Physical Property Changes in a Lime-Treated Expansive Clay Caused by Leaching

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The effects that continuous water leaching has on the engineering and physical properties of a lime-treated expansive clay in north-central Texas were determined. Seventy laboratory-prepared lime-treated clay samples were subjected to continuous accelerated leaching for periods of 45 and 90 days in large-diameter, flexible-wall leach cylinders. The soils' physical properties were measured before and after leaching, then graphically and statistically analyzed for significant changes. Results indicated that leaching does have detrimental impact on the physical properties of lime-treated expansive clays. The property changes are related to lime content and initial moisture content. Permeability of all samples increased dramatically with the addition of lime. Maximum detrimental changes generally occurred at lime contents at or less than the lime modification optimum. At lime contents at or above the lime stabilization optimum, the detrimental effects of leaching were minimized or eliminated. Changes to properties upon leaching varied depending on their compaction water content relative to the optimum.

Expansive clays exhibit high potential for volume change because of changes in soil moisture. Jones and Jones (*1*) estimated that the annual cost of damage to facilities built on expansive clays in the United States exceeded $9 billion.

One of the most common and effective physiochemical treatments of expansive clay is to add lime, either calcium hydroxide [$Ca(OH)_2$] or quicklime (CaO) to the soil. Lime treatment has been widely used for many years and is currently used in more than 40 states for stabilizing runways, buildings, roads, and parking lots (*2,3*). Although much is known about the phenomenon of soil-lime reactions in expansive clays, little work has been done to investigate leaching of these lime-treated soils. Of particular concern was determining whether the benefits of lime treatment were reduced through leaching over time.

PURPOSE

The long-term effects of continuous leaching on a lime-treated expansive clay from North Central Texas were studied by performing continuous leaching on laboratory-prepared specimens and analyzing the physical property changes that occurred.

Seventy laboratory-compacted samples of various soil-lime mixtures were leached with distilled and demineralized water in specially designed large-diameter, flexible-wall cells for periods of 45 and 90 days. Physical property tests done before the start of the leach cycle, then repeated at the end of the leach cycle, provided indication of changes in the properties. Variables investigated included changes in lime content, initial compaction moisture content, and leach durations. Constants maintained were compactive effort, cure conditions, and leaching flow pressure.

Laboratory testing was conducted on three different expansive clays from the same geologic formation. Therefore, repeatability and conformation of results were enhanced.

BACKGROUND

Although soil-lime permanency has been frequently questioned by engineers, it is generally accepted that the physical changes occurring within the soil-lime mass remain relatively permanent. Eades and Grim (*4*) questioned the permanency of lime in the soil and tested pure clay minerals. They speculated that, if stabilization was caused by only flocculation or ion exchange, percolating ground water could possibly remove calcium in the soil-lime mixture. They concluded, without leach testing, that formation of crystalline silicate hydrates would be permanent and not susceptible to leaching. However, the percentage of lime added to the soil must be sufficient to generate large calcium silicate pozzolans (*5*).

Durability of Projects

The permanency of lime-treated soils is often upheld by discussing the numerous long-standing successful lime-stabilized construction projects. Gutschick (*6*) cited several successful projects throughout the United States that were built in the 1960s and 1970s. Kelly (*7*) undertook an extensive field investigation that verified the long-term effectiveness of roads at various military installations in the South that had been lime stabilized in the 1940s and 1950s.

Tests on the reconstructed lime-treated Friant-Kern Canal in California showed, after 7 years of cyclic immersion, that the effective lime content had decreased from the original 4 percent quicklime by approximately 1 percent. However, the dry unit weight remained constant and the strength increased (*8*).

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The Dallas–Fort Worth (DFW) International Airport was completed in 1973 and contained 2,400,000 yd^2 of lime-treated subgrade material. The airport has provided 15 continuous years of service without major maintenance (*9*).

Barenberg (*10*) conducted a series of leach tests on lime-cement-fly-ash-aggregate (LCFAA) mixtures to study the migration of lime and cement under pavements. Test results indicated that less than 0.1 percent of the approximately 4.0 percent original lime plus cement content had been leached.

Stocker (*11*) percolated small amounts of water through lime and cement-treated samples to study the dissolution of cementatious material. Small amounts of dissolution did occur in his tests, but substantial cementation reduction was minimal.

