UFC 3-250-11
16 January 2004

UNIFIED FACILITIES CRITERIA (UFC)

SOIL STABILIZATION FOR PAVEMENTS

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UNIFIED FACILITIES CRITERIA (UFC)

SOIL STABILIZATION FOR PAVEMENTS

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TM 5-822-14, dated 25 October 1994. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TM 5-822-14, dated 25 October 1994.

FOREWORD

\1\
The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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AUTHORIZED BY:

DONALD L. BASHAM, P.E.
Chief, Engineering and Construction
U.S. Army Corps of Engineers

DR. JAMES W WRIGHT, P.E.
Chief Engineer
Naval Facilities Engineering Command

KATHLEEN I. FERGUSON, P.E.
The Deputy Civil Engineer
DCS/Installations & Logistics
Department of the Air Force

Dr. GET W. MOY, P.E.
Director, Installations Requirements and Management
Office of the Deputy Under Secretary of Defense (Installations and Environment)

SOIL STABILIZATION FOR PAVEMENTS

DEPARTMENT OF THE ARMY, THE NAVY, AND THE AIR FORCE
OCTOBER 1994

TECHNICAL MANUAL
NO. 5-822-14
AIR FORCE MANUAL
NO. 32-1019

HEADQUARTERS
DEPARTMENTS OF THE ARMY,
AND THE AIR FORCE
WASHINGTON, DC, *25 October 1994*

SOIL STABILIZATION FOR PAVEMENTS

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CHAPTER 1

INTRODUCTION

1-1. Purpose. This manual establishes criteria for improving the engineering properties of soils used for pavement base courses, subbase courses, and subgrades by the use of additives which are mixed into the soil to effect the desired improvement. These criteria are also applicable to roads and airfields having a stabilized surface layer.

1-2. Scope. This manual prescribes the appropriate type or types of additive to be used with different soil types, procedures for determining a design treatment level for each type of additive, and recommended construction practices for incorporating the additive into the soil. It applies to all elements responsible for Army and Air Force pavement and design construction.

1-3. References. Appendix A contains a list of references used in this manual.

1-4. Definitions.

a. Soils. Naturally occurring materials that are used for the construction of all except the surface layers of pavements (i.e., concrete and asphalt) and that are subject to classification tests (ASTM D 2487) to provide a general concept of their engineering characteristics.

b. Additives. Manufactured commercial products that, when added to the soil in the proper quantities, improve some engineering characteristics of the soil such as strength, texture, workability, and plasticity. Additives addressed in this manual are limited to portland cement, lime, flyash, and bitumen.

c. Stabilization. Stabilization is the process of blending and mixing materials with a soil to improve certain 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, texture or plasticity, or act as a binder for cementation of the soil.

d. 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, a central plant, or a borrow area. The blended material is then spread and compacted to required densities by conventional means.

e. Additive stabilization. Additive stabilization is achieved by the addition of proper percentages of cement, lime, fly ash, bitumen, or combinations of these materials to the soil. The selection of type and determination of the percentage of additive to be used 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 modify soil properties such as gradation, workability, and plasticity. When it is desired to improve the strength and durability significantly, larger quantities of additive are used. After the additive has been mixed with the soil, spreading and compaction are achieved by conventional means.

f. 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.

1-5. Uses of Stabilization. Pavement design is based on the premise that minimum specified structural quality will be achieved for each layer of material in the pavement system. Each layer must resist shearing, avoid excessive deflections that cause 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 so that a reduction in the required thickness of the soil and surface layers may be permitted.

a. Quality improvement. The most common improvements achieved through stabilization include better soil gradation, reduction of plasticity index or swelling potential, and increases in durability and strength. In wet weather, stabilization may also be used to provide a working platform for construction operations. These types of soil quality improvement are referred to as soil modification.

b. Thickness reduction. The strength and stiffness of a soil layer can be improved through the use of additives to permit a reduction in design thickness of the stabilized material compared with an unstabilized or unbound material. Procedures for designing pavements that include stabilized soils are presented in TM 5-822-5/AFM 88-7, Chap. 3, TM 5-825-2/AFM 88-6, Chap. 2, TM

5-825-3/AFM 88-6, Chap. 3. The design thickness of a base or subbase course can be reduced if the stabilized material meets the specified gradation, strength, stability, and durability requirements indicated in this Technical Manual for the particular type of material.

CHAPTER 2

SELECTION OF ADDITIVE

2-1. Factors to be Considered. In the selection of a stabilizer, 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 improvement desired, the required strength and durability of the stabilized layer, and the cost and environmental conditions.

a. Soil types and additives. There may be more than one candidate stabilizer applicable for one soil type, however, there are some general guidelines that make specific stabilizers more desirable based on soil granularity, plasticity, or texture. Portland cement for example is used with a variety of soil types; however, since it is imperative that the cement be mixed intimately with the fines fraction (< .074 mm), the more plastic materials should be avoided. Generally, well-graded granular materials that possess sufficient fines to produce a floating aggregate matrix (homogenous mixture) and best suited for portland cement stabilization. Lime will react with soils of medium to high plasticity to produce decreased plasticity, increased workability, reduced swell, and increased strength. Lime is used to stabilize a variety of materials including weak subgrade soils, transforming them into a “working table” or subbase; and with marginal granular base materials, i.e., clay-gravels, “dirty” gravels, to form a strong, high quality base course. Fly ash is a pozzolanic material, i.e. it reacts with lime and is therefore almost always used in combination with lime in soils that have little or no plastic fines. It has often been found desirable to use a small amount of portland cement with lime and fly ash for added strength. This combination of lime-cement-flyash (LCF) has been used successfully in base course stabilization. Asphalt or bituminous materials both are used for waterproofing and for strength gain. Generally, soils suitable for asphalt stabilization are the silty sandy and granular materials since it is desired to thoroughly coat all the soil particles.

b. Selection of candidate additives. The selection of candidate/stabilizers is made using figure 2-1 and table 2-1. The soil gradation triangle in figure 2-1 is based upon the soil grain size characteristics and the triangle is divided into areas of soils with similar grain size and therefore pulverization characteristics. The selection process is continued with table 2-1 which indicates for each area shown in figure 2-1 candidate stabilizers and restrictions based on grain size and/or plasticity index (PI). Also provided in the second column of table 2-1 is a listing of soil classification symbols applicable to the area determined from figure 2-1. This is an added check to insure that the proper area was selected. Thus, information on grain size distribution and Atterberg limits must be known to initiate the selection process. Data required to enter figure 2-1 are: percent material passing the No. 200 sieve and percent material passing the No. 4 sieve but retained on the No. 200 (i.e., total percent material between the No. 4 and the No. 200 sieves). The triangle is entered with these two values and the applicable area (1A, 2A, 3, etc.) is found at their intersection. The area determined from figure 2-1 is then found in the first column of table 2-1 and the soil classification is checked in the second column. Candidate stabilizers for each area are indicated in third column and restrictions for the use of each material are presented in the following columns. These restrictions are used to prevent use of stabilizing agents not applicable for the particular soil type under consideration. For example, assume a soil classified as a SC, with 93 percent passing the No. 4 and 25 percent passing the No. 200 with a liquid limit of 20 and plastic limit of 11. Thus 68 percent of the material is between the No. 4 and No. 200 and the plasticity index is 9. Entering figure 2-1 with the values of 25 percent passing the No. 200 and 68 percent between the No. 4 and No. 200, the intersection of these values is found in area 1-C. Then going to the first column of table 2-1, we find area 1-C and verify the soil classification, SC, in the second column. From the third column all four stabilizing materials are found to be potential candidates. The restrictions in the following columns are now examined. Bituminous stabilization is acceptable since the PI does not exceed 10 and the amount of material passing the No. 200 does not exceed 30 percent. However it should be noted that the soil only barely qualifies under these criteria and bituminous stabilization probably would not be the first choice. The restrictions under portland cement indicate that the PI must be less that the equation indicated in footnote b. Since the PI, 9, is less than that value, portland cement would be a candidate material. The restrictions under lime indicate that the PI not be less than 12 therefore lime is not a candidate material for stabilization, The restrictions under LCF stabi-

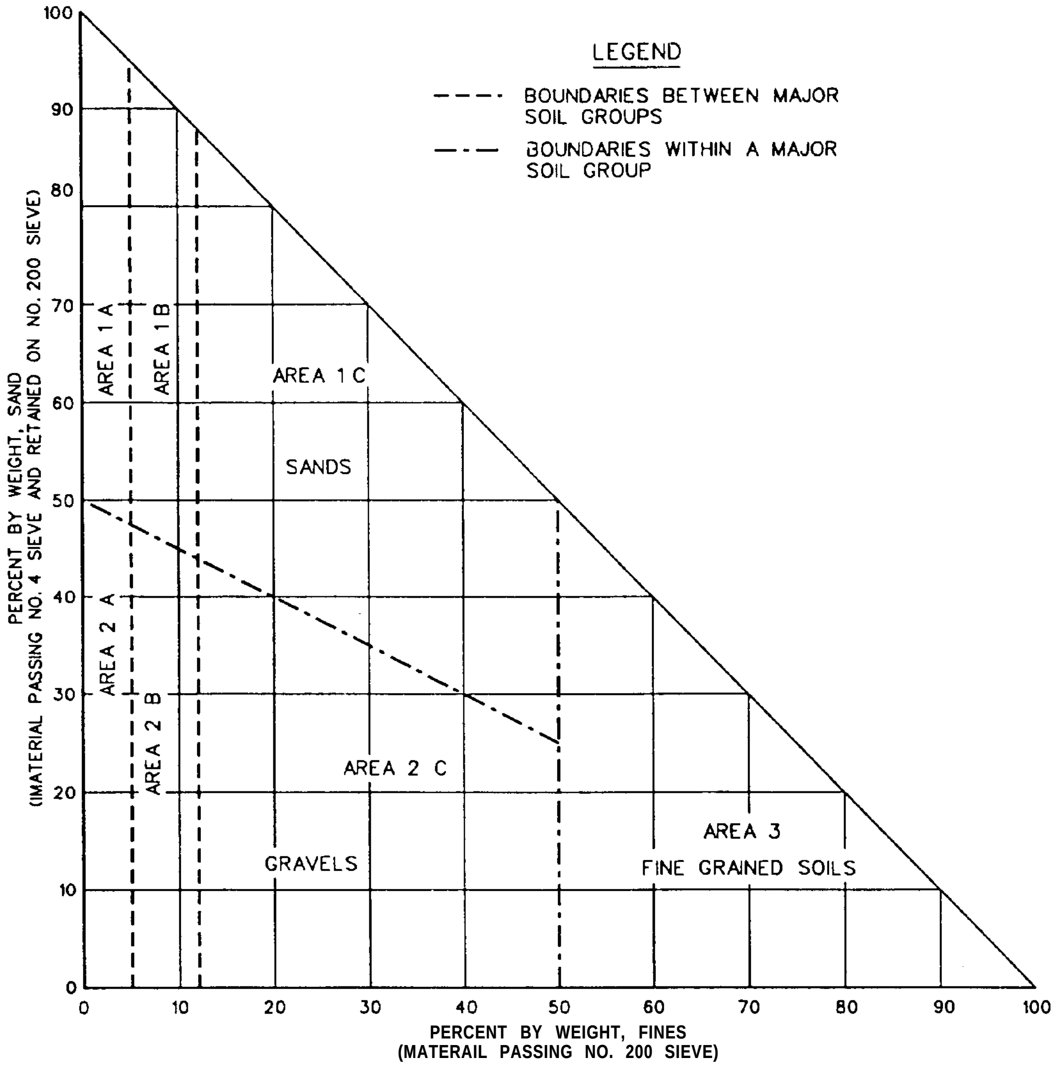


Figure 2-1. Gradation triangle for aid in selecting a commercial stabilizing agent.

lization indicate that the PI must not exceed 25, thus LCF is also a candidate stabilizing material. At this point, the designer must make the final selection based on other factors such as availability of material, economics, etc. Once the type of stabilizing agent to be used is determined, samples must be prepared and tested in the laboratory to develop a design mix meeting minimum engineering criteria for field stabilization.

2-2. Use of stabilized soils in Frost Areas.

a. Frost considerations. While bituminous, portland cement, lime, and LCF stabilization are the most common additives other stabilizers may be used for pavement construction in areas of frost design but only with approval obtained from the HQUSACE (CEMP-ET), Washington, DC 20314-1000 or the appropriate Air Force Major Command.

b. Limitations. In frost areas, stabilized soil is only used in one of the upper elements of a pavement system if cost is justified by the reduced pavement thickness. Treatment with a lower degree of additive than that indicated for stabilization (i.e., soil modification) 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 has firmly cemented material. A possible exception is modification of 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 should also be tested to ascertain that the desired improvement is dura-

Table 2-1. Guide for selecting a stabilizing additive.

Area	Soil 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 to exceed 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% 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% 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% 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% by weight	Well-graded material only
		(2) Portland cement	--[b]		Material should contain at least 45% 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	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-619B. Restriction on liquid (LL) and plasticity index (PI) is in accordance with Method 103 in MIL-STD-621A.

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

ble through repeated freeze-thaw cycles. The improvement should not be achieved at the expense of making the soil more susceptible to ice segregation.

c. Construction cutoff dates. Materials stabilized with cement, lime, or LCF should be constructed early enough during the construction 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 Fahrenheit than at 70 or 80 degrees Fahrenheit. Chemical reactions will not occur rapidly for lime-stabilized soils when the soil temperature is less than 60 degrees Fahrenheit and is not expected to increase for one month, or cement-stabilized soils when the soil temperature is less than 40 degrees Fahrenheit and is not expected to increase for one 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 (e.g. 30 days) may be essential.

2-3. Thickness Reduction for Base and Subbase Courses. Stabilized base and subbase course materials must meet certain requirements of gradation, strength, and durability to qualify for reduced layer thickness design. Gradation requirements are presented in the sections covering design with each type of stabilizer. Unconfined compressive strength and durability requirements for bases and subbases treated with cement, lime, LF, and LCF are indicated in tables 2-2 and 2-3, respectively. For bituminous stabilized materials to qualify for reduced thickness, they must meet strength requirements in TM 5-825-21 AFM 88-6, Chap. 2. All stabilized materials except those treated with bitumen must meet minimum durability criteria to be used in pavement structures. There are no durability criteria for bituminous stabilized materials since it is assumed that they will be sufficiently waterproof if properly designed and constructed.

Table 2-2. Minimum unconfined compressive strength for cement, lime, lime-cement, and lime-cement-fly ash stabilized soils

	Minimum Unconfined Compressive strength, psi[a]	
Stabilized Soil Layer	*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 28 days for lime, lime fly ash, or lime-cement-fly ash stabilization.

Table 2-3. Durability requirements

Type of Soil Stabilized	*Maximum Allowable Weight Loss After 12 Wet-Dry or Freeze-Thaw Cycles Percent of Initial Specimen Weight*
Granular, PI < 10	11
Granular, PI > 210	8
Silt	8
Clays	6

CHAPTER 3

DETERMINATION OF STABILIZER CONTENT

3-1. Stabilization with Portland Cement. Portland cement can be used either to modify and improve the quality of the soil or to transform the soil into a cemented mass with increased strength and durability. The amount of cement used will depend upon whether the soil is to be modified or stabilized.

a. Types of portland cement. Several different types of cement have been used successfully for stabilization of soils. Type I normal portland cement and Type IA air-entraining cements were used extensively in the past and gave about the same results. At the present time, Type II cement has largely replaced Type I cement as greater sulfate resistance is obtained while the cost is often the same. High early strength cement (Type III) has been found to give a higher strength in some soils. Type III cement has a finer particle size and a different compound composition than do the other cement types. Chemical and physical property specifications for portland cement can be found in ASTM C 150.

b. Screening tests for organic matter and sulfates. The presence of organic matter and/or sulfates may have a deleterious effect on soil cement. Tests are available for detection of these materials and should be conducted if their presence is suspected.

(1) *Organic matter.* A soil may be acid, neutral, or alkaline and still respond well to cement treatment. Although certain types of organic matter, such as undecomposed vegetation, may not influence stabilization adversely, organic compounds of lower molecular weight, such as nucleic acid and dextrose, act as hydration retarders and reduce strength. When such organics are present they inhibit the normal hardening process. A pH test to determine the presence of organic material is presented in appendix B. If the pH of a 10:1 mixture (by weight) of soil and cement 15 minutes after mixing is at least 12.0, it is probable that any organics present will not interfere with normal hardening.

(2) *Sulfates.* Although sulfate attack is known to have an adverse effect on the quality of hardened portland cement concrete, less is known about the sulfate resistance of cement stabilized soils. The resistance to sulfate attack differs for cement-treated coarse-grained and fine-grained soils and is a function of sulfate concentrations. Sulfate-clay reactions can cause deterioration of fine-grained soil-cement. On the other hand, granular soil-cements do not appear susceptible to sulfate attack. In some cases the presence of small amounts of sulfate in the soil at the time of mixing with the cement may even be beneficial. The use of sulfate-resistant cement may not improve the resistance of clay-bearing soils, but may be effective in granular soil-cements exposed to adjacent soils and/or ground water containing high sulfate concentrations. A procedure for determining the percent SO_4 is presented in appendix C. The use of cement for fine-grained soils containing more than about 1 percent sulfate should be avoided.

c. Water for hydration. Potable water is normally used for cement stabilization, although sea water has been found to be satisfactory.

d. Gradation requirements. Gradation requirements for cement stabilized base and subbase courses are indicated in table 3-1.

e. Cement content for modification of soils.

(1) *Improve plasticity.* 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

Table 3-1. Gradation requirements for cement stabilized base and subbase courses

Type Course	*Sieve Size*	*Percent Passing*
Base	1½ in.	100
	¾ in.	70-100
	No. 4	45-70
	No. 40	10-40
	No. 200	0-20
Subbase	1½ in.	100
	No. 4	45-100
	No. 40	10-50
	No. 200	0-20

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

$$A = 100BC \quad \textbf{(eq 3-1)}$$

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

(2) *Improve gradation.* If the objective of modification is to improve the gradation of a granular soil through the addition of fines then particle-size analysis (ASTM D 422) should be conducted on samples at various treatment levels to determine the minimum acceptable cement content.

(3) *Reduce swell potential.* Small amounts of portland cements may reduce swell potential of some swelling soils. However, portland cement generally is not as effective as lime and may be considered too expensive for this application. The determination of cement content to reduce the swell potential of fine-g-rained 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 is the design cement content. Procedures for measuring swell characteristics of soils are found in MIL-STD-621A, 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.

(4) *Frost areas.* Cement-modified soil may also be used in frost areas, but in addition to the procedures for mixture design described in (1) and (2) above, cured specimens should be subjected to the 12 freeze-thaw cycles prescribed by ASTM D 560 (but omitting wire-brushing) or other applicable freeze-thaw procedures. This should be followed by determination of frost design soil classification by means of standard laboratory freezing tests. If cement-modified soil is used as subgrade, its frost-susceptibility, determined after freeze-thaw cycling, should be used as the basis of the pavement thickness design if the reduced subgrade design method is applied.

