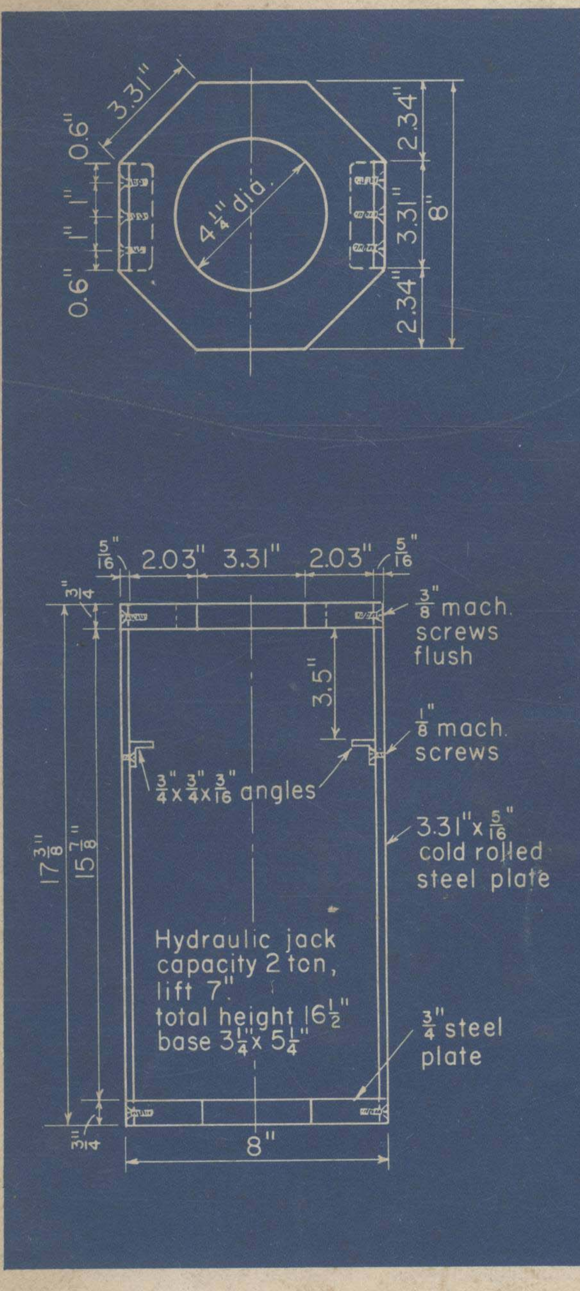
ENGINEERING BULLETIN

Soil-Cement Laboratory Handbook



PORTLAND CEMENT pca ASSOCIATION

Soil-Cement Laboratory Handbook

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FOREWORD

For many years engineers have worked to develop a practical method of combining common soils with portland cement to produce a hardened, durable paving material at low cost. The first recorded road projects in which a mixture of soil and cement was used were built in South Dakota, Iowa, Ohio, California, and Texas. In 1933, 1934, and 1935, the South Carolina State Highway Department built several sections of road base with a soil-cement mixture. This work was notable because it proved beyond doubt that soil and cement could be mixed together to produce a construction material suitable for paving roads.

In 1935, the Development Department of the Portland Cement Association began extensive research to determine whether scientific control methods could be developed to produce uniformly satisfactory mixtures of portland cement and various soils. This investigation established scientific soil-cement testing and construction procedures that ensure dependable results. As part of this initial work, the moisture-density test, the wet-dry test, and the freeze-thaw test for soil-cement mixtures were developed. These tests were adopted as standards by the American Society for Testing Materials in 1944, and by the American Association of State Highway Officials in 1945. After 13 years of successful use, the test methods were revised by ASTM and by AASHO in 1957 to incorporate the information and experience gained during that period. The revisions have greatly reduced the time, manpower, and material required to run the laboratory tests.

In the United States and Canada, as well as in other countries, there has been rapid growth in soil-cement paving construction. The outstanding performance record of the millions of square yards of soil-cement proves that the testing and construction principles are sound. These principles have transformed low-cost paving construction from a "cut-and-try" process into a sound engineering procedure.

This *Soil-Cement Laboratory Handbook* and the related publications, *Soil-Cement Construction Handbook* and *Soil-Cement Inspector's Manual*, present in practical form the complete procedure for testing and constructing soil-cement paving.

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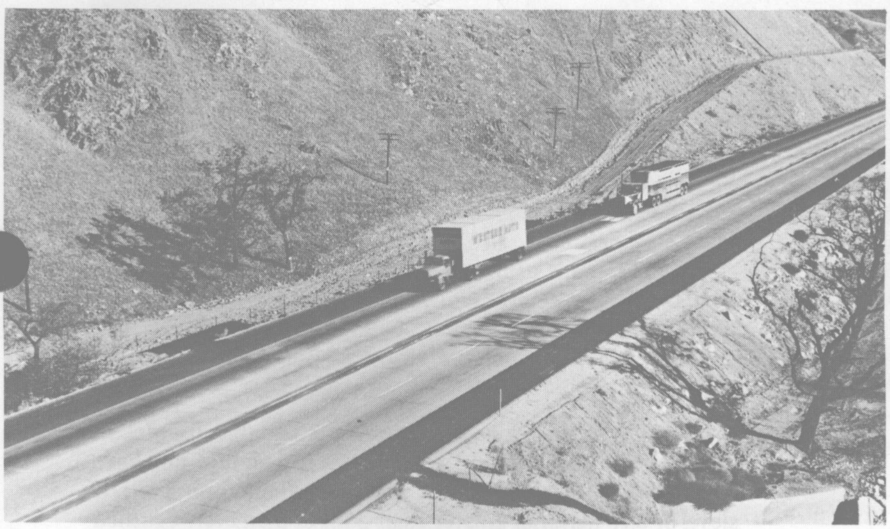

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INTRODUCTION

The primary requisite for producing soil-cement with satisfactory characteristics and serviceability is that an adequate quantity of portland cement be incorporated with the pulverized soil. Secondary requisites are (1) that the proper amount of water be mixed uniformly with the soil-cement mixture and (2) that the moistened soil-cement mixture be compacted to proper density before cement hydration. These fundamental factors can be determined for any soil by laboratory tests and can be accurately and simply controlled in construction.

