EVALUATION OF ENVIRONMENTAL INFLUENCES ON A LIME-MODIFIED HIGHLY PLASTIC CLAY

by

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ABSTRACT

A laboratory study was undertaken to evaluate the effect of environmental influence on the properties of Regina Clay modified with two and four percent lime. Regina Clay, a highly plastic, expansive clay, was used for this study because it is a common subgrade material in Saskatchewan. Two and four percent lime were used since these percentages are generally used to modify highway subgrades in Saskatchewan. Three types of environmental conditions were studied. Lime-modified specimens were subjected to curing under a constant temperature and humidity, wet/dry cycles and freeze/thaw cycles. Reference test data is also presented for the case of no lime addition.

Unconfined compressive strength tests and volume change measurements were used to evaluate the influence of the three environmental conditions. Water content profiles were also established for the specimens subjected to freeze/thaw cycles. The specimens subjected to wet/dry and freeze/thaw cycles were initially cured for seven days under a constant temperature and humidity.

From this study, it was found that environmental conditions have a significant influence on the strength and volume change characteristics of a lime-modified highly plastic clay.

Curing period and lime percentage are important for strength development in lime-modified clays. The laboratory results show that the four percent lime modified specimens had higher cured strengths than the two percent lime modified specimens. Regardless of the lime percentage, significant immediate reductions in volume change were observed after one day of curing.

The wet/dry cyclic tests showed that both the two and four percent lime-modified specimens subjected to only one cycle of wetting and drying completely disintegrated upon resubmergence for a second cycle of wetting and drying. These results indicate that the lime-modified Regina Clay would not be a durable material if subjected to cycles of wetting and drying. At the same time, it is suggested that this test is quite extreme for testing lime-modified clays, and an attempt should be made to devise a more suitable test.

The freeze-thaw tests showed that as the number of cycles increased, the strength of the lime-modified specimens decreased. However, the specimens treated with four percent lime did not decrease in strength as much as the specimens treated with two percent lime.

INTRODUCTION

A lime modification research program was initiated by the Saskatchewan Highways and Transportation in collaboration with the Geotechnical Division of the University of Saskatchewan to study the effect of lime modification on the swelling, strength and durability characteristics of Regina clay. Some results from this study were presented at the Transportation Research Board annual meeting, TRB Committee A2J03, August, 1987, by Sweeney, Wong and Fredlund. Aging was found to have a detrimental effect on strength. It, however, appears to have no significant effect on swell and plasticity index.

The addition of lime, even in small quantities, alters the highly plastic clay into a non swelling, quasi-granular cemented material. Now the long term strength and durability of this material is a concern.

OUTLINE OF STUDY

This study is focussed on three environmental conditions. They are:

i) the curing environment,
ii) wetting and drying cycles, and
iii) freezing and thawing cycles.

The details of the laboratory testing program are outlined in Table 1. In all three cases, the environmental influences are evaluated in terms of their effects on the unconfined compressive strength and the volume change characteristics of the lime-modified Regina clay. In addition, changes in water content profiles were also determined for specimens which were subjected to freeze-thaw cycles.

DESCRIPTION OF TESTS AND LABORATORY PROCEDURES

All specimens were prepared by compaction using a mechanical dynamic compactor. Only material passing the 2 mm (No. 10) sieve was used. The compaction procedures were either in accordance with standard Proctor (ASTM Designation D 698-78), or a modified form of standard Proctor procedure. In the modified form, the blow counts per layer was increased. The hammer weight, ram stroke and the number of layers were maintained the same as in the standard Proctor compaction. The increased compaction was required to achieve compacted density of lime modified clay equal to that of the untreated clay. This is to be consistent with present compaction specifications in Saskatchewan.

Table 1 Laboratory Testing Program

1) Curing Under Constant Temperature and Humidity
Constants: Curing temperature (21°C) or (70°F)
Relative humidity (90%)
1 soil type, 1 lime type
Initial water content (15.0%)
Variables: Curing time (1, 7, 21, 195 days)
Lime content (0.0, 2.0, 4.0%)
Aging water content (25.0, 30.0, 35.0%)
Aging period (1, 24 hours)
Compactive effort (standard, increased)
Properties to be determined:
1) Unconfined compressive strength
2) Volume change

2) Wetting and Drying
Constants: 7 days curing at 21°C and 90% relative humidity
1 soil type, 1 lime type
Aging period (1 hour)
Initial water content (15.0%)
Variables: Lime content (0.0, 2.0, 4.0%)
Aging water content (25.0, 30.0, 35.0%)
Number of Cycles (1)
Compactive effort (standard, increased)
Properties to be determined:
1) Unconfined compressive strength
2) Volume change (plus visual description)

3) Freezing and Thawing
Constants: 7 days curing at 21°C and 90% relative humidity
1 soil type, 1 lime type
Open system freezing
Aging period (1 hour)
Initial water content (15.0%)
Variables: Lime content (0.0, 2.0, 4.0%)
Aging water content (25.0, 30.0, 35.0%)
Number of cycles (1,3)
Compactive effort (standard, increased)
Properties to be determined:
1) Unconfined compressive strength
2) Volume change
3) Water content profiles

Unconfined Compressive Strength Tests

The unconfined compressive strength tests were performed according to ASTM Designation D 2166-66 (1979). A constant strain rate of 1 percent was used on samples with a length to diameter ratio of 2.4 to 1. A 50.8 mm (2 inch) Shelby tube was hydraulically pressed through the compacted sample to obtain a specimen for the unconfined compression test. This yields specimen of 27.2 mm (1.9 inch) in diameter by 117.0 mm (4.6 inch) in length.

Volume Change Tests

In the curing study, the one-dimensional volume change tests were performed according to ASTM Designation D 4546-85. The test specimens were formed by manually pressing a 64 mm (2.5 inch) steel consolidation ring into a compacted soil sample by means of a trimming table. The specimen was allowed to swell in the oedometer under an overburden pressure of 7 kPa (1 psi).

