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LIME-CEMENT COMBINATION STABILIZATION

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Army Construction Engineering Research Laboratories
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13. ABSTRACT

Soil stabilization is used extensively in road and airfield construction. In particular, soil-cement appears to be a favorite among the engineers. As the plasticity of a soil increases, the ability to adequately mix the cement with the soil becomes a critical factor. Also the quantity of cement required to stabilize the soil becomes excessive.

For soils which are highly plastic the current Army Technical Manuals on soil stabilization recommend the use of lime. Studies performed by this laboratory and other construction agencies have found many highly plastic soils which do not increase in strength upon the addition of lime. However, one benefit which is always obtained by the addition of lime is a reduction in plasticity, which improves the workability of the soil. In other words, the lime makes the soil more friable and easier to mix, spread and compact.

A possible construction procedure that is overlooked almost entirely is the use of combination stabilization, which utilizes lime to improve the workability of the soil, and portland cement to form the cement agent.

Previous investigations in cement stabilization have found that the strength and durability of cement stabilized soil is very sensitive to changes in compacted density. When lime is mixed with highly plastic soils flocculation and agglomeration of the soil occurs, which makes the soil more friable. However, the compacted density of the soil is less than untreated soil. This same reduction in density occurs with the lime-cement treated soil. It has been proven in studies by this laboratory and other investigators that the strength of lime-cement stabilized is satisfactory. However, sufficient durability studies have not been made to determine if the reduced compacted density is detrimental.

The objective of the study was to determine the effect of reduced compacted density on the durability of cement stabilized clays, pretreated with lime.

The results of the study indicated that, as expected, the compacted dry densities of the lime-cement specimens were lower than those stabilized with only cement. However, this reduction in density did not impair the durability of cement stabilized clay soils, which were pretreated with lime. Most of the test results indicated an improved resistance to freeze-thaw.

An evaluation of the unconfined compressive strength results obtained during freeze-thaw shows that lime pretreatment improved the strengths.

14. KEY WORDS

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LIME-CEMENT COMBINATION STABILIZATION

(ILIR Study)

by

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May 1973

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Soil stabilization is used extensively in road and airfield construction. In particular, soil-cement appears to be a favorite among the engineers. As the plasticity of a soil increases, the ability to adequately mix the cement with the soil becomes a critical factor. Also the quantity of cement required to stabilize the soil becomes excessive.

For soils which are highly plastic the current Army Technical Manuals on soil stabilization recommend the use of lime. Studies performed by this laboratory and other construction agencies have found many highly plastic soils which do not increase in strength upon the addition of lime. However, one benefit which is always obtained by the addition of lime is a reduction in plasticity, which improves the workability of the soil. In other words, the lime makes the soil more friable and easier to mix, spread and compact.

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An evaluation of the unconfined compressive strength results obtained during freeze-thaw shows that lime pretreatment improved the strengths.

FOREWORD

This investigation was conducted by Materials Division of the Construction Engineering Research Laboratory (CERL) in Champaign, Illinois. The work was performed as part of an In-House Laboratory Independent Research project. Technical Monitor was Colonel E. S. Townsley.

CERL personnel directly concerned with this study were Messrs. Lovick P. Suddath, III, Robert C. Gunkel and Edgar M. Cundiff. The Director of CERL is Colonel R. W. Reisacher and the Chief of Materials Division is Mr. E. A. Lotz.

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INTRODUCTION

Problem

From Engineer Battalion Operational Reports generated in South East Asia, and from discussions with engineers who have either visited or been stationed in Vietnam, it was learned that soil stabilization is used extensively in road and airfield construction. In particular, soil-cement appears to be a favorite among the engineers. As the plasticity of a soil increases, the ability to adequately mix the cement with the soil becomes a critical factor. Also the quantity of cement required to stabilize the soil becomes excessive.

For soils which are highly plastic the current Army TM on soil stabilization recommends the use of lime. Studies performed by this laboratory and other construction agencies have found many highly plastic soils which do not increase in strength upon the addition of lime. However, one benefit which is always obtained by the addition of lime is a reduction in plasticity, which improves the workability of the soil. In other words, the lime makes the soil more friable and easier to mix, spread and compact.

A possible construction procedure that is overlooked almost entirely is the use of combination stabilization, which utilizes lime to improve the workability of the soil, and portland cement to form the cement agent. The Army TM recognizes the possibility by saying: "It may be possible in some cases to use a compound type stabilization in which the soil is treated first with lime and then either portland cement or bituminous material". Then the manual leaves the field engineer cold by saying; "In the final selection of a stabilizing agent for a specific job it is the responsibility of the engineer in charge, through use of all available information to determine the best agent or combination of agents to accomplish the job". Information on combined stabilizers in the soil stabilization literature is practically non-existent, and the field engineer must pass up an excellent procedure for many difficult field problems.

It must be emphasized that this process will not only save construction time, but may reduce the volume of stabilizer required on a project, and will furnish a better stabilized layer.

Specific Technical Problem: Previous investigations in cement stabilization have found that the strength and durability of cement stabilized soil is very sensitive to changes in compacted density, Figure 1. When lime is mixed with highly plastic soils flocculation and agglomeration of the soil occurs, which makes the soil more friable. However, the compacted density of the soil is less than the untreated soil. This same reduction in density occurs with the lime-cement treated soil. It has been proven in studies by this laboratory and other investigators that the strength of lime-cement stabilized is satisfactory. However, sufficient durability studies have not been made to determine if the reduced compacted density is detrimental.

Technical Objective: To determine the effect of reduced compacted density on the durability of cement stabilized clays, pretreated with lime.

Background

Cement Stabilization has been widely used for many types of soil. This method of stabilization is not a simple process, because of the many variables that must be considered in the fine grained fraction of the soil. The stabilizing effect is primarily due to the hydration of portland cement. This hydration results in the formation of a calcium aluminate and calcium silicate bonding agents, and the production of free lime. The plasticity is reduced and the workability is improved somewhat by cation exchange, flocculation and agglomeration reactions occuring in the fine grained fraction of the soil. Characteristics of the soil which effect the reaction with cement are:

a. Plasticity
b. Clay Content
c. Gradation
d. Organic Matter
e. Soil pH

Pulverization of the soil before the addition of cement is very important, and as the clay content and plasticity increases the job becomes more difficult. Also, uniformity of mixing is essential. Some field studies have shown that only 60 to 80 percent of laboratory indicated strengths can be achieved in the field.

Combined Stabilization has been studied and utilized on a very limited basis. In this study combined stabilization is concerned with the use of lime in combination with cement stabilizers. This process utilized the ability of lime to flocculate and agglomerate a clay soil, thus reducing the plasticity, and improving the workability of the soil. Then the cement can be uniformly mixed with the soil. The term pretreatment will be used in this report to denote the mixture of lime, for improvement workability with the soil prior to the addition of the stabilizer.

CHAPTER II

APPROACH

General

To study durability of the stabilized soil in the laboratory it was noted that the most severe deterioration is caused by contraction, expansion and other destructive forces which result from wetting and drying and/or freezing and thawing. The wet-dry test simulates contractive forces caused by changes in moisture, however, when considering soils pretreated with lime where flocculation of the soil particles has occured, it is resistant to contraction. The freeze-thaw test simulates expansive forces because of the expansion of water during freezing. Pretreatment with lime causes a decrease in compacted density which means the void volume is greater, and there would be more room for moisture within the soil skeleton. Thus it was decided that a freeze-thaw condition would be the best method to study the effect of lime pretreatment on the durability of cement stabilized clay soils.

Factors to Consider

The field conditions required for detrimental freezing action are a freezing temperature, an available source of water, a thermal gradient, and cycles of freezing and thawing. These requirements should be met to have a realistic freeze-thaw test.

A study was made of several widely used freeze-thaw procedures for stabilized soils. In the ASTM (D560) and AASHO (T136) test the specimens are frozen by applying a freezing temperature all around the specimen, which is unlike the situation in the field. Thus a thermal gradient is developed between the exterior face and the interior, not between the top and bottom as in a pavement. Also, the specimen absorbs water during thawing, but during freezing the need for water to form ice lens can only be satisfied by a redistribution of moisture in the sample. The measure of the freeze-thaw effect by brushing to determine a weight loss is another part of the test that fails to simulate field conditions.

The British have developed a freeze-thaw test (1) which comes close to meeting the requirements for a realistic evaluation. They use a procedure which freezes the sample from the top down; develops a thermal gradient and makes a constant source of unfrozen water available. The specimens are evaluated by measuring the strength loss during freezing and thawing as compared to control specimens. However, no provisions are made for adapting the test to different climatic conditions.

George and Davidson (2) developed a modified test based on the British procedure. They established a freeze temperature based on the minimum air temperature during the winter months. To develop a temperature gradient in the sample, the ground temperature at the 20" level was selected. The number of freeze-thaw cycles were based on a daily maximum and minimum air temperature which could produce the most unfavorable conditions. To evaluate the test an index of resistence to freezing was determined using the ratio of the unconfined compressive strength after freeze-thaw to that of control specimens.

Dempsey and Thompson (3) used the British Test and the modifed test developed by George and Davidson as guidelines for a durability test for lime-soil mixtures. In their test they selected the freezing temperature, thermal gradient, thaw temperature and number of freeze-thaw cycles based on weather conditions at Champaign, Illinois. The four methods used to evaluate the freeze-thaw durability of lime-soil mixtures were unit length change, unconfined compressive strength, moisture distribution, and a visual inspection. All methods were found to adequately assess the freeze-thaw durability of the lime soil mixtures, however, unit length change, and unconfined compressive strength were the most informative.

Type of Tests and Specimens

A procedure based on a modification of the British test was selected as the best method to accomplish the objective of this study. For comparative purposes, ASTM-AASHO brushing test was performed on one specimen for each stabilizer combination. The detailed test procedure for the study is presented in Chapter III.

For this study it was desired to have clay soils with a range in plasticity. The two soils chosen were a lean clay (CL) and fat clay (CH) according to the Unified Soil Classification System. The properties of the soils are given in Table II.

The cement and pretreatment lime percentages were selected in the following manner: The optimum cement content was selected using procedures outlined in Chapter 2 of the PCA Soil Cement Laboratory Handbook. The optimum values were bracketed $\pm$ 4% for the fat clay (CH) and $\pm$ 3% for the lean clay (CL). The cement contents were held constant for both the lime-cement and cement stabilized clays.

The lime pretreatment was determined by studying the effect of lime on the Atterberg Limits of the soil. The actual value is the lime percentage which makes a significant change in the plasticity index (liquid limit minus plastic limit) or a minimum of 2 percent. The 2 percent value has been found to be the minimum value which can be effectively mixed with the soil.