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

(1) *Step 1.* Determine the classification and gradation of the untreated soil following procedures in ASTM D 422 and D 2487, respectively.

(2) *Step 2.* Using the soil classification select an estimated cement content for moisture-density tests from table 3-2.

Table 3-2. Cement requirements for various soils

Soil *Classification*	*Initial Estimated Cement Content percent dry weight*
GW, SW	5
GP, GW-GC, GW-GM, SW-SC, SW-SM	6
GC, GM, GP-GC, GP-GM, GM-GC, SC, SM, SP-SC, SP-SM, SM-SC, SP	7
CL. ML, MH	9
CH	11

(3) *Step 3.* Using the estimated cement content, conduct moisture-density tests to determine the maximum dry density and optimum water content 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 procedures outlined in MIL-STD 621, Method 100 (CE 55 effort), or ASTM D 1557 will be used to conduct the moisture density test.

(4) *Step 4.* Prepare triplicate samples of the soil-cement mixture for unconfined compression and durability tests at the cement content selected in step 2 and at cement contents 2 percent above and 2 percent below that determined in step 2. The samples should be prepared at the density and water content to be expected in field construction. For example, if the design density is 95 percent of the laboratory maximum density, the samples should also be prepared at 95 percent. 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 &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) or freeze-thaw (ASTM D 560) tests as appropriate. The frost susceptibility of the

treated material should also be determined as indicated in appropriate pavement design manuals.

(5) *Step 5.* Compare the results of the unconfined compressive strength and durability tests with the requirements shown in tables 2-2 and 2-3. 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. If the results of the specimens tested do not meet both the strength and durability requirements, then a higher cement content may be selected and steps 1 through 4 above repeated.

3-2. Stabilization with lime. In general, all lime treated finegrained soils exhibit decreased plasticity, improved workability and reduced volume change characteristics. However, not all soils exhibit improved strength characteristics. It should be emphasized that the properties of soil-lime mixtures are dependent on many variables. Soil type, lime type, lime percentage and curing conditions (time, temperature, moisture) are the most important.

a. Types of lime. Various forms of lime have been successfully used as soil stabilizing agents for many years. However, the most commonly used products are hydrated high-calcium lime, monohydrated dolomitic lime, calcitic quicklime, and dolomitic quicklime. Hydrated lime is used most often because it is much less caustic than quicklime, however, the use of quicklime for soil stabilization has increased in recent years mainly with slurry-type applications. The design lime contents determined from the criteria presented herein are for hydrated lime. If quicklime is used the design lime contents determined herein for hydrated lime should be reduced by 25 percent. Specifications for quicklime and hydrated lime may be found in ASTM C 977.

b. Gradation requirements. Gradation requirements for lime stabilized base and subbase courses are presented in table 3-3.

c. 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.

d. Lime content for lime-stabilized soils. The following procedures are recommended for determining the lime content of lime stabilized soils.

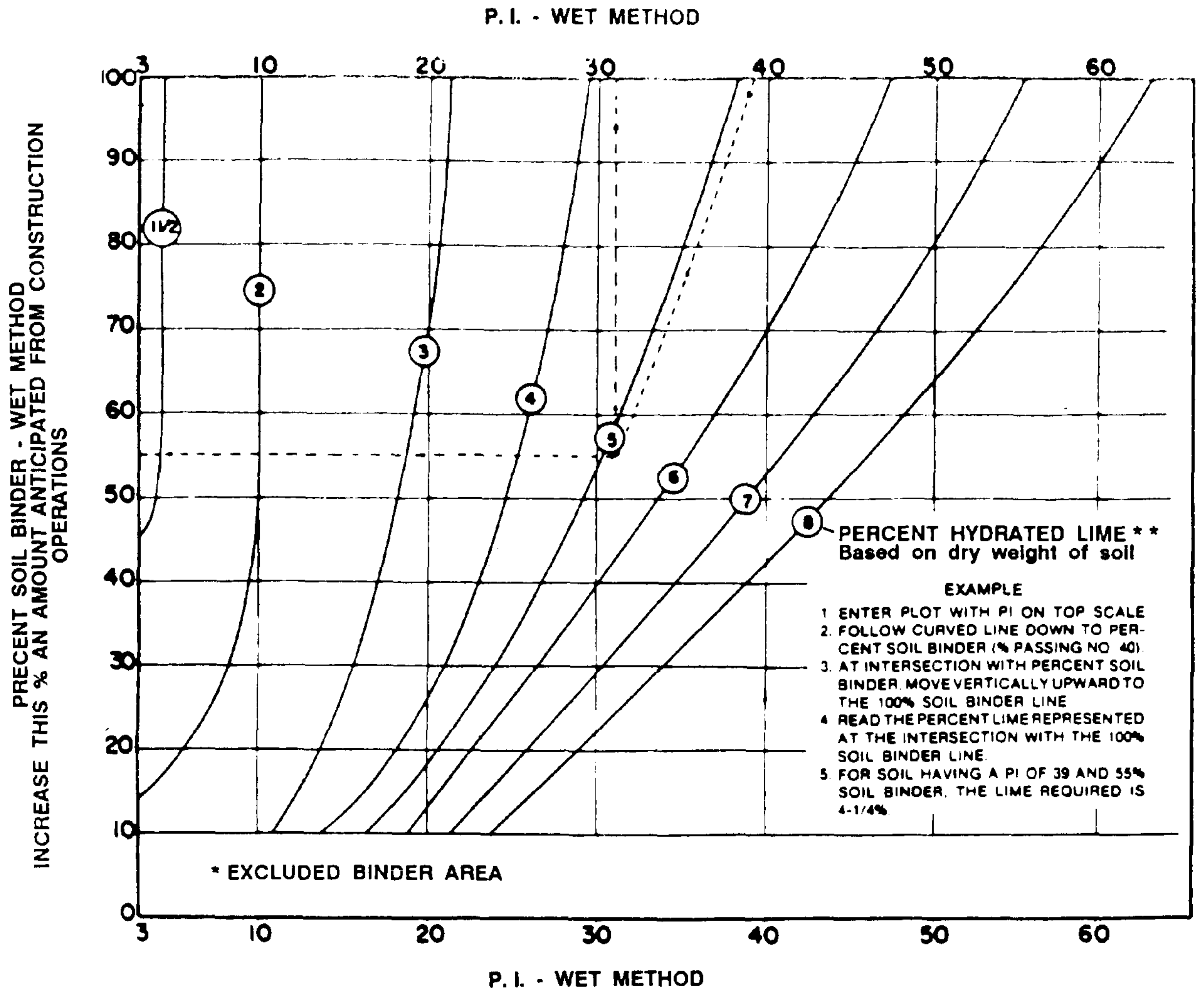
(1) *Step 1.* The preferred method for determining an initial design lime content is the pH test. In this method several lime-soil slurries are prepared at different lime treatment levels such as 2, 4, 6, and 8 percent lime and the pH of each slurry is determined. The lowest lime content at which a pH of about 12.4 (the pH of free lime) is obtained is the initial design lime content. Procedures for conducting the pH test are indicated in appendix D. An alternate method of determining an initial design lime content is by the use of figure 3-1. Specific values required to use figure 3-1 are the PI and the percent of material passing the No. 40 sieve.

Table 3-3. Gradation requirements for lime stabilized base and subbase courses

Type Course	*Sieve* Size	*Percent Passing*
Base	1½ in.	100
	¾ in.	70-100
	No. 4	45-70
	No. 40	10-40
	No. 200	0-20
Subbase	1½ in.	100
	No. 4	45-100
	No. 40	10-50
	No. 200	0-20

(2) *Step 2.* Using the initial design lime content conduct moisture-density tests to determine the maximum dry density and optimum water content of the soil lime mixture. The procedures contained in ASTM D 3551 will be used to prepare the soil-lime mixture. The moisture density test will be conducted following procedures in MIL-STD 621 Method 100 (CE 55 effort) or ASTM D 1557.

(3) *Step 3.* Prepare triplicate samples of the soil lime mixture for unconfined compression and durability tests at the initial design lime content and at lime contents 2 and 4 percent above design if based on the preferred method or 2 percent above at 2 percent below design if based on the alternate method. The mixture should he prepared as indicated in ASTM D 3551. If less than 35 percent of the soil is retained on the No. 4 sieve, the sample should be approximately 2 inches in diameter and 4 inches high. If more than 35 percent is retained on the No. 4 sieve, samples should be 4 inches in diameter and 8 inches high. The samples should be prepared at the density and water content expected in field construction. For example, if the design density is 95 percent of the laboratory maximum density, the sample should be prepared at 95 percent density. Specimens should be cured in a sealed container to prevent moisture loss and lime carbonation. Sealed metal cans, plastic bags, and so forth are satisfactory. The preferred method of curing is 73 degrees F for 28 days. Accelerated



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

** Percent of relatively pure lime usually 90% or more of Ca and/or Mg hydroxides and 85% 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 termes as "Lasting Effects" and "Temporary Resulst" are used.

Figure 3-1. Chart for the initial determination of lime content.

curing at 120 degrees F for 48 hours has also been found to give satisfactory results; however, check tests at 73 degrees for 28 days should also be conducted. Research has indicated that if accelerated curing temperatures are too high, the pozzolanic compounds formed during laboratory curing could differ substantially from those that would develop in the field.

(4) *Step 4.* Test three specimens using the unconfined compression test. If frost design is a consideration, test three specimens to 12 cycles of freeze-thaw durability tests (ASTM D 560) except wire brushing is omitted. The frost susceptibility of the treated material should be determined as indicated in appropriate design manuals.

(5) *Step 5.* Compare the results of the unconfined compressive strength and durability tests with the requirements shown in tables 2-2 and 2-3. The lowest lime content which meets the unconfined compressive strength requirement and demonstrates the required durability is the design lime content. The treated material also must meet frost susceptibility requirements as indicated in the appropriate pavement design manuals. If the mixture should meet the durability requirements but not the strength requirements, it is considered to be a modified soil. If results of the specimens tested do not meet both the strength and durability requirements, a higher lime content may be selected and steps 1 through 5 repeated.

3-3. Stabilization with Lime-Fly Ash (LF) and Lime-Cement-Fly Ash (LCF). Stabilization of coarse-grained soils having little or no tines can often be accomplished by the use of LF or LCF combinations. Fly ash, also termed coal ash, is a mineral residual from the combustion of pulverized coal. It contains silicon and aluminum compounds that, when mixed with lime and water, forms a hardened cementitious mass capable of obtaining high compressive strengths. Lime and fly ash in combination can often be used successfully in stabilizing granular materials since the fly ash provides an agent, with which the lime can react. Thus LF or LCF stabilization is often appropriate for base and subbase course materials.

a. Types of fly ash. Fly ash is classified according to the type of coal from which the ash was derived. Class C fly ash is derived from the burning of lignite or subbituminous coal and is often referred to as “high lime” ash because it contains a high percentage of lime. Class C fly ash is self-reactive or cementitious in the presence of water, in addition to being pozzolanic. Class F fly ash is derived from the burning of anthracite or bituminous coal and is sometimes referred to as “low lime” ash. It requires the addition of lime to form a pozzolanic reaction.

b. Evaluation of fly-ash. To be acceptable quality fly ash used for stabilization must meet the requirements indicated in ASTM C 593.

c. Gradation requirements. Gradation requirements for LF and LCF stabilized base and subbase course are indicated in table 3-4.

Table 3-4. Gradation requirements for fly ash stabilized base and subbase courses

Type Course	*Sieve Size*	*Percent Passing*
Base	2 in.	100
	¾ in.	70-100
	3/8 in.	50-80
	No. 4	35-70
	No. 8	25-55
	No. 16	10-45
	No. 200	0-15
Subbase	1½ in.	100
	No. 4	45-100
	No. 40	10-50
	No. 200	0-15

d. Selection of lime-fly ash content for LF and LCF mixtures. Design with LF is somewhat different from stabilization with lime or cement. For a given combination of materials (aggregate, fly ash, and lime), a number of factors can be varied in the mix design process such as percentage of lime-fly ash, the moisture content, and the ratio of lime to fly ash. It is generally recognized that engineering characteristics such as strength and durability are directly related to the quality of the matrix material. The matrix material is that part consisting of fly ash, lime, and minus No. 4 aggregate fines. Basically, higher strength and improved durability are achievable when the matrix material is able to “float” the coarse aggregate particles. In effect, the fine size particles overfill the void spaces between the coarse aggregate particles. For each coarse aggregate material, there is a quantity of matrix required to effectively fill the available void spaces and to “float” the coarse aggregate particles. The quantity of matrix required for maximum dry density of the total mixture is referred to as the optimum fines content. In LF mixtures it is recommended that the quantity of matrix be approximately 2 percent above the optimum fines content. At the recommended fines content, the strength development is also influenced by the ratio of lime to fly ash. Adjustment of the lime-fly ash ratio will yield different values of strength and durability properties.

(1) *Step 1.* The first step is to determine the optimum fines content that will give the maximum density. This is done by conducting a series of moisture-density tests using different percentages of fly ash and determining the mix level that yields maximum density. The initial fly ash content should be about 10 percent based on dry weight of the mix. It is recommended that material larger than ¾ in. be removed and the test conducted on the minus ¾ in. fraction. Tests are run at increasing increments of fly ash, e.g. 2 percent, up to a total of about 20 percent. Moisture density tests should be conducted following procedures indicated in MIL-STD 621, Method 100 (CE 55 effort) and ASTM D 1557. The design fly ash content is then selected at 2 percent above that yielding maximum density. An alternate method is to estimate optimum water content and conduct single point compaction tests at fly ash contents of 10-20 percent, make a plot of dry density versus fly ash content and determine the fly ash content that yields maximum density. The design fly ash content is 2 percent above this value. A moisture density test is then conducted to determine the optimum water content and maximum dry density.

(2) *Step 2.* Determine the ratio of lime to fly ash that will yield highest strength and durability. Using the design fly ash content and the optimum water content determined in step 1, prepare triplicate specimens at three different lime-fly ash ratios following procedures indicated in MIL-STD 621 Method 100 (less effort) or ASTM D 1557. Use LF ratios of 1:3, 1:4, and 1:5. If desired about 1

percent of portland cement may be added at this time.

(3) *Step 3.* Test three specimens using the unconfined compression test. If frost design is a consideration, subject three specimens to 12 cycles of freeze-thaw durability tests (ASTM D 560) except wire brushing is omitted. The frost susceptibility of the treated material shall also be determined as indicated in appropriate design manual.

(4) Compare the results of the unconfined compressive strength and durability tests with the requirements shown in tables 2-2 and 2-3. The lowest LF ratio content, i.e., ratio with the lowest lime content which meets the required unconfined compressive strength requirement and demonstrates the required durability, is the design LF content. The treated material must also meet frost susceptibility requirements as indicated in the appropriate pavement design manuals. If the mixture should meet the durability requirements but not the strength requirements, it is considered to be a modified soil. If the results of the specimens tested do not meet both the strength and durability requirements, a different LF content may be selected or additional portland cement used and steps 2 through 4 repeated.

e. Selection of cement content for LCF mixtures. Portland cement may also be used in combination with LF for improved strength and durability. If it is desired to incorporate cement into the mixture, the same procedures indicated for LF design should be followed except that, beginning at step 2, the cement shall be included. Generally, about 1 to 2 percent cement is used. Cement may be used in place of or in addition to lime however, the total tines content should be maintained. Strength and durability tests must be conducted on samples at various LCF ratios to determine the combination that gives best results.

3-4. Stabilization with Bitumen. Stabilization of soils and aggregates with asphalt differs greatly from cement and lime stabilization. The basic mechanism involved in asphalt stabilization of fine-grained soils is a waterproofing phenomenon. Soil particles or soil agglomerates are coated with asphalt that prevents or slows the penetration of water which could normally result in a decrease in soil strength. In addition, asphalt stabilization can improve durability characteristics by making the soil resistant to the detrimental effects of water such as volume. In noncohesive materials, such as sands and gravel, crushed gravel, and crushed stone, two basic mechanisms are active: waterproofing and adhesion. The asphalt coating on the cohesionless materials provides a membrane which prevents or hinders the penetration of water and thereby reduces the tendency of the material to lose strength in the presence of water. The second mechanism has been identified as adhesion. The aggregate particles adhere to the asphalt and the asphalt acts as a binder or cement. The cementing effect thus increases shear strength by increasing cohesion. Criteria for design of bituminous stabilized soils and aggregates are based almost entirely on stability and gradation requirements. Freeze-thaw and wet-dry durability tests are not applicable for asphalt stabilized mixtures.

a. Types of bituminous stabilized soils.

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

(2) *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.

(3) *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 material that have a high PI, i.e. above 10.

b. 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, method of construction, and weather conditions. In frost areas, the use of tar as a binder should be avoided because of its high-temperature susceptibility. 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, 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:

(1) Open-graded aggregate.

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

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

(2) Well-graded aggregate with little or no material passing the No. 200 sieve.

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

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

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

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

(a) Medium-curing liquid asphalt MC-250 and MC-800.

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

(c) Slow-setting asphalt emulsions SS-1, SS-01h, CSS-1, and CSS-lh.

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-70, SC-250, MC-70, and MC-250 are used.

c. Soil gradation. The recommended soil gradations for subgrade materials and base or subbase course materials are shown in tables 3-5 and 3-6, respectively.

Table 3-5. Recommended gradations for bituminousstabilized subgrade materials

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

Table 3-6. Recommended gradations for bituminous-stabilized base and subbase materials

Sieve Size	*1½ in. Maximum*	*1-in. Maximum*	*¾-in. Maximum*	*½-in. Maximum*
1½-in.	100	-	-	-
l-in.	84 ± 9	100	-	-
¾-in.	76 ± 9	83 ± 9	100	-
M-in.	66 ± 9	73 ± 9	82 ± 9	100
3/8-in.	59 ± 9	64 ± 9	72 ± 9	83 ± 9
No. 4	45 ± 9	48 ± 9	54 ± 9	62 ± 9
No. 8	35 ± 9	36 ± 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

d. Mix design. Guidance for the design of bituminous-stabilized base and subbase courses is contained in TM 5-822-8/AFM 88-6, Chap. 9. For subgrade stabilization, the following equation may be used for estimating the preliminary quantity of cutback asphalt to be selected:

$$p = \frac{0.02(a) + 0.07(b) + 0.15(c) + 0.20(d)}{(100 - S)} \times 100 \quad \text{(eq 3-2)}$$

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 sieve 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

S = percent solvent

The preliminary quantity of emulsified asphalt to be used in stabilizing subgrades can be determined from table 3-7. The final design content of cutback or emulsified asphalt should be selected based upon the results of the Marshal Stability test procedure (MIL-STD 620A). 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

Table 3-7. Emulsified asphalt requirements

Percent Passing No. 200 Sieve	*Pounds of Emulsified Asphalt per 100 pound 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	7.6
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

modified or another type of bituminous material should be used. Poorly graded materials may be improved by the addition of suitable tines 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 liner sizes.

