ENGINEER MANUAL

EM 1110-3-137
April 1984

ENGINEERING AND DESIGN

Soil Stabilization for Pavements Mobilization Construction

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314

EM 1110-3-137

DAEN-ECE-G

Engineer Manual
No. 1110-3-137

9 April 1984

Engineering and Design
SOIL STABILIZATION FOR PAVEMENTS
Mobilization Construction

1. Purpose. This manual provides guidance for the design and improvement of the structural quality and workability of soils used for base courses, subbase courses, select materials, and subgrades for pavements construction for U.S. Army mobilization facilities.

2. Applicability. This manual is applicable to all field operating activities having mobilization construction responsibilities.

3. Discussion. Criteria and standards presented herein apply to pavement construction considered crucial to a mobilization effort. These requirements may be altered when necessary to satisfy special conditions on the basis of good engineering practice consistent with the nature of the construction. Design and construction of mobilization facilities must be completed within 180 days from the date notice to proceed is given with the projected life expectancy of five years. Hence, rapid construction of a facility should be reflected in its design. Time-consuming methods and procedures, normally preferred over quicker methods for better quality, should be de-emphasized. Lesser grade materials should be substituted for higher grade materials when the lesser grade materials would provide satisfactory service and when use of higher grade materials would extend construction time. Work items not immediately necessary for the adequate functioning of the facility should be deferred until such time as they can be completed without delaying the mobilization effort.

FOR THE COMMANDER:

PAUL F. KAVANAUGH
Colonel, Corps of Engineers
Chief of Staff

DEPARTMENT OF THE ARMY
U. S. Army Corps of Engineers
Washington, DC 20314

EM 1110-3-137

Engineer Manual
No. 1110-3-137

9 April 1984

Engineering and Design
SOIL STABILIZATION FOR PAVEMENTS
Mobilization Construction

LIST OF TABLES

CHAPTER 1

GENERAL

1-1. Purpose and scope. This manual presents criteria for improving the structural quality and workability of soils used for base courses, subbase courses, select materials, and subgrades for pavements. It is applicable to all elements responsible for Army pavement construction at mobilization facilities.

1-2. Definitions. The following definitions are applicable to this manual.

a. Soils. The term "soils" refers to naturally occurring materials that are used for the construction of all except the surface layers of pavements and that are subject to classification tests to provide a general concept of their engineering characteristics. Also included are the materials normally used for base courses, subbase courses, select material layers, and subgrades. The soil classification system to be used in evaluating these characteristics is described in MIL-STD-619.

b. Stabilization. Stabilization is the process of blending and mixing materials with a soil to improve the pertinent properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, change certain properties, or act as a binder for cementation of the soil.

c. Modification. Modification refers to the stabilization process that results in improvement in some property of the soil but does not by design result in a significant increase in soil strength and durability.

d. Additive. Additive refers to a manufactured commercial product that, when added to the soil in the proper quantities, will improve the quality of the soil layer. This manual is restricted to the use of portland cement, lime, lime-cement-fly ash, and bitumen, alone or in combination, as additives to stabilize soils.

1-3. Methods of stabilization. The two general methods of stabilization presented are mechanical and additive. The effectiveness of stabilization is dependent upon the ability to obtain uniformity in blending the various materials. Mixing in a stationary or traveling plant is preferred; however, other means of mixing, such as scarifiers, plows, disks, graders, and rotary mixers, have been satisfactory.

a. Mechanical stabilization. Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification. The soil blending may take place at the construction site, at a central plant, or at a borrow area. The blended material is then spread and compacted to required densities by conventional means.

b. Additive stabilization. Two types of additive stabilization are chemical and bituminous. Chemical stabilization is achieved by the addition of proper percentages of cement, lime, fly ash, or combinations of these materials to the soil. Bituminous stabilization is achieved by the addition of proper percentages of bituminous material to the soil. The selection and determination of the percentage of additive to be added is dependent upon the soil classification and the degree of improvement in soil quality desired. Generally, smaller amounts of additives are required when it is simply desired to alter soil properties, such as gradation, workability, and plasticity, than when it is desired to improve the strength and durability sufficiently to permit a thickness reduction design. After the additive has been mixed with the soil, spreading and compaction are achieved by conventional means.

CHAPTER 2

PURPOSE OF STABILIZATION

2-1. Uses of stabilization. Pavement design is based on the premise that specified levels of quality will be achieved for each soil layer in the pavement system. Each layer must resist shearing within the layer, avoid excessive elastic deflections that would result in fatigue cracking within the layer or in overlying layers, and prevent excessive permanent deformation through densification. As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is generally increased enough to permit a reduction in the required thickness of the soil and surface layers.

a. Improve quality. The most common soil quality improvements through stabilization include better soil gradation, reduction of plasticity index or swelling potential, and increases in durability and in strength. It is also common to stabilize a soil by an additive in order to provide an all-weather working platform for construction operations. These types of soil quality improvement are referred to as soil modifications.

b. Reduce thickness. The tensile strength and stiffness of a soil layer can be improved through the use of additives and thereby permit a reduction in the thickness of the stabilized layer and overlying layers within the pavement system. Before a stabilized layer can be used to reduce the required thickness in the design of a pavement system, the stabilized material must meet the durability requirements given in paragraph 2-2 on various types of additive stabilization and the minimum strength requirements shown in table 2-1.

Table 2-1. Minimum Unconfined Compressive Strengths for Cement, Lime, and Combined Lime-Cement-Fly Ash Stabilized Soils

