Experimental Lime Stabilization in Nebraska

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The Nebraska Department of Roads in 1956 performed an experiment involving the use of hydrated lime in the stabilization of plastic soils, and in the upgrading of inferior base course materials. The experiment included a preliminary laboratory study and a field construction project.

This paper reports and summarizes the tests performed on the various materials before and after adding hydrated lime, and presents the results of deflection measurements at half-year intervals since the construction of the field project.

● WIDESPREAD experimentation in the use of hydrated lime for stabilization of soils and base materials has apparently established that this material has a place in the construction of highways. Each year, new research on this subject is reported. The principal uses of the hydrated lime appear to be in two categories as follows: (a) to improve highly plastic subgrade soils and (b) to improve the performance of inferior base course materials.

The State of Nebraska has large areas within its borders where the subgrade and embankment soils used in the construction of highways are highly plastic, and poor in load supporting ability, when wet. The two principal areas of undesirable soils are: (a) glacial till area of eastern Nebraska and (b) the clay and shale areas in the northern part of the state.

In general, base course materials available in Nebraska are considered to be of mediocre quality. Materials which must be used in the construction of highways include principally the following:

1. The rounded coarse sands and gravels of the Platte and other rivers, and those of glacial origin.
2. Wind-blown, fine sands.
3. Mortar beds (low quality limey sandstone) from tertiary deposits.
4. Gravels composed of soft, limey sandstone.
5. Limited quantities of limestone.

Of these base materials, only the limestones of the eastern part of the state are considered to provide base courses of superior quality.

If the permanent stabilization of the heavy plastic soils of Nebraska is possible by the addition of small percentages of lime, or if it is found that the inferior base course materials can be improved by this method, a great benefit would result for the highway program. For this reason, it was proposed that an experiment be conducted using hydrated lime in the improvement of subgrades and base courses.

The experiment was a combined effort of the engineering staffs of the Bureau of Public Roads and the Nebraska Department of Roads. The authors appreciate the opportunity to summarize and report the results of this cooperative effort.

PRELIMINARY INVESTIGATION

Preliminary Field Investigation

The experimental project (Project No. F-43(4)) is located in Johnson County, about 60 mi south and east of Lincoln, in the southeastern part of Nebraska. This project, a part of State Highway No. 3, begins about one mi north of Vesta and extends in an easterly direction for a distance of about seven mi, ending at the concrete pavement on the west edge of Tecumseh. About two mi were included in the experiment.

TABLE 1

LABORATORY TEST RESULTS FOR PRELIMINARY SUBGRADE SOIL SAMPLES, LIME-TREATED SUBGRADE SOIL SECTION

Location[1]	Plasticity Tests			Hydrometer Analysis			% Ret. No. 200 Sieve	AASHO Soil Class.
	LL	PL	PI	Sand	Silt[2]	Clay		
1047+00	45	19	26	34	29	37	29	A-7-6(15)
1056+00	50	23	27	20	38	42	13	A-7-6(17)
1059+00	51	21	30	26	33	41	18	A-7-6(18)
1077+00	48	19	29	32	36	32	16	A-7-6(17)
1086+00	46	20	26	30	34	36	20	A-7-6(16)
1092+00	51	21	30	17	46	37	5	A-7-6(18)
1101+00	49	21	28	18	43	39	10	A-7-6(17)
1107+00	45	21	24	25	39	36	11	A-7-6(15)

[1] Depth of samples approximately 7 to 31 in. below finish grade elevation.
[2] 0.005 mm to 0.05 mm.

The area traversed by the project is in a diversified farming region, with corn, sorghums, and small grains as the principal crops. The temperatures in the area range from 103 F in the summer to -10 F in the winter, with an annual average of 51 F. The annual precipitation averages about 31 in. of which about 7 in. is in the form of snow. The frost normally penetrates from 12 to 18 in., however, during prolonged cold periods the frost may penetrate to as much as 24 in.

Upon completion of the subgrade survey and laboratory tests of the subgrade soils, study indicated that the soils and situation between Station 1047 and Station 1107 and between Station 1148 and Station 1200 were typical, and sufficiently uniform to serve as the experimental sections.

The 6,000 ft section between Station 1047 and Station 1107 was selected for the lime treated subgrade soil section. The terrain traversed by this section is a hilly upland plain, with good surface drainage due to the hills and poor subsurface drainage due to the impervious soils. The soils encountered in the subgrade, through this section were predominantly glacial clays. Table 1 shows the laboratory test results of the preliminary samples in this section.

TABLE 2

LABORATORY TEST RESULTS FOR PRELIMINARY SUBGRADE SOIL SAMPLES; LIME-TREATED BASE COURSE SECTION

Location[1]	Plasticity Tests			Hydrometer Analysis			% Ret. No. 200 Sieve	AASHO Soil Class.
	LL	PL	PI	Sand	Silt[2]	Clay		
1149+00	58	25	33	4	45	51	2	A-7-6(20)
1155+00	58	24	34	2	47	51	1	A-7-6(20)
1164+00	70	26	44	4	41	55	3	A-7-6(20)
1173+00	50	25	25	7	47	46	2	A-7-6(16)
1191+00	61	23	38	7	45	48	2	A-7-6(20)

[1] Depth of samples approximately 14 to 38 in. below finish grade elevation.
[2] 0.005 mm to 0.05 mm.

TABLE 3

LABORATORY TEST RESULTS FOR PRELIMINARY SAMPLES
COARSE SAND AND AFTONIAN SILT

Coarse Sand
Gradation Ranges

Sieve Number	1 in.	¾ in.	⅜ in.	4	10	20	30	40	50	80	100	200
Percent Ret.	0-4	0-9	0-20	0-30	1-42	4-65	11-74	19-81	44-90	69-94	71-95	74-96

Percent Calcareous (est.)..... Nil
Percent Shale (est.).......... Nil

Aftonian Silt

Plasticity Tests			Hydrometer Analysis			Grad. % Ret.	
LL	PL	PI	Sand	Silt[1]	Clay	No. 100	No. 200
28-31	22-25	4-7	33-46	38-51	14-18	0	1-4

[1]0.005 mm to 0.05 mm.

The 5,200 ft section between Station 1148 and Station 1200 was selected for the lime treated base course section. Surface drainage between Station 1148 and Station 1192 is slow due to the level terrain, while drainage between Station 1192 and Station 1200 is fair due to the slope toward the Big Nemaha River. Subsurface drainage throughout the section is poor due to the impervious soils. The soils in this section are subsoils of glacial origin and parent glacial clays, Table 2 shows their laboratory test results.

At the time of the soil survey the area in the vicinity of the project was thoroughly prospected for local aggregates. The available aggregates include fine sand, glacial coarse sand, soil binder and aftonian silt. Of these, the coarse sand and aftonian silt were selected for use in the lime treated base course mixtures. Table 3 shows the test results for the preliminary samples of these two materials. It will be noted that the coarse sand is not a favorable material for use in base course construction. Aftonian silt is an interglacial wind-blown layer which was deposited between the Nebraskan and Kansan glacial stages. As encountered at this location it was a white flour-like material.

TABLE 4

ROUTINE METHODS OF TEST PERFORMED ON UNTREATED AND LIME-TREATED SOILS

Test	Method
Preparation of sample	AASHO T87-49
Sieve analysis	AASHO T11-49
Hydrometer analysis	AASHO T88-54
Liquid limit	AASHO T89-54
Plastic limit	AASHO T90-54
Plasticity index	AASHO T91-54
Shrinkage limit, shrinkage ratio, lineal shrinkage, and volumetric change	AASHO T92-54
Field moisture equivalent	AASHO T93-54
Maximum density and optimum moisture	AASHO T99-49 (Except that new material was used for each point on the curve)
Capillarity, absorption failure, and cementation	Nebraska procedure (see Appendix A)

Preliminary Laboratory Testing

Upon completion of the preliminary field investigation a comprehensive laboratory study was undertaken. This investigation was divided into the following parts:

1. Treatment of a fine-grained subgrade soil with hydrated lime.
2. Treatment of sand-aftonian silt mixtures with hydrated lime.
3. Comparison of four pozzolans (aftonian silt, volcanic ash, flyash and peorian loess) when mixed with sand and hydrated lime.

In the following paragraphs each of the three laboratory studies is discussed.

TABLE 5

LABORATORY TEST RESULTS FOR PRELIMINARY SOIL-LIME MIXTURES

Tests	[1]	One Hour Cure					2 Day Cure					14 Day Cure					240 Day Cure				
	[1]	0% Lime[2]	1% Lime[2]	3% Lime[2]	6% Lime[2]	10% Lime[2]	0% Lime[2]	1% Lime[2]	3% Lime[2]	6% Lime[2]	10% Lime	0% Lime[2]	1% Lime[2]	3% Lime[2]	6% Lime[2]	10% Lime[2]	0% Lime[2]	1% Lime[2]	3% Lime[2]	6% Lime[2]	10% Lime[2]
Sieve Analysis, % Ret.																					
No. 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	1	1	1	1	1	1	1	1	1	2	5	1	1	1	3	6	1	1	2	13	17
40	4	4	4	4	4	4	4	3	5	9	16	4	4	4	10	16	4	4	8	28	31
50	7	6	6	6	7	8	9	6	8	15	22	7	7	7	15	22	7	7	15	35	39
100	14	13	13	14	17	18	14	13	18	27	36	14	13	16	28	35	13	14	30	49	53
200	19	18	18	20	24	24	20	18	27	36	46	18	18	23	37	43	19	20	42	60	62
Hydrometer Analysis																					
Sand	31	27	29	48	67	74	29	31	57	78	77	27	30	56	76	77	26	30	70	83	90
Silt[3]	33	38	42	42	30	24	35	45	34	21	23	37	47	34	27	23	37	47	25	16	10
Clay	36	35	29	10	3	2	36	24	9	1	0	36	23	10	2	0	37	23	5	1	0
Colloids	31	32	15	5	1	0	33	11	4	0	0	33	10	4	1	0	34	10	2	0	0
Specific Gravity	2.63	2.70	2.70	2 70	2.66	2.66	2.67	2.69	2.70	2.69	2.69	2.69	2.69	2.69	2.67	2.67	2.67	2.67	2.66	2.67	2.66
Liquid Limit	47	51	44	35	32	32	45	38	35	NP	NP	48	37	36	NP	NP	49	38	35	NP	NP
Plastic Limit	21	21	23	27	31	32	21	23	29	34	37	20	23	28	NP	NP	22	23	30	NP	NP
Plasticity Index	26	30	21	8	1	NP	24	15	6	NP	NP	28	14	8	NP	NP	27	15	5	NP	NP
Capillarity	5'4"	4'26"	12'4"	23'52"	8'37"	6'39"	6'43"	14'03"	18'48"	5'02"	5'09"	5'29"	15'02"	18'55"	6'01"	3'32"	5'28"	12'11"	15'54"	6'16"	2'49"
Absorption Failure	5'4"	4'26"	12'34"	2 hr+	2 hr+	2 hr+	6'43"	14'56"	2 hr+	2 hr+	2 hr+	5'29"	31'02"	2 hr+	2 hr+	2 hr+	5'28"	55'28"	2 hr+	2 hr+	2 hr+
Cementation	200+	200+	200+	200+	180	145	200+	200+	200+	101	119	200+	200+	200+	147	108	200+	200+	200+	200+	169
Shrinkage Limit	12.5	11.8	16.3	26.5	27.5	29.7	11.1	18.9	25 8	27.3	30.7	11.3	15.1	25.7	27.6	28.9	9.2	12 9	22.8	26.2	27.9
Shrinkage Ratio	1.87	1.91	1.74	1.48	1.46	1.45	1.93	1.68	1.51	1.45	1.39	1.92	1.81	1.50	1.45	1.43	1.99	1.85	1.58	1.49	1.38
Lineal Shrinkage	5.1	6.3	4.9	1.9	3.9	3.1	6.2	2.1	1.1	3.3	3.3	6.8	5.7	1.9	2.6	4 1	9.8	9.5	5.1	5.4	5.6
Volumetric Change	17.1	21.7	16.2	6.07	12.83	9.9	21.3	6.6	3.4	10.6	10.7	23.5	19.2	5.8	8.2	13 4	35.8	34.2	16.7	17.9	18.8
Field Moist. Equivalent	21.6	23.1	25.6	30.6	36.6	36.5	22.1	22.8	28.0	34.6	38.4	23.6	25.7	29.5	33.2	38.3	27.0	31.4	33.4	38.2	41.5
Optimum Moisture, %	19.5	–	–	–	–	–	19.0	19.0	21.0	21.0	22.0	–	–	–	–	–	–	–	–	–	–
Maximum Density, gm/cc	1.65	–	–	–	–	–	1.67	1.65	1.62	1.56	1.54	–	–	–	–	–	–	–	–	–	–
Stability, Total Load, lb	–	278	635	942	1185	1483	263	712	1497	2013	2498	292	812	2130	3360	4020	198	362	1458	3133	5027
Percent Moist, as Tested	–	18.1	18.0	18.0	18.1	17.9	18.8	18.5	18.6	18.8	18.4	18.6	18.6	17.6	17.3	17.8	18.8	18.6	18.3	18.5	18.6
Unconfined Compressive Strength, 4- by 4-in. Cylinders, P.S.I.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	45	62	253	586	758
Percent Moist, as Tested	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	19.2	69.1	19.4	19.2	18.3
Unconfined Compressive Strength, 2- by 2-in. Cylinders, P.S.I.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	50	74	346	772	1377
Percent Moist, as Tested	–	–	–	–	–	–											19.0	19.0	18.8	19.3	19.0
AASHO Soil Class	A-7-6 (16)	A-7-6 (18)	A-7-6 (13)	A-4(8)	A-4(8)	A-4(8)	A-7-6 (15)	A-6(10)	A-4(8)	A-4(6)	A-4(4)	A-7-6 (17)	A-6 (10)	A-4 (8)	A-4(6)	A-4 (4)	A-7-6 (17)	A-6 (10)	A-4 (5)	A-4(1)	A-4 (1)

[1] Test results of soil as received in laboratory.
[2] Lime added, percent by weight.
[3] 0.005 mm to 0.05 mm.

Experimental Treatment of a Fine-Grained Subgrade Soil with Hydrated Lime.—The first of the three studies presents data showing changes in test results observed when hydrated lime was added to plastic soil in the following percentages by weight: 1, 3, 6 and 10. All tests were made to duplicate, as nearly as possible, the actual field conditions of the soils as to moisture, density and curing.

The soil used in this phase of the study was sampled from the left backslope at Station 1085. It was a plastic reddish-brown glacial clay AASHO soil classification A-7-6(16) representative of the subgrade soil on this project. Table 4 indicates the procedures used in the soil tests.

Upon receipt of the soil sample at the laboratory it was dried in an oven for approximately 48 hours at 140 F, then pulverized to pass the No. 4 sieve. A representative sample was taken from this material and routine soil tests including moisture-density determination, were performed on the soil sample as prepared in the laboratory. These test results are shown in Table 5.

Upon completion of the routine soil tests, soil-lime mixtures were prepared by dry mixing 1, 3, 6 and 10 percent hydrated lime (by weight) with four portions of the soil previously prepared to pass the No. 4 sieve. Cylinders (4- by 4-in.) were molded from each soil-lime mixture, as well as the untreated soil, to the approximate optimum moisture content and the maximum density previously determined on the untreated soil. After molding, each cylinder was immediately wrapped in aluminum foil to prevent loss of moisture and placed in closed containers in the moist room at a temperature of 70 F + 2 F, for curing. The cylinders were then removed to perform the routine soil tests, as outlined in Table 4, (excluding the maximum density-optimum moisture tests), at intervals of one hour, 2 days, 14 days and 240 days. The results of these tests are shown in Table 5 and Figures 1 through 8.

It will be noted from Table 5 that the addition of hydrated lime to plastic soil has a marked effect on the soil character. Small amounts change the nature of the plastic soils somewhat, while the addition of 6 or 10 percent shows a radical change in their physical characteristics.

Figures 1 through 4 indicate that the lime treatment apparently causes the agglomeration of some of the silt and clay sized particles with the net result that the soil is somewhat coarsened. The biggest textural changes caused by the lime appear to have taken place in the particle size range covered by the hydrometer test. This physical change reflects not only the percentage of lime added but also the length of curing time. This phenomenon is such that a clay was so changed by the addition of lime that after 14 days it was reclassified as loam to sandy loam, and after 240 days' curing it was classified as clay loam to sand. However, it should be pointed out that the particles

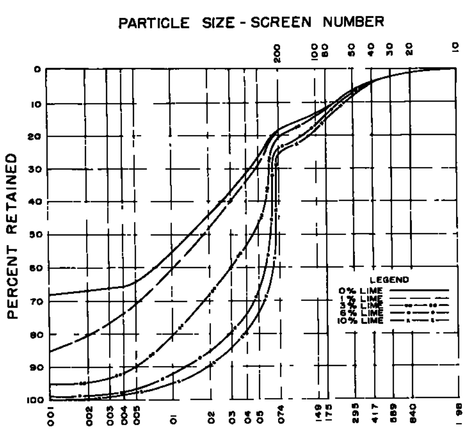

Figure 1. Effect of lime-treatment on grain size of soil—1 hour cure.

