Strength Loss in Lime-Stabilized Clay Soils When Moistened and Exposed to Freezing and Thawing

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A total of 216 specimens of an A-7-5 silty clay soil were compacted with Harvard miniature apparatus with specimens divided between two test procedures (open and closed) and 2 levels of lime addition (0 to 10 percent). Curing was at 120 F for 2 days while sealed in aluminum foil.

Half of the 108 open-system specimens were placed in a 70 F, 100 percent humidity environment for 5 days before testing. All open-system specimens were allowed to absorb moisture while freezing at 0 F for 12 hr and thawing in the 70 F, 100 percent humidity environment for 12 hr. Unconfined compressive strength, moisture absorption, length changes, degrees of saturation, and porosities were determined at zero, 1, 3, or 5 cycles of freezing and thawing.

Half of the closed-system specimens were soaked in water for 24 hr before testing. All specimens were frozen and thawed 12 hr each under the same conditions as the open-system specimens except for being sealed in aluminum foil. Results were obtained at zero, 1, 5, or 20 cycles. Results of the study indicated that (a) the strengths of all lime-stabilized specimens, whether or not exposed to freezing and thawing, are several times greater than the strengths of nonstabilized specimens; (b) moisture treatments prior to freezing and thawing greatly increased strength losses after freezing and thawing; (c) most strength loss occurred during the first cycle of freezing and thawing; and (d) freezing and thawing seemed to have little, if any, effect on porosity.

•IN Virginia, hydrated lime is being used extensively to improve plastic clay subgrade materials under primary highways. These improvements may permit reduction in base thicknesses of highways, resulting in large monetary savings. However, even though definite improvements result from adding lime to the clay soils, one hesitates to actually decrease base thicknesses from normal design values because of a lack of knowledge as to possible loss of improvement when the stabilized soils are exposed to field moisture conditions and such weathering agencies as freezing and thawing.

The effect of freezing and thawing on unconfined compressive strength of lime-stabilized soils was discussed by Walker and Karabulut (1) in 1964. It was shown that stabilized clay soils may lose strength on exposure to freezing and thawing, perhaps due to hydraulic pressures as described by Powers' hypothesis (2) for concrete.

The purpose of this discussion is to present results of additional freeze-thaw tests conducted with and without pretreatment of samples with moisture, extending the 1964

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study previously mentioned, and to describe briefly the current work being conducted at Virginia Polytechnic Institute aimed at measuring changes in pore characteristics in lime-stabilized soils.

FREEZING AND THAWING TESTS

Since the work reported in 1964 dealt only with closed-system testing, it was decided to use both open and closed-system tests in order to determine how the soil actually behaves. In an open system, the specimen is free to take on or lose water; in a closed system it is prevented from gaining or losing moisture. The advantage of using a closed-system test is its ease of operation. If a relatively impermeable soil is exposed to an open-system test, the results should be similar to those obtained from a closed test, since little water would be gained or lost in either case.

Open-System Test

A total of 108 specimens were subjected to the open-system test, 54 having zero percent lime and 54 with 10 percent lime by dry weight of soil. Half of each group of specimens were placed in a 70 F, 100 percent humidity environment for 5 days before being subjected to freezing and thawing (hereafter referred to as the 5-day moist-room treatment). The rest were subjected to freezing and thawing immediately after curing. All specimens were set on a porous stone in a water bath while freezing in a home-type deep freeze unit (zero F environment) and while thawing in the 70 F, 100 percent humidity environment. Both the freezing and thawing periods were 12 hr. Strength determinations were made after zero, 1, 3, or 5 cycles of freezing and thawing. Moisture and height measurements were determined for each specimen prior to strength testing.