Permeability Changes

The studies of permeability changes in lime-treated clays are widely varied. Townsend and Kylm (*12*) hypothesized and found through testing that lime stabilization would increase the pore volume caused by flocculation, thus increasing permeability. Ranganathan (*13*,p.331) found a 10-fold increase in permeability of a lime-treated expansive clay. Fossenberg (*14*,p.221), however, found a reduction in the permeability of a lime-treated clay. Gutschick (*6*) found that the permeability of a lime-fly-ash-aggregate lime mixture used on an irrigation channel initially increased but decreased with time to that of the natural clay.

Stocker (*11*) noted that for strong, advanced stages of lime modification in a soil mass, the permeability tended to decrease. However, for less modified soils, there may be an apparent reduction in permeability.

Summary

Extensive research has been conducted over the last 30 years to study the complex nature of soil-lime reactions. Much is known about those reactions and how they can affect the physical properties of an expansive clay. However, no comprehensive analysis has been undertaken to study what effects leaching would have on the long-term properties of lime-treated expansive clays. The research reported here focused on those property changes.

LABORATORY TEST PROGRAM

Soil Properties

The soils chosen for this research were the locally available well-documented (*9*) weathered clay shales from the Eagle Ford geologic formation. Three separate sites were chosen from this formation and the soils from each site were independently tested for repeatability of the leaching process. The soil sites will be referred to throughout this report as Sites 1, 2, and 3. Tests of the natural clays had plasticity index (PI) values ranging from 30 to 100. Swelling pressures ranged from 0.5 ton per square foot (tsf) to as high as 4 tsf. Unconfined compressive strengths for the soils from all sites averaged 5 tsf. Table 1 presents the average properties for the clays from all three sites.

TABLE 1 SOIL PROPERTIES FROM SITES 1, 2, AND 3

Property	Data Site		
	No.1	No.2	No.3
Silt and Clay (<0.002756in) (%)	85	90	98
Clay Fraction (<0.000079in) (%)	35	12	60
Specific Gravity	2.74	2.71	2.73
Maximum Dry Unit Weight (pcf)	103.5	101.0	100.0
Optimum Moisture (%)	22.5	22.5	24.5
Liquid Limit (%)	63	60	76
Plastic Limit (%)	33	27	31
Plasticity Index (%)	30	33	45
Linear Shrinkage (%)	22.0	17.7	24.4
Swell Pressure (psf)	977.6	1104.7	2117.9
Free Swell (%)	1.80	3.21	11.97
Unconfined Compressive Strength (tsf)	5.46	5.02	4.62
Permeability (ft/min x 10^{-9})	10.4	45.3	13.6

The Eagle Ford clays contained from 12 to 60 percent clay and 85 to 98 percent clay and silt size particles. The soils were classified as CH in the Unified Soil Classification System. Montmorrillonite and calcite were the most predominant minerals present in all clays tested.

Test Procedures

All laboratory physical property testing was done in accordance with the U.S. Army Corps of Engineers Manual (EM) 1110-2-1906 (*15*), except for the swell pressure and free swell testing. Swell pressure tests were conducted until no swelling occurred after 24 hr. Free swell tests (of 33 psf overburden) allowed samples to swell vertically until at least 48 hr. The Texas Test Method, Tex-107-E, was used to determine linear shrinkage. Unconfined compressive strengths were determined using a strain rate of 0.5 percent per minute.

All soils tested were first slaked through a No. 40 sieve, air-dried at 120°F, then lightly pulverized before testing. All testing before leaching was conducted on remolded samples. All swelling, strength, and permeability tests were conducted on samples compacted to meet 95 percent of standard Proctor maximum dry unit weight (ASTM D698) at optimum moisture content (OMC) for the various soil-lime mixtures.

Soil-Lime Reactivity

The soils were investigated for their hydrated lime reactivity before any leach tests were conducted, to identify the range of lime contents for use during leach testing and to establish baseline data for comparing changes in physical properties after leaching. Lime content values chosen for each site were based on their lime modification optimum (LMO) value using the Eades and Grim pH test (*16*), confirmed by Atterberg limits. The lime content values chosen included the lime stabilization optimum (LSO), at which maximum unconfined compressive strength occurs. Lime content values chosen for all testing were as follows: Site 1 Soil, 0, 1, 2, 3, 4, 6, and 8 percent; Site 2 Soil, 0, 1, 2, 3, 5, and 7 percent; and Site 3 Soil, 0, 1, 2, 3, 5, 7, and 9 percent. The LMO values were determined to be 4.0 percent for Site 1 soils and 3.0 percent for soils from Sites 2 and 3. The LSO values were found to be 6.0 percent for soils from Sites 1 and 3 and between 6.0 and 7.0 percent for Site 2 soils.