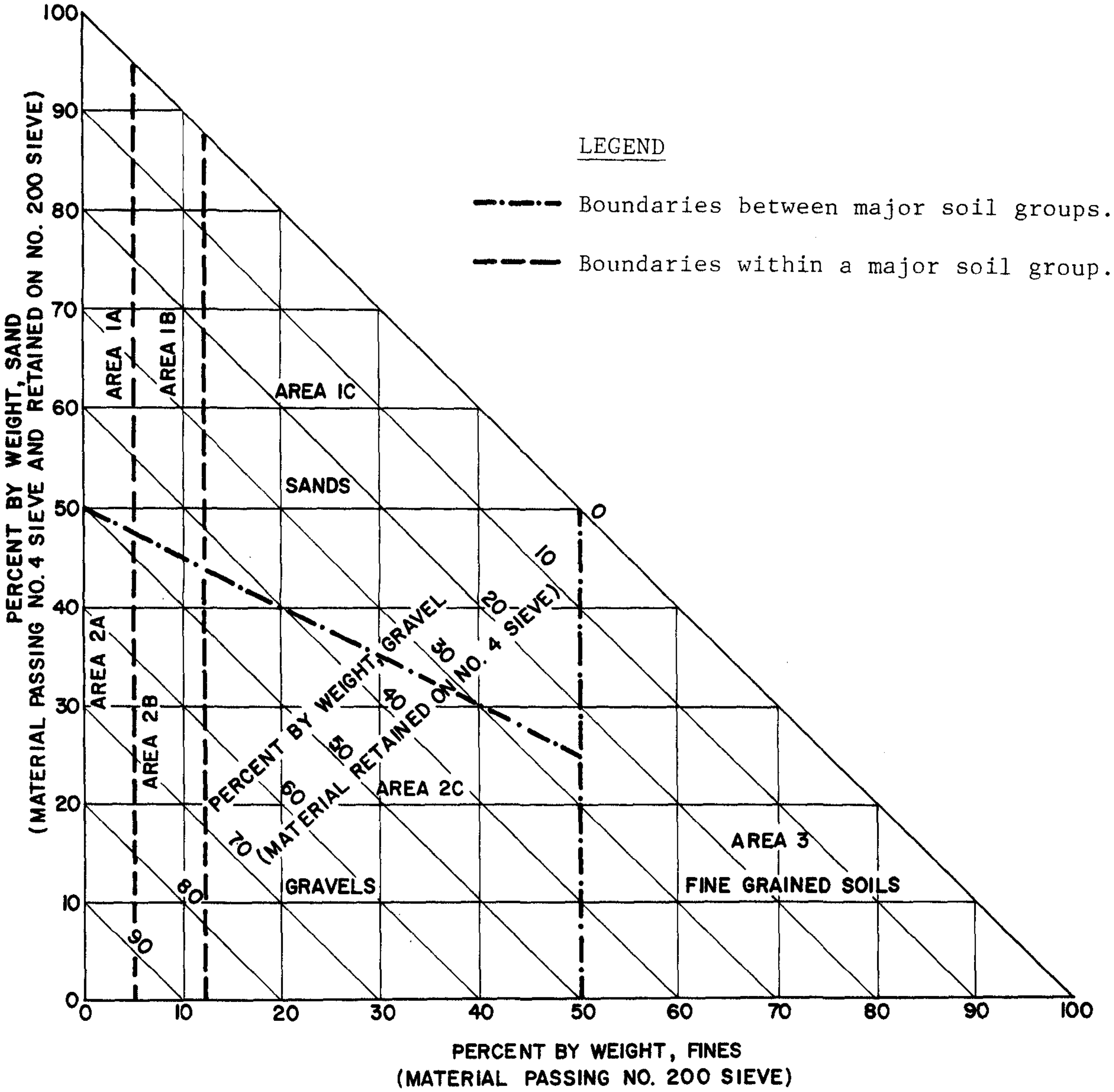
Stabilized Soil Layer	Minimum Unconfined Compressive Strength, psi[a]	
	Flexible Pavement	Rigid Pavement
Base course	750	500
Subbase course, select material or subgrade	250	200

[a]Unconfined compressive strength determined at 7 days for cement stabilization and 7 or 28 days for lime or lime-cement-fly ash stabilization (See chapter 4)

2-2. Selection of stabilizer additive. In the selection of a stabilizer additive, the factors that must be considered are the type of soil to be stabilized, the purpose for which the stabilized layer will be used, the type of soil quality improvement desired, the required strength and durability of the stabilized layer, and cost and environmental conditions.

a. The soil gradation triangle in figure 2-1 is based upon the pulverization characteristics of the soil that, when combined with certain restrictions relative to liquid limit (LL) plasticity index (PI), and soil gradation contained in table 2-2, provide guidance for the selection of the additive best suited for stabilization. Figure 2-1 is entered with the percentage of gravel (percent material retained on No. 4 sieve), sand (percent material passing No. 4 sieve and retained on the No. 200 sieve), and fines (percent material passing the No. 200 sieve) to determine the area in which the soil gradation falls. The area (1A, 2C, 3, etc.) indicated at the intersection of the three material percentages is used to enter table 2-2 to select the type of stabilizing additive considering the various restrictions and remarks. For example, a soil having a PI of 15 and containing 67 percent gravel, 26 percent sand, and 7 percent fines falls in Area 2B of figure 2-1. Table 2-2 indicates that cement, lime, lime-cement-fly ash, or bitumen could be considered. However, the PI of 15 eliminates bitumen, and the fact that only 33 percent of the material passes the No. 4 sieve indicates that lime or a combination of lime-cement-fly ash will be the better additive for stabilization.

b. The next consideration in the selection of an additive will be the use of the stabilized layer. If it is only desired to modify the properties of the soil (i.e., lower the PI and increase percent fines) so that it would qualify as a subbase or base course material, lime may well be the best additive. If, however, high strengths and good durability are required to effect a reduction in pavement thickness, the use of a lime-cement or lime-cement-fly ash combination may be the best additive. Actually, the best additive can only be determined by studies as outlined later in this manual. The success of additive stabilization depends, to a large extent, upon attaining complete and uniform distribution of the additive in the soil. This step is most critical when using bitumens or portland cement as additives. These materials work well in coarse-grained soils that pulverize more easily. Generally, as the percent fines and the PI increase, pulverization becomes more difficult, and it is harder to obtain uniform distribution of the stabilizing additive. For these types of soils, preprocessing or pretreatment with other additives may be necessary. For example, fine-grained soils may be pretreated with lime to aid in their pulverization, making mixing of a bitumen or cement additive more successful.



