An Evaluation of Lime and Cement Stabilization

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Stabilization of clay materials is of interest to any engineer who must deal with this type of soil. Stabilization techniques can be mechanical or chemical, or both, but the addition of a stabilizing agent is generally the favored approach. Lime in one form or another has been the most widely used stabilization agent for clay. However, portland cement to stabilize clay has been promoted and used in some applications. It was the purpose of this research to define the effectiveness of hydrated lime and portland cement on three Texas clays. Variables evaluated included two levels of treatment, two levels of pulverization, two compaction efforts, two moisture conditions, and a range of curing times. On the basis of the results and conditions of this test program, lime treatment of expansive, high-plasticity soils was more favorable for compressive strength attainment than was cement treatment of these soils. In general, lime treatment produced higher dry-conditioned strengths, but the major advantage was in the wet-conditioned strengths. Lime treatment provided significantly better resistance to moisture damage when these soils were compacted by the modified compactive effort. Cement treatment of low-plasticity sandy clay produced significantly higher compressive strengths than did lime treatment of this soil.

The modification of soils to improve their engineering properties has been practiced for many years. Many investigations and research programs have addressed the development of materials evaluation and mixing techniques to determine the best combinations of soils and stabilizing agents. Economics have also played an important role in determining the best procedures and materials. Recently, material and construction economics have made more materials competitive, thus opening the way for more approaches than were previously used.

In many parts of Texas, engineers must deal with several different types of clay materials varying from extremely expansive to moderately active. Stabilization or modification of these clays is necessary for proper construction. In the past, lime has been used primarily for clay soil stabilization, and cement has been preferred for granular or sandy soils. However, cement has been promoted and used on some clay soils in Texas. To better understand this application of cement with clay soils, a research project was undertaken. Several variables were introduced to evaluate both hydrated lime and portland cement as stabilizing agents for clay materials. The experimental program and results are discussed here.

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EXPERIMENTAL PROGRAM

The objectives of the study were to compare the dry and wet unconfined compressive strength characteristics of soils treated with hydrated lime and portland cement, to evaluate the importance of pulverization for the unconfined compressive strength of soils treated with portland cement, and to determine the effect of compactive effort.

The experimental program involved three soils, two stabilizing agents (hydrated lime and portland cement), two levels of treatment, two levels of pulverization, two levels of compaction, two levels of moisture conditioning, and a range of curing times.

Materials

Soils

Three Texas soils were used in the study. Two of the soils were from Dallas County and are described as Dalco sandy clay and Dalco clay. The third soil was from Harris County near Houston and is described as Beaumont clay. The characteristics of the three soils are given in Table 1.

Additives

The three soils were treated with commercially available portland cement and hydrated lime. The cement was Type I portland cement manufactured by Alamo Cement Company of San Antonio, Texas. The lime was hydrated lime manufactured by Austin White Lime Company of Austin, Texas.

The three soils were treated with 4 and 7 percent portland cement or hydrated lime, based on the dry weight of the soil. These treatment levels would be expected to fully stabilize the lime-treated soils and modify the cement-treated soils. However, these application rates are currently being used and compared.

Laboratory Procedure

The following laboratory procedures were used in an attempt to simulate field conditions.

TABLE 1 CHARACTERISTICS OF SOILS USED IN THIS STUDY

Soil	Liquid Limit	Plastic Limit	Plasticity Index	Minus No. 200 Sieve Material	Unified Soil Classification
Dalco clay	72	33	39	100	CH
Dalco sandy clay	27	16	11	49	SC
Beaumont clay	60	24	36	100	CH

Pulverization

The soils were oven-dried at 110°F for 5 days. The soils were then pulverized and separated on the 3/4-in. sieve and the No. 4 sieve. The three soil sizes were combined to produce soils that satisfied the following gradation requirements:

- Pulverized: 100 percent passing the No. 4 sieve and
- Unpulverized: 85 percent passing the No. 4 sieve and 15 percent passing the 1 1/2-in. sieve and retained on the 3/4-in. sieve.

Treatment

Portland Cement Four or seven percent cement was added to the dry soil along with sufficient water to produce the optimum moisture content for the cement and soil mixture. The soil and cement were mixed for approximately 5 min using a 1-ft^3 Lancaster automatic mixer. The soils were compacted immediately after mixing without curing, which simulates the current practice of cement modification of clay soils.

Hydrated Lime Four or seven percent hydrated lime was added to the soil in the form of a lime-water slurry. The amount of water was equal to that required to produce the optimum water content for the mixture. The soil and lime were mixed for approximately 5 min using the Lancaster mixers. The lime-treated mixtures were placed in plastic bags and allowed to mellow (cure) for 3 days before compaction. This curing procedure, which may not be required if adequate pulverization can be obtained, is similar to the procedure often used in lime stabilization construction.

No Treatment The soil was mixed at the optimum water content for approximately 5 min. Compaction occurred immediately after mixing.

Compaction

The three treated and untreated soils were compacted at the optimum moisture for maximum dry density using the following compactive efforts and procedures:

Dalco sandy clay: Modified Proctor (ASTM D 1557)
Dalco clay: Modified Proctor (ASTM D 1557)
Beaumont clay: Modified Proctor (ASTM D 1557)
Standard Proctor (ASTM D 688)

As previously mentioned, the untreated and cement-treated soils were compacted immediately after mixing without a curing period, and the lime-treated soils were compacted after a 3-day mellowing period. Additional water was added, as needed, to bring the mixture to the optimum water content for compaction.

Curing

One set of specimens was tested immediately after compaction and served as a control. All of the other specimens were wrapped in plastic to prevent loss of moisture and were placed in a room at 72°F and 65 percent relative humidity. Specimens were under these conditions for periods of 0, 7, 28, or 119 days. After the initial curing period, the specimens to be subjected to wetting were unwrapped, removed, and placed on porous stones in a pan of water in a room at 100 percent humidity for 7 days. The specimens to be tested in the dry condition were allowed to cure for an additional 7 days. Thus the total cure times were 7, 14, 35, and 126 days, except for the specimens tested immediately after compaction (Table 2).

TABLE 2 CURING TIMES

Cure	Days				
Initial	0	0	7	28	119
Additional	0	7	7	7	7
Total	0	7	14	35	126

Testing

Immediately after the prescribed total curing period, the specimens were tested in unconfined compression according to ASTM D 1663. Specimens were loaded at a constant deformation rate of 0.115 in./min at 75°F, and the load and corresponding vertical deformations were recorded on an X-Y plotter.

Properties Analyzed

Plasticity characteristics (Atterberg limits) and unconfined compressive strengths were determined for the treated and untreated soils.

Atterberg Limits

The liquid limit, plastic limit, and plasticity index were determined immediately after treatment for portland cement and after a 3-day mellowing period for hydrated lime.

Unconfined Compressive Strength

The unconfined compressive strength was determined over the range of curing times. Tests were conducted on both dry and wet specimens as described under curing.

Experiment Design

A summary of the experimental design is given in Table 3. Two replicate specimens per cell or test condition were tested as indicated by the numbers. The specimens for the longer-term curing conditions were prepared first in order to minimize the time required for the study. All treatment levels were coded to minimize bias during testing.

PRESENTATION OF RESULTS

The primary objective of this study was to compare the strength and plasticity characteristics of three cement-treated and lime-treated Texas soils. Unconfined compression tests on compacted specimens were used to evaluate the strengths of the treated soils. The strengths of dry and wet specimens were compared to establish the moisture susceptibility, or retained strength, of the treated soils. The importance of pulverization for the strength of cement-treated soils and the effects of the degree of compactive effort on both cement-treated and lime-treated soils were evaluated.

