Comparative Effects of Hydraulic, Calcitic And Dolomitic Limes and Cement in Soil Stabilization

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The addition of lime to soils brings about changes that are reflected in the plasticity and strength characteristics of the soils. To study these changes, representative samples of different types of lime, hydraulic, calcitic hydrated, dolomitic monohydrate, and dolomitic dihydrate were selected. For comparison, a sample of type I cement was also used. The effects on plasticity were studied with a very heavy clay (gumbotil), and the effects on unconfined compressive strength with two fine-grained soils (friable loess and plastic loess). The results obtained so far indicate that there are marked differences in the plasticity and strength results, depending on the type of stabilizer used.

•MUCH WORK has been done at Iowa State University on the effectiveness of the different types of hydrated limes in soil stabilization (1, 2, 3, 6, 7, 8, 9, 11, 12). The investigation reported herein was undertaken as a further check on the comparative effects of calcitic hydrated, dolomitic monohydrate, and dolomitic dihydrate limes.

Lime is available in several forms (Table 1). One of the varieties is hydraulic lime, which is regarded as an intermediate product between lime and cement. This lime has never been evaluated in soil stabilization. It is believed that this product could be a successful stabilizer of plastic soils by giving better workability than cement and yielding higher strengths than other limes.

In addition, a type I portland cement was also used for comparison. The Atterberg limits and shrinkage tests were used to evaluate the ability of the different additives to modify a soil, and the unconfined compressive strength as an index of the stability after curing for several periods.

MATERIALS

Soils

A highly plastic soil, known as gumbotil was used for the Atterberg limits and shrinkage tests. This soil, considered as a fossil B horizon developed from Kansan stage till, contains about 60 percent montmorillonitic clay. It is one of the most difficult soils to work with in the field.

Two Wisconsin stage loess soils, representative of the major surface deposits in Iowa, were used for strength studies; samples were selected to represent a friable, calcareous loess, and a plastic, leached loess. A field description and physical and chemical properties of each soil are given in Table 2.

Additives

The chemical composition of each additive used in this investigation is given in Table 3.

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High-calcium limes are produced from calcareous materials (generally from limestone but also from chalk and oyster shells) containing 95 to 99 percent calcium carbonate. Dolomitic limes are produced from the mineral dolomite, a type of limestone containing from 30 to 45 percent magnesium carbonate and the rest calcium carbonate. Hydraulic lime is a type of cementitious lime that will set and harden under water like portland cement, but retains some of the plastic properties of lime. It is obtained by calcining impure limestone containing 15 to 20 percent silica and alumina so that sufficient calcium silicates and aluminates are formed to give the lime its characteristic hydraulic properties.

TABLE 1

FORMS OF LIME

Quicklime:
- High-calcium (calcitic), CaO
- Dolomitic, CaO and MgO

Hydrated lime:
- High-calcium (calcitic), $Ca(OH)_2$
- Dolomitic monohydrate, $Ca(OH)_2$ and MgO
- Dolomitic dihydrate, $Ca(OH)_2$ and $Mg(OH)_2$

Hydraulic lime, lime and calcium silicates and aluminates

TABLE 2

PROPERTIES OF SOILS USED

Property	Friable Loess	Plastic Loess	Gumbotil
Laboratory designation	20-2	528-4	528-8
Sample location	Harrison Co., Iowa	Keokuk Co., Iowa	Keokuk Co., Iowa
Soil series	Hamburg	Mahaska	-
Horizon	C	C	Fossil B
Sampling depth (ft)	39.0-40.0	3.0-6.5	6.5-8.5
Textural composition (%):			
Gravel (above 2mm)	0.0	0.0	0.0
Sand (2-0.074mm)	0.8	3.5	20.1
Silt (0.074-0.005mm)	82.8	55.0	16.5
Clay (below 0.005mm)	16.4	41.5	63.4
Clay (below 0.002mm)	11.6	33.0	60.4
Atterberg limits (%):			
Liquid limit	32	51	68
Plastic limit	27	21	23
Plasticity index	5	30	45
Chemical properties:			
pH[1]	8.4	6.0	7.1
C.E.C,[2] (meg/100 g)	15.6	23.5	39.9
Carbonates[3] (%)	10.9	1.2	1.8
Organic matter[4] (%)	0.5	0.3	0.2
Predominant clay mineral	Montmorillonite	Montmorillonite	Montmorillonite
Classification:			
Textural[5]	Silty loam	Silty clay	Clay
AASHO	A-4(8)	A-7-6(18)	A-7-6(20)
Unified	ML	CH	CH

[1] Glass electrode method using suspension of 15 g soil in 30 cc distilled water.
[2] Ammonium acetate (pH=7) method on soil fraction below 2 mm.
[3] Versenate method for total calcium.
[4] Potassium bichromate method.
[5] From soil texture chart used by U. S. Bureau of Public Roads.

