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	6¼ in.
Minimum	5¾ 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 ¾-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

indicated that they could be grouped into two distinct types. Therefore, they were combined to form two composite soils, both classified as A-4 gravelly sandy loams, with liquid limits of 31 and 36, and plasticity indices of 11 and 13, respectively. Moisture-density tests were run on these soils, and specimens molded and subjected to wetting-drying and freezing-thawing durability tests. The data are summarized in Tables 1 and 2.

The laboratory data indicated that the soils could be hardened by the addition of 8 per cent cement by volume, and this was used during construction, except for three sections on which 10 per cent was used. These sections were on grades of 10, 10, and 8 per cent respectively, the first 10 per cent section being on an 11 deg. 30 min. curve superelevated 1½ in. per ft. Details of construction procedures followed on this section will be given later. The third section also included a sharp curve superelevated 1½ in. per ft. The additional 2 per cent of cement used on these three sections was intended as insurance, due to the difficulties of controlling the shifting materials on such steep grades and superelevation. This increase was a comfort at first but as construction proceeded it seemed quite likely that it was not needed as good control was effected in spite of the unusual circumstances.

The methods employed in processing may perhaps be best described by outlining a typical day's run—the second.

On the day previous to processing, the soil bed was prepared; first, by scarifying, and secondly, by pulverizing to a degree so that 80 per cent of the soil would pass through a No. 4 sieve. Owing to the friable nature of the soil and also to the presence of stones, neither scarifying nor pulverizing presented any unusual difficulties. It was found that by scarifying to a depth of about 5½ in. the resulting thickness of the finished soil-cement was approximately the required 6 in.

After pulverization, water was added to bring the moisture content approximately to the optimum. This prewetting had the advantages of:

a—Permitting the moisture, during the night, to equalize throughout the soil bed.

b—Softening any crusted lumps of clay and rendering them more easily broken down.

c—Facilitating the succeeding day's run by shortening the moist mixing period.

d—Doing away with the discomfort of dust and a small cement loss.

e—Lessening the tendency of the dry cement to gravitate to the subgrade where it is hard to recover.

f—Resulting in a more rapid "dry mix" and final mix.

The water was applied to the raw soil with the distributors, each increment being mixed by using a disc harrow and field cultivator. An interesting phase uncovered during the prewetting was demonstrated when the micaceous soil at a moisture content of 9 per cent became so slippery that it provided insufficient traction for the rubber-tired equipment. However, after the cement was incorporated, water could be added to bring the mixture to the optimum moisture content of 16 per cent without being slippery.

Since our typical day's run was on an up-hill grade of 10 per cent and since it extended around a sharp curve calling for maximum superelevation (1½ in. per ft., making the outer edge of the pavement 27 inches higher than the inner, or a cross grade of 12½ per cent), the tendency of the soil with every manipulation to crawl rapidly down grade in both directions, required special attention. It became necessary to operate the motor grader continuously to buffer the soil up-hill and toward the

TABLE 1

GRAIN ANALYSES AND PHYSICAL TEST CONSTANTS

Soil No.	Gradation—Per cent of total							Physical test constants			Specific gravity[2]
	Gravel		Sand		Silt	Clay	Colloids[1]				
	Retained on No. 4 sieve	No. 4 to No. 10 (2.0 mm.)	2.0 to 0.02 mm.	0.25 to 0.05 mm.	0.05 to 0.005 mm.	0.005 to 0.000 mm.	0.001 to 0.000 mm.	L. L.	P. I.	S. L.	
602–A	25[a]	11	16	13	21	12	4	31	11	19	2.70
604–A	20[b]	12	21	16	17	14	9	36	13	22	2.76

[1] Also included in clay fraction.
[2] Fraction passing No. 10 sieve.
[a] Plus No. 4 material: Sp. Gr. = 2.36, absorption = 6.1 per cent.
[b] Plus No. 4 material: Sp. Gr. = 2.21, absorption = 9.2 per cent.