U.S. Army Corps of Engineers

FIGURE 2-1. GRADATION TRIANGLE FOR AID IN SELECTING A COMMERCIAL STABILIZING AGENT

Table 2-2. Guide for Selecting a Stabilizing Additive

Area	Soils Class.[a]	Type of Stabilizing Additive Recommended	Restriction on LL and PI of Soil	Restriction on Percent Passing No. 200 Sieve[a]	Remarks
1A	SW or SP	(1) Bituminous			
		(2) Portland Cement			
		(3) Lime-Cement-Fly Ash	PI not to exceed 25		
1B	SW-SM or SP-SM or SW-SC or SP-SC	(1) Bituminous	PI not to exceed 10		
		(2) Portland Cement	PI not to exceed 30		
		(3) Lime	PI not less than 12		
		(4) Lime-Cement-Fly Ash	PI not to exceed 25		
1C	SM or SC or SM-SC	(1) Bituminous	PI not to exceed 10	Not to exceed 30 percent by weight	
		(2) Portland Cement	----b		
		(3) Lime	PI not less than 12		
		(4) Lime-Cement-Fly Ash	PI not to exceed 25		
2A	GW or GP	(1) Bituminous			Well-graded material only
		(2) Portland Cement			Material should contain at least 45 percent by weight of material passing No. 4 sieve
		(3) Lime-Cement-Fly Ash	PI not to exceed 25		
2B	GW-GM or GP-GM or GW-GC or GP-GC	(1) Bituminous	PI not to exceed 10		Well-graded material only
		(2) Portland Cement	PI not to exceed 30		Material should contain at least 45 percent by weight of material passing No. 4 sieve
		(3) Lime	PI not less than 12		
		(4) Lime-Cement-Fly Ash	PI not to exceed 25		
2C	GM or GC or GM-GC	(1) Bituminous	PI not to exceed 10	Not to exceed 30 percent by weight	Well-graded material only
		(2) Portland Cement	---b		Material should contain at least 45 percent by weight of material passing No. 4 sieve
		(3) Lime	PI not less than 12		
		(4) Lime-Cement-Fly Ash	PI not to exceed 25		
3	CH or CL or MH or ML or OH or OL or ML-CL	(1) Portland Cement	LL less than 40 and PI less than 20		Organic and strongly acid soils falling within this area are not susceptible to stabilization by ordinary means
		(2) Lime	PI not less than 12		

[a] Soil classification corresponds to MIL-STD-619. Restriction on liquid limit (LL) and plasticity index (PI) in accordance with Method 103 in MIL-STD-621.

[b] $PI \quad 20 + \frac{50 - \text{percent passing No. 200 sieve}}{4}$

U.S. Army Corps of Engineers

2-3. Use of stabilized soils in frost areas.

a. Additives. Bitumens, portland cement, lime, and combinations of lime, portland cement, and fly ash (LCF) are the most common additives for use in stabilized soils.

b. Limitations of use. In frost areas, stabilized soil usually will be used only in a layer or layers comprising one of the upper elements of a pavement system and directly beneath the pavement surfacing layer, where the added cost of stabilization is compensated for by its structural advantage in effecting a reduction in the required thickness of the pavement system. Treatment with a lower degree of chemical stabilization should be used in frost areas only with caution and after intensive tests, because weakly cemented material usually has less capacity to endure repeated freezing and thawing than firmly cemented material. A possible exception is the use of a low level of stabilization to improve a soil that will be encapsulated within an impervious envelope as part of a membrane-encapsulated-soil-layer pavement system. A soil that is unsuitable for encapsulation due to excessive moisture migration and thaw weakening may be made suitable for such use by moderate amounts of a stabilizing additive. Materials that are modified by small amounts of a chemical additive to improve certain properties of the soil without significant cementation also should be tested to ascertain that the desired improvement is durable through repeated freeze-thaw cycles. The improvement should not be achieved at the expense of making the soil more susceptible to ice segregation. Additional discussions on the use of stabilized soil in seasonal frost areas are presented in EM 1110-3-138.

c. Construction cutoff dates. For materials stabilized with cement, lime, or LCF whose strength increases with time of curing, it is essential that the stabilized layer be constructed sufficiently early in the season to allow the development of adequate strength before the first freezing cycle begins. The rate of strength gain is substantially lower at 50 degrees F. than at 70 or 80 degrees F. Chemical reactions will not occur rapidly for (1) lime-stabilized soils when the soil temperature is less than 60 degrees F. and is not expected to increase for 1 month, or (2) cement-stabilized soils when the soil temperature is less than 40 degrees F. and is not expected to increase for 1 month. In frost areas, it is not always sufficient to protect the mixture from freezing during a 7-day curing period as required by the applicable guide specifications, and a construction cutoff date well in advance of the onset of freezing conditions may be essential.

CHAPTER 3

STABILIZATION WITH PORTLAND CEMENT

3-1. Stabilization approaches. Portland cement can be used either to modify and improve the quality of the soil or to transform the soil into a cemented mass, which significantly increases its strength and durability. The amount of cement additive will depend upon whether the soil is to be modified or stabilized.

3-2. Cement content for modification of soils.

a. Modification of quality. The amount of cement required to improve the quality of the soil through modification is determined by the trial-and-error approach. If it is desired to reduce the PI of the soil, successive samples of soil-cement mixtures must be prepared at different treatment levels and the PI of each mixture determined. The Referee Test of ASTM D 423 and ASTM D 424 procedures will be used to determine the PI of the soil-cement mixture. The minimum cement content that yields the desired PI is selected, but since it was determined based upon the minus 40 fraction of the material, this value must be adjusted to find the design cement content based upon total sample weight expressed as the following equation:

$$A = 100Bc$$

where:

A = design cement content, percent total weight of soil
B = percent passing No. 40 sieve size, expressed as a decimal
c = percent cement required to obtain the desired PI of minus 40 material, expressed as a decimal.

b. Modification of gradation. If the objective of modification is to improve the gradation of granular soil through the addition of fines, the particle-size analysis, using the ASTM D 422 procedure, should be conducted on samples at various treatment levels to determine the minimum acceptable cement content. The determination of cement content to reduce the swell potential of fine-grained plastic soils can be accomplished by molding several samples at various cement contents and soaking the specimens along with untreated specimens for 4 days. The lowest cement content that eliminates the swell potential or reduces the swell characteristics to the minimum becomes the design cement content. Procedures for measuring swell characteristics of soils are found in MIL-STD-621, Method 101. The cement content determined to accomplish soil modification should be checked to see whether it provides an unconfined compressive strength great enough to qualify for a reduced thickness design in accordance with criteria established for soil stabilization.

c. Modification for frost areas. Cement-modified soil also may be used in frost areas, but in addition to the procedures for mixture design described in 3-2.a. and 3-2.b. above, cured specimens should be subjected to the freeze-thaw cycles prescribed by ASTM D 560 (but omitting wire-brushing) or other applicable freeze-thaw procedures, followed by frost-susceptibility determinations in standard laboratory freezing tests. For cement-modified soil used in the base course, the frost susceptibility, determined after freeze-thaw cycling, should meet the requirements set forth for the base course. If cement-modified soil is used as the subgrade, its frost susceptibility, determined after freeze-thaw cycling, should be used as the basis of the pavement thickness design if the reduced subgrade strength design method is applied (EM 1110-3-138). For mobilization, the use of ASTM D 560 may be altered to 6 cycles of 6 hours of freeze/wet - 6 hour thaw/dry. Percentages of stabilizer selected for use may be based on local performance history in lieu of these tests.

