UFC 3-250-11
30 November 2020

UNIFIED FACILITIES CRITERIA (UFC)

SOIL STABILIZATION AND MODIFICATION FOR PAVEMENTS

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

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

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

Change No.	Date	Location

This UFC supersedes UFC 3-250-11, *Soil Stabilization for Pavements*, dated January 16, 2004.

FOREWORD

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 most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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- Whole Building Design Guide web site http://www.wbdg.org/ffc/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

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UNIFIED FACILITIES CRITERIA (UFC) REVISION SUMMARY SHEET

Document: UFC 3-250-11, *Soil Stabilization and Modification for Pavements*

Superseding: This UFC supersedes UFC 3-250-11, *Soil Stabilization for Pavements*, dated January 16, 2004.

Description: This UFC documents the standard practice of stabilizing and modifying soil for use in pavement and operating surfaces. It provides guidance for improving the engineering properties of soils used for pavement base courses, subbase courses, and subgrades by the use of additives mixed into the soil to effect the desired improvement. This UFC is also applicable to roads, airfields, and construction platforms having a stabilized surface layer.

Reasons for Document: This update brings the document in compliance with UFC 1-300-01, *Criteria Format Standard*. Editorial changes were made to improve readability, correct typographical errors, and update outdated references.

Impact: Cost impact is negligible; improved guidance typically results in improved performance and reduced lifecycle cost.

Unification Issues: None

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FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1-1 PURPOSE.

This UFC documents the standard practice for improving the engineering properties of soils used for operating surfaces, pavement base courses, subbase courses, and subgrades by the use of additives mixed into the soil to effect the desired improvement. It also provides criteria and guidance for the stabilization and modification of soils for pavements, operating surfaces, and construction platforms. This UFC is also applicable to roads, airfields, and construction platforms having a stabilized surface layer. These soil improvements consist of applying a chemical such as lime, cement, or bitumen to a layer of soil or aggregate that will be included within a pavement area. Stabilization or modification measures discussed herein are useful to limit expansive soil's ability to expand and contract due to changes in moisture content, increase the soil's shear strength to prevent or minimize pumping, or to bind soils or aggregates.

1-2 SCOPE.

This UFC prescribes the appropriate type(s) of additive to be used with different soil types, procedures for determining a design treatment level for each type of additive, and standard construction practices for incorporating the additive into the soil. This UFC provides criteria and guidance on stabilization or modification using portland cement, lime, lime-fly ash, lime-cement-fly ash, bitumen, polymer, lime-cement, lime-bitumen, or geo-synthetic fibers.

1-3 APPLICABILITY.

Soil stabilization and modification are optional. The installation, in conjunction with the designers of record, determines whether to include soil stabilization or modification in the pavement design. Apply the requirements in this UFC when soil stabilization or modification is included in the design. These requirements are dependent upon each individual site's soil conditions.

1-4 USES OF STABILIZATION/MODIFICATION.

Pavement design is based on the premise that the specified structural quality will be achieved for each layer of material in the pavement system. Each layer resists shearing, avoids excessive deflections that cause cracking within the layer or in overlying layers, and prevents excessive permanent deformation. As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is increased so a reduction in the required thickness of the soil and surface layers is achieved.

1-4.1 Quality Improvement.

The most common improvements achieved through stabilization/modification include better soil gradation, reduced plasticity index (PI) or swelling potential, and increased durability and strength. Stabilization may be used to provide a working platform for construction.

1-4.2 Thickness Reduction.

The strength 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 and evaluating pavements that include stabilized soils are presented in UFC 3-250-01, *Paving Design for Roads and Parking Areas*, UFC 3-250-03, *Standard Practice Manual for Flexible Pavements*, and UFC 3-260-02, *Pavement Design for Airfields*. 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 UFC for the particular type of material. See Appendix A for examples of reducing design thickness when using stabilized materials.

1-4.3 Operating Surfaces.

Stabilized materials can be used to construct operating surfaces. These cases are typically for temporary construction platforms, roads, or airfields where poor soils exist and conventional pavements cannot be feasibly constructed. For roads and airfields, adhere to the strength, durability, and construction criteria in this UFC.

1-5 DEFINITIONS.

Appendix B contains a list of acronyms and definitions.

1-6 REFERENCES.

Appendix C contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 SELECTION OF ADDITIVE

2-1 FACTORS TO CONSIDER.

In the selection of a stabilizer, the factors to consider 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, the type and availability of the additive, the cost, and environmental conditions.

2-1.1 Soil Types and Additives.

There may be more than one candidate stabilizer applicable for an individual soil type; however, there are 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 the cement be mixed intimately with the fines fraction (< 0.074 mm), avoid plastic soils unless steps are taken to reduce the plasticity. Generally, well-graded granular materials that possess fines to produce homogenous mixtures are best suited for portland cement stabilization. Lime will react with soils of medium to high plasticity to lower its plasticity, increase workability, reduce swell potential, and increase shear strength. In some cases, adding lime prior to adding soil cement will improve the workability of the soil cement. Lime is used to stabilize a variety of materials, including weak subgrade soils, transforming them into a "working table" or subbase; with marginal granular base materials (i.e., clay-gravels and "dirty" gravels) lime forms a strong, high-quality base course. Fly ash is a pozzolanic material—it reacts with lime and is therefore almost always used in combination with lime in soils that have little or no plastic fines. The use of portland cement with lime and fly ash for added strength is often required. This combination of lime-cement-fly ash (LCF) has been used successfully in base course stabilization. Asphalt, bituminous, or polymer materials are used for waterproofing and gaining strength. Generally, soils suitable for asphalt or polymer stabilization are silty sands and granular materials because thoroughly coating all the soil particles is desirable. Fibers may be used in combination with some additives to improve strength and crack resistance, but they severely limit workability after mixing with soil.

Do not create a solid, rigid, or brittle surface that will lead to reflective cracking of the surface pavement when designing stabilized base and subbase layers for pavements. Each type of stabilization method has limitations and appropriate uses; therefore, create and test a representative mix design for each individual scenario of the planned field operations. Evaluate each stabilized soil layer to establish the appropriate thickness of stabilized soil to prevent undesired effects to the finished pavement surfaces. Include a bond breaker when overlaying a stabilized layer using portland cement.

2-1.1.1 Portland Cement Stabilization.

Cement stabilization utilizes mixing dry portland cement powder into the subbase soils to increase the shear strength within the treated layer. Typically, this is accomplished by using a dosage rate of 3 to 6 percent by weight portland content and mixing it approximately 1 to 2 feet (0.3 to 0.6 m) in depth. These are general estimations; the procedure to determine the dosage rate is described in paragraph 3-1 and its subparagraphs. Use layered elastic pavement design procedures described in UFC 3-260-02 to determine the depths to which mixing must occur.

2-1.1.2 Lime Stabilization or Modification.

Lime modification utilizes mixing dry hydrated lime (powder) or quicklime (granulated) into the subgrade/subbase soils to lower the PI of the soil to control the shrink/swell potential of the soil. Lime stabilization utilizes mixing lime or quicklime into the subgrade, select fill, and or subbase material to increase the pH to generate a pozzolanic reaction that increases the soil's shear strength. This requires fine-grained soils with a minimum fraction of silt and clay to be reactive and is not effective on granular materials. Typically, lime modification is performed on the upper layer of subgrade, select fill, and/or subbase and mixing is approximately 0.75 to 2 feet (0.2 to 0.6 m) in depth**.** These are general estimations; the procedure to determine the dosage rate is described in paragraph 3-2 and its subparagraphs. Use layered elastic pavement design procedures described in UFC 3-260-02 to determine the depths to which mixing must occur.

2-1.1.3 Lime-Fly Ash or Lime-Cement-Fly Ash Stabilization.

Fly ash acts similarly to portland cement and is used to reduce the quantity of lime or portland cement necessary to achieve the desired stabilization/modification effect. Fly ash is a cheaply obtained industrial byproduct used for cost reduction and can stabilize more coarse gradations than lime alone. Fly ash physical and chemical properties can vary widely. Investigate each locally available product for its applicability to the specific project. Additional information is in paragraph 3-3.

2-1.1.4 Bitumen or Polymer Stabilization.

Bitumen and polymer stabilization increases adhesive properties, the shear strength of the soils, and decreases the effects of water on the treated soils. Bitumen and polymers are not effective against freeze-thaw action and testing the durability of the finished product is not possible. Additional information is in paragraph 3-4.

2-1.1.5 Lime-Cement or Lime-Bitumen Stabilization.

A lime-cement and lime-bitumen combination is used primarily when lime is needed to control the shrink/swell potential of soils and the treated soil has a low shear strength. Portland cement-bitumen is used to increase the shear strength to a desired minimum strength. Bitumen and polymers are not effective against freeze-thaw action and testing the durability of the finished product is not possible. Additional information is in paragraph 3-5.

2-1.1.6 Geosynthetic Fiber Stabilization.

Geosynthetic fiber stabilization increases the shear strength of the soils. It is not effective in controlling shrink/swell characteristics of soils. Installation of the fibers can be problematic in the field. It requires material-specific experience and attentive quality control and quality assurance to ensure proper construction. Additional information is in paragraph 3-6.

2-1.2 Screening Tests for Organic Matter and Sulfates.

The presence of organic matter and/or sulfates frequently has deleterious effects on stabilized soil or the additives used, preventing the stabilization process from occurring. Perform testing for detection of these materials if their presence is suspected.

2-1.2.1 Organic Matter.

A soil may be acidic, neutral, or alkaline and still respond well to cement treatment. Although certain types of organic matter, such as undecomposed vegetation, may not adversely influence stabilization, organic materials such as humic acid 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 A. 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. Refer to ACI 230.1R, *Report on Soil Cement*, for additional guidance. Limit soil organic content to a maximum of 2 percent by weight and a minimum pH of 5.3 or more prior to the addition of soil cement, lime, or fly ash.

2-1.2.2 Sulfates.

Cements in contact with sulfates can generate a reaction that is expansive in nature and can damage aboveground, below ground, and nearby facilities if present with cement, lime, or fly ash-stabilized soils. The resistance to sulfate attack differs for cement-treated coarse-grained and fine-grained soils and is a function of sulfate concentrations. If sulfate concentration exceeds 0.1 percent by weight do not use cement or fly ash stabilization without prior authorization by the Pavements Discipline Working Group (DWG). Use the procedure in Appendix A or the current version of ASTM C1580, *Standard Test Method for Water-Soluble Sulfate in Soil*, to determine the concentrations of sulfate in the existing soil and groundwater. Do not design, specify, construct, or install soil cement, lime, or fly ash for soils containing more than 0.1 percent sulfate.

2-1.3 Traditional Additives.

2-1.3.1 Cement.

Portland cement can be used either to modify and improve the quality of the soil or transform the soil into a cemented mass with increased strength and durability. Cement can be used effectively as a stabilizer for a wide range of materials; however, the soil should have a PI less than 30 or the stabilization effects will be minimal. For coarse-grained soils, the amount passing the No. 4 (4.75 mm) sieve should be greater than 45 percent or the stabilization effects will be minimal. The amount of cement used depends on whether the soil is to be modified or stabilized.

When designing, specifying, or constructing using cement to stabilize base material for support of a rigid pavement, a bond breaker between the pavement concrete and the cement-stabilized base material to prevent adhesion at that interface is required. Adhesion of the concrete pavement to the cement-stabilized base results in unacceptable cracking. An asphalt emulsion bond breaker is not recommended because once the emulsion begins to dry and harden it does not perform as a bond breaker and instead causes further adherence problems. To create a bond break, install a layer of #89 stone meeting ASTM C33, *Standard Specification for Concrete Aggregates*, specifications between 0.25 and 0.5 inches (6.3 and 12.7 mm) in thickness. Then install a fabric meeting the requirements of AASHTO M288, *Standard Specification for Geosynthetic Specification for Highway Applications*, class I fabric with elongation less than 50 percent at the specified strengths, or install a double layer of liquid membrane-forming compound on the stabilized base prior to the placement of concrete. Do not design, specify, or install a layer of plastic or rubberized sheet material as a bond breaker without prior approval of the Pavements DWG. Do not design, specify, or construct PCC pavement slabs with joint spacing greater than 13 feet (4 m) over cement-stabilized base.

2-1.3.2 Lime.

Experience shows that lime will react with many medium-, moderately fine-, and fine-grained soils to produce decreased plasticity, increased workability, reduced swell, and increased strength. Consider using lime to stabilize soils classified according to the Unified Soil Classification System (USCS) as CH, CL, MH, ML, OH, OL, SC, SM, GC, GM, SW-SC, SP-SC, SM-SC, GW-GC, GP-GC, ML-CL, and GM-GC. Consider lime with all soils having a PI greater than 12 and more than 25 percent of the soil passing the No. 200 (0.075 mm) sieve. Do not design, specify, or construct lime-stabilized subgrade, subbase, or base soils with a sulfate content greater than 0.1 percent.

2-1.3.3 Fly Ash.

Fly ash, when mixed with lime, can effectively stabilize most coarse- and medium-grained soils; however, the PI cannot be greater than 25 and remain effective. Soils classified by the USCS as SW, SP, SP-SC, SW-SC, SW-SM, GW, GP, GP-GC, GW-GC, GP-GM, GW-GM, GC-GM, and SC-SM can be stabilized with fly ash. Some sources of fly ash may contain high amounts of sulfates. In some soils, this may lead to the formation of ettringite, which may swell excessively. Do not design, specify, or construct fly ash-stabilized subgrade, subbase, or base soils with a sulfate content greater than 0.1 percent.

2-1.3.4 Bituminous.

Most bituminous soil stabilization has been performed with asphalt cement, cutback asphalt, and asphalt emulsions. Soils that can be stabilized effectively with bituminous materials usually contain less than 30 percent passing the No. 200 (0.075 mm) sieve and have a PI less than 10. Soils classified by the USCS as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, SW-GM, SP-GM, SW-GC, GP-GC, GM, GC, and GM-GC can be effectively stabilized with bituminous materials, provided the above-mentioned gradation and plasticity requirements are met.

2-1.3.5 Combination.

Combinations of lime and cement are often acceptable expedient stabilizers. Lime can be added to the soil to increase the soil's workability and mixing characteristics as well as reduce its plasticity. Cement or fly ash can then be mixed into the soil to provide rapid strength gain. Combinations of lime and asphalt are often acceptable stabilizers. The lime addition may prevent stripping at the asphalt-aggregate interface and increase the mixture's stability. Do not design, specify, or construct lime cement combination-stabilized subgrade, subbase, or base soils with a sulfate content greater than 0.1 percent.

2-1.4 Non-Traditional Additives.

2-1.4.1 Polymers.

Polymer emulsions (sometimes referred to as latex) can be used for soil stabilization. The most common types of polymer emulsions used for soil stabilization are polyvinyl acetate-based copolymers. These materials have excellent adhesive characteristics and provide stiffness, toughness, and water resistance. Polymer emulsions typically consist of 45 to 60 percent polymer content by weight and cure mainly by water loss. These materials may be limited by shelf life. Do not mix polymer emulsions with gray water or salt water for dilution. Soils that can be stabilized with polymer emulsions are similar to those that can be stabilized by bitumen.

2-1.4.2 Fibers.

Numerous fiber types (e.g., polypropylene, polyvinyl alcohol, nylon, and natural) and morphologies (monofilament, fibrillated, and tape) are available. Most soils can be stabilized with fibers; however, mixing may be difficult in highly plastic soils. This difficulty limits the use of fibers for stabilizing fine-grained soils.

2-1.4.3 Non-traditional Additives.

A variety of other non-traditional soil stabilization and modification additives, such as acids, lignin derivatives, enzymes, tree resin emulsions, and silicates, are available from the commercial sector. These additives vary widely in their chemical composition and action mechanism, may be liquid or solid, and are often touted to be applicable for most soils. Research studies in this area have demonstrated that many non-traditional soil additives have little to no benefit for granular soil types. Sandy and gravelly soils are often problematic for stabilization, requiring a binder such as cement, polymer, or asphalt emulsion to provide cohesion between soil grains. Medium- and fine-grained soils are likely to benefit most from the other non-traditional stabilizers; however, these are treated on a case-by-case basis. Do not design, specify, or construct otherwise stabilized subgrade, subbase, or base soils without prior approval by the Pavements DWG.

