corrected by the use of more water in the mix and more rolling with the sheepsfoot roller.

Two or more compaction tests were made for each day's processing. Thirty-one were made altogether. All of the tests, after the first day's experimental run, came within the Ohio State highway specification requirement of a minimum of 92 per cent compaction. The 29 compaction tests, omitting the two on the first day's experimental run, gave the following results:

Minimum	92.0 per cent compaction
Maximum	106.0 per cent compaction
Average	99.1 per cent compaction

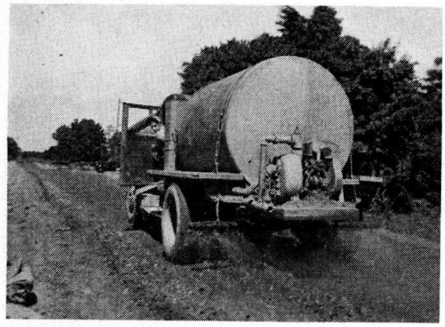

Figure 3. Replacing water lost by evaporation during processing

Some very interesting information was obtained when the percentage figures for moisture in the machine mixes were correlated with the percentages for the corresponding compaction tests. The moisture contents, arranged in groups varying by even percentage from the optimum, gave compaction percentages for each group as shown in Table 1.

TABLE 1

Moisture in machine mix		Number of tests	Compaction, percentage		
Percentage points	Average for group %		Minimum	Average	Maximum
2.0 or more above optimum.........	+3.7	1	....	97.9	.....
1.0 to 2.0 above optimum...........	+1.6	4	92.0	98.2	102.2
0 to 1.0 above optimum...........	+0.1	2	99.3	99.8	100.3
0 to 1.0 below optimum...........	−0.5	6	96.0	100.8	105.6
1.0 to 2.0 below optimum...........	−1.5	9	94.8	100.2	104.4
2.0 or more below optimum..........	−3.6	9	84.6	93.2	97.1
Total tests................................		31	Av.	98.0	

Table 1 shows that when the moisture in the soil-cement mix was kept within 2 points of the optimum moisture content, the compaction was within the 92 per cent minimum requirement of the Ohio State highway specifications.

The making of the partial moisture density curves, showing the maximum dry weight and optimum moisture content for each of the machine mixed samples, proved to be a great help in obtaining more exact compaction percentages when calculating the compaction tests, than would have been obtained by using the general soil curves for this project, since the maximum density on the same type of soil varied according to the amount of small aggregate present in the sample.

The depth of hardened pavement obtained by measurement at the thirty-one compaction holes showed:

Maximum	$6\frac{1}{4}$ in.
Minimum	$5\frac{3}{4}$ in.
Average	6.01 in.

These results indicate the uniformity of depth obtained on this project with the roadbuilding machine.

OBSERVATIONS ON CONSTRUCTION PROCEDURE

The surface condition of the compacted pavement was influenced by variation, from the optimum, of the moisture content of the soil-cement mix. When either too wet or too dry, rolling cracks developed in the top mulch when it was rolled with the smooth roller. These cracks were transverse to the road; showed during rolling; were not noticeable during the curing period; but could again be seen when the pavement dried out. They were approximately $\frac{3}{4}$-in. deep.

Where stones larger than one inch were encountered in some areas, and when the finishing operations were delayed, considerable raveling occurred on the road surface after curing and drying. This raveling was not detrimental to this project as the loose stones were brushed off and any depressions were filled by the bituminous surface treatment.

CONSTRUCTION IN THE HILLS OF MARYLAND

By J. E. Wood

The term, "slippery when wet" applies aptly to the stony clay soils of north central Maryland. Add to these features the steep grades and sharp curves incident to the predominantly hilly countryside, and we can realize that here the highway engineer encounters problems that those in more even country escape.

It was under such conditions that a soil-cement road was constructed in Carroll County in August, 1939. The limited appropriation, and the steeply rolling topography, together with the fact that the project was of the farm-to-market class, helped reconcile us to the questionable design of grades up to 10 per cent, and curvature consisting of one 11 deg. 30 min. curve, three 7 deg. curves and one 4 deg. curve.

The surface soil was shallow, being the product of the disintegration of the micaceous shale bedrock lying directly underneath. The soil was still impregnated with fragmentary masses of the rock, varying greatly in size, and ranging 20 to 45 per cent retained on a No. 4 sieve. In places the bedrock was barely beneath the subgrade.

The width processed with soil-cement was 18 ft.; the depth, 6 in. The end furthest from Manchester lay in a valley. From this point, construction followed windingly up-hill to the crest of the ridge, along which the road then extended to the other terminus. Of the seven days' processing, three were spent on the uphill climb.

Preliminary tests on seven samples