LIME TREATMENT AT DEPTH

FINAL REPORT

by

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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.

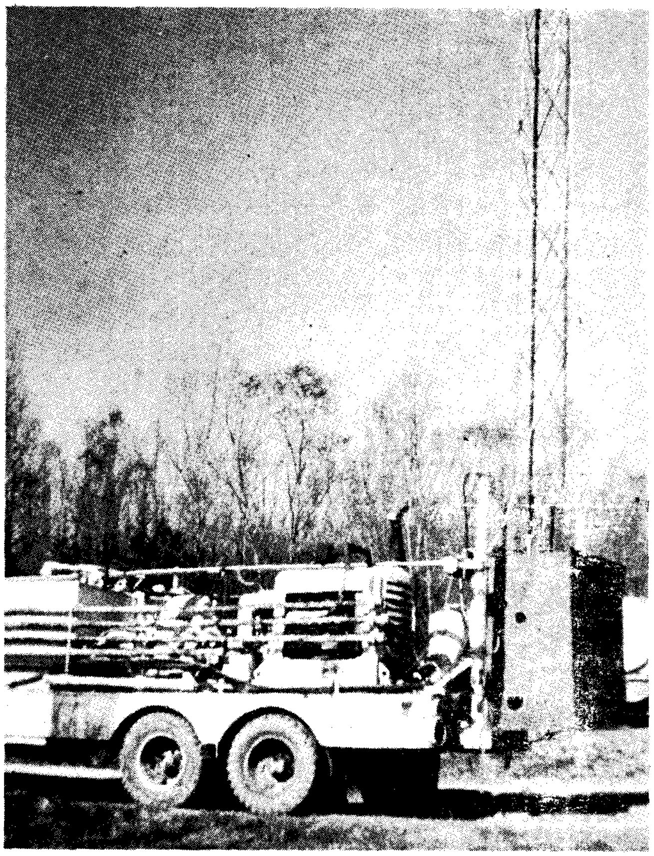


Figure 1

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.

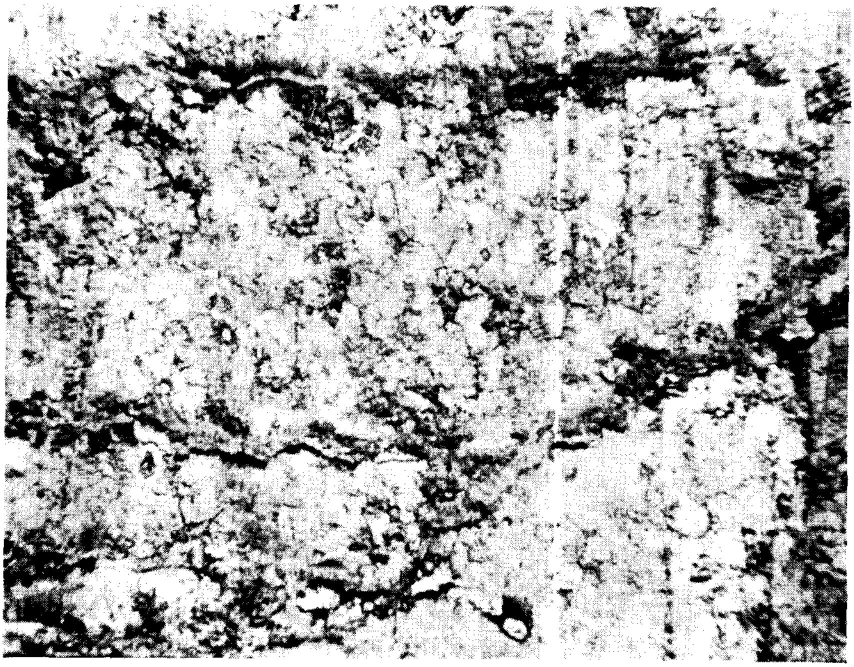


Figure 3

3. General Observations: 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
1230+00	U	12/17/64	0-3'	Medium Silty Clay	57	29	28	7.2	-	16.8	1.71
TS-5	T	5/3/65	0-4'	Silty Clay	54	21	33	8.2	-	19.0	1.66
Hole 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.

