MODIFICATION OF A GUMBOTIL SOIL BY LIME AND PORTLAND CEMENT ADMIXTURES

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SYNOPSIS

This paper reports the results of a laboratory study of the effect of various percentages of lime and portland cement upon the engineering properties of a heavy, sticky, gumbo soil which is rather frequently encountered in highway construction in southwest Iowa The soil is a very old, highly weathered montmorillonitic material of Nebraskan or Kansan age and contains about forty-five percent of five-micron clay. It is an A-7-6 (20) soil in the Bureau of Public Roads classification system

Various percentages of unslaked lime (CaO) and of portland cement were added to the soil in the dry state and the influence of these admixtures was observed by comparing the results of certain tests of the mixtures with the test results on the untreated soil The properties chosen for these comparisons were the liquid limit, plastic limit, and plasticity index; the shrinkage limit, shrinkage ratio, linear shrinkage and volumetric change, the standard AASHO density and optimum moisture content; and the CBR with soil molded to standard AASHO density.

The results of these comparisons indicate that a marked and favorable modification of the soil is accomplished by both these admixtures in all properties studied with the exception of the standard AASHO density and optimum moisture content No change in these properties was observed. The comparisons further indicate that the unslaked lime was considerably more effective at low percentages of admixture in producing the observed modification than the portland cement.

Gumbotil or "gumbo" is a peculiar gray to nearly black, waxy, sticky soil which is encountered frequently in southwest Iowa and in other glaciated regions of the Illinoisan, Kansan and Nebraskan stages of the Pleistocene epoch. This soil is a heavy, impervious, clayey material developed in the zone of accumulation under poor drainage conditions and contains relatively high percentages of fine clay and colloidal material. Gumbo is very plastic at normal moisture contents and presents very serious problems in design, construction and maintenance of highways in regions of its occurrence. Any practical means of modifying this soil to improve its engineering properties would be a boon to engineers responsible for the highways in such regions and would greatly benefit the highway user. The purpose of this paper is to summarize the results of a laboratory study in which various percentages of unslaked lime (CaO) and of portland cement were added to a gumbotil and the changes in engineering properties of the soil determined

The sample of gumbo used in this study was taken from a pit dug in the back slope of a cut section on the north side of Iowa Primary Road 92 at station 740 + 60 approximately 4 mi. east of US Highway 71, near Cumberland, in Cass County, Iowa. The sample pit was 2 to 3 ft. below the slope surface and 10 or 12 ft. below the natural ground surface before the highway cut was made The location of the sample is such that the soil is presumed to be of Nebraskan age, though some authorities believe it is Kansan. In any event, it is a very old and highly weathered material. It was selected for study because outwardly it appeared to be similar to the so-called "black cotton" soil, or Regur, which exists over large areas in southern India.

The soil as sampled was first analyzed by the standard identification tests specified by the AASHO. The mechanical analysis was also determined by a long-arm centrifuge to obtain the particle size distribution of the fraction smaller than 1 micron. The results of the mechanical analysis by both the standard

TABLE 1
MECHANICAL ANALYSIS OF GUMBOTIL SOIL

Sieve No. U S Std	Standard AASHO Bouyoucos Hydrometer Method		Long-Arm Centrifuge Method	
	Size	Percent Finer	Size	Percent Finer
	mm		*mm.*	
4	4.7	100		
10	2.0	99.8		
20	0.83	99.4		
40	0.42	98.3		
60	0.25	96.6		
140	0.105	94.8		
200	0.074	94.3		
Equivalent spherical size computed from measurement of settling velocity by means of Stokes' law	0.039	86.1	0.041	87.3
	0.027	77.2	0.023	71.0
	0.018	66.8	0.0175	65.9
	0.010	55.7	0.0125	61.1
	0.007	50.6	0.009	57.0
	0.005	44.7	0.0075	52.6
	0.001	25.5	0.00525	46.6
			0.00375	41.8
			0.00280	36.8
			0.00222	34.5
			0.0016	29.0
			0.00135	25.2
			0.00098	21.3
			0.00075	17.5
			0.00057	15.2
			0.00046	13.6
			0.00034	10.0
			0.00023	9.0
			0.00016	8.0

differential thermal method. The thermal curve of the soil sample and standard curves for pure montmorillonite and kaolinite are shown in Figure 3. This analysis indicated that the predominant clay mineral in the minus 0.2-micron fraction of the soil was montmorillonite, with some kaolinite also present.