TABLE 2

DURABILITY DATA FROM TWELVE CYCLES OF TESTS

Soil No.	Cement content by volume %		Density lb. per cu. ft. oven dry weight		Moisture content oven dry weight %		Solids by volume, ave. %	Total soil loss % of original dry weight	
	Theoretical	Obtained ave.	Theoretical	Obtained ave.	Theoretical	Obtained ave.		Wet-dry	Freeze-thaw
602–A	0 0*	0 0*	120.6 113.8*	119.9 112.0*	12.8 15.0*	13.6 16.4*	73.8 66.5*	100	100
	6.1 7.5*	6.1 7.5*	118.1 112.1*	118.4 111.7*	12.9 15.0*	13.1 15.2*	72.2 65.5*	3	5
	8.1 10.0*	8.0 9.9*	118.4 111.7*	118.0 110.8*	13.5 15.8*	13.8 16.3*	71.9 64.9*	2	3
	10.2 12.5*	9.8 12.2*	118.8 112.3*	117.2 109.6*	14.1 16.5*	14.4 17.2*	71.4 64.0*	1	3
604–A	6.3 7.5*	6.3 7.5*	112.2 107.6*	112.4 107.6*	16.2 18.0*	16.6 18.4*	68.0 61.8*	Not Molded	4
	8.5 10.0*	8.3 9.9*	111.8 107.2*	111.6 106.4*	16.1 17.8*	16.3 18.1*	67.0 61.2*	2	4
	10.7 12.5*	10.4 12.4*	111.4 106.9*	111.1 105.9*	15.9 17.5*	16.5 18.4*	67.0 60.7*	1	2

* Minus No. 4 material only. Note quantity retained on No. 4 sieve given in Table 1.

high edge of the curve. It was these conditions, together with the extreme stoniness of the soil that limited this day's run to 700 ft.

Processing as such began the following morning, when the first operation was to haul, space and spread the cement.

To guide the spotting of the cement, a 200-foot rope was marked by tags at the correct intervals, the line being moved ahead as the spotting proceeded.

The spotting and spreading required about $1\frac{1}{2}$ hours. (Fig. 1.)

Figure 1. Cement sacks spotted and being dumped to form continuous transverse windrows, preparatory to leveling with spike tooth harrow.

Next came the field cultivator and the disc harrow each of which has its characteristic, yet indispensable, mixing action and each supplementing the other in efficiency. These machines operated about 30 min. or until the free cement had been incorporated with the top soil. The gang plows were then brought into action and operated simultaneously with the other equipment, the plows being of special value in controlling depth of treatment, in cutting the subgrade to a true plane and in bringing up from the bottom any unmixed soil and cement that may have escaped the cultivator and disc. For best efficiency and to avoid turnout, the various units were routed to operate in trains back and forth through the day's run, backtracking in directions with each round trip. (Fig. 2.)

However, on the steep grade it was necessary to work the gang plows in the up-hill direction only, thus also throwing the material toward the high edge of the curve. So great was the displacement of the mix on this hillside run that it became necessary, at times, to stop all other equipment to permit the motor grader to keep the surface in place.

During all mixing operations a gang of men was engaged in casting aside the

Figure 2. Dry mixing operations with two gang plows turning up bottom material, followed by heavy duty field cultivator. Note motor grader in background keeping the continuously shifting, loose material in place.

oversized stones that continually came to the surface.

The application of moisture followed immediately the completion of dry mixing. To minimize the tendency of the water to run down hill, the field cultivator followed the distributor as closely as possible. Since the soil, which had been moistened the night before, now more readily absorbed the added water as it was applied, the moisture mixing was more easily accomplished. The disc harrow was used to a less, and the gang plows to a greater extent than in the dry mixing period. Here, again, the motor grader had the Herculean task of keeping the surface in shape; but as the soil-cement increased in weight with the added water, the traction of the grader had to be supplemented with a 50 h.p. tractor on the up-hill pull.

When the required moisture had been applied and completely mixed with the soil-cement, the field cultivator was employed to stir up and loosen the entire mass, all other equipment being excluded.

