Soil Stabilization with Lime-Flyash Mixtures: Preliminary Studies with Silty and Clayey Soils

T. Y. CHU, Assistant Professor of Civil Engineering,
D. T. DAVIDSON, Associate Professor of Civil Engineering,
W. L. GOECKER, Research Assistant, and
Z. C. MOH, Research Assistant,
Iowa Engineering Experiment Station, Iowa State College

Introductory Remarks by the Chairman: One of the oldest inorganic cementing materials used by the Western World is a combination of hydrated lime with volcanic cinders. Many venerable structures still standing in Western Europe two thousand years after their construction attest to the quality of this hydraulic cement. While volcanic ashes are still employed where available for this purpose, modern industry is producing a similar material in the form of flyashes.

Unfortunately, all flyashes are not alike or equally suited for cementing and stabilization purposes. For proper evaluation of the soil stabilizing ability of flyash-lime mixtures dependable testing methods must be developed and standardized. Davidson and his associates at the Iowa Engineering Experiment Station have undertaken to develop a tentative test method for this purpose and are presenting it together with a preliminary evaluation of the merits of lime-flyash stabilization with a number of silty and clayey soils.

● THE use of admixtures for the stabilization of soils has been a subject of great interest to highway engineers in recent years. Various organic and inorganic materials have been investigated for possible use as stabilizing agents in the construction of subbase, base, or surface courses. Mixtures of lime and flyash are among those that have shown promise (1, 2). This paper presents results of laboratory studies of lime-flyash stabilization of silty and clayey soils sampled in Texas, Virginia, Iowa, and Kentucky (see Table 1). The main objectives of the studies were to (1) develop a test method for the preliminary evaluation of lime-flyash-stabilized silty and clayey soils and (2) make a preliminary evaluation of the merits of lime-flyash stabilization with the soils sampled.

MECHANISM OF LIME-AND-FLYASH STABILIZATION

Flyash is the gray, dust-like ash which results from burning powdered coal. The coal is burned while in suspension in air, and the resulting ash consists largely of tiny spheres of silica and alumina glass. The ash is similar to volcanic ash used in early Roman construction (3) and is a pozzolanic material, that is, it is not in itself a cement, but it reacts with lime and water to form a cement. This cementitious material may be regarded as a calcium silicate, but since good pozzolans ordinarily contain small percentages of alkalies, sodium and potassium, it is likely that more-complex compounds are also important. On the other hand, on the basis of free-lime determinations in hydrated mixtures of portland cement and flyash (4), some engineers believe that lime acts only as a catalyst to hydrate the flyash.

It is the reaction of lime and flyash which is utilized to stabilize soils. Theoretically, the stabilized soils should be compacted to a maximum to make maximum grain-contact areas available for cementing. Such a maximum compaction for any given compactive effort is obtained at an optimum moisture content which, however, may differ from the moisture content needed for a complete lime-and-flyash reaction.

FACTORS AFFECTING LIME-FLYASH STABILIZATION

The stability of lime-flyash-soil mixtures is affected by many variables. The variables listed in Figure 1 are the more-important ones affecting the stability of a processed soil in which lime and flyash are the only additives. The use of a small amount of a third additive to improve the effectiveness of lime-flyash stabilization will introduce still other variables. It is

planned ultimately to evaluate as many of the variables as possible in the Iowa Engineering Experiment Station research on lime-flyash stabilization, of which the work presented in this paper is a part. The studies with silty and clayey soils have been inches high and 2 inches in diameter were developed to meet these requirements.

The experiments conducted in developing the test procedures deal with many of the previously mentioned variables affecting the stability of lime-flyash-soil mixtures.

