Evaluation of Strength Properties of Several Soils Treated with Admixtures

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This paper is a study of soil stabilization with various admixtures. Using compressive strength to evaluate stability, five selected soils of widely varying physical properties were stabilized with portland cement, a lime and fly ash mixture, phosphoric acid, and asphaltic cutback (RC-3).

Moisture-density tests were made with the soils and admixtures to determine the effect of the admixtures on standard Proctor maximum density and optimum moisture. Using this density and moisture data, samples 2.8 in. in diameter by 5.6 in. in height were statically compacted. After curing for 7 and 28 days, the samples were tested by an unconfined compression test and the triaxial test using a confining pressure of 20 psi. Additional tests were made on the soil-portland cement mixture for determining the effect of that stabilizer on the angle of internal friction and cohesion.

Results indicate that phosphoric acid slightly increased the density in all soils. Portland cement, lime-fly ash and RC-3 increased the density in the uniformly-graded soils. There was little effect from the addition of portland cement or RC-3 in the well-graded soils whereas lime-fly ash caused a marked reduction in density in these soils.

Strength tests indicated that portland cement was the most effective stabilizer in all soils giving high strength gains. The addition of portland cement also increased the angle of internal friction and cohesion. The lime-fly ash admixture and phosphoric acid caused slight increases in all soils. Some soils had a negligible strength increase with the addition of RC-3, whereas other soils indicated a reduction in strength.

●SOIL STABILIZATION with portland cement and other admixtures has become of great importance in recent years. The tremendous increase in vehicles and vehicle-miles has brought about a need for more highways and the ever-increasing truck traffic has created a need for more stable roads. With the available supply of high quality soil for base construction rapidly diminishing in many areas, the highway engineer is confronted with the problem of transporting suitable soils to the area or artificially producing a high quality soil by mixing the available soil with an admixture.

The use of various admixtures combined with soil has been widespread in many areas in recent years. This has been particularly true in the construction of secondary-type roads. Stabilization has proved its worth, but a problem which remains in many areas is the type and amount of admixture necessary to transform this unsuitable soil into a load-supporting base material. This paper concerns the comparative effectiveness of stabilization of several soils with various admixtures.

MATERIALS

The soils chosen for this study are typical of some of the roadbuilding soils available in various locations throughout Georgia. A description of these soils is given in Table 1 with the grain-size distribution shown in Figure 1. Soil I is a brownish, well-graded, clayey, silty sand; Soil II is a reddish-brown, uniform, silty, clayey sand; Soil III is a greyish-white uniform sand; Soil IV is a red, well-graded, silty, sandy clay; and Soil V is a yellowish-brown, well-graded, clayey, silty sand.

According to the Georgia Highway Department classification and usage, only Soil II would be suitable for base construction without treatment with aggregate or an admixture. Soils I, III and IV would be suitable for subgrade construction without treatment while Soil V would require treatment before using as a subgrade and would not normally be used for base construction even with treatment.

The admixtures studied were Type I normal portland cement, asphaltic cutback RC-3,

TABLE 1

DESCRIPTION OF SOILS

Soil No. Location by County	I Carroll	II Effingham	III Camden	IV Fulton	V Fulton
Textural analysis					
% retained by wt.					
Sieve No. 10	3	0	0	3	2
Sieve No. 40	14	54	2	19	24
Sieve No. 60	37	68	7	28	36
Sieve No. 100	44	74	53	37	46
Sieve No. 200	62	83	92	46	55
Total Silt Sizes, %	21	2	3	22	24
Total Clay Sizes, %	6	11	—	27	14
Specific Gravity	2.67	2.63	2.69	2.70	2.69
Liquid Limit	13	14	—	29	37
Plastic Limit	—	—	—	23	—
Plastic Index	NP	NP	NP	6	NP
AASHO Classification	A-2-4(0)	A-2-4(0)	A-3-(0)	A-4-(4)	A-4-(2)
Ga. Hwy. Dept. Classification	C-1 Topsoil	A-1 Topsoil	A-1 Subgrade	1-B Embankment	II-A Embankment

a combination of line and fly ash, and phosphoric acid. An analysis of the portland cement and the fly ash is given in Table 2.

METHOD OF TESTING

The soils used were air-dried to a uniform moisture content and sieved through a No. 4 sieve with only the minus 4 material used in the tests.

Moisture-density tests conforming to standard ASTM and AASHO specifications were performed on each soil and each soil combined with the test increments of stabilizer. An exception was Soil III where no moisture-density tests were made with phosphoric acid.

Mixing was done with a mechanical mixer using a total mixing time of 10 min. The dry admixtures and soil were proportioned and mixed dry; then optimum water content for standard Proctor maximum density was added and mixed for the remainder of the 10 min. For the mixture with phosphoric acid, the acid was combined with the water before adding to the soil for mixing. The mixture with RC-3 was first mixed for 3 min with the optimum amount of water, then the asphalt was added and mixing continued for 7 more minutes.

Molding of all the soils and mixtures was done immediately after mixing except when RC-3 was used as the admixture. The soil and RC-3, after mixing, was allowed to stand in the open air until it had a "tacky" feel before molding. Molding was done by static compaction in a 2.8-in. diameter mold compacting the sample to a height of 5.6 in. A predetermined weight of material to give the standard Proctor maximum density, as determined from the moisture-density curve, was placed in the mold and rodded before compaction. Compaction was accomplished by forcing the pistons in each end of the mold together until the 5.6-in. height was attained.

