Simplified Methods of Testing Soil-Cement Mixtures

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Ten years ago, standard laboratory testing procedures for soil-cement mixtures were adopted by both ASTM and AASHO, incorporating the best information and experience available. These procedures have proved satisfactory for establishing control factors for soil-cement construction. Thousands of miles of soil-cement paving for roads and streets, as well as for many airports, parking areas, and similar projects, have been constructed on the basis of these control factors. Dependability of the standardized tests is attested to by the outstanding performance of these projects.

Invaluable as they are, the standard tests are time consuming and require considerable effort and material. By applying the information and experience gained from testing hundreds of soils in the ensuing 10 years, the Portland Cement Association has been able to modify and shorten the test methods gradually. Some steps have been eliminated altogether. The basic concept of providing hardened soil-cement strong and durable enough to withstand the stresses resulting from wetting and drying and freezing and thawing has been retained. Use of the shortened test procedure has resulted in considerable savings of time, manpower and materials.

This paper discusses in detail the modifications that have been made. For example, cement contents are expressed in relation to weight of soil, rather than on a volume basis. Only one moisture-density test is made. Total material is used, except that material larger than ¾-in. is replaced by an equal amount of No. 4 to ¾-in. material. A total of only four test specimens, instead of twelve, are required for the wet-dry and freeze-thaw tests. Volume and moisture change specimens are eliminated.

For most sandy soils, test work can be reduced even further. Only a moisture-density test, a silt and clay content determination and 7-day compressive strengths are required. This short-cut procedure utilizes charts based on a correlation of data obtained from previous ASTM-AASHO tests on more than 2,000 soils.

For emergency construction and for small projects where detailed testing is not feasible, or where facilities are not available, a simple procedure involving molding and inspection of specimens to establish safe construction control factors is given.

The value of identifying soils occurring on soil-cement projects by soil series name as identified by the United States Department of Agriculture is stressed as a means of further reducing laboratory testing.

●LABORATORY and field experience during the past 20 years have 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 as a low-cost paving. One of the key factors accounting for 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 uniform high quality of thousands of miles of soil-cement pavement.

Although soils are complex chemically, they react in specific ways or patterns when combined with portland cement and water. The manner in which a given soil reacts with various amounts of 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 generally are required and the minimum cement content that can be used safely is determined for each significant soil type on the job. State highway department and many other laboratories are well equipped to run complete detailed tests. The cost of laboratory tests for major projects is 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 sufficient laboratory tests to determine a safe, but not necessarily minimum, cement factor which can be used for construction.

Figure 1. Soil-cement road after 18 years of service proves the dependability of the test procedures.

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

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 quality 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[1] and American Association of State Highway Officials 10 years ago:

"Method of Test for Moisture-Density Relations of Soil-Cement Mixtures", ASTM Designation: D558-44; AASHO Standard T-134-45.

"Method of Wetting-and-Drying Test of Compacted Soil-Cement Mixtures", ASTM Designation; D559-44; AASHO Standard T-135-45.

"Method of Freezing and Thawing Test of Compacted Soil-Cement Mixtures", ASTM Designation: A560-44; AASHO Standard T-136-45.

The outstanding service record of soil-cement paving for roads and streets, as well as for many airports, parking areas, and similar projects which were built using control factors obtained by these test methods prove their dependability. But invaluable as they are, they require considerable time and work in laboratory calculations and manipulations. The Portland Cement Association has modified the procedures on the basis of the information and experience gained from testing hundreds of soils during the

[1] Reprints available free in the United States and Canada upon request to the Portland Cement Association, or for a nominal charge from headquarters, American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pennsylvania.

past 10 years since adoption of the standards. In addition, by correlating test data obtained in the testing of over 2,000 sandy soils, a special short-cut testing procedure was evolved for determining cement factors for sandy soils.[2] As a result, substantial savings in both time and manpower for laboratory testing have been possible.

This paper gives a general discussion of the ASTM-AASHO test methods as modified by the Portland Cement Association. This is followed by a general discussion of the special short-cut testing procedures for sandy soils. A discussion of test methods used for emergency construction, and for small projects is given. The value of identifying the soils occurring on a project by soil series name as identified by the United States Department of Agriculture is stressed as a further means of reducing testing requirements. The interrelation of these test methods is shown graphically in the flow diagram (Figure 2).

MODIFIED TEST METHODS

The three ASTM-AASHO test methods listed above determine the fundamental control factors for quality soil-cement. The moisture-density test establishes the proper density and the optimum moisture content while the wet-dry and freeze-thaw tests are used to determine the minimum cement content for durability. The discussion which follows describes the ASTM-AASHO test methods as modified and used by the Portland Cement Association.

