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 from standpoint of service, prompted the Oklahoma State Highway Commission, upon the advice and recommendation of Chief Engineer Van T. Moon, to authorize the stabilization of the subgrade of this project with portland cement, to a depth of six in. and to a width of one ft. each side of the proposed 9-in., 6-in., 9-in. by 20 ft. portland cement concrete surface. Construction procedures were to be similar to those used in building light traffic soil-cement roads.

SPECIFICATIONS

Grading and drainage construction was covered by the standard specifications with a special provision that fills of one ft. or more were to be placed in six in. layers, sprinkled as directed by the resident engineer, and rolled. Fills of one ft. or less were not placed in lifts or compacted under the grade and drainage contract.

However, extremely dry weather, under which part of the light fills were placed, made it necessary to sprinkle and compact 6 in. of sub-base directly beneath the proposed soil-cement treatment, throughout these portions. Revised grade line necessitated lowering cuts and raising fills from a minimum of a few inches to a maximum of approximately 4 ft.

"Cement modified" subgrade specifications were based upon those recommended by the Portland Cement Association, as developed and used for base course stabilization, or "cement-hardened soil" projects constructed in other States. The quantity of cement required was to be determined from tests on the soils to be treated, as in place in the top six in. of subgrade upon completion of grading operations. The percentage to be governed by the "volume changes" or "modifications" of the soil and not the "durability" or "hardening" characteristics.

Gradation requirements for soil upon completion of pulverization, were that 80 per cent by weight, exclusive of gravel and stone should pass a No. 4 sieve.

Moisture requirements for the completed blend of cement and soil were that prior to compaction, the moisture content should be within plus or minus 2 per cent of the optimum moisture as determined by the Proctor method.

The compaction requirements were that the uniform completed blend of soil, cement, and water should be compacted to a density equal to 90 per cent of standard dry density as determined by the Proctor method.

FIELD SOILS SURVEY AND DESIGN

In order to avoid any construction delays due to sampling and testing for design of the subgrade treatment, it was found desirable to provide a field soils laboratory.

SAMPLING OF COMPLETED GRADE

Accurate sampling is the first and most important step towards the realization of any comprehensive attempt to analyze soils and correct subgrade, because the value of the most precise and accurate test results can only be judged by the samples they represent. This phase of the soils work presented an unusually difficult problem because of the sharp variations in soil types present in excavations, and these being placed at random in the comparatively light embankment construction. It was very often impossible to assign definite station limits to any particular soil, and in many cases areas were selected having a predominance of a soil type of a more or less uniform combination of several types. After a study of the work as completed and observing grading operations, the method of composite sampling was resorted to, in most instances.

Such representative samples of the soil to be treated were pulverized to pass the No. 4 sieve and divided for the several portions required by use of a "sample splitter." Duplicate samples in all cases were immediately transmitted to the central laboratory for check test of the field analysis, and also to determine the centrifuge moisture equivalent and mechanical analyses.

The liquid limit, plastic limit, field moisture equivalent, shrinkage limit and shrinkage ratio of the raw soil were determined. From these results the volume ratios were calculated for the equations,

$$\frac{\text{Vol. at S.L.}}{\text{Vol. at F.M.E.}} \times 100$$

and

$$\frac{\text{Vol. at S.L.}}{\text{Vol. at L.L.}} \times 100.$$

The "optimum moisture" was determined by the Proctor Method.

TABLE 1

TYPICAL FIELD DESIGN MIX TEST RESULTS

	Raw soil	Soil-cement mixtures			
Cement, by vol. per cent	0	4.0	6.1	8.1	10 1
Cement, by wt. per cent	0	3.5	5.5	7.5	9.5
Liquid limit	45.2	42.3	41 0	39.2	38.6
Plastic limit	21.1	26.2	26 8	28.4	28.3
Plasticity index	24.1	16.1	14.2	10.8	10.3
Field moist. equiv.	28.6	31 6	31 2	32.3	33.7
$\left(\frac{\text{Vol. at S. L.}}{\text{Vol. at F. M. E.}} \times 100\right)$	76.4	83.6	87.4	90.7	89.5
Shrinkage limit	12.7	20 3	22 5	25.9	26.2
Shrinkage ratio	1.95	1.71	1 65	1.59	1.57
$\left(\frac{\text{Vol. at S. L.}}{\text{Vol. at L. L.}} \times 100\right)$	61 1	72.6	76.7	82.8	83 4
Optimum mositure	16 5	....	..	....	...
Moisture of specimen, per cent	.....	19.3	17.3	18.7	17 8
Standard density	109 0	....	....	....	....