Moisture-dry unit weight curves were developed for all the soil-lime mixtures to determine optimum moisture contents and maximum dry unit weights for each. Because a Harvard miniature device was to be used, trial work revealed that compacting in the miniature device with four layers and 25 blows per layer (of 40 lbf from the Harvard tamper) approximated unit weights produced using standard Proctor equipment.

Physical property testing was conducted on samples at their respective OMC values. These property tests revealed that the expansive behavior of the Eagle Ford clays could be dramatically reduced with the addition of small amounts of hydrated lime. For example, with only 3.0 percent lime added, PI values decreased by up to 75 percent and vertical swells decreased by as much as 96 percent. Figure 1 shows the typical reduction of swell pressure achieved.

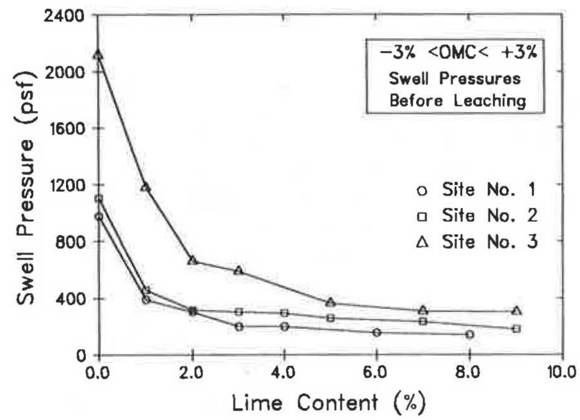

FIGURE 1 Effects of lime on swell pressures before leaching.

Leach Test Program

Leach Test Equipment

In order to model prolonged leaching on lime-treated clays, nine large-diameter, flexible-wall leach cells were designed and built. A triaxial membrane was placed on the inside of the cylinder that allowed an air-confining pressure to be applied to the sides of the sample, thus preventing leakage along the side of the sample. Pressurized water was applied to the sample from the top and was dispersed by flowing over a porous stone before reaching the sample. A porous stone was also placed on the bottom of the sample to prevent soil washout.

The nine cells were individually controlled to allow for continuous and simultaneous leach testing without halting all the tests to perform set up, take down, or maintenance operations on a single cell. The filtered distilled and demineralized leach water was supplied to the samples from a 38-gal tank that had regulated air pressure applied to it to generate the flow. Leachate was collected after it passed through the samples into 5-gal carboys, as shown in Figure 2.

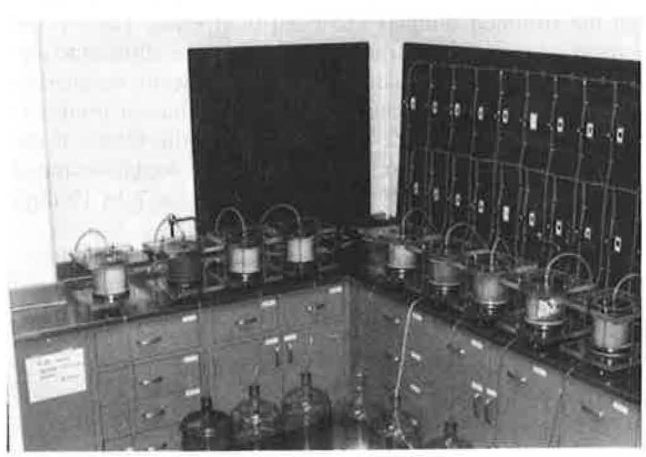

FIGURE 2 Multiple leach cell testing operation.

Leach Sample Preparation

Bulk quantities of the natural soils were air-dried at 120°F for a minimum of 5 days. The soils were then passed through a No. 4 sieve to remove rocks and organic material. Material not passing a No. 4 sieve was pulverized and then mixed with the material passing the No. 4 sieve. The required percentages of hydrated lime and water were mixed into the soil. The soil-lime-water mixture was covered with plastic wrap and mellowed for 24 hr.

