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March 1971

CERL

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A STUDY OF THE EFFECTS OF LIME AND CEMENT ON PADDY AND LATERITE MATERIAL

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ABSTRACT

Laboratory tests were performed on samples of paddy and laterite soils obtained from the proposed right-of-way of the Rangoon-Mandalay Highway, Burma. These tests were conducted to determine the basic engineering properties of the soils and to evaluate the feasibility of stabilizing these soils with lime and cement.

The addition of lime to these soils had little beneficial effect on either soil. This was due to the non-reactive nature of the soils and the poor stabilizing quality of the lime available in Burma.

Special tests using American lime indicated a strength increase of about 300% over the natural soil strength, compared to an increase of less than 100% with Burma lime.

Addition of cement, on the order of 6% by dry weight of soil, effectively stabilizes both soils. Unconfined compressive strengths of both are increased on the order of 300%.

FOREWORD

This report describes a study performed by the Special Projects Branch of the Construction Engineering Laboratory (CEL)*, Ohio River Division Laboratories for the Civil Engineering Branch, Engineering Division, Military Construction, Office of the Chief of Engineers. The study was conducted in accordance with the "Instructions and Outline for the Evaluation of Materials for Overseas Construction." It is part of a long-range investigation of materials from overseas construction areas, especially those materials which are considered to have undesirable properties from a construction standpoint.

The U.S. Army Engineer District, Gulf, Tehran, and the Project Engineer, CE, Rangoon, Burma, obtained and shipped the materials used.

Messrs. N.B. Schomaker, R. C. Gunkel, G. M. Schanz, and E. M. Cundiff were actively engaged in the study. Mr. R. L. Hutchinson, Chief of CEL, supervised the work. This report was prepared at CERL by Mr. R. E. Aufmuth under the direction of Mr. E. A. Lotz, Chief of the Materials Laboratory.

This report has been reviewed by the Office of the Chief of Engineers and revised on the basis of comments received.

**In October 1968 the CEL became the Construction Engineering Research Laboratory (CERL), located in Champaign, Illinois since 1 July 1969.*

CONTENTS

strength, and durability tests were performed on soil passing a No. 4 sieve. The Atterberg limits test was performed on the soil passing a 0.420-mm (No. 40) sieve. Tests performed on the natural soils and on these soils mixed with lime and cement are listed in Table 1. Except as otherwise stated, the procedures described in "Materials Testing," TM 5-530/AFM 88-51, February 1966, were used.

Testing. The differential thermal analysis was performed on that portion of the soil passing the 74 μ (No. 200) sieve. The test specimen was brought to equilibrium with air at 45–50% relative humidity, placed in an electric furnace and heated at a uniform rate to the range from 1000°C to 1050°C. As the sample was heated, a thermogram was recorded, starting at 50°C. The thermogram was interpreted by comparing it with curves from standard materials of known composition and by referring to similar tests on soils previously studied.

X-ray analyses were performed on the No. 200 sieve material to determine the gross identification of the silt and clay-sized matter, and on the 2μ (No. 325 sieve) material to further differentiate between the clay mineral species. The specimens were analyzed on a General Electric XRD-6 Diffractometer using nickel-filtered CuKα radiation at 45KV and 22ma.

The lime content required for stabilizing these soils was determined from unconfined compressive strength tests performed on various soil-lime specimens cured for 90 days at room temperature. Essentially, this concentration was considered as that amount of lime which when added to a soil produced maximum strength gain after 90 days of curing at room temperature.

Immersion tests were performed on specimens of each soil compacted to the same density and water content as those for the unconfined compression tests. Two specimens were prepared for each immersion test. Each was cured for 28 days, immersed for 24 hrs in tap water, and then tested for unconfined compressive strength.

The wet-dry test was performed in accordance with ASTM:* D 559-57. Although this test procedure is specifically for soil-cement specimens, it served as a basis of comparison for all the wet-dry test specimens. Two specimens for each soil, 1.31 in. in diameter by 2.81 in. long, were compacted and cured for 28 days. In each cycle of the wet-dry test: the specimens were weighed and measured; immersed in tap water for 5 hrs; removed from water and drained; weighed and measured; dried for 42 hrs in an oven at 72.2°C; weighed and measured; then one of the duplicate specimens was lightly brushed and weighed. The specimens were subjected to additional cycles until they deteriorated or until 12 cycles had been completed.

The freeze-thaw test was performed in accordance with ASTM: D 559-60. This test procedure, which is intended for soil-cement specimens, formed a basis of comparison for all the freeze-thaw specimens. Two specimens for each soil, 1.31 in. in diameter by 2.81 in. long were compacted as described in TM 5-530/AFM 88-51, and cured for 28 days. After being weighed and measured, the specimens were placed on a water-saturated felt pad within the specimen carrier. The assembly was placed in a freezer with a constant temperature of −23°C for 24 hrs, then removed and placed to thaw in a moist room at 21°C for 23 hrs. Free water was supplied to the felt pads to permit the specimens to absorb water by capillary action during the thawing period. The specimens were then brushed, the amount of heave was measured, and they were turned over end-for-end before being replaced on saturated pads, completing one cycle. The specimens were subjected to additional cycles until they deteriorated or had undergone 12 cycles.

3 TEST RESULTS AND DISCUSSION

Data. Test results are presented in Tables 1–5 and Figures 1–10.

Discussion. As Figures 7 and 8 show, the addition of lime does little to increase the strength of either soil, the paddy soil reacting slightly more than the laterite. The limited strength increase with lime was traced to the quality of the German lime, as discussed in Appendix I. Both soils show better than 300% strength increase over the natural soil with 6% cement added and better than 600% increase with 9% cement.