Moisture-Density Test

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

In the standard procedure, the optimum moisture content and maximum density are determined on the portion of the soil passing a No. 4 sieve. This procedure makes no provision for soils containing material retained on the No. 4 sieve, even though it is desirable to determine the maximum density and optimum moisture of the total mixture so that test specimens will represent the material to be used during construction as nearly as possible.

In the previous practice, the optimum moisture and maximum density of the total mixture was computed from data obtained from the minus No. 4 fraction by taking into account the amount, specific gravity and absorbtion of the plus No. 4 material. The computations were made on the assumption that the addition of plus No. 4 material in-

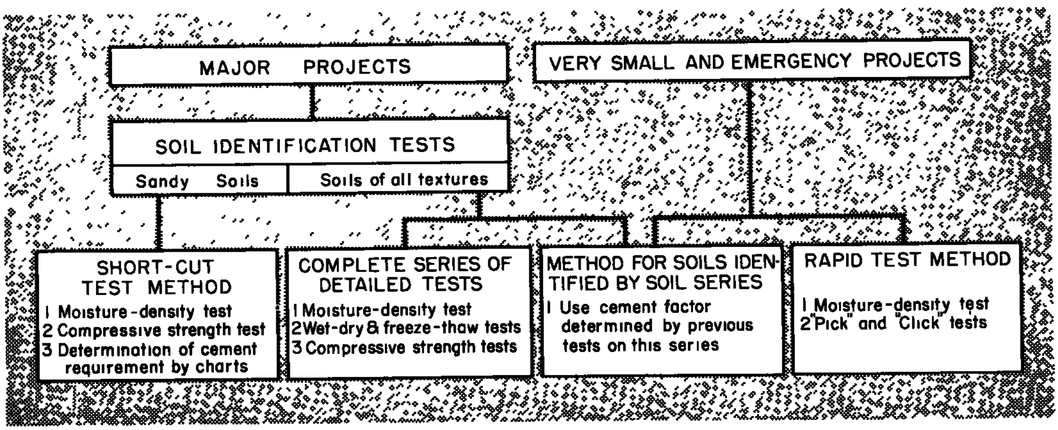

Figure 2. Interrelation of methods of testing soil-cement mixtures.

[2] Soil-Cement Test Data Correlation Affords Method of Quickly Determining Cement Factors for Sandy Soils" presented by J. A. Leadabrand and L. T. Norling at 32nd Annual Meeting of the Highway Research Board, January 1953.

creases the density of the mixture by displacing the minus No. 4 soil in equal volume. No allowance was made for possible increase in void space, although it is obvious that it should be taken into account. But this is difficult to do accurately, since the void spac depends on the amount, size, and shape of plus No. 4 particles.

Experience has shown that when the above procedure is followed the densities obtained in preparing laboratory test specimens using calculated optimum moisture content may be considerably less than the theoretical maximum density. The difference increases as the amount of plus No. 4 material is increased. In some cases, using soils having about 40 percent of plus No. 4 material, actual densities have been as much as 10 pcf. below the calculated theoretical density, apparently due to voids not accounted for in the calculations.

The Portland Cement Association, therefore, has modified the ASTM-AASHO moisture density procedure for soils containing plus No. 4 material as follows:

1. The soil sample used in the test has the same plus No. 4 content as the original soil material. However, ¾-inch material is the maximum size used. Should there be material larger than ¾ inch in the original soil, it is replaced by an equivalent weight of No. 4 to ¾-inch-size material. A maximum size of ¾ inch was selected because a 4-inch-diameter mold is used. This also is the maximum size material used in preparing soil-cement specimens for wet-dry and freeze-thaw testing.
2. A 750-grain moisture sample is taken. This larger size moisture sample is necessary in order to obtain a representative moisture content.
3. When performing the test using fragile soil materials that tend to crush or break down under the weight of the compaction rammer, a separate batch of soil-cement is used for determining each point on the moisture-density curve.

Wet-Dry and Freeze-Thaw Tests

Most soil-cement mixtures have sufficient stability to carry traffic immediately after being compacted to maximum density at optimum moisture content. As the cement hydrate the stability of soil-cement is increased tremendously. The ASTM-AASHO wet-dry and the freeze-thaw tests were developed to determine the resistance of hardened soil-cemen to repeated moisture and temperature variations and to alternate freezing and thawing.