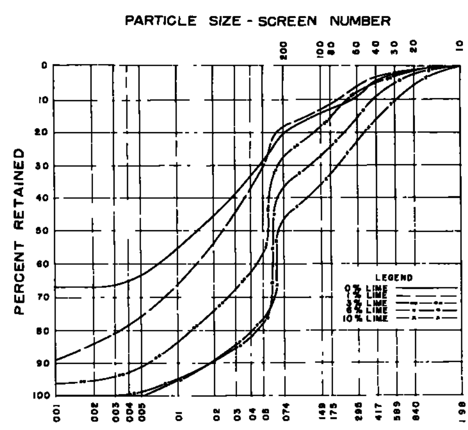

Figure 2. Effect of lime-treatment on grain size of soil—2 day cure.

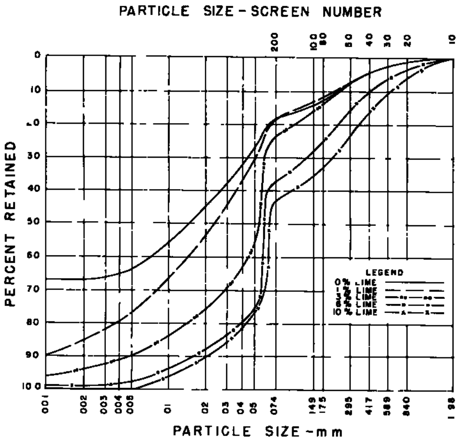

Figure 3. Effect of lime-treatment on grain size of soil—14 day cure.

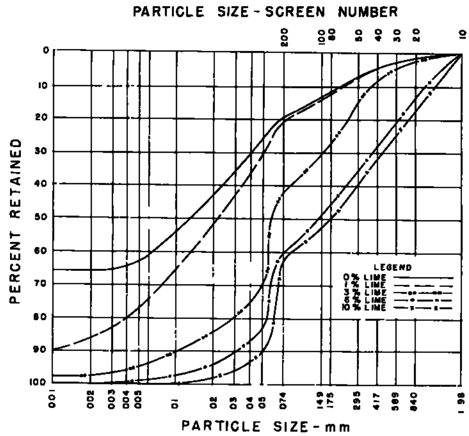

Figure 4. Effect of lime-treatment on grain size of soil—240 day cure.

appeared to be weakly bonded. For this reason, it was necessary to establish a standard 5-min agitation period in the mechanical mixer as part of the sieve analysis procedure.

One of the most publicized features of lime is its ability to reduce the plasticity index of soils. The laboratory tests on this experiment show that the addition of as little as 6 percent lime reduces the plasticity index from 30 to 1 in only one hr and to 0 in 2 days (Fig. 5). The addition of 10 percent lime reduced the plasticity index of the plastic soil to 0 in one hr. This reduction in plasticity index is the result of lowering the liquid limit and raising the plastic limit.

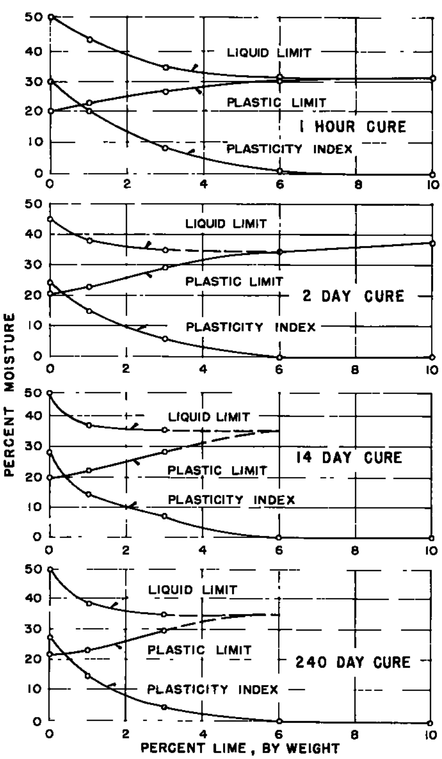

Figure 5. Plasticity tests of lime-treated soil.

Figures 6 and 7 show the effect of lime, when added to a plastic soil on the field moisture equivalent, capillarity time, shrinkage ratio, and volumetric change. In Figure 6 it will be noted that the capillarity time of 1 and 3 percent lime-treated specimens show an increase over the untreated soils, while the 6 and 10 percent specimens show very little change over the untreated soil. The field moisture equivalent tests show an increase as greater percentages of lime are added, but shrinkage ratio values are lowered by the addition of lime. It is interesting to note that 3 percent lime reduces the volumetric change of the soil more than 6 or 10 percent lime.

It will be noted on Figures 6 and 7 that the patterns of the changes in soil test results due to the lime are similar, regardless of this period of cure. However, the curves for the 240 days' cure do show some

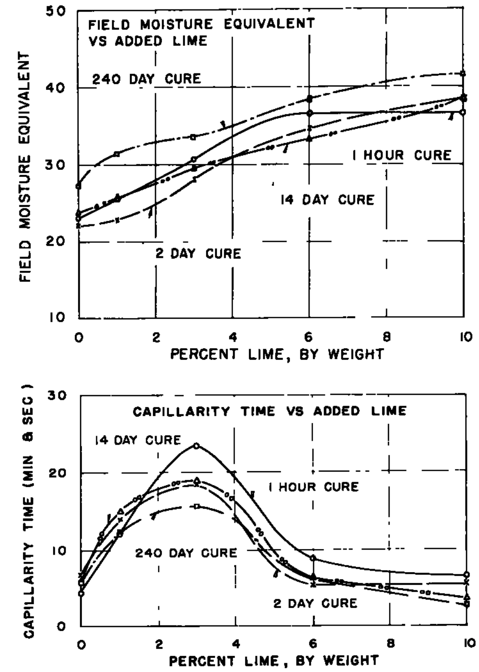

Figure 6. Effect of lime on the field moisture equivalent and capillarity on plastic soil.

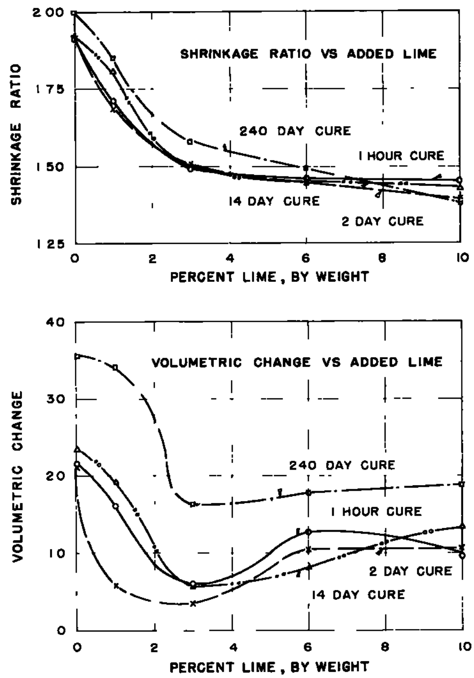

Figure 7. Effect of lime on the shrinkage properties of plastic soil.

variance from those of the other curing periods. This variance is particularly noticeable in the volumetric change curve and this is the accumulative effect of the higher field moisture equivalent and shrinkage ratio values and the lower shrinkage limit values. A possible explanation for the deviations of the 240-day tests is that they were performed by a different laboratory technician, than the tests for the other curing periods.

In connection with the capillarity test, attention is invited to the absorption failure test (Table 5). It will be noted that the absorption failure time has increased from a matter of minutes to over two hours, with the addition of 3 or more percent lime. This indicates that the addition of lime to a plastic soil increases its resistance to slaking.

Maximum density and optimum moisture values were determined on the soil-lime mixtures, as well as on the untreated soil, which had cured in the moist room for a period of 48 hr. The results of these tests are shown in Table 5. It will be noted that as greater percentages of hydrated lime are added the maximum density decreases and the optimum moisture increases.

The final test performed on the soil-

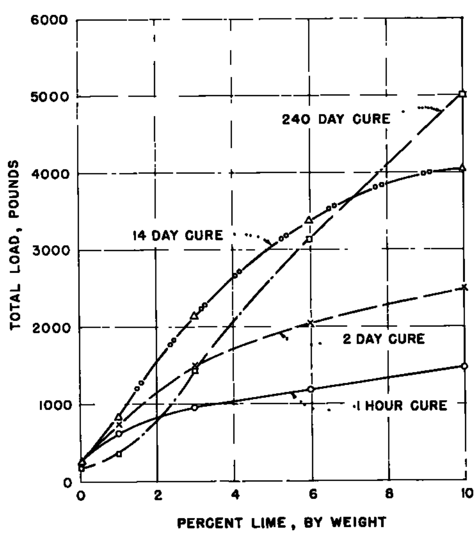

Figure 8. Extrusion (strength) tests of soil-lime mixtures.

TABLE 6

TEST RESULTS FOR MATERIALS USED IN PRELIMINARY LABORATORY MIXTURES

Tests	Aftonian Silt	Sand	Hydrated Lime
Sieve Analysis: (AASHO T11-49) (Total percent retained)			
3/4 In.	–	0	–
3/8 In.	–	1	–
No. 4	–	2	–
10	–	5	–
20	–	14	–
40	–	61	–
50	–	81	–
100	0	90	–
200	8	92	0
Hydrometer Analysis: (AASHO T88-54)			
Sand, percent	55	–	–
Silt[1], percent	36	–	–
Clay, percent	9	–	–
Colloids, percent	6	–	–
Specific Gravity	2.66	–	–
Liquid Limit (AASHO T89-54)	24	–	–
Plastic Limit (AASHO T90-54)	23	–	–
Plasticity Index (AASHO T91-54)	1	–	–
Cementation (Nebr. Method)	15	–	–
Chemical Composition: (ASTM C25-47)			
Calcium oxide, CaO, percent	–	–	97.8
Magnesium oxide, MgO, percent	–	–	0.1
Silica, SiO_2, percent	–	–	0.9
Iron oxide, Fe_2O_3	–	–	0.1
Aluminum oxide, Al_2O_3	–	–	0.2
Loss on Ignition, percent	–	–	30.8
Carbon Dioxide, CO_2, percent	–	–	5.7

[1]0.005 mm to 0.05 mm

lime mixtures was the strength or stability test. This test was performed as nearly as possible in accordance with ASTM Designation D915-49T. The following exceptions in equipment were made:

Forming Mold—A forming mold with an inside diameter of 2.00 in. and 5.00 in. in height replaced the specified mold.

Compaction Tamper—A compaction tamper weighing 1.930 gm, 12 in. in length, with a tamping face diameter of 1.10 in. replaced the specified compaction tamper.

Soil-lime mixtures were prepared by mixing 1, 3, 6 and 10 percent by weight of hydrated lime, with portions of soil pulverized to pass the No. 10 sieve. Cylinders were then molded from each mixture and from untreated soil using the optimum moisture and maximum density values determined in the routine compaction tests of the soil alone. Initial compaction was accomplished by placing the material in the mold in two equal layers and giving each layer 12 blows with the compacting tamper. The mold was then placed in the testing machine and molded to a height of 2.00 ± 0.02 in. at a rate of 0.1 in. per min. The final load was held for 2 min. Each cylinder was then wrapped in aluminum foil and placed in closed containers in the moist room at a temperature of 70 F ± 2 F for curing. The cylinders were removed from the moist room at intervals of 1 hr, 2 days, 14 days and 240 days for strength or extrusion testing. Upon removal from the moist room each cylinder was weighed and measured, then loaded at a rate of 1 in. per min. The extrusion or strength values were taken at the maximum load required to cause failure of the test specimen. A moisture sample was taken from each cylinder at completion of the test to determine actual moisture content. The strength values are shown in Table 5 and Figure 8. It will be noted from Figure 8 that the addition of lime greatly increases the strength of the soil when tested in the extrusion test.

TABLE 7

TEST RESULTS FOR SAND-AFTONIAN SILT-LIME MIXTURES 16 DAY CURING TIME

Composition of Mixture Percent by Weight			Density as Molded	Moisture Percent		Unconfined Compressive Strength,	Computed Gradation, Percent Retained, Sieve Number							
Hydrated Lime	Aftonian Silt	Sand	gm/cc	As Molded	As Tested	Pounds	3/4 In.	4	10	20	40	50	100	200
0	20	80	2.00	10 5	10.3	160	1	2	4	11	48	64	71	75
2	20	78	1.97	10.4	9.9	500	1	2	4	11	48	63	70	74
4	20	76	1 96	10.6	10.2	703	1	2	4	11	46	62	68	72
7	20	73	1 94	10.5	10.6	1110	1	2	4	10	45	59	66	69
0	15	85	1 99	10.5	10.2	150	1	2	4	12	52	68	76	79
2	15	83	1.98	10.5	9.9	550	1	2	4	12	51	67	75	77
4	15	81	1.97	10.5	10.2	620	1	2	4	11	49	66	73	76
7	15	78	1.94	10.7	10.1	855	1	2	4	11	48	63	70	73
0	10	90	1.84	7.1	7.1	80	1	2	4	13	55	73	81	84
2	10	88	1.97	10.8	9.7	430	1	2	4	12	54	71	79	82
4	10	86	1.98	10.5	10.0	525	1	2	4	12	52	70	77	80
7	10	83	1.95	10.4	10.0	698	1	2	4	12	51	67	75	77

Experimental Treatment of Sand-Aftonian Silt Mixtures with Hydrated Lime.—The second of the preliminary laboratory investigations was concerned with the use of hydrated lime to improve a base course material of inferior quality. This type of material (coarse sand) has been used extensively in Nebraska in the construction of subbases. The object was to determine if a satisfactory base course material can be developed by the addition of hydrated lime and a pozzolan to the coarse sands. Since in this case an aftonian silt was found on the project, it was decided to use it as the pozzolan. Another phase of the laboratory work was concerned with the comparison of this material with other available materials for use as a pozzolan.

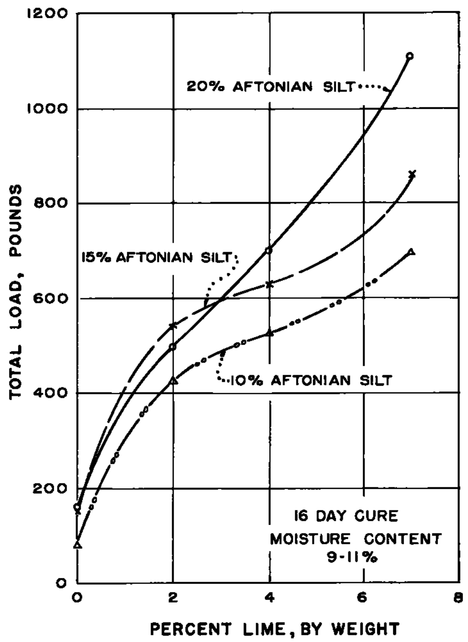

Figure 9. Unconfined compression tests of sand-aftonian silt-lime mixtures.

With the exception of the hydrated lime the materials used in this part of the preliminary investigation were obtained from sources located in the vicinity of the project. The test results for the samples actually used in the laboratory experiments are shown in Table 6.

The first step in this investigation was to prepare three maximum density-optimum moisture curves using the coarse sand and 10, 15 and 20 percent aftonian silt with 4 percent hydrated lime added to each mixture. These tests were conducted in accordance with AASHO Designation T 99-49. The 10 percent mixture had an optimum moisture of 10.3 percent and maximum density of 1.98 gm per cc. The 15 percent mixture had an optimum moisture of 10.2 percent and maximum density of 1.98 gm per cc and the 20 percent mixture had an optimum moisture of 9.8 percent and maximum density of 1.96 gm per cc.

The second phase of this part of the laboratory experiment was to mold 4- by 4-in. cylinders, in accordance with AASHO Designation T 99-49, using coarse sand and aftonian silt mixtures with and without hydrated lime. These cylinders were molded to the approximate optimum moisture and maximum density values determined in the tests mentioned in the preceding paragraph. The percentages of each material in these cylinders are shown in Table 7.

After molding, each cylinder was wrapped in aluminum foil to prevent loss of moisture and placed in closed containers in the moist room at a temperature of 70 F $\pm$ 2 F, for curing. The cylinders were cured in this manner for a period of 16 days at which time their unconfined compressive strengths were determined. The results of these tests are shown in Table 7 and Figure 9. The moisture content of the specimens at the time of the test were very nearly the same as those at the time of molding. From Figure 9, it will be noted that 20 percent aftonian silt was probably more than the optimum, if only 2 percent hydrated lime is added, but when 4 and 7 percent of hydrated lime was used, the highest percent of aftonian silt resulted in the highest strengths.

Unconfined Compressive Strength of Sand-Lime Mixtures Combined with Aftonian Silt, Volcanic Ash, Flyash or Peorian Loess.—This part of the laboratory investigation covers tests which were conducted to compare the unconfined compressive strengths which develop when aftonian silt, volcanic ash, flyash, and peorian loess are mixed separately with standard ottawa sand and various percentages of hydrated lime.

The sand used in all of the unconfined compressive strength tests was a graded standard ottawa sand. The aftonian silt, volcanic ash, and peorian loess were obtained from various locations in the state. The flyash and hydrated lime were obtained from commercial sources. The analyses of these materials are shown in Table 8.