The pH of the soil was determined by means of a Beckman pH meter and the organic matter content by oxidation and titration with ferrous ammonium sulphate Other tests conducted were the modified AASHO density test and the CBR test, both as specified by the Corps of Engineers, U. S. Army The CBR test was also conducted with the soil compacted to standard AASHO density The properties of the natural soil as sampled, which is classified as A-7-6(20) in the revised Bureau of Public Roads classification system,[1] are shown in Table 2

After the properties of the natural soil were determined, various amounts of lime and of portland cement were added to the soil and the stabilizing effect of the admixtures observed by comparing the properties of the soil plus

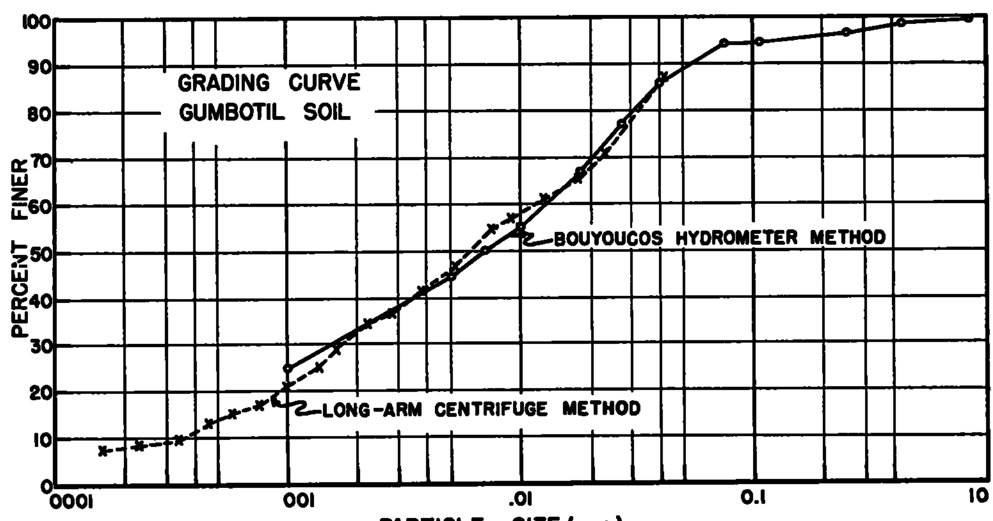

Figure 1. Mechanical Analyses of Soil Used

hydrometer method and the long-arm centrifuge method are shown in Table 1 and Figure 1. A photograph of the long-arm centrifuge is shown in Figure 2.

The type of clay mineral in the colloidal fraction of the soil was determined by the admixtures with those of the natural soil. The properties chosen for these comparisons were

[1] "Report of Committee on Classification of Materials for Subgrades and Granular Type Roads" *Proceedings*, Highway Research Board, Vol 25, p 375-392 (1945).

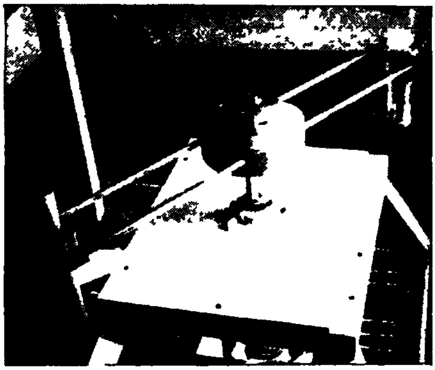

Figure 2. Long-Arm Centrifuge Used to Measure Particle Size

work. It has a specific gravity from 3 15 to 3.40 The portland cement used was a commercial grade obtained from a local lumber yard. The specific gravity of cement is about 3 20. The lime was pulverized and passed through a 100-mesh sieve before it was added to the soil. The portland cement was used in pulverized form as taken from the bag. Both the lime and cement were added to the soil in amounts expressed as a percentage of the dry weight of the soil.

