Louisiana Highway Research

HIGH-PRESSURE LIME INJECTION

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by

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SYNOPSIS

In order to try to cope with unstable soil conditions in Louisiana, the Louisiana Department of Highways in cooperation with the United States Department of Commerce, Bureau of Public Roads, initiated a study to test the effectiveness of in-place lime treatment.

Originally designed to test the electro-osmosis technique for lime-water movement, this experiment was revised to encompass two other methods of in-place lime treatment when the electro-osmosis method, as tested, proved to be unsatisfactory. The two techniques now incorporated in the testing program are the drill-lime method and the pressure-injection method.

The drill-lime technique as contemplated for this project consists of drilling holes in a failing roadbed and filling them with a lime slurry-aggregate mixture. This portion of the project has not been started at this time. This report consists of a preliminary evaluation of the pressure-injection method of in-place lime treatment.

Results obtained indicate that a good distribution of lime was achieved at depths up to twenty feet. Changes in plasticity were evident at about one month after treatment, but were not large. More tests will be made six months after the injections were completed and a further evaluation will be made at that time.

HIGH - PRESSURE LIME INJECTION

INTRODUCTION

The presence of unstable soils in many areas of Louisiana results in numerous problems in design and construction in these areas. These problem soils are primarily of two categories, the first of which consists of the high organic so called "muck" soil, with the other being primarily soils with high clay contents and extreme plasticity that may, or may not, contain significant amounts of organic material. It is with the second category that this study is concerned. These soils are extremely mobile when moisture contents are high and they are frequently found in areas where the moisture content is near or above the liquid limit. Normal practice in this situation has been to either treat the top six or eight inches of this material with lime, or to place a better material above this soil and stabilize with cement. In many cases these approaches have been used in combination. Under some conditions these methods have not been entirely satisfactory, however, since mechanical and economic limitations on the depth of manipulation of the soil have prevented the achievement of sufficient depth of treatment to give the stability desired.

In order to attempt to find some solution which will alleviate this situation, the Louisiana Department of Highways in cooperation with the United States Department of Commerce, Bureau of Public Roads, has initiated a study of methods of in-place lime treatment and partial stabilization. Several approaches to the problem are being tried. A report has previously been prepared covering the electro-osmosis method of lime movement. This report is primarily concerned with an initial evaluation of the pressure-injection method.

SCOPE

This program was originally designed to test the effectiveness of the electro-osmosis method of water movement for the distribution of lime. The movement of water was satisfactory but no appreciable amount of lime was moved. This method was abandoned and two alternate methods were proposed. These are the drill-lime method and the pressure-injection method. In the drill-lime method, holes are bored at varying distances from each other, filled with lime slurry, and sealed. The pressure-injection method involves the placement of lime by a high the ground. Figure 2 shows the injector truck and Figure 3 shows a close-up of the injection apparatus.

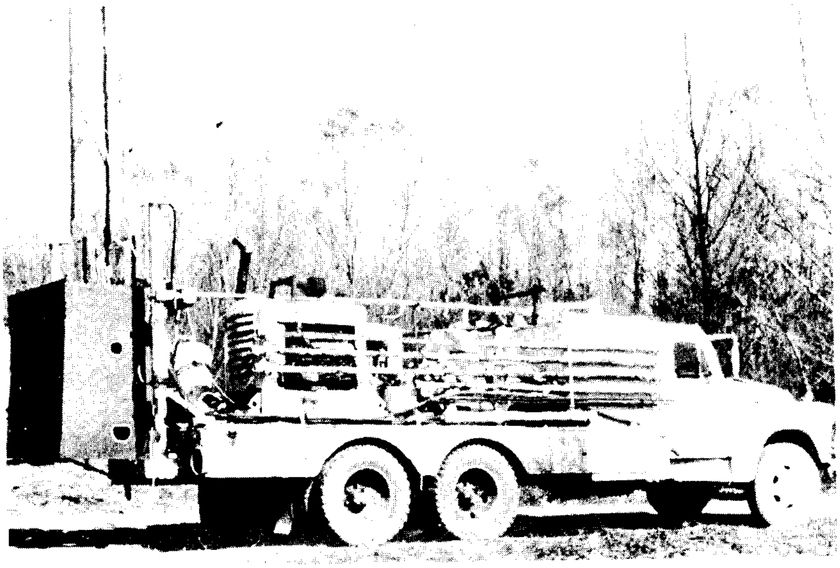

Figure 2 - General View of Injection Apparatus

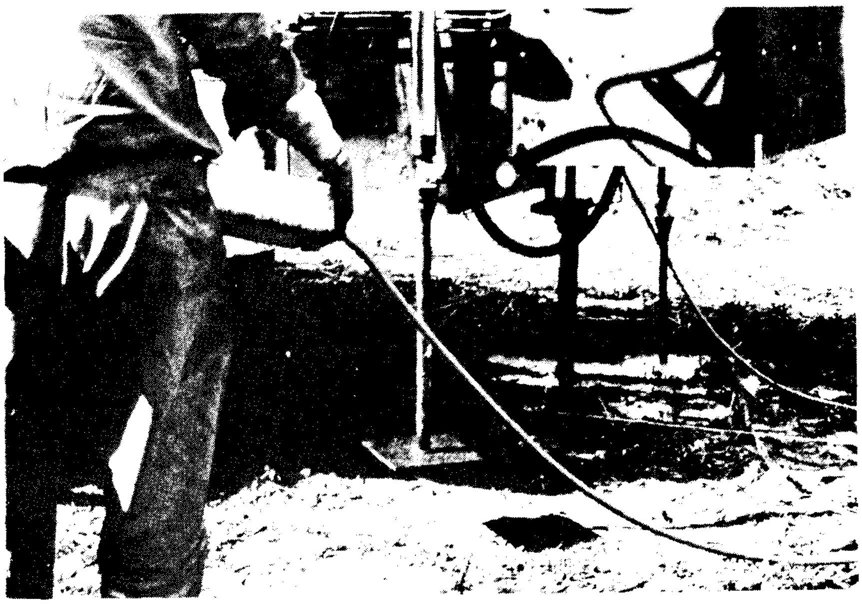

Figure 3 - Close Up of Injection Apparatus Showing Injector Nozzle & Control Panel

pressure injector which is forced into the ground to various depths by a hydraulic ram. A report has been submitted on the electro-osmosis evaluation and no work has yet been done on the drill-lime method. This report is an initial evaluation of the pressure-injection method.

OPERATIONAL PROCEDURE

The lime for this project was injected in slurry form into six 50 x 44 foot sections with injections spaced at 5 foot intervals in each direction. Three of the sections were injected with .5% lime by weight and three with 1.5% lime by weight. For each percentage of lime one section was injected to a depth of 5 feet, one section to a depth of 10 feet, and one section to a depth of 20 feet. A typical testing segment is shown in Figure 1.

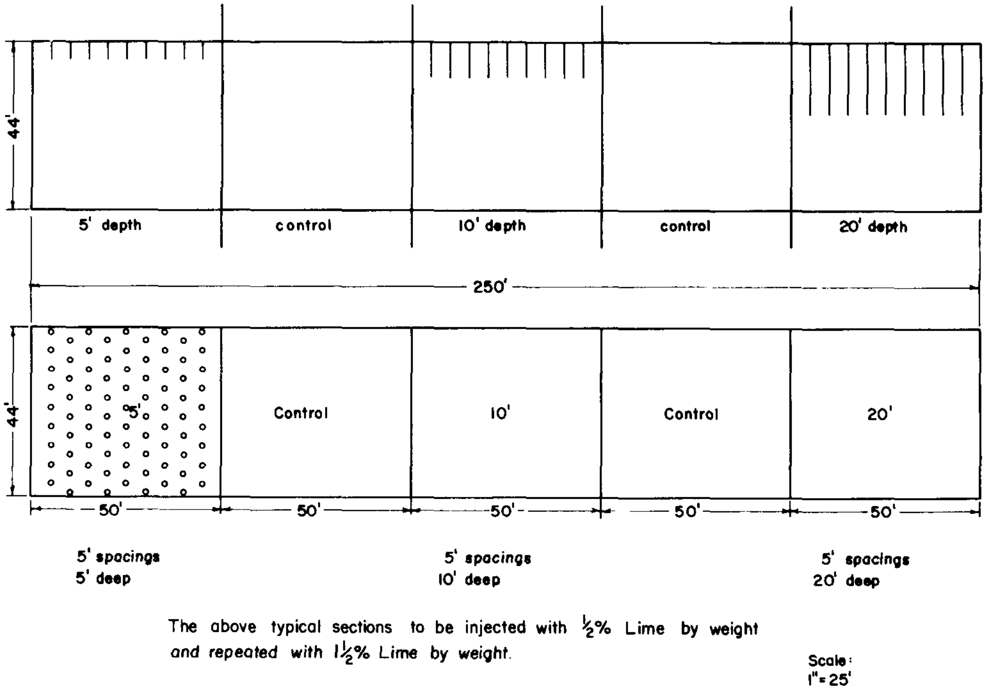

Figure 1 - Typical Testing Segment

The lime on this project was injected by "Hi-Pressure Soil Stabilizers, Inc." of Baton Rouge, Louisiana, under an agreement with the Department of Highways in cooperation with the United States Department of Commerce, Bureau of Public Roads. The equipment used for injecting the lime is an adaptation of oil field cementing equipment. A separate blender truck was used to mix the slurry which was then pumped into a tank on the injector truck. The slurry is forced by a pump capable of pressures of about 600 PSI through a special tapered injector into

The injection of the slurry was electronically controlled and was programmed to make an injection each 8.5 inches of depth. The amount of the injection was controllable and was changed several times during the injection process to see whether the amount of liquid in the injection had any effect on loss of the slurry to the surface. The strength of the slurry was, of course, changed when the amount of the injection was changed to maintain the amount of lime being injected at a constant level. The injection apparatus was equipped with a mechanical seal at ground level which was very effective in stopping feed-back around the injector.

During the injection process, a definite bulging or rising of the soil near the injection is noticeable. This, of course, is to be expected as new material is being introduced and some displacement of the in-place material necessarily must occur. The magnitude of this bulging does not seem sufficient to cause undue alarm, except when injections are made too close to the surface or in very loose soils, in which case a break-out of the slurry is likely to occur.