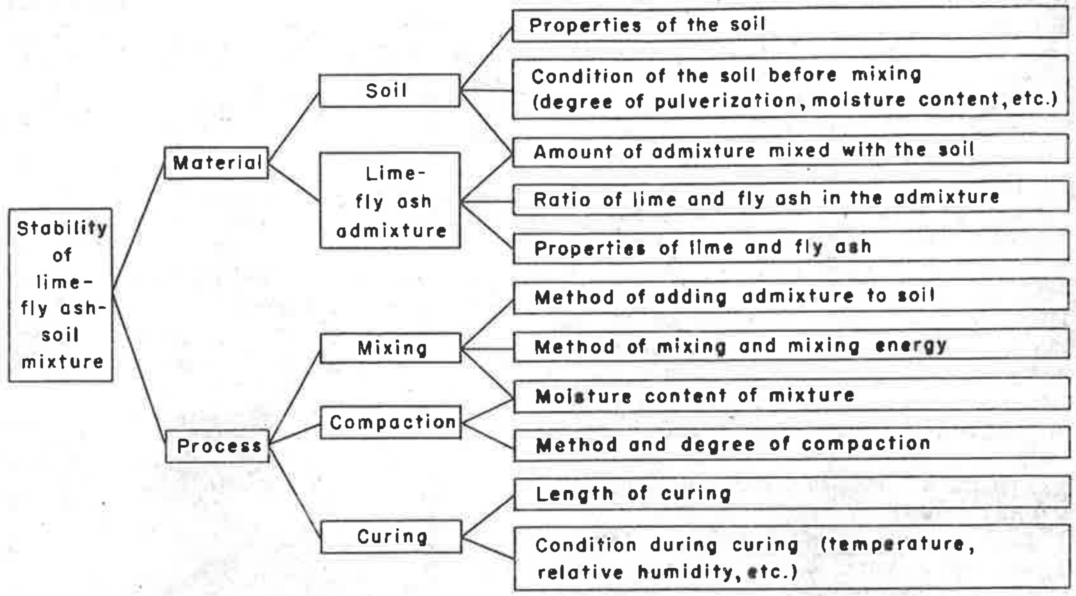

Figure 1. Factors effecting the stability of lime-flyash-soil mixtures.

primarily concerned with: (1) amount of lime and flyash to be added, (2) ratio of lime to flyash, (3) moisture content during mixing and compaction, (4) length of curing, and (5) curing conditions.

TEST METHOD FOR PRELIMINARY EVALUATION

One of the first things needed for conducting the preliminary evaluation studies of lime-and-flyash-stabilized silty and clayey soils was a simple method of test to provide data for determining benefits to the stability of the soils processed and for selecting the more promising combinations of lime, flyash, and soil for further studies. Other features desired in the test were: (1) use of small test specimens molded to near standard Proctor density, (2) use of curing conditions similar to those obtainable in the field, (3) testing of specimens after immersion in water, and (4) attainment of a fairly high degree of reproducibility of test results.

Test procedures utilizing the unconfined-compression test and specimens 2

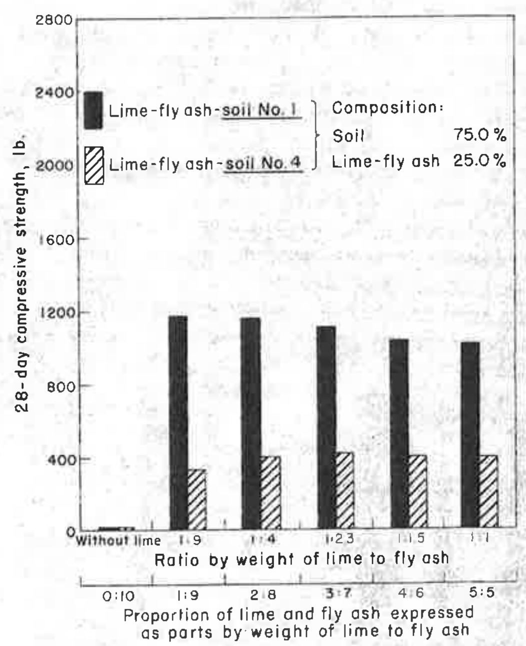

Figure 2. Effect of variations in the Ratio of lime to flyash on the compressive strength of two lime-flyash stabilized soils.

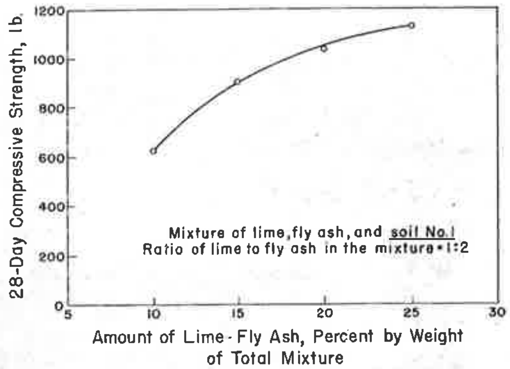

Figure 3. Effect of variations in the amount of lime and flyash on the compressive strength of a lime-flyash-stabilized soil.

They are discussed in Appendix A. On the basis of these experiments, the method of test presented in Appendix B is recommended for the preliminary evaluation of lime-flyash-stabilized silty and clayey soils.

The main steps in conducting the test are as follows:

1. Preparation of mixtures. Lime, flyash, and pulverized soil are dry mixed. The proper amount of water is then mixed with the three materials to obtain a uniform mixture at optimum moisture content for standard Proctor density.

