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Chapter 5

Soil Stabilization

This chapter presents criteria and tests for improving the structural quality and workability of soils used for base courses, subbase courses, select materials, and subgrades for pavements. It is applicable to all elements responsible for Army, Air Force, or Navy pavement construction.

SECTION I. MECHANICS OF SOIL STABILIZATION AND MODIFICATION

Stabilized soils can often be adequate for airfields, traffic pavements, and parking and storage areas where an all-weather surface is required, yet traffic does not justify a higher-strength pavement. Surface treatments are also used to provide dust control. The most widely recognized form of stabilization is compaction, which improves the mechanical stability of virtually any soil. However, compaction alone is often not enough.

STABILIZATION

Stabilization is the process of blending and mixing materials with a soil to improve the soil's strength and durability. The process may include blending soils to achieve a desired gradation or mixing commercially available additives that may alter the gradation, change the strength and durability, or act as a binder to cement the soil.

USES OF STABILIZATION

Pavement design is based on the premise that specified levels of quality will be achieved for each soil layer in the pavement system. Each layer must—

- Resist shearing within the layer.
- Avoid excessive elastic deflections that would result in fatigue cracking within the layer or in overlying layers.
- Prevent excessive permanent deformation through densification.

As the quality of a soil layer is increased, the ability of that layer to distribute the load over a greater area is generally increased enough to permit a reduction in the required thickness of the soil and surface layers.

Improve Quality

Stabilization is commonly used for better soil gradation, reduction of the PI or swelling potential, and increased durability and strength. Soils stabilized by additives often provide an all-weather working platform for construction operations. These types of soil-quality improvements are referred to as soil modifications.

Reduce Thickness

A soil layer's tensile strength and stiffness can be improved by using additives and can thereby reduce the thickness of the stabilized layer and overlying layers within the pavement system. Procedures for designing pavements that use stabilized soils are presented in TM 5-822-5, Chapter 3, and TM 5-825-2, Chapter 2. Before a stabilized layer can be used to reduce the required thickness in the design of a pavement system, the stabilized material must meet the durability requirements of various types of additive stabilization and the minimum strength requirements. Generally, as the percent of fines and the PI increase, pulverization becomes more difficult and it is harder to obtain uniform distribution of the stabilizing additive. For these types of soils, preprocessing or pretreatment with other additives may be necessary. For example, fine-grained soils may be pretreated with lime to aid in their pulverization, making the mixing of a bitumen or cement additive more successful.

METHODS OF STABILIZATION

The two general stabilization methods are mechanical and additive. The effectiveness of stabilization depends on the ability to obtain uniformity in blending the various materials. Mixing in a stationary or traveling plant is preferred. However, other means of mixing (such as scarifiers, plows, disks, graders, and rotary mixers) have been satisfactory.

The soil-stabilization method is determined by the amount of stabilizing required and the conditions encountered on the project. An accurate soil description and classification are essential for selecting the correct materials and procedure. FM 5-410, Chapter 9, lists the most suitable treatments for various soil types to stabilize these soils for different objectives.

Mechanical

Mechanical stabilization is accomplished by mixing or blending two or more gradations of material to obtain a mixture meeting the required specifications. The blending of these materials may take place at the construction site, at a central plant, or at a borrow area. The blended material is then spread and compacted to the required densities by conventional means. If, after blending these materials, the mixture does not meet the specifications, then stabilization with an additive may be necessary.

Additive

Additive refers to a manufactured commercial product that, when added to the soil in the proper quantities, will improve the quality of the soil layer. The two types of additive stabilization discussed mainly in this chapter are chemical and bituminous. Chemical stabilization is achieved by the addition of proper percentages of portland cement, lime, lime-cement-fly ash (LCF), or combinations of these materials to the soil. Bituminous stabilization is achieved by the addition of proper percentages of bituminous material to the soil. Selecting and determining the percentage of additives depend on the soil classification and the degree of improvement in the soil quality desired. Smaller amounts of additives are usually required to alter soil properties (such as gradation, workability, and plasticity) than to improve the strength and durability sufficiently to permit a thickness-reduction design. After the additive has been mixed with the soil, spreading and compacting are achieved by conventional means.

MODIFICATION

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

Soil modification usually results in something less than a thoroughly cemented, hardened, or semihardened material. This type of stabilization may be accomplished by—

- Compacting.
- Blending mechanically.
- Adding cementing material in small amounts.
- Adding chemical modifiers.

Cement and lime modifiers (cement-modified and lime-modified soils) are used in quantities too small to provide high-strength cementing action. They reduce the plasticity of clay soils. Calcium chloride or sodium chloride are added to the soil to retain moisture (and also control dust), to hold fine material for better compaction, and to reduce frost heave by lowering the freezing point of water in the soil. Bituminous materials (such as cutback asphalts or APSB) and certain chemicals (such as polyvinylacetate emulsion [DCA-1295]) are used to waterproof the soil's surface and to control dust

SECTION II. STABILIZING AGENTS

This section provides a method for determining the type or types of stabilizers and the amount of stabilizer to be used with a particular soil. It also considers the stabilization of soils with lime, cement, fly ash, and bituminous materials.