For the modified British freeze-thaw test the following conditions were used. A freezing temperature of 20° F was selected to insure slow but complete freezing of the specimen. This would allow the specimens to take on a maximum amount of moisture. A thaw temperature of 45° F was selected to insure complete thawing but would retard the strength gain during the tests. The thaw temperature of 77° F used in the standard test is unrealistic and allows the specimens to gain strength during each thaw period. The lower part of the specimens was exposed to unfrozen water during the freeze cycle by placing each specimen in a vacuum flask with only the top exposed to the freezing temperature. A sketch of the apparatus is shown in Figure 2. The test consisted of 12 cycles of 16 hours freezing and 8 hours thawing.

Unit length change, unconfined compressive strength, moisture distribution and a visual rating were used to evaluate the durability of the specimens subject to the above test.

For comparative purposes the ASSHO and ASTM freeze-thaw test was performed on one specimen for each stabilizer percentage used. The test was performed at the same temperatures and cycle time as the specimens subject to the modified British test.

Table I showing the number of specimens and test condition for each soil evaluated in the study.

Evaluation Methods

Unit Length Change In work by other researchers on soil-cement (4), length change has been found to be a sensitive measurement of deterioration during freeze-thaw testing. It is felt that unit length change would be an effective evaluation for the lime-cement stabilized soil, also. Unit length change is expressed in inches of length change per inch of specimen length.

For this study three samples were formed for each stabilizer combination and measurement were made at the end of each freeze and thaw period. Readings were taken to the nearest .001 inches, and compared to the initial readings taken after the 24 hour soak period.

Unconfined Compressive Strength Dempsey and Thompson (3) concluded that, although unconfined compressive strength may not reflect the formation of all minute cracks or localized weaknesses, it is with adequate replication a direct measure of deterioration.

For this study three samples were tested in unconfined compression after the 24 hour period and 3, 6 and 12 cycles of freeze thaw. Also, three samples were cured at the thaw temperature for a period of time equal to 12 cycles of freeze-thaw to determine the strength gain which would occur if the specimen were not frozen.

Moisture Distribution The moisture content and moisture distribution in the specimens subject to one directional freezing should be indicative of the permeability and capillarity. Each sample tested in unconfined compression was divided into three parts and the moisture content determined. The amount of moisture in the soil voids should be reflected in both the unit length change and the reduction in unconfined compressive strength of the specimens.

Visual Examination To assist in the final evaluation of the effect of various stabilizers, each sample was visually inspected before testing in unconfined compression. Based on the general external appearance, the durability of each specimen was rated as poor (P), fair (F), good (G), or excellent (E). The excellent rating was given to specimens that display no surface deterioration; the poor rating to those which show extensive surface deterioration; and the fair or good to specimens in between.

CHAPTER III

TEST PROCEDURES

General

Laboratory tests were performed in accordance with procedures outlined in TM 5-530/ AFM 88-51, Materials Testing, February 1966, except as noted.

The chemical analysis was performed in accordance with procedures outlined in Methods of Soil Analysis, Agronomy #9, Part 2, American Society of Agronomy, 1965.

The x-ray analysis was performed on a Norelco XRD 5000 diffractometer using Ni-filtered Cu $K\alpha$ radiation.

Specimen Preparation The sample size for the AASHO-ASTM freeze-thaw test was a 4" diameter by 4.5" high. For the modified British test, a Harvard Miniature Compaction mold was used to form samples 1.313" diameter by 7.813" high using a drop hammer compactor.

The soils were processed thru a No. 4 sieve and mixed with water approximately 12 hours before compaction. The pretreatment lime was also mixed with the soil 12 hours prior to compaction. When the cement was added to the soil it was compacted as rapidly as possible. The samples were compacted in 5 layers with 15 blows per layer.

All samples were cured 7 days to 70° F and 90 percent relative humidity. After the 7th day the samples were soaked for 48 hours prior to beginning the freeze thaw test.

Conduct of Test AASHO-ASTM freeze-thaw test was performed in the following manner:

1. Specimens were placed on a saturated pad and allowed to freeze at 20° F for 16 hours.
2. Then the specimens were allowed to thaw for 8 hours at 45° F with free water available for pad.
3. Specimens were then brushed with two firm strokes on all areas with a wire brush.
4. Each specimen was weighted and turned end for end before the next freeze cycle.
5. After the 12th cycle of freezing and thawing the specimens were brushed, weighted and then dried to determine the moisture content and weight loss.

The modified British freeze-thaw test was performed as follows:

1. After the soaking period, each specimen was encased in a rubber membrane with both ends exposed, and placed in a vacuum flask with the water level approximately 1/2 inch above the bottom of the sample holder as shown in Figure 2.

2. The vacuum flask was then placed in the freezer for 16 hours at 20° F.

3. During the thaw period the specimen was removed from the vacuum flask, and allowed to thaw for 8 hours at 45° F with free water available to the bottom of the sample.

4. After the initial soak period and each freeze and thaw cycle, the sample length change was measured with a comparator.

5. At the end of the initial soak period and after 3, 6 and 12 cycles of freeze-thaw, three specimens were tested in unconfined compression.

6. Three additional specimens were allowed to cure for 45° F for a period of time equal to 12 cycles of freeze-thaw.

7. Upon completion of the unconfined compression tests, the specimens subjected to freeze-thaw were cut in three parts to determine the moisture distribution.

During the program, all specimens were evaluated visually after the initial cure period and prior to being tested in unconfined compression. Based on the general external appearance, the durability of each specimen was rated as poor (P), fair (F), good (G), or excellent (E). The poor rating was given to specimens which displayed extensive surface deterioration and ice lensing; the excellent rating to those which displayed little or no surface checking and ice lensing; the fair or good rating to those in between.

CHAPTER IV

TEST RESULTS

The properties of the clay soils used in this study are given in Table II. The grain size analysis for the soils and the effects of lime on the Atterberg Limits of the soils are shown in Figures 3 and 4 respectively.

As noted in the test procedures, all samples were compacted using the same effort so that the effect of lime pretreatment could be determined. The average density for the lean clay (CL) was 113.1 and 115.5 pounds per cubic foot for the lime-cement and cement stabilized soils, respectively. The differences were larger for the fat clay (CH) with 94.5 pcf for the lime-cement specimens and 100.4 pcf for the cement specimens.

The average values for the durability study are given in Tables III and IV. Each value represents the average of three specimens except for the AASHO-ASTM freeze-thaw test which was performed on one specimen.

Figures 5 and 6 show a summary of the unconfined compressive strengths for the various stabilizer combinations at different phases of the tests. To better study the effect of freeze-thaw, all strengths were normalized using the index of resistence to freezing. This index was calculated by dividing the unconfined compressive strength after 3, 6 and 12 cycles of freeze-thaw by the strength after curing. To correct for the strength gain which occurs during the test, the difference between the initial strength and the strength of the specimens allowed to cure at 45° F for 12 days are proportionally subtracted from the strengths after freeze-thaw testing. This information is shown in Figures 7 and 8.

A plot of moisture content showing the distribution throughout the test is shown in Figures 9 and 10. This shows the combined effect of freeze-thaw, thermal gradient, and a free water source exposed to the lower end of the specimen.

Unit length change with respect to cycles of freezing and thawing are shown in Figures 11 and 12.

To better show the effect of lime pretreatment on the durability of cement stabilized soils, unconfined compressive strength, unconfined compressive strength change, an index of resistance to freezing is plotted for each group of 3 specimens subjected to freeze-thaw. Each point represents the same cement content and number of freeze-thaw cycles with the only variable being the lime pretreatment used. This information is shown on Figures 13, 14, and 15.

CHAPTER V

ANALYSIS AND DISCUSSION

Unconfined Compressive Strength A comparison of the unconfined compressive strength results shows that the use of lime as a pretreatment for clay soils stabilized with cement is not detrimental from the standpoint of durability. In fact, Figure 13 shows that in all cases the strength is higher when the soil is pretreated with lime. If Figures 5 and 6 are studied considering total stabilizer percentage, lime plus cement or cement, the pretreated specimens are still as good or better than the specimens stabilized with cement alone.

Considering the change in unconfined compressive strength during the freeze-thaw tests, the lime-cement specimens either showed more strength increase or less strength decrease than the cement stabilized soils in 78 percent of the tests. These results are shown in Figure 14.

The index of resistence to freezing indicated that the lime-cement specimens were more durable in 83 percent of the tests.

The use of a thaw temperature lower than normally used did not completely prevent the specimens from gaining strength during the tests. However, some of the strength gained by the samples cannot be attributed to the thaw period but is the strength gain caused by a decrease in the moisture content early in the test.

The best indication of strength gain during the test can be obtained from the data on the specimens subjected to the thaw temperature during the entire freeze-thaw period. These samples were sealed to prevent moisture loss.

Unit Length Change Both the lean and the fat clay showed a smaller length change when pretreated with lime. Again if the total percentage of stabilizer is considered, the lime-cement stabilized soil is superior to soil stabilized only with cement.

Since it is generally felt that an increase in density reduces the permeability of soil, it is possible that greater hydraulic pressures are developed in the pores of the cement stabilized soil. Thus, the greater length change can be assumed to be attributed to a decrease in permeability caused by an increase in density.

Moisture Distribution The effects of freeze-thaw on moisture distribution and moisture change are shown on Figures 9 and 10. The lime-cement stabilized lean clay (CL) had a smaller change in maximum moisture variation, final degree of saturation and change in saturation during the test than the cement stabilized soil. The fat clay (CH) stabilized with lime-cement had a higher moisture content variation during the test, but both the final degree of saturation and the change in saturation was less.

This data also indicates that pretreatment with lime is not detrimental to the durability of the cement stabilized soil. Table V shows a summary of the changes in moisture content and degree of saturation during the tests.

Weight Loss The AASHO and ASTM Durability Test which gives the brushing weight loss of the stabilized soil due to freeze-thaw was not a sensitive indicator of the effect of various stabilizer combinations. The acceptable weight loss according to TM 5-822-4 for both of the soils tested was 6%. Only one stabilizer combination failed to meet this criteria as shown in Table III. All other combinations were satisfactory with the lime pretreated specimens indicating better durability for the fat clay and lesser durability for the lean clay. This test appears to be more sensitive to a change in the individual running the test than the modified British procedure.

CHAPTER VI

CONCLUSIONS

As expected, the compacted dry densities of the lime-cement specimens were lower than those stabilized with only cement. However, the results of this study indicate that this reduction in density does not impair the durability of cement stabilized clay soils, which are pretreated with lime. Most of the tests results indicate an improved resistence to freeze-thaw.

An evaluation of the unconfined compressive strengths results obtained during freeze-thaw shows that lime pretreatment improves both the initial and final strengths.

Based on acceptable weight loss criteria currently used for the design of soil cement, the lime pretreatment is not detrimental.

