COLD WEATHER LIME STABILIZATION

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In recent years, lime stabilization of poor quality subgrade soils to upgrade quality or provide acceptable subbase material has increased in popularity as a construction alternative. However, in many situations, specifications relative to cutoff dates for lime stabilization construction have rendered the alternative unfeasible. Previous studies have revealed that soil-lime mixtures cured prior to subjection to freeze-thaw conditions undergo autogenous healing that resulted in continued strength gain. The purpose of this study was not to evaluate the ramifications of autogenous healing of soil-lime mixtures but to evaluate the behavior of soil-lime mixtures subjected to cold weather stabilization. The basic premise involved in this study was that soil-lime mixtures subjected to freeze-thaw conditions immediately after compaction would not undergo pozzolanic reactions until favorable curing conditions were attained. Soil-lime reaction that would not occur during cold weather treatment would then be renewed under favorable conditions to produce latent strength gains. The scope of this study involved the investigation of the behavior of only one soil subjected to cold weather lime stabilization. The selected soil was evaluated at only one lime content, which was established as the stabilization lime content for that soil.

•STRENGTH GAINS associated with lime stabilization of clayey soils are derived primarily from cementitious bonds developed as a result of pozzolanic reactions. Pozzolanic reactions are lime-soil reactions involving calcium ions that are provided in the form of high-calcium lime and natural pozzolans in clayey soils that are hydrates of silica and alumina. The rate of reaction is highly dependent on reaction temperature as are other less complex chemical reactions.

Anday (1, 2) conducted studies on curing lime-stabilized Virginia soils and revealed that pozzolanic reactions, thus strength gains, were curtailed below temperatures of approximately 50 F (283 K). Through these studies, he found that only one strength-maturity curve could be expected for a given lime-stabilized soil provided that the minimum temperature required for lime-soil reaction exists. Inasmuch as 50 F (283 K) was observed to be approximately the minimum requirement, his data revealed that a maturity of 750 degree-days [calculated with 50 F (283 K) as the datum temperature] is required to develop strength gains in the field. (A requirement for development of approximately 750 degree-days after lime stabilization should be used only when cementation by pozzolanic reaction is required or desired.)

Autogenous healing is the phenomenon that occurs when pozzolanic reactions occur along newly exposed reaction surfaces, thus producing cementitious bonding along fractures and failure planes. Studies conducted by Thompson and Dempsey (3) revealed that autogenous healing occurred in cured lime-soil mixtures after they were subjected to freeze-thaw cycles. Samples tested in this study were rapidly cured for 2 days at 120 F (322 K) before freeze-thaw testing. Unconfined compression tests were conducted immediately after freeze-thaw cycles and at various time periods after completion of freeze-thaw tests. Results of these tests revealed increased strength with time as a result of autogenous healing.

Evaluation of frost parameters in freeze-thaw testing of soil-lime mixtures proved to be quite variable in relation to climatic conditions, geographical location, and the

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position of stabilized materials in the pavement section (4, 5). From these results it is evident that, with current knowledge, the testing of lime-stabilized materials should be correlated with local climatic conditions. Although there exists a wide variety of frost parameters throughout the United States, a standard laboratory testing procedure for freeze-thaw testing should be developed and standardized for lime-stabilized materials.

MATERIALS AND TESTS

The residual limestone material used in the study was obtained from a depth of approximately 10 ft (3.0 m) below the surface in an excavation located west of Knoxville, Tennessee. The soil was classified as a CH material according to the unified classification system and as an A-7-6(11) material according to the AASHTO classification system. Some of the physical properties of the soil are as follows: specific gravity, 2.72; liquid limit, 64; plastic limit, 40; plasticity index, 24; and percentage of material passing sieve No. 10, 100; No. 40, 96; No. 80, 78; No. 200, 50; and 0.02 mm, 42.

The percent high-calcium, hydrated lime used in stabilizing the soil was established by means of the pH method recommended by Eades and Grim (6). Figure 1 shows the results of the pH tests on soil-lime slurries. Although 4 percent by dry weight of hydrated lime produced a pH of 12.5, a lime content of 6 percent was used for stabilization because this percentage was found to produce maximum 28-day strength gain under normal curing conditions.

A standard procedure was adopted for preparing soil-lime mixtures to ensure uniform moisture distribution during the compaction process. All specimens were compacted with a Harvard miniature compaction apparatus that used kneading compaction. Moisture contents and densities of all samples were held within 1 percent of optimum moisture content and 1 lb/ft^3 (16.01 kg/m^3) maximum density respectively. Test specimens were wrapped and sealed in wax immediately after compaction. Control specimens were subjected to normal curing for periods of 7, 14, 21, and 28 days. Other test specimens were subjected to various cycles of freezing and thawing.