TESTING PROGRAM

Samples were taken from each of the injection sections prior to the injection. Six borings were made by auger in each section to the depth that the injection was to be made and samples were taken of each stratum of material. In addition, if there was no change in material a sample was obtained for each five foot increment of depth. In-place moisture contents were taken for each sample. It was discovered that no samples could successfully be taken below 12 to 15 feet by hand auger since the soil became so fluid that it would not remain in the auger and caving was occurring. A complete set of samples to the bottom of the 20 foot injection sections was therefore not obtained from the hand borings. The samples were tested for the following properties:

1. Atterberg Limits
2. Volumetric Shrinkage
3. Mechanical Analysis
4. pH Value
5. Quantitative Analysis (Calcium Content)

In addition to the borings mentioned in the preceding paragraphs, one deep boring in each of the test sections was taken to obtain undisturbed samples for testing for unconfined compressive strength. These borings were made to a depth of 30 feet and continuous samples were taken.

Figure 4 shows the placement of the hand borings made in a typical injection section prior to lime placement. Injection of all sections was completed February 27, 1965, and samples by hand borings were secured from one hole

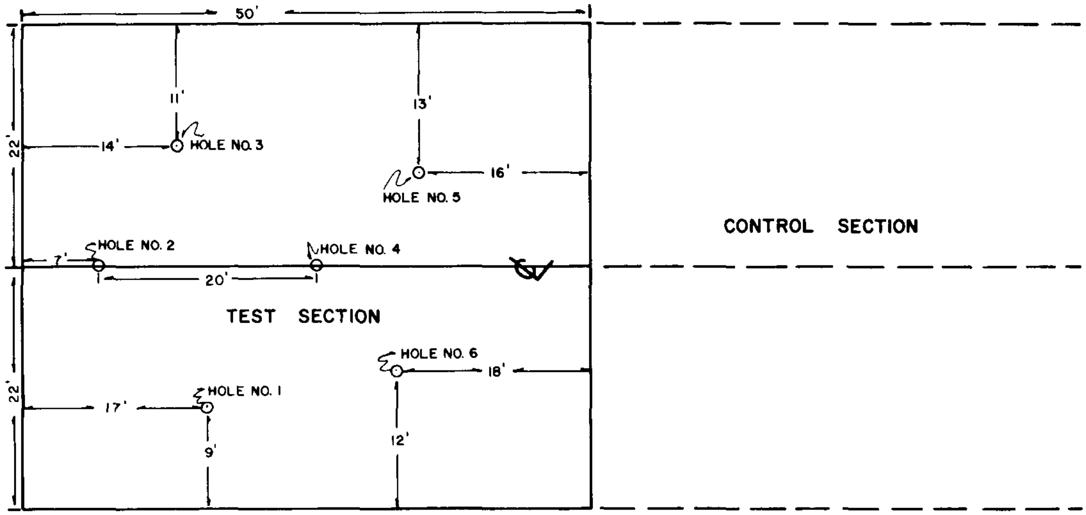

Figure 4 - Typical Test Section Showing Location of Borings for Disturbed Samples

in each section on March 23, 1965. These samples were taken from near Hole No. 1 in Section No. 1, Hole No. 2 in Section No. 2, etc. to obt-in a somewhat diversified sampling cross-section. Results of the tests at these locations before and after placement are shown in Table I. Undisturbed samples were taken from one hole in each injection section April 1 through April 5, 1965. The results of these tests and the original undisturbed tests taken in these sections are shown in Table III. In adition, samples by hand borings were taken near Hole No. 1 of test Section No. 6 on April 20, 1965, and near Holes No. 1 and 2 of test Section 5 on May 3, 1965. The results of these tests and the comparable before-treatment tests are shown in Table II.

The following test procedures were used:

1. LDH TR 407-64 Method of Mechanical Analysis of Soils

2. LDH TR 409-64 Method of Unconfined Compression Test for Soils

3. LDH TR 411-64 Method of Dry Preparation of Disturbed Soil Samples for Test

4. AASHO T 89 Methods of Determining Liquid Limit of Soils

5. AASHO T 90 Methods of Determining the Plastic Limit of Soils

6. AASHO T 91 Method of Calculating the Plasticity Index of Soils

7. AASHO T 92 Methods of Determining the Shrinkage Factors of Soils

8. The method of test used for determining the Calcium Oxide content was an adaptation of ASTM C 114-58 (Chemical Analysis of Portland Cement)

9. The pH was determined according to the manufacturers directions for the instrument used.

DISCUSSION OF TEST RESULTS

The testing process for this project includes three broad categories, each of which will be discussed separately prior to an evaluation of the combined results. These categories are (1) The Injection Process, (2) Disturbed Samples and Tests, and (3) Undisturbed Samples and Tests.

I. The Injection Process

The site chosen for the high-pressure injection process is a portion of hydraulic fill placed approximately nine years ago as part of U.S. 51 Relocation but now designated as Interstate Route 55. The material in this area was removed to approximately 20 feet and replaced by hydraulically placed material. Most of this material has a high clay content, and due to this fact and the method of placement, a large part of the present fill is a conglomeration of large clods or lumps. The water table at the time of original sampling was approximately 3.5 feet below the top of the fill.

Control of the return of the slurry to the surface around the injector was very satisfactory. However, during the injection process various quantities of the lime slurry would break out of the soil at distances ranging from one foot to about five feet from the injection point. Attempts were made by the contractors' personnel, with varying degrees of success, to stop this return of the slurry to the surface by driving wooden pegs into the holes where the leakage was occurring. It is extremely difficult to estimate the amount of slurry which returned to the surface in this manner. It seems probable, however, that possibly as little as 2 or 3 per cent loss occurred at some injections and that a maximum loss of perhaps 30 per cent may have occurred at other holes. It also seems probable that the larger losses were occurring in those areas where the placing of the lumps of material in the fill caused a cavity or series of cavities in the soil and provided easy access to the surface. Such large losses probably would not occur in normally stratified soils where areas of weakness are generally in a horizontal plane. All of this material cannot be said to be wasted since the first injection was made at a depth of 15 to 18 inches and some slurry is needed at the surface to treat this soil.

II. Disturbed Samples and Tests

Table I shows the results of tests taken before and after lime treatment. The results before treatment are shown on one line with the results from the comparable section after treatment shown immediately below. Dates of sampling are also shown. These results show that in every case there was an increase in the pH of the samples taken after the injection of the lime. These samples are composites of the material over the depths shown. Special care was taken to assure that the samples were obtained at least one foot from an injection point so that lime encountered would not be pooled lime in the injection hole itself. These results indicate that some lime was distributed in each sample increment. There are fluctuations in the pH from sample to sample which probably indicate some non-uniformity of distribution. The calcium content of the samples shows the same type of increase shown by the pH, however, an additional complicating factor is introduced in the evaluation of the calcium content of the individual samples by the fact that some of the soil in this area contains fragments of shell. The overall picture, however, should not be too greatly influenced by the presence of the shell since a general increase in calcium content is noted after the injection of the lime.

Changes in the shrinkage limit and the shrinkage ratio are also apparent, but are not as definitive as the changes in pH and calcium content. The general trend, however, is for a higher shrinkage limit and a lower shrinkage ratio.

The plasticity index of the material does not show any definite trend where injections of 0.5% lime by weight were made (Test Sections 1, 2, and 3). The tendency, however, in the sections injected with 1.5% lime by weight (Sections 4, 5, and 6) is for a lowering of the pasticity index. This does not hold true in all individual cases since some of the soils show a large decrease or increase in plasticity index which is not confirmed by the other data (calcium content, pH, shrinkage limit, and shrinkage ratio). Some of the samples are simply different material than that secured during the original borings. The hydraulic placement caused fairly large changes in soil character with very small changes in horizontal distance.

Additional samples were taken as close as possible to some of the original holes to try to eliminate the changes due to horizontal variation. These results are shown in Table II and though some improvement in correlation of soil types is noted, some individual samples are obviously not the same material originally

TABLE I
DISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Location Station No.		Date Sampled	Depth	Soil Description	LL	PL	PI	pH	% CaO	SL	SR
1226+00 TS-1	U	12-10-64	1-4'	Silty Clay	54	26	28	6.9	1.89	15.7	1.75
Hole 1	T	3-23-65	0-3'	Med. Silty Clay	65	20	45	7.8	1.41	15.7	1.79
	U		4-6'	Silty Clay	58	23	35	6.7	-	17.6	1.75
	T		3-5'	Med. Silty Clay	50	21	29	7.5	-	19.6	1.67
1227+00											
TS-2	U	12-10-64	0-2.5'	Silty Clay	54	25	29	7.5	-	17.8	1.75
Hole 2	T	3-23-65	0-3.5'	Med. Silty Clay	56	22	34	9.6	-	18.9	1.71
	U		4-7'	Heavy Clay	83	24	59	8.4	-	14.0	1.91
	T		3.5-8'	Heavy Clay	86	20	66	8.9	-	11.0	1.91
	U		7-10'	Heavy Clay	82	24	58	8.4	1.66	9.5	1.86
	T		8-10'	Med. Silty Clay	67	18	49	9.0	2.19	14.0	1.86
1228+00											
TS-3	U	12-15-64	0-2.5'	Lt. Silty Clay	51	21	30	7.8	1.37	14.2	1.81
Hole 3	T	3-23-65	0-3'	Silty Clay	58	21	37	10.3	3.36	16.1	1.73
	U		3.5-8'	Heavy Clay	104	27	77	8.6	1.33	11.2	1.85
	T		3-7'	Heavy Clay	87	23	64	9.5	2.48	14.5	1.84
	U		8-13'	Heavy Clay	72	20	52	8.6	1.68	10.6	1.96
	T		7-12'	Sandy Loam	55	39	16	11.9	11.83	36.9	1.34
1229+00											
TS-4	U	12-16-64	1.5-4'	Silty Clay	46	23	23	7.2	2.15	20.2	1.68
Hole 4	T	3-23-65	0-3'	Silty Clay	44	32	12	11.6	5.18	30.9	1.46
	U		4-5'	Silty Clay	73	26	47	7.2	-	13.6	1.83
	T		3-5'	Silty Clay	48	21	27	8.6	-	20.0	1.71
1230+00											
TS-5	U	12-17-64	1-2'	Silty Clay	52	26	26	7.1	-	19.4	1.73
Hole 5	T	3-23-65	0-2'	Med. Silty Clay	71	20	51	8.5	-	14.9	1.89
	U		2-5'	Heavy Clay	77	23	54	7.7	1.61	15.5	1.82
	T		2-5'	Lt. Silty Clay	55	36	19	11.8	4.87	30.5	1.44
	U		7-10'	Heavy Clay	85	23	62	8.4	1.69	14.4	1.86
	T		5-10'	Heavy Clay	78	20	58	9.2	2.60	13.5	1.89
1231+00											
TS-6	U	12-28-64	0-5'	Med. Silty Clay	62	24	38	7.4	1.43	19.0	1.68
Hole 5	T	3-23-65	0-5'	Silty Clay	53	25	28	10.6	3.20	20.1	1.66
	U		5-10'	Heavy Clay	102	26	76	8.6	1.56	14.1	1.86
	T		5-7'	Med. Silty Clay	56	21	35	9.2	2.63	15.2	1.73
	U		10-15'	Med. Silty Clay	62	21	41	8.4	1.97	16.4	1.96
	T		7-12'	Heavy Clay	95	21	74	9.1	3.15	12.6	1.91
	U		15-20'	Med. Silty Clay	61	20	41	8.4	-	16.8	1.89
	T		16-20'	Lt. Silty Clay	47	15	32	8.9	-	14.3	1.87

