cycle by brushing with a rather soft bristle brush Brushing with a stiff bristle wire brush apparently causes greater losses than actually occur from the disintegrating forces of the durability tests and specimens made with sandy soil and low cement contents can be entirely destroyed by vigorous brushing

Much remains to be learned about designing and constructing this type of road The work to date has shown that adequate preliminary field soil surveys and laboratory tests as well as thorough field control are essential to the successful construction of cement stabilized roads

AN EXPERIMENTAL SOIL-CEMENT ROAD IN ILLINOIS

By V L Glover

Engineer of Materials, Illinois Division of Highways

During September, 1936, a soil-cement road, the first to be constructed in Illinois, was built near Rockford, Winnebago County The preliminary tests were made jointly by the Division of Highways, Springfield, and the Portland Cement Association, Chicago Construction work was done by the Winnebago County Highway Department The section was 6,000 ft long and the soil-cement surface was 18 ft wide and 6 in thick The section was entirely experimental and was constructed at approximately the same time that several other experimental sections were under way in the middle west

Preliminary soil samples were taken before the grading work was completed It was believed that they would be sufficiently representative of the soils involved in the project that the field control information could be satisfactorily based upon the test data for these samples and that the construction work could be started as soon as the tests were completed

LABORATORY SOIL TESTS

Except for a few minor changes, the laboratory tests were made in accordance with the recommended procedure outlined in the Portland Cement Association Progress Report on Laboratory Investigation of Soil-Cement Mixtures, dated May 1, 1936

Physical Test Constants and Grain Size The test data in Table 1 indicated that with the exception of a short section of clay loam on the north end of the project, the soil would classify as a sandy loam, and as an A-2 subgrade material grading to either the A-3 or A-4 groups

These data also showed that the soils represented by Samples 36-2282, 36-2283, and 36-2285 were very similar but that Sample 36-2285 had the highest liquid limit and plasticity index Therefore, it was recommended that the laboratory control tests be confined to this last named sample because previous tests indicated that the cement required increased as the liquid limits and plasticity indices increased It was decided, however, to conduct the complete control tests on all of the samples taken

Moisture-Density Tests The optimum moisture content-maximum density data determined for each soil sample and for each soil sample combined with 4, 6, and 10 per cent cement, by weight, are shown in Table 2 The selection of these percentages of cement was based upon a comparison of the data shown in Table 1 with similar data for soils previously tested and for which complete soil-cement data had been obtained

The curves plotted from the data secured by these tests are shown in Figures 1 to 5, inclusive An inspection of these curves appears to establish a lack

TABLE 1
PHYSICAL TEST CONSTANT AND GRAIN SIZES

Sample Number	Station	Classification	U S B P R Group	Mechanical Analysis Per Cent Passing Sieve Number						
				3/8	4	10	20	40	100	200
36-2281	0 + 60	Clay Loam	A-4-2	100	97 4	97 1	96 4	93 7	78 9	75 8
36-2282	19 + 75	Sandy Loam	A-2			100	99 6	91 6	20 0	14 7
36-2283	37 + 50	Sandy Loam	A-2			100	99 8	91 6	29 0	24 0
36-2284*	37 + 50	Fine Sand	A-3			100	99 8	93 8	13 1	6 6
36-2285	45 + 00	Sandy Loam	A-2			100	99 6	95 0	53 4	48 2

Sample Number	Sand +0 05	Silt 05- 005	Clay 005- 000	Colloids −0 001	Liquid Limit	Plastic Index	Field Moisture	Shrinkage Limit	Shrink age Ratio
36-2281	33	40	27	17	26 5	11 2	18 0	16 0	1 8
36-2282	88	5	7	4	13 6	—	16 0	9 0	2 0
36-2283	81	10	9	4	14 0	—	16 0	12 0	2 0
36-2284*	95	2	3	2	17 4	—	18 0	13 0	1 8
36-2285	59	24	17	5	22 4	4 9	21 0	16 0	1 8

* Subgrade, sampled 2 feet below No 36-2283

TABLE 2
PROCTOR MOISTURE-DENSITY DATA

Sample Number	Per Cent Cement		Optimum Moisture Content, %	Maximum Density lb per cu ft
	By Weight	By Volume*		
36-2281	0	0	15 4	112 6
	4	4 57	15 7	112 0
	6	6 81	15 3	112 8
	10	10 85	15 0	111 7
36-2282	0	0	8 7	121 2
	4	5 00	9 0	122 4
	6	7 45	8 4	123 8
	10	12 02	9 6	124 5
36-2283	0	0	9 4	125 8
	4	5 11	9 7	124 5
	6	7 45	9 7	124 4
	10	12 02	9 6	124 0
36-2284	0	0	10 5	112 9
	4	4 79	9 0	117 5
	6	7 13	9 1	118 8
	10	11 81	8 0	121 7
36-2285	0	0	13 6	113 4
	4	4 68	13 2	113 4
	6	6 81	13 5	112 4
	10	10 85	13 4	112 7