Recommended treatment 8.0 per cent cement by volume.

DESIGN

To determine the percentage of cement required in each soil type a series of "trial mixes" with the soil and cement were prepared. Individual $1\frac{1}{2}$-lb. samples of soil, sufficient for about $\frac{1}{3}$ or $1\frac{1}{2}$ in. depth in a Proctor mold, were mixed with quantities of cement which were increased in amounts of about 2 per cent to cover the range of cement contents selected to provide specimens having cement contents both above and below the percentage estimated to produce the desired soil characteristics. These trial mixes were prepared at estimated optimum moisture, and compacted in Proctor molds. The specimens were removed from the molds and stored for seven days in the moist closet. At the end of this curing period, they were again ground and the foregoing soil constants again determined. Typical test results of this procedure arc shown in Table 1.

The guiding values recommended as being desirable to obtain a subgrade having small volume changes due to moisture changes, were that the "cement modified" subgrade should have a ratio of the volume at shrinkage limit to volume at field moisture equivalent of about 0.90, and a ratio of the volume at shrinkage limit to volume at liquid limit of about 0.80. The lowest per cent of cement required to obtain these desired results as indicated by the tests in Table 1 was selected as the "Design Mix."

The standard density and optimum moisture of the soil-cement mixture, as thus designed for each soil was determined using the standard Proctor procedure, with exception that a special type hammer, as designed by the Kansas State Highway Department, was substituted. This hammer derives the equivalent of the force of the standard, or original 5.5 lb. Proctor Hammer dropped a distance of 18 in. and is obtained by dropping a 9½-lb. cylinder on a ⅜ in. guide rod. This cylinder is dropped through the controlled height of 12 in. and transfers the energy to a base cylinder having the same area as the standard hammer, and which is attached to the guide rod. There is a loop attached to the upper end of the guide rod which serves as a handle. With this type hammer the operator can readily control the distribution of the required blows over the entire surface of the layer being compacted. Comparative tests indicate that densities obtained with this hammer are slightly higher (102.4 per cent) than those secured by the standard Proctor Test Method, A.A.S.H.O. T-99-38.

FIELD TESTS—RECORDS OF CONSTRUCTION

To determine the compliance with specification requirements for gradation of pulverized soil, composite samples of the material being processed from at least three points across the roadway were taken, at not greater than 300 ft. intervals, or more often as seemed desirable, and in each representative type soil involved. These samples were usually taken as pulverizing was being completed.

As the contractor's work was laid out as to the road length, or stations to be processed, the original mix design requirements were reviewed as to the station limits for quantity of cement required by the construction forces, and the interval, or spacing, per bag of cement furnished the contractor for his use in delivering and spreading the cement.

As dry mixing of the cement and the soil progressed, inspection was made from time to time, to adjust the operation of equipment as necessary to secure a uniform mix throughout the depth and width of the treatment. As dry mixing was being completed, moisture samples were taken throughout the area in much the same manner as samples secured for pulverization tests. From these moisture determinations the amount of water to bring the mix to optimum requirement was estimated. Additional moisture tests were made during damp mixing to assure uniformity, and to ascertain that the optimum requirement had been reached throughout the mixture at which time compaction could be started. These moisture determinations were made over a gas fire, with continual stirring, to secure the earliest possible results.

As the rolling and packing seemed to be completed, density tests were made at selected points in the several types soil, or mixtures, and at intervals not greater than 300 ft. The sand density method was used for this determination, which was compared to the standard density previously obtained for this particular mixture.

At least seven days after processing, four samples were obtained from each days mix for comparative information, for check tests against the original design, and for further tests for information on the effect of aging. In addition, moisture samples were taken just ahead of paving operations, in order to complete records of the project as paving was placed.

