passing No. 4 sieve, should be equal to any soils of finer grading or pulverization, and since practically all of this heavy clay soil (except one stretch of heavy clay with coarse sand) was readily pulverized to this new requirement, it is recommended that such specification be used in future pulverization projects on which "modified soils" are to be produced. Or, that practical grading limits for the soil to be treated be predetermined and wider limits provided if necessary.

It is recommended that density of completed work be specified as the percentage of the density of "five hr." delayed compaction.

No protection or curing was specified for this work. It is believed, however, some provision for protection of cement mix in progress should be provided. On one section heavy rain fell on the finished mix just as rolling started. Subsequent tests indicated the volume change values were not as designed. Two per cent additional cement was reprocessed in a portion of the section, and 5 per cent in the remainder.

RESEARCH SECTIONS

Three sections for future comparison of results were provided in soils of a type requiring treatment. At these locations no cement was added to the raw soil.

One of these sections was brought to optimum moisture and compacted with sheepsfoot rollers (Table 2).

Half of another section was completed as above and the remainder was sprinkled without moisture control, and rolled with the sheepsfoot roller (Table 3).

On the third section, half was compacted at optimum moisture with sheepsfoot rollers. The other half was shaped, sprinkled (no optimum control), and rolled with a 5-ton tandem roller, as provided in the State standard specification for preparation of subgrade for pavement.

DATA

Table 5 summarizes the laboratory test results for all sections of the work.[2]

[2] Complete details of field and laboratory tests for all sections and for each cement used are on file with the Highway Research Board and available on special inquiry.

Additional data on the moisture content of the "modified soil" at the time of placing the concrete pavement and on the hours of rolling required or performed are on file with the Oklahoma State Highway Commission.

DISPERSION OF SOILS AND SOIL-CEMENT MIXES

By E. J. Sampson and H. G. Henderson

The original purpose of this experiment was to determine the difference, if any, in the results obtained in the mechanical analysis (A.A.S.H.O. T-88) of soil-cement mixes using standard sodium silicate as the dispersing agent, and other dispersing agents that might prove more effective in dispersing this type of material.

As the experiment progressed other interesting information became evident, and is included herein.

PROCEDURE

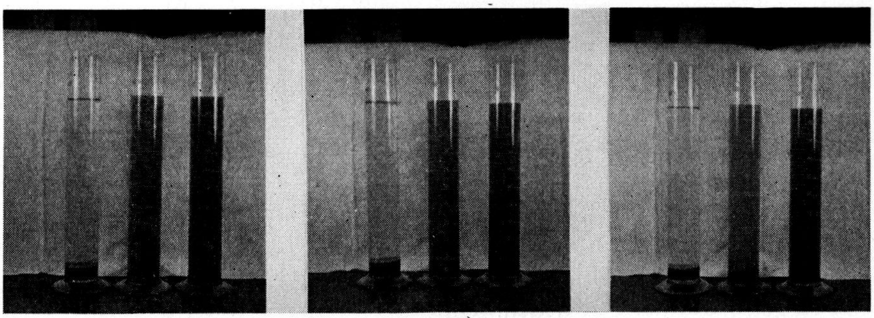
Five soils of known cement requirements for satisfactory modification (4.0, 5.3, 6.1, 10.8, and 13.8 per cent by volume) were selected.

Each soil was ground to pass the No. 4 sieve, mixed with the required amount of cement and water, and placed in a bucket having a tight fitting top. The bucket was shaken vigorously at half-hour intervals over a period of five hours, when the sample was removed and compacted at the optimum moisture content in the Proctor mold using the Kansas modified compaction hammer.

Two full size Proctor specimens were molded of each soil-cement mix to provide material for analysis at 7, 14, 28, 90-day and 1-year cure. The specimens were immediately removed from the mold, and placed in damp sand to cure. The material for each series of tests was cut from the specimen, leaving the balance intact to continue curing.