* Calculated

of any definite relationship between the moisture-density and the various cement contents However, the curves for samples 36-2282 and 36-2284 (Figures 2 and 4) show that the density of these

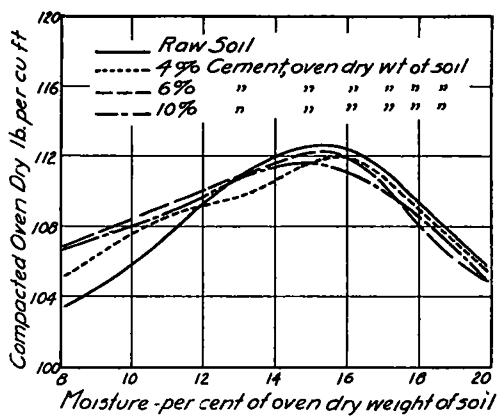

Figure 1. Moisture-Density Relations. Clay Loam, Group A-4-2, Sample 36-2281

soils increased with increasing percentages of cement, but the increases were not in direct proportion to the increments of cement incorporated in the raw soils The optimum moisture contents, however, for even these particular soils did not vary in any definite manner

In some of the earlier work, there was a tendency for the curves, plotted from the data secured for soils with higher clay contents, to be more or less irregular in shape However, when such soils were broken down until they would pass a No 8 sieve, moistened, and allowed to remain in a moist closet for approximately 18 hours, the resulting curves were no longer so irregular in shape

Moisture-Penetration Tests After each of the soil cylinders used in the moisture-density tests had been weighed, an effort was made to secure moisture-penetration data, but the results were so obviously erratic that they were disregarded

Durability Tests Up to this point, the soil-cement mixtures were made by adding 4, 6, and 10 per cent cement to the raw soil on the basis of the oven dry weight of the soil The same increments of cement, by volume, were used in the durability test specimens

The following formula was used to convert the cement contents of the

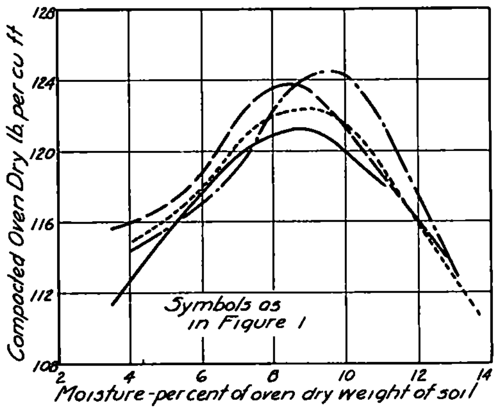

Figure 2. Moisture-Density Relations. Sandy Loam, Group A-2, Sample 36-2282.

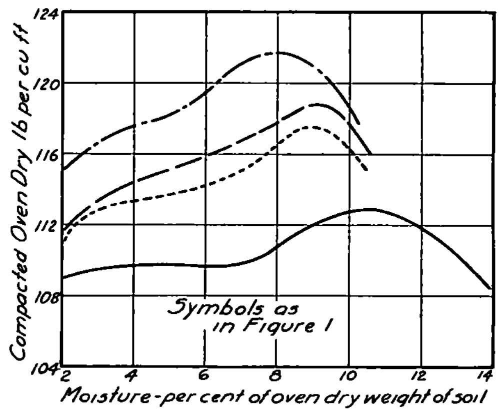

Figure 4 Moisture-Density Relations. Fine Sand, Group A-3, Sample 36-2284

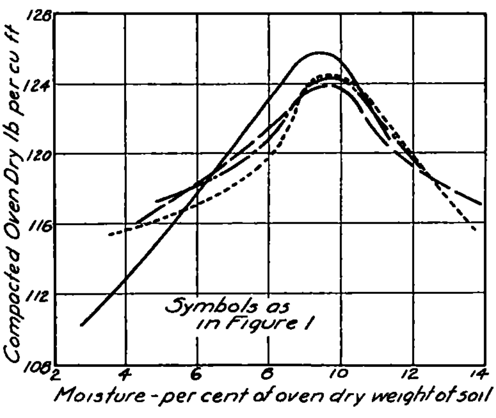

Figure 3 Moisture-Density Relations. Sandy Loam, Group A-2, Sample 36-2283.

