

Lime-Soil Mixtures for Low-Volume Road Construction in Egypt

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Some experimental research findings on the application of hydrated lime to the superficial soils of the valley and delta of the Nile River for the purpose of low-volume road construction are described. Eight soil samples and one type of commercial lime were included in the experimental program. Statistical techniques were used to analyze the effects of lime content, curing temperature, curing time, and soil type on the increase in the unconfined compressive strength of lime-soil mixtures. Suggestions and guidelines for the use of hydrated lime to improve the properties of local soils and nearby paving materials are given in the conclusion.

The construction of low-volume, low-cost rural roads is receiving growing emphasis among the transportation officials in Egypt as part of its national development policy. These roads are planned and designed to encourage the economic development of rural localities, improve the mobility of rural residents, and help redistribute the population in order to relieve the severe urban problems that exist in large cities. Because of limited capital funds for road construction programs, highway engineers have sought the use of available low-cost stabilization materials to improve the properties of local soils and the nearby paving materials. The fact that limestone is an abundant resource in Egypt made hydrated lime a desirable stabilizing material in low-volume road construction.

This paper presents some experimental research findings on the application of hydrated lime to the soils of the valley and delta of the Nile River. The potential improvements in strength, plasticity, volume changes, durability, and workability that result from the addition of small amounts of lime to almost any fine-grained soil have been the subject of extensive research efforts and are reviewed and summarized elsewhere (1-3). However, the effects of applying lime to a particular soil cannot be exactly predicted without testing the individual soil in question. This is particularly relevant to the alluvial soils of the Nile River, which have experienced extensive advanced weathering during the trip from mid-east Africa to the Mediterranean.

Four reactions are reported in the literature to explain the mechanisms of lime-soil stabilization (4,5). These are the cation-exchange, flocculation, carbonation, and pozzolanic reactions. The first two reactions influence soil plasticity, volume changes, and workability, whereas the pozzolanic reaction is responsible for strength increase (4,5). Soil properties that affect the rate and magnitude of the pozzolanic reaction include clay mineralogy, organic carbon, percentage of clay fraction, exchange-complex characteristics, soil pH, and amounts of silica, alumina, iron oxide, free carbonates, free sulfates, and sodium enrichment (6-10). Other factors that influence the strength increase of lime-soil mixtures are lime content, curing conditions, and mixture density (2-4,11).

MATERIALS, TEST SPECIMENS, AND EXPERIMENTATION

Eight soil samples that represented the superficial soils of the Nile valley and delta were included in this study. The samples were taken from a depth of approximately 1 m (3.3 ft) below the ground surface and shipped to the laboratory in sealed containers to permit evaluation of the natural moisture con-

tent. Soils were air dried, hand crushed, sieved to finer than 4.75 mm (0.2 in) (no. 4 sieve), and stored for subsequent analysis. The engineering and mineralogical properties of the different soil samples are summarized in Table 1, and the chemical properties are presented in Table 2.

The lime used is a commercial-grade, high-calcium hydrated lime manufactured by the Cairo Sand Bricks Company. Analysis of the single lime batch used in this study showed 70.41 percent available calcium oxide and a maximum particle size of 0.037 mm (0.001 in) (no. 400 sieve).

Three levels of lime content--3, 5, and 7 percent by weight of the dry soil--were used in the experimental program. Test specimens from the natural soils and lime-treated soils were prepared by using a mold 10 cm high by 5 cm in diameter (4 by 2 in). Natural soils were thoroughly mixed with the appropriate amount of water and molded. Lime-treated soils were mixed in the dry state, and mixing continued while the proper amount of water was added. All specimens were compacted at optimum moisture content determined in accordance with ASTM C593. Compacted specimens were sealed and cured in a constant-temperature cabinet at 21°C and 60°C (70°F and 140°F). Curing periods were 3, 7, 14, 21, 35, and 56 days.