Results of the immersion tests, presented in Table 4, show that both natural soil types disintegrated

*American Society for Testing and Materials prior to the end of the 24-hr immersion period. Addition of lime to both soils increased the resistance of the soils to saturation only slightly. The unconfined strengths with lime added are less than the strengths of the natural soils (Figs. 7, 8).

Addition of cement to each soil greatly increased the resistance to saturation. The immersion strengths (Table 4) are slightly more than half the unaltered soil-cement strengths (Figs. 7, 8).

Additional durability tests consisted of wet-dry and freeze-thaw cycles performed on the soils both in their natural state and when mixed with lime and cement (Figs. 9, 10). The soil-lime specimens showed little resistance to repeated wetting and drying. The paddy-cement specimens showed similar results until the maximum cement content was reached. This effect may be due to the large amount of clay-size material resulting in a poor soil-cement mix. The laterite-cement specimens showed considerable resistance to wetting and drying.

Freeze-thaw test results (Figs. 9, 10) show trends similar to those of the wet-dry tests, in that the soil-lime specimens show poor durability characteristics. The laterite-lime (4 and 6% lime) specimens show less durability than the natural soil specimens. The cement additives increased the resistance to freezing and thawing.

Test	Lime	Cement
Specific Gravity	2.43	3.08
Fineness (sq cm/gm test sample)	14,180	2,640

Appendix I summarizes the results of tests on Burma soils with United States and rehydrated German lime. It is evident that the U.S. lime and rehydrated German lime are more beneficial for stabilization than the Burma lime as received. Appendix II summarizes the results of California Bearing Ratio (CBR), moisture-density, Atterberg limits, and gradation tests performed on these soils by the Corps of Engineers' Mediterranean Division.

4 SUMMARY AND CONCLUSIONS

From the test results, the paddy soil is classified as a fat clay (CH) and the laterite soil as a lean clay (CL). Mediterranean Division test results indicate that the paddy soil has a very poor CBR 4 at 95% compactive effort, CE55* while the laterite exhibits a very good CBR value 75 at 95% compactive effort, CE55. Both of these soils may be effectively stabilized with cement (6% by dry weight of soil), yielding a strength increase in excess of 300%.

Neither of these soils reacted with the German lime obtained from Burma. Strength increases were about 50 psi for the paddy soil and 0 psi for the laterite. However, with United States lime or rehydrated Burma lime the strength increase for the paddy soil was on the order of 250 psi for 28-day cure specimens. The laterite was less reactive, exhibiting only 20 to 50 psi increase for the same cure times.

TABLE 1
Classification Test Results on Natural Soils

Test	Paddy	Laterite
Gradation (#200)	89.0%	50.0%
Specific Gravity	2.72	2.78
Atterberg Limits: LL	54.3	40.2
PL	24.5	14.5
PI	29.8	25.7
Maximum Dry Density	115.7 lb/cu ft	122.3 lb/cu ft
Optimum Moisture	14.0%	14.6%

TABLE 2
Chemical Analysis Results on Burma Soils and Stabilizing Agents

Constituents	Paddy	Laterite	Lime	Cement
Silica (SiO_2)	66.28%	58.16%	22.18	1.92%
Alumina (Al_2O_3)	14.60	15.12	4.76	0.90
Iron Oxide (Fe_2O_3)	7.46	15.80	3.14	
Calcium Oxide (CaO)	0.12	0.06	64.49	40.48
Magnesium Oxide (MgO)	0.96	0.47	1.39	25.62
Sulphates (SO_4)	0.04	0.03	1.88	
Loss on Ignition	6.28	7.25	1.49	30.22
Moisture	2.27	0.94		
Undetermined	1.99	2.17	0.63	0.86
	100.00%	100.00%	100.00%	100.00%

Corps of Engineers procedure detailed in Military Standard 621-A

TABLE 3
X-Ray Analysis Results

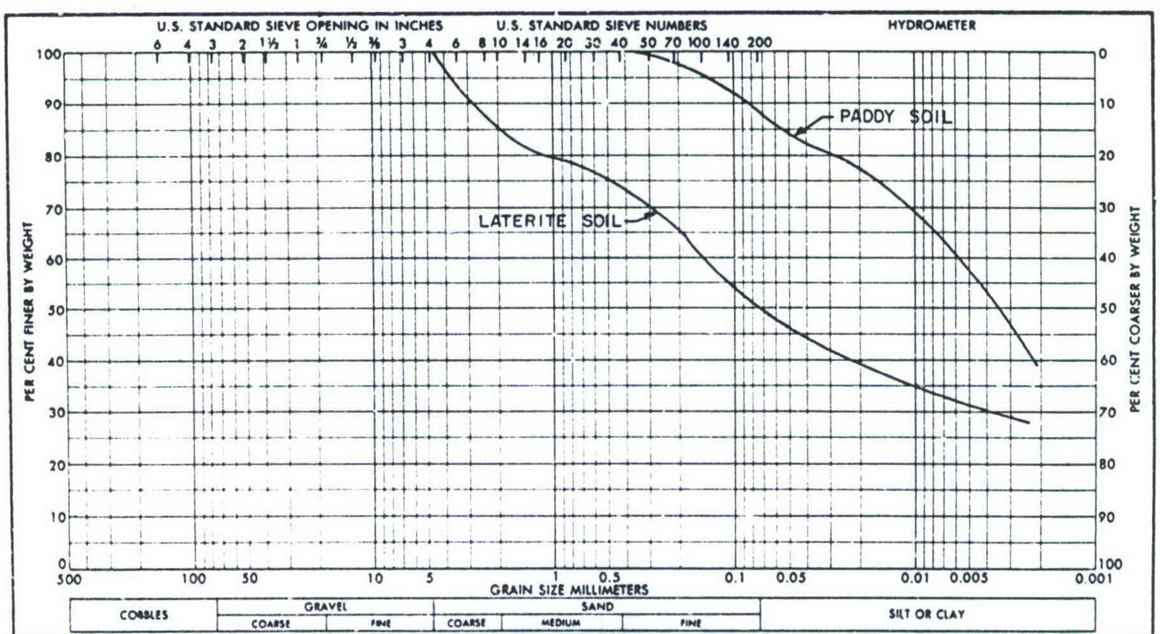
Soil	Non-Clay	Clay
Paddy	Quartz	Kaolinite
	Goethite	Illite
		Montmorillonite
		Mixed-Layer
Laterite	Quartz	Kaolinite
	Hemetite	Illite
	Feldspar	Chlorite