Because no recommended or standard procedure for freeze-thaw testing of lime-soil mixtures exists, a procedure similar to that for soil-cement mixtures (AASHTO T 136-57) was adopted. Specimens were subjected to a temperature of 0 F (255 K) for a period of 24 hours before being thawed for the same period in a moist room at 73 F (296 K). Thus, a period of 48 hours was required for a complete freeze-thaw cycle. During the freeze-thaw testing, no attempt was made to prevent volume change of the specimens. Moisture contents and compacted moisture contents were the same after freeze-thaw testing.

Test specimens were subjected to freeze-thaw cycles ranging from one to six. Subsequent to freeze-thaw treatment, samples were tested by unconfined compression at intervals of 0, 7, 14, 21, and 28 days after normal curing.

At least three test specimens were used to establish each strength data point. Consequently, 18 specimens were tested from each sequence of freeze-thaw treatment.

RESULTS

Soil-lime mixtures subjected to adverse curing conditions immediately after compaction lay dormant until curing conditions conducive to lime-soil reactions were present.

Figure 2 shows compressive strengths for samples that were subjected to various cycles of freeze-thaw after curing under normal conditions. Because specimens subjected to freeze-thaw cycles were not restrained from volume change, there exists a significant loss of strength in all specimens at zero curing time. Samples subjected to three and six cycles of freezing were found to possess negligible compressive strength at 0 day's curing. Subsequent curing of freeze-thaw specimens produced rates of strength increase nearly the same as those for control specimens.

Although the freeze-thaw tests to which the samples were subjected are more severe than field conditions, results indicate that 28-day strength gains under normal curing conditions will be attained by lime-soil mixtures subjected to adverse curing conditions immediately after compaction, if conducive curing conditions do occur at some later

Figure 1. Results of pH tests on soil-lime slurries.

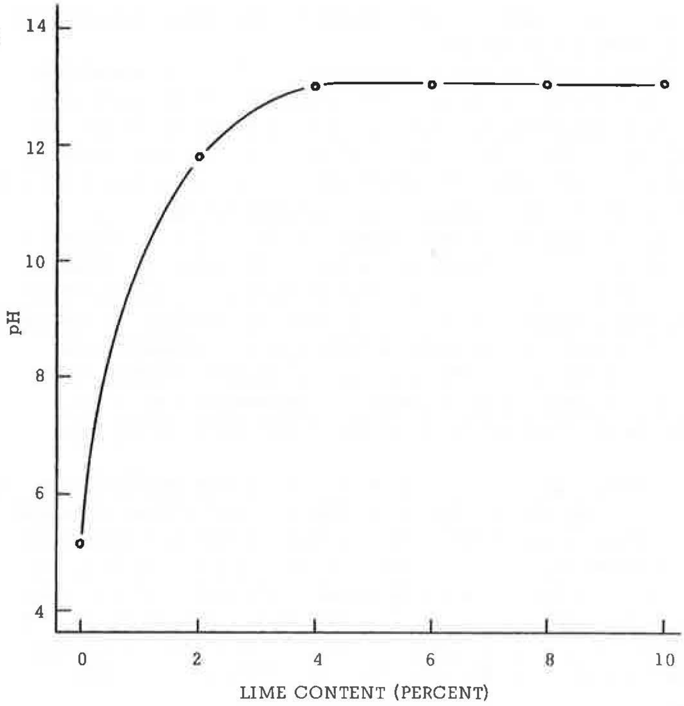
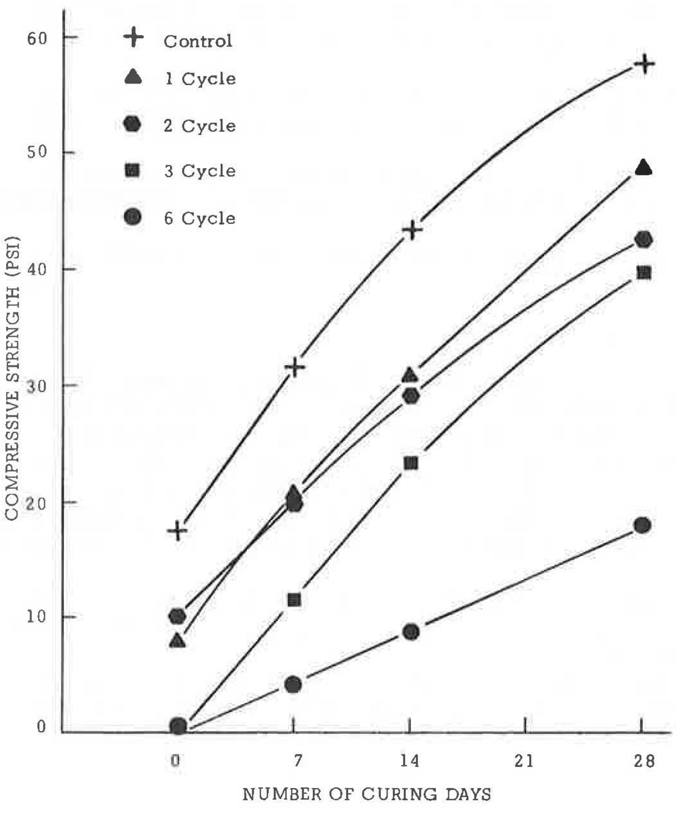