TABLE 3

CHEMICAL COMPOSITION OF ADDITIVES USED[a]

Additive	Lab. Symbol	Constituents (% by weight)							
		CaO	$Ca(OH)_2$	MgO	$Mg(OH)_2$	SiO_2	R_2O_3[b]	SO_3	Loss on Ignition
High-calcium hydrated lime	CL	73.50	97.10[c]	0.90	TR[d]	1.30	0.25	ND[e]	24.00
Dolomitic monohydrate lime	ML	47.32	62.50[c]	39.11	TR	1.10	0.75	ND	16.10
Dolomitic dihydrate lime	DL	43.80	57.90[c]	28.20	40.80[c]	0.60	0.50	ND	26.90
High-calcium hydraulic hydrated lime	HL	59.06	52.00[f]	3.98	TR	17.10	5.40	1.27	12.81
Type I portland cement	PC	64.05	TR	2.90	TR	21.62	8.02	2.26	0.58

[a]Data supplied by respective chemical manufacturers.
[b]$Al_2O_3 + Fe_2O_3$.
[c]Calculated hydroxide equivalent.
[d]Traces.
[e]Not determined.
[f]Estimated from loss on ignition.

Portland cement is made by burning a mixture of calcareous (such as marls, chalk, or limestone) and argillaceous (such as clay or shale) material to clinkering temperature, and grinding the resulting clinker to fine powders of calcium silicates and aluminates, which hydrate to give the material its cementing properties.

EXPERIMENTAL PROCEDURES

Preparation and Curing of Specimens

All soils were previously air dried and ground with mortar and pestle to pass the No. 10 sieve. The batches were mixed in a Hobart kitchen mixer, model C-100. The additive was first mixed with the dry soil and then the materials were wet mixed for 2 min.

Cylindrical 2- by 2-in. test specimens were prepared at a density near the standard AASHO using the Iowa State compaction apparatus (1, 10).

The specimens were wrapped in waxed paper and sealed with cellophane tape to prevent carbonation of the additive by carbon dioxide in the air. The specimens were then placed in a moisture room having a relative humidity between 90 and 100 percent and a temperature of 71 ± 3 F.

Strength Testing

Strength determinations were made on mixtures containing 2, 5, 8, and 12 percent of each additive used. For every percentage, additive, moisture-density, and moisture-strength relationships were obtained using five different moisture contents and three specimens molded for every point. One of the three specimens was cured for

7 days, one for 28 days, and one for 84 days. After the specified curing period, the specimens were immersed in distilled water for 24 hr, and were then tested to failure under unconfined compression at a loading rate of 0.1 in. per min. From the moisture-strength curves, the maximum unconfined compressive strengths were obtained.

Atterberg Limits Testing

ASTM Methods D423-59 and D424-59 were followed except that after the soil, additive, and distilled water were mixed together, the mix was scraped into a porcelain pan, covered, and stored in a near 100 percent humidity room for 1 hr to allow for uniform wetting of the sample. After being seasoned, enough of the mixture for four liquid limit tests was placed in an evaporating dish. This procedure was followed on the soil passing the No. 40 sieve with additives of 0, 1, 3, 6, and 10 percent by the oven-dry weight of soil.

A sample weighing about 10 g was taken from the mixture prepared for the liquid limit test. Four plastic limits were rolled for each of the mixture studies (On 1, 3, 4, 6, and 10 percent additive by oven-dry weight of soil). The plastic limit of the mix at each percentage additive was determined as the average of the moisture contents of the four threads rolled.

Shrinkage Tests

ASTM Methods D427-39 were used for mixtures containing 2 and 8 percent of each additive. Shrinkage limit and shrinkage ratio were then calculated to determine the effectiveness of different additives for the modification of a soil.

RESULTS

Modification of Soil

The quick changes in a soil caused by the addition of some stabilizing agents as reflected in such physical properties as plasticity and shrinkage can be considered as a modification of the soil. To study these effects of the addition of limes and cement, a highly plastic gumbotil soil was selected. Atterberg limits and shrinkage properties were measured 1 hr after the soil and additives were wet mixed.

Plasticity Properties. —Plasticity tests were performed to find the relative influence of each additive on a highly plastic soil (Fig. 1; Table 4). The shape of the curves is characteristic of montmorillonitic clay soils treated with lime (5). The liquid limit gradually decreases with the increase in additive, and the plastic limit increases with increase in additive up to a certain point. At that point, further increases in the amount of additive do not further affect the plastic limit.

