tory study of moisture-density relations requires much less time and might be supplemented by a compression test or something similar as routine procedure. In addition, it appears that the difficulty of representative sampling necessitates control of compaction by field control tests conducted in the field in conjunction with each day's work In this case the preliminary laboratory tests lose much of their value as control media and are useful only in preliminary design

While it is perhaps too early to eliminate the more elaborate laboratory investigations now being attempted, it appears that there is sufficient evidence to outline the following tentative procedure which gives promise of being adequate for field control

Preliminary to Construction

1 Mapping of soil series by preliminary survey
2 Classification of soils by correlation of soil survey and grading operations
3 Mechanical analysis of samples taken from finished grade at frequent intervals to supplement classification made from the soil survey
4 Preliminary determination of void characteristics of representative soils by moisture-density tests
5 Design of the soil-cement mixture by the cement-voids ratio, proportioning soil and cement by absolute volumes
6 Molding of cylinders for compressive strength tests or for durability tests as long as the latter are needed

During Construction

1 Tests on raw soil, measurement of moisture content and loose volume measurement of scarified soil to control depth of scarification
2 Tests on final soil-cement mixture, moisture determinations to control moisture content, compaction test of final mixture to check proportions and mixing, and for a control of compaction in the road Specimens should be preserved for compression test

In connection with the procedure preliminary to construction it may be pointed out that items 4, 5, and 6 may all be performed in the field if the design of the mixture could be standardized, as for example at a cement-voids ratio of 15 per cent Determination of the total voids could be based on the moisture-density relations for the raw soil, a correction made for estimated bulking, and the cement content fully determined When sufficient data are available to establish a relation, perhaps between compressive strength and durability, the field cylinders could be cured in the field and sent to the laboratory for test The control procedure in soil-cement stabilization would then correspond quite closely to the present procedure in controlling operations in concrete construction

SOIL-CEMENT STABILIZATION IN MISSOURI

By F V Reagel

Engineer of Materials and Tests, Missouri State Highway Department

The progress report on laboratory work with soil-cement mixtures published in May 1936 by the Portland Cement Association included the results of treating some typical Missouri clay soils These results encouraged the Department to test the practicability of such treatment in certain field test sections which resulted both in demonstrating a place for such a road type and in developing improved construction procedure

Test sections consisted of worn out gravel roads which were programmed for improvement consisting of base construc-

tion to support thin bituminous surface treatments

ROUTE 5, TIPTON TO FORTUNA, MONITEAU COUNTY

The first section consisted of cement stabilization of 1 4 miles of roadbed on Missouri Route 5 north of Fortuna in Moniteau County Representative samples of the soil (Table 1) were submitted to the Portland Cement Association and upon their resulting recommendation (Table 2) the work was undertaken in the late Fall of 1936 by the State maintenance forces The Materials Bureau was assigned to study and control the mixtures

From the data presented in Table 2 it was decided to use 12 per cent of cement by volume for the entire road, and that the optimum moisture content should be varied to meet field conditions, using Table 2 as a guide

The surface was to be 22 ft wide except the last 600-ft section, which was 30 ft Grade stakes were set at 50-ft intervals in order to check the depth of processing at all stages of the work After the existing roadbed was scarified to a depth of six inches further pulverizing, due to the clay encountered, developed into an extended operation requiring the use of 24-in farm disks, spike tooth cultivators and unique field cultivators, called "quack grass diggers" This implement also proved useful later in mixing the cement and the water Preparation of the roadbed required a full day's work per section On the next day the water was applied, the water and cement mixed with the soil in the amounts prescribed and the final mixture spread and compacted to

