Expanded Short-Cut Test Method for Determining Cement Factors for Sandy Soils

L. T. NORLING, Laboratory Chief, and
R. G. PACKARD, Assistant Laboratory Chief,
Soil-Cement Bureau, Portland Cement Assoiciation

The short-cut testing procedures are presented as two methods. Method A is used for sandy soils having no material retained on the No. 4 sieve. Method B, newly developed, is used for sandy soils containing material retained on the No. 4 sieve. Comparisons of data have verified the accuracy and dependability of the newly developed charts used with Method B. Data show that Method B provided safe cement factors for 204 (97.6 percent) of the 209 soils studied.

● IN 1952, THE PORTLAND CEMENT ASSOCIATION developed a short-cut method for determining cement factors for soil-cement construction using sandy soils. The method evolved from a correlation of data obtained from testing 2,229 sandy soils using complete ASTM or AASHO test procedures. The original short-cut test method was the subject of the Highway Research Board papers presented in January 1953 (1) and in January 1955 (2).

The short-cut test method does not involve new tests or additional equipment. Instead, it is possible to eliminate some tests by using charts developed from previous tests on similar soils. Thus, the only tests required are a grain size analysis, a moisture-density test and compressive strength tests. Relatively small samples are needed. All tests, except for the 7-day compressive strength tests, may be completed in one day.

The original charts for the short-cut test method were based on the fraction of the soil passing a No. 4 sieve. This was because the data then available for correlation were based on tests of specimens designed on that fraction. To use this method with soils containing material retained on the No. 4 sieve, it was necessary first to determine, by charts, the cement requirement of the soil fraction passing the No. 4 sieve and then, for field construction, to calculate the cement requirement of the total mixture. Also, the maximum density and optimum moisture content of the total soil-cement mixture were calculated for field construction based on tests on the fraction passing the No. 4 sieve.

It is important to determine the maximum density and optimum moisture content of a mixture that represents, as nearly as possible, the material to be used in building soil-cement. Therefore, for several years, the Portland Cement Association and others have run the moisture-density test and designed soil-cement test specimens on total material (2). This reduces considerably the calculations needed for soils containing material retained on the No. 4 sieve. Further, it results in a maximum density more easily duplicated in test specimens. In 1957 this procedure was adopted as standard by the American Society for Testing Materials and bears ASTM Designation D558-57 (3).

The object of the work reported in this paper was to expand the short-cut method to permit the use of data from tests on the total soil-cement mixture. New charts and recommended procedures were developed for soils containing material retained on the No. 4 sieve. This procedure is referred to in this paper as Method B. The original charts and procedures (Method A) are still used for soils having no material retained on the No. 4 sieve.

The short-cut test procedures do not always indicate the minimum cement factor that can be used with a particular sandy soil. However, they almost always provide a safe cement factor generally close to that indicated by standard ASTM-AASHO

wet-dry and freeze-thaw tests. The procedure should prove even more accurate if test data from more localized areas are used to verify the charts.

The short-cut test method is coming into wider use by engineers and testing laboratories handling soil-cement projects. In time, the method may largely replace the standard tests as experience with it grows and the procedures are verified for local sandy soils.

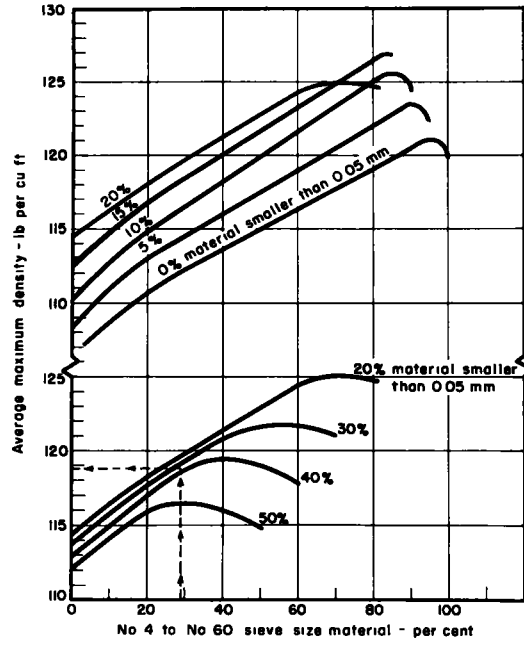

Figure 1. Average maximum densities of soil-cement mixtures having no material retained on No. 4 sieve.

PROCEDURES FOR DETERMINING CEMENT FACTORS

Two methods have been developed for establishing cement requirements for many sandy soils. Method A is used for soils having no material retained on the No. 4 sieve. The new procedure, Method B, is used for soils containing material retained on the No. 4 sieve.

The short-cut method may be applied only to soils containing less than 50 percent material smaller than 0.05 mm (silt and clay) and less than 20 percent material smaller than 0.005 mm (clay). These were the gradation limits for the soils included in the correlation used to develop the original charts. Dark gray to black soils with appreciable amounts of organic impurities were not incleded in the correlation and therefore may not be tested by these procedures. This is also true of miscellaneous granular materials such as cinders, caliche, chat, chert, marl, red dog, scoria, shale, and slag. Moreover, the short-cut procedures do not apply to granular soils having material retained on the No. 4 sieve if that material has a bulk specific gravity less than 2.45.