The test results confirm the belief that durable stabilized layers can be formed using a combination of lime and cement. This technique will give design and construction engineers a procedure that makes it possible to more easily and uniformly mix stabilizer with clay soils and at the same time obtain a stronger, more durable end product.

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Table I

Stabilizer Combinations and Number of Samples

Stabilizer Combinations		Number Specimens					
Stabilizer	Lime	A	A	A	-	-	-
Combinations	Cement	A	B	C	A	B	C
Modified British Freeze-Thaw Test							
Freeze-Thaw Cycles	0	3	3	3	3	3	3
	3	3	3	3	3	3	3
	6	3	3	3	3	3	3
	12	3	3	3	3	3	3
Samples cured at thaw temperature for time equal to 12 cycles freeze-thaw.		3	3	3	3	3	3
AASHO - ASTM							
Freeze-Thaw Test		1	1	1	1	1	1

Table II

Summary of Soil Properties

Items	Soil: Lean Clay	Soil: Fat Clay
Unified Soil Classification	CL	CH
Liquid Limit	38	66
Plastic Limit	20	29
Plasticity Index	18	37
pH	6.5	8.2
Optimum Moisture Content %	13.2	20.5
Maximum Dry Density	117.5	105.5
Organic Carbon %		
wet combustion	0.51	0.55
dry combustion	0.33	2.65
Wet Chemical Analysis		
Silica ($Si\ O_2$)	67.12	45.70
Allumina ($Al_2\ O_3$)	10.88	13.28
Iron Oxide ($Fe_2\ O_3$)	8.68	6.16
Calcium Oxide ($Ca\ O$)	0.51	12.00
Magnesium Oxide ($Mg\ O$)	1.09	2.73
Loss @ 105° C	4.78	5.29
Loss @ 800° C	5.07	13.65
Undetermined	1.87	1.19
Cation Exchange Capacity me/100 gm	17.13	38.97
Base Saturation	94.75	100+
Exchangeable Cations me/100 gm		
Calcium	11.63	55.20
Magnesium	3.93	3.73
Potassium	0.21	1.29
Sodium	0.46	0.42
Calcium Carbonate Equivalent %	1	20
Clay Minerals Present	Kaolinite Illite	Montmorillonite Kaolinite Illite (trace)
Non-clay Minerals Present	Mica Quartz	Calcite Quartz Feldspar

Table III

Freeze-Thaw Data
(Average Values for Lean Clay)

Soil Type	Stabilizer Information: Lime %	Stabilizer Information: Cement %	Stabilizer Information: Total Stab. %	Freeze-Thaw Cycles	Dry Unit Weight lbs/cu ft	Average Unit Weight lbs/cu ft	Molding Moisture Content %	Unit Length Change (in/in) Freeze	Unit Length Change (in/in) Thaw	Unconfined Compressive Strength (psi)	Visual Rating	Moisture Content % Top	Moisture Content % Middle	Moisture Content % Bottom	Moisture Content % Complete Sample	Brush Test** Wt. Loss %	Brush Test** Visual Rating
Lean	2	6	8	0	112.6	113.0	15.9			208.5	E				17.4		
Clay				3	113.1			-.0005	-.0001	246.6	E	16.4	16.9	17.6			
(CL)				6	113.7			+.0038	+.0027	228.7	F	18.1	18.5	18.8			
				12	113.4			+.0231	+.0182	132.9	F	21.2	19.3	18.7			
				12*	112.6					300.9	E				16.5	7	P-F
Lean	2	9	11	0	113.2	113.2	15.8			288.6	E				16.5		
Clay				3	112.6			-.0005	-.0003	358.8	E	16.0	16.3	16.7			
(CL)				6	113.7			.0000	+.0001	359.5	G	17.4	18.7	18.2			
				12	113.5			+.0138	+.0105	291.0	F	18.7	19.3	19.4			
				12*	112.8					346.2	E				16.8	6	F
Lean	2	12	14	0	113.1	113.1	16.2			339.4	E				17.5		
Clay				3	112.7			-.0004	-.0004	367.6	E	15.2	16.5	16.8			
(CL)				6	113.6			-.0005	-.0003	391.4	E	15.4	17.7	18.3			
				12	113.3			+.0194	+.0117	229.8	G	20.0	19.5	18.9			
				12*	112.7					365.5	E				17.0	4	G
Lean	0	6	6	0	115.9	115.7	15.1			162.6	E				16.9		
Clay				3	116.1			+.0108	+.0081	115.1	G	17.6	18.0	18.2			
(CL)				6	115.5			+.0346	+.0262	71.7	P	19.1	19.7	20.0			
				12	115.4			+.0420	+.0262	---	VP	21.2	21.1	23.1			
				12*	115.6					141.1	E				16.5	5	G
Lean	0	9	9	0	115.5	115.7	15.0			195.3	E				18.2		
Clay				3	116.3			+.0006	+.0004	216.5	E	16.2	17.2	17.8			
(CL)				6	115.7			+.0190	+.0111	153.4	F	18.7	18.4	18.8			
				12	115.3			+.0611	+.0305	---	VP	20.3	21.6	23.1			
				12*	115.8					210.6	E				17.8	4	G
Lean	0	12	12	0	114.5	115.1	15.4			224.1	E				18.4		
Clay				3	115.4			+.0036	+.0011	258.5	E	16.7	18.4	19.3			
(CL)				6	115.3			+.0125	+.0082	225.3	G	17.4	19.0	20.0			
				12	115.0			+.0395	+.0228	---	VP	19.4	20.5	20.5			
				12*	114.0					241.5	E				19.0	4	E

NOTE: * Samples cured for 12 days in thaw cabinet
** 4.0 x 4.5 in. Samples

Table IV

Freeze-Thaw Data
(Average Values for Fat Clay)

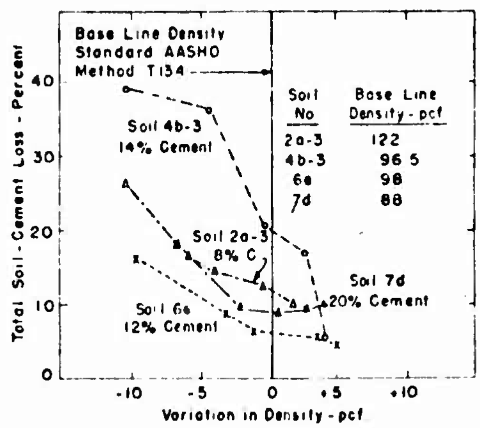
Soil Type	Stabilizer Information: Lime %	Stabilizer Information: Cement %	Stabilizer Information: Total Stab. %	Freeze-Thaw Cycles	Dry Unit Weight lbs/cu ft	Average Unit Weight lbs/cu ft	Molding Moisture Content %	Unit Length Change (in/in): Freeze	Unit Length Change (in/in): Thaw	Unconfined Compressive Strength (psi)	Visual Rating	Moisture Content %: Top	Moisture Content %: Middle	Moisture Content %: Bottom	Moisture Content %: Complete Sample	Brush Test**: Wt. Loss %	Brush Test**: Visual Rating
Fat Clay (CH)	4	10	14	0	93.0	94.0	22.3			312.3	E				25.3		
				3	94.3			-.0005	-.0005	394.7	E	25.9	26.2	25.1			
				6	94.1			-.0003	.0000	281.4	G	24.3	26.2	25.2			
				12	94.2			-.0010	-.0010	310.7	G	27.4	27.6	27.8			
				12*	94.5					390.8	E				24.9	3.7	G
Fat Clay (CH)	4	14	18	0	94.6	94.5	22.5			454.9	E				25.5		
				3	94.7			-.0004	-.0001	419.2	E	27.5	27.2	27.3			
				6	9[illegible].7			+.0001	+.0001	475.1	E	24.9	24.5	25.5			
				12	94.3			+.0001	+.0003	335.0	G	28.3	27.3	26.6			
				12*	94.1					442.1	E				25.5	2.2	G
Fat Clay (CH)	4	18	22	0	94.6	94.9	22.5			442.1	E				25.7		
				3	95.3			.0000	-.0001	635.6	E	26.6	26.7	26.3			
				6	95.0			-.0001	-.0001	530.1	E	24.6	24.8	25.9			
				12	95.0			+.0008	+.0010	574.3	E	26.2	26.7	27.7			
				12*	94.7					599.7	E				25.5	2.0	G
Fat Clay (CH)	0	10	10	0	101.1	100.7	23.0			173.1	E				24.7		
				3	100.4			-.0001	-.0004	218.1	E	24.0	24.1	24.2			
				6	100.1			+.0008	+.0007	216.0	E	25.1	25.2	25.0			
				12	101.0			+.0069	+.0069	112.6	G	26.2	25.7	26.2			
				12*	101.0					247.3	E				24.2	4.0	F
Fat Clay (CH)	0	14	14	0	100.7	100.9	22.4			332.7	E				24.6		
				3	100.8			-.0004	-.0004	414.5	E	23.5	24.7	24.3			
				6	100.8			-.0004	-.0003	244.7	G	23.9	25.0	26.0			
				12	100.5			+.0010	+.0011	238.2	G	25.4	25.7	26.9			
				12*	101.6					395.2	E				24.1	4.5	G
Fat Clay (CH)	0	18	18	0	99.1	99.5	23.7			389.1	E				24.7		
				3	9[illegible].5			-.0010	-.0010	327.9	E	22.8	25.3	25.4			
				6	99.4			+.0001	+.0001	291.3	E	24.6	25.5	25.7			
				12	99.3			+.0013	+.0014	302.6	E	26.3	26.4	26.1			
				12*	100.1					382.7	E				23.8	1.0	VG

NOTE: * Samples cured for 12 days in thaw cabinet
** 4.0 x 4.5 in. Samples

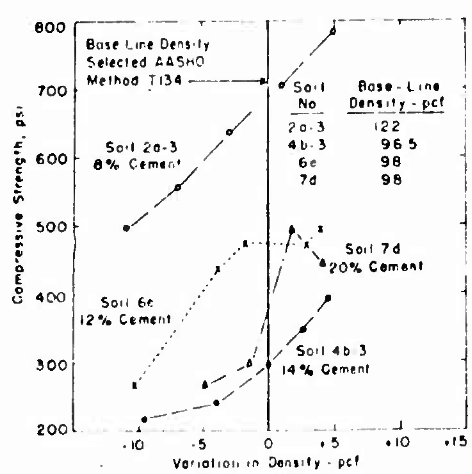
Table V

Summary of Moisture Content Change and Saturation During Freeze-Thaw Test

Soil Type	Stabilizer Information			Moisture Content Change			Saturation Beginning Freeze-Thaw	Maximum Final Saturation	Maximum Change Saturation
	Lime %	Cement %	Total Stab. %	Top %	Middle %	Bottom %	%	%	%
Lean Clay (CL)	2	6	8	5.3	3.4	2.8	95	115	20
	2	9	11	2.9	3.5	3.6	90	105	15
	2	12	14	3.3	3.3	2.7	95	109	14
	0	6	6	6.1	6.0	8.0	98	134	36
	0	9	9	5.3	6.6	8.1	105	134	29
	0	12	12	4.0	5.1	5.1	106	118	12
Fat Clay (CH)	4	10	14	5.1	5.3	5.5	81	89	8
	4	14	18	5.3	4.3	4.1	83	92	9
	4	18	22	3.7	4.2	5.2	84	91	7
	0	10	10	3.2	2.7	3.2	92	98	6
	0	14	14	3.0	3.3	4.5	92	101	9
	0	18	18	2.6	2.7	2.4	90	96	6



Effect of density on soil-cement loss from freeze-thaw test.*



Effect of density on 28-day compressive strength.*

NOTE: Soils 6e and 7d are clays

* From: FACTORS INFLUENCING PHYSICAL PROPERTIES OF SOIL-CEMENT MIXTURES

by
Earl J. Felt

Figure 1. Effect of density on weight loss and unconfined compressive strength of soil-cement.