After molding, the samples were placed in polyethylene freezer bags and sealed to prevent any change in moisture conditions. Curing was done for 7 and 28 days in a

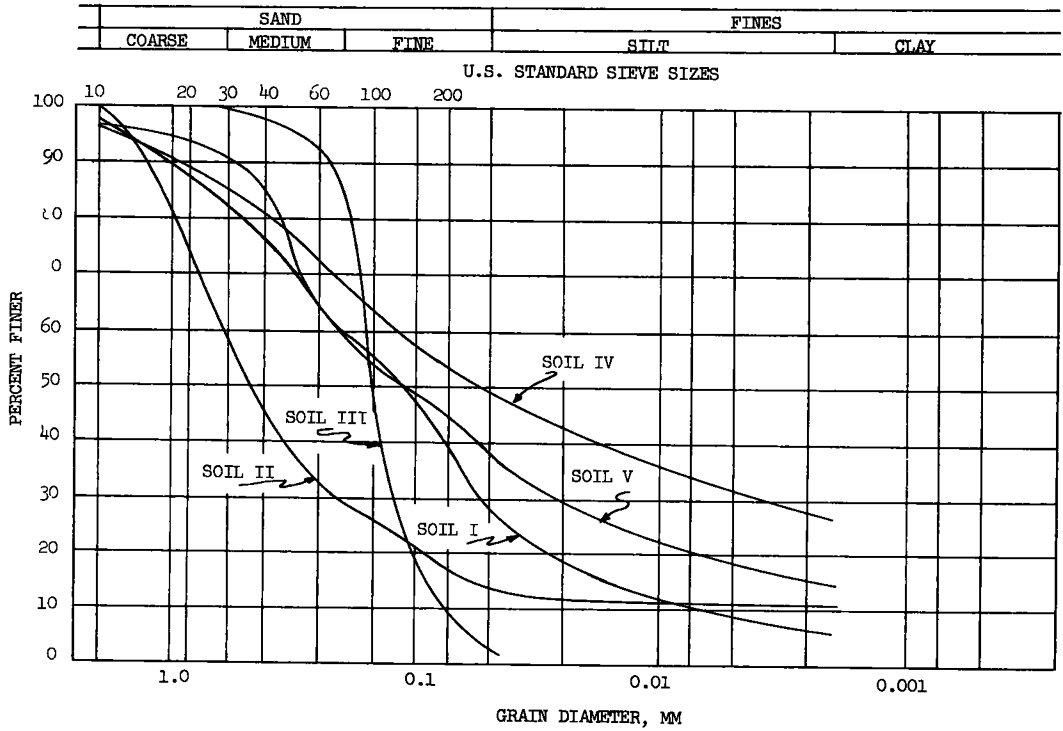

Figure 1. Grain-size distribution.

TABLE 2

ANALYSIS OF PORTLAND CEMENT AND FLY ASH

	Portland Cement	Macon, Ga. Fly Ash	Columbia, S.C. Fly Ash
Chemical composition %			
Silicon dioxide, SiO_2	20.46	41.40	45.92
Ferric oxide, Fe_2O_3	2.44	8.65	16.50
Aluminum oxide, Al_2O_3	5.90	21.05	32.00
Sulphur trioxide, SO_3	2.08	1.16	0.84
Calcium oxide, CaO	62.87	—	—
Magnesium oxide, MgO	4.18	5.36	1.40
Carbon, C	—	1.66	2.32
Loss on ignition	1.38	3.12	2.24
Specific surface area			
Blaine (sq cm/gm)	3,464	3,427	1,760

moisture room with approximately 70 F and 90 percent relative humidity.

Compressive strength determinations were made by both the unconfined compression test and the triaxial test using a lateral confining pressure of 20 psi. All samples were tested in a moist condition as they were removed from the plastic bags. Twenty-eight day samples of each soil with no admixture and with 6, 9, 12 and 15 percent portland cement were also tested triaxially using a confining pressure of 50 psi. Loading was at a rate of 0.05 in. per minute.

EVALUATION OF TEST RESULTS

Testing of the soils with the various admixtures involved determining maximum dry density and optimum moisture and compressive strength. Compressive strength data of the soils and soil-portland cement mixtures were also evaluated to determine the cohesion and angle of internal friction. Various increments of each of the four admixtures were combined with each of the five soils. Portland cement was added in increments of 2 percent ranging from 2 to 12 percent; lime-fly ash was used on a basis of 75 percent soil and 25 percent lime-fly ash with the ratio of lime to fly ash varying by a 1:1, 1:2, 1:5 and 1:9 ratio; phosphoric acid was added at 1 and 2 percent; the amount of RC-3 used was 3, 5 and 7 percent. All percentages of admixtures were based on the dry weight of the soil. The phosphoric acid was an 85 percent concentration and the percentages used were based on this concentration. Figures 2 through 6 show the relationship of admixtures and density.

Effects of Admixtures on Maximum Dry Density and Optimum Moisture

The addition of phosphoric acid caused an increase in density in all soils. Optimum moisture of the soil-acid mixture remained approximately the same or decreased slightly as compared to the soils with no admixture. A part of the increased density may be attributed to a replacement of a portion of the moisture by the acid which has a higher specific gravity.

