Durability of Soil-Lime-Flyash Mixes Compacted Above Standard Proctor Density

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Lime-flyash stabilized Kansas dune sand, Iowa silt (loess) and Texas coastal plain clay show a definite increase in durability when compacted to densities above standard Proctor. In fact, silt and clay mixes gained strength more rapdily through artificial weathering than after sustained moist curing.

Two-in. by 2-in. cylindrical specimens prepared with 25 percent lime-flyash and optimum ratios of lime to flyash (1:9 for sand and silt, and 2:8 for the clay) were cured for 14 days at near 100 percent relative humidity and 70 F prior to being subjected to cycles of freezing and thawing or wetting and drying. Moisture absorption, swelling and unconfined compressive strength of the specimens, after various cycles of freeze-thaw and wet-dry were used as a means of analyzing the durability of the stabilized soils.

The increases in strength during wet-dry and freeze-thaw tests over normal moist curing, are attributed to improved intimacy of contact between lime and flyash grains following dissolution and reprecipitation of the lime.

● STUDIES BY Goecker et al (3) have indicated that compaction to a density greater than standard Proctor greatly improved the resistance of soil-lime-flyash to wetting and drying or freezing and thawing. The present study was undertaken to check the resistance of lime-flyash stabilized soils compacted to densities above standard Proctor and within the capabilities of present-day compaction equipment.

Three compactive efforts were used: (1) between standard and modified Proctor density, (2) equivalent to modified Proctor and (3) above modified Proctor. These are listed in Table 1.

The criteria used to evaluate the effects of increased density on durability of the specimens after various cycles of wetting and drying or freezing and thawing were unconfined compressive strength, moisture absorption and average increase in height of specimens, the latter being an indication of volume change or swelling.

MATERIALS

Soils

Soils selected for this study are the same as those used by Viskochil et al (5). The silt is a friable, calcareous loess from western Iowa; the clay is a deltaic deposit from the coastal plain region of Texas; and the sand is from a stable dune area associated with the Arkansas River in south central Kansas. Tables 2 and 3 give field information and the various physical and chemical properties of the soil samples.

Lime and Flyash

The lime used in this study is a hydrated calcitic (high calcium) lime from the Linwood Stone Products Co., Buffalo, Iowa. A laboratory analysis furnished by the manufacturer is shown in Table 4. The flyash used is from Paddy's Run Station, Louisville Gas and Electric Co., Louisville, Kentucky. A chemical analysis of the flyash was obtained from the Robert W. Hunt Co., Chicago, Illinois, and is shown in Table 4.