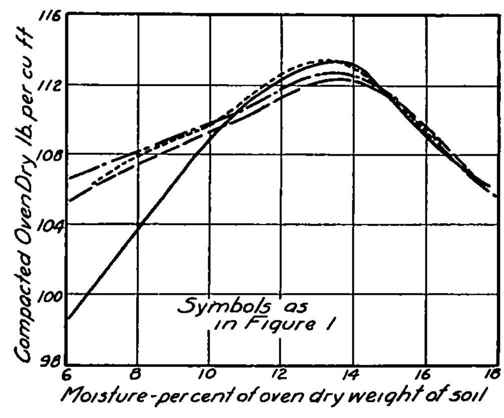

Figure 5. Moisture-Density Relations Sandy Loam, Group A-2, Sample 36-2285.

moisture-density soil-cement mixtures, compacted at their optimum moisture contents, to the volume basis

$$\frac{W - \dfrac{W(100)}{100+C}}{94} \times 100 = \text{the equivalent percentage of cement, by volume,}$$

when W = Weight of one cubic foot of soil-cement mixture compacted at its optimum moisture content,

C = Percentage of cement based on oven dry weight of the soil,

94 = Weight of one cubic foot of cement

The percentages of cement, by weight, used for the moisture-density tests and the equivalent percentages on the volume basis are shown in Table 2 These equivalent percentages, by volume, were plotted against the unit oven dry weights of the corresponding mixtures, compacted at their optimum moisture contents (Fig 6) and the resulting curves used to determine the unit oven dry weight which should be obtained for any of the soils in question in either their raw state or when combined with any percentage of cement, by volume, when compacted at their optimum moisture content The cement contents, by volume (4, 6, and 10 per cent), were in turn converted to equivalent percentages, by weight, for laboratory control, during the durability tests

The equivalent percentages of cement, by volume, were also plotted against the optimum moisture contents determined for the raw soils and the various soil-cement mixtures (Figure 7) and the resulting curves used to determine the optimum moisture contents for the various soil-cement mixtures used in the durability tests

As soon as the above mentioned work was completed, the test specimens used for the durability tests were made up according to the data given in Table 3. The actual optimum moisture content and the density secured for the different specimens varied somewhat from the

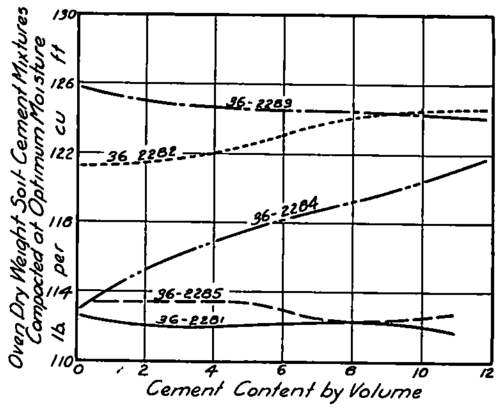

Figure 6. Chart for determining the unit oven dry weight of laboratory samples compacted at optimum moisture containing various percentages of cement by volume.

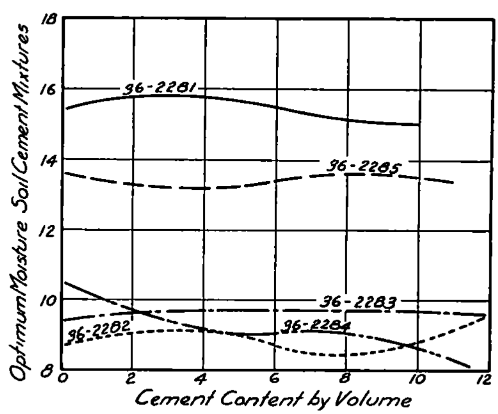

Figure 7 Chart for determining the optimum moisture contents of laboratory samples containing various percentages of cement by volume.

figures given, but these variations were well within the specified limits

The durability specimens were cured for 7 days in a moist room instead of being exposed to the laboratory air according to the procedure outlined. Despite the fact that the relative humidity of the moist room was maintained above 90 per cent during the curing period, a slight loss of weight was recorded after the first day's curing. This was remedied by covering the specimens with a damp

TABLE 3

DATA FOR MOLDING DURABILITY TEST SPECIMENS

Sample Number	Per Cent Cement		Optimum Moisture Content, %*	Maximum Density lb. per cu. ft.*
	By Volume	By Weight		
36-2281	0	0	15.4	112.6
	4	3.47	15.7	112.0
	6	5.29	15.5	112.2
	10	9.16	15.0	112.0
36-2282	0	0	8.7	121.2
	4	3.18	9.1	122.0
	6	4.81	8.7	123.0
	10	8.17	8.8	124.4
36-2283	0	0	No specimens made.	
	4	3.11	9.7	124.6
	6	4.75	9.7	124.4
	10	8.19	9.7	124.2
36-2284	0	0	No specimens made.	
	4	3.32	9.1	116.9
	6	5.01	9.0	118.2
	10	8.47	8.6	120.4
36-2285	0	0	13.6	113.4
	4	3.43	13.2	113.4
	6	5.25	13.4	113.0
	10	9.12	13.5	112.5

* Interpolated.

canvas, care being taken that the canvas did not touch the specimens and add moisture rather than prevent loss.