Atterberg Limits

Both cement and lime produced no change or a slight increase in the liquid limits and a large increase in the plastic limits, thus producing a significant decrease in the plasticity indexes of the treated soils.

TABLE 3 EXPERIMENTAL DESIGN FOR UNCONFINED COMPRESSION TESTS

Soil	Compactive Effort	Moisture Condition	Total Cure Time (days)	Untreated Pulverized at 0%	Cement-Treated[a] Pulverized 4%	Cement-Treated[a] Pulverized 7%	Cement-Treated[a] Unpulverized 4%	Cement-Treated[a] Unpulverized 7%	Lime-Treated[a] Pulverized 4%	Lime-Treated[a] Pulverized 7%
Dalco clay	Modified Proctor	Dry	0	2	2	2	–	–	2	2
			7	2	2	2	2	2	2	2
			14	2	2	2	2	2	2	2
			35	2	2	2	2	2	2	2
			126	2	2	2	2	2	2	2
		Wet	7	2	2	2	2	2	2	2
			14	2	2	2	2	2	2	2
			35	2	2	2	2	2	2	2
			126	2	2	2	2	2	2	2
Beaumont clay	Modified Proctor	Dry	0	2	–	2	–	–	–	2
			7	2	–	2	–	–	–	2
			14	2	–	2	–	–	–	2
			35	2	–	2	–	–	–	2
			126	2	–	2	–	–	–	2
		Wet	7	2	–	2	–	–	–	2
			14	2	–	2	–	–	–	2
			35	2	–	2	–	–	–	2
			126	2	–	2	–	–	–	2
	Standard Proctor	Dry	0	2	2	2	2	2	2	2
			7	2	2	2	2	2	2	2
			14	2	2	2	2	2	2	2
			35	2	2	2	2	2	2	2
			126	2	2	2	2	2	2	2
		Wet	7	2	2	2	2	2	2	2
			14	2	2	2	2	2	2	2
			35	2	2	2	2	2	2	2
			126	2	2	2	2	2	2	2
Dalco sandy clay	Modified Proctor	Dry	0	2	2	2	2	2	2	2
			7	2	2	2	2	2	2	2
			14	2	2	2	2	2	2	2
			35	2	2	2	2	2	2	2
			126	2	2	2	2	2	2	2
		Wet	7	2	2	2	2	2	2	2
			14	2	2	2	2	2	2	2
			35	2	2	2	2	2	2	2
			126	2	2	2	2	2	2	2

NOTE: Total specimens = 428.

[a]Additive expressed as percentage by dry weight of soil.

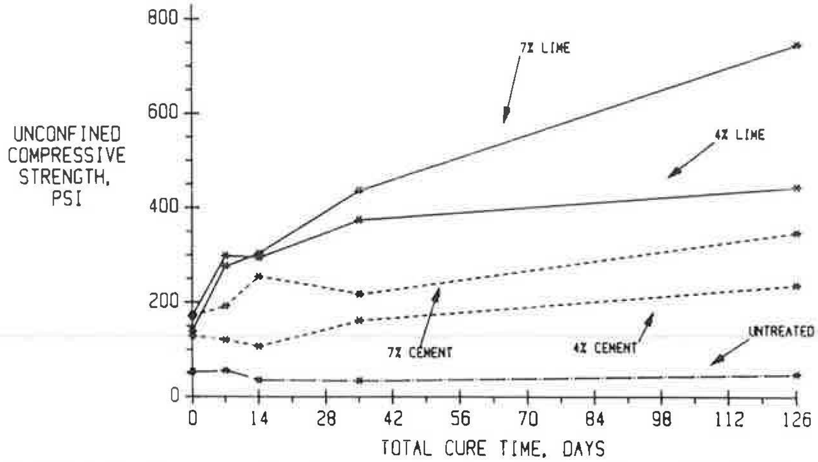

FIGURE 1 Dry unconfined compressive strength for pulverized Dalco clay treated with cement or lime (modified AASHTO).

The higher-plasticity Dalco clay exhibited approximately a 50 percent decrease in the plasticity index, whereas Beaumont and Dalco sandy clays exhibited lower reductions in plasticity indexes. The lime was slightly more effective in reducing the plasticity index; however, except for the Dalco sandy clay, the differences were of no practical significance.

Unconfined Compressive Strength

The relationships between unconfined compressive strength and total cure time are shown in the figures. In general, both cement and lime treatment increased the strengths of the three soils. In addition, the strength tended to increase with increased curing time.

Pulverized Soil

The effect of cement and lime treatment of soils that were pulverized to 100 percent passing the No. 4 sieve was dependent on soil type, or soil plasticity, and the compactive effort used to produce the specimens.

Dalco Clay Lime-treated Dalco clay specimens exhibited significantly higher strengths than did the cement-treated specimens when tested in either the dry or the wet condition.

The dry unconfined compressive strengths (Figure 1) of the 4 and 7 percent lime-treated Dalco clay were relatively high with 126-day strengths of approximately 450 and 750 psi, respec-

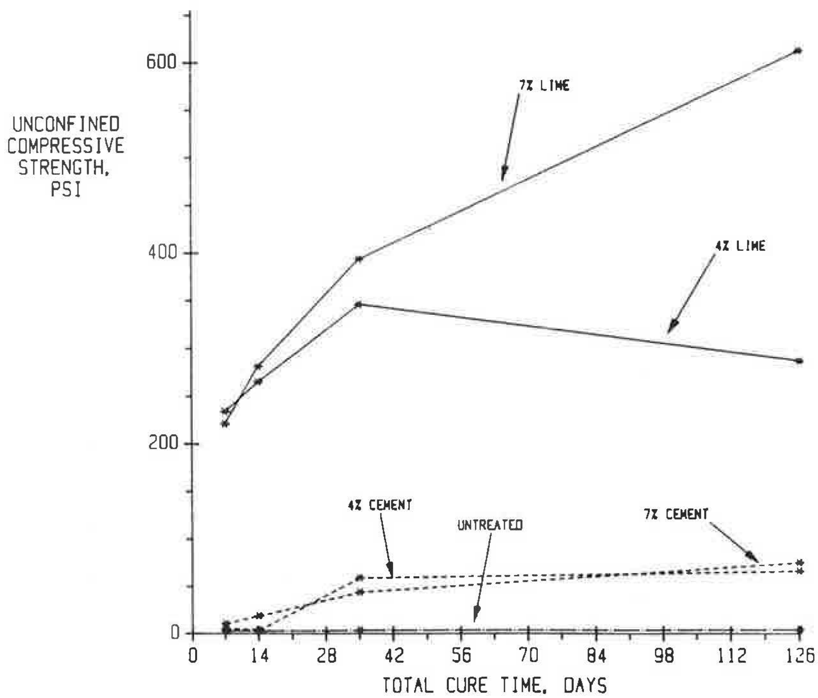

FIGURE 2 Wet unconfined compressive strength for pulverized Dalco clay treated with cement or lime (modified AASHTO).

FIGURE 3 Failure of cement-treated specimens before testing.

tively. The 4 and 7 percent cement-treated clays exhibited 126-day strengths of about 240 and 350 psi, respectively.

The wet cement-treated soil (Figure 2) had low strengths at 7 and 14 days of total curing, and in some cases the specimen could not be tested (Figure 3). The strengths increased with further curing but were still less than 80 psi after 126 days. In comparison, the 4 and 7 percent lime-treated soils had wet strengths of 286 and 612 psi, respectively, after 126 days.