In the plasticity tests, the lime and the cement were added to the soil in the amounts of 1, 2, 3, 4 and 8 percent The soil and the admixtures were mixed thoroughly in the dry

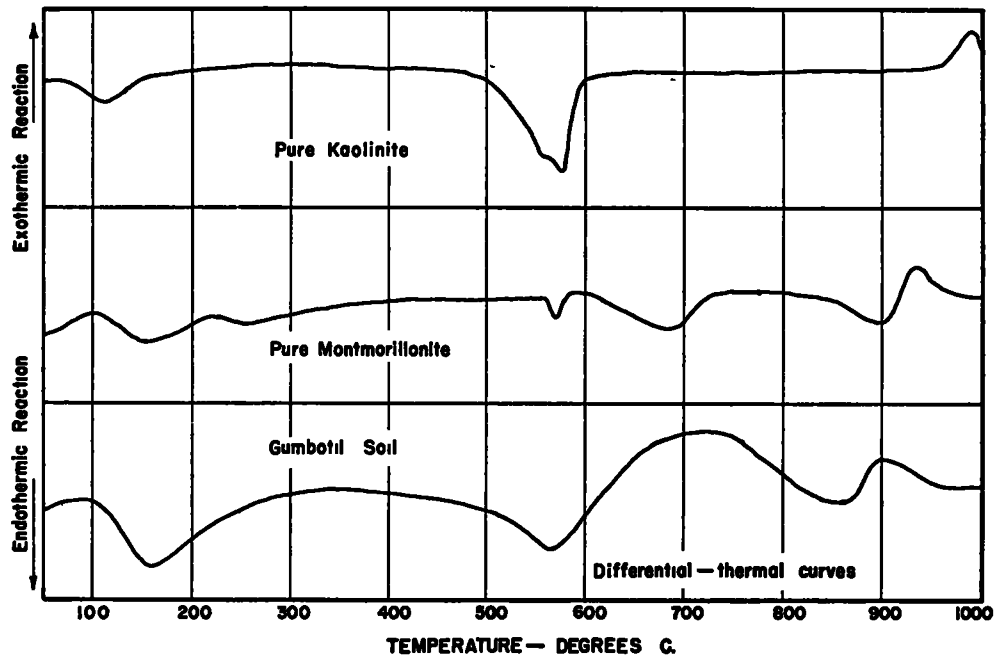

Figure 3. Differential-Thermal Curves of Test Soil Compared with Standard Samples

the liquid limit, plastic limit and plasticity index; the shrinkage limit, shrinkage ratio, linear shrinkage and volumetric change, the standard AASHO density and optimum moisture content; and the CBR with the soil molded to standard AASHO density

The lime used was USP calcium oxide obtained from the chemistry department of Iowa State College It corresponded roughly with the commercial unslaked or lump lime formerly used widely in masonry and plaster

powdered state. Then water was added to the mixture in sufficient quantity to produce a plastic mass Each mixture was then divided into two parts. One part was tested for liquid limit and plastic limit after standing in a humidifier for one hour. The other part was allowed to stand for 48 hr. before testing. The results of the plasticity tests on the natural soil and the various soil-lime and soil-cement mixtures are shown in Table 3 and Figures 4 and 5 The changes in liquid limit