Figure 2. Compressive strengths of samples after normal curing and freeze-thaw cycles.



date. Consequently, pozzolanic reactions may be dormant during low temperatures but regain reaction potential under suitable temperatures.

Because 28-day compressive strength of lime-clay mixtures has become somewhat standard for relative strength comparisons, the 28-day strength gain of all specimens was analyzed as a percentage of the control specimens for various freeze-thaw cycles. Figure 3 shows the results of that evaluation. Results for this particular soil indicate that almost a linear relationship exists between relative strength and freeze-thaw cycles.

As previously mentioned, Anday found that approximately 750 degree-days [50 F (283 K)] were required for soil-lime mixtures to reach maturity in the field. Based on this hypothesis, an investigation of curing conditions in the Knoxville area was undertaken. When average air temperatures were used, lime stabilization could feasibly be continued into late fall if freezing temperatures during hours of construction did not prevent adequate mixing operations. Inasmuch as an accumulation of degree-days would continue well into winter months, no adverse effects should be expected relative to strength gains at maturity. Because ground temperatures are generally somewhat higher than air temperatures, the estimations of cold weather lime-soil curing are conservative.

If a relationship similar to that shown in Figure 3 were developed for particular soils, an approximation could be made regarding the curing time required to produce strength gains comparable to those under normal conditions. Generation of this type of information would allow cold weather lime treatment to be conducted when other climatological factors permitted. Soil-lime mixture would lie dormant during extreme weather conditions only to be renewed in favorable curing conditions. Construction practices of this nature would allow lime stabilization to be conducted well into winter months in areas where favorable climatic conditions exist, with the exception of ambient temperatures that may fall below freezing at night.

CONCLUSIONS

Based on data from this study, the following conclusions may be drawn:

1. Lime-stabilized soils subjected to extreme freeze-thaw conditions immediately after compaction undergo significant strength gains when curing conditions become favorable for pozzolanic reactions;
2. Residual strength gains obtained after severe freeze-thaw testing indicate that cold weather lime treatment may extend construction cutoff dates under certain conditions;
3. Development of realistic cutoff dates for lime stabilization should be based on local climatic conditions, soils, and performance requirements for lime-stabilized subgrades; and
4. Development of a standard procedure for freeze-thaw testing of lime-soil mixtures should be investigated.

CASE HISTORY

Expansion of the McGhee-Tyson Airport in Knoxville, Tennessee, involved the construction of a new terminal building with aprons and taxiways to service the new facility.

Pavement designs and compaction requirements for the aprons and taxiways were based on a 350-kip (1 556 878 N) dual-tandem wheel load, gross aircraft weight. The rigid pavement design consisted of 14 in. (35.6 cm) of portland cement concrete, 7 in. (17.8 cm) of cement-treated subbase, and 6 in. (15.2 cm) of lime-stabilized subgrade. The rigid pavement design was based on a modulus of subgrade reaction of the stabilized subgrade of 300 pci (8.3 kg/cm^3).

The natural subgrade soil used in construction of the lime-stabilized layer was a residual soil weathered from dolomitic limestone. This soil is highly plastic and is classified as an E-8 or an A-7-6 material.

The lime-stabilized subgrade was designed for 6 percent by dry weight of hydrated lime. Twenty-eight-day unconfined compressive strengths obtained from this design averaged 400 psi (28.1 kg/cm^2) when compacted at modified AASHTO density.

Figure 3. Results of evaluation of 28-day strength gain as a percentage of control specimens.