CHANGES FOUND NECESSARY—PULVERIZATION

The first section to be processed involved some of the heavier type soils on the project. It was found practically impossible to pulverize this soil to the requirement that 80 per cent pass the No. 4 sieve. Much time was spent with the different pieces of equipment in special methods of manipulation in an effort to secure specification requirements under the cool weather conditions prevailing (late October). The work moved on into somewhat lighter type soils, and when no appreciable improvement in gradation was found, pre-wetting and sprinkling during pulverizing was resorted to. Gradation samples were taken before and after premoistening, during dry mixing with cement, and after final mix was at or near optimum moisture requirement with the result that no appreciable improvement was affected. However, the test data show that additional pulverization was obtained during both dry and damp mixing after cement application. It was quite evident that in these types of soil the equipment, machinery, and methods commonly used for this work could not produce a pulverization of much more than 60 per cent through the No. 4 sieve. It was therefore found desirable and practical to change the specifications as follows:

> "That the gradation of the raw soil prior to addition of cement be such that 95 per cent pass the 1-in. sieve, and at least 60 per cent pass the No. 4 sieve."

The average condition, as recorded during the construction of the project, indicates 98 per cent passing the 1-in. sieve, and 67 per cent pasing the No. 4.

That further information might be available as to the effects of pulverization or gradation of the soil on the final blend, soils analyses of completed cement mixtures of both coarse and fine gradings of soil were made, which show no appreciable variation, or difference. Further comparative tests were made on soil-cement cylinders with soil of the coarser or revised pulverization requirement and also of soil, all of which passed the No. 4 sieve. These soil-cement specimens were measured for volume change, and absorption, one each during 26½ days, and one each for 77½ days exposed to capillary moisture, and at the end of that time complete soil analysis was made. None of these results showed any apparent difference to be reflected in either the coarse or the fine graded or pulverized soil. It appears, therefore, that the change to requirement of only 60 per cent passing the No. 4 sieve will have no detrimental effect on this subgrade treatment.

DENSITY

In the early mixes completed it was found that densities in place were not comparable to the (regular) moisture-density curves determined in the laboratory, immediately compacted after mixing the sample. All the methods and procedure were thoroughly checked for errors or discrepancies, with no results. Samples of the mixture in place compacted in Proctor molds showed lower densities indicating that the change or "modification" and moisture-density relation of the soil was effected over a period of several hours during wetting and mixing. A series of moisture-density determinations, delayed for a period of several hours after mixing, developed the fact that the principle change in density was attained in approximately 5 hr.

These "five hr." delayed tests were made during the remainder of the work. The mixture of soil-cement for test was slightly moistened and placed in tight buckets and stirred or agitated at intervals through a period of 5 to 6 hr. after which moisture-density determinations were made using the standard Proctor procedure. Such "five hr." delayed determination, or, comparison of density with compacted sample of the finished road mixture should be specified for control of construction of this type. Project records show the comparison of density and moisture in place with both the "Regular" and "five hr." compaction.

CONCLUSIONS

After carefully determining the requirements for correction of the particular soil in the subgrade, care must be observed to secure the design ratio of this soil to the materials for correction.

Grading must be accurately finished to elevation and section of subgrade for pavement prior to construction of the treated subgrade. Scarifying or "breaking out" this grade to the true section and elevation, at the required depth for the treatment, is of utmost importance. A scarifier, or gang plow, or both, of proper design, and manned by skilled operators should be used throughout, so that this initial work will be carefully controlled and completed to provide a true sub-base section or "work table" for the control of all subsequent pulverization, mixing, processing, and compacting.

The loosening or "breaking out" of six in. of soil in completed roadway provided an excess thickness of finish mix sufficient for any normal irregularities or adjustments in grade or section, and permitted the paving "planer" to cut or trim surplus from the grade rather than to level or fill with untreated or raw soil. As work progressed this surplus was available for the few low areas that occurred in the grade. Proper care and accuracy in this stage of construction is of great importance.

During the initial stages of compaction, no rubber tired equipment or traffic was allowed and the off-set tandem disc was used behind the roller to prevent surface crusting. After about an hour of rolling the disc was replaced with a spiketooth harrow. Particularly during dry weather it was found necessary to sprinkle the surface two or three times during the rolling operation. As rolling neared completion the road was shaped frequently with motor patrol and final compaction was completed using a pneumatic-tired roller.

Contrary to the expectations of some, the final shaping of the completed treated subgrade just before paving was not difficult. The contractor had provided and used, two extra sets of cutting bits for both his subgrade machine and planer, and by changing to new bits as necessary very little delay developed on account of "hard" subgrade. In general, the finished "modified" subgrade was practically perfect as indicated by paving records of the daily yield of concrete, averaging 99.28 per cent, thickness tests and measurements of final cores in the completed concrete pavement.