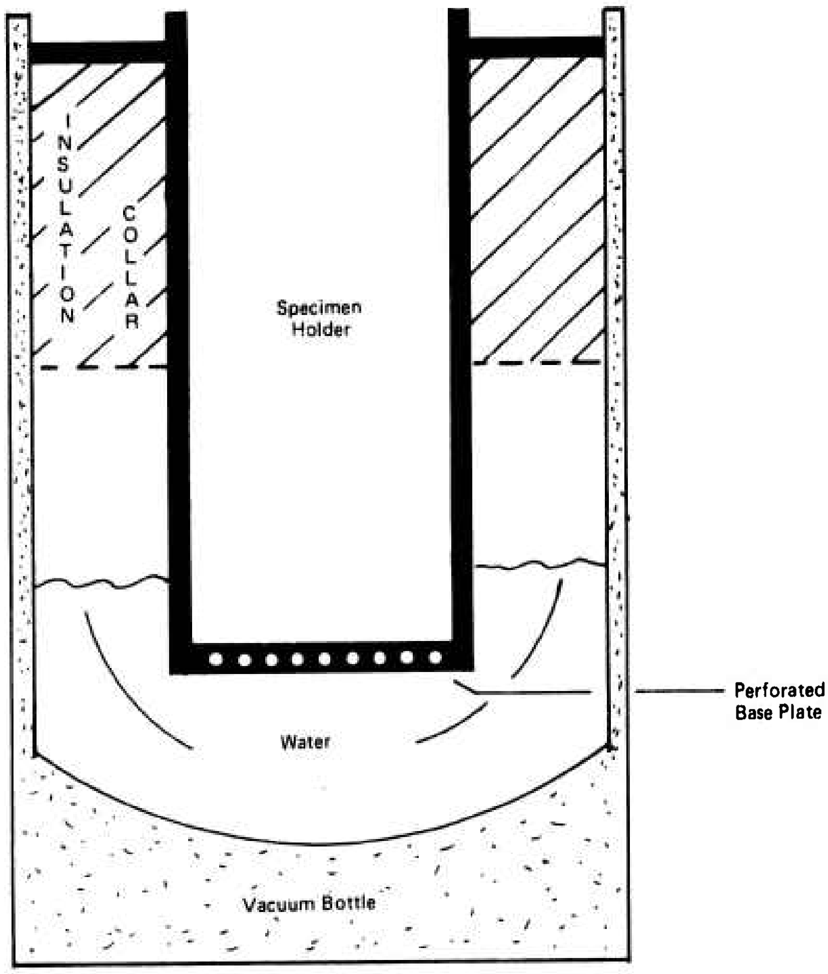


Figure 2. Freeze-thaw apparatus.

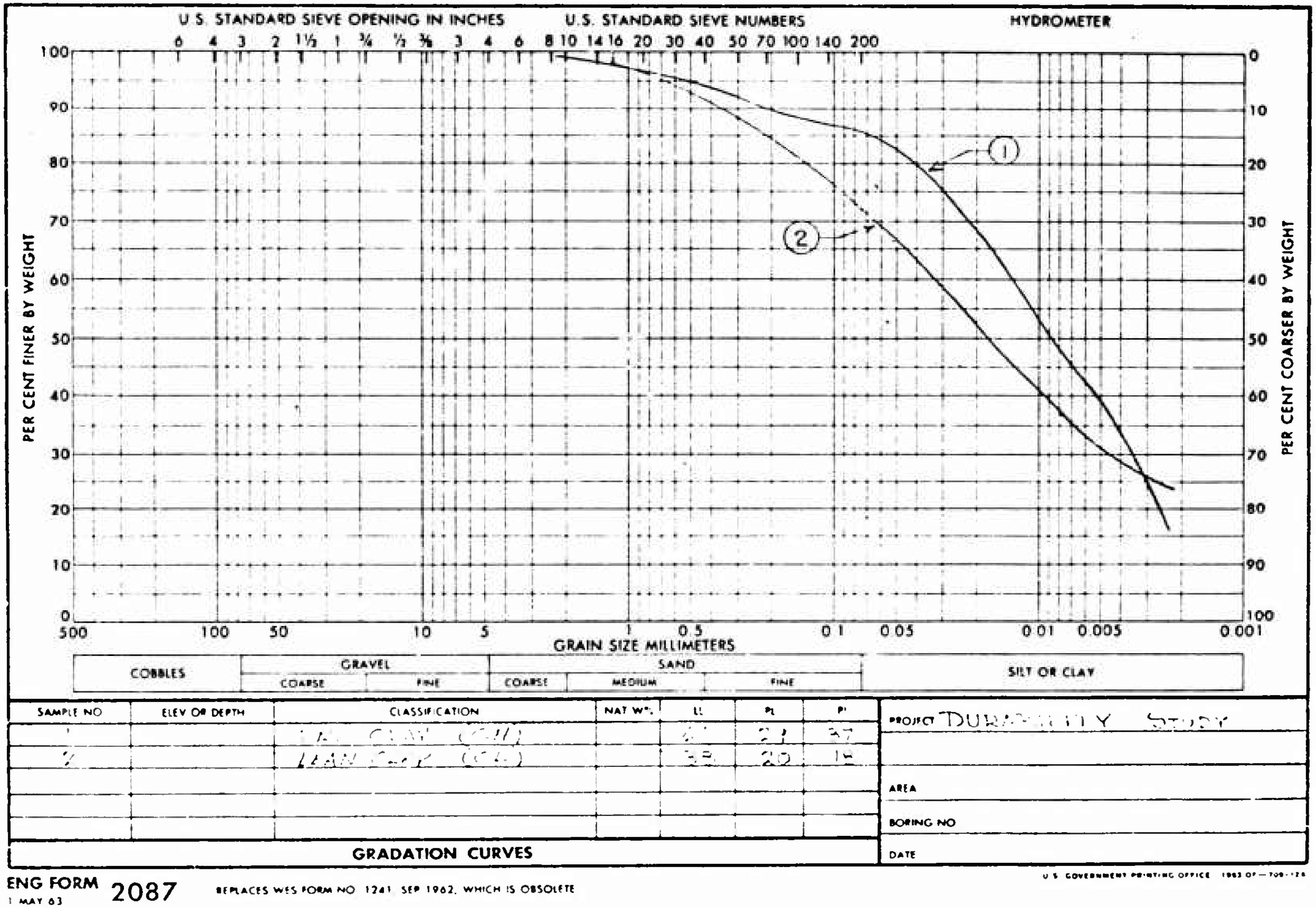
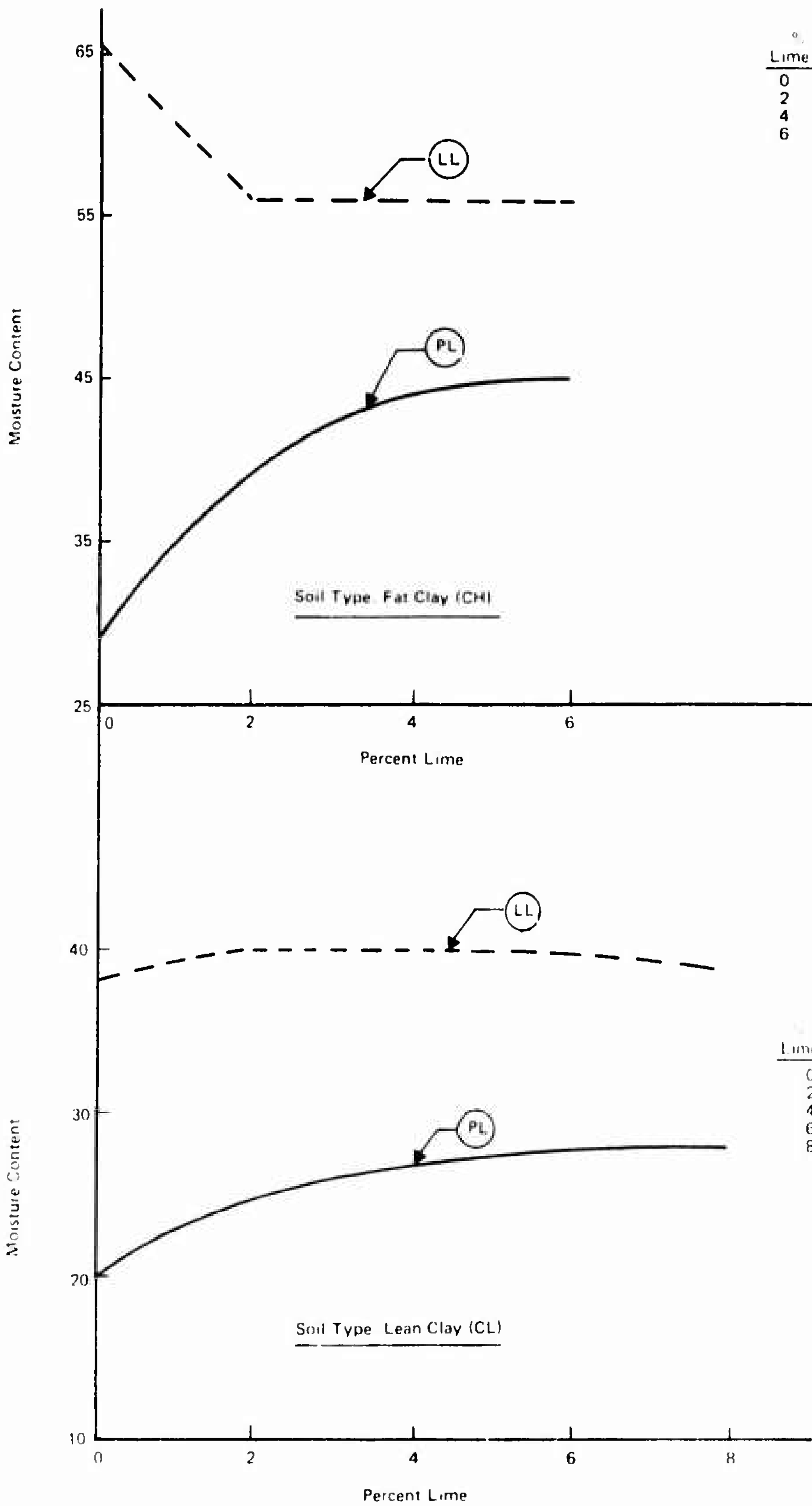


Figure 3. Gradation curves.