TABLE 4
Immersion Test Results

% Lime	Strength lb/sq in.	% Cement	Strength lb/sq in.
	Paddy Soil		
2	23.5	3	25.3
4	71.4	6	169.7
6	61.7	9	390.8
	Laterite Soil		
2	20.3	3	54.2
4	14.6	6	311.0
6	41.0	9	618.5

TABLE 5
Atterberg Limits: Burma Soils Mixed with Lime

Soil		Lime Content (% dry weight of soil)							
PADDY	Natural	1	2	3	4	5	6	7	9
Liquid limit	54.3	65.7	65.0	66.5	–	62.5	–	66.0	63.0
Plastic Limit	24.5	28.5	31.1	35.3	–	38.2	–	40.5	39.4
Plasticity Index	29.8	37.2	33.9	31.2	–	24.3	–	25.5	23.6
LATERITE									
Liquid Limit	40.2	38.8	39.2	43.8	44.6	–	45.7	44.0	–
Plastic Limit	25.7	20.3	24.2	25.4	27.5	–	32.3	27.4	–
Plasticity Index	14.5	18.4	14.9	18.4	17.1	–	13.5	16.6	–



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
LATERITE	1.0'–4.0	REDDISH BR. SANDY SILTY CLAY (CL)		40.2	25.7	14.5
SOIL			SP. GRAVITY	2.78		
PADDY	2.0'–5.0'	BROWN FAT CLAY (CH)		54.3	24.5	29.8
SOIL			SP. GRAVITY	2.72		

Figure 1. Burma soils gradation curves.

MOISTURE-DENSITY CURVES

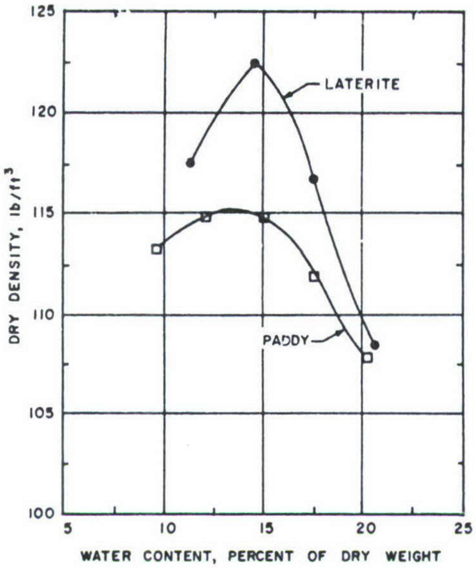


Figure 2. Natural soil.

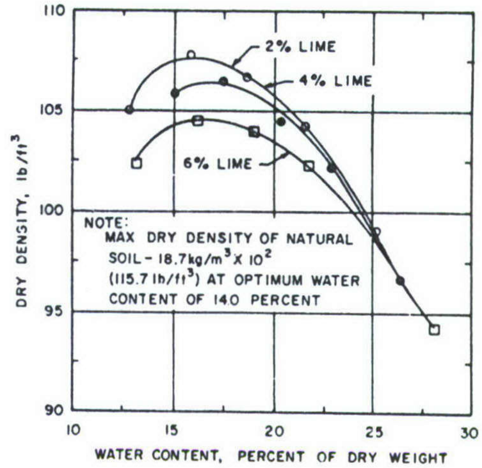


Figure 3. Lime-paddy soil.

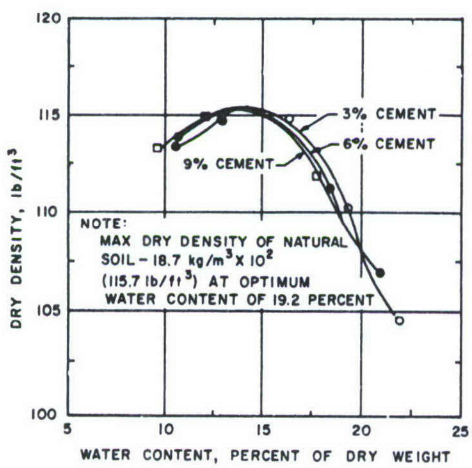


Figure 4. Cement-paddy soil.