Closed-System Test

A like number of specimens were prepared for the closed-system tests having zero and 10 percent lime content by dry weight of soil. Half of the specimens were soaked in water for 24 hr and then wrapped in aluminum foil and sealed with paraffin prior to exposure to freezing and thawing. The remaining specimens, also wrapped in foil and sealed with paraffin, were exposed to freezing and thawing immediately after curing. The same 12-hr freeze and 12-hr thaw cycle was used as with the open-system test—only the porous stone and water bath were omitted. The closed-system specimens were tested for unconfined compressive strength after zero, 1, 5, and 20 cycles of freezing and thawing. The same measurements were made as for the open-system specimens.

MATERIALS

Soil

The clay soil used for this study was obtained from an excavation near the coliseum on the Virginia Polytechnic Institute campus, Blacksburg, Virginia. The reddish-brown soil had a liquid limit (LL) of 61 percent, a plastic limit (PL) of 30 percent, and a plasticity index (PI) of 31 percent. The soil was classified according to the AASHO classification system as A-7-5. Standard AASHO density was 96 pcf at an optimum moisture content of 27 percent.

Lime

The hydrated lime used was manufactured by the Gibsonburg Lime Products Company, Gibson, Ohio. It contained 5 percent calcium cabronate, as determined by drying a sample in an oven at 900 C for 3 hr.

Soil-Lime Mixture

When 10 percent lime by dry weight of soil was added, the LL dropped from 61 to 59 percent, the PL increased from 30 to 48 percent, the PI dropped from 31 to 11 percent, standard AASHO density dropped from 96 to 84 pcf and the optimum moisture increased from 27 to 29 percent.

PREPARATION OF SAMPLES

The air-dried soil was moist cured in a plastic bag for 24 hr and then compacted with a Harvard miniature apparatus at approximately optimum moisture content. Compaction was in 3 layers using the Harvard plunger apparatus loaded with a 40-lb spring, applying 25 blows to each layer. For the soil used, this compaction procedure produces densities closely approximating those obtained with the standard AASHO procedure.

Three specimens were produced per batch. After weight and volume determinations, the specimens were immediately wrapped in aluminum foil and sealed with wax to preserve their moisture content while curing. One specimen from each batch was not subjected to freezing and thawing, permitting the establishment of zero-cycle strength values.

Curing was accomplished by placing the sealed specimens in an oven at 120 F for 48 hr. Previous investigations by Anday (3) showed that this is approximately equivalent to 45 days of simulated field curing near Charlottesville, Virginia.

RESULTS AND DISCUSSION

Effect on Unconfined Compressive Strength

Tables 1 and 2 summarize the unconfined compressive strength results for the closed-system and open-system tests. Several points may be noted:

1. Strengths of all lime-stabilized specimens, whether or not exposed to freezing and thawing, are several times greater than the strengths of nonstabilized specimens.
2. The test employed was highly destructive to un-limed soil, with only that soil protected from moisture before and during freezing surviving with a significant amount of its original strength.
3. Resistance of lime-stabilized specimens to the test conditions depended to a greater extent on whether or not they were exposed to moisture prior to freezing than whether or not the test was open system or closed system in its design.
4. For the closed-system test, one cycle of freezing and thawing appeared to produce most, if not all, of the damage observed.

TABLE 1

EFFECT OF CLOSED-SYSTEM FREEZING AND THAWING ON UNCONFINED COMPRESSIVE STRENGTH

Test Condition	No. of Specimens	Cycles of Freezing and Thawing	Unconfined Compressive Strength (psi)	Strength Loss (percent)[a]
0% lime, no soaking	9	0	58	—
	6	1	41	36
	6	5	34	45
	6	20	25	39
10% lime, no soaking	9	0	323	—
	6	1	232	29
	6	5	276	18
	6	20	223	25
10% lime, 1-day soaking	9	0	340	—
	6	1	119	61
	6	5	183	50
	6	20	131	61
0% lime, 1-day soaking	All specimens disintegrated upon immersion in water			

[a]Percent strength losses were calculated on a batch basis and then averaged.