% Lime	PL	LL	PI
0	29	66	37
2	39	56	17
4	44	56	12
6	45	56	11

Lime	PL	LL	PI
0	20	38	18
2	25	40	15
4	25	40	15
6	27	39	12
8	28	39	11

Figure 4. Lime content effect on Atterberg Limites.

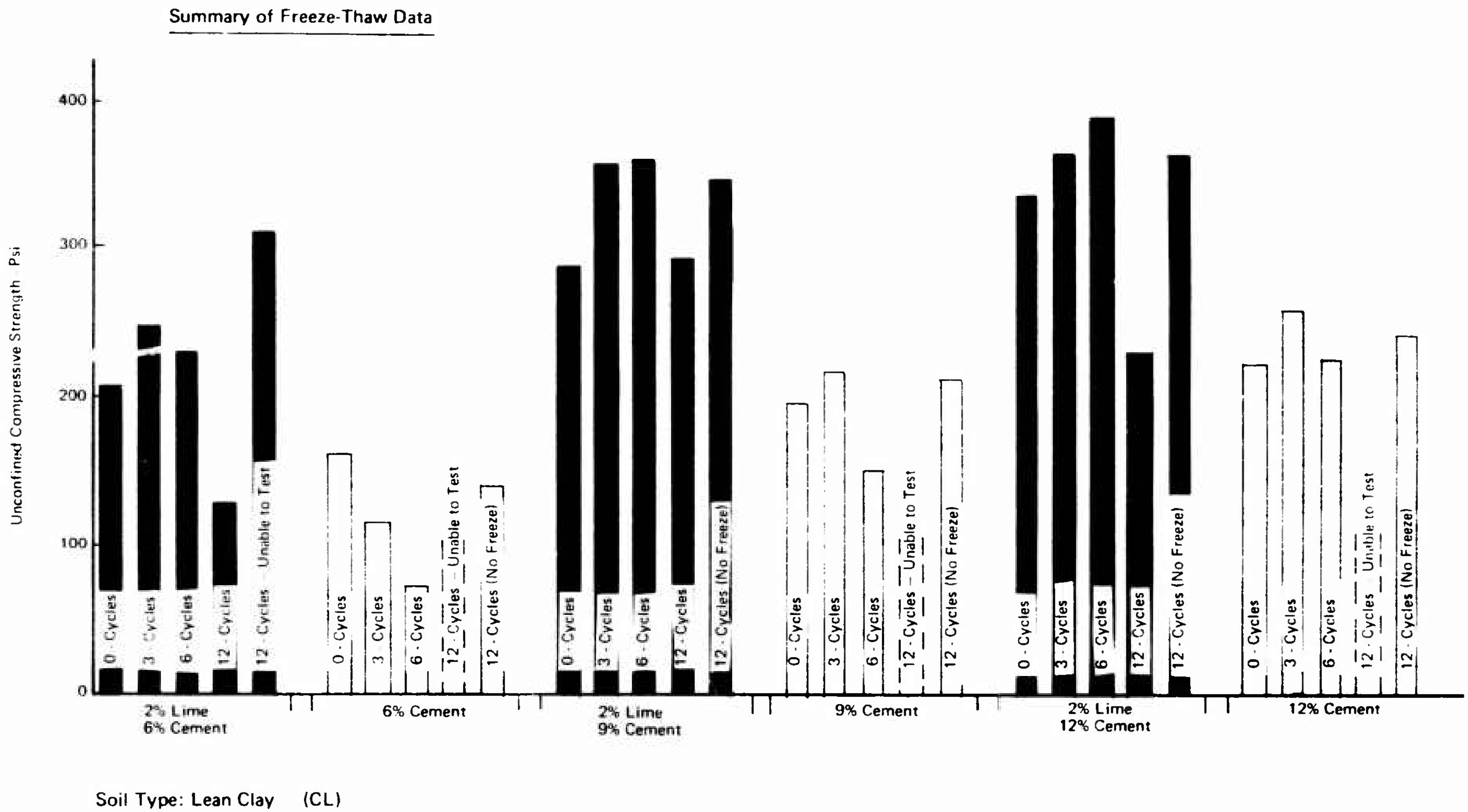
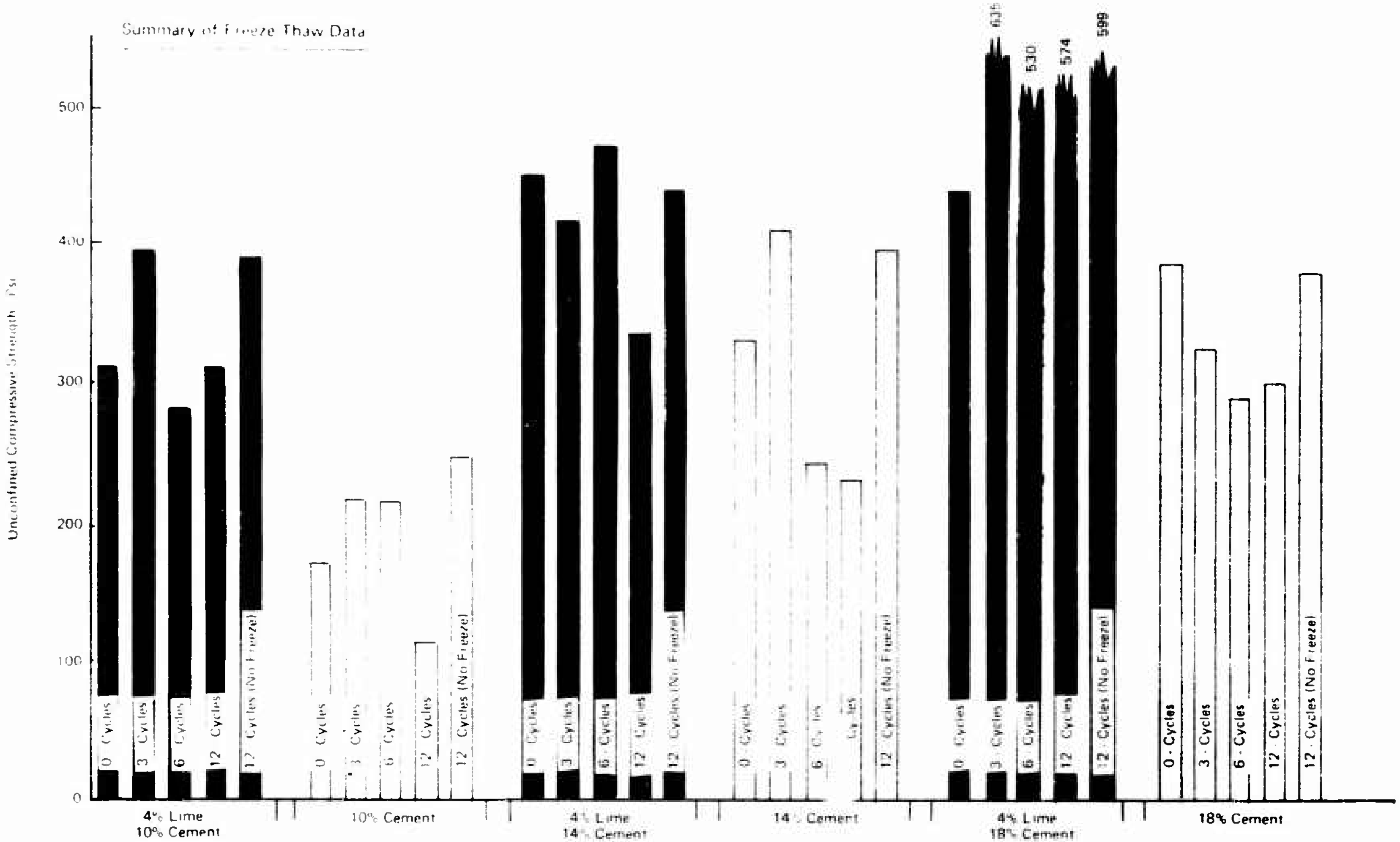


Figure 5. Influence of freeze-thaw cycles on unconfined compressive strength (CL).



Soil Type: Fat Clay (CH)

Figure 6. Influence of freeze-thaw cycles on unconfined compressive strength (CH).