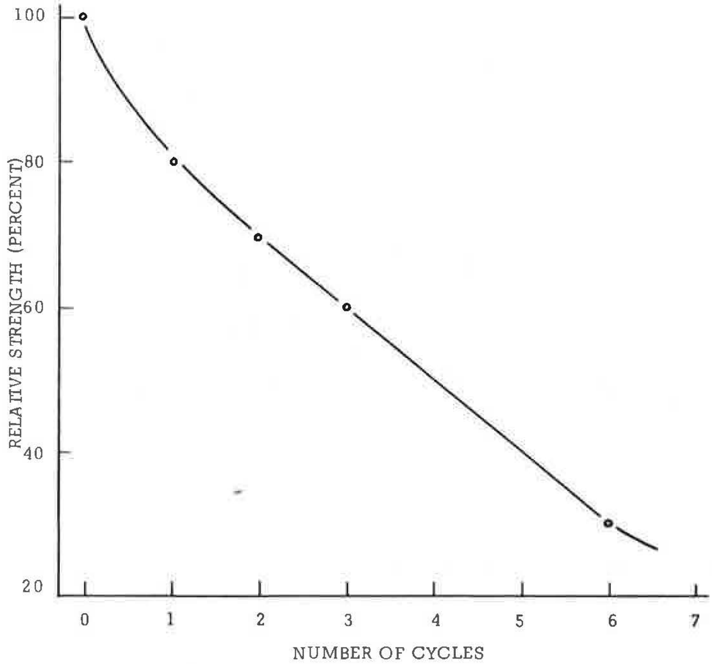


Figure 4. Results of plate bearing test for lime-stabilized subgrade.

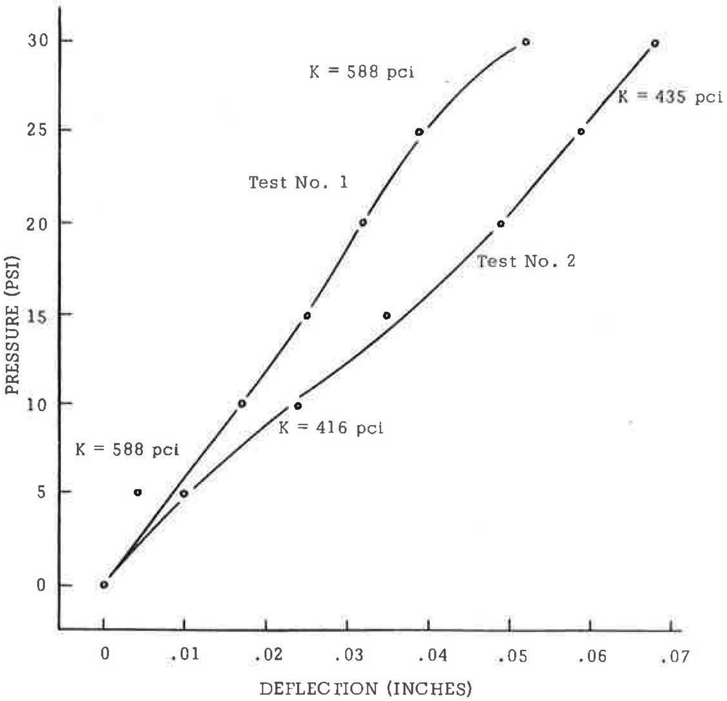


Figure 5. Cumulative degree-days versus time curves.

