Stabilization of Expansive Clay with Hydrated Lime and with Portland Cement

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● THIS PAPER describes procedures and results of laboratory tests on California expansive clay canal soil treated with hydrated lime and with portland cement to show the degree of soil stabilization that could be obtained with these admixtures. Small cylindrical specimens of the compacted soil with lime or with cement in amounts ranging from 0 to 6 percent were subjected to tests to determine expansion upon wetting, shrinkage upon drying, unconfined compression, and wet-dry durability characteristics. The results showed that the presence of either admixture substantially reduced expansion and shrinkage characteristics of the soil and increased soil stability. The cement reduced soil shrinkage upon drying somewhat more than did the lime, but the lime was superior in causing the soil to resist deterioration from wetting and drying action. The recommended amount for the field use of either admixture was 4 percent by weight of the soil.

The laboratory tests described herein were conducted on expansive clay (locally known as "Porterville" clay) from Friant-Kern Canal located in the Central Valley of California near the city of Fresno. The purpose of the tests was to provide a basis for recommending a procedure for stabilizing the canal side slopes and prevent the recurrence of sloughing which has been a maintenance problem in the expansive clay areas. The recommendations called for a trial reconstruction of several sloughed areas with compacted clay containing 4 percent lime or portland cement. Upon further investigation, it was decided that, even if successful, such a method would probably not be used because (a) the sloughing appeared to be on a decrease and (b) the more simple reconstruction measures which consist generally of resloping from the original 1½ : 1 to 2 : 1 with some stabilization with rock were much less expensive. Therefore, the trial test section was not constructed. Estimates did show that if the larger trouble areas could have been located and the admixtures had been incorporated in the slopes during the original canal construction, the cost would have been about the same as the cost required to repair these areas since construction.

The ideas for this proposed canal soil stabilization originated from a knowledge that the general type of stabilization described herein is being investigated for and used to a limited extent in highway pavement subgrades. In some areas where expansive clay soils are encountered, it would be more economical to stabilize the clay subgrade with lime or portland cement to prevent pavement displacement with change of soil moisture than to remove and replace the clay with more suitable, but scarce materials.

ACTION OF LIME OR PORTLAND CEMENT ON SOIL

Hydrated lime ($Ca(OH)_2$) reacts chemically with some clay soils to change their properties and make them more stable. The details of this reaction are not fully known, but the stabilization is apparently caused by two processes. In one, a base-exchange reaction occurs with a replacement of certain ions, such as the replacement of sodium with calcium. In the other, a cementing agent is formed which acts to bind the soil particles together. The most likely explanation for this is that the calcium of the lime combines with silica and alumina in the soil to form various calcium-alumino-silicate compounds which have cementing properties. Thus, lime has been found to have a stabilizing effect, not only on Na-montmorillonites, but also on other types of montmorillonites and on other groups of the clay family (1).

A previous study (2) by Goldberg and Klein at the University of California included Porterville clay from the Central Valley area as one of several soils treated with lime and investigated in the laboratory. The conclusion from this investigation was that hydrated lime reduced the swelling characteristics of the clay. When the amount of lime used was between 2 and 6 percent, the reduction in expansion was marked and in direct

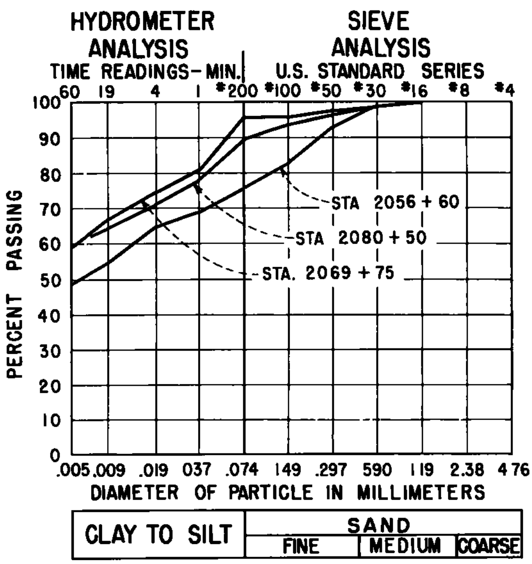

Figure 1. Grading of soil used in lime, and cement stabilization tests--expansive clay from Friant-Kern Canal.

proportion to the amount used; above and below this range for lime, the reduction in swelling was much less noticeable. The stability of the soil was increased as the expansion was decreased principally from the binding action and from a lower soil-water content.