The decrease of the plasticity index of a highly plastic soil is regarded as an improvement in its engineering properties. The limes as well as the cement, in amount greater than about 2 percent, decreased the plasticity index of the gumbotil soil, and improved its engineering characteristics as a result. The degree of improvement varies somewhat with the kind and amount of additive. The greatest improvement was obtained with high-calcium hydrated lime and the least with cement. The dolomitic limes showed an intermediate degree of improvement.

The soil and soil-additive mixtures were classified under the AASHO soil classification system to show the improvements of soils by the addition of lime or cement (Table 3).

Plasticity tests were also run with the gumbotil and the various main compounds found in hydrated lime to obtain more information on the influence of different types of lime in the modification of the plasticity characteristics of a clayey soil (Table 5).

The compound chiefly responsible for lowering the plasticity index is calcium hydroxide; magnesium hydroxide causes an insignificant reduction; and magnesium oxide lowers the plasticity index to a degree intermediate between calcium hydroxide and magnesium hydroxide. This explains why high-calcium hydrated lime was slightly more effective than dolomitic limes in improving the plasticity characteristics of gumbotil soil.

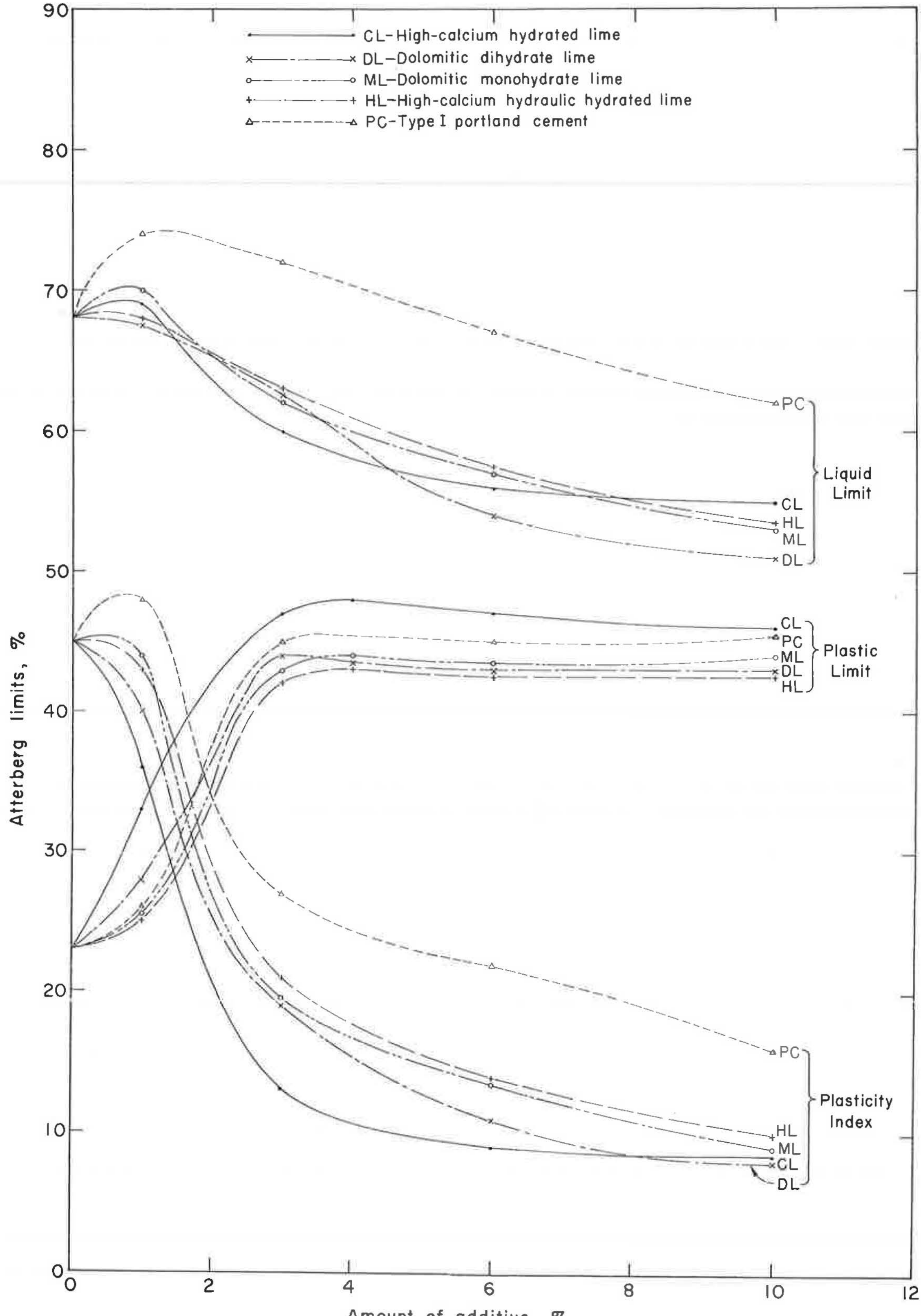

Figure 1. Effect of various additives on Atterberg limits of gumbotil.