3-3. Cement content for cement-stabilized soil. The following procedure is recommended for determining the design cement content for cement-stabilized soils.

a. Step 1. Determine the classification and gradation of the untreated soil following procedures in MIL-STD-619 and ASTM D 422, respectively. The soil must meet the gradation requirements shown in table 3-1 before it can be used in a reduced thickness design.

Table 3-1. Gradation Requirements

Type Course	Sieve Size	Percent Passing
Base	2-inch	100
	1-1/2-inch	70-100
	1-inch	45-100
	3/4-inch	--
	1/2-inch	30-90
	No. 4	20-70
	No. 10	15-60
	No. 30	--
	No. 40	5-40
	No. 200	0-20
Subbase	3-inch	100
	No. 4	--
	No. 10	--
	No. 100	--
	No. 200	0-25

b. Step 2. Select an estimated cement content from table 3-2 using the soil classification.

Table 3-2. Estimated Cement Requirements for Various Soil Types

Soil Classification[a]	Initial Estimated Cement Requirement Percent Dry Weight
GW-SW	5
GP, SW-SM, SW-SC, SW-GM, SW-GC	6
GM, SM, GC, SC, SP-SM, SP-SC, GP-GM GP-GC, SM-SC, GM-GC	7
SP, CL, ML, ML-CL	10
MH, OH	11
CH	10

[a] Soil classification corresponds to MIL-STD-619.

c. Step 3. Using the estimated cement content, determine the moisture-density relations of the soil-cement mixture. The procedure contained in ASTM D 558 will be used to prepare the soil-cement mixture and to make the necessary calculations; however, the apparatus and procedures outlined in MIL-STD-621, Method 100, Compaction Effort Designation CE-55 will be used to compact the soil-cement mixture.

d. Step 4. Using the untreated soil gradation characteristics, cement content, and maximum dry density determined in Steps 1, 2, and 3, respectively, verify the estimated cement content using table 3-3 or table 3-4 and figure 3-1 depending upon soil classification. If the estimated cement content from Step 2 varies by more than plus or minus 2 percent from the value in table 3-3 or table 3-4, conduct additional moisture-density tests, varying the cement content, until the value from table 3-3 or table 3-4 is within plus or minus 2 percent of that used for the moisture-density test. The moisture-density test will be performed as outlined in Step 3.

e. Step 5. Prepare samples of the soil-cement mixture for unconfined compression and durability tests at the dry density and at the cement content determined in Step 4 and at cement contents 2

Table 3-3. Average Cement Requirements for Granular and Sandy Soils

Material Retained on No. 4 Sieve percent	Material Smaller Than 0.05 mm percent	Cement Content, Percent by Weight Maximum Dry Density, pcf (Treated Material) 116-120	121-126	127-131	132-137	138-142	143 or more
0-14	0-19	10	9	8	7	6	5
	20-39	9	8	7	7	5	5
	40-50	11	10	9	8	6	5
15-29	0-19	10	9	8	6	5	5
	20-39	9	8	7	6	6	5
	40-50	12	10	9	8	7	6
30-45	0-19	10	8	7	6	5	5
	20-39	11	9	8	7	6	5
	40-50	12	11	10	9	8	6

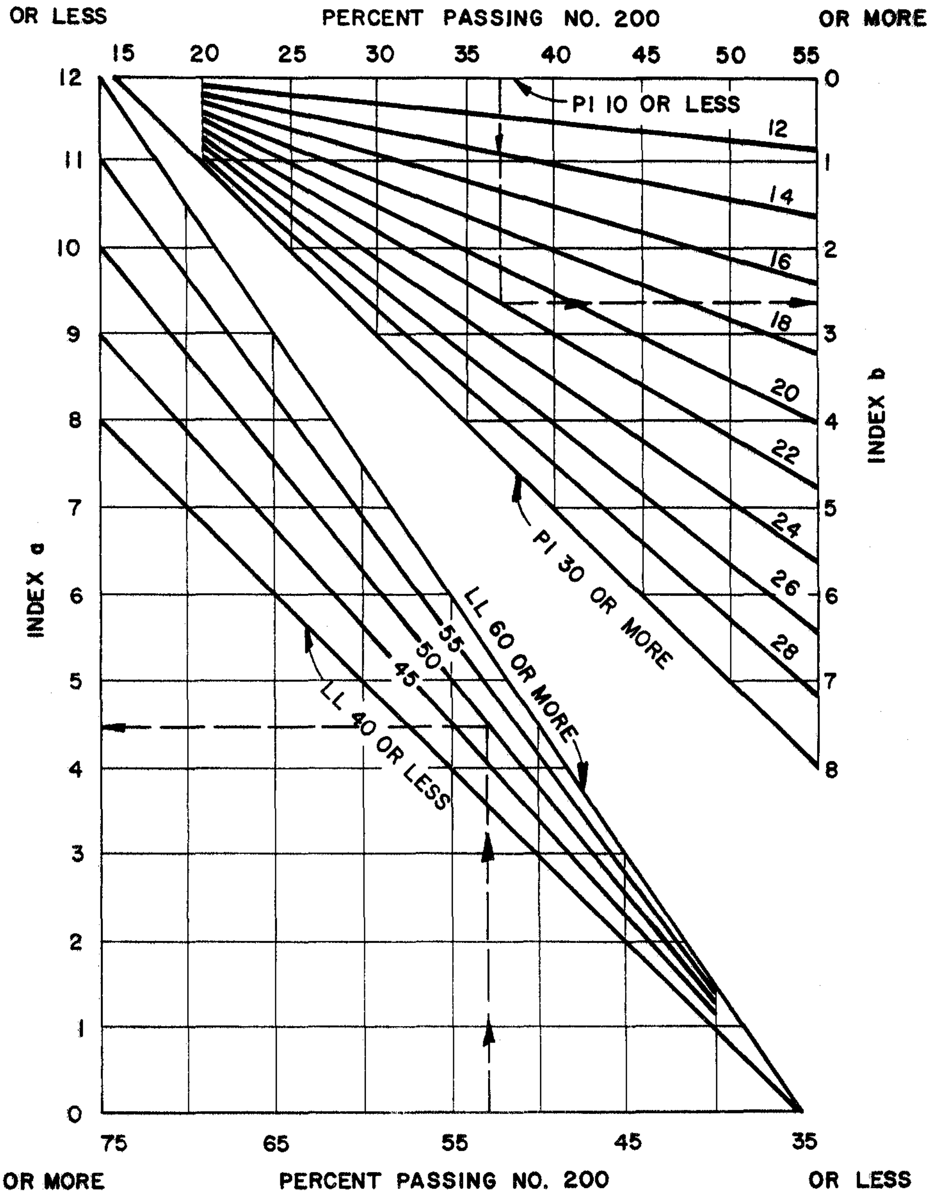
Note: Base course goes to 70 percent retained on the No. 4 sieve.