Wetting and Drying Test. The recommended wetting and drying test procedure was followed for 18 cycles. Pictures of the specimens were taken after 12 and 18 cycles. The condition of the specimens at the end of the 18 cycles is shown in Figures 8 to 11, inclusive. No pictures were taken of the specimens for Sample No. 36-2284, because this material represented the subsoil and was tested

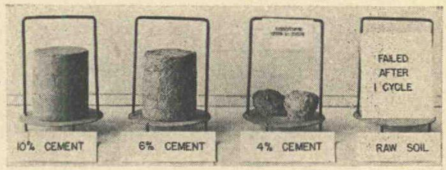

Figure 8. Brushed specimens for sample 36-2281 after 18 cycles of wetting and drying.

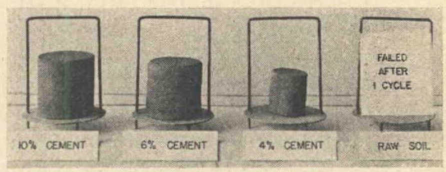

Figure 9. Brushed specimens for sample 36-2282 after 18 cycles of wetting and drying.

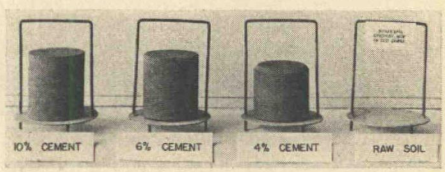

Figure 10. Brushed specimens for sample 36-2283 after 18 cycles of wetting and drying.

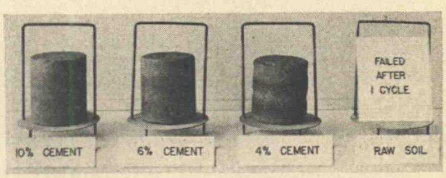

Figure 11. Brushed specimens for sample 36-2285 after 18 cycles of wetting and drying.

for only 12 cycles. No volume changes were noted.

The moisture absorbed by the soil-cement specimens during the 5-hour period of immersion was so nearly constant from cycle to cycle that no detailed record of the results is shown Sample 36-2283, with 4 per cent cement, showed a maximum variation of about 3 per cent at 6 cycles, after which the specimen began slaking Other samples showed variations of less than one per cent throughout the duration of the test or until slaking losses prevented measurements.

The soil losses and moisture changes are given in Table 4

Freezing and Thawing Tests At the end of the 7-day curing period the remaining two specimens of each set of the durability specimens were tested according to the recommended freezing and thawing procedure, except that 24-hour freezing periods were used instead of the recommended 20-hour periods, because the temperature of the room was maintained at from 0° to 5°F, instead of the lower temperature recommended

This test was continued for 18 cycles of freezing and thawing Pictures of the specimens were taken after 12 and 18 cycles had been completed The condition of the specimens at the end of the 18-cycle period is shown in Figures 12

TABLE 4

DURABILITY TESTS SHOWING THE EFFECT OF CEMENT ON THE SOIL SAMPLES

Sample Number	Per Cent Cement by Volume	Wetting and Drying Data			Freezing and Thawing Tests		
		Volume Change, %	Soil Loss, %	Maximum Moisture Change*	Volume Change, %	Soil Loss, %	Maximum Moisture Change*
36-2281	0	Raw soil failed after 1 cycle			7 0 at 5	+70 0 at 2	5 0 at 3
	4	No	78 0 at 15	1 0 at 4	5 0 at 8	77 0	3 0 at 5
	6	No	9 0	1 0 at 5	1 0 at 12	18 0	2 0
	10	No	No	1 0	No	1 0	2 0
36-2282	0	Raw soil failed after 1 cycle				+70 0 at 2	4 0 at 2
	4	No	72 0	No	No	+70 0 at 5	3 0 at 7
	6	No	17 0	1 0	No	86 0 at 13	4 0 at 7
	10	No	6 0	No	No	50 0	2 0
36-2283	0	No raw soil specimens					
	4	No	16 0	No	No	+70 0 at 6	2 0 at 4
	6	No	No	No	No	25 0	1 0
	10	No	No	No	No	No	No
36-2284	0	No raw soil specimens					
	4	No	26 0 at 12	No at 7	No	38 0 at 12	2 0 at 6
	6	No	7 0 at 12	1 0 at 12	No	5 0 at 12	1 0 at 12
	10	No	1 0 at 12	No	No	2 0 at 12	1 0 at 12
36-2285	0	Raw soil failed after 1 cycle				+70 0 at 2	7 0 at 2
	4	No	11 0	No at 14	No	85 0	5 0 at 11
	6	No	1 0	No	No	32 0	5 0
	10	No	No	No	No	No	4 0

Note Percentages are based on results after 18 cycles, unless designated by at 12, etc

* Maximum moisture change represents the difference in the moixture content at the time of molding and the maximum moisture absorbed during the duration of the durability tests or until soil losses prevented further determinations

to 15, inclusive. No pictures were taken of the specimens for Sample No. 36-2284. The soil losses are shown in Table 4.