The first phase of the laboratory study was to prepare eight dry mixtures having the compositions shown in Table 9.

Optimum moisture-maximum density determinations were then made on each of the dry mixes. These tests were conducted in accordance with the procedure outlined in AASHO Designation: T99-49. The results of these tests are shown in Table 9.

Using the approximate maximum density and optimum moisture values determined in the first phase of this part of the laboratory investigation, 2- by 2-in. cylinders were molded with each mixture. These cylinders were molded in accordance with the procedure described in ASTM Designation: D915-49T. This procedure and exceptions to the standard procedure were previously described in the section of this report concerning the experimental treatment of a fine-grained subgrade soil with hydrated lime. After molding, the cylinders were wrapped in aluminum foil, and placed in closed containers in the moist room at a temperature of 70 F $\pm$ 2 F, for curing.

The cylinders were removed from the moist room for unconfined compressive strength tests at intervals of 2, 7, 14 and 90 days. Upon removal from the moist room each cylinder was weighed and measured and immediately tested in unconfined compression at a loading rate of 0.1 in. per min. The results of the unconfined compressive strength tests are shown in Table 9 and Figure 10. At the 90 day testing period the compressive strength developed in both flyash mixtures is considerably greater than that developed in the other mixtures. From Figure 10 it will also be noted that in all cases the strength developed in the mixtures with 6 percent of hydrated lime is greater than the strength developed in mixtures having 4 percent hydrated lime.

TABLE 8

TEST RESULTS FOR MATERIALS USED IN PRELIMINARY LABORATORY MIXTURES

Tests	Hydrated Lime	Aftonian Silt	Flyash	Volcanic Ash	Peorian Loess	Ottawa Sand
Sieve Analysis: (AASHO T11-49) (Total Percent Retained)						
No. 20	—	—	—	1	—	0
30	—	—	—	1	—	2
40	—	—	—	2	—	35
50	—	—	0	5	0	69
100	—	0	1	19	1	98
200	0	8	5	40	1	100
Hydrometer Analysis: (AASHO T88-54)						
Sand	—	55	13	54	11	—
Silt[1]	—	36	71	42	67	—
Clay	—	9	16	4	22	—
Specific Gravity	—	2.66	2.45	2.44	2.70	—
Liquid Limit: (AASHO T89-54)	—	24	27	NP	35	—
Plastic Limit: (AASHO T90-54)	—	23	26	NP	24	—
Plasticity Index: (AASHO T91-54)	—	1	1	NP	11	—
Cementation (Nebr. Procedure)	—	15	2	8	200+	—
Chemical Analysis						
Silicon Dioxide, Percent	0.9	—	44.3	—	—	—
Aluminum Oxide, Percent	0.2	—	24.1	—	—	—
Ferric Oxide, Percent	0.1	—	17.2	—	—	—
Calcium Oxide, Percent	97.8	—	4.3	—	—	—
Magnesium Oxide, Percent	0.1	—	0.5	—	—	—
Sulfur Trioxide, Percent	—	—	1.4	—	—	—
Loss on Ignition, Percent	30.8	—	3.5	—	—	—
Carbon Dioxide, Percent	5.7	—	—	—	—	—
Insoluble Residue, Percent	—	—	74.2	—	—	—
Ratio of Al_2O_3 to Fe_2O_3	—	—	1.4	—	—	—
Tricalcium Aluminate, Percent	—	—	35	—	—	—
Sodium Oxide, Percent	—	—	0.67	—	—	—
Potassium Oxide, Percent	—	—	2.18	—	—	—
Total Alkali, Percent	—	—	2.85	—	—	—
Equiv. Alkali, Percent	—	—	2.10	—	—	—
Water Soluble Alkali, Percent	—	—	0.12	—	—	—
Phosphorus Pentoxide, Percent	—	—	0.05	—	—	—
Manganic Oxide, Percent	—	—	0 08	—	—	—
Chloroform Soluble Organic Substances, Percent	—	—	0.0005	—	—	—
Free Lime, Percent	—	—	0.6	—	—	—
Free Carbon, Percent	—	—	2.8	—	—	—

[1] 0.005 mm to 0.05 mm

TABLE 9

TESTS RESULTS FOR SAND-LIME MIXTURES COMBINED WITH AFTONIAN SILT, VOLCANIC ASH, FLYASH OR PEORIAN LOESS

Mix No.	Composition of Mixes				Maximum Density of Mixture, gm/cc	Optimum Moisture of Mixture, Percent	2 Day Curing Time			7 Day Curing Time			14 Day Curing Time			90 Day Curing Time		
	Sand Percent	Hydrated Lime, Percent	Other Ingredient				Den. as Molded, gm/cc	Moist. as Tested, Percent	Unconfined Compressive Strength, Pounds	Den. as Molded, gm/cc	Moist. as Tested, Percent	Unconfined Compressive Strength, Pounds	Den. as Molded, gm/cc	Moist. as Tested, Percent	Unconfined Compressive Strength, Pounds	Den. as Molded, gm/cc	Moist. as Tested, Percent	Unconfined Compressive Strength, Pounds
			Percent	Type of Material														
1	80	4	16	Aftonian Silt	1.93	9.0	1.91	8.0	45	1.92	8.4	63	1.92	8.7	80	1.93	8.2	467
2	70	6	24		2.00	8.0	1.99	8.0	177	1.99	7.9	252	1.99	8.2	362	2.00	7.7	1442
3	80	4	16	Flyash	1.96	9.5	1.95	8.6	87	1.96	8.2	172	1.96	8.6	445	1.97	8.3	4353
4	70	6	24		1.95	9.5	1.95	8.3	268	1.96	8.3	445	1.95	8.6	1245	1.96	8.7	6113
5	80	4	16	Volcanic Ash	1.84	11.0	1.80	10.7	25	1.81	10.5	90	1.83	10.4	198	1.83	10.3	787
6	70	6	24		1.82	11.6	1.81	11.6	112	1.81	11.3	353	1.82	11.3	575	1.82	11.1	1760
7	80	4	16	Peorian Loess	2.00	10.0	1.95	8.9	55	1.96	8.8	85	1.97	8.7	122	1.98	8.4	785
8	70	6	24		1.98	10.3	1.95	10.3	153	1.97	9.8	242	1.97	9.7	310	1.98	9.3	1373

DESIGN AND PRECONSTRUCTION SAMPLING OF EXPERIMENTAL PROJECT

Design of the Experimental Lime-Treated Sections

The data obtained in the preliminary field and laboratory studies seemed to justify the construction of an experimental project, including a lime-treated subgrade soil section and a lime-treated base course section.

The standard design thicknesses of the bases and surfacing for the proposed project

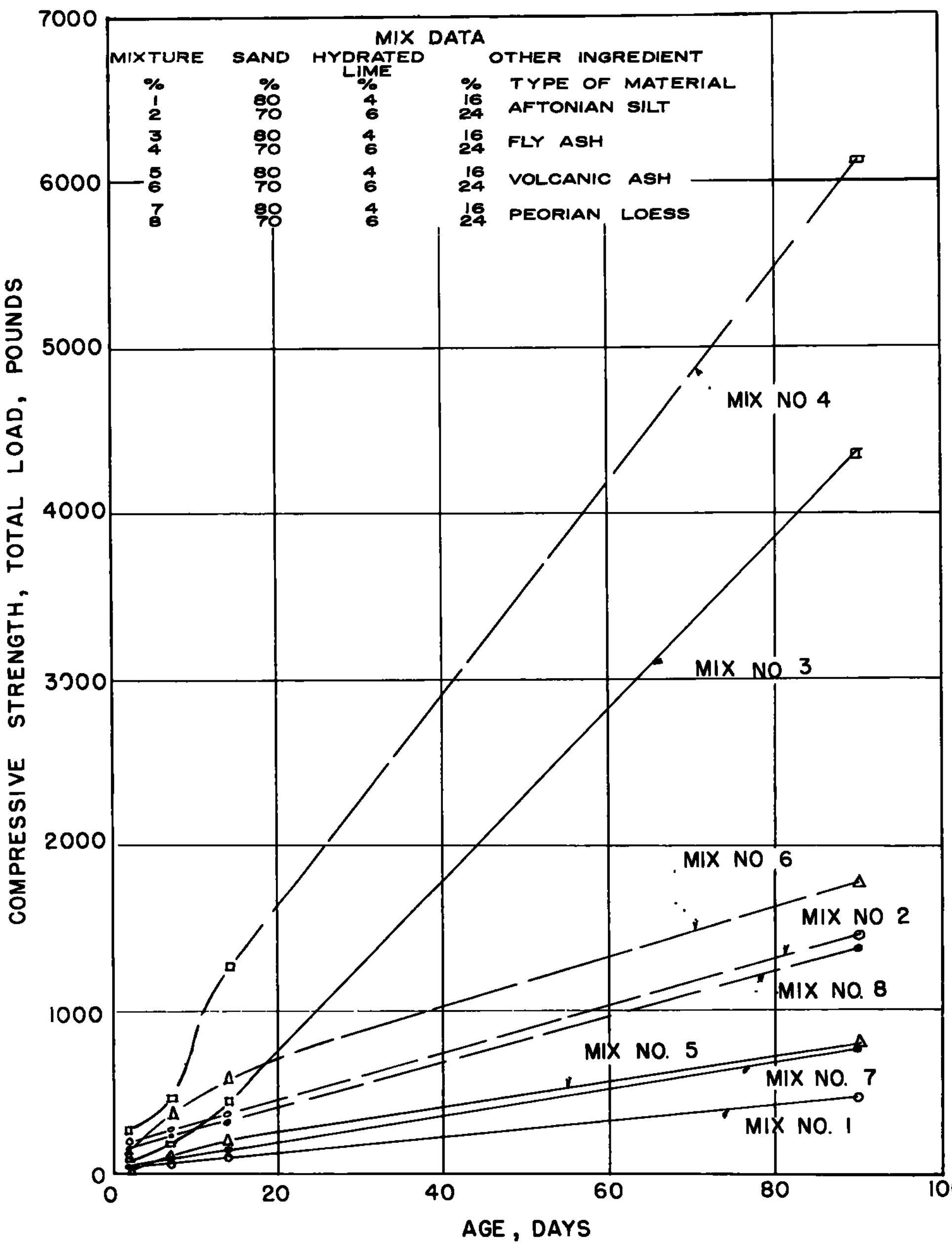

Figure 10. Unconfined compressive strength of sand-lime mixtures combined with aftonian silt, volcanic ash, flyash, or peorian loess.

TABLE 10

TRAFFIC INFORMATION

1956 Daily Average — Estimated Total Vehicles	485
1956 Daily Average — Estimated Total Commercial Vehicles, Including Trucks, Semi-Trailers, Truck-Trailer Combinations and Busses	105
1956 Daily Average — Estimated Total Semi-Trailers and Truck-Trailer Combinations (included in the above figure)	12
30th Highest Hour of the Year (1956) Estimated	70
Estimated Number of Axles per Day exceeding 5 Tons	22
Estimated Number of Axles per Day exceeding 7 Tons	11
Estimated Number of Axles per Day exceeding 8 Tons	5
Estimated Number of Axles per Day exceeding 9 Tons	1

were based on the Nebraska flexible pavement thickness curves, which take into consideration the soils, traffic, situation and precipitation. These design data were: (a) group index of 20 (AASHO Classification); (b) estimated total of 485 vehicles per day (Table 10); (c) good to fair surface drainage and poor subsurface drainage; and (d) approximately 31 in. of precipitation per year. From this information the standard design thickness for the base was 11 in. and for the surface course 3 in. It was further decided that these thicknesses would be held constant throughout the experimental sections (Fig. 11).

Table 11 shows the location and design of each section in the experimental portion of the project.

Subdivisions No. 1 and 5 were established as control sections in order that the performance of the sections in which lime was used could be compared with the standard design for the project. Each section also includes a subdivision, No. 3 and 7, where the lime addition is about equal to the average amount recommended in the literature. Included, also, in each of the two experimental sections are subdivisions having lime percentages significantly higher and lower than the average for the material.

Pre-Construction Sampling

Prior to construction permanent test sites were selected and appropriately marked in each subdivision of the experimental sections. The locations of these permanent test sites are shown in Tables 23 and 24.

At the time the permanent test sites were selected, samples of the subgrade soil were taken at each site. In the lime-treated subgrade soil section the subgrade soil was sampled at two depths: (a) 7 to 14 in. below finish grade elevation; and (b) 14 to 26 in. below finish grade elevation.

The 7- to 14-in. depth represents the subgrade soil that would be lime-treated and all soil tests as outlined in Table 4, including unconfined compressive strength tests were performed. The moisture-density relationship was determined on the untreated soil as well as on the lime-treated soil (lime-soil-water mixtures were allowed to cure for 24 hr in the moist room prior to compaction). The results of these tests are shown in Tables 17, 18 and 19. The subgrade soil samples from the 14- to 26-in. depth represent the subgrade immediately below the lime treatment. Table 23 shows the results of the tests of these subgrade samples.

In the lime-treated base course section the subgrade soil was sampled between the depths of 14- and 26-in. below finish grade elevation. This represents the subgrade immediately below the granular subbase course. The results of tests of these samples are shown in Table 24. The moisture-density relationships of the coarse sand-aftonian silt-lime mixture were also determined (the mixture was allowed to cure for 24 hr in the moist room prior to compaction). The curve data are shown in Table 20.

CONSTRUCTION PROCEDURES AND COST DATA

Lime-Treated Subgrade Soil

On August 8, 1956 construction began on the lime-treated subgrade soil section. Each of the three lime-treated sections were constructed separately. In the following paragraphs the construction procedures are discussed.

Scarifying and Pulverizing the Subgrade Soil.—In preparing the subgrade for lime stabilization the width of the roadbed was adjusted to a uniform 41 ft. A scarifier attached to a motor grader then loosened the subgrade soil the entire width of the roadbed

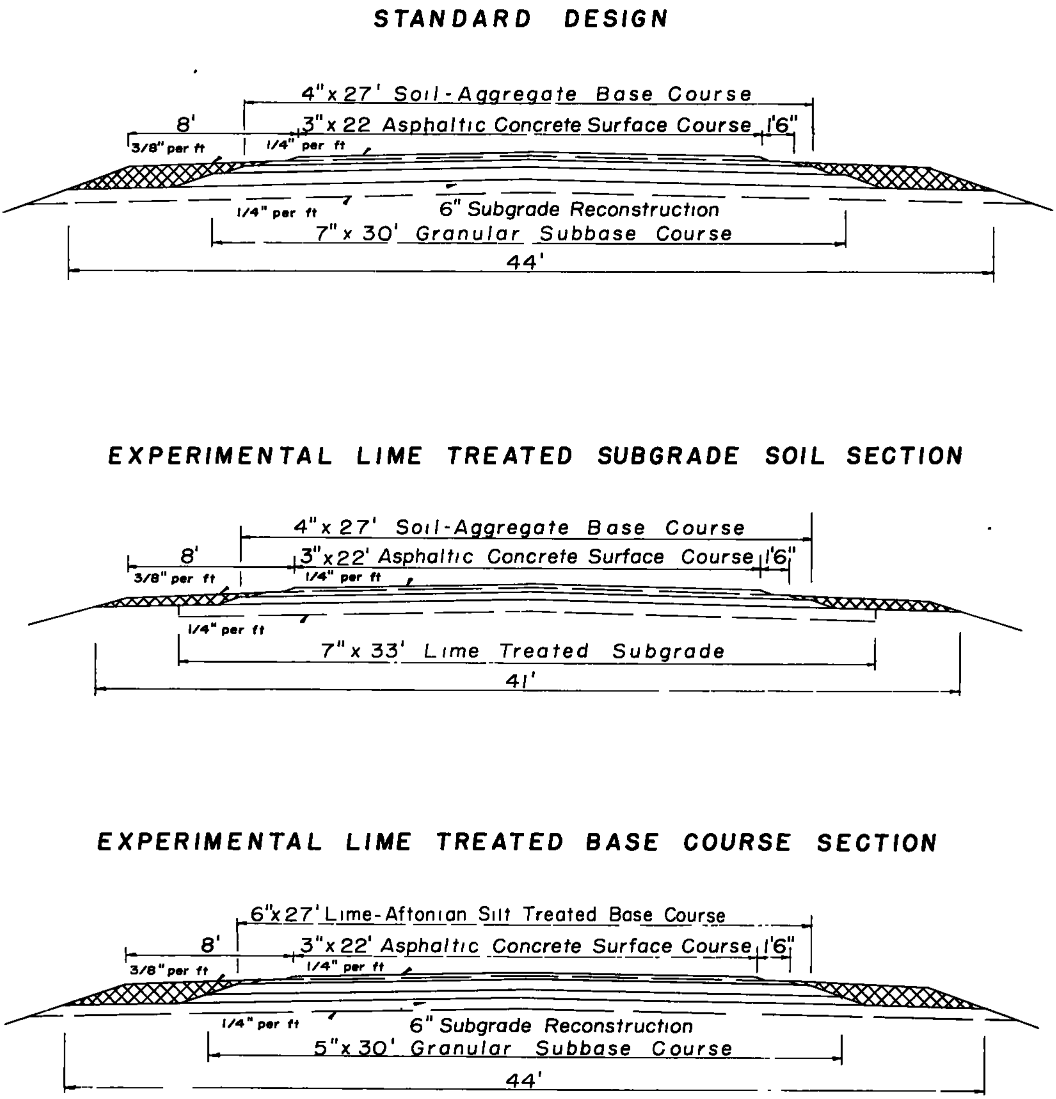

Figure 11. Typical cross-sections.