2-1.4.4 Non-traditional Combinations.

Soil blended with combinations of traditional and non-traditional additives has been shown to be more effective than soil blended with a single additive. Polymer emulsions and hydraulic cements with and without synthetic fibers combine well, as do synthetic fibers and hydraulic cements. These combinations have shown promise in laboratory testing and field demonstrations. A synergism exists between emulsions and hydraulic cement: the water in the emulsion hydrates the cement and the polymer adds flexibility, water resistance, and crack resistance. The use of fibers improves the resistance of the soil to deformation and resists the tensile stresses that lead to cracking. However, fibers are difficult to use during construction as they reduce workability and are difficult to place in wind as they blow around and even be blown completely out of the construction area.

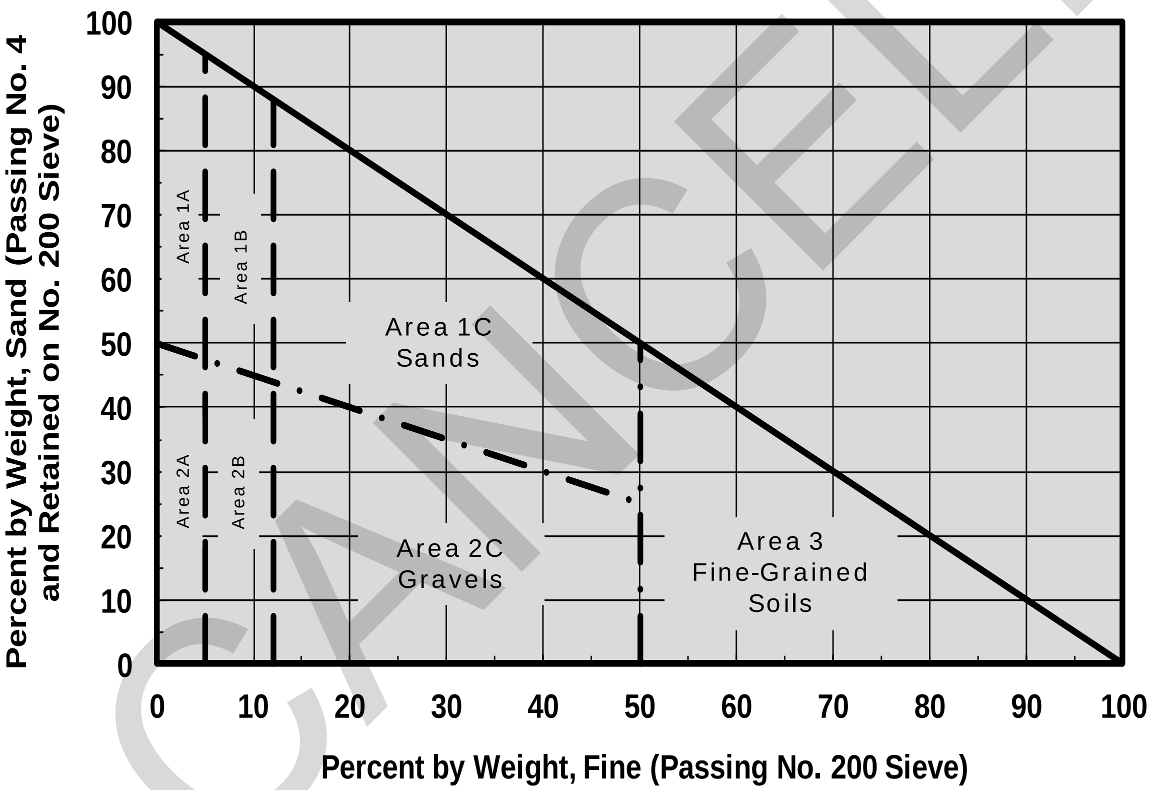
2-1.5 Selection of Candidate Additives.

2-1.5.1 Candidate Stabilizers.

The selection of candidate stabilizers is made using Figure 2-1 and Table 2-3. The soil gradation triangle in Figure 2-1 is based upon the soil grain-size characteristics. The triangle is divided into areas of soils with similar grain size and therefore pulverization characteristics. The selection process is continued with Table 2-3, which indicates candidate stabilizers for each area shown in Figure 2-1, with restrictions-based percent passing the No. 200 (0.075

mm) sieve, on grain size and/or PI. Also provided in the second column of Table 2-3 is a listing of soil classification symbols applicable to the area determined from Figure 2-1. This is an added check to ensure the proper area has been selected. Thus, the soil is characterized in terms of grain-size distribution and Atterberg limits to initiate the additive selection process. Data required to enter Figure 2-1 are (1) percent material passing the No. 200 (0.075 mm) sieve and (2) percent material passing the No. 4 (4.75 mm) sieve but retained on the No. 200 (0.075 mm) sieve (i.e., total percent material between the No. 4 (4.75 mm) and the No. 200 (0.075 mm) 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 2-3 and the soil classification is checked in the second column. Candidate stabilizers for each area are indicated in the third column and restrictions for the use of each material are presented in the subsequent columns.

Figure 2-1 Gradation Triangle for Aid in Selecting Commercial Stabilizing Agent



2-1.5.2 Restrictions.

These restrictions prevent the use of stabilizing agents that are not applicable for the particular soil type under consideration. For example, assume a soil classified as an SC, with 93 percent passing the No. 4 (4.75 mm) sieve and 25 percent passing the No. 200 (0.075 mm) sieve with a liquid limit (LL) of 20 and a plastic limit of 11. Thus, 68 percent of the material is between the No. 4 and No. 200 (0.075 mm) sieves and the PI is 9. Entering Figure 2-1 with the values of 25 percent passing the No. 200 (0.075 mm) sieve and 68 percent between the No. 4 (4.75 mm) and No. 200 (0.075 mm) sieves, the intersection of these values is found in area 1-C. Then, going to the first column of Table 2-3, we find area 1-C and verify the soil classification, SC, is included 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/polymer stabilization is acceptable since the PI does not exceed 10 and the amount of material passing the No. 200 (0.075 mm) sieve does not exceed 30 percent. However, note that the soil barely qualifies under these criteria and bituminous/polymer stabilization is probably not the first choice. The restrictions under portland cement indicate the PI is less than the equation indicated in footnote b. Since the PI, 9, is less than that value, portland cement is 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 stabilization indicate that the PI does not exceed 25; thus, LCF is also a candidate stabilizing material. At this point, the designer makes 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 are prepared and tested in the laboratory to develop a design mix meeting minimum engineering criteria for field stabilization.

2-1.5.3 Fibers.

Fibers can be used in many soil types because they provide mechanical stabilization. Monofilament, tape, and fibrillated fibers are most common for improving soils. They provide immediate improvements in load bearing and crack resistance by enhancing strain resistance. Fibers mixed into soil without adhesives (i.e., cement) rely on mechanical interlock, friction, and fiber entanglement between themselves and soil particles to anchor the fiber in place. Thus, a high surface area fiber (such as a tape fiber) may be more efficient in a fine-grained clay soil than in a coarse-grained soil such as gravel, where fewer soil grains are in contact with the fiber. Longer fibers generally result in improved performance but hamper construction. They are more difficult to mix and considerable “balling” may occur, diminishing efficiency. After mixing, workability is sharply reduced, making blade work and grading difficult.

2-2 USE OF STABILIZED SOILS IN FROST AREAS.

2-2.1 Frost Considerations.

Pavement systems may experience two general types of freeze-thaw action. Cyclic freeze-thaw occurs in the material when freezing occurs as the advancing frost line moves by and thawing subsequently occurs. Heaving conditions develop when a quasi-equilibrium frost line condition is established in the stabilized material layer. If the material is frost-susceptible, the static frost line situation provides favorable conditions for moisture migration and subsequent ice lens formation and heaving. While bituminous, polymer, 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 from the Pavements DWG. Additives and cold weather placement techniques are also available for portland cement stabilization and are addressed in Chapter 4.

2-2.2 Limitations.

In frost areas, stabilized soil is used in one of the upper elements of a pavement system only if the cost is justified by the reduced pavement thickness. Use a soil treatment with a lower degree of additive than that indicated for stabilization (i.e., soil modification) in frost areas only with caution and after intensive tests because weakly cemented material usually has less capacity to endure repeated freezing and thawing than firmly cemented material. A possible exception is modifying a soil that will be encapsulated within an impervious envelope as part of a membrane-encapsulated-soil-layer pavement system. A soil unsuitable for encapsulation due to excessive moisture migration and thaw weakening may be made suitable by moderate amounts of a stabilizing additive. Test modified materials to ascertain the desired improvement is durable through repeated freeze-thaw cycles. Do not stabilize soils to improve the strength at the expense of making the soil more susceptible to ice segregation.

2-2.3 Construction Cutoff Dates.

Construct materials stabilized with cement, lime, or LCF 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 °F (10 °C) than at 70 °F or 80 °F (21 °C or 27 °C). Chemical reactions will not occur rapidly for (1) lime-stabilized soils when the soil temperature is less than 60 °F (16 °C) and is not expected to increase for one month or (2) cement-stabilized soils when the soil temperature is less than 40 °F (4 °C) and is not expected to increase for one month. In frost areas, set a construction cutoff date well in advance of the onset of freezing conditions (e.g., 30 days) because it is not adequate to protect the mixture from freezing during a seven-day curing period as required by the applicable guide specifications if the lime or cement reactions continue past the seven-day period.

2-3 THICKNESS REDUCTION FOR BASE AND SUBBASE COURSES.

Ensure the stabilized base and subbase course materials meet the requirements of gradation, strength, and durability to qualify for reduced layer thickness design. Gradation requirements are presented in paragraphs 3-1 through 3-6 covering design with each type of stabilizer. Unconfined compressive strength and durability requirements for bases and subbases treated with cement, lime, lime-cement, lime-fly ash (LF), and LCF are indicated in Tables 2-1 and 2-2, respectively. For bituminous-stabilized materials to qualify for reduced thickness, ensure they meet strength requirements in UFC 3-260-02. Polymer emulsion materials qualify for reduced thickness when they meet a minimum unconfined compressive strength of 400 psi (2.76 MPa). Ensure all stabilized materials except those treated with bitumen and polymer emulsion meet minimum durability criteria to be used in pavement structures. There are no durability criteria for bituminous- or polymer emulsion-stabilized materials since it is assumed they will be waterproof if properly designed and constructed.

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

Stabilized Soil Layer	Minimum Unconfined Compressive Strength psi (MPa)[a]	
	Flexible pavement	Rigid pavement
Base course	750 (5.17)	500 (3.45)
Subbase course, select material or subgrade	250 (1.72)	200 (1.38)
[a] Unconfined compressive strength determined at 7 days for cement stabilization and 28 days for lime, LF ash, or LCF ash stabilization.		

Table 2-2 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 > 10	8
Silt	8
Clays	6

2-4 DRYING WET SOILS.

2-4.1 Chemicals.

The chemicals of choice for drying are oxides of calcium and magnesium, generally referred to as quicklime. Depending on the source, they may be further defined as high-calcium quicklime, magnesium quicklime, or dolomitic quicklime. These substances contain metal oxides (e.g., calcium oxide, CaO) that react with water to form the metal hydrate (e.g., $CaO\cdot(OH)_2$). As quicklime hydrates with water in the soil, it releases considerable heat (i.e., is exothermic), which in turn evaporates more water and further reduces the moisture content of the soil. Because this reaction is fast and exothermic, it is effective for drying soils down to freezing temperatures.

2-4.2 Lime.

Lime is a generic term used to cover a variety of materials. Only quicklime is effective for drying soils. Hydrated lime has already combined with water and will not draw moisture into new chemical forms. It will have certain chemical reactions (cation exchange) with some clay minerals that will make them less plastic and easier to dry by conventional methods, but this is much different from the avid drying of quicklime that is not related to soil type. Be aware that “agricultural lime” has no value for engineering stabilization or drying uses. Do not construct stabilized soil materials using agricultural lime.

Any product that contains free quicklime (CaO) can be used as a drying agent. The more CaO it contains, the more effective it will be as a drying agent. Portland cement, fly ash (particularly high calcium Class C ashes), and kiln dust are examples of common industrial materials with significant CaO content that can be used for soil drying. Their effectiveness for drying is directly dependent on their free CaO content. Quicklime is a caustic material; hence, normal safety precautions for such materials need to be followed (long sleeves and pants, rubber gloves, goggles, and mask). Quicklime is a relatively granular material and does not dust like the much finer hydrated lime. While safety precautions are required to handle this material, they are within the range of precautions used on construction sites. Quicklime is a commonly used industrial and construction material and the safety precautions required are reasonable to comply with in the field to ensure worker health and safety. Delivery is typically by dump truck and mixing is typically with a conventional field rotary mixer. Thorough mixing enhances uniform drying.

2-4.3 Amounts.

Amounts for use are generally by trial and error. Take a known weight of a wet soil sample and mix with a known amount of quicklime and see visually and texturally if it dries the wet soil sample. The reaction with CaO is quick and results will be evident very rapidly. Repeat but vary the amount of additive. This is a practical way to ascertain if non-quicklime materials such as portland cement, fly ash, or kiln dust have free CaO to be effective to dry the soil. A qualitative assessment of a simple test of this sort is generally all that is justified for military engineering applications. This will also provide a rough initial estimate of the amount of additive to use for drying.

2-4.4 Factors.

Three factors are involved with drying of the soil: chemical hydration of CaO, exothermic-reaction-caused evaporation, and normal evaporation because of ambient conditions. Therefore, trying to assign exact formulas for how much quicklime to add to gain a specific reduction in moisture content is not justified. It is better to make multiple additions to close in on the desired moisture content. One to two percent quicklime for each percent reduction in desired moisture content is a good starting point.

Table 2-3 Guide for Selecting a Stabilizing Additive

Area	Class (b)	Type of Stabilizer	Restriction (LL and PI)	RESTRICTION (% PASS NO. 200) (c)	REMARK
1A	SW or SP	1. Polymer/bituminous emulsion and cement 2. Portland cement 3. Lime-cement-fly ash 4. 2 and 3 with fiber (a)	PI not to exceed 25	3 & 4. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
1B	SW-SM or SP-SW or SW-SC or SP-SC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. PI not to exceed 30 3. PI not less than 12 4. PI not to exceed 25	3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
1C	SM or SC or SM-SC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. (b) 3. PI not less than 12 4. PI not to exceed 25	1. Not to exceed 30% by weight 3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
2A	GW or GP	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime-cement-fly ash and fiber (a) 4. 2 and 3 with fiber (a)	PI not to exceed 25	3 & 4. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Well-graded material only. Material to contain at least 45% by weight of material passing No. 4 (4.75 mm) sieve. Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
2B	GW-GM or GP-GM or GW-GC or GP-GC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. PI not to exceed 30 3. PI not less than 12 4. PI not to exceed 25	3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Well-graded material only. Material to contain at least 45% by weight of material passing No. 4 (4.75 mm) sieve. Soils near or above their optimum moisture content may require drying prior to emulsion stabilization.
2C	GM or GC or GM-GC	1. Polymer/bituminous emulsion and cement 2. Portland cement and fiber (a) 3. Lime and fiber (a) 4. Lime-cement-fly ash and fiber (a) 5. 2, 3, and 4 with fiber (a)	1. PI not to exceed 10 2. (c) 3. PI not less than 12 4. PI not to exceed 25	1. Not to exceed 30% by weight 3, 4, 5. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Well-graded material only. Select Material to contain at least 45% by weight of material passing No. 4 (4.75 mm) sieve.
3	CH or CL or MH or ML or OH or OL or ML-CL	1. Portland cement and fiber (a) 2. Lime (a) 3. 2 with fiber (a)	1. LL less than 40 and PI less than 20 2. PI not less than 12	2 & 3. Lime requires at least 25% passing the No. 200 (0.075 mm) sieve	Organic and strongly acidic soils falling within this area are not susceptible to stabilization by conventional means.