TYPES OF STABILIZERS

To select the proper stabilizer type for a particular soil, perform a sieve-analysis test and an Atterberg-limits test according to the procedures given in this manual.

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.

Cement can be used effectively as a stabilizer for a wide range of materials; however, the soil should have a PI less than 30. For coarse-grained soils, the amount passing the No. 4 sieve should be greater than 45 percent. The amount of cement used depends on whether the soil is to be modified or stabilized.

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. Soils classified according to the 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 should be considered as potentially capable of being stabilized with lime. Lime should be considered with all soils having a PI greater than 10 and more than 25 percent of the soil passing the No. 200 sieve.

FLY ASH

Fly ash, when mixed with lime, can be used effectively to stabilize most coarse- and medium-grained soils; however, the PI should not be greater than 25. 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.

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 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.

COMBINATION

Combination stabilization is specifically defined as lime-cement, lime-asphalt, and LCF stabilization. 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 to reduce its plasticity. Cement 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.

TIME REQUIREMENTS FOR TESTING

The more thorough a testing program, the more assurance there is for the long-term success of the project. Time is often of primary concern to a military engineer—particularly in a tactical situation—and the rapid completion of a project may override the requirement for a complete series of laboratory tests (see *Table 5-1*). Because of this, the method presented allows for a rapid or expedient approximation along with a more precise laboratory determination of the type and quantity of stabilizer. An estimate for testing time is presented in *Table 5-1*.

Table 5-7. Estimated time required for test procedures

Construction Type	Stabilizing Agent	Time Required*
Expedient	Lime LCF Cement Bitumen	None None None None
Nonexpedient	Lime LCF Cement Bitumen	30 days 30 days 6 to 9 days 1 day
***These criteria do not include time required for gradation.**		

STABILIZER SELECTION

When selecting a stabilizer additive, many factors must be considered. These factors, design criteria, and the selection and mixing of stabilizers can be found in FM 5-410, Chapter 9; TM 5-822-14; and FM 5-430-00-2.

If lime is used as a preliminary additive to reduce the PI or to alter the soil gradation before adding the primary stabilizing agent (such as bitumen or cement), then the design's lime content is the minimum treatment level that will achieve the desired results. For nonplastic and low PI materials in which lime alone generally is not satisfactory for stabilization, adding fly ash may produce the necessary reaction.

The lime used for soil stabilization is also used to determine lime requirements in the pH test.

EQUIPMENT

Use the following items for the pH test:

- A pH meter (the meter must be equipped with an electrode having a pH range of 14).
- 150-milliliter (or larger) plastic bottles with screw-top lids.
- Distilled water, free of carbon dioxide.
- A balance.
- An oven.

STEPS

Perform the following steps to determine the pH:

Step 1. Standardize the pH meter with a buffer solution having a pH of 12.45.

Step 2. Weigh, to the nearest 0.01 gram, representative samples of air-dried soil passing the No. 40 sieve and equal to 20.0 grams of oven-dried soil.

Step 3. Pour the soil samples into the 150-milliliter plastic bottles with screw-top lids.

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

Step 5. Mix the soil thoroughly and dry the lime.

Step 6. Add 100 milliliters of the distilled water to the soil-lime mixtures.

Step 7. Shake the soil-lime-water mixture for a minimum of 30 seconds or until there is no evidence of dry material on the bottom of the bottle.

Step 8. Shake the bottles for 30 seconds every 10 minutes.

Step 9. Transfer part of the slurry, after 1 hour, to a plastic beaker and measure the pH.

Step 10. Record the pH for each of the soil-lime mixtures. The lowest percent of lime giving a pH of 12.40 is the percent required to stabilize the soil. If the pH does not reach 12.40, the minimum lime content giving the highest pH is required to stabilize the soil.

SOIL STABILIZATION IN FROST AREAS

While bituminous, portland-cement, lime, and combinations of 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—

- Headquarters, Department of the Army (DAEN-MPE-D), Washington, DC 20314 (for Army projects).
- Headquarters, Air Force Engineering and Services Center (AFESC/DEM), Tyndall AFB, FL 32401 (for Air Force projects).
- Headquarters, Naval Facilities Engineering Command, Alexandria, VA 22332 (for Navy or Marine Corps projects).

LIMITATIONS

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

CONSTRUCTION CUTOFF

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

WEATHER

Hot, dry weather is preferred for all types of bituminous stabilization. When asphalt cements are used for stabilization, proper compaction must be obtained. If thin lifts of asphalt-stabilized material are being placed, the air temperature should be 40°F and rising and the compaction equipment should be used immediately after lay-down operations. Adequate compaction can be obtained at freezing temperatures if thick lifts are used. When cutbacks and emulsions are used, the air and soil temperatures should be above freezing. Heavy rains on mixed, uncompacted material may be detrimental.

PICK-AND-CLICK TESTS

Specimens covering a wide range of cement contents (for example: 10, 14, and 18 percents) are molded at optimum moisture and maximum density. After at least 36 hours of hardening while kept moist and after a 3-hour soaking period, the specimens are inspected by picking with a pointed instrument (such as a dull ice pick or bayonet) and by sharply clicking each specimen against a hard object (such as concrete or another sound specimen) to determine their relative hardness when set. If the specimen cannot be penetrated more than 1/8 to 1/4 inch by picking, and if it produces a clear or solid tone upon clicking, an adequate cement factor (CF) is indicated. When a dull thud or plunky sound is obtained, there is inadequate cement even though the specimen may resist picking.