The mellowed mixture was compacted in a 6-in.-diameter mold using the compactive effort required to obtain 95 percent of the standard Proctor maximum dry unit weight for the soils at their various lime contents. The compacted samples were double-wrapped in plastic wrap, coated with wax, and placed in an oven to cure for 48 hr at 120°F. This accelerated cure method was chosen as the standard for all lime-treated samples. Moisture content checks at the end of the cure period showed minimum decreases, generally less than 1 percent.

The cured samples were then placed in the test cylinders between the porous stones and sealed in the cells. A confining pressure of approximately 15 psi was applied and then the flow pressure valve was opened to start the leach process. Flow pressures of 10 psi were used throughout to minimize disturbance to the test specimens, yet allowing the water sufficient time to migrate through and interact with the soil-lime specimen. Leach test samples were duplicated for all lime and moisture content mixtures.

Postleach Testing

At the completion of the leach test, the cell was disconnected from the master control panel and disassembled. The sample was cut in half, so as to make top and bottom samples. A moisture content sample was obtained from each of these sample halves. The leach sample halves were then wrapped in a double layer of plastic wrap until ready for complete testing (2 days). Each half was tested under identical conditions. The results included, therefore, four tests that were averaged.

Samples to determine swell pressure, free swell, and unconfined compressive strength were trimmed from the leached sample halves. Because all testing was conducted at OMC, and the trimmed samples exceeded their OMC (nearly 100 percent saturated), the trimmed samples were allowed to air-dry for up to 6 hr. The samples were periodically weighed to determine weight loss caused by drying. Once a predetermined weight was reached on the basis of the OMC of the soil-lime mixture, the trimmed samples were double-wrapped in plastic wrap and allowed to equilibrate for 7 to 10 days before testing.

The remainder of the leaching soil samples was air-dried, pulverized, and passed through a No. 40 sieve. This material was used for Atterberg limits and linear shrinkage testing.

RESULTS

The leach test program was conducted to study the effects of leaching on compacted soil-lime samples with three variables considered, the amount of lime used, the moisture used at compaction, and the duration of leaching. Leaching was conducted for 45 and 90 days with the majority of testing being conducted at 45 days using a 10-psi flow pressure. The lime contents used have been discussed. Moisture contents used at the time of compaction were selected on the basis of three ranges: (a) ± 3 percent of optimum moisture (OMC); (b) -8 to -3 percent below optimum (dry or $-$OMC); and (c) $+3$ to $+8$ percent above optimum (wet or $+$OMC). Table 2 presents a summary of the 70 leach tests conducted.

Permeability

For all three soil sites, the permeabilities of the lime-treated clay increased with the addition of as little as 1 percent lime. The amount of increase ranged from a 7-fold increase to a maximum 342-fold increase. The maximum increase in permeability for all three soils appeared at or near the LMO value. At very low or very high lime contents, the increase in permeability was less pronounced, as shown in Figure 3a. However, even at very high lime contents permeability was still much greater than that of the natural soil.

During all leach testing, permeabilities of the lime-treated clays decreased during leaching. This behavior is consistent with that of other research (*6*). This decrease was fairly rapid at the start of the test, but after approximately 300 hr, the permeabilities reached a point where they were decreasing at a much slower rate, as shown in Figure 3b. This same leveling phenomenon has been noted when soils are leached with industrial fluids (*17*). It is speculated that this leveling of the permeabilities is a result of the samples' becoming saturated during the leach process. The flow rates became relatively steady during saturation and continued to slowly decrease with leaching.

Treated samples compacted wet of optimum displayed the lowest permeabilities. The highest permeabilities occurred in samples compacted dry of optimum with lime contents at their LMO.

Changes in permeability in lime-treated clays are, therefore, believed to be directly related to the ion complex within the clay soil. With the addition of small amounts of lime (less than the LMO value), clay soil particles flocculate to some degree and pozzolanic reactions do not occur on a large scale, resulting in a small increase in permeability. Maximum flocculation and agglomeration occur at the LMO value, opening up large flow channels and producing extremely large permeability increases. At lime contents exceeding the LMO value, the soil pH is sufficiently elevated that silica and alumina hydrates are formed, producing massive crystalline structures and effectively blocking flow channels. Permeabilities declined as lime percentages were increased, but sufficient channels remained so that permeabilities well exceeded that of the natural soil.