(a) Monofilament polypropylene fiber – Length and denier will vary depending on soil type
(b) Soil classification corresponds to ASTM D2487-17. Restriction on liquid limit (LL) and plasticity index (PI) is in accordance with ASTM D4318-17e1.
(c) PI ≤ 20 + 50 – percent passing No. 200 (0.075 mm) sieve

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CHAPTER 3 DETERMINING 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.

3-1.1 Types of Portland Cement.

Several different types of cement have been successfully used for stabilizing soils. Type I normal portland cement and Type IA air-entraining cements were used extensively in the past with similar results. At the present time, Type II cement has greater sulfate resistance obtained while the cost is often the same. High early strength cement (Type III) has been found to give higher strength in certain soils and cures much faster than Type I or Type II. Type III cement has a finer particle size than the other cement types. Chemical and physical property specifications for portland cement can be found in ASTM C150, *Standard Specification for Portland Cement*.

3-1.2 Water for Hydration.

Potable water is normally used for cement stabilization, although seawater has been found to be satisfactory.

3-1.3 Gradation Requirements.

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

Table 3-1 Gradation Requirements for Cement-Stabilized Base and Subbase Courses

Type Course	Sieve Size	Percent Passing
Base	1.5 inch (37.5 mm)	100
	0.75 inch (19 mm)	70–100
	No. 4 (4.75 mm)	45–70
	No. 40 (0.425 mm)	10–40
	No. 200 (0.075 mm)	0–20
Subbase	1.5 inch (37.5 mm)	100
	No. 4 (4.75 mm)	45–100
	No. 40 (0.425 mm)	10–50
	No. 200 (0.075 mm)	0–20

3-1.4 Cement Content for Modifying Soils.

3-1.4.1 Improved Plasticity.

In a majority of cases, lime is preferred over soil cement to reduce the PI or control expansive behavior. If lime is not locally or economically available for a project, it is possible to use cement to reduce the plasticity. Do not design, specify, or install soil cement to reduce the PI of a soil without prior authorization by the Pavements DWG. The amount of cement required to improve the quality of the soil through modification is determined by the trial-and-error approach, as described below.

To reduce the PI of the soil, prepare successive samples of soil-cement mixtures prepared at different treatment levels and the PI of each mixture determined in accordance with ASTM D4318, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*. The minimum cement content that yields the desired PI is selected but, since it was determined based upon the minus No. 40 (0.425 mm) sieve material, this value is adjusted to find the design cement content based upon total sample weight expressed as:

$$A = 100BC$$

where

A = design cement content, percent total weight of soil
B = percent passing No. 40 (0.425 mm) sieve size, expressed as a decimal
C = percent cement required to obtain the desired PI of minus No. 40 (0.425 mm) sieve material, expressed as a decimal

3-1.4.2 Improved Gradation.

If the objective of modification is to improve the gradation of a granular soil through the addition of fines then conduct a particle size analysis (ASTM D7928, *Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis*) on samples at various treatment levels to determine the minimum acceptable cement content.

3-1.4.3 Reduced Swell Potential.

Portland cement may reduce swell potential of certain expansive soils. However, portland cement is not as effective as lime in reducing swell potential and may be considered too expensive for this application. Determining cement content to reduce the swell potential of fine-grained plastic soils can be accomplished by molding several samples at various cement contents and soaking the specimens along with untreated specimens for four 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 ASTM D4546-14e1, *Standard Test Methods for One-Dimensional Swell or Collapse of Soils*. Check the cement content found to accomplish soil modification to determine whether it provides an unconfined compressive strength great enough to qualify for a reduced thickness design in accordance with criteria established for soil stabilization.

3-1.4.4 Frost Areas.

Cement-modified soil may also be used in frost areas but, in addition to the procedures for mixture design described in paragraphs 3-1.5.1 through 3-1.5.5, cured specimens are subjected to the 12 freeze-thaw cycles prescribed by ASTM D560, *Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures* (but omitting wire-brushing). Follow the 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, is used as the basis of the pavement thickness design if the reduced subgrade design method is applied.

3-1.5 Cement Content for Stabilized Soil.

Determine the design cement content for cement-stabilized soils using the following procedure.

3-1.5.1 Step 1.

Determine the gradation, Atterberg limits, and classification of the untreated soil following procedures in ASTM D7928, ASTM D4318, and ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, respectively.

3-1.5.2 Step 2.

Using the soil classification, select 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

3-1.5.3 Step 3.

Conduct moisture-density tests at the estimated cement content and at cement contents 2 percent above and 2 percent below the initial estimated cement content from Table 3-2 to determine the maximum dry density and optimum water content of the soil-cement mixtures at each cement content. Use the procedure in ASTM D558, *Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures*, to prepare the soil-cement mixture and make the necessary calculations. Use the procedures in ASTM D1557, *Standard Test Methods for Laboratory Compaction*

Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3)), to conduct the moisture density test. The maximum dry density determined in the laboratory will be used to set an allowable range for field density (see ASTM D1557, Section 12). In most cases, the density of the cement-treated soil will be higher than for the untreated soil due to the high specific gravity of portland cement; so, as the amount of cement dosage increases, the density may increase slightly.

3-1.5.4 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. Prepare the samples at compaction time and minimum density to be expected in field construction. For example, if the design field density is 97 ± 2 percent of the laboratory maximum density at 9 ± 2 percent moisture content, prepare the samples at 97 percent density and 9 percent moisture content. If field compaction will be not be immediate then compact the samples at a time after mixing representative of when field compaction will occur. Prepare the samples in accordance with ASTM D1632, *Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory*, except that when more than 35 percent of the material is retained on the No. 4 (4.75 mm) sieve, use a 4-inch (100-mm) -diameter by 8-inch (200-mm) -high mold to prepare the specimens. Cure the specimens for seven days in a humid room before testing. Test three specimens using the unconfined compression test in accordance with ASTM D1633, *Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders*, and subject three specimens to durability tests, either wet-dry (ASTM D559, *Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures*) or freeze-thaw (ASTM D560) tests, as appropriate. Determine the frost susceptibility of the treated material as indicated in UFC 3-260-02.

3-1.5.5 Step 5.

Compare the results of the average of the three unconfined compressive strength and durability tests with the requirements shown in Tables 2-1 and 2-2. The lowest cement content that meets the required unconfined compressive strength requirement <u>and</u> demonstrates the required durability is the design cement content. If the mixture meets 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 higher cement content may be selected and steps 3 and 4 above repeated.

3-2 STABILIZATION WITH LIME.

Generally, lime-treated, fine-grained soils exhibit decreased plasticity, improved workability, and reduced volume change characteristics. However, not all soils exhibit improved strength characteristics. Note that the properties of soil-lime mixtures are dependent on many variables. Soil type, lime type, lime percentage, and curing conditions (time, temperature, and moisture) are the most important. Perform preliminary lime reactivity testing on each soil type intended for use on a project as not all soil-lime combinations are reactive.

Prior to designing a stabilization program to treat a shrink/swell soil, thoroughly examine the geological/geotechnical conditions with respect to the groundwater and runoff water. Eliminate or mitigate the water source that causes expansive soil to swell rather than treating the soil or reduce the treatment regimen to save costs as much as possible. This requires the initial design study to be robust and thorough, with specific attention paid to the water conditions above and below the surface. Modifying the soils at the surface without mitigating water intrusion to the expansive soils at or below the surface will result in premature failure and poor performance of the soil layer.

Designing a lime treatment based on the potential vertical rise (PVR) has the potential to overestimate the actual vertical rise and therefore over-prescribe the amount of lime treatment depth and quantity required once the water source is mitigated. Conversely, if the water source is not removed, diverted, or mitigated in some way, the stabilization treatment will likely not be adequate to handle the swell induced during a surge of water flow into the expansive zone.

3-2.1 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. Under certain circumstances, the quantity of lime may be reduced if quicklime is used in lieu of hydrated lime; however, only reduce the amount of lime prescribed by the mix design at the direction of the Pavements DWG. Specifications for quicklime and hydrated lime may be found in ASTM C977, *Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization*.

3-2.2 Gradation Requirements.

Consider lime stabilization of soils containing a minimum of 25 percent passing the No. 200 (0.075 mm) sieve.

3-2.3 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. Highly weathered soils may require higher lime content than usually specified by previous guideline documents. The following procedures are recommended for determining the lime content of lime-stabilized soils.

3-2.3.1 Step 1.

The preferred method for determining initial design lime content is the pH test (ASTM D6276, *Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization*). 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 at least 12.4 (the pH of free lime) is obtained is the initial design lime content. This is the initial starting point and is the minimum required lime content for the pozzolanic reactions to occur.

3-2.3.2 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. Use the procedures in ASTM D3551, *Standard Practice for Laboratory Preparation of Soil-Lime Mixtures Using Mechanical Mixer*, to prepare the soil-lime mixture. Conduct the moisture density test following procedures in ASTM D1557.

3-2.3.3 Step 3.

Prepare samples of the soil-lime mixture—three each 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 and 2 percent below design if based on the alternate method. Prepare the mixture as indicated in ASTM D3551. If less than 35 percent of the soil is retained on the No. 4 (4.75 mm) sieve, mold approximately 2-inch (50 mm) -diameter and 4-inch (100 mm) -high samples. If more than 35 percent is retained on the No. 4 (4.75 mm) sieve, mold 4-inch (100 mm) -diameter and 8-inch (200 mm) -high samples. Prepare the samples at the density and water content expected in field construction. For example, if the design density is 95 percent of the laboratory maximum density, prepare the sample at 95 percent density. Cure specimens 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 °F (23 °C) for 28 days. Accelerated curing at 120 °F (49 °C) for 48 hours has also been found to give satisfactory results; however, conduct additional check tests at 73 °F (23 °C) for 28 days. Research has shown that if accelerated curing temperatures are too high, the pozzolanic compounds formed during laboratory curing differ substantially from those that develop in the field.

3-2.3.4 Step 4.

Test three specimens using the unconfined compression test in accordance with ASTM D2166/D2166M, *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil*. If frost design is a consideration, subject an additional three specimens to 12 cycles of freeze-thaw durability tests (ASTM D560), except omit wire brushing. Determine the frost susceptibility of the treated material as indicated in UFC 3-260-02.

3-2.3.5 Step 5.

Compare the results of the unconfined compressive strength and durability tests with the requirements shown in Tables 2-1 and 2-2. The lowest lime content that meets the unconfined compressive strength requirement <u>and</u> demonstrates the required durability is the design lime content. Ensure the treated material also meets frost susceptibility requirements as indicated in UFC 3-260-02. If the mixture meets 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, 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 fines 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, form a hardened cementitious mass capable of obtaining high compressive strengths. Lime and fly ash in combination can often be successfully used to stabilize 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.

3-3.1 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; however, using Class C fly ash has proven to be sensitive and difficult at times. Class F fly ash is derived from the burning of anthracite or bituminous coal and is sometimes referred to as "low lime" ash, depending on locale. It requires the addition of lime to form a pozzolanic reaction. Volcanic ash, rice hull ash (Type N natural pozzolans), and slag (ground-granulated blast-furnace slag [GGBFS]) may be used as stabilizers, where available. In certain geographic locations, they are widely available and have been used successfully as stabilizers for many years.

3-3.2 Evaluation of Fly Ash.

Fly ash used for stabilization is acceptable quality when it meets the requirements indicated in ASTM C593, *Standard Specification for Fly Ash and Other Pozzolans for Use with Lime for Soil Stabilization*.

3-3.3 Gradation Requirements.

LF and LCF stabilization are useful only in soils with a PI less than 25 and less than 50 percent passing the No. 200 (0.075 mm) sieve.

3-3.4 Selection of Lime-Fly Ash Content for LF and LCF Mixtures.

Design with LF is different from stabilization with lime or cement. For a given combination of materials (aggregate, fly ash, and lime), a number of factors—such as percentage of lime-fly ash, the moisture content, and the ratio of lime to fly ash—can be varied in the mix design process. In general, 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. Higher strength and improved durability are achievable when the matrix material is able to "float" the coarse aggregate particles. In effect, the fine-sized particles overfill the void spaces between the coarse aggregate particles. For each coarse aggregate material, a quantity of matrix is required to effectively fill the available void spaces and "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.

3-3.4.1 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. Start with the initial fly ash content of approximately 10 percent based on dry weight of the mix. It is recommended that material larger than 0.75 inch (19 mm) be removed and the test conducted on the minus 0.75 inch (19 mm) fraction. Tests are run at increasing increments of fly ash (e.g., 2 percent) up to a total of about 20 percent. Conduct moisture-density tests following procedures in ASTM D1557. The design fly ash content is then selected at 2 percent above that yielding maximum density. An alternate method is to conduct single-point compaction tests at fly ash contents of 10 to 20 percent of the estimated optimum water content, 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 for the LF-stabilized soil.

3-3.4.2 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, each set at three different lime-fly ash ratios, following procedures in ASTM D1557. 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.

3-3.4.3 Step 3.

Test three specimens using the unconfined compression test in ASTM D2166/D2166M. If frost design is a consideration, subject three additional specimens to 12 cycles of freeze-thaw durability tests (ASTM D560) but omit wire brushing. Determine the frost susceptibility of the treated material as indicated in UFC 3-260-02.

3-3.4.4 Step 4.

Compare the results of the unconfined compressive strength and durability tests with the requirements shown in Tables 2-1 and 2-2. The lowest LF ratio content (i.e., the ratio with the lowest lime content, which meets the required unconfined compressive strength requirement <u>and</u> demonstrates the required durability) is the design LF content. Also, meet frost-susceptibility requirements as indicated in UFC 3-260-02 for the treated material. If the mixture meets the durability requirements but not the strength requirements, it is considered to be a modified soil. If the results of the specimens tested meet neither the strength nor the durability requirement, select a different LF content or use additional portland cement and repeat steps 2 through 4.

3-3.5 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, follow the same procedures indicated for LF design but include cement beginning at step 2. Generally, about 1 to 2 percent cement is used. Cement may be used in place of or in addition to lime; however, maintain the total fines content. Conduct strength and durability tests on samples at various LCF ratios to determine the combination that gives best results.

3-4 STABILIZATION WITH BITUMEN AND POLYMER EMULSION.

Stabilizing soils and aggregates with asphalt and polymer emulsion differs greatly from stabilizing soils with cement and lime. The basic mechanism involved in stabilizing fine-grained soils is a waterproofing phenomenon. Soil particles or soil agglomerates are coated with an asphalt or polymer film that prevents or slows the penetration of water, which typically results in a decrease in soil strength. In addition, asphalt or polymer stabilization can improve durability characteristics by making the soil resistant to the detrimental effects of water, such as volume changes. In non-cohesive materials—such as sands and gravel, crushed gravel, and crushed stone—two basic mechanisms are active: waterproofing and adhesion. The asphalt or polymer coating on the cohesionless materials provides a membrane that prevents or hinders the penetration of water, thereby reducing the tendency of the material to lose strength in the presence of water. The second mechanism is adhesion. The aggregate particles adhere to the binder and the binder acts as a cement between soil particles. The cementing effect thus increases shear strength by increasing cohesion. Criteria for design of bitumen-stabilized soils are based almost entirely on stability and soil gradation requirements. For polymer emulsions, the criteria are based solely on unconfined compressive strength. Freeze-thaw and wet-dry durability tests are not applicable for asphalt-stabilized or polymer-stabilized mixtures.

3-4.1 Types of Bituminous-Stabilized Soils.

3-4.1.1 Sand Bitumen.

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

3-4.1.2 Gravel or Crushed Aggregate Bitumen.

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

3-4.1.3 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 has a high PI (i.e., above 10).

3-4.2 Types of Bitumen.

3-4.2.1 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, location, method of construction, and weather conditions. Generally, 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, use viscosity-grade asphalt cements. 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 safety, reduced energy consumption, and environmental regulations. The specific type and grade of bitumen will depend on the characteristics of the aggregate, the type of construction equipment, and the climatic conditions. Generally, the following types of bituminous materials will be used for the soil gradation indicated:

3-4.2.1.1 Open-graded Aggregate.