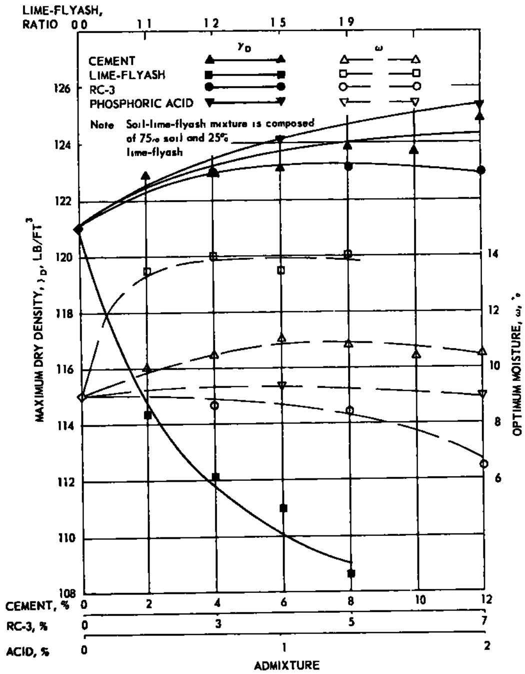

Figure 2. Relationship of maximum dry density and optimum moisture versus admixture for Soil I.

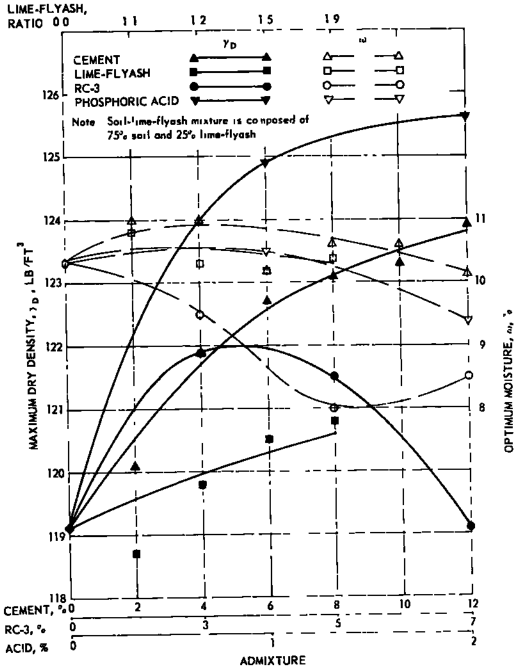

Figure 3. Relationship of maximum dry density and optimum moisture versus admixture for Soil II.

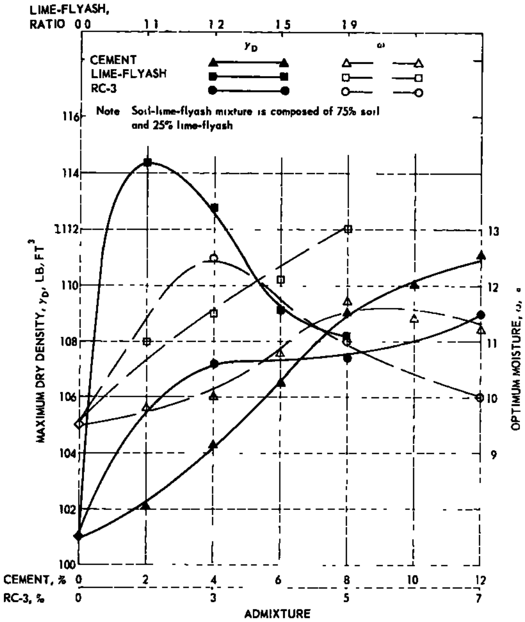

Figure 4. Relationship of maximum dry density and optimum moisture versus admixture for Soil III.

In Soils II and III, both uniform in gradation, the addition of portland cement or lime-fly ash increased the density. This increase in density was greater in Soil III which was the more uniform soil. The increased density is probably caused by the better gradation afforded by the addition of the finer particles of the admixtures. The only explanation for the higher density obtained in Soil III with the addition of lime-fly ash as compared to the addition of cement is that a greater amount of admixture was used in the case of lime-fly ash. Due to the much higher specific gravity of the cement, it would be expected to obtain the greatest density from this admixture. Optimum moisture was not critical in Soil III and varied only slightly with the addition of these two admixtures but in Soil II, optimum moisture increased with the addition of each of the admixtures. The greater amount of finer particles, as found in Soil II, would necessarily require a greater amount of moisture for compaction. Change in density of these two soils by the addition of RC-3 also can be attributed to better

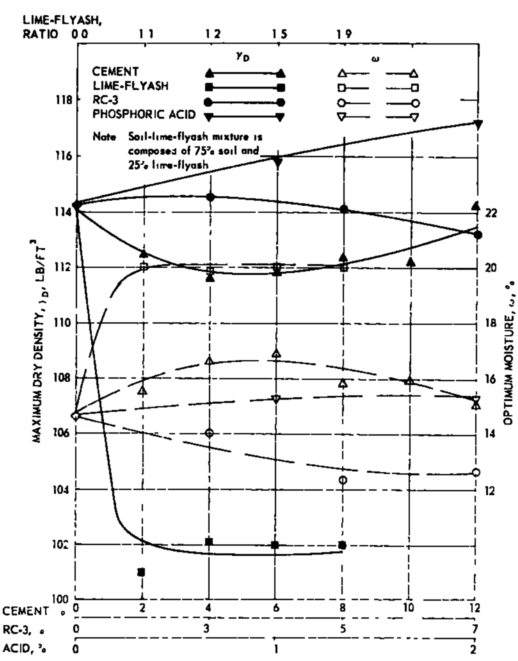

Figure 5. Relationship of maximum dry density and optimum moisture versus admixture for Soil IV.