3-5. Stabilization with Lime-Cement and Lime-Bitumen. The advantage in using combination stabilizers is that one of the stabilizers in the combination compensates for the lack of effectiveness of the other in treating a particular aspect or characteristics of a given soil. For instance, in clay areas devoid of base material, lime has been used jointly with other stabilizers, notably portland cement or asphalt, to provide acceptable base courses. Since portland cement or asphalt cannot be mixed successfully with plastic clays, the lime is incorporated into the soil to make it friable, thereby permitting the cement or asphalt to be adequately mixed. While such stabilization practice might be more costly than the conventional single stabilizer methods, it may still prove to be economical in areas where base aggregate costs are high. Two combination stabilizers are considered in this section: lime-cement and lime-asphalt.

a. Lime-cement. Lime can be used as an initial additive with portland cement or the primary stabilizer. The main purpose of lime is to improve workability characteristics mainly by reducing the plasticity of the soil. The design approach is to add enough lime to improve workability and to reduce the plasticity index to acceptable levels. The design lime content is the minimum that achieves desired results. The design cement content is arrived at following procedures for cement stabilized soils presented in paragraph 3-1.

b. Lime-asphalt. Lime can be used as an initial additive with asphalt as the primary stabilizer. The main purpose of lime is to improve workability characteristics and to act as an anti-stripping agent. In the latter capacity, the lime acts to neutralize acidic chemicals in the soil or aggregate which tend to interfere with bonding of the asphalt. Generally, about 1-2 percent lime is all that is needed for this objective. Since asphalt is the primary stabilizer, the procedures for asphalt stabilized materials as presented in paragraph 3-4 shall be followed.

3-6. Lime Treatment of Expansive Soils. Expansive soils as defined for pavement purposes are those that exhibit swell in excess of three percent. Expansion is characterized by heaving of a pavement or road when water is imbibed in the clay minerals. The plasticity characteristics of a soil often are a good indicator of the swell potential as indicated in table 3-8. If it has been determined that a soil has potential for excessive swell, lime treatment may be appropriate. Lime will reduce swell in an expansive soil to greater or lesser degrees depending on the activity of the clay minerals present. The amount of lime to be added is the minimum amount that will reduce swell to acceptable limits. Procedure for conducting swell tests are indicated in MIL-STD 621 Method 101 or ASTM D 1883. The depth to which lime should be incorporated into the soil is generally limited by the construction equipment used. However, 2 to 3 feet generally is the maximum depth that can be treated directly without removal of the soil.

Table 3-8. Swell potential of soils

Liquid Limit	*Plasticity Index*	*Potential Swell*
>60	>35	High
50-60	25-35	Marginal
<50	<25	Low

CHAPTER 4

CONSTRUCTION PROCEDURES

4-1. Construction with Portland Cement.

a. General construction steps. In soil-cement construction the objective is to thoroughly mix a pulverized soil material and cement in correct proportions with sufficient moisture to permit maximum compaction. Construction methods are simple and follow a definite procedure:

(1) Initial preparation

(a) Shape the area to crown and grade.

(b) If necessary, scarify, pulverize, and prewet the soil.

(c) Reshape to crown and grade.

(2) Processing

(a) Spread portland cement and mix.

(b) Apply water and mix.

(c) Compact.

(d) Finish.

(e) Cure.

b. Mixing equipment. Soil, cement, and water can be mixed in place using traveling mixing machines or mixed in a central mixing plant. The types of mixing equipment are

(1) Traveling mixing machines.

(a) Flat-transverse-shaft type:

1 Single-shaft mixer (fig 4-1).

2 Multiple-shaft mixer (fig 4-2).

(b) Windrow-type pugmill (fig 4-3).

(2) Central mixing plants.

(a) Continuous-flow-type pugmill (fig 4-4).

(b) Batch-type pugmill (fig 4-5).

(c) Rotary-drum mixers (fig 4-6).

Whatever type of mixing equipment is used, the general principles and objectives are the same. Some soil materials cannot be sufficiently pulverized and mixed in central mixing plants because of their high silt and clay content and plasticity. Almost all types of soil materials, from granular to fine grained, can be adequately pulverized and mixed with transverse-shaft mixers. The exception is material containing large amounts of highly plastic clays. These clays may require more mixing effort to obtain pulverization. Revolving-blade central mixing plants and traveling pugmills can be used for nonplastic to slightly plastic granular soils. For coarse, nonplastic granular materials, a rotary-drum mixer can provide a suitable mix; however, if the material includes a small amount of slightly plastic fines, mixing may not be adequate.

c. Equipment for handling and spreading cement. There are a number of methods of handling cement. On mixed-in-place construction using traveling mixing machines, bulk cement is spread on the area to be processed in required amounts by mechanical bulk cement spreaders (fig 4-7). Bag cement is sometimes used on small jobs. Cement spreaders for mixed-in-place construction are of two general types: those that spread cement over the soil material in a blanket (fig 4-8) and those that deposit cement on top of a partially flattened or slightly trenched windrow of soil material (fig 4-9). Cement meters on continuous-flow central mixing plants are of three types: the belt with strikeoff, screw, or vane. Cement for batch-type pugmill mixers and rotary drum-mixers is batch-weighed.

d. Construction. Construction with soil cement involves two steps-preparation and processing. Variations in these steps, dictated by the type of mixing equipment used, are discussed in this chapter. Regardless of the equipment and methods used, it is essential to have an adequately compacted, thorough mixture of pulverized soil material and other proper amounts of cement and moisture. The completed soil-cement must be adequately cured.

(1) *Preparation.* Before construction starts, crown and grade should be checked and any fine grading should be completed. Since there is little displacement of material during processing, grade at the start of construction will determine final grade to a major extent. If borrow material is to be used, the subgrade should be compacted and shaped to proper crown and grade before the borrow is placed. Any soft subgrade areas should be corrected. To avoid later costly delays, all equipment should be carefully checked to ensure it is in good operating condition and meets construction requirements of the job. Guide stakes should be set to control the width and guide the operators during construction. Arrangements should be made to receive, handle, and spread the cement and water efficiently. The number of cement and water trucks required depends on length of haul, condition of haul roads, and anticipated rate of production. For maximum production, an adequate cement and water supply is essential. The limits of the different materials and their corresponding cement requirements should be established by the project engineer. Prewetting by adding moisture before cement is applied often saves time during actual processing. Friable granular materials,

Figure 4-1. Transverse single-shaft mixer processing soil-cement in place. Multiple passes are required.

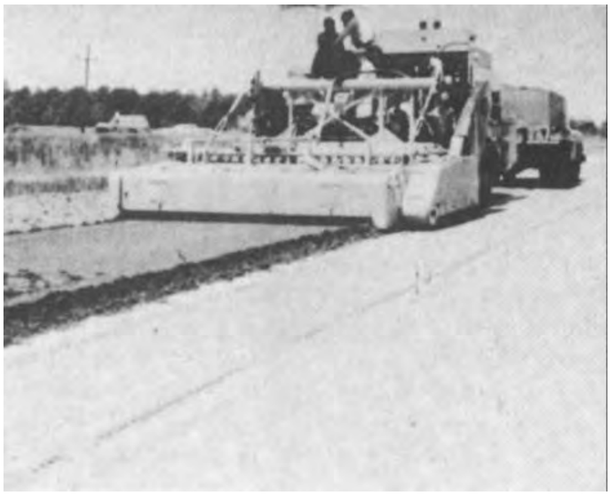


Figure 4-2. Multiple-transverseshaft mixer mixing soil, cement, *and water in one pass.*

Figure 4-3. Windrow-type traveling pugmill mixing soil-cement from windrows of soil material.

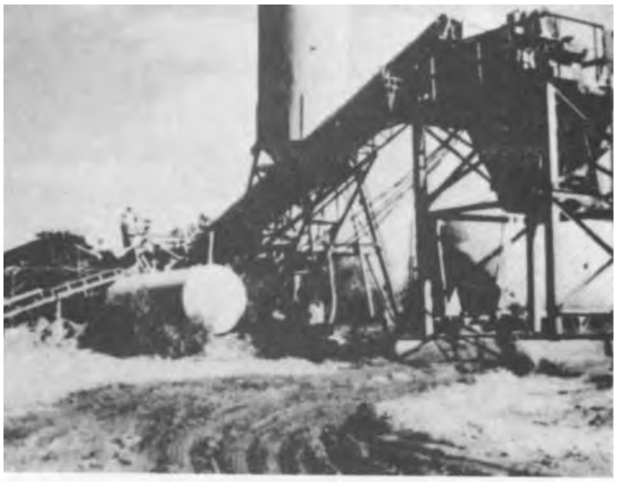


Figure 4–4. Twin-shaft, continuous-flow central mixing plant mixing soil, cement, and water.

Figure 4–5. Batch-type central plant used for mixing soil-cement.

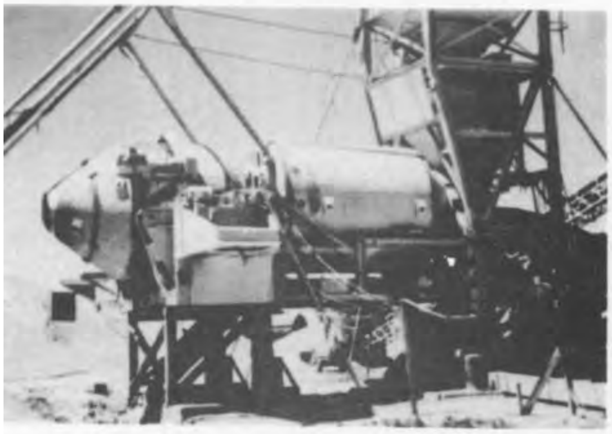


Figure 4–6. Rotary-drum central mixing plant.

Figure 4-7. Bulk portland cement being transferred pneumatically from a bulk transport truck *to a job truck.*

Figure 4-8. Mechanical cement spreader attached to a job dump truck spreading cement in regulated quantities.

Figure 4-9. Windrow-type mechanical spreader placing cement on windrow.

which are most commonly used, require little or no scarification or pulverization. Silty and clayey soils may require extra effort to pulverize them, particularly if they are too dry or too wet. Soils that are difficult to pulverize when dry and brittle can be broken down readily if water is added and allowed to soak in; whereas, sticky soils can be pulverized more easily when they have been dried out a little. Most specifications require that the soil material be pulverized sufficiently so that at the time of compaction 100 percent of the soil-cement mixture will pass a l-inch sieve and a minimum of 80 percent will pass a No. 4 sieve, exclusive of any gravel or stone. Gravel or stone should be no more than 2-inches maximum size. The final pulverization test should be made at the conclusion of mixing operations. When borrow material is specified, it should be distributed on an accurately graded, well-compacted roadway in an even layer or uniform windrow, depending on the type of mixing equipment to be used. It should be placed by weight or volume as required by the specifications.

(2) *Processing.* For maximum efficiency and to meet specification time limits, a day's work should be broken down into several adjacent sections rather than one or two long sections. This procedure will result in maximum daily production and will prevent a long stretch of construction from being rained out in case of a sudden severe rainstorm.

(a) Handling and spreading cement. Bulk cement is normally trucked to the jobsite in bulk transport trucks or shipped to the nearest railroad siding in enclosed hopper cars. Compressed air or vibrators are used to loosen the cement in the hopper cars during unloading. Transfer to cement trucks is done pneumatically or by a screen or belt conveyor. The trucks are usually enclosed or fitted with canvas covers. The cement is weighed in truckloads on portable platform scales or at a nearby scale. Soil materials that contain excessive amounts of moisture will not mix readily with cement. Sandy soils can be mixed with a moisture content at optimum or slightly above; whereas, clayey soils should have a moisture content below optimum when cement is spread. Cement should not be applied onto puddles of water. If the soil material is excessively wet, it should be aerated to dry it before cement is applied. Handling and spreading procedures for different types of equipment are presented below.

1. Mechanical cement spread, mixed-in-place construction. A mechanical cement spreader is attached to the dump truck. As the truck moves forward, cement flows through the spreader, which regulates the quantity of cement placed on the prepared soil. To obtain a uniform cement spread, the spreader should be operated at a constant, slow speed and with a constant level of cement in the hopper. A true line at the pavement edge should be maintained with a string line. The mechanical spreader must have adequate traction to produce a uniform cement spread. Traction can be aided by wetting and rolling the soil material before spreading the cement. When operating in loose sands or gravel, slippage can be overcome by the use of cleats on the spreader wheels or by other modifications; sometimes, the spreader is mounted on a tractor or high lift. The mechanical cement spreader can also be attached directly behind a bulk cement truck. Cement is then moved pneumatically from the truck through an air separator cyclone that dissipates the air pressure, and falls into the hopper of the spreader. Forward speed must be slow and even. Sometimes a motor grader or loader pulls the truck to maintain this slow, even forward speed. Pipe cement spreaders attached to cement transport trucks have been used in some areas with variable results. Improvements in this type of equipment are being made.

2. Bagged-cement spread, mixed-in-place construction. When bags of cement are used on small jobs, a simple but exact method for properly placing the bags is necessary. The bags should be spaced at approximately equal transverse and longitudinal intervals that will ensure the proper percentage of cement. Positions can be spotted by flags or markers fastened to chains at proper intervals to mark the transverse and longitudinal rows. When the bags are opened, the cement should be dumped so that it forms fairly uniform transverse windrows across the area being processed. A spike-tooth harrow, a nail drag, or a length of chain-link fence can be used to spread the cement evenly. The drag should make at least two round trips over the area to spread the cement uniformly.

3. Cement application, central-mixing-plant construction. When a continuous-flow central mixing plant is used, the cement is usually metered onto the soil aggregate and the two materials are carried to the pugmill mixer on the main feeder belt. Variations in moisture and in gradation of the soil aggregate will result in variations in the amount of material being fed onto the feeder belt. A high bulkhead placed in front of the soil hopper will help to obtain a more uniform flow through the soil material feeder. The chance of loss of cement due to wind can be minimized by the use of a small plow attachment that will form a furrow for the cement in the soil aggregate. After the cement is added, a second plow attachment a little farther up on the main feeder belt closes the furrow and covers the cement. A cover on the main feeder belt will also minimize cement loss due to wind. One of three types of cement meters-belt, screw, or vane-can be used to proportion the cement on a volumetric basis. Each requires a 450- to 750-pound capacity surge tank or hopper between the cement silo and the cement feeder. This tank maintains a constant head of cement for the feeder, thus providing a more uniform cement discharge. Compressed air of 2- to 4-pounds per square inch pressure should be used to prevent arching of cement in the silo and the surge tank. Portable vibrators attached to the surge tank can be used instead of air jets. A positive system should be included to stop the plant automatically if the cement flow suddenly stops. The correct proportion of cement, soil material, and water entering the mixing chamber must be determined by calibrating the plant before mixing and placing operations begin.

(b) Mixing and application of water. Procedures for applying water and mixing depend on the type of mixing machine used. A thorough mixture of pulverized soil material, cement, and water must be obtained. Uniformity of the mix is easily checked by digging trenches or a series of holes at regular intervals for the full depth of treatment and inspecting the color of the exposed soil-cement mixture. Uniform color and texture from top to bottom indicate a satisfactory mix; a streaked appearance indicates insufficient mixing. Proper width and depth of mixing are also important. Following are methods of applying water and mixing for the different types of mixing machines.

1. Windrow-type traveling mixing machine. Windrow-type traveling mixing machines will pulverize friable soil materials. Other soils, however, may need preliminary pulverizing to meet specification requirements. This is usually done before the soil is placed in windrows for processing. The prepared soil material is bladed into windrows and a proportion pulled along to make them uniform in cross section. When borrow materials are used, a windrow spreader can be used to proportion the material. Nonuniform windrows cause variations in cement content, moisture content, and pavement thickness. The number and size of windrows needed depend on the width and depth of treatment and on the capacity of the mixing machine. Cement is spread on top of the partially flattened or slightly trenched, prepared windrow. The mixing machine then picks up the soil material and cement and dry-mixes them with the first few paddles in the mixing drum. At that point water is added through spray nozzles and the remaining paddles complete the mixing. A strike-off attached to the mixing machine spreads the mixed soil-cement. If a motor grader is used to spread the mixture and a tamping roller is used for compaction, the mixture should first be loosened to ready it for compaction. If two windrows have been made, the mixing machine progresses 350 to 500 feet along one windrow and then is backed up to process the other windrow for 700 to 1,000 feet. The cement spreading operation is kept just ahead of the mixing operation. Water is supplied by tank trucks. A water tank installed on the mixer will permit continuous operation while the tank trucks are being switched. As soon as the first windrow is mixed and spread on one section of the roadway, it is compacted. At the same time a second windrow is being mixed and spread. It in turn is then compacted. Finishing of the entire roadway is completed in one operation. Water requirements are based on the quantity of soil material and cement per unit length of windrow. See figures 4-10 and 4-11 for construction sequences for windrow-type operations.