- Rapid- and medium-curing liquid asphalts RC-250, RC-800, and MC-3000
- Medium-setting asphalt emulsion MS-2 and CMS-2

3-4.2.1.2 Well-graded Aggregate with Little or No Material Passing the No. 200 (0.075 mm) Sieve.

- Rapid- and medium-curing liquid asphalts RC-250, RC-800, MC-250, and MC-800
- Slow-curing liquid asphalts SC-250 and SC-800
- Medium-setting and slow-setting asphalt emulsions MS-2, CMS-2, SS-1, and CSS-1

3-4.2.1.3 Aggregate with a Considerable Percentage of Fine Aggregate and Material Passing the No. 200 (0.075 mm) Sieve.

- Medium-curing liquid asphalts MC-250 and MC-800
- Slow-curing liquid asphalts SC-250 and SC-800
- Slow-setting asphalt emulsions SS-1, SS-01h, CSS-1, and CSS-1h

3-4.2.2 The simplest type of bituminous stabilization is applying liquid asphalt to the surface of an unbound aggregate road. For this type of operation, slow- and medium-curing liquid asphalts—SC-70, SC-250, MC-70, and MC-250—and slow-setting emulsions as defined in paragraph 3-4.2.1 are used.

3-4.3 Soil Gradation.

The recommended soil gradations for subgrade materials and base or subbase course materials are shown in Tables 3-3 and 3-4, respectively.

Table 3-3 Recommended Gradations for Bituminous-Stabilized Subgrade Materials

Sieve Size	Percent Passing
3 inch (75 mm)	100
No. 4 (4.75 mm)	50–100
No. 30 (0.600 mm)	38–100
No. 200 (0.075 mm)	2–30

Table 3-4 Recommended Gradations for Bituminous-Stabilized Base and Subbase Materials

Sieve Size	1.5 inch (37.5 mm) Maximum	1 inch (25 mm) Maximum	0.75 inch (19 mm) Maximum	0.5 inch (12.5 mm) Maximum
1.5 inch (37.5 mm)	100	--	--	--
1 inch (25 mm)	84 ± 9	100	--	--
0.75 inch (19 mm)	76 ± 9	83 ± 9	100	--
0.5 inch (12.5 mm)	66 ± 9	73 ± 9	82 ± 9	100
3/8 inch (9.5 mm)	59 ± 9	64 ± 9	72 ± 9	83 ± 9
No. 4 (4.75 mm)	45 ± 9	48 ± 9	54 ± 9	62 ± 9
No. 8 (2.36 mm)	35 ± 9	36 ± 9	41 ± 9	47 ± 9
No. 16 (1.18 mm)	27 ± 9	28 ± 9	32 ± 9	36 ± 9
No. 30 (0.600 mm)	20 ± 9	21 ± 9	24 ± 9	28 ± 9
No. 50 (0.300 mm)	14 ± 7	16 ± 7	17 ± 7	20 ± 7
No. 100 (0.150 mm)	9 ± 5	11 ± 5	12 ± 5	14 ± 5
No. 200 (0.075 mm)	5 ± 2	5 ± 2	5 ± 2	5 ± 2

3-4.4 Mix Design.

Guidance for the design of bituminous-stabilized base and subbase courses is in UFC 3-250-01. For subgrade stabilization, the following equation may be used for estimating the preliminary quantity of cutback asphalt to be selected:

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

where

p = percent cutback asphalt by weight of dry aggregate
a = percent of mineral aggregate retained on No. 50 (0.300 mm) sieve
b = percent of mineral aggregate passing No. 50 (0.300 mm) sieve and retained on No. 100 (0.150 mm) sieve
c = percent of mineral aggregate passing No. 100 (0.150 mm) sieve and retained on No. 200 (0.075 mm) sieve
d = percent of mineral aggregate passing No. 200 (0.075 mm) sieve
S = percent solvent

The preliminary quantity of emulsified asphalt to be used in stabilizing subgrades can be determined from Table 3-5. Select the final design content of cutback or emulsified asphalt based upon the results of the Marshall Stability Test (ASTM D6927, *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*). The minimum Marshall Stability recommended for subgrades is 500 lb (227 kg). If a soil does not show increased stability when reasonable amounts of bituminous materials are added, modify the gradation of the soil or use another type of bituminous material. Poorly graded materials may be improved by the addition of suitable fines containing considerable material passing the No. 200 (0.075 mm) sieve. The amount of bitumen required for a given soil increases with an increase in percentage of the finer sizes.

Table 3-5 Emulsified Asphalt Requirements

Percent Passing No. 200 (0.075 mm) Sieve	Pounds (kg) of Emulsified Asphalt per 100 Pounds (45 kg) of Dry Aggregate at Percent Passing No. 10 (2 mm) Sieve					
	< 50	60	70	80	90	100
0	6.0 (2.7)	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)
2	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)
4	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)
6	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)
8	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)
10	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)	8.4 (3.8)
12	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)	8.4 (3.8)	8.6 (3.9)
14	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)	8.4 (3.8)
16	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)	8.2 (3.7)
18	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.7 (3.5)	7.9 (3.6)
20	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)	7.6 (3.4)
22	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)	7.5 (3.4)
24	6.0 (2.7)	6.3 (2.8)	6.5 (2.9)	6.7 (3.0)	7.0 (3.2)	7.2 (3.3)
25	6.2 (2.8)	6.4 (2.9)	6.6 (3.0)	6.9 (3.1)	7.1 (3.2)	7.3 (3.3)

3-4.5 Polymer Emulsion.

Due to the wide variety of polymer emulsion properties, it is best to follow the manufacturer's recommendations for starting dosage amounts for the classification and gradation of the soil.

3-4.5.1 Polymer Content for Stabilized Soil.

The following procedure is recommended for determining the design polymer content. It is similar to that for cement and lime stabilization where the optimum moisture content is first determined for the initial trial polymer content followed by a trial-and-error approach to determine the design polymer content.

3-4.5.1.1 Step 1.

Determine the gradation, Atterberg limits, and classification of the untreated soil following procedures in ASTM D6913/D6913M-17, *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*, D4318-17e1, and D2487-17, respectively.

3-4.5.1.2 Step 2.

Using the manufacturer's recommendation as a starting point, select an initial polymer content for moisture-density tests (ASTM D1557).

3-4.5.1.3 Step 3.

Using the initial polymer emulsion content, determine the amount of water that will be added to the soil from the polymer emulsion based upon its percent solids. Then conduct moisture-density tests to determine the maximum dry density (MDD_{OMC}) and optimum water content (OMC) of the soil-polymer mixture at each polymer emulsion content. Use the procedure in ASTM D558 to prepare the soil-polymer mixture and make the necessary calculations; however, use the procedures in ASTM D1557 to conduct the moisture-density tests.

3-4.5.1.4 Step 4.

Prepare triplicate samples of the soil-polymer mixture for unconfined compression tests at the initial polymer content selected in step 2 and at polymer contents 1 percent above and 1 percent below that determined in step 2. For example, if the design field density is 97 ± 2 percent of the laboratory maximum density at 9 ± 2 percent moisture content, prepare the samples at 97 percent density and 9 percent moisture content. If field compaction will not be immediate then compact the samples at a time after mixing representative of when field compaction will occur. Prepare the samples in accordance with ASTM D1632 except that when more than 35 percent of the material is retained on the No. 4 (4.75 mm) sieve, use a 4-inch (100 mm) -diameter by 8-inch (200 mm) -high mold to prepare the specimens. Cure the specimens for seven days at 77 °F (25 °C) in a 50 percent humidity environment before testing. Test three specimens using the unconfined compression test in accordance with ASTM D1633.

3-4.5.1.5 Step 5.

Ensure the average of the three tests are above 400 psi (2.76 MPa). The lowest polymer content that meets the required unconfined compressive strength is the design polymer content. If the results of the specimens tested do not meet the strength requirements then lower or higher polymer content may be selected and steps 1 through 4 above repeated.

3-4.5.2 Portland Cement Content for Polymer-Stabilized Soil.

Portland cement may be used in combination with polymer emulsion. The polymer provides strength, flexibility, and water resistance while the cement provides strength and helps the emulsion cure by reacting with the emulsion water. The mix design procedure is the same as described in paragraph 3-4.5.1. Begin the initial trial with a polymer emulsion content suggested by the manufacturer. If used in combination, the initial trial cement is 1 percent and does not exceed the design polymer emulsion content.

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 successfully mixed 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 this stabilization practice may 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.

3-5.1 Lime-Cement.

Lime can be used as an initial additive with portland cement or alone as 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 reduce the PI 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 in paragraph 3-1.

3-5.2 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 act as an anti-stripping agent. In the latter capacity, the lime acts to neutralize acidic chemicals in the soil or aggregate that tend to interfere with bonding of the asphalt. Generally, about 1 to 2 percent lime is all that is needed for this objective. When asphalt is the primary stabilizer, follow the procedures for asphalt-stabilized materials in paragraph 3-4.

3-5.3 Lime Treatment of Expansive Soils.

Expansive soils as defined for pavement purposes are those that exhibit swell in excess of 3 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 are often a good indicator of the swell potential, as indicated in Table 3-6. 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 degree, 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, less than 1 percent swell. Use the procedure for conducting swell tests described in ASTM D4546-14e1. The maximum depth that the lime is incorporated into the soil is typically limited by the construction equipment used. However, 2 to 3 feet (0.6 m to 0.9 m) generally is the maximum depth that can be treated directly without removal of the soil. Once the design lime content has been determined, perform testing to verify the intended lime stabilization will also prevent soil expansion. The lime content necessary to reduce the PI is not always suitable to control shrink/swell.

Table 3-6 Swell Potential of Soils

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

3-6 STABILIZATION WITH FIBERS.

Fiber stabilization in soils is an emerging field. Polypropylene fibers are the most common for soil applications. It is best to follow manufacturer's recommendations for starting dosage amounts for the classification and gradation of the soil. Fibers are very efficient at adding toughness to the soil; they usually do not add stiffness but improve ductility. Fibers may be used alone but are recommended to be used with an adhesive (cement, bitumen, or polymer). Fibers blended with cement reduce the amount of shrinkage cracking. Criteria on the amount of fibers to use are not available at this time; however, there are general guidelines to follow. Refer to UFC 3-220-08FA, *Engineering Use of Geotextiles*, for additional guidance in using geosynthetic materials.

Testing has shown that monofilament and tape fibers are more efficient for rapid stabilization. Fibrillated fibers require extensive mixing (multiple passes of a soil mixer) to effectively defibrillate the fiber for maximum efficiency. Fibers mixed into soil without adhesives (i.e., cement) rely exclusive on mechanical interlock, friction, and fiber entanglement with other fibers and between soil particles to anchor the fiber in place. Thus, a high surface area fiber (such as a tape fiber) may be more efficient in a fine-grained clay soil than in a coarse-grained soil such as gravel, where fewer soil grains are in contact with the fiber.

Fiber amounts will vary depending on the length, denier, and morphology. Fiber lengths for soils typically range from 0.5 to 3 inches (13 to 76 mm). Longer fibers are recommended if no adhesives are used. Successful soil stabilization projects have been performed on virgin granular soils with 2 inch (51 mm) long discrete fibers. Longer fibers generally result in improved performance but hamper construction, as they are more difficult to mix due to entanglement. Shorter fibers (less than 1 inch [25 mm]) are recommended when using adhesives, as the adhesive helps to create a composite network of fiber through the soil. A recommended fiber starting dosage is 0.1 percent with a maximum of 0.8 percent. Increased amounts of fiber may reduce the stiffness of the soil and become difficult to mix with soil.

CHAPTER 4 CONSTRUCTION PROCEDURES

4-1 CONSTRUCTION WITH PORTLAND CEMENT.

4-1.1 General Construction Steps.

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

4-1.1.1 Initial Preparation.

4-1.1.1.1 Shape the area to crown and grade.

4-1.1.1.2 If necessary, scarify, pulverize, and pre-wet the soil.

4-1.1.1.3 Reshape to crown and grade.

4-1.1.1.4 Precompact.

4-1.1.2 Processing.

4-1.1.2.1 Spread portland cement and mix.

4-1.1.2.2 Apply water, if necessary, to achieve the optimum moisture content.

4-1.1.2.3 Mix the additive and soil thoroughly.

4-1.1.2.4 Compact.

4-1.1.2.5 Finish.

4-1.1.2.6 Cure.

4-1.2 Mixing Equipment.

Soil, cement, and water can be mixed in place using traveling mixing machines or mixed in a central mixing plant.

4-1.2.1 Traveling Mixing Machines.

4-1.2.1.1 Transverse single-shaft mixer

4-1.2.1.2 Windrow-type pugmill

4-1.2.2 Central Mixing Plants.

4-1.2.2.1 Continuous flow-type pugmill

4-1.2.2.2 Batch-type pugmill

4-1.2.3 Principles and Objectives.

Regardless of the type of mixing equipment used, the general principles and objectives are the same. Certain soil materials cannot be pulverized and mixed in central mixing plants because of their high silt and/or clay content and plasticity. If necessary, determine if the soil materials can be pulverized and mixed by running a trial batch. Almost all types of soil materials, from granular to fine-grained, can be adequately pulverized and mixed with transverse-shaft mixers, given proper moisture control. The exception is material containing predominantly 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 non-plastic to slightly plastic granular soils. For coarse, non-plastic 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. For plastic soils, it is very important to pulverize the soil thoroughly prior to mixing with the additive to reduce the “clod” size. Reducing the average particle size through pulverization increases the specific surface area of the soil, thereby improving the coating and ability of the additive to penetrate further into the particles.

4-1.3 Equipment for Handling and Spreading Cement.

There are a number of methods for handling cement. For 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. It is permissible to use bag cement on jobs that are too limited in size to require mass quantities of cement. Cement spreaders for mix-in-place construction are of two general types: those that spread cement over the soil material in a blanket and those that deposit cement on top of a partially flattened or slightly trenched windrow of soil material. For centrally mixed soil-cement projects, cement meters on continuous-flow central mixing plants are of three types: the belt with strikeoff, screw, or vane. The cement for batch-type pugmill mixers and rotary drum-mixers is batch weighed.

4-1.4 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 proper amounts of cement and moisture. Adequately cure the completed soil-cement.

4-1.4.1 Preparation.

Before construction starts, check the crown and grade and complete fine grading. 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, compact and shape the subgrade to the proper crown and grade before the borrow material is placed. Correct any soft subgrade areas. To avoid costly delays, carefully check all equipment to ensure it is in proper operating condition and meets construction requirements of the job. Utilize guide stakes and string lines to control the width and guide the operators during construction. Make arrangements 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 project engineer establishes the limits of the different materials and their corresponding cement requirements. Pre-wetting the soil by adding moisture before cement is applied often saves time during actual processing. Friable granular materials, 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 slightly. Most specifications require that the soil material be pulverized so that at the time of compaction 100 percent of the soil-cement mixture will pass a 1 inch (25 mm) sieve and a minimum of 80 percent will pass a No. 4 (4.75 mm) sieve, exclusive of any gravel or stone. Ensure gravel or stone are no more than 2 inch (50 mm) maximum size or the stabilization effects will be minimal. Test the final pulverization at the conclusion of mixing operations. When borrow material is specified, distribute it on an accurately graded, well-compacted roadway in an even layer or uniform windrow, depending on the type of mixing equipment to be used. Place the fill by weight or volume as required by the specifications. Pre-compaction of the soil can help ensure the target design cement content and proper layer thickness are reached as well as provide a stable construction platform for equipment operation.

4-1.4.2 Processing.

For maximum efficiency and to meet specification time limits, break down a day's work 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. This will help reduce issues from compaction of adjacent sections due to rapid cement curing.

4-1.4.2.1 Handling and Spreading Cement.