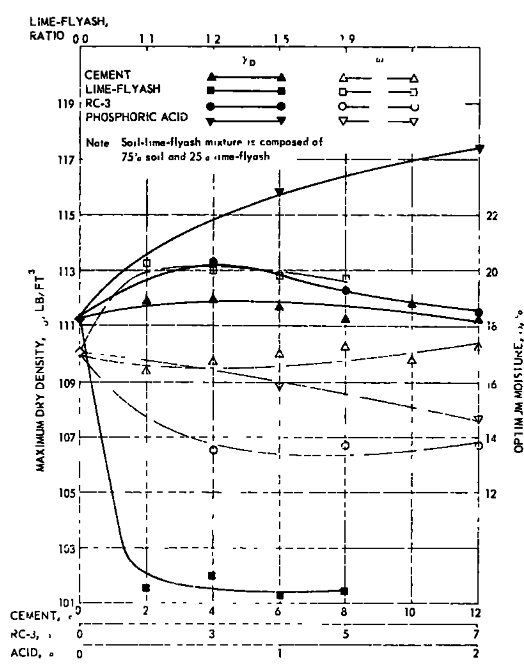

Figure 6. Relationship of maximum dry density and optimum moisture versus admixture for Soil V.

filling of voids and in the case of Soil II, where the density was reduced with the higher asphalt content, an overfilling of voids caused displacement of some soil particles.

Soils I, IV and V are all well-graded and the addition of portland cement should be of less benefit in increasing the density. This is substantiated from the density figures of these soils where it is shown that the cement had little effect on the density. From a gradation standpoint, lime-fly ash should have little effect on these soils but it is noted that a marked decrease in density was obtained. Probably this admixture created a greater amount of voids and the 25 percent addition of lime-fly ash caused a replacement of some soil particles.

The little change produced by the addition of RC-3 was probably due to the replacement of some of the moisture by the RC-3 as noted in the reduced optimum moisture for the well-graded soils.

Effects of Admixtures on Compressive Strength

In evaluating the molded samples, only samples molded within 1 percent of optimum moisture were used. For each test, 4 samples were molded for unconfined compression at 7 and 28 days and 4 samples for triaxial testing at 7 and 28 days. For compressive strength evaluation, only the values which were within 10 percent of the average of the other samples were used. In most instances the results were consistent and represent the average of 4 samples tested.

Figures 7 through 16 depict the variation in compressive strength as brought about by the addition of the different admixtures. In all of the soils tested, portland cement produced the greatest improvement in strength. All soils reacted favorably with the portland cement and no problem was encountered with the soil-cement mixture

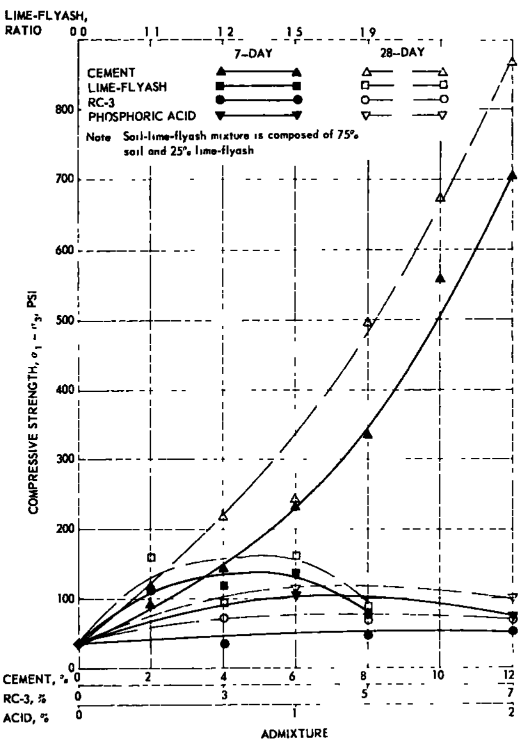

Figure 7. Relationship of confined compressive strength and admixture for Soil I.

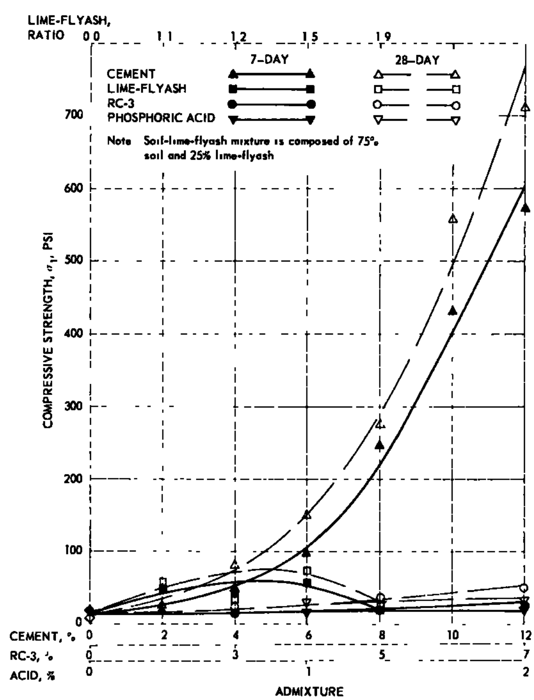

Figure 8. Relationship of unconfined compressive strength and admixture for Soil I.