2. Multishaft traveling mixing machine. Since most multi-shaft traveling mixing machines have a high-speed pulverizing rotor, preliminary pulverization is usually unnecessary. The only preparation required is shaping the soil material

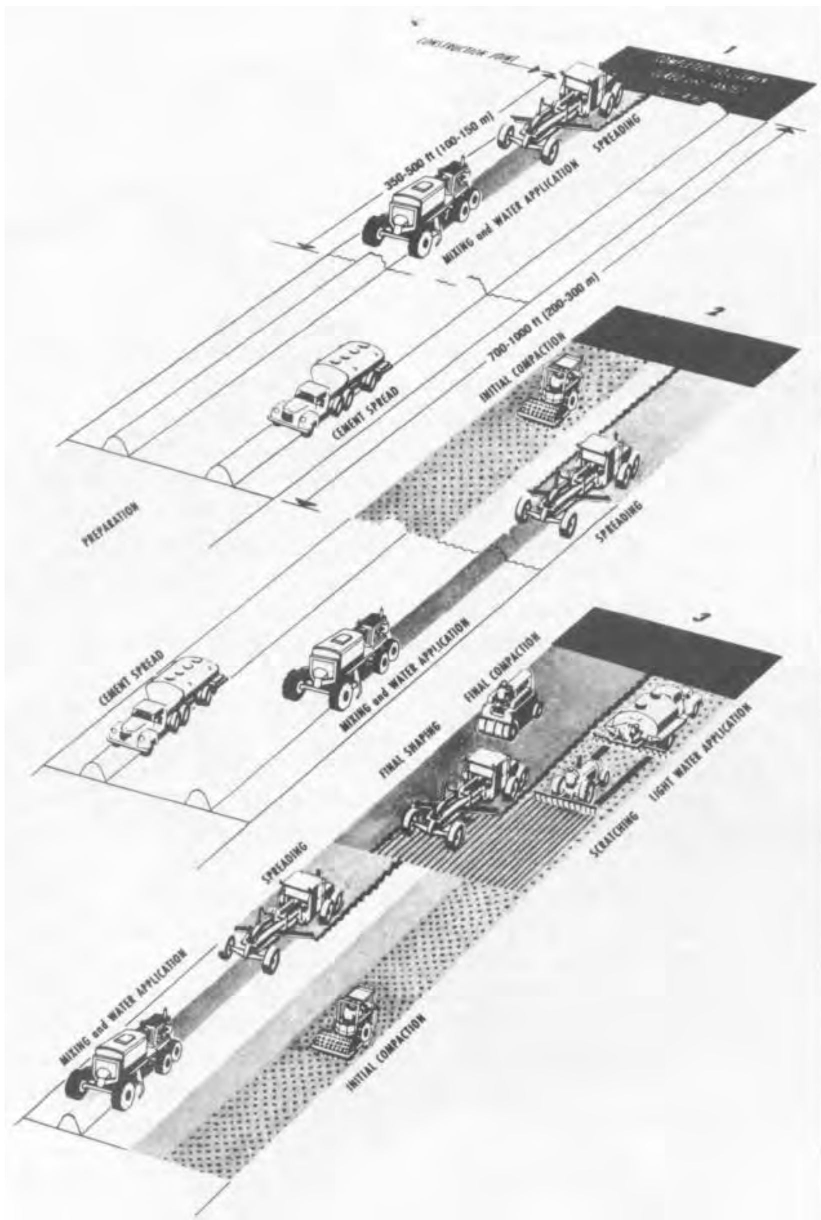


Figure 4-10. Sketch of soil-cement processing operations with windrow-type traveling pugmill.

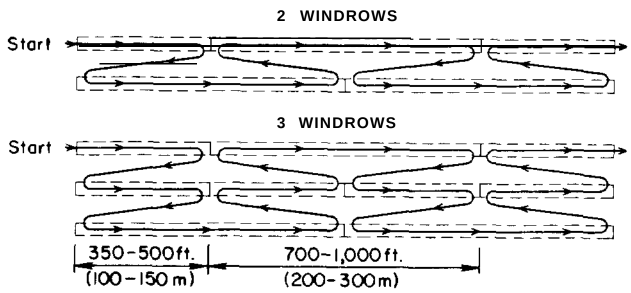


Figure 4-11. Plan for processing with windrow-type traveling pugmill.

to approximate crown and grade. If an old roadbed is extremely hard and dense, prewetting and scarification will facilitate processing. Processing is done in lanes 350 to 500 feet long and as wide as the mixing machine. Cement is spread on the soil material in front of the mixing machine. Cement spreading should be completed in the first working lane and under way in the second lane before mixing operations are begun. This ensures a full-width cement spread without a gap between lanes and keeps spreading equipment out of the way of mixing equipment. See figures 4-12 and 4-13 for an illustration of the construction sequence.

3. Single-shaft traveling mixing machine. Soil-cement construction with single-shaft traveling mixers differs from the preceding examples in that more than one mixing pass is required. The basic principles and objectives are the same, however. Shaping, scarifying, and pulverizing the roadway are the first steps of preparation, as described previously in this chapter. Since most single-shaft traveling mixers were not designed to scarify, the soil material may need to be loosened with a scarifier. Prewetting the soil material is common practice. Applying water at this stage of

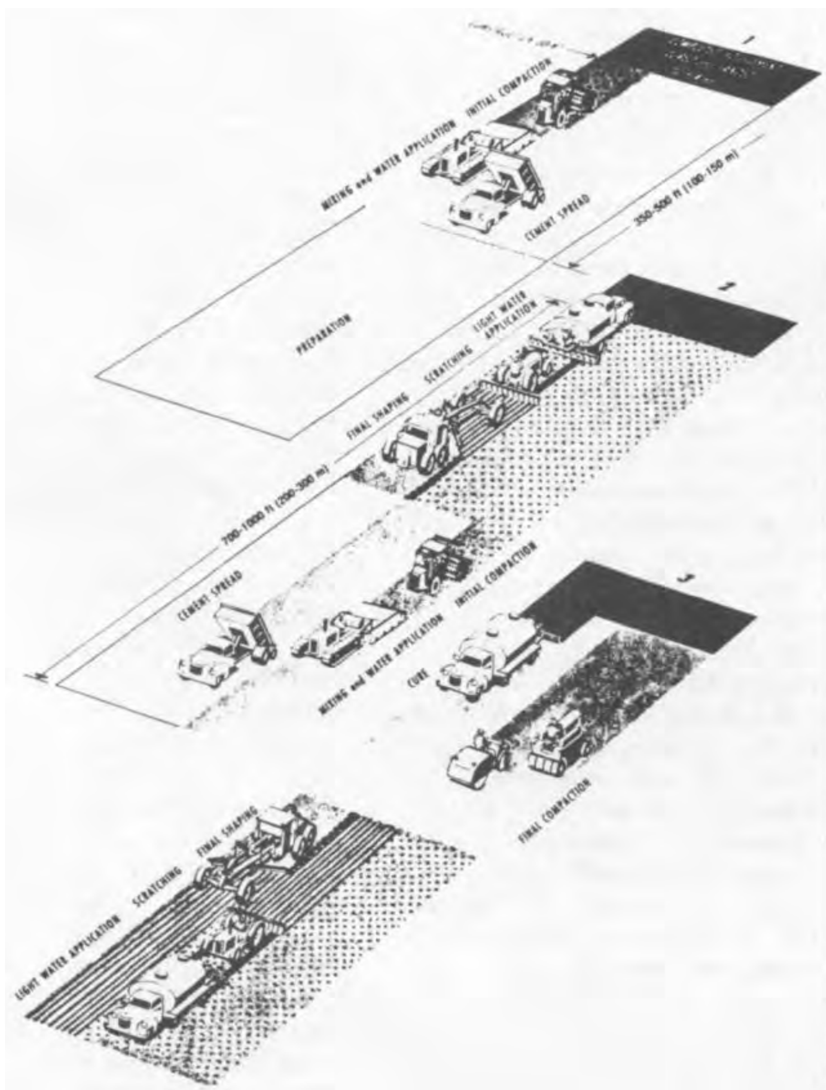


Figure 4-12. Sketch of soil-cement processing operations with multiple-transverse-shaft traveling mixing machine.

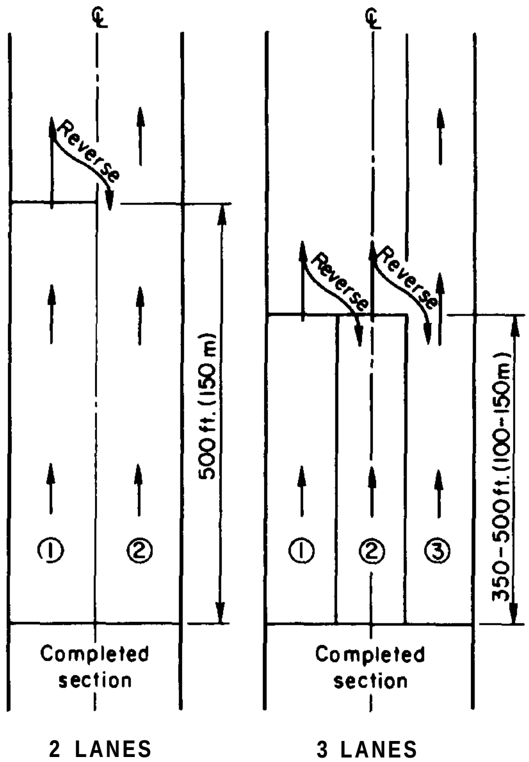


Figure 4-13. Plan for processing with multiple-transverse-shaft traveling mixing machine.

construction saves time during actual processing operations because most of the required water will already have been added to the soil material. In very granular materials, prewetting prevents cement from sifting to the bottom of the mix by causing it to adhere more readily to the sand and gravel particles. Mixing the soil material and cement is easier if the moisture content of the raw material is two or three percentage points below optimum. However, very sandy materials can be mixed even if the moisture content is one or two percentage points above optimum. Moisture should be applied uniformly during prewetting. By mixing it into the soil material, evaporation losses are reduced. Because of the hazard of night rains, some prefer to do the prewetting in the early morning. After scarifying and prewetting, the loose, moist soil material is shaped to crown and grade. Cement is spread by a mechanical cement spreader or from bags. Occasionally, the prewet soil material becomes compacted by cement-spreading equipment. In such cases, mixing can be hastened by loosening the material again after cement is spread, usually with the scarifier on a motor grader. The scarifier teeth should be set so that the cement will flow between them and not be carried forward or displaced by the scarifier frame. The mixer picks up the soil material and cement and mixes them in place. Water, supplied by a tank truck, is usually applied to the mixture by a spray bar mounted in the mixing chamber, or it can be applied ahead of the mixer by water pressure distributors. The soil material and cement must be sufficiently blended when water contacts the mixture to prevent the formation of cement balls. The number of mixing passes depends on the type of soil material and its moisture content and on the forward speed of the mixer. See figure 4-14 for construction sequences.

(c) Central mixing plant. Central mixing plants are often used for projects involving borrow materials. The basic principles of thorough mixing, adequate cement content, proper moisture content, and adequate compaction apply. Friable granular borrow materials are generally used because of their low cement requirements and ease in handling and mixing. Pugmill-type mixers, either continuous flow or batch, or rotary-drum mixers are used for this work. Generally the twin-shaft continuous-flow pugmill is used on highway projects. Facilities for efficiently storing, handling, and proportioning materials must be provided at the plant. Quantities of soil material, cement, and water can be proportioned by volume for weight. Mixing is continued until a uniform mixture of soil material, cement, and water is obtained. To reduce evaporation losses during hot, windy conditions and to protect against sudden showers, haul trucks should be equipped with protective covers. To prevent excessive haul time, not more than 60 minutes should elapse between the start of moist-mixing and the start of compaction. Haul time is usually limited to 30 minutes. The mixed soil-cement should be placed on the subgrade without segregation in a quantity that will produce a compacted base of uniform density conforming to the specified grade and cross section. The mixture should be spread to full roadway width either by one full-width spreader or by two or more spreaders operating in staggered positions across the roadway. Less preferable is the use of one piece of spreading equipment operating one lane at a time in two or more lanes. No lane should be spread so far ahead of the adjoining lane that a time lapse of more than 30 minutes occurs between the time of placing material in adjoining lanes at any location. The subgrade should be damp when the soil-cement is placed. Bituminous pavers have been used for spreading soil-cement although modification may be necessary to increase volume capacity before they can be used. Compaction equipment should follow immediately behind the spreader. When compacting the first lane, a narrow compacted ridge should be left adjacent to the

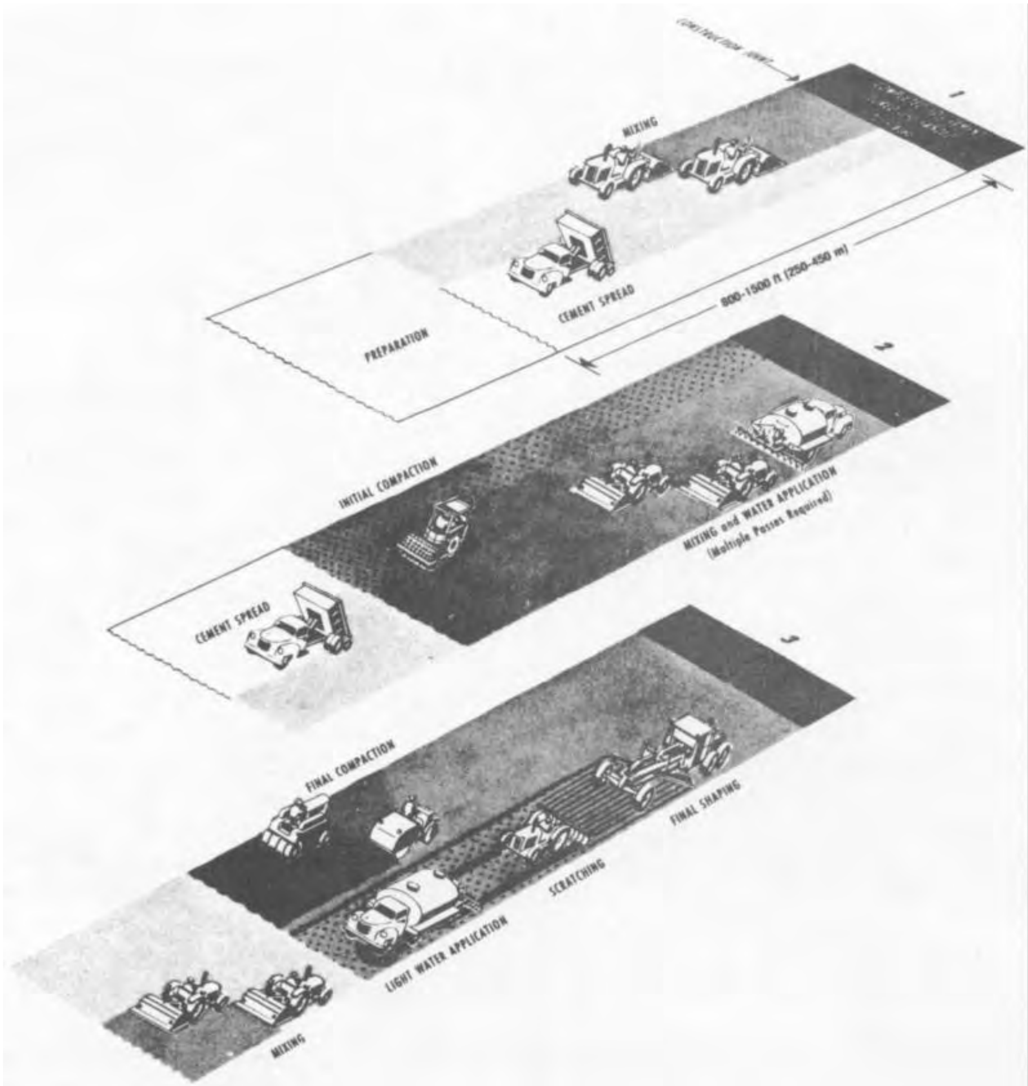


Figure 4-14. Sketch of soil-placement processing operations with single-transverse-shaft mixers.

second lane to serve as a depth guide when placing the mix in the second lane. Water spray equipment should be available to keep the joint areas damp. The amount of water needed to bring the soil-cement mixture to required moisture content in continuous-flow-type mixing plants is based on the amount of soil material and cement coming into the mixing chamber per unit of time. The amount of water required in batch-type central mixing plants is similarly calculated, using the weights of soil material and cement for each batch.

(3) *Compaction.* The principles governing compaction of soil-cement are the same as those for compacting the same soil materials without cement treatment. The soil-cement mixture at optimum moisture should be compacted to maximum density and finished immediately. Moisture loss by evaporation during compaction, indicated by a greying of the surface, should be replaced with light applications of water. Tamping rollers are generally used for initial compaction except for the more granular soils. Self-propelled and vibratory models are also used. To obtain adequate compaction, it is sometimes necessary to operate the rollers with ballast to give greater unit pressure. The general rule is to use the greatest contact pressure that will not exceed the bearing capacity of the soil-cement mixture and that will still "walk out" in a reasonable number of passes. Friable silty and clayey sandy soils will compact satisfactorily using rollers with unit pressures of 75 to 125 pounds per square inch. Clayey sands, lean clays, and silts that have low plasticity can be compacted with 100- to 200-pounds per square inch rollers. Medium to heavy clays and gravelly soils required greater unit pressure, i.e., 150 to 300 pounds per square inch. Compacted thickness up to 8 or 9 inches can be compacted in one lift. Greater thicknesses can be compacted with equipment designed for deeper lifts. When tamping

rollers are used for initial compaction, the mixed material must be in a loose condition at the start of compaction so that the feet will pack the bottom material and gradually walk out on each succeeding pass. If penetration is not being obtained, the scarifier on a motor grader or a traveling mixer can be used to loosen the mix during start of compaction, thus allowing the feet to penetrate. Vibratory-steel-wheeled rollers and grid and segmented rollers can be used to satisfactorily compact soil-cement made of granular soil materials. Vibratory-plate compactors are used on nonplastic granular materials. Pneumatic-tired rollers can be used to compact coarse sand and gravel soil-cement mixtures with very little plasticity and very sandy mixtures with little or no binder material, such as dune, beach, or blow sand. Some permit rapid inflation and deflation of the tires while compacting to increase their versatility. Pneumatic-tired rollers pulled by track-type tractors equipped with street plates can be used to compact cohesionless sand mixtures. The weight and vibration of the tractor aid in compaction. Heavy three-wheeled steel rollers can be used to compact coarse granular materials containing little or no binder material. Gravelly soils that contain up to about 20 percent passing the No. 200 sieve and have low plasticity are best suited for compaction with these rollers. Tandem-steel-wheeled rollers are often used during final rolling to press down or set rock particles and to smooth out ridges. There are two general types of road cross section: trench and featheredge. Both can be built satisfactorily with soil-cement. In trench-type construction, the shoulder material gives lateral support to the soil-cement mixture during compaction. In the featheredge type of construction, the edges are compacted first to provide some edge stability while the remaining portion is being compacted. The edge slope should not be steeper than 2:1 to facilitate shaping and compacting. Shoulder material is placed after the soil-cement has been finished. Occasionally, during compaction and finishing, a localized area may yield under the compaction equipment. This may be due to one or more causes: the soil-cement mix is much wetter than optimum moisture; the subsoil may be wet and unstable; or the roller may be too heavy for the soil. If the soil-cement mix is too damp, it should be aerated with a cultivator, traveling mixer, or motor grader. After it has dried to near optimum moisture, it can be compacted. For best results, compaction should start immediately after the soil material, cement, and water have been mixed. Required densities are then obtained more readily; there is less water evaporation; and daily production is increased.

(4) *Finishing.* There are several acceptable methods for finishing soil-cement. The exact procedure depends on equipment, job conditions, and soil characteristics. Regardless of method, the fundamental requirements of adequate compaction, close to optimum moisture, and removal of all surface compaction planes must be met to produce a high quality surface. The surface should be smooth, dense, and free of ruts, ridges, or cracks. When shaping is done during finishing, all smooth surfaces, such as tire imprints and blade marks, should be lightly scratched with a weeder, nail drag, coil spring, or spiketooth harrow to remove cleavage or compaction planes from the surface. Scratching should be done on all soil-cement mixtures except those containing appreciable quantities of gravel. The surface should be kept damp during finishing operations. Steel-wheeled rollers can be used to smooth out ridges left by the initial pneumatic-tired rolling. Steel-wheeled rollers are particularly advantageous when rock is present in the surface. A broom drag can sometimes be used advantageously to pull binder material in and around pieces of gravel that have been set by the steel-wheeled roller. Instead of using a steel roller, surfaces can be shaved with the motor grader and then rerolled with a pneumatic-tired roller to seal the surface. Shaving consists of lightly cutting off any small ridges left by the finishing equipment. Only a very thin depth is cut and all material removed is bladed to the edge of the road and wasted. The final operation usually consists of a light application of water and rolling with a pneumatic-tired roller to seal the surface. The finished soil-cement is then cured.