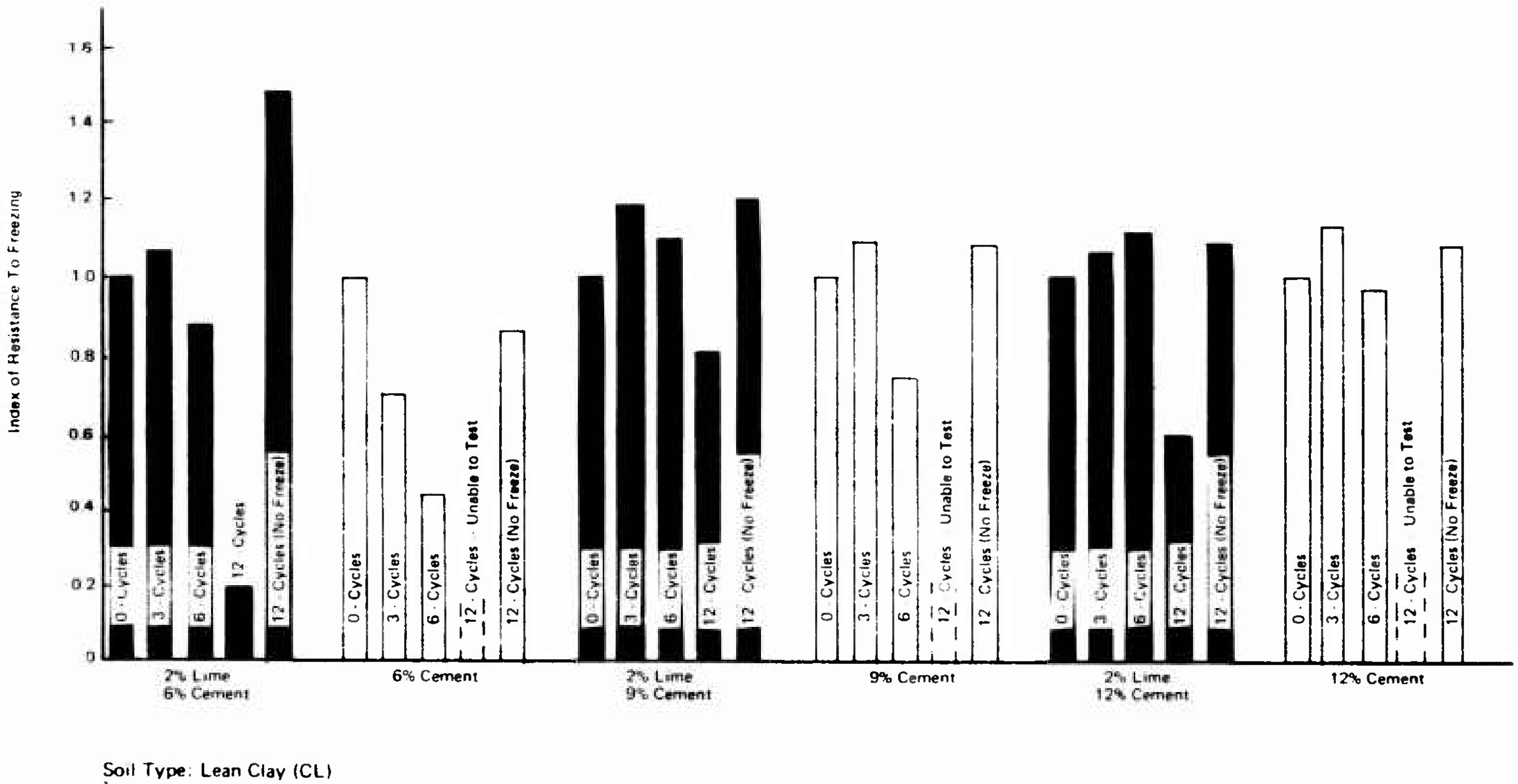


Figure 7. Influence of freeze-thaw cycles on index of resistence to freezing (CL).

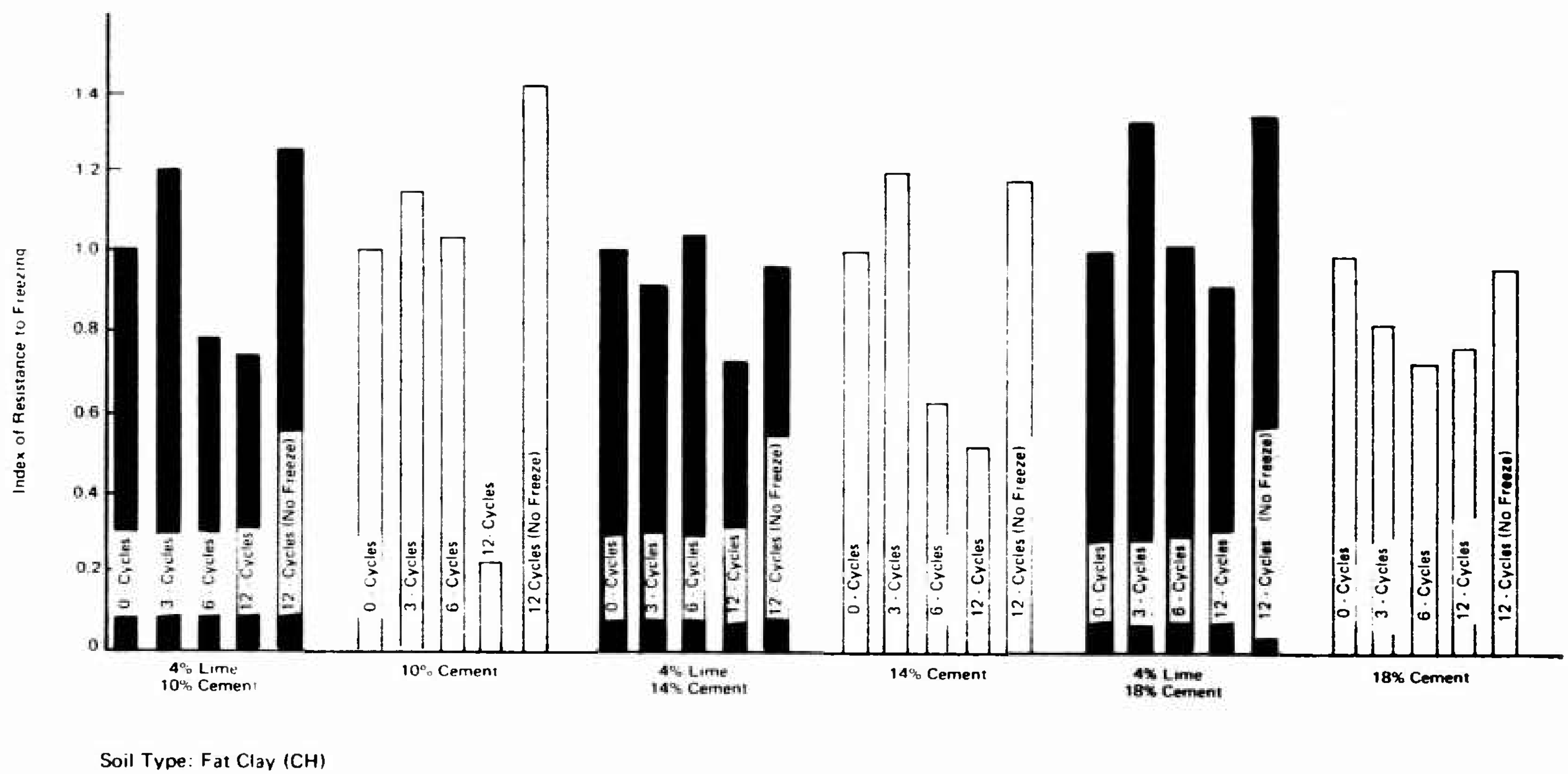


Figure 8. Influence of freeze-thaw cycles on index of resistence to freezing (CH).

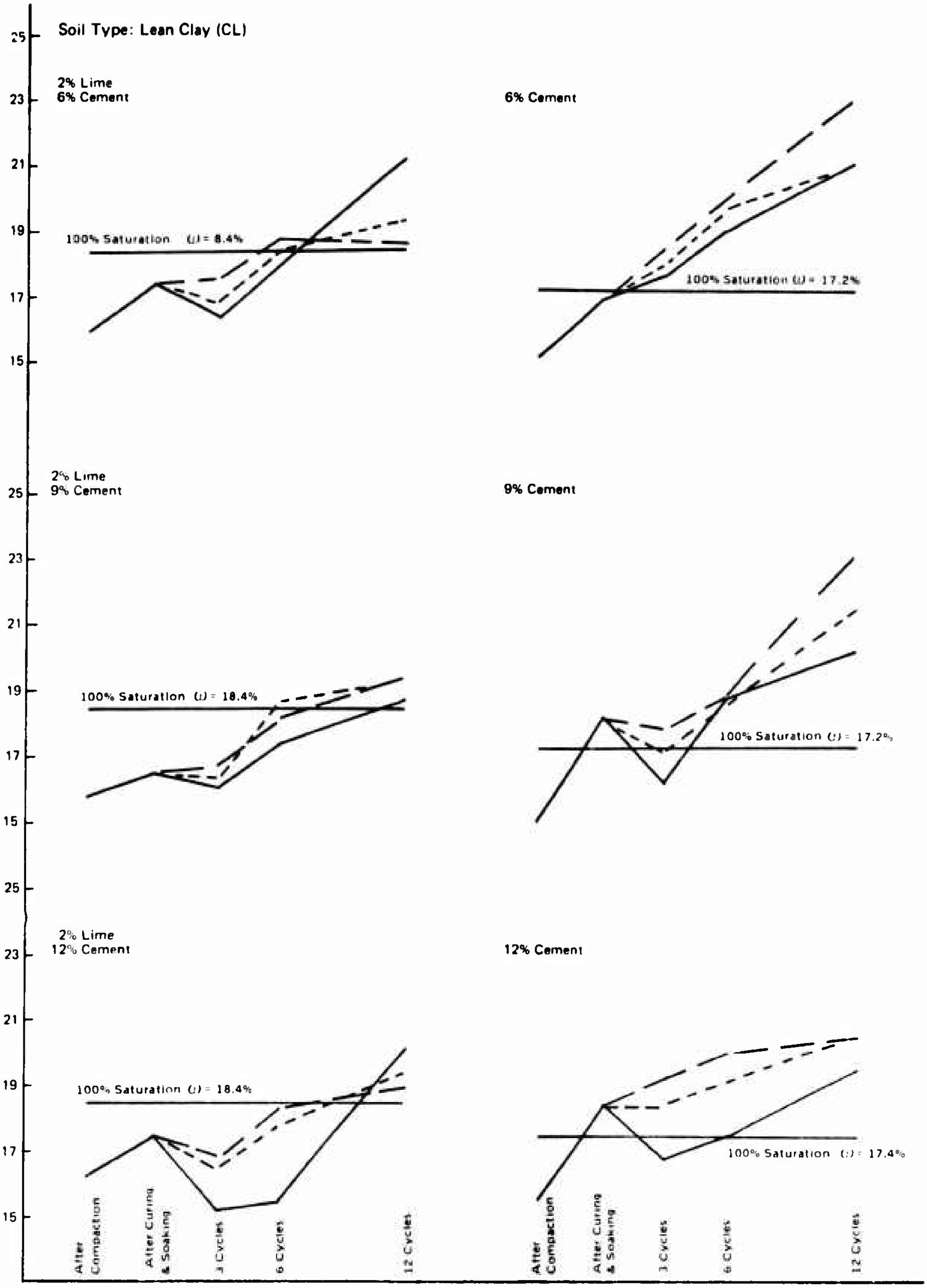


Figure 9. Influence of freeze-thaw cycles on moisture distribution (CL).