TABLE 1

SHOWING GRAIN SIZE AND TEST CONSTANTS FOR FINAL TESTS OF MISSOURI SOIL SAMPLES, ROUTE 5, MONITEAU COUNTY

Test Constants								Grain Size Per Cent of Total Sample						
P C A Lab No	Liquid Limit	Plastic Limit	P I	F M E	Shrinkage Limit	Shrinkage Ratio	U S B P R Soil Group	Pass 1 in Ret ¾ in	Pass ¾ in Ret ¼ in	Pass ¼ in Ret #10	Coarse sand 2 0 to 0 25 m m	Fine sand 0 25 to 0 05 m m	Silt 0 05 to 0 005 m m	Clay less than 0 005 m m	Colloids* less than 0 001 m m
27	46 5	23 8	22 7	36 2	13 9	1 90	A-7 (Clay loam)	8 27	13 25	0 98	11 4	8 6	31 3	26 2	11 1
29	34 7	21 1	13 6	25 5	19 0	1 76	A-4 (Loam)	7 05	15 55	7 45	9 6	9 35	33 5	17 5	5 5
33	54 0	21 1	32 9	29 0	16 1	1 85	A-6 (Clay)	6 55	7 85	1 78	2 0	8 9	33 7	39 2	13 6

* Also included in clay fraction

TABLE 2

CEMENT RECOMMENDED FOR EACH SOIL COVERED IN TABLE 1

P C A Soil No	Cement Content by Volume, Per Cent	Optimum Moisture Content, Per Cent	Maximum Density, lb per cu ft
27	12	15 5	111
29	10	13 2	114
33	13	16 5	103

grade. Due to uncertain weather conditions and the realization that rainfall following the preparation would result in loss of all the work done in pulverizing the roadbed materials, the work was protected by covering the section with Sisalkraft paper This detail proved to be successful and almost essential for the time of the year in question which was from October 30 to November 28, 1936

Cement was spotted along the road at the rate of four sacks equally spaced across the road at three foot intervals along the road The cement was spread by hand rakes Dry mixing of the cement with the pulverized roadbed materials followed and was continued until no concentration or segregation of the cement could be observed The equipment for this mixing consisted of the 24-in disks and field cultivators with spike tooth harrows in tandem Ordinary bituminous distributors were used for the several applications of water required to bring the moisture to or slightly above the optimum moisture content as predetermined One or more round trips of the cultivator and disks were made between applications of water After all of the required water had been added, wet mixing was continued until a uniform dispersion of the moisture to the depth of the loosened material was obtained

The material was then compacted with sheepsfoot tampers loaded so as to apply pressure of 100 lb per sq in This method of compaction resulted in a rough dented surface with one-half to one inch of loose mulch on top A motor blade finished off the irregularities and final compaction and smoothness were obtained by use of a three-wheel ten-ton roller A straw cover was spread over the completed surface as a protection from freezing and to reduce moisture loss during the curing period

The foregoing procedure required completion of individual sections on separate days so that in working a new section the turning of the equipment on a previously completed section was unavoidable In order not to mar the finished section approximately 25 ft adjacent to the new section were covered with 6 in of loose soil This protecting soil was later removed by hand However, these "turn arounds" are markedly rough and unsightly as compared to the rest of the road.

Fourteen sections comprising 1 52 miles were completed before the inclement weather and lateness of the season stopped the work

The prevailing weather conditions were unfavorable The average daily maximum temperature during the entire construction period was 56°F, and the average daily minimum was 27°F Below freezing temperatures were recorded during the night following construction on 12 of the 14 sections Rainy weather also delayed the work and the 14 daily sections were spread over 28 working days

Cement was applied so as to give 12 per cent by volume for the designed 6 in compacted thickness It soon developed that the processing was loosening the roadbed to a greater depth than anticipated and the final compacted thickness varied from 6 to 10 in , averaging $7\frac{3}{4}$ in with a corresponding variation in cement content of from 12 to 7 2 per cent, averaging 9 3 per cent

The optimum moisture content of 16 per cent as recommended from laboratory tests was increased, after field trial and observation to 19 per cent and with slight variation was held at that point Moisture tests were made at the completion of the dry mixing for determining the amount of water to be added Additional moisture tests were made during wet mixing in order to secure the optimum moisture content At this stage density determinations on samples were made by the Proctor method A split mold was used and the cylinders were

cured and saved for further study and durability tests

In order to obtain accurate measurements of compacted thickness the wet mixed material was removed from selected points and an 18-in square of heavy wrapping paper was placed on the undisturbed subbase and buried After compaction the depth to the paper could be definitely measured