U.S. Army Corps of Engineers

Table 3-4. Average Cement Requirements for Silty and Clayey Soils

Group Index[a]	Material Between 0.05 and 0.005 mm percent	Cement Content, Percent by Weight Maximum Dry Density, pcf (Treated Material)						
		99-104	105-109	110-115	116-120	121-126	127-131	132 or more
0-3	0-19	12	11	10	8	8	7	7
	20-39	12	11	10	9	8	8	7
	40-59	13	12	11	9	9	8	8
	60 or more	--	--	--	--	--	--	--
3-7	0-19	13	12	11	9	8	7	7
	20-39	13	12	11	10	9	8	8
	40-59	14	13	12	10	10	9	8
	60 or more	15	14	12	11	10	9	9
7-11	0-19	14	13	11	10	9	8	8
	20-39	15	14	11	10	9	9	9
	40-59	16	14	12	11	10	10	9
	60 or more	17	15	13	11	10	10	10
11-15	0-19	15	14	13	12	11	9	9
	20-39	16	15	13	12	11	10	10
	40-59	17	16	14	12	12	11	10
	60 or more	18	16	14	13	12	11	11
15-20	0-19	17	16	14	13	12	11	10
	20-39	18	17	15	14	13	11	11
	40-59	19	18	15	14	14	12	12
	60 or more	20	19	16	15	14	13	12

[a]Taken from figure 3-1



NOTE: Group Index = Index a + Index b.

REPRINTED FROM SOIL-CEMENT LABORATORY HANDBOOK (EB052.06S) WITH PERMISSION OF THE PORTLAND CEMENT ASSOCIATION, SKOKIE, ILLINOIS.

FIGURE 3-1. CHARTS FOR CALCULATING GROUP INDEX VALUES percent above and 2 percent below that determined in Step 4. The samples should be prepared in accordance with ASTM D 1632 except that when more than 35 percent of the material is retained on the No. 4 sieve, a 4-inch-diameter by 8-inch-high mold should be used to prepare the specimens. Cure the specimens for 7 days in a humid room before testing. Test three specimens using the unconfined compression test in accordance with ASTM D 1633, and subject three specimens to durability tests, either wet-dry (ASTM D 559) tests for pavements located in nonfrost areas or freeze-thaw (ASTM D 560) tests for pavements located in frost areas (EM 1110-3-138). For mobilization, the use of ASTM D 560 may be altered to 6 cycles of 6 hours of freeze/wet - 6 hour thaw/dry. Percentages of stabilizer selected for use may be based on local performance history in lieu of these tests.

f. Step 6. Compare the results of the unconfined compressive strength and durability tests with the requirements shown in tables 2-1 and 3-5. The lowest cement content, which meets the required unconfined compressive strength requirement and demonstrates the required durability, is the design cement content. If the mixture should meet the durability requirements but not the strength requirements, the mixture is considered to be a modified soil.

Table 3-5. Durability Requirements

Type of Soil Stabilized[a]	Maximum Allowable Weight Loss After 12 Wet-Dry or 6 Freeze-Thaw Cycles Percent of Initial Specimen Weight
Granular, PI less than 10	11
Granular, PI greater than 10	8
Silt	8
Clays	6

[a]Refer to MIL-STD-619 and MIL-STD-621.

CHAPTER 4

STABILIZATION WITH LIME

4-1. Stabilization approaches. Lime can be used either to modify some of the physical properties and thereby improve the quality of a soil or to transform the soil into a stabilized mass, which increases its strength and durability. The amount of lime additive will depend upon whether the soil is to be modified or stabilized. The lime to be used may be either hydrated or quicklime, although the preponderance of stabilization is accomplished using hydrated lime, since quicklime is highly caustic and dangerous to use. The design lime contents determined from the criteria presented herein are for hydrated lime. As a guide, the lime contents determined herein for hydrated lime should be reduced by 25 percent to determine a design content for quicklime.

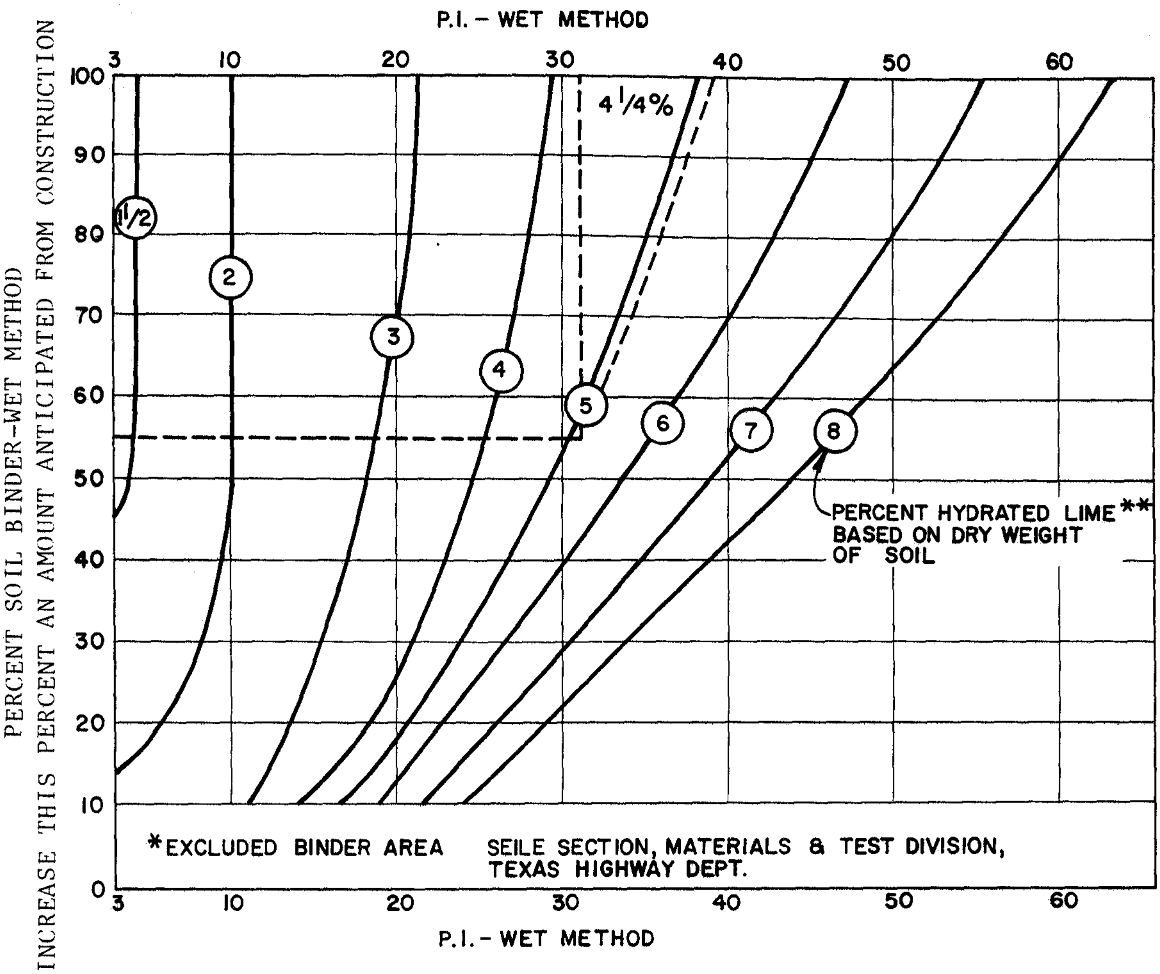
4-2. Lime content for lime-modified soils. The amount of lime required to improve the quality of a soil is determined through the same trial-and-error process used for cement-modified soils.