TABLE 4

RESULTS OF PLASTICITY TESTS ON GUMBOTIL TREATED WITH VARIOUS ADDITIVES

Additive		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHO Class.
Kind	Amount (%)				
None	0	68	23	45	A-7-6(20)
High-calcium hydrated lime	1	69	33	36	A-7-5(20)
	3	60	47	13	A-7-5(13)
	4		48		
	6	56	47	9	A-5(11)
	10	55	46	9	A-5(11)
Dolomitic monohydrate lime	1	70	26	44	A-7-6(20)
	3	62	43	19	A-7-5(16)
	4		44		
	6	57	43	14	A-7-5(13)
	10	53	44	9	A-5(10)
Dolomitic dihydrate lime	1	68	28	40	A-7-6(20)
	3	63	44	19	A-7-5(16)
	4		43		
	6	54	43	11	A-7-5(11)
	10	51	43	8	A-5(10)
High-calcium hydraulic hydrated lime	1	68	25	43	A-7-6(20)
	3	63	42	21	A-7-5(16)
	4		44		
	6	57	43	14	A-7-5(13)
	10	53	43	10	A-5(10)
Type I portland cement	1	74	26	48	A-7-6(20)
	3	72	45	27	A-7-5(19)
	6	67	45	22	A-7-5(17)
	10	62	46	16	A-7-5(14)

TABLE 5

RESULTS OF PLASTICITY TESTS ON GUMBOTIL TREATED WITH CHEMICAL REAGENTS

Chemical		Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	AASHO Class.
Kind	Amount (%)				
None	0	68	23	45	A-7-6(20)
$Ca(OH)_2$	2	60	43	17	A-7-5(15)
	8	55	45	10	A-5(11)
MgO: Heavy	2	63	30	33	A-7-5(20)
	8	68	39	29	A-7-5(20)
Light	2	70	39	31	A-7-5(20)
	8	75	45	30	A-7-5(20)
$Mg(OH)_2$	2	70	28	42	A-7-6(20)
	8	70	31	39	A-7-5(20)

Shrinkage Tests. —Shrinkage limit is the moisture content of a drying soil below which any decrease in moisture content is accompanied by only a very small decrease is volume. Shrinkage ratio is the ratio of the percentage of volume change to the percentage of moisture loss occurring above the shrinkage limit, which is a measure of the rate of volume change. In general, a high shrinkage limit and a low shrinkage ratio are desired to reduce the shrinkage of a soil, on drying.

The shrinkage characteristics of the gumbotil soil were greatly improved by the addition of lime or cement (Table 6). The lowest amount of additive tried, 2 percent of high-calcium hydrated lime, increased the shrinkage limit in a much greater pro-

TABLE 6

RESULTS OF SHRINKAGE TESTS ON GUMBOTIL TREATED WITH VARIOUS ADDITIVES

Additive		Shrinkage Limit (%)	Shrinkage Ratio
Kind	Amount (%)		
None	0	7.7	2.08
High-calcium hydrated lime	2	25.4	1.52
	8	37.1	1.26
Dolomitic monohydrate lime	2	13.5	1.86
	8	41.8	1.22
Dolomitic dihydrate lime	2	13.5	1.86
	8	38.5	1.20
High-calcium hydraulic hydrated lime	2	13.3	1.78
	8	35.7	1.28
Type I portland cement	2	15.3	1.65
	8	37.4	1.22

portion than any of the other limes or cement. For 8 percent additive all limes as well as cement cause a comparatively similar increase in the shrinkage limit. The increase in shrinkage limit, which is fivefold when the soil was treated with 8 percent additive, and the decrease in shrinkage ratio indicate that the soil will shrink less on drying when treated with lime or cement.

Cementation of Soils

The gain of strength of soil-lime and soil-cement mixtures while being cured is thought to be caused by the formation of cementitious compounds. To study the cementation properties of lime and cement, a plastic and a friable fine-grained soil were selected. Because this study included the determination of moisture-density and moisture-strength relationships, a discussion of these is given first.

Maximum Dry Density. —The addition of lime or cement to a soil lowers its maximum density for the same compactive effort. Figures 2 and 3 show the greatest decreasing rate in the maximum density is for small amounts of additive—as the amount of additive is increased the maximum density tends to decrease at a slower rate. Additions of calcitic and dolomitic limes decreased the maximum density to a greater extent than hydraulic lime or cement; hydraulic lime is intermediate between cement, which showed the least decrease in maximum density, and the other limes.