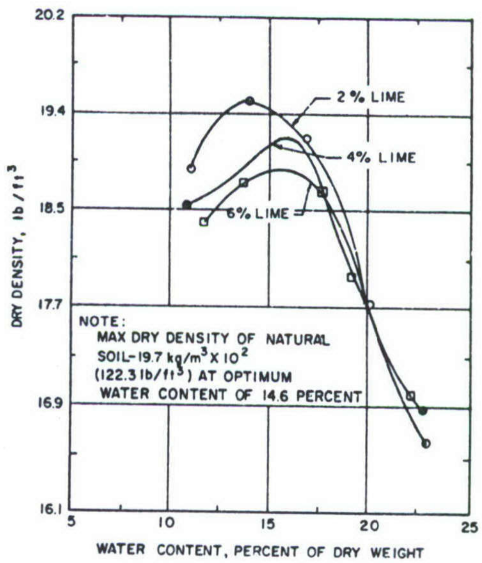


Figure 5. Lime-laterite soil.

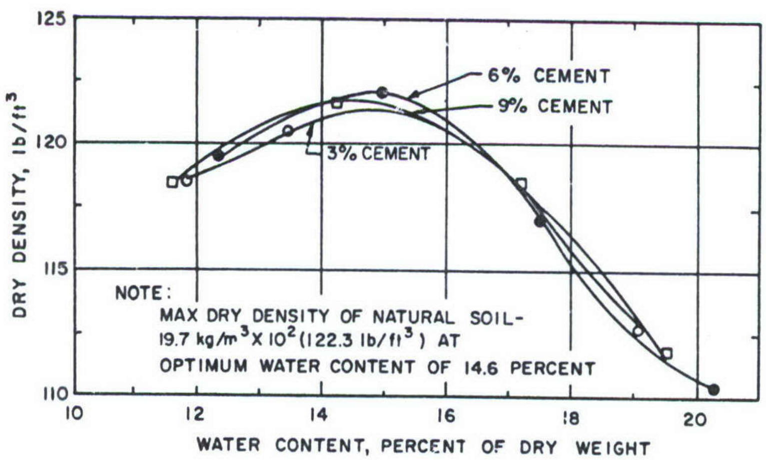


Figure 6. Cement-laterite soil.

SUMMARY OF UNCONFINED COMPRESSIVE STRENGTH vs PERCENT LIME AND CEMENT

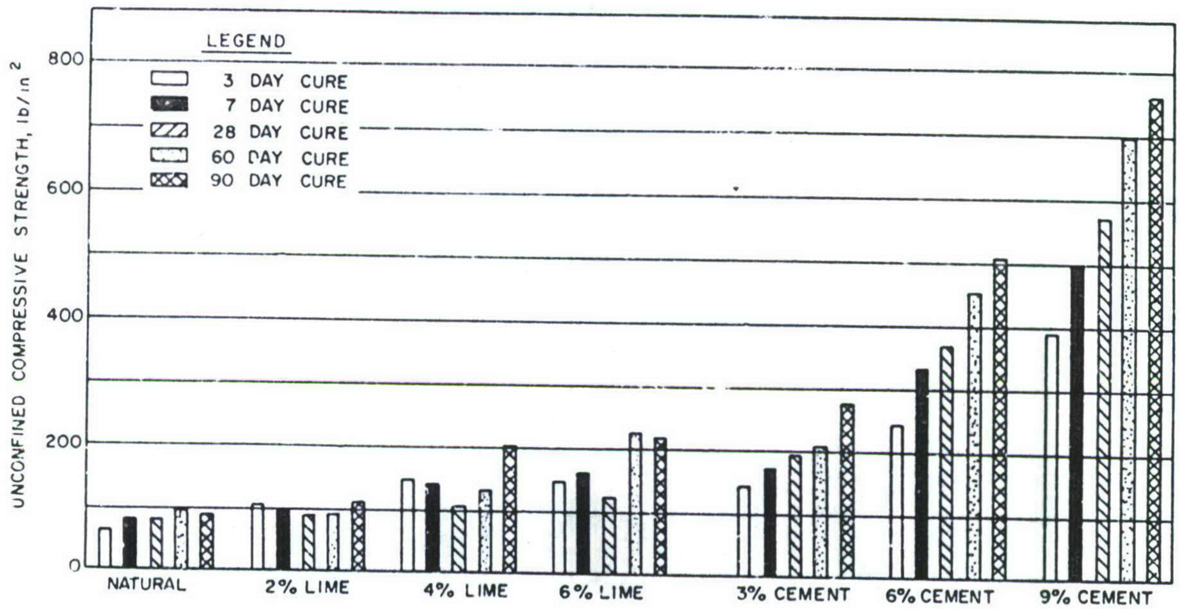


Figure 7. Paddy soil.