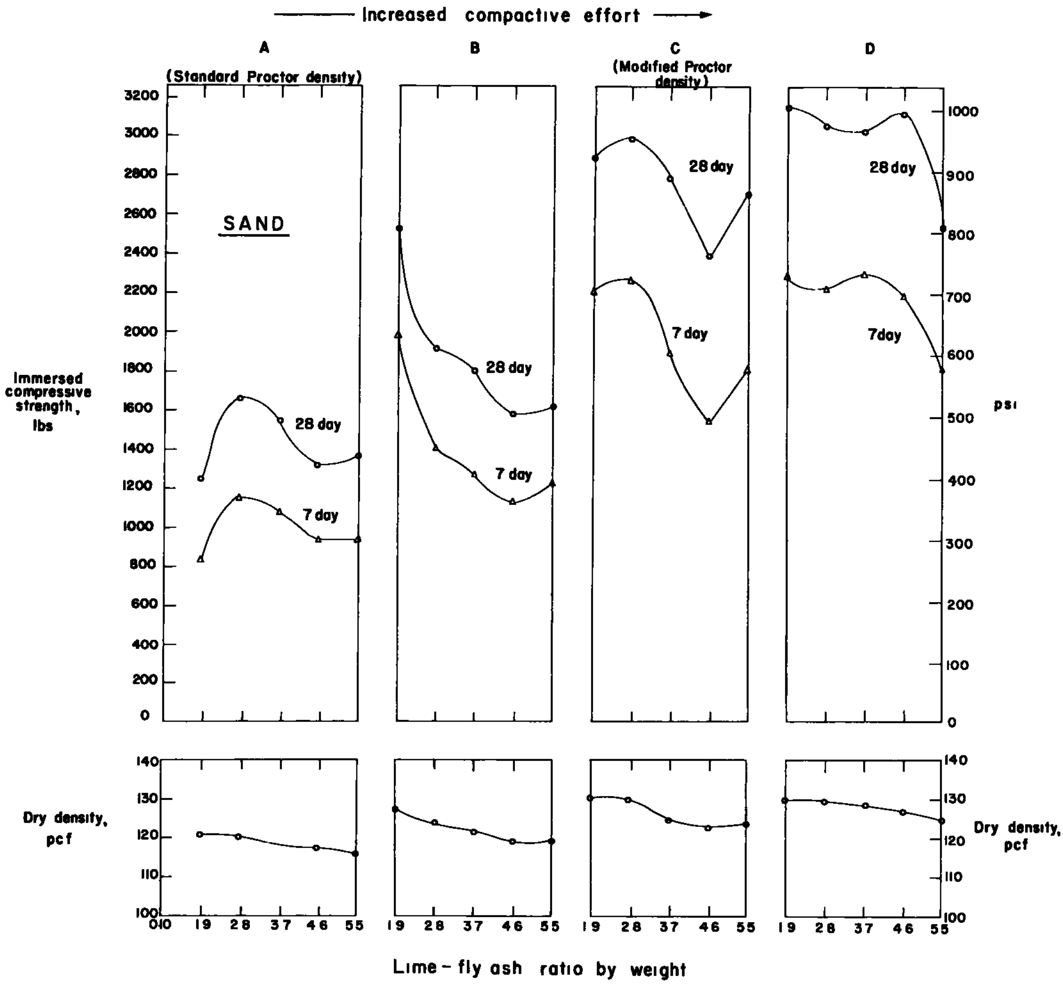

Figure 1. Effect of variations in lime to flyash ratio, compactive effort, and curing on compressive strength and density of lime-flyash stabilized sand.

METHOD OF TEST

Mixing

The soils were air dried, pulverized and screened through a No. 10 sieve. Each soil was dry mixed by hand with the various amounts of lime and flyash. Predetermined amounts of distilled water were then hand mixed into the blend and mixing was completed with a Hobart, Model C100, mixer at moderate speed for three minutes.

TABLE 1

DESIGNATIONS OF COMPACTIVE EFFORT[a]

Compaction	Density Obtained
A	Standard Proctor density
B	Between standard and modified density
C	Modified Proctor density
D	Above modified density

[a]After Viskochil et al (5)

Molding

Two-in. diameter by 2-in. high specimens were molded at each density using a drop hammer molding apparatus (5). Compaction of 2-in. by 2-in. specimens to standard and modified Proctor densities with this apparatus has been correlated very closely with recognized laboratory compactive procedures (1, 5).

Curing

Curing was accomplished in a humidity cabinet at approximately 70 F and near 100 percent relative humidity. After designated lengths of curing the samples were measured for height and weight.

TABLE 2

FIELD INFORMATION ON SOIL SAMPLES[a]

	Kansas Sand	Iowa Silt	Texas Clay
Geological origin	Recent dune sand from the Great Bend tract	Wisconsin age loess from near Missouri River	Deltaic (Beaumont clay) from coastal plain
Soil Series	Pratt	Hamburg	Lake Charles
Horizon	C	C	C
Location	28 mi. S. of Great Bend	In the town of Missouri Valley	South of Houston
Sampling depth, ft	1½-3½	49-50	3¼-12 (Composite)

[a]After Viskochil et al (5)