4-3. Lime content for lime-stabilized soils.

a. Strength requirements. To take advantage of the thickness reduction criteria, the lime-stabilized soil must meet the unconfined compressive strengths shown in table 2-1 as well as the durability requirements in table 3-5.

b. Procedures. When lime is added to a soil, a combination of reactions begins to take place immediately and is nearly complete within an hour, although substantial strength gain is not reflected for some time. These reactions result in a change in both the chemical composition and physical properties. Most lime, when placed in a water solution, has a pH of about 12.4. Therefore, the pH is a good indicator of the desirable lime content of a soil-lime mixture. The reaction that takes place when lime is introduced to a soil generally causes a significant change in the plasticity of the soil; therefore, the changes in the plastic and liquid limits also become an indicator of the desired lime content. Two methods are presented for the determination of the initial design lime content.

(1) Step 1. The preferred method is to prepare several mixtures at different lime treatment levels and determine the pH of each mixture after 1 hour. The lowest lime content producing the highest pH of the soil-lime mixture is the initial design lime content. Procedures for conducting a pH test on lime-soil mixtures are presented in appendix A. In frost areas, specimens must be subjected to the freeze-thaw test as discussed in Step 2 below. An alternate method of determining an initial design lime content is by the use of figure 4-1. Specific values required to use figure 4-1 are the PI and the percent of



EXAMPLE

1. Enter plot with Pl on top scale.
2. Follow curved line down to percent soil binder (o/o passing No. 40).
3. At intersection with percent soil binder, move vertically upward to the 100 percent soil binder line.
4. Read the percent lime represented at the intersection with the 100 percent soil binder line.
5. For soil having a Pl of 39 and 55 percent soil binder, the lime required is 4 - 1/4 percent.

* Exclude use of chart for materials less than 10 percent - No. 40 and cohesionless materials (P.I. less than 3).

** Percent of relatively pure lime usually 90 percent of more of CO and/or MG hydroxides and 85 percent or more of which pass the No. 200 sieve. Percentages shown are for stabilizing subgrades and base courses where lasting effects are desired. Satisfactory temporary results are sometimes obtained by the use of as little as 1/2 of above percentages. Reference to cementing strength is implied when such terms as "Lasting Effects" and "Temporary Results" are used.

Reprinted with permission from the National Lime Association

FIGURE 4-1. CHART FOR THE INITIAL DETERMINATION OF LIME CONTENT material passing the No. 40 sieve. These properties are determined from plastic limit and gradation tests on the untreated soil following procedures established in MIL-STD-621.

(2) Step 2. After the initial lime content has been estimated, conduct a moisture-density test with the lime-soil mixture following the procedures for soil-cement in ASTM D 558, except that the mixture should be allowed to cure no less than 1 hour and no more than 2 hours in a sealed container before molding. Compaction will be accomplished in accordance with MIL-STD-621, Method 100, Compaction Effort Designation CE-55. The moisture-density should be determined at lime contents equal to design plus 2 and plus 4 percent for the preferred method and at design plus or minus 2 percent for the alternate method. In frost areas, cured specimens should be subjected to ASTM D 560 (but omitting wire-brushing) or other applicable freeze-thaw procedures, followed by frost susceptibility determinations in standard laboratory freezing tests (EM 1110-3-138). For mobilization, the use of ASTM D 560 may be altered to 6 cycles of 6 hours of freeze/wet - 6 hour thaw/dry. Percentages of stabilizer selected for use may be based on local performance history in lieu of these tests. For lime-stabilized or lime-modified soil used in lower layers of the base course, the frost susceptibility, determined after freeze-thaw cycling, should meet the requirements set forth for the base course (EM 1110-3-138). If lime-stabilized or lime-modified soil is used as the subgrade, its frost susceptibility, determined after freeze-thaw cycling, should be used as the basis of the pavement thickness design if the reduced subgrade strength design method is applied.

(3) Step 3. Unconfined compression tests should be performed at the design percent of maximum density on three specimens for each lime content tested. The design value would then be the minimum lime content yielding the required strength. Procedures for the preparation of lime-soil specimens are similar to those used for cement-stabilized soils with two exceptions. After mixing, the lime-soil mixture should be allowed to mellow for not less than 1 hour or more than 2 hours; after compaction, each specimen should be wrapped securely to prevent moisture loss and cured in a constant temperature chamber at 73 degrees plus or minus 2 degrees F for 28 days. For mobilization, the required curing of the sample may be reduced to 7 days at 140 F. as an approximation of the 28 day soil strength. Caution must be taken, however, since certain pozzolanic reactions may occur at higher test temperatures which would not be duplicated at construction temperatures. In addition, the relationship between age, temperature, and strength is not the same for all lime-soil mixtures. Procedures for conducting unconfined compression tests are similar to those used for soil-cement specimens except that in lieu of moist curing, the lime-soil specimens should remain securely wrapped until testing.