The differences in maximum density for the same compactive effort might have some influence in the strengths obtained with the different additives. This influence is not exactly known but appears to be important because the strength of soil-lime and soil-cement mixtures greatly depends on density (4, 11).

The optimum moisture contents of soils with different additives are shown in Figures 2 and 3. Limes as additives increase the optimum moisture contents of both plastic loess and friable loess, and cement increases the optimum moisture content of plastic loess and decreases that of friable loess.

Maximum Strength. —The optimum moisture content for maximum strength differed slightly from the optimum moisture content for maximum density. The difference between both moistures was never greater than one moisture content percentage. The maximum strength was sometimes slightly to the wet side of the maximum density and sometimes slightly to the dry side, depending on the kind and amount of additive, and on the curing period. In practical work the optimum moisture content for maximum density for the compactive effort applied will secure the maximum or very nearly the maximum strength .

Comparative Effects of Additives on Maximum Strength. —Maximum strengths obtained with soil-lime and soil-cement mixtures are shown in Figures 4 and 5. The poor performance of dolomitic dihydrate lime with both soils and for the three curing periods used is clearly seen. After 7 days curing, cement produces greater strengths than any of the limes tested, but after 28 or 84 days curing, some of the limes, for

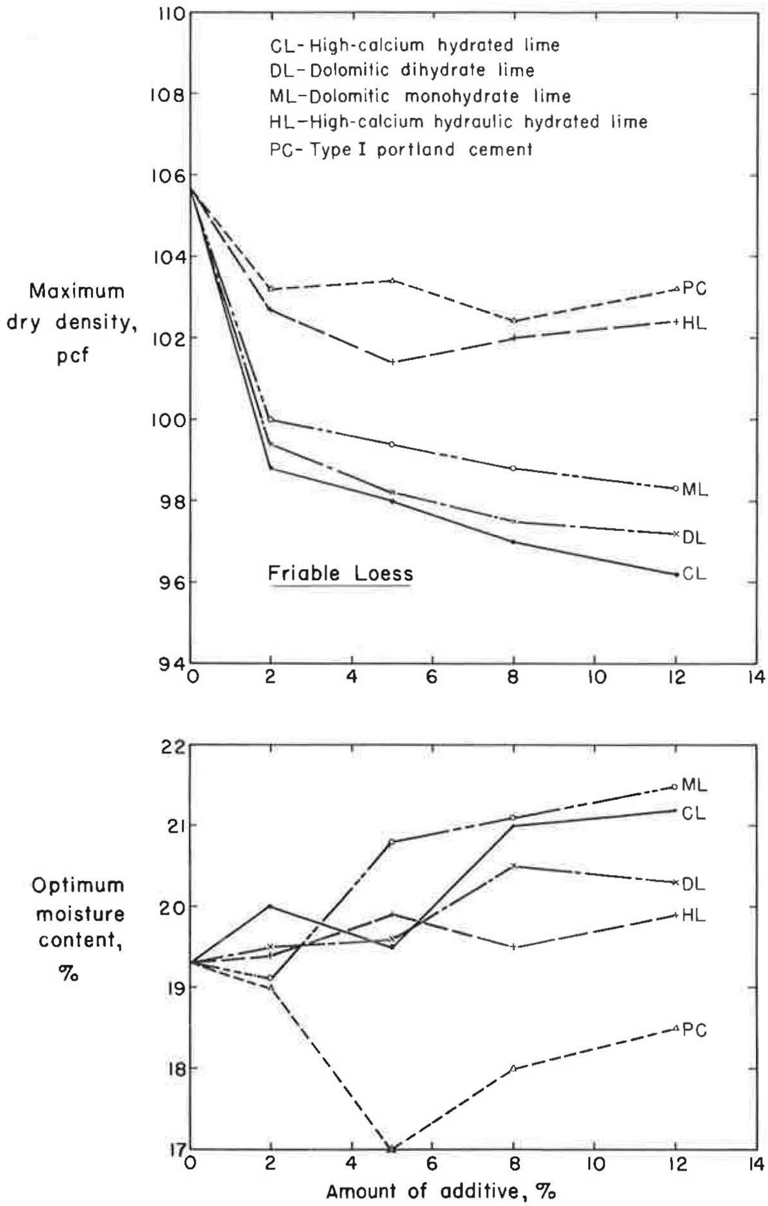

Figure 2. Effect of various additives on maximum dry density and optimum moisture content of friable loess.

lower amounts of additive, performed as well or better than cement. The strengths obtained with 5 percent dolomitic monohydrate lime after 28 and 84 days curing are as high as those obtained with the same amount of cement.