2. Molding of specimens. Immediately after mixing, the moist mixture is used for the molding of specimens 2 inches in diameter by 2 inches high. The molding apparatus shown in Figure 4 was used to compact specimens to near standard Proctor density.

3. Curing of specimens. The specimens are cured in a moist cabinet capable of maintaining a temperature of 70±3 F. and a relative humidity of not less than 90 percent. Some of the specimens are cured for 7 days and others for 28 days.

4. Testing of specimens. Cured specimens are completely immersed in distilled water at near 70 F. for 24 hours and then are tested for compressive strength by the unconfined-compression test. The maximum test load causing failure of the specimen is taken as its compressive strength.

TABLE 1

BRIEF DESCRIPTION OF THE FOUR SOIL SAMPLES

Soil	No. 1	No. 2	No. 3	No. 4
Source	Texas	Virginia	Iowa	Kentucky
Geological Origin	Coastal plain deposit, largely deltaic (Beaumont clay)	Residual soil on diorite	Friable loess from near Missouri River floodplain	Natural levee deposit from Ohio River
Soil Series	Lake Charles	Davidson	Hamburg	Melvin*
Horizon	C	B	C	C*
Engineering Classification (AASHO)	A-7-6(20)	A-7-5(18)	A-4(8)	A-6(8)

*There is some question as to whether the soil should be classified in Melvin or Lindside series. The sample is probably from the C horizon.

PRELIMINARY EVALUATION OF STABILIZED SILTY AND CLAYEY SOILS

A main objective of the overall lime-flyash-soil investigation is to evaluate combinations of lime and flyash as stabilizing agents for a wide variety of soils

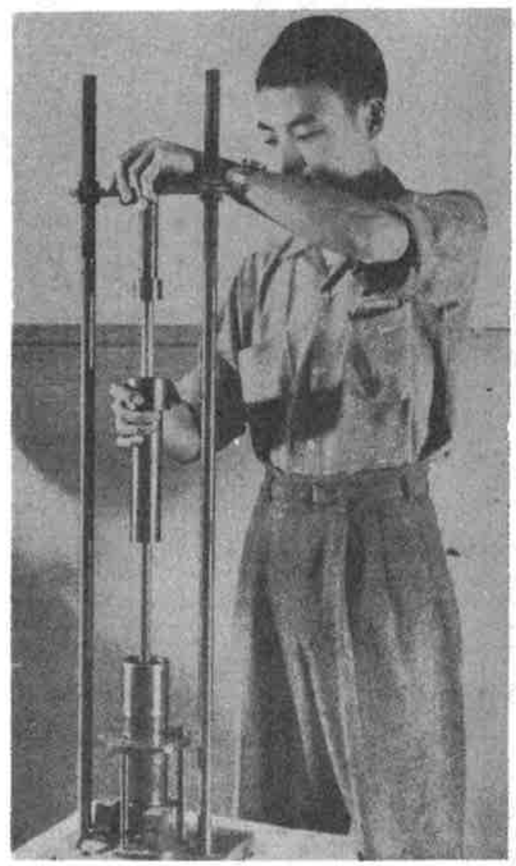

Figure 4. Compaction apparatus for molding test specimens 2 inches in diameter by 2 inches high. This apparatus was also used for determining moisture-density relations of raw soils and lime-flyash-soil mixtures.

TABLE 2

PROPERTIES OF THE FOUR SOIL SAMPLES

Soil		No. 1	No. 2	No. 3	No. 4
	Sand-Size	7.7	3.4	0.7	7.7
Textural	Silt-Size	48.2	12.0	78.3	55.7
Composition,	Clay-Size	44.1	84.6	21.0	36.6
Percent	Colloidal-Size	36.8	72.9	15.8	19.4
Textural Classification[a]		Clay	Clay	Silty clay loam	Silty clay
Liquid Limit, Percent		57.4	75.2	31.8	33.0
Plastic Limit, Percent		19.9	51.2	24.6	22.4
Plasticity Index		37.5	24.0	7.2	10.6
Shrinkage Limit, Percent		14.4	27.3	25.2	22.9
Centrifuge Moisture Equivalent, Percent		21.2	29.5	15.2	21.4
Field Moisture Equivalent, Percent		21.2	47.2	26.4	25.5
Specific Gravity, 25 C./4 C.		2.67	2.91	2.68	2.69
Predominant Clay Mineral[b]		Montmo-rillonite	Halloysite	Montmo-rillonite	Montmo-rillonite or illite
Cation Exchange Cap., m.e./100g		25.5	11.3	13.4	11.1
pH		5.9	4.1	7.8	4.5
Carbonates, Percent		2.7	1.0	10.2	1.2
Organic Matter, Percent		0.62	0.52	0.17	0.94

[a] Textural Classifications are based on the Bureau of Public Roads System except that 0.074 mm. was used as the lower limit of the sand fraction.
[b] Determined by the differential thermal analysis of the fraction passing no. 200 sieve.

occurring in different parts of the United States.