Before applying the short-cut procedures, it is necessary (a) to determine the gradation of the soil, and (b) to determine the bulk specific gravity of the material retained on the No. 4 sieve to see if it meets the above requirements. If a the soil passes the No. 4 sieve, Method A should be used. If materials is retained on the No. 4 sieve, Method B is used.

Method A

Step 1: Determine by test the maximum density and optimum moisture content for a mixture of the soil and portland cement.[1]

Note 1: Use Figure 1 to obtain an estimated maximum density of the soil-cement mixture being tested. This estimated maximum density and the percentage of material smaller than 0.05 mm (No. 270 sieve) may be used with Figure 2 to determine the cement content by weight to use for the test.

Step 2 : Use the maximum density obtained by test in Step 1 to determine from Figure 2 the indicated cement requirement.

Step 3: Use the indicated cement factor obtained in Step 2 to mold compressive

[1] "Method of Test for Moisture-Density Relations of Soil-Cement Mixtures," ASTM Designation D558; AASHO Designation T134.

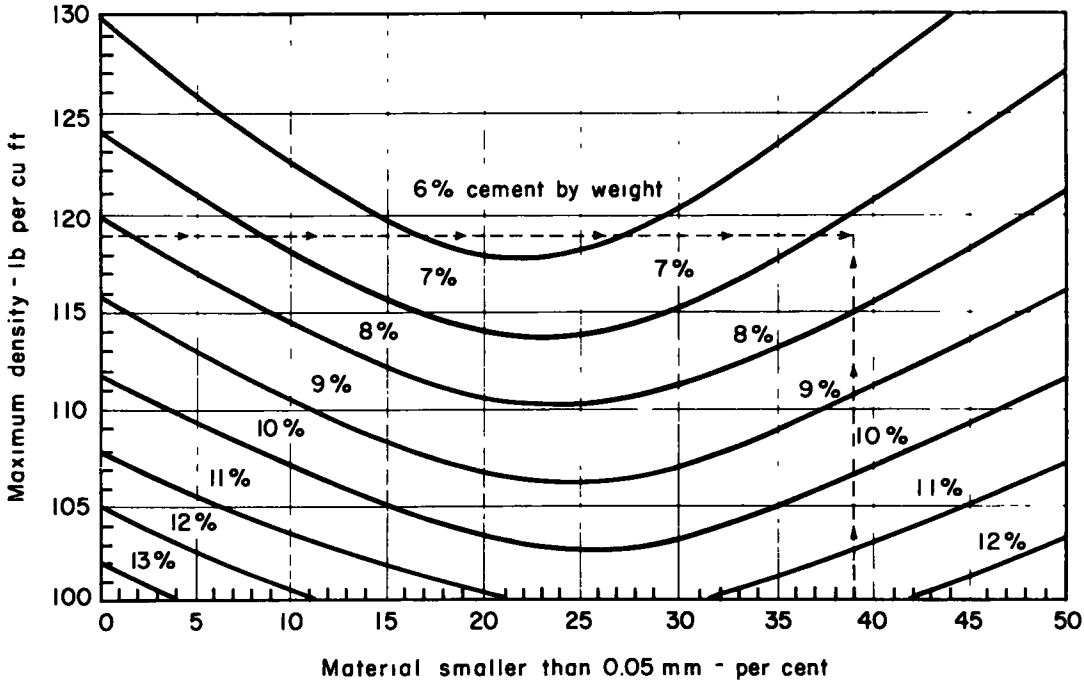

Figure 2. Indicated cement content of soil-cement mixtures having no material retained on the No. 4 sieve.

strength specimens[2] in triplicate at maximum density and optimum moisture content.

Step 4 : Determine the average compressive strength of the specimens after 7 days moist curing.

Step 5 : On Figure 3, plot the average compressive strength value obtained in Step 4. If this value plots above the curve, the indicated cement factor by weight, determined in Step 2, is adequate. For field construction use Figure 4, to convert this cement content by weight to a volume basis.

Note 2 : If the average compressive strength value plots below the curve of Figure 3, the indicated cement factor obtained in Step 2 is probably too low. Additional tests will be needed to establish a cement requirement. These tests generally require the molding of two test specimens, one at the indicated cement factor obtained in Step 2 and one at a cement content two percentage points higher. The specimens are then tested by ASTM-AASHO freeze-thaw test procedures.

Method B

Step 1 : Determine by test the maximum density and optimum moisture content for a mixture of the soil and portland cement.[3]

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[2] Specimens of 2-in. diameter by 2-in. height or 4-in. diameter by 4.6-in. height may be molded. The 2-in. specimens shall be submerged in water one hour before testing and the 4-in. specimens four hours. The 4-in. specimens shall be capped before testing.

[3] "Method of Tests for Moisture-Density Relations of Soil-Cement Mixtures," ASTM Designation D558.