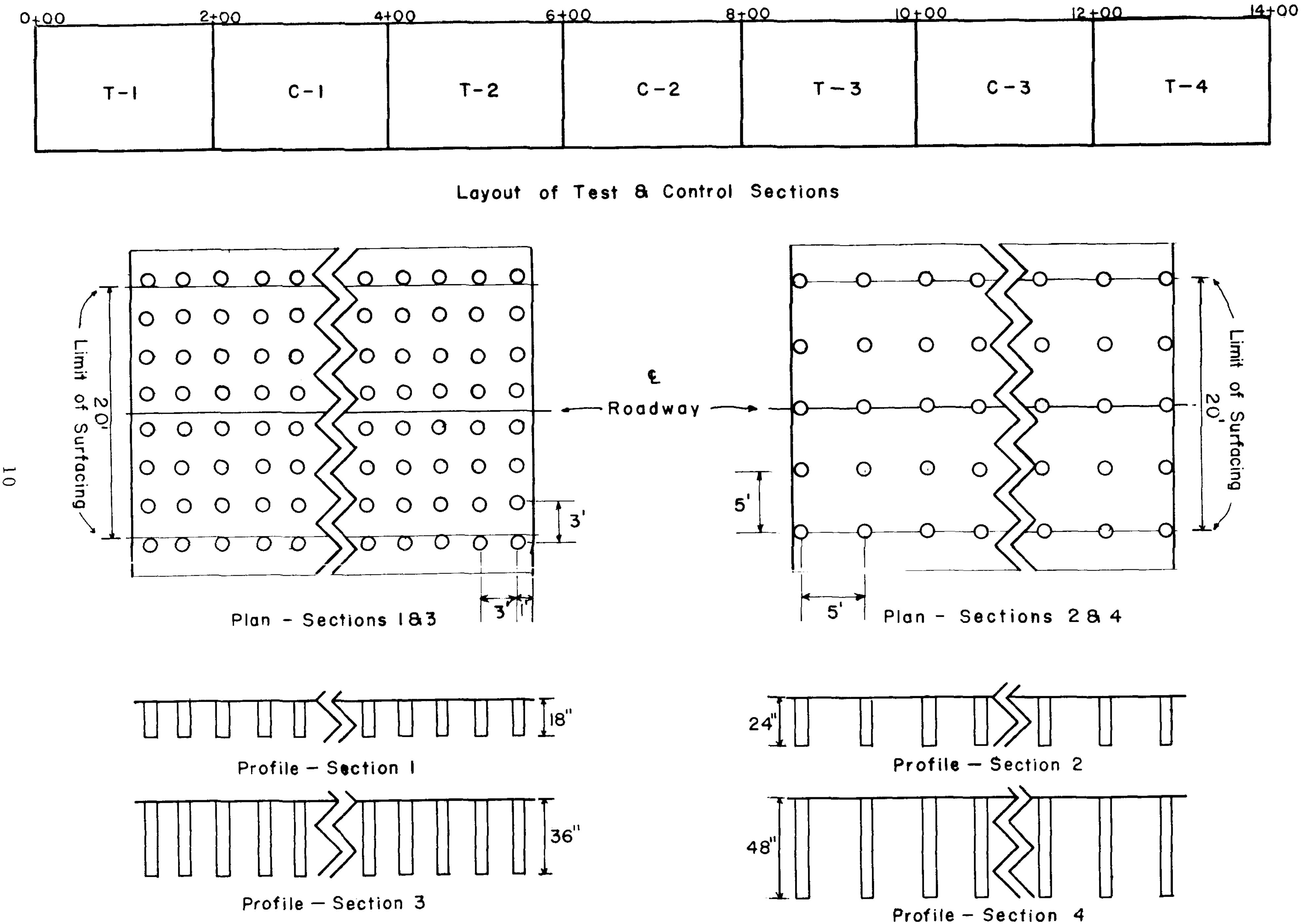


Figure 4 - Placement of Drill Holes in Test Section

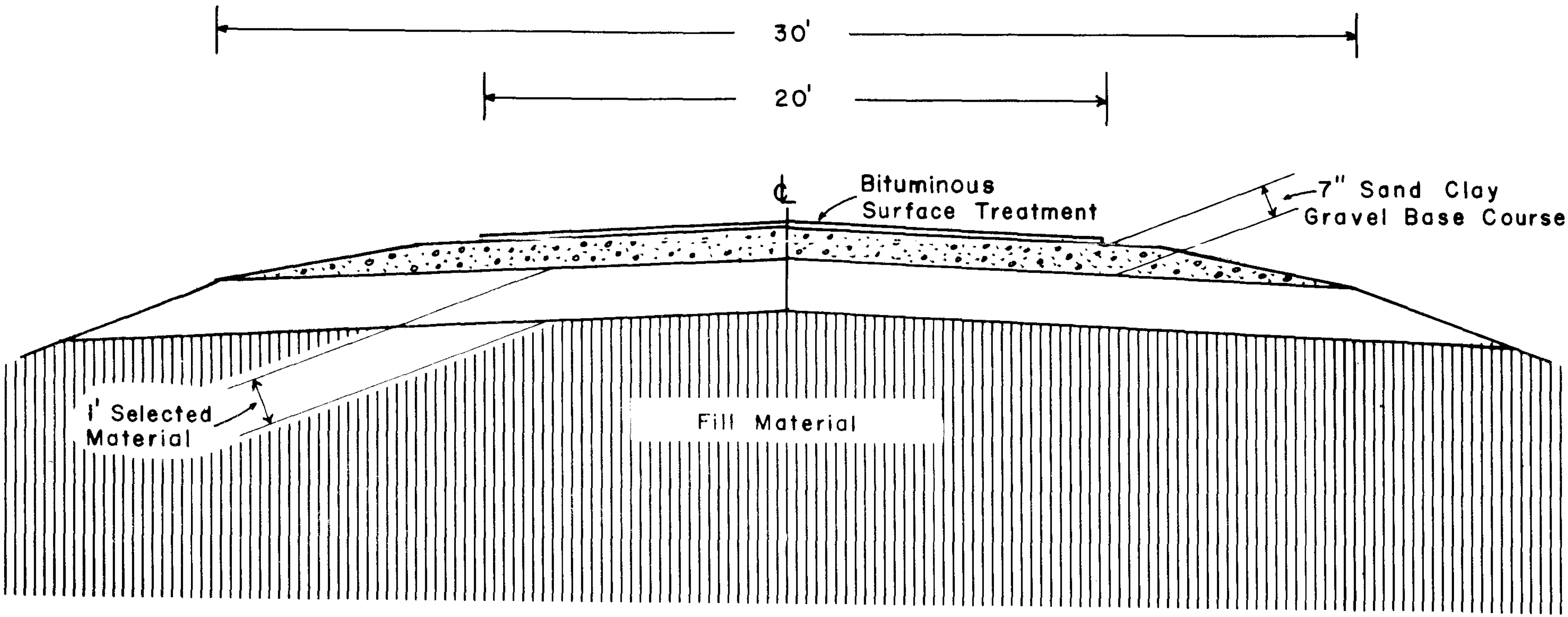


Figure 5 - Typical Section