Bulk cement is typically 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 moisture content at optimum or slightly above. Ensure that clayey soils have a moisture content below optimum when cement is spread. Do not apply cement onto puddles of water. If the soil material is excessively wet, aerate it 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.** Mechanical cement spreaders may be built into a truck, attached to a dump truck, or pulled behind a vehicle. As the vehicle moves forward, cement flows through the spreader, which regulates the quantity of cement placed on the prepared soil. To obtain a uniform cement spread, operate the spreader at a constant, slow speed and with a constant level of cement in

the hopper. Maintain a true line at the pavement edge with a string line. To produce a uniform cement spread, ensure the mechanical spreader has adequate traction. 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. Operate the spreader with a slow, even forward speed to avoid variation in the spread rate. 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. Many modern cement spreaders utilize automated controls to ensure the correct amount of cement is metered during placement.

(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. A grid or lane placement may be used. For grids, space the bags at approximately equal transverse and longitudinal intervals that will ensure the proper percentage of cement. For lanes, the bags are spaced equally within the lane. Positions can be spotted by flags or markers fastened to lines at proper intervals to mark the transverse and longitudinal rows. When the bags are opened, dump the cement so it forms fairly uniform transverse windrows across the area being processed. A spiketooth harrow, nail drag, or length of chain-link fence can be used to spread the cement evenly. Make at least two round trips using the drag over the area to uniformly spread the cement.

(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 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 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 forms 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-lb (204- to 340-kg) -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. Use compressed air of 2- to 4-lb/in.^{2} pressure 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. Include a positive system to automatically stop the plant if the cement flow suddenly stops. The correct proportion of cement, soil material, and water entering the mixing chamber is determined by calibrating the plant before mixing and placing operations begin.

4-1.4.2.2 Mixing and Applying Water.

Procedures for applying water and mixing depend on the type of mixing machine used. Thoroughly mix the pulverized soil material, cement, and water. 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 improper 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 particle-size 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. Non-uniform 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, first loosen the mixture to ready it for compaction. If two windrows have been made, the mixing machine progresses 350 to 500 feet (107 to 152 m) along one windrow and then is backed up to process the other windrow for 700 to 1,000 feet (213 to 305 m). 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 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.

(2) **Single-Shaft Traveling Mixing Machine.** The only preparation required is shaping the soil material to the approximate required crown and grade. If

an old roadbed is extremely hard and dense, prewetting and scarification will facilitate processing. Applying water at this stage of 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, pre-wetting 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. Apply moisture uniformly during pre-wetting. By mixing it into the soil material, evaporation losses are reduced. Because of the hazard of night rains, some contractors prefer to do the pre-wetting in the early morning. After scarifying and pre-wetting, the loose, moist soil material is shaped to crown and grade. Pre-compaction of the soil can help ensure the target design cement content and proper layer thickness are achieved and provide a solid working platform for the spreading and mixing equipment. Cement is spread by a mechanical cement spreader or from bags. 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 distribution equipment. Blend the soil material and cement when free water contacts the mixture to prevent the formation of cement balls. Accomplish processing in lanes 250 to 500 feet (76 to 152 m) long and as wide as the mixing machine. Cement is spread on the soil material in front of the mixing machine. Complete cement spreading in the first working lane and begin cement spreading 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. If water is being applied by injection, not the mixing chamber, then minimize the overlap of additional lanes to prevent overwatering. This can be readily accomplished using string lines.

4-1.4.2.3 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, and rotary-drum mixers are used for this work. Generally, the twin-shaft continuous-flow pugmill is used on highway projects. Provide facilities for efficiently storing, handling, and proportioning materials at the plant. Quantities of soil material, cement, and water can be proportioned by volume for achieving the desired mixture based upon dry unit weight. Mixing is continued until a uniform mixture of soil material, cement, and water is obtained. Equip haul vehicles with protective covers to reduce evaporation losses due to excessive temperature, high winds, and to protect the mixture against sudden rain. To prevent excessive haul time, do not allow more than 60 minutes to elapse between the start of moist-mixing and the start of compaction. Haul time is usually limited to 30 minutes. Place the mixed soil-cement 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. Spread the mixture 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. Do not spread cement so far ahead of the adjoining lane that a time lapse of more than 30 minutes occurs between the times of placing material in adjoining lanes at any location. Dampen the subgrade immediately prior to placing the soil-cement. Bituminous pavers have been used for spreading soil-cement, although modification may be necessary to increase volume capacity before they can be used. Perform compaction immediately behind the spreader. Leave a narrow, compacted ridge adjacent to the second lane during compaction of the first lane to serve as a depth guide when placing the mix in the second lane. Make equipment and water available and within reach 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.

4-1.4.3 Compaction.

The principles governing compaction of soil-cement are the same as those for soil materials without cement treatment. Compact the soil-cement mixture at optimum moisture to maximum density and finish immediately. Treat moisture loss by evaporation during compaction, indicated by a graying of the surface, with light applications of water. Tamping rollers are generally used for initial compaction except for the more granular soils. Self-propelled, vibratory, and pneumatic rubber-tired models are also used. To obtain adequate compaction, it is sometimes necessary to operate the rollers with ballast to give greater unit pressure, depending on the soil characteristics as determined in the field at the time of construction. 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 lb/in^2. Clayey sands, lean clays, and silts that have low plasticity can be compacted with 100- to 200-lb/in^2 rollers. Medium to heavy clays and gravelly soils require greater unit pressure: 150 to 300 lb/in^2. Compacted thickness up to 8 or 9 inch (200 to 230 mm) 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, ensure the mixed material is in a loose condition at the start of compaction so 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 that contains granular soil materials. Vibratory-plate compactors are used on non-plastic granular materials. Pneumatic rubber-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 rollers are fabricated to permit rapid inflation and deflation of the tires while compacting to increase their versatility. 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 (0.075 mm) 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 smooth out ridges.

There are two general types of road cross-sections: 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 edge stability while the remaining portion is being compacted. Do not construct the edge slope 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, aerate it with a cultivator, traveling mixer, or motor grader. After it has dried to near-optimum moisture, it can be compacted. For best results, start compaction immediately after the soil material, cement, and water have been mixed. It is critical that compaction occur as soon after mixing the materials as possible because hydration of the cement will begin as soon as the dry cement comes into contact with moist soil or free mixing water added to achieve optimum moisture content for compaction. Required densities are then obtained more readily, there is less water evaporation, and daily production is increased. Perform compaction by moving side-to-side over an area and not back and forth in a lane until the required number of passes is reached. This will help incrementally compact the soil and knead the soil back and forth across adjacent lanes to prevent a seam.

4-1.4.4 Finishing.

There are several acceptable methods for finishing soil-cement. The exact procedure depends on the available equipment, job conditions, and soil characteristics. Regardless of method, meet all fundamental requirements of adequate compaction, close to optimum moisture, and remove all surface compaction planes to produce a high-quality surface. It is critical that the design crown and grade be established prior to mixing to minimize the corrections required after mixing and compaction when the stabilized material is hardening due to hydration. If proper preparation and mixing are achieved, finishing is typically not necessary except at construction joints. If finishing is needed, finish the surface smooth, dense, and free of ruts, ridges, or cracks. When shaping is done during finishing, scarify (scratch) all smooth surfaces, such as tire imprints and blade marks, with a weeder, nail drag, coil spring, or spiketooth harrow to remove cleavage or compaction planes from the surface. Scratching may be done on all soil-cement mixtures except those containing appreciable quantities of gravel. Keep the surface damp during finishing operations. Steel-wheeled rollers can be used to smooth out ridges left by the initial pneumatic-tire rolling. Steel-wheeled rollers are particularly advantageous when rock is present in the surface. A broom drag can 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 rubber-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 rubber-tired roller to seal the surface. Any surface corrections are achieved immediately after compaction since the stabilized soil will be rapidly gaining strength. The finished soil-cement is then cured.

4-1.4.5 Curing.

Compacted and finished soil-cement contains moisture for cement hydration. A moisture-retaining cover is placed over the soil-cement soon after completion to retain this moisture and allow the cement to hydrate. Most soil-cement is cured with a bituminous material surface application but other materials such as polymer emulsion, waterproof paper or plastic sheets, wet straw or sand, fog-type water spray, and wet burlap or cotton mats are satisfactory. The type of bituminous material most commonly used is emulsified asphalt SS-1. Polymer emulsions may also be used. The rate of application varies from 0.15 to 0.30 US gal/sq yd (0.68 to 1.36 liter/sq m). At the time of application, ensure the soil-cement surface is free of all dry, loose, and extraneous material. Moisten the surface with a fog spray before emulsion materials are applied. In most cases, a light application of water is placed immediately ahead of the emulsion application. This helps improve penetration into the surface and increases adhesion.

4-1.4.6 Construction Joints.

After each day's construction, form a transverse vertical construction joint by cutting back into the completed soil-cement to the proper crown and grade. This is usually the last task performed at night or the first task performed the following morning. This may be accomplished using the mixer or a dry-cut walk-behind saw can be used to provide a clean cutting edge. Ensure the joint is vertical and perpendicular to the centerline. After the next day's mixing has been completed at the joint, clean the area of all dry and unmixed material and re-trim if necessary. Mixed moist material is then bladed into the area and thoroughly compacted. 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, apply it right up to the joint and sanded to prevent pickup.

4-1.4.7 Multiple-Layer Construction.

When the specified thickness of soil-cement base course exceeds the depth (usually 8 or 9 inches [200 to 230 mm] compacted) that can be compacted in one layer, construct in multiple layers. Construct all layers to be less than 4 inches (100 mm) 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 at a later time. With mixed-in-place construction, take care to eliminate any raw-soil seams between the layers.

4-1.5 Special Construction Problems.

4-1.5.1 Rainfall.

Attention to a few simple precautions before processing will greatly reduce the possibility of serious damage from wet weather. For example, crown any loose or pulverized soil so it will shed water and trench low places in the grade where water can accumulate so the water will freely drain off. 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 1.5 inches (25 to 37.5 mm) of rain. If rain falls during cement-spreading operations, stop spreading cement and quickly mix the cement already spread into the soil mass. A heavy rainfall that occurs after most of the water has already been added, however, can be serious. The best defense against rainfall is not to allow the cement placement to exceed the mixing and compaction. It is easy for the placement and mixing to outpace compaction because compaction is usually the slowest step. Then, if rainfall becomes imminent, try to obtain rapid compaction by using every available piece of equipment so the section will be compacted and shaped before too much damage results. In such instances, it may be necessary to complete final blade work later; any material bladed from the surface is wasted. After the mixture has been compacted and finished, rain will not harm it.

4-1.5.2 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 with adequate results. For clayey soils, the moisture content needs to be below optimum for efficient mixing. It may be necessary to dry out the soil material by aeration prior to mixing. 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 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.

4-1.5.3 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, do not place soil-cement when the temperature is 40 °F (4.4 °C) or below. Moreover, protect it to prevent its freezing for a period of seven days after placement and until it has hardened by a suitable covering of hay, straw, or other protective material.

4-2 CONSTRUCTION WITH LIME.

4-2.1 Lime Stabilization Methods.

There are three recognized lime-stabilization methods: in-place mixing, plant mixing, and pressure injection.

4-2.1.1 In-Place Mixing.

In-place mixing may be subdivided into three methods: mixing lime with the existing materials in place at the construction site or pavement; 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; and mixing in which the borrow source soil is hauled to the construction site and processed in place as in the first method.

The following procedures are for in-place mixing:

4-2.1.1.1 One increment of lime is added to clays or granular base materials that are easy to pulverize. The material is mixed and compacted in one operation and no mellowing period is required. (The term "mellow" refers to the reaction of the lime on clay to make it more friable and easier to pulverize.)

4-2.1.1.2 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.

4-2.1.1.3 One increment of lime is added for soil modification and pulverization before treatment with cement or asphalt.

4-2.1.1.4 One increment of lime is added to produce a working table. Proof rolling is required instead of pulverization and density requirements.

4-2.1.1.5 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.

4-2.1.1.6 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 (600 mm). Greater depths are possible but to date have not been attempted. A second increment of lime is added to the top 6 to 12 inches (130 to 300 mm) for complete stabilization. Plows and rippers are used to break down the 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 lime for soil modification under certain circumstances results in a frost-susceptible material that can produce a weak sublayer. Perform trial batches to determine these characteristics prior to construction.
- One increment of lime is applied for complete stabilization to a depth of 18 in (460 mm). 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 (150 mm), second to 9 inches (230 mm), third to 12 inches (300 mm), fourth to 15 inches (380 mm), and then a few passes to a depth of 18 inches (460 mm) to accomplish full pulverization. The full 18 inch (460 mm) is compacted from the top by vibratory and conventional heavy rollers. Make all attempts to compact in normal 8- to 9-inch (200 to 230 mm) lifts if the stabilized soil will be used near the surface of a pavement.

4-2.1.2 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. 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 stipulates that changes in lime content may be necessary to meet changing soil conditions encountered during construction.

4-2.1.3 Pressure Injection.

Pressure injections of lime slurry to depths of 7 to 10 feet (2.1 to 3 m) for control of swelling and unstable soils on highways and under building sites are usually placed on 5-foot (1.5-m) spacing and attempts are made to place horizontal seams of lime slurry at 8 to 12 inches (200 to 300 mm) intervals. Stabilize the top 6- to 12-inch (150 to 300 mm) layer by conventional methods.

4-2.2 Construction Steps.

4-2.2.1 Soil Preparation.

Bring the in-place subgrade soil to final grade and alignment. The finished grade elevation may require adjustment because of the potential fluff action of the lime-stabilized layer because 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, lower the subgrade elevation 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 (6 mm) because this material is not often well-reacted due to lime loss 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. If the lime is applied in a slurry form, scarify prior to adding lime.

4-2.2.2 Lime Application.

4-2.2.2.1 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 costliest method of lime application. Fifty-pound bags of lime are delivered in dump or flatbed trucks and placed by hand to give the required distribution. 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 leveled either by hand-raking or by a spike-tooth harrow or drag pulled by a tractor or truck. Immediately after, the lime is sprinkled with water 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 heavy equipment. For 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. These trucks are efficient, being capable of hauling 15 to 24 tons (13,600 to 21,800 kg). One type is equipped with one or more integral screw conveyors that discharge at the rear. 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 or pipe spreader bar-mounted at the rear. 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 auger trucks, spreading is handled by means of a portable, mechanical-type spreader attached to the rear 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 uniformly distribute the lime across the spreader width. When boots or spouts are used, 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 the required amount of lime can be applied in one or more passes. With 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 downspout pipes. Fingertip 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 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, including screw, belt, or drag-chain conveyors, bucket elevators, and screw elevators. The screw-type conveyors are most commonly used, with units of 10 to 12 inches (254 to 305 mm) in diameter being recommended for high-speed unloading. To minimize dusting, enclose all conveyors. 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; the lime is weigh-batched before loading. Generally, a batch plant setup is practical only on exceptionally large projects such as a runway, airport, or main apron at an installation. Obviously, the self-unloading tank truck is the least costly method of spreading lime because there is no rehandling of material and payloads can be carried and spread quickly.

4-2.2.2.2 Dry Quicklime.

Quicklime may be applied in bags or bulk. Because of higher cost, bagged lime is used only for drying of isolated wet spots or on small jobs. The distribution of bagged quicklime is similar to that of bagged hydrated lime except that an emphasis on safety is needed. First, the bags are accurately spaced on the area to be stabilized and, after spreading, water is applied and mixing operations started immediately. The fast watering and mixing operation helps minimize the danger of burns. Quicklime may be applied in the form of pebbles of approximately 3/8 inch (9.5 mm), 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 hydrated lime. However, because of its coarser size and higher density, quicklime may also be tailgated either from a regular dump truck with tailgate-opening controls to ensure accurate distribution or from a bulk transport truck. Because quicklime is anhydrous and generates heat on contact with water, take special care during stabilization to avoid lime burns. Where quicklime is specified, provide the engineer with a detailed safety program covering precautions and emergency treatment available on the jobsite. Include in the program protective equipment for eyes, mouth, nose, and skin, as well as a first-aid kit containing an eyewash station. Ensure this protective equipment is available on the jobsite during spreading and mixing operations. Actively enforce this program for protecting workers and others in the construction area.