This handbook is devoted principally to the methods of making laboratory tests for determining the above control factors.

Since soil constitutes a very large portion of a soil-cement mixture, proper soil identification, classification, and sampling are also recognized as fundamental. The term "soil" as used in soil-cement testing and construction refers to any combination of the soil separates: gravel, sand, silt and clay, crushed materials, and materials such as cinders, slag, shale, caliche, chert, scoria, etc. Any mineral material that will pass the soil-cement tests is suitable for use in soil-cement. For practical reasons the soil should not have more than about 45 percent material retained on a No. 4 sieve or any material greater than 2 in. in diameter. Crushed stone and gravel base course materials that have more than 45 percent retained on the No. 4 sieve are being used successfully. However, because of their coarse gradation, these materials may require higher cement contents than less coarsely graded materials. When coarse-graded aggregates are used for soil-cement, it is important, as with all soil-cement materials, that the mix design be based on the ASTM or AASHO standard freeze-thaw and wet-dry tests.

The following subjects are discussed in the order listed:

1. Methods of testing soil-cement.
2. Selection of cement contents for tests.
3. Details of soil-cement test methods.
4. Compressive-strength and other supplementary tests.
5. Establishment of cement factors for construction.
6. Short-cut test procedures for sandy soils.
7. Rapid test procedure.
8. Testing of unusual sandy soils.
9. Testing of plastic soil-cement.
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CHAPTER 1

METHODS OF TESTING SOIL-CEMENT

Laboratory and field experience during more than 35 years has shown conclusively that soils can be hardened adequately by the addition of relatively small quantities of portland cement to produce a strong, durable material suitable for low-cost paving. A key to successful application of soil-cement to the paving field is careful predetermination of engineering control factors in the laboratory and their application throughout construction. Adherence to this principle has accounted for the uniformly high quality of thousands of miles of soil-cement pavement.

The composition of soils varies considerably and this affects the degree to which they react when combined with portland cement and water. The way a given soil reacts with cement is determined by simple laboratory tests made on mixtures of cement with the soil. The amount of laboratory testing required for a given project depends on the requirements of the constructing agency, the number of soil types encountered, the size of the job, and similar factors.

On major projects, for example, detailed tests are generally required and the minimum cement content that can be used safely is determined for each significant soil type on the job. State highway department laboratories and many others are well equipped to run complete, detailed tests. The cost of laboratory tests for major projects is quite small in comparison with the total cost of the project.

On smaller projects, particularly where testing facilities and manpower are limited, it is sometimes considered advantageous to conduct only enough laboratory tests to determine a safe, but not necessarily minimum, cement factor that can be used for construction.

For emergency construction and for very small projects where laboratory testing facilities are not available or detailed testing is not feasible or practical, a quick and very simple test procedure that involves molding and inspection of specimens has been used successfully. It provides a safe cement factor, but one that may be appreciably higher than the minimum for adequate hardness.

The various test methods are shown graphically in Fig. 1.

In some areas, special test methods and criteria have been developed specifically for local conditions. For the particular soils and climate involved, these locally developed test methods also have proved satisfactory.

In all cases the tests are performed to determine three fundamental requirements for soil-cement:

1. How much portland cement is needed to harden the soil adequately?
2. How much water should be added?
3. To what density must the soil-cement be compacted?

Detailed test methods for determining these control factors were approved by the American Society for Testing Materials in 1944 and by the American Association of State Highway Officials in 1945. After 13 years of successful use, the test methods were revised by ASTM and by AASHO in 1957 to incorporate the information and experience gained during that period. The revisions materially reduce the amount of work and calculation required for routine testing. These test methods are:

Methods of Test for Moisture-Density Relations of Soil-Cement Mixtures, ASTM Designation: D558; AASHO Designation: T134.

Methods of Wetting and Drying Test of Compacted Soil-Cement Mixtures, ASTM Designation: D559; AASHO Designation: T135.

Methods of Freezing and Thawing Test of Compacted Soil-Cement Mixtures, ASTM Designation: D560; AASHO Designation: T136.

The dependability of these test methods has been proved by the outstanding service record of soil-cement paving for

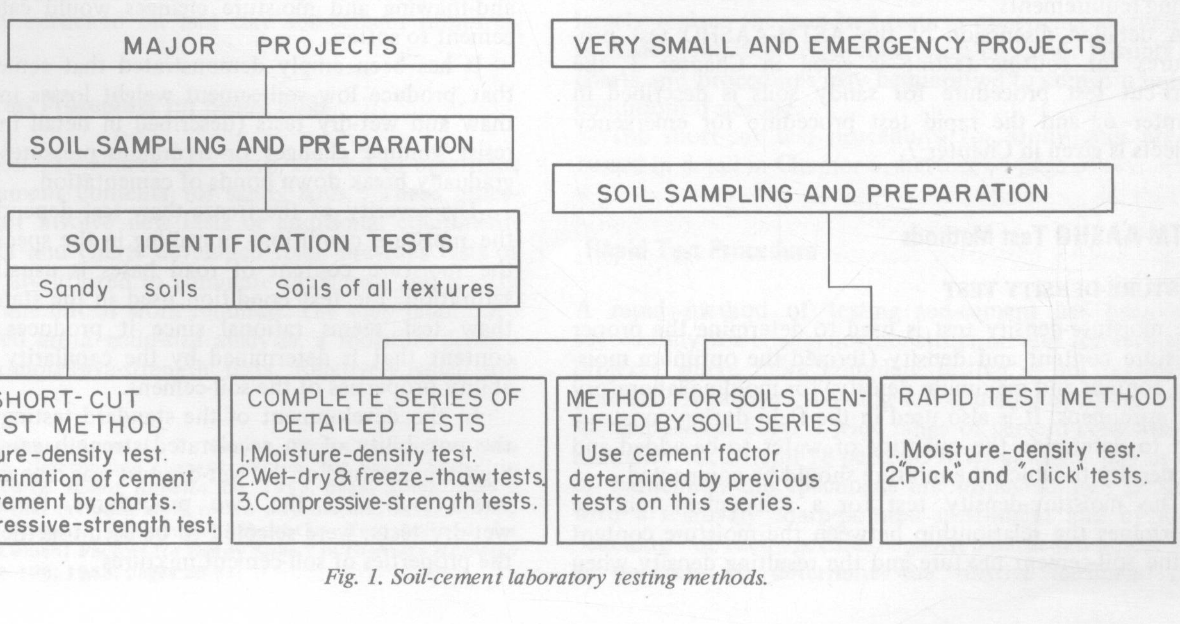

Fig. 1. Soil-cement laboratory testing methods.