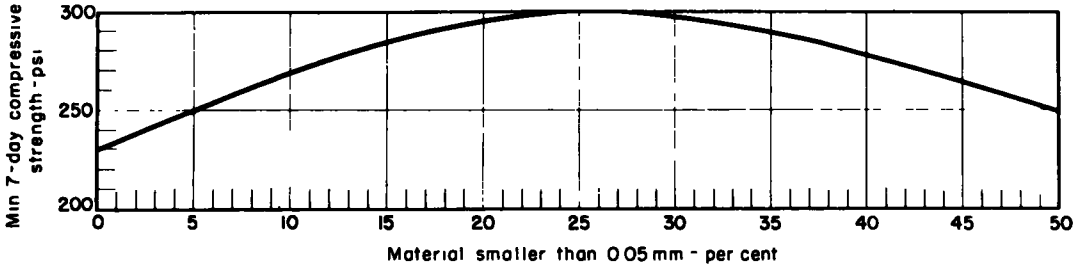

Figure 3. Minimum 7-day compressive strengths required for soil-cement mixtures having no material retained on the No. 4 sieve.

Note 3: Use Figure 5 to determine an estimated maximum density of the soil cement mixture being tested. This estimated maximum density, the percentage of material smaller than 0.05 mm (No. 270 sieve) and the percentage of material retained on the No. 4 sieve may be used with Figure 6 to determine the cement content by weight to use in the test.

The soil sample for the test shall contain the same percentage of material retained on the No. 4 sieve as the original soil sample contains. However, ¾-in. material is the maximum size used. Should there be material larger than this in the original soil sample, it is replaced in the test sample by an equivalent weight of material passing the ¾-in. sieve and retained on the No. 4 sieve.

Step 2: Use the maximum density obtained by test in Step 1 to determine from Figure 6 the indicated cement requirement.

Step 3: Use total material as described in Step 1 and the indicated cement factor obtained in Step 2 to mold compressive strength specimens[4] in triplicate at maximum density and optimum moisture content.

Step 4: Determine the average compressive strength of the specimens after 7 days moist curing.

Step 5: Determine from Figure 7 the minimum allowable compressive strength for the soil-cement mixture. If the average compressive strength obtained in Step 4 equals or exceeds the minimum allowable strength, the indicated cement factor by weight obtained in Step 2 is adequate. For field construction, use Fig-

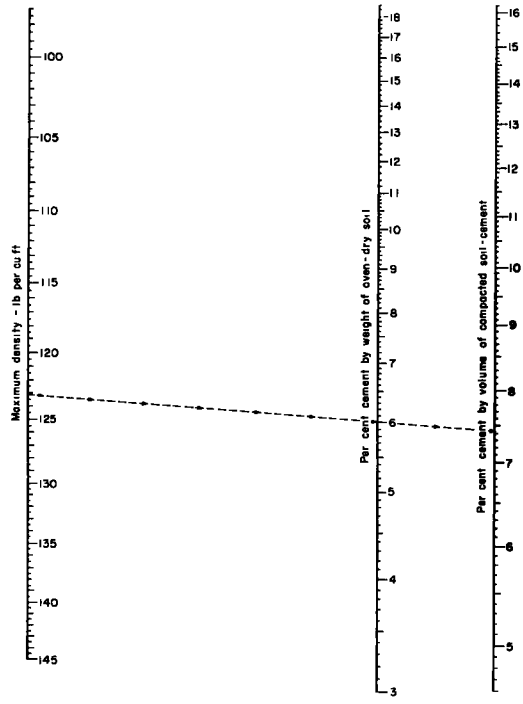

Figure 4. Relation of cement content by weight of oven-dry soil to cement content by volume of compacted soil-cement mixture.

[4] Specimens of 4-in. diameter by 4.6-in. height shall be molded. They shall be submerged in water four hours and shall be capped before testing.

ure 4 to convert this cement content by weight to a volume basis.

Note 4: If the average compressive strength value is lower than the minimum allowable, the indicated cement factor obtained in Step 2 is probably too low. Additional tests as described in Note 2 are needed.

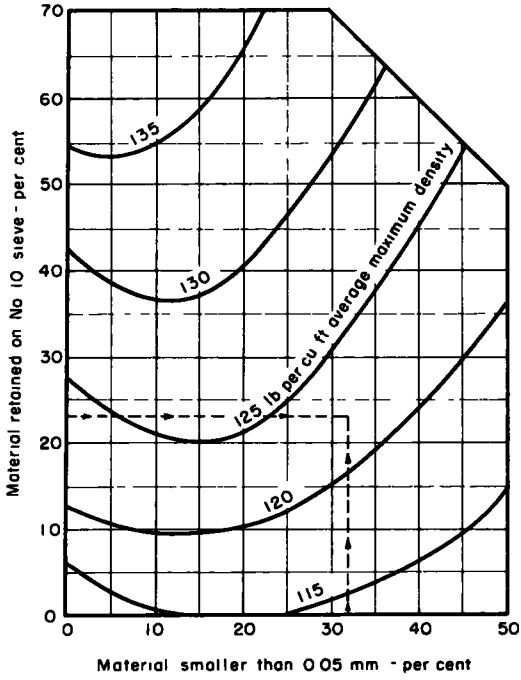

Figure 5. Average maximum densities of soil-cement mixtures having material retained on the No. 4 sieve.