The specimen's age is a factor, and a specimen that may not test properly at first may harden properly a few days later. Some satisfactory specimens require 7 days or longer to produce adequate hardening. The test results will indicate the proper content. If the results show that some intermediate content may be satisfactory, new test specimens (at the suggested content) should be prepared and tested. It is important to remember that too much cement is not harmful (although more expensive), but too little cement will not produce a satisfactory stabilization.

WET-DRY AND FREEZE-THAW TESTS

After determining the maximum density and OMC, mold the specimens for the wet-dry and freeze-thaw tests.

PREPARATION

Prepare the specimens using the computed OMC and the cement contents previously described for the different soil classifications. Select the cement contents in 2 percent increments on either side of the median value. Mold two specimens for each of the three cement contents—one for the wet-dry test and one for the freeze-thaw test. Use the same procedure to mold the specimens as used for the OMC determination. Take special care to scarify the surfaces between layers to ensure a good bond. When the second layer is being placed, take a 750-gram sample for a moisture determination. Place the molded specimens in a moisture cabinet in an atmosphere of high humidity for 7 days to permit cement hydration before testing.

WET-DRY TEST PROCEDURE

After the 7-day curing period, submerge the specimens in tap water at room temperature for a period of 5 hours and then remove them. Dry the specimens in an oven at 160°F for 42 hours and then remove them. Wire brush the entire surface area to remove all material loosened during wetting and drying. Use two firm strokes on each portion of the surface. Apply these strokes the full height and width with a 3-pound force. One cycle consists of 5 hours of water immersion, 42 hours of drying, and 1 hour of handling. Repeat the operation for a total of 12 cycles. After 12 cycles of the test, dry the specimens to a constant weight at 230°F, and weigh them to determine the oven-dry weights.

FREEZE-THAW TEST PROCEDURE

After the curing period, place water-saturated felt pads about 1/4 inch thick, blotters, or similar absorptive materials between the specimens and specimen carriers. Place the assembly in a freezing cabinet with a constant temperature not warmer than -10°F for 24 hours and then remove them. Allow the assembly to thaw in a moist room or in suitable covered containers with a temperature of 70°F and a relative humidity of 100 percent for 23 hours. Make free water available to the absorbent pads to permit the specimens to absorb water by capillarity during the thawing period. Give the specimens two firm strokes on all areas with the wire brush to remove material loosened during freezing and thawing. If necessary, use a sharp-pointed instrument to remove any scale that has formed. One cycle consists of 24 hours of freezing, 23 hours of thawing, and 1 hour of handling (total 48 hours). After being brushed at the end of each thawing period, turn the specimens over, end for end, before replacing them on the water-saturated pads. Continue the test for a total of 12 cycles, dry the specimens to a constant weight at 230°F, and weigh them to determine their oven-dry weights.

CALCULATIONS AND CRITERIA

The results of the wet-dry and freeze-thaw cycles are indicated as soil-cement losses. These losses are computed by using the original dry weights and final corrected dry weights.

Water-of-Hydration Correction

The final oven-dry weight of the specimen includes some water used for cement hydration that cannot be driven off at 230°F. The average amount of this water retained in the specimen is based on the type of soil—gravels,

$\pm$ 1 1/2; sand, $\pm$ 2 1/2 percent; silt, $\pm$ 3 percent; and clays, $\pm$ 3 1/2 percent. This correction is computed by the following formula:

$$\textit{corrected oven-dry weight} = \left(\frac{\textit{measured oven-dry specimen wt}}{\textit{percent water retained}} + 100\right) \times 100$$

Example: A sample composed mostly of sand weighs 3.77 pounds at the end of the test. Water of hydration is 2.5 percent.

$$\textit{corrected oven-dry weight} = \left(\frac{3.77}{2.5} + 100\right) \times 100$$

Soil-Cement Loss

The soil-cement loss can now be calculated as a percentage of the original dry weight, or—

$$\textit{soil-cement loss} =$$

$$\left(\frac{\textit{original oven-dry weight} - \textit{final corrected oven-dry weight}}{\textit{original oven-dry weight}}\right) \times 100$$

Example: A sample of soil has an original weight of 3.99 pounds.

$$\textit{soil-cement loss} = \left(\frac{3.99 - 3.68}{3.99}\right) \times 100$$

This value would be reported to the nearest whole number or as 8 percent.

Weight-Loss Criteria

The minimum cement content recommended for use is the one for which losses of specimen weight during 12 cycles of the wet-dry test or freeze-thaw test conform to the following standards:

- GW, GM, GC, SW, SM, SC, and SP soils—not over 14 percent.
- ML and MH soils—not over 10 percent.
- GL, CH, OH, and OL soils—not over 7 percent.