TS - Test Section
U - Untreated Soil
T - Lime-Treated Soil

TABLE II
DISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Location Sta. No.		Date Sampled	Depth	Soil Description	LL	PL	PI	pH	% Ca O	SL	SR
1230 + 00											
TS - 5	U	12-17-64	1.5-3.5'	Heavy Clay	85	24	61	8.1	1.73	13.5	1.87
Hole 1	T	5-3-65	0-4'	Heavy Clay	73	20	53	9.7	3.18	18.2	1.78
	U		3.5-8'	Heavy Clay	83	21	62	8.7	-	12.1	1.93
	T		4-8'	Heavy Clay	83	21	62	8.9	-	15.7	1.84
	U		8-10'	Clay Loam	32	16	16	8.7	1.76	18.5	1.74
	T		8-10'	Clay Loam	27	19	8	9.1	2.42	20.7	1.68
1230 + 00											
TS-5	U	12-17-64	0-3'	Med. Silty Clay	57	29	28	7.2	-	16.8	1.71
Hole 2	T	5-3-65	0-4'	Silty Clay	54	21	33	8.2	-	19.0	1.66
	U		4-8'	Med. Silty Clay	65	20	45	8.3	-	14.9	1.82
	T		4-6.5'	Med. Silty Clay	76	20	56	9.3	-	16.5	1.79
	U		8-10'	Heavy Clay	96	25	71	8.8	1.50	15.1	1.82
	T		6.5-10'	Heavy Clay	90	24	66	8.7	2.28	14.5	1.87
1231 + 00											
TS - 6	U	12-28-64	0-2'	Med. Silty Clay	55	23	32	7.6	-	17.0	1.74
Hole 1	T	4-20-65	0-2'	Med. Silty Clay	53	23	30	10.4	-	23.5	1.61
	U		2-7'	Med. Silty Clay	73	24	49	8.5	2.10	16.3	1.82
	T		2-7'	Heavy Clay	88	20	68	8.9	2.06	14.7	1.84

U - Untreated Soil
T - Lime-treated Soil
TS - Test Section

sampled. The changes in character of the soils in these cases are of such magnitude and nature as to eliminate the probability that these changes are due to the lime. This condition, for example, is apparent in Test Section 5, Hole No. 2 from 4 to 6.5 feet deep.

The same trend seen in Table I, for Plasticity Index, pH, Shrinkage Limit, Shrinkage Ratio, and Calcium Content is also seen in Table II. It should be pointed out that in Table I, Hole 3 of Test Section 3 at the 7-12 foot level a large concentration of lime slurry was encountered and it is probable that the values for pH, plasticity index, calcium content, etc., are valid.

III. Undisturbed Samples and Tests

Table III shows the results of tests on undisturbed samples taken before and after lime injection. As with the disturbed samples the top line at each depth shows the sample taken prior to lime placement and the second line shows the results at the same depth after injection of the lime. These samples are different from the disturbed samples in that they are not composites of the increment of depth. Each undisturbed sample consists of an approximate 8 inch segment of the 3 foot increment sampled.

The same general picture for plasticity index and calcium content as shown by the disturbed samples is evident. In some specific cases, however, no increase in calcium content is noted. This is at least partially due to the type of samples mentioned above. It is probable that some samples were taken between the 8.5 inch spaced injection points and for some reason, possibly a weakness in another plane of the soil, little or no lime was forced into this segment of soil. As in the disturbed samples, additional complications were caused by the variegated horizontal pattern of the soil causing samples of entirely different material to be secured by the coring before and after placement of the lime. The unconfined compressive strengths of the soil samples taken before and after lime injection are not definitive enough to show an identifiable trend. In some individual cases a gain in strength is noted but a general tendency of increased strength is not apparent. It should be remembered however that lime placement had been finished only slightly more than a month at the time that the after-placement samples were taken. It would not normally be expected that drastic changes in strength would occur in such a small time increment. Additional samples will be taken later and it is hoped that more definite conclusions may be drawn at that time.

FUTURE RESEARCH

The following recommendations are submitted for future work in this field:

1. It is recommended that high-pressure injection be used on a small section of hard-to-maintain roadway that is in use, in the same area and at the same time that the drill-lime portion of this research project is being carried out. This would be an excellent opportunity to evaluate the relative merits, such as speed of action, noticeability of improvement under traffic reduction in maintenance cost, etc.

The drill-lime procedure has been found satisfactory for this type of work in several states. It seems that the pressure injection method should yield a more rapid and thorough distribution of the lime-slurry. The addition of this study to the present project would entail additional expense. It seems probable, however, that the information gained would be worth the additional cost.

2. As an alternative item to 1 above, or in addition to it, it is recommended that a section of road be let under normal contract to use the pressure injection method of lime treatment. This would allow a further evaluation of the process under actual construction conditions.

3. As a further alternative, it is recommended that consideration be given by the Department to leasing this device for use by maintenance forces for a period of time sufficient for a complete evaluation of the equipment.

TABLE III
UNDISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Test Section 1

Location Sta. No.		Depth	Soil Description	Qu	MC	LL	PI	% Organic	% Ca O
1226 + 33	U	0-3'	Med. Silty Clay	1.24	37	56	28	10	1.25
1226 + 37	T		Med. Silty Clay	0.92	38	57	34	-	2.45
	U	3-6'	Silty Clay	0.63	37	46	12	8	1.12
	T		Silty Clay	0.79	40	43	20	10	2.11
	U	6-9'	Med. Silty Clay	0.11	53	69	45	-	1.78
	T		Med. Silty Clay	0.24	49	51	32	-	2.33
	U	9-12'	Heavy Clay	1.45	39	129	90	-	1.96
	T		Med. Silty Clay	0.14	43	55	35	-	2.93

U - Untreated Soil
T - Lime-treated Soil
Qu - Tons per square foot

TABLE III
UNDISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Test Section 2

Location Sta. No.		Depth	Soil Description	Qu	MC	LL	PI	% Organic	% Ca O
1227 + 35	U	0-3'	Lt. Silty Clay	0.78	46	58	30	-	1.84
1227 + 35	T		Silty Clay	1.13	35	47	25	10	1.74
	U	3-6'	Heavy Clay	0.21	63	107	77	-	1.54
	T		Med. Silty Clay	0.30	52	59	37	-	2.03
	U	6-9'	Heavy Clay	1.48	57	89	61	-	1.61
	T		Heavy Clay	0.13	64	87	60	-	2.63
	U	9-12'	Silty Loam	0.28	22	NP	NP	-	1.73
	T		Med. Silty Clay	0.19	49	51	31	-	2.30
	U	12-15'	Lt. Silty Clay	0.23	48	44	25	7	1.98
	T		Silty Loam	0.15	29	NP	NP	5	2.46

U - Untreated Soil
T - Lime-treated Soil
Qu - Tons per square foot

TABLE III
UNDISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Test Section 3

Location Sta. No.		Depth	Soil Description	Qu	MC	LL	PI	% Organic	% Ca O
1228 + 38	U	0-3'	Silty Clay	0.53	29	44	19	-	1.32
1228 + 36	T		Silty Clay	0.80	43	50	22	14	1.77
	U	3-6'	Silty Clay	0.30	52	53	26	13	1.22
	T		Lt. Silty Clay	0.43	48	35	14	10	3.86
	U	6-9'	Heavy Clay	0.19	71	109	83	-	1.54
	T		Heavy Clay	0.21	75	90	62	-	2.15
	U	9-12'	Heavy Clay	0.21	55	76	48	-	1.58
	T		Heavy Clay	0.22	59	63	39	-	2.28
	U	12-15'	Lt. Silty Clay	0.14	44	44	25	-	2.95
	T		Med. Silty Clay	0.16	56	54	34	-	2.44
	U	15-18'	Lt. Silty Clay	0.25	40	50	32	-	3.89
	T		Loam	0.55	27	NP	NP	-	2.51
	U	18-20'	Silty Loam	0.28	30	NP	NP	-	1.81
	T		Silty Loam	0.15	30	NP	NP	-	2.44
	U	20-21'	Organic	0.26	62	56	28	19	1.46
	T		Silty Loam	0.15	30	NP	NP	-	2.44
	U	21-24'	Silty Clay Loam	0.48	30	NP	28	-	2.14
	T		Silty Clay Loam	0.86	28	NP	21	5	2.42
	U	24-27'	Heavy Clay	0.28	36	93	64	-	2.40
	T		Med. Silty Clay	0.26	56	61	40	-	2.48

U - Untreated Soil
T - Lime-treated Soil
Qu - Tons per square foot

TABLE III
UNDISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Test Section 4

Location Sta. No.		Depth	Soil Description	Qu	MC	LL	PI	% Organic	% Ca O
1229 + 30	U	0-3'	Silty Clay	0.93	32	49	21	7	1.05
1229 + 32	T		Med. Silty Clay	0.56	52	48	13	16	3.80
	U	3-6'	Silty Clay	0.53	50	50	20	12	1.24
	T		Silty Clay	0.62	36	48	25	12	1.82
	U	6-9'	Med. Silty Clay	0.23	56	81	52	-	1.91
	T		Med. Silty Clay	0.38	42	52	27	12	1.87
	U	9-12'	Med. Silty Clay	0.21	57	67	45	-	1.70
	T		Heavy Clay	0.24	78	79	48	-	2.08

U - Untreated Soil
T - Lime-treated Soil
Qu - Tons per square foot

TABLE III
UNDISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Test Section 5

Location Sta. No.		Depth	Soil Description	Qu	MC	LL	PI	% Organic	% Ca O
1230 + 38	U	0-3'	Med. Silty Clay	0.63	45	66	40	11	1.68
1230 + 40	T		Heavy Clay	0.67	44	64	36	10	2.46
	U	3-6'	Heavy Clay	0.33	40	48	25	8	1.83
	T		Med. Silty Clay	0.49	44	51	21	10	3.38
	U	6-9'	Silty Clay	0.31	50	50	23	10	1.82
	T		Med. Silty Clay	0.33	50	54	35	13	1.87
	U	9-12'	Heavy Clay	0.19	78	108	66	-	2.18
	T		Heavy Clay	0.19	82	90	59	-	1.86
	U	12-15'	Med. Silty Clay	0.24	50	65	36	-	2.79
	T		Med. Silty Clay	0.25	46	56	36	8	2.15