It is highly desirable that proper and sufficient pieces of equipment for pulverization and processing be available on the work. There is believed to be no substitute for a gang plow (2 to 4 bottom), a regulated depth scarifier, springtooth harrow (power lift and depth regulated), offset tandem disc harrow at least 18- to 20-in. discs, double spiketooth drag harrow, and one way disc plow.

An ample water supply must be available, and it is recommended that application be provided by two or more pressure distributors. On this project, with paving also in progress, a portable water storage tank on the work enabled the distributor trucks to load more quickly than would have been possible from pipe line, and thus deliver water at a satisfactory rate.

All sheepsfoot rollers to be used should be of same general design as to spacing and area of feet and weight.

Results of tests during construction, and the final characteristics of the modified soils, indicate that the revised grading or pulverization requirement of 95 per cent passing 1-in. and 60 per cent

TABLE 2

EXPERIMENTAL SECTION

Raw Soil—Sta. 1307+65 to Sta. 1310+65—Field Sample 2

Water-Treated Subgrade—Raw Soil

Pulverization same as cement treated section Sta. 1301+50 to Sta. 1307+65. Compacted with sheepsfoot rollers.

Moisture and Density (As built 11-10-'38)

Station	Dry den.	Stan. den.	% Stan den.	% Moist.	Opt. moist.
1309+25	82.5	96.5	85.5	19.6	26.5

TABLE 3

RESEARCH SECTIONS—CEMENT OMITTED

Station 1016+00 to Sta. 1022+00—Raw Soil Field Sample 37. Water-Treated Subgrade Section

A. Station 1016+00 to Station 1019+00—Raw Soil

Water was added to pulverized raw soil as required to provide moisture within 2 per cent of optimum, and mixed in with disc, springtooth harrow and plow to a depth of 6 inches. Packed out with sheepsfoot rollers.

Moisture and Density (As built 12-21-'38)

Station	Dry den.	Stan. den.	% Stan. den.	% Moist.	Opt. moist.
1017+50	110.5	115.5	95.7	13.5	14.0

REGULAR PAVING SUBGRADE

B. Station 1019+00 to Station 1022+00—Raw Soil

Quantity of water added was not predetermined. Rolled with flat wheel roller. Subgrade was not pulverized but was scarified 6 inches deep.

Moisture and Density (As built 12-21-'38)

Station	Dry den.	Stan. den.	% Stan. den.	% Moist.	Opt. moist.
1020+50	106.3	115.5	92.0	9.3	14.0

TABLE 4

RESEARCH SECTIONS—CEMENT OMITTED

Station 1120+00 to Station 1126+00—Raw Soil Field Sample 26. Water-Treated Subgrade Section

A. Station 1120+00 to Station 1123+00—Raw Soil

Water was added to pulverized raw soil as required to provide moisture within 2 per cent of optimum, and mixed in with disc, springtooth harrow and plow to a depth of 6 inches. Packed out with sheepsfoot roller.

Moisture and Density (As built 11-30-'38)

Station	Dry den.	Stan. den.	% Stan den.	% Moist.	Opt. moist.
1121+50	97.8	106.0	92.3	19.8	19.0

REGULAR PAVING SUBGRADE

B. Station 1123+00 to Station 1126+00—Raw Soil

Quantity of water added was not predetermined. Rolled with sheepsfoot rollers. Section pulverized to a depth of 6 inches before selected for experiment.

Moisture and Density (As built 11-30-'38)

Station	Dry den.	Stan. den.	% Stan. den.	% Moist.	Opt. moist.
1124+50	102.6	106.0	96.8	11.8	19.0

Standard Compaction 112.1—Per Cent Standard Compaction 97.9.