All of the raw soil specimens showed some volume change, but accurate measurements could not be made due to softening and distortion. The soil-cement specimens showed no appreciable volume change, except in the case of the 4 per cent specimen for Sample No. 36-2281, which developed a volume change of less than 7 per cent.

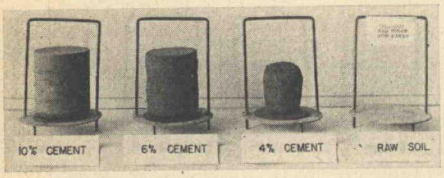

Figure 12. Brushed specimens for sample 36-2281 after 18 cycles of freezing and thawing.

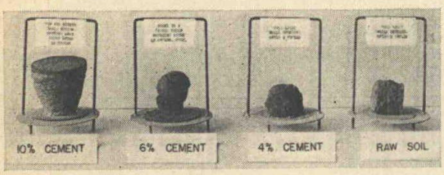

Figure 13. Brushed specimens for sample 36-2282 after 18 cycles of freezing and thawing.

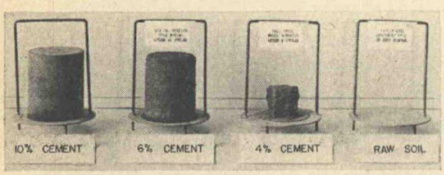

Figure 14. Brushed specimens for sample 36-2283 after 18 cycles of freezing and thawing.

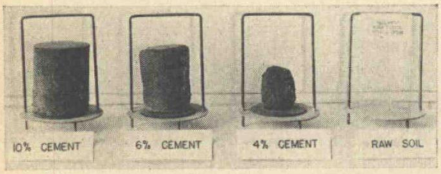

Figure 15. Brushed specimens for sample 36-2285 after 18 cycles of freezing and thawing.

The individual moisture contents of the specimens were determined throughout both the curing period and the freezing and thawing test, the latter at the end of each thawing period, and are shown in Table 4.

Check and Compression Tests. After completion of the grading on this project, a second set of samples was taken. The physical test constants and grain sizes checked the data determined for the preliminary samples.

Compression test cylinders for each sample combined with 6 and 10 per cent cement, by weight, were molded and broken at the end of two and six day periods. These data showed sufficient similarity to the strengths obtained from similar tests which had been made on soils satisfactorily hardened with cement to indicate that the soils on this project should react favorably with cement.

Conclusions. Upon completion of the laboratory tests, the data obtained by the Division of Highways were compared with the data obtained by the Portland Cement Association. This comparison showed a remarkable similarity in results, especially in view of the fact that the samples were not taken at the same locations.

The agreement of the data obtained by the two laboratories and between the data for the preliminary samples and the samples taken after the grading was completed, indicated that it would not be necessary to make additional tests.

Since the clay loam on the north end of the project had been replaced with sandy loam during the grading operations, the physical test constants and grain size data showed that the soil on this entire section corresponded very closely to the sandy loam represented by Sample No. 36-2285.

The results of the durability tests (Table 4) showed quite definitely the stabilizing influence of the cement on the type soil predominating on this project and also indicated that the addition of 10 per cent cement, by volume, to the soil would produce better results than the lower percentages tested

Based upon the Proctor moisture-density data for the representative soil-cement mixture, containing 10 per cent cement, by volume, an optimum moisture content of 16 per cent and a density or dry weight per cubic foot, compacted at the optimum moisture content, of 112 pounds were selected for field control during the construction work on this project

CONSTRUCTION

Due largely to a lack of experience with this type of work, considerable equipment was used which should have been replaced by more satisfactory equipment Equipment was made up but never used, and other equipment was rented and shipped to the job but never used

The following equipment was used on the project

- One 60-ton tractor, used with scarifier and blade grader
- Two 35-ton tractors, used with disk harrows
- One No 2 blade grader
- One 7-tooth scarifier
- Two 20-inch disk harrows, used for pulverizing and mixing
- One 24-inch disk harrow, tried out in an attempt to pulverize and mix to the full depth in a single operation
- Two sheepsfoot rollers, one single section and one double section
- One No 6 road maintainer, used for shaping after compaction and for spreading curing material
- Two distributors, one 700 gallon and one 900 gallon, used to apply water
- One dual-pneumatic tired tractor, used for final compaction
- One 8-ton three-wheel roller, used for finishing
- Trucks, several used for hauling cement, turn-around material, and compacting