U - Untreated Soil
T - Lime-treated Soil
Qu - Tons per square foot

TABLE III
UNDISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Test Section 6

Location Sta. No.		Depth	Soil Description	Qu	MC	LL	PI	% Organic	% Ca O
1231 + 30	U	0-2'	Heavy Clay	0.50	46	71	42	9	1.43
1231 + 29	T		Heavy Clay	0.76	45	69	39	-	2.64
	U	2-4.5'	Silty Clay	0.43	50	54	30	12	1.19
	T		Med. Silty Clay	0.46	49	54	27	14	2.27
	U	4.5-7'	Silty Clay	0.52	51	52	27	12	0.93
	T		Med. Silty Clay	0.46	49	54	27	14	2.27
	U	7-10'	Med. Silty Clay	0.39	49	63	35	11	1.05
	T		Lt. Silty Clay	0.37	39	42	20	10	1.47
	U	10-13'	Med. Silty Clay	0.22	52	72	50	-	1.86
	T		Heavy Clay	0.35	76	83	56	-	2.74
	U	13-16'	Med. Silty Clay	0.30	50	66	44	-	1.68
	T		Med. Silty Clay	0.28	53	57	35	-	2.47
	U	16-19'	Sandy Loam	-	23	NP	NP	-	2.52
	T		Lt. Silty Clay	0.25	47	49	30	-	2.98
	U	19-22'	Heavy Clay	0.35	54	85	60	-	2.22
	T		Lt. Silty Clay	0.32	48	42	24	-	2.78
	U	22-25'	Silty Clay	0.35	78	60	26	14	1.49
	T		Silty Clay	0.40	51	41	17	10	1.74
	U	25-28'	Silty Clay	0.33	65	52	22	12	1.24
	T		Silty Clay	0.26	50	49	30	-	1.77

U - Untreated Soil
T - Lime-treated Soil
Qu - Tons per square foot

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LIME TREATMENT AT DEPTH

FINAL REPORT
by

C. M. HIGGINS
Soils Research Engineer

Research Report No. 41

Research Project No. 63-7S
Louisiana HPR 1(6)

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research and Development Section
In Cooperation with
U. S. Department of Transportation
Federal Highway Administration
BUREAU OF PUBLIC ROADS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The presence of unstable cohesive soils is a constant problem in highway construction in Louisiana. An intimate mixture of soil and lime has been proven effective in improving the quality of these soils and lending stability to them. Economic considerations, however, make mixing of the soil and lime, by conventional methods, to the depths required for embankment stability, impractical by conventional methods.

In order to test methods for in-place stabilization the Department, in cooperation with the Federal Highway Administration, Bureau of Public Roads, initiated a study of (1) movement of lime by electro-osmosis, (2) injection of lime slurry from a high-pressure nozzle forced into the ground by hydraulic pressure and (3) the placement of lime in previously drilled holes.

Neither the electro-osmosis nor the drill lime method effected any measurable improvement in soil characteristics. Of the three methods the pressure-injection method is the most effective. However this method, as presently used, does not distribute the lime satisfactorily throughout the soil. Modification in equipment or technique could possibly make this process workable. However, economic considerations would probably limit the process to maintenance use unless a considerable lowering of the overall cost can be made.

LIME TREATMENT AT DEPTH

INTRODUCTION

Unstable cohesive soils which may or may not contain appreciable amounts of organic matter are constantly encountered in construction in South Louisiana and, to some extent, in other areas of the state. These soils exist largely in a saturated or near-saturated state with many occurring below the water table. When loads are placed over these soils (even when the soils occur at appreciable depths) a large amount of subsidence occurs, much of it differential subsidence due to the changing nature of the soil. If some type of stabilization or improvement of these soils could be made, so that at least some stability and resistance to subsidence could be effected, it would be a tremendous advantage in the design of roadways.

With this fact in mind, a study of in-place treatment with lime was undertaken by the Department in cooperation with the Federal Highway Administration, Bureau of Public Roads.

An interim report covering a study of stabilization by lime transported by electro-osmosis has previously been submitted and a report covering the initial evaluation of the pressure-injection method has also been submitted. This report contains a final evaluation of pressure-injection and an evaluation of drill lime (post hole) treatment.

PRESSURE-INJECTION

General - The operational procedure and testing program were outlined in an interim report entitled "High-Pressure Lime Injection," August 1965, (LDH Report No. 17), and will not be discussed in this report. However, additional results have been obtained and in order to discuss them in the proper perspective certain of the results reported in the interim report will be repeated herein.

Discussion of Test Results - As outlined in the interim report on this project the testing process included three main categories; (1) the injection process, (2) disturbed samples and tests, and (3) undisturbed samples and tests. Further checking has been done since the interim report in the first two of these categories. However, due to the erratic nature of the undisturbed samples and tests, no further tests were made in this category. Instead of undisturbed samples and tests this report will include a third category consisting of general observations of the test sites.

1. The Injection Process: The problems encountered during placement with loss of slurry to the surface were discussed in the previous report. A picture of the injection apparatus with the boom required for the 20 foot injections is shown in Figure 1.

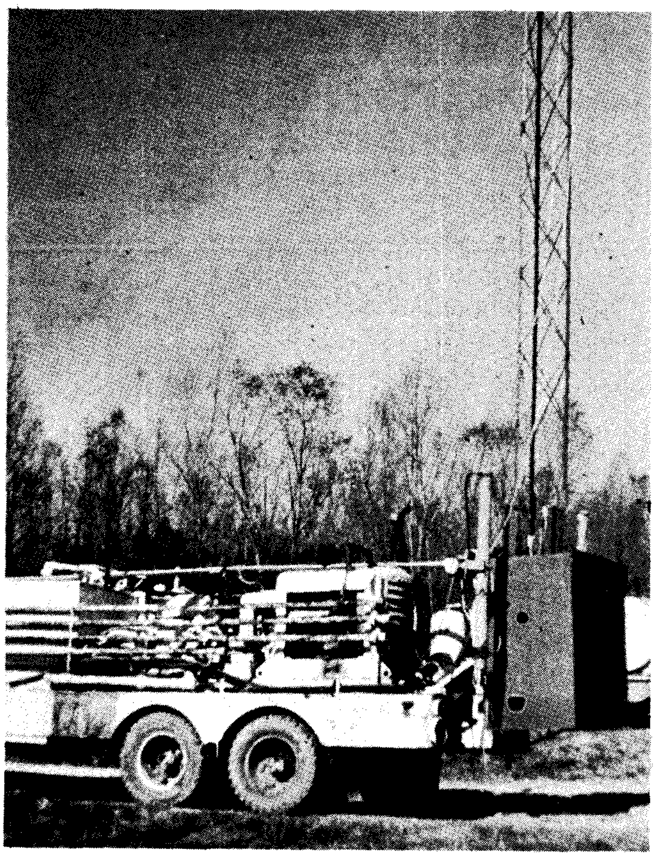


Figure 1

Test pits were dug at the injection site at the time of the injections, and at approximately two years and four years after the injection. Observation of these pits revealed that the lime distribution within the soil was stratified in nature, that is, that the slurry traveled from the injection point in a continuous stream of slurry and did not diffuse into the surrounding soil to any great extent. Figure 2 shows a view in one of the original test pits dug in early 1965. Note the injection hole (white vertical line) and the lime seams radiating outward . Each of the stepped areas at the end of the pit and the bottom of the pit are locations where layers of lime were encountered and exposed during the process of excavating the pit. The distance of travel of the slurry was approximately the same in all

Figure 2

directions from the injection point if the soils were similar and if no voids or other easy access routes were encountered. The strata were primarily horizontally oriented though almost never completely so (Figure 3). Where areas of weak soil, root channels or other voids were encountered the slurry tended to follow these paths. Inspection of the test pits also revealed that little, if any, lime was distributed into the heavier clays at the test site. The high-pressure injection method appears to operate by creating enough pressure to physically tear the soil apart and force the slurry into the aperture thus formed. Observation of the test pits indicate that when the heavy clays were encounted there occurred a slight bulging of the soil but no tearing apart. The probable result is that the slurry rose under pressure through the enlarged area around the injector tube and entered the fissures previously created in the overlying lighter soils. In any event there is no apparent distribution of lime into the heavier clay materials.

2. Disturbed Samples and Tests: Tables 1 and 2 show the results of all disturbed samples taken at the test area. The samples shown in Table 2 were taken as close as possible to the original sampling holes in order to eliminate as nearly as possible sampling errors due to horizontal variation of the soils in the fill. A statistical examination of the test results indicates that no definite improvement of the soils has been demonstrated. However, as mentioned in the interim report, the results do indicate a trend toward higher pH's and calcium contents. Considering the variable nature of the soils combined with the small percentages of lime, one would not expect

dramatic changes in the soil properties.

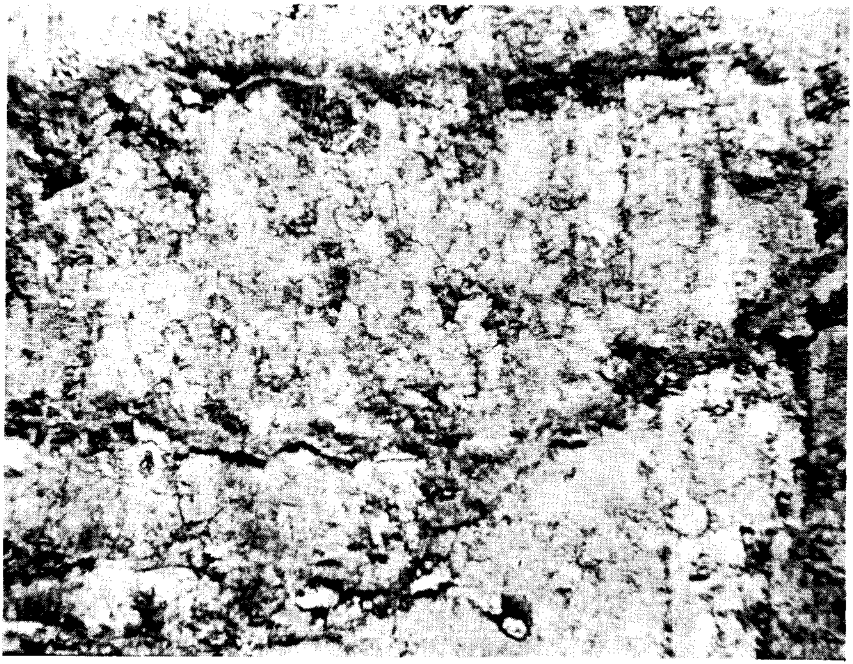


Figure 3

3. <u>General Observations:</u> The test pits made at the time of the injection revealed a stratified distribution of the slurry, generally horizontally oriented at the injection points and from 1/8 inch to as much as one inch in diameter. The soil appeared to have been physically torn apart in most cases (except where voids were pre-existing) and the slurry forced through the cracks thus formed. As a result of the tearing apart of the soil, there existed disturbed and somewhat loosened areas of soil adjacent to the cracks.