Thus, for the dry condition, the strengths of the lime-treated specimens were approximately two times stronger than those of the cement-treated specimens. For the wet specimens (Figure 2), however, the differences were much greater and in some cases the lime-treated clays were 10 times stronger than the cement-treated material. Indeed, the wet-conditioned compressive strengths of lime-treated soils were greater than the dry-conditioned strengths of the cement-treated soils at both 4 and 7 percent treatment levels (Figures 4 and 5). These trends were evident throughout the 126-day curing period.

Beaumont Clay The modified compacted Beaumont clay in the dry condition had essentially equal strengths when treated with 7 percent cement or lime (Figure 6). After 126 days of curing, however, the lime-treated soils were slightly stronger than the cement-treated soil. When tested in the wet condition, the strength of the lime-treated soils greatly exceeded the strength of the cement-treated soil, indicating a significant loss of strength for the cement-treated specimens.

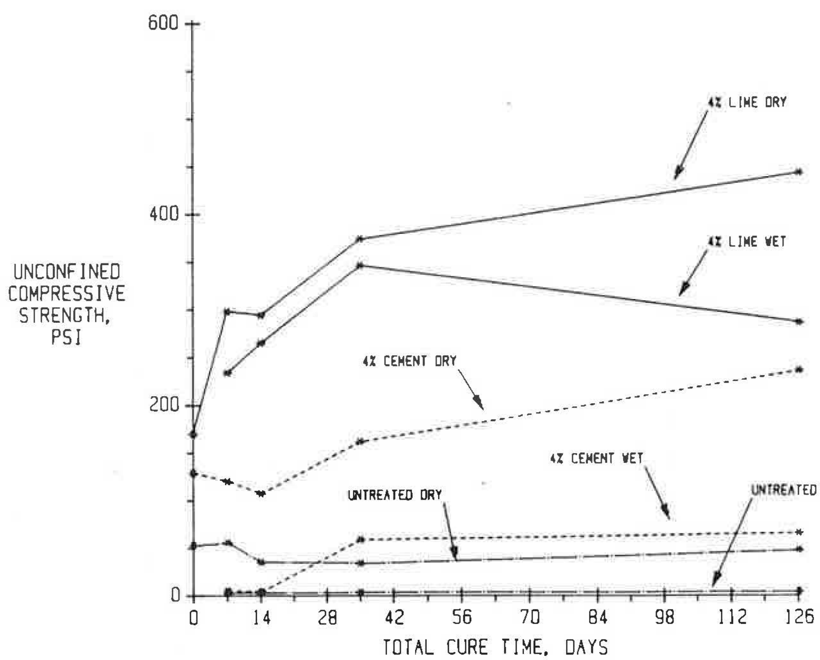

FIGURE 4 Dry and wet unconfined compressive strengths for 4 percent cement- and lime-treated pulverized Dalco clay (modified AASHTO).

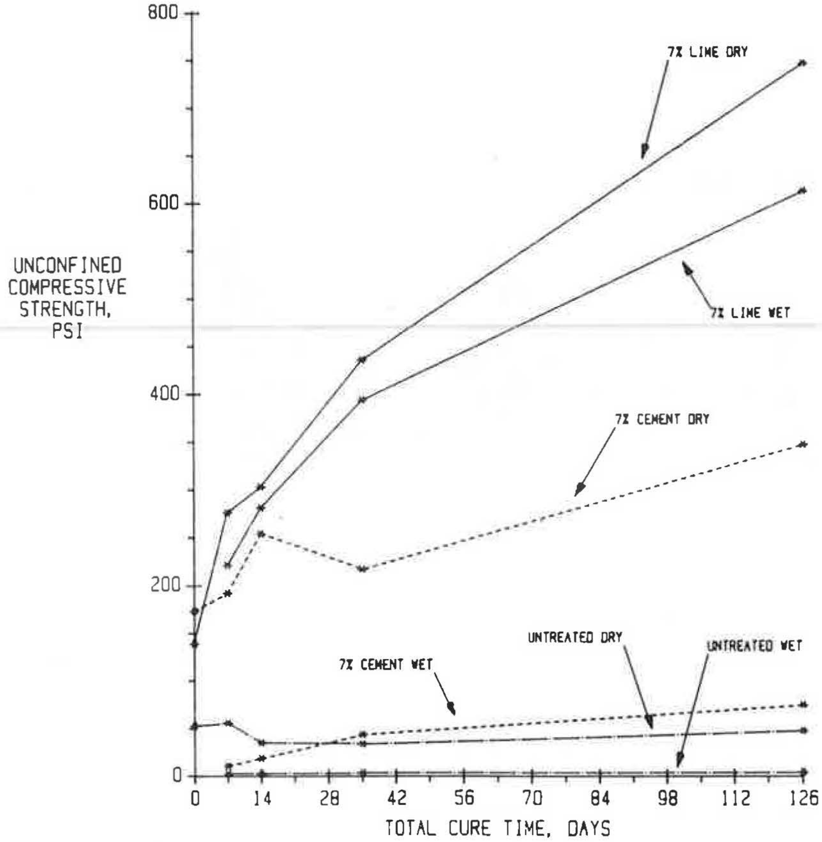

FIGURE 5 Dry and wet unconfined compressive strengths for 7 percent cement- and lime-treated pulverized Dalco clay (modified AASHTO).

In contrast, for the standard compacted Beaumont clay specimens tested in the dry condition, 4 and 7 percent cement-treated specimens exhibited greater strengths than 4 and 7 percent lime-treated specimens, respectively (Figure 7). When tested in the wet condition (Figure 8), the cement-treated specimens still had higher strengths, but the difference in strengths between the cement-treated and the lime-treated soils was slight (Figures 9 and 10). At 126 days, clay specimens treated with 7 percent lime were stronger.

Dalco Sandy Clay The relationships between strength and curing time are shown in Figures 11–14. Cement treatment of the Dalco sandy clay produced significantly greater strengths than did lime treatment in both the dry and the wet condition (Figures 11 and 12). After 126 days of curing, the dry strengths were 1,532 and 1,090 psi for the cement-treated specimens with 7 and 4 percent cement, and 478 and 372 psi for the lime-treated specimens. In the wet condition, after 126 days of curing, the strengths for the cement-treated specimens were about 720 and 400 psi, and strengths for the lime-treated specimens were about 260 and 220 psi. Thus a greater loss was exhibited for the cement-treated soils than for the lime-treated soils. Nevertheless, the cement-treated soils with both 4 and 7 percent cement were stronger than the lime-treated soils. This trend is basically opposed to the trends exhibited by the Dalco clay and is attributed to the coarser grain size and lower plasticity of the sandy clay.

Unpulverized Soil

It has been suggested that a high degree of soil pulverization is not necessary before the addition of portland cement. This in effect would leave small clods of soil coated with cement and would not allow the cement to be intimately mixed with the soil particles. Thus, for the cement-treated portion of the study, the soil was mixed with unpulverized soil as previously described.

The relationship between unconfined compressive strength and total cure time for unpulverized cement-treated specimens, along with the comparable relationships for pulverized soil, are shown in Figures 15–20. All of these relationships show substantially lower strengths for the unpulverized specimens than for the comparable pulverized specimens. For Beaumont clay, the effects of degree of pulverization were only examined for the standard compacted specimens.