TABLE 2

EFFECT OF OPEN-SYSTEM FREEZING AND THAWING ON UNCONFINED COMPRESSIVE STRENGTH

Test Condition	No. of Specimens	Cycles of Freezing and Thawing	Unconfined Compressive Strength (psi)	Strength Loss (percent)[a]
0% lime,	9	0	63	—
no moist-	6	1	14	79[b]
room treatment	6	3	2	97
	6	5	1	98
10% lime,	9	0	305	—
no moist-	6	1	209	24
room treatment	6	3	129	52
	6	5	225	37
0% lime,	9	0	54	—
5-day	6	1	5	92
moist-room	6	3	1	99
treatment	6	5	1	98
10% lime,	9	0	264	—
5-day	6	1	177	45
moist-room	6	3	44	81
treatment	6	5	60	76

[a]Percent strength losses were calculated on a batch basis and then averaged.
[b]Of four samples compacted at 24 percent moisture, three lost 64 percent and one lost 91 percent; and of two samples compacted at 26 percent moisture, both lost 94 to 95 percent.

5. For open-system testing, samples with 10 percent lime showed higher strengths after 5 cycles of freezing and thawing than after 3 cycles. The data presented here are preliminary and not conclusive on this point, but this anomaly has since been observed to appear consistently in similar tests with other heavily limed clay soils in this laboratory.

Table 3 indicates other interesting comparisons. In all cases, percent strength losses are considerably lower for the stabilized specimens as compared to the non-stabilized specimens. Perhaps of more importance is that with but one exception, the strength of stabilized specimens, as a factor of nonstabilized specimen strength, did not significantly change with increasing cycles of freezing and thawing. The stabilized open-system specimens that received no moisture treatment apparently were able to withstand the additional cycles of freezing better than the moisture-treated open-system specimens.

TABLE 3

COMPARISON OF UNCONFINED COMPRESSIVE STRENGTHS FOR STABILIZED AND NONSTABILIZED SPECIMENS

Test Condition	Cycles of Freezing and Thawing	Percent Strength Loss		Strength[a] as Factor of Non-stabilized Strength
		Nonstabilized	Stabilized	
Closed system,	1	36	29	5.7
no soaking	5	45	18	8.3
	20	39	25	9.1
Open system,	1	79	24	15.0
no moist-room	3	97	52	75.0
treatment	5	98	37	204.0
Open system,	1	92	45	39.4
5-day moist-	3	99	81	88.0
room treatment	5	98	76	50.0

[a]Calculated on a batch basis and then averaged.

TABLE 4

POROSITY AND DEGREE OF SATURATION OF LIME-STABILIZED SPECIMENS

Test Condition	Cycles of Freezing and Thawing	Average Porosity (percent)[a]	Degree of Saturation (percent)[b]
Closed system, no soaking	0	49.0	88.7
	1	48.2	88.3
	5	49.7	92.2
	20[b]	–	–
Closed system, 1-day soaking	0	48.6	81.0
	1	49.1	91.9
	5	47.7	87.9
	20	–	–
Open system, no moist-room treatment	0	49.5	87.8
	1	48.9	87.1
	3	50.1	90.5
	5	49.8	94.0
Open system, 5-day moist-room treatment	0	49.0	91.5
	1	48.7	96.3
	3	51.6	98.6
	5	50.5	96.8

[a]Measured after designated number of freeze-thaw cycles.
[b]20-cycle specimens were too mutilated for accurate measurement.

Effect on Porosity and Degree of Saturation

As shown in Table 4, there is no apparent effect of freezing and thawing on porosity, with the possible exception of the open-system moisture-treated specimens. Townsend and Klym (4) discussed the possibility of sufficiently high hydraulic pressures being generated to exceed the tensile strength of the pore structure of the stabilized soil. They suggested that subsequent rearrangement of pore geometry and loss of pore structure confinement can result in strength loss and porosity increase. Because of this, work currently being done at Virginia Polytechnic Institute is aimed at more closely examining possible changes in porosity occurring on exposure to freezing and thawing.

The degree of saturation data given in Table 4 seem to indicate the expected moisture increases with time (if not cycles of freezing and thawing) in the open system, but not the closed.