In a general rating of the different additives with the two soils used, cement could be considered the best followed in order by dolomitic monohydrate, high-calcium hydraulic hydrated, high-calcium hydrated and dolomitic dihydrate limes.

The differences in strength obtained for the different additives are due chiefly to the chemical compositions of limes and cement. Calcium silicates and aluminates (present in cement and to a lesser extent in high-calcium hydraulic lime) are responsible

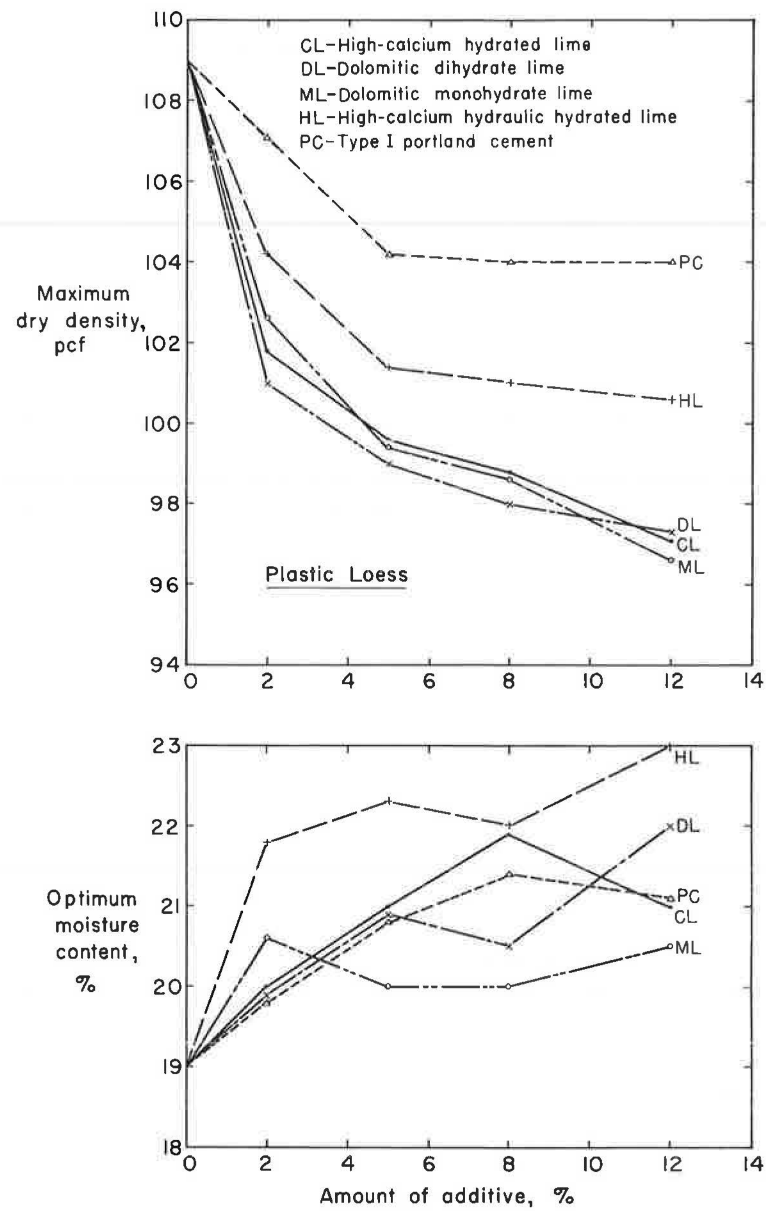

Figure 3. Effect of various additives on maximum dry density and optimum moisture content of plastic loess.

for a great part of the strength obtained. Magnesium oxide as well as calcium hydroxide is also important in the development of strength. Magnesium hydroxide does not contribute much to strength.

In previous studies made with synthetic limes with different ratios of calcium to magnesium, specimens treated only with magnesium oxide developed a strength comparable with that obtained with the same amount of calcium hydroxide alone (7). However specimens treated only with magnesium hydroxide did not show any strength. The study also showed that there is an optimum amount of calcium hydroxide plus magnesium oxide to produce a maximum strength.