Volume change measurements for the wet/dry and freeze/thaw tests were performed by measuring changes in the length and diameter of specimens after each cycle.

In the wetting/drying tests, standard proctor mold samples of 101 mm (4 inch) in diameter by 117 mm (4.6 inch) in length were used. Straight pins were pressed into the specimen to mark where the measurements of diameter and length were to be taken. Three measurements of the diameter and the length were made prior to and after each cycle. The measurements continued after each cycle until the specimen has disintegrated.

In the freezing/thawing tests, 50.8 mm diameter by 117 mm length specimens were used. Two length measurements and three diameter measurements were taken prior to and after one and three freeze/thaw cycles.

Curing Tests

The specimens were cured in a moisture room at a constant temperature of 20°C (70°F) and relative humidity of 90 percent. These specimens were wrapped in plastic wrap, taped and waxed to avoid any moisture loss during curing. Unconfined compressive strength and one-dimensional volume change tests were performed after curing periods of 1, 7, 21 and 195 days.

Wetting/DryingTests

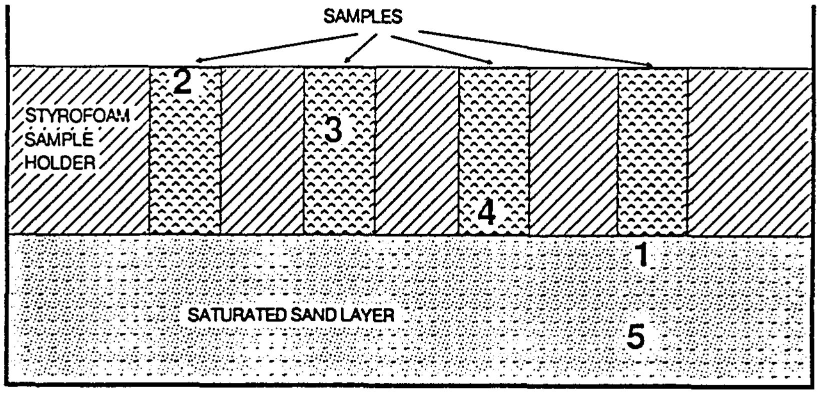
The wetting/drying tests were performed in accordance with ASTM Designation D 559-82, which is called "Standard methods for wetting and drying tests of compacted soil-cement mixtures". The procedure requires that specimens be submerged for five hours at room temperature (wet) before being placed in an oven for 42 hours at 71°C (140°F) (dry). Three-dimensional volume change measurements and unconfined compressive strength tests were performed after one and three wet/dry cycles. The specimens were cured for seven days under constant temperature (20°C) and relative humidity (90%) prior to the test. No brushing for weight loss was performed.

Freezing/Thawing Tests

An open system was used for the freezing/thawing tests. The open system allowed the specimens free access to water during freezing and thawing. It follows the procedure of ASTM Designation D 560-82, "Standard methods for freezing and thawing tests for compacted soil-cement mixtures". A cycle of freezing and thawing consisted of maintaining a temperature of

-16°C for 24 hours in a cooling unit and another 24 hours in a moisture room at a temperature of 20°C. The specimens were cured for seven days under constant temperature (20°C) and relative humidity (905) prior to the tests.

The set-up was consisted of a plastic picnic cooler, a styrofoam holder for the specimens and a layer of saturated sand placed below the styrofoam sample holder to act as the water table. This arrangement allowed the specimens free access to water (Figure 1).



numbers 1-5 show location of thermocouples

Figure 1 Components of Freeze/Thaw Unit and Location of Thermocouples

Temperature measurements were made in order to establish the freezing and thawing rates for the samples. Prior to conducting the freeze/thaw tests on lime-modified samples, dummy specimens attached with copper constantan thermocouples were placed inside the apparatus. Figure 1 shows the location of the thermocouples. In the tests with the dummy specimens, the specimens froze but the sand layer did not freeze. This was a desired condition.

Prior to and after each freeze/thaw cycle, length and diameter measurements were taken. After the measurements were made the unconfined compressive strength test was performed.

After the unconfined compressive strength test was completed the sample was divided into thirds (i.e., top, middle, and bottom). The water content of each third was determined to establish the water content distribution along the length of the sample.

DESCRIPTION OF MATERIALS

The index properties of the soil used in the test program are summarized in Table 2. This soil is classified as a CH soil on the Unified Soil Classification system. The average specific gravity was 2.83. The maximum standard Proctor dry density was 1.42 Mg/m^3 at an optimum water content of 30.0%. The grain size distribution is shown in Figure 2. It consists of approximately 70% clay.

Table 2 Index Properties of Regina Clay

Atterberg limits (average of six tests)		w(%)	
Plastic Limit		27	
Plasticity Index		57	
Specific Gravity	2.82		
Percent Clay	70%		
Percent Swell tests (Standard Compaction Specimens)		w(%)	Swell (%)
		24.7	14.5
		29.6	9.2
		35.1	4.7
Compaction tests		Optimum w(%)	Maximum Dry Density (Mg/m^3)
Standard Proctor		30.6	1.41
Modified Proctor		22.5	1.65
Unconfined Compression test (Standard Compaction Specimens)		w(%)	Strength (kPa)
		26.4	272.7
		29.5	266.2
		31.0	300.9
		33.3	179.5

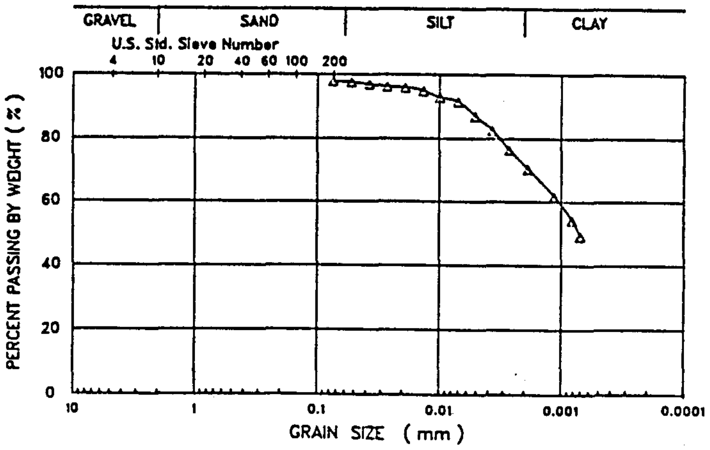


Figure 2 Grain Size Curve for Regina Clay

X-ray diffraction analysis indicates that the major clay minerals present are smectite and illite (Table 3). The soil swells excessively when wet and shrinks upon drying, forming large shrinkage cracks.