Observation of later and deeper test pits revealed that the distribution in the heavier clays was extremely limited, with the most likely cause being bulging of the highly plastic soils allowing the slurry to go around the outside of the injector and back up to lighter and already fractured soils.

TABLE 1
DISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Location Station No.		Date Sampled	Depth	Soil Description	LL	PL	PI	pH	% CaO	SL	SR
1226+00	U	12/10/64	1-4'	Silty Clay	54	26	28	6.9	1.89	15.7	1.75
TS-1	T	3/23/65	0-3'	Medium Silty Clay	65	20	45	7.8	1.41	15.7	1.79
Hole 1	T	10/20/65	0-3.5'	Silty Clay	49	18	31	8.0	2.78	24.1	1.63
	U		4-6'	Silty Clay	58	23	35	6.7	-	17.6	1.75
	T		3-5'	Medium Silty Clay	50	21	29	7.5	-	19.6	1.67
	T	8/20/65	3.5-5'	Silty Clay	46	20	26	8.0	3.14	21.0	1.71
1227+00	U	12/10/64	0-2.5'	Silty Clay	54	25	29	7.5	-	17.8	1.75
TS-2	T	3/23/65	0-3.5'	Medium Silty Clay	56	22	34	9.6	-	18.9	1.71
Hole 2	T	10/19/65	0-3'	Medium Silty Clay	66	19	47	8.3	2.74	19.6	1.73
	U		4-7'	Heavy Clay	83	24	59	8.4	-	14.0	1.91
	T		3.5-8'	Heavy Clay	86	20	66	8.9	-	11.0	1.91
	T	10/21/65	4-8'	Clay Loam	27	12	15	8.8	2.14	16.0	1.71
	U		7-10'	Heavy Clay	82	24	58	8.4	1.66	9.5	1.86
	T		8-10'	Medium Silty Clay	67	18	49	9.0	2.19	14.0	1.86
	T		8-10'	Medium Silty Clay	61	18	43	9.0	-	22.3	1.67
1228+00	U	12/15/64	0-2.5'	Light Silty Clay	51	21	30	7.8	1.37	14.2	1.81
TS-3	T	3/23/65	0-3'	Silty Clay	58	21	37	10.3	3.36	16.1	1.73
Hole 3	T	10/21/65	0-3'	Light Silty Clay	45	17	28	8.3	-	20.0	1.66
	U		3.5-8'	Heavy Clay	104	27	77	8.6	1.33	11.2	1.85
	T		3-7'	Heavy Clay	87	23	64	9.5	2.48	14.5	1.84
	T	10/22/65	4-6'	Heavy Clay	86	25	61	9.0	-	12.2	1.77
	U		8-13'	Heavy Clay	72	20	52	8.6	1.68	10.6	1.96
	T		7-12'	Sandy Loam	55	39	16	11.9	11.83	36.9	1.34
	T	10/22/65	10-12'	Medium Silty Clay	65	16	49	8.9	-	19.4	1.72
1229+00	U	12/16/64	1.5-4'	Silty Clay	46	23	23	7.2	2.15	20.2	1.68
TS-4	T	3/23/65	0-3'	Silty Clay	44	32	12	11.6	5.18	30.9	1.46
Hole 4	T	10/21/65	0-3.5'	Clay Loam	52	21	31	8.4	-	24.3	1.61

TS - Test Section
U - Untreated
T - Lime-Treated Soil

TABLE 1 (CONT'D)
DISTURBED SAMPLES
BEFORE AND AFTER LIME INJECTION

Location Station No.		Date Sampled	Depth	Soil Description	LL	PL	PI	pH	% CaO	SL	SR
	U		4-5'	Silty Clay	73	26	47	7.2	-	13.6	1.83
	T		3-5'	Silty Clay	48	21	27	8.6	-	20.0	1.71
	T		3.5-5'	Medium Silty Clay	58	21	37	82	-	21.0	1.65
1230+00	U	12/17/64	1-2'	Silty Clay	52	26	26	7.1	-	19.4	1.73
TS-5	T	3/23/65	0-2'	Medium Silty Clay	71	20	51	8.5	-	14.9	1.89
Hole 5	T	11/18/65	0-3'	Silty Clay	51	31	20	10.5	-	21.7	1.47
	U		2-5'	Heavy Clay	77	23	54	7.7	1.61	15.5	1.82
	T		2-5'	Light Silty Clay	55	36	19	11.8	4.87	30.5	1.44
	T	11/18/65	3-7'	Silty Clay	55	19	36	8.1	-	14.5	1.76
	U		7-10'	Heavy Clay	85	23	62	8.4	1.69	14.4	1.86
	T		5-10'	Heavy Clay	78	20	58	9.2	2.60	13.5	1.89
	T	11/18/65	7-10'	Heavy Clay	76	20	56	8.7	-	11.39	1.82
1231+00	U	12/28/64	0-5'	Medium Silty Clay	62	24	38	7.4	1.43	19.0	1.68
TS-6	T	3/23/65	0-5'	Silty Clay	53	25	28	10.6	3.20	20.1	1.66
Hole 5	T	11/17/65	0-5'	Medium Silty Clay	60	19	41	8.2	-	12.6	1.78
	U		5-10'	Heavy Clay	102	26	76	8.6	1.56	14.1	1.86
	T		5-7'	Medium Silty Clay	56	21	35	9.2	2.63	15.2	1.73
	T		5-7'	Heavy Clay	91	23	68	8.6	-	9.9	1.85
	U		10-15'	Medium Silty Clay	62	21	41	8.4	1.97	16.4	1.96
	T		7-12'	Heavy Clay	95	21	74	9.1	3.15	12.6	1.91
	T		10.5-15'	Medium Silty Clay	56	17	39	8.7	-	14.4	1.79
	U		15-20'	Medium Silty Clay	61	20	41	8.4	-	16.8	1.89
	T		16-20'	Light Silty Clay	47	15	32	8.9	-	14.3	1.87
	T		15-18'	Light Silty Clay	55	16	39	8.7	-	15.6	1.74

TS - Test Section
U - Untreated Soil
T - Lime-Treated Soil

TABLE 2
DISTURBED SAMPLES
BEFORE AND AFTER INJECTION

Location Station No.		Date Sampled	Depth	Soil Description	LL	PL	PI	pH	% CaO	SL	SR
1230+00	U	12/17/64	1.5-3.5'	Heavy Clay	85	24	61	8.1	1.73	13.5	1.87
TS-5	T	5/3/65	0-4'	Heavy Clay	73	20	53	9.7	3.18	18.2	1.78
Hole 1	T	10/18/65	0-3'	Heavy Clay	90	23	67	8.4	3.89	15.5	1.79
	U		3.5-8'	Heavy Clay	83	21	62	8.7	-	12.1	1.93
	T		4-8'	Heavy Clay	83	21	62	8.9	-	15.7	1.84
	T		3-7'	Heavy Clay	78	16	62	8.9	1.80	16.0	1.89
	U		8-10'	Clay Loam	32	16	16	8.7	1.76	18.5	1.74
	T		8-10'	Clay Loam	27	19	8	9.1	2.42	20.7	1.68
	T		7-10'	Light Silty Clay	37	13	24	9.0	2.95	19.9	1.73
12[illegible]	U	12/17/64	0-3'	Medium Silty Clay	57	29	28	7.2	-	16.8	1.71
T[illegible]	T	5/3/65	0-4'	Silty Clay	54	21	33	8.2	-	19.0	1.66
[illegible] 2	T	10/19/65	0-3'	Medium Silty Clay	54	21	33	7.7	2.09	19.9	1.73
	U		4-8'	Medium Silty Clay	65	20	45	8.3	-	14.9	1.82
	T		4-6.5'	Medium Silty Clay	76	20	56	9.3	-	16.5	1.79
	T		3-5'	Medium Silty Clay	54	21	33	8.8	1.61	17.99	1.70
	U		8-10'	Heavy Clay	96	25	71	8.8	1.50	15.1	1.82
	T		6.5-10'	Heavy Clay	90	24	66	8.7	2.28	14.5	1.87
	T		5-10'	Heavy Clay	77	22	55	-	1.34	16.3	1.88
1231+00	U	12/28/64	0-2'	Medium Silty Clay	55	23	32	7.6	-	17.0	1.74
TS-6	T	4/20/65	0-2'	Medium Silty Clay	53	23	30	10.4	-	23.5	1.61
Hole 1	T	10/20/65	0-4'	Heavy Clay	85	27	58	8.8	3.43	13.1	1.91
	U		2-7'	Medium Silty Clay	73	24	49	8.5	2.10	16.3	1.82
	T		2-7'	Heavy Clay	88	20	68	8.9	2.06	14.7	1.84
	T		4-8'	Medium Silty Clay	66	17	49	8.3	7.03	14.1	1.76

TS - Test Section
U - Untreated Soil
T - Lime-Treated Soil

Observations made in test pits after four years revealed two interesting points:

First, the area of soil definitely affected by the lime extended from $\frac{1}{2}$ inch to perhaps $1\frac{1}{2}$ inches upward and downward from the slurry filled cracks. Beyond these distances there was no detectable increase in the friability or stability of the soil. It should be noted at this point that a road has never been constructed over this fill and therefore, the fill has not been subjected to traffic action. The action of traffic might have caused greater penetration, and more rapid movement of the lime especially through the somewhat loosened soil adjacent to the pressure created cracks.

Second, immediately after the injection of the lime the seams of lime and some of the surrounding soil showed definite evidence of the presence of available calcium when exposed to pH indicators as, of course, was expected. However, where test pits were dug after four years it was noted that the lime seams did not exhibit any color change when exposed to pH indicators, except at the very center of the seams. The outer portion of the seams was composed of a hard substance (later shown to be calcium carbonate) which did not react with a pH indicator. The effective sealing off of the active lime within the cracks by this coating seems to indicate the probability that no further effect from the active lime present can be expected on the surrounding soil. This would lead to the conclusion that the effective total treatment of the soil due to the injected lime will be the $\frac{1}{2}$ to $1\frac{1}{2}$ inch portions on each side of the crack already affected by the lime. Once more it should be reiterated that this fill has never been subjected to traffic.

Conclusions -

1. The distribution of the lime within the fill was a stratified one. The lime slurry flowed through narrow fissures apparently caused by the pressure exerted on the slurry at the injector.