Destructive Mechanism of Freezing and Thawing

The destructive mechanism of freezing and thawing on the strength of clay soils may be considered to be a process whereby:

1. Ice lenses are built up in the soil with consequent expansion and loss in strength upon thawing;
2. The pore structure is sufficiently strong to generate hydraulic pressures by the movement of unfrozen water in advance of a moving ice front; or
3. Perhaps a combination of 1 and 2.

For the unstabilized soil specimens, the open-system test was truly open system in its effect; the development of ice lenses was apparently a dominant factor in their destruction. Figure 1b shows a typical example of this. Figure 1a shows the specimens prior to freeze-thaw testing. Closed-system specimens, with or without lime stabilization, showed no such damage. Figure 1d shows typical closed-system specimens, these having been exposed to 5 cycles of freezing and thawing. From the appearance of lime-stabilized samples subjected to open-system freezing, Figure 1c, one would question whether the open-system freezing of lime-stabilized clay was open system in its effect. No bulging or similar signs of ice-lens development are evident. A review of data on change in length and water content during treatment for the lime-stabilized specimens, some of which are summarized in Table 5, suggests that the action of open-system freezing varied little from that of closed-system freezing. These results are in line with the hypothesis of Townsend and Klym (4) which suggests that lime-stabilized clays having more than 200-psi compressive strength together with less than 95 percent saturation may effectively resist the heave and ice-lens development associated with open-system freezing. Only in the case of samples held in the moist room for 5 days did the average degree of saturation exceed the 95 percent level.

The fact that the severe effects of open-system freezing may, as suggested by Townsend and Klym, be overcome with lime stabilization and the prevention of a high degree of saturation in the stabilized soil is gratifying. The problem remains, however, of understanding and dealing with the destructive effects of closed-system freezing. Of particular importance seems to be the condition of the soil just prior to freezing and the effects of the initial freezing cycle. It is apparent at this time that the soil responds

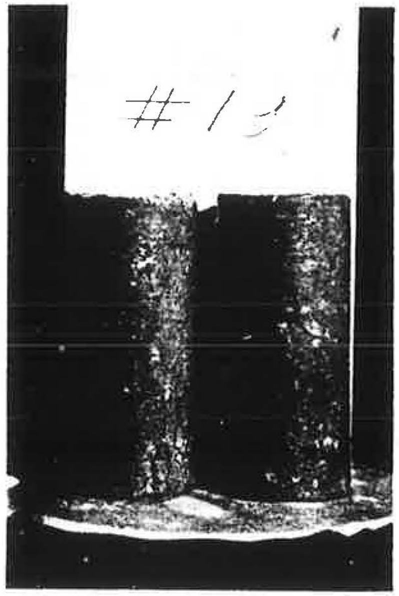

Figure 1a. Open-system specimens with zero percent lime after 5 days in moist room.

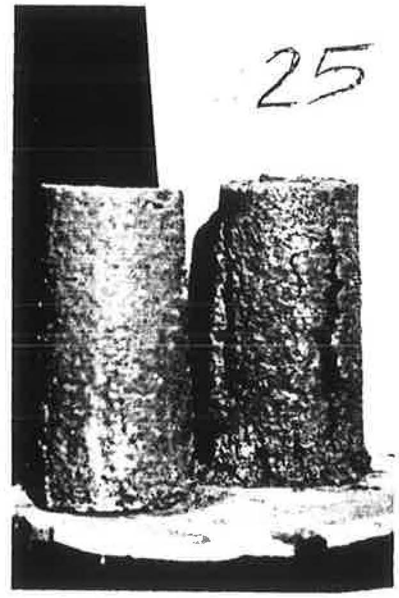

Figure 1b. Specimens after 3 cycles of open-system freezing and thawing, 5 days in moist room, lime content—zero percent.

Figure 1c. Specimens after 3 cycles of open-system freezing and thawing, 5 days in moist room, lime content—10 percent.