The facts that a 700 and 900 gallon distributor were used on this project, that they were filled at a stream about a mile away, that about 45 minutes were required to fill and empty each distributor, made the application of water slow and expensive, increased the mixing time, and tended to reduce the effectiveness of the cement

The compaction work carried on with the sheepsfoot rollers would have been speeded up and been more satisfactory if the rollers used had been the type with the larger feet

The 8-ton smooth roller used for the final finishing operations gave some trouble because it had a tendency to shove and crack the surface and to pick up the material from the roadway It is necessary to work out a definite technique in the use of smooth rollers for this type of work

The data in Table 5 shows that the construction work was divided into eight increments, varying from 500 to 900 feet in length The average time required for treatment was two hours per 100 ft of surface, which included the time required to spread and mix the cement, apply the water, and to compact and finish the surface This average time, however, does not include the scarifying and pulverizing operations which were carried on when there was no actual processing in progress, although these operations together with the curing preparations, moving turn-arounds, and incidentals increased the total time

In general, the following construction procedure was used

Scarifying, Pulverizing, and Shaping The section to be treated was scarified to the full width and depth shown on the plans and brought to grade with the blade grader The soil was then pulverized with disk harrows and all lumps were completely broken down Whenever the moisture content of the soil exceeded the specified optimum moisture content by more than 2 per cent, the pulverizing was continued until the moisture content was within the specified 2 per cent As soon as the soil was pulverized, it was shaped to the approximate cross-section shown on the plans In shaping, however, the soil was pulled about 2 ft away from the edges to prevent waste or segregation of the cement

Applying, Checking, and Mixing the Cement The cement was spread at the rate of 9 bags to each 10 linear feet of roadway to give the 10 per cent by volume specified The cement was spread uniformly over the surface with rakes and shovels, and mixed with the pulverized soil by means of disk harrows. An inspection of the resulting mixture, however, disclosed the fact that the cement had not been incorporated to the full depth of the pulverized soil Therefore, the mixed portion was halved into windrows on either shoulder The remaining portion was then loosened with disk harrows and spread over the previously mixed and windrowed material, after which each windrow of mixed and unmixed material was bladed into the roadway and thoroughly mixed with the disk harrows

TABLE 5

CONSTRUCTION DATA FOR EACH SECTION

	Section Number							
	1	2	3	4	5	6	7	8
Length (Feet)	500	500	800	900	900	800	900	700
Date Treated	9–18	9–19	9–22	9–24	9–26	9–29	10–2	10–3
Temperature (high)	73	76	87	61	62	69	61	65
Temperature (low)	42	44	55	45	51	43	34	42
Original Moisture	9 0	8 0	8 5	6 0	7 5	12 0	12 0	11 0
Final Moisture	15 0	15 0	15 5	13 0	15 0	16 0	15 0	15 5
Approximate time of each operation during treatment (hours)								
Spreading Cement	1½	1	1½	1	1½	1½	1	1½
Mixing Cement	3½	3½	5	4	4	4½	6	4½
Applying Water	4	4	6½	5½	5½	3	5	2½
Compacting	2	2½	3	1½	3	3	2	1½
Finishing	2	2	2	5	—*	2	2	2
Total Time	13	13	18	17	14	14	16	12
Density tests run by sand method								
Date Tested	9–21	9–21	10–1	10–1	10–4	10–4	10–4	—
Moisture Content	11 1	11 1	11 7	8 7	11 1	11 7	14 9	—
Wt Per Cu Ft	117 8	120 1	118 1	122 6	122 7	121 6	119 1	—

* Rain during final compaction

Applying Water After satisfactorily mixing the cement and pulverized soil the full depth of the section, approximately 40 per cent of the mixture was windrowed in preparation for application of water, to avoid repetition of the difficulties experienced in mixing the cement to the full depth The addition of water in two lifts necessitated a constant check on the moisture content of the mixture to prevent the use of water in excess of the optimum moisture content

The moisture content of the soil-cement mixture was determined from an average of several moisture tests and the amount of water necessary in order to satisfy the optimum moisture of the mixture was calculated from the data given in Table 6

This table is based on the weight per cubic foot of the oven dry soil-cement mixture compacted at optimum moisture content, i e , 112 lb per cu ft , compacted with 16 per cent moisture For example suppose after having applied and thoroughly mixed the required amount of cement, the average moisture content is found to be 7 0 per cent As 16 0 per cent is the optimum, it is, therefore, necessary to add 9 0 per cent Since this particular section is 800 feet in length, 8 times 1089 gallons, from the table, is the total amount of water necessary

The original and final moisture contents shown in Table 5 represent the averages of several determinations made on each section The original moisture data represent the percentage of moisture contained in the mixture after the cement had been thoroughly mixed with the soil, and the final moisture data show the percentage in the mixture at the time of starting compaction