TABLE 5

LABORATORY TEST RESULTS

Station to Station	970+00 976+00		980+40 993+00		993+00 1003+75		1003+75 1016+00		1022+00 1035+00		1035+00 1044+00		1044+00 1068+00	
Cement by volume, per cent	5.5		5.5		6.0		6.0		6.0		4.0		8.0	
	Soil[1]	S-C[2]	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C
Sample number	5698	5817	5700	5813	5702	5809	5701	5805	5697	5742	5385	5739	5385	5733
Coarse sand	5.4	7.5	12.0	13.0	19.8	19.5	21.6	23.7	16.5	15.7	13.5	15.8	7.1	7.0
Fine sand	28.8	42.1	24.8	40.9	31.4	44.3	32.8	42.7	32.2	48.9	41.0	51.4	23.9	36.2
Silt	38.5	49.8	40.6	42.5	30.8	32.6	25.3	30.5	27.1	32.4	28.9	29.8	45.2	54.9
Clay	27.3	0.6	23.6	3.6	18.0	3.6	20.3	3.1	24.2	3.0	16.6	3.0	23.8	1.9
Colloids	15.2	0.6	12.6	2.6	9.3	2.1	11.2	2.4	13.0	1.4	7.4	1.4	10.3	1.4
Liquid limit	38.7	33.3	40.1	36.5	42.0	39.7	43.1	39.9	37.2	33.2	38.3	30.9	48.0	41.5
Plasticity index	20.3	9.5	20.8	11.3	25.5	15.6	25.2	11.7	19.7	10.4	19.9	10.4	24.9	13.8
Field moist. equiv.	23.8	29.0	24.5	29.2	23.5	32.0	25.5	36.8	21.3	28.2	24.9	25.4	28.9	33.7
$\frac{\text{Vol. at S. L.}}{\text{Vol. at F. M. E.}} \times 100$	87.1	94.8	84.8	91.4	85.0	85.2	83.5	89.8	88.2	96.7	84.4	92.8	76.7	87.9
Shrinkage limit	15.8	25.3	14.9	24.2	14.1	21.6	14.9	29.1	14.3	26.0	15.0	20.8	13.5	25.0
Shrinkage ratio	1.86	1.54	1.88	1.58	1.90	1.67	1.87	1.46	1.90	1.55	1.87	1.69	1.96	1.60
$\frac{\text{Vol. at S. L.}}{\text{Vol. at L. L.}} \times 100$	71.7	89.0	67.8	83.7	66.2	76.7	65.5	86.5	69.7	89.8	61.1	85.3	59.8	79.2
Soil group	A4-7	A2-4	A4-7	A4-5	A4-7	A4-5	A4-7	A4-5	A4-7	A-4	A-4	A2-4	A6-7	A-5
Dry densities[3], lbs. per cu. ft.														
Regular	113.5		112.5		113.0		115.0		114.5		115.5		111.5	
5 Hour	106.5		106.0		107.0		109.0		112.0		111.5		104.0	
Station	971+50		985+00		994+00		1009+00		1025+00		1037+00		1049+00	
Roadway	106.4		99.2		106.0		103.7		99.3		101.8		99.3	
Station	974+50		988+00		997+00		1012+00		1028+00		1040+00		1055+00	
Roadway	109.1		100.7		107.0		106.9		106.6		110.7		97.8	
Station	.		991+00		1000+00		1015+00		1031+00		1043+00		1062+00	
Roadway	. .		97.9		106.5		106.1		100.4		102.2		93.5	