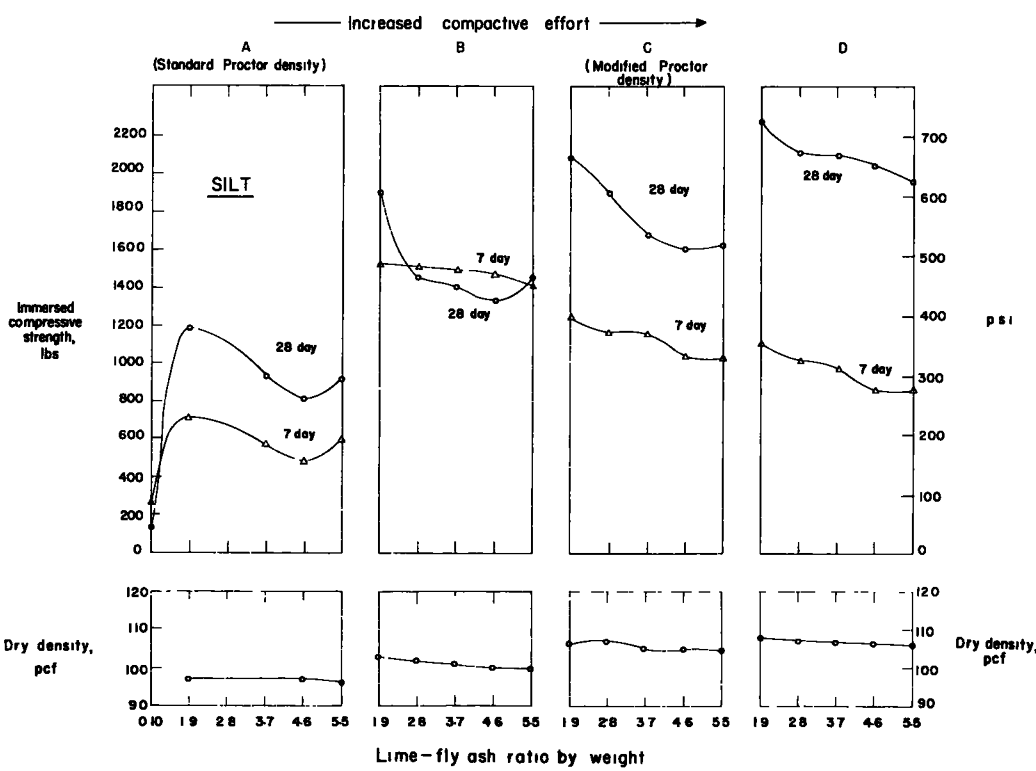

Figure 2. Effect of variations in lime to flyash ratio, compactive effort, and curing on compressive strength and density of lime-flyash stabilized silt.

TABLE 3

PROPERTIES OF SOIL SAMPLES[a]

	Kansas Sand	Iowa Silt	Texas Clay
Textural composition, percent			
Gravel (> 2 mm)	0	0	0
Sand (2 - 0.074 mm)	86.4	0.7	7.7
Silt (74 - 5 μ)	4.0	78.3	48.2
Clay (< 5 μ)	9.6	21.0	44.1
Colloids (< 1 μ)	8.6	15.8	36.8
Predominant clay mineral[b]	Montmorillonite	Ca montmorillonite	Ca montmorillonite
Specific gravity 25C/4C	2.67	2.68	2.67
Chemical properties:			
Cat. ex. cap., m.e./100 gm[c]	7.3	13.4	25.5
Carbonates, percent[d]	0	10.5	0
pH	5.6	7.8	5.9
Organic matter, percent[c]	0.4	0.2	0.6
Physical properties, percent :			
Liquid limit	-	32	57
Plastic limit	-	25	20
Plasticity index	NP	7	37
Shrinkage limit	18	25	14
Centrifuge moist. equiv.	5	15	21
Field moist. equiv.	21	26	21
Classification:			
Textural	Sand	Silty clay loam	Clay
Engineering (AASHO)	A-2-4(0)	A-4(8)	A-7-6(20)

[a] After Viskochil et al (5)
[b] From x-ray and differential thermal analysis of whole soil
[c] Fraction passing No. 40 sieve
[d] From differential thermal analysis

Wet-Dry Testing

The method of wet-dry test adopted was as follows:

1. Specimens were prepared at the designated density and optimum moisture content, then moist cured for fourteen days.
2. Specimens were air dried for 24 hours at room temperature and then completely immersed in distilled water for 24 hr. This completed one cycle of wetting and drying. Further cycles were a repetition of this step.
3. After designated cycles of wetting and drying specimens were wiped with a towel to a surface dry condition, measured for height and weight, and tested for unconfined compressive strength.

Freeze-Thaw Testing

The method of freeze-thaw test adopted was as follows:

1. Specimens were prepared at the designated density and optimum moisture content. After moist curing for fourteen days, specimens were placed on ½-in. thick felt pads set in approximately ¼ in. of water.
2. Specimens on moist felt pads were placed in a freezer at - 10 F for 24 hr.