2. The direction of the created fissures was generally horizontal at the level of the injector tip except where planes of weakness or pre-existing voids provided easy access.

3. The slurry moved approximately the same horizontal distance in all directions from the injector tip except where planes of weakness or pre-existing voids were encountered.

4. Little penetration of the slurry into the heavier clays occurred. It seems probable that a bulging of the highly plastic material allowed the slurry to go around the injector and up to previously fractured lighter soils.

5. The area of noticeable treatment extended from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches above and below the slurry seam.

6. At the end of four years, there apparently is no active lime available for further treatment of the surrounding soils.

7. It seems possible that if the injections could be placed at intervals of perhaps three inches, or if a continuous injection could be made, an effective treatment of the soil mass might be accomplished, except in the heavier clays. Whether escape of slurry into previously injected areas, or other mechanical limitations, would preclude this type of treatment is problematical.

DRILL LIME

General - The roadway chosen for drill lime placement was constructed in 1950, by placement of material native to the area into a fill which averages approximately five feet in height. The water table in this area ranges from four or five feet below the bottom of the fill in extremely dry periods to approximately the level of the bottom of the fill during wet periods. Prior to 1965 this road was subjected to very light traffic. However, in 1965 a bridge was completed across the Mississippi River in this area, increasing both the volume and the character of the traffic. Much heavier loads are now moved over the test area by trucks that use the new bridge instead of the one in Baton Rouge (about 30 miles north of the test area).

The soils in the fill range from fairly good silty clay loams and silty clays (placed as selected material) in a thin upper stratum (approximately one foot) to medium silty clays and heavy clays with plasticity indices up to 60 as depth increases.

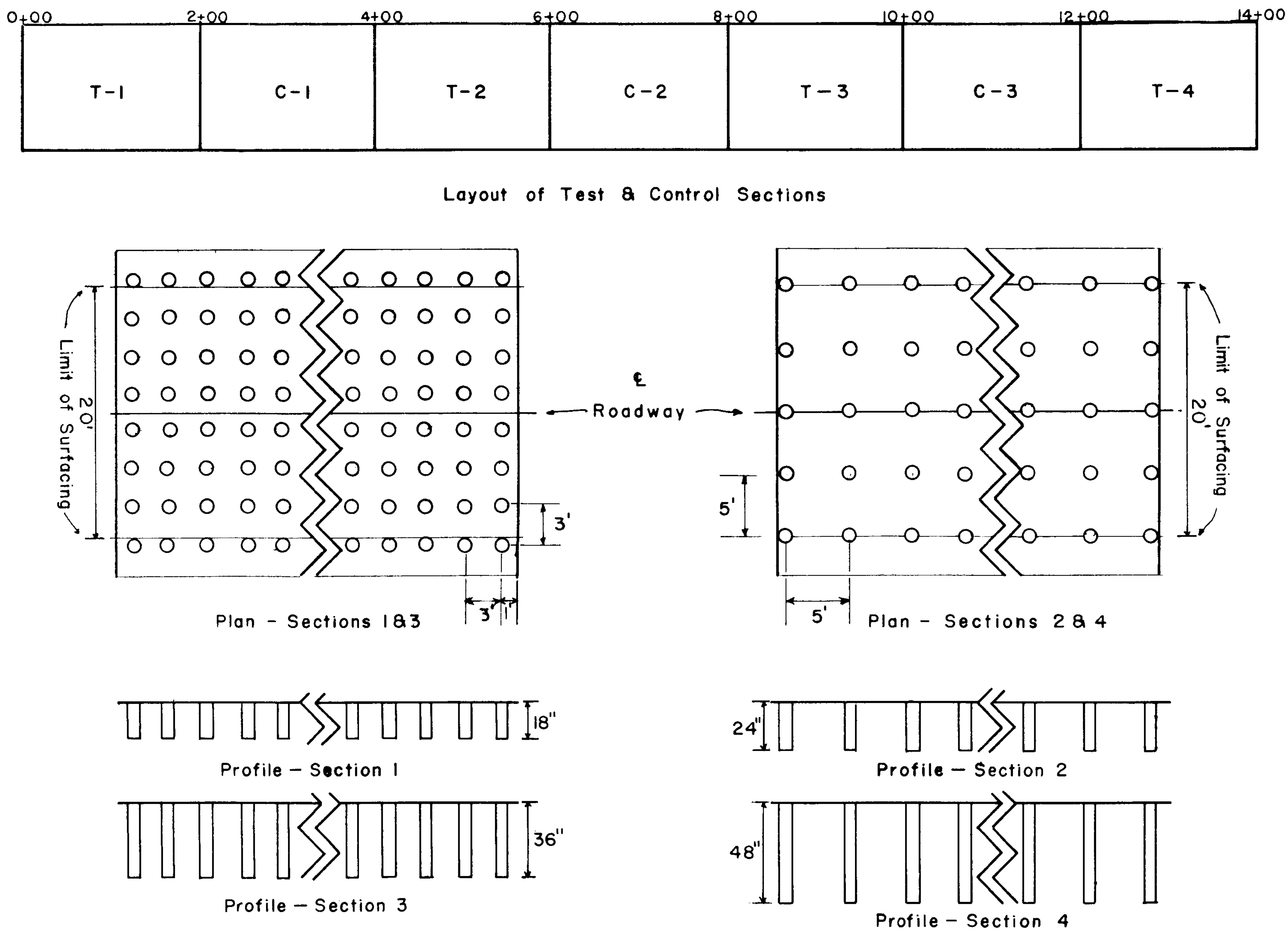


Figure 4 - Placement of Drill Holes in Test Section

After 1965, when the opening of the bridge increased the traffic loads, a large amount of subsidence started to occur on the roadway. Since the subsidence appeared to be occurring in the fill itself, this area was chosen to test drill lime stabilization.

Methodology - Figure 4 shows the general layout of the test and control sections as well as individual plan and profile views of the placement of the holes in the test sections. Four test sections and three control (untreated) sections were utilized in the study. It may be noted that in test section one the holes were spaced three feet apart and were 18 inches deep, in test section two the holes were spaced five feet apart and were 24 inches deep, in test section three the holes were placed three feet apart and were 36 inches deep, and in test section four the holes were placed five feet apart and were 48 inches deep.

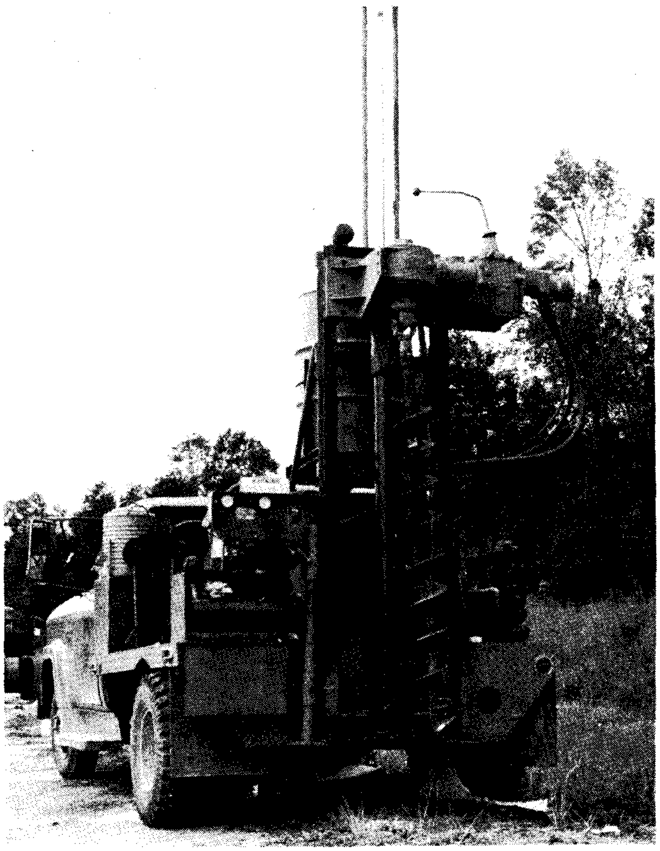


Figure 6

The existing roadbed consists of the previously described embankment material with seven inches of untreated sand clay gravel and a three course surface treatment (Figure 5). The lime was placed in holes made utilizing a nine inch screw type auger and a drill truck (Figure 6).

One half bag of lime (25 pounds) was placed in the 18 inch and 24 inch holes while one bag (50 pounds) was placed in the 36 inch and 48 inch holes. Water was added to the lime where sufficient water was not evident in the holes. Gravel was mixed with the lime and water to the level of the base and compacted as much as possible. The remainder of the hole was filled with a cold-laid asphaltic mix and compacted thoroughly (Figure 7).

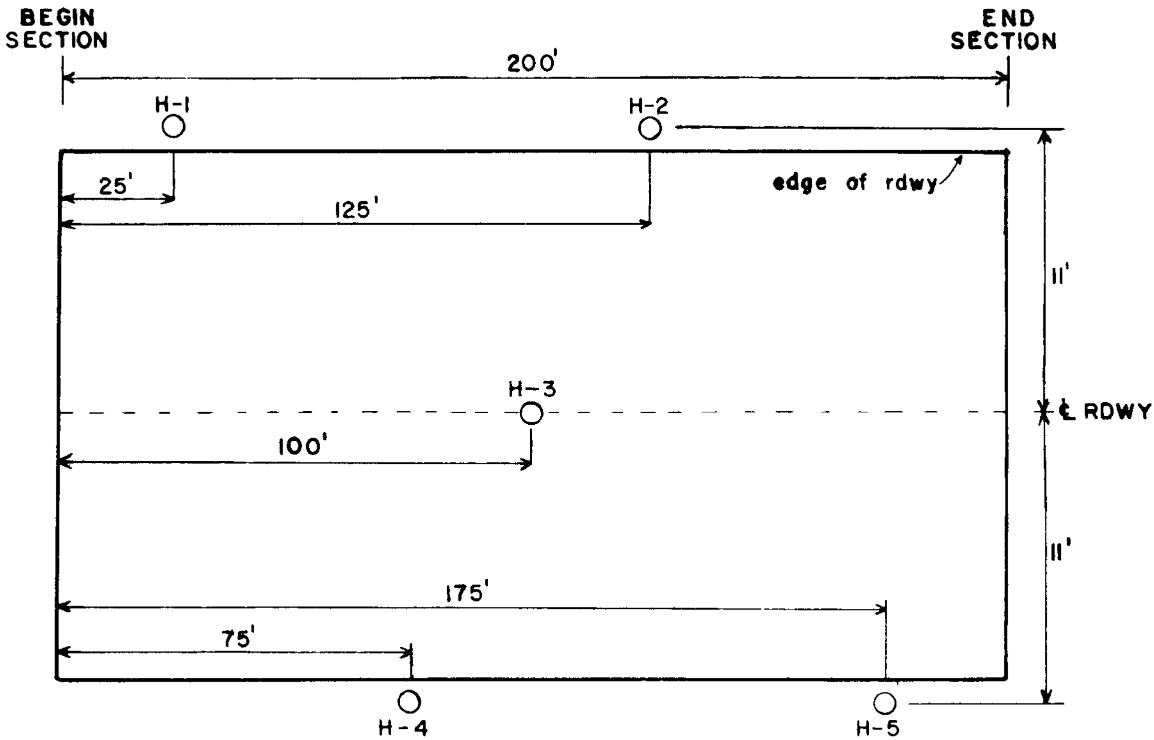
Figure 7

Sampling and Testing - Figure 8 shows the sampling plan used for obtaining samples for disturbed and undisturbed tests of the material in the roadbed. Tests of the soils were made in the test and control sections prior to the beginning of the project and at 12 months after placement of the lime, with tests being made at selected locations at 3, 6, and 9 months after lime placement. The disturbed samples of material were tested as follows after each sampling:

1. pH
2. Atterberg limits
3. Grain-size analysis
4. Calcium content
5. R-value

The soils were tested prior to final site selection for reactivity with lime to determine their suitability for lime treatment.