Portland cement which contains a large proportion of lime as one of its original ingredients is believed to have a base exchange and cementing action on soil similar to that of lime. When small quantities of cement on the order of those used in this study are mixed with soil, the resulting material is commonly called "cement modified" soil. This should be distinguished from standard soil cement in which a much larger proportion of cement is used to form a more rigid and durable product. Past studies have shown that a small amount of cement will lower plasticity and shrinkage characteristics of silt-clay soils. This study affords a direct comparison of the two admixtures on the same soil type.

SOIL SAMPLES

In August 1956, soil samples for the stabilization studies were obtained from the locations on Friant-Kern Canal shown in Table 1.

Table 2 shows the results of Atterberg limits tests on these samples.

The gradation and compaction characteristics of these samples are shown in Figures 1 and 2.

Chemical and petrographic tests made on similar expansive clay from the same area, used in a study of electrochemical treatment (3), showed that the soil is a Ca-beidellite clay with a base exchange capacity ranging between 34 to 54 me/100 grams. The exchangeable base is predominantly calcium. Sodium in amounts from 4 to 10 percent of the total exchange capacity is present.

TABLE 1

Station	Canal Slope	Distance Above Water [a]
2056 + 60	Left	6 in.
2069 + 75	Right	12 in.
2080 + 50	Left	12 in.

[a] The water elevation at the time of sampling was 439.6.

TABLE 2

Station	Liquid Limit	Plasticity Index	Shrinkage Limit
2056 + 60	54.7	33.7	6.9
2069 + 75	63.3	36.6	6.2
2080 + 50	57.7	35.5	6.9

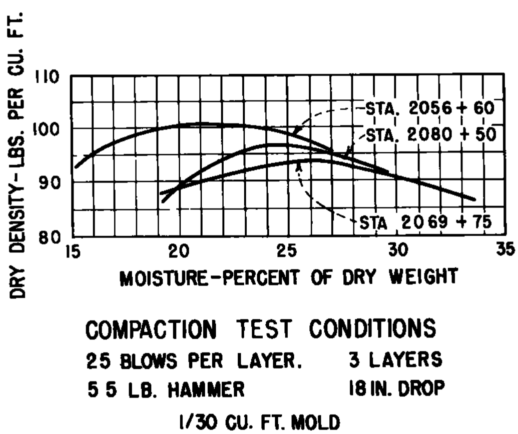

Figure 2. Compaction test curves of soil used in lime and cement stabilization tests--expansive clay from Friant-Kern Canal.

LIME AND CEMENT USED IN THE TEST PROGRAM

Laguros, Davidson, and Chu (4) have shown that the composition of the lime used for soil stabilization influences the properties of the stabilized soil to a considerable extent. No investigation of this effect was introduced in this study; the lime used was one available in the laboratory at the time. The lime conformed to requirements of ASTM Designation C6-46T (Tentative Specifications for Normal Finishing Hydrated Lime) except for the additional requirement that it "should contain not less than 75 percent of calcium oxide and not more than 5 percent magnesia, based upon the non-volatile portion and shall be of such fineness that the residue on a No. 325 sieve is not greater than 5 percent." A chemical analysis showed that the lime contained 98.16 percent calcium oxide and 0.09 percent magnesia.

The cement used for the stabilization was regular Type I.