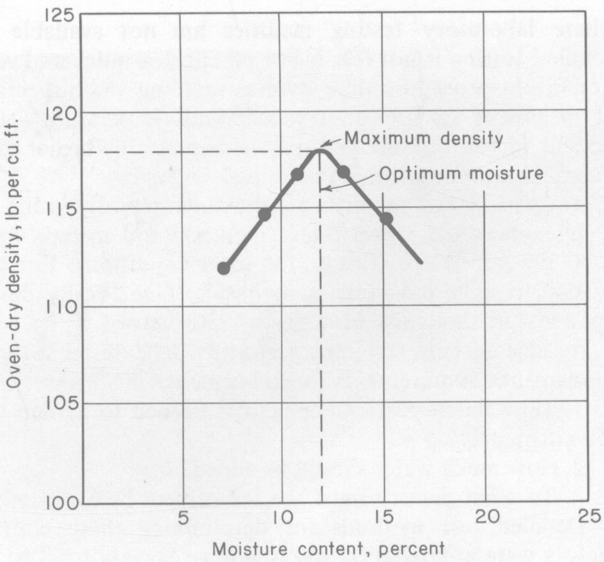

Fig. 2. Typical moisture-density curve.

roads and streets, as well as for many airports, parking areas, and similar projects that were built using control factors obtained by these test methods. But, invaluable as they are, they require considerable time to obtain the factors needed for construction. In a continuing effort to reduce the time and manpower needed for laboratory testing, the Portland Cement Association has developed a special short-cut test procedure for determining cement factors for sandy soils.

The following paragraphs give a general discussion of the ASTM-AASHO test methods. This is followed by a general discussion of the special short-cut test procedures for sandy soils, and then by a discussion of test methods used for emergency construction and for very small projects. The value of identifying the soils occurring on a project by soil series name, as identified by the U.S. Department of Agriculture, is stressed as an additional means of reducing testing requirements.

A detailed discussion of the ASTM-AASHO test procedures for routine testing is given in Chapter 3; the short-cut test procedure for sandy soils is described in Chapter 6; and the rapid test procedure for emergency projects is given in Chapter 7.

ASTM-AASHO Test Methods

MOISTURE-DENSITY TEST

The moisture-density test is used to determine the proper moisture content and density (termed the optimum moisture content and maximum density) for molding laboratory test specimens. It is also used in the field during construction to determine the quantity of water to be added and the density to which the mixture should be compacted.

The moisture-density test for a soil-cement mixture determines the relationship between the moisture content of the soil-cement mixture and the resulting density when the mixture is compacted before cement hydration with a standard compactive force. A typical moisture-density curve is shown in Fig. 2.

While soil, cement, and water are being mixed, a distinct change is taking place in the mixture. Apparently there is a base exchange phenomenon occurring. The soil becomes more or less coagulated, which causes an increase in internal friction.

Therefore, moisture-density relations of a soil-cement mixture will vary slightly as a result of this chemical phenomenon and of the partial cement hydration that has taken place during damp-mixing. These effects will be noted as an increase in the optimum moisture content and a decrease in the maximum density of the soil-cement mixture as the damp-mixing time increases. For this reason, moisture-density tests in the laboratory are made on the soil-cement mixture as rapidly as possible. This is necessary because test specimens, which are designed from these test data, are molded after a few minutes of mixing soil, cement, and water, and before cement hydration.

Specifications for soil-cement construction require that moisture-density relations be established in the field toward the end of the damp-mixing procedure, with the use of soil-cement taken directly from the area being constructed. If need be, laboratory soil-cement moisture-density tests that simulate the time elements of field mixing operations may be run. Results will closely approximate the actual field optimum moisture and maximum density.

During construction, estimates of water requirements are based on moisture-density tests made in the laboratory until the mixture is close to the optimum moisture and until the optimum moisture prevailing in the moist soil-cement at time of compaction has been determined.

Details of performing the moisture-density test are given in Chapter 3, starting on page 15.

FREEZE-THAW AND WET-DRY TESTS

The freeze-thaw and wet-dry tests were designed to determine whether the soil-cement would stay hard or whether expansion and contraction on alternate freezing-and-thawing and moisture changes would cause the soil-cement to soften.

It has been amply demonstrated that cement contents that produce low soil-cement weight losses in the freeze-thaw and wet-dry tests (described in detail in Chapter 3) resist volume changes or hydraulic pressures that could gradually break down bonds of cementation.

The severity of the freeze-thaw test depends largely on the moisture conditions prevailing in the specimens. Since the moisture content of road bases is usually less than saturation, the test condition used in the standard freeze-thaw test seems rational since it produces a moisture content that is determined by the capillarity and permeability properties of the soil-cement.

In the development of the standard testing procedures, the possibility of an accelerated strength gain due to the high temperature of the wet-dry test was recognized. This is one reason that the two procedures, freeze-thaw and wet-dry tests, were selected to be used together to measure the properties of soil-cement mixtures.