TABLE 11

DESIGN OF EXPERIMENTAL SECTIONS

Lime-Treated Subgrade Soil Section

Subdivision Number	1	2	3	4
Station to Station	1047 to 1062	1062 to 1077	1077 to 1092	1092 to 1107
Surface Course	3 in. Asph Conc	3 in. Asph Conc	3 in. Asph Conc	3 in. Asph Conc
Base Course	4 in. Soil Agg	4 in. Soil Agg	4 in. Soil Agg	4 in. Soil Agg
Subbase Course	7 in. Granular	None	None	None
Subgrade Treatment	None	7 in.	7 in.	7 in.
Percent Lime	None	3%	6%	10%
Remarks	Standard Design	—	—	—

Lime-Treated Base Course Section

Subdivision Number	5	6	7	8
Station to Station	1148 to 1161	1161 to 1174	1174 to 1187	1187 to 1200
Surface Course	3 in. Asph Conc	3 in. Asph Conc	3 in. Asph Conc	3 in. Asph Conc
Soil Agg. Base Co.	4 in.	None	None	None
Lime-Aftonian Silt Base Course	None	6 in.	6 in.	6 in.
Percent Aftonian Silt	None	15%	20%	20%
Percent Lime	None	2%	4%	7%
Granular Subbase Course	7 in.	5 in.	5 in.	5 in.
Remarks	Standard Design	—	—	—

to a depth of approximately 6 in. The remainder of the soil was loosened during mixing operations. After scarification the loosened soil was pulverized with a rotary tiller to the extent that no chunks remained larger than 3 in. in greatest dimension, and so that not more than 40 percent of the soil remained in chunks which would be retained on the 1-in. sieve. After pulverization the soil was placed in a windrow.

Spreading Lime.—Prior to placing the lime the windrow was flattened to a 30-ft width. The 50-lb lime bags were then spotted by hand, on the flattened windrow in transverse rows, in conformity with the individual lime requirements for the particular subdivisions. After 300 to 400 ft of bags had been placed, the bags were split open and the contents dumped in piles. Table 12 shows the distribution of the soil and lime.

Since this project was of an experimental nature and considerable control was desired when placing the lime, the method employed was suitable. However, if constructing a project of considerable length this method might be too inefficient and faster methods of handling the lime would be desirable.

Mixing.—The first step in the mixing procedure consisted of pulling a farm harrow through the piles of lime to level and spread it evenly across the flattened windrow. A motor grader with scarifier attachment made one pass through the flattened windrow, and a small amount of water was added. This procedure was followed to reduce wind loss. After several passes through the dry material with a rotary tiller, motor graders were used to bring up the sides of the flattened windrow. Some water was added to the mixture at this time. After the mixture had been windrowed the motor graders cut out small windrows for further mixing with the tiller. Enough water was added during this operation so that the moisture content was between the optimum value and two percentage points above. This procedure was followed until the windrow had been completely turned. Check of the windrow showed that the lime and soil were well mixed and that the moisture content was within the special provision limits.

Compaction.—After the soil-lime mixture had cured in the windrow for approximately 12 hr, motor graders were used to spread the mixture uniformly across the roadbed and the sheepsfoot rollers were started. Water was added during this operation to compensate for evaporation loss. The special provisions required that the mixtures be compacted to not less than 95 percent of maximum density. No difficulties were encountered in attaining the required density except in Subdivision No. 2 (3 percent lime). In this subdivision too much water was added and the resulting moisture contents were between 23.1 and 25.8 percent. At this high moisture content the density did not rise above 90 percent of maximum. Subsequently the compacted mixture was scarified to a depth of about 4 in., dried, and recompacted. In-place density tests taken after recompacting showed that the material was compacted to the requirements of the special provisions. From experience it is believed that the moisture content of the mixture during compaction should be no greater than 2 percent above optimum. Table 13 shows the range of final densities obtained in the compacted material in this section.

TABLE 12

DISTRIBUTION OF SOIL AND LIME IN THE LIME-TREATED SUBGRADE SOIL SECTION

Subdivision Number	Hydrated Lime		Subgrade Soil	Combined Windrow
	Percent By Weight	Ton/Sta	Approx. No. of Tons/Sta	Approx. No. of Tons/Sta
2	3	2.8	90.2	93
3	6	5.3	83.7	89
4	10	8.8	79.2	88

Curing.—Upon completion of laydown operation in the lime-treated subgrade subdivisions no loaded vehicles, other than sprinkling equipment, were allowed on the subgrade for a 5-day curing period. During this period the surface was sprinkled with water at frequent intervals to offset the effects of evaporation. Due to the extremely hot dry weather, sprinkling was continued until the soil aggregate base course was placed.

Lime-Treated Base Course

On August 30, 1956, construction began on the lime-treated base course. Each of the three lime-treated sections were constructed separately. In the following paragraphs the construction procedures are discussed.

Placing the Sand-Lime-Aftonian Silt.—In the method employed the sand was placed and windrowed. The aftonian silt was windrowed alongside the sand and the two materials combined and thoroughly mixed. After the sand and aftonian silt materials had been mixed and windrowed, the windrow was flattened to about a 30-ft top. Fifty lb bags of hydrated lime were then placed, opened and dumped in the same manner as described in the lime-treated subgrade soil section. Table 14 shows the percentages and tonnages of each of the materials used in each subdivision.

Mixing.—After dumping the lime bags a farm harrow was pulled through the piles of lime to level and spread it evenly across the flattened windrow. The surface was lightly sprinkled and the material bladed in from the edges to prevent lime loss by wind. Dry mixing was accomplished with a rotary tiller and motor grader and it was continued until the entire windrow was a homogeneous mixture. Upon completion of dry mixing, water was added uniformly and mixing was continued until all the material was approximately at optimum moisture content. Prior to laydown the mixture was allowed to cure in the windrow for approximately 14 hours.

Compaction.—In this section the mixture was spread evenly across the roadbed, sprinkled to maintain the moisture at near optimum and compacted with a pneumatic-tired roller. The special provisions required that the density attained be not less than 100 percent of maximum. The range of densities on the compacted material is shown in Table 15.

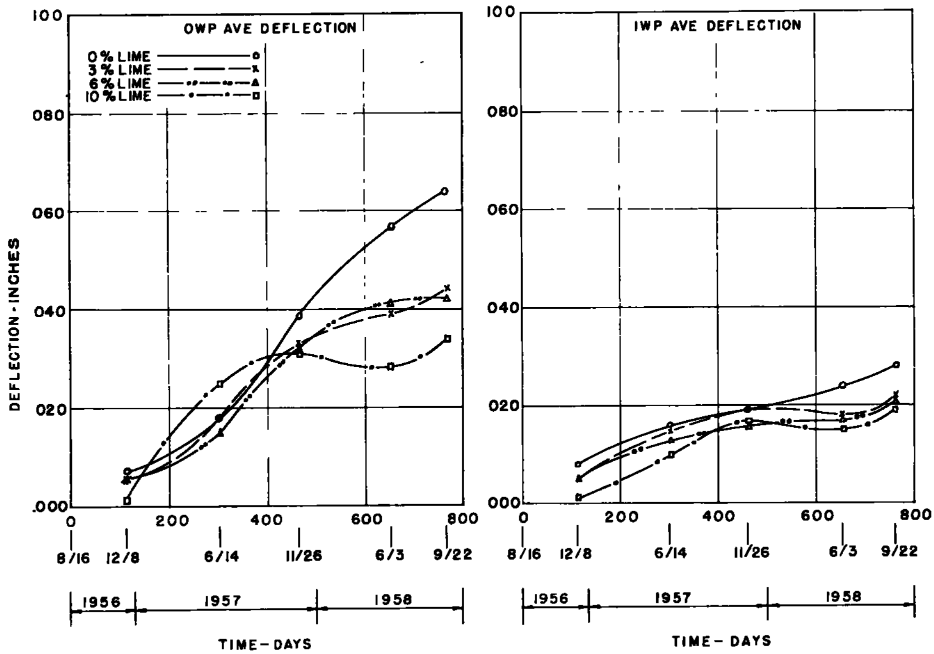

Figure 12. Average flexible pavement deflection; lime-treated soil section.

Curing.—After the base course was compacted and shaped to the typical cross section, it was sprinkled for a period of 4 days. Following this curing period the base was allowed to dry for 3 days, during which time it was sprinkled only enough to prevent cracking or raveling of the surface. When the moisture content of the base course was satisfactory a prime coat was applied.

Prime Coat.—The prime coat, Mc-1 asphaltic oil, was applied at the rate of 0.30 gal. per sq yd. However, there was practically no penetration of the prime oil into the base course material. Since there might be detrimental effects to the asphaltic concrete from the excess prime oil, it was bladed off and the base was re-primed. The rate of application of the new prime coat was approximately one-half the original or 0.15 gal. per sq yd. With the reduced rate no excess asphalt remained on the surface. It appears that a lime stabilized base will absorb very little asphaltic oil, and the amount should be reduced by approximately 50 percent of that required on a conventional stabilized base.

Cost Estimate

A cost study on the square yard basis was made on the experimental lime subdivisions and the standard design subdivisions (Table 16). When reviewing this estimate it should be kept in mind that the lime stabilization in Nebraska was of an experimental nature, and therefore, the bid prices were probably higher than normal.

TABLE 13

CONSTRUCTION DENSITIES OF THE LIME-TREATED SUBGRADE SOIL

Subdivision Number	Percent Lime	Optimum Moisture	Maximum Density	Range of Density (Percent of Max)	Range of Moisture (Percent)
2	3	17.7	1.72	96% to 98%	18.2% to 20.6%
3	6	18.8	1.66	96% to 105%	18.1% to 19.1%
4	10	19.3	1.64	96% to 103%	21.0% to 21.2%

TABLE 14

DISTRIBUTION OF AGGREGATES IN THE LIME-TREATED BASE COURSE SECTION

Subdivision Number	Lime		Coarse Sand		Aftonian Silt		Combined Windrow (Tons/Sta)
	%	Tons/Sta	%	Tons/Sta	%	Tons/Sta	
6	2	1.7	83	68.9	15	12.4	83
7	4	3.3	76	63.1	20	16.6	83
8	7	5.8	73	60.6	20	16.6	83

TABLE 15

CONSTRUCTION DENSITIES OF THE LIME-TREATED BASE COURSE

Subdivision Number	Percent Lime	Optimum Moisture	Maximum Density	Range of Density (Percent of Max)	Range of Moisture (Percent)
6	2	10.5	1.92	105% to 106%	6.3% to 8.0%
7	4	9.5	1.93	104% to 107%	8.6% to 9.1%
8	7	10.0	1.97	101% to 107%	6.4% to 6.8%

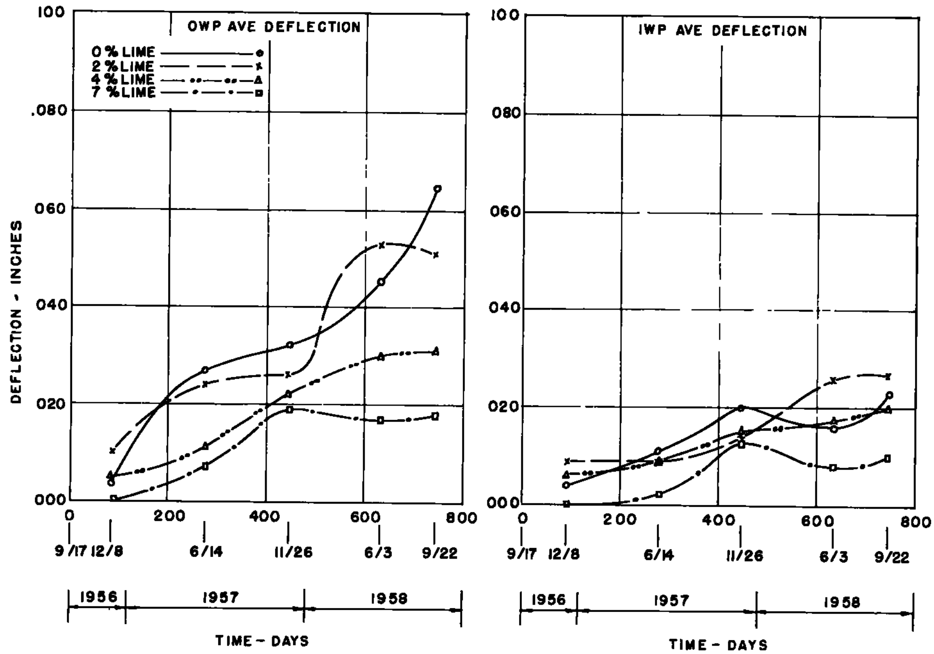

Figure 13. Average flexible pavement deflection; lime-treated base course section.

TABLE 16

COST DATA BASED ON BID OF LOW BIDDER FOR PROJECT

Lime-Treated Subgrade Soil Section

Type of Construction	Subdivision No. 1[a]	Subdivision No. 2	Subdivision No. 3	Subdivision No. 4
	STA 1047 To STA 1062	STA 1062 To STA 1077	STA 1077 To STA 1092	STA 1092 To STA 1107
	0% Lime	3% Lime	6% Lime	10% Lime
Granular Subbase Course				
Dimension	7 in. x 30 ft	–	–	–
Cost per Sq Yd	$0.45	–	–	–
Soil Aggregate Base Course				
Dimension	4 in. x 27 ft	4 in. x 27 ft	4 in. x 27 ft	4 in. x 27 ft
Cost per Sq Yd	$0.52	$0.52	$0.52	$0.52
Lime Treated Subgrade Soil				
Dimension	–	7 in. x 33 ft	7 x 33 ft	7 in. x 33 ft
Cost per Sq Yd	–	$0.43	$0.65	$0.96
Total Cost per Sq Yd	$0.97	$0.95	$1.17	$1.48

Lime-Treated Base Course Section

Type of Construction	Subdivision No 5[a]	Subdivision No. 6	Subdivision No. 7	Subdivision No. 8
	STA 1148 To STA 1161	STA 1161 To STA 1174	STA 1174 To STA 1187	STA 1187 To STA 1200
	0% Lime	2% Lime	4% Lime	7% Lime
Granular Subbase Course				
Dimension	7 in. x 30 ft	5 in. x 30 ft	5 in. x 30 ft	5 in. x 30 ft
Cost per Sq Yd	$0.45	$0.35	$0.35	$0.35
Soil Aggregate Base Course				
Dimension	4 in. 27 ft	–	–	–
Cost per Sq Yd	$0.52	–	–	–
Lime Treated Base Course				
Dimension	–	6 in. x 27 ft	6 in. x 27 ft	6 in. x 27 ft
Cost per Sq Yd	–	$0.64	$0.81	$1.07
Total Cost per Sq Yd	$0.97	$0.99	$1.16	$1.42

[a] Standard Design

POST CONSTRUCTION SAMPLING, TESTING, AND DISCUSSION OF RESULTS

Sampling

The first series of samples of the lime-treated subgrade soil were taken 16 days after construction. At this time an attempt was made to take undisturbed cores of the material. This attempt was unsuccessful but disturbed samples, as well as in-place density tests, were taken. The results of these tests are shown in Tables 17, 18 and 19. No attempt was made to take cores of the lime-treated base course at a similar curing period.

In December 1956, another unsuccessful attempt was made to take undisturbed cores of both the lime-treated subgrade soil and lime-treated base course. No samples of either material were obtained at this time.