The density of the finished roadbed was also determined by sounding with a 4-in posthole auger The material removed was carefully retained and weighed and the moisture content determined The quantity of dry standard Ottawa sand required to backfill the hole was used to determine the volume of the compact material recovered From these data the dry weight per cubic foot obtained was determined The Proctor test gave an average result of 103 2 lbs , the roadbed measurements averaged 102 4 lbs

This was a new type of construction which of course necessitated breaking in a crew Operations were also hindered by rainy weather during the first part of the construction period As a result, the cost on the first two sections was 75 cents per square yard As the crew became more proficient costs decreased until on the last two sections the cost was 41 cents per square yard

The total cost of the project was $9,214 52 or $0 457 per square yard This covers only time and material used in construction and does not include the cost of moving in equipment, preparing and maintaining detour, moving out equipment, shouldering and engineering Cost data are given in Table 3

The total cost of the project, including moving in equipment, preparing and maintaining detour, moving out equipment, shouldering and engineering was $12,870 23, making the cost per square yard $0 639

This section was allowed to stand without surface treatment until the middle of the summer of 1937 During this time no base weakness developed; however, considerable surface scaling occurred, approaching pot-holes in some spots particularly at "turn-arounds" These holes were fairly successfully hand-patched with soil-cement mixtures However, a light surface treatment was not effective in correcting the surface defects that developed and a later bituminous drag treatment was necessary to give the section good riding quality

In evaluating the results of this section it should be noted that the work was seriously handicapped by the lateness of the season and the accompanying inclement weather A substantial part of the cost can be charged to long delays as well as to inexperience with this type of construction

TABLE 3

COST DATA—MONITEAU COUNTY

Pulverizing	$1,055 99
Cement (including hauling and spreading)	6,145 33
Mixing (Dry)	239 51
Mixing (Wet)	837 00
Packing	185 47
Final Finish	92 92
Turn-around	97 06
Curing, Moist Straw	271 32
Supervision (not including engineering)	289 92
Total	$9,214 52

ROUTE 100TR, WASHINGTON—NEW HAVEN, FRANKLIN COUNTY

In connection with an extensive field study of variations in materials and methods in base construction and soil stabilization on Route 100TR, Franklin County, two miles of soil-cement stabilization were built These sections were constructed to obtain definite cost and manipulation data as well as to determine the service values of the various suggested

types of stabilization under uniform field conditions The subgrade consisted almost entirely of the Union Silt Loam, a loessial type soil of the A-4 group The original wearing surface consisted of approximately one inch of mixed stone and gravel rather poorly bonded Samples representing a six-inch depth were taken in duplicate and submitted to the Highway Materials laboratory and to the Portland Cement Association for tests and recommendations Typical test results showing the character of the material are given in Figures 1 and 2 and Table 4 On one section, with two variations in cement content, namely, six and eight per cent by volume, the preparation, mixing and spreading was carried on in practically the same manner as on the previous work on Route 5, Moniteau This method is referred to as the "Road-mix" method On the other section, with the same variations in cement content, the "Traveling plant" method, consisting of a Barber-Greene traveling plant and an attached Barber-Greene finisher for mixing and spreading, was used

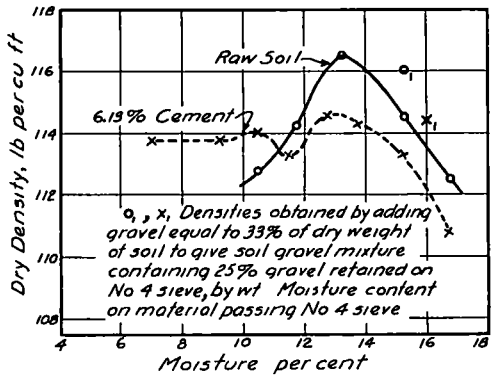

Figure 1. Moisture-Density Relations. The raw soil is that part passing the No. 4 sieve The cement mixture contains 7 05 per cent cement by volume of soil, 6 13 per cent by weight of dry soil Franklin County, Station 970 Route 100, Sample No 151.