Results of a chemical analysis on the Regina clay are presented in Table 4. Two chemical concentrations which are important in lime treatment of soils are the soluble sulfate and organic contents. The Regina clay used contained 2000 ppm (0.20 %) of soluble sulfate and 10000 ppm (1.0%) organic carbon.

The lime used was a commercial calcitic lime (CaO), commonly referred to as quick lime. The composition and gradation of the lime are given in Table 5. The lime was stored in sealed containers to prevent carbonation.

Table 3 X-Ray Diffraction Analysis of Regina Clay Sample

Smectite/Illite mixed layer (approximately 20% Illite)	48.0 %
Illite	9.0 %
Kaolinite	10.0 %
Quartz	33.0 %

Table 4 Analysis of Regina Clay Saturation Extract

Sodium Adsorption Ratio (S.A.R.)	2.4
Electrical Conductivity	4.3 mS*/cm
pH	7.9
Cation Exchange Capacity	40 meq**/100gm

Ions in Saturated Extract	Concentration (ppm)
Sodium (Na^+)	275
Calcium (Ca^{++})	617
Magnesium (Mg^{++})	217
Potassium (K^+)	38
Chloride (Cl^-)	370
Sulfate (SO_4^{--})	2,116
Organic Carbon	10,000

*S stands for siemen. 1 siemen = 1 mho = 1 amp/volt
** milliequivalents of cations per 100 gms of dry mass of a sample.

Table 5 Chemical and Mechanical Analysis of Lime

Chemical:	Ingredient	(% by weight)
	CaO	94.9
	MgO	1.45
	CaO + MgO	96.35
	SiO_2	1.9
	R_2O_3	1.1
	Impurities	3.0
	Loss on Ignition	0.4

Mechanical:	Sieve	(% passing)
	2.00 mm	100
	160 μm	100

EFFECT OF CURING ON UNCONFINED COMPRESSIVE STRENGTH

A series of unconfined compressive strength tests were performed on specimens of lime-modified Regina clay. These specimens were prepared at different combinations of aging water content, aging period, lime content and compactive effort. The results of the unconfined compressive strength tests are presented in Table 6.

Table 6 Unconfined Compressive Strength Test Results (Curing Tests)

Sample	1 Day Curing		7 Day Curing		21 Day Curing		195 Day Curing	
Description Li,Comp,Age	Aging w (%)	Strength kPa	Aging w (%)	Strength kPa	Aging w (%)	Strength kPa	Aging w (%)	Strength kPa
2.0,Std,1	25.9	394.3	26.2	395.2	25.7	647.1	24.7	390.5
2.0,Std,1	30.6	475.3	30.8	792.2	29.0	698.5	28.9	410.9
2.0,Std,1	35.6	313.7	35.4	352.1	34.6	484.2	33.7	522.1
4.0,Std,1	26.7	386.4	27.3	643.4	25.6	848.4	25.2	1236.7
4.0,Std,1	31.2	416.3	31.3	919.8	30.8	1289.1	30.3	1503.1
4.0,Std,1	35.7	337.4	35.3	724.9	35.1	941.9	34.0	1092.9
2.0,Inc/32,1	26.0	451.1	26.2	464.9	24.8	642.7	24.7	795.6
2.0,Inc/32,1	30.5	387.2	30.6	508.4	29.6	648.5	29.3	1012.7
2.0,Inc/32,1	35.2	296.2	35.6	412.5	34.0	491.9	33.5	577.0
4.0,Inc/42.1	26.6	537.3	26.9	829.7	26.3	1012.3	25.6	1963.2
4.0,Inc/42,1	30.9	381.9	30.5	764.8	31.4	585.7*	29.6	1156.2
4.0,Inc/42,1	35.7	362.7	35.1	694.6	35.1	947.1	34.8	282.9*
2.0,Std,24	N/A	N/A	30.3	354.3	30.4	411.9	30.6	335.7
4.0,Std,24	N/A	N/A	30.6	294.0	30.3	730.0	30.9	726.3

Li - Lime Percentage
Comp - Compactive Effort, Standard or Increased
Age - Aging Period in Hours
* - sample damaged prior to testing
Std. - Standard Compactive Effort
Inc/32 - Increased Compactive Effort with 32 Blows/Layer
N/A - Unable to perform measurement

In Figure 3 is presented a typical plot of unconfined compressive strength versus curing period for Regina Clay specimens treated with four percent lime. The one hour aging period curve shows that the strength increases with curing period. The increase is rapid initially and then continues at a slow and steady rate after about 20 days of curing. A dramatic initial strength gain is also evident from the 24 hour aging period curve. The actual strengths though are not as high. Also no appreciable strength gain is evident after about 20 days of curing.

The dramatic initial strength gain is due to the immediate flocculation and agglomeration of the soil particles resulting in the soil having a flocculated structure. Part of this strength gain may be due to carbonation, which is the reaction of lime with carbon dioxide to form relatively weak calcium carbonate bonds. The immediate reaction would have

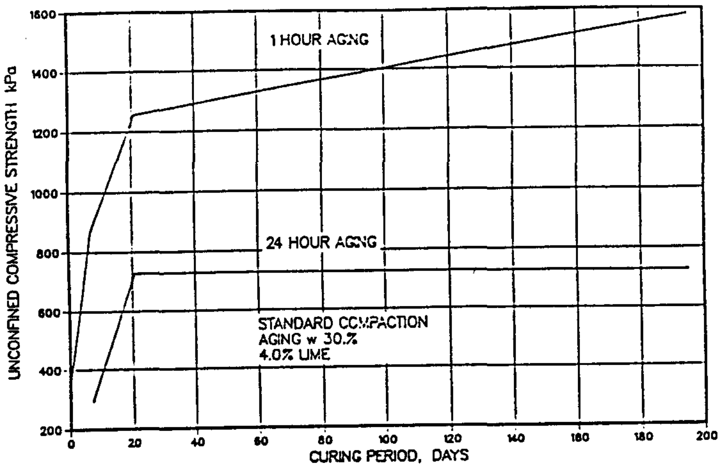


Figure 3 Effects of Aging Period on Cured Unconfined Compression Strengths

used up the major portion of the lime with very little left for long term pozzolanic reaction and by the 20th day, most of the lime may have already been consumed in reaction.