No further sampling was attempted until April 1958 (600 day curing time). At this time there was moderate success in obtaining partial cores of the material in both lime-treated sections. The undisturbed pieces of the material were large enough for density determination and some cores were sufficient in size so that 2- by 2-in. cubes could be

TABLE 17

TABULATION OF LABORATORY TEST RESULTS SUBDIVISION NO. 2 STATION 1062 + 00 TO STATION 1077 + 00
3 PERCENT LIME-TREATED SUBGRADE SOIL

	Test Site No. 2a (Fill) Station 1066 + 00[1]						Test Site No. 2b (Cut) Station 1076 + 00[1]					
	Untreated Soil	3% Lime-Treated Subgrade Soil					Untreated Soil	3% Lime-Treated Subgrade Soil				
	Prior to Const.	16 Days After Const.			600 Days After Const.		Prior to Const.	16 Days After Const.			600 Days After Const.	
Tests	9' Rt.	Cents	9' Rt.	14' Rt.	9' Rt.	14' Rt.	9' Lt.	Cents	9' Lt.	14' Lt.	9' Lt.	14' Lt.
Sieve Analysis, % Ret.												
1 in.	—	—	—	—	—	—	0	—	—	—	0	—
3/8 in.	0	—	—	—	1	—	1	—	—	—	2	—
No. 4	2	0	0	0	3	—	3	0	0	0	2	0
10	2	1	1	1	5	0	7	3	2	1	4	2
20	4	12	8	8	8	7	10	11	11	10	9	12
40	7	24	18	18	13	18	13	19	21	21	15	23
50	9	29	24	24	17	25	16	24	27	27	18	28
100	15	40	35	35	24	37	22	33	37	38	27	38
200	19	47	42	42	30	45	27	40	45	47	34	45
Hydrometer Analysis												
Sand	24	57	51	50	66	50	33	51	55	61	64	66
Silt[2]	37	32	37	38	28	42	36	37	33	31	32	30
Clay	39	11	12	12	6	8	31	12	12	8	4	4
Specific Gravity	2.67	2.66	2.66[3]	2.66[3]	2.67[3]	2.66[3]	2.66	2.66	2.66[3]	2.66[3]	2.67[3]	2.66[3]
Liquid Limit	47	39	40	39	38	40	44	37	37	37	38	39
Plastic Limit	23	29	29	28	32	28	20	28	30	30	31	32
Plasticity Index	24	10	11	11	6	12	24	9	7	7	7	7
Capillarity	10'13"	17'25"	23'22"	28'41"	3'31"	16'11"	12'23"	33'38"	27'4"	32'10"	7'53"	21'7"
Absorption Failure	34'42"	2 hr +	2 hr +	2 hr +	3'35"	2 hr +	20'26"	2 hr +	2 hr +	2 hr +	27'42"	2 hr +
Cementation	200 +	200 +	200 +	200 +	200 +	200 +	200 +	200 +	200 +	200 +	200 +	200 +
Shrinkage Limit	12.23	21.34	23.21	17.54	19.7	21.2	12.71	19.51	23.44	23.04	21.7	24.6
Shrinkage Ratio	1.86	1.589	1.561	1.639	1.603	1.60	1.84	1.644	1.522	1.541	1.568	1.49
Lineal Shrinkage	7.1	4.8	4.1	6.7	6.9	5.2	6.4	5.2	2.5	4.6	6.1	4.7
Volumetric Change	22.64	15.71	13.47	22.71	23.6	17.1	21.69	17.44	7.90	14.99	20.5	15.3
Field Moist. Equivalent	24.4	31.23	31.85	31.39	34.4	31.90	24.5	30.12	28.63	32.74	34.8	34.9
Chemical Analysis, Lime												
Top Half, Percent	1.0[4]	2.7[5]	2.8[5]	2.9[5]	2.5[5]	2.4[5]	0.7[4]	4.0[5]	4.0[5]	3.2[5]	3.3[5]	3.1[5]
Bottom Half, Percent	—	2.7[5]	2.6[5]	2.5[5]	2.6[5]	2.6[5]	—	2.6[5]	2.6[5]	3.4[5]	2.5[5]	2.5[5]
Unconfined Compression Strength Test												
Total Load, lb	698[6]	—	—	—	—	—	540[6]	—	—	—	—	—
P.S.I.	56	—	—	—	—	—	43	—	—	—	—	—
Percent, Moisture	18.7	—	—	—	—	—	17.8	—	—	—	—	—
Optimum Moisture, %	17.5	17.7	17.7	17.7	17.7	17.7	17.5	17.7	17.7	17.7	17.7	17.7
Maximum Density, Gm/cc	1.73	1.72	1.72	1.72	1.72	1.72	1.73	1.72	1.72	1.72	1.72	1.72
Actual Moisture, %	17.4	—	17.7	—	21.2	22.7	9.8	—	17.8	—	20.5	24.2
Actual Density, Gm/cc	1.72	—	1.67	—	1.66	1.61	1.90	—	1.66	—	1.58	1.60
Percent Optimum	99	—	100	—	120	128	56	—	101	—	116	137
Percent Maximum	99	—	97	—	97	94	110	—	97	—	92	93
AASHO Soil Class.	A-7-6 (15)	A-4(4)	A-6(5)	A-6(5)	A-4(7)	A-6(5)	A-7-6 (14)	A-4(5)	A-4(4)	A-4(4)	A-4(6)	A-4(4)

[1] Depth of sample approximately 7 to 14 in. below finish grade.
[2] 0.005 mm to 0.05 mm.
[3] Assumed.
[4] Chemical analysis of percent lime in untreated soil.
[5] Lime content corrected for original lime content.
[6] 4 by 4 in. molded cylinder.

sawed from them for unconfined compressive strength tests. Besides the cores enough material was obtained for soil testing. Also at this time in-place density tests and material for soil testing were taken from the soil aggregate base course (Table 21), granular subbase course (Table 22), and subgrade soil (Tables 23, 24, 25 and 26). A volumeasure was used in measuring the in-place densities of the two base course materials, while specimens for the density tests of the subgrade soil were taken by Shelby tube.

Testing

The tests performed on the post-construction samples of the lime-treated subgrade

TABLE 18

TABULATION OF LABORATORY TEST RESULTS SUBDIVISION NO. 3 STATION 1077+00 TO STATION 1092+00
6 PERCENT LIME-TREATED SUBGRADE SOIL

Tests	Test Site No. 3a (Cut) Station 1084+00[1]						Test Site No. 3b (Fill) Station 1089+00[1]					
	Untreated Soil	6% Lime-Treated Subgrade Soil					Untreated Soil	6% Lime-Treated Subgrade Soil				
	Prior to Const.	16 Days After Const.			600 Days After Const.		Prior to Const.	16 Days After Const.			600 Days After Const.	
	9'Rt.	Cents	9'Rt.	14'Rt.	9'Rt.	14'Rt.	9'Lt.	Cents	9'Lt.	14'Lt.	9'Lt.	14' Lt.
Sieve Analysis, % Ret.												
1 in.	–	0	–	–	–	–	–	–	–	–	–	–
3/4 in.	–	1	0	0	–	–	–	–	–	–	0	–
No. 4	0	2	1	1	0	0	0	0	0	0	3	0
10	1	7	2	2	3	1	1	4	1	1	16	2
20	2	20	14	18	18	22	3	19	14	8	34	19
40	3	30	26	31	31	36	6	31	26	17	48	33
50	4	35	32	37	36	41	9	37	31	22	54	39
100	7	44	42	48	48	53	16	48	48	33	63	50
200	9	52	52	58	54	61	23	58	50	43	69	59
Hydrometer Analysis												
Sand	22	79	78	78	82	82	38	80	78	84	77	84
Silt[2]	52	21	21	22	18	18	31	20	20	16	20	16
Clay	26	0	1	0	0	0	31	0	2	0	3	0
Specific Gravity	2.66	2.65	2.65[3]	2.65[3]	2.67[3]	2.66[3]	2.67	2.65[3]	2.65[3]	2.65[3]	2.67[3]	2.66[3]
Liquid Limit	40	31	32	31	NP	NP	44	33	31	33	34	NP
Plastic Limit	21	NP	31	NP	NP	NP	20	NP	30	NP	31	NP
Plastic Index	19	NP	1	NP	NP	NP	24	NP	1	NP	3	NP
Capillarity	6'12"	5'44"	5'35"	5'36"	2'44"	4'25"	9'05"	7'30"	8'59"	8'42"	20'3"	6'59"
Absorption Failure	6'12"	2 hr.+	2 hr.+	2 hr.+	2 hr.+	2 hr.+	9'05"	2 hr.+	2 hr.+	2 hr.+	21'9"	2 hr.+
Cementation	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+
Shrinkage Limit	17.75	28.39	26.15	23.77	28.5	28.9	12.93	25.86	20.93	28.07	24.24	28.4
Shrinkage Ratio	1.72	1.346	1.369	1.507	1.381	1.34	1.84	1.440	1.576	1.489	1.532	1.37
Lineal Shrinkage	3.8	2.3	5.3	6.3	4.3	5.2	5.2	4.3	6.8	6.1	4.5	4.4
Volumetric Change	10.92	7.02	17.57	20.87	14.1	16.9	18.16	15.54	23.16	20.33	14.6	14.4
Field Moist. Equivalent	24.1	33.59	38.99	37.61	38.7	41.5	22.8	36.25	35.62	36.69	33.9	38.9
Chem. Analysis, Lime												
Top Half, %	0.5[4]	7.7[5]	6.9[5]	6.1[5]	5.7[5]	6.2[5]	1.2[4]	5.6[5]	5.6[5]	6.4[5]	4.4[5]	6.1[5]
Bottom Half, %	–	4.4[5]	6.0[5]	5.7[5]	4.4[5]	5.4[5]	–	5.0[5]	5.6[5]	6.2[5]	4.5[5]	6.5[5]
Unconfined Compressive Strength Test												
Total Loads, Lbs.	790[6]	–	–	–	–	1100[7]	703[6]	–	–	–	–	–
P.S.I.	63	–	–	–	–	275	56	–	–	–	–	–
% Moisture	16.9	–	–	–	–	19.7	17.0	–	–	–	–	–
Optimum Moisture,%	16.5	18.8	18.8	18.8	18.8	18.8	16.5	18.8	18.8	18.8	18.8	18.8
Maximum Density, Gm/cc	1.76	1.66	1.66	1.66	1.66	1.66	1.76	1.66	1.66	1.66	1.66	1.66
Actual Moisture, %	13.3	–	16.4	–	17.0	19.8	12.2	–	19.1	–	19.0	20.5
Actual Density, Gm/cc	1.83	–	1.63	–	1.67	1.54	1.75	–	1.60	–	1.66	1.60
% Optimum	81	–	87	–	90	105	74	–	102	–	101	109
% Maximum	104	–	98	–	101	93	99	–	96	–	100	96
AASHO Soil Class.	A-6 (12)	A-4(3)	A-4(3)	A-4(1)	A-4(2)	A-4(1)	A-7-6 (14)	A-4(1)	A-4(3)	A-4(4)	A-2-4 (0)	A-4(1)

[1] Depth of sample approximately 7 to 14 in. below finish grade.
[2] 0.005 mm to 0.05 mm
[3] Assumed.
[4] Chemical analysis of percent lime in untreated soil.
[5] Lime content corrected for original lime content.
[6] 4 by 4 in. molded cylinder.
[7] 2 by 2 in. cube cut from core.

soil included those outlined in Table 4 (except AASHO T99-49) and also in-place moisture density determinations and chemical analyses for percentage of lime. Only sieve analysis, unconfined compressive strength tests, and chemical analyses for percentage of lime were performed on the lime-treated base course samples. Tests performed on the soil aggregate base course and granular subbase course samples included sieve and hydrometer analysis, determination of plasticity index, specific gravity, and in-place moisture density tests. Tests of the untreated subgrade soil samples in both lime-treated sections included those outlined in Table 4 (except AASHO T99-49) and in-place moisture density determinations.

TABLE 19

TABULATION OF LABORATORY TEST RESULTS SUBDIVISION NO. 4 STATION 1092+00 TO STATION 1107+00
10 PERCENT LIME-TREATED SUBGRADE SOIL

Tests	Test Site No. 4a (Cut) Station 1096+00[1]						Test Site No. 4b (Fill) Station 1106+00[1]					
	Untreated Soil	10% Lime-Treated Subgrade Soil					Untreated Soil	10% Lime-Treated Subgrade Soil				
	Prior to Const.	16 Days After Const.			600 Days After Const.		Prior to Const.	16 Days After Const.			600 Days After Const.	
	9' Lt.	Cents	9' Lt.	14' Lt.	9' Lt.	14' Lt.	9' Rt.	Cents	9' Rt.	14' Rt.	9' Rt.	14" Rt.
Sieve Analysis, % Ret.												
1 in.	–	–	–	–	–	–	–	–	–	–	–	–
3/8 in.	–	–	–	–	–	–	–	–	–	–	–	0
No. 4	–	–	–	0	0	0	0	1	–	–	0	1
10	0	0	0	1	2	2	1	1	0	0	2	2
20	1	9	7	11	20	33	1	7	6	5	20	22
40	1	20	17	21	33	46	3	17	14	13	32	37
50	1	24	22	25	37	50	4	22	19	18	37	42
100	3	33	30	33	43	57	10	34	32	29	47	54
200	6	40	39	41	48	63	20	46	44	41	55	63
Hydrometer Analysis												
Sand	20	81	81	80	84	88	33	79	82	82	82	86
Silt[2]	49	19	19	20	14	12	34	21	18	18	17	14
Clay	31	0	0	0	2	0	33	0	0	0	1	0
Specific Gravity	2.67	2.65	2.65[3]	2.65[3]	2.67[3]	2.66[3]	2.65	2.65	2.65[3]	2.65[3]	2.67	2.66
Liquid Limit	47	36	36	37	NP	NP	40	31	32	30	NP	NP
Plastic Limit	22	NP	NP	NP	NP	NP	22	NP	NP	NP	NP	NP
Plasticity Index	25	NP	NP	NP	NP	NP	18	NP	NP	NP	NP	NP
Capillarity	15'4"	4'25"	4'3"	3'3"	19'12"	8'24"	15'7"	6'5"	5'44"	5'15"	3'13"	5'34"
Absorption Failure	22'7"	2 hr.+	2 hr.+	2 hr.+	2 hr.+	2 hr.+	39'8"	2 hr.+	2 hr.+	2 hr.+	2 hr.+	2 hr.+
Cementation	200+	200+	200+	200+	182	200+	200+	200+	200+	152	200+	200+
Shrinkage Limit	14.96	27.09	27.41	27.82	29.7	33.2	14.03	24.65	25.70	25.99	27.6	28.1
Shrinkage Ratio	1.80	1.449	1.375	1.331	1.358	1.30	1.80	1.361	1.351	1.366	1.314	1.30
Lineal Shrinkage	4.8	5.5	5.6	6.5	5.6	4.2	4.70	5.2	5.00	5.1	5.3	3.6
Volumetric Change	16.27	17.93	18.41	21.89	18.5	13.8	15.60	17.19	16.48	16.62	17.9	11.6
Field Moist. Equivalent	24.0	39.47	40.79	44.26	43.3	43.8	22.70	37.27	37.88	38.15	41.2	37.0
Chem. Analysis, Lime												
Top Half, %	1.0[4]	10.3[5]	9.8[5]	9.8[5]	8.6[5]	9.6[5]	0.5[4]	7.5[5]	7.5[5]	6.9[5]	6.1[5]	7.0[5]
Bottom Half, %	–	9.7[5]	9.4[5]	8.7[5]	5.8[5]	10.1[5]	–	7.1[5]	7.0[5]	6.8[5]	6.8[5]	6.4[5]
Unconfined Compression Strength Test												
Total load, lb	780[6]	–	–	–	–	–	703[6]	–	–	–	–	–
P.S.I.	62	–	–	–	–	–	56	–	–	–	–	–
% Moisture	18.7	–	–	–	–	–	17.7	–	–	–	–	–
Optimum Moisture, %	18.0	19.3	19.3	19.3	19.3	19.3	18.0	19.3	19.3	19.3	19.3	19.3
Maximum Density, Gm/cc	1.69	1.64	1.64	1.64	1.64	1.64	1.69	1.64	1.64	1.64	1.64	1.64
Actual Moisture, %	19.3	–	20.6	–	23.5	26.6	10.2	–	21.5	–	18.3	20.5
Actual Density, Gm/cc	1.76	–	1.62	–	1.56	1.37	1.81	–	1.58	–	1.65	1.58
% Optimum	107	–	107	–	122	138	57	–	111	–	95	106
% Maximum	104	–	99	–	95	84	107	–	97	–	101	96
AASHO Soil Class.	A-7-6 (15)	A-4(5)	A-4(5)	A-4(5)	A-4(3)	A-4(0)	A-6 (11)	A-4(4)	A-4(4)	A-4(5)	A-4(2)	A-4(0)

[1] Depth of samples approximately 7 to 14 in. below finish grade.
[2] 0.005 mm to 0.05 mm.
[3] Assumed.
[4] Chemical analysis of percent lime in untreated soil.
[5] Lime content corrected for original lime content.
[6] 4 by 4 in. molded cylinder.