Atterberg Limits

Figure 4 shows a typical diagram of the effects of leaching on Atterberg limits of the lime-treated clay from Site 1. After leaching, plastic limit (PL) and liquid limit (LL) values de-

TABLE 2 SUMMARY OF VARIABLES USED DURING LEACH TESTING FOR ALL SOIL SITES

Soil Site	Variables					
	Percent Lime (%)	Leach Durations		Moisture Content (%)[a]		
		45 days	90 days[b]	-OMC	OMC	+OMC
1	0	X	X	-	X	X
	1	X	-	X	X	X
	2	X	-	-	X	-
	3	X	X	X	X	X
	4	X	-	X	X	X
	6	X	X	X	X	X
	8	X	-	-	X	-
2	0	X	X	-	X	X
	1	X	-	X	X	X
	2	X	-	X	X	X
	3	X	X	X	X	X
	5	X	-	X	X	X
	7	X	X	-	X	-
3	0	X	X	-	X	-
	1	X	-	-	X	-
	2	X	-	-	X	-
	3	X	X	-	X	-
	5	X	-	-	X	-
	7	X	-	-	X	-
	9	X	X	-	X	-

[a] -OMC = -8% to -3% below OMC; OMC = -3% < OMC < +3%; +OMC = +3% to +8% above OMC
[b] 90 Tests were conducted at OMC only
\- Not tested

creased, whereas PI values increased. Maximum increase in postleach PI value appeared in samples with 1 to 3 percent lime, for those leached 45 days and compacted at OMC. Samples leached 90 days had even larger increases in PI value. The largest increase in PI value occurred in Site 3 material with 3 percent lime, which increased from a PI value of 11 to 31. Maximum increases in PI values during leaching occurred in samples compacted wet of optimum with the minimum increase for samples compacted dry of (or at) optimum moisture.

The increase in PI value after leaching was less as more lime was added to the soils. When approximately 6 percent or more lime had been added to the soils from all three sites, the PI value after leaching was less than or equal to the PI value before leaching. The duration of the leach cycle did not have an adverse impact on the PI value of the soils when at

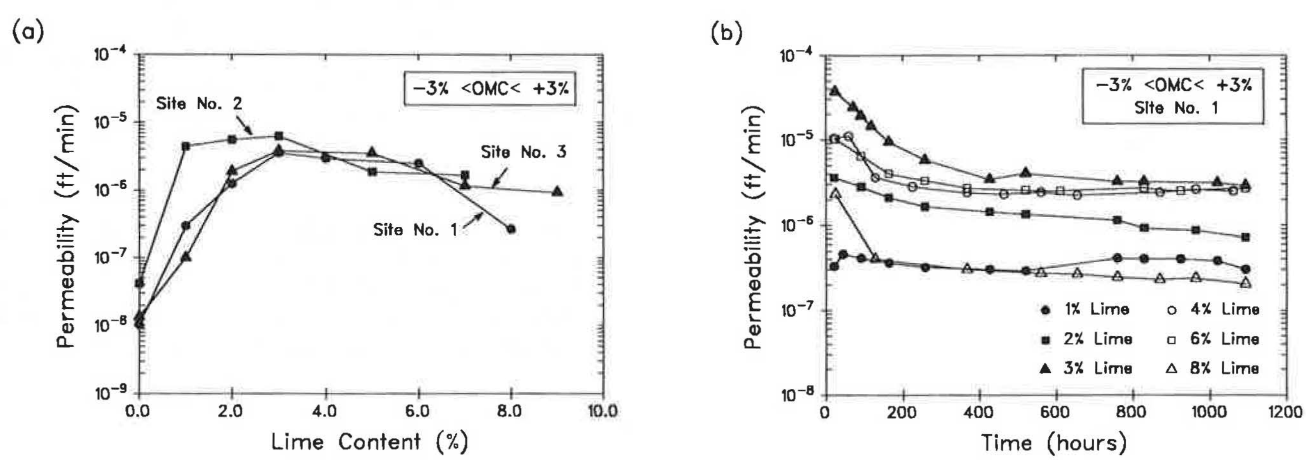

FIGURE 3 (a) Lime content versus permeabilities after 600 hr of leaching; (b) permeability changes during 45 days of leaching.