The effects of inclusion of unpulverized clods were more pronounced in the wet-conditioned specimens. This was expected because during wet curing there was more available water to cause swelling of the clods. Swelling of the clods caused disruption of the specimens and thus lowered the unconfined compressive strength.

The effects of the inclusion of unpulverized clods were more

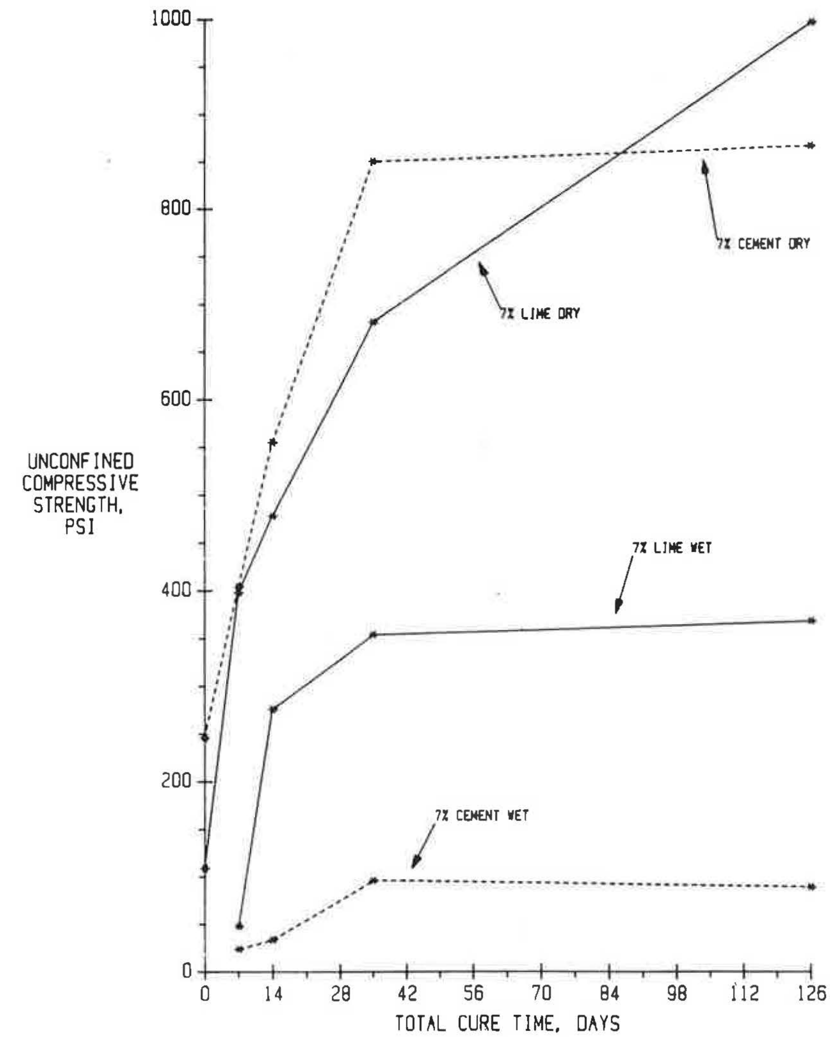

FIGURE 6 Dry and wet unconfined compressive strengths for 7 percent cement- and lime-treated pulverized Beaumont clay (modified AASHTO).

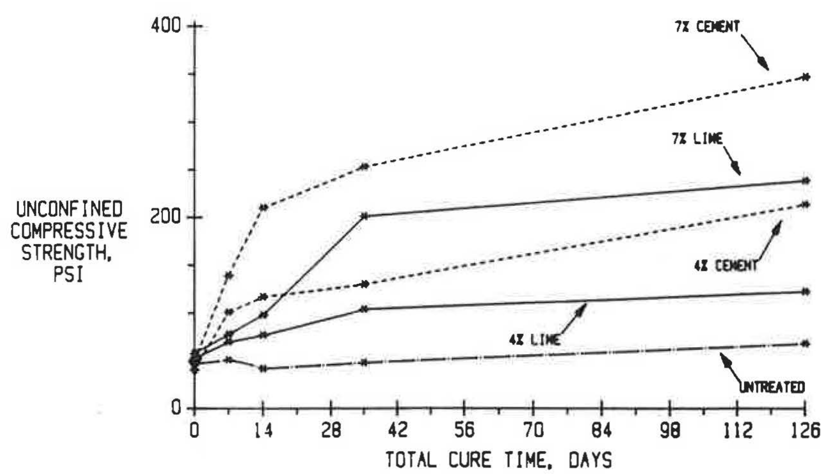

FIGURE 7 Dry unconfined compressive strengths for pulverized Beaumont clay treated with cement or lime (standard AASHTO).

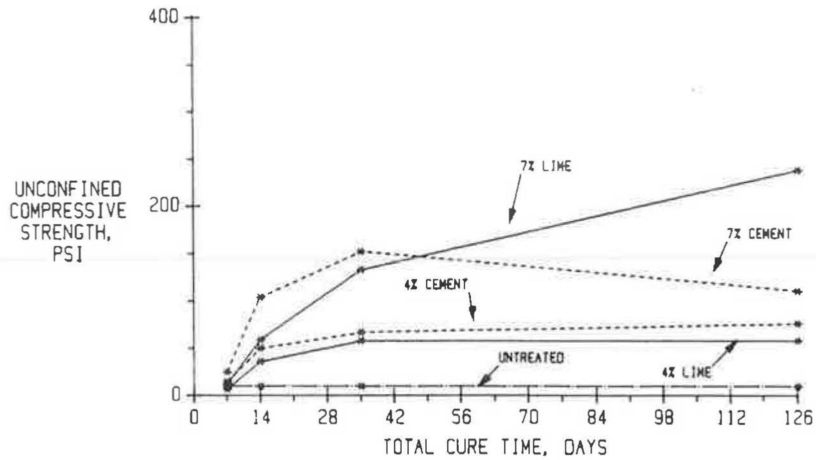

FIGURE 8 Wet unconfined compressive strengths for pulverized Beaumont clay treated with cement or lime (standard AASHTO).

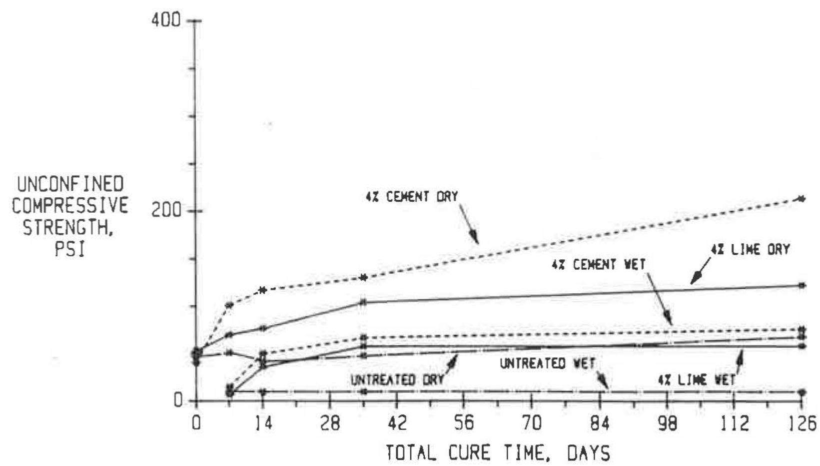

FIGURE 9 Dry and wet unconfined compressive strengths for 4 percent cement- and lime-treated pulverized Beaumont clay (standard AASHTO).