LABORATORY TEST PROGRAM

Besides the gradation and compaction tests shown in Figures 1 and 2, the laboratory test program consisted of the following tests on specimens treated with lime or cement:

1. Atterberg limits, shrinkage, expansion, and unconfined compression tests on specimens containing 0, 2, 4, 6, and 8 percent lime and on specimens containing 2, 4, and 6 percent cement.
2. Triaxial shear and compaction tests on specimens containing 4 percent lime.
3. Wet-dry durability tests on specimens containing 4 percent lime and on specimens containing 4 percent cement.

Preparation of Specimens

With the exception of some of the unconfined compressive strength specimens which were compacted in molds, the actual test specimens were cut from larger soil specimens of 8-in. diameter by 3-in. height. The larger specimens were prepared by compacting soil, mixed with the desired amounts of lime or cement, at optimum moisture and Proctor maximum density for the untreated soil.

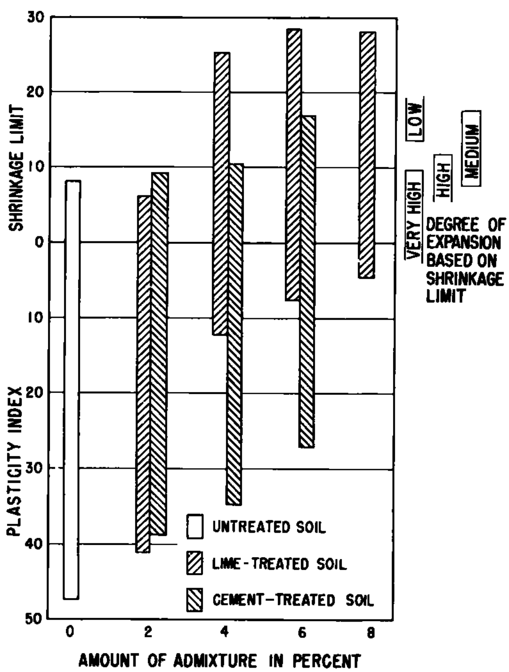

Figure 3. Effect of lime or cement admixtures on the results of Atterberg limits tests of expansive clay from Friant-Kern Canal.

Prior to cutting the smaller test specimens, the larger soil specimens were cured for 28 to 40 days in a 50 percent humidity room. In the room they were suspended over a pan of water and beneath a burlap cover which was supported on a framework. The ends of the burlap were placed in the water to keep it continuously wet and raise the humidity of the atmosphere immediately around the soil.

The smaller test specimens were formed by cutting the soil away by hand beneath a cutting ring of the proper diameter and gently forcing the ring downward over the soil to form the cylindrical specimen. This is a standard Bureau of Reclamation procedure for cutting undisturbed specimens (5).

Atterberg Limits Tests

Atterberg tests for liquid, plastic and shrinkage limits were conducted on the untreated and treated soils after the 30-day curing period. The results of these