3. After removal from the freezer, specimens were allowed to thaw in open air at room temperature for two hours.
4. Specimens were placed in a humidity cabinet at approximately 70 F and 100 percent relative humidity for 22 hr. This completed one cycle of freezing and thawing. Further cycles were a repetition of steps 2, 3, and 4.
5. The specimens to be tested were measured for height and weight and tested for unconfined compressive strength.

Compressive Test

After completion of curing and/or various cycles of wet-dry or freeze-thaw, all specimens were tested for unconfined compressive strength. The rate of deformation of the testing machine was held constant at 0.05 in. per min. per in. of specimen height.

Absorption and Volume Change

The percentage of moisture absorbed during the wet-dry and freeze-thaw test was determined by subtracting the weight of the specimen after molding from the weight after immersion and dividing by the oven-dry weight of the specimen. Though the actual volume change was not measured, an easily determinable indicator of volume change was used—the average increase in height of specimens. This was determined by subtracting the height of the specimen after molding from the height after various cycles and dividing by the height after molding.

EVALUATION OF TEST RESULTS

Selection of Mixes

Research by Viskochil et al (5) indicates that increasing the density of lime-flyash stabilized soils greatly increases strengths, as shown in Figures 1, 2 and 3. It will be noticed that as lime content increases, the density and immersed compressive strength at each compactive effort in general tend to decrease, probably because of increased clay aggregation by the lime (5).

Figures 1, 2 and 3 indicate that optimum ratios of lime to flyash at densities greater

TABLE 4

PROPERTIES OF LIME AND FLYASH[a]

	Linwood hydrated lime	Louisville Flyash
Specific gravity	2.29	2.67
Fineness		
Percent passing No. 325 sieve	99.00	94.30
Specific surface, sq cm/gm		3470
Chemical analysis, percent		
Total $Ca(OH)_2$	97.82	
Available $Ca(OH)_2$	97.38	
MgO	0.49	0.52
$CaCO_3$	0.77	8.36
Fe and Al oxides	0.82	
SiO	0.80	38.90
Al_2O_3		22.92
SO_3		2.00
Free water		0.17
Loss on ignition	24.56	2.10

[a]After Viskochil et al (5)

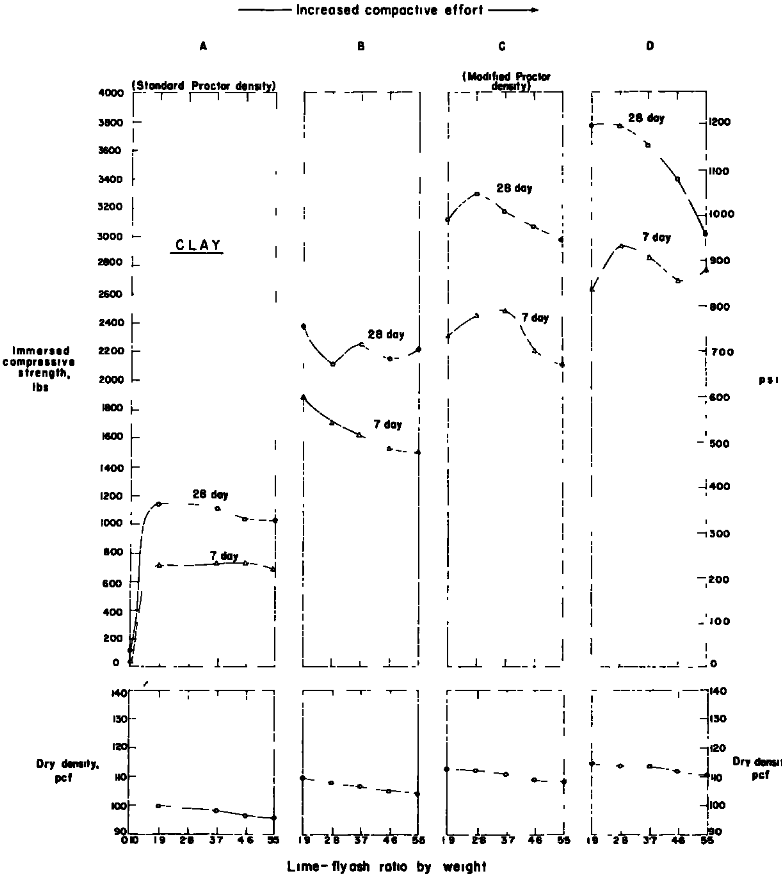

Figure 3. Effect of variations in lime to flyash ratio, compactive effort, and curing on compressive strength and density of lime-flyash stabilized clay.