(5) *Curing.* Compacted and finished soil-cement contains sufficient moisture for adequate cement hydration. A moisture-retaining cover is placed over the soil-cement soon after completion to retain this moisture and permit the cement to hydrate. Most soil-cement is cured with bituminous material, but other materials such as waterproof paper of plastic sheets, wet straw or sand, fog-type water spray, and wet burlap or cotton mats are entirely satisfactory. The types of bituminous materials most commonly used are RC-250, MC-250, RT-5, and emulsified asphalt SS-1. Rate of application varies from 0.15 to 0.30 US gallons per square yard. At the time of application, the soil-cement surface should be free of all dry, loose and extraneous material. The surface should also be moist when the bituminous materials are applied. In most cases a light application of water is

placed immediately ahead of the bituminous application.

(6) *Construction joints.* After each day's construction, a transverse vertical construction joint must be formed by cutting back into the completed soil-cement to the proper crown and grade. This is usually done the last thing at night or the first thing the following morning, using the toe of the motor-grader blade or mixer. The joint must be vertical and perpendicular to the centerline. After the next day's mixing has been completed at the joint, it must be cleaned of all dry and unmixed material and retrimmed if necessary. Mixed moist material is then bladed into the area and compacted thoroughly. The joint is left slightly high until final rolling when it is trimmed to grade with the motor grader and rerolled. Joint construction requires special attention to make sure the joints are vertical and the material in the joint area is adequately mixed and thoroughly compacted. When bituminous material is used as a curing agent, it should be applied right up to the joint and sanded to prevent pickup.

(7) *Multiple-layer construction.* When the specified thickness of soil-cement base course exceeds the depth (usually 8 or 9 inches compacted) that can be compacted in one layer, it must be constructed in multiple layers. No layer should be less than 4 inches thick. The lower layer does not have to be finished to exact crown and grade, nor do surface compaction planes have to be removed since they are too far from the final surface to be harmful. The lower layer can be cured with the moist soil that will subsequently be used to build the top layer-which can be built immediately, the following day, or some time later. With mixed-in-place construction, care must be taken to eliminate any raw-soil seams between the layers.

e. Special construction problems.

(1) *Rainfall.* Attention to a few simple precautions before processing will greatly reduce the possibility of serious damage from wet weather. For example, any loose or pulverized soil should be crowned so it will shed water, and low places in the grade where water can accumulate should be trenched so the water will drain off freely. As shown by the construction of millions of square yards of soil-cement in all climates, it is unlikely that rainfall during actual construction will be a serious problem to the experienced engineer or contractor. Usually construction requires the addition of water equivalent to 1 to 1½ inches of rain. If rain falls during cement-spreading operations, spreading should be stopped and the cement already spread should be quickly mixed into the soil mass. A heavy rainfall that occurs after most of the water has already been added, however, can be serious. Generally, the best procedure is to obtain rapid compaction by using every available piece of equipment so that the section will be compacted and shaped before too much damage results. In such instances it may be necessary to complete final blading later; any material bladed from the surface is wasted. After the mixture has been compacted and finished, rain will not harm it.

(2) *Wet soils.* Excessively wet material is difficult to mix and pulverize. Experience has shown that cement can be mixed with sandy materials when the moisture content is as high as 2 percent above optimum. For clayey soils, the moisture content should be below optimum for efficient mixing. It may be necessary to dry out the soil material by aeration. This can be done by using single-shaft traveling mixers with the hood in a raised position, or by cutting out the material with the tip of a motor grader blade and working and aerating with a disc. The maintenance of good crown and surface grade to permit rapid runoff of surface water before soil-cement processing is the best insurance against excessive amounts of wet material.

(3) *Cold weather.* Soil-cement, like other cement-using products, hardens as the cement hydrates. Since cement hydration practically ceases when temperatures are near or below freezing, soil-cement should not be placed when the temperature is 40 degrees F or below. Moreover, it should be protected to prevent its freezing for a period of 7 days after placement, and until it has hardened, by a suitable covering of hay, straw, or other protective material.

4-2. Construction with lime.

a. Lime stabilization methods. Basically, there are three recognized lime stabilization methods; in-place mixing, plant mixing, and pressure injection.

(1) *In-place mixing.*

(a) In-place mixing may be subdivided into three methods: mixing lime with the existing materials already a part of the construction site or pavement (fig 4-15); off-site mixing in which lime is mixed with borrow and the mixture is then transported to the construction site for final manipulation and compaction (fig 4-16); and mixing in which the borrow source soil is hauled to the construction site and processed as in the first method.

(b) The following procedures are for in-place mixing:

One increment of lime is added to clays or granular base materials that are easy to pulverize.

Figure 4-15. In-place mixing of lime with existing base and paving material on city street.

Figure 4-16. Off-site mixing pads for Mississippi River levee repair project.

The material is mixed and compacted in one operation, and no mellowing period is required.

One increment of lime is added and the mixture is allowed to mellow for a period of 1 to 7 days to assist in breaking down heavy clay soils. (The term mellow refers to the reaction of the lime on clay to make it more friable and easier to pulverize.)

One increment of lime is added for soil modification and pulverization before treatment with cement or asphalt.

One increment of lime is added to produce a working table. Proof rolling is required instead of pulverization and density requirements.

Two increments of lime are added for soils that are extremely difficult to pulverize. Between the applications of the first and second increments of lime, the mixture is allowed to mellow.

(c) Deep stabilization may be accomplished by one of two approaches.

One increment of lime is applied to modify soil to a depth of 24 inches (fig 4-17 through fig 4-19). Greater depths are possible but to date have not been attempted. A second increment of lime is

Figure 4-17. Deep stabilization after lime spreading the plow cuts 24 inches deep.

Figure 4-18. Root plow for scarifying to a depth of 18 inches.

Figure 4-19. Scarifying existing clay subgrade with lime on city street project.

added to the top 6 to 12 inches for complete stabilization. Plows and rippers are used to break down the large clay chunks in the deep treatment. Heavy disc harrows and blades are also used in pulverization of these clay soils. In frost zones, the use of small quantities of lime for soil modification under some circumstances may result in a frost susceptible material that in turn can produce a weak sublayer.

One increment of lime is applied for complete stabilization to a depth of 18 inches. Mechanical mixers are now available to pulverize the lime-clay soil to the full depth by progressive cuts as follows: first-pass cut to a depth of 6 inches, second to 9 inches, third to 12 inches, fourth to 15 inches, and then a few passes to a depth of 18 inches to accomplish full pulverization. The full 18 inches is compacted from the top by vibratory and conventional heavy rollers.

(2) *Plant mixing.* The plant-mix operation usually involves hauling the soil to a central plant where lime, soil, and water are uniformly mixed and then transported to the construction site for further manipulation (fig 4-20 through fig 4-22). The amount of lime for either method is usually predetermined by test procedures. Specifications may be written to specify the actual strength gain required to upgrade the stabilized soil, and notations can be made on the plans concerning the estimated percent of lime required. This note should also stipulate that changes in lime content may be necessary to meet changing soil conditions encountered during construction.

(3) *Pressure injection.* Pressure injections of lime slurry to depths of 7 to 10 feet, for control of swelling and unstable soils on highways (fig 4-23) and under building sites, are usually placed on 5-foot spacings, and attempts are made to place horizontal seams of lime slurry at 8- to 12-inch intervals. The top 6- to 12-inch layer should be completely stabilized by conventional methods.

b. Construction steps.

Figure 4-20. Lime-treated gravel with lime fed by screw conveyor.

Figure *4-21. Lime-cement-fly ash aggregate base course.*

Figure *4-22. Enclosed soil holds lime for adding to marginal crushed stone base material.*

Figure 4-23. Lime slurry pressure injection (LSPI) rig treating a failed highway slope.

(1) *Soil preparation.* The in-place subgrade soil should be brought to final grade and alignment. The finished grade elevation may require some adjustment because of the potential fluff action of the lime-stabilized layer resulting from the fact that some soils tend to increase in volume when mixed with lime and water. This volume change

may be exaggerated when the soil-lime is remixed over a long period of time, especially at moisture contents less than optimum moisture. The fluff action is usually minimized if adequate water is provided and mixing is accomplished shortly after lime is added. For soils that tend to fluff with lime, the subgrade elevation should be lowered slightly or the excess material trimmed. Trimming can usually be accomplished by blading the material onto the shoulder of embankment slopes. The blading operation is desirable to remove the top 0.25 inch because this material is not often well cemented due to lime loss experienced during construction. Excess rain and construction water may wash lime from the surface, and carbonation of lime may occur in the exposed surface. If dry lime is used, ripping or scarifying to the desired depth of stabilization can be accomplished either before or after lime is added (fig 4-19). If the lime is to be applied in a slurry form, it is desirable to scarify prior to the addition of lime.

(2) *Lime application.*

(a) Dry hydrated lime. Dry lime can be applied either in bulk or by bag. The use of bagged lime is generally the simplest but also the most costly method of lime application. Bags of 50 pounds are delivered in dump or flatbed trucks and placed by hand to give the required distribution (fig 4-24). After the bags are placed they are slit and the lime is dumped into piles or transverse windrows across the roadway. The lime is then levelled either by hand raking or by means of a spike-tooth harrow or drag pulled by a tractor or truck. Immediately after, the lime is sprinkled to reduce dusting. The major disadvantages of the bag method are the higher costs of lime because of bagging costs, greater labor costs, and slower operations. Nevertheless, bagged lime is often the most practical method for small projects or for projects in which it is difficult to utilize large equipment. For large stabilization projects, particularly where dusting is no problem, the use of bulk lime has become common practice. Lime is delivered to the job in self-unloading transport trucks (fig 4-25). These trucks are large and efficient, capable of hauling 15 to 24 tons. One type is equipped with one or more integral screw conveyors that discharge at the rear. In recent years pneumatic trucks have increased in popularity and are preferred over the older auger-type transports. With the pneumatic units the lime is blown from the tanker compartments through a pipe or hose to a cyclone spreader to a pipe spreader bar-mounted at the rear (fig 4-26). Bottom-dump hopper trucks have also been tried, but they are undesirable because of difficulty in unloading and obtaining a uniform rate of discharge. With the auger trucks, spreading is handled by means of a portable, mechanical-type spreader attached to the rear (fig 4-27) or through metal downspout chutes or flexible rubber boots extending from the screw conveyors. The mechanical spreaders incorporate belt, screw, rotary vane, or drag-chain conveyors to distribute the lime uniformly across the spreader width. When boots or spouts are used instead, the lime is deposited in windrows; but because of lime's lightness and flowability, the lime becomes distributed rather uniformly across the spreading lane. Whether mechanical spreaders, downspouts, or boots are used, the rate of lime application can be regulated by varying the spreader opening, spreader drive speed, or truck speed so that the required amount of lime can be applied in one or more passes. With the pneumatic trucks, spreading is generally handled with a cyclone spreader mounted at the rear, which distributes the lime through a split chute or with a spreader bar equipped with several large downspout pipes. Finger-tip controls in the truck cab permit the driver to vary the spreading width by adjusting the air pressure. Experienced drivers can adjust the pressure and truck speed so that accurate distribution can be obtained in one or two passes. When bulk lime is delivered by rail, a variety of conveyors can be used for transferring the lime to transport trucks; these include screw, belt, or drag-chain conveyors, bucket elevators, and screw elevators. The screw-type conveyors are most commonly used, with large diameter units of 10- to 12-inches being recommended for high-speed unloading. To minimize dusting, all types of conveyors should be enclosed. Rail-car unloading is generally facilitated by means of poles and mechanical or air-type vibrators. Lime has also been handled through permanent or portable batching plants, in which case the lime is weigh-batched before loading. Generally, a batch plant setup would only be practical on exceptionally large jobs. Obviously, the self-unloading tank truck is the least costly method of spreading lime, because there is no rehandling of material and large payloads can be carried and spread quickly.

(b) Dry quicklime. Quicklime may be applied in bags or bulk. Because of higher cost, bagged lime is only used for drying of isolated wet spots or on small jobs. The distribution of bagged quicklime is similar to that of bagged hydrate, except that greater safety emphasis is needed. First, the bags are spaced accurately on the area to be stabilized, and, after spreading, water is applied and mixing operations started immediately. The fast watering and mixing operation

Figure 4-24. Application of lime by the bag for a small maintenance project.

Figure 4-25. Application of lime by a bulk *pneumatic truck.*

Figure 4-26. Bulk pneumatic truck spreading lime from bar spreader.

Figure 4-27. Distribution of quicklime from mechanical spreader on city street.

helps minimize the danger of burns. Quicklime may be applied in the form of pebbles of approximately 3/8 inch, granular, or pulverized. The first two are more desirable because less dust is generated during spreading. Bulk quicklime may be spread by self-unloading auger or pneumatic transport trucks, similar to those used for dry hydrate. However, because of its coarser size and higher density, quicklime may also be tailgated from a regular dump truck with tailgate opening controls to ensure accurate distribution (fig 4-28). Because quicklime is anhydrous and generates heat on contact with water, special care should be taken during stabilization to avoid lime burns. Where quicklime is specified, the contractor should provide the engineer with a detailed safety program covering precautions and emergency treatment available on the jobsite. The program should include protective equipment for eyes, mouth, nose, and skin, as well as a first-aid kit containing an eyeball wash. This protective equipment should be available on the jobsite during spreading and mixing operations. The contractor should actively enforce this program for the protection of the workers and others in the construction area.

(c) Slurry method. In this method either hydrated lime or quicklime and water are mixed into a slurry. With quicklime, the lime is first slaked and excess water added to produce the slurry.

(d) Slurry made with hydrated lime. This method was first used in the 1950s and is currently very popular, especially where dust from using dry lime is a problem. The hydrated lime-water slurry is mixed either in a central mixing tank (fig 4-29), jet mixer (fig 4-30), or in a tank truck. The slurry is spread over the scarified roadbed by a tank truck equipped with spray bars (fig 4-31 and fig 4-32). One or more passes may be

Figure 4-28. Spreading of granular quicklime.

required over a measured area to achieve the specified percentage based on lime solids content. To prevent runoff and consequent nonuniformity of lime distribution that may occur under certain conditions, it may be necessary to mix the slurry and soil immediately after each spreading pass (fig 4-33). A typical slurry mix proportion is 1 ton of lime and 500 gallons of water, which yields about 600 gallons of slurry containing 31 percent lime solids. At higher concentrations there is difficulty in pumping and spraying the slurry. Forty percent solids is a maximum pumpable slurry. The actual proportion used depends on the percentage of lime specified, type of soil, and its moisture condition. When small lime percentages are required, the slurry proportions may be reduced to 1 ton of lime per 700 to 800 gallons of water. Where the soil moisture content is near optimum, a stronger lime concentration would normally be required. In plants employing central mixing, agitation is usually accomplished by using compressed air and recirculating pump, although pugmills have also been used. The most typical slurry plant incorporates slurry tanks large enough to handle whole tank truck loads of hydrated lime of approximately 20 tons. For example, on one job two 15,000 gallon tanks, 10 feet in diameter by 26 feet in length, were used, each fitted with an 8-inch perforated air line mounted along the bottom. The air line was stopped 18 inches short of the end wall, thereby providing maximum agitation in the lime-feeding zone. A typical batch consisted of 10,000 gallons of water (charged first) and 20 tons of lime, producing about 12,000 gallons of slurry in less than 25 minutes. Loading of the tank trucks was handled by a standard water pump, with one slurry tank being unloaded while the slurry was being mixed in the other tank. On another job the contractor used a similar tank and air line, but, in addition, a 4-inch recirculating pump was used for mixing; the same pump loaded the tank trucks. To keep the lime from settling, the contractor devised a hand-operated scraper fitted with air jets. The newest and most efficient method of slurry production, which eliminates batching tanks, involves the use of a compact jet slurry mixer. Water at 70 pounds per square inch and hydrated lime are charged continuously in a 65:35 (weight) ratio into the jet mixing bowl where slurry is produced instantaneously. The mixer and auxiliary equipment can be mounted on a small trailer and transported to the job readily, giving great flexibility to the operation. In the third type of slurry setup, measured amounts of water and lime are charged separately to the tank truck, with the slurry being mixed in the tank either by compressed air or by a recirculating pump mounted at the rear. The water is metered and the lime proportioned volumetrically or by means of weight batchers. Both portable and permanent batching plants are used. Mixing with air is accomplished at the plant. The air jets are turned on during the loading operation, and remain on until the slurry is thoroughly mixed which takes about 10 to 15 minutes. The use of a recirculating pump, however, permits mixing to occur during transit to the job. Usually, 2-, 3-, or 4-inch pumps are used in this operation, with the slurry being recirculated through the tank by means of a perforated longitudinal pipe extending the length of the tank and capped at one end. Spreading from the slurry distributors is effected by gravity or by pressure spray bars, the latter being preferred because of better distribution. The use of spray deflectors is also recommended for good distribution. The general practice in spreading is to make either one or two passes per load. However, several loads may be needed in order to distribute the required amount of lime. The total number of passes will depend on the lime requirement, optimum moisture of the soil, and type of mixing employed. Windrow mixing with the grader generally requires several passes.

(e) Double application of lime. In some areas where extremely plastic, gumbo clay (PI 50+) abounds, it may prove advantageous to add the requisite amount of lime in two increments to facilitate adequate pulverization and obtain complete stabilization. For example, 2 or 3 percent lime is added first, partially mixed, then the layer is sealed and allowed to cure for up to a week. The remaining lime is then added preparatory to final mixing. The first application mellows the clay and helps in achieving final pulverization, and the second application completes the lime-treatment process.

Figure 4-29. Slurry mixing tank using recirculating pump for mixing hydrate and *water.*

Figure 4-30. Jet slurry mixing plant.

Figure 4-31. Spreading of lime slurry.

Figure 4-32. Recirculation pump on top of a 6,000-gallon wagon agitates *the slurry.*

Figure 4-33. Grader-scarifier cutting slurry into stone base.

Figure 4-34. Portabatch lime slaker.

(f) Slurry made with quicklime. A recent unit developed for making lime slurry from quicklime is the Portabatch Slaker (fig 4-34). This unit consists of a lo-foot diameter by 40-foot tank that incorporates a 5-foot diameter single shaft agitator turned by a 100-horse power diesel engine. The batch slaker can handle 20 to 25 tons of quicklime and about 25,000 gallons of water, producing the slurry in about 1 to 1.5 hours. Because of the exothermic action of quicklime in water, the slurry is produced at a temperature of about 185 degrees F.