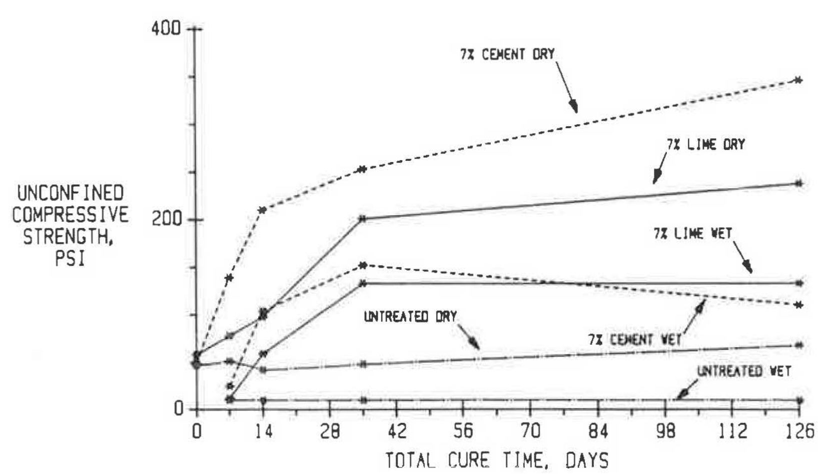

FIGURE 10 Dry and wet unconfined compressive strengths for 7 percent cement- and lime-treated pulverized Beaumont clay (standard AASHTO).

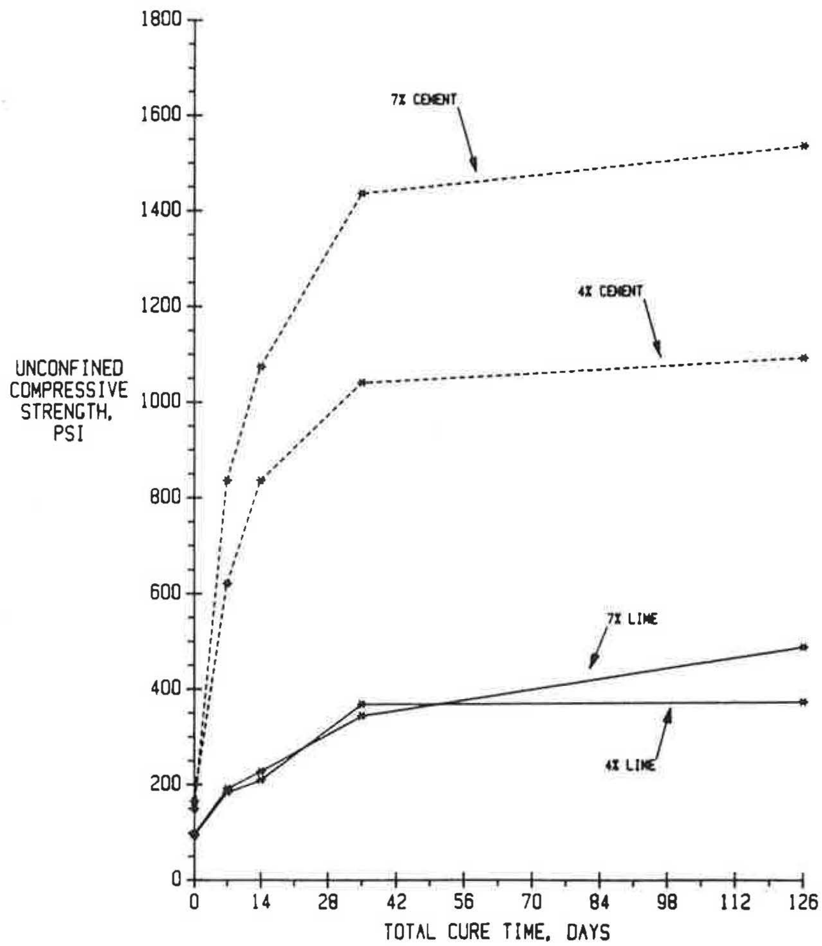

FIGURE 11 Dry unconfined compressive strength for pulverized Dalco sandy clay treated with cement or lime (modified AASHTO).

pronounced in the high-plasticity clays. The cement-treated Beaumont clay and Dalco clay had greater reductions in strength for the unpulverized specimens, especially the wet-conditioned specimens. Still, the very sandy clay, Dalco sandy clay, showed significant strength losses when unpulverized and pulverized specimens were compared.

Effects of Compactive Effort

The unconfined compressive strengths of standard and modified compacted 7 percent treated Beaumont clay specimens were compared to examine the effects of the degree of compactive effort. Unconfined compressive strength–total cure time relationships are shown in Figures 21 and 22.

In the dry condition, the increase from standard to modified compactive effort produced a two- to threefold increase in strength for the lime- and cement-treated specimens. In the wet condition, the increase in compactive effort produced a similar increase in strength for the lime-treated specimens. The modified compacted cement-treated specimens' strengths were actually about 35 percent lower than the standard compacted cement-treated specimens' strengths.

The high-plasticity Beaumont clay has a tendency to swell in the presence of water unless a stabilization treatment reduces this tendency. An increase in compactive effort produces an increase in swell pressure along with an increase in the density of a clay. The modified compacted cement-treated specimens appeared to have the swell pressure from water content increase superimposed on the increased swell pressure from the higher compactive effort. This increased swell pressure caused disruption of the modified compacted cement-treated specimens, leading to low strengths. The lime-treated modified compacted specimens did not show a decrease in strength from the standard compacted specimens when both were tested in the wet condition. It has to be assumed that the lime treatment reduced the tendency of this soil to swell in the presence of water.

CONCLUSIONS

The following conclusions are based on the findings of this study and the conditions evaluated.

Unconfined Compressive Strength

1. Lime treatment produced higher strengths than did cement treatment for the modified compacted high-plasticity

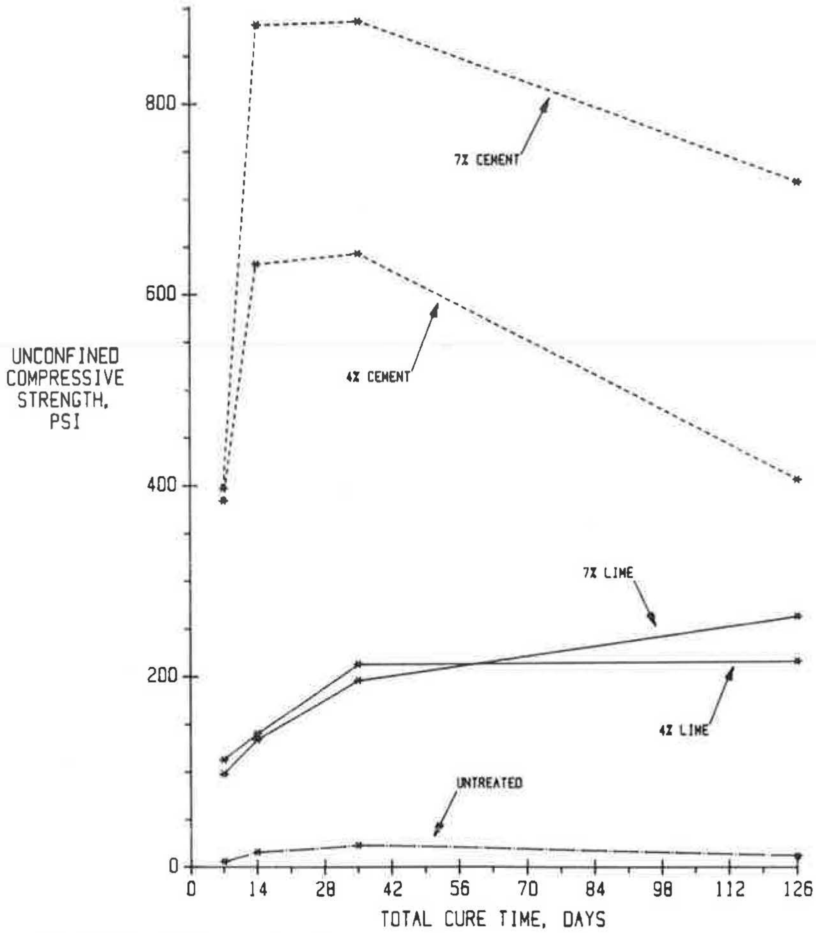

FIGURE 12 Wet unconfined compressive strength for pulverized Dalco sandy clay treated with cement or lime (modified AASHTO).