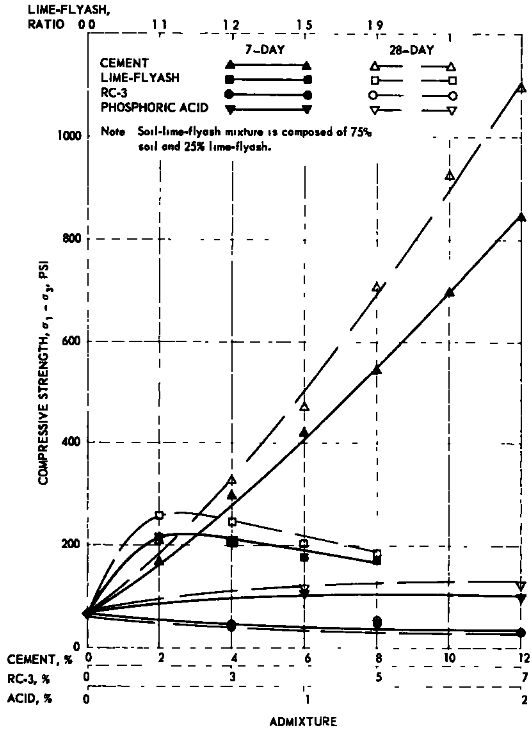

Figure 9. Relationship of confined compressive strength and admixture for Soil II.

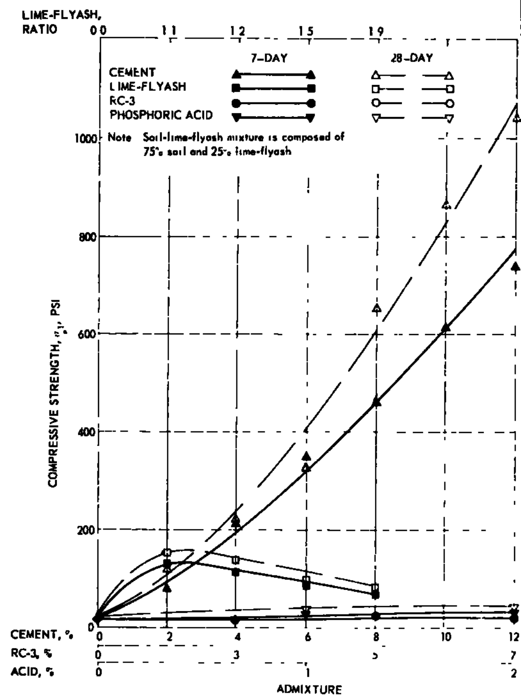

Figure 10. Relationship of unconfined compressive strength and admixtures for Soil II.

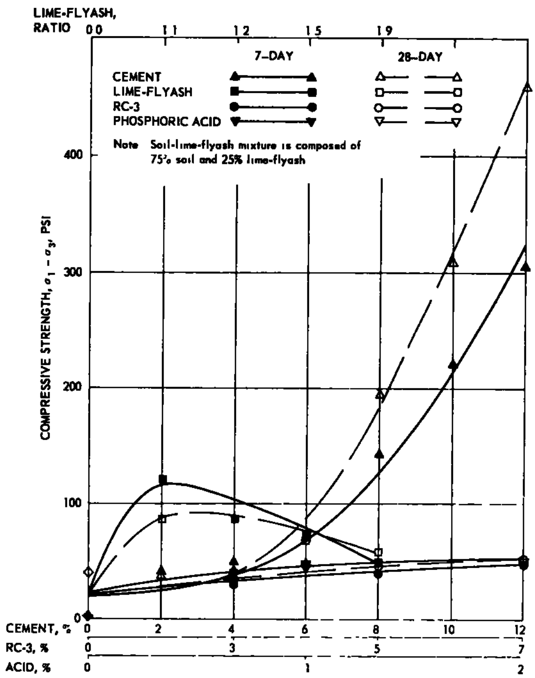

Figure 11. Relationship of confined compressive strength and admixture for Soil III.

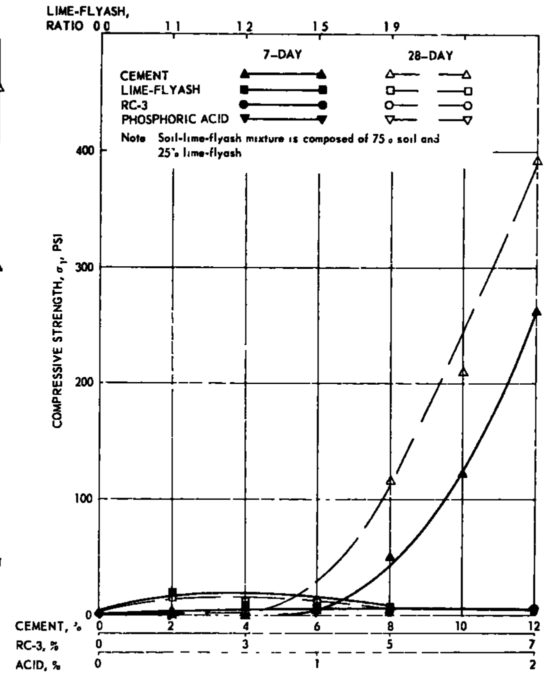

Figure 12. Relationship of unconfined compressive strength and admixture for Soil III.