The four soil samples used in the studies reported in this paper are silty and clayey textures soils sampled in Texas, Virginia, Iowa, and Kentucky. The sources and a brief description of the samples are given in Table 1 and important properties are compared in Table 2.

Especially noteworthy are the difference in clay mineral composition of the two clay textured soils (No. 1 and No. 2) and the high carbonate content of Soil 3. A major portion of the carbonates in this soil occur in the silt-size range. The properties of the hydrated lime and the flyash used are given in Table 3. Future studies will include quicklime and other varieties of lime and flyash.

Preliminary evaluations of the lime and flyash with each of the four soils were made by using the previously described test method. The lime-and-flyash content of a mixture is expressed in percent by weight of the total mixture. The proportion of lime and flyash in the mixture is expressed as a ratio by weight of lime to flyash. Compressive strength values reported are the

TABLE 3

PROPERTIES OF THE HYDRATED LIME AND FLYASH USED

Properties	Hydrated Lime[a]	Flyash[b]
Specific gravity	----	2.67
Fineness:		
Material passing no. 325 sieve, percent	99.0	94.3
Specific surface area, sq. cm. per g. (Based on the specific gravity of 2.67)	----	3,470
Chemical analysis:		
Silicon dioxide, percent	0.80	38.90
Aluminum oxide, percent	----	22.92
Iron and aluminum oxides, percent	0.82	----
Magnesium oxide, percent	0.49	0.52
Sulfur trioxide, percent	----	2.00
Calcium carbonate, percent	0.77	8.36
Total calcium hydroxide, percent	97.82	----
Available calcium hydroxide, percent	97.38	----
Loss on ignition	24.56	2.10

[a] The hydrated lime and the test data were furnished by the Linwood Stone Products Co., Inc., Buffalo, Iowa.
[b] The flyash was from the Paddy's Run Station, Louisville Gas and Electric Co., Louisville, Kentucky; the tests on flyash were made by the Robert W. Hunt Co., Chicago, Illinois.

average of three test specimens. The findings are as follows:

1. Moisture-density relations. Lime-flyash admixtures affect the moisture-density relationship. As shown by the illustrative data in Table 4, maximum dry density is decreased and the optimum moisture is usually slightly increased. The decrease in density observed may not be very important since the stability of lime-flyash-stabilized soils also depends on many other factors.

2. Compressive strength. The addition of lime and flyash to the soils materially improves their stability as indicated by the compressive strength of 24-hr. immersed specimens. Untreated specimens fail during the immersion period. As shown by the data in Table 5, the compressive strength of stabilized soil specimens range from about 200 lb. to over 700 lb. after 7-day moist-curing at

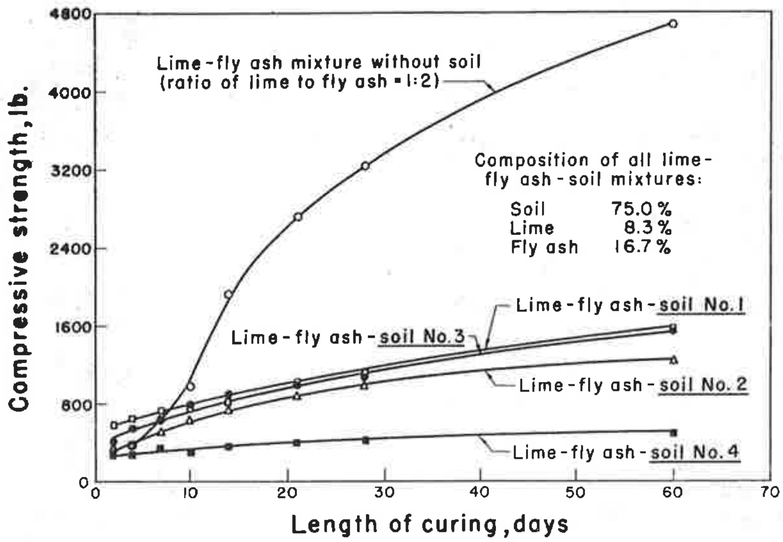

Figure 5. Relationship between length of curing and compressive strength. The curves compare the rate of increase in compressive strength of mixtures of lime and flyash with each of the four soils. A curve representing a lime-flyash mixture without soil is also shown.