The flocculated structure and the bonds that are developed during aging are partially destroyed by compaction. Once these are destroyed they may not re-develop. The flocculated structure and the bond formation are a result of reaction with lime. The more advanced the reactions are, the less free lime there is available for further reaction. This is why the cured strength for the 24 hour aged specimen is much lower than the one hour aged specimen. In practice, this will mean that compaction should follow mixing as soon as possible to achieve the highest strengths.

Figure 4 is a plot of unconfined compressive strength versus curing period for specimens treated with 2% and 4% lime. In the initial stages both the 2% and 4% lime-modified specimens gain strength at similar rates. The 4% lime-modified specimens continue to gain strength at a rapid rate up to about 20 days and then continue to increase at a slower rate. On the other hand, the 2% lime-modified specimens appear to stop gaining strength

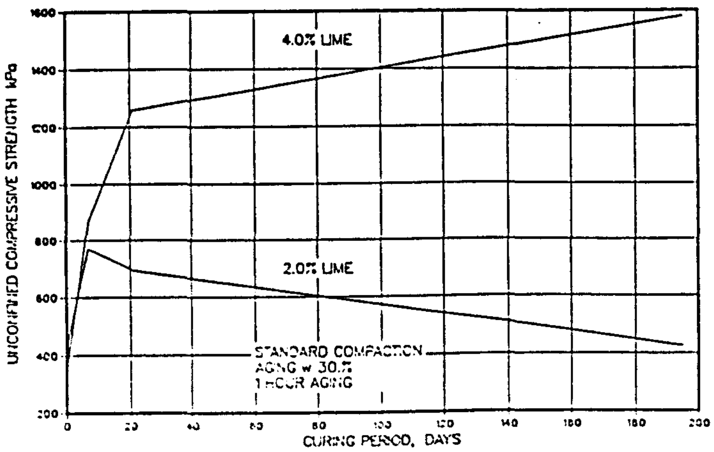


Figure 4 Effects of Lime Percentage on Cured Unconfined Compressive Strength

after about one week of curing, and in fact show a substantial drop after 195 days of curing. This would suggest that 2% lime is inadequate for a full immediate reaction with the soil.

Similar material prepared with increased compactive effort show that the unconfined compressive strengths of the 2% lime specimens are close to that of the 4% lime specimens (Figure 5). The strengths of the 4% lime specimen prepared by increased compactive effort are consistently lower than that prepared by Standard compaction (Figure 6). Whereas Figure 7 shows that in the 2% lime specimens, the unconfined compressive strengths are higher in specimens prepared by increased compactive effort. This is probably due to the greater extent of structure breakdown and breakage of bonds in the 4% lime specimens due to the increased compactive effort. In lime modified soil, there is a conflict between density and soil structure. Reaction with lime results in a flocculated structure and also bonding between particles. This results in a reduction in compacted density. Increased compactive effort is required to achieve an equivalent density as the untreated soil. This increased compactive effort would result in the

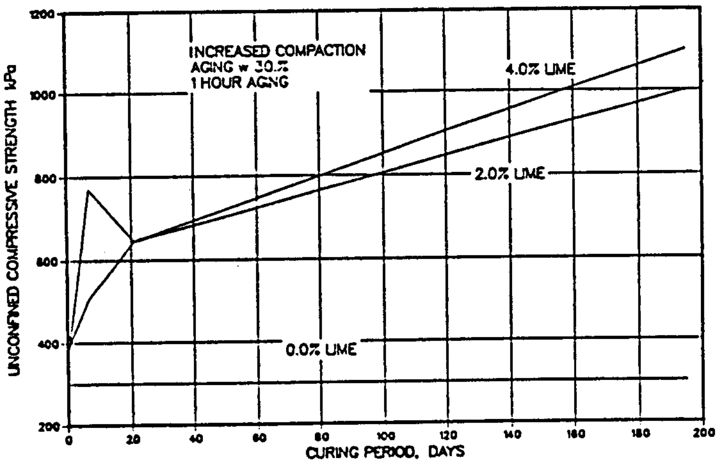


Figure 5 Effects of Lime Percentage on Cured Unconfined Compressive Strength of 'Heavy' Compacted Specimens

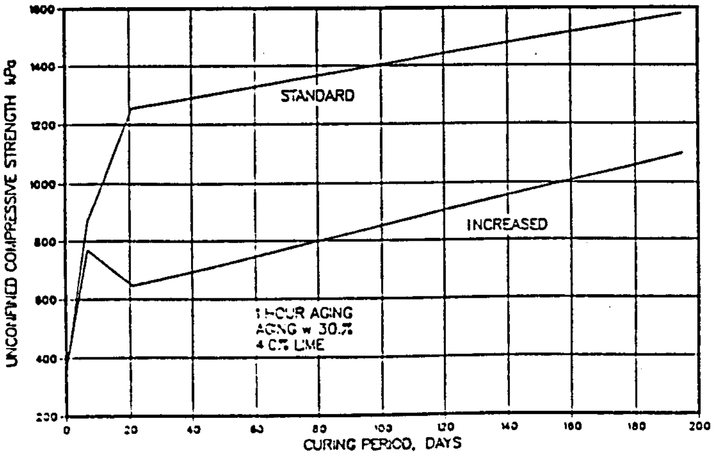


Figure 6 Effects of Compactive Effort on Cured Unconfined Compressive Strength of 4% Lime Modified Regina Clay