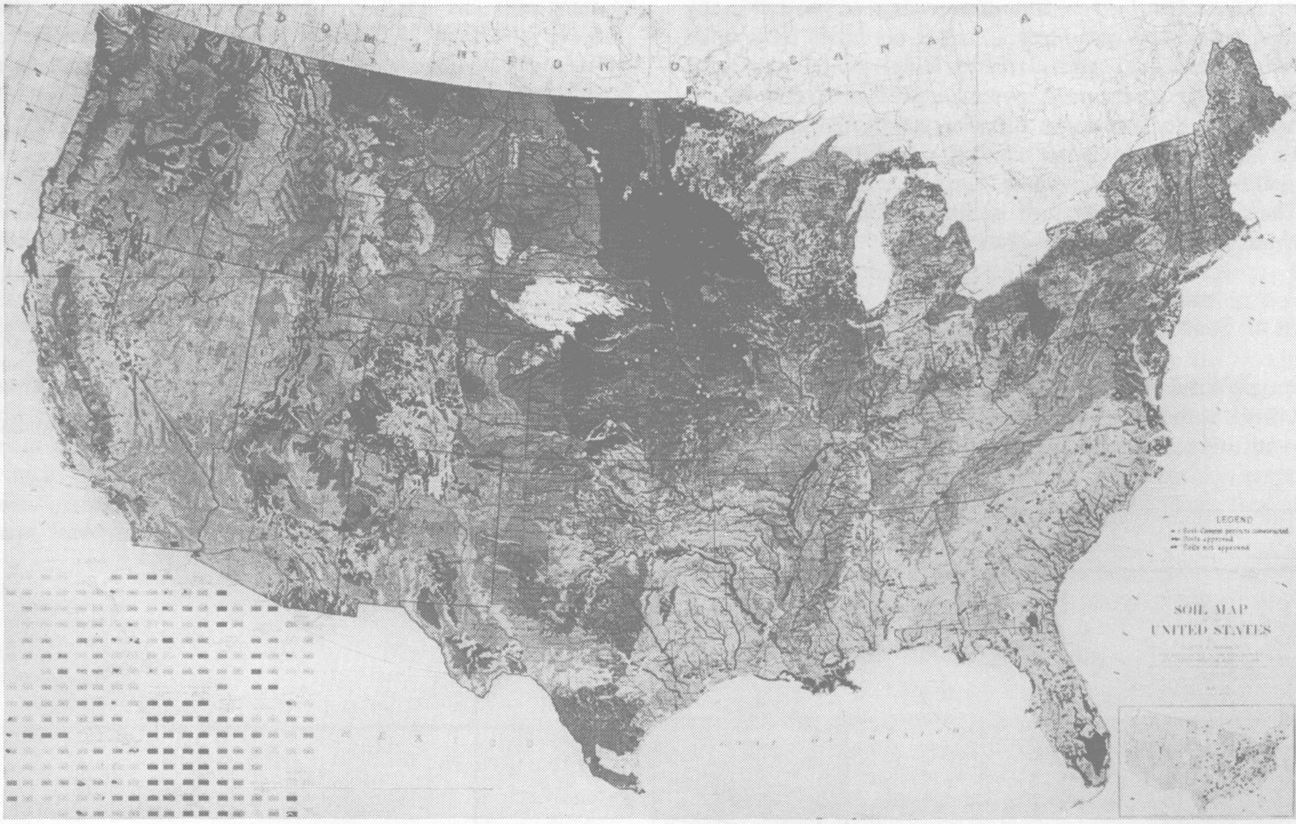

Fig. 3. Major soil series in the United States. (From "Soils of the United States," Part III, Atlas of American Agriculture, *U.S. Department of Agriculture.) Varying shades on map show varying soil series.*

The wire brush used in these tests produces some abrasion on sandy soil-cement specimens, thus removing some material in addition to that loosened by the alternate freezing-and-thawing and wetting-and-drying. This abrasion is considered when cement recommendations are selected. For instance, greater soil-cement losses are permitted for satisfactorily hardened sandy soil-cement mixtures than for satisfactorily hardened silt and clay soil-cement mixtures.

Short-Cut Test Procedures for Sandy Soils

Short-cut test procedures have been evolved to determine adequate cement contents for sandy soils.* These procedures do not involve new tests or additional equipment. Instead, data and charts developed from previous tests of similar soils are utilized to eliminate some tests and greatly reduce the amount of work required. The only laboratory tests required are a grain-size analysis, a moisture-density test, and compressive-strength tests. Relatively small soil samples are needed, and all tests except the 7-day compressive-strength tests can be completed in one day.

While these procedures do not always give the minimum cement factor that can be used, they provide a safe cement factor generally close to that indicated by standard ASTM-AASHO wet-dry and freeze-thaw tests. The procedures are finding wide application by engineers and builders and may largely replace the standard tests as experience in their use is gained and the relationships are checked. Possibly the charts and procedures may be modified to conform to local conditions if needed.

The short-cut test procedures for sandy soils are discussed in detail in Chapter 6, starting on page 37.

Rapid Test Procedure

A rapid method of testing soil-cement has been used successfully for emergency construction and for very small projects where more complete testing is not feasible or practical. It involves molding and visually inspecting several specimens that cover a wide range of cement contents—for example, 10, 14 and 18 percent. After at least a day or two of hardening, the specimens are inspected by "picking" with a relatively sharp-pointed instrument and by sharp "clicking" of each specimen against a hardened object such as concrete to determine the relative hardness. If a

*J. A. Leadabrand and L. T. Norling, "Soil-Cement Test Data Correlation In Determining Cement Factors for Sandy Soils," in *Highway Research Board Bulletin* 69, 1953, pages 29-46. Also a second paper that includes more recent information, L. T. Norling and R. G. Packard, "Expanded, Short-Cut Test Method for Determining Cement Factors for Sandy Soils," in *Highway Research Board Bulletin* 198, 1958, pages 20-31.

specimen cannot be penetrated more than 1/8 to 1/4 in. by picking and if it produces a clear or solid tone upon clicking, an adequate cement factor is indicated.

Even an inexperienced person can soon differentiate between satisfactorily and unsatisfactorily hardened specimens and will be able to select a safe cement content to harden the soil.

The rapid test procedure is discussed in more detail in Chapter 7, starting on page 41.