At the end of each curing condition, the specimens were tested for unconfined compressive strength by using a Farnell compression-testing machine. Loads were applied at a constant rate of deformation of 0.12 cm/min (0.05 in/min), and the maximum load was recorded for each specimen. The unconfined compressive strength was estimated by the average strength of a series of six specimens.

RESULTS AND DISCUSSION

Table 3 summarizes most of the results of tests for unconfined compressive strength for the eight soil samples used in this study. Soils II, IV, V, and VII showed remarkable increase in strength with the addition of lime, whereas soils I, III, VI, and VIII were not reactive to lime. The major clay minerals in soil types II, IV, V, and VII are kaolinite and montmorillonite, whereas in soils I, III, VI, and VIII the predominant minerals are illite, chlorite, and quartz.

To investigate the statistical significance of lime content and soil type on the unconfined compressive strength of lime-soil mixtures, a randomized complete block design was used that had three percentages of lime (3, 5, and 7 percent) that represented the treatment levels and four lime-reactive soils that formed the blocks. Only lime-reactive soils (types II, IV, V, and VII) were included in the analysis, since strength is not a major factor in determining the appropriate treatment for non-reactive soils. Results of the analysis of variance indicated that lime content has a significant effect on the average strength of lime-reactive soils at the 0.05 level of significance. Soil type, on the other hand, was found to be not significant at the same level. In general, for a given soil type and set of curing conditions the relationship between lime content and strength peaks at a certain optimum

Table 1. Engineering and mineralogical soil properties.

Soil No.	Drainage	Atterberg Limits (%)			Classification		Specific Gravity	Moisture-Density		Clay < 2 μ m (%)	Major Clay Minerals ^a
		Liquid Limit	Plastic Limit	Plasticity Index	AASHTO	Unified		γ_d max (t/m ³)	W _{opt} (%)		
I	Poor	55	34	21	A-7-5 (15)	MH	2.67	1.52	24	0	A,F,Q
II	Poor	55	28	27	A-7-6 (17)	CH	2.69	1.54	23.5	22	K,M,Q
III	Poor	44	25	19	A-7-6 (13)	CL	2.75	1.59	22.7	14	I,C,G,Q
IV	Mode-rate	70.5	42	28.5	A-7-5 (19)	MH	2.63	1.42	28	23	K,M,I,Q
V	Mode-rate	54.4	28.7	25.7	A-7-6 (16)	CH	2.71	1.64	18.3	27	K,M,Q
VI	Poor	73.5	34.5	39	A-7-5 (20)	CH	2.75	1.47	25	8.5	I,C,A,Q
VII	Poor	79.5	33	46.5	A-7-5 (20)	CH	2.75	1.48	27.5	20	K,M,Q
VIII	Poor	48	30	18	A-7 (13)	ML	2.61	1.52	25	0	I,A,G,Q

Note: 1 ton = 0.9 Mg.

^aSymbols used are as follows: A = albite, C = chlorite, F = feldspars, G = gibbsite, I = illite, K = kaolinite, M = montmorillonite, Q = quartz.

Table 2. Chemical soil properties.

Soil No.	pH	Organic Carbon (%)	Cation Exchange Capacity (meq/100 g)	Exchangeable Cations (meq/L)					Exchangeable Anions (meq/L)				
				Ca	Mg	Na	K	Total	CO ₃	HCO ₃	CL	SO ₄	Total
I	6.0	1.60	38.0	8.9	2.5	8.4	0.2	20.0	0	1.8	10.0	8.2	20.0
II	7.7	0.25	28.5	75.5	369.0	960.0	0.2	1404.7	0	1.4	1314.0	89.8	1405.2
III	6.7	1.16	42.5	31.6	57.2	12.0	0.3	101.1	0	0.5	82.0	18.7	101.2
IV	8.2	0.00	53.5	19.2	30.2	25.0	0.3	74.7	0	0.7	12.0	62.0	74.7
V	8.9	1.15	44.5	6.8	11.9	34.0	1.0	53.7	0	0.9	10.0	42.8	53.7
VI	5.5	1.73	34.0	4.7	7.7	50.0	1.0	63.4	0	1.8	37.0	24.6	63.4
VII	8.0	0.52	38.0	50.7	54.4	230.0	3.0	338.1	0	1.2	245.0	91.9	338.1
VIII	7.9	1.80	18.0	33.0	21.2	45.0	1.0	100.2	0	1.8	36.0	69.4	100.2

Note: 1 L = 0.264 gal; 1 g = 34 oz.