All tests were conducted according to A.A.S.H.O. (T-87 to T-94), except that sodium oxalate or sodium carbonate was used as the dispersing agent in the mechanical analyses. These two agents were made up as follows: A saturated solution of sodium oxalate and a 3.7 per cent solution of sodium carbonate. This sodium carbonate solution was selected so that the density of these two agents and the standard sodium silicate would be approximately the same. Except where noted, 20 cc. of dispersing agent were used.

As the work progressed additional possibilities became apparent and the tests were divided into four series, each designed to indicate some characteristic. These series and their individual remarks follow.



1 2 3 4 5 6 7 8 9

Figure 1. Soil cement suspensions after 24 hour sedimentation. Cured seven days before analysis.

Photo. No.	Cement %	Dispersing agent	Coarse sand %	Fine sand %	Passing No. 200 %	Silt %	Clay %	Colloids %
1	4.0	Sodium silicate....	11.4	59.2	45.6	28.8	0.6	0.6
2	4.0	Sodium oxalate....	16.0	45.8	47.6	30.8	7.4	4.5
3	4.0	Sodium carbonate..	16.0	45.2	48.8	32.4	6.4	1.5
4	5.3	Sodium silicate....	11.6	40.9	54.2	45.6	1.9	1.5
5	5.3	Sodium oxalate....	7.2	48.0	52.6	36.8	8.0	3.2
6	5.3	Sodium carbonate..	9.6	41.0	59.6	40.4	9.0	4.3
7	6.1	Sodium silicate....	15.6	49.4	41.2	33.1	1.9	0.5
8	6.1	Sodium oxalate....	16.2	51.8	40.0	26.1	5.9	2.5
9	6.1	Sodium carbonate..	15.0	51.7	42.2	25.5	7.8	4.5

Effect of Different Dispersing Agents: At least three analyses were made for each soil and soil-cement mixture using a different dispersing agent in each analysis, sodium silicate, sodium oxalate, and sodium carbonate. Table 1 shows these results on mixture cured 14 days. Three photographs of soil-cement suspensions at the end of 24 hours sedimentation, and their mechanical test results are shown in Figure 1.

Variation in Quantity of Dispersing Agent: This series of tests was made on soil-cement mixes cured for 14 days, using double portions (40 cc.) of the dispersing agents. Upon the completion of these tests and a review of the results, another series was run, using either larger or smaller quantities of dispersing agent depending upon the results obtained in the previous tests. This series was intended to furnish preliminary information on the feasibility of conducting future experiments to determine the optimum quantity of various dispersing agents.

Effect of Curing Soil-Cement Mixes: This series of tests was made on material taken from the specimen at the desired curing time. It was intended to use all three dispersing agents on this series, but due to the scarcity of material in some instances, it was impossible to complete the tests using the various agents. For that reason only those tests using sodium silicate are included in this report. See Table 2.

Effect of Prewashing Soil-Cement Mixes: This series was made on material cured 28 days, to permit more complete hydration of the cement, and thus to more nearly simulate the action of water on the modified soil-cement subgrade, and, to indicate the permanency of this transition.

The 50 g. sample for mechanical analysis was stirred in 200 cc. of distilled water, allowed to settle and the clear liquid decanted. This process was repeated for 7 extractions, all extracts being tested for pH values by the colorimetric method. Upon completion of the washing process the mechanical analysis was completed. Triplicate samples were run of each material, using each of the three dispersing agents.

Data: Typical data obtained from these tests, of which there were 145, are given in Tables 1, 2 and 3 and Figure 1.

CONCLUSIONS

Effect of Different Dispersing Agents: These data taken from 75 analyses using 20 cc. of dispersing agent, and 28 analyses using other than 20 cc., a total of 103 including both raw soils and soil-cement mixes, indicate in general an appreciable difference in the effectiveness of the dispersing agents used. The agents in the order of their ability to disperse these raw soils and soil-cement mixes are sodium carbonate, sodium oxalate and sodium silicate.