Tests on Soils Identified by Soil Series

A very helpful tool for the engineer in reducing soil-cement test work is the identification of soils by the Department of Agriculture soil classification system.* In this classification system, soils are subdivided into groups called soil series.

*The Department of Agriculture soil classification system is described in *PCA Soil Primer* published by Portland Cement Association. The following publications are excellent references:

1. "Soils of the United States," *Atlas of American Agriculture*, Part III, U.S. Department of Agriculture, 1935.
2. Charles E. Kellogg, *Development and Significance of the Great Soil Groups of the United States*, U.S. Department of Agriculture Miscellaneous Publication No. 229, 1936.
3. U.S. Department of Agriculture *Yearbook of Agriculture, 1938, Soils and Men*.
4. H. Jenny, *Factors of Soil Formation*, New York, McGraw-Hill Book Co., 1941.
5. F. F. Riecken and Guy D. Smith, "Lower Categories of Soil Classification: Family, Series, Type and Phase," page 107; and James Thorp and Guy D. Smith, "Higher Categories of Soil Classification: Order, Suborder and Great Soil Groups," page 117, *Soil Science*, Vol. 67, January to June 1949.
6. *Soil Survey Manual*, U.S. Department of Agriculture Handbook No. 18, 1951.

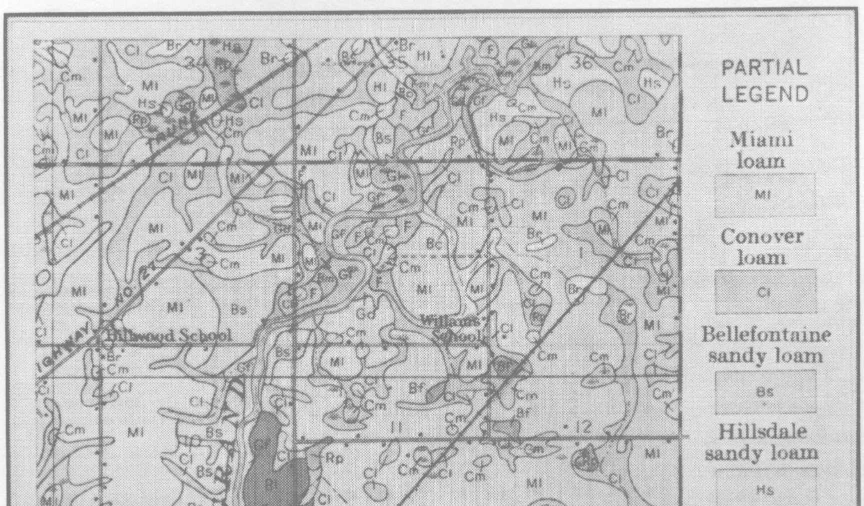

Fig. 4. Reprint of a small section of a typical detailed soil map (Eaton County, Mich.). From Development and Significance of the Great Soil Groups of the United States, *Miscellaneous Publication No. 229, U.S. Department of Agriculture.*

Soils of a certain soil series have similar characteristics of subsoil (B horizon), parent material (C horizon), climate, vegetation, and age. Large areas may be covered by soils of the same series (See Fig. 3).

Identifying soils by series name is important in soil-cement work because it has been found that soils of the same soil series and horizon require the same amount of cement for adequate hardening. Once the cement requirement of a given soil series and horizon has been determined by laboratory tests, another complete series of soil-cement tests is not needed for this particular soil series when it is again encountered.

Thus, by identifying soils by soil series, the need for conducting soil-cement tests can be sharply reduced or eliminated for large areas. An increasing number of engineers are making use of this system of classification to reduce their soil-cement testing work. Soil surveys have been made over a large portion of the United States and maps have been prepared by the Department of Agriculture. County maps are available to the public and can be viewed or obtained from the U.S. Department of Agriculture, county extension agents, colleges, universities, libraries, or from other sources.

The Highway Research Board reports periodically the status of soil mapping by the Department of Agriculture and other agencies through publications sponsored by the Committee of Exploration and Classification of Earth Materials. These publications list the soil surveys completed and those started since the preceding publication, thus providing the engineer with the latest information on soil surveys and mapping.

Grain-size and physical-test-constant tests are also helpful in the identification and classification of soils, and the data can be used to good advantage in conjunction with the soil series identification system. These tests also provide additional information to permit the construction engineer to identify on the project the various soil types that were tested in the laboratory.

CHAPTER 2

SELECTION OF CEMENT CONTENTS FOR TESTS

This chapter will be of major interest to the laboratory engineer because it will assist him in determining what cement contents to investigate in the soil-cement tests. The field engineer and administrative engineer will also be interested because the properties of soil-cement mixtures and the relationships existing among these properties and various test values are discussed. Information is presented that will enable engineers to estimate probable cement factors so that job estimates can be made before any tests are made.

In order to obtain the maximum amount of information from the wet-dry and freeze-thaw tests, it is important that the laboratory engineer design the soil-cement specimens properly. For instance, if specimens are designed with very high cement contents, they will all pass the wet-dry and freeze-thaw tests, and a minimum cement factor will not have been determined. On the other hand, if the specimens are designed with inadequate cement contents, they will all fail in the tests.

The principal requirement of a hardened soil-cement mixture is that it withstand exposure to the elements. Strength might also be considered a principal requirement; however, since most soil-cement mixtures that possess adequate resistance to the elements also possess adequate strength, this requirement is secondary.

Therefore, in a study to determine when a certain soil-cement mixture has been adequately hardened, the requirement of adequate resistance to exposure is the first considered. That is, will the hardened soil-cement mixture withstand the wetting and drying and the freezing and thawing cycles of nature and still maintain at least the stability inherent in the mass at the time the roadway was opened to traffic?

For instance, consider a hypothetical road subgrade made from a clay loam soil without cement, packed to maximum density at a moisture content slightly less than its optimum moisture content. This mass can withstand relatively heavy loads without failure, although it cannot offer much resistance to abrasive forces.