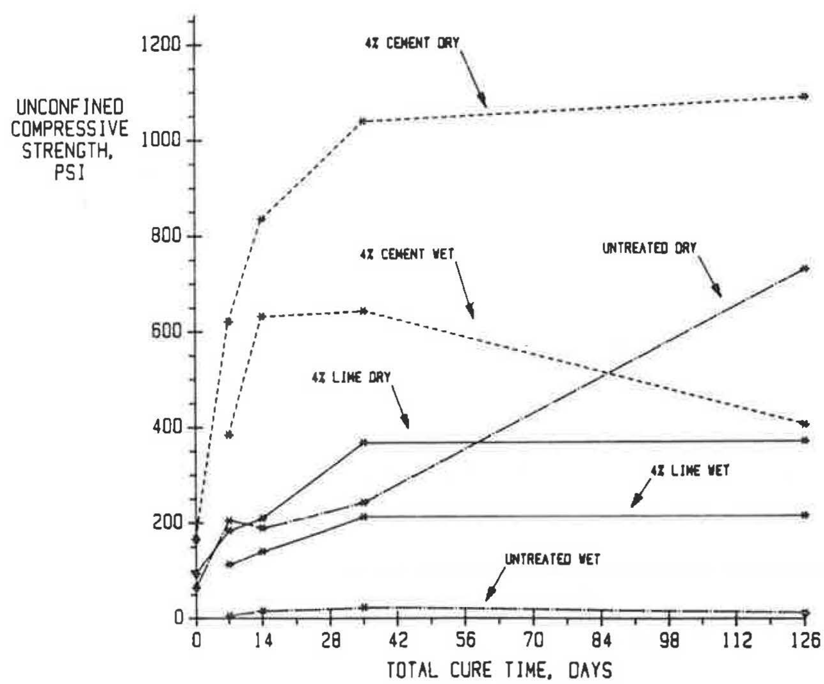

FIGURE 13 Unconfined compressive strength for pulverized Dalco sandy clay treated with 4 percent cement and lime (modified AASHTO).

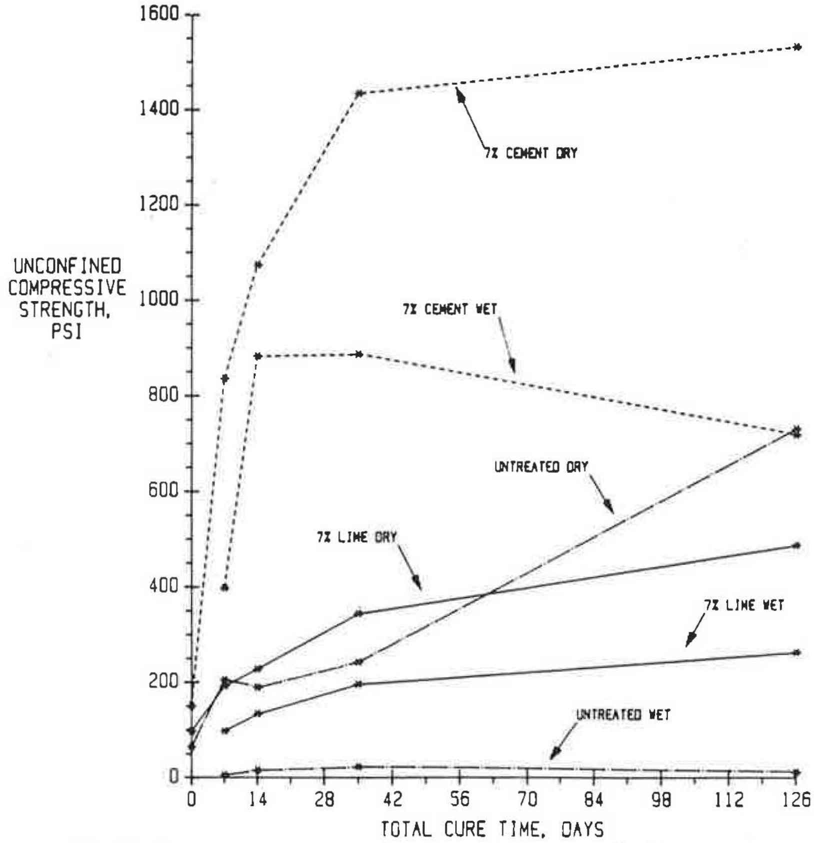

FIGURE 14 Unconfined compressive strength for pulverized Dalco sandy clay treated with 7 percent cement and lime (modified AASHTO).

Dalco and Beaumont clays. Significantly higher strengths were obtained from wet condition tests.

2. Cement treatment produced significantly higher strengths than did lime treatment for the modified compacted, low-plasticity, Dalco sandy clay. Higher strengths were obtained in both dry and wet condition tests.

3. Similar strength results were obtained from the cement- and lime-treated standard compacted Beaumont clay.

4. Wet-conditioned, modified compacted, cement-treated Dalco or Beaumont clays had low strengths. Extremely low strengths were recorded at total cure times of 7 and 14 days.

Moisture Susceptibility

1. Lime treatment of the modified compacted high-plasticity clays provided a greater retention of their dry-conditioned

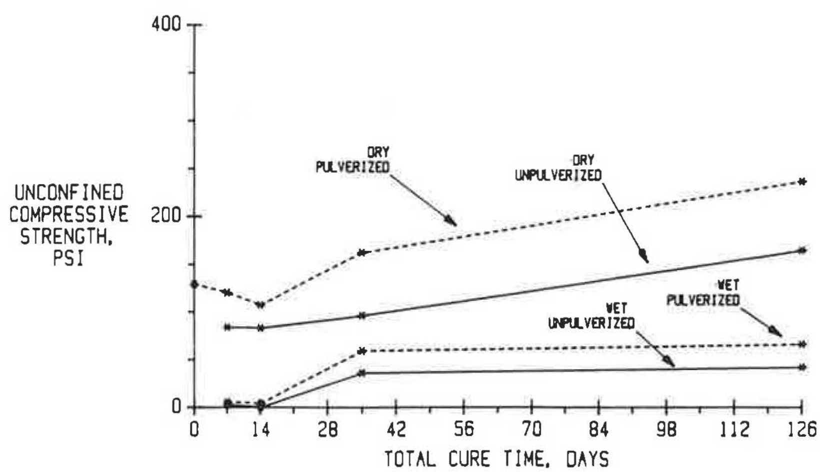

FIGURE 15 Effects of pulverization on dry and wet unconfined compressive strengths of 4 percent cement-treated Dalco clay (modified AASHTO).