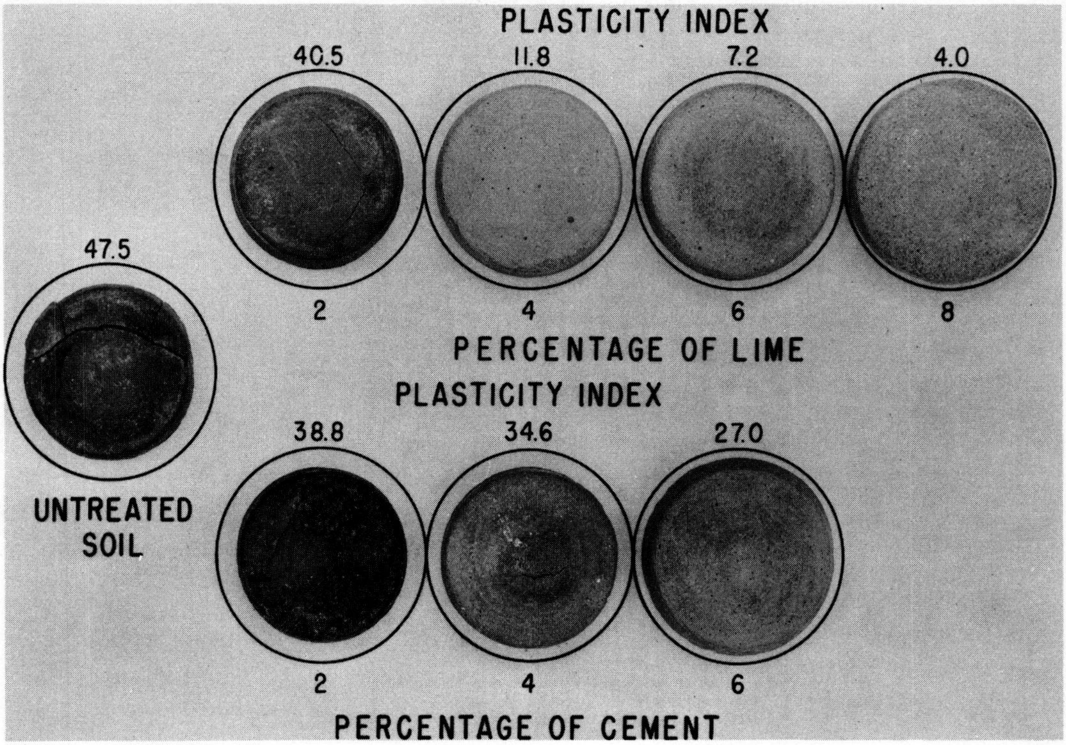

Figure 4. Comparison of sizes of the Atterberg shrinkage limit pats after drying of untreated, lime-, or cement-treated Friant-Kern expansive soil.

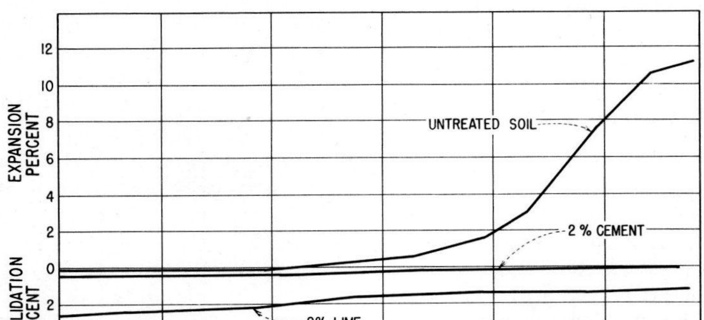

Figure 5. Expansion or consolidation of wetted specimens with time. Friant-Kern Canal expansive clay treated with lime or cement.

tests are plotted in Figure 3. An actual photograph of the dried shrinkage limit pats, for a comparison of the amount of shrinkage after oven drying is shown in Figure 4.

Expansion and Shrinkage Tests

Expansion tests were conducted on cylindrical specimens 4¼ in. in diameter by 1¼ in. in height in conventional one dimensional consolidometers. For this test, the specimen, which contained the residual moisture after curing under the conditions described above, was subjected to a load of 1 psi and the expansion recorded while an excess of water was kept in contact with the specimen. The results of these tests are shown in Figures 5 and 6.

TABLE 3

Percent Lime	Percent Cement	Moisture Content: Before Test	After Test: Expansion	After Test: Unconfined Compression: Cut Specimens	After Test: Unconfined Compression: Molded Specimens
0		21.8	32.4	33.9	37.8
2		24.9	29.8	35.0	32.5
	2	27.2	27.1	29.7	32.3
4		30.0	30.2	30.6	33.9
	4	29.4	-	-	31.2
6		30.5	30.4	31.8	31.2
	6	27.3	-	-	28.2
8		30.3	30.2	31.3	35.9

For the shrinkage test, specimens were cut to consolidation specimen size and allowed to dry in laboratory air for a period of 25 days. Then the volumes of the dried specimens were determined by immersion in mercury. The shrinkage, based on the original volume, was computed and expressed as a percentage. The volume change due to expansion and/or shrinkage for each specimen is shown in Figure 6.