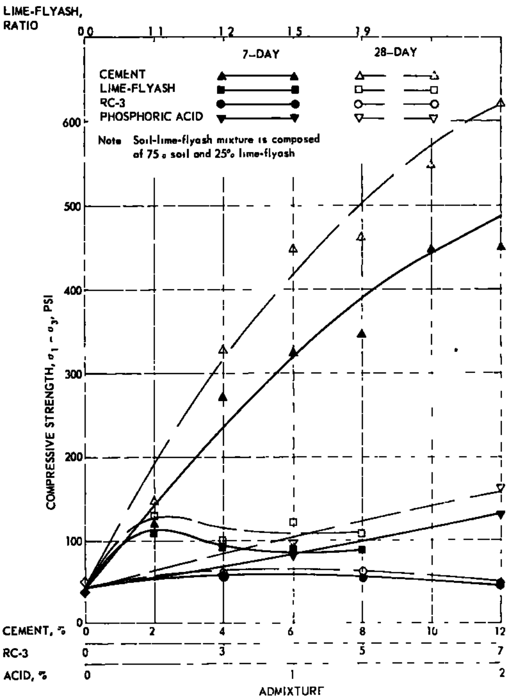

Figure 13. Relationship of confined compressive strength and admixture for Soil IV.

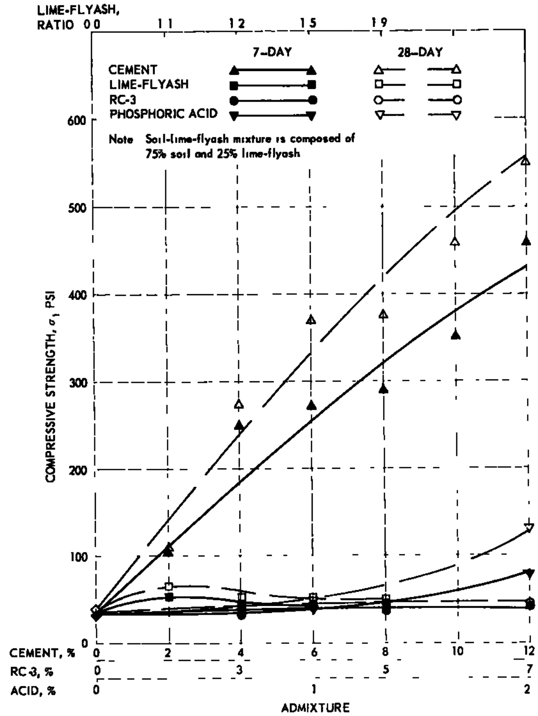

Figure 14. Relationship of unconfined compressive strength and admixture for Soil IV.

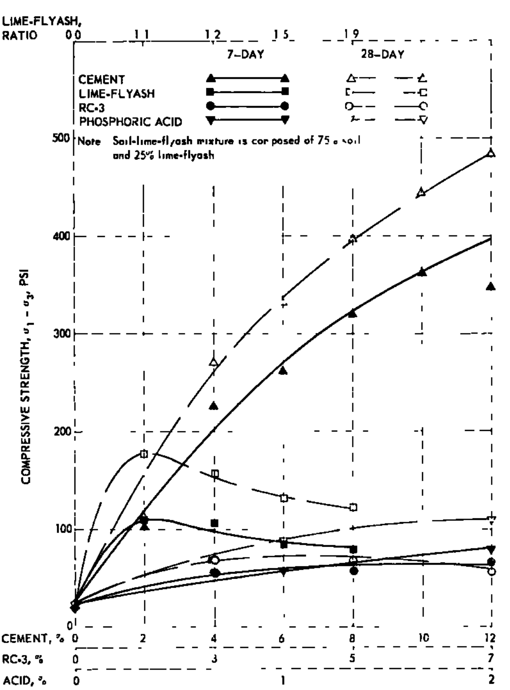

Figure 15. Relationship of confined compressive strength and admixture for Soil V.

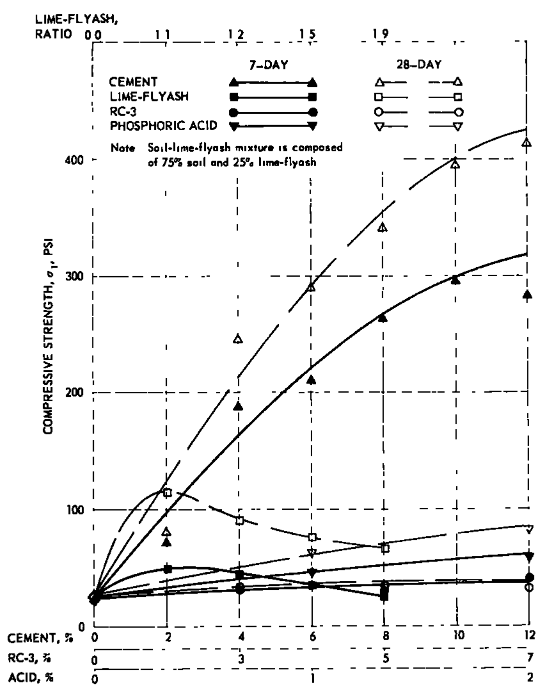

Figure 16. Relationship of unconfined compressive strength and admixture for Soil V.

hardening. The lime-fly ash mixture improved the strength of all soils approximately 300-400 percent. Phosphoric acid caused an increase in strength in the finer-grained soils with the greatest benefit in the soil with the highest clay content. From a dry strength standpoint, RC-3 gave little or no benefit, even causing a decrease in strengtl in one soil.

Effect of Amount of Admixture on Strength

Increasing the percentage of portland cement caused an increase in strength. Streng gains were noted in the soil-cement mixtures with as low as 2 percent cement. The amount of increase appears to vary with the fineness of the soil with the finer soils showing greater improvement at lower percentages while the coarser materials had a greater rate of strength increase at the higher percentages. Soil III differed somewhat in that little strength improvement was noted below 6 percent cement. Above 6 percent cement the strength of the soil increased very rapidly.