Table 3. Results of tests for unconfined compressive strength.

Soil No.	Natural Soil (kg/cm ²)	3 Percent Lime (kg/cm ²)						5 Percent Lime (kg/cm ²)						7 Percent Lime (kg/cm ²)					
		21°C			60°C			21°C			60°C			21°C			60°C		
		7- Day	35- Day	56- Day	7- Day	35- Day	56- Day	7- Day	35- Day	56- Day	7- Day	35- Day	56- Day	7- Day	35- Day	56- Day	7- Day	35- Day	56- Day
I	22.4	11.9	21.0	19.5	19.8	22.7	23.0	10.8	19.7	21.3	17.5	21.5	21.8	10.1	14.7	17.2	13.0	17.6	18.2
II	4.4	5.7	12.3	13.9	11.7	17.5	18.9	14.5	28.2	31.9	26.8	43.3	44.0	11.1	21.6	23.4	19.9	31.4	32.6
III	13.3	8.3	13.8	14.3	13.5	14.9	15.1	12.1	15.4	15.9	14.1	16.0	16.2	7.9	10.3	11.7	10.1	12.9	13.2
IV	8.8	6.9	19.8	22.4	17.8	28.7	30.9	7.2	30.0	34.1	29.5	46.1	47.3	5.7	16.5	18.5	15.4	22.7	25.2
V	21.1	14.2	23.5	25.8	22.3	34.3	35.8	22.6	27.5	32.6	26.1	41.3	45.7	9.3	12.9	14.3	12.1	19.4	23.7
VI	15.7	8.9	15.2	16.9	13.9	17.1	17.9	5.5	8.2	8.8	9.1	13.0	15.3	5.1	7.4	8.1	8.6	11.4	12.9
VII	9.1	9.5	24.2	26.6	22.1	35.2	37.7	12.6	20.1	23.7	19.0	30.2	32.4	5.4	15.3	17.4	13.5	20.9	27.8
VIII	16.0	9.7	16.3	17.1	14.5	17.5	18.1	9.9	18.0	19.3	16.9	18.7	18.9	9.4	16.9	18.2	15.1	17.3	17.7

Note: 1 kg = 2.204 lb; 1 cm² = 0.155 in²; t°C = (t°F - 32)/1.8.

lime content. Increasing the percentage of lime beyond this optimum level not only results in no additional increase in strength but also may reduce the strength to that below the strength at optimum lime content.

Figures 1, 2, and 3 depict the effects of the percentage of organic carbon, percentage of clay fraction, and soil pH on the increase in strength of lime-soil mixtures. As expected, organic carbon has a negative impact on the strength gain because it retards the long-term pozzolanic reaction (4). The results of Figure 1 indicate that soils that contained more than 1 percent organic carbon do not react satisfactorily to lime. In Figure 2, it may be noted that soils that have a clay fraction that exceeds 20 percent are the same soils that showed a remarkable increase in strength due to lime treatment. The clay fraction of a soil is the major source of silica and alumina, which react with lime to form cementing agents such as calcium silicate

and calcium aluminate. The estimated coefficient of correlation between the clay fraction and the strength increase is 0.70 based on the results of Figure 2.

Soil pH, an indicator of the degree of weathering, varied from 5.5 to 8.9 for the natural soils used in this study. As the amount of absorbed hydrogen ions increases, the soil pH decreases, which implies a weathered soil. In general, a high pH value indicates that soil silica and/or alumina are available for the pozzolanic reaction. Examination of the results of Figure 3 reveals that soils that have a pH value greater than 7.0 are lime-reactive soils. The estimated correlation coefficient between soil pH and strength gain is 0.56 based on the data in Figure 3. Similar values of this correlation coefficient were found by Thompson (4) and by Harty and Thompson (9).