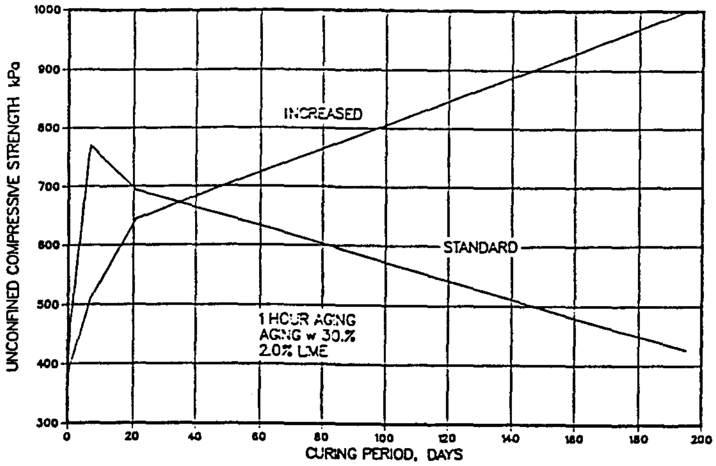


Figure 7 Effects of Compactive Effort on Cured Unconfined Compressive Strength of 2% Lime Modified Regina Clay

breakdown of the structure and bonds and may lose more strength than may be gained by the increased density. It may be inferred from Figures 6 and 7 that the destruction of the soil structure is more serious in the specimens with higher lime contents. At higher lime content, the reaction with lime is faster, more advanced and more developed by the time the specimens are to be compacted.

Figure 8 shows a plot of unconfined compressive strength versus curing period for 2% lime-modified specimens with aging water contents of 25%, 30% and 35%. It is seen that the highest strengths were achieved at an aging water content of 30%, which is approximately the optimum water content for untreated Regina clay.

Water is required for hydration of the lime and also for reaction. Water contents below 30% may be insufficient for a full reaction and water content in excess of that required for full reaction is detrimental to strength.

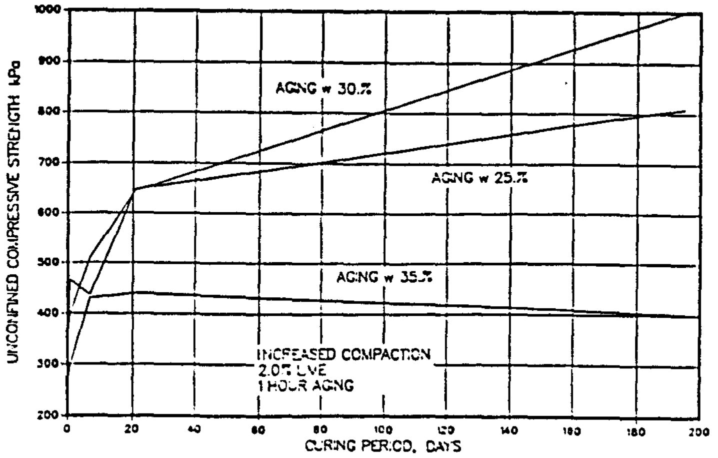


Figure 8 Effects of Aging Water Content on Cured Unconfined Compressive Strength

EFFECT OF CURING ON ONE-DIMENSIONAL VOLUME CHANGE

The effects of curing on the one-dimensional volume change behavior of lime-modified Regina clay are shown in Figures 9 and 10. The effect of lime on the volume change is immediate. The percent swell is reduced from approximately 9.5% for the untreated Regina clay to less than 1% for both the 2% and the 4% lime-modified specimens. The percent swell is reduced further to almost zero percent with curing of 1 day to a few days.

The fact that the swell was reduced close to zero percent indicates that 2% lime is sufficient to satisfy the soils demand for lime as far as volume change is concerned. The almost immediate reduction in swell would suggest that the effect of lime is to alter the structure of the clay, from a cohesive highly plastic clay to that of a flocculated quasi-granular material. The reduced swell may be attributed to the decreased affinity for water of this altered material.

It may be deduced from Figure 10 that the flocculated structure is very important to reducing swell. With increased compactive effort, the structure is partially destroyed and hence, percent swell increases.