TABLE 2

PROPERTIES OF GUMBOTIL SOIL

Moisture content (as sampled)	28 0%
Hygroscopic moisture	4 5%
Field moisture equivalent	37 6%
Centrifuge moisture equivalent	43 0%
Liquid limit	69 0%
Plastic limit	27 3%
Plasticity index	41 7
Shrinkage limit	9.5%
Shrinkage ratio	2.1
Volumetric change	59.5%
Linear shrinkage	14 3%
Effective size	0 0003 mm
Uniformity coefficient	37
BPR classification (revised)	A-7-6 (20)
True specific gravity (pycnometer method)	2 68
Organic matter	0 79%
pH (Beckman pH meter)	8 15
Predominate clay mineral (—0 2 micron fraction)	Montmorillonite
tandard AASHO density	97 5 pcf
Optimum moisture	25 3%
odified AASHO density	109 0 pcf
Optimum moisture	19 0%
California Bearing Ratio Tests—sample molded to Mod AASHO density	
CBR (as molded)	24 5%
CBR (soaked 4 days)	1 7%
Expansion (soaked 4 days)	4 1%
California Bearing Ratio Tests—sample molded to Std AASHO density	
CBR (as molded)	2 5%
CBR (soaked 4 days)	1 2%
Expansion (soaked 4 days)	1 0%

of lime and 4 percent of cement These results are given in Table 5.

California Bearing Ratio tests and swell tests were made on mixtures containing 2 and 4 percent lime, and 4 percent cement. These tests were conducted according to the specifications of the U. S. Corps of Engineers, except that the soil was compacted in the molds to standard AASHO density instead of the usual Modified AASHO density. The results of the CBR test and the swell test are given in Table 6

The comparisons between the properties of this gumbotil soil in its natural state and those of the soil plus admixtures indicate that, in general, the engineering properties of the soil were improved by the addition of lime and of portland cement. There was a marked decrease in liquid limit produced by the addition of both these materials. Also, the plastic limit was increased and consequently the plasticity

TABLE 3

RESULTS OF PLASTICITY TESTS ON GUMBO SOIL AND VARIOUS MIXTURES OF SOIL-LIME AND SOIL-CEMENT

Mixture	One-Hour Hydration			48-Hour Hydration			
	Liquid Limit	Plastic Limit	Plasticity Index	Liquid Limit	Plastic Limit	Plasticity Index	BPR Class
	%	%		%	%		
Natural soil	69.0	27.3	41 7				A-7-6(20)
Soil-Lime Mixtures							
Soil + 1% lime	64 0	47.0	17.0	60 5	46 0	13 5	A-7-5(13)
Soil + 2% lime	61 5	49 5	12.5	55 5	47 5	8 0	A-5 (11)
Soil + 3% lime	57 0	46 0	11.0	51 0	46 0	5 0	A-5 (10)
Soil + 4% lime	54.5	44 5	10 0	48 5	44 5	4 0	A-5 (10)
Soil + 8% lime	51.0	43 5	7.5	45 5	43 5	2 0	A-5 (9)
Soil-Cement Mixtures							
Soil + 1% cement	62.0	32 0	30 0	62 3	30 7	31 6	A-7-5(20)
Soil + 2% cement	60 0	38 0	20.0	63 5	36 0	27.5	A-7-5(19)
Soil + 3% cement	58 0	36.0	22.0	60 8	37 4	23 4	A-7-5(17)
Soil + 4% cement	55 0	35 0	20.0	55 5	39 0	16 5	A-7-5(14)
Soil + 8% cement	55 0	47 5	7 5	48 5	45 0	3 5	A-5 (10)

and plasticity index brought about by the addition of various percentages of lime and of cement are reflected by corresponding changes in the Bureau of Public Roads classification of the soil plus admixtures. The classifications and group index ratings of the modified soils are shown in Table 3.

Standard AASHO shrinkage tests were conducted on mixtures containing 2 and 4 percent of lime and of cement. The results of these tests are given in Table 4 and Figure 6. Standard AASHO density tests were conducted on mixtures containing 2 and 4 percent index was decreased. The decrease in PI was from 41 7 for the natural soil to 2.0 for 8 percent lime admixture, and 3.5 for 8 percent cement. However, as the percent added increased, the lime produced a much more rapid decrease in PI than the cement. For example, 2 percent of lime reduced the PI to 8.0, whereas 2 percent of cement only reduced it to 27.5.