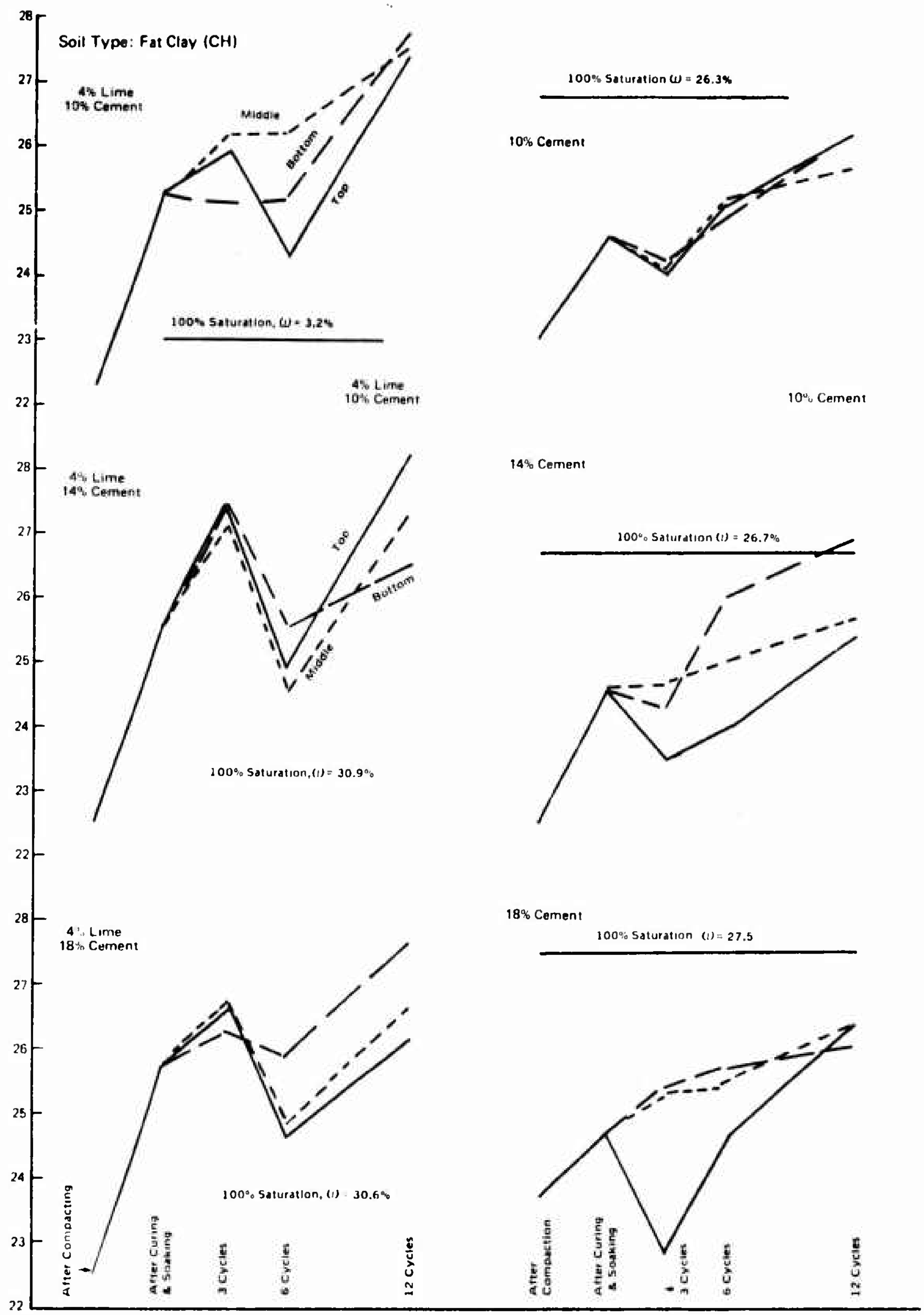
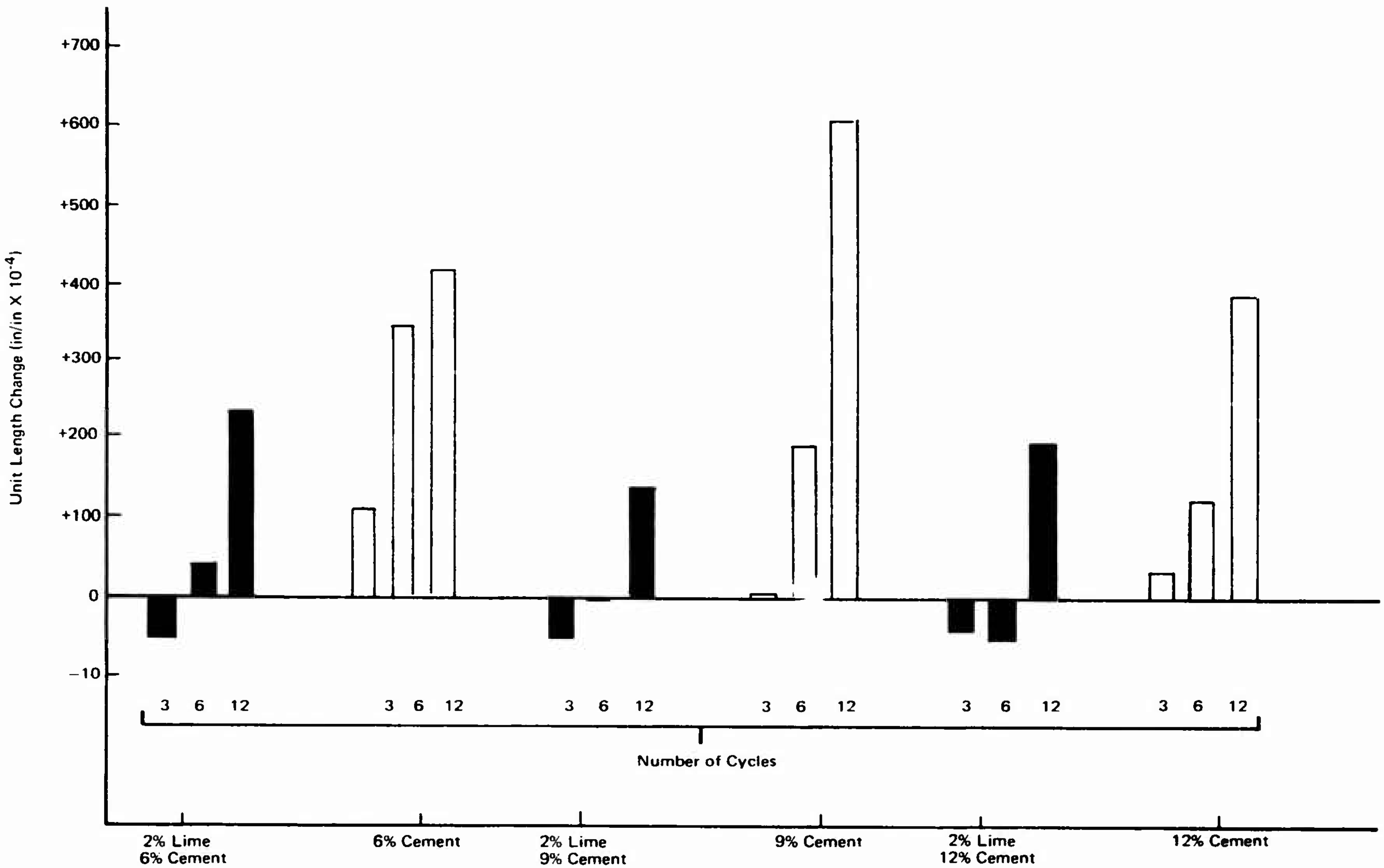


Figure 10. Influence of freeze-thaw cycles on moisture distribution (CH).



Soil Type: Lean Clay (CL)

Figure 11. Influence of freeze-thaw cycles on unit length change (CL).

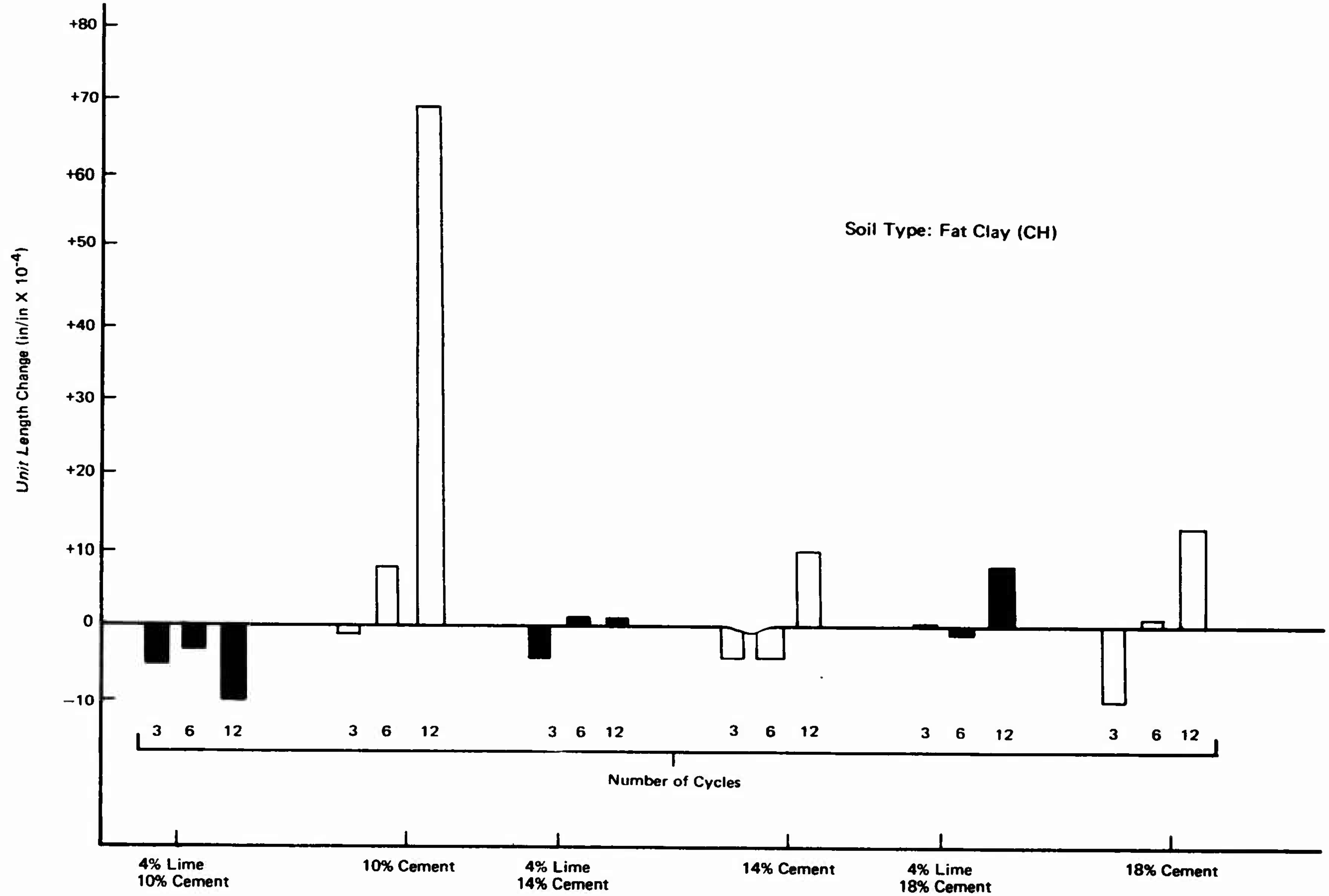


Figure 12. Influence of freeze-thaw cycles on unit length change (CH).