(g) Some of the advantages and disadvantages of dry hydrated lime are as follows:

1 *Advantages:*

Dry lime can be applied two or three times faster than a slurry.

Dry lime is very effective in drying out soil.

2 *Disadvantages:*

Dry lime produces a dusting problem that makes its use undesirable in urban areas.

The fast drying action of the dry lime requires an excess amount of water during the dry, hot seasons.

(h) Some of the advantages and disadvantages of dry quicklime are as follows:

1. *Advantages:*

More economical as it contains approximately 25 percent more available lime.

Greater bulk density for smaller-sizes silos.

Faster drying action in wet soils.

Faster reaction with soils.

Construction season can be extended, in both spring and fall, because of faster drying.

2. *Disadvantages:*

Field hydration less effective than commercial hydrators, producing a coarser material with poorer distribution in soil mass.

Quicklime requires more water than hydrate for stabilization, which may present a problem in dry areas.

Greater susceptibility to skin and eye burns.

(i) Some of the advantages and disadvantages of slurry lime are as follows:

1. *Advantages:*

Dust-free application is more desirable from an environmental standpoint.

Better distribution is achieved with the slurry.

In the lime slurry method, the lime spreading and sprinkling operations are combined, thereby reducing job costs.

During summer months slurry application prewets the soil and minimizes drying action.

The added heat when slurry is made from quicklime speeds drying action, which is especially desirable in cooler weather.

2. *Disadvantages:*

Application rates are slower. High capacity pumps are required to achieve acceptable application rates.

Extra equipment is required, therefore, costs are higher.

Extra manipulation may be required for drying purposes during cool, wet, humid weather, which could occur during the fall, winter, and spring construction season.

Not practical for use with very wet soils.

(3) Pulverization and mixing. To obtain satisfactory soil-lime mixtures adequate pulverization and mixing must be achieved. For heavy clay soils two-stage pulverization and mixing may be required, but for other soils one-stage mixing and pulverization may be satisfactory. This difference is primarily due to the fact that the heavy clays are more difficult to break down.

(a) Two-stage mixing. Construction steps in two-stage mixing consist of preliminary mixing, moist curing for 24 to 48 hours (or more), and final mixing or remixing. The first mixing step distributes the lime throughout the soil, thereby facilitating the mellowing action. For maximum chemical action during the mellowing period, the clay clods should be less than 2 inches in diameter. Before mellowing the soil should be sprinkled liberally to bring it up to at least two percentage points above optimum moisture in order to aid the disintegration of clay clods The exception to excess watering would be in cool, damp weather when evaporation is at a minimum. In hot weather, however, it may be difficult to add too much water. After preliminary mixing, the roadway should be sealed lightly with a pneumatic roller as a precaution against heavy rain, because the compacted subgrade will shed water, thereby preventing moisture increases that might delay construction. Generally, in 24 to 48 hours the clay becomes friable enough so that desired pulverization can be easily attained during final mixing. Additional sprinkling may be necessary during final mixing to bring the soils to optimum moisture or slightly above (fig 4-35). In hot weather more than optimum moisture is needed to compensate for the loss through evaporation. Although disc harrows (fig 4-36) and grader scarifiers are suitable for preliminary mixing, high-speed rotary mixers (fig 4-37 to fig 4-39) or one-pass travel plant mixers (fig 4-15) are required for final mixing. Motor graders are generally unsatisfactory for mixing lime with heavy clays.

(b) One-stage mixing. Both blade and rotary mixing, or a combination, have been used successfully in projects involving granular base materials. However, rotary mixers are preferred for more uniform mixing, finer pulverization, and faster operation. They are generally required for highly plastic soils that do not pulverize readily and for reconstructing worn-out roads in order to pulverize the old asphalt.

(c) Blade mixing. When blade mixing is used in conjunction with dry lime, the material is generally bladed into two windrows, one on each

Figure *4-35. Watering of lime-treated clay on airport project.*

Figure 4-36. Mixing with a disc harrow.

Figure 4-37. Rotary mixer.

Figure 4-38. Train of rotary mixers.

Figure 4-39. Rotary mixer on primary road project.

side of the roadway. Lime is then spread on the inside of each windrow or down the center line of the road. The soil is then bladed to cover the lime. After the lime is covered, the soil is mixed dry by blading across the roadway. After dry mixing is completed, water is added to slightly above the optimum moisture content and additional mixing is performed. To ensure thorough mixing by this method, the material should be handled on the mold board at least three times. When blade mixing is used with the slurry method, the mixing is done in thin lifts that are bladed to windrows. One practice is to start with the material in a center windrow, then blade aside a thin layer after the addition of each increment of slurry, thereby forming side windrows. The windrowed material is then bladed back across the roadway and compacted, provided that its moisture content is at optimum. A second practice is to start with a side windrow, then blade in a thin 2-inch layer across the roadway, add an increment of lime, and blade this layer to a windrow on the opposite side of the road. On one job this procedure was repeated several times until all the material was mixed and bladed to the new windrow. Because only one-half of the lime had been added at this time, the process was repeated, moving the material back to the other side. This procedure is admittedly slow, but it provides excellent uniformity.

(d) Central mixing. Premixing lime with granular base materials is becoming popular on new construction projects, particularly where submarginal gravels are used. Because the gravel has to be processed anyway to meet gradation specifications, it is a relatively simple matter for the contractor to install a lime bin, feeder, and pugmill at the screening plant. On one project a small pugmill was installed at the head pulley of the collecting belt conveyor (fig 4-20) and at another operation a larger pugmill plant was utilized (fig 4-21). The general practice is to add the optimum

moisture at the pugmill, thereby permitting immediate compaction after laydown. Figure 4-22 shows a crushed-stone plant where lime was added to upgrade a clay bearing crushed stone.

(e) Pulverization and mixing requirements. Pulverization and mixing requirements are generally specified in terms of percentages passing the 1½-inch or 1-inch screen and the No. 4 sieve. Typical requirements are 100 percent passing the 1 inch, and 60 percent passing the No. 4 sieve, exclusive of nonslaking fractions. However, in some applications the requirements are relaxed. For example, the South Dakota Highway Department only requires 100 percent passing the 1.5 inch screen with no requirement for the No. 4 sieve. Other specifications may only require 40 to 50 percent passing the No. 4 sieve. In certain expedient construction operations, formal requirements are eliminated and the "pulverization and mixing to the satisfaction of the engineer" clause is employed.

(4) *Compaction.* For maximum development of strength and durability, lime-soil mixtures should be properly compacted. Many agencies require at least 95 percent of ASTM D 698 density for subbase and 90 percent for bases. Some agencies have required 95 percent ASTM D 1557 maximum density. Although such densities can be achieved for more granular soil-lime mixtures, it is difficult to achieve this degree of compaction for lime-treated, fine-grained soils. If a thick soil-lime lift is to be compacted in one lift, many specifications require 95 percent of ASTM D 698 maximum density in the upper 6 to 9 inches, and lower densities are accepted in the bottom portion of the lift. To achieve high densities, compacting at approximately optimum moisture content with appropriate compactors is necessary. Granular soil-lime mixtures are generally compacted as soon as possible after mixing, although delays of up to 2 days are not detrimental, especially if the soil is not allowed to dry out and lime is not allowed to carbonate. Fine-grained soils can also be compacted soon after final mixing, although delays of up to 4 days are not detrimental. When longer delays (2 weeks or more) cannot be avoided, it may be necessary to incorporate a small amount of additional lime into the mixture (0.5 percent) to compensate for losses due to carbonation and erosion. Various rollers and layer thicknesses have been used in lime stabilization. The most common practice is to compact in one lift by first using the sheeps-foot roller (fig 4-40 and fig 4-41) until it "walks out," and then using a multiple-wheel pneumatic roller (fig 4-42). In some cases, a flat wheel roller is used in finishing. Single lift compaction can also be accomplished with vibrating impact rollers (fig 4-43) or heavy pneumatic rollers, and light pneumatic or steel rollers used for finishing. When light pneumatic rollers are used alone, compaction is generally done in thin lifts usually less than 6 inches. Slush rolling of granular soil-lime mixtures with steel rollers is not recommended. During compaction, light sprinkling may be required, particularly during hot, dry weather, to compensate for evaporation losses.

(5) *Curing.* Maximum development of strength and durability also depends on proper curing. Favorable temperature and moisture conditions and the passage of time are required for curing. Temperatures higher than 40 degrees F to 50 degrees F and moisture contents around optimum are conducive to curing. Although some specifications require a 3- to 7-day undisturbed curing period, other agencies permit the immediate placement of overlaying paving layers if the compacted soil-lime layer is not rutted or distorted by the equipment. This overlying course maintains

Figure 4-40. Self-propelled sheepsfoot roller.

Figure 4-41. Dougle sheepsfoot roller.

Figure 4-42. Pneumatic roller completes compaction of LCF base.

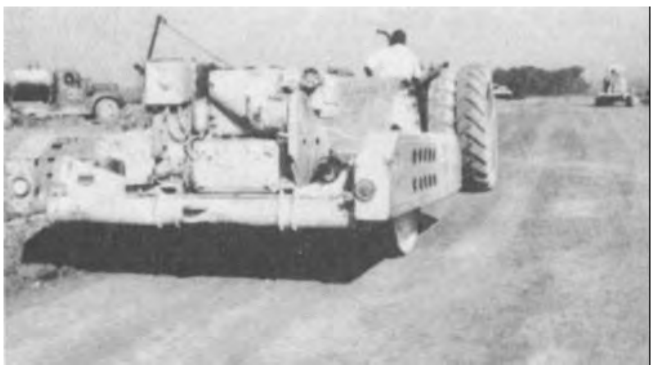


Figure 4-43. Vibrating roller completes compaction of subgrade.

the moisture content of the compacted layer and is an adequate medium for curing. Two types of curing can be employed: moist and asphaltic membrance. In the first, the surface is kept damp by sprinkling with light rollers being used to keep the surface knitted together. In membrane curing, the stabilized soil is either sealed with one shot of cutback asphalt at a rate of about 0.10 to 0.25 gallons per square yard within 1 day after final rolling, or primed with increments of asphalt emulsion applied several times during the curing period. A common practice is to apply two shots the first day and one each day thereafter for 4 days at a total rate of 0.10 to 0.25 gallons per square yard. The type of membrane used, amount, and number of shots vary considerably. Usually, it is difficult to apply more than 0.2 gallons of asphalt prime because the lime-stabilized layer is relatively impervious after compaction.

4-3. Construction with Lime-Fly Ash (LF) and Lime-Cement-Fly Ash (LCF). Construction procedures for LC and LCF are similar to those used for lime stabilization. Although both field in place and central plant mixing may be used with LF and LCF, the latter procedure is recommended to obtain adequate proportioning and mixing. With LCF, it also should be noted that the presence of cement requires that the stabilized mixture be compacted as soon as possible.

4-4. Construction with Bitumen. Bituminous stabilization can involve either hot-mix or cold-mix materials. Bitumen and aggregate or soil can be blended in place or in a central plant. Construction procedures presented in this manual are for cold-mix materials mixed in place or in a central plant. Construction procedures for hot-mix hot-laid materials are similar to those used for asphalt concrete and applicable standard construction procedures should be followed when these materials are involved.

a. Equipment for Mixed-in-Place Materials. Some pieces of equipment used for mixed-in-place bituminous stabilization are similar to those used in standard construction and will not be described here. These include water distributors, compaction equipment, and windrow sizers. Only equipment especially associated with or having special features applicable to bituminous stabilization will be discussed.

(1) Mixing equipment.

(a) Travel plants. Travel plants are self-propelled pugmill plants that proportion and mix aggregates and asphalt as they move along the road. There are two general types of travel plants: one that moves through a prepared aggregate windrow on the roadbed, adds and mixes the asphalt as it goes and discharges to the rear a mixed windrow ready for aeration and spreading (fig 4-44) and one that receives aggregate into its hopper from haul trucks, adds and mixes asphalt, and spreads the mix to the rear as it moves along the roadbed (fig 4-45). Certain features and performance capabilities are common to all travel plants, enabling them to operate effectively and to produce a mix meeting design and specification criteria. To begin, the tracks or wheels on which the machine moves must be so sized, designed, and positioned that they do not damage or rut the surface on which it operates when the plant is fully loaded. The basic purpose of the travel plant is to mix asphalt and aggregate. Some machines are equipped with devices that maintain the proper proportions automatically. Others, however, require that a uniform speed be maintained to ensure uniform proportioning. Regardless of the type, the manufacturer's recommended procedures for calibrating and operating the travel plant should be followed carefully. Finally, the efficient travel plant should be capable of thoroughly mixing the asphalt and aggregates, uniformly dispers-

Figure 4-44. Windrowtype pugmill travel plant.

Figure 4-45. Hopper-type pugmill travel plant.

ing the asphalt and adequately coating the aggregate particles, thus producing a mixture that is uniform in color. Hopper travel plants, and in some cases, windrow plants, require devices for ensuring accurate controls of the flow of aggregates from the hopper to the pugmill so that correct mix proportions are maintained. Feed of asphalt to the pugmill similarly requires accurate calibration. Typically, a positive displacement pump is utilized to deliver asphalt to the mixing chamber via a spray bar.

(b) Rotary-type mixers. Rotary or mechanical on-site mixing is accomplished by what is essentially a mobile mixing chamber mounted on a self-propelled machine. Within the chamber, usually about 7 feet wide and open at the bottom, are one or several shafts transverse to the roadbed, on which are mounted tines or cutting blades that revolve at relatively high speed. As the machine moves ahead, it strikes off behind it a uniform course of asphalt-aggregate mixture. Some rotary mixers have up to four shafts or rotors (fig 4-46 and fig 4-47), but most have only one. Some single shaft mixers are equipped with a system that adds asphalt by spraying it into the mixing chamber as the machine moves ahead, with the amount of spray being synchronized with the travel speed (fig 4-48). Other machines, however, must be used in conjunction with an asphalt distributor that sprays asphalt on to aggregates immediately ahead of the mobile mixer (fig 4-49). Both types of machine have the common capability of effecting a smooth bottom cut and then blending the material with asphalt into the mixture specified. But each type individually is marked by certain devices and features that enable it to perform. Machines with built-in asphalt feeding must have the capability for accurate metering and blending of asphalt into the in-place materials in synchronization with a continuous forward movement. Furthermore, they must have spray bars that will distribute the liquid uniformly across the mixer's width. They must be equipped with controls for both depth of cutting and processing and for spreading the mixed material being laid out behind. Rotary mixers without asphalt spraying equipment generally feature controls that permit adjustment of cutting depth to at least a lo-inch adjustment of tail board and adjustment of the hood itself for aeration purposes.

Figure 4-46. Multiple rotary mixer.

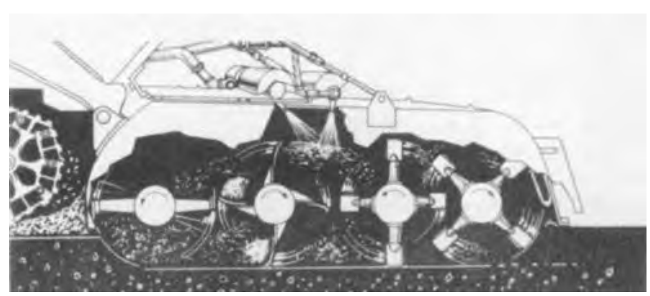


Figure 4-47. A processing chamber of a multiple rotary mixer.

Figure 4-48. Single-shaft rotary mixer with asphalt supply tank.

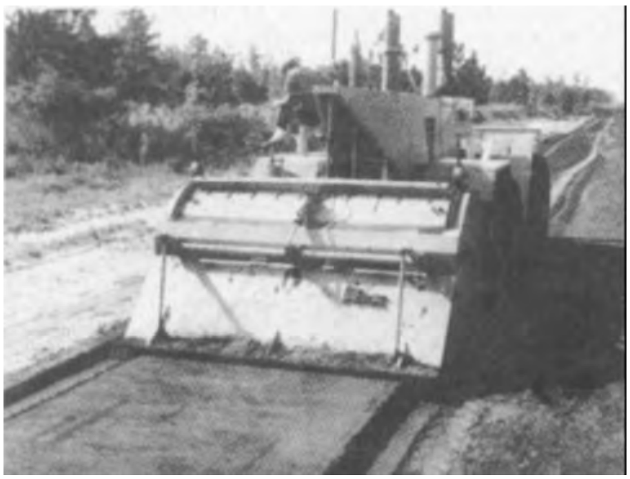


Figure 4-49. Single-shaft rotary mixer without asphalt.

(c) *Motor graders.* Blade mixing is the on-site mixing of asphalt and in-place materials on the roadbed by a motor grader (fig 4-50). The asphalt is applied directly ahead of the motor grader by an asphalt distributor. For most effective blade mixing, the motor grader should have a blade at least 10 feet long, and should have a wheelbase of at least 15 feet. Motor graders used for final layout and finishing of the surface should be equipped with smooth, rather than treaded, pneumatic tires. Scarifier or plow attachments may be mounted before, behind, or both before and behind the blade.

(d) *Asphalt distributor.* The asphalt distributor is a key piece of equipment in cold mix construction, particularly when rotary pulverizer mixers without built-in asphalt feed are used, or when blade mixing is utilized. The asphalt distributor, either truck, or trailer-mounted, consists of an insulated tank, self-contained heating system, a pump, and a spray bar and nozzles through which the liquid asphalt is applied under pressure onto the prepared aggregate materials (fig 4-51). Asphalt distributors range in performance and capability, with some capable of spreading up to 15 feet

Figure 4-50. Mixing *with motor grader.*

Figure 4-51. Distributor applying asphalt.

at controlled rates to as high as 3 gallons per square yard. It is important to keep an adequate supply of asphalt at or near the jobsite to avoid delays. In rural areas, it may be advisable to have an asphalt supply truck at the project.

(2) *Spreading equipment.* Some cold mixes may be spread to the required depth without aeration. Generally, these are open-graded mixes, placed under climatic conditions that will allow evaporation of moisture or volatiles within a reasonable time. They may be spread by a travel plant, from windrows by motor grader or by large multipurpose equipment, such as a cutter-trimmer-spreader. On the latter machine, guidance and grade are electronically controlled by sensors that take reference from wires stretched along one or both sides of the roadway.

b. Mixed-in-Place Construction.