Similar favorable modification of the soil was noted with respect to the shrinkage factors and the strength of the soil as revealed by the CBR tests. Both the lime and cement improved these properties of the soil, and again the lime was the more effective of the two for equal amounts of admixture. It will be noted in Table 6 that soaking the samples containing the lime and cement admixtures increased the CBR values as compared to the values "as molded". This, of course, is contrary to the usual effect of soaking natural soils and is probably due to the cementing action of the admixtures.

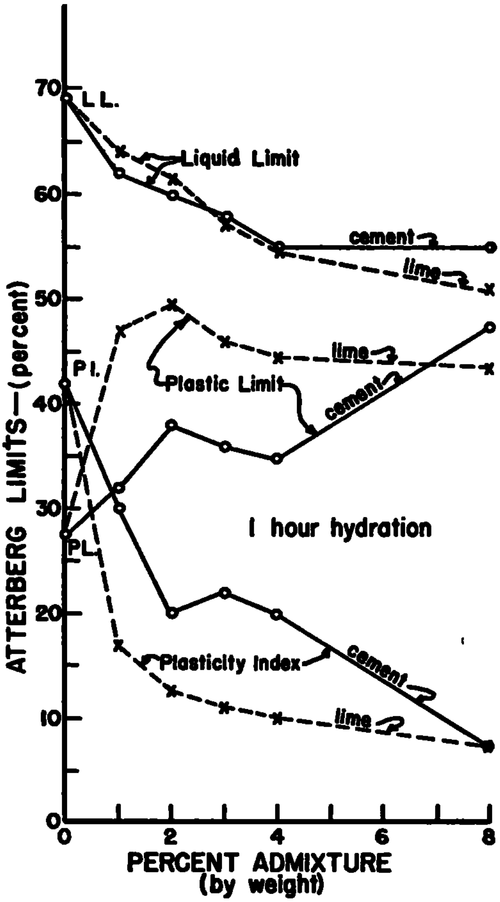

Figure 4. Atterberg Limit Test Results after 1-Hour Hydration

The addition of either lime or cement did not improve the density characteristics of the soil. In fact they appear to be affected somewhat adversely. The addition of 4 percent of lime to the soil decreased the standard AASHO density from 97 5 pcf. for the natural soil to 92 8 pcf. Two percent lime and 4 percent cement reduced the density to 96.3 and 96.5 pcf. respectively. These changes are not considered to be significant in view of the very

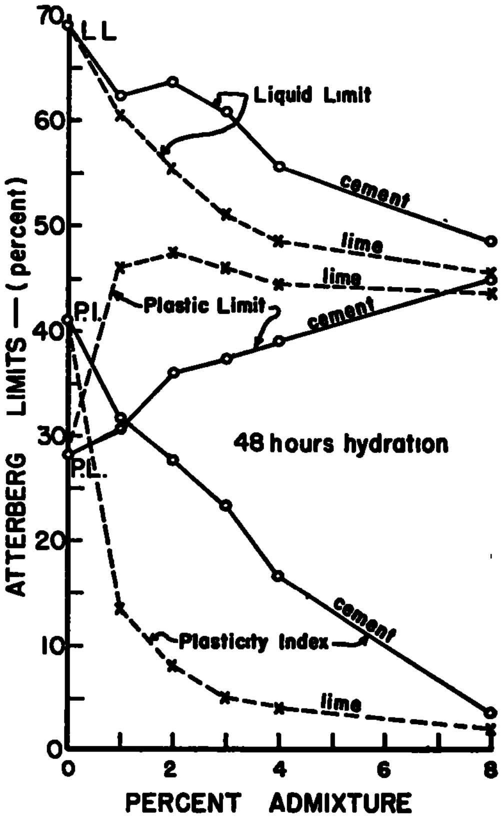

Figure 5. Atterberg Limit Test Results after 48-Hour Hydration

TABLE 4
RESULTS OF SHRINKAGE TESTS ON GUMBO SOIL AND VARIOUS MIXTURES OF SOIL-LIME AND SOIL-CEMENT

Mixture	Shrinkage Limit	Shrinkage Ratio	Volumetric Change	Linear Shrinkage
	%		%	%
Natural soil	9 5	2 1	59 5	14 3
Soil-Lime Mixtures				
Soil + 2% lime	24 0	1 6	22 5	6 5
Soil + 4% lime	29 0	1 4	13 0	4 0
Soil-Cement Mixtures				
Soil + 2% cement	13 0	2 0	48 7	12 5
Soil + 4% cement	21 9	1 7	26 7	7 5

favorable modification of the soil with respect to plasticity, shrinkage and swell, and strength properties.