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.

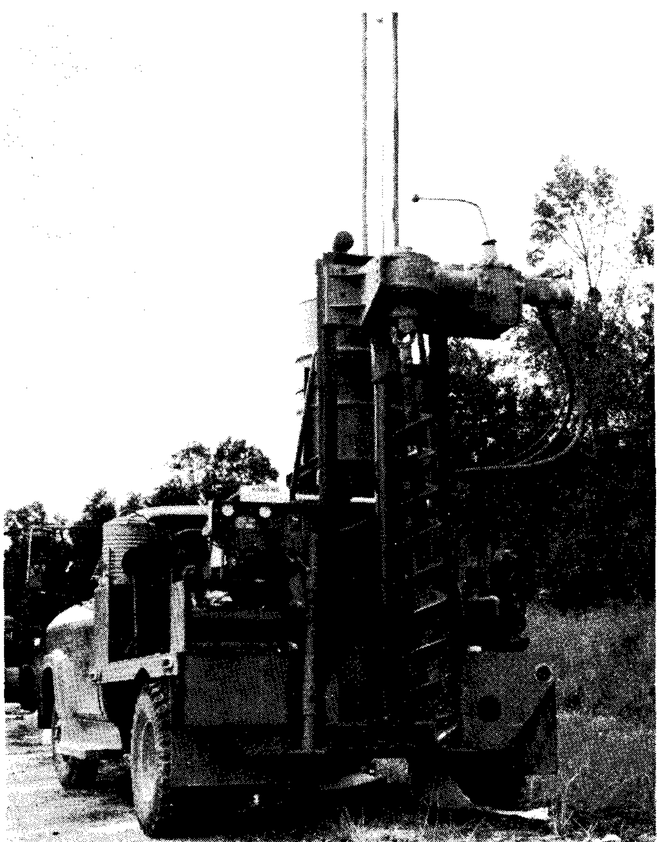


Figure 6

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).