Difficulties experienced in applying water did not materialize except on Section 6 and this was probably due to lack of drainage Whenever the original moisture content varied somewhat throughout a section, it was expected that the rate of applying water would have to be varied accordingly However, there appeared to be a natural balance between the original moisture and the optimum moisture that tended to counteract this variable As an example, on Section 4, the original moisture varied from 6 4 per cent at the north end to 4 1 per cent near the south end This section appeared to contain more sand than the other sections, with the sand content increasing toward the south end of the section, consequently having less water holding capacity and a low optimum moisture content toward that end Water was applied at the same rate, however, throughout the entire section, and although the final moisture content varied, the consistency of the mixture appeared the same for the entire section

TABLE 6

DATA USED TO DETERMINE THE GALLONS OF WATER NECESSARY TO BRING THE MOISTURE CONTENT OF THE SOIL-CEMENT MIXTURE TO THE OPTIMUM

Per Cent Water to be Added	Gallons per Linear Foot of Roadway	Gallons per 100 Linear Feet of Roadway	Gallons per Square Yard of Roadway
1	1 2101	121 01	605
2	2 4202	242 02	1 210
3	3 6303	363 03	1 815
4	4 8404	484 04	2 420
5	6 0505	605 05	3 025
6	7 2606	726 06	3 630
7	8 4707	847 07	4 235
8	9 6808	968 08	4 840
9	10 8909	1089 09	5 445
10	12 1010	1210 10	6 050
11	13 3111	1331 11	6 655
12	14 5212	1452 12	7 260

Shaping and Compacting After making sure that the moisture content was within 2 per cent of the optimum, the mixture was loosened as much as possible shaped to the lines and grade shown on the plans, and compacted to the required density with sheepsfoot rollers The compacted section was then shaped to conform to the lines and grade shown on the plans, and the roller marks removed with a blade maintainer, after which the surface was given a final rolling with an 8-ton 3-wheel roller

Curing The first two increments were left uncured after completion The other increments, however, were cured with wet earth for seven days A pneumatic tired maintainer was used to spread the curing material to prevent marring the finishing surface

Turn-Arounds Before starting the work on a new section, that part of the previous treated section to be used for turning equipment was covered with at least 6 inches of earth to protect the surface Planks or plates were placed to grade on the end of the completed section to protect it during the subsequent construction operations A thin section of traffic tread plate proved more satisfactory than planks as the protective layer of earth was not necessarily so thick and consequently the mixture did not build up and compact so much above grade at this point

Experimental Surface The last increment, which was 700 ft long, was given a surface application of pea gravel After compaction, the section was shaped to the lines and grade shown on the plans, and a mulch was spread evenly over the section to act as a mortar for the pea gravel surface. The washed pea gravel was then spread over the surface at the rate of 25 pounds to the square yard by adjusting the end gates of the trucks to the desired rate of flow The surface was then wetted slightly and compacted with trucks, after which the final rolling was done with the 8-ton 3-wheel roller The 25-lb treatment of gravel was apparently excessive, because there was considerable loose gravel on the surface after the rolling was completed, and it is probable that about 15 lb per sq yd would have been sufficient

Density Tests Density tests of the surface of all increments excepting the one treated with pea gravel were made by the sand method The material was removed to the approximate depth of the surface with a 4-inch soil auger after the surface had hardened sufficiently to prevent spalling during boring All of the material so removed was retained and its oven dry weight determined The hole left by the auger was filled with standard Ottawa sand, the sand being poured at a constant rate of flow from a receptacle containing a known weight of sand The weight of sand poured into the hole was then determined and the weight per cubic foot of the compacted surface computed by the following formula

$$W_1 = \frac{WS_1}{S}$$

in which—W = the weight of the material removed from the surface,

S = the weight of the sand used to fill the hole,

W_1 = the weight per cubic foot of the material in surface,

S_1 = the weight per cubic foot of the sand

All weights were on an oven dry basis The densities determined by this method are shown in Table 5

RESULTS

When first completed, this project had the characteristic appearance of this type of surface Within two days after the first two increments were placed, hair checking appeared on the surface and it was supposed that these were caused by the rapid and excessive drying out which resulted from lack of curing, therefore, all other increments were cured for seven days In spite of this, transverse cracks and some hair checking appeared on these increments within three days after completion

When examined in December, 1936, approximately three months after completion, the interval between transverse cracks was about 15 feet on all increments except the one covered with gravel, on that increment, the interval was about 30 feet At that time, longitudinal cracking was apparent in only one increment, where a continuous crack, at approximately the centerline, extended through the entire length of the increment, a distance of about 800 feet

When examined in April, 1937, scaling and pitting had developed, but aside from being somewhat rough, the surface was in fair condition In order to protect the surface and to provide better riding qualities, all but 400 feet of the project was given a bituminous surface treatment in August, 1937