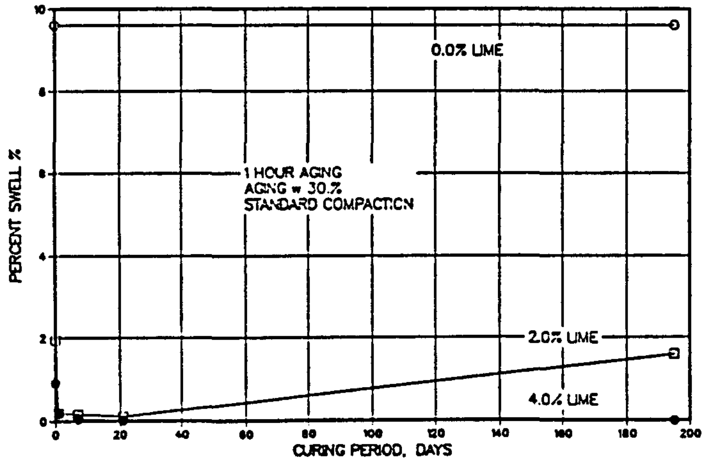


Figure 9 Effect of Lime Percentage on Cured One-Dimensional Swell

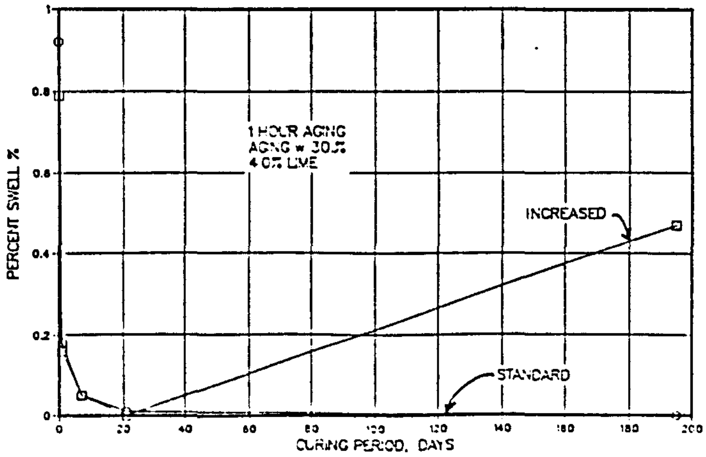


Figure 10 Effects of Compactive Effort on Cured One-Dimensional Swell

EFFECT OF WETTING AND DRYING CYCLES ON THE UNCONFINED COMPRESSIVE STRENGTH

The untreated Regina clay specimens completely disintegrated upon being submerged in water. The lime-modified specimens were able to withstand only one cycle of wetting and drying. After one cycle, the specimens disintegrated upon re-submergence in water.

The results of the unconfined compressive strength test after 1 wetting and drying cycle are presented in Table 7. The samples were tested after drying was complete. The water contents of the samples after drying were approximately 2%. After drying, the specimens were very brittle and registered a high unconfined compressive strength.

Figure 11 shows a typical plot of unconfined compressive strength after 1 wetting and drying cycle versus initial aging water content. The highest strengths are achieved with aging water contents near the optimum water content of the untreated material. Also the specimens with four percent lime had higher strengths than the two percent lime-modified specimens at equal water contents. The higher strengths of the four percent lime-treated specimens is a result of more cementing agents being formed with the greater amount of calcium available.

It should be mentioned, however, that this mode of testing is considered too severe for lime-modified clay. A better procedure needs to be developed.

Table 7 Unconfined Compressive Strength Test (Wet/Dry Cycles)

Sample Description Li,Comp,Age	Wet/Dry 1 Cycle Aging w (%) A	B	Strength (kPa)
0, Std, NA	24.3	N/A	0.0
0, Std, NA	30.6	N/A	0.0
0, Std, NA	34.4	N/A	0.0
2, Std, 1	24.6	1.4	1145.9
2, Std, 1	29.3	2.0	2473.9
2, Std, 1	34.3	2.7	2900.8
4.0,Std, 1	25.2		1236.7
4.0,Std, 1	31.2	2.7	2613.1
4.0,Std, 1	35.0	3.4	2769.4
2.0,Inc/32,1	24.9	2.0	2128.4
2.0,Inc/32,1	29.7	2.2	2953.6
2.0,Inc/32,1	33.9	2.9	2053.1
4.0,Inc/42,1	24.7	1.7	2144.3
4.0,Inc/42,1	29.6	3.7	3389.3
4.0,Inc/42,1	38.3	3.3	3192.7

A	Aging water content before wetting
B	Aging water content after drying
N/A	Not applicable

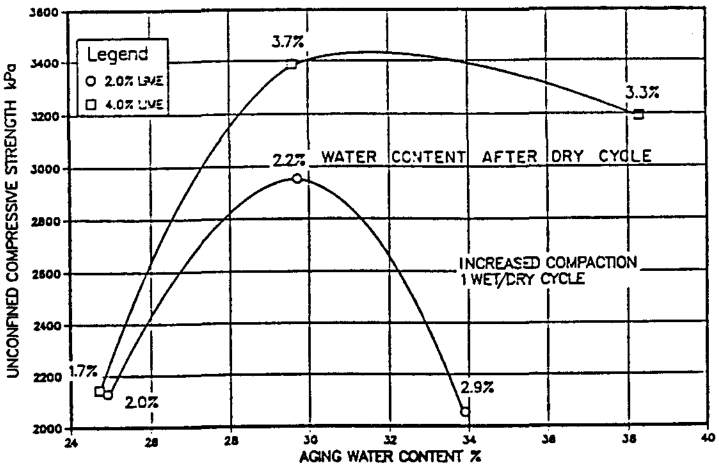


Figure 11 Effect of Aging Water Content on Unconfined Compressive Strength after Wet/Dry Cycles

EFFECT OF WETTING AND DRYING CYCLES ON THE VOLUME CHANGE CHARACTERISTICS

The influence of different aging water contents on the volume change characteristics of lime-modified Regina clay after 1 wetting and drying cycle is shown in Figures 12 and 13. The volume change measurements were made upon the completion of the drying cycle. The figures show that the shrinkage upon drying increased with initial aging water content.

The volume change versus aging water content for specimens treated with 2% and 4% lime are presented in Figure 12. The volume changes are fairly similar at aging water contents below 30% (optimum of untreated soil). At higher aging water contents the 2% specimens exhibit much greater shrinkage upon drying. This again can be explained by the fact that the 4% specimens have more cementing agent due to the greater amount of calcium available. It is therefore less susceptible to shrinkage.

The influence of different compactive efforts (hence densities) on volume change is portrayed in Figure 13. Variation in compactive effort

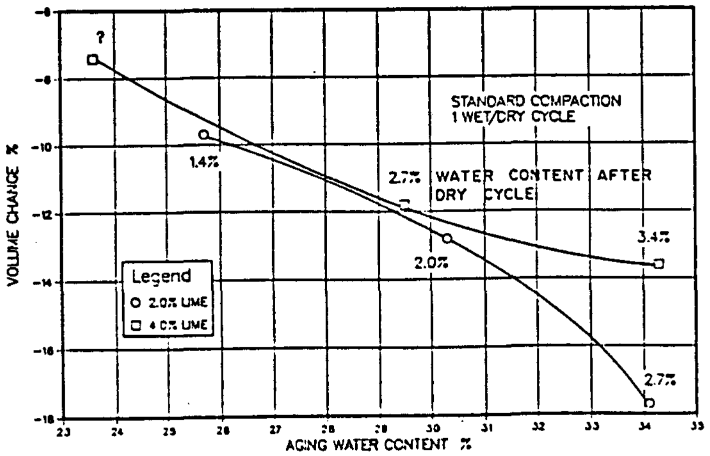


Figure 12 Effects of Aging Water Content on Volume Change of Standard Compacted Specimens after Wet/Dry Cycles