(4) Step 4. Compare results of the unconfined compressive tests with the criteria in table 2-1. The design lime content must be the

lowest lime content of specimens meeting the strength criteria indicated.

4-4. Lime and other additives. If lime is used as a preliminary additive to reduce the PI or alter the gradation of a soil preparatory to the addition of the primary stabilizing agent such as bitumen or cement, then the design lime content is the minimum treatment level that will achieve the desired results. For nonplastic and low-PI materials in which lime alone generally is not satisfactory for stabilization, the addition of fly ash may be needed to produce the necessary reaction.

CHAPTER 5

STABILIZATION WITH LIME-CEMENT-FLY ASH (LCF)

5-1. Reaction with soils. Stabilization of coarse-grained soils having little or no fines can often be accomplished by the use of the LCF combination. Fly ash is a pozzolanic material, consisting mainly of silicon and aluminum compounds that, when mixed with lime and water, forms a hardened cementitious mass capable of obtaining high compressive strengths. Thus, lime and fly ash in combination can often be used successfully in stabilizing granular materials having few fines since the fly ash provides an agent with which the lime can react. In addition to lime and fly ash, a small amount of portland cement is also added to accelerate and increase strength gain. ASTM C 593 provides guidance in the selection of fly ash.

5-2. Suitable materials. Types of materials suitable for the LCF stabilization are coarse-grained soils having no more than 12 percent of the material passing the No. 200 sieve. In addition, the PI of the minus 40 fraction should not exceed 25.

5-3. LCF content. ASTM C 593 should be used for the determination of mix proportions of the LCF except that in addition to lime and fly ash as indicated in the procedure, about 1 percent portland cement should also be added for strength. Minimum unconfined compressive strength requirements are indicated in table 2-1. If test specimens do not then meet strength requirements, add cement in increments of 1/2 percent until strengths are adequate. The total quantity of additives should not exceed 15 percent by weight. In frost areas, the LCF mixture should meet the weight loss criteria specified for cement-stabilized soils. ASTM D 560 should be followed except that the specimens should be compacted in accordance with the procedure described in MIL-STD-621, Method 100, Compaction Effort Designation CE-55. For mobilization, the use of ASTM D 560 may be altered to 6 cycles of 6 hours of freeze/wet - 6 hour thaw/dry. Percentages of stabilizer selected for use may be based on local performance history in lieu of these tests.

CHAPTER 6

STABILIZATION WITH BITUMEN

6-1. Types of bituminous-stabilized soils.

a. Sand bitumen. A mixture of sand and bitumen in which the sand particles are cemented together to provide a material of increased stability.

b. Gravel or crushed aggregate bitumen. A mixture of bitumen and a well-graded gravel or crushed aggregate that, after compaction, provides a highly stable waterproof mass of subbase or base course quality.

c. Bitumen lime. A mixture of soil, lime, and bitumen that, after compaction, may exhibit the characteristics of any of the bitumen-treated materials indicated above. Lime is used with materials that have a high PI, i.e., above 10.

6-2. Soil gradation. The recommended soil gradations for subgrade materials and base or subbase course materials are shown in tables 6-1 and 6-2, respectively.

Table 6-1. Recommended Gradations for Bituminous-Stabilized Subgrade Materials

Sieve Size	Percent Passing
3 inch	100
No. 4	50-100
No. 30	38-100
No. 200	2-30

6-3. Types of bitumen. Bituminous stabilization is generally accomplished using asphalt cement, cutback asphalt, or asphalt emulsions. The type of bitumen to be used depends upon the type of soil to be stabilized, methods of construction, and weather conditions. In frost areas, the use of tar as a binder should be avoided because of its high-temperature susceptibility; however, material availability may require the use of tars in nonfrost areas. Asphalts are affected to a lesser extent by temperature changes, but a grade of asphalt suitable to the prevailing climate should be selected. As a general rule, the most satisfactory results are obtained when the most viscous liquid asphalt that can be readily mixed into the soil is used. For higher quality mixes in which a central plant is used, viscosity-grade asphalt cements should be used. Much bituminous stabilization is performed in place with the bitumen being applied directly on the soil or soil-aggregate system and the mixing and compaction operations being conducted immediately thereafter. For this type of construction,

Table 6-2. Recommended Gradations for Bituminous-Stabilized Base and Subbase Materials

Sieve Size	1-1/2-inch Maximum	1-inch Maximum	3/4-inch Maximum	1/2-inch Maximum
1-1/2-inch	100	--	--	--
1-inch	84 ± 9	100	--	--
3/4-inch	76 ± 9	83 ± 9	100	--
1/2-inch	66 ± 9	73 ± 9	82 ± 9	100
3/8-inch	59 ± 9	64 ± 9	72 ± 9	83 ± 9
No. 4	45 ± 9	48 ± 9	54 ± 9	62 ± 9
No. 8	35 ± 9	37 ± 9	41 ± 9	47 ± 9
No. 16	27 ± 9	28 ± 9	32 ± 9	36 ± 9
No. 30	20 ± 9	21 ± 9	24 ± 9	28 ± 9
No. 50	14 ± 7	16 ± 7	17 ± 7	20 ± 7
No. 100	9 ± 5	11 ± 5	12 ± 5	14 ± 5
No. 200	5 ± 2	5 ± 2	5 ± 2	5 ± 2

U.S. Army Corps of Engineers

liquid asphalts, i.e., cutbacks and emulsions, are used. Emulsions are preferred over cutbacks because of energy constraints and pollution control efforts. The specific type and grade of bitumen will depend on the characteristics of the aggregate, the type of construction equipment, and climatic conditions. Generally, the following types of bituminous materials will be used for the soil gradation indicated:

a. Open-graded aggregate.

(1) Rapid- and medium-curing liquid asphalts RC- and MC-70, 250, and 800, and MC-3000.

(2) Medium-setting asphalt emulsion MS-2 and CMS-2.

(3) Tars RT-1 and RT-2.

b. Well-graded aggregate with little or no material passing the No. 200 sieve.

(1) Rapid- and medium-curing liquid asphalts RC-250, RC-800, MC-250, and MC-800.

(2) Slow-curing liquid asphalts SC-250 and SC-800.

(3) Medium-setting and slow-setting asphalt emulsions MS-2, CMS-2, SS-1, and CSS-1.

(4) Tars RT-1, RT-2, RT-3, and RT-4.

c. Aggregate with a considerable percentage of fine aggregate and material passing the No. 200 sieve.