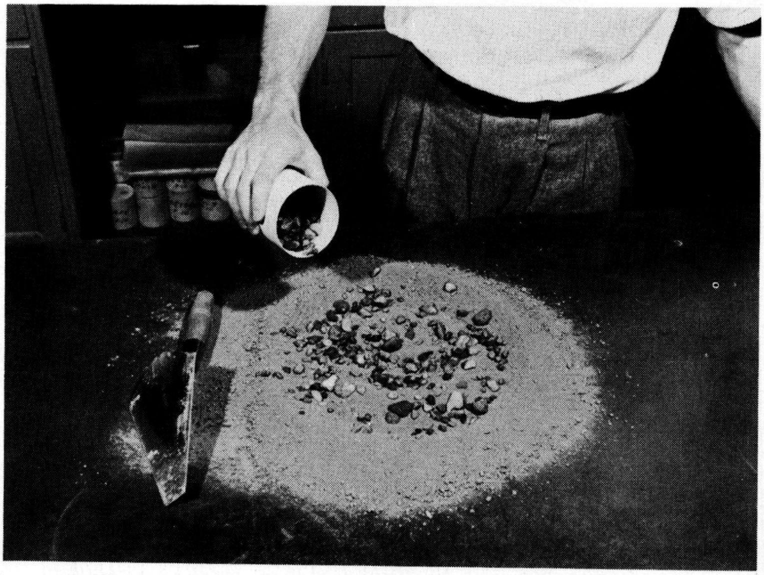

Figure 3. No. 4-to-¾-inch sieve size material is used in performing the moisture-density test.

Data obtained from the tests permit selection of the minimum cement content required for durability.

The standard ASTM-AASHO wet-dry and freeze-thaw test procedures have been modified and shortened to some extent by the Portland Cement Association for use in its Soil-Cement Laboratory. These modifications materially reduce the number of test specimens required, reduce the amount of daily routine handling of specimens and result in a more practical procedure. Successful construction and excellent performance of many projects built using cement factors obtained from these modified tests prove their adequacy.

The modifications follow:

1. Volume and moisture change specimens (referred to in the ASTM standard as No. 1 specimens) are considered unnecessary and are not molded since experience has shown that the brushing test is more critical. Generally this will mean a saving of six test specimens since they usually were prepared at three cement contents for both wet-dry and freeze-thaw tests.

2. Freeze-thaw specimens to be subjected to brushing are molded usually at three cement contents with a two percentage point range between specimens. However, only one wet-dry specimen at the median cement content is molded. Experience has also shown that the soil-cement losses incurred during the tests are almost always higher for the freeze-thaw specimens than for comparable wet-dry specimens. Exceptions sometimes occur in the case of soils with high silt and clay content and coarse grained "one size" sands. Because of such soils, one wet-dry specimen generally is molded.

3. The time schedule of the freezing and thawing test has been changed slightly for practical reasons. Freezing and thawing time has been increased, thereby reducing the time for brushing and handling specimens. This reduction is possible mainly because of the elimination of the volume and moisture change specimens. The time schedule used is: 24 hours of freezing, 23 hours of thawing, 1 hour brushing and handling specimens, or 48 hours total time for one cycle.

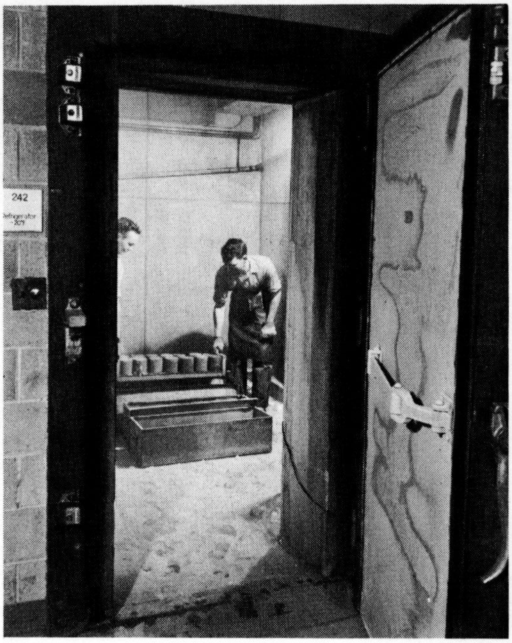

Figure 4. First portion of freeze-thaw test cycle consists of 24 hours' freezing at temperature not warmer than -10 F.