The highest gain in strength by using lime-fly ash occurred with a ratio of 1:1 lime to fly ash. The silty soil, Soil I, differed in that little change was noted in the strength gain until a 1:9 lime-fly ash ratio was used, where this strength gain decreased. The addition of 2 percent phosphoric acid was of greater benefit than 1 percent except in Soil I where the lower percentage gave slightly higher strength.

Varying the amount of RC-3 had only a slight effect on the strength. Where a streng increase occurred the 3 and 5 percents were usually the most beneficial.

General Discussion of Strength Results

The improvement in compressive strength brought about by the addition of portland cement was as expected. Of the admixtures used, the hydration of portland cement should produce the best cementing bond of the soil particles. Although the lime-fly ash

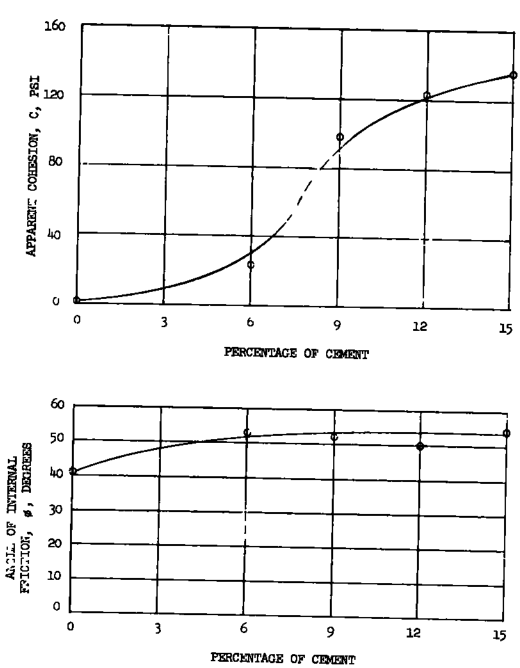

Figure 17. Apparent cohesion and angle of internal friction versus cement content for Soil I.

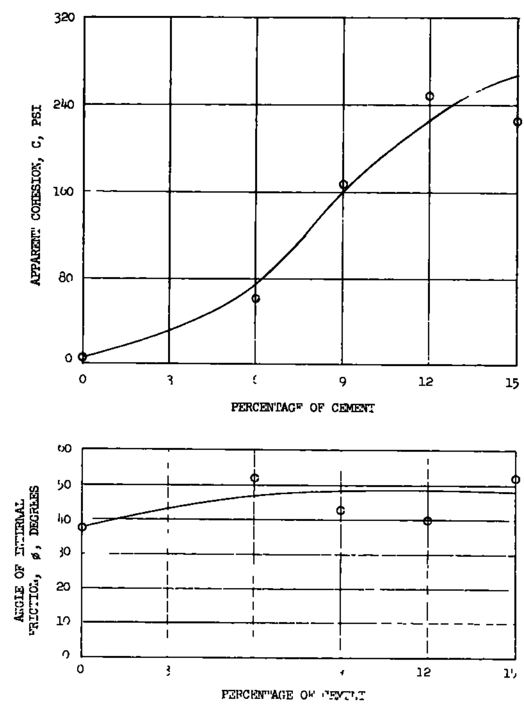

Figure 18. Apparent cohesion and angle of internal friction versus cement content for Soil II.

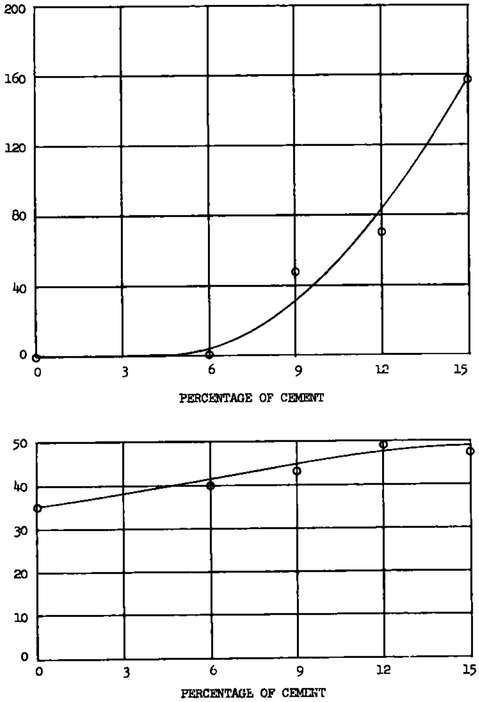

Figure 19. Apparent cohesion and angle of internal friction versus cement content for Soil III.

admixture produces a cementing action similar to portland cement, certainly this is not as strong a bond and this is substantiated by the test results. It may be expected then, in any soil which contains no elements detrimental to the "hardening" of the cement, to obtain a greater strength with portland cement as compared to lime and fly ash. Another problem in the use of fly ash is the vastly dissimilar cementing properties obtained from fly ash produced at different plants. The non-linear increase in strength brought about by the increasing percentages of cement is explained by the gradation of the soil grains, especially in the sand range. A greater rate of increase in strength at the higher cement contents was noted in Soils I, II and III, where Soils II and III are uniformly graded and Soil I, although well-graded in its entirety is fairly uniform in the sand range. A soil with strong grains should become stronger with a greater amount of cementing agent to bond these particles together.