The same soil mixed with cement and compacted to maximum density at optimum moisture content will have stability before the cement hydrates at least equal to that of the raw soil.

But consider the two cases at a later date under a condition of slow drainage when moisture, by capillary action or in some other manner, has permeated the masses. The voids in the raw soil become filled with water and the soil loses the original inherent physical stability that was built into it by compaction to maximum density. This is

Table 1. Cement Requirements of AASHO Soil Groups

AASHO soil group	Usual range in cement requirement		Estimated cement content and that used in moisture-density test, percent by wt.	Cement contents for wet-dry and freeze-thaw tests, percent by wt.
	percent by vol.	percent by wt.		
A-1-a	5– 7	3– 5	5	3– 4– 5– 7
A-1-b	7– 9	5– 8	6	4– 6– 8
A-2	7–10	5– 9	7	5– 7– 9
A-3	8–12	7–11	9	7– 9–11
A-4	8–12	7–12	10	8–10–12
A-5	8–12	8–13	10	8–10–12
A-6	10–14	9–15	12	10–12–14
A-7	10–14	10–16	13	11–13–15

not so, however, with the adequately hardened soil-cement mixture, which has continually increased in stability since its construction because of cement hydration and resultant cementation. Its air voids may become filled with water too, but its stability will still be much greater than that built into it originally.

The next important requirement to consider is economy. Available data indicate that about 85 percent of all soils likely to be used for soil-cement can be adequately hardened by the addition of 14 percent cement or less. To determine whether or not a soil falls into this category would not require much testing. However, more than 50 percent of all soils so far tested for soil-cement require only 10 percent cement or less for adequate hardening. To identify these soils requires more testing. Since soil-cement is in the low-cost paving field, the testing engineer on large jobs should determine by test the minimum quantity of cement that can be safely used with each soil. By this procedure, the lowest-cost soil-cement construction possible will be obtained.

Estimating Cement Requirements

The following information will aid the engineer in estimating cement requirements of the soils proposed for use and in determining what cement factors to investigate in the laboratory tests.

As a general rule, it will be found that the cement requirement of soils increases as the silt and clay content increases, gravelly and sandy soils requiring less cement for adequate hardness than silt and clay soils.

The one exception to this rule is that poorly graded, one-size sand materials that are devoid of silt and clay require more cement than do sandy soils containing some silt and clay.

In general, a well-graded mixture of stone fragments or gravel, coarse sand, and fine sand either with or without small amounts of slightly plastic silt and clay material will require 5 percent or less cement by weight. Poorly graded one-size sand materials with a very small amount of nonplastic silt, typical of beach sand or desert blow sand, will require about 9 percent cement by weight. The remaining sandy soils will generally require about 7 percent. The nonplastic or moderately plastic silty soils generally require about 10 percent cement by weight, and plastic clay soils require about 13 percent or more.

Table 1 gives the usual range in cement requirements for subsurface soils of the various AASHO* soil groups. "A" horizon soils may contain organic or other material detrimental to cement reaction and may require higher cement factors. For most A horizon soils, the cement content in Table 1 should be increased four percentage points if the soil is dark grey to grey and six percentage points if the soil is black. It is usually not necessary to increase the cement factor for a brown or red A horizon soil. Testing of "poorly reacting" sandy surface soils is discussed in detail in Chapter 8. These cement contents can be used as preliminary estimates, which are then verified or modified as additional test data become available.

STEP-BY-STEP PROCEDURE

The following procedure will prove helpful to the testing engineer in setting up cement contents to be investigated:

Step 1: Determine from Table 1 the preliminary estimated cement content by weight based on the AASHO soil group.

Step 2: Use the preliminary estimated cement content obtained in Step 1 to perform the moisture-density test.

Step 3: Verify the preliminary estimated cement content by referring to Table 2 if the soil is sandy or to Table 3 if it is silty or clayey. These tables take into consideration the maximum density and other properties of the soil, which permits a more accurate estimate. In the case of A horizon soils, the indicated cement factor should be increased as discussed above for Table 1.

Sandy soils:

(1) Using the percentage of material smaller than 0.05 mm., the percentage of material retained on the No. 4 sieve, and the maximum density obtained by test in Step 2, determine from Table 2 the estimated cement content.

(2) Mold wet-dry and freeze-thaw test specimens at the estimated cement content by weight obtained in (1) and at cement contents two percentage points above and below that cement factor.**

Silty and clayey soils:

(1) Using the percentage of material between 0.05 mm. and 0.005 mm., the AASHO group index, and the maximum density obtained by test in Step 2, determine from Table 3 the estimated cement content.

(2) Mold wet-dry and freeze-thaw test specimens at the estimated cement content obtained in (1)

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*Charts and tables for use in classifying soils by the American Association of State Highway Officials Soil Classification System (AASHO Designation: M145) are given in the Appendix.

**If the estimated cement content is 5 percent or less, it is good practice to use 1 percentage point increments below 5 percent.

Table 2. Average Cement Requirements of B and C Horizon Sandy Soils

Material retained on No. 4 sieve, percent	Material smaller than 0.05 mm., percent	Cement content, percent by wt. — Maximum density, lb. per cu.ft. 105–109	110–114	115–119	120–124	125–129	130 or more
0–14	0–19	10	9	8	7	6	5
	20–39	9	8	7	7	5	5
	40–50	11	10	9	8	6	5
15–29	0–19	10	9	8	6	5	5
	20–39	9	8	7	6	6	5
	40–50	12	10	9	8	7	6
30–45	0–19	10	8	7	6	5	5
	20–39	11	9	8	7	6	5
	40–50	12	11	10	9	8	6