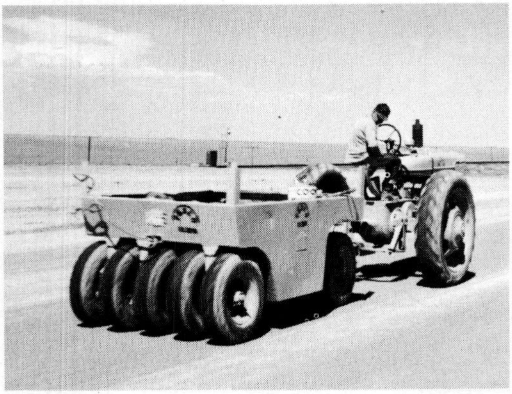

Figure 5, The sandy soil encountered on this soil-cement project required but few tests, using the short-cut test procedures.

SHORT-CUT TESTING PROCEDURES FOR SANDY SOILS

One of the most significant reductions in the amount of work in testing soil-cement mixtures was made possible by development of a special short-cut testing procedure for sandy soils. This procedure was presented in a paper "Soil-Cement Test Data Correlation Affords Method of Quickly Determining Cement Factors for Sandy Soils" by the authors at the Thirty-Second Annual Meeting of the Highway Research Board, January 1953. The procedure is based on correlations of data obtained from the standard ASTM-AASHO and supplementary tests on 2,229 sandy soil-cement mixtures. Since then 295 more soils have been tested using both the modified procedures described in the preceeding sections above and the short-cut method. This comparison of data further confirmed the validity of the short-cut procedures.

As explained in the original paper referred to above, the short-cut testing procedures do not involve new tests or additional laboratory equipment. Instead, data and charts developed from previous tests of similar soils are utilized to eliminate the need for 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 can be completed in one day, except for results of 7-day compressive strength tests.

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

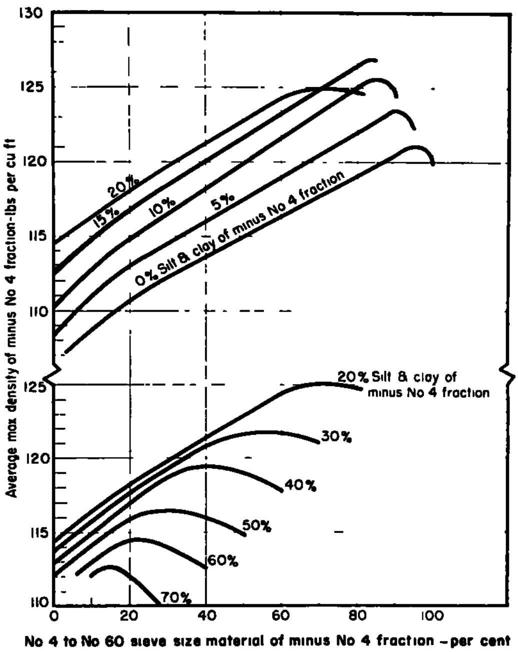

Figure 6. Average maximum densities of the minus No. 4 fraction of soil-cement mixtures.

As originally prepared, the charts for the short-cut procedure were based on cement contents calculated on a volume basis. In the following discussion the accompanying charts show cement contents by weight of soil. The maximum densities shown were obtained by using the minus No. 4 fraction of the soil. Charts based on the maximum density obtained by tests using the total mixture instead of the minus No. 4 fraction are being developed.

The nomenclature of textural classification used in the following discussion has been revised to conform with the revised system now in use by the U.S. Department of Agriculture.

The short-cut testing procedures that follow involve: (1) determining the texture of the soil to permit its placement in either Group I or II; (2) running a moisture-density test on a mixture of portland cement and the minus No. 4 fraction of the soil; (3) determining the indicated portland cement requirement by the use of charts; and (4) verifying the indicated cement requirement by compressive strength tests.

Preliminary Steps

1. Make a grain-size analysis of the soil.
2. If the soil contains less than 20 percent material smaller than 0.005 mm. and less than 50 percent smaller than 0.05 mm., the short-cut procedure can be used and the soil is placed in either Group I or II as follows:

Group I. Less than 20 percent smaller than 0.05 mm. and less than 25 percent gravel larger than No. 10 sieve or 20 to 50 percent smaller than 0.05 mm.

Group II. Less than 20 percent smaller than 0.05 mm. and more than 25 percent gravel larger than No. 10 sieve.

Dark gray to black sandy soils, obviously containing appreciable organic impurities together with miscellaneous granular materials such as cinders, caliche, chat, chert marl, red dog, scoria, shale, slag, etc., should be tested using the full modified procedures as described previously until information on local materials of these types is sufficient to permit use of short-cut procedures.