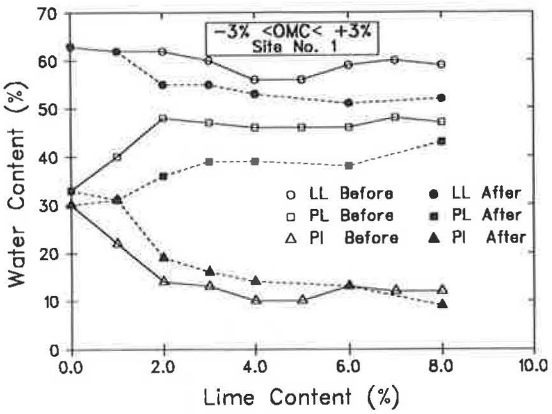

FIGURE 4 Atterberg limits before leaching and after leaching 45 days.

least 6 percent lime had been added. Increases in lime content did not appear to affect the PL and LL values, which were generally lower after leaching.

Linear Shrinkage

A typical diagram depicting the effects of leaching on linear shrinkage is shown in Figure 5 for Site 3 material compacted at OMC. Shrinkage increased after leaching with the maximum increases occurring at lime contents less than (or at) the LMO value. In Site 3 material, samples compacted wet of optimum had the least amount of increase in shrinkage, whereas those compacted dry had the highest shrinkage after leaching. Leaching 90 days appeared to have a more detrimental impact on the higher lime content samples than leaching 45 days. For the samples with the lower lime contents, 45 days of leaching generally appeared to be more detrimental.

As the lime was increased in the leached samples, the increase in postleach shrinkage was less. When 6 to 7 percent lime had been added to samples, this linear shrinkage was less than or equal to the shrinkage noted before leaching.

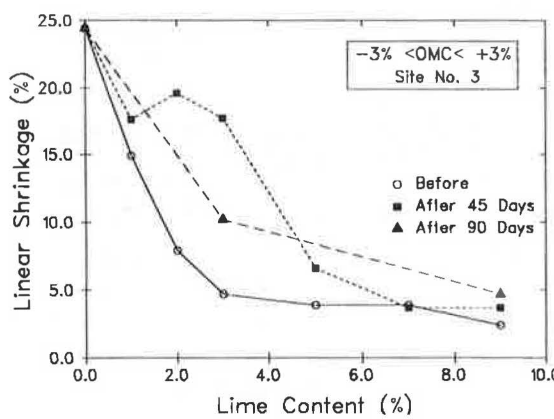

FIGURE 5 Linear shrinkage before leaching and after leaching 45 and 90 days.

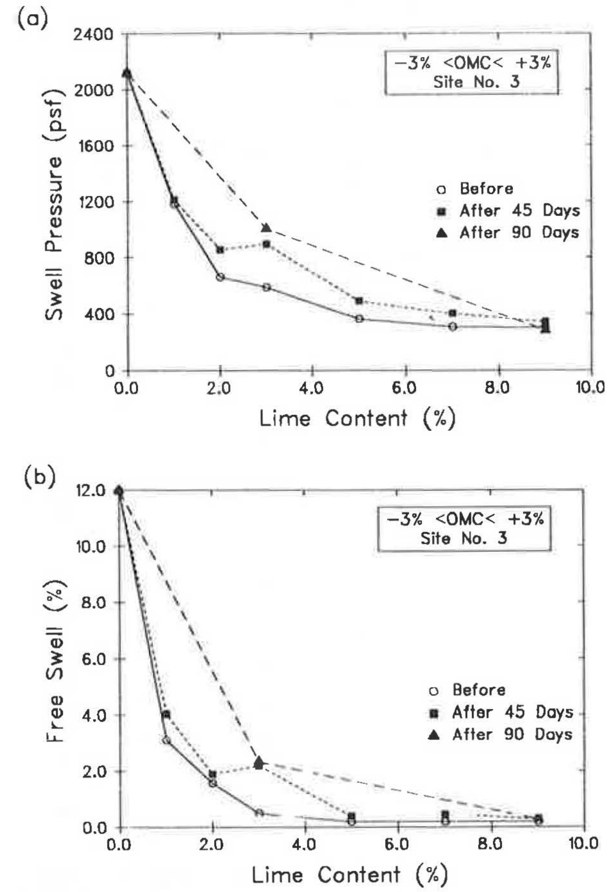

FIGURE 6 (a) Swell pressure and (b) free swell before leaching and after leaching 45 and 90 days.