Visual inspection of the hydrometer tests indicated a slight degree of flocculation in some soil-cement mixes; however the sieve analysis showed in all cases an actual increase in particle diameter or formation of more or less permanent clusters resulting in a coarser gradation than that of the raw soil. See Table 1.

Effect of Variation in Quantity of Dispersing Agent: These data are based upon 45 analyses made using 10 cc. to 60 cc. of dispersing agent. They indicate that variation in the quantity of agent used produces marked variation in results. However, there were no discoverable correlations in the data; for instance, there appeared to be no correlation of the optimum quantities of the different dispersing agents for any particular material; for a given agent, the optimum quantity varied with the particular material. There seemed to be no relationship between the cement content of the soil-cement mix and the optimum quantity of any agent.

The number of analyses made were insufficient to disclose precisely the optimum quantity of dispersing agent in any case; hence the results serve only to indicate the complexity of the problem. Since it is recognized that the stability of a colloidal suspension depends upon both the nature and the concentration of substances present in solution, each soil presents an individual problem in the selec-

TABLE 1

EFFECT OF DIFFERENT DISPERSING AGENTS ON RAW SOILS AND ON 14 DAY CURE SOIL-CEMENT MIXTURES

Field No.	Cement %	Dispersion agent	Coarse sand %	Fine sand %	Passing No. 200 %	Silt %	Clay %	Colloids %
6155-A-I	0	Sodium silicate.......	16.2	39.4	54 0	38.9	5.5	2.1
-A-II	0	Sodium oxalate......	17.4	35.7	54.2	27.6	19.3	15.0
-A-III	0	Sodium carbonate....	15.2	38.7	54.0	27.8	18.3	14.1
-E-I	4.0	Sodium silicate.......	15.6	57.9	46.6	25.1	1.4	1.1
-E-II	4 0	Sodium oxalate......	15.8	46.0	46 2	31.8	6.4	3.1
-E-III	4.0	Sodium carbonate...	15.6	46.9	46.0	31.1	6.4	3.1
6158-A-I	0	Sodium silicate.......	10.6	28.6	69.8	45.2	15.6	7.0
-A-II	0	Sodium oxalate......	9.8	30.2	69.8	36.4	23.6	15.0
-A-III	0	Sodium carbonate....	10.0	27.1	70.4	39.3	23.6	15.2
-E-I	5.3	Sodium silicate	12.0	45.1	54 0	38.6	4.3	1.1
-E-II	5.3	Sodium oxalate......	9.6	42.5	59.4	40.6	7.3	3.1
-E-III	5.3	Sodium carbonate....	10.2	41.0	58.2	39.4	9.4	6.1
6157-A-I	0	Sodium silicate.......	15.4	38.9	55 6	29 9	15.8	5.0
-A-II	0	Sodium oxalate.....	12.4	36.6	56.6	25.2	25.8	17.2
-A-III	0	Sodium carbonate....	16.2	34 9	55.8	23.1	25.8	17.2
-E-I	6.1	Sodium silicate.......	12.0	57.4	38 8	29.3	1.3	1.1
-E-II	6.1	Sodium oxalate......	16.8	50.9	39.8	25.0	7.3	5.1
-E-III	6.1	Sodium carbonate ...	16.4	48.5	43.4	25.8	9.3	5.1
6156-A-I	0	Sodium silicate.......	1.2	15.2	97.6	41.7	41.9	22.3
-A-II	0	Sodium oxalate......	1.2	8 7	97.2	26.2	63.9	4.8
-A-III	0	Sodium carbonate...	1.2	9.4	97.0	26.3	63 1	4.3
-E-I	10.8	Sodium silicate.......	15 0	53 9	35.0	29.6	1.5	1.2
-E-II	10 8	Sodium oxalate......	12 2	56 2	35.6	30.1	1.5	1.2
-E-III	10 8	Sodium carbonate...	11.2	58 9	34 4	26.6	3 3	3.1
5368-A-I	0	Sodium silicate.......	4 8	13.9	92.8	46 4	34.9	13.1
-A-II	0	Sodium oxalate......	5.2	10.2	92 4	30.7	53.9	23.4
-A-III	0	Sodium carbonate ...	4.2	10.0	92.8	28.3	57.5	19.3
-E-I	13.8	Sodium silicate... ...	16.8	51.4	36.2	30.3	1.5	1.2
-E-II	13.8	Sodium oxalate......	17.6	49 3	39.0	31.7	1.4	1.2
-E-III	13.8	Sodium carbonate....	14.2	56.1	35.0	28.2	1.5	1 5