Undisturbed samples were taken and tested in the field for vane shear.



SAMPLING LAYOUT OF TEST & CONTROL SECTIONS

Figure 8

In addition to the above tests, the following on site determinations were made:

1. The dynamic deflection characteristics of the fill at 0, 3, 6, and 12 months after lime placement. A Lane Wells Dynaflect Device was utilized for this testing.

2. The elevation of the fill one year prior to placement of the lime, immediately prior to placement of the lime, and at 3, 6, 9, and 12 months after lime placement.

3. The elevation of the water table monthly after lime placement.

4. Test pits for visual observation of the lime in the holes and surrounding soil.

Discussion of Results - Prior to final selection of the site, the area selected for testing was sampled thoroughly and tested in the laboratory to determine that the soils were suitably stratified and identifiable so that subsequent testing would not involve a problem in locating the originally tested material. A statistical analysis indicated that a satisfactory condition did exist. In addition the soils were tested for reactivity with lime to see if there was sufficient reaction with lime to identify changes in physical characteristics due to the action of the lime. The results of these tests indicated a satisfactory reaction with lime (Table 3).

A check of the traffic records revealed that the average daily traffic increased from approximately 382 vehicles per day prior to 1965 to approximately 1,325 vehicles per day after this date. The average daily 18 kip equivalent loads increased from about 28 to 95.9 during this same period.

A definite subsidence of the entire fill and a considerable amount of side shoving began to occur in 1965. When the first series of levels were run for this project in September, 1966 the average level of the roadway was in excess of 2/10 of a foot below the as constructed elevations. Just prior to the start of lime placement in September 1967, an additional set of levels were run which indicated that the roadway had continued to subside and was two to three hundreths of a foot below the elevation of the previous year (September 1966).

TABLE 3
LIME REACTIVITY

	Raw	½%	1%	2%	3%	4%	5%	6%
Soil Class	Med. Silty Clay							
AASHO A Group	A-7-6 (19)							
Liquid Limit	56	50	48	46	39	38	40	
Plastic Limit	15	16	17	23	28	30	29	NP
Plastic Index	41	34	31	23	11	8	11	
Soil Class	Silty Clay							
AASHO A Group	A-7-6 (18)							
Liquid Limit	49	49	46	40	40	38	38	41
Plastic Limit	19	20	21	23	28	29	35	36
Plastic Index	30	29	25	17	12	9	3	5
Soil Class	Heavy Clay							
AASHO A Group	A-7-6 (20)							
Liquid Limit	83	84	73	61	61	53	51	50
Plastic Limit	16	18	17	19	25	31	26	35
Plastic Index	67	66	56	42	36	22	25	15
Soil Class	Silty Clay							
AASHO A Group	A-7-6 (19)							
Liquid Limit	53	53	50	47	44	40	38	40
Plastic Limit	14	15	15	20	27	30	31	31
Plastic Index	39	38	35	27	17	10	7	9
Soil Class	Silty Clay							
AASHO A Group	A-7-6 (18)							
Liquid Limit	48	48	46	43	40	38	39	40
Plastic Limit	12	13	14	16	23	24	26	27
Plastic Index	36	35	32	27	17	14	13	13

Placement of the lime began during the latter part of September, 1967 and was completed by late October, 1967. As previously mentioned samples were taken and tests were made at 3, 6, 9, and 12 months after placement of the lime. The results of these tests were as follows:

1. Statistical analysis of the results of testing for pH, plasticity index, and calcium content at all testing intervals revealed either no significant change or a change so small in terms of real values as to have no practical significance (Table 4).

2. Grain-size analysis at the various testing intervals also revealed no evidence of changes due to interaction with the lime placed in the holes.

3. R-values run on the material at 12 months revealed no change due to the lime treatment. R-values for the only layer (the top one) where any significant values could be obtained averaged 11 in the test sections and 11 in the control sections.

4. Deflections at eight feet right of the centerline and at eight feet left of the centerline are shown in Table 5. It may be noted from these data that there is no significant improvement in the deflection characteristics of any of the test sections when compared to the readings in the control sections. It may be noted, in fact, that the average deflections in the control sections at eight feet left of the centerline are slightly less than those in the test sections. The deflection readings do, however, reflect seasonal changes due to fluctciation in the water table (see Table 6).

5. Vane shear tests run on undisturbed cores in the tube of the sampler, utilizing a motorized laboratory vane device run from a car battery, showed no improvement in the treated areas (Figure 9).

6. Elevations taken in the test sections and the control sections indicate no lessening of subsidence in the test sections due to treatment with lime. Figures 10 and 11 and Table 7 show the average subsidence in test and control sections during the first year after treatment with lime. It may be noted that at eight feet left and right of the centerline (wheel paths) where the greatest subsidence occurred, the average subsidence was actually greater in the test sections than in the control sections.

TABLE 4
STATISTICAL ANALYSIS

Sect.	Layer	Property	0 months Mean	0 months Std. Dev.	12 months Mean	12 months Std. Dev.	t(1) value	n
1	1	PI	18.00	2.54	19.00	1.41	-0.7671 (NS)	5
1	2	PI	33.40	1.34	34.60	1.94	-1.1341 (NS)	5
1	1	pH	7.98	0.10	8.04	0.10	-0.9554 (NS)	5
1	2	pH	7.24	0.17	7.62	0.30	-2.4096 *	5
1	1	CaO	1.06	0.30	0.99	0.24	0.3995 (NS)	5
1	2	CaO	0.69	0.00	0.94	0.34	-1.5479 **	5
2	1	PI	21.20	3.90	19.40	1.52	0.9623 (NS)	5
2	2	PI	40.40	4.15	38.20	1.64	1.1001 (NS)	5
2	1	pH	8.06	0.24	7.96	0.17	0.7651 (NS)	5
2	2	pH	7.48	0.19	7.30	0.07	1.9758 (NS)	5
2	1	CaO	1.30	0.39	1.13	0.30	0.7454 (NS)	5
2	2	CaO	0.88	0.13	0.93	0.36	-0.3009 (NS)	5
3	1	PI	19.60	1.67	19.20	2.86	0.2697 (NS)	5
3	2	PI	41.80	2.39	43.80	3.70	-1.0154 (NS)	5
3	3	PI	52.20	7.56	52.20	4.97	0.000 (NS)	5
3	1	pH	8.20	0.16	8.02	0.16	1.7733 (NS)	5
3	2	pH	7.30	0.38	7.28	0.05	0.1296 (NS)	4
3	3	pH	7.30	0.48	7.14	0.15	0.7123 (NS)	5
4	1	PI	19.60	1.95	21.20	1.92	-1.3066 (NS)	5
4	2	PI	42.80	3.77	46.00	6.89	-0.9110 (NS)	5
4	3	PI	51.50	2.65	52.25	4.57	-0.2839 (NS)	4
4	1	pH	8.38	0.11	8.00	0.12	5.2126 (NS)	5
4	2	pH	7.52	0.22	7.24	0.11	2.5664 (NS)	5
4	3	pH	7.53	0.05	7.10	0.08	9.0811 (NS)	4
4	1	CaO	1.31	0.19	0.78	0.24	3.7662 (NS)	5
4	2	CaO	1.01	0.16	0.94	0.32	0.4375 (NS)	5
4	3	CaO	1.12	0.23	0.87	0.39	1.1475 (NS)	4

(1) Negative t means increase after 12 months
(NS) Not significant
* Significant at $\alpha = .05$
** Significant at $\alpha = .10$

TABLE 5
DEFLECTION VALUES
(MILLI-INCHES)

	8' Left of ℄			8' Right of ℄		
	Dec. 1967	March 1968	Sept. 1968	Dec. 1967	March 1968	Sept. 1968
T1	2.54	2.95	3.17	2.95	3.29	2.84
C1	2.06	3.15	2.81	2.73	3.12	3.00
T2	2.54	3.43	3.15	2.50	3.35	2.88
C2	2.24	3.01	2.77	2.33	2.91	2.83
T3	2.07	3.06	2.59	2.56	2.99	2.61
C3	1.91	3.30	2.45	2.96	3.28	2.82
T4	2.33	3.44	2.78	2.68	2.84	2.96
Average of Test Sections	2.37	3.22	2.92	2.67	3.12	2.82
Average of Control Sections	2.07	3.15	2.77	2.67	3.10	2.88

TABLE 6
WATER TABLE ELEVATIONS

Date	Elevation-Feet (MSL)
11/13/67	+0.86
12/5/67	-0.14
1/5/68	+3.88
2/14/68	+3.34
3/8/68	+4.11
4/17/68	+4.23
6/18/68	+0.44
7/5/68	+0.27
8/1/68	+2.02
8/19/68	+3.36
9/17/68	+2.23

NOTE: Road surface elevation at this location = +8.65 feet MSL.