This laboratory study indicates that it is possible to modify favorably the gumbotil soils of southwest Iowa by the addition of lime

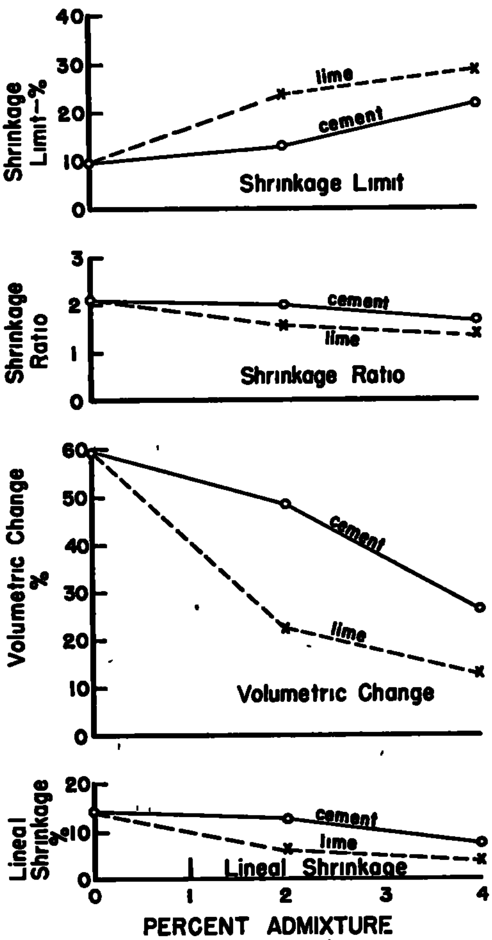

Figure 6. Results of Shrinkage Tests at 0, 2, and 4 Percent Admixture

or portland cement Also, the indications are that lime is more effective than portland cement and produces more extensive modification for the same amount of added material.

The authors realize that the favorable results achieved in this laboratory study represent a goal which probably could not be completely obtained in the field. However, further study along this line, particularly with reference to practical methods of combining the materials in the field and the observation of field results, would appear to be justified.

TABLE 5
STANDARD AASHO DENSITY TEST ON GUMBO SOIL AND VARIOUS MIXTURES OF SOIL-LIME AND SOIL-CEMENT

Mixture	Maximum Density	Optimum Moisture
	pcf	%
Natural soil	97 5	25 3
Soil + 2% lime	96 3	24 8
Soil + 4% lime	92 8	26 0
Soil + 4% cement	96 5	23 0

TABLE 6
CALIFORNIA BEARING RATIO TESTS ON GUMBO SOIL AND VARIOUS MIXTURES OF SOIL-LIME AND SOIL-CEMENT
(specimens molded to standard AASHO density)

Mixture	Penetration	As Molded		Soaked 4 days		
		Load	CBR	Load	CBR	Swell
	in	*psi.*	%	*psi*	%	%
Natural soil	0 1	42		22		1.0
	0 5	59	2 5	30	1 2	
Soil + 2% lime	0 1	170		450		0
	0 5	190	7 3	600	23 0	
Soil + 4% lime	0 1	83		200		0
	0 5	170	6 6	240	9 3	
Soil + 4% cement	0 1	93		150		0 08
	0 5	120	4 6	170	6 7	

ACKNOWLEDGEMENT

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REFERENCE

PATEL, OCHHAVLAL HIMATLAL "Stabilization of Gumbotil Soil for Highway Use" Unpublished thesis, Library, Iowa State College, Ames, Iowa, (1948)