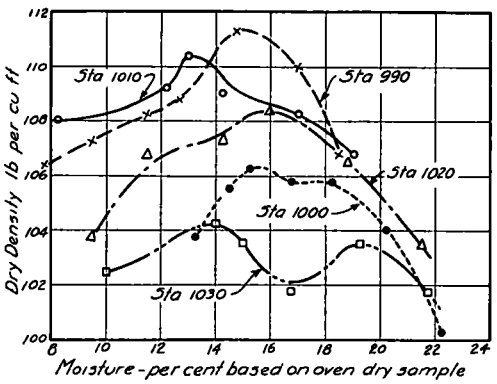

Figure 2. Moisture-Density Relations The curves are for that fraction of the soil sample which passed the ¾-in. sieve, with enough cement added to give approximately 7 per cent by volume of the mixture at maximum density.

TABLE 4

ROUTE 100TR, FRANKLIN COUNTY

Typical gradation and soil analyses of original materials

Screen or Sieve	Per Cent Passing
1-in round	100
¾-in round	98
½-in round	95
No 4	89
No 20	84
No 40	81

Clods retained on ½-in round = 24%

Materials passing No 40 mesh sieve

Lower liquid limit—35
Lower plastic limit—17
Plasticity index—18
Silt—Diameter 0 5 to 0 005 mm —56%
Clay—Diameter smaller than 0 005 mm —30%
Colloids—Diameter smaller than 0 001 mm —17%

Road-Mix.

This work benefited by the previous experience on Route 5, Moniteau and progressed smoothly with good organiza-

tion in both equipment and procedure This section was divided in two subsections, No 44 having 6 percent cement and No 45 having 8 percent cement The following is a list of the equipment used

Preliminary scarifying and pulverizing
1—60 Crawler type tractor
1—35 " " "
1—Block Scarifier
1—Double 24-inch disc
1—Motor patrol

Cement Processing and Compaction
2—two-ton trucks
3—35 Crawler type tractors
2—Double 24-inch discs
1—Cultivator (quack-grass digger)
3—Distributors
2—Motor patrols
2—Sheepsfoot tampers (double units)
1—Spike tooth harrow
1—10-ton, three-wheel roller

A section one-quarter mile long was cement processed each day This required an average total working time of 15 hr and 38 min

This time, by operations was divided as follows

Distributing and spreading cement	2 hr 41 min
Dry mixing	2 " 49 "
Applying water and wet mixing	4 " 19 "
Constructing joint	0 " 38 "
Compacting and shaping	3 " 41 "
Smooth rolling	1 " 30 "

The average miles for the various types of equipment in order to process one mile are as follows

DRY MIX			WET MIX		
Disc	Cultivator	Motor Patrol	Disc	Cultivator	Motor Patrol
40	34	18	92	58	32

COMPACTING AND SHAPING

Sheepsfoot Tamper	Spike Harrow	Motor Patrol
50	*18	12

* The spike tooth harrow was attached behind the sheepsfoot tamper in order to eliminate the tamper marks preliminary to rolling with the flat wheel roller

Two rollings were necessary with the smooth roller in order to finish the surface

The average gradation of the material at completion of dry mixing and start of wet mixing is given in Table 5

TABLE 5

Openings	Percentage Passing Sec No 44	Percentage Passing Sec No 45
1½-in round	100 0	100 0
1-in round	100 0	98 3
¾-in round	98 7	94 8
½-in round	95 6	90 3
No 4 Sieve	90 6	84 5
⅜-in Sieve	89 0	82 4
No 20 Sieve	84 0	76 9
No 40 Sieve	81 2	75 1
Soil clods retained on ½-in round	26 9	24 6

The averages of the field test results are shown in Table 6 Density and weight per cubic foot were determined by the Proctor method

The use of straw for curing was abandoned on this section Sisalkraft paper was used for curing a section approximately 150 ft in length The balance of the surface was primed with 0 15 of a gallon of TC-2 tar on the day following construction

Developments in construction procedure produced some interesting features The main criticism of former work concerned the unsatisfactory condition resulting from the "turn-arounds"

incident to each day's run. On these sections the material to be treated, next to the header dividing it from the completed previous day's run, was bladed forward for all the processing. Just previous to compaction the header was removed and the material was bladed back, shaped and compacted to conform with the previous work. Finishing with the flat-wheel roller removed practically every evidence of the joint.

construction of the mile followed a uniform procedure.