than standard Proctor are 1:9 for the sand and silt, and 2:8 for the clay. These ratios were used in the wet-dry and freeze-thaw testing described in this paper. On the basis of previous studies, a mix with 25 percent lime-flyash was chosen as being satisfactory and economical. All test points were run in duplicate or in triplicate.

Wet-Dry Tests

Silt. Wet-dry test results with silt are shown in Figure 4, along with freeze-thaw results with the same soil. The wet-dry cycles apparently cause a general increase rather than a decrease in strength. Similar trends have been reported elsewhere for lime and lime-flyash stabilized soils (2, 4). Strength curves in Figure 4 for different compactive efforts tend to diverge after 12 cycles, but this was accompanied by a similar divergence in the data for each point, indicating greater statistical error. Therefor no particular significance is attached to the upturn or downturn of the curves after 12 cycles. On a strength basis alone there is an advantage to compacting the silt to modified Proctor density (effort C), but the wet-dry tests show little benefit from compacting beyond this.

Curves for moisture absorption and expansion during wet-dry cycles are also shown in Figure 4. During early cycles all specimens absorbed water and expanded. Increased compaction reduced expansion but tended to increase the absorption of water, perhaps due to improved capillarity. After five cycles the absorption by specimens molded to compactive effort D is drastically reduced—this could be due either to reduced permeability or increased cementation tending to hold the specimen together.

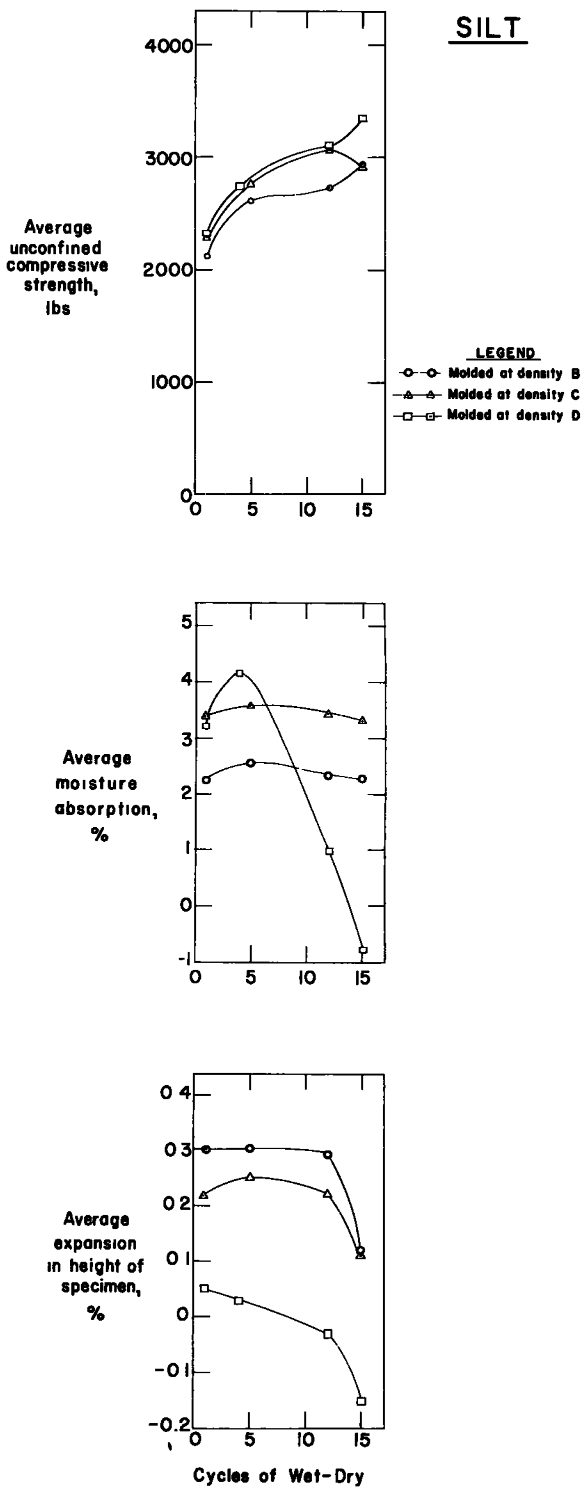

Figure 4. Effect of compactive effort, wetting and drying, and freezing and thawing on compressive strength, moisture absorption and expansion of lime-flyash stabilized silt.