(1) Medium-curing liquid asphalts MC-250 and MC-800.

(2) Slow-curing liquid asphalts SC-250 and SC-800.

(3) Slow-setting asphalt emulsions SS-1, SS-1h, CSS-1, and CSS-1h.

(4) Medium-setting asphalt emulsions MS-2 and CMS-2.

(5) Tars RT-3, RT-4, RT-5, and RT-6.

d. Unbound aggregate. The simplest type of bituminous stabilization is the application of liquid asphalt to the surface of an unbound aggregate road. For this type of operation, the slow- and medium-curing liquid asphalts SC-250, MC-70, and MC-250 are used. Tar types RT-5 and RT-6 may be used in nonfreezing climates.

6-4. Mix design. Guidance for the design of bituminous-stabilized base and subbase courses is contained in EM 1110-3-131 and EM 1110-3-141. For subgrade stabilization, the following equation may be used for estimating the preliminary quantity of cutback asphalt to be selected:

$$p = \frac{0.02(a) + 0.07(b) + 0.15(c) + 0.20(d)}{(100 - S)} \times 100$$

where:

p = percent cutback asphalt by weight of dry aggregate
a = percent of mineral aggregate retained on No. 50 sieve
b = percent of mineral aggregate passing No. 50 and retained on No. 100 sieve
c = percent of mineral aggregate passing No. 100 and retained on No. 200 sieve
d = percent of mineral aggregate passing No. 200 sieve
S = percent solvent

The preliminary quantity of emulsified asphalt to be used in stabilizing subgrades can be determined from table 6-3. The final design content of cutback or emulsified asphalt should be selected based upon the results of the Marshall Stability test procedure (MIL-STD-620). The minimum Marshall Stability recommended for subgrades is 500 pounds. If a soil does not show increased stability when reasonable amounts of bituminous materials are added, the gradation of the soil should be modified or another type of bituminous material should be used. Poorly graded materials may be improved by the addition of suitable fines containing considerable material passing the No. 200 sieve. The amount of bitumen required for a given soil increases with an increase in percentage of the finer sizes.

Table 6-3. Emulsified Asphalt Requirements

Percent Passing No. 200 Sieve	Pounds of Emulsified Asphalt per 100 Pounds of Dry Aggregate at Percent Passing No. 10 Sieve					
	50	60	70	80	90	100
0	6.0	6.3	6.5	6.7	7.0	7.2
2	6.3	6.5	6.7	7.0	7.2	7.5
4	6.5	6.7	7.0	7.2	7.5	7.7
6	6.7	7.0	7.2	7.5	7.7	7.9
8	7.0	7.2	7.5	7.7	7.9	8.2
10	7.2	7.5	7.7	7.9	8.2	8.4
12	7.5	7.7	7.9	8.2	8.4	8.6
14	7.2	7.5	7.7	7.9	8.2	8.4
16	7.0	7.2	7.5	7.7	7.9	8.2
18	6.7	7.0	7.2	7.5	7.7	7.9
20	6.5	6.7	7.0	7.2	7.5	7.7
22	6.3	6.5	6.7	7.0	7.2	7.5
24	6.0	6.3	6.5	6.7	7.0	7.2
25	6.2	6.4	6.6	6.9	7.1	7.3

U.S. Army Corps of Engineers

APPENDIX A

PH TEST TO DETERMINE LIME REQUIREMENTS FOR LIME STABILIZATION

A-1. Materials. Lime to be used for soil stabilization.

A-2. Apparatus.

a. PH meter (the pH meter must be equipped with an electrode having a pH range of 14).

b. 150-millilitre (or larger) plastic bottles with screw-top lids.

c. 50-millilitre plastic beakers.

d. Distilled water that is free of CO_2.

e. Balance.

f. Oven.

g. Moisture cans.

A-3. Procedure.

a. Standardize the pH meter with a buffer solution having a pH of 12.45.

b. Weigh to the nearest 0.01 gram representative samples of air-dried soil, passing the No. 40 sieve and equal to 20.0 grams of oven-dried soil.

c. Pour the soil samples into 150-millilitre plastic bottles with screw-top lids.

d. Add varying percentages of lime, weighted to the nearest 0.01 gram, to the soils. (Lime percentages of 0, 2, 3, 4, 5, 6, 8, and 10, based on the dry soil weight, may be used.)

e. Thoroughly mix soil and dry lime.

f. Add 100 millilitres of distilled water that is CO_2-free to the soil-lime mixtures.

g. Shake the soil-lime and water for a minimum of 30 seconds or until there is no evidence of dry material on the bottom of the bottle.

h. Shake the bottles for 30 seconds every 10 minutes.

i. After 1 hour, transfer part of the slurry to a plastic beaker and measure the pH.

j. Record the pH for each of the soil-lime mixtures. The lowest percent of lime giving a pH of 12.40 is the percent required to stabilize the soil. If the pH does not reach 12.40, the minimum lime content giving the highest pH is required to stabilize the soil.

APPENDIX B

REFERENCES

Government Publications.

Department of Defense.

MIL-STD-619B	Unified Soil Classification System for Roads, Airfields, Embankments and Foundations.
MIL-STD-620A & Notice 1	Test Methods for Bituminous Paving Materials.
MIL-STD-621A & Notice 1,2	Test Method for Pavement Subgrade, Subbase, and Base Course Materials.

Department of the Army.

EM 1110-3-131	Flexible Pavements for Roads, Streets, Walks, and Open-Storage Areas.
EM 1110-3-132	Rigid Pavements for Roads, Streets, Walks, and Open-Storage Areas.
EM 1110-3-138	Pavement Criteria for Seasonal Frost Conditions.
EM 1110-3-141	Airfield Flexible Pavement.
EM 1110-3-142	Airfield Rigid Pavement.

Nongovernment Publications.

American Society for Testing and Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103

C 593-76a	Fly Ash and Other Pozzolans for Use with Lime.
D 422-63 (R 1972)	Particle-Size Analysis of Soils.

D 423-66 (R 1972)	Liquid Limit of Soils.
D 424-59 (R 1971)	Plastic Limit and Plasticity Index of Soils.
D 558-57 (R 1976)	Moisture-Density Relations of Soil-Cement Mixtures.
D 559-57 (R 1976)	Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures.
D 560-57 (R 1976)	Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures.
D 1632-63 (R 1979)	Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory.
D 1633-63 (R 1979)	Compressive Strength of Molded Soil-Cement Cylinders.