(1) *Windrows.* Several types of cold-mix construction require that the aggregates be placed in

windrows prior to mixing and spreading. If windrows are to be used, the roadway must be cleared of all vegetation to a width sufficient to accommodate both windrow and traffic while the mixture cures. Because the thickness of the new pavement is directly proportional to the amount of aggregate in the windrow(s), accurate control and measurement of the volume of the windrowed material is necessary. Usually, there is not enough loose material on the road surface to use in the road mix. In this case, it is best to blade the loose material onto the shoulder rather than perform the several operations that are necessary to blend it with the material brought in from other sources. Sometimes, however, incorporating the existing material on the roadbed into the mixture is considered practical, if it is uniform and enough is available. When this is done, the loose aggregate must first be bladed into a windrow and measured. Next, it must be made to meet grading specifications by adding other aggregates as necessary. Finally, the windrow is built up to the required volume with implanted material that meets the specifications. If two or more materials are to be combined on the road to be surfaced, each should be placed in its own windrow. These windrows are then mixed together thoroughly before asphalt is added.

(2) *Determining asphalt application rate.* Before mixing operations begin, the correct asphalt application rate and forward speed of the spray bar equipped mixer or asphalt distributor must be determined for the quantity of aggregate in the windrow. Also, when using emulsified asphalt, it is frequently necessary to moisten the aggregate before applying the asphalt and the water application rate and forward speed of the water distributor must be determined.

(3) *Control of asphalt.* Asphalt is added to the aggregate from an asphalt distributor or by a travel mixer. Whichever method is used, close control of quantity and viscosity is required to ensure a proper mixture. Maintaining the correct viscosity is critical because the asphaltic material must be fluid enough to move easily through the spray nozzles and to coat adequately the aggregate particles: Cutback asphalts, and occasionally emulsified asphalts, even though already fluid, require some heating in order to bring them to a viscosity suitable for spraying. If the proper grade of asphalt has been used, and the mixing is done correctly, the cutback or emulsified asphalt will remain fluid until the completion of mixing. As the actual temperature of the mixture is controlled by that of the aggregate, care must be taken to see that mixing is not attempted at aggregate temperatures below 50 degrees F.

(4) *Mixing.*

(a) Travel plant mixing. Travel-plant mixing offers the advantage of closer control of the mixing operation than is possible with blade mixing. With the windrow-type travel plant, the machine moves along the windrow, picking up the aggregate, mixing it with asphalt in the pugmill, and depositing the mixture in a windrow, ready for aerating or spreading. For this type of plant, the asphalt application rate must be matched accurately with the width and thickness of the course, forward speed of the mixer, and the density of the in-place aggregate. As the thickness is specified, the density is fixed, and the asphalt application rate is set; the variable is the forward speed. If the aggregate windrow is so large that all of the asphalt cannot be incorporated in one mixing pass, it should be split into two or more windrows and the proper amount of asphalt added to each windrow as it is mixed. Sometimes, further mixing of the windrowed material may be necessary after the addition of the asphalt. Unless the travel mixer can be used as a multiple pass mixer, this addition mixing usually is done with a motor grader. This ensures that all of the windrowed material is incorporated into the mix. It also aerates the mixture for the removal of diluents. The number of passes with the motor grader required for this purpose varies with different job conditions. After the mixing and aeration procedure is completed, the windrow should be moved to one side of the area to be surfaced in preparation for spreading. The hopper-type travel plant operates by mixing, in its pugmill, the proper amount of asphalt with aggregate that is deposited by haul trucks, directly into the plant’s hopper; then it spreads the mixture. Except when using open-graded mixtures, care must be taken to ensure sufficient evaporation of diluents from the mix prior to compaction.

(b) Rotary mixing. As with windrow travel plants, rotary mixers equipped with built-in spraying systems require that the asphalt application rates be matched accurately with the width and thickness of the course, forward speed of the mixer, and the density of the in-place aggregate. However, when utilizing a rotary mixer not equipped with spraybars, an asphalt distributor, operating ahead of the mixer, applies asphalt to the aggregate. Incremental applications of asphalt and passes of the mixer are usually necessary to achieve the specified mixture. Most rotary mixers are now equipped with a spray system. When using this type of mixer the following steps are recommended:

Step 1. Spread the aggregate to uniform grade and cross section with motor graders.

Step 2. Thoroughly mix the aggregate by one or more passes of the mixer. When ready for the asphalt the moisture content of the aggregate should not exceed 3 percent, unless laboratory tests indicate that a higher moisture content will not be harmful when the asphalt is added.

Step 3. Add asphalt in increments of about 0.50 gallons per square yard until the total required amount of asphalt is applied and mixed in. A total of 0.4 to 0.7 gallons per square yard per inch of compacted thickness of the course is usually necessary. If the mixer is not equipped with spraybars the asphalt usually is applied with an asphalt distributor.

Step 4. Make one or more passes of the mixer between applications of asphalt, as necessary to thoroughly mix it in.

Step 5. Maintain the surface true to grade and cross-section by using a motor grader during the mixing operations.

Step 6. Aerate the mixture by additional manipulation, if needed.

(c) Blade mixing. With blade mixing, the imported or in-place material is shaped into a measured windrow, either through a spreader box or by running through a windrow shaper. The windrow is then flattened with the blade to about the width of the distributor spraybar. The asphalt is applied by successive passes of the asphalt distributor over the flattened windrow, each application not exceeding 0.75 gallons per square yard. After each pass of the distributor the mixture is worked back and forth across the roadbed with the blade, sometimes added by auxiliary mixing equipment. Prior to each succeeding application of asphalt, the mixture is reformed into a flattened windrow. The material in the windrow is subjected to as many mixings, spreading, shapings, and flattenings as are needed to disperse the asphalt thoroughly throughout the mixture, and to coat effectively the aggregate particles. During mixing, the vertical angle of the mold board may require adjustment from time to time in order to achieve a complete rolling action of the windrow as it is worked. As large a roll as possible should be carried ahead of the blade, since pressure from the weight of the aggregate facilitates mixing. Additionally, during mixing, care must be taken to see that neither extra material be taken from the mixing table and incorporated into the windrow nor any of the windrow be lost over the edge of the mixing table or left on the mixing table without being treated. Sometimes, when cutback asphalt is used, the formation of "oil balls," i.e., concentrated clusters of fine aggregate saturated and coated with excessive amounts of asphalt can make a mix difficult to spread and compact. This condition can be corrected by windowing the mixture into a tight windrow and allowing it to cure for a few days. After mixing and aeration have been completed, the windrow is moved to one side of the roadbed in readiness for subsequent spreading. If it is left for any length of time, periodic breaks in the windrow should be cut to ensure drainage of rainwater from the roadbed.

(5) *Aeration.* Before compaction, most of the diluents that have made the asphalt cold mix workable must be allowed to evaporate. In most cases, this occurs during mixing and spreading and very little additional aeration is required, but extra manipulation on the roadbed is needed occasionally to help speed the process and dissipate the excess diluents. Until the mix is sufficiently aerated, it usually will not support rollers without excessive pushing under the rolls. Generally, the mixture is sufficiently aerated when it becomes tacky and appears to "crawl." Many factors affect the rate and the required amount of aeration. Fine-g-rained and well-graded mixtures will require longer aeration than open-graded and coarse-grained mixtures, all other things being equal. Also, if an asphalt cold-mix base course is to be surfaced within a short length of time, aeration before compaction should be more complete than if the course is not to be surfaced for some time; the surface acts as a seal, greatly retarding the removal of diluents.

(a) Emulsified asphalt mixes. Experience has shown that break-down rolling of emulsified asphalt mixes should begin immediately before, or at the same time as, the emulsion starts to break (indicated by a marked color change from brown to black). About this time, the moisture content of the mixture is sufficient to act as a lubricant between the aggregate particles, but is reduced to the point where it does not fill the void spaces, thus allowing their reduction under compactive forces. Also, by this time, the mixture should be able to support the roller without undue displacement.

(b) Cutback asphalt mixes. When using cutback asphalt, correct aeration will be achieved when volatile content is reduced to about 50 percent of that contained in the original asphaltic material, and the moisture content does not exceed 2 percent by weight of the total mixture.

(6) *Spreading and compacting.* With mixing and aeration completed, spreading and compacting the cold mix follows. Achieving a finished section and smooth riding surface conforming to the plans

is the objective of these final two construction steps. The mixture should always be spread to a uniform thickness (whether in a single pass or in several thinner layers) so that no thin spots exist in the final mat. Mixtures that do not require aeration may be spread to the required thickness immediately after mixing and then compacted with pneumatic-tired vibratory or steel-tired rollers. Mixtures that require aeration, however, are generally deposited upon the roadbed in windrows and then are spread from these windrows. The windrow may be placed along the centerline of the road, or along one side if the mixture is to be spread by blade. Because there is a tendency to leave a hump in the road when blade spreading from a center-line windrow, it is considered better practice to place the windrow to the side for spreading. Blade spreading should be accomplished in successive layers, with no layer thinner than about 1.5 times the diameter of the maximum particle size. As each layer is spread, compaction should follow almost immediately with a pneumatic-tired roller. Because the tires of the motor grader compact the freshly spread mix, their tracks will appear as ridges in the finished mat unless there is adequate rolling between the spreading of each successive layer. The roller should follow directly behind the motor grader in order to eliminate these ridge marks (fig 4-52). If, at any time during compaction, the asphalt mixture exhibits undue rutting or shoving, rolling should be stopped. Compaction should not be attempted until there is a reduction diluent content, occurring either naturally or by mechanical aeration. After one course is thoroughly compacted and cured, other courses may be placed on it. This operation should be repeated as many times as necessary to bring the road to proper grade and crown. For a smooth riding surface the motor grader should be used to trim and level as the rollers complete compaction of the upper layer. After the mat has been shaped to its final required cross section, it must then be finish rolled, preferably with a steel-tired roller, until all roller marks are eliminated. Sometimes, a completed course may have to be opened temporarily to traffic. In this event, to prevent tire pickup, it may be advisable to seal the surface by applying a dilution of slow-setting emulsified asphalt and potable water (in equal parts) at a rate of approximately 0.10 gallons per square yard. This should be allowed to cure until no pickup occurs. For immediate passage of traffic, sanding may be desirable to avoid pickup.

c. Equipment for Plant Mixing.

(1) *Mixing equipment.*

Figure 4-52. Spreading and compacting *train.*

(a) Stationary plants. Generally, stationary plant mixing is accomplished at a location away from the road site, frequently at the aggregate source. A stationary plant consists of a mixer and equipment for heating the asphalt (if necessary) and for feeding the asphalt, aggregate, and additives (if needed) to the mixer. It is similar in many respects to the hot-mix plant, except that it has no dryer or screens other than a scalping screen. Like the bigger hot-mix plant, a stationary cold-mix plant may be either a batch or continuous type, although the latter is most prevalently used for cold-mix construction (figs 4-53 and 4-54). Any type of plant that can produce an asphalt mixture conforming to the specifications can be used. But, as a minimum, it should be equipped with temperature and metering devices to control accurately the asphalt material being applied to the aggregate and controlled feeders for proportioning aggregates and additives. Although not always a plant component, a storage silo allows a more continuous mixing operation, resulting in better mix uniformity.

(b) Haul trucks. Several types of haul trucks may be used for cold mix produced in stationary plants; the type selected depends on the spreading equipment. The traditional raised-bed end-dump truck can be used with windrowers or pavers with hoppers. Bottom dumps produce windrows and are not used with pavers with hoppers unless a low-lift loader is used to transfer the mix to the hopper. Horizontal discharge trucks deposit the mix directly into the paver's hopper without raising the bed. These trucks may also be used with windrow spreader boxes. A sufficient number of haul trucks with smooth, clean beds should be available to ensure uniform operation of the mixing plant and paver.

(2) *Spreading equipment.*

(a) Paver. If climatic conditions and aggregate gradation permit evaporation of moisture or

Figure 4-53. Stationary cold-mix plant.

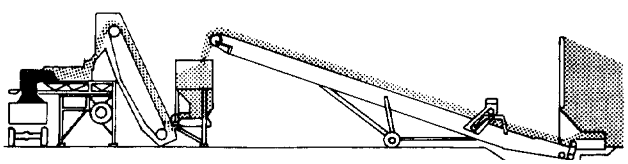


Figure 4-54. Flow diagram of a typical cold-mix continuous plant.

volatiles without aeration by manipulation, a conventional self-propelled asphalt paver may be used to place asphalt cold mixture (fig 4-55). A full-width paver may be used if the plant can produce enough mixture to keep the paver moving without start-stop operation (fig 4-56).

(b) Spreaders. Spreading equipment such as the Jersey Spreader and towed spreaders are commonly used. The Jersey Spreader is a hopper, with front wheels, that is attached to the front end of a crawler or rubber-tired tractor, into which the asphalt mixture is dumped. The mixture falls directly to the road and is struck off and spread to controlled thickness (fig 4-57). To begin spreading the mixture at the specified depth, the tractor should be driven onto blocks or boards of a height equal to the depth of spread and placed so that the tractor will ride directly onto the newly-placed material. Once spreading has begun, a continuous

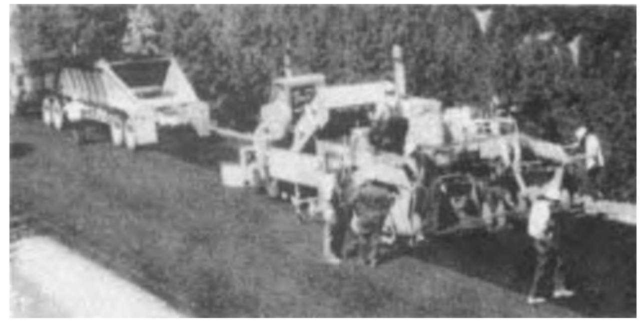


Figure 4-55. Spreading cold mix with conventional paver.

Figure 4-56. Spreading cold mix with full-width cutter-trimmer modified for paving.

flow of mixture from the haul truck to the spreader must be maintained. Towed-type spreaders are attached to the rear of haul trucks (fig 4-58). The asphalt cold mix is deposited into the hopper and falls directly to the surface being paved. As the truck moves forward, the mixture is struck off by a cutter bar, a blade, or by the screed and is ironed out by the screed or by rollers. Many towed-type spreaders have floating screeds. In order for the spreader to start out spreading to full depth, blocking should be placed under the screen before any mixture is dumped into the hopper. The hopper should be kept full of material during paving operations to ensure a full, even spread. The spreader should be towed at a uniform speed for any given setting of the screed or strike-off gate. Variations in towing speed will vary spread thickness.

d. Central Plant Mix Construction.

(1) *Preparation of mixture.* In batch-type plants, mixing is usually accomplished by a twin-shafted pugmill having a capacity of not less than 2,000 pounds. The correct amounts of asphalt and aggregate, generally determined by weight, are fed into the pug-mill. The batch is then mixed and discharged into a haul truck before another batch is mixed. In the continuous-mixing plant, the devices feeding asphalt, aggregate, and water, if needed, are interlocked to maintain automatically the correct proportions. Typically, automatic feed-

Figure 4-57. Jersey spreader.

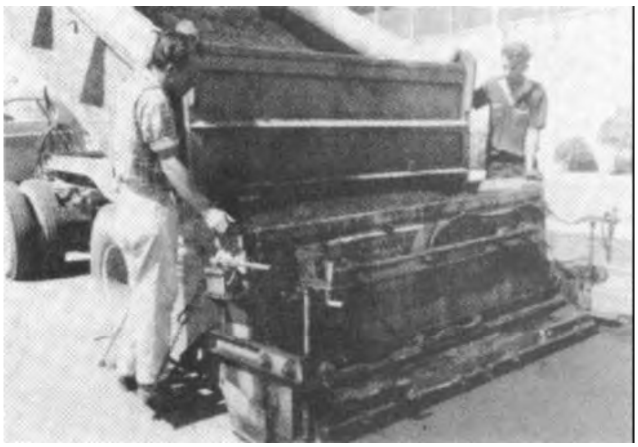


Figure 4-58. Towed-type spreader.

ers measure and govern the flow of aggregates in relation to the output of a positive displacement asphalt metering pump. A spray nozzle arrangement at the mixer distributes the asphalt over the aggregate. As the proportioned materials move through the pugmill, completely mixed material, ready for spreading, is discharged for subsequent hauling to the road site.

(2) *Aerating plant* mix. Mixtures that require aerating are generally deposited upon the roadbed in windrows and then are spread from these windrows. The cold mix is spread with a motor grader and aerated by blading it back and forth, or it is aerated by rotary tiller mixing equipment.

(3) *Spreading and compacting plant mix.* If aeration is not required-as is generally the case with plant-mixed emulsified asphalt mixes-the mixture is most effectively spread with asphalt pavers having automatic controls. For deep lifts, however, other equipment such as the Jersey Spreader type, towed spreaders, large cutter-trimmer-spreaders, or motor graders may be used. Similar to mixed-in-place, central plant cold mixes gain stability as the diluents (that have made the mix workable) evaporate. It is important not to hinder this process. Therefore, lift thicknesses are limited by the rate that the mixture loses its diluents. The most important factors affecting this loss are the type of asphalt, diluent content, gradation, and temperature of the aggregate, wind velocity, ambient temperature, and humidity. Because of these variables, local experience is likely to be the best guide in determining allowable placement thicknesses. The mixture should be spread uniformly on the roadbed, beginning at the point farthest from the mixing plant. Hauling over freshly placed material should not be permitted except when required for completion of the work.

CHAPTER 5

QUALITY CONTROL

5-1. General Purpose. Quality control is essential to ensure that the final product will be adequate for its intended use. It must also ensure that the contractor has performed in accordance with the plans and specification, as this is a basis for payment. This section identifies those control factors which are most important in soil stabilization construction with cement, lime, lime-fly ash, and asphalt.

5-2. Cement Stabilization. Those factors which are most important for a quality control standpoint in cement stabilization are: pulverization, cement content, moisture content, uniformity of mixing, time sequence of operations, compaction, and curing. These are described in detail below.

a. Pulverization. Pulverization is generally not a problem in cement construction unless clayey or silty soils are being stabilized. A sieve analysis is performed on the soil during the pulverization process with the No. 4 sieve used as a control. The percent pulverization can then be determined by calculation. Proper moisture control is also essential in achieving the required pulverization.

b. Cement content. Cement content is normally expressed on a volume or dry weight basis. Field personnel should be aware of quantities of cement required per linear foot or per square yard of pavement. Spot check can be used to assure that the proper quantity of cement is being applied, by using a canvas of known area or, as an overall check, the area over which a known tonnage has been spread.

c. Moisture content. The optimum moisture content determined in the laboratory is used as an initial guide when construction begins. Allowance must be made for the in situ moisture content of the soil when construction starts. The optimum moisture content and maximum density can then be established for field control purposes. Mixing water requirements can be determined on the raw soil or on the soil-cement mix before addition of the mixing water. Nuclear methods can be used to determine moisture content at the time construction starts and during processing.

d. *Uniformity of mixing.* A visual inspection is made to assure the uniformity of the mixture throughout the treated depth. Uniformity must be checked across the width of the pavement and to the desired depth of treatment. Trenches can be dug and then visually inspected. A satisfactory mix will exhibit a uniform color throughout; whereas, a streaked appearance indicates a nonuniform mix. Special attention should be given to the edges of the pavement.

e. Compaction. Equipment used for compaction is the same that would be used if no cement were present in the soil, and is therefore dependent upon soil type. Several methods can be used to determine compacted density: sand-cone, balloon, oil, and nuclear method. It is important to determine the depth of compaction and special attention should be given to compaction at the edges.

f. Curing. To assure proper curing a bituminous membrane is frequently applied over large areas. The surface of the soil cement should be free of dry loose material and in a moist condition. It is important that the soil-cement mixture be kept continuously moist until the membrane is applied. The recommended application rate is 0.15 to 0.30 gallons per square yard.