Stability Tests

The stability of the untreated and treated soil was determined by unconfined compressive strength tests and one triaxial shear test on the specimen containing 4 percent lime.

The unconfined compressive strength test specimens were 1⅜ in. in diameter by 2¾ in. in height. The specimens were soaked in water for 7 days prior to testing. The load on the specimens was applied at the rate of 0.005 in. per minute. The triaxial shear tests were conducted in accordance with standard Bureau of Reclamation procedures (5). The results of these tests were plotted in Figure 7a.

Moisture Content

The moisture content of specimens was determined before and after the expansion tests and the unconfined compression tests. These results are shown in Table 3.

Wet-Dry Durability Tests

In order to find the stability of the treated soil after periods of wetting and drying, specimens containing 4 percent lime and others containing 4 percent cement were subjected to cycles of wetting and drying and then to the unconfined compressive strength test. These specimens were subjected alternately to 24 hours' submergence in water at approximately 70 F and 24 hours in air at 100 F under an incandescent lamp (Figure 8). Immediately after the final 24-hour submergence

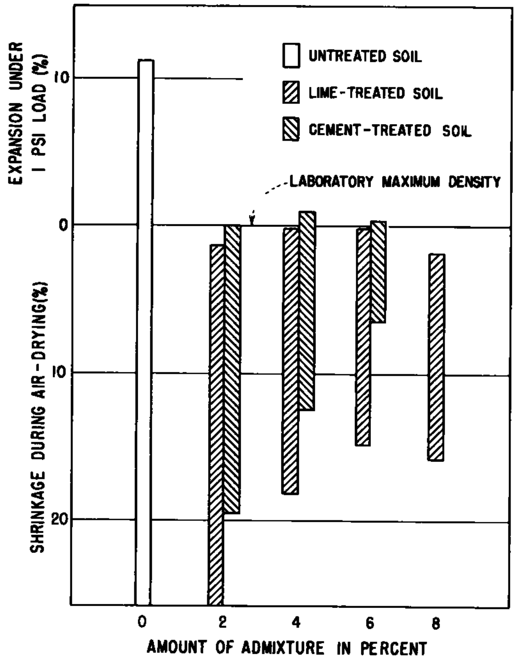

Figure 6. Expansion and shrinkage of untreated, lime-, or cement-treated specimens of expansive clay from Friant-Kern Canal.

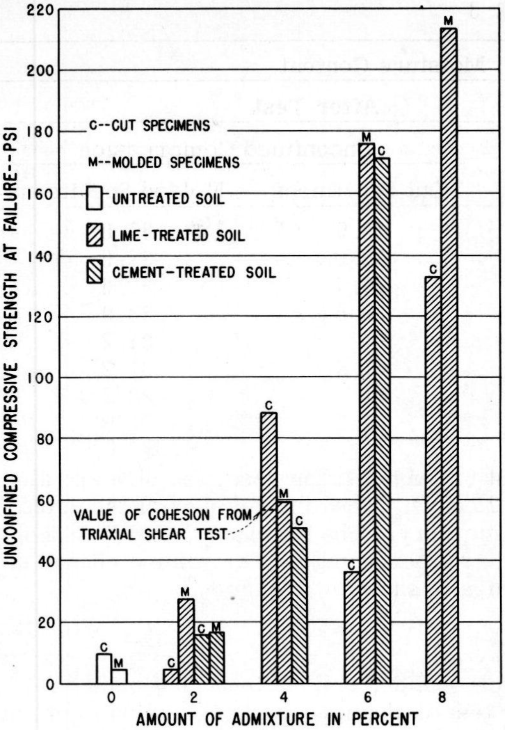

Figure 7a. Unconfined compressive strength of lime- or cement-treated expansive clay from Friant-Kern Canal.