TABLE 20

LABORATORY TEST RESULTS FOR LIME-TREATED BASE COURSE STATION 1161 TO STATION 1200

Tests	Subd. No. 6, Sta 1161 to Sta 1174, 2% Lime					Subd. No. 7, Sta 1174 to Sta 1187, 4% Lime					Subd. No. 8, Sta 1187 to Sta 1200, 7% Lime				
	Sta 1170	Test Site 6a (Fill) Sta 1167		Test Site 6b (Fill) Sta 1171		Sta 11800	Test Site 7a (Fill) Sta 1178		Test Site 7b (Fill) Sta 1183		Sta 1195	Test Site 8a (Cut) Sta 1192		Test Site 8b (Fill) Sta 1199	
	During Const.	600 Days After Const.		600 Days After Const.		During Const.	600 Days After Const.		600 Days After Const.		During Const.	600 Days After Const.		600 Days After Const.	
	9'Rt	9'Rt	14'Rt	9'Lt	14'Lt	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt
Sieve Analysis, % Ret.															
1 in.	—	—	—	—	0	—	—	—	—	—	—	—	—	—	—
3/8 in.	0	—	—	0	1	0	0	0	0	0	0	0	0	—	—
No. 4	1	0	0	1	1	3	1	1	0	1	1	2	1	0	0
10	3	2	2	3	2	5	3	2	1	2	3	3	4	1	1
20	11	8	11	11	10	12	16	11	9	12	13	14	14	9	6
30	27	25	28	30	27	23	35	26	25	29	24	31	28	23	20
40	55	51	57	54	53	49	56	49	49	56	52	52	51	45	40
50	69	68	72	69	67	63	70	62	65	70	66	67	65	58	55
80	76	76	79	76	74	69	76	69	71	76	72	75	72	66	64
100	77	78	81	77	76	71	78	70	73	78	74	77	74	68	67
200	79	82	84	81	80	73	84	75	78	82	76	83	78	74	72
Chemical Analysis Lime, Percent	—	3.8	3.6	4.0	4.2	—	6.1	4.9	6.3	6.1	—	7.8	7.4	11.6	11.2
Optimum Moisture, %	10.5	10.5	10.5	10.5	10.5	10.5	9.5	9.5	9.5	9.5	10.0	10.0	10.0	10.0	10.0
Maximum Density, gm/cc	1.92	1.92	1.92	1.92	1.92	1.93	1.93	1.93	1.93	1.93	1.97	1.97	1.97	1.97	1.97
Actual Moisture, %	8.0	7.1	8.3	8.3	5.4	9.1	8.7	10.7	8.7	9.5	6.7	7.9	9.5	6.6	7.8
Actual Density, gm/cc	2.01	1.92	1.88	1.93	1.98	2.00	1.92	1.95	1.87	1.89	2.03	1.96	1.94	1.88	1.99
Percent of Optimum	76	68	79	79	51	96	92	113	92	100	67	79	95	66	78
Percent of Maximum	105	100	98	100	103	104	99	101	97	98	103	99	99	96	101
Unconfined Compressive Strength Test															
Total Load, lb	—	—	—	660[1]	—	—	—	1670	—	2980[1]	—	3180[1]	—	1620[1]	—
P.S.I.	—	—	—	165	—	—	—	430	—	745	—	795	—	405	—
% Moisture as Tested	—	—	—	8.9	—	—	—	9.8	—	8.3	—	8.2	—	8.0	—

[1] 2 by 2 in. cube cut from core.

TABLE 21

TEST RESULTS FOR SOIL AGGREGATE BASE COURSE

Tests	Subd No. 1 Sta 1047 to Sta 1062[1]					Subd No 2 Sta 1062 to Sta 1077[1]					Subd. No 3 Sta 1077 to Sta 1092[1]					Subd. No. 4 Sta 1092 to Sta 1107[1]					Subd No. 5 Sta 1148 to Sta 1161[1]				
	Sta 1050	Test Site 1a (Fill) Sta 1052		Test Site 1b (Cut) Sta 1059		Sta 1070	Test Site 2a Fill) Sta 1106		Test Site 2b (Cut) Sta 1076		Sta 1080	Test Site 3a (Cut) Sta 1084		Test Site 3b (Fill) Sta 1089		Sta 1100	Test Site 4a (Cut) Sta 1096		Test Site 4b (Fill) Sta 1106		Sta 1150	Test Site 5a (Cut) Sta 1151		Test Site 5b (Fill) Sta 1159	
	During Const	600 Days After Const.		600 Days After Const.		During Const	600 Days After Const.		600 Days After Const		During Const.	600 Days After Const.		600 Days After Const		During Const	600 Days After Const		600 Days After Const.		During Const.	600 Days After Const		600 Days After Const.	
	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt	9'Rt	9'Rt	14'Rt	9'Lt	14'Lt	9'Rt	9'Rt	14'Rt	9'Lt	14'Lt	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt
Sieve Analysis, % Ret.																									
1 in.	0	0	0	0	–	0	0	–	0	0	0	0	–	0	–	0	0	0	0	0	0	0	4	0	0
3/8 in.	5	4	3	9	11	3	9	13	8	6	5	4	10	2	6	4	5	6	4	6	4	4	8	6	4
No 4	22	17	9	22	29	20	37	38	29	29	21	15	29	15	18	22	16	22	20	18	16	19	15	18	17
10	50	42	20	41	53	48	59	60	55	57	49	41	57	46	34	50	43	51	52	46	45	45	29	48	39
20	61	55	37	50	62	59	65	66	64	66	62	55	69	58	45	62	55	63	66	60	58	57	41	63	51
40	78	75	70	72	81	78	80	81	79	80	79	75	84	76	68	78	73	79	79	75	74	74	65	78	68
50	85	82	80	81	87	84	85	87	85	86	85	82	88	82	78	84	80	84	83	81	81	81	75	85	77
100	90	88	87	87	91	89	89	90	89	89	90	87	92	87	85	90	85	89	88	86	87	87	84	90	86
200	92	90	88	89	93	91	90	92	91	91	92	89	93	89	87	92	87	90	89	88	89	89	87	92	88
Hydrometer Analysis																									
Sand	94	94	90	92	94	93	93	94	93	93	94	93	94	91	91	94	89	91	92	90	93	93	92	95	90
Silt[2]	2	2	4	3	3	3	3	2	3	3	2	3	3	4	4	2	5	5	4	5	3	3	3	2	5
Clay	4	4	6	5	3	4	4	4	4	4	4	4	3	5	5	4	6	4	4	5	4	4	5	3	5
Specific Gravity	2 65	2 67[3]	2.67[3]	2 67[3]	2.67[3]	2 65[3]	2 67[3]	2 67[3]	2.67[3]	2.67	2 65[3]	2.67[3]	2 67[3]	2.67[3]	2.67	2 65	2.67[3]	2.67[3]	2.67[3]	2.67	2.63	2 67[3]	2.67[3]	2.67[3]	2.66
Liquid Limit	19	19	20	21	20	21	23	22	21	23	17	22	20	22	21	18	23	24	21	24	21	20	21	18	19
Plastic Limit	15	15	16	17	16	16	17	14	17	15	15	17	16	16	15	17	17	17	17	16	15	15	15	16	14
Plasticity Index	4	4	4	4	4	5	6	8	4	8	2	5	4	6	6	1	6	7	4	8	6	5	6	2	5
Optimum Moisture, %	7.0	7.0	7 0	7 0	7 0	7 0	7 0	7 0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7 0	7.0	7.0	7 0	7 0	7.0	7 0	7.0	7 0	7.0
Maximum Density gm/cc	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2 08	2.08	2.08	2.08	2 08	2 08	2.08	2.08
Actual Moisture, %	7.5	4.7	5.3	4 2	4 7	9 5	4 2	3 6	3.6	4 7	6 2	4.2	4 2	2 6	4.2	6.7	4 2	5 8	4.2	4 7	4.2	3.6	5 3	3 1	3 6
Actual Density, gm/cc	2.20	2.16	1 82	2 04	2.05	2.24	2 32	1 85	1 62	2 14	2.26	2.02	2 05	2 06	1.98	2 16	1 68	1.94	2.06	1 49	2.22	1 96	1.91	1 90	1 87
Percent of Optimum	107	67	76	60	67	136	60	51	51	67	89	60	60	37	60	96	60	93	60	67	60	51	76	44	51
Percent of Maximum	106	104	88	98	99	107	112	89	78	103	109	97	99	99	95	104	81	83	99	72	107	94	92	91	90
AASHO Soil Class.	A-1-a (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-a (0)	A-1-b (0)	A-1-a (0)	A-2-4 (0)	A-1-a (0)	A-2-4 (0)	A-1-b (0)	A-1-b (0)	A-1-a (0)	A-1-b (0)	A-1-b (0)	A-1-a (0)	A-1-b (0)	A-2-4 (0)	A-1-a (0)	A-2-4 (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)

[1]Depth of sample approximately 3 to 7 in. below finish grade elevation
[2]0 005 mm to 0.05 mm
[3]Assumed

TABLE 22

TESTS RESULTS FOR GRANULAR SUBBASE COURSE

Tests	Subd No 1 Sta 1047 to 1062[1]					Subd. No 5 Sta 1148 to 1161[1]					Subd. No. 6 Sta 1161 to 1174[1]					Subd. No 7 Sta 1174 to 1187[1]					Subd. No. 8 Sta 1187 to 1200[1]				
	Sta 1050	Test Site 1a (Fill) Sta 1052		Test Site 1b (Cut) Sta 1059		Sta 1150	Test Site 5a (Cut) Sta 1151		Test Site 5b (Fill) Sta 1159		Sta 1170	Test Site 6a (Fill) Sta 1167		Test Site 6b (Fill) Sta 1171		Sta 1180	Test Site 7a (Fill) Sta 1178		Test Site 7b (Fill) Sta 1183		Sta 1190	Test Site 8a (Cut) Sta 1192		Test Site 8b (Fill) Sta 1199	
	During Const.	600 Days After Const.		600 Days After Const.		During Const.	600 Days After Const		600 Days After Const		During Const.	600 Days After Const		600 Days After Const.		During Const.	600 Days After Const.		600 Days After Const.		During Const.	600 Days After Const.		600 Days After Const	
	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt	9'Rt	9'Rt	14'Rt	9'Lt	14'Lt	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt	9'Rt	14'Rt
Sieve Analysis, % Ret.																									
1 in.	0	0	—	0	0	0	0	1	0	0	—	—	—	—	—	0	—	—	—	—	0	0	0	0	0
¾ in.	1	2	0	6	4	3	1	5	6	3	0	—	0	0	0	1	0	1	0	—	2	1	4	1	1
No 4	4	7	3	8	6	6	5	8	9	7	1	0	2	1	1	3	1	2	2	0	4	5	5	2	2
10	10	16	7	16	11	11	11	14	16	14	4	2	3	2	2	7	3	4	5	2	8	8	9	5	6
20	27	34	13	34	24	26	27	30	29	26	10	10	9	8	7	15	11	13	16	10	18	19	17	15	18
40	63	68	66	72	56	63	60	64	57	56	59	56	55	53	51	55	57	61	63	50	57	56	51	54	58
50	76	79	79	83	69	75	73	77	70	68	76	74	74	70	68	68	74	80	79	65	71	75	69	67	70
100	83	85	86	88	76	85	83	84	85	83	83	81	80	78	76	82	82	87	87	72	83	84	77	76	79
200	85	87	88	90	79	88	86	88	88	87	86	84	83	80	77	88	85	90	89	74	85	86	79	80	82
Hydrometer Analysis																									
Sand	88	89	91	94	82	90	91	91	92	91	85	87	87	84	82	90	88	93	91	—	87	89	85	85	88
Silt	5	6	4	3	9	4	5	4	4	4	7	5	5	7	7	4	5	2	3	—	6	5	8	6	5
Clay	7	5	5	3	9	6	4	5	4	5	8	8	8	9	11	6	7	5	6	—	7	6	7	9	7
Specific Gravity	2 66	2 67[3]	2.67[3]	2.67[3]	2.67	2.65	2 67[3]	2 67[3]	2 67	2.65[3]	2.65[3]	2.65[3]	2 65[3]	2.65[3]	2.65[3]	2.65[3]	2.65[3]	2 65[3]	2.65[3]	—	2.65[3]	2.65[3]	2.65[3]	2 65[3]	2.65
Liquid Limit	21	22	19	19	24	19	20	20	19	NP	26	25	24	28	27	19	18	NP	20	—	22	NP	21	25	23
Plastic Limit	17	17	16	15	16	17	17	17	16	NP	16	15	15	16	16	15	16	NP	15	—	18	NP	16	17	15
Plasticity Index	4	5	3	4	8	2	3	3	3	NP	10	10	9	12	11	4	2	NP	5	—	4	NP	5	8	8
Optimum Moisture, %	12.3	12.3	12.3	12.3	12 3	12 3	12 3	12.3	12 3	12.3	13 0	13.0	13 0	13.0	13.0	13 0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13 0	13.0
Maximum Density, gm/cc	1.87	1.87	1 87	1.87	1.87	1 87	1 87	1.87	1.87	1.87	1 82	1 82	1 82	1.82	1.82	1.82	1 82	1 82	1.82	1.82	1.82	1.82	1.82	1.82	1.82
Actual Moisture, %	13 0	5.8	5.8	5.3	8 7	10 5	5.3	7 0	5 3	5 8	11.1	6.4	8.1	7 5	9.3	10 1	7.0	7.0	9 3	6 4	10 5	5.3	10.5	2.1	6 0
Actual Density, gm/cc	2.01	1.98	1 87	1.88	1.77	2.06	1.90	1.64	1.83	1 85	1.82	2 17	1 97	2.08	1.85	1.76	1.98	1 86	1 97	1.94	2.01	2.10	1.98	1 97	2.16
Percent of Optimum	106	47	47	43	71	85	43	57	43	47	85	49	62	58	72	78	54	54	72	49	81	41	81	16	46
Percent of Maximum	107	106	100	100	95	110	102	88	98	99	100	119	108	114	102	97	109	102	108	107	110	115	109	108	119
AASHO Soil Class.	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-2-4 (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-2-4 (0)	A-2-4 (0)	A-2-4 (0)	A-2-6 (0)	A-2-6 (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-2-4 (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-2-4 (0)	A-2-4 (0)

[1] Sample depth in subdivision 1 and 5 approximately 7 to 14 in below finish grade, in subdivision 6, 7 and 8 approximately 9 to 14 in below finish grade.
[2] 0 005 to 0 05 mm
[3] Assumed.

TABLE 23

TEST RESULTS FOR UNTREATED SUBGRADE SOIL BELOW LIME TREATMENT, LIME-TREATED SUBGRADE SOIL SECTION

Tests	Subd. No 1 Sta 1047 to Sta 1062[1]				Subd. No 2 Sta 1062 to Sta 1077[1]			
	Test Site 1a (Fill) Sta 1052		Test Site 1b (Cut) Sta 1059		Test Site 2a (Fill) Sta 1066		Test Site 2b (Cut) Sta 1076	
	Prior to Const	600 Days After Const.	Prior to Const	600 Days After Const.	Prior to Const.	600 Days After Const.	Prior to Const.	600 Days After Const.
	9'Lt	9'Lt	9'Rt	9'Rt	9'Rt	9'Rt	9'Lt	9'Lt
Sieve Analysis, % Ret								
1 in	–	–	–	–	–	–	–	–
⅜ in.	–	0	–	–	–	–	–	–
No 4	0	1	–	–	–	–	–	–
10	2	2	0	0	0	0	0	0
20	5	5	1	1	1	1	1	1
40	10	10	4	4	2	3	2	2
50	14	14	7	7	3	4	3	2
100	23	23	12	12	5	7	6	4
200	28	28	16	16	7	9	9	8
Hydrometer Analysis								
Sand	37	33	24	25	13	15	17	19
Silt[2]	24	31	37	29	46	49	44	45
Clay	39	36	39	36	41	36	39	36
Specific Gravity	2 69[3]	2 67[3]	2 67[3]	2.67[3]	2.66	2 67[3]	2.67[3]	2 67[3]
Liquid Limit	44	47	41	39	44	43	44	42
Plastic Limit	22	22	21	23	23	24	23	24
Plasticity Index	22	25	20	16	21	19	21	18
Capillarity	–	28'42"	–	4'32"	–	6'3"	–	6'24"
Absorption Failure	–	40'53"	–	4'33"	–	6'3"	–	6'26"
Cementation	200+	200+	200+	200+	200+	200+	200+	200+
Shrinkage Limit	–	12.2	–	10.1	–	11.4	–	11.2
Shrinkage Ratio	–	1.92	–	1 98	–	1.92	–	1.90
Lineal Shrinkage	–	9 9	–	10.6	–	11.7	–	11.6
Volumetric Change	–	36.4	–	39.6	–	45.0	–	44.1
Field Moist. Equivalent	–	31.2	–	30.1	–	34 8	–	34.4
AASHO Soil Class.	A-7-6 (14)	A-7-6 (15)	A-7-6 (12)	A-6(10)	A-7-6 (13)	A-7-6 (12)	A-7-6 (13)	A-7-6 (12)

Tests	Subd. No. 3 Sta 1077 to Sta 1092[1]				Subd. No. 4 Sta 1092 to 1107[1]			
	Test Site 3a (Cut) Sta 1084		Test Site 3b (Fill) Sta 1089		Test Site 4a (Cut) Sta 1096		Test Site 4b (Fill) Sta 1106	
	Prior to Const.	600 Days After Const	Prior to Const	600 Days After Const	Prior to Const	600 Days After Const	Prior to Const.	600 Days After Const.
	9'Rt	9'Rt	9'Lt	9'Lt	9'Lt	9'Lt	9'Rt	9'Rt
Sieve Analysis, % Ret								
1 in	–	–	–	–	–	–	–	–
⅜ in.	–	–	–	–	–	–	–	–
No 4	–	–	0	–	–	–	–	–
10	–	–	2	0	0	–	0	0
20	–	–	4	1	1	0	1	1
40	–	–	9	6	1	1	2	2
50	–	0	13	13	1	1	3	3
100	0	1	24	24	2	2	8	8
200	1	1	31	31	5	4	14	13
Hydrometer Analysis								
Sand	16	22	39	42	15	18	28	22
Silt[2]	68	68	24	23	48	51	36	41
Clay	16	10	37	35	37	31	36	37
Specific Gravity	2.63[3]	2.69	2 66[3]	2.67[3]	2 63[3]	2.67[3]	2.63[3]	2 67[3]
Liquid Limit	29	31	41	46	46	47	40	47
Plastic Limit	24	28	21	22	20	24	19	22
Plasticity Index	5	3	20	24	26	23	21	25
Capillarity	–	1'15"	–	7'6"	–	9'19"	–	5'57"
Absorption Failure	–	2'9"	–	7'6"	–	9'19"	–	6'2"
Cementation	200+	200+	200+	200+	200+	200+	200+	200+
Shrinkage Limit	–	21.7	–	9.3	–	12.1	–	10.4
Shrinkage Ratio	–	1.61	–	1.98	–	1.89	–	1.94
Lineal Shrinkage	–	5.3	–	12 5	–	11.1	–	11 5
Volumetric Change	–	17.5	–	49.1	–	42.3	–	44.4
Field Moist. Equivalent	–	32.6	–	34.1	–	34.5	–	33.3
AASHO Soil Class.	A-4(8)	A-4(8)	A-7-6 (11)	A-7-6 (13)	A-7-6 (16)	A-7-6 (15)	A-6(12)	A-7-6 (15)