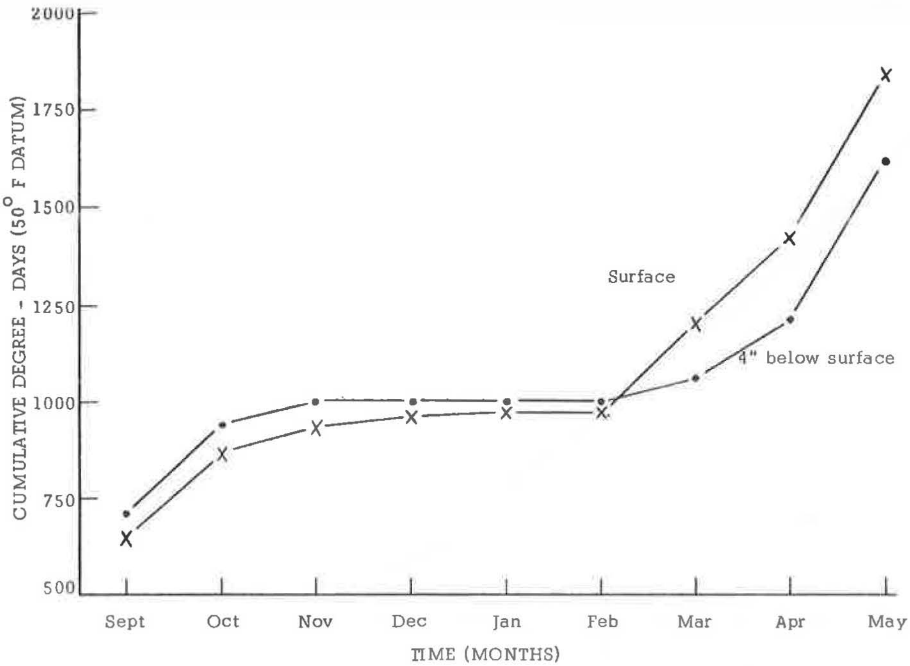
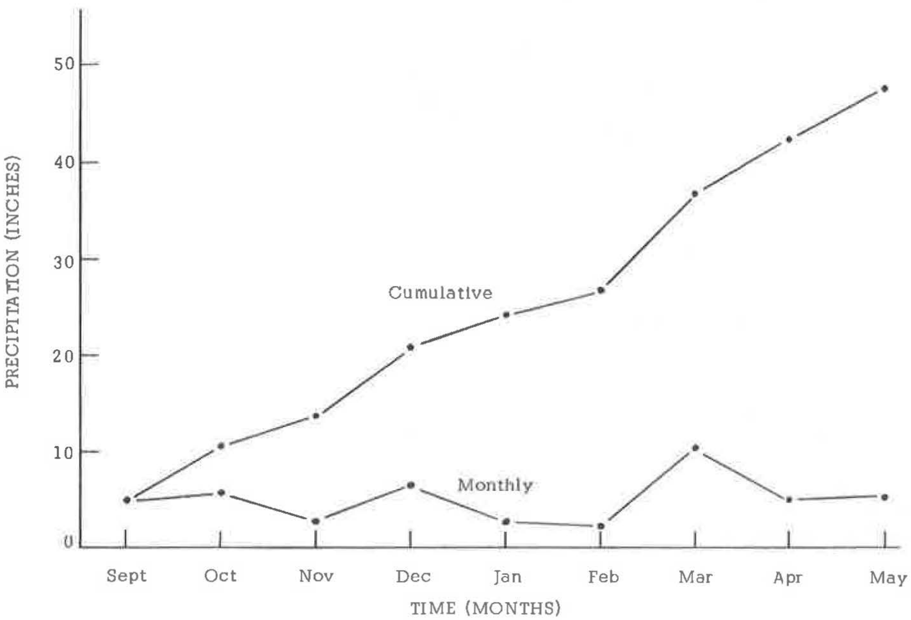


Figure 6. Precipitation versus construction time for McGhee-Tyson Airport.



Before the initiation of the lime stabilization construction, a test section was built to establish construction procedures and to ensure that a modulus of subgrade reaction in excess of 300 pci (8.3 kg/cm^3) would be obtained with the lime stabilization design. Figure 4 shows the results of the plate bearing test conducted on the test section. As indicated, the K-values obtained from two tests were in excess of 400 pci (11.1 kg/cm^3) with an average of 511 pci (14.2 kg/cm^3) resulting from the test. Modulus of subgrade reaction values obtained from six tests on natural soil averaged 100 pci (2.8 kg/cm^3).

Construction of the lime-stabilized subgrade began around September 1, 1972, and continued to mid-November 1972. During this period, approximately half the lime-stabilized subgrade was completed. Inspection of the cumulative degree-days versus time curves (Fig. 5) reveals that almost no curing occurred from November 1972 until February 1973 when the temperatures were such that degree-days of curing began to accumulate rapidly.

Performance of the lime-stabilized subgrade that was unprotected throughout the winter and spring clearly demonstrated the advantages of cold weather lime stabilization. During the period of dormancy, the lime-stabilized subgrade was subjected to a series of adverse conditions relative to both temperature and precipitation. As shown in Figure 6, approximately 48 in. (122 cm) of precipitation accumulated from September 1972 until May 1973 when construction was resumed. In March 1973, 10.25 in. (26 cm) of rainfall occurred giving rise to both a 50- and 100-year flood in east Tennessee.

Despite the extremely adverse conditions, the unprotected lime-stabilized subgrade protected the final grade from excessive erosion and saturation. The lime-stabilized subgrade layer was in excellent condition at the beginning of the 1973 construction season. After the excessive rainfalls in the spring, the stabilized subgrade was readied for application of the cement-treated subbase by rerolling to tighten the surface that had fluffed during periods of freezing.

Experience at the McGhee-Tyson Airport has demonstrated that lime-stabilized subgrade preparation late in the construction season is beneficial relative to protecting finished grades and expediting continued construction operations at the beginning of a new construction season.

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