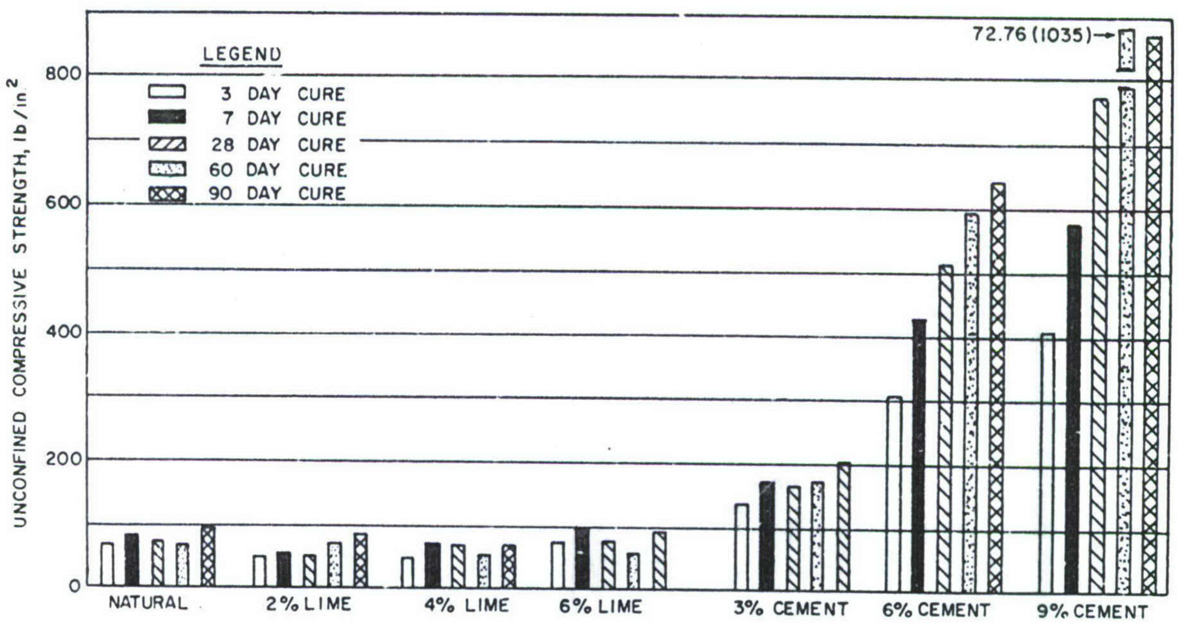


Figure 8. Laterite soil.

WET-DRY, FREEZE-THAW CYCLE RESULTS

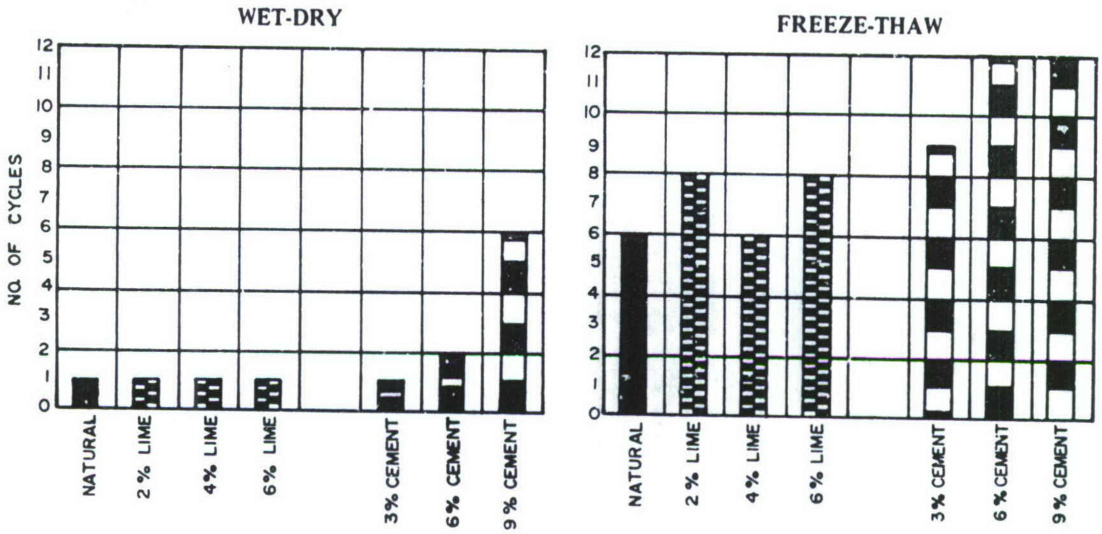


Figure 9. Paddy soil.

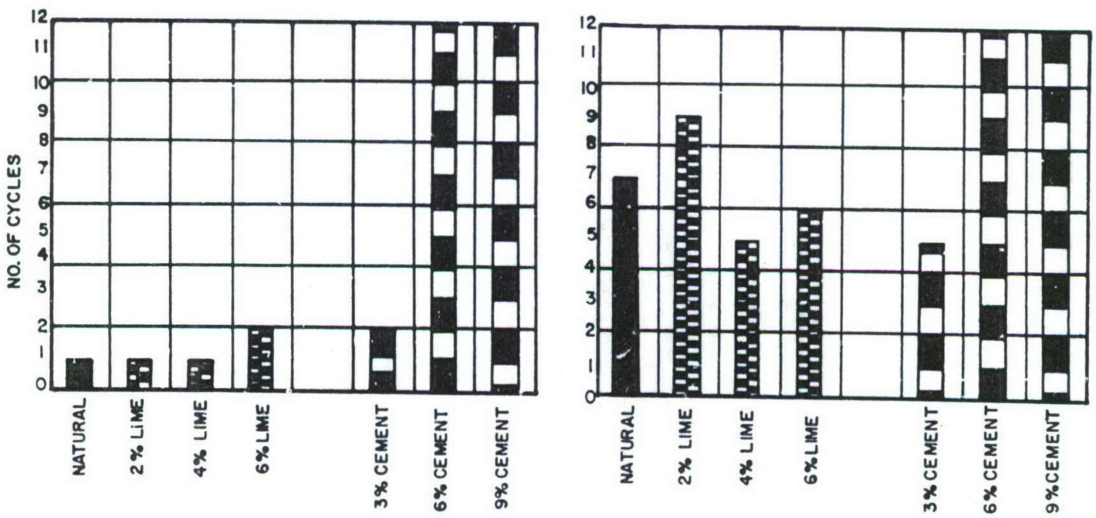


Figure 10. Laterite soil.

APPENDIX I: SPECIAL TESTS

General. During the investigation of the Burma soils, it was noted that the unconfined compressive strength results were erratic. Numerous reruns were made, but the results were still inconsistent. Unconfined compressive strengths decreased with increasing age a reversal of past experience. Normally the strength increases as the curing age increases.