Strength Criteria

The strength of soil-cement specimens tested in compression at various ages should increase with age and with increases in cement. The ranges of cement contents should produce results meeting the requirements above. A sample that has an unconfined compression strength of about 300 psi after curing 7 days and shows increasing strength with age can be considered adequately stabilized.

Cement Weight-to-Volume Conversion

The required cement content by weight must be converted to the equivalent cement content by volume for control during construction since this is the easier quantity to use in the field. The following formula illustrates the calculation:

$$volume\ of\ cement\ (percent) = \frac{D - \left(\frac{D}{C}\right)}{94} \times 100$$

where—

D = oven-dry density of soil-cement, in pcf

$$C = \frac{100 + percent\ cement\ by\ weight}{100}$$

94 = weight of 1 cubic foot of cement

The nomograph in *Figure 5-1* makes the conversion without computation. Use a straightedge placed at the soil-cement density and at the percent by weight of cement. Read the percent of cement by volume on the right-hand scale.

MODIFIED MIX DESIGN FOR SANDY SOILS

Sandy soils are usually the most readily and economically stabilized because they require the least amount of cement for adequate hardening and they contain a minimum amount of material that prevents intimate mixing of soil and cement. The following shortcut testing procedures for sandy soils will not always indicate the minimum cement contents required, but the results will be close enough to be on the safe side and economical. If time permits, the procedures for the freeze-thaw test are followed for greater design economy.

The two procedures used are for—

- Soils with no material retained on the No. 4 sieve.
- Soils with material retained on the No. 4 sieve.

The procedures can be used only with soils containing less than 50 percent of material smaller than 0.05 millimeter (silt and clay) and less than 20 percent smaller than 0.005 millimeter (clay). Dark gray to black sandy soils obviously containing appreciable organic impurities together with miscellaneous granular materials (such as cinders, caliche, chat, chart, marl, red dog, scoria, shale, and slag) should be tested using the full procedures and not tested by the modified methods for sandy soils. When coarse-grained or sandy soils (usually of groups GW, GP, GM, SW, or SM) are encountered, they may be classified for testing purposes using either the first or the second procedure. There is one other exception. Granular soils with materials retained on the No. 4 sieve whose bulk specific gravity is less than 2.45 cannot be tested.

Perform the following steps for modifying the mix design for sandy soils:

Step 1. Determine the soil gradation.

Step 2. Determine the bulk specific gravity of the material retained on the No. 4 sieve.

Step 3. Perform the moisture-density test of an estimated soil-cement mixture.

Step 4. Locate the indicated cement requirements from the charts.

Step 5. Perform compressive-strength tests to verify the cement requirement.