DEVELOPMENT OF CHARTS AND PROCEDURE FOR METHOD B

The original charts developed in 1952 (Method A) were based on the fraction of the soil-cement mixture passing the No. 4 sieve. To develop Method B, these charts were converted to factors expressed in terms of total sample. These conversions are described below.

Chart for Determining Indicated Cement Content

Figure 6, used to determine the indicated cement content of soil-cement mixtures containing material retained on the No. 4 sieve, was developed from Figure 2. First, the original curves in Figure 2 were approximated by a family of parabolas representing cement contents.

These parabolas are represented by the equation:

$$c = \frac{A\,(s-24)^2 - d + 140.4}{4} \qquad (1)$$

where:

c = cement requirement of the fraction passing the No. 4 sieve, percent by weight.

A = a constant used to approximate the curves in Figure 2.

s = percent material smaller than 0.05 mm in the fraction of the soil passing the No. 4 sieve.

d = maximum density of soil-cement mixture passing the No. 4 sieve, lb per cu ft.

Next, the above equation was expressed in terms of the total sample. To do this it was necessary to determine the relationship between each variable expressed in terms of the fraction passing the No. 4 sieve and the corresponding variable when expressed in terms of the total sample. These relationships can be expressed by the following equations:

$$d = \frac{D - 0.9\,RG}{(1-R)} \qquad (2)$$

$$c = \frac{C}{(1-R)} \qquad (3)$$

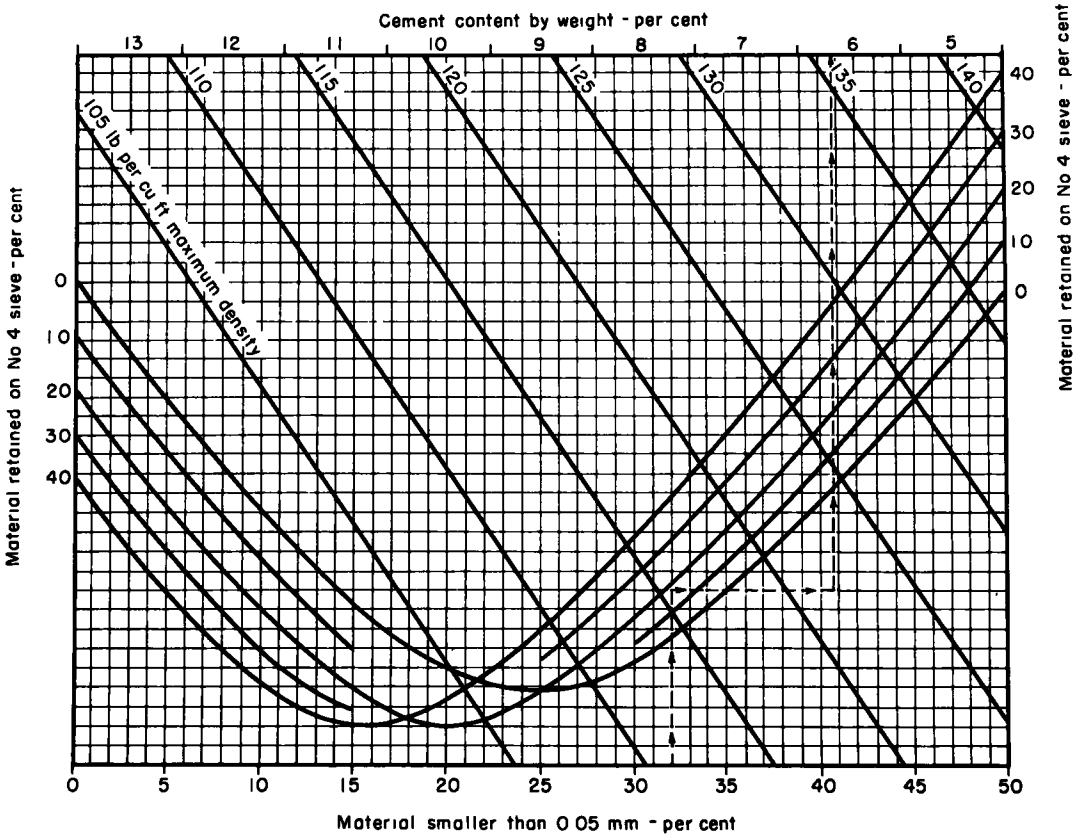

Figure 6. Indicated cement content of soil-cement mixtures having material retained on the No. 4 sieve.

$$s = \frac{S}{(1-R)} \tag{4}$$

Where: d = maximum density of soil-cement mixture passing the No. 4 sieve, lb per cu ft.

D = maximum density of total soil-cement mixture, lb per cu ft.

R = percent of material retained on the No. 4 sieve divided by 100.