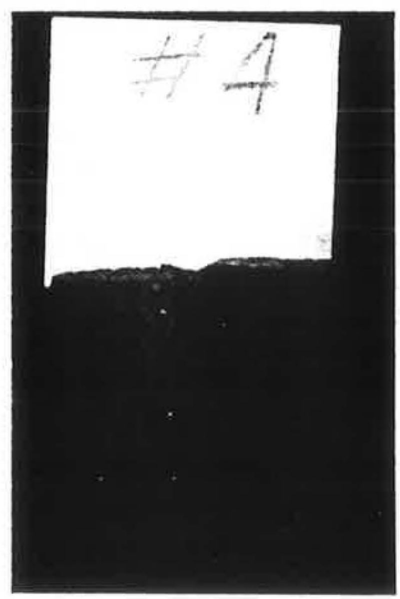

Figure 1d. Typical closed-system specimens, zero percent lime, 5 closed cycles.

TABLE 5

CHANGES IN LENGTH AND WATER CONTENT FOR STABILIZED SPECIMENS

Test Condition	No. Freezing Cycles					
	1			2		
	% Strength Loss	Water Content Change	% Length Change	% Strength Loss	Water Content Change	% Length Change
Closed system, no soaking	20	-0.3	<1	18	1.4	<1
Open system, no moist-room treatment	24	0	<1	37	2.0	<1
Closed system, 1-day soaking	61	1.4	<1	50	3.4[a]	<1
Open system, 5-day moist-room treatment	45	1.0	<1	76	2.8	2

[a]Samples compacted appreciably drier than other samples employed in study.

in some way to adjust to the hydraulic pressures induced by freezing. Also apparent is that pretreatment of the compacted soil with moisture emphasizes its damaging influence.

CURRENT WORK

It seems likely that the damage caused by closed-system freezing is related to a remolding involving adjustment of pore-size distribution early in the freezing process, possibly with little change in total porosity, as observed in these experiments. Current work at Virginia Polytechnic Institute is aimed at studying pore-size distribution in lime-stabilized soils in relation to frost-thaw treatments with a view toward characterizing this change and studying its progression, if such exists, with repeated cycles of freezing and thawing.

Perhaps of equal merit of investigation is the effect of freezing and thawing on permeability. Townsend (9) noted that the change in permeability was negligible in specimens which had attained adequate resistance to frost deterioration. However, if a sample is subjected to freezing and thawing, perhaps some of the reaction products of the lime-clay combination are present in the voids. As hydraulic pressures begin to move water through the soil, some of these products may be moved out and thus initially increase the permeability while the soil generally retains its strength. If at this time the strength of the soil is overcome by excessive pressures, a collapse of the soil structure might take place causing a decrease in permeability. If not, the increase in permeability may be retained and the front susceptibility of the clay increased. Since this is speculation, permeability studies are also under way at Virginia Polytechnic Institute in order to present a clearer picture of the situation.

Although it is felt that conclusions presented in this study are valid for the data obtained, a method of freezing and thawing closer to that occurring in nature would be preferable. A new procedure has been developed and is being used in an extensive series of tests in connection with porosity and permeability studies covering a wider variety of soils.

CONCLUSIONS

It is hoped that the results of this study help shed a little light on what happens to lime-stabilized clays exposed to freezing and thawing. Unfortunately, the results are not sufficiently definitive to recommend specific reductions in pavement or base thicknesses. However, it should be noted that the largest strength loss suffered by the stabilized specimens (60 psi for 10 percent lime, 5 cycles, 5-day moist-room treatment) resulted in a compressive strength roughly equivalent to nonstabilized specimens not exposed to freezing and thawing. This might suggest that designs for pavements built on stabilized soils could be based on strengths of nonstabilized soils tested without moisture treatment (such as is used in the CBR test) until more definitive information can be obtained.

Where a significant lime-soil reaction takes place, there is no doubt that important strength benefits are derived. Work should continue in evaluating exactly what these benefits are.

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