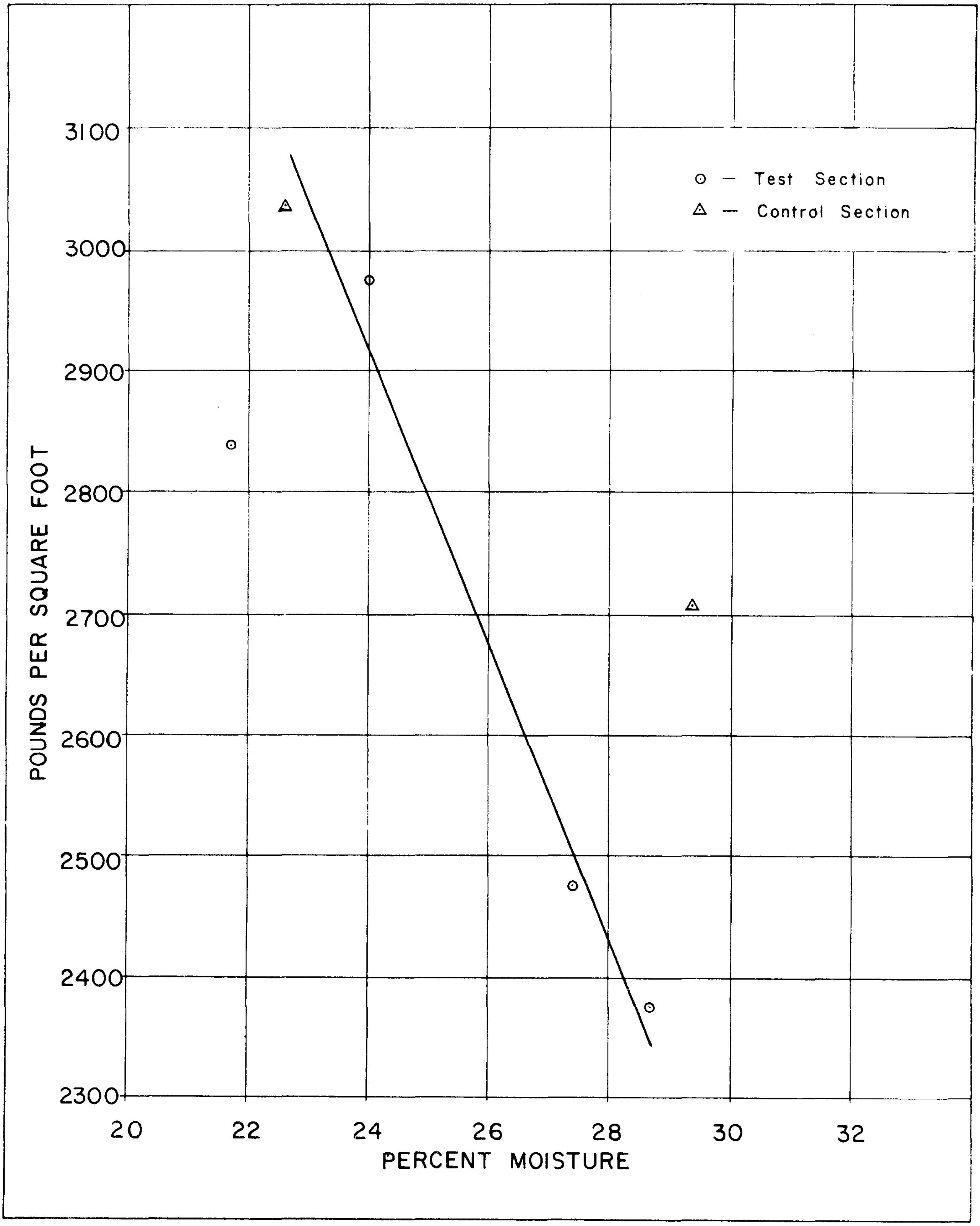


Figure 9 - Vane Shear Averages

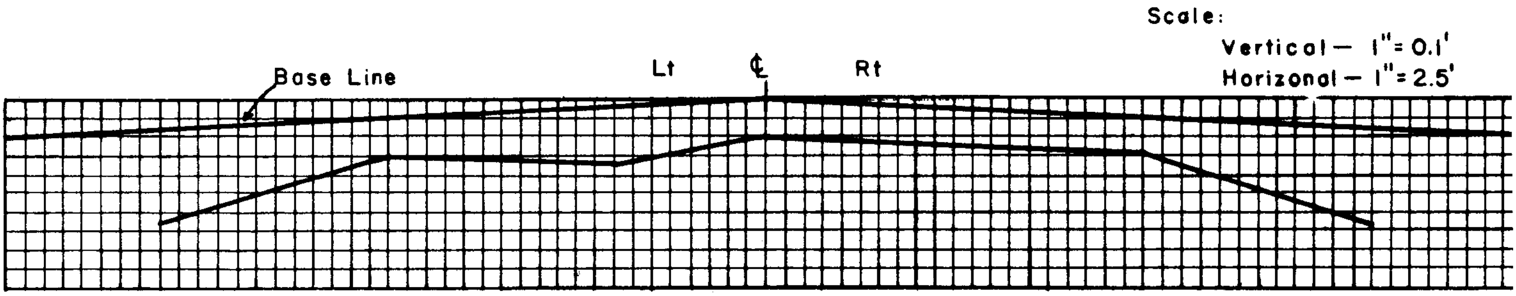


Figure 10 - Average Subsidence of Test Sections

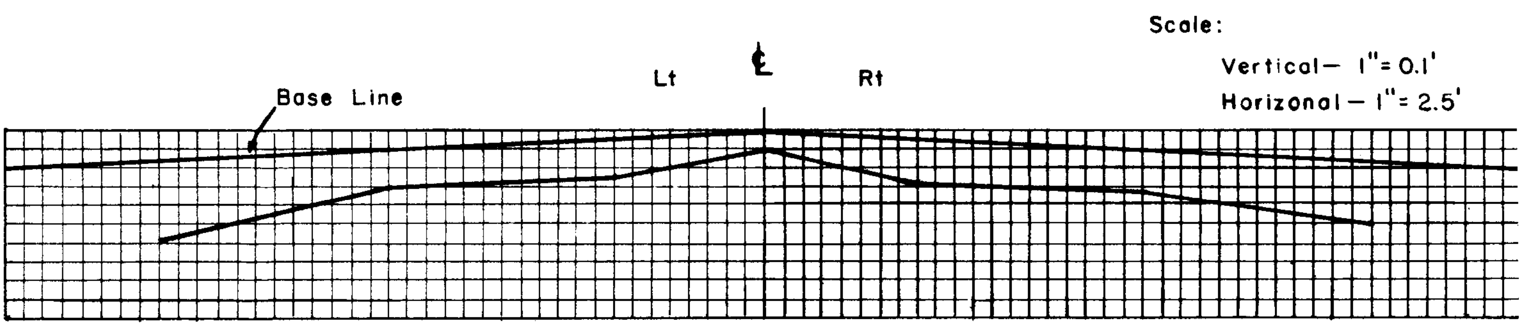


Figure 11 - Average Subsidence of Control Sections

TABLE 7
AVERAGE SUBSIDENCE (feet)

TEST SECTIONS

Time Interval	8'Lt	5'Lt	2'Lt	℄	2'Rt	5'Rt	8'Rt
1966-1968	.07	.05	.05	.04	.04	.04	.07
1966-1967	.02	.03	.02	.02	.02	.02	.02
1967-1968	.05	.02	.03	.02	.02	.02	.05

CONTROL SECTIONS

1966-1968	.06	.03	.03	.02	.03	.04	.05
1966-1967	.02	.01	.01	.01	.01	.02	.02
1967-1968	.04	.02	.02	.01	.02	.02	.03

Average consolidation of fill from construction in 1950 to 1966 check date = 0.22 feet.

7. Observation of pits dug between holes and up to the periphery of the actual lime column revealed no apparent movement of the lime from the holes where it was placed. pH indicators showed no color change until sprayed on the soil with which the lime column was in actual contact. Samples of the soil taken as close as $\frac{1}{2}$ inch from the contact point with the lime column revealed no significant changes in calcium content or pH. The lime in the column appeared in many places to be forming a hard crust which might prevent movement. Figure 12 shows a typical lime column exposed in a test pit after one year. It may be noted that the soil adjacent to the lime is standing firmly and does not appear granular or friable.

Conclusions - No significant improvement was noted at the end of one year due to treatment with lime in drilled holes. Perhaps a longer period of treatment could reveal some improvement due to the treatment. However, the beginning of the formation of a crust on the columns similar to that noted in the lime injection areas at Manchac makes extensive later movement doubtful.

Figure 12

SUMMARY

In-place treatment of soils with lime was approached in a three-pronged attack in an effort to determine the feasibility of any or all of the proposed methods. The methods tried were first, movement of lime by electro-osmosis, second, high-pressure injection of lime slurry by penetrating the ground hydraulicly and pumping at extremely high-pressures and third, drill lime treatment, which consists of the placement of lime in previously drilled holes.

The results of the tests indicated the following:

Electro-Osmosis -

1. A good movement of water was obtained with a resultant electro-chemical hardening around the negative electrodes.

2. The results indicated that very little lime was moved by the water and that the time required to effect a sufficient movement of lime to change the characteristics of the soil would not be economically feasible, if possible at all.

High-Pressure Injection -

1. The distribution of the lime within the fill was a stratified one. The lime slurry flowed through narrow fissures apparently caused by the pressure exerted on the slurry at the injector.

2. The direction of the created fissures was generally horizontal at the level of the injector tip except where planes of weakness or pre-existing voids provided easy access.

3. The slurry moved approximately the same horizontal distance in all directions from the injector tip except where planes of weakness or pre-existing voids were encountered.

4. Little penetration of the slurry into the heavier clays occurred. It seems probable that a bulging of the highly plastic material allowed the slurry to go around the injector and up to lighter soils previously fractured.

5. The area of noticeable treatment extended from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches above and below the slurry seam.

6. At the end of four years, there apparently is no active lime available for further treatment of the surrounding soils.

7. It seems possible that if the injections could be placed at intervals of perhaps three inches or if a continuous injection could be made, an effective treatment of the soil mass might be accomplished except in the heavier clays. Whether escape of slurry into previously injected areas or other mechanical limitations would preclude this type of treatment is problematical.

Drill Lime -

No significant improvement was noted at the end of one year due to treatment with lime in drilled holes. Perhaps a longer period of treatment could reveal some improvement due to the treatment. However, the beginning of the formation of a crust on the columns similar to that noted in the lime injection areas at Manchac makes extensive later movement doubtful.

The results of this study indicate that of the three methods tested the high-pressure injection method is the most effective. With refinements and improvements, such as closer injection spacing or perhaps continuous injection, the high-pressure injection process might become a workable and useful tool. However, of the three processes, this is probably the most expensive and unless a considerable reduction in cost can be effected its use would probably have to be limited to treatment of existing conditions. Construction using this process would probably not be economically feasible at the present cost.

REFERENCES

1. Higgins, C. M., "High Pressure Lime Injection," Louisiana Department of Highways, Research Report No. 17, August 1965.

2. "In-Situ Stabilization of Soils at Depth," Louisiana Department of Highways, Research Report (Unpublished), August 1964.