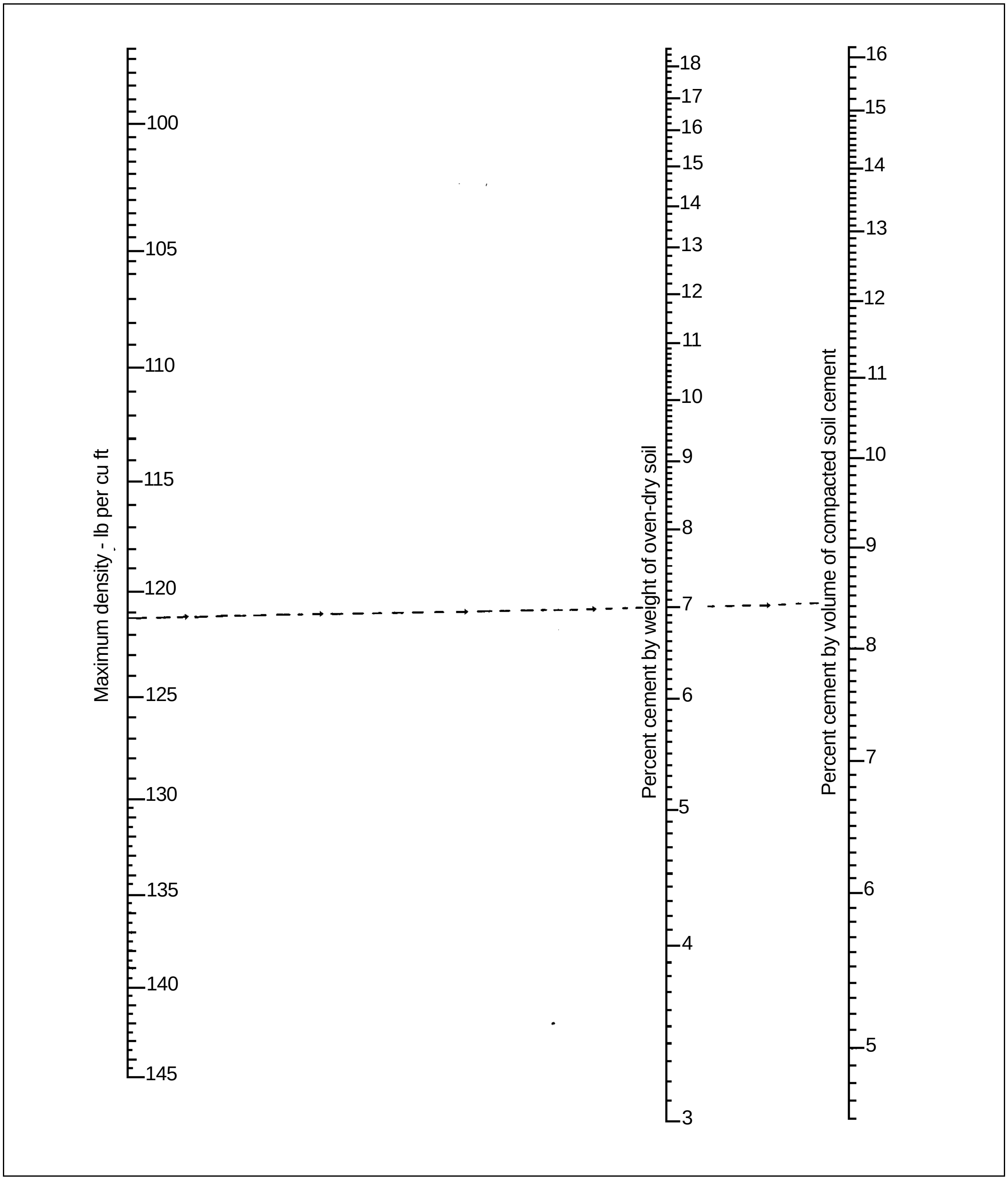

Figure 5-33. Relation of cement content by weight to cement content by volume

SOILS WITH NO MATERIAL RETAINED ON THE NO. 4 SIEVE

Perform the following steps for soils with no material retained on the No. 4 sieve:

Step 1. Determine the maximum density and OMC for a mixture of soil and cement. (*Figure 5-2* will give an estimated density. This value and the percentage of material smaller than 0.05 millimeter are used with *Figure 5-3* to determine an indicated cement content.)

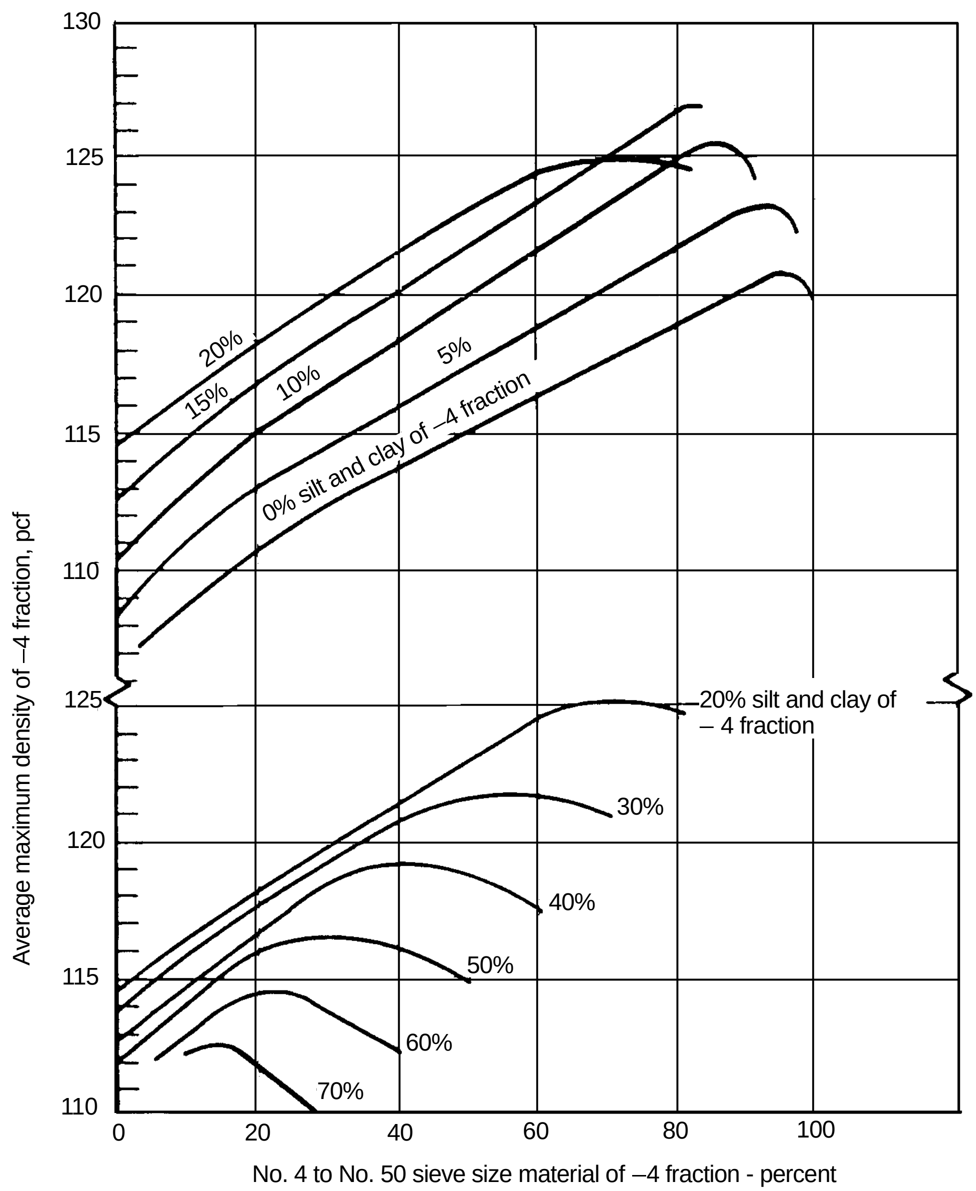

Figure 5-34. Average maximum densities of the –4 fraction of soil-cement mixtures

Step 2. Use the maximum density value and *Figure 5-3* to determine an indicated cement requirement.