G = bulk specific gravity of material retained on the No. 4 sieve x 62.4.

c = cement requirement of the fraction passing the No. 4 sieve, percent by weight.

C = cement requirement of total sample, percent by weight.

s = percent material smaller than 0.05 mm in the fraction of soil passing the No. 4 sieve.

S = percent material smaller than 0.05 mm in the total sample.

Equations 2, 3 and 4 were then substituted in Equation 1. This resulted in the following equation used to construct Figure 6:

$$C = \frac{(1-R)\,A\left(\frac{S}{1-R} - 24\right)^2 - D + 140.4 + 0.9RG - 140.4R}{4} \qquad (5)$$

To simplify the construction and use of Figure 6, an average value of 156.0 (250 x 62.4) was used for G in Equation 5.

The validity of using Equations 2, 3 and 4 for constructing Figure 6, as described above, is based on a study of the following relationships:

Density. It had been the practice in soil-cement testing to determine the maximum density on the fraction passing the No. 4 sieve and then to calculate the theoretical maximum density of the total mixture. These calculations assumed that the addition

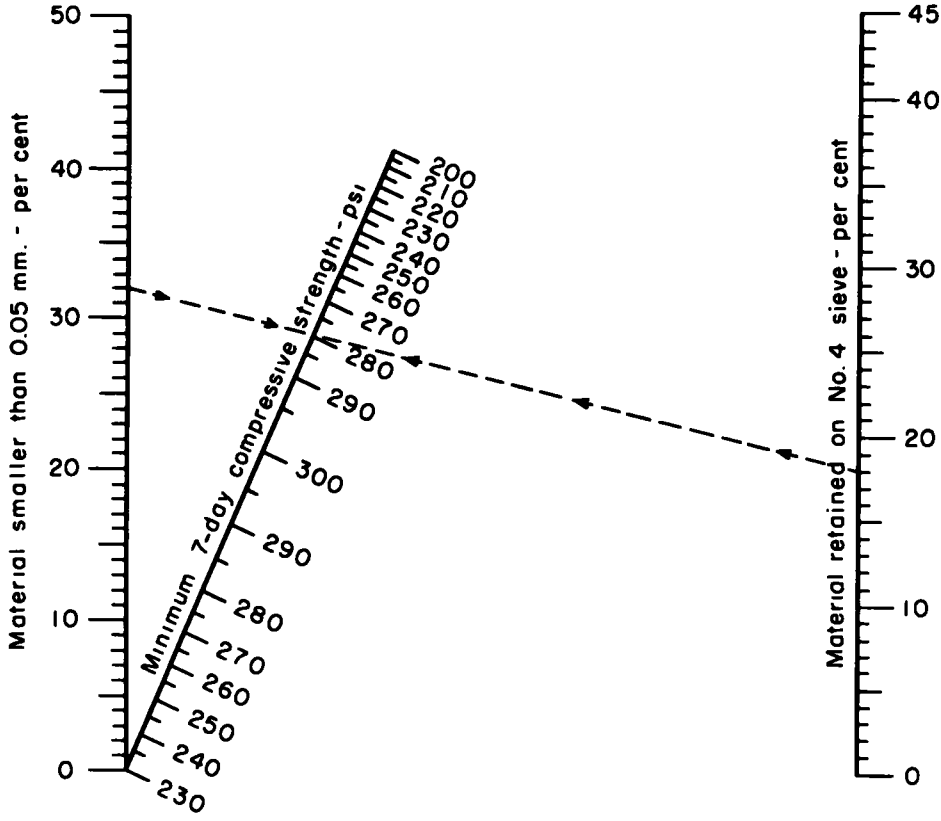

Figure 7. Minimum 7-day compressive strengths required for soil-cement mixtures having material retained on the No. 4 sieve.

of material retained on the No. 4 sieve increases the density of the soil-cement mixture by displacing, in equal volume, the mixture passing the No. 4 sieve. No allowance was made for possible increase in void space. As a result, the densities obtained in test specimens were often considerably less than the calculated maximum density. The difference was in proportion to the amount of material retained on the No. 4 sieve. In some cases, actual densities of test specimens containing about 40 percent material retained on the No. 4 sieve would be as much as 10 lb per cu ft below the calculated theoretical density. This difference apparently was due to the voids not accounted for in the calculations.

The Civil Aeronautics Administration (6) has used a correction equation for determining the relationship between the maximum density of the total sample and the max-

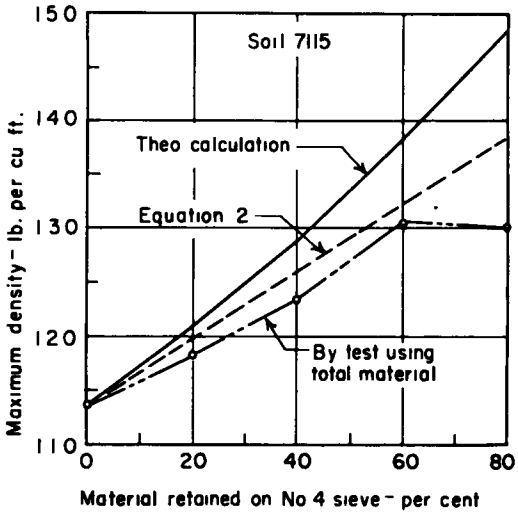

Figure 8. Effect of material retained on the No. 4 sieve on the maximum density, Soil No. 7115.