Over this fluffy bed at optimum moisture content the sheepsfoot rollers began to operate. The spike tooth harrow, with teeth set vertically, was attached to one of the rollers to equalize the surface, erase indentations of the roller feet and prevent compaction planes.

When the bottom two-thirds had attained its density, the motor grader was put into service, in a preliminary way, to give the surface its general shape. The rollers continued operating through this stage and, in fact, until the final compaction and final shaping were concluded almost simultaneously.

At this stage, to secure a more uniform surface mulch, about one inch in thickness, the spike-tooth harrow with teeth set vertically and bearing the weight of two men was dragged over the entire compacted area. On the last round-trip with the spike-tooth, the broom drag was attached behind. This device effectively filled in the longitudinal depressions left by the spikes and gave a uniformly distributed loose mulch. (Fig. 3.)

A 10-ton, three-wheeled road roller, beginning at the edges and lap-rolling toward the center, next gave a well knit and dense finish. Better to key in some of the surface stones and erase roller markings, a light spray of water was added and squeegeed in with pneumatic tires. A two-in. earth covering, which was kept moist, was used for cover to prevent evaporation losses.

The stoniness and the slipperiness of the soil and its proneness to shimmy downhill and to the low edge of the curve not only presented problems of interest and even excitement, but also resulted in that degree of satisfaction which only success under difficulties can bring. The surface was excellent, both as to appearance and quality.

In the field, moisture control was governed by tests made:

a—Before applying moisture to the raw soil on the day preceding processing.

b—At the close of the dry mixing period.

c—Near or at the close of moist mixing.

d—After final rolling when density and thickness determinations were made.

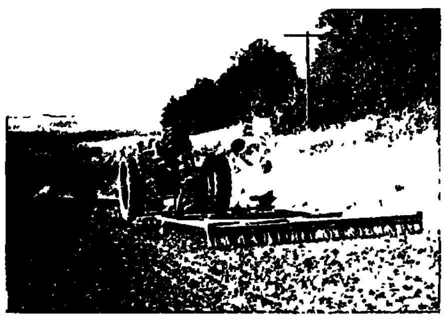

Figure 3. Spike tooth harrow removing compaction planes, followed by broom drag to produce uniformly distributed loose mulch prior to surface consolidation.

A completely equipped mobile soils laboratory [1] gave fingertip control of all the variable elements of the project by making frequent determinations of the No. 4 material, the moisture content and both the density obtained and maximum density.

It was found that with the soil just at optimum moisture content, or slightly above, the free stones in the surface mulch became firmly embedded or healed

[1] See page 296 for a description of the mobile laboratory.

over during smooth rolling. On some of the hot, drying days it became necessary to moisten the surface just before working up the final mulch with the spike-tooth harrow.

During processing, the subgrade was kept under control by constant measurements from a string line stretched between grade stakes. Here close cooperation between the inspector and the operators of the gang plows was essential. During the finishing operations, the same close attention to measurements was given to the final crown and grade in the same way.

A new answer to one detail in soil-cement road construction had been developed in the state of Illinois just before the Maryland work started. This pertains to the joint at the meeting of the current with the preceding day's run. The new method permits the equipment to turn around without driving on or endangering previously completed work. To accomplish this result, the soil for a length of 25 ft. just ahead of the joint was removed entirely to subgrade, and wasted. This space provided ample turning room for the equipment. Near the conclusion of the moist mixing period, a 25-ft. section of the processed soil-cement mixture at the opposite end of the day's run was picked up by a traveling scraper and transferred back to refill