TABLE 4

DATA ILLUSTRATING THE EFFECT OF LIME AND FLYASH ON MOISTURE-DENSITY VALUES[a]

Soil	Lime and Flyash Admixture,[b] Percent	Maximum Dry Density, lb. per cu. ft.	Optimum Moisture Content, Percent
No. 1	33	97.8	22.5
	No admixture	109.5	18.3
No. 2	33	87.8	32.2
	No admixture	85.6	37.1
No. 3	33	97.7	20.6
	No admixture	109.9	18.2
No. 4	33	97.3	22.6
	No admixture	108.6	17.8

[a] Determined with the molding apparatus shown in Figure 4. The molding procedure was correlated to give moisture-density values closely approximating those obtainable by the standard Proctor density test (ASTM Designation: D698-42T).

[b] Ratio of lime to flyash is 1 to 1.

TABLE 5

COMPRESSIVE STRENGTH OF THE FOUR SOILS STABILIZED WITH LIME AND FLYASH ADMIXTURES

Soil	Lime-Flyash Admixture[a]	Compressive Strength 7-day	Compressive Strength 28-day
	percent	lb.	lb.
No. 1	15	640	900
	25	740	1,130
No. 2	15	230	350
	25	525	1,005
No. 3	15	485	735
	25	640	1,045
No. 4	15	225	255
	25	350	430

[a] Ratio of lime to flyash is 1 to 2.

near 70 F. and increases to as much as 1,130 lb. after 28-day curing. Criteria for judging the adequacy of these strength values must be determined by additional studies.

The data on hand indicate that the texture of fine-grained soils may not be the controlling factor in their response to lime-and-flyash treatments. Test results for Soils 1, 2, and 3 show that about the same degree of stabilization can be obtained with silty or clayey textured soils. Sufficient data are not yet available to explain the comparatively low compressive strengths obtained with Soil 4.

3. Ratio of lime to flyash. Variations in the ratio of lime to flyash will affect the

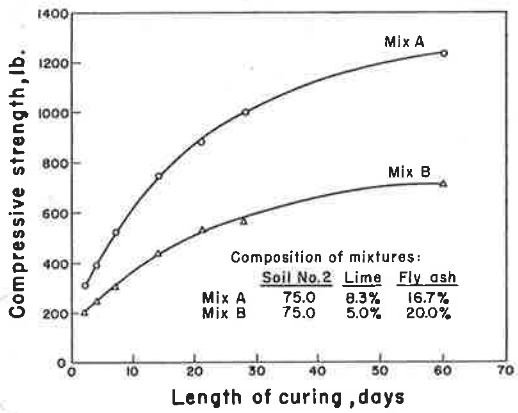

Figure 6 Curves comparing the rate of increase in compressive strength of lime-flyash-soil mixtures containing varying proportions of lime and flyash. The ratio of lime to flyash in Mix A is about 1 to 2, that in Mix B is 1 to 4.

compressive strength of mixtures of lime, flyash, and soil. The effect may not be great for some soils when the variation is within a certain range. This is illustrated for Soils 1 and 4 by the data in Figure 2. The variation in compressive strength is small when the lime-and-flyash ratio is within the range 1 to 1 to 1 to 9. The same general relationship was found for a mixture of lime and flyash without soil. Further studies of the ratio of lime to flyash are planned.

4. Amount of lime-and-flyash admixture. For a given ratio of lime to flyash, the compressive strength of the lime-flyash-soil mixture will increase with an increase in the amount of lime and flyash used. This is shown in Table 5; the mixtures containing 25 percent of lime and flyash have higher compressive strengths than those containing 15 percent. The relationship between amount of lime and flyash and compressive strength is further illustrated by the curve in Figure 3.

5. Selection of compositions for further investigation. Results of the preliminary evaluation studies may be used as a guide in selecting several lime-flyash-soil mixtures for additional study by test methods which have been more closely correlated with service behavior in the field. The wetting-and-drying and freezing-and-thawing test procedures used for soil-cement mixtures (ASTM Designation: D559 and D560) have been used for this purpose by other investigators (1, 2, 5).

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Appendix A

Development of Test Method for Preliminary Evaluation

In developing the test method, a series of experiments were performed to determine the most desirable ways of preparing, curing, and testing lime-flyash-soil specimens. The properties of the lime, the flyash, and the four soils used in the experiments are given in Tables 1, 2, and 3. Lime-and-flyash admixtures are expressed in percent by weight of the lime-flyash-soil mixture; ratios of lime to flyash are by weight. Most of the data reported are the average of results obtained from tests using three specimens.