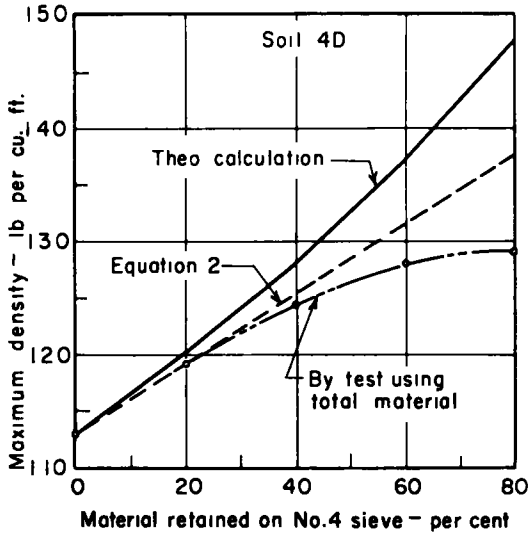

Figure 9. Effect of material retained on the No. 4 sieve on the maximum density, Soil No. 4D.

imum density of the fraction passing the No. 4 sieve. Equation 2 expresses this relationship.

Mainfort and Lawton (7) reported further studies on compaction tests using total material. They concluded that the correction formula may be used to predict maximum densities obtained on the total material if the amount of material retained on the No. 4 sieve is not over 40 to 60 percent. Most soil-cement mixtures contain less than this. Specifications for soil-cement generally limit the amount to 45 percent.

The Portland Cement Association made similar studies by comparing the maximum densities obtained by test on the total material and maximum densities obtained by Equation 2. Typical results are given in Figures 8 and 9. Also given is a comparison of the maximum densities calculated on the assumption that the addition of material retained on the No. 4 sieve increases the density of the mixture by displacing, in equal volume, the mixture passing the No. 4 sieve.

Soil No. 7115 (Fig. 8) is a natural gravel and sand. Material retained on the No. 4 sieve was separated from the material passing the No. 4 sieve. It was then recombined in the desired proportions. Soil No. 4D (Fig. 9) is an A-4 silt loam to which were added varying percentages of material retained on the No. 4 sieve.

Thus, if the amount of material retained on the No. 4 sieve is not over 40 to 60 percent the maximum densities obtained with Equation 2 approximate quite closely the maximum densities obtained by test using total material. This further shows the validity of using Equation 2 to convert the short-cut charts to total material.

Cement Content. The original short-cut test method indicated a cement content adquate for the fraction of the soil-cement mixture passing the No. 4 sieve. This was then converted by charts to a cement requirement of the total sample. The validity of this conversion was determined in the original 1952 correlation (1). This showed that the cement requirement of the fraction passing the No. 4 sieve is unchanged when material retained on the No. 4 sieve is added. Because the material retained on the No. 4 sieve requires no extra cement, the requirement of the total sample lessens proportionally when that material is added. Thus, Equation 3 which expresses this relationship can be used to convert the original short-cut charts to total material.

Material Smaller than 0.05 mm . It was next necessary to consider the relationship between the amount of material smaller than 0.05 mm in the fraction of the soil

TABLE 1

COMPARISON OF COMPRESSIVE STRENGTHS OF SOIL-CEMENT SPECIMENS

	7-Day Compressive Strength			
	2-in. diameter x 2-in high		4-in. diameter x 4.6-in. high	
Soil No.[1]	Number of Specimens	Average Strength, psi	Number of Specimens	Average Strength, psi
6006	3	458	3	467
6017	3	276	3	282
5992	3	564	3	575
4d	3	307	3	337
6018	3	283	3	261
6023	3	385	3	362
6046	3	388	3	421
S-1	3	239	2	192
TD-2	3	327	2	335
6741	3	356	2	341
6739	3	671	2	624
6738	3	420	2	417
6718	3	282	2	280

[1] The fraction of the soil passing a No. 4 sieve only used in test specimens.

sample passing the No. 4 sieve and the amount smaller than 0.05 mm in the total sample. This relationship is, by proportion, that expressed in Equation 4.

Chart for Determining Minimum 7-Day Compressive Strengths

Figure 7 gives the minimum allowable 7-day compressive strengths for soil-cement mixtures having material retained on the No. 4 sieve. The chart was developed from Figure 3. Thus, the minimum compressive strength criteria for Method A (Fig. 3) is the basis for Figure 7 used with Method B. The validity of using the Method A minimum compressive strength criteria for Method B is based on the following studies:

1. To determine how the compressive strengths are affected by adding material retained on the No. 4 sieve, holding constant the cement content by weight in the fraction passing the No. 4 sieve.
2. The effect of using 4-in. diameter by 4.6-in. high compressive strength specimens required for Method B rather than 2-in. diameter by 2-in. high specimens which may be used for Method A.