Special tests were initiated in an attempt to determine if the poor results were caused by the Burma lime with which the tests were prepared. Three specimens containing 4% United States lime were prepared for each curing period (7 and 28 days), and unconfined compressive strengths were measured. These strengths were then compared with the strengths of the specimens using the lime from Burma.

Because the results of the special tests indicated that the lime produced the erratic results, additional tests were performed to determine how the lime was responsible.

Additional Tests on Lime Types. The first series of tests consisted of performing chemical and x-ray diffraction analyses on the United States lime and re-hydrating the lime from Burma. Also, three soil-lime specimens for each curing period of 7 and 28 days were prepared using 6% re-hydrated lime. The 6% lime was used instead of the 4% to insure that enough lime was present for re-hydration. All the specimens were compacted at the same density and water content as the initial test specimens. After curing, the unconfined compressive strengths were determined.

The second series of tests consisted of performing pH measurements on various percentages of lime from Burma and the United States, admixed with a kaolinite clay. Twenty grams of soil (dry weight basis) were placed in a 115-ml polyethylene bottle and mixed with successive percentages of both limes. Distilled water (100 ml) was then added to each bottle. The samples were then placed in a forced draft oven at 60°C for 72 hrs. Twice daily, the samples were removed from the oven, mixed thoroughly, and replaced in the oven. The pH of each sample was determined after 72 hrs.

Test Results. The results of the chemical analysis and x-ray diffraction analysis are as follows:

CHEMICAL ANALYSIS

Constituents	Quantity (%) Burma Lime	United States Lime
Silica (SiO_3)	1.92	0.46
Alumina (Al_2O_3)	0.90	0.13
Iron Oxide (Fe_2O_3)	--	0.21
Clacium Oxide (CaO)	40.48	69.32
Magnesium Oxide (MgO)	25.62	1.50
Loss on Ignition	30.22	28.40

X-RAY DIFFRACTION ANALYSIS

Calcium Hydroxide (Portlandite)	40.00	96.00
Magnesium Hydroxide	35.00	--
Calcium Carbonate (Calcite)	25.00	4.00

Classification Tests. The chemical analysis of the limes indicates that the lime from Burma contained a lesser amount of CaO and more MgO than the United States lime. The x-ray diffraction analysis of the lime from Burma also indicates that considerably more calcium carbonate was present than in the United States lime.

Unconfined Compression Tests. Tests of the soil-lime specimens indicate a considerable increase in strength for both the 7- and 28-day cured specimens compared to specimens compacted with Burma lime. This increase was anticipated from previous experience and confirmed that the inconsistent results were caused by use of the lime obtained from Burma.

The average unconfined compressive strengths for the paddy and laterite soils, admixed with various limes and cured for 7 and 28 days, are shown in Table IA and Figure IA.

pH tests. In the pH tests the two types of lime admixed with the relatively pure clay mineral kaolinite, higher pH levels were obtained with the U.S. lime. Figure IB plots pH versus percent lime.

Discussion. Previous literature on the mechanism of soil stabilization (Refs. 3--7) generally indicates that over a period of time after addition of lime to a soil, a cementitious gel consisting of calcium silicate and/or aluminates is formed. The referenced literature generally indicates that high pH facilitates the formation of the gel by causing the silica to be dissolved out of the structure of the clay minerals; it can then combine with the Ca+ to form calcium silicates. In the pH test described above, greater pH levels were obtained with the lime from the United States than with the lime from Burma. Therefore, the increase in strength using the United States lime could result in the increase in pozzolanic or cementing action caused by the greater percentages of CaO in United States lime.

It was also theorized that the strength variability observed in the initial tests could have been caused by the detrimental expansion characteristics of the MgO and the excessive amount of calcium carbonate present in the lime from Burma. Therefore, an x-ray diffraction analysis was performed, and additional specimens were prepared using rehydrated Burma lime. These soil-rehydrated lime specimens indicated a greater increase in strength for both 7- and 28-day curing age than those specimens using the non-rehydrated lime from Burma. However, this increase was not as great as obtained by using United States lime, nor was there any appreciable difference in strength between the 7- and 28-day cured specimens. This was attributed to the fact that as the x-ray analysis indicated, not much unhydrated MgO was present.

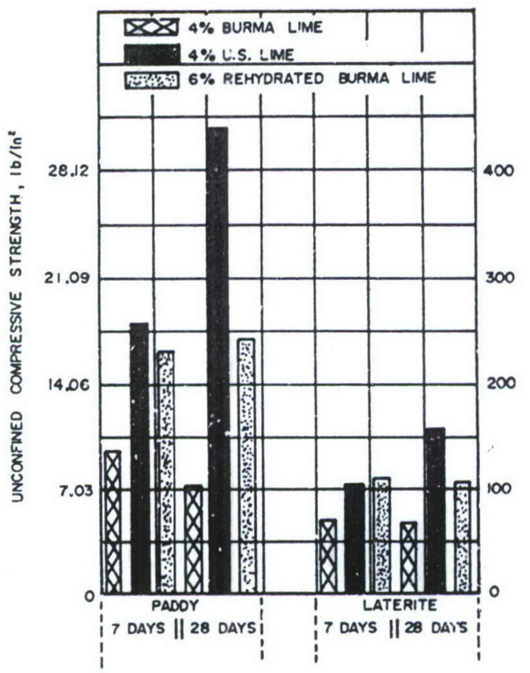


Figure IA. Comparison of unconfined compressive strength for Burma and U. S. lime.