The existing road surface was scarified to an approximate depth of six inches with a block scarifier, after which the materials were disked and cultivated with double sets of 24-in. farm discs and "quack grass diggers". After the material was well pulverized, it was placed in two similar windrows along each edge of the road and a final check taken on the

TABLE 6

Sec. No.	Cem. Design	Cem. Actual	Average Compacted Thick.-in.	Moisture		Density at final Moisture	Roadbed Density	Optimum Moisture	Maximum Density
				Initial	Final				
	%	%		%	%			%	
44	6.0	6.36	5.66	8.3	16.2	101	100	14.5	104
45	8.0	7.04	6.82	9.2	15.2	99	98	15.9	103

Figure 3. Close-up of surface of 8 per cent cement soil-cement mixed-in-place base after 7 days of cover with Sisalkraft paper. Note only very slight incipient cracking of surface.

Construction cost data are shown in Table 7. The cost of armor coating was approximately $1,500.00 per mile.

Traveling-Plant Mix:

The efficiency of the traveling plant in mixing soil, cement and water was tested on another one mile section. This section was sub-divided into equal sections of six and eight percent cement but the depth. The windrows were joined again along the centerline of the road. Usually one-quarter of a mile of pulverized windrow was kept in advance of the machine and Sisalkraft paper was on hand to cover the pulverized windrow in case rain fell. Sacks of cement were placed at the specified rate per station and were emptied on top of the windrowed material. The pulverized material and cement were partially mixed before entering into the pugmill by the action of the spiral feeders to the bucket elevator and by dumping into the closed storage hopper above the apron feeder. The amount of water added to the pugmill was slightly higher than the optimum required as allowance was made for evaporation before final compaction was completed.

The pugmill discharged the mixed materials directly into a hopper on the finishing machine which spread the materials over the undisturbed subgrade. Immediately behind the finishing machine the mixed material was sheepsfooted in short stretches until the tamper feet did not penetrate more than one to two inches from the top of the unconsolidated surface. Final shaping of the

TABLE 7

FINAL COST DATA—ROUTE 100TR FRANKLIN COUNTY

Sections 44–45, Road Mix, Net Length 5185 ft.

	Labor	Equip. Rental
Reshaping Roadbed	$12.46	$18.22
Scarifying & Pulverizing	70.88	91.51
Hauling & Spreading Cement	267.75	43.55
Dry Mixing	40.30	105.39
Wet Mixing	52.80	120.20
Compaction	14.60	63.55
Final Shaping & Rolling	44.05	44.40
Water (72590 Gal.)	54.30	248.20
Total	$557.14	$735.02

Total Cost of Manipulation for Section	$1,292.16
Total Cost of Manipulation per Station	24.90

Section 44, 6 per cent Cement, Net Length 2636 ft.

Manipulation—26.36 Sta. @ 24.90	$656.36
Cement	877.14
Tarpaulins for Covering Cement	64.07
Other Equipment, Gas, Oil, and Grease	45.95
Engineering	80.70
Supplies, Tools, & Repairs	30.90
Signs & Barricades	6.66
Supervision	128.09
Supply Truck, Freight, etc.	67.88
Total	$1,957.75
Cost Per Mile	$3,923.35

Section 45, 8 per cent Cement, Net Length 2549 ft.

Manipulation—25.49 Sta. @ 24.90	$635.80
Cost of Cement	1,142.46
Tarpaulins for Covering Cement	64.07
Other Equipment, Gas, Oil, and Grease	44.50
Engineering	78.20
Supplies, Tools, & Repairs	29.95
Signs and Barricades	6.45
Supervision	123.98
Supply Truck, Freight, etc.	65.71
Total	$2,191.12
Cost Per Mile	$4,536.48

surface was done with a motor grader. It was necessary to add a small amount of water to the surface at this stage of the operation as the mix on the surface was usually fairly dry. After the final shaping was done, a 7-ton roller made two complete passes over the width of the road.