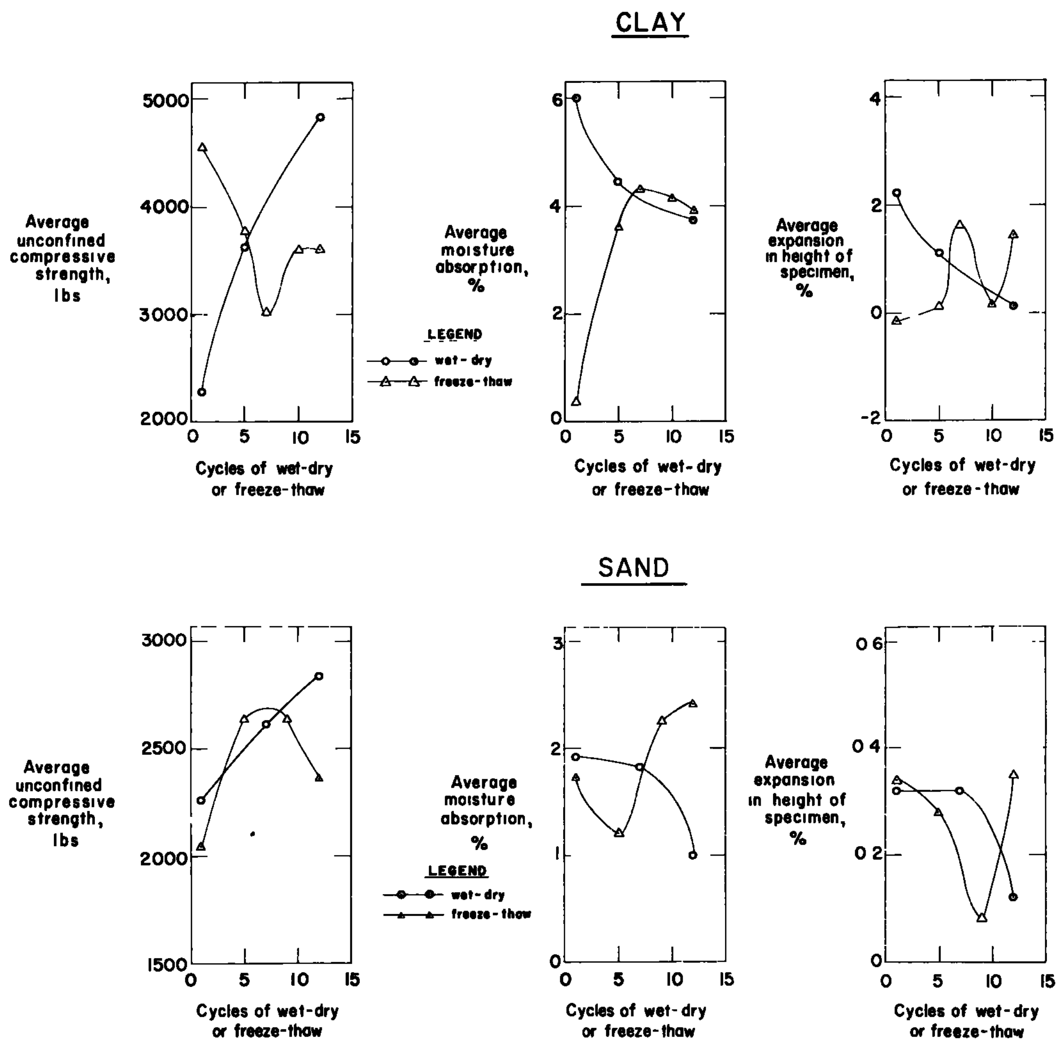

Figure 5. Effect of wetting and drying, and freezing and thawing on compressive strength, moisture absorption, and expansion of lime - flyash stabilized clay and sand compacted to modified Proctor density.