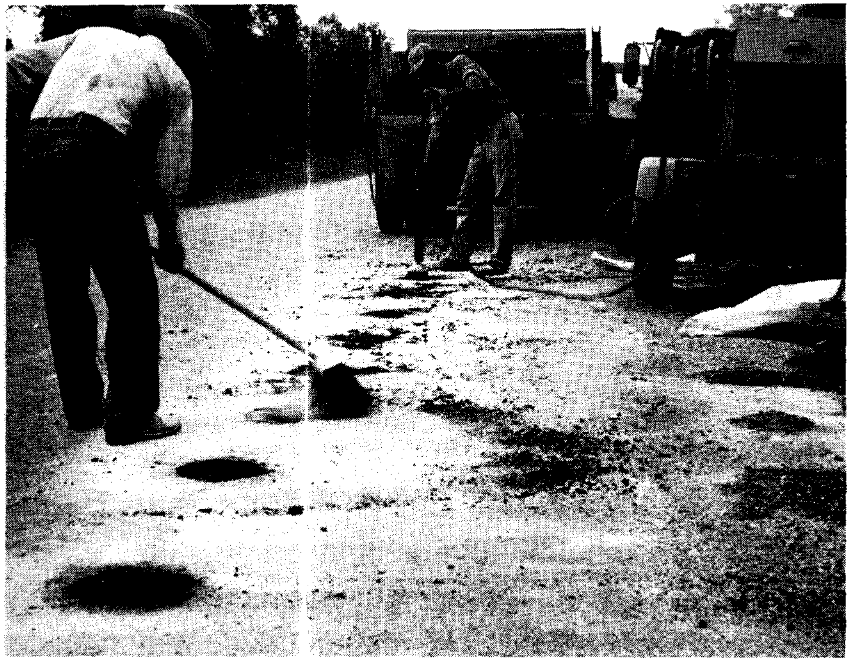


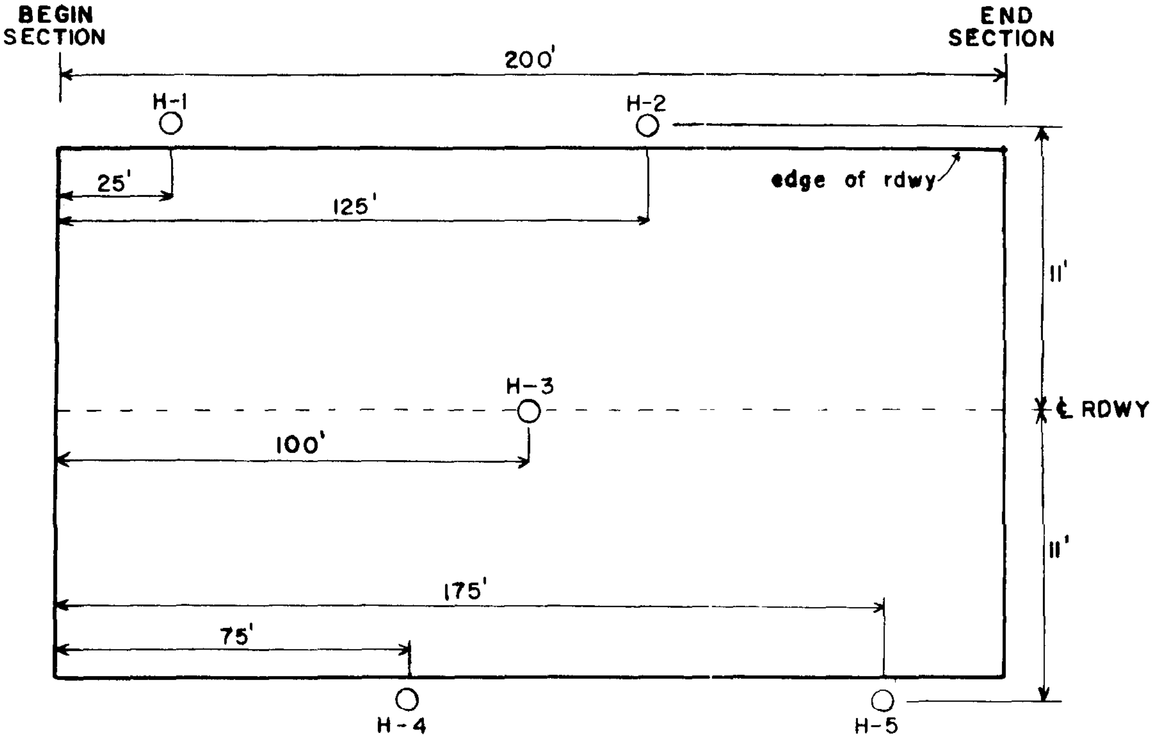
Figure 7

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 332 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 hundredths 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.