TABLE 7

CONSTRUCTION COSTS, EXCLUSIVE OF CEMENT

	Cost for 12000 Sq Yds	Cost per Sq Yd
Moving to and from Section	$294 77	$0 02457
Assembling Machinery and Machinery Costs	158 30	0 01319
Greasing and Gasing Costs	41 07	0 00342
Scarifying Costs	52 79	0 00439
Trenching Costs	202 47	0 01687
Grading Surface	63 55	0 00529
Discing Costs	376 77	0 03139
Mixing Costs	117 76	0 00981
Tamping Costs	68 12	0 00568
Cement Costs (Delivery and Handling)	615 47	0 05129
Water	713 85	0 05949
Rolling	22 91	0 00190
Joints	51 05	0 00425
Curing Pavement	50· 55	0 00421
Lights	60 93	0 00508
Miscellaneous Labor Costs and Materials	264 13	0 02202
Freight Costs	222 79	0 01858
Total Costs	$3,377 28	$0 28144

Construction costs, exclusive of cement, are shown in Table 7 The cost per square yard is not so high as would be expected after considering the experiences with the equipment, the number of operations required, the cost of labor, and the fact that the work was delayed by a lack of experience

SUBSEQUENT STUDIES

The average density of the finished surface, determined by the sand method was 120 3 lb per cu ft or 8 3 lb per cu ft more than the density requirement for this project It was assumed that this increased density was due to one or more of the following reasons overcompaction of the soil-cement mixture, an error in the average density of the finished surface as determined by the sand method, or an error in the density requirement

Therefore, Proctor moisture-density tests were made on samples taken from each of the remaining five increments, prior to compaction, in an effort to determine the reason for the density increase noted above. The average density secured by these tests amounted to 118 6 lb per cu ft or only about 1 per cent less than the average density obtained by the sand method, thus discrediting the first two assumptions and indicating that the third assumption was true However, since the job was underway and because of the time required to duplicate the control tests, the project was completed on the basis of the preliminary data

After the job was completed, a composite sample was made in the laboratory from 60 samples of the soil on this project, taken at 100-ft intervals just before the cement was added Ten per cent of cement, by weight, was added to this sample and moisture-density tests made by the Proctor method The curve established by these tests showed a maximum density of 125 5 lb per cu ft and an optimum moisture content of 9 5 per cent The densities determined on the job by the Proctor method were then plotted, at their respective moisture contents, with the curve mentioned above, which showed that the individual tests made in the field checked very closely the laboratory results for the composite sample These two studies showed that the material in the finished surface was not compacted to its maximum density, probably due to the fact that it had been compacted at 6 5 per cent in excess of its optimum moisture content, that there was no appreciable error in the densities obtained for the finished surface by the sand method, that there was no appreciable error in the densities obtained in the field by the Proctor method, and that the density and optimum moisture content requirements for this project were undoubtedly in error due to the fact that the preliminary sample selected for the control tests did not represent the material on the project

Since gradation is unquestionably an important factor in the density of soils, and especially so with respect to surfaces of this type, mechanical analyses and hydrometer tests were also made in the laboratory on each of the 60 samples mentioned above The average results for these tests indicated that the soil on this project consisted of 74 per cent sand, 15 per cent silt, and 11 per cent clay, or 15 per cent more sand, 9 per cent less silt, and 6 per cent less clay than was present in the preliminary sample selected for job control This difference in gradation and character of the material undoubtedly proves that the sample upon which the job requirements were based was not representative of the soil on this project

CONCLUSIONS

1 Preliminary samples on which the job control data are to be based should not be taken until the grading operations have been completed

2 Extreme care should be exercised in taking the samples on which the job control data are to be based The locations at which the samples are taken should be carefully selected and a sufficient number of samples secured to represent satisfactorily the soil types and variations within these types

3 The equipment for preparing the soil, mixing the cement, distributing and incorporating the water, and compacting the mixture, should be such that the actual time of processing will be reduced to the minimum

4 Comprehensive field tests should be conducted during the progress of the job

EXPERIMENTAL SOIL-CEMENT STABILIZATION AT CHEBOYGAN, MICHIGAN

By W S Housel

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During the summer of 1936 the Michigan State Highway Department undertook the experimental soil-cement stabilization of a section of the Shore Line Highway near Cheboygan The Portland Cement Association cooperated in the project by conducting preliminary laboratory tests to supplement those conducted by the Research and Testing Division of the State Highway Department and also assisted in the control and supervision during construction

Construction was started on August 15 Because of frequent rains the first section of 350 ft was not processed until August 25 The last section of 700 ft was processed on October 22 and the project was discontinued on November 6 when it appeared hopeless to attempt further construction in the face of adverse weather conditions Special mention is made of the weather as it constituted the greatest difficulty encountered in the work There were 22 days out of the