Since the latter effect does not appear in the compressive strength, one can conclude that pozzolanic reaction products may be plugging the pores or at least rendering them impermeable to water.

Clay and Sand Soils. The clay and sand were tested after compaction to modified Proctor density (effort C). Results are presented in Figure 5. Both clay and sand show a uniform increase in strength through the wet-dry cycles, and moisture absorption and expansion both are reduced.

Comparison to normal moist curing. Compressive strengths after normal moist curing are plotted in Figure 6 for the silt and Figure 7 for the sand and the clay. The silt and the clay are considerably benefited by wet-dry cycles, whereas the sand is not. Similar data by Goecker et al (3) show that clay and silt were benefited by prolonged soaking, but again the sand was not.

Freeze-Thaw Tests

Silt. All silt specimens gained strength through the first 10 or 12 freeze-thaw cycles, then took the more logical trend downward (Fig. 4). A satisfactory resistance is in-

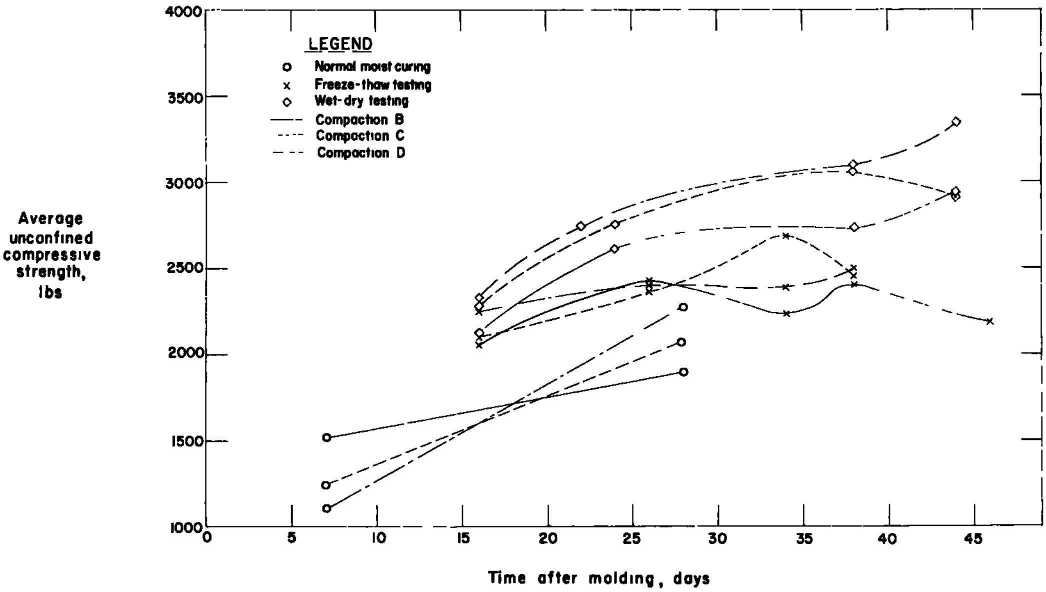

Figure 6. Relationship of effect of compactive effort, curing, wetting and drying, and freezing and thawing on compressive strength of lime-flyash stabilized silt.