The analysis-of-variance techniques were also applied to study the separate effects of curing

Figure 1. Effect of organic carbon on strength increase.

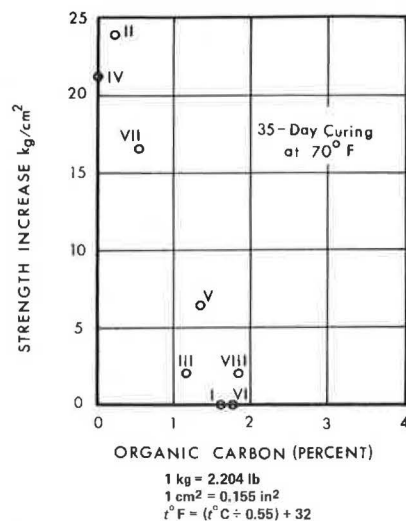
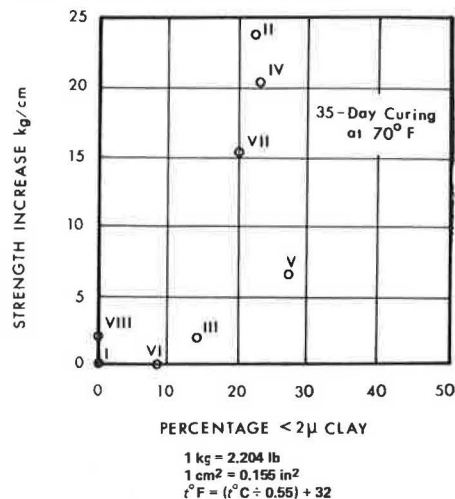


Figure 2. Effect of clay fraction on strength increase.



temperature and curing time on the strength increase of lime-soil mixtures. Two curing temperatures, 21°C and 60°C (70°F and 140°F), represented the treatment levels in the first randomized block design, and three curing periods--7, 35, and 56 days--made up the treatment levels in the second randomized block design. In each design, soil types II, IV, V, and VII formed the blocks. The effects of curing temperature and curing period on the strength increase were found to be statistically significant at the 0.05 level. Figure 4 shows representative plots of the unconfined compressive strength of soil type IV treated with 5 percent lime at different curing conditions.

CONCLUSIONS

The purpose of this research was to establish design criteria and guidelines for applying lime stabilization to the soils of the Nile valley and delta. The following conclusions and suggestions are based on the test results and analyses presented in this paper.

1. The basic data required by the highway engineer to evaluate the potential applicability of lime

Figure 3. Effect of soil pH on strength increase.

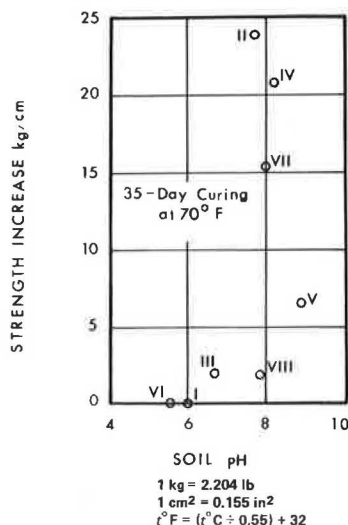
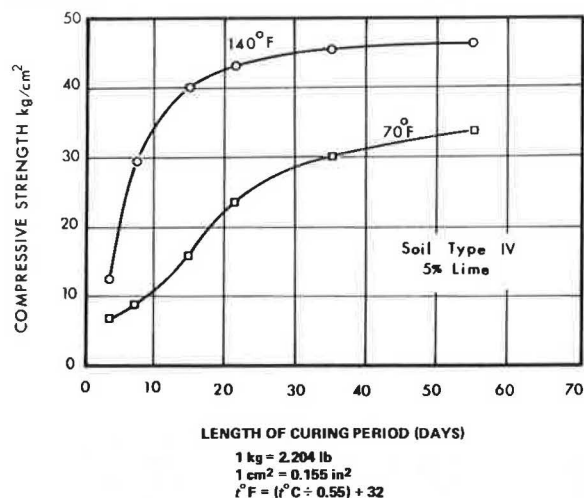