Step 3. Mold three compressive-strength specimens at maximum density and OMC.

Step 4. Moist-cure the specimens for 7 days and test for strength.

Step 5. Plot the value of the averaged compressive strength of *Figure 5-4, page 5-14*. If this plot is above the curve, the CF is probably too low and needs adjusting. Prepare two new test specimens: one at the cement content as computed above, and the second with a 2 percent higher cement content. Perform the full freeze-thaw test on these two specimens.

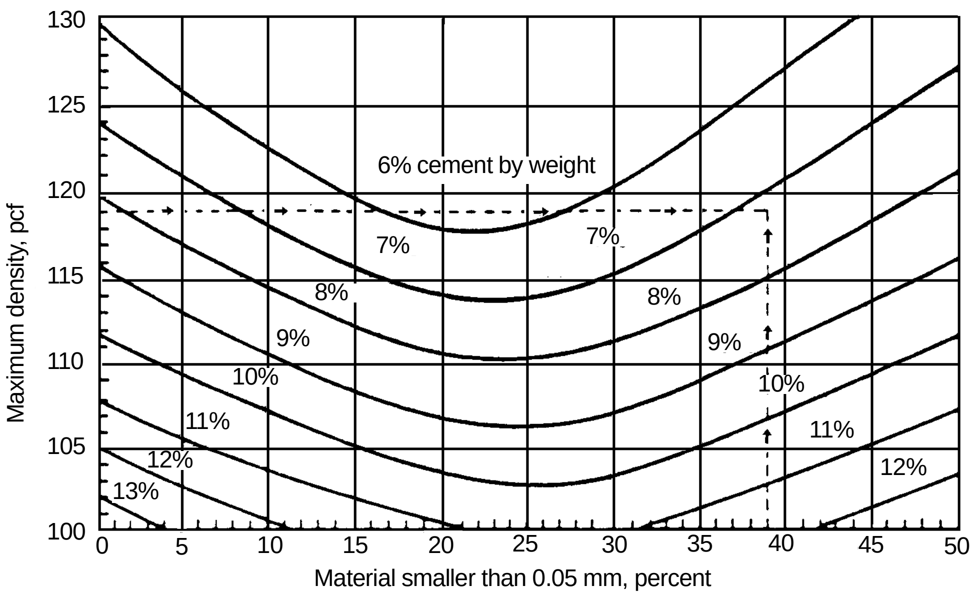

Figure 5-35. Indicated cement contents of soil-cement mixtures not containing material retained on the No. 4 sieve

SOILS WITH MATERIAL RETAINED ON THE NO. 4 SIEVE

Perform the following steps for soils with material retained on the No. 4 sieve:

Step 1. Determine the maximum density and OMC for a mixture of soil and cement. Use *Figure 5-5, page 5-14*, for an estimated maximum density. Using this density, the percentage of material retained on the No. 4 sieve, and the percentage smaller than 0.05 millimeter, determine the moisture content (see *Figure 5-6, page 5-15*). The 45 percent maximum retained on the No. 4 sieve still applies. Also, replace any material larger than 1/4 inch with an equivalent weight of the material passing the 1/4-inch sieve and retained on the No. 4 sieve.

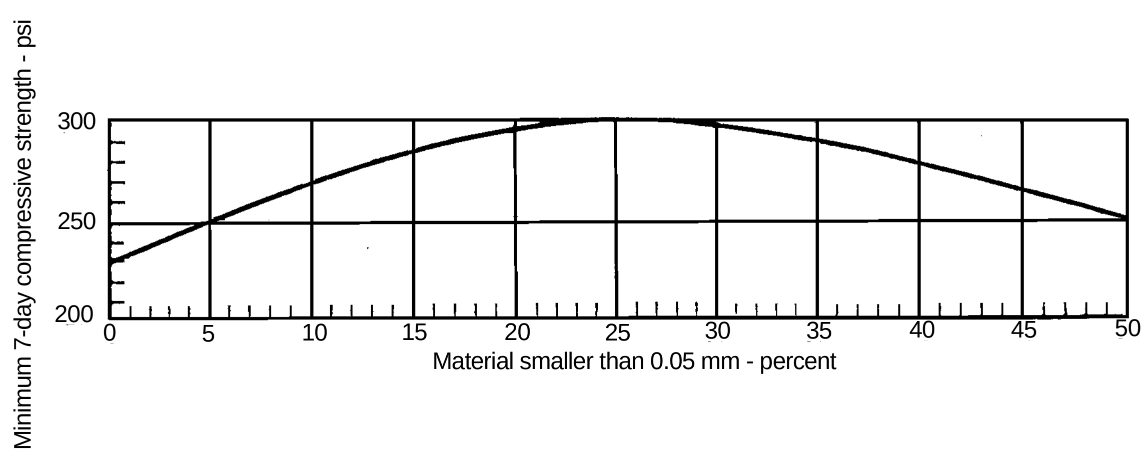

Figure 5-36. Minimum 7-day compressive strengths required for soil-cement not containing material retained on the No. 4 sieve