5-3. lime Stabilization. The most important factors to control during soil-lime construction are pulverization and scarification, lime content, uniformity of mixing, time sequence of operations, compaction and curing.

a. Pulverization and scarification. Before application of lime, the soil is scarified and pulverized. To assure the adequacy of this phase of construction, a sieve analysis is performed. Most specifications are based upon a designated amount of material passing the 1 inch and No. 4 sieves. The depth of scarification or pulverization is also of importance as it relates to the specified depth of lime treatment. For heavy clays, adequate pulverization can best be achieved by pretreatment with lime, but if this method is used, agglomerated soil-lime fractions may appear. These fractions can be easily broken down with a simple kneading action and are not necessarily indicative of improper pulverization.

b. Lime content. When lime is applied to the pulverized soil, the rate at which it is being spread can be determined by placing a canvas of known area on the ground and, after the lime has been spread, weighing the lime on the canvas. Charts can be made available to field personnel to determine if this rate of application is satisfactory for the lime content specified. To accurately determine the quantity of lime slurry required to provide the desired amount of lime solids, it is necessary to know the slurry composition. This can be done by checking the specific gravity of the slurry, either by a hydrometer or volumetric-weight procedure.

c. Uniformity of mixing. The major concern is to obtain a uniform lime content throughout the depth of treated soil. This presents one of the most difficult factors to control in the field. It has been reported that mixed soil and lime has more or less the same outward appearance as mixed soil without lime. The use of phenolphthalein indicator solution for control in the field has been recommended. This method, while not sophisticated enough to provide an exact measure of lime content for depth of treatment, will give an indication of the presence of the minimum lime content required for soil treatment. The soil will turn a reddishpink color when sprayed with the indicator solution, indicating that free lime is available in the soil (pH = 12.4).

d. Compaction. Primarily important is the proper control of moisture-density. Conventional procedures such as sand cone, rubber balloon, and nuclear methods have been used for determining the density of compacted soil lime mixtures. Moisture content can be determined by either oven-dry methods or nuclear methods. The influence of time between mixing and compacting has been demonstrated to have a pronounced effect on the properties of treated soil. Compaction should begin as soon as possible after final mixing has been completed. The National Lime Association recommends an absolute maximum delay of one week. The use of phenolphthalein indicator solution has also been recommended for lime content control testing. The solution can be used to distinguish between areas that have been properly treated and those that have received only a slight surface dusting by the action of wind. This will aid in identifying areas where density test samples should be taken.

e. Curing. Curing is essential to assure that the soil lime mixture will achieve the final properties desired. Curing is accomplished by one of two methods: moist curing, involving a light sprinkling of water and rolling; or membrane curing, which involves sealing the compacted layer with a bituminous seal coat. Regardless of the method used, the entire compacted layer must be properly protected to assure that the lime will not become nonreactive through carbonation. Inadequate sprinkling which allows the stabilized soil surface to dry will promote carbonation.

5-4. Lime-Fly Ash (LF) and Lime-Cement-Fly Ash (LCF). The nature of lime-fly ash and lime-cement-fly ash stabilization is similar to that for lime only. Consequently, the same factors involved for quality control are suggested.

5-5. Bituminous Stabilization. The factors that seem most important to control during construction with bituminous stabilization are surface moisture content, viscosity of the asphalt, asphalt content, uniformity of mixing, aeration, compaction, and curing.

a. Surface moisture content. The surface moisture of the soil to be stabilized is of concern. Surface moisture can be determined by conventional methods, such as oven-drying, or by nuclear methods. The Asphalt Institute recommends a surface moisture of up to three percent or more for use with emulsified asphalt and a moisture content of less than three percent for cutback asphalt. The gradation of the aggregate has proved to be of significance as regards moisture content. With densely graded mixes, more water is needed for mixing than compaction. Generally, a surface moisture content that is too high will delay compaction of the mixture. Higher plasticity index soils require higher moisture contents.

b. Viscosity of the asphalt. The Asphalt Institute recommends that cold-mix construction should not be performed at temperatures below 50 degrees F. The asphalt will rapidly reach the temperature of the aggregate to which it is applied and at lower temperature difficulty in mixing will be encountered. On occasion, some heating is necessary with cutback asphalts to assure that the soil aggregate particles are thoroughly coated.

c. Asphalt content. Information can be provided to field personnel which will enable them to determine a satisfactory application rate. The asphalt content should be maintained at optimum or slightly below for the specified mix. Excessive quantities of asphalt may cause difficulty in compaction and result in plastic deformation in service during hot weather.

d. Uniformity of mixing. Visual inspection can be used to determine the uniformity of the mixture. With emulsified asphalts, a color change from brown to black indicates that the emulsion has broken. The Asphalt Institute recommends control of three variables to assure uniformity for mixed-in-place construction: travel speed of application equipment; volume of aggregate being treated; and flow rate (volume per unit time) of emulsified asphalt being applied. In many cases, an asphalt content above design is necessary to assure uniform mixing.

e. Aeration. Prior to compaction, the diluents that facilitated the cold-mix operation must be allowed to evaporate. If the mix is not sufficiently aerated, it cannot be compacted to acceptable limits. The Asphalt Institute has determined that the mixture has sufficiently aerated when it becomes tacky and appears to "crawl." Most aerating occurs during the mixing and spreading stage, but occasionally additional working on the roadbed is necessary. The Asphalt Institute has reported that overmixing in central plant mixes can cause emulsified asphalts to break early, resulting in a mix that is difficult to work in the field.

f. Compaction. Compaction should begin when the aeration of the mix is completed. The Asphalt Institute recommends that rolling begin when an emulsified asphalt mixture begins to break (color change from brown to black). Early compaction can cause undue rutting or shoving of the mixture due to overstressing under the roller. The density of emulsion stabilized bases has often been found to be higher than that obtained on unstabilized bases for the same compaction effort.

g. Curing. Curing presents the greatest problem in asphalt soil stabilization. The Asphalt Institute has determined that the rate of curing is dependent upon many variables: quantity of asphalt applied, prevailing humidity and wind, the amount of rain, and the ambient temperature. Initial curing must be allowed in order to support compaction equipment. This initial curing, the evaporation of diluents, occurs during the aeration stage. If compaction is started too early, the pavement will be sealed, delaying dehydration, which lengthens the time before design strength is reached. The heat of the day may cause the mixture to soften, which prohibits equipment from placing successive lifts until the following day. This emphasizes the need to allow sufficient curing time when lift construction is employed. The Asphalt Institute recommends a 2- to 5-day curing period under good conditions when emulsified bases are being constructed. Cement has been used to accelerate curing.

APPENDIX A

REFERENCES

Government Publications.

Department of Defense

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

Departments of the Army and Air Force

TM 5-822-5/ AFM 88-7 Chap. 3	Pavement Design for Roads, Streets, Walks, and Open-Storage Areas
TM 5-822-8/ AFM 88-6 Chap. 9	Bituminous Pavements-Standard Practice
TM 5-825-2/ AFM 88-6 Chap. 2	Flexible Pavements Design for Airfields
TM 5-825-3/ AFM 88-6 Chap. 3	Rigid Pavements for Airfields

Nongovernment Publications

American Society for Testing and Materials (ASTM): 1961 Race Street, Philadelphia, PA 19103

Soil Stabilization with Admixtures

C 51-90	Terminology Relating to Lime and Limestone (as Used by the Industry)
C 150-89	Specification for Portland Cement
C 593-89	Fly Ash and Other Pozzolans for Use with Lime
C 977-89	Specification for Quicklime and Hydrated Lime for Soil Stabilization
D 98-87	Specification for Calcium Chloride
D 422-63	Particle-Size Analysis of Soils
D 423-66	Test for Liquid Limit of Soils
D 424-59	Test for Plastic Limit and Plasticity Index of Soils
D 558-82	Test Methods for Moisture-Density Relations of Soil-Cement Mixtures
D 559-89	Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures
D 560-89	Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures
D 698-78	Test methods for Moisture-Density Relations of Soils and Soil Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop
D 806-89	Test Method for Cement Content of Soil-Cement Mixtures
D 1411-82	Test Methods for Water-Soluble Chlorides Present as Admixes in Graded Aggregate Road Mixes

D 1557-78	Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop
D 1632-87	Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory
D 1633-84	Test Method for Compressive Strength of Molded Soil-Cement Cylinders
D 1634-87	Test Method for Compressive Strength of Soil-Cement Using Portions of Beams Broken in Flexure (Modified Cube Method)
D 1635-87	Test Method for Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading
D 1883-84	Bearing Ratio of Laboratory Compacted Soils
D 2487-85	Test Methods for Classification of Soils for Engineering Purposes
D 2901-82 (1986)	Test method for Cement Content of Freshly Mixed Soil-Cement
D 3155-83	Test Method for Lime Content of Uncured Soil-Lime Mixtures
D 3551-83	Method for Laboratory Preparation of Soil-Lime Mixtures Using a Mechanical Mixer
D 3668-78 (1985)	Test Method for Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures
D 3877-80 (1985)	Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures
D 4223-83	Practice for Preparation of Test Specimens of Asphalt-Stabilized Soils
D 4318-84	Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D 4609-86	Guide for Screening Chemicals for Soil Stabilization
D 4832-88	Test Method for Preparation and Testing of Soil-Cement Slurry Test Cylinders

APPENDIX B

pH TEST ON SOIL-CEMENT MIXTURES

B-1. Materials. Portland cement to be used for soil stabilization.

B-2. Apparatus. Apparatuses used are the pH meter (the pH meter must be equipped with an electrode having a pH range of 14), 150-millilitre plastic bottles with screw-top lids, 500-millilitre plastic beakers, distilled water, balance, oven and moisture cans.

B-3. Procedure.

a. Standardization. Standardize the pH meter with a buffer solution having a pH of 12.00.

b. Representative samples. Weight to the nearest 0.01 grams, representative samples of air-dried soil, passing the No. 40 sieve and equal to 25.0 grams of oven-dried soil.

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

d. Portland cement. Add 2.5 grams of the portland cement.

e. Mixture. Thoroughly mix soil and portland cement.

f. Distilled water. Add sufficient distilled water to make a thick paste. (Caution: Too much water will reduce the pH and produce an incorrect result.)

g. Blending. Stir the soil-cement and water until thorough blending is achieved.

h. Transferal After 15 minutes, transfer part of the paste to a plastic beaker and measure the pH.

i. Interference. If the pH is 12.1 or greater, the soil organic matter content should not interfere with the cement stabilizing mechanism.

APPENDIX C

DETERMINATION OF SULFATE IN SOILS GRAVIMETRIC METHOD

C-1. Gravimetric Method.

a. Scope. Applicable to all soil types with the possible exception of soils containing certain organic compounds. This method should permit the detection of as little as 0.05 percent sulfate as SO,.

b. Reagents. Reagents include barium chloride, 10 percent solution of $BaCl_2 \cdot 2H_2O$ (Add 1 milliliter 2 percent HCl to each 100 milliliter of solution to prevent formation of carbonate.); hydrochloric acid, 2 percent solution (0.55 N); magnesium chloride, 10 percent solution of $MgCl_2 \cdot 6H_2O$; demineralized water; and silver nitrate, 0.1 N solution.

c. Apparatus. Apparatus used are a beaker, 100 milliliter; burner and ring stand; filtering flask, 500 milliliter; Buchner funnel, 90 milliliter; filter paper, Whatman No. 40, 90 millimeter; filter paper, Whatman No. 42, 90 millimeter; Saran Wrap; crucible, ignition, or aluminum foil, heavy grade; analytical balance; and aspirator or other vacuum source.

d. Procedure.

(1) Select a representative sample of air-dried soil weighing approximately 10 grams. Weigh to the nearest 0.01 gram. (Note: When sulfate content is anticipated to be less than 0.1 percent, a sample weighing 20 gram or more may be used.) (The moisture content of the air-dried soil must be known for later determination of dry weight of the soil.)

(2) Boil for 1-1/2 hours in beaker with mixture of 300-milliliter water and 15-milliliter HCl.

(3) Filter through Whatman No. 40 paper, wash with hot water, dilute combined filtrate and washings to 50 milliliter.

(4) Take 100 milliliter of this solution and add $MgCl_2$ solution until no more precipitate is formed.

(5) Filter through Whatman No. 42 paper, wash with hot water, dilute combined filtrates and washings to 200 milliliter.

(6) Heat 100 milliliter of this solution to boiling and add $BaCl_2$ solution very slowly until no more precipitate is formed. Continue boiling for about 5 minutes and let stand overnight in warm place, covering beaker with Saran Wrap.

(7) Filter through Whatman No. 42 paper. Wash with hot water until free from chlorides (filtrate should show no precipitate when a drop of $AgNO_3$ solution is added).

(8) Dry filter paper in crucible or on sheet of aluminum foil. Ignite paper. Weight residue on analytical balance as $BaSO_4$.

e. Calculation.

$$\text{Percent SO,} = \frac{\text{Weight of residue}}{\text{Oven-dry weight of initial sample}} \times 411.6$$

where

Oven-dry weight of initial sample

$$= \frac{\text{Air-dry weight of initial sample}}{1 + \frac{\text{Air-dry moisture content (percent)}}{100 \text{ percent}}}$$

Note: If precipitated from cold solution, barium sulfate is so finely dispersed that it cannot be retained when filtering by the above method. Precipitation from a warm, dilute solution will increase crystal size. Due to the absorption (occlusion) of soluble salts during the precipitation by $BaSO_4$, a small error is introduced. This error can be minimized by permitting the precipitate to digest in a warm, dilute solution for a number of hours. This allows the more soluble small crystals of $BaSO_4$ to dissolve and recrystallize on the larger crystals.

C-2. Turbidimetric Method

a. Reagents. Reagents include barium chloride crystals (Grind analytical reagent grade barium chloride to pass a 1-millimeter sieve.); ammonium acetate solution (0.5 N) (Add dilute hydrochloric acid until the solution has a pH of 4.2); and distilled water.

b. Apparatus. Apparatus used are a moisture can; oven, 200-milliliter beaker; burner and ring stand; filtering flask; Buchner funnel, 90 millimeter; filter paper, Whatman No. 40, 90 millimeter; vacuum source; spectrophotometer and standard tubes (Bausch and Lombe Spectronic 20 or equivalent) and pH meter.

c. Procedure.

(1) Take a representative sample of air-dried soil weighing approximately 10 grams, and weight to the nearest 0.01 grams. (The moisture content of the air-dried soil must be known for later determination of dry weight of the soil.)

(2) Add the ammonium acetate solution to the soil. (The ratio of soil to solution should be approximately 1:5 by weight.)

(3) Boil for about 5 minutes.

(4) Filter through Whatman No. 40 filter paper. If the extracting solution is not clear, filter again.

(5) Take 10 milliliter of extracting solution (this may vary, depending on the concentration of sulfate in the solution) and dilute with distilled water to about 40 milliliter. Add about 0.2 gram of barium chloride crystals and dilute to make the volume exactly equal to 50 milliliter. Stir for 1 minute.

(6) Immediately after the stirring period has ended, pour a portion of the solution into the standard tube and insert the tube into the cell of the spectrophotometer. Measure the turbidity at 30-second intervals for 4 minutes. Maximum turbidity is usually obtained within 2 minutes and the readings remain constant thereafter for 3-10 minutes. Consider the turbidity to be the maximum reading obtained in the 4-minute interval.

(7) Compare the turbidity reading with a standard curve and compute the sulfate concentration (as SO_4) in the original extracting solution. (The standard curve is secured by carrying out the procedure with standard potassium sulfate solutions.)

(8) Correction should be made for the apparent turbidity of the samples by running blanks in which no barium chloride is added.

d. Sample calculation.

Given:

Weight of air-dried sample = 10.12 grams
Water content = 9.36 percent
Weight of dry soil = 9.27 grams
Total volume of extracting solution = 39.1 milliliters

10 milliliters of extracting solution was diluted to 50 milliliters after addition of barium chloride (see step 5). The solution gave a transmission reading of 81. From the standard curve, a transmission reading of 81 corresponds to 16.0 parts per million. (See fig C-l)

Concentration of original extracting solution = 16.0 x 5 = 80.0 parts per million.

$$\text{Percent } SO_4 = \frac{80.0 \times 39.1 \times 100}{1{,}000 \times 1{,}000 \times 9.27} = 0.0338 \text{ percent}$$

e. Determination of standard curve.

(1) Prepare sulfate solutions of 0, 4, 8, 12, 16, 20, 25, 30, 35, 40, 45, and 50 parts per million in separate test tubes. The sulfate solution is made from potassium sulfate salt dissolved in 0.5 N ammonium acetate (with pH adjusted to 4.2).

(2) Continue steps 5 and 6 in the procedure as described in Determination of Sulfate in Soil by Turbidimetric Method.

(3) Draw standard curve as shown in figure C-l by plotting transmission readings for known concentrations of sulfate solutions.

Figure C-1. Example standard curve for spectrophotometer.

APPENDIX D

pH TEST TO DETERMINE LIME REQUIREMENTS FOR LIME STABILIZATION

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

D-2. Apparatus. Apparatus include pH meter (the pH meter must be equipped with an electrode having a pH range of 14), 150-milliliter (or larger) plastic bottles with screw-top lids, 50-milliliter plastic beakers, distilled water that is free of CO,, balance, oven, and moisture cans.

D-3. Procedure.

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

b. Weight samples. 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 samples. Pour the soil samples into 150-milliliter plastic bottles with screw-top lids.

d. Add lime. Add varying percentages of lime, weighed 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. Mix. Thoroughly mix soil and dry lime.

f. Add distilled water. Add 100 milliliters of distilled water that is CO,-free to the soil-lime mixtures.

g. Snake soil-lime and water. 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 bottles. Shake the bottles for 30 seconds every 10 minutes.

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

j. Record pH. 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 123.40, the minimum lime content giving the highest pH is required to stabilize the soil.

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By Order of the Secretaries of the Army and Air Force:

GORDON R. SULLIVAN
General, United States Army
Chief of Staff

Official:

MILTON H. HAMILTON
Administrative Assistant to the Secretary of the Army

OFFICIAL

JAMES E. MCCARTHY, Maj *General, USAF*
The Civil Engineer

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Air Force: F

* U.S. G.P.O.:1994-300-723:58