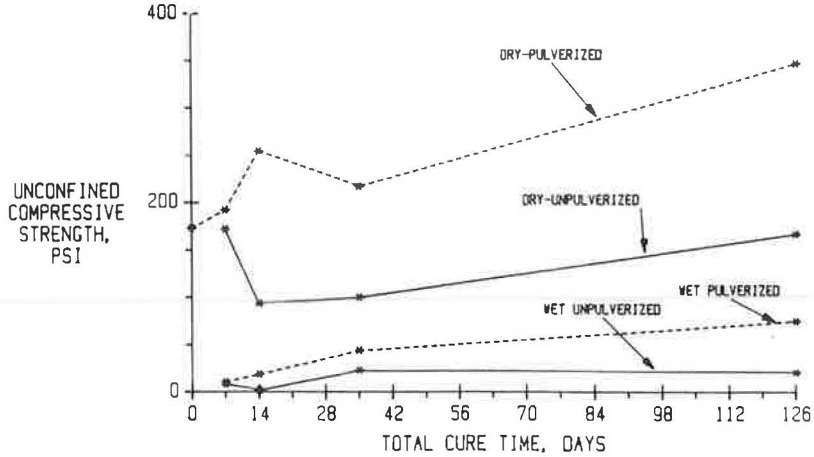

FIGURE 16 Effects of pulverization on dry and wet unconfined compressive strengths of 7 percent cement-treated Dalco clay (modified AASHTO).

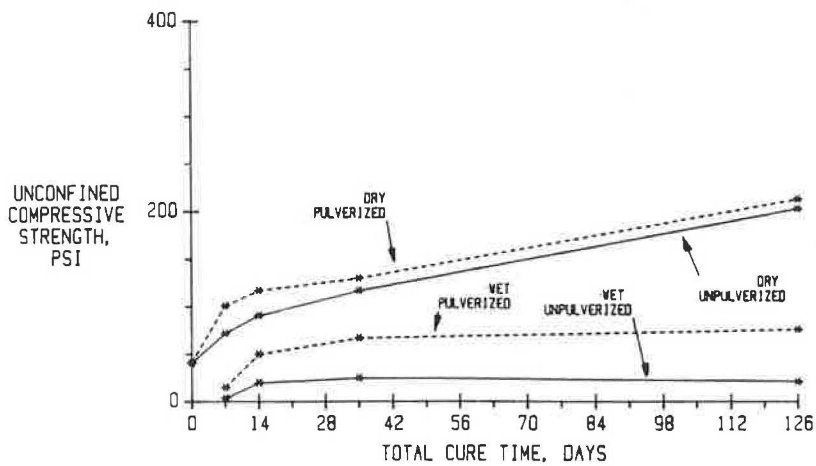

FIGURE 17 Effects of pulverization on dry and wet unconfined compressive strengths of 4 percent cement-treated Beaumont clay (standard AASHTO).

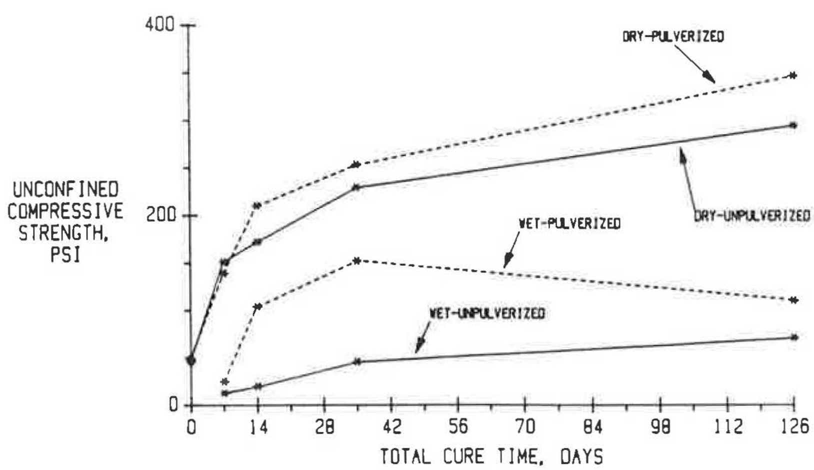

FIGURE 18 Effects of pulverization on dry and wet unconfined compressive strengths of 7 percent cement-treated Beaumont clay (standard AASHTO).

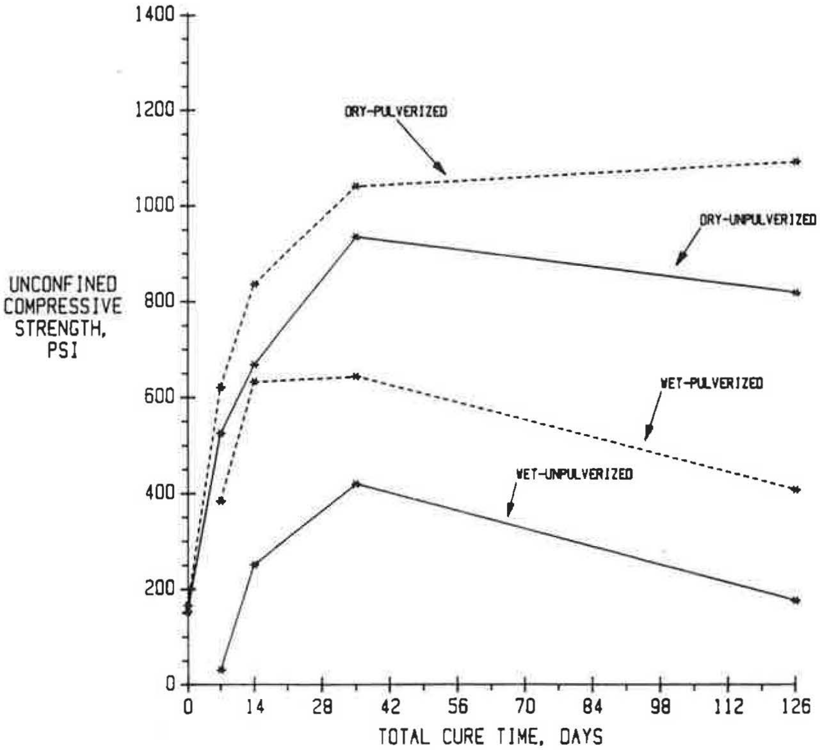

FIGURE 19 Effects of pulverization on dry and wet unconfined compressive strengths of 4 percent cement-treated Dalco sandy clay (modified AASHTO).