Straw was used for curing, although a bituminous curing agent called "Curcrete" was used at the rate of 0.10 gallon per square yard in one place for experimental purposes. The straw was wetted occasionally with water. Due to hot weather and heavy local traffic this method of curing did not prove very effective. Where "Curcrete" was used there was slightly less early checking and cracking but after several weeks there was no apparent difference between the surfaces having straw or "Curcrete" curing. Both are probably good methods of curing, provided the straw is kept well dampened and covered over the entire surface and the application of "Curcrete" is sufficient to form a continuous film over the entire surface. The straw was raked onto the shoulders after 7 days and burned. Several weeks after the placing of the mix, one-half of the surface was primed with MC-1 and the other half with TC-2, each approximately 0.20 gal. per sq. yd.

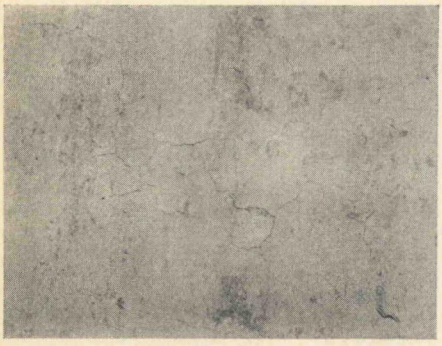

Figure 4. Incipient cracking of surface on 6 per cent cement soil-cement machine mix base. The cracks were of surface nature and approximately one inch deep. This surface later developed into a pitting and ravelling stage and a drag treatment was placed over it before sealing.

It was found necessary to place a drag treatment on the surfaces of the two machine mix sections because of the bad raveling which occurred before the seal coat work began. The riding surface was also wavy. This condition can be explained plausibly by the fact that the continuous operation of the machine required finishing and compaction in very short stretches. The stone for the surface treatment consisted of 60 lb. per sq. yd. of ¾-in. to ¼-in. limestone chats, 16 lb. per sq. yd. of ⅜-in. to ⅛-in. limestone screenings, and 0.65 gal. per sq. yd. of RC-3. This treatment filled in the raveled areas and corrected most of the waviness of the surface. The seal coat consisted of 0.25 gal. of 250 penetration asphalt and 25 lb. of ½-in. to No. 10 pea gravel.

TABLE 8

Section	Initial Moisture	Final Moisture	Density at Final Moisture	Final Density of Roadway
	%	%	*lb. per cu. ft.*	*lb. per cu. ft.*
6% Cement	9.1	18.8	99	97
8% Cement	11.2	19.6	100	96½

Section	Maximum Density	Optimum Moisture	Depths	
			Loose	Compacted
	lb. per cu. ft.	%	*in.*	*in.*
6% Cement	106	18.1	8.5	5.4
8% Cement	108	18.0	7.1	4.9

Average field test results are given in Table 8. Density and weight per cubic foot were determined by the Proctor method.

Construction cost data for the 6 and 8 per cent cement sections by the Barber-Greene traveling plant are shown in Table 9. The cost of drag treatment was $1,708.35 per mile and of armor coating was approximately $1,500.00 per mile.

ROUTE 13, ST. CLAIR COUNTY, OSCEOLA NORTH

This section of road-mix soil-cement stabilization is of interest in that it is the only Missouri section constructed under contract. The project, which is 4.975 miles long, was commenced September 18 and completed October 15, 1937. The cement processing was done in 20 working days. The longest section processed in one day was 1600 ft., and the average length processed per day for the entire project was 1313 ft. The soils encountered varied in character as is indicated by the typical test results in Table 10.

TABLE 9

FINAL COST DATA—ROUTE 100 TR—FRANKLIN COUNTY

Sections 41, 42, 43, Traveling Plant, Net Length 5276.35 ft.

	Labor	Equip. Rental	Materials	
			Straw	Curcrete
Scarifying & Pulverizing	$124.08	$297.48		
Hauling & Spreading Cement	162.75	85.15		
Spreading	40.15	216.94		
Compaction	30.50	85.29		
Final Shaping & Rolling	41.50	86.29		
Curing (49700 Gal.)	63.99	128.00	$10.80	
Total	$462.97	$899.15	$10.80	

Total for Section Manipulation	$1,372.92
Cost of Manipulation Per Station	26.02

Section 41, 6% Cement, 5 in. Thick, Net Length 1256.35 ft.