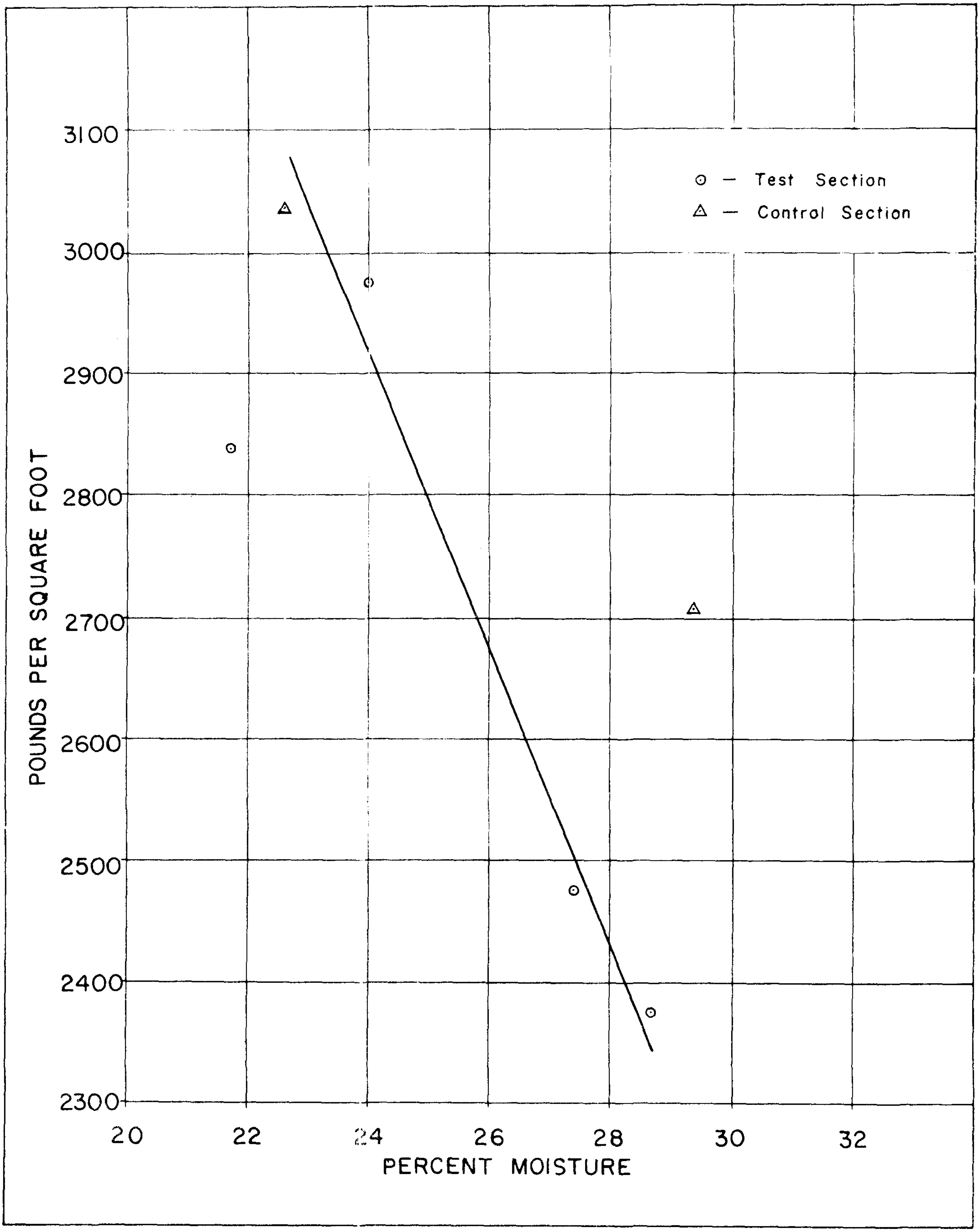


Figure 9 - Vane Shear Averages

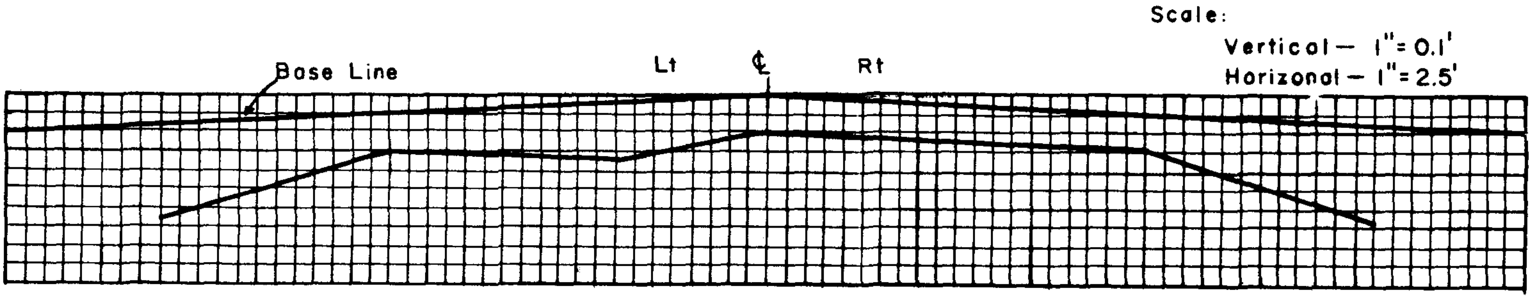


Figure 10 - Average Subsidence of Test Sections

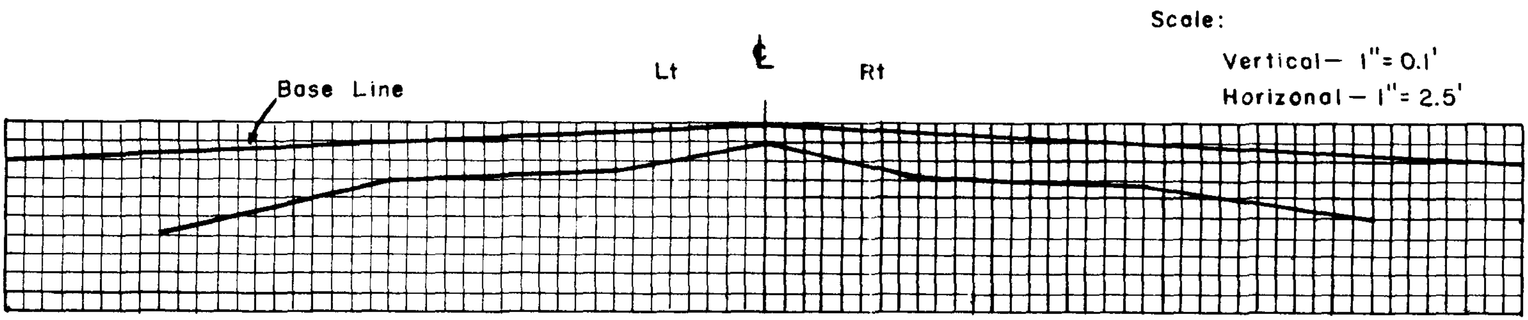


Figure 11 - Average Subsidence of Control Sections

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

Time Interval	8'Lt	5'Lt	2'Lt	℄	2'Rt	5'Rt	8'Rt
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 [illegible] 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.