Results of these studies are given in Figure 19 and Table 1. They indicate that the compressive strength is not changed appreciably by the two factors. Thus, data from specimens of either size may be used interchangeably. Further, the minimum compressive strength criteria given in Figure 3 based on the fraction passing the no. 4 sieve, may be used with the new short-cut procedure for soils containing material retained on the No. 4 sieve (Method B). The use of Figure 3 with Method B, however, would make it necessary to calculate, for each sandy soil being tested, the quantity of material smaller than 0.05 mm in the fraction passing the No. 4 sieve. To avoid this calculation, Figure 7, in which the quantity of material smaller than 0.05 mm in the total sample is used directly, was developed. To do this, a nomograph based on Equation 4 was constructed. Then the original plotted values of "s" on the diagonal line were replaced with the corresponding values of compressive strength obtained from Figure 3.

Chart for Determining Average Maximum Densities

Method A uses Figure 1 for estimating maximum densities of soil-cement mixtures having no material retained on the No. 4 sieve. However, Figure 1 is not accurate for Method B using soils containing material retained on the No. 4 sieve. Therefore, more accurate relationships for determining approximate maximum densities for Method B were determined by plotting a number of gradation or "soil separate" factors agains the actual maximum densities obtained by tests on 209 soils. Two factors—the percent material smaller than 0.05 mm and the percent material retained on the No. 10 sieve—gave the best approximation. They are the basis for Figure 5.

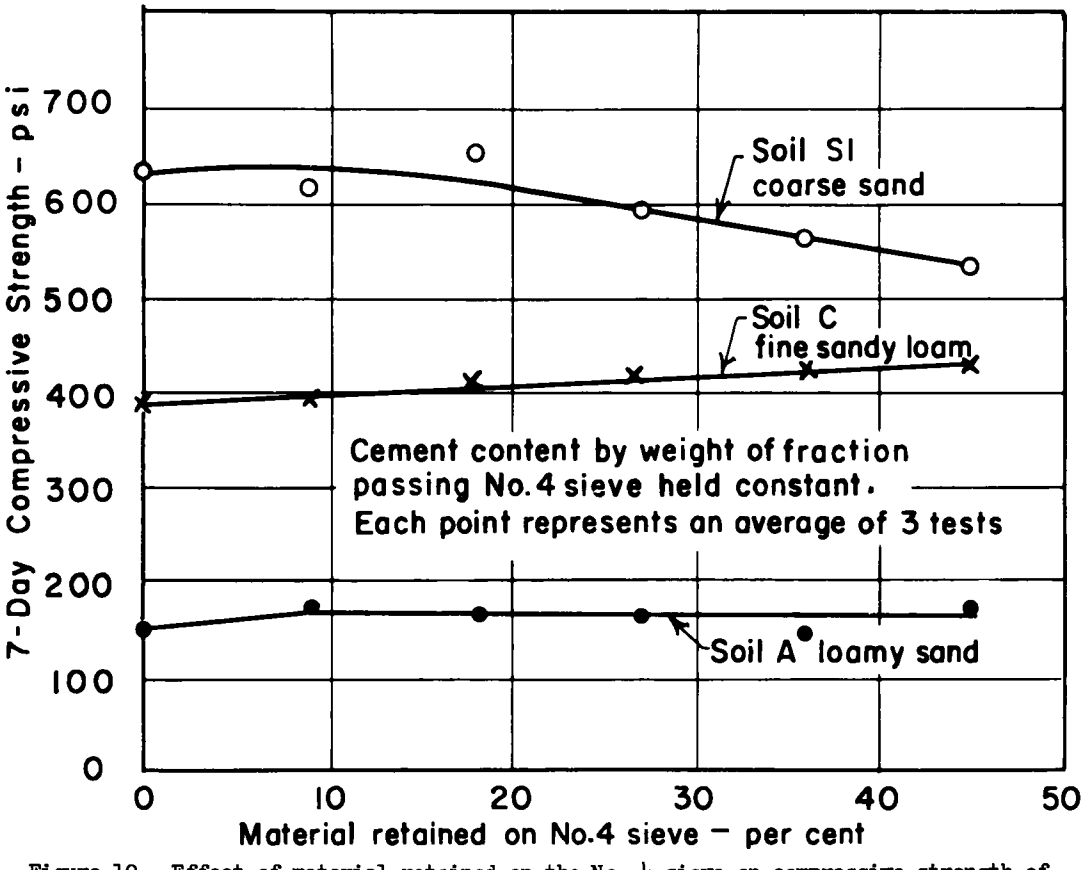

Figure 10. Effect of material retained on the No. 4 sieve on compressive strength of soil-cement specimens.