Manipulation—12.56 Sta. @ 26.02	$326.81
Mixing—458 Cu. Yds. @ 30¢	137.40
Water—16506 Gal. @ 40¢ per 100	66.02
Cement—214½ bbls. @ 1.98	424.71
Curcrete	25.92
Cost of Pumping Water	14.85
Labor for Mixing	54.40
Freight and Unloading on B. G. Finisher	54.98
Freight and Unloading B. G.	11.97
Windrow Cover	21.11
Other Equipment, Gas, Oil, & Grease	21.92
Engineering	38.50
Supplies, Tools, & Repairs	14.73
Signs & Barricades	3.18
Supervision	61.09
Supply Truck, Freight, etc.	32.38
Total	$1,309.97
Cost Per Mile	$5,504.07

TABLE 9—*Concluded*

Section 42—8% Cement, 6 in. Thick, Net Length 1350 ft.

Manipulation—13.5 Sta. @ 26.02	$351.27
Mixing—543 Cu. Yds. @ 30¢	162.90
Water—17755 Gal. @ 40¢ per 100	71.02
Cement—303½ bbls. @ 1.98	600.93
Cost of Pumping Water	17.62
Labor for Mixing	64.40
Freight and Unloading on B. G. Finisher	59.14
Freight and Unloading B. G.	12.88
Windrow Cover	22.71
Other Equipment, Gas, Oil, & Grease	23.58
Engineering	41.45
Supplies, Tools, & Repairs	15.85
Signs and Barricades	3.42
Supervision	65.71
Supply Truck, Freight, etc.	34.83
Total	$1,547.61
Cost Per Mile	$6,045.35

Section 43—6% Cement, 6 in. Thick, Net Length 2670 ft.

Manipulation—26.7 Sta. @ 26.02	$694.73
Mixing—887 Cu. Yds. @ 30¢	266.10
Water—35094 Gal. @ 40¢ per 100	140.38
Cement—453½ bbls. @ 1.98	897.93
Cost of Pumping Water	28.71
Labor for Mixing	104.80
Freight and Unloading on B. G. Finisher	116.88
Freight and Unloading B. G.	25.40
Windrow Cover	44.80
Other Equipment, Gas, Oil, & Grease	46.49
Engineering	81.70
Supplies, Tools, & Repairs	31.25
Signs and Barricades	6.75
Supervision	129.63
Supply Truck, Freight, etc.	68.70
Total	$2,684.25
Cost Per Mile	$5,315.35

In addition to the variations in soil another new condition was introduced by the fact that a considerable portion of the road consisted of the remains of a failed oil mat surface which could not be entirely removed. In some portions of the section bituminous treated materials were found in the mix.

The contract specified 8 percent cement by compacted volume of the finished road, 6 in. thick. However, during the course of construction an exceptionally heavy clay soil (Lab. No. 77) was encountered on 1.12 miles and the cement on this portion of the project was increased to 10 percent.

Field test methods recommended by the Portland Cement Association were

used to control moisture-density relationships during construction The average results obtained are as follows.

Percent Moisture		Dry weight at Optimum Moisture	Finished Base	Thickness of Base
Initial	Final			
		lb per cu ft	*lb per cu ft*	*inches*
8 6	14 1	113	105	7 5

The outstanding feature on this project was the trial and adoption of a different piece of equipment for loosening the roadbed, dry mixing and wet mixing. Considerable difficulty had been experienced in the past, in controlling the depth and uniformity of scarification This same difficulty was encountered at the beginning of this job and it was suggested that a gang plow be given a trial Two 14-in plows in gang were tried out on the fifth section constructed The roadbed on this section was first scarified with a Duoclaw scarifier and then plowed The plow was pulled by a R D 4 Diesel caterpillar tractor Subsequent investigations showed that the scarified depth could be controlled more accurately and a more uniform subgrade cross-section obtained by this method The plow was used very effectively from time to time during the pulverizing operations to turn the cloddy material to the surface, where it was broken down more readily by the discs