TABLE 3

Results of Density and Depth Determinations

Station	Compacted depth in.	Field density test of minus No. 4 damp mix dry wt., lb. per cu. ft.	Density of minus No. 4 material in completed road, dry wt., lb. per cu. ft.	Density of minus No. 4 material in completed road, % of field density	Density of total material in completed road, dry wt., lb. per cu. ft.
2+00	6 1/16	.....	.....	.....	127.7
4+00	5 5/16	114.0	116.1	101.8	124.8
6+00	5	114.3	116.7	102.1	119.7
8+00	5 3/4	108.3	104.8	96.8	120.7
11+00	5 7/8	111.0	.....	.....	121.5
13+00	5 9/16	.....	.....	.....	121.7
15+00	5 1/2	111.9	111.9	100.0	124.8
17+00	5 5/8	.....	.....	.....	125.2
19+00	5 7/16	110.7	109.6	99.0	117.8
22+00	5 3/8	.....	.....	.....	109.7
24+00	6 1/8	111.0	110.1	99.2	123.8
26+00	5 15/16	111.6	110.4	98.9	119.7
28+00	5 5/8	115.2	118.7	103.0	125.3
30+00	5	.....	.....	.....	118.1
32+50	5 3/4	.....	.....	.....	122.5
35+00	5 1/8	108.6	115.1	106.0	120.0
37+50	6 1/4	.....	.....	.....	117.5
40+00	5 3/4	108.0	113.9	105.5	114.8
42+00	5 9/16	.....	.....	.....	111.3
44+00	5 1/2	.....	.....	.....	117.5
47+00	6	112.2	112.5	100.3	123.3
49+00	5 1/16	111.0	110.1	99.2	121.6
51+00	5 7/8	.....	.....	.....	120.4
54+00	5 1/2	.....	.....	.....	130.2
56+00	5 1/4	.....	.....	.....	130.5

the gap. This transfer was effected just prior to the final turnover of the soil-cement before sheepsfooting.

During construction, control of moisture contents and densities was governed by frequent field moisture-density tests run on the minus No. 4 roadway material toward the conclusion of the damp mixing period. Following completion of each section, density and depth determinations were made at intervals of approximately 200 ft. The results of 25 determinations, ranging from 111 to 131 lb. per cu. ft., including the plus No. 4 material, averaged 121 lb. per cu. ft. for the entire project. The densities of the minus No. 4 material in the completed road, ranging from 97 to 106 per cent, averaged 101 per cent of the values determined by field moisture-density tests at the same locations. These data are tabulated in Table 3.

CONCRETE PAVEMENT SUBGRADE, DESIGN, CONSTRUCTION, CONTROL

By Carl R. Reid

This report, in addition to the records of construction, presents briefly the project design and specifications, the detail of tests for design and control of "cement modified soil" construction, special tests and determinations for comparison of the effect of pulverization of the soil for mixing with cement and the effect of time on moisture-density relations in soil-cement mixtures. Comment is made on construction and suggested methods believed of interest and value in specifying and supervising this type of stabilization.

The project is identified as Federal Aid Project 215-F & G, Comanche County. It is located on U. S. 62 and begins two and one-half miles east of Indiahoma and extends west to the Kiowa County Line, a distance of 7.004 miles.

The original improvement of this highway was completed in October, 1930 to the then standard grade and drainage to a width of 30 ft. and bridges having a roadway width of 22 ft. To complete the improvement in 1938 with high type surfacing required widening the roadbed to 36 ft. and revisions in grade to provide the increased sight distance now required.

Upon completion of the revised plans for this improvement, the usual preliminary soils surveys were made and in addition a study of all local materials was made in order to analyze and report on the probable types or methods of improvement. No examination was made of the density of embankments in place.

Upon examination of the soils analyses it was found that a large portion of the subgrade would be of highly expansive clay soil of the A-6 and A-7 groups, interspersed with less expansive and silty clays of the A-4 group, together with various combinations of all three. It was evident that in order to be assured of a satisfactory improvement, stabilization of a large portion of this subgrade would be required, or a special base and surface design provided to take care of this subgrade condition.

A sample of the heavier clay was sent to the Portland Cement Association, for analyses and recommendations. They suggested that a "cement modified" soil designed for proper reduction of the volume change characteristics should produce a satisfactory, stable subgrade. Their report called for approximately 8 per cent of portland cement by volume to produce this result. Comparing this requirement with soils indicated by the soils survey, estimates for this improvement were prepared which averaged about 6 per cent for the project.

A review of the several types of improvement as to the comparative costs, and the value of finished construction