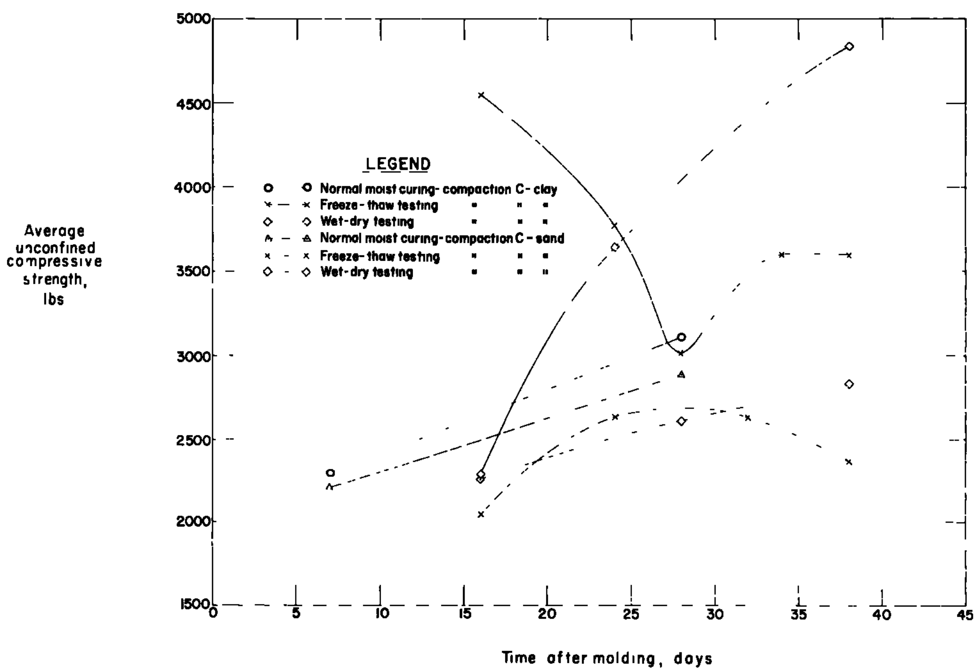

Figure 7. Relationship of effect of curing, wetting and drying, and freezing and thawing on compressive strength of lime-flyash stabilized clay and sand compacted to modified Proctor density.

dicated for all three compactive efforts, since the strengths after weathering are higher than those before weathering started. Moisture absorption trends upward, indicating progressive failure during freezing and thawing. Expansion remains small, but the silt compacted with effort D shows a gradual increase, suggesting overcompaction.

Overcompaction was previously noted for effort D with this soil, but had disappeared after 28 days normal curing (5, conclusion 3).

Clay and Sand Soils. Strengths of clay and of sand specimens during cycles of freeze-thaw correlate well with the moisture absorption (Fig. 5). The clay shows a drastic increase in absorption up to 5 cycles, after which the specimens slowly lose water. Strengths drop about 50 percent from the first to the fifth cycle, after which there is a slow gain. A slight volume expansion also takes place after the fifth cycle.

Curves for the sand are somewhat reversed to those for clay, but show the same relationships. Moisture absorption increases on the ninth cycle, and coincident with this the strengths go down. A sharp increase in volume is noted after the eighth cycle.

Comparison to Normal Moist Curing. Freeze-thaw cycles benefit the strengths of the silt and are somewhat deleterious to the strengths of the sand (Fig. 6 and 7). The same results were found with wetting and drying. The clay is uniquely benefited by freezing and thawing for one cycle. After this the strength progressively decreases until it approximates that obtained during normal moist curing; then strengths start back up.

CONCLUSIONS

The obvious conclusion is that high density does improve durability of soil-lime-flyash, to the extent that after an initial moist cure, clay and silt soils gain strength even more rapidly during wet-dry or freeze-thaw cycles than they do in a continued moist cure. The sand soil gave comparable strength gains in either weathering cycles or moist cure. The comparatively high durabilities were realized by compacting to modified Proctor density. Previous studies showed the durability of soil-lime-flyash to be questionable after compaction to standard Proctor (3).

The uniqueness of a strength gain during a supposedly destructive testing program deserves more than a passing remark. Wetting and drying could result in periodic dissolution and redistribution of part of the lime, giving greater intimacy of contact and promoting the reactions with flyash. Prolonged soaking in water can apparently give the same mobility, as strengths are then high also (3). Similar results from lime stabilization indicate the importance of contact between lime and soil grains.

Beneficial effects of freeze-thaw cycles are more problematical and have not been noted before. The extreme case was with the clay, where strength was doubled by one cycle. After this, destruction started, but the trend again reversed after the fifth cycle. Benefits were less marked with the silt and nil for the sand, further emphasizing the importance of surface reactions not only with flyash, but also with soil. In dolomitic lime, the solubility of MgO and $Mg(OH)_2$ increases with a rising temperature whereas the solubility of $Ca(OH)_2$ decreases. Therefore, a critical redistribution of lime may result from a single freeze-thaw cycle. The redistribution is apparently of lesser importance with coarse-grained soils, which have lower surface area for cementation reactions.

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