In Soils IV and V, the non-linearity in strength increase is also evident but the

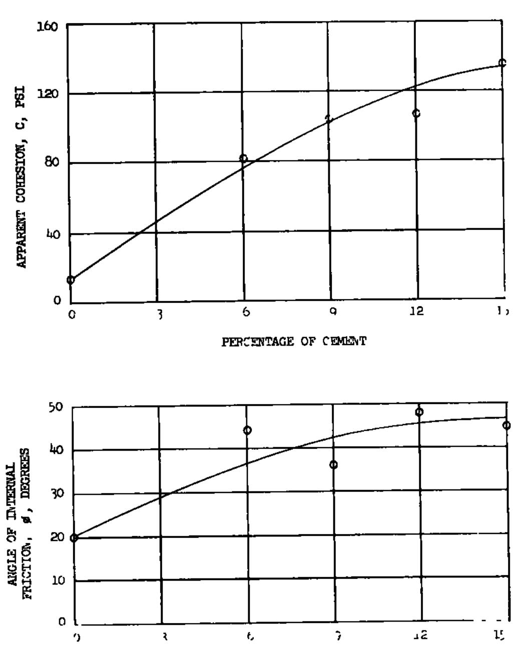

Figure 20. Apparent cohesion and angle of internal friction versus cement content for Soil IV.

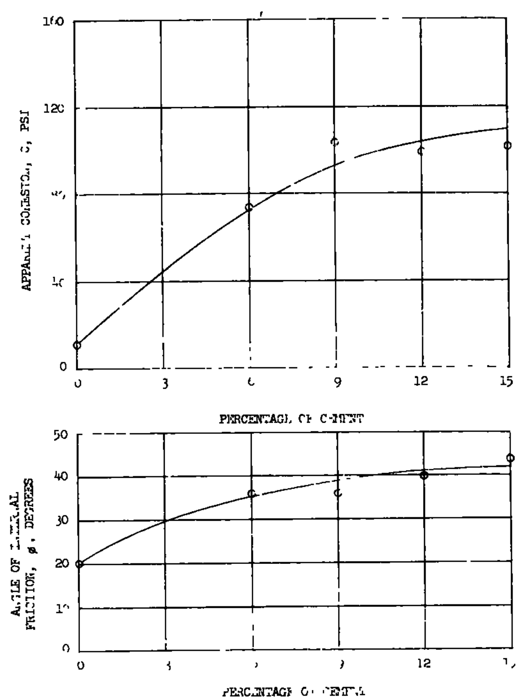

Figure 21. Apparent cohesion and angle of internal friction versus cement content for Soil V.

greatest rate of strength increase is obtained at the lower cement contents. This is probably due to the breaking of the softer grains of these two soils at the higher cement contents.

The low strengths obtained with RC-3 as an admixture could be attributed to the low "cohesion" afforded by asphalt. In the instances where the strength was reduced with RC-3, the cohesive bond of the soil was probably destroyed and replaced by a lower cohesion from the asphalt.

It has been proposed that the stabilizing properties of phosphoric acid are due to a molecular attraction of the phosphorous ions with certain ions in the soil, possibly aluminum. This has not been investigated in this study and no further explanation is given.

Effects of Portland Cement on Cohesion and Angle of Internal Friction

A Mohr's envelope was plotted for each soil and the soils combined with 6, 9, 12 and 15 percent portland cement. The variation in cohesion and angle of internal friction are shown in Figures 17 through 21.

As shown in these figures, the angle of internal friction and cohesion increases sharply with the addition of portland cement with the exception of Soil III, the fine uniform sand, where the increases are less noticeable at the low percentages. An interesting point here is the almost constant angle obtained as the cement content increases. While the cohesion continues to increase with increasing cement content up through 15 percent, the rate of increase begins to decrease at about 9 percent. Soil III is an exception here but it would be expected to have the same tendency at a higher cement content.

These findings would substantiate the changes obtained in physical properties of a soil with a small addition of portland cement such as reduced PI, LL and volume changes. The cementation is acting to produce a larger soil grain from several small grains thereby altering the properties of the soil.

CONCLUSIONS

The following conclusions have been reached as a result of this study:

1. The effects of admixture on maximum dry density and optimum moisture vary with the soil gradation: (a) the effects of admixtures on density are more pronounced in the uniform soils where an increased density can be expected; and (b) less variation occurred in the well-graded soils with the exceptions of a marked reduction in density due to the addition of lime-fly ash and a substantial increase in density with the addition of phosphoric acid to the more clayey soil.

2. The improvement in strength varied with the soil and particular admixture: (a) portland cement was by far the most beneficial stabilizing agent producing a large strength gain in all soils; (b) the addition of 25 percent lime-fly ash improved the strength of all soils; (c) phosphoric acid caused a nominal increase in strength of all soils with the greatest benefit in the more clayey soil; and (d) the addition of RC-3 caused negligible strength increases and in some instances caused a strength reduction.

3. The variation in strength in most cases depends on the amount of admixture used: (a) increasing the percentage of portland cement increased the strength non-linearly; (b) the smallest percent of fly ash in the lime-fly ash mixture (that is, the 1:1 ratio), gave the greatest strength improvement except in one soil where little change was noted from a 1:1 to 1:5 ratio; (c) the higher percentage of phosphoric acid produced a greater benefit; and (d) the amount of RC-3 used was negligible.

4. Cohesion and the angle of internal friction were increased by the addition of portland cement: (a) the angle of internal friction increased sharply with small amounts of cement to approximately a constant angle with increasing cement content while the cohesion increased as the cement content increased; and (b) as the rate of increase in cohesion decreases at higher cement contents and the angle is approximately constant, the efficiency of high cement contents to obtain higher strength may be considerably reduced.

ACKNOWLEDGMENTS

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