TABLE 2

EFFECT OF CURING ON SOIL-CEMENT MIXTURES DISPERSED WITH STANDARD SODIUM SILICATE

Field No.	Cement %	Curing time days	L. L.	P. L.	P. I.	Shrinkage limit	Ratio	Coarse sand %	Fine sand %	Passing No. 200 %	Silt %	Clay %	Colloids %
6155-A-I	0	..	31.7	18 7	13.0	16 1	1.88	16 2	39.2	54.0	38 9	5.5	2.1
-C-I	4.0	7	34.0	24.2	9.8	22 2	1 71	11.4	59.2	45 6	28.8	0 6	0.6
-H-I	4.0	28	31.3	26.0	5 3	24.2	1.65	16 0	53 1	41.6	29 3	1.6	1.6
-K-I	4 0	90	31 9	28 2	3.7	24.5	1 62	18.4	49.6	39.0	29.7	2.3	0 9
6158-A-I	0	..	33.9	20.5	13.4	16.3	1 85	10.6	28.6	69 8	45 2	15.6	7.0
-C-I	5 3	7	37.0	28.4	8.6	24 2	1 62	11.6	40.9	54 2	45 6	1.9	1 5
-H-I	5 3	28	35.4	29 4	6.0	29.2	1.48	7.8	49 7	48.2	39.0	3.5	2.5
-K-I	5.3	90	36 7	31 2	5.5	27.8	1.54	15.6	44.4	47.6	36 3	3.7	0.9
6157-A-I	0	..	35.1	18.7	16.4	15.0	1.88	15.4	38.9	55.6	29.9	15.8	5.0
-C-I	6 1	7	34 5	28.1	6.4	24.1	1.62	15.6	49.4	41 2	33.1	1 9	0.5
-H-I	6.1	28	34 4	30.2	4.2	27.1	1 54	18.2	54 8	33.2	25.4	1 6	1.6
-K-I	6 1	90	37.4	31 0	6.4	29.8	1.45	24.4	50.5	31.6	23 8	1 3	0.8
6156-A-I	0	..	57.2	27.9	29 3	14.5	1 92	1.2	15.2	97 6	41.7	41.9	22 3
-C-I	10.8	7	49.9	35.8	14.1	28.5	1.57	14 4	52.1	36.6	31.1	2.4	2.3
-H-I	10 8	28	44.5	37 7	6.8	29.6	1.50	22 4	54.4	26 6	21.4	1.8	1 8
-K-I	10.8	90	43.6	40.3	3.3	34 8	1.42	23 6	55.6	25.6	19 6	1.2	0 8
5368-A-I	0	..	87 0	37 8	49.2	10.3	2.13	4.8	13.9	92 8	46.4	34.9	13.1
-C-I	13.8	7	58 6	42.9	15 7	29.4	1.50	20.8	50.4	34.2	26 3	2.5	1.5
-H-I	13.8	28	54.2	45 9	8.3	36 8	1.37	24.6	50.2	27.2	22 7	2.5	1.6
-K-I	13.8	90	52.6	47 4	5.2	44.0	1.27	43.2	39.8	21 0	14 7	2.3	0.9