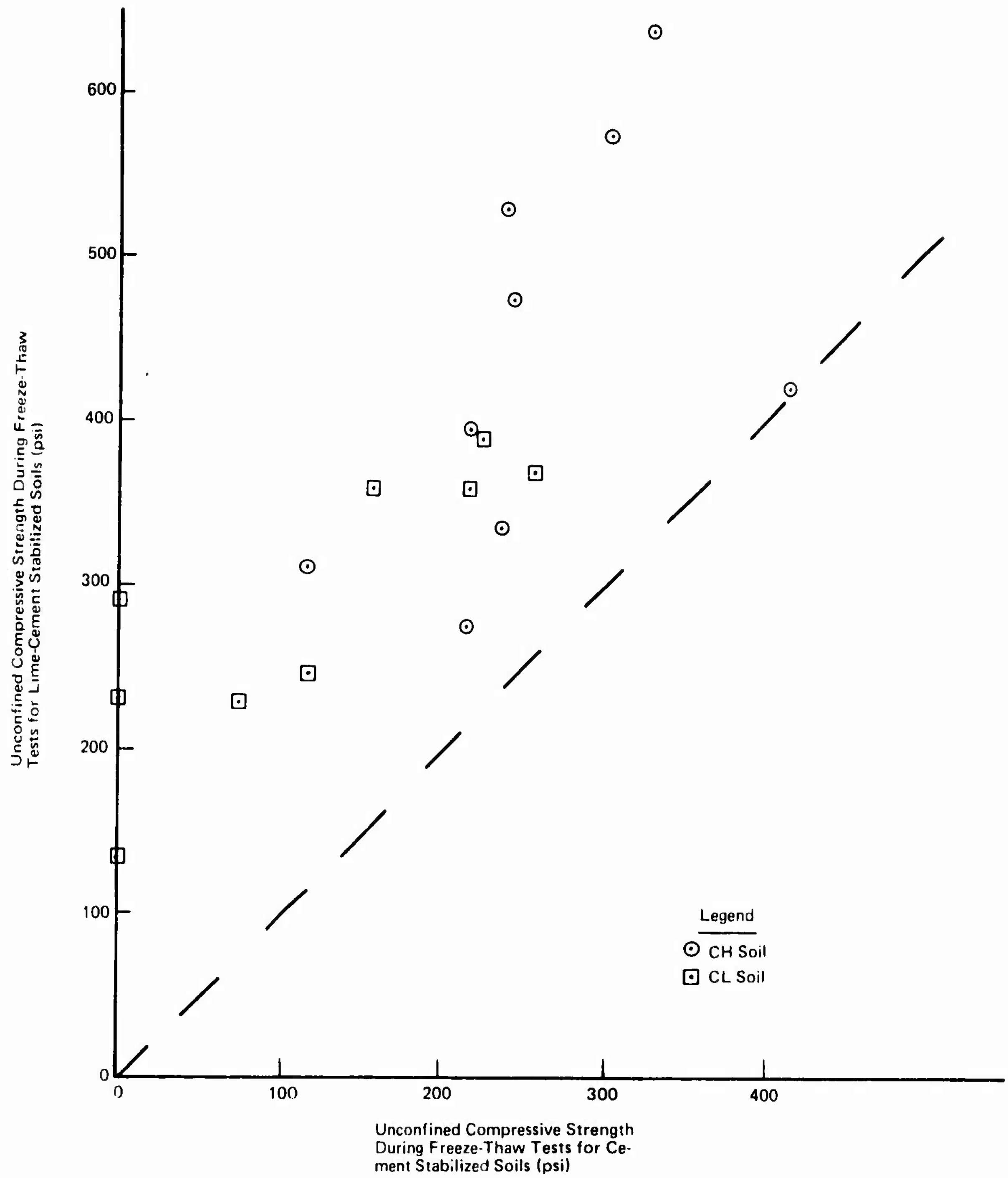


Figure 13. Effect of lime pretreatment on unconfined compressive strength.

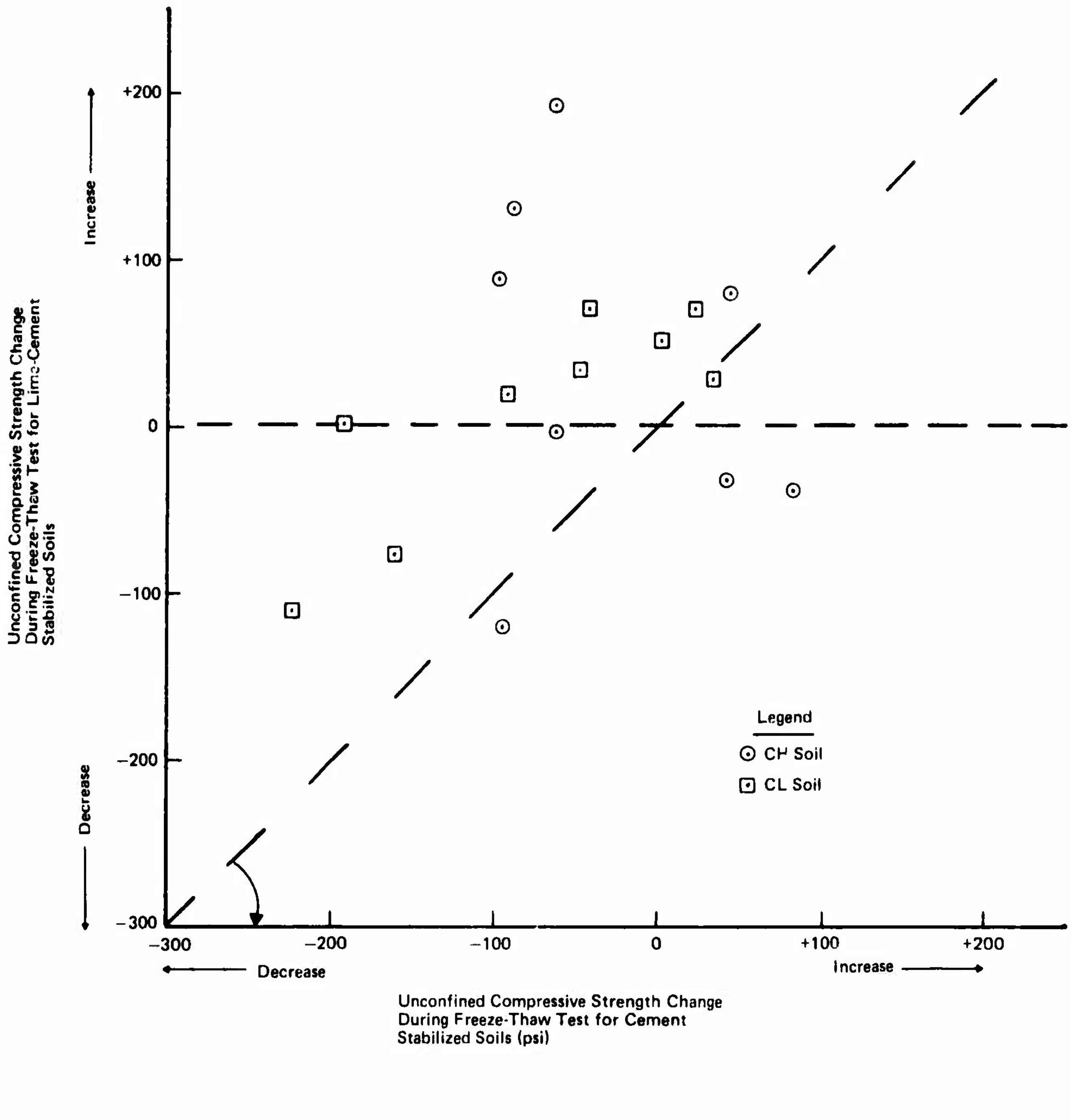


Figure 14. Effect of lime pretreatment on unconfined compressive strength change.

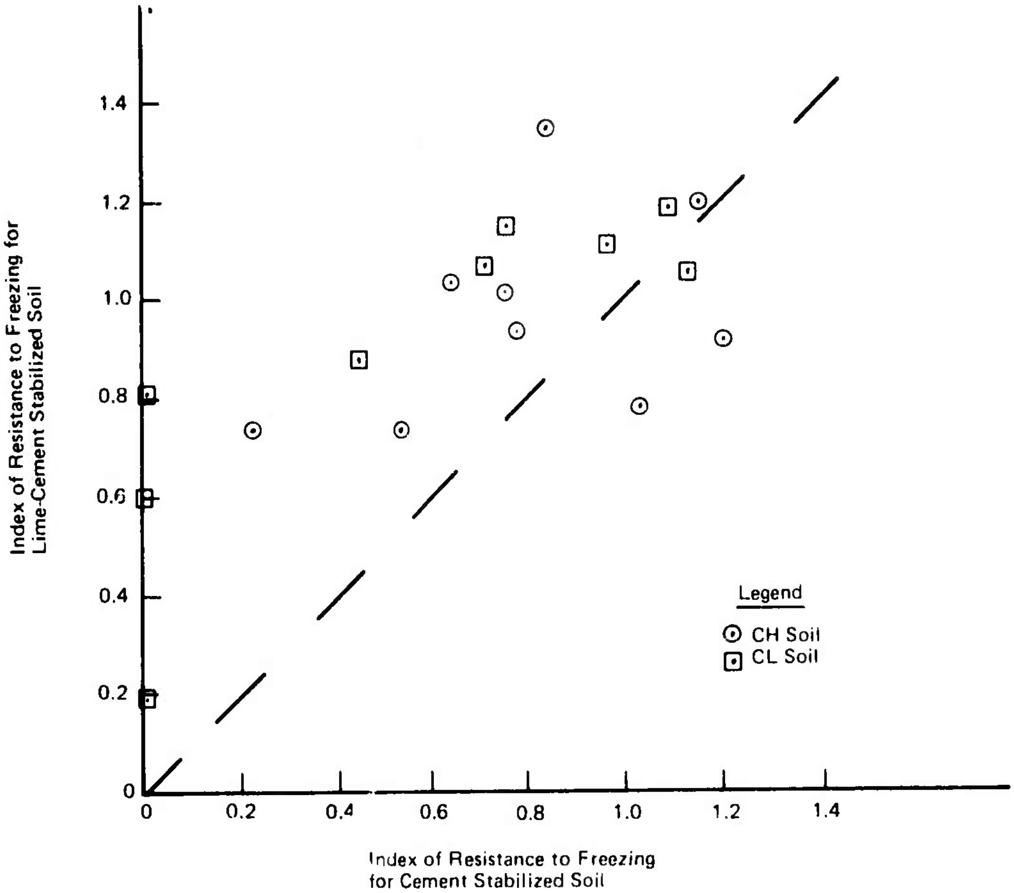


Figure 15. Effect of lime pretreatment on index of resistance to freezing.