PREPARATION OF SPECIMENS

The moisture content of a lime-flyash-soil mixture during compaction and the method and degree of compaction have an important effect on the stability of the compacted mixture. In the lime-and-flyash-stabilization studies with silty and clayey soils, specimens 2 inches in diameter and 2 inches high are molded to near standard Proctor density. The molding apparatus used is shown in Figure 4.

The lime-flyash-soil mixture is placed in the molding cylinder in one layer and compacted by a 5-lb. hammer dropping from a height of 12 inches. Experiments with a number of fine-grained raw soils and stabilized soils showed that five blows of the hammer on each side of the specimen are needed to compact the soil or stabilized mixture to near standard Proctor density. The details of the compaction apparatus and the procedure for its use will be given in another paper. ("Some Laboratory Tests for the Evaluation of Stabilized Soils", to be presented at the 1955 Annual Meeting of the American Society for Testing Materials by T. Y. Chu and D. T. Davidson).

The moisture-density relations and the moisture-compressive-strength relations were studied with mixtures of lime and flyash and each of the four soils. Specimens used for determining compressive strength were cured at 70 ± 3 F. in a moist cabinet for seven days and then were tested according to the procedure given in Appendix B.

Results of the experiments (see Table A) indicate that for most of the mixtures the amount of moisture required for maximum dry density is more than that required for highest compressive strength. However, the difference, if there is any, between the two moisture requirements is not great. Since the moisture content giving maximum dry density can be determined with less effort and in a much shorter time, it seems desirable to use this moisture content for preparing lime-flyash-soil specimens.

TABLE A

COMPARISON OF THE MOISTURE CONTENT GIVING MAXIMUM DENSITY WITH THAT GIVING HIGHEST COMPRESSIVE STRENGTH OF LIME, FLYASH, AND SOIL MIXTURES

Soil	Lime and Flyash Admixture,[a] Percent	Moisture Content, Percent	
		For Maximum Dry Density	For Highest 7-day Compressive Strength
No. 1	25	21.6	20.8
	33	22.5	21.5
No. 2	33	32.2	32.2
No. 3	25	20.3	16.8
	33	20.7	18.8
No. 4	33	22.5	19.0

[a] Ratio of lime to flyash is 1 to 1.

CURING OF SPECIMENS

The stability of lime-flyash-soil mixtures is dependent upon the length of curing and such curing conditions as the temperature and the relative humidity during curing. On the basis of the following curing experiments, it appears desirable to cure specimens in a moist cabinet capable of maintaining a temperature of 70 ± 3 F. and

TABLE B

DATA ILLUSTRATING THE EFFECT OF VARIATIONS IN TEMPERATURE DURING CURING ON THE COMPRESSIVE STRENGTH OF LIME, FLYASH, AND SOIL MIXTURES

Soil	Lime and Flyash Admixture, Percent	Ratio of Lime to Flyash	Compressive Strength, lb.				
			Cured at 140±2 F[a] for 7 days	Cured at 110±2 F[a] for 7 days	Cured at 70±3 F[b]		
					7-day	28-day	60-day
No. 1	25	1:2	3600	1850	740	1130	1580
No. 2	15	1:2	430	315	230	350	320
	25	1:2	1590	1200	525	1005	1235
	25	1:4	765	590	310	575	725
No. 3	25	1:2	7040	N.D.[c]	640	1045	1550
No. 4	15	1:2	1575	265	225	255	310
	25	1:2	3125	550	350	430	505
	25	1:4	2330	335	300	380	425

[a] Specimens were kept in air-tight containers to prevent evaporation during curing.
[b] Specimens were cured in a moist cabinet capable of maintaining a relative humidity of not less than 90 percent.
[c] Not determined.

TABLE C

DATA ILLUSTRATING THE EFFECT OF VARIATIONS IN RELATIVE HUMIDITY DURING CURING ON THE COMPRESSIVE STRENGTH OF LIME-FLYASH-SOIL MIXTURES

Soil	Lime and Flyash Admixture,[a] Percent	Compressive Strength, lb.					
		7-day Curing at 70±3 F.			28-day Curing at 70±3 F.		
		32% R. H.[b]	65% R. H.	100% R. H.	32% R. H.	65% R. H.	100% R. H.
No. 1	25	530	480	540	765	770	770
No. 2	25	360	405	380	940	870	860
No. 3	25	810	735	590	1170	1120	980
No. 4	25	370	355	330	575	425	380
Lime and flyash mixture without soil, (ratio 1 to 2)		880	1110	740	880	2475	2885

[a] Ratio of lime to flyash is 1 to 2.
[b] Relative humidity.

a relative humidity of not less than 90 percent for periods of 7 and 28 days. In these experiments the compressive strength was determined by using 24-hr. immersed specimens, as discussed in Appendix B.