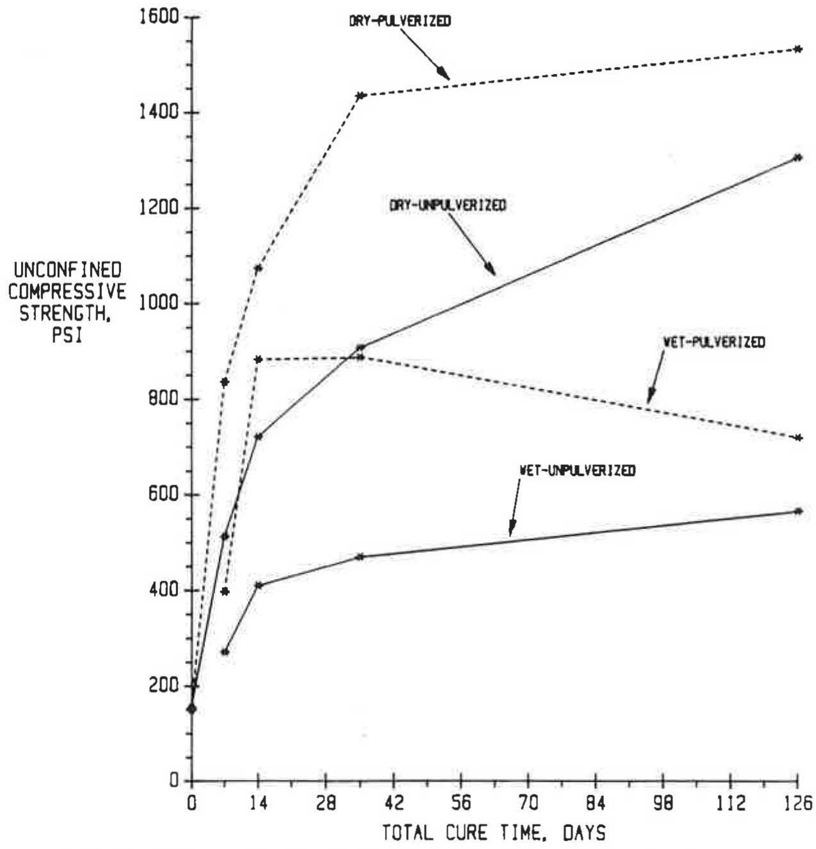

FIGURE 20 Effects of pulverization on dry and wet unconfined compressive strengths of 7 percent cement-treated Dalco sandy clay (modified AASHTO).

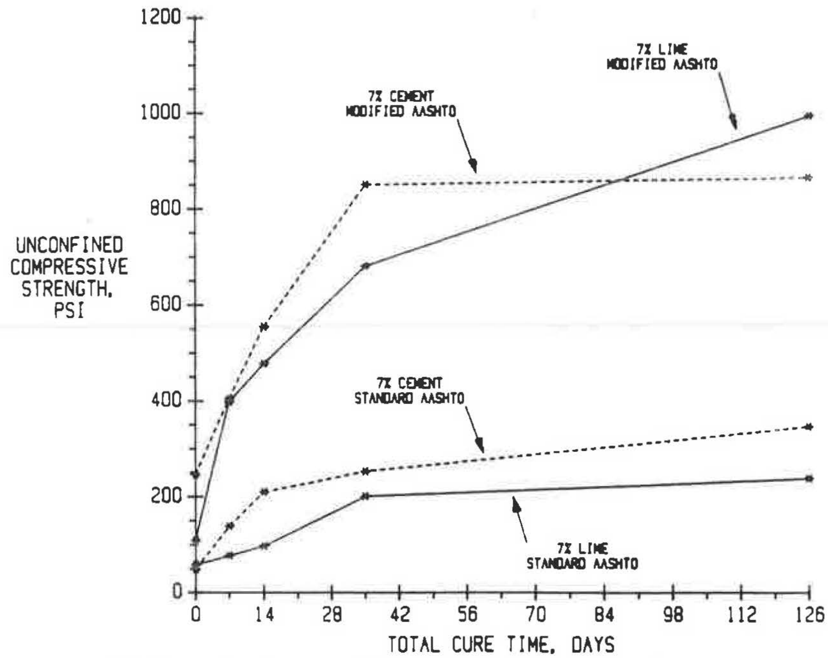

FIGURE 21 Unconfined compressive strength for dry, pulverized Beaumont clay, modified or standard AASHTO compaction with cement or lime.

strength when they were exposed to moisture. Lime treatment provided two to four times greater retention of strength than did cement treatment.

2. Lime-treated standard compacted Beaumont clay had slightly higher strength retention from the dry to the wet condition. Although cement treatment gives higher strengths for both dry and wet conditions than does lime, the amount of strength loss (difference between dry and wet strengths) is less for lime.

Effects of Degree of Pulverization

1. A small amount (15 percent) of unpulverized (3/4 in. to 1 1/2 in.) soil in a cement-treated soil mixture was found to cause a considerable loss in strength compared with a cement-treated completely pulverized (100 percent minus 1/4 in.) soil mixture. This trend was evident for all three soils tested.

2. Lower strengths were obtained for the wet- and dry-

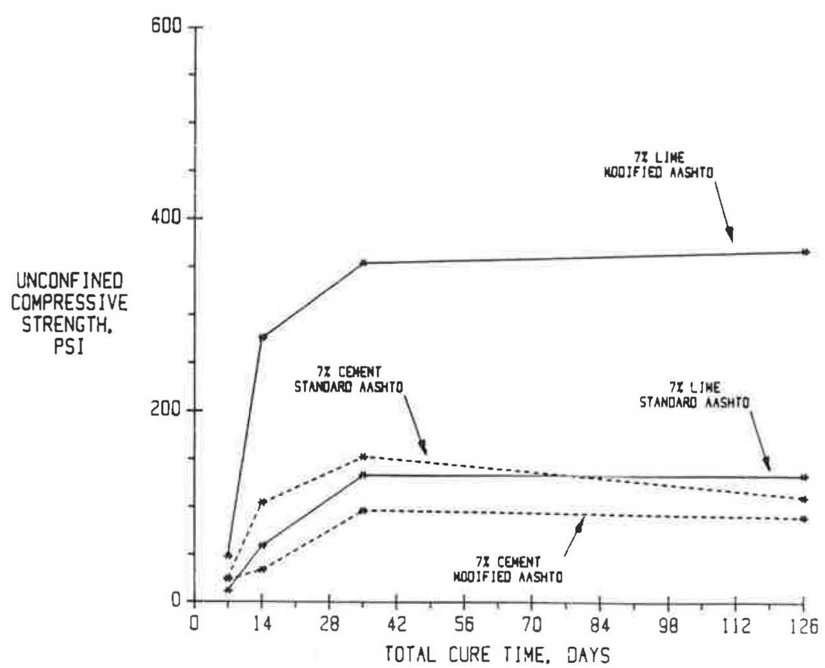

FIGURE 22 Unconfined compressive strength for wet, pulverized Beaumont clay, modified or standard AASHTO compaction with cement or lime.

conditioned unpulverized cement-treated soil specimens, but a larger decrease in strength was observed in the wet-conditioned specimens.

3. Swelling of the dry unpulverized soil clods during curing was thought to be the major cause of distress in the specimens, which led to lower strengths.

Effects of Degree of Compactive Effort

1. Dry-conditioned compressive strengths increased greatly for the lime- or cement-treated Beaumont clay when the compactive effort was increased from standard to modified compactive effort.

2. Wet-conditioned strengths decreased greatly for the cement-treated Beaumont clay when the compactive effort was increased from standard to modified compactive effort. Lime-treated Beaumont clay's wet-conditioned compressive strengths increased about the same percentage as did the dry-conditioned strengths with increased compactive effort.

3. Increased swelling pressure induced by the increased compactive effort was thought to be the cause of the loss of strength in the wet-conditioned cement-treated clay specimen.

4. Lime treatment appeared to reduce the swelling tendencies of the expansive Beaumont clay whereas the cement treatment did not.

Summary

On the basis of the results and conditions of this test program, lime treatment of the expansive high-plasticity soils was more favorable for compressive strength attainment than was cement treatment of these soils. In general, lime treatment produced higher dry-conditioned strengths, but the major advantage was in the wet-conditioned strengths. Lime treatment provided significantly better resistance to moisture damage when these soils were compacted by the modified AASHTO compactive effort.

Cement treatment of the low-plasticity sandy clay produced significantly higher compressive strengths than did lime treatment of this soil.

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