Conclusions. The primary cause of inconsistent results was the low CaO and high $CaCO_3$ content of the Burma lime. The detrimental expansion characteristics of the Burma lime's MgO content is considered to be only of secondary importance in producing inconsistent results. Based on test results, no definite optimum lime content was determined for the paddy and laterite soils, although the 90-day strength with 6% soil-non-rehydrated lime specimens produced the greatest strength.

TABLE IA
Average Unconfined Compressive Strengths

Quantity % Lime	Days	Paddy lb/in²	Laterite lb/in²
4% Burma Lime	7	140.2	72.2
	28	104.4	70.6
4% U.S. Lime	7	260.3	108.1
	28	416.8	161.9
6% Burma Lime	7	160.1	97.7
	28	120.8	78.8
6% U.S. Lime	7	274.5	–
	28	363.8	–
6% Burma Lime (Rehydrated)	7	234.8	114.7
	28	245.3	109.2
	60	326.5	111.8

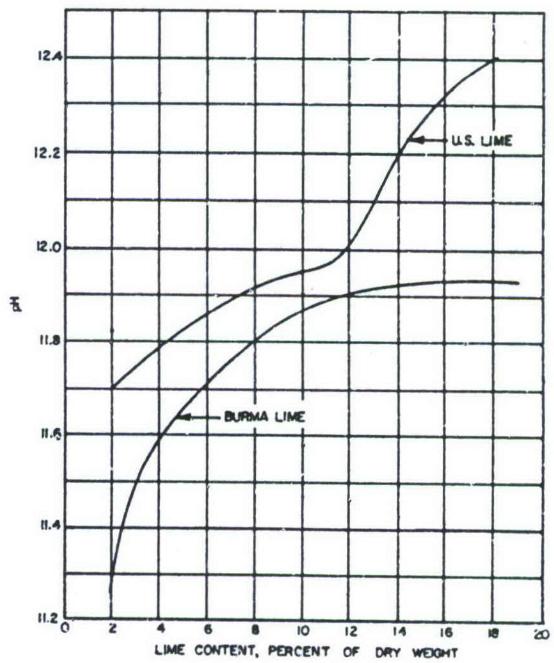
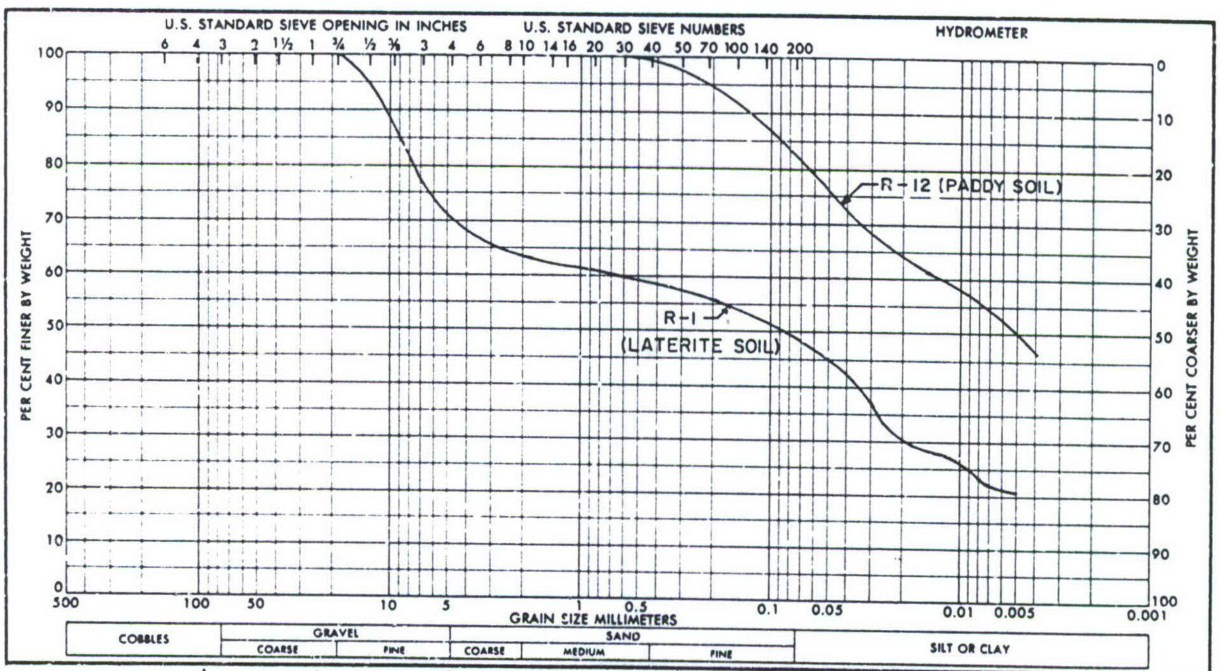


Figure IB. Correlation of pH vs lime content of Burma and U. S. lime.

APPENDIX II : PRELIMINARY SOIL INVESTIGATION /RANGOON-MANDALAY HIGHWAY

U.S. Army Corps of Engineers Mediterranean Division



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
R-1	1.0'-4.0'	SAND-CLAY MIX (SC) TP-1 STA 353+00	—	33	23	10
R-12	2.0'-5.0'	LEAN CLAY (CL) TP-8 STA 1025+00	21	44	16	28

Figure IIA. Gradation curves.