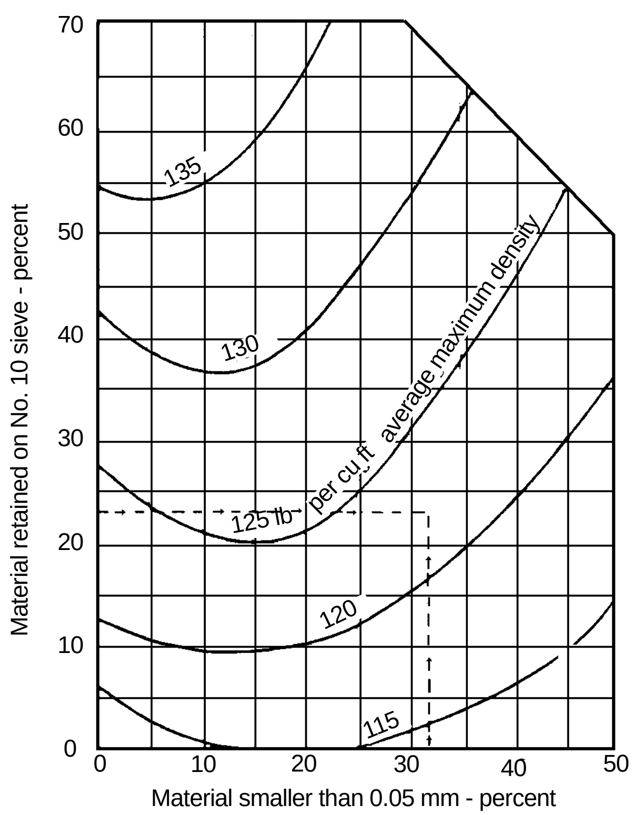

Figure 5-37. Average maximum densities of soil-cement mixtures containing material retained on the No. 4 sieve

Step 2. Determine the indicated cement requirement using the maximum density from above and *Figure 5-6*.

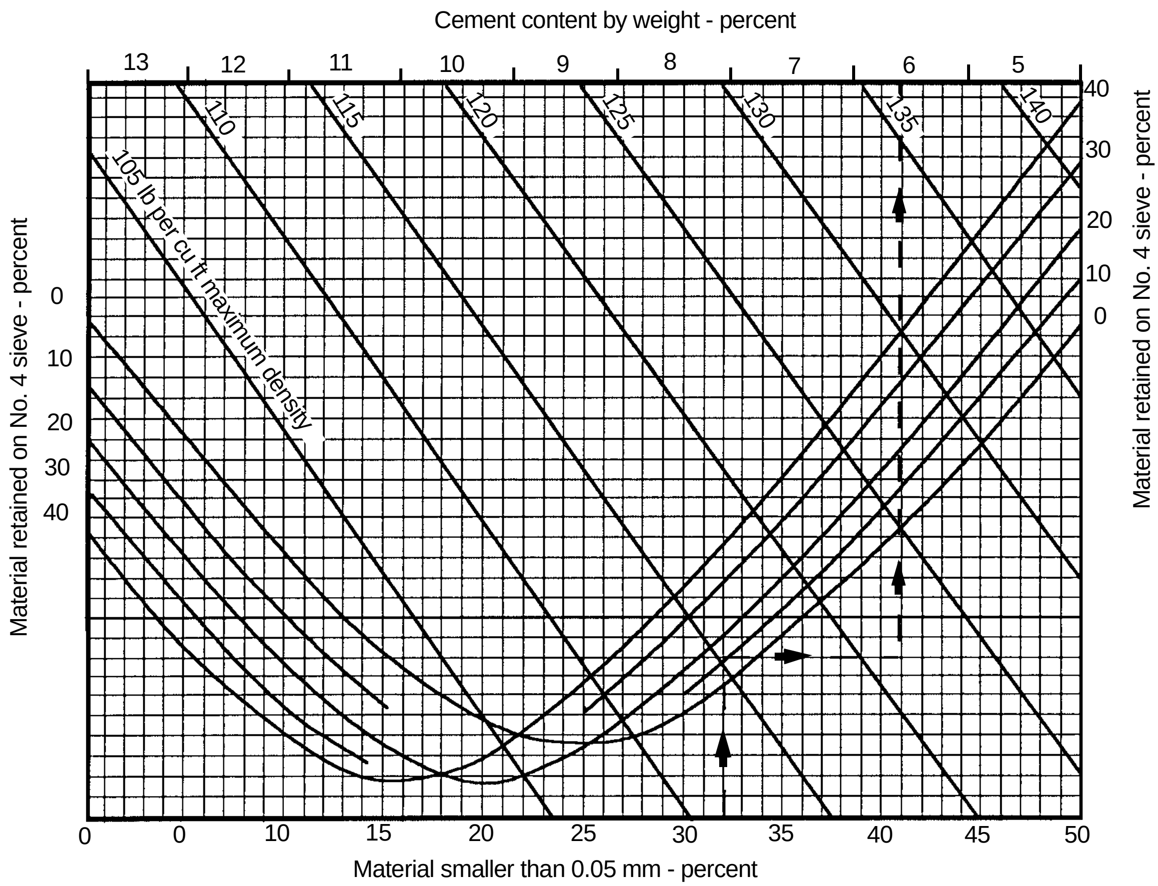

Figure 5-38. Indicated cement contents of soil-cement mixtures containing material retained on the No. 4 sieve

Step 3. Mold-test specimens at maximum density and OMC.