Swell Properties

Swelling Pressure

The results of leaching on the swelling pressures of the clay tested from Site 3 are shown in Figure 6a for the samples tested at the OMC value. The results are typical for all three sites. Tests indicated increases in swell pressure after leaching at all lime contents. These increases ranged from as little as 13 percent to as high as 98 percent. The maximum increase in swell pressure occurred in samples treated with lime contents of 3 to 6 percent. When 7 to 8 percent lime had been added, the swelling pressure after leaching was approximately equal to that before leaching. Maximum increases of swelling pressure occurred in samples compacted wet of optimum, whereas those compacted dry of (and at) the OMC value produced lower increases in swelling pressures. Samples leached 90 days had slightly higher swell pressures at the lower lime contents than samples leached 45 days. However, at the higher lime contents, there was no significant difference in swell pressures caused by changes in leach duration.

Free Swell

In samples tested for free swell after leaching, there was an increase in swell for samples tested at all lime contents. Figure

6b shows typical changes in swell after leaching 45 and 90 days for Site 3 material compacted at OMC. Maximum increases in postleach free swell occurred in samples tested with 3 to 4 percent lime, with increases ranging from 115 to 340 percent. When approximately 6 percent lime had been added to all materials, free swell increases became negligible, although there still was some slight increase in swell. Maximum increases of postleach free swell occurred in samples compacted wet of optimum, whereas samples compacted dry had slightly lower increases in swell than those compacted at optimum moisture. Samples leached 90 days displayed little difference in swell increase over those leached 45 days for Site 3 soil. However, for the other two sites at lower lime contents, 90 days of leaching produced higher swell than did 45 days of leaching.

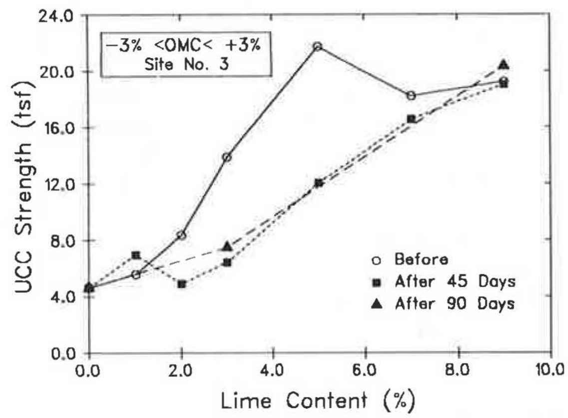

FIGURE 7 Unconfined compressive strength before leaching and after leaching 45 and 90 days.

Unconfined Compressive Strength

Unconfined compressive strength tests run on samples leached 45 and 90 days indicated that materials with very low lime content had considerable loss in strength during leaching. The maximum loss was a decrease of 76 percent for Site 1 material with 1 percent lime. As the amount of lime was increased in the soils, the loss of shear strength declined such that after 7 to 8 percent lime was added to the soils, the loss was negligible. After approximately 8 percent lime had been added to the soils, the postleach strength was actually higher. Samples leached 90 days had similar results to those leached 45 days, except in material from Site 1, which had a higher strength loss after leaching 90 days. Figure 7 shows a typical plot of the strengths measured after leaching 45 and 90 days for Site 3 material compacted at optimum moisture.

The maximum strength measured after leaching occurred in samples compacted at optimum moisture or slightly wet of optimum, although it was less than the preleach strength measured. Samples compacted dry of optimum displayed dramatic strength loss after leaching, averaging over 52 percent less strength when compared to samples compacted at the OMC value.

DISCUSSION OF PHYSICAL PROPERTY CHANGES

In all physical property tests conducted, postleach testing revealed that there were detrimental effects on the stabilizing attributes of lime-treated clays. The samples treated with lime contents of 1 to 4 percent displayed the largest detrimental changes during leaching. However, in all physical property tests conducted, there was a minimum lime content beyond which leaching was not significantly detrimental. This optimal lime content varied slightly between property tests. For Atterberg limits and linear shrinkage, the optimal lime content was found to be between 5 and 6 percent; for swelling properties, it varied between 6 and 8 percent; and for strength, it was found to be 7 to 8 percent.