Table 3. Average Cement Requirements of B and C Horizon Silty and Clayey Soils

Group index*	Material between 0.05 mm. and 0.005 mm., percent	Cement content, percent by wt. — Maximum density, lb. per cu.ft. 90–94	95–99	100–104	105–109	110–114	115–119	120 or more
0– 3	0–19	12	11	10	8	8	7	7
	20–39	12	11	10	9	8	8	7
	40–59	13	12	11	9	9	8	8
	60 or more	—	—	—	—	—	—	—
4– 7	0–19	13	12	11	9	8	7	7
	20–39	13	12	11	10	9	8	8
	40–59	14	13	12	10	10	9	8
	60 or more	15	14	12	11	10	9	9
8–11	0–19	14	13	11	10	9	8	8
	20–39	15	14	11	10	9	9	9
	40–59	16	14	12	11	10	10	9
	60 or more	17	15	13	11	10	10	10
12–15	0–19	15	14	13	12	11	9	9
	20–39	16	15	13	12	11	10	10
	40–59	17	16	14	12	12	11	10
	60 or more	18	16	14	13	12	11	11
16–20	0–19	17	16	14	13	12	11	10
	20–39	18	17	15	14	13	11	11
	40–59	19	18	15	14	14	12	12
	60 or more	20	19	16	15	14	13	12

*Group index values determined by charts used in AASHO M 145-49 (see Fig. 5). The newer group index chart used with Interim Recommended Practice for the Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes (AASHO M 145-661), is given on page 61. This new chart cannot be used to determine group index values for Table 3 since this table is based on AASHO M 145-49.

and at cement contents two percentage points above and below that cement factor.

To help in determining how well the soil reacts, it is advantageous to save half of the last moisture-density test specimen and to place it in an atmosphere of high humidity for inspection daily. This half specimen, called the "tail-end" specimen (see Fig. 6), is obtained during the usual procedure of cutting the last specimen of the moisture-density test in half vertically (details are given on page 21) so that a representative moisture sample can be taken. The criteria used in the rapid test procedure, as discussed in Chapter 7, can be used to judge the hardness of the tail-end specimen. Generally, tail-end specimens are satisfactorily hardened in two to four days and it is not uncommon for them to be satisfactory a day after molding.

A study of compressive-strength data, as discussed in Chapter 4, is also helpful in checking the estimated cement factor.

Miscellaneous Soils

A number of miscellaneous materials or special types of soils, such as caliche, chert, cinders, scoria, shale, etc., have been used successfully in soil-cement construction. In some cases, these materials have been found in the roadway or street that was to be paved with soil-cement; in other cases, in order to reduce the cost of the project, they have been used as borrow materials to replace soils that required high cement contents for adequate hardening.

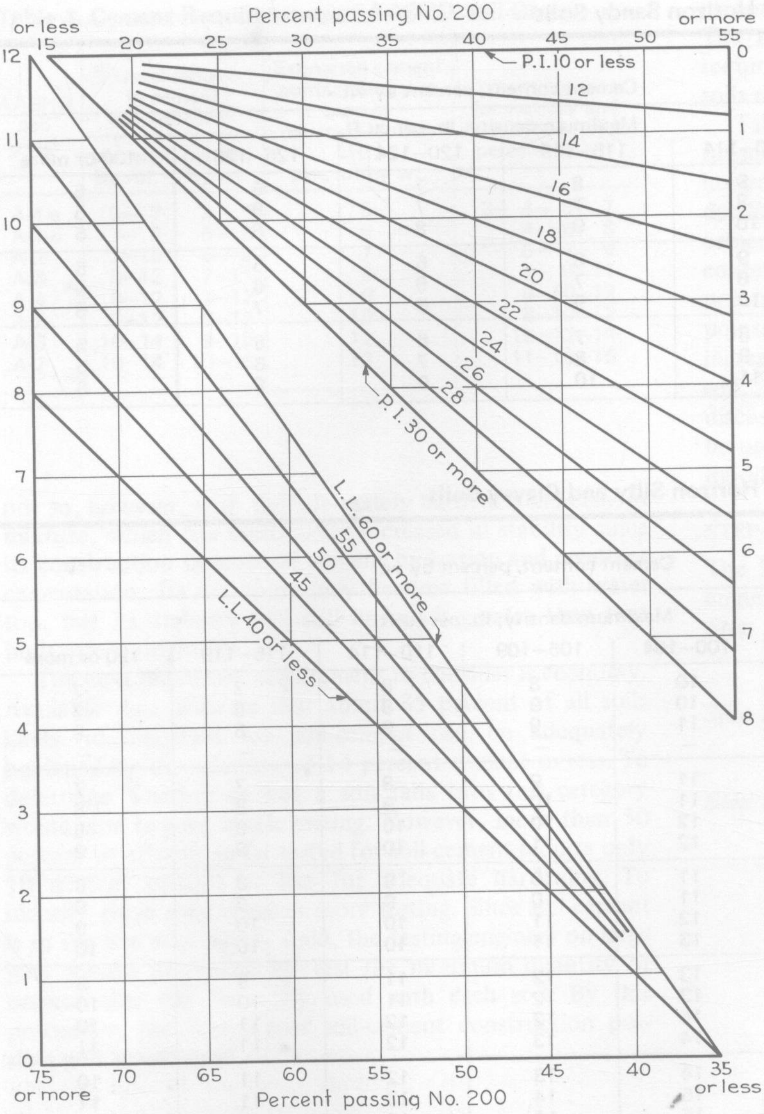

Fig. 5. Charts for calculating group index values for use with Table 3. The group index is the sum of the values obtained by using the liquid limit and the plasticity index.

Fig. 6. Soil-cement specimens saved from tail end of moisture-density test procedure. Rate of hardening of the soil-cement mixture is investigated from day to day with a dull-pointed instrument.

The procedure for testing miscellaneous materials is the same as that used for regular soils. Average cement requirements of a number of miscellaneous materials and cement contents to be investigated in the laboratory tests are given in Table 4. As test data are accumulated and experience is gained with local miscellaneous materials, it may be found that future testing can be reduced or eliminated for similar materials.