Station to Station	1068+00 1071+00		1071+00 1074+50		1074+50 1080+50		1080+50 1087+50		1087+50 1098+00		1098+00 1110+00		1110+00 1120+00	
Cement by volume, per cent	7.0		8.0		7.0		8.0		11.0		10.0		9.0	
	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C
Sample number	5384	5728	5383	5727	5384	5726	5283	5724	5382	5721	5381	5718	5380	5713
Coarse sand	11.6	16.9	7.8	8.8	11.6	13.5	7.8	10.4	7.0	9.6	9.7	10.0	7.0	6.8
Fine sand	21.5	36.6	23.3	39.5	21.5	32.0	23.3	42.6	27.5	43.5	28.7	39.4	22.4	51.4
Silt	48.0	45.3	47.9	50.0	48.0	51.3	47.9	44.5	45.5	45.4	41.0	49.0	47.4	41.2
Clay	18.9	1.2	21.0	1.7	18.9	3.2	21.0	2.5	20.0	1.5	20.6	1.6	23.2	0.6
Colloids	8.3	0.7	8.4	1.7	8.3	2.3	8.4	2.5	1.2	1.5	7.3	1.6	9.8	0.6
Liquid limit	45.9	39.9	45.5	37.3	45.9	38.1	45.5	41.2	58.3	44.3	49.6	44.9	53.1	43.1
Plasticity index	24.6	11.0	22.6	9.2	24.6	10.8	22.6	10.3	32.4	11.8	25.2	14.1	29.6	12.7
Field moist. equiv.	27.3	34.2	28.5	31.3	27.3	32.1	28.5	35.4	30.1	37.8	30.2	36.5	28.2	36.3
$\frac{\text{Vol. at S. L.}}{\text{Vol. at F. M. E.}} \times 100$	79.5	89.8	77.3	93.5	79.5	88.9	77.3	87.3	72.2	98.2	73.9	86.6	75.4	90.3
Shrinkage limit	14.1	26.9	13.6	26.8	14.1	24.3	13.6	26.2	11.4	32.9	12.6	26.7	12.1	28.9
Shrinkage ratio	1.96	1.54	1.96	1.54	1.96	1.60	1.96	1.58	2.06	1.45	2.00	1.56	2.01	1.50
$\frac{\text{Vol. at S. L.}}{\text{Vol. at L. L.}} \times 100$	61.5	83.3	61.5	85.8	61.5	81.7	61.5	80.8	50.9	85.8	57.5	77.8	54.8	82.4
Soil group	A6-7	A-5	A6-7	A4-5	A6-7	A4-5	A6-7	A-5	A6-7	A-5	A6-7	A-5	A6-7	A-5
Dry densities[3], lbs. per cu. ft.														
Regular	112.0		110.0		112.0		110.0		106.0		109.0		105.0	
5 Hour	105.0		106.0		105.0		106.0		95.0		103.5		100.0	
Station	1068+00		1074+00		1077+00		1083+00		1090+50		1099+50		1111+50	
Roadway	99.8		93.5		103.5		99.0		99.6		96.2		91.0	
Station	1071+00		. . .		1080+00		1084+50		1093+50		1102+50		1114+50	
Roadway	90.8		. .		96.2		99.2		97.8		92.6		86.2	
Station	. .		....		. .		. . .		1096+50		1108+50		1117+50	
Roadway	. .		..		....		....		92.1		87.7		96.8	

[1] Tests conducted in laboratory on the original raw soil.
[2] Tests conducted in laboratory on the processed soil-cement from the completed subgrade just prior to paving.
[3] Compaction obtained with modified Kansas rammer.

TABLE 5—(*Continued*)