These amounts of lime are approximately the lime contents established as the LSO values of the soils, i.e., the amounts of lime necessary to provide optimal pozzolanic reactions. It is believed that leaching greatly increases the water molecule concentration, causing the soil-lime water system to attempt to diffuse any loosely held calcium cations away from the clay particle surface while also increasing the adsorbed water layer surrounding the clay particle. This process ultimately results in increases in PI value, shrinkage, and swelling properties.

When the lime content of expansive clays is below the optimum concentration for maximum pozzolanic reaction, flocculation bonding is relatively weak and could possibly be removed by flowing water during leaching, as suggested by Diamond and Kinter (*18*). Therefore, longer leach durations on the samples mixed at the lower lime contents should result in more detrimental effects. This research supports that theory because many samples leached 90 days had larger increases in PI value, free swell, and swell pressure than those leached 45 days.

Furthermore, if flowing water breaks down flocculation, then it follows that a higher permeability would increase the rate of breakdown. The highest permeability in this research occurred in samples compacted at their LMO values. The largest increase in postleach linear shrinkage, PI value, and swelling properties occurred in samples compacted with 3 to 4 percent lime. When enough lime is added to the soil, it is believed that the increase in calcium concentration offsets the increase in water molecules caused by leaching, and pozzolanic reaction products will begin to close off flow channels and produce permanent interparticle bonding.

In order to minimize the effects of leaching on strength losses, it was necessary to increase the amount of lime added to the samples to at least 1 percent above the LSO value. The additional water added during leaching may prevent adequate pozzolan formation until the calcium present is sufficient to offset the disruptive presence of additional water.

A statistical analysis was performed on the data to determine if the changes in properties measured were statistically significant. The t statistic was used to test the significance of the differences in the means of the test results before leaching to the means of the test results after leaching.

Before testing for significant difference between the means, equal population variances were tested using the F distribution. All F tests indicated that there was insufficient evidence to refute the assumption of equal population variances.

All t statistics were tested at the $\alpha = 0.05$ primary level of significance and the $\alpha = 0.10$ secondary level of significance. All results were recorded as either a statistically significant difference between the means before and after leaching or as insufficient evidence (IE) to refute the null hypothesis of no difference in the means.

The statistical analysis indicated that the changes in the physical properties after leaching were statistically significant at lower lime contents and that at lime contents between 5 and 7 percent, the difference in means had less significance. The only exception was that the statistical analysis indicated that there was insufficient evidence to suggest that the LL value was significantly reduced. Statistical analyses on strength and linear shrinkage indicated that nondetrimental effects could be achieved at lime contents approximately ½ to 1 percent below those revealed by graphical comparisons.

CONCLUSIONS AND RECOMMENDATIONS

The intent of this research was to test the effects of continuous water leaching on lime-treated expansive clay. Physical property testing was conducted on the soils before and after leaching for changes in lime reactive characteristics. The results were analyzed graphically and statistically. Some specific conclusions follow:

1. The permeabilities of lime-treated samples were 7 to 340 times higher than those of the natural clays with the maxima occurring at the LMO values.
2. There are detrimental changes in soil-lime mixtures during continuous leaching, the maximum being in materials with below-LMO percentages of lime, for all physical properties measured.
3. The change to properties during leaching tended to be proportional to the duration of the leach cycle.
4. There was a range of lime contents, ±2 percent of the LSO value, for each physical property tested that minimized or eliminated the detrimental effects of leaching.
5. Samples compacted dry of optimum exhibited the highest increase in permeability and linear shrinkage and much lower strength. Samples compacted wet of optimum displayed the highest increase in postleach PI value and swell properties.
6. Statistical analysis of the physical changes after leaching confirmed that the detrimental effects were statistically significant, except for reduction of the LL value.
7. The statistical analysis of shrinkage and strength results indicated that ½ to 1 percent less lime could be used to minimize detrimental effects than the amount revealed by graphical analysis.

On the basis of the results of this study, the following recommendations are made:

1. For the Eagle Ford clays tested in this research, the detrimental effects caused by leaching can be minimized or eliminated if the lime content is at least 1 percent over the LSO value.
2. Lime-treated soils should be compacted within 1 percent of their OMC value.
3. Additional leach testing should be conducted on other expansive clays to develop a comprehensive analysis of the effects of leaching on different clays. Variables to consider should be longer leach cycles, various cure times, and compaction criteria.

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