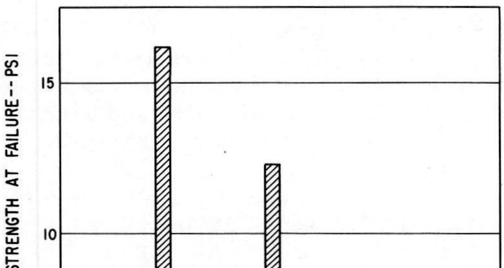

Figure 7b. Unconfined compressive strength of wet-dry test specimens with 4 percent admixture--expansive clay from Friant-Kern Canal.

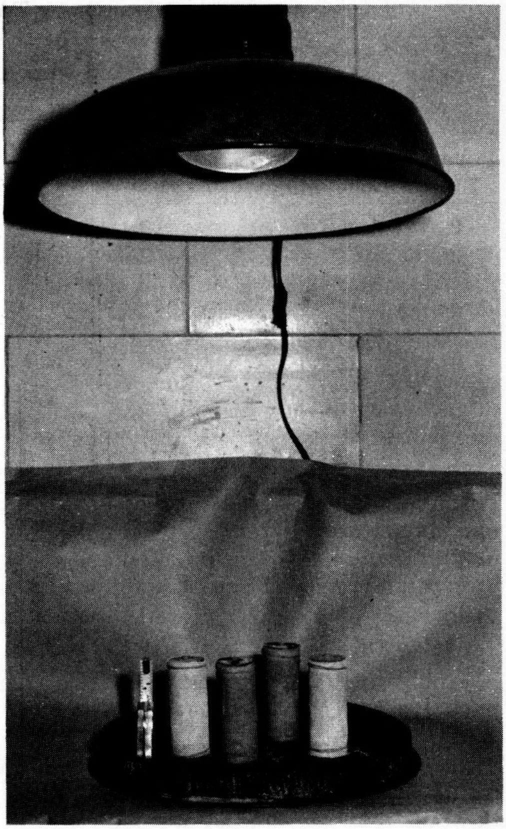

Figure 8. Specimens treated with 4 percent lime or 4 percent cement are being dried under the incandescent lamp at 100 F temperature during the drying cycle of the wet-dry durability tests.

period, unconfined compressive strength tests with a rate of loading of 0.005 in. per minute were conducted on duplicate specimens after 1, 5, and 10 cycles of wetting and drying. The results of these tests are shown in Figure 7b.

DISCUSSION OF RESULTS

The results of the tests made on lime- or cement-treated Friant-Kern expansive clay specimens show that the presence of either admixture improves the soil for uses such as compacted earth lining or compacted embankment.

Figure 3 shows a plot of the effect of the admixtures on Atterberg limits test results. The use of 2 percent lime or cement reduced the plasticity index of soil only slightly and had practically no effect on the shrinkage limit, but the use of 4 percent or more of lime markedly

TABLE 4

SUMMARY OF TEST RESULTS

Cement (%)	Lime (%)	Atterberg Limits			Unconfined Compression[a] (maximum stress in psi)		Consolidometer Test			Triaxial Shear	
		LL	PI	SL	Cut Specimens	Molded Specimens	Expansion (%)	Shrinkage[b] (%)	Total (%)	Tan ϕ	Cohesion (psi)
	0	71.9	47.5	8.1	9.3 9.3	4.7 3.2 4.0	11.2	25.8	37.0		
	2	65.4	40.9	6.5	5.5 4.3 4.9	31.7 23.7 27.7	-1.3	25.8	24.5		
2		64.1	38.8	9.4	15.3 15.8 15.9	16.4	0.1	19.6	19.7		
	4	47.2	11.8	25.3	103.6 72.7 88.1	40.1 79.1 59.6	-0.1	18.2	18.1	1.23	28.5
4		61.0	34.6	10.5	51.7 50.5 51.1		0.9	12.4	13.3		
	6	43.4	7.2	28.4	33.1 39.3 36.2	122.5 229.9 176.2	-0.1	14.8	14.7		
6		53.8	27.0	17.2	173.0 172.4 172.7		0.3	6.5	6.8		
	8	42.1	4.0	28.4	128.7 138.1 133.4	319.0 109.3 214.1	-1.7	15.8	14.1		