LABORATORY TEST RESULTS

Station to Station	1126+00 1144+50		1144+50 1148+97		1150+26 1151+75		1151+75 1158+00		1158+00 1162+50		1162+50 1181+00		1181+00 1189+00		1189+00 1197+25		1197+25 1207+50		1207+50 1212+50		1212+50 1219+50		1219+50 1222+50		1222+50 1236+50		1236+50 1246+00	
Cement by volume, per cent	9.5		4.0		4.0		6.0		4.0		7.0		7.0		6.0		4.0		4.0		9.0		4.0		5.5		5.0	
	Soil[1]	S-C[2]	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C
Sample number	5379	5708	5378	5703	5145	5596	5140	5595	5141	5593	5146	5589	5147	5583	5216	5580	5216	5577	5217	5573	5218	5571	5219	5568	5220	5567	5251	5564
Coarse sand	7.7	9.0	9.0	8.7	16.0	16.1	23.5	21.5	13.7	11.4	13.5	17.2	14.4	16.5	20.1	15.4	13.8	18.9	19.4	20.6	11.6	13.9	6.6	7.0	17.0	16.3	18.6	16.5
Fine sand	16.1	39.2	35.1	41.0	31.0	46.6	28.5	47.1	30.6	38.1	18.0	35.4	20.9	40.0	22.5	11.3	28.2	35.4	23.8	30.0	18.2	27.0	20.3	25.4	30.4	31.0	29.2	34.2
Silt	44.1	51.3	40.0	49.8	29.2	36.5	26.3	29.0	33.2	47.7	35.5	46.2	35.8	30.7	34.2	72.1	35.5	44.5	35.1	47.2	39.2	57.0	51.6	63.9	30.4	50.4	26.6	47.2
Clay	32.1	0.5	15.1	0.5	23.8	0.8	21.7	2.4	22.5	2.8	33.0	1.2	28.9	12.8	23.2	1.2	22.5	1.2	21.7	2.2	31.0	2.1	21.5	3.7	22.2	2.3	25.6	2.1
Colloids	11.7	0.5	4.8	0.5	11.8	0.8	13.3	2.4	13.8	1.4	15.9	0.8	11.9	9.7	11.0	0.8	11.0	0.0	11.6	1.3	13.0	1.5	7.9	3.7	9.7	2.3	12.8	1.3
Liquid limit	65.1	50.2	35.2	32.7	40.0	33.0	42.0	35.2	33.0	31.1	50.0	37.1	48.0	44.5	45.5	39.5	32.0	36.7	39.0	34.9	47.5	40.2	33.0	32.4	36.0	35.0	45.0	39.6
Plasticity index	40.8	18.0	17.0	11.9	20.0	8.6	21.5	8.3	14.5	7.2	28.5	11.0	25.5	12.1	21.5	6.6	14.0	12.1	18.5	9.0	27.0	14.0	15.0	8.5	18.0	14.0	26.0	13.2
Field moist. equiv.	27.1	36.4	23.0	23.8	25.0	29.1	26.5	30.4	25.0	28.6	30.5	30.6	28.0	37.1	32.5	36.6	24.5	30.4	27.5	30.5	27.0	33.1	23.5	27.8	24.0	27.3	25.5	31.9
$\frac{\text{Vol. at S. L.}}{\text{Vol. at F. M. E.}} \times 100$	73.7	87.8	88.0	91.8	83.5	91.4	82.8	92.2	85.3	89.0	73.5	94.5	78.1	89.0	75.0	88.8	85.2	89.7	81.7	89.5	76.3	89.4	88.8	95.3	84.0	91.3	80.0	87.1
Shrinkage limit	10.2	27.4	15.8	18.7	14.5	23.4	15.5	25.1	16.0	21.3	12.5	26.8	14.0	29.0	15.0	28.2	15.5	23.6	15.5	3.3	11.5	25.7	16.5	24.6	14.5	21.8	13.0	23.0
Shrinkage ratio	2.12	1.55	1.87	1.75	1.9	1.65	1.9	1.61	1.9	1.67	2.0	1.56	2.0	1.53	1.9	1.50	1.9	1.66	1.9	1.64	2.0	1.60	1.8	1.57	2.0	1.68	2.0	1.66
$\frac{\text{Vol. at S. L.}}{\text{Vol. at L. L.}} \times 100$	46.3	73.8	73.4	80.4	67.3	86.5	65.4	85.9	75.5	85.8	57.1	86.0	59.5	80.8	63.3	85.5	76.0	82.2	69.2	84.0	58.2	81.0	77.2	89.0	69.9	81.8	61.0	78.4
Soil group	A-6	A-5	A2-4	A2-4	A4-7	A-4	A4-7	A-4	A2-4	A2-4	A-7	A4-5	A-7	A-5	A-7	A4-5	A-4	A-4	A4-7	A-4	A-6	A4-5	A-4	A-4	A-4	A-4	A-7	A4-5
Dry densities[3], lbs. per cu. ft.																												
Regular	108.5		115.5		117.0		116.5		116.7		110.5		109.5		110.5		117.5		113.6		111.7		111.6		115.7		114.6	
5 Hour	107.0		111.5		. .		. .		112.5		101.0		102.5		104.5		111.5		108.0		103.0		110.5		108.5		112.5	
Station	1129+00		1147+00		1151+00		1153+00		1159+00		1163+00		1184+50		1190+00		1198+70		1208+00		1213+00		1221+00		1226+00		1239+50	
Roadway	95.7		109.2		111.4		107.8		101.0		103.7		91.6		98.4		99.9		100.8		103.2		93 2		94.1		106.2	
Station	1135+00		. .		...		1156+00		. .		1166+50		1188+50		1195+40		1204+50		...		1216+00		. .		1229+00		1245+00	
Roadway	100.8		. .		.		100.3		.		90.8		103.4		94.6		99.3		....		102.8		.		105.6		112.6	
Station	1141+00		.		. .		...		..		1175+00		....		1196+00		1206+00		....		1219+00		.		1233+00		. .	
Roadway	97.8		....		....		....		...		94.9		...		97.4		106.1		....		94.8		. .		104.8		....	

[1] Tests conducted in laboratory on the original raw soil.
[2] Tests conducted in laboratory on the processed soil-cement from the completed subgrade just prior to paving.
[3] Compaction obtained with modified Kansas rammer.