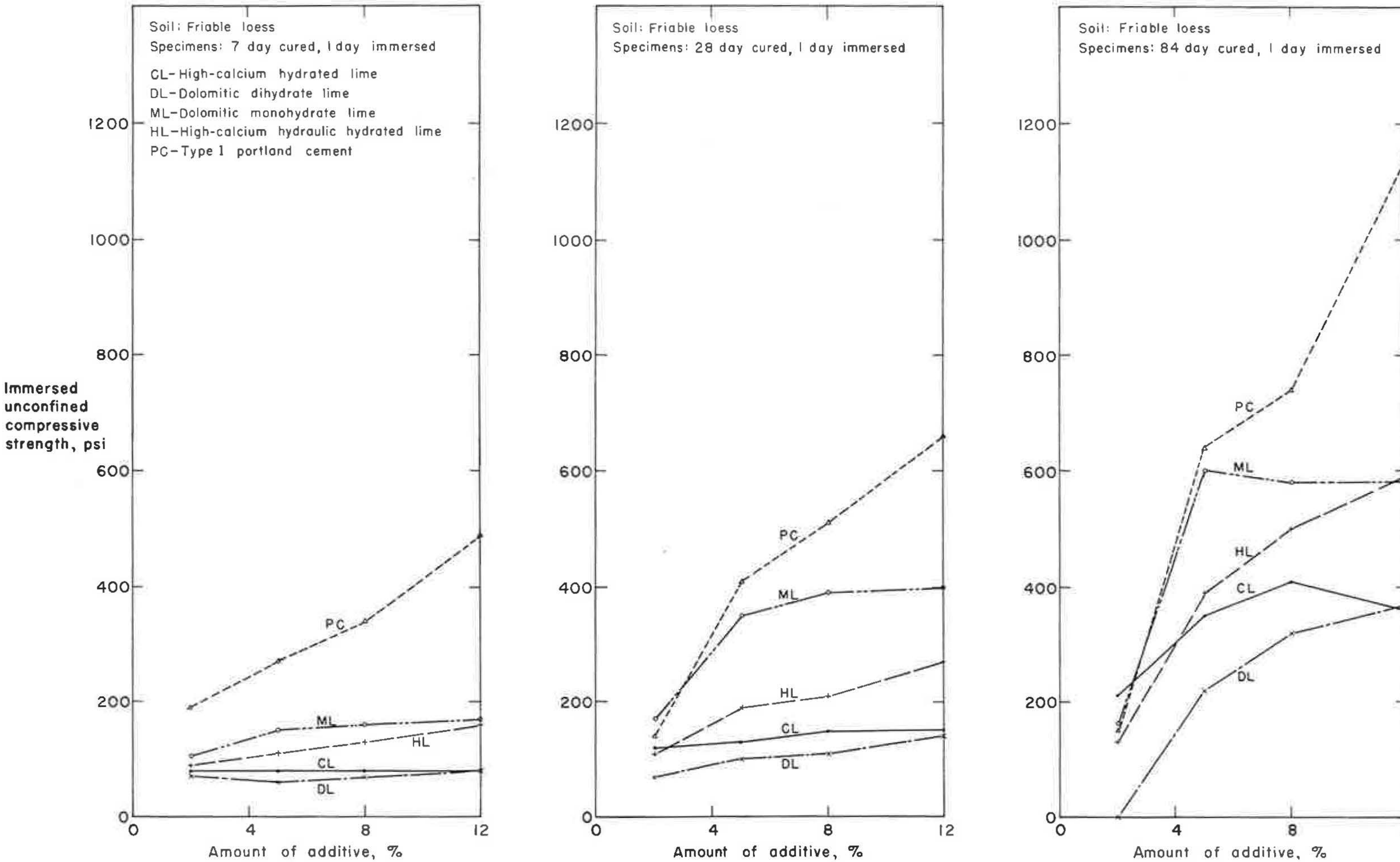

Figure 4. Effect of various additives on immersed unconfined compressive strengths of friable loess.