Table 4. Average Cement Requirements of Miscellaneous Materials

Type of miscellaneous material	Estimated cement content and that used in moisture-density test		Cement contents for wet-dry and freeze-thaw tests, percent by wt.
	percent by vol.	percent by wt.	
Shell soils	8	7	5– 7– 9
Limestone screenings	7	5	3– 4– 5– 7
Red dog	9	8	6– 8–10
Shale or disintegrated shale	11	10	8–10–12
Caliche	8	7	5– 7– 9
Cinders	8	8	6– 8–10
Chert	9	8	6– 8–10
Chat	8	7	5– 7– 9
Marl	11	11	9–11–13
Scoria containing material retained on the No. 4 sieve	12	11	9–11–13
Scoria not containing material retained on the No. 4 sieve	8	7	5– 7– 9
Air-cooled slag	9	7	5– 7– 9
Water-cooled slag	10	12	10–12–14

CHAPTER 3

DETAILS OF SOIL-CEMENT TEST METHODS

This chapter will be of major interest to the laboratory engineer because it discusses details of methods for testing soil-cement mixtures.

The complete series of tests, which are here described in detail, will determine the minimum amount of cement required to harden the soil adequately. State highway departments and commercial laboratories generally have the necessary equipment to run these tests. On smaller projects, such as some county and city work where testing facilities are at a minimum and where it is not so important to determine the minimum cement content, a complete series of laboratory tests is not always needed. For example, if the soils are sandy, short-cut test procedures, as described in Chapter 6, are run in many cases. For emergency construction and for very small projects where testing facilities are not available, a rapid test procedure, as described in Chapter 7, has been used successfully to indicate safe cement factors.

The test procedures given in this chapter are similar to the ASTM-AASHO methods specified for routine soil-cement testing. For research work on soil-cement and for tests of unusual soils, some additional testing involving the molding and testing of volume- and moisture-change specimens is specified by ASTM and AASHO.

Two methods for determining moisture-density relations of soil-cement mixtures and for molding wet-dry and freeze-thaw test specimens are described. The first is to be used with soils containing material retained on the No. 4 sieve, and the second with soils not containing material retained on the No. 4 sieve.

The soil sample used in the moisture-density test and in the wet-dry and freeze-thaw test specimens has the same percentage of material retained on the No. 4 sieve as the original soil material. Three-quarter-in. material is the maximum size used. Should there be material larger than ¾ in. in the original soil, it is replaced with an equivalent weight of No. 4 to ¾-in. material.

Proportioning Cement

In soil-cement testing, cement quantities are proportioned on a weight basis in terms of percent of total oven-dry soil, and all laboratory calculations are made on this basis. At the completion of tests, the recommended cement content by weight may be converted to the equivalent cement content by volume for field construction, because adding cement on a volume basis may simplify construction control depending on the type of construction. Proportioning on a volume basis for field construction is in terms of percentage of a U.S. bag of cement in a compacted cubic foot of soil-cement, assuming that a bag of cement weighs 94 lb.* Thus 10 percent by volume indicates 9.4 lb. of cement per cubic foot of compacted soil-cement. If the roadway is 6 in. thick, 1 sq.yd. of roadway contains 3 X 3 X ½ X 0.10 X 94, or 42.3 lb. of cement.

The criteria used to determine adequate cement factors for soil-cement were developed as percent cement by volume in terms of a 94-lb. U.S. bag of cement. The equivalent cement content by volume, based on an 80-lb. Canadian bag, can be calculated by multiplying the value based on a 94-lb. bag by 1.175. Thus, 10 percent by volume (based on a 94-lb. bag of cement) is equivalent to 0.10 X 1.175, or 11.75 percent by volume based on an 80-lb. bag. The amount of cement per square yard for a 6-in.-thick base is 3 X 3 X ½ X 0.1175 X 80, or 42.3 lb.

Fig. 7. Pulverizing soil through No. 4 sieve.

Preparing Soil for Testing

Seventy-five to 100 lb. of soil is sufficient to run a complete series of soil and soil-cement tests. When necessary, the sample is first dried until it is friable under a trowel. Drying may be accomplished by air-drying or by using drying apparatus that limits the temperature of the sample to 60 deg. C. (140 deg. F.). To prepare the soil for testing, it is separated on the 2-in., ¾-in. and No. 4 sieves. All clods are broken up or pulverized in such a way as to avoid reducing the natural size of individual particles. The pulverized soil passing the No. 4 sieve should be well mixed and then stored in a covered container throughout the duration of the tests. This will prevent any major moisture changes.

The quantity of material larger than 2 in. is not included in calculations of grain-size distribution. The quantity, however, is noted and the material discarded. If the soil contains material retained on the ¾-in. and No. 4 sieves, the quantities are calculated, recorded, and included in calculations of grain-size distribution in the total sample. A portion of Form Sheet No. 1, page 52, is provided for this purpose.

The material larger than ¾ in. is stored until soil-cement test specimens have been molded, after which it is usually discarded. The material larger than the No. 4 sieve and smaller than ¾ in. is soaked in water and later added, in a saturated and surface-dry condition, to the soil used for the moisture-density test and in the wet-dry and freeze-thaw test specimens. It is added in such amount, by dry weight, that the percentage of material from the No. 4 sieve size up to ¾-in. size in an individual soil-cement test specimen equals the percentage of material larger than the No. 4 sieve and smaller than 3 in. in the original total sample.

In many instances, the roadway material used for soil-cement will include the old bituminous surfacing. This offers a practical and economical way of salvaging existing materials. When soil samples contain bituminous surfacing material, the pulverizing effort used should be sufficient to produce the approximate pulverization that will be obtained in the field. Some of the bituminous material or bituminous-coated material will thus be pulverized and included in tests on the portion of the soil passing the No. 10 and No. 40 sieves. It may also be necessary to pulverize an additional amount of bituminous material larger than ¾ in. so that the specimens made from the fraction smaller than ¾ in. will contain a representative amount of bituminous material. The bituminous material retained on the No. 4 sieve is handled and included in the test specimens in the same way that other materials retained on the No. 4 sieve are handled.

Determining Moisture-Density Relations of Soil-Cement Mixtures

A. For Soils Containing Material Retained on the No. 4 Sieve

To facilitate understanding of the discussions on the moisture-density test and on molding test specimens, illustrations of actual laboratory problems follow.

*Canadian bags of cement weigh 80 lb.