RESULTS OBTAINED IN CHECKING TEST PROCEDURE FOR METHOD B

The Portland Cement Association tested the accuracy of Method B by comparing the cement requirements obtained by this method and the requirements obtained on total material tested by ASTM wet-dry and freeze-thaw methods (4, 5). The comparison considered results of tests of 209 soils. First, a cement factor for each soil was selected from Figure 6. This factor was considered adequate if the compressive strength at this cement content equaled or exceeded the minimum allowable strength given in Figure 7. If the strength were lower than the minimum allowable, additional testing was considered necessary to determine the cement requirement. The cement factors thus obtained were then compared with those obtained from ASTM tests. The comparison showed the following results:

Adequate cement factors, or the need for further testing, were indicated for 204 (97.6 percent) of the 209 soils. For 5 of the soils (2.4 percent) the procedure did not indicate adequate cement factors nor did it indicate the need for further testing. The strengths for these soils at the indicated cement content were higher than the minimum allowable strengths given in Figure 7.

Using results obtained from ASTM wet-dry and freeze-thaw tests as a yardstick,

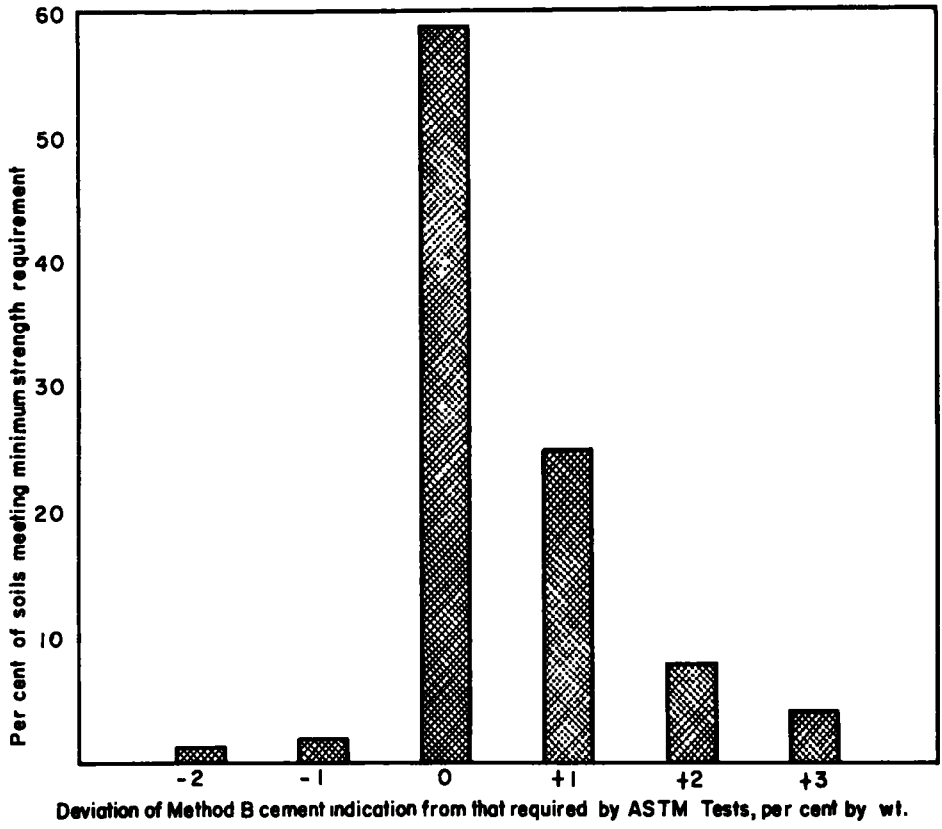

Figure 11. Accuracy of short-cut test (Method B).

the accuracy of Method B is shown in Figure 11. The reliability of 97.6 percent compares favorably with the 98.6 percent reported in the original 1952 correlation (1).

SUMMARY

In 1952, the Portland Cement Association developed a short-cut procedure for determining cement requirements for sandy soils. The short-cut procedure was based on a correlation of data from ASTM or AASHO tests on 2,229 sandy soils. The method permits all tests to be completed in one day, except the 7-day compressive strength tests.

The original charts for the short-cut procedure were based on the fraction of the soil-cement mixture passing a No. 4 sieve. For soils containing material retained on the No. 4 sieve it was necessary first to determine the cement requirement of the fraction passing the No. 4 sieve and then to convert this to the cement requirement of the total mixture. Similarly, the maximum density and optimum moisture content of the total soil-cement mixture were calculated for field construction based on tests on the fraction passing the No. 4 sieve.

Soil-cement testing of soils containing material retained on the No. 4 sieve now requires the use of total material. Therefore, for soils with material retained on the No. 4 sieve, the short-cut charts were converted from relationships based on the fraction passing a No. 4 sieve to relationships expressed in terms of the total sample.

As a result, two procedures are given for determining cement factors: Method A for soils having no material retained on the No. 4 sieve and Method B for soils containing material retained on the No. 4 sieve. Method A uses charts developed in 1952. Method B, newly developed, uses charts based on the total material.

The reliability of Method B was checked with ASTM-AASHO test data for 209 sandy soils. The procedure provided safe cement factors or showed the need for further testing for 97.6 percent of the soils. While the cement factors obtained were not always the minimum that could be used, they were practical.

The procedure and chart should be used in their present form until local test data and experience permit revision of the charts for local soil conditions.

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