4-2.2.2.3 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.

4-2.2.2.4 Slurry Made with Hydrated Lime.

This method was first used in the 1950s and remains popular, especially where dust from using dry lime is a problem. The hydrated lime-water slurry is mixed either in a central mixing tank, jet mixer, or in a tank truck. The slurry is spread over the scarified roadbed by a tank truck equipped with spray bars. One or more passes may be 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. A typical slurry mix proportion is 1 ton (907 kg) of lime and 500 gal (1893 L) of water, which yields about 600 gal (2271 L) of slurry containing 31 percent lime solids. At higher concentrations there is difficulty in pumping and spraying the slurry; 40 percent solids is the maximum pumpable slurry. The actual proportion used depends on the percentage of lime specified, the type of soil, and its moisture condition. When small lime percentages are required, the slurry proportions may be reduced to 1 ton (907 kg) of lime per 700 to 800 gal (2650 to 3028 L) of water. Where the soil moisture content is near optimum, a stronger lime concentration is typically required. In plants employing central mixing, agitation is usually accomplished by using compressed air and recirculating pumps, although pugmills have also been used. The typical slurry plant incorporates slurry tanks that handle whole tanker truckloads of hydrated lime of approximately 20 tons (18,144 kg). The mixer and auxiliary equipment can be mounted on a small trailer and readily transported to the job, giving great flexibility to the operation. In another 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. Spreading from the slurry distributors is effected by gravity or pressure spray bars, the latter being preferred because of better distribution. The use of spray deflectors is also recommended for proper distribution. The general practice in spreading is to make either one or two passes per load; however, several loads may be needed to distribute the required amount of lime. The total number of passes will depend on the lime requirement, the optimum moisture of the soil, and the type of mixing employed. Windrow mixing with the grader generally requires several passes.

4-2.2.2.5 Double Application of Lime.

In areas where extremely plastic 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 mellow for up to a week. The remaining lime is then added before final mixing. The first application mellows the clay and helps achieve final pulverization and the second application completes the lime-treatment process.

4-2.2.2.6 Slurry Made with Quicklime.

A slurry lime rig consists of a 10-foot (3 m) -diameter by 40-foot (12.2 m) tank that incorporates a 5-foot (1.5 m) -diameter single-shaft agitator turned by a diesel engine. The batch slaker can handle 20 to 25 tons (18,144 to 22,680 kg) of quicklime and about 25,000 gal (94,635 L) 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 °F (85 °C).

4-2.2.2.7 Advantages and Disadvantages of Dry Hydrated Lime.

(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 dry, hot seasons.

4-2.2.2.8 Advantages and Disadvantages of Dry Quicklime.

(1) Advantages:

- Dry quicklime is more economical since it contains approximately 25 percent more available free lime.
- It has greater bulk density for smaller-sized silos.
- It has faster drying action in wet soils and faster reaction with all soils. Construction season can be extended in both spring and fall because of faster drying.

(2) Disadvantages:

- The field hydration of dry quicklime, which produces a coarser material with poorer distribution in soil mass, is less effective than commercial hydration.
- Quicklime requires more water than hydrated lime for stabilization, which may present a problem in dry areas.
- Workers with dry quicklime have greater susceptibility to skin and eye burns.

4-2.2.2.9 Advantages and Disadvantages of Lime Slurry.

(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 watering operations are combined, reducing job costs.
- During summer months, a slurry application wets the soil and minimizes drying action.
- The added heat when slurry is made from quicklime speeds the 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, or humid weather, which occurs during the fall, winter, and spring construction season.
- Lime slurries are not practical for use with very wet soils.

4-2.2.3 Pulverization and Mixing.

To obtain satisfactory soil-lime mixtures, achieve adequate pulverization and mixing. For heavy clay soils, two-stage pulverization and mixing may be required but, for other soils, one-stage mixing and pulverization may be satisfactory. The difference is primarily due to heavy clays being more difficult to break down. Perform a test strip at the beginning of new projects to establish the most efficient pulverization, additive distribution, and mixing process for the available equipment and existing site conditions.

4-2.2.3.1 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, ensure the clay clods are less than

2 inches (50 mm) in diameter or the reaction will not completely reach all soils. Before mellowing, liberally sprinkle the soil to bring it up to at least two percentage points above optimum moisture to aid the disintegration of clay clods. The exception to excess watering is in cool, damp weather when evaporation is at a minimum. In hot weather and coarser gradations, it may be difficult to add too much water. After preliminary mixing, lightly seal the roadway with a pneumatic rubber-tired 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 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. In hot weather, more than optimum moisture is needed to compensate for loss through evaporation. Although disc harrows and grader scarifiers are suitable for preliminary mixing, high-speed rotary mixers or one-pass travel plant mixers are required for final mixing. Motor graders are generally unsatisfactory for mixing lime with heavy clays.

4-2.2.3.2 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 readily pulverize and for reconstructing worn-out roads to pulverize the old asphalt.

4-2.2.3.3 Blade Mixing.

When blade mixing is used in conjunction with dry lime, the material is generally bladed into two windrows, one on each side of the roadway. Lime is then spread on the inside of each windrow or down the centerline 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, handle the material on the moldboard 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 (50 mm) layer across the roadway, add an increment of lime, and blade this layer to a windrow on the opposite side of the road. This procedure is repeated several times until all the material is mixed and bladed to the new windrow. Because only half of the lime has been added at this time, the process is repeated, moving the material back to the other side. This procedure is slow but it may be necessary when rotary mixing equipment cannot be easily obtained.

4-2.2.3.4 Central Mixing.

Premixing lime with granular base materials is common on new construction projects, particularly where marginal 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. The general practice is to add the optimum moisture at the pugmill, thereby permitting immediate compaction after laydown.

4-2.2.3.5 Pulverization and Mixing Requirements.

Pulverization and mixing requirements are generally specified in terms of percentages passing the 1.5 inch (37.5 mm) or 1 inch (25 mm) screen and the No. 4 (4.75 mm) sieve. Typical requirements are 100 percent passing the 1 inch (25 mm) screen and 60 percent passing the No. 4 (4.75 mm) sieve, exclusive of nonslaking fractions. In certain expedient construction operations, formal requirements are eliminated and the "pulverization and mixing to the satisfaction of the engineer" clause is employed.

4-2.2.4 Compaction.

For maximum development of strength and durability, properly compact lime-soil mixtures to at least 95 percent of ASTM D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))*, density for subbase and 90 percent for bases for roads and non-traffic areas. Frequently, agencies require 95 percent ASTM D1557 maximum density, particularly for airfield projects. Although such densities can be achieved for 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, some project specifications require 95 percent of ASTM D698 maximum density in the upper 6 to 9 inches (150 to 230 mm) while 90 to 92 percent is acceptable in the bottom portion of the lift. However, do not use deep mixing techniques routinely for airfield projects. To achieve maximum densities, compacting at near 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 two 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 four days are not detrimental. When longer delays (two 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 sheepsfoot roller until it "walks out" and then use a multiple-wheel pneumatic rubber-tired roller. Occasionally, a flat wheel roller is used in finishing. Single-lift compaction can also be accomplished with vibrating impact rollers or heavy pneumatic rollers, and light pneumatic or steel rollers can be used for finishing. When light pneumatic rollers are used alone, compaction is generally done in thin lifts, usually less than 6 inches (150 mm). During compaction, light sprinkling may be required, particularly during hot, dry weather, to compensate for evaporation losses.

4-2.2.5 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 °F to 50 °F (4.4 °C to 10 °C) and moisture contents around optimum are conducive to curing. Although some project specifications require a three- to seven-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 the moisture content of the compacted layer and is an adequate medium for curing. Two types of curing can be employed: moist and asphaltic membrane. 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 sealed with asphalt at a rate of 0.10 to 0.25 gal/sq yd (0.45 to 1.13 liter/sq m). The membrane may need to be applied in multiple applications, depending on how much can be applied to the surface at one time without running off.

4-3 CONSTRUCTION WITH LIME-FLY ASH (LF) AND LIME-CEMENT-FLY ASH (LCF).

Construction procedures for LF 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, note that the presence of cement requires the stabilized mixture be compacted as soon as possible.

4-4 CONSTRUCTION WITH BITUMEN OR POLYMER EMULSION.

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 UFC are for cold-mix materials that are mixed in place (asphalt or polymer emulsions) or in a central plant. Construction procedures for hot-mix hot-laid materials are similar to those used for asphalt concrete. Follow applicable standard construction procedures when these materials are involved. Foamed bitumen stabilization is an in-place technique that involves injecting water into hot bitumen to create a foaming effect that efficiently coats soil particles. The use of cutback asphalts (asphalt mixed with solvent such as diesel or naphtha) as stabilizing materials are generally not acceptable due to environmental and health safety concerns. Procedures described below are applicable to a variety of liquid stabilizers.

4-4.1 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, graders, and windrow sizers. Only equipment especially associated with or having special features applicable to liquid stabilization will be discussed.

4-4.1.1 Mixing Equipment.

4-4.1.1.1 Travel Plants.

Travel plants are a less common method of stabilization. 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 a mixed windrow to the rear of the machine ready for aeration and spreading, 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. Certain features and performance capabilities are common to all travel plants, enabling them to operate effectively and produce a mix meeting design and specification criteria.

4-4.1.1.2 Rotary-type Mixers.

Rotary or mechanical onsite mixing is the most common form of stabilization and is accomplished by what is essentially a mobile mixing chamber mounted on a self-propelled machine. A reclaimer-stabilizer machine is the most versatile mixing machine as it can mill asphalt and mix most soils. Within the chamber, usually about 6 to 8 feet (1.8 to 2.4 m) wide and open at the bottom, is a rotating drum with cutting blades or milling teeth that revolve at relatively high speed. A dedicated soil mixer can also be used but has only tines for mixing and is much less powerful. As the machine moves ahead, it strikes off behind it a uniform course of soil. Most single-shaft mixers are equipped with a liquid injection system (LIS) that adds water or emulsion by spraying it directly into the mixing chamber as the machine moves ahead, with the flow rate of liquid being synchronized with the travel speed to reach a prescribed dosage. This is an excellent method for achieving proper mixing of liquid and soil. If not equipped with an LIS, use the mixer in conjunction with a liquid distributor that sprays the liquid onto the aggregate or soil immediately ahead of the mobile mixer. Both types of machines have the common capability of effecting a smooth bottom cut and then blending the material into the specified mixture. Ensure machines with an LIS have the capability for accurate metering and blending of liquid into the in-place materials in synchronization with a continuous forward movement, have spray bars that will distribute the liquid uniformly across the mixer's width, and are equipped for controlling the depth of cutting. Foamed asphalt stabilization is accomplished using a reclaimer-stabilizer machine specially outfitted for injecting foamed asphalt into the mixing chamber.

4-4.1.1.3 Motor Graders.

Blade mixing is the onsite mixing of materials on the roadbed by a motor grader. This is also a common form of in-place mixing, albeit slow and less efficient than mixing machines. The stabilizing material (generally a slow-setting asphalt or polymer emulsion) is applied directly ahead of the motor grader by an asphalt distributor or other spray device. For most effective blade mixing, equip the motor grader with a blade at least 10 feet (3 m) long and a wheelbase of at least 15 feet (4.6 m). Equip motor graders used for final layout and finishing of the surface with smooth, rather than treaded, pneumatic tires. Scarifier or plow attachments may be mounted before, behind, or both before and behind the blade. This method is not generally recommended for bitumen or polymer emulsion mixing due to the adhesive nature of the additives and the propensity to form pockets of unmixed additive.

4-4.1.1.4 Liquid Distributor.

The liquid distributor is a key piece of equipment in cold mix construction with liquid additives, particularly when rotary mixers without built-in liquid injection systems are used or when blade mixing is utilized. The liquid distributor, either truck or trailer-mounted, may consist of an insulated tank, self-contained heating system, a pump, and a spray bar and nozzles through which the liquid is applied under pressure onto the prepared aggregate materials. The most common liquid distributors are made for asphalts and range in performance and capability. It is important to keep an adequate supply of asphalt or polymer emulsion at or near the jobsite to avoid delays. In rural areas, it may be advisable to have a bulk supply truck at the project.

4-4.2 Mixed-in-Place Construction.

4-4.2.1 Windrows.

Several types of cold-mix construction require the aggregates be placed in windrows prior to mixing and spreading. If windrows are to be used, clear the area of all vegetation to a width 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 necessary to blend it with the material brought in from other sources. However, sometimes incorporating the existing material on the roadbed into the mixture is considered practical if it is uniform and the necessary quantity is available. When this is done, the loose aggregate is first bladed into a windrow and measured. Next, it is 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, place each in its own windrow. These windrows are then thoroughly mixed together before asphalt is added.

4-4.2.2 Determining Liquid Stabilizer Application Rate.

Before mixing operations begin, determine the correct asphalt or polymer emulsion application rate and forward speed of the spray bar-equipped mixer or liquid distributor for the quantity of aggregate in the windrow. Also, when using emulsified asphalt or polymer, it is necessary to moisten the aggregate before applying the emulsion.

For polymer emulsions, ensure the starting soil moisture content is well below optimum. If not, the additional moisture present in the emulsion will result in a moisture content above optimum, leading to lower density during compaction. Although this is also true for asphalt emulsions, the asphalt coating is capable of lubricating the soil for compaction. Therefore, aerating the material to moisture contents below optimum is acceptable for asphalt emulsion stabilization but not for a polymer emulsion.

4-4.2.3 Control of Liquid Stabilizers.

Liquid stabilizer is added to the aggregate from an asphalt distributor or by a travel mixer. Whichever method is used, close control of quantity, dilution, and viscosity is required to ensure a proper mixture. Maintaining the correct and consistent viscosity is critical to ensure the liquid material is fluid enough to move easily through the spray nozzles at the correct flow rate, adequately coat the aggregate particles, and reach the target moisture content necessary for compaction of the stabilized soil. Cutback asphalts, and occasionally emulsified asphalts, even though already fluid, may require heating 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, take care to see that mixing is not attempted at aggregate temperatures below 50 °F (10 °C).

4-4.2.4 Mixing.

4-4.2.4.1 Travel Plant Mixing.

Travel-plant mixing offers the advantage of closer control of the mixing operation than possible with other common mixing methods. 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, match the liquid application rate accurately with the width and thickness of the course, the forward speed of the mixer, and the density of the in-place aggregate. As the thickness is specified, the density is fixed and the liquid application rate is set; the variable is the forward speed. If the aggregate windrow is such that all of the liquid cannot be incorporated in one mixing pass, split it into two or more windrows and the proper amount of liquid added to each windrow as it is mixed. Further mixing of the windrowed material may be necessary after adding the liquid. Unless the travel mixer can be used as a multiple-pass mixer, this additional mixing is usually accomplished with a motor grader. This ensures all of the windrowed material is incorporated into the mix. It also aerates the mixture for the removal of diluents if cutback asphalt is used. The number of passes with the motor grader required for this purpose varies with job conditions. After the mixing and aeration procedure is completed, move the windrow to one side of the area to be surfaced in preparation for spreading.

4-4.2.4.2 Rotary Mixing.

- Liquid Stabilizers.

  As with windrow travel plants, rotary mixers equipped with built-in liquid injection systems require the liquid application rates be accurately matched with the width and thickness of the course, the forward speed of the mixer, the target design stabilizer content, and the optimum moisture content to reach the target density of the in-place aggregate. However, when utilizing a rotary mixer not equipped with a spraybar, a liquid distributor may be used to apply liquid to the aggregate/soil ahead of the mixer. Incremental applications of liquid and passes of the mixer are usually necessary to achieve the specified mixture. Most rotary mixers are now equipped with a spray system. Note that when using water-based liquid stabilizers, ensure the soil moisture content is well below optimum. To reach the design stabilizer content and the optimum moisture content for the mixed soil, properly dilute the mix. Prepare the soil to proper grade and cross-section. If possible, pre-compaction of the soil can help ensure the target design stabilizer content and proper layer thickness are reached. Usually, mixing is accomplished in a single pass of a rotary mixer for efficiency. This requires strict control of mixing speed and pump rates to achieve the desired dosage rate of stabilizer and moisture.