TABLE 5—(*Continued*)
Laboratory Test Results

Station to station	1246+00 1249+00		1249+00 1258+00		1258+00 1261+25		1261+25 1266+50		1266+50 1269+00		1269+00 1272+00		1272+00 1282+00		1282+00 1294+00		1294+00 1301+50		1301+50 1307+65	
Cement by volume, per cent	8.0		8.0		8.0		11.0		8.0		4.0		8.0		8.0		8.0		16.0	
	Soil[1]	S-C[2]	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C	Soil	S-C
Sample number	5253	5560	5252	5558	5253	5556	5254	5554	5253	5553	5321	5552	5322	5551	5323	5547	5324	5542	5135	5540
Coarse sand	12.0	13.9	7.2	10.2	12.0	17.1	8.2	11.1	12.0	16.3	16.2	19.9	18.7	24.9	7.1	10.3	22.9	22.8	2.0	11.6
Fine sand	32.1	41.9	21.1	49.6	32.1	39.0	19.8	41.1	32.1	40.8	40.7	44.3	26.8	54.1	15.4	39.4	19.8	39.5	17.1	45.4
Silt	29.9	39.0	28.7	37.5	29.9	40.7	32.3	45.2	29.9	41.1	29.1	33.5	31.2	17.7	43.0	45.5	31.3	33.6	42.6	38.4
Clay	26.0	5.2	43.0	2.7	26.0	3.2	39.7	2.6	26.0	1.8	14.0	2.3	23.3	3.3	34.5	4.8	26.0	4.1	38.3	4.6
Colloids	12.6	1.3	20.4	1.5	12.6	1.3	22.2	1.5	12.6	0.0	1.7	1.3	11.2	1.3	13.2	2.3	9.6	2.0	14.5	1.6
Liquid limit	49.0	37.6	65.2	40.9	49.0	42.6	58.3	45.5	49.0	42.7	38.8	38.4	49.3	39.1	51.4	42.8	56.3	47.1	88.0	51.1
Plasticity index	28.0	14.0	38.2	11.2	28.0	10.6	35.3	12.3	28.0	15.4	20.8	12.8	28.3	10.7	29.4	12.5	33.5	15.3	50.5	15.0
Field moist. equiv.	26.0	27.6	31.6	34.1	26.0	37.4	26.2	37.5	26.0	33.4	20.4	29.8	26.5	33.7	25.7	35.4	26.1	36.5	49.0	41.4
$\frac{\text{Vol. at S. L.}}{\text{Vol. at F. M. E.}} \times 100$	77.5	91.4	66.9	90.8	77.5	88.9	74.6	95.5	77.5	92.6	91.5	91.5	76.2	95.4	76.6	88.8	77.2	89.8	55.3	91.3
Shrinkage limit	11.5	22.1	9.2	27.8	11.5	29.3	10.0	34.2	11.5	28.3	15.6	24.2	11.3	30.6	10.9	27.4	11.6	29.2	10.5	34.7
Shrinkage ratio	2.0	1.67	2.2	1.58	2.0	1.54	2.1	1.45	2.0	1.57	1.90	1.65	2.05	1.53	2.06	1.57	2.05	1.55	2.1	1.42
$\frac{\text{Vol. at S. L.}}{\text{Vol. at L. L.}} \times 100$	57.1	79.7	42.6	82.8	57.1	83.0	46.3	85.8	57.1	81.5	69.5	84.2	56.0	85.5	54.5	80.4	51.8	78.3	38.2	81.0
Soil group	A6-7	A-4	A-6	A4-5	A6-7	A-5	A-6	A-5	A6-7	A-5	A4-7	A4-5	A-6	A-5	A-6	A-5	A-6	A-5	A6-7	A-5
Dry densities[3], lbs. per cu. ft.																				
Regular	114.0		106.9		102.0		103.5		114.0		120.0		113.5		108.0		107.5		96.5	
5 Hour	112.0		105.9		...		...		112.0		115.5		110.0		105.0		103.5		92.5	
Station	1248+00		1251+00		1259+00		1263+00		1269+00		1272+00		1275+00		1284+50		1295+00		1303+00	
Roadway	103.0		98.2		90.6		81.7		108.0		111.1		104.4		99.8		100.2		84.6	
Station	...		1256+00		...		1266+00		...		...		1278+00		1290+50		1298+00		1306+00	
Roadway	...		90.6		...		80.0		...		...		102.1		97.0		99.4		86.8	
Station	...		...		...		...		...		...		1278+50		1292+00		1300+00		...	
Roadway	...		...		...		...		...		...		110.2		98.7		103.2		...	

[1] Tests conducted in laboratory on the original raw soil.
[2] Tests conducted in laboratory on the processed soil-cement from the completed subgrade just prior to paving.
[3] Compaction obtained with modified Kansas rammer.

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