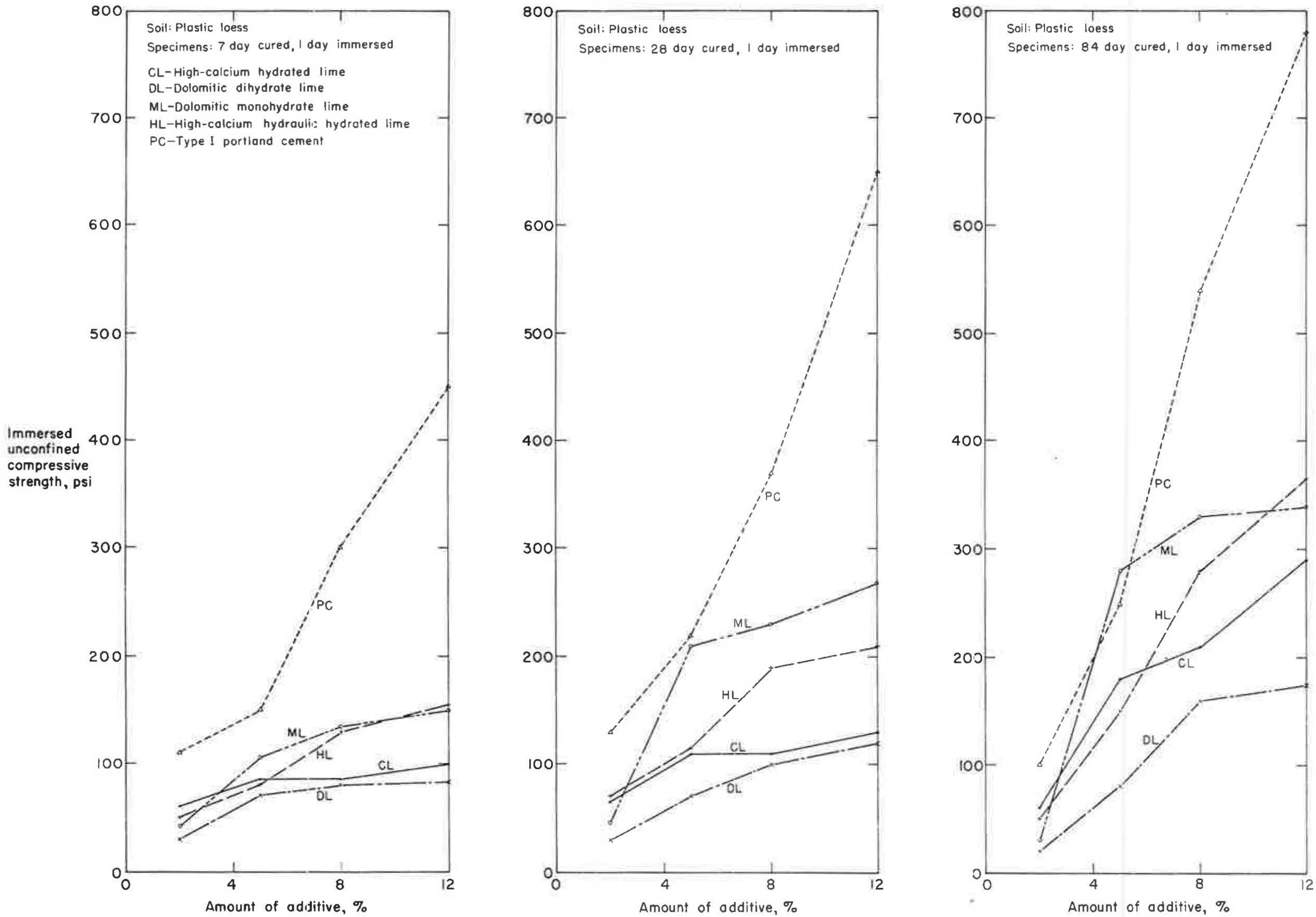

Figure 5. Effect of various additives on immersed unconfined compressive strengths of plastic loess.

The data obtained show that dolomitic monohydrate lime is as good or better than high-calcium hydrated lime in the development of strength of fine-grained soils with predominant montmorillonitic clays and for curing temperatures near 70 F. It also shows that hydraulic lime can also be used in soil stabilization and that hydraulic lime may be better than non-hydraulic limes in larger amounts and longer curing times.

CONCLUSIONS

Based on this investigation, the following conclusions can be drawn:

1. Lime is a more effective stabilizer for reducing the plasticity of a soil than cement.
2. Among the limes tested, high-calcium hydrated lime rated first in lowering the plasticity. The other three types of limes (dolomitic monohydrate, dolomitic dihydrate, and high-calcium hydraulic hydrated) gave a similar performance.
3. Among the major constituents of hydrated limes, calcium hydroxide, followed by magnesium oxide, is mainly responsible for the lowering of plasticity. The influence of magnesium hydroxide is practically negligible.
4. The shrinkage properties of a soil were markedly reduced by the addition of different types of lime and cement. High-calcium hydrated lime showed slight advantage over the others at lower percentage of content.
5. Portland cement was found more effective in increasing soil strength on curing, followed in order by dolomitic monohydrate, high-calcium hydraulic, high-calcium hydrated and dolomitic dihydrate limes. For low additive levels, up to about 5 percent and for curing periods of 28 days or longer some of the limes were as effective as cement in improving the strength of the soils tested.
6. Hydraulic lime can be used effectively in soil-lime stabilization. Hydraulic lime is equivalent to other types in reducing soil plasticity. It also is better in larger amounts and longer curing time than monohydraulic lime in producing strength.
7. Based on the trends found in this study, the best all-round stabilizer for clayey soils seems to be a high-magnesium hydraulic monohydrate lime.

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