[1]Depth of sample approximately 14 to 26 in below finish grade elevation (below lime treatment).
[2]0.005 mm to 0.05 mm.
[3]Assumed

TABLE 24

TEST RESULTS FOR UNTREATED SUBGRADE SOIL BELOW GRANULAR SUBBASE COURSE, LIME-TREATED BASE COURSE SECTION

Tests	Subd No 5 Sta 1148 to Sta 1161[1]				Subd No 6 Sta 1161 to Sta 1174[1]				Subd No 7 Sta 1174 to Sta 1187[1]				Subd No 8 Sta 1187 to Sta 1200[1]			
	Test Site 5a (Cut) Sta 1151		Test Site 5b (Fill) Sta 1159		Test Site 6a (Fill) Sta 1167		Test Site 6b (Fill) Sta 1171		Test Site 7a (Fill) Sta 1178		Test Site 7b (Fill) Sta 1183		Test Site 8a (Cut) Sta 1192		Test Site 8b (Fill) Sta 1199	
	Prior to Const	600 Days After Const	Prior to Const	600 Days After Const.	Prior to Const	600 Days After Const	Prior to Const	600 Days After Const	Prior to Const	600 Days After Const	Prior to Const	600 Days After Const.	Prior to Const	600 Days After Const	Prior to Const.	600 Days After Const.
	9'Lt	9'Lt	9'Rt	9'Rt	9'Rt	9'Rt	9'Lt	9'Lt	9'Lt	9'Lt	9'Rt	9'Rt	9'Lt	9'Lt	9'Rt	9'Rt
Sieve Analysis, % Ret.																
1 in.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
⅜ in.	—	—	—	—	—	—	—	—	0	0	—	—	—	—	—	—
No. 4	—	—	—	0	0	—	0	0	1	1	—	—	—	—	—	0
10	0	0	0	1	1	0	2	2	2	3	—	0	—	—	0	1
20	1	1	1	2	1	1	5	4	4	5	0	1	0	0	1	2
40	1	2	2	3	2	2	5	6	8	7	1	1	1	1	6	5
50	2	2	2	3	3	2	6	7	9	8	2	1	2	2	6	7
100	4	4	4	5	3	3	7	9	10	10	3	2	2	3	12	13
200	5	5	5	6	4	5	9	11	11	11	3	4	3	3	16	17
Hydrometer Analysis																
Sand	12	10	11	13	15	14	18	19	20	19	10	7	12	10	27	26
Silt[2]	43	44	43	44	45	47	46	45	43	42	52	53	51	52	45	44
Clay	45	46	46	43	40	39	36	36	37	39	38	40	37	38	28	30
Specific Gravity	2.67[3]	2 67[3]	2 67	2.67	2 67[3]	2.62	2 67[3]	2.65	2.67[3]	2 66	2 67[3]	2 63	2 67[3]	2 72	2 67[3]	2 67
Liquid Limit	52	54	51	50	48	49	44	45	47	48	50	49	50	51	40	37
Plastic Limit	31	30	29	26	27	28	23	25	26	27	27	28	27	26	23	21
Plasticity Index	21	24	22	24	21	21	21	20	21	21	23	21	23	25	17	16
Capillarity	—	6'12"	—	5'42"	—	16'16"	—	40'34"	—	19'45"	—	14'57"	—	5'28"	—	21'32"
Absorption Failure	—	6'12"	—	5'42"	—	16'16"	—	43'27"	—	19'45"	—	14'57"	—	5'28"	—	21'56"
Cementation	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+	200+
Shrinkage Limit	—	8 9	—	9.0	—	13 3	—	14.7	—	12 5	—	12 9	—	11 7	—	12 8
Shrinkage Ratio	—	1 98	—	1.97	—	1 81	—	1 79	—	1.85	—	1 84	—	1.90	—	1.85
Lineal Shrinkage	—	16.2	—	14 7	—	13.4	—	10.4	—	12.7	—	12 8	—	11 0	—	11 1
Volumetric Change	—	68.7	—	60 3	—	53.4	—	38 8	—	50.0	—	50.8	—	41.4	—	41.8
Field Moist Equivalent	—	43.6	—	39.6	—	42 8	—	36 4	—	39 5	—	40 5	—	33.5	—	35.4
AASHO Soil Class	A-7-5 (15)	A-7-5 (16)	A-7-6 (15)	A-7-6 (16)	A-7-6 (14)	A-7-6 (14)	A-7-6 (13)	A-7-6 (13)	A-7-6 (14)	A-7-6 (14)	A-7-6 (15)	A-7-6 (14)	A-7-6 (15)	A-7-6 (16)	A-6(11)	A-6(10)

[1] Depth of sample approximately 14 to 26 in below finish grade elevation.
[2] 0.005 to 0.05 mm
[3] Assumed.

TABLE 25

MOISTURE AND DENSITY TESTS FOR UNTREATED SUBGRADE SOIL BELOW LIME TREATMENT, LIME-TREATED SUBGRADE SOIL SECTION

	Subd. No. 1, Sta. 1047 to Sta 1062						Subd No 2, Sta. 1062 to Sta. 1077						Subd No. 3, Sta 1077 to Sta. 1092						Subd No 4, Sta. 1092 to Sta. 1107					
	Test Site 1a (Fill) Sta. 1052			Test Site 1b (Cut) Sta. 1059			Test Site 2a (Fill) Sta. 1066			Test Site 2b (Cut) Sta. 1076			Test Site 3a (Cut) Sta 1084			Test Site 3b (Fill) Sta 1089			Test Site 4a (Cut) Sta. 1096			Test Site 4b (Fill) Sta. 1106		
	Prior to Const	600 Days After Const.		Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const		Prior to Const	600 Days After Const.		Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const		Prior to Const.	600 Days After Const.	
Tests	9'Lt	9'Lt	14'Lt	9'Rt	9'Rt	14'Rt	9'Rt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt	9'Rt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt	9'Lt	9'Lt	14'Lt	9'Rt	9'Rt	14'Rt
Optimum Moisture, %	17 5	17.5	17 5	17 5	17 5	17.5	17.5	17 5	17 5	17 5	17.5	17.5	16.5	16.5	16 5	16.5	16.5	16.5	18.0	18.0	18.0	18 0	18 0	18.0
Maximum Density, gm/cc	1 73	1 73	1.73	1 73	1 73	1 73	1 73	1.73	1.73	1.73	1 73	1 73	1.76	1.76	1.76	1.76	1.76	1 76	1.69	1 69	1.69	1.69	1.69	1.69
Depth Below Final Grade Elevation, In	14-26	12-24	12-24	14-26	14-26	13-25	14-26	14-26	14-26	14-26	14-26	14-26	14-26	13-25	14-26	14-26	14-26	14-26	14-26	13-25	14-26	14-26	14-26	15-27
Actual Moisture, %	12 4	20 5	22 3	17 2	22.0	22 5	16 8	20.2	24 4	11 9	18 1	—	14 2	23 4	24 1	12 3	17 8	19 9	18 3	22 5	24.3	11 8	22 2	—
Actual Density, gm/cc	1.82	1 69	1 67	1 71	1 64	1 64	1 72	1 68	1 60	1 82	1 75	—	1 84	1.60	1 56	1 78	1 73	1.69	1.72	1 53	1.63	1.82	1.63	—
Percent of Optimum	71	117	127	98	126	129	96	115	139	68	103	—	86	142	146	75	108	121	102	125	135	66	123	—
Percent of Maximum	105	98	97	99	95	95	99	97	92	105	101	—	104	91	89	101	98	96	102	91	96	108	96	—
Depth Below Final Grade Elevation, in	—	24-36	24-36	—	26-38	25-37	—	26-38	26-38	—	26-38	26-38	—	25-37	26-38	—	26-38	26-38	—	25-37	26-38	—	26-38	27-39
Actual Moist, %	—	18 7	22 2	—	19 8	21 9	—	23.5	21 5	—	18 7	23 6	—	28 6	28 4	—	14.9	21.4	—	22 0	23.8	—	22.2	22.6
Actual Density, gm/cc	—	1 66	1.69	—	1.67	1.54	—	1.59	1.68	—	1.51	1.63	—	1 46	1 46	—	1 62	1.60	—	1.67	1.59	—	1.65	1.55
Percent of Optimum	—	107	127	—	113	125	—	134	123	—	107	135	—	173	172	—	90	130	—	122	132	—	123	126
Percent of Maximum	—	96	98	—	97	89	—	92	97	—	87	94	—	83	83	—	92	91	—	99	94	—	98	92
Depth Below Final Grade Elevation, in	—	36-48	36-48	—	—	—	—	—	—	—	—	—	—	—	—	—	38-50	38-50	—	—	—	—	38-50	39-51
Actual Moisture, %	—	22 6	22.3	—	—	—	—	—	—	—	—	—	—	—	—	—	16.8	21 5	—	—	—	—	14 3	19 8
Actual Density, gm/cc	—	1 65	1 65	—	—	—	—	—	—	—	—	—	—	—	—	—	1.70	1.67	—	—	—	—	1 75	1.74
Percent of Optimum	—	129	127	—	—	—	—	—	—	—	—	—	—	—	—	—	102	130	—	—	—	—	79	110
Percent of Maximum	—	95	95	—	—	—	—	—	—	—	—	—	—	—	—	—	97	95	—	—	—	—	104	103
Depth Below Final Grade Elevation, in	—	48-60	48-60	—	—	—	—	—	—	—	—	—	—	—	—	—	50-62	50-62	—	—	—	—	50-62	51-63
Actual Moist, %	—	20 5	22 3	—	—	—	—	—	—	—	—	—	—	—	—	—	17.3	18.5	—	—	—	—	10.2	10.7
Actual Density, gm/cc	—	1 71	1 68	—	—	—	—	—	—	—	—	—	—	—	—	—	1 62	1 70	—	—	—	—	1.62	1 82
Percent of Optimum	—	117	127	—	—	—	—	—	—	—	—	—	—	—	—	—	105	112	—	—	—	—	57	59
Percent of Maximum	—	99	97	—	—	—	—	—	—	—	—	—	—	—	—	—	92	97	—	—	—	—	96	108

TABLE 26

MOISTURE AND DENSITY TESTS FOR UNTREATED SUBGRADE SOIL BELOW GRANULAR SUBBASE COURSE; LIME-TREATED BASE COURSE SECTION

Tests	Subd No. 5, Sta. 1148 to Sta 1161						Subd No. 6, Sta. 1161 to Sta. 1174					
	Test Site 5a (Cut) Sta 1151			Test Site 5b (Fill) Sta 1159			Test Site 6a (Fill) Sta 1167			Test Site 6b (Fill) Sta. 1171		
	Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const.		Prior to Const	600 Days After Const.	
	9'Lt	9'Lt	14'Lt	9'Rt	9'Rt	14'Rt	9'Rt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt
Optimum Moisture, %	18.7	18.7	18.7	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
Maximum Density, gm/cc	1 68	1 68	1.68	1 59	1 59	1 59	1.59	1.59	1.59	1.59	1.59	1.59
Depth Below Final Grade Elevation, in.	14-26	12-24	14-26	14-26	14-26	15-27	14-26	13-25	13-25	14-26	12-24	11-23
Actual Moisture, %	16.7	24 7	31 1	17.1	23.3	–	19.0	28.9	–	23.0	–	33.7
Actual Density, gm/cc	1.72	1.60	1.46	1.61	1.66	–	1.65	1.36	–	1.49	–	1 24
Percent of Optimum	89	132	166	90	123	–	100	152	–	121	–	177
Percent of Maximum	102	95	87	101	104	–	104	86	–	94	–	78
Depth Below Final Grade Elevation, in.	–	24-36	26-38	–	26-38	27-39	–	25-37	25-37	–	24-36	23-35
Actual Moisture, %	–	21 4	30.2	–	25.8	20.9	–	26.6	30.1	–	24.4	26 9
Actual Density, gm/cc	–	1.60	1.43	–	1.57	1.63	–	1 39	1.40	–	1.59	1.53
Percent of Optimum	–	114	161	–	136	110	–	140	158	–	128	142
Percent of Maximum	–	95	85	–	99	102	–	87	88	–	100	96

Tests	Subd. No. 7, Sta 1174 to Sta. 1187						Subd. No. 8, Sta 1187 to Sta. 1200					
	Test Site 7a (Fill) Sta. 1178			Test Site 7b (Fill) Sta. 1183			Test Site 8a (Cut) Sta. 1192			Test Site 8b (Fill) Sta. 1199		
	Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const.		Prior to Const.	600 Days After Const.	
	9'Lt	9'Lt	14'Lt	9'Rt	9'Rt	14'Rt	9'Lt	9'Lt	14'Lt	9'Rt	9'Rt	14'Rt
Optimum Moisture, %	19.0	19.0	19.0	19.0	19 0	19 0	20 1	20.1	20.1	20.1	20.1	20.1
Maximum Density, gm/cc	1.59	1 59	1 59	1 59	1.59	1.59	1.59	1.59	1.59	1 59	1.59	1.59
Depth Below Final Grade Elevation, in.	14-26	12-24	12-24	14-26	13-25	10-22	14-26	13-25	11-23	14-26	12-24	11-23
Actual Moisture, %	22.1	31.0	31.5	20.6	–	–	15.2	–	29.7	17 9	23.5	9.9
Actual Density, gm/cc	1.56	1.38	1.37	1.64	–	–	1.76	–	1.43	1.70	1.50	1.76
Percent of Optimum	116	163	166	108	–	–	76	–	148	89	117	49
Percent of Maximum	98	87	86	103	–	–	111	–	90	107	94	111
Depth Below Final Grade Elevation, in.	–	24-36	24-36	–	25-37	22-34	–	25-37	23-35	–	24-36	23-35
Actual Moisture, %	–	31.0	21.1	–	29.4	28.7	–	19.4	28.5	–	13.7	11.2
Actual Density, gm/cc	–	1.53	1.64	–	1 32	1.43	–	1.67	1.38	–	1.85	1.55
Percent of Optimum	–	163	111	–	155	151	–	97	142	–	68	56
Percent of Maximum	–	96	103	–	83	90	–	105	87	–	116	97

Discussion of the Lime-Treated Subgrade Soil

The laboratory test results for the two testing periods have been tabulated in Tables 16, 17 and 18. Also included in each table are the laboratory test results of the untreated subgrade soils obtained prior to construction. These tests are included for comparison between the untreated and lime-treated soils.

Chemical analysis for lime content was performed on the untreated soil samples and on the lime-treated soils in order to determine the actual percentage of lime added. It will be noted that in general the lime content is close to plan quantity.

While enough undisturbed material was obtained during the 600-day sampling for moisture and density tests, only one core was sufficiently large to cut a 2- by 2-in. cube for unconfined compressive strength tests. The 600-day moisture tests show a general increase in the moisture content (in all but three tests) over the 16-day tests. These changes may be greater than normal due to the unusually high precipitation since construction. The tests show some variance in density between the 16- and 600-day tests. There is no consistent relationship between percentage of lime and loss or gain in density. However, all of the densities under the surfaced area except one (Test Site 2b, 3 percent lime) are above 95 percent of maximum, while four of the six densities taken outside the surfaced area are below 95 percent of maximum.

In general the results of the field tests agree with the findings of the experimental laboratory tests.

Discussion of the Lime-Treated Base Course

In the lime-treated base course section partial cores were obtained from all test sites. All of the cores were large enough to perform moisture-density tests and in five of the twelve test sites the cores were such that cubes could be cut for unconfined compression strength tests.

In preparing the five samples for unconfined compressive strength tests one 2- by 2-in. cube was sawed from each partial core. These cubes were then placed, uncovered, in the moist room at a temperature of 70 F $\pm$ 2 F for a period of 7 days. Upon removal from the moist room each cube was immediately tested in unconfined compression at a loading rate of 1,000 lb per sq in. per min. The moisture contents of the cubes were also measured and recorded. When reviewing the results of these tests it should be kept in mind that each value represents one test only. It will be noted in Table 20, that the strengths shown in the 4 and 7 percent subdivisions are considerably higher than that of the 2 percent subdivision. From these tests it might be assumed that the strength developed when 7 percent lime is added is not much greater than the strength developed from 4 percent lime. However, it is probable that the strength tests performed on the field specimens are not indicative of the true strength relationships.

Chemical analysis for lime percentage was performed on each sample. It will be noted in Table 20 that the lime percentage, as tested, is considerably higher than the plan quantity. While no original lime content analyses were performed on the coarse sand, such analyses were performed on the aftonian silt. These tests yielded an average of 0.46 percent lime. Since the lime was placed very carefully it is difficult to explain this discrepancy. It is possible that the coarse sand carried one to two percent lime in its natural state.