- Foamed Asphalt Stabilization.

  Foamed asphalt stabilization is an efficient and economical method for stabilizing soil. Water is injected into a stream of hot asphalt, causing the asphalt to foam. The hot foam is then immediately sprayed onto the soil inside the mixing chamber of a reclaimer-stabilizer machine. The foaming action provides an efficient coating of asphalt, effectively waterproofing the soil particles. It is best used on sandy and gravelly soils and is gaining popularity for full-depth reclamation of old asphalt pavements.

4-4.2.4.3 Blade Mixing.

Use a slow-setting stabilizer-applied liquid 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 liquid is applied by successive passes of the asphalt distributor over the flattened windrow. After each pass of the distributor, the mixture is worked back and forth across the roadbed with the blade. 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 needed to disperse the asphalt thoroughly throughout the mixture and effectively coat the aggregate particles. During mixing, the vertical angle of the moldboard may require adjustment from time to time to achieve a complete rolling action of the windrow as it is worked. Carry as much material in a roll as possible ahead of the blade since pressure from the weight of the aggregate facilitates mixing. During mixing, take care to ensure 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. When the blade-mixing technique is used, the formation of "additive balls," or concentrated clusters of fine aggregate saturated and coated with excessive amounts of liquid additive, can make a mix difficult to spread and compact. For bitumen, asphalt emulsions, or cutback asphalts, this condition can be corrected by windrowing 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, cut periodic breaks in the windrow to ensure drainage of rainwater from the roadbed. Unfortunately, the formation of “additive balls” with polymer emulsions is more difficult to correct since polymer emulsions harden as the emulsion water evaporates. For polymer emulsions, obtain a rotary mixer if the blade-mixing technique produces significant “additive balls” after reasonable attempts to blade-mix the additive with the soil.

4-4.2.5 Aeration.

4-4.2.5.1 Emulsified Asphalts and Polymers.

Begin compaction of emulsified liquids 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 acts 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 is able to support the roller without undue displacement or pickup onto the roller surface. Begin compaction of polymer emulsions immediately after mixing.

4-4.2.5.2 Cutback Asphalt Mixes.

When using cutback asphalt, correct aeration will be achieved when the 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. Before compaction for cutback asphalt, allow most of the diluents that have made the mix workable 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 occasionally needed to help speed the process and dissipate the excess diluents. Until the mix is aerated, it usually will not support rollers without excessive shoving. Generally, the mixture is aerated when it becomes tacky and appears to "crawl." Fine-grained and well-graded mixtures will require longer aeration than open-graded and coarse-grained mixtures, all else being equal. Also, if an asphalt cold-mix base course is to be surfaced within a short length of time, aerate the surface before compaction more completely than if the course is not to be surfaced for a longer period of time; the surface acts as a seal, greatly retarding the removal of diluents.

4-4.2.6 Spreading and Compacting.

With mixing and aeration completed, spreading (if necessary) 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. Always spread the mixture to a uniform thickness (whether in a single pass or in several thinner layers) so 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 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. Accomplish spreading by blade in successive layers, with no layer thinner than approximately 1.5 times the diameter of the maximum particle size. As each layer is spread, compact the layer immediately with a pneumatic-tired roller as soon as the layer will bear the effort without shoving. 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. Eliminate ridge marks by rolling directly behind the motor grader. If, at any time during compaction, the asphalt mixture exhibits undue rutting or shoving, stop rolling. After one course is thoroughly compacted and cured, other courses may be placed over it. Repeat this operation as many times as necessary to bring the pavement to proper grade and crown. For a smooth riding surface, use the motor grader 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, then finish roll, preferably with a steel-wheeled roller, until all roller marks are eliminated. A completed course may have to be temporarily opened 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 gal/sq yd (0.45 liter/sq m). Allow this to cure until no pickup occurs. For immediate passage of traffic, sanding may be desirable to avoid pickup.

4-4.3 Central Plant Mix Construction.

4-4.3.1 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 lb (907 kg). The correct amounts of asphalt and aggregate, generally determined by weight, are fed into the pugmill. 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 automatically maintain the correct proportions. Typically, automatic feeders 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.

4-4.3.2 Aerating Plant Mix.

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

4-4.3.3 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, cutter-trimmer-spreaders, or motor graders may be used. Similar to mixed-in-place, central plant cold mixes gain stability as the diluents, which 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. Spread the mixture uniformly on the roadbed, beginning at the point farthest from the mixing plant. Hauling over freshly placed material is not permitted except when required for completion of the work.

4-5 CONSTRUCTION WITH FIBERS.

Equipment for placing fibers has not reached a commercial stage. Generally, fibers are placed manually by spacing bags of discrete fibers in a grid pattern or by lanes, similar to the way bagged cement and lime are placed. Like cement, spread the fibers uniformly within the area. Using the backside of a rake will help, as the rake tines drag the fibers. Placing fibers on days with winds above 15 miles per hour (24 kilometers per hour) is not recommended. Wetting the fibers after spreading will help hold them in place, if necessary. Fibers are difficult to efficiently mix and may require multiple passes of a rotary mixer to achieve even dispersal throughout the soil. Fibrillated fibers may also require multiple passes of a rotary mixer to "open" the fibrils. If using cement or lime, spread the dry material first then follow with the fibers.

It is very important to start with the soil well-prepared and properly graded to minimize or even eliminate any post-mixing soil work. After mixing, working the fibrous soil can be very difficult. It is not recommended to grade or move the material unless absolutely necessary. Before compaction, it can be moved with graders and rakes and mildly graded, but once compacted, grading the surface results in tears and rips that make repair problematic. After compaction, the material is best handled by remixing with a rotary mixer to loosen it before working the soil.

CHAPTER 5 QUALITY CONTROL

5-1 PURPOSE

Quality control is essential to ensure the final product will be adequate for its intended use and ensure the contractor has performed in accordance with the plans and specifications, as this is a basis for payment. This chapter identifies those control factors that are most important in soil stabilization construction with cement, lime, lime-fly ash, bituminous additives, and polymer emulsions.

5-2 CEMENT STABILIZATION.

The most important factors from 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.

5-2.1 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 (4.75 mm) sieve used as a control. The percent pulverization can then be determined by calculation. Proper moisture control is also essential to achieve the required pulverization. Most specifications require the soil material be pulverized so at the time of compaction 100 percent of the soil-cement mixture will pass a 1 inch (25 mm) sieve and a minimum of 80 percent will pass a No. 4 (4.75 mm) sieve, exclusive of any gravel or stone. Ensure gravel or stone are no more than a 2 inch (50 mm) maximum size or the cement cannot effectively stabilize the soil. Perform the final pulverization test at the conclusion of mixing operations.

5-2.2 Cement Content.

Cement content is typically expressed in terms of a percentage of the dry weight of the soil being treated. Occasionally, cement content is expressed in terms of volume; however, this is less frequent due to the complication it adds in calculating quantities for batching. Be aware of quantities of cement required per linear foot or per square yard of pavement. Spot checks can be performed to assure 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.

5-2.3 Moisture Content.

The optimum moisture content for the soil-additive mixture determined in the laboratory is used as an initial guide when construction begins. Make allowance 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 adding the mixing water. Nuclear methods can be used to determine moisture content at the time construction starts and during processing. In general, field compaction equipment imparts more energy into the soil than laboratory equipment and the field optimum moisture content may be slightly lower than that reported in laboratory results.

5-2.4 Uniformity of Mixing.

A visual inspection is performed to assure the uniformity of the mixture throughout the treated depth. Check uniformity 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 non-uniform mix. Pay special attention to the edges of the pavement.

5-2.5 Compaction.

Equipment used for compaction is the same used if no cement were present in the soil and is therefore dependent upon soil type. Two methods can be used to determine compacted density: sand-cone (ASTM D1556, *Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method*) and nuclear (ASTM D6938, *Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)*). It is important to determine the depth of compaction and pay special attention to compaction at the edges.

5-2.6 Curing.

To assure proper curing, a bituminous or polymer emulsion or liquid curing compound is frequently applied over the stabilized areas. Ensure the surface of the soil cement is free of dry, loose material and in a moist condition. It is important the soil-cement mixture be kept continuously moist until the membrane is applied. The recommended application rate is 0.15 to 0.30 gal/sq yd (0.68 to 1.36 liter/sq m).

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.

5-3.1 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 (25 mm) and No. 4 (4.75 mm) 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.

5-3.2 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 specified lime content. 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.

5-3.3 Uniformity of Mixing*.*

The major goal is to obtain 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 with 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 reddish pink color when sprayed with the indicator solution, indicating that free lime is available in the soil (pH = 12.4). Alternatively, soil samples can be collected at various locations and depths and subjected to pH tests using field portable equipment.

5-3.4 Compaction*.*

The most important compaction factor is the proper control of moisture and density. Conventional procedures such as sand cone (ASTM D1556) and nuclear methods (ASTM D6938) have been used for determining the density of compacted soil-lime mixtures. Moisture content can be determined by either oven-dry methods (ASTM D2216, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*) or nuclear methods (ASTM D6938). The influence of time between mixing and compacting has been demonstrated to have a pronounced effect on the properties of treated soil. Begin compaction 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, as stated in paragraph 5-3.3. 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 wind action. This will aid in identifying areas to perform density testing.

5-3.5 Curing*.*

Curing is essential to assure the soil-lime mixture will achieve the final properties desired. Curing is accomplished by one of two methods: (1) moist curing, involving a light sprinkling of water and rolling; or (2) membrane curing, which involves sealing the compacted layer with a bituminous seal coat or liquid curing compound. Regardless of the method used, properly protect the entire compacted layer to ensure 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 LF and LCF stabilization is similar to that for lime only. Consequently, the same factors involved for quality control are suggested.

5-5 BITUMINOUS AND POLYMER STABILIZATION.

The factors that seem most important to control during construction with bituminous and polymer stabilization are moisture content, viscosity of the liquid, additive content, uniformity of mixing, aeration, compaction, and curing.

5-5.1 Moisture Content.

The moisture of the soil to be stabilized is of concern. Moisture content can be determined by conventional methods, such as oven-drying (ASTM D2216), or by nuclear methods (ASTM D6938). The Asphalt Institute recommends surface moisture of up to 3 percent or more for use with emulsified asphalt and a moisture content of less than 3 percent for cutback asphalt. The gradation of the aggregate is significant to 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 PI soils require higher moisture content. For polymer emulsions, ensure the starting soil moisture content is well below optimum. If not, the additional moisture present in the emulsion will result in a moisture content above optimum, leading to lower density during compaction. Although this is also true for asphalt emulsions, the asphalt coating is capable of lubricating the soil for compaction. Therefore, aerating the material to moisture contents below optimum is acceptable for asphalt-emulsion stabilization but not for polymer emulsion.

5-5.2 Viscosity of Asphalt.

The Asphalt Institute recommends avoiding cold-mix construction at temperatures below 50 °F (10 °C). The asphalt will rapidly reach the temperature of the aggregate to which it is applied and, at the lower temperature, difficulty mixing will be encountered. On occasion, heating is necessary with cutback asphalts to assure the soil aggregate particles are thoroughly coated. For emulsions, ensure the temperature is above the minimum film-forming temperature, a basic property of all emulsions.

5-5.3 Asphalt and Polymer Content.

Information that will enable field personnel to determine a satisfactory application rate can be provided to them. Maintain the asphalt content 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.

Similarly, maintain the actual polymer content at or slightly below optimum for the design mix. The actual polymer content is computed based upon the percent solids of the polymer emulsion. In addition, check the polymer emulsion for consistency in terms of percent solids of the delivered product at random.

5-5.4 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 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. The inspection of polymer-stabilized soil is less obvious; take extreme care to ensure the material is mixed thoroughly and to full depth.

5-5.5 Aeration.

Prior to compaction, allow the diluents that facilitated the cold-mix operation to evaporate. If the mix is not aerated, it cannot be compacted to acceptable limits. The Asphalt Institute has determined that the mixture has aerated when it becomes tacky and appears to "crawl." Most aerating occurs during the mixing and spreading stage but occasionally additional work 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 with in the field.

5-5.6 Compaction.

Begin compaction 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.

5-5.7 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: the quantity of asphalt applied, the prevailing humidity and wind, the amount of rain and sunlight, and the ambient temperature. Allow initial curing in order to support compaction equipment. This initial curing, which allows 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 curing time when lift construction is employed. The Asphalt Institute recommends a two- to five-day curing period under recommended conditions when emulsified bases are being constructed. Cement has been used to accelerate curing. Polymeric emulsions cure by evaporation of the dilution water. Thus, the use of a curing membrane is not recommended.

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APPENDIX A BEST PRACTICES

A-1 THICKNESS CRITERIA-STABILIZED SOIL LAYERS

A-1.1 Equivalency Factors.

The use of stabilized soil layers within a flexible pavement provides the opportunity to reduce the overall thickness of the pavement structure required to support a given load. To design a pavement containing stabilized soil layers requires applying equivalency factors to a layer or layers of a conventionally designed pavement. To qualify for application of equivalency factors, ensure the stabilized layer meets appropriate strength and durability requirements set forth in this UFC. An equivalency factor represents the number of inches (millimeters) of a conventional base or subbase that can be replaced by 1 inch (25 mm) of stabilized material. Equivalency factors for stabilized materials are determined as shown in Table A-1. Limit the cement content to 4 percent by weight or less to prevent excessive reflective cracking. Selecting an equivalency factor from the table is dependent upon the classification of the soil to be stabilized.

Table A-1 Equivalency Factors for Stabilized Material

Material	Equivalency Factors	
	Base	Subbase
Asphalt-stabilized		
All-bituminous concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
SW, SP, SM, SC	(*)	1.50
Cement-stabilized		
GW, GP, SW, SP	1.15	2.30
GM, GC	1.00	2.00
ML, MH, CL, CH	(*)	1.70
SC, SM	(*)	1.50
Lime-stabilized		
ML, MH, CL, CH	(*)	1.00
SC, SM, GM, GC	(*)	1.10
Lime, Cement, Fly Ash-Stabilized		
ML, MH, CL, CH	(*)	1.30
SC, SM, GM, GC	(*)	1.40
Unbound crushed stone	1.00	2.00
Unbound aggregate	(*)	1.00
* Not used for base course material.		

A-1.2 Thickness Design for Stabilized Soil Layers.

To use the equivalency factors requires that a conventional flexible pavement be designed to support the design load conditions. If it is desired to use a stabilized base or subbase course, the thickness of the conventional base or subbase is divided by the equivalency factor for the applicable stabilized soil.

A-1.2.1 Example 1.

Assume a conventional flexible pavement has been designed that requires a total thickness of 16 inches (406 mm) above the subgrade. The minimum thicknesses of the AC and the base are 2 and 4 inches (51 and 102 mm), respectively, and the thickness of the subbase is 10 inches (254 mm). It is desired to replace the base and the subbase with a cement-stabilized gravelly soil (GP) having an unconfined compressive strength of 890 psi (6.14 MPa). The material qualifies for application as a base course since its strength is greater than 750 psi (5.17 MPa), as required by this UFC. From Table A-1, the equivalency factor for a base is 1.15. Therefore, 4 inches ÷ 1.15 = 3.48 inches (102 mm ÷ 1.15 = 88.7 mm) of stabilized base course. Since the minimum required thickness is 4 inches (102 mm), the excess of stabilized base course of 4 inches – 3.48 inches = 0.52 inches (102 mm – 88.7 mm = 13.3 mm) is computed as the equivalent thickness of non-stabilized subbase material, which is equal to 0.52 inches * 2.3 = 1.12 inches (13.3 mm * 2.3 = 30.6 mm). This equivalent subbase thickness is accounted for in the stabilized base; therefore, the needed non-stabilized subbase is thinner than 10 inches (254 mm) and equal to 10 inches – 1.12 inches = 8.88 inches (254 mm – 21.2 mm = 232.8 mm). The next step includes calculating the equivalent thickness of the subbase stabilized material as 8.88 inches ÷ 2.3 = 3.86 inches (223.4 mm ÷ 2.3 = 97.1 mm). The required minimum thickness for the stabilized subbase is 4 inches (102 mm). Therefore, the total thickness of the cement-stabilized pavement is 2 inches (51 mm) of AC, 4 inches (102 mm) of cement-stabilized gravelly soil base, and 4 inches (102 mm) of cement-stabilized gravelly soil subbase.