Figure 4. Relationship between compressive-strength results and curing conditions.



stabilization to a particular soil are soil pH, organic carbon content, percentage of clay fraction, and characteristics of the cation-exchange complex.

2. Remarkable increase in the strength of a lime-soil mixture can be expected if the following conditions are met: (a) The percentage of organic carbon is less than 1 percent, (b) the soil pH is greater than 7, and (c) the amount of clay fraction is more than 20 percent.

3. For a given lime-reactive soil, the relationship between lime content and strength peaks at a certain optimum lime content, the value of which ranges in general from 3 to 7 percent. The optimum lime content for a soil that has a relatively low pH value is greater than that required for a soil that has a high pH value. Increasing the percentage of lime beyond this optimum level not only results in no additional increase in strength but also may reduce the strength to that below the strength at optimum lime content.

4. The strength of a lime-treated soil is directly influenced by both curing temperature and curing time. In general, most of the strength gain takes place during the first five weeks at tempera-

tures of approximately 20°C to 25°C (68°F to 77°F). Higher curing temperatures help accelerate the increase in strength.

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Polymer Stabilization of Sandy Soils for Erosion Control

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The usefulness of a number of polymeric materials in increasing the resistance of cohesionless sandy soils to wind and water erosion was studied. Erosion resistance, compressive strength, and permeability of treated soil samples were measured. Film properties of individual polymers were also studied. These properties were then related to the performance of the polymer in controlling erosion. The optimum dilution of polymer with water and the quantity of polymer required to provide a nonerosive surface were determined for three different soils. A copolymer of butadiene-styrene is suggested as an ideal polymer for controlling erosion without significantly reducing the permeability of the treated soil. Other polymers such as polyvinyl acetate and acrylic polymers were found to be water sensitive in various degrees and consequently did not perform well. From a practical viewpoint, the application of polymers to soils by spraying has an obvious advantage over mechanically mixing polymers and soils. In the study it was found that less polymer is required to provide a nonerosive surface if spraying is used. In addition, aqueous-base polymers have numerous advantages over solution-base polymers.

Various materials and methods have been proposed for controlling erosion of agricultural lands and other terrain surfaces such as highway cut-and-fill slopes. The common methods of erosion control are the application of asphaltic products or portland cement, the establishment of vegetative cover, or the provision of riprap. All these methods and materials have limited usefulness and require frequent maintenance, which increases the total cost of a project. Another possibility is the use of polymeric materials, which have great potential for use as soil stabilizers for erosion control and for other purposes. Some of these polymeric compounds have already been used in the field and have been

found quite successful (1-6). In this study, the usefulness of this versatile group of materials for application in soil stabilization has been evaluated and some of the fundamental properties and characteristics related to their performance have been identified. A full account of the studies reported here has been made by Siddiqi (7).

MATERIALS

Ten different polymeric products were studied by using three different soils. The soils were essentially noncohesive sands of varying fine (< no. 200-sieve) content obtained from different locations in Oklahoma. The pattern of results for the three soils is quite similar; consequently, the results for only one of the soils are presented. Figure 1 shows the grain-size analyses of the soils. Table 1 presents general information about the polymers used in the study. All but one of these polymers were in the form of a liquid that can be diluted with water as desired. Altak 59-50, a solution-base polymer, was included in the study for comparison purposes. This polymer requires MEK peroxide for curing and styrene as thinner.

EXPERIMENTAL PROCEDURE

Some samples for the study of erosion control and permeability were prepared by spraying the diluted