[a] Specimens soaked in water for 7 days.
[b] Shrinkage of 4¼-in. diameter by 1½-in. specimens after air drying.

reduced the plasticity index and increased the shrinkage limit; this converts it to a soil of better workability and of less susceptibility to volume change with a change in moisture conditions. As the plot shows, the cement affected these soil properties to a much lesser degree. The difference in the amount of shrinkage of the untreated and various treated soil specimens after the oven drying of the shrinkage limit pats is shown in Figure 4.

As shown by the plot (on the extreme right of Figure 3) of the general range of values of shrinkage limit for soils having a very high to low degree of expansion, as established by previous studies on expansive clays (6), the use of 4 percent or more of the admixtures converted the soil from one of very high expansive potential to one of medium-to-low expansiveness.

It is notable that either 2 percent lime or 2 percent cement reduced the expansion of the soil specimen, subjected to a 1-psi load and a water source, from about 10 percent expansion to practically 0 expansion (Figures 5 and 6). The effect of the lime and cement was about the same in reducing soil expansion, but the cement reduced the shrinkage of air-dried soil specimens about 25 to 50 percent more than did the lime, as seen in Figure 6. This is probably due to the superior cementing action of the cement.

The use of 4 percent or more of lime (also cement, but to a lesser extent) markedly increased the unconfined compressive strength of the soil, as seen in Figure 7a. The value of cohesion from the one triaxial shear test conducted was within the same order of magnitude of cohesion obtained from the unconfined tests if the value of cohesion is considered to be one-half the unconfined compressive strength; the latter relationship has often been used for practical applications. As shown in Figure 7b, the specimens with 4 percent lime resisted the action of wetting and drying better and resulted in much higher compressive strengths at the end of 1, 5, and 10 cycles than did the soil specimens with 4 percent cement.

The cost of cement in Denver is $1.32 for a 94-lb bag while the cost of lime is about $1.00 for a 50-lb bag; therefore, the cost of lime is about 1.4 times the cost of cement on an equal weight basis.

CONCLUSIONS AND RECOMMENDATIONS

From the results of laboratory tests on specimens of Friant-Kern expansive clay treated with lime or portland cement as admixtures, the following conclusions are drawn:

1. The use of either lime or cement reduces the plasticity, shrinkage, and expansion properties of the soil and increases soil stability, generally in proportion to the amount of admixture used.
2. Although the cement admixture reduced the soil shrinkage under air drying somewhat more than an equal amount of lime (probably because of superior cementing action), the properties of the lime-treated soil were more favorable in other respects, expecially in reduction of plasticity and in increased unconfined strength after wetting and drying action.
3. The recommended amount of lime or cement admixture for use in a field installation is 4 percent.

REFERENCES

1. Gallaway, B.M., and Buchanan, S.J., "Lime Stabilization of Clay Soil," Bulletin 124, Texas Engineering Experiment Station (1951).
2. Goldberg, Irving, and Klein, Alexander, "Some Effects of Treating Calcium Clays with Calcium Hydroxide," 50th Annual Meeting of the American Society for Testing Materials (June 1952).
3. Karpoff, K.P., "Laboratory Study of Electrochemical Treatment of Expansive Clay Soils in the Embankments and Subgrade of the Friant-Kern Canal, Central Valley Project, California," USBR Earth Laboratory Report No. EM-391 (1955).
4. Laguros, J.G., Davidson, D.T., and Chu, T.Y., "Evaluation of Lime for Stabilization of Loess," Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa (1956).
5. USBR "Earth Manual," (1951 and 1956).
6. Holtz, W.G., and Gibbs, H.J., "Engineering Properties of Expansive Clays," American Society of Civil Engineers, "Transactions," Volume 121, p. 641 (1956).

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