Temperature During Curing

A comparison of the compressive strengths of test specimens cured at various temperatures is shown in Table B. The data for 7-day specimens indicate that the use of elevated temperatures (140 ± 2 F and 110 ± 2 F) results in a compressive strength much higher than obtained by curing at 70 ± 3 F. For many of the mixtures tested, the compressive strengths of 7-day specimens cured at near 140 F. are even much higher than the compressive strengths of 60-day specimens cured at near 70 F. It is concluded that curing at near 140 F. as used by other investigators (2) gives results which may not be attainable in the field by conventional methods of curing.

Relative Humidity During Curing

The effect of the relative humidity during curing on compressive strength is illustrated by the data in Table C. For many of the mixtures tested, the highest compressive strength is obtained with relative humidities lower than 100 percent. Since no uniform trend of variation in compressive strength is indicated by the test data, it is not possible to select a relative humidity which will result in the highest compressive strength for all mixtures. Because of this, the curing of specimens at a relative humidity not lower than 90 percent is recommended.

Effect of Carbon Dioxide in the Air

The data of experiments with mixtures of lime and flyash and each of the four soils indicate that the effect on the compressive strength of cured specimens of carbon dioxide in the air during curing is not great. For this reason, it appears not to be necessary to control the amount of carbon dioxide present during the curing period.

Length of Curing

The compressive strength of mixtures of lime, flyash, and soil increases with an increase in the length of curing. Among various factors affecting the rate of increase in compressive strength are the kind of soil stabilized and the amount and proportion of lime and flyash used. Curves illustrating the influence of these variables on the rate of increase in compressive strength are given in Figures 5 and 6. The data shown were obtained by using specimens cured for varying periods at 70 ± 3 F. and in a relative humidity of not less than 90 percent.

Especially noteworthy in Figure 5 is the remarkably rapid increase in compressive strength of the lime-and-flyash mixture without soil during the 60-day curing period studies. These data and the data of related experiments suggest that the relationship between the compressive strength of a lime-flyash-soil mixture and the amount if lime and flyash used is as follows: If the ratio of lime to flyash is maintained constant, the larger the amount of lime and flyash, the faster the increase in the compressive strength of the lime-flyash-soil mixture. Experiments are being made to verify this relationship and to investigate curing periods longer than 60 days.

From the above discussion, it is apparent that a fairly long curing period is desirable in evaluating the stability of mixtures of lime, flyash, and soil. It may be that a curing period longer than one month may not be practical, especially when results are urgently needed in planning seasonal construction projects. A solution is to use the conventional 7-day and 28-day curing periods used for testing portland-cement concrete.

TESTING OF SPECIMENS

Specimens after curing are immersed in distilled water for 24 hours. The water absorption and the volume change of a specimen during immersion can be determined by weighing and measuring the height and diameter of the specimen before and after the immersion. The compressive strength after immersion can be determined by the unconfined-compression test.

Test data obtained in the experiments with silty and clayey soils indicate that the compressive strength values are usually sufficient for preliminary evaluation purposes. The compressive strength of a

specimen may be expressed in terms of the total load causing failure of the specimen during the unconfined compression test; or it may be expressed as a unit stress (in psi.) computed from the total load causing failure. The first alternative is recommended in the test method given in Appendix B.

Appendix B

Recommended Test Method for the Preliminary Evaluation Of Lime-and-Flyash-Stabilized Silty and Clayey Soils

This method describes test procedures for evaluating the effectiveness of lime-and-flyash stabilization of silty and clayey soils.[1] The test may also be used as an aid in the selection of lime-flyash-soil mixtures for final evaluation tests.

APPARATUS

The apparatus used in this test consists of the following: (1) Mechanical Mixer, a mechanical mixer capable of producing uniform mixtures of soil, lime, flyash, and water; (2) Compaction Apparatus, a compaction apparatus capable of preparing stabilized soil specimens of uniform density. An apparatus found suitable for molding specimens, 2-inch diameter and 2-inch high is shown in Figure 4; (3) Moist Cabinet, a moist cabinet capable of maintaining a temperature of 70±3 F. and a relative humidity of not less than 90 percent; (4) Testing Machine, a loading device of more than 5,000-lb. capacity, capable of applying the load through a uniform motion of the testing head at a rate of 0.1-inch per minute; and (5) Balance, No. 10 Sieve, Etc.