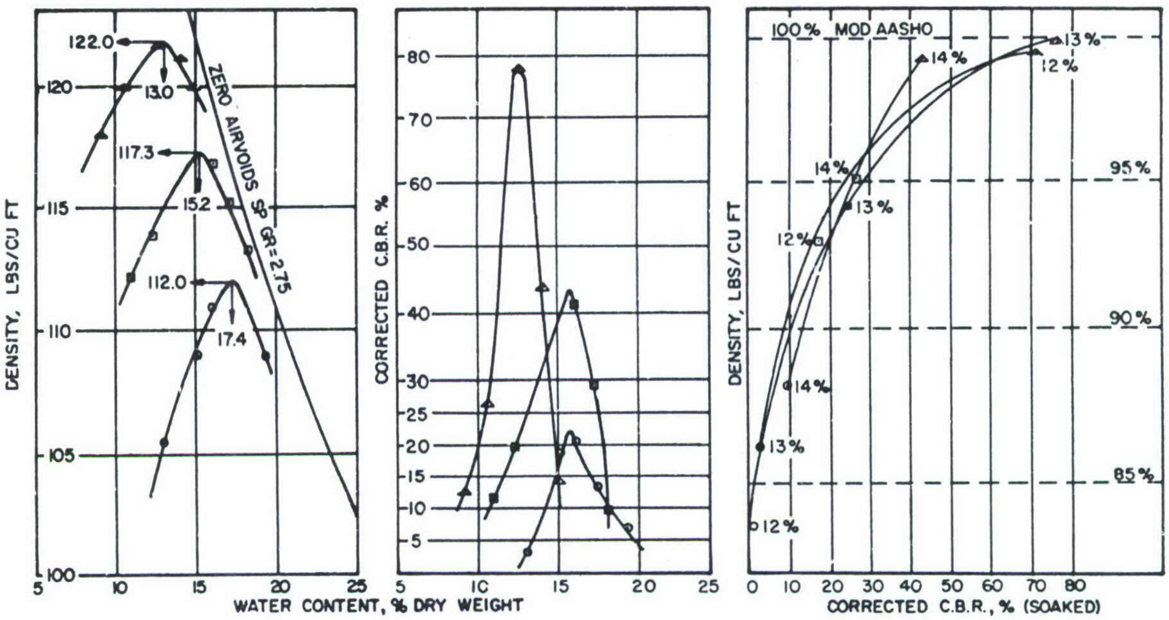


Figure IIB. Paddy soil: project 63-02; test pit #8; station 1025+00; sample #R-12; depth 2.0 – 5.0 ft.

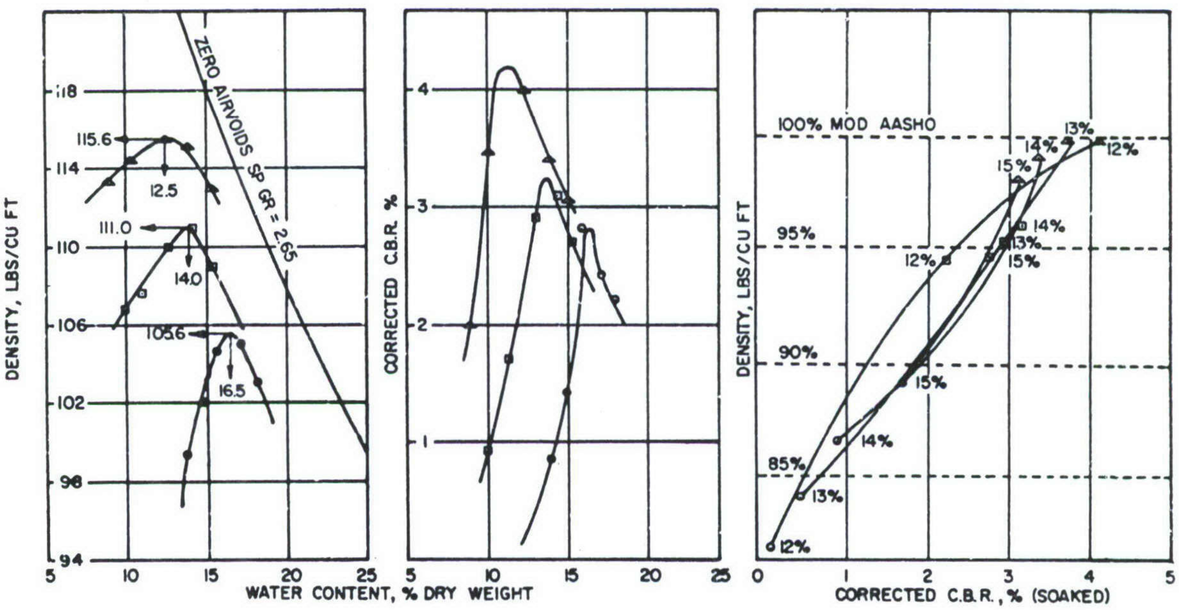


Figure IIC. Laterite soil: project 63-20; test pit #1; station 353+00; sample #R-1; depth 1.0 – 4.0 ft.

<u>LEGEND</u>

▲ CE 55 COMPACTIVE EFFORT

▣ CE 26 COMPACTIVE EFFORT

⊙ CE 12 COMPACTIVE EFFORT

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The addition of lime to these soils had little beneficial effect on either soil. This was due to the non-reactive nature of the soils and the poor stabilizing quality of the lime available in Burma.

Special tests using American lime indicated a strength increase of about 300% over the natural soil strength, compared to an increase of less than 100% with Burma lime.

Addition of cement, on the order of 6% by dry weight of soil, effectively stabilizes both soils. Unconfined compressive strengths of both are increased on the order of 300%.

14. KEY WORDS

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