The tests of the lime-treated base course show that the moisture content of the material is close to that at time of lay-down. There seems to be a slight decrease in some of the densities since construction.

Benkelman Beam Deflection Tests

Since December 8, 1956 Benkelman Beam deflection tests have been performed on the surface of the pavement twice each year, for a total of five sets of tests. In all cases the deflection readings are taken 30 ft beyond the permanent test sites in order to stay clear of the locations disturbed by sampling. The results of these tests are shown in Table 27. Figures 12 and 13 show the changes in average deflection with time. Each point is the average of the deflections in two test sites. Charts are included for the outer wheel paths (OWP) and inner wheel paths (IWP).

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FLEXIBLE PAVEMENT DEFL

LIME-TREATED S

Date of Deflection Test	Subdivision No. 1 Sta 1047 to Sta 1062 0% Lime								Subdivision No. 2 Sta 1062 to Sta 1					
	Test Site 1a (Fill) Sta 1052 + 30: Lt.				Test Site 1b (Cut) Sta 1059 + 30: Rt.				Test Site 2a (Fill) Sta 1066 + 30: Rt.				Test S Sta 1	
	Deflection		Temperature		Deflection		Temperature		Deflection		Temperature		Deflectio	
	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IW
December 8, 1956	0.008"	0.008"	19 F	19 F	0.006"	0.008"	20 F	20 F	0.006"	0.006"	17 F	19 F	0.006"	0.0
June 14, 1957	0.012"	0.010"	74 F	83 F	0.024"	0.022"	73 F	84 F	0.020"	0.020"	73 F	81 F	0.016"	0.0
November 26, 1957	0.042"	0.020"	62 F	70 F	0.036"	0.018"	62 F	71 F	0.036"	0.016"	63 F	72 F	0.030"	0.0
June 3, 1958	0.072"	0.030"	79 F	93 F	0.042"	0.018"	84 F	101 F	0.038"	0.014"	84 F	98 F	0.040"	0.0
September 22, 1958	0.072"	0.032"	80 F	88 F	0.056"	0.024"	83 F	95 F	0.040"	0.024"	81 F	94 F	0.048"	0.0

LIME-TREATED

Date of Deflection Test	Subdivision No. 5 Sta 1148 to Sta 1161 0% Lime								Subdivision No. 6 Sta 1161 to Sta 1					
	Test Site 5a (Cut) Sta 1151 + 30: Lt.				Test Site 5b (Fill) Sta 1159 + 30: Rt.				Test Site 6a (Fill) Sta 1167 + 30: Rt.				Test S Sta 1	
	Deflection		Temperature		Deflection		Temperature		Deflection		Temperature		Deflection	
	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IW
December 8, 1956	0.004"	0.004"	20 F	19 F	0.004"	0.004"	20 F	20 F	0.008"	0.008"	18 F	19 F	0.012"	0.0
June 14, 1957	0.024"	0.008"	76 F	82 F	0.030"	0.014"	75 F	88 F	0.022"	0.008"	76 F	86 F	0.026"	0.0
November 26, 1957	0.036"	0.020"	66 F	78 F	0.028"	0.020"	66 F	78 F	0.028"	0.012"	66 F	78 F	0.024"	0.0
June 3, 1958	0.044"	0.014"	92 F	110 F	0.046"	0.018"	92 F	110 F	0.040"	0.016"	92 F	110 F	0.066"	0.0
September 22, 1958	0.074"	0.018"	85 F	99 F	0.056"	0.028"	85 F	98 F	0.038"	0.024"	82 F	98 F	0.064"	0.0

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ONS BY BENKELMAN BEAM

ADE SOIL SECTION

Lime		Subdivision No. 3 Sta 1077 to Sta 1092 6% Lime								Subdivision No. 4 Sta 1092 to Sta 1107 10% Lime							
Cut) : Lt.		Test Site 3a (Cut) Sta 1084 + 30: Rt.				Test Site 3b (Fill) Sta 1089 + 30: Lt.				Test Site 4a (Cut) Sta 1096 + 30: Lt.				Test Site 4b (Fill) Sta 1106 + 30: Rt.			
perature		Deflection		Temperature		Deflection		Temperature		Deflection		Temperature		Deflection		Temperature	
R	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT
F	19 F	0.006"	0.006"	18 F	19 F	0.006"	0.004"	18 F	19 F	0.002"	0.002"	20 F	20 F	0.000"	0.000"	18 F	19 F
F	80 F	0.012"	0.010"	76 F	83 F	0.018"	0.016"	76 F	82 F	0.012"	0.010"	78 F	84 F	0.038"	0.010"	77 F	83 F
F	72 F	0.026"	0.018"	64 F	72 F	0.038"	0.014"	65 F	72 F	0.016"	0.016"	67 F	74 F	0.046"	0.018"	67 F	74 F
F	104 F	0.022"	0.016"	85 F	107 F	0.060"	0.018"	92 F	107 F	0.020"	0.014"	92 F	114 F	0.036"	0.016"	92 F	109 F
F	94 F	0.026"	0.018"	84 F	102 F	0.058"	0.024"	84 F	96 F	0.024"	0.014"	84 F	100 F	0.044"	0.024"	85 F	97 F

COURSE SECTION

Lime		Subdivision No. 7 Sta 1174 to Sta 1187 4% Lime								Subdivision No. 8 Sta 1187 to Sta 1200 7% Lime							
Fill) : Lt.		Test Site 7a (Fill) Sta 1178 + 30: Lt.				Test Site 7b (Fill) Sta 1183 + 30: Rt.				Test Site 8a (Cut) Sta 1192 + 30: Lt.				Test Site 8b (Fill) Sta 1199 + 30: Rt.			
perature		Deflection		Temperature		Deflection		Temperature		Deflection		Temperature		Deflection		Temperature	
R	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT	OWP	IWP	AIR	MAT
F	19 F	0.006"	0.006"	18 F	18 F	0.004"	0.006"	18 F	18 F	0.000"	0.000"	18 F	18 F	0.000"	0.000"	18 F	18 F
F	85 F	0.010"	0.010"	77 F	86 F	0.012"	0.008"	77 F	89 F	0.010"	0.002"	77 F	81 F	0.004"	0.002"	77 F	88 F
F	77 F	0.020"	0.018"	64 F	75 F	0.024"	0.012"	62 F	73 F	0.020"	0.012"	62 F	73 F	0.018"	0.014"	60 F	71 F
F	110 F	0.032"	0.024"	92 F	108 F	0.028"	0.010"	92 F	112 F	0.016"	0.006"	91 F	108 F	0.018"	0.010"	91 F	108 F
F	95 F	0.040"	0.028"	82 F	98 F	0.022"	0.012"	82 F	93 F	0.022"	0.008"	80 F	93 F	0.014"	0.012"	79 F	90 F

The vehicle used for the deflection tests is a 1948 International dual wheel, single axle, dump truck. The tires are 12 ply 10.00- by 20-in., inflated to 60 lb. The truck is loaded with scale weights and the axle weight for each testing period was as follows:

Period 1 — December 8, 1956 = 18,100 lb
Period 2 — June 14, 1957 = 18,120 lb
Period 3 — November 26, 1957 = 18,140 lb
Period 4 — June 3, 1958 = 18,150 lb
Period 5 — September 22, 1958 = 17,900 lb

It will be noted that the deflections for both lime-treated sections in the first testing period December 8, 1956, were extremely low. While these deflections were taken during a cold period (19 F average air temperature) neither the ground, base courses, nor subgrade were frozen.

Lime-Treated Subgrade Soil Section. — The deflections in the untreated subdivisions (No. 1) show an almost constant increase during all five testing periods. In the lime-treated subdivisions deflection-time curves closely parallel the curve for the untreated section through the first three periods. However, in the last two testing periods the curves for the lime-treated sections seem to be leveling off below the curve for the untreated section. It will be noted, in Table 27, that the deflection in the outer wheel path of Test Site 4b is considerably higher than the deflection in Test Site 4a. Since this high reading has been included in the averages as shown in Figure 12 it is responsible for keeping the outer wheel path deflection curve much higher than it would be if this reading were more in line with that of Test Site 4a. There is no apparent reason for this high deflection. Since it is possible that Test Site 4b may not be representative a new location (designated Test Site 4c) has been tested during the last two testing periods. While these test results are more in line with those of Test Site 4a they are not included in the average deflections nor are they recorded in Table 27. Deflection readings in Test Site 4c may be included in a later report if this location turns out to be more representative than Test Site 4b.

Attention is also invited to the plot of the inner wheel path deflections. These deflections while showing a general increase are considerably lower than the deflections in the outer wheel path. As in the case of the outer wheel path, deflections for the lime-treated subdivisions were lower than those in the control section, during the last two testing periods.

Lime-Treated Base Course Section. — As in the lime-treated subgrade experiment, deflections at all test sites have been increasing with time. In the outer wheel path, the deflections in the untreated section and the 2 percent lime section have been about equal. The rate of increase of deflection with time has been lower for the 4 and 7 percent lime-treated sections and the curves for these sections seem to be leveling off.

Deflection readings for the inner wheel path are smaller than those for the outer wheel path and seem to have a slightly different pattern. It will be noted on this figure that the curves for the standard section, the 2 and 4 percent lime sections are similar and approximately equal. The deflections observed in the 7 percent lime section are definitely smaller than the others.

CONCLUSIONS

Since this project has been open to traffic for only two years and since the condition of the pavement throughout the entire project is superior, with no cracking or failure, no definite conclusions are warranted at this time. It can be said that to date, the pavements in the lime-treated sections have performed as well or better than the pavements in the standard control sections.

It is planned to continue with the deflection testing program for several years. Additional tests will be made from time to time on samples from the various courses and the subgrade as seem desirable.

When sufficient data become available to justify more extensive conclusions, another report will be submitted.

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Appendix A

OUTLINE OF PROCEDURES FOR PERFORMING TESTS DESIGNATED NEBRASKA PROCEDURE

Cementation Test: Nebraska Procedure

1. Scope — The cementation test is intended to show the relative cohesion of the soil in a consolidated dry state.
2. Apparatus —

   a. A balance
   b. Mixing pans
   c. Flat-bottom pie pans
   d. Spatula
   e. Calipers
   f. Press capable of exerting a load of 132 Kg/sq cm on a 25 mm diameter briquette
   g. Forming mold having an inside diameter of 25 mm
   h. Cementation test machine

3. Preparation of Soil Briquettes — A portion of the material passing the No. 40 sieve, shall be mixed with sufficient water to form a plastic mixture. A weighed portion of this mixture shall be placed in a metal die, 25 mm inside diameter, and subjected to a pressure of 132 Kg/sq cm for an instant in a press. The cylindrical briquette resulting shall be exactly 25 mm in height. If it does not measure this height, subsequent samples of the plastic mixture shall be taken in such quantity that the resulting briquette after compression will be exactly 25 mm in height. Three briquettes shall be made and allowed to air-dry for approximately 20 hr after which they shall be oven-dried for 4 hr in an oven at a temperature of 220 F and then cooled in a desiccator for at least 20 min.

4. Cementation Test — The three oven-dried briquettes shall be tested in a machine as follows: The machine shall be arranged so that a 1-Kg hammer is raised to a height of 1 cm and allowed to fall freely on a plunger which transmits the shock of the blows of the hammer to the briquette, successive blows being struck by the hammer at a rate of 40 to 70 per min, until the briquette fails, which is indicated by the failure of the plunger or hammer to rebound. The briquette shall be placed on the anvil under the plunger without lateral support, and may be fastened in place on the anvil by a drop of shellac. The average number of blows required to produce failure is the result to be reported, and is the coefficient of cementation.

Capillarity and Absorption Failure: Nebraska Procedure

1. Scope — The Capillarity Test is performed on soils to show the resistance possessed by the soil to capillarity rise of water. The Absorption Failure Test is performed on soils to show the resistance to slaking. The results of both tests are reported in hours, minutes, and seconds.
2. Apparatus — Same apparatus as required in the Cementation Test.
3. Preparation of Soil Briquettes — The soil briquettes for these tests are prepared in the same manner as the briquettes for the Cementation Test. Three briquettes will be required to perform these tests.
4. Capillarity and Absorption Failure Tests — The three oven-dried briquettes shall be placed in a flat-bottom pan, containing water ½ in. in depth, so that each briquette is not closer than 2 in. from the sides of the pan or to another briquette. The time required for the water to rise and wet the top of the briquette is recorded as the capillarity time. The time required for the briquette to fall apart or slack down is recorded as the absorption failure. If the briquette falls apart or slacks down before its entire top is wet with capillarity water, the capillarity time is recorded as being longer than the absorption failure time. The time reported shall be the average of the three briquettes.

Determination of Lime-Content of Soil-Lime Mixtures: Nebraska Procedure

Dry and grind the entire portion of the soil-lime sample to pass a 40-mesh sieve. Take a 25- to 35-gram, representative portion of the ground material by quartering. Place the representative sample in a weighing bottle and dry to constant weight in a 105 C oven. (Usually an overnight drying period is sufficient).

Weigh out, on an analytical balance, 5 grams of the oven-dried representative sample. Place in a 250-ml beaker, add 50 ml of HCI (1:1), cover, and boil gently for five minutes on a hot plate.

Add 25 ml of hot water to the beaker, stir, allow to settle momentarily, and then decant through a 11-cm Whatman No. 1 (or No. 41) filter paper. The filtrate should be received in a 250-ml volumetric flask. When the liquid has passed through the filter paper, wash the residue once by decantation, using hot water; then transfer the residue to the filter, using a stream of hot water. The beaker should be rapidly policed, the loosened material being transferred to the filter paper. The material on the filter should be washed an additional four times, each washing consisting of 10 to 15 ml of hot water directed in a stream from the wash bottle. Very small amounts of residue will occasionally pass through the filter. These ordinarily may be disregarded. (Excessive boiling, resulting in gelation of the silica, may cause slow filtration. A longer settling time before filtration may help speed the filtering process.)

When washing has been completed, discard the filter, and dilute the filtrate in the volumetric flask to 250 ml with cold water. The temperature of the solution should be near the calibration temperature of the flask. Agitate the flask to thoroughly mix the contents, then pipette a 50-ml aliquot into the original 250-ml beaker. Dilute to

100 ml. Make the solution slightly ammoniacal, boil 1 to 2 min, and allow the hydroxides to settle. (If the sample contains ferrous iron, it is desirable to add a few drops of nitric acid, before precipitation of the hydroxides.)

Filter the hydroxides through a 11-cm Whatman No. 1 (or No. 41) filter paper, receiving the filtrate in a 600-ml beaker. Wash the original 250-ml beaker into the filter once with a stream of hot ammonium nitrate (2 percent) solution and follow by washing the hydroxide precipitate once or twice with hot ammonium nitrate (2 percent) solution. Set the filtrate aside, and place the original 250-ml beaker under the funnel. Puncture the paper with a glass rod, and wash the hydroxides into the beaker, using a stream of hot ammonium nitrate (2 percent) solution to remove most of the precipitate from the filter paper. Treat the paper with 20-ml of hot HCI (1:3), directing the acid over the paper with a glass rod or the lip of a graduated cylinder. Wash the paper several times with hot water, and then discard the paper. Dilute the solution to 75 ml. Make the solution slightly ammoniacal, and boil 1 to 2 min. Allow the precipitate to settle, then decant through a No. 1 (or No. 41) paper as before, receiving the filtrate in the 600-ml beaker previously set aside. Wash and police the beaker, in which precipitation took place, finally washing the precipitate on the filter 3 or 4 times with ammonium nitrate (2 percent) solution. Discard the paper and precipitate.

Add 2 ml of ammonium hydroxide to the filtrate, which will now have a volume of 250 to 350 ml. Heat the solution to boiling and add 10- to 15-ml of hot, saturated ammonium oxalate solution. Boil gently until the precipitate becomes granular, then set aside on the water bath for 30 min or more. Before filtering off the calcium oxalate, verify completeness of precipitation, and make sure that a slight excess of NH_4OH is present.

Filter the mixture through a 11-cm Whatman No. 42 filter paper making sure that all precipitate is being retained. Thoroughly clean the beaker, in which precipitation took place with a rubber policeman and transfer the contents to the filter paper with a stream of hot water. Wash the filter paper 8 to 10 times with hot water (not over 75 ml) using a stream from the wash bottle.

Transfer the filter paper and contents to a 400-ml beaker containing 125 ml of water and 6 ml of H_2SO_4. Heat the solution to 85 C and titrate with standard 0.1 N potassium permanganate.

Make a blank determination, following the same procedure and using the same amounts of all reagents.

Calculate the lime content of the soil-lime mixture as follows:

$$\%\ Ca(OH)_2 = \frac{(A-B)\ E \times 1.3213}{S} \times 100$$

In which

A = $KMnO_4$ solution required for titration of the sample, ml;
B = $KMnO_4$ solution required for titration of the blank, ml;
E = CaO equivalent of the $KMnO_4$ solution, g per ml = 0.028 x $KMnO_4$ normality;
S = weight of sample in aliquot titrated, g; and
1.3213 = gravimetric factor for converting CaO to $Ca(OH)_2$.