TABLE 3

EFFECT OF PRE-WASHING 28-DAY CURE SOIL-CEMENT MIXTURES FOR MECHANICAL ANALYSIS

Field No.	Cement %	Dispersing agent	Remarks	Coarse sand %	Fine sand %	Passing No. 200 %	Silt %	Clay %	Colloids %
6155-H-I	4.0	Sodium silicate...	....	16 0	53 1	41.6	29 3	1.6	1.6
6155-J-I	4 0	Sodium silicate...	Washed	12.6	55.9	39.8	28.8	2 7	0.0
6155-H-II	4.0	Sodium oxalate...	....	11 4	54 6	41.2	26 5	7.5	3.5
6155-J-II	4.0	Sodium oxalate...	Washed	16.2	48.9	43 2	28.9	6.0	1.6
6155-H-III	4.0	Sodium carbonate	....	11.6	53.0	43.0	28 7	6 7	3 5
6155-J-III	4.0	Sodium carbonate	Washed	16 0	48.5	45 2	29.5	6 0	3.5
6158-H-I	5.3	Sodium silicate...	....	7.8	49.7	48 2	39.0	3.5	2.5
6158-J-I	5.3	Sodium silicate...	Washed	12.0	51.7	51.6	34.7	1.6	1.6
6158-H-II	5.3	Sodium oxalate...	....	11.8	46.7	50.6	36.0	5.5	3.4
6158-J-II	5.3	Sodium oxalate...	Washed	8.8	51.4	49.8	34.4	5.4	0.9
6158-H-III	5.3	Sodium carbonate	....	12.6	42.5	51.0	36.6	8.3	5 5
6158-J-III	5.3	Sodium carbonate	Washed	11.0	44.5	51.6	37.1	7.4	2.9
6157-H-I	6 1	Sodium silicate...	....	18.2	54.8	33.2	25.4	1.6	1.6
6157-J-I	6.1	Sodium silicate...	Washed	19.0	61.6	32.6	18.9	0.5	0.0
6157-H-II	6.1	Sodium oxalate...	....	20 8	51.6	32.8	22.1	5.5	3.5
6157-J-II	6.1	Sodium oxalate...	Washed	14.0	61.0	31.2	19.6	5.4	2.9
6157-H-III	6 1	Sodium carbonate	....	18.4	54.3	34.6	21.8	5.5	3.5
6157-J-III	6.1	Sodium carbonate	Washed	18.8	54.4	34 2	22.4	4.4	1.9
6156-H-I	10.8	Sodium silicate...	....	22.4	54 4	26.6	21.4	1.8	1.8
6156-J-I	10.8	Sodium silicate...	Washed	26.2	53.3	25.4	18.4	2.1	1.5
6156-H-II	10.8	Sodium oxalate..	....	23.0	57.2	23.4	18.0	1.8	1.6
6156-J-II	10 8	Sodium oxalate...	Washed	20.4	57.1	29.0	20 4	2.1	0.0
6156-H-III	10.8	Sodium carbonate	....	23 8	52.8	27.0	16.0	7.4	3.6
6156-J-III	10.8	Sodium carbonate	Washed	22.4	52.9	28.4	15.3	9.4	3 9
5368-H-I	13.8	Sodium silicate...	....	24.6	50.2	27.2	22.7	2.5	1.6
5368-J-I	13.8	Sodium silicate...	Washed	29.4	49 6	25.4	19.3	1.7	0.6
5368-H-II	13.8	Sodium oxalate...	....	25 4	52.4	26.8	20.5	1.7	0.6
5368-J-II	13.8	Sodium oxalate..	Washed	26.0	51.9	28 8	21.3	0.8	0.0
5368-H-III	13.8	Sodium carbonate	....	27.4	51.0	25.6	19.0	2.6	0.7
5368-J-III	13.8	Sodium carbonate	Washed	28.6	44.0	27.8	24 7	2 7	1.6

tion of the most suitable dispersing agent and its optimum quantity. This fact places the question of optimum quantity beyond the scope of this experiment.