A-1.2.2 Example 2.

Assume a conventional flexible pavement has been designed that requires 3.5 inches (89 mm) of AC surface, 4 inches (102 mm) of crushed stone base, and 18 inches (458 mm) of subbase. It is desired to construct an all-bituminous pavement (ABC). The equivalency factor from Table A-1 for a base course is 1.15 and for a subbase, 2.30. The thickness of AC required to replace the base is 4 inches ÷ 1.15 = 3.48 inches (102 mm ÷ 1.15 = 88.7 mm). Since the minimum required thickness is 4 inches (102 mm), the excess of stabilized base course of 4 inches – 3.48 inches = 0.52 inches (102 mm – 88.7 mm = 13.3 mm) is computed as the equivalent thickness of non-stabilized subbase material, which is equal to 0.52 inches * 2.3 = 1.12 inches (13.3 mm * 2.3 = 30.6 mm). This equivalent subbase thickness is accounted in the stabilized base; therefore, the needed non-stabilized subbase is thinner than 18 inches (459 mm) and equal to 18 inches – 1.12 inches = 16.88 inches (458 mm – 21.2 mm = 437 mm). The next step computes the equivalent thickness of subbase-stabilized material as 16.88 inches ÷ 2.3 = 7.34 inches (437 mm ÷ 2.3 = 190 mm). The total thickness of the ABC pavement is 3.5 inches + 4 inches + 7.34 inches = 14.84 inches ~15 inches (89 + 102 + 190 = 381 mm ~390 mm)

A-2 PH TEST ON SOIL-CEMENT MIXTURES

A-2.1 Materials.

Portland cement will be used for soil stabilization.

A-2.2 Apparatus.

Apparatus are the pH meter (equip the pH meter with an electrode having a pH range of 14), 150-ml plastic bottles with screw-top lids, 500-ml plastic beakers, distilled water, balance, oven, and moisture cans.

A-2.3 Procedure.

A-2.3.1 Standardization. Standardize the pH meter with a buffer solution having a pH of 12.00.

A-2.3.2 Representative Samples. Weight to the nearest 0.01 g representative samples of air-dried soil passing the No. 40 (0.425 mm) sieve and equal to 25.0 g of oven-dried soil.

A-2.3.3 Soil Samples. Pour the soil samples into 150-ml plastic bottles with screw-top lids.

A-2.3.4 Portland cement. Add 2.5 g of portland cement.

A-2.3.5 Mixture. Thoroughly mix soil and portland cement.

A-2.3.6 Distilled Water. Add distilled water to make a thick paste. (Caution: Too much water will reduce the pH and produce an incorrect result.)

A-2.3.7 Blending. Stir the soil-cement and water until thorough blending is achieved.

A-2.3.8 Transferal. After 15 minutes, transfer part of the paste to a plastic beaker and measure the pH.

A-2.3.9 Interference. If the pH is 12.1 or greater, the soil organic matter content should not interfere with the cement-stabilizing mechanism.

A-3 DETERMINATION OF SULFATE IN SOILS - GRAVIMETRIC AND TURBIDIMETRIC METHOD

A-3.1 Gravimetric Method.

A-3.1.1 Scope.

Applicable to all soil types with the possible exception of soils containing certain organic compounds, this method permits the detection of as little as 0.05 percent sulfates as SO_4.

A-3.1.2 Reagents.

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

A-3.1.3 Apparatus.

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

A-3.1.4 Procedure.

A-3.1.4.1 Select a representative sample of air-dried soil weighing approximately 10 g. Weigh to the nearest 0.01 g. (Note: When sulfate content is anticipated to be less than 0.1 percent, a sample weighing 20 g or more may be used.) (Measure the moisture content of the air-dried soil for later determination of dry weight of the soil.)

A-3.1.4.2 Boil for 1.5 hours in a beaker with mixture of 300-ml water and 15-ml HCl.

A-3.1.4.3 Filter through Whatman No. 40 paper, wash with hot water, and dilute combined filtrate and washings to 50 ml.

A-3.1.4.4 Take 100 ml of this solution and add $MgCl_2$ solution until no more precipitate is formed.

A-3.1.4.5 Filter through Whatman No. 42 paper, wash with hot water, and dilute combined filtrates and washings to 200 ml.

A-3.1.4.6 Heat 100 ml of this solution to boiling and add $BaCl_2$ solution very slowly until no more precipitate is formed. Continue boiling for about five minutes and let stand overnight in a warm place, covering the beaker with Saran Wrap.

A-3.1.4.7 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 or continue washing).

A-3.1.4.8 Dry filter paper in crucible or on sheet of aluminum foil. Ignite paper. Weight residue on analytical balance as $BaSO_4$.

A-3.1.5 Calculation.

$$Percent\ SO_4 = \frac{Weight\ of\ residue}{Oven\ dry\ weight\ of\ initial\ sample} \times 411.6$$

Where:

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

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.

A-3.2 Turbidimetric Method.

A-3.2.1 Reagents.

Reagents include $BaCl_2$ crystals (grind analytical reagent-grade $BaCl_2$ to pass a 1-mm sieve), ammonium acetate solution (0.5 N) (add dilute hydrochloric acid until the solution has a pH of 4.2), and distilled water.

A-3.2.2 Apparatus.

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

A-3.2.3 Procedure.

A-3.2.3.1 Take a representative sample of air-dried soil weighing approximately 10 g and weight to the nearest 0.01 g. (Measure the moisture content of the air-dried soil for later determination of dry weight of the soil.)

A-3.2.3.2 Add the ammonium acetate solution to the soil until the ratio of soil to solution is approximately 1:5 by weight.

A-3.2.3.3 Boil for about five minutes.

A-3.2.3.4 Filter through Whatman No. 40 filter paper. If the extracting solution is not clear, filter again.

A-3.2.3.5 Take 10 ml of extracting solution (this may vary, depending on the concentration of sulfate in the solution) and dilute with distilled water to about 40 ml. Add about 0.2 g of $BaCl_2$ crystals and dilute to make the volume exactly equal to 50 ml. Stir for one minute.

A-3.2.3.6 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 four minutes. Maximum turbidity is usually obtained within two minutes and the readings remain constant thereafter for three to ten minutes. Consider the turbidity to be the maximum reading obtained in the four-minute interval.

A-3.2.3.7 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.)

A-3.2.3.8 Correct for the apparent turbidity of the samples by running blanks in which no $BaCl_2$ is added.

A-3.2.4 Sample Calculation.

Given:	Weight of air-dried sample	= 10.12 g
	Water content	= 9.36 percent
	Weight of dry soil	= 9.27 g
	Total volume of extracting solution	= 39.1 ml

10 ml of extracting solution was diluted to 50 ml after addition of $BaCl_2$ (see paragraph A-3.2.3, 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 Figure A-1.)

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

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

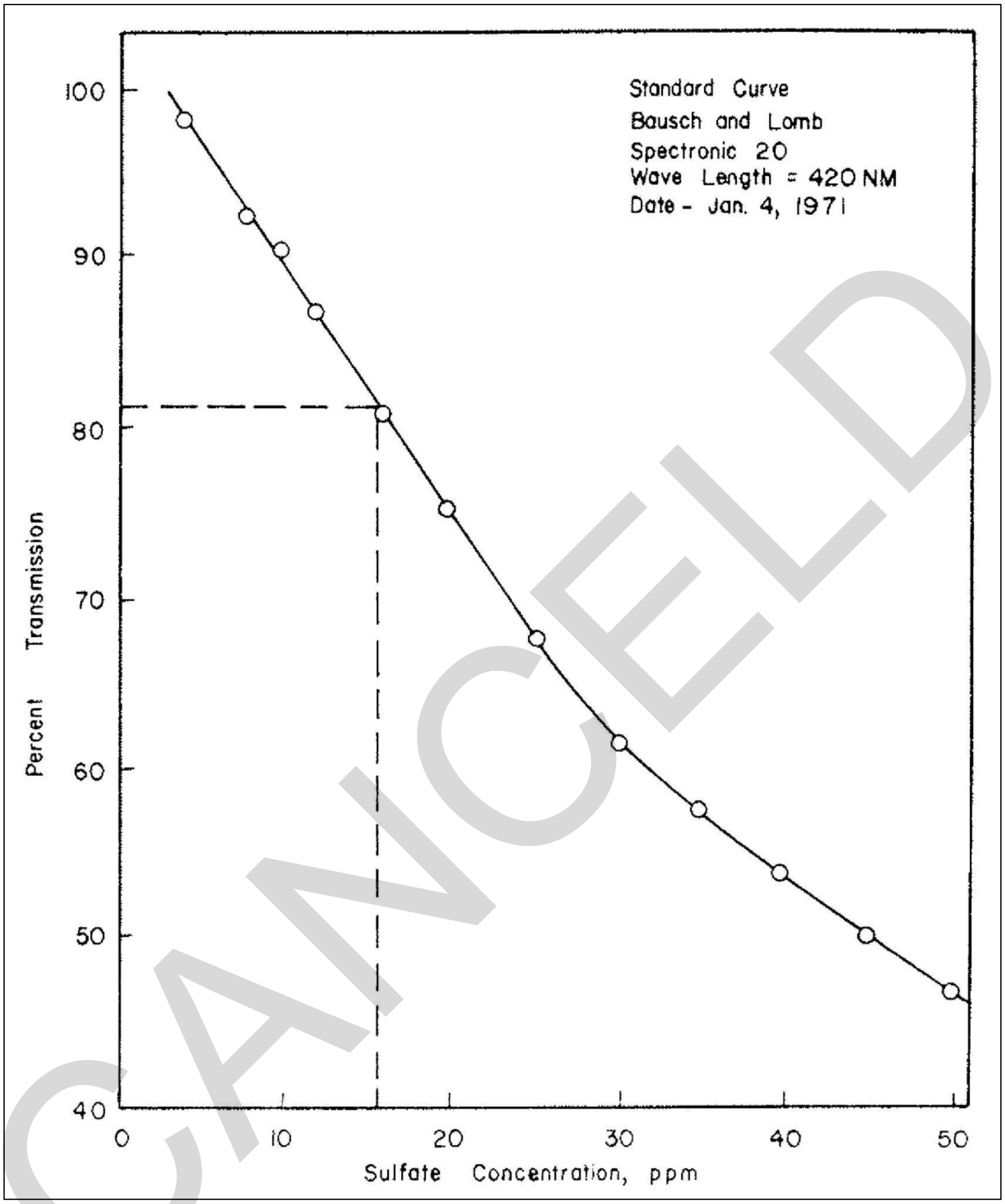
A-3.2.5 Determination of Standard Curve.

A-3.2.5.1 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 Normal ammonium acetate (with pH adjusted to 4.2).

A-3.2.5.2 Continue steps 5 and 6 in the procedure (paragraph A-3.2.3).

A-3.2.5.3 Draw a standard curve as shown in Figure A-1 by plotting transmission readings for known concentrations of sulfate solutions.

Figure A-1 Example Standard Curve for Spectrophotometer



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APPENDIX B GLOSSARY

B-1 ACRONYMS

°C	degree Celsius
°F	degree Fahrenheit
AASHTO	American Association of State Highway and Transportation Officials
ABC	all-bituminous pavement
ACI	American Concrete Institute
$AgNO_3$	Silver nitrate
$BaCl_2$	Barium chloride
$BaSO_4$	Barium sulfate
CaO	calcium oxide
DWG	Discipline Working Group
FAA	Federal Aviation Administration
ft	foot
g	gram
gal	gallon
gal/sq yd	gallon per square yard
H_2O	water
HCl	hydrochloric acid
in.	inch
kg	kilogram
L	liter
lb	pound
lb/in^2	pound per square inch
LCF	lime-cement fly ash
LF	lime-fly ash

LIS — liquid injection system

LL — liquid limit

m — meter

$MgCl_2$ — magnesium chloride

ml — milliliter

mm — millimeter

MPa — megapascal

N — Normal

pH — scale of acidity

PI — plasticity index

psi — pound per square inch

USCS — Unified Soil Classification System

B-2 TERMS

Additive Stabilization: Stabilization is achieved by adding the proper percentages of additives to the soil. Selecting the type and determining the percentage of additive to be used is dependent upon the soil classification, conservation of deleterious materials such as sulfates and organics, and the degree of improvement in soil quality desired. Non-traditional additives such as polymer, fiber, lignin derivatives, enzymes, acids, etc. will be addressed where appropriate; however, due to the specialized nature of many of these materials, defining specific criteria for all additives is beyond the scope of this UFC. Generally, smaller amounts of additives are required when only modification of soil properties such as gradation, workability, and plasticity is desired. When significant strength and durability improvement is desired, greater quantities of additive are needed. After the additive has been mixed with the soil at the optimum moisture content, spreading and compaction are achieved by conventional means.

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 are termed “traditional” additives and include materials such as lime, cement, fly ash, and asphalt emulsions. “Non-traditional” additives such as polymer emulsions, fiber, lignin derivatives, enzymes, acids, and other materials used to improve soil qualities are more recent entries into the commercial market. Additives addressed in this UFC are portland cement, lime, fly ash, bitumen, polymer emulsion, fiber, and select combinations of these.

Durability: Durability refers to the resistance of the soil to weathering, primarily by the action of water and abrasion after wet-dry and freezing and thawing cycles (ASTM D559 and D560).

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 at the optimum moisture content by conventional means. Compaction and fiber addition are also means of mechanical stabilization. Compaction consists of the mechanical rearrangement of soil particles into a denser configuration, typically resulting in increased strength and/or durability. The addition of fibers into a soil can mechanically stabilize the soil by creating interlock between particles.

Modification: Modification refers to the stabilization process that results in improvement in some material property of the soil such as the plasticity index (PI) but does not, by design, result in a significant increase in soil strength and durability.

Optimum Moisture Content: The optimum moisture content of soil is the water content, measured in percentage by unit weight, at which a maximum dry unit weight can be achieved after a given compactive effort. (See ASTM D1557 for further information.) A higher or lower moisture content will result in a lower maximum dry unit weight after compaction.

Soils: Soils are naturally occurring materials used for the construction of all except the surface layers of pavements (i.e., concrete and asphalt) and subject to classification tests (ASTM D2487) to provide a general concept of their engineering characteristics.

Stabilization: Stabilization is the process of blending and mixing materials with a soil to improve engineering properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of additives that may alter the chemistry, gradation, texture, plasticity, or water absorption or act as a binder for cementation of the soil. Stabilization results in a significant increase in the strength and/or durability of the stabilized material.

Strength: In the context of this UFC, "strength" refers to the unconfined compressive tests measured using ASTM D1633.

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APPENDIX C REFERENCES

DOD

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UFC 3-250-01, *Paving Design for Roads and Parking Areas*

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AASHTO M288, *Standard Specification for Geosynthetic Specification for Highway Applications*, https://store.transportation.org/

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 230.1R, *Report on Soil Cement*, https://www.concrete.org/

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

https://www.astm.org/

C33, *Standard Specification for Concrete Aggregates*

C150, *Standard Specification for Portland Cement*

C593, *Standard Specification for Fly Ash and Other Pozzolans for Use with Lime for Soil Stabilization*

C977, *Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization*

C1580, *Standard Test Method for Water-Soluble Sulfate in Soil*

D6913/D6913M-17, *Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis*

D558, *Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures*

D559, *Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures*

D560, *Standard Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures*

D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))*

D1556, *Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method*

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D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*

D3551, *Standard Practice for Laboratory Preparation of Soil-Lime Mixtures Using Mechanical Mixer*

D4546-14e1, *Standard Test Methods for One-Dimensional Swell or Collapse of Soils*

D4318-17e1, *Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils*

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D6927, *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*

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