Step 4. Moist-cure for 7 days and test for compressive strength and average.

Step 5. Use *Figure 5-7, page 5-16,* to determine the allowable compressive strength for the soil-cement mixture. Connect the points on the right- and left-hand scales of the nomograph, and read the minimum required compressive strength from the inclined center scale. If the strength is equal to or greater than the allowable strength, the cement content is adequate. If the strength is too low, the CF is also too low and a full test should be performed.

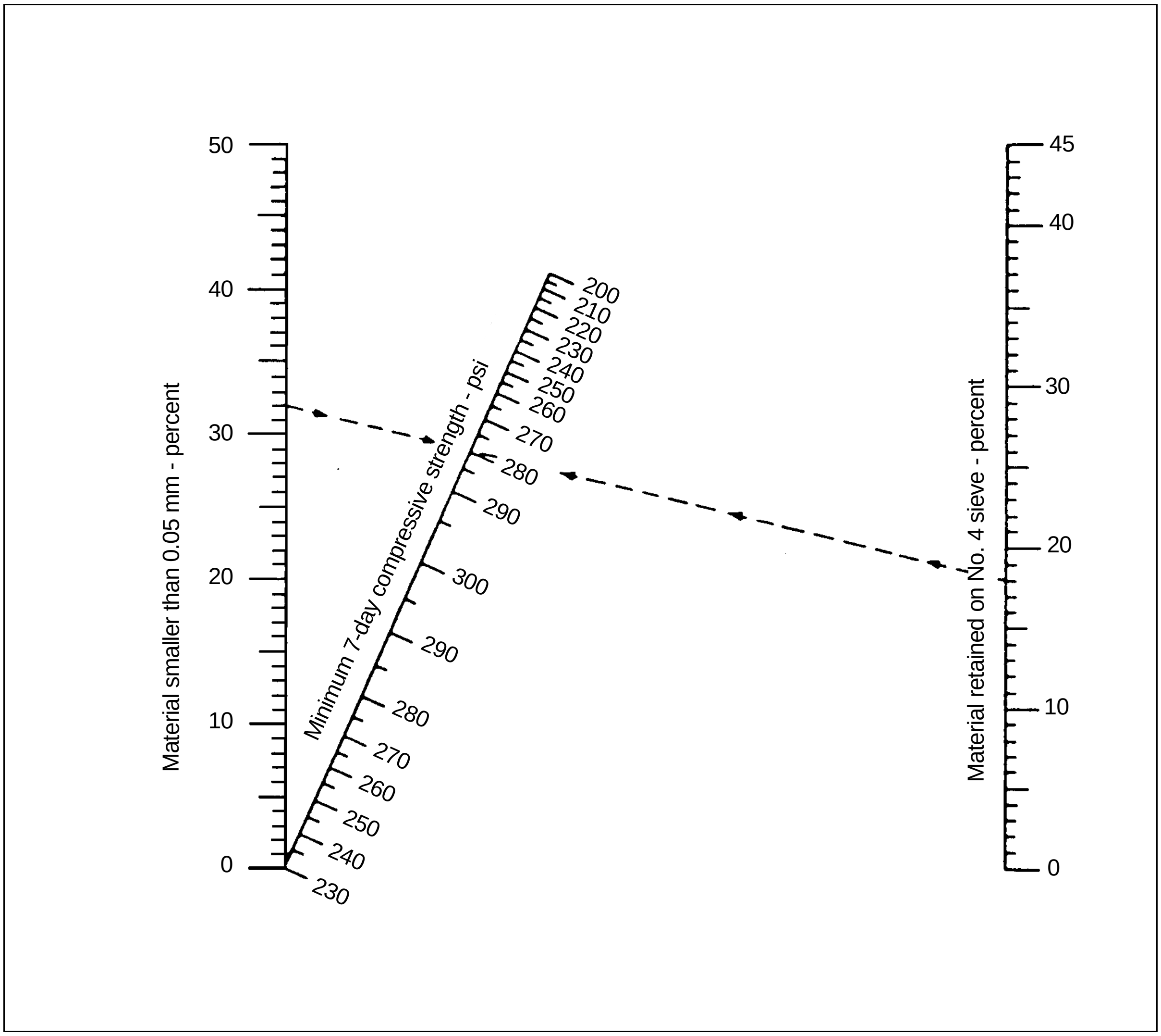

Figure 5-39. Minimum 7-day compressive strengths required for soil-cement mixtures containing material retained on the No. 4 sieve

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