The plow was later tried in combination with the discs in the dry and wet mixing operations The results were very satisfactory and the plow was used in place of the orchard cultivator, for these operations, on the remainder of the project The plow was definitely effective in turning over the material and in that way both moisture and cement could be brought to the same percentage in top and bottom so that no variation in set with depth could be noted This weakness had been observed on other sections. The total cost of the soil-cement stabilization section was $26,818 90 or $5,396 16 per mile, exclusive of surface treatment

TABLE 10

GRAIN SIZE

Lab No	Pass 1 in Ret ¾ in	Pass ¾ in Ret No 4	Pass No 4 Ret No 10	Coarse Sand 2 00–25 mm	Fine Sand 0 25–0 05 mm	Silt 0 05–0 005 mm	Clay less than 0 005 mm	Colloids less than 0 001 mm
75	8 7	6 3	5 9	9 1	23	33	14	7
76	0 7	1 5	0 7	4 1	12	56	25	15
77	6 6	7 8	3 4	5 2	16	33	28	19

TEST CONSTANTS

Lab No	L L	P L	P I	F M E	S L	S R	Group
75	25 5	18 8	6 7	22 1	15 6	1.82	A-2
76	28 5	20 1	8 4	25 3	16 6	1 75	A-4
77	41 7	18 6	23 1	31 2	12 3	1 94	A-6

SUMMARY OF PROJECTS IN THIS REPORT

(1) In examining the cost data of the various sections it was found that the cement cost, together with the handling charge, could be considered a fixed charge and can be closely approximated by the figure 2 5 cents per square yard for each percentage of cement used On this

basis, the other costs of the various sections can be compared by deducting the cost of the cement.

COST MINUS CEMENT

	Per Sq Yd	Per Mile
Route 5, Monteau County	$0 34	$4,350 00
Route 100, Franklin		
Road Mix	0 15	1,950 00
Machine Mix	0 27	3,450 00
Route 13, St Clair		
County	0 20	2,550 00

Part of the excess cost on Route 5, Monteau, has already been explained, however, another item is the character of the soil, the proper preparation of A-6 clay for treatment requiring considerable more manipulation than the readily friable A-4.

(2) The costs as given are reasonable and in the range of what one can expect to pay for a reliable base in the low cost program

(3) Some surface treatment to provide a wearing course is required before putting the road under traffic

(4) The results obtained do not appear to justify the extra cost of the machine mixing as carried on in this case

(5) In the processing it developed that by proper care and provision the objectionable conditions that develop on "turn-arounds" could be eliminated Another development in processing indicates that the use of gang plows in turning over the material during the disking and mixing operations is more effective in preparation of the material and in uniform mixing than the "Orchard Cultivators"

(6) With good organization it appears that a complete crew of men and equipment will complete, as an average, one quarter mile per working day

SOIL-CEMENT BASE, WAYNE COUNTY, IOWA

BY FRANK L DAVIS

Resident Engineer, Iowa State Highway Commission

During 1937, 1 64 miles of soil-cement stabilization base were built in Wayne County, Iowa by the State Highway Commission The section had been maintained with a traffic bound gravel surface since 1923

The new base course was built 26-ft wide, 4-in deep and with a finished crown of 5-in The material for the base was secured by scarifying the surface to the depth necessary to produce the required yardage of material About 60 per cent of the original gravel surfacing material was recovered and used

To make the final 4-in depth, 2127 cu yd. of material per mile were required from the road bed

Cement was mixed with the base material in the ratio of 1 to 10 by weight The optimum moisture content was found to be 11 per cent, which required the application of 5 09 gal of water per sq yd less the moisture contained in the material

The characteristics of the material in the base are given in Table 1

The job was done on contract by the road mix method

The base material was taken from the road bed with two No 11 auto patrols with scarifier attachments By removing half of the scarifier teeth and setting the rest to the correct depth below the scarifier block, it was possible to scarify to the full depth by running the scarifier block tight to the road surface The operation followed a heavy rain and by using one patrol to pull the other machine with the scarifier, the material was loosened to the full depth in one opera-