Effect of Curing Soil-Cement Mixes: These conclusions, based on 20 complete tests (see Table 2) can be conveniently enumerated as follows, in general, as the curing time increases:

1. The liquid limit remains practically constant.
2. The plastic limit increases.
3. The plasticity index decreases appreciably.
4. The shrinkage limit increases.
5. The shrinkage ratio decreases.
6. The centrifuge moisture equivalent decreases.
7. The field moisture equivalent increases.
8. The quantity of coarse sand increases.
9. The quantity of fine sand decreases.
10. The percentage passing the No. 200 sieve decreases.
11. The silt decreases.
12. The clay and colloids remain practically constant.

Effect of Pre-washing Soil-Cement Mixtures: Data for this comparison are taken from 30 analyses of 28-day cure material. The salient fact to be noted in this comparison is, that repeated washing did not greatly alter the behavior of the soil-cement mixes during the hydrometer analysis. In samples that showed a tendency to flocculate, pre-washing increased this tendency in some instances, and decreased it in others, but in general, the results were much the same as for the unwashed samples. It is significant that washing did not result in any disintegration of this modified soil, or destroy its alkalinity.

COST DATA

Litehiser, Ohio: The laying of the five miles of soil-cement pavement required 13 working days of approximately 10 hours each. The average length completed per day was 1,827 ft., with record days of 2,200 ft., 2,500 ft., and one day with a maximum of 2,600 ft. A total of 4,782 barrels of portland cement was used on the project, or 956 barrels per mile. Due to the hot dry weather during construction, 600,000 gallons of water were necessary, about one-half being used in the soil-cement mix and the other half being used in the finishing operations and for moistening the straw cover used for curing the pavement.

The cost of the soil-cement pavement and bituminous surface treatment, not including the grading or any other improvements to the road, is as follows:

	Cost per sq. yd.	Cost per mile
Soil-Cement Pavement	$0.38	$3,969
Bituminous Surface Treatment	.14	1,491
Total	$0.52	$5,460

TABLE 1

SOUTH CAROLINA COSTS

CONSTRUCTED BY CONTRACT

Length miles	Theoretical thickness in.	Cost per sq. yd	Year constructed
10 47	6	$0 495	Winter 1936 Spring 1937
7.7	6	0.480	Fall 1937 Spring 1938
13 7	6	0 50	Summer 1938
4.5	4	0.36	Summer 1938
6.4	4	0.35	Summer 1938
6.8	5	0.35	Summer 1938
0.8	6	0.50	Fall 1939

These prices include application of tar prime.

CONSTRUCTED BY STATE FORCES

1.4	4-6	$0.384	Fall 1935
2.1	6	0.368	Summer 1936

Mills, South Carolina: Prices on several projects are as follows, Table 1.

The costs of projects constructed by the State forces do not include insurance, taxes, etc. Average costs of wearing surfaces were:

Single treatment wearing surface of asphalt and stone approximately 10 cents per sq. yd.

Mixed-in-place treatment with 50 lb. of aggregate and cut-back asphalt approximately 16 cents per sq. yd.

Hicks, North Carolina: Cost data on North Carolina Projects are given in Table 2.

Woods, Maryland: The contract unit prices for the project were: 17 cents per sq. yd. for processing including water requirements and $2.20 per bbl. for cement. Cement contents of 8 and 10 per cent, 0.36 and 0.45 bags per sq. yd. of 6-in. compacted depth were used. The job averaged 0.396 bags or $0.218 per sq. yd. The total average cost for the entire project was $0.388 per sq. yd. or $4,097 per mile.

TABLE 2

NORTH CAROLINA COST DATA

County	Length mi.	Area sq. yd.	Cement used % by vol.	Av. cement used % by vol.	Unit costs per sq. yd.[1]		
					Cement	Hauling and processing	Total S-C base
Carteret..........	3.1	11,807	11.8	11 8	$0 30	$0.16	$0.46
Beaufort....	5 0	15,924	7 to 12	10.39	0.26	0.12	0 38
Wake............	2.1	24,582	8 to 12	9 91	0.27	0.14	0.41
Alamance.........	2 4	28,671	10 to 14	11.51	0.29	0.135	0.425[2]

[1] Built with State forces. Includes rental on equipment and cost of field testing.

[2] Convict labor used.