SAMPLES

Representative samples of soil, hydrated lime, and flyash are used for the test. With some modifications in the test procedure, other types of lime may also be used.

PREPARATION OF SOIL

An air-dried sample of soil is pulverized and screened through a No. 10 sieve. The pulverization should be so done as not to reduce the size of the individual soil particles. The entire sample of many silty and clayey soils will pass through the sieve. It is believed that the test method also may be used for soils containing particles retained on the sieve, if the retained fraction is less than 15 percent by weight of the total soil sample.

PREPARATION OF MIXTURE OF LIME, FLYASH, AND SOIL

The pulverized soil is dry mixed with a predetermined amount of hydrated lime and flyash. The proper amount of distilled water is then mixed with the three materials to obtain a mixture at optimum moisture content for maximum density. Both the dry and the wet mixing may be done with a mechanical mixer.

MOLDING OF SPECIMENS

Immediately after mixing, the moist mixture is used for molding specimens 2 inches in diameter and 2 inches high. (Specimens having a height-diameter ratio of one are used mainly for convenience in molding. If desired, specimens 2 inches in diameter and 4 inches or more in height may be used.) Usually three or more specimens are prepared for each test result required. It is desirable to so mold the specimens as to simulate the compacted lime-flyash-soil mixture obtainable under actual field conditions. The density of specimens molded may be determined by weighing the specimens and by measuring their height, since the diameter of all specimens is constant.

CURING OF SPECIMENS

Specimens are cured in a moist cabinet capable of maintaining a temperature of

[1] This test method is recommended mainly on the basis of experiments using several silty and clayey soils and one variety each of hydrated lime and flyash. Experiments with a wider variety of lime, flyash, and soil are needed to verify the suitability of the test procedure and to make improvements in it.

70 ± 3 F. and a relative humidity of not less than 90 percent. The length of the curing period may be 7 or 28 days.

TESTING OF SPECIMENS

After specimens are cured, they are completely immersed in distilled water at about 70 F. for 24 hours. Each specimen is then tested for unconfined compressive strength. The rate of deformation during testing is 0.1 inch per minute. The maximum test load causing failure of the specimen is taken as its compressive strength.

Soil Stabilization with Resins and Chemicals

R. C. MAINFORT
Highway and Construction Materials Department
Dow Chemical Company

Introductory Remarks by the Chairman: Many federal, state, and private agencies have made essential contributions to the practice and science of soil stabilization. Most noteworthy among these are the Bureau of Public Roads, the state highway departments, the engineering departments of the Army, the Navy, and the Airforce, the Civil Aeronautics Administration, and the Bureau of Reclamation.

It is natural that the quality and quantity of contributions of these and other agencies varied with time, one or another being leading at one particular period. At one time, there was a golden age for the Civil Aeronautics Administration with respect to soil and soil stabilization research when Grieme had assembled a staff of keen and active men. Among these were David S. Jenkins, now director of the Saline Water Conversion Program of the Department of the Interior; George W. McAlpin, now chief soils engineer of the State of New York; and R. C. Mainfort, presently with the Dow Chemical Company.

During this period the CAA not only sponsored at various universities research that was of utmost importance and has by now largely become classical, but organized its own laboratories for further evaluation and supplementation of this research. Mainfort, who remained with the Soils and Pavement Research Section of the CAA until this section was dissolved, has enriched this symposium with a concise and condesned review of the work he directed while associated with the CAA.

● FOR several years various organizations have investigated the possibility of using chemical additives to alter the characteristics of natural soils in order that they might be more successfully used as a structural material. The desired effect might be obtained by bonding, waterproofing, or otherwise modifying the natural soil so that the resulting mixture can withstand the detrimental forces of weather, moisture, and load application. From the standpoint of highway and airport construction, the application of such techniques should permit the economical and efficient utilization of soils for the construction of durable wearing surfaces and base courses.

The improvement of natural soil by the addition of chemical admixtures is generally referred to as "chemical soil stabilization." For the purpose of this report, the term is used to describe any method whereby the engineering properties of natural soils are improved by the chemical or physicochemical interaction between an admixture and a soil and includes the use of such general materials as cement and bitumen.

Most of these soil stabilizers fulfill their function by imparting their own properties to the resulting mixtures. Recent studies, however, indicate that a group of substances, referred to as "trace chemicals," are capable of altering soil properties almost entirely by interaction with the surfaces of the soil particles (1). Such surface-active substances show promise of being effective in quantities in the range of 0.1 to 0.5 percent by weight of the soil.

The overall testing of prospective soil-