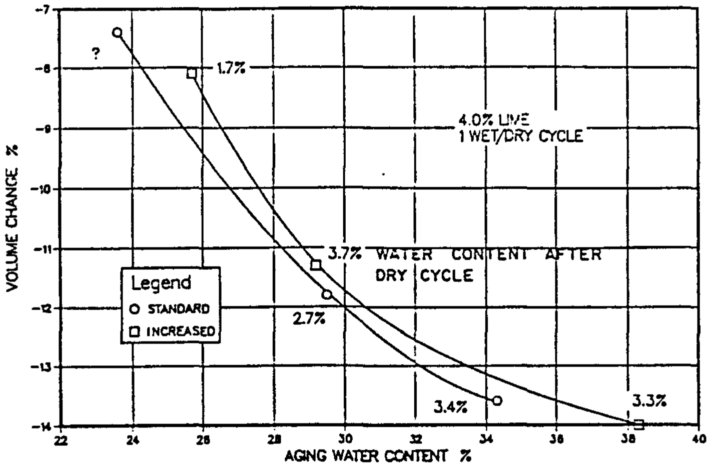


Figure 13 Effect of Compactive Effort on Volume Change after Wet/Dry Cycles

does not seem to greatly influence the amount of shrinkage upon drying. Specimens compacted with increased efforts exhibit less than half a percent lower shrinkage. Their greater density may have provided slightly greater resistance to changes in water content.

EFFECT OF FREEZE/THAW CYCLE ON THE UNCONFINED COMPRESSIVE STRENGTH

The effect of freeze/thaw cycle on the unconfined compressive strength is presented in Figures 14. The results show that the resistance to breakdown due to freeze thaw cycle is greatest for the 4% specimen and least for the untreated soil. This again is due to the greater availability of calcium in the 4% specimen for the formation of cementing bonds. In the same figure, it is also seen that the specimens compacted by an increased effort have lower unconfined compressive strengths before freeze/thaw and after 1 freeze/thaw cycle. This again emphasizes the precaution that must be exercised in specifying the compaction specification for lime-modified soils. As mentioned earlier, there is a conflict between soil structures and density. The increased effort probably resulted in substantial breakdown of cementing bonds.

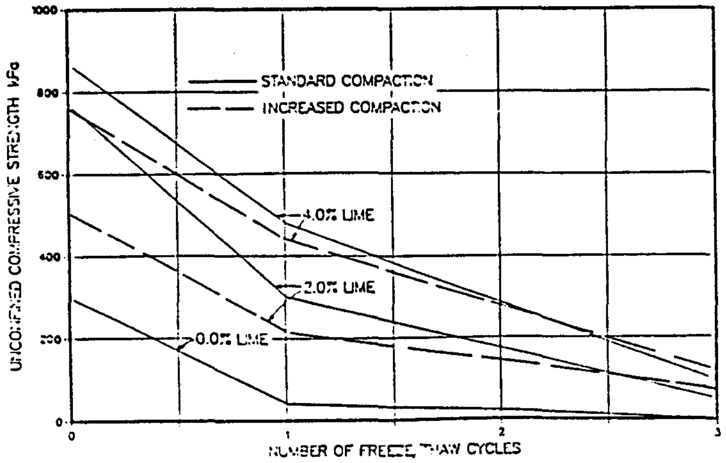


Figure 14 Effects of Compactive Effort and Lime Percentage on Unconfined Compressive Strength after Freeze/Thaw Cycles

The untreated specimens suffered extensive damage after just one freeze/thaw cycle. At the end of one cycle, an extensive nugget like structure was observed in the untreated specimens. The appreciable loss in strength of the untreated clay was a result of high water contents upon thawing (Figure 17).

The lime-modified specimens did not exhibit the same nugget like

The influence of aging water contents on the unconfined compressive strength of lime-modified Regina clay subjected to freeze/thaw cycle is presented in Figures 15 and 16. Once again it is observed that the highest strengths are obtained at aging water content close to the optimum water content of the untreated soil.

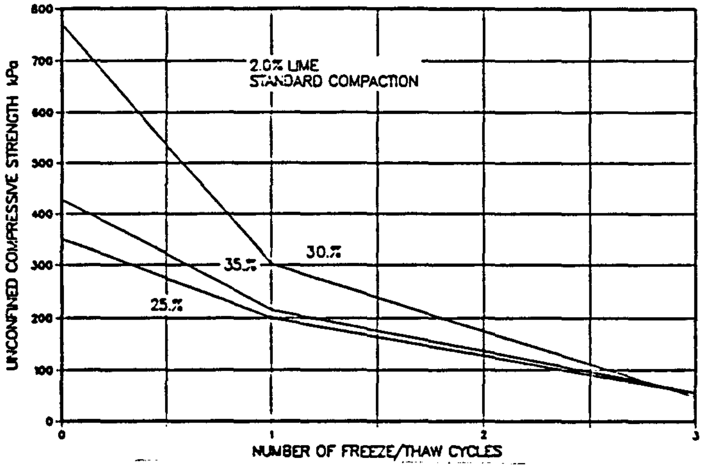


Figure 15 Effects of Aging Water Content on Unconfined Compressive Strength of 2% Lime Modified Regina Clay after Freeze/Thaw Cycles

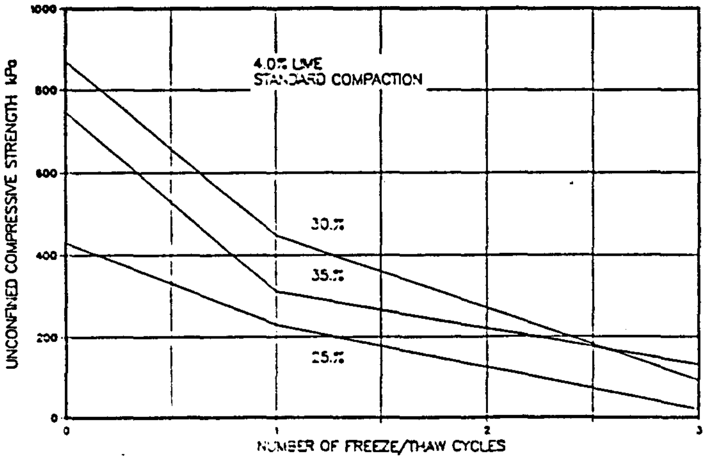


Figure 16 Effects of Aging Water Content on Unconfined Compressive Strength of 4% Lime Modified Regina Clay after Freeze/Thaw Cycles

EFFECT OF FREEZE-THAW CYCLE ON VOLUME CHANGE

There is no distinct trend in the volume change characteristics.

The results of volume change measurement after one and three freeze/thaw cycles are presented in Table 8.

The results show that the volume change of the lime-modified specimens are considerably smaller than the untreated specimens. It is also observed that generally, the specimens compacted with a standard effort exhibit less volume change than those specimens compacted with greater compactive effort.

Table 8 Volume Change Test Results (Freeze/Thaw Cycles)

(- Sign Means Volume Decrease)

Sample Description	Aging Volume Change			
	After 1 Cycle		After 3 Cycles	
Li,Comp,Age	w (%)	(%)	w (%)	(%)
0.0,Std,NA	25.2	-11.7	25.2	N/A
0.0,Std,NA	29.4	-7.35	29.4	-5.77
0.0,Std,NA	34.9	-2.78	34.9	N/A
2.0,Std,1	25.3	-0.03	25.8	-0.78
2.0,Std,1	30.4	-0.20	30.4	0.94*
2.0,Std,1	35.0	N/A	34.9	0.38*
4.0,Std,1	27.5	0.54	25.6	0.00*
4.0,Std,1	30.7	0.50	30.3	0.79
4.0,Std,1	35.0	1.93	34.6	-0.67*
2.0,Inc/32,1	25.4	1.59*	25.6	-1.37
2.0,Inc/32,1	29.4	-1.51	30.0	-1.08
2.0,Inc/32,1	33.6	0.94	34.3	-0.48
4.0,Inc/42,1	25.6	-.092	25.2	-1.69*
4.0,Inc/42,1	28.7	0.36	29.9	N/A
4.0,Inc/42,1	33.4	0.25	34.4	N/A*

* Layer separation prior to testing.

EFFECT OF FREEZE/THAW ON THE EVENTUAL WATER CONTENT DISTRIBUTION

The water content distribution of the specimens after three freeze/thaw cycles are shown plotted in Figure 17. Also shown on these Figures are the initial water content of the specimens, which are generally about 30%. After three freeze/thaw cycles, there is a dramatic increase in water content for the untreated specimens. The water content increased to about 45-46% from an initial of about 30.0%. The lime-modified specimens, on the other hand, had much smaller increases. As explained earlier, this is probably due to the cementing bonds holding the structure together and

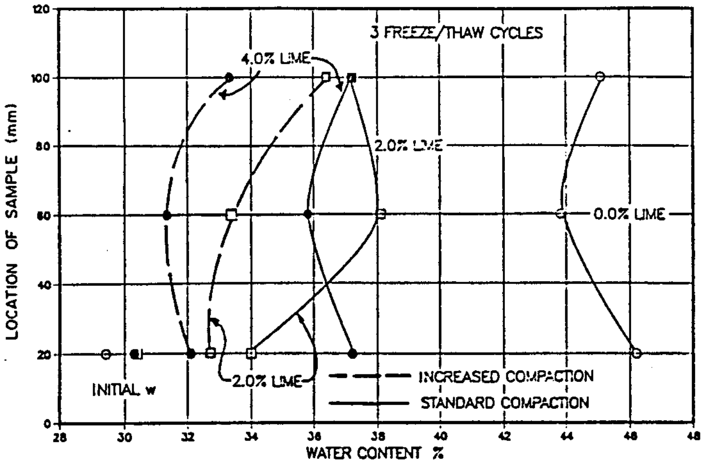


Figure 17 Effects of Compactive Effort and Lime Percentage on Water Content Profile after Freeze/Thaw Cycles

preventing expansion. Also the surface phenomenon of the lime-modified material is such that there is now a reduced affinity for water.

The results also show that the specimens compacted with increased effort exhibit less change in water content. The higher density due to the increased compactive effort may have provided greater resistance to freeze/thaw cycles. Thus the smaller changes in water content.

CONCLUSION

The study shows that the environmental conditions have a significant influence on the unconfined compressive strength and volume change characteristics of lime-modified Regina clay. The more notable findings are:

1. Curing contributes to strength gain. Strength gain is especially significant during the first week of curing.
2. Compaction destroys structure. Caution must be exercised when compacting lime-modified Regina clay. A balance needs to be established with regard to density and structure. Destruction of soil structure is more significant the higher the lime content. This is probably due to the increased rate of reaction resulting in greater extent of structure development during the same time period.
3. Compaction after prolonged aging may result in lower unconfined compressive strength. This is due to the partial destruction of the flocculated structure by compaction. Aging should be minimized so that the major structure development takes place after compaction.

4. Optimum strength is obtained with aging water content of about 30%.

5. The addition of lime significantly reduced the volume change characteristics of Regina clay. As little as 2% lime reduces the percent swell from about 9.5% for the untreated soil to less than 0.5 percent. The reduction in swell is immediate, suggesting that the

6. Overcompaction can cause a breakdown of flocculated structure and result in higher swell.

7. The procedure adopted for Wetting and Drying tests is too severe.

8. Untreated Regina clay completely disintegrated upon submergence in water. Lime modified specimens were able to withstand only one wet/dry test cycle. Lime-modified Regina clay does not appear to be a durable material if subjected to wetting and drying cycles.

9. The strength of lime-modified Regina clay decreased significantly with freeze/thaw cycles. The higher lime content specimens exhibit greater resistance due to the formation of more extensive cementing bonds with the greater availability of calcium.