Group I Soils

Step 1: Determine by test the maximum density and optimum moisture content for a mixture of the minus-No. 4 soil and portland cement. The cement content by weight to use can be obtained from Figure 8 by using the combined silt and clay content (smaller than 0.05 mm.) of the minus-No. 4 fraction of the soil[3] and an estimated density obtained from Figure 6.

Step 2: Using the maximum density obtained by test in Step 1, determine from Figure 8 the indicated cement factor by weight of the minus-No. 4 soil.

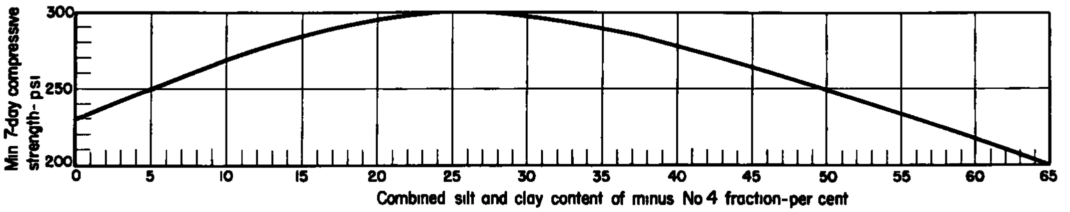

Figure 7. Minimum 7-day compressive strengths required for Group I soils at the indicated cement content obtained from Figure 8.

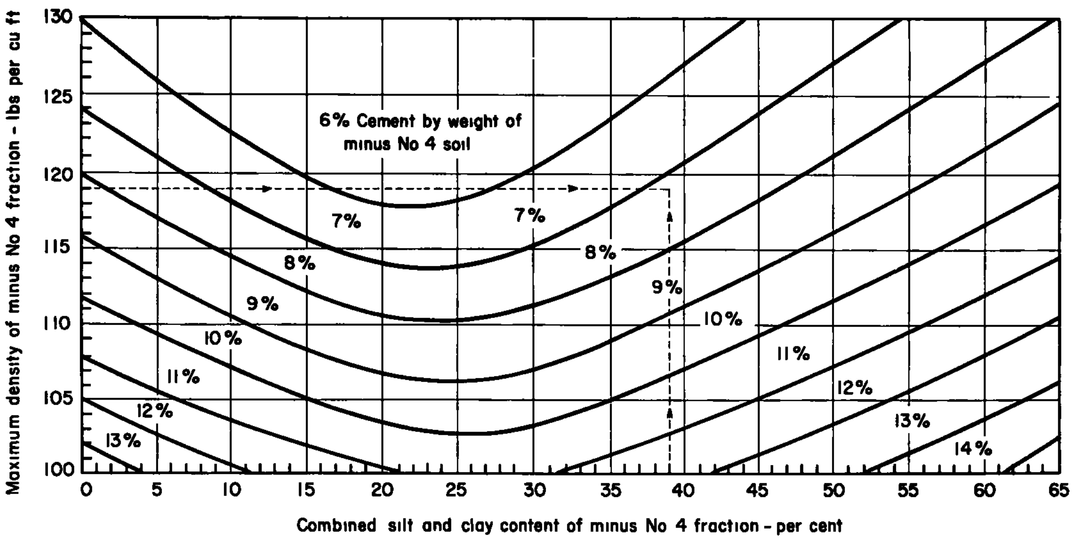

Figure 8. Indicated cement content by weight of minus No.4 fraction of Group I soils.

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[3] The percentage of combined silt and clay is usually given in relation to the total soil mixture for identification and classification purposes. If the soil contains material retained on the No. 4 sieve, it is necessary to convert this figure to the percent based on the minus No. 4 fraction. Likewise, this is true of the amount of material between the No. 4 and 60 sieves. The conversions may be made using the following formulas:

$$\% \text{ (No. 4 to No. 60 sieve size) of No. 4 fraction} = \frac{\% \text{ (No. 4 to No. 60 sieve size) of total}}{100 - \% \text{ plus No. 4}} \times 100$$

$$\% \text{ (silt + clay) of No. 4 fraction} = \frac{\% \text{ (silt + clay) of total}}{100 - \% \text{ plus No. 4}} \times 100$$

Step 3: (A) Mold three compressive-strength specimens[4] at maximum density and optimum moisture using minus No. 4 soil and the cement factor obtained in Step 2. (B) Determine the average compressive strength of the specimens after 7 days of moist-room curing.

Step 4: (A) On Figure 7 plot the average compressive strength value obtained in Step 3. If this value falls above the curve shown, the indicated cement factor by weight of the minus No. 4 soil obtained in Step 2 is adequate. If the original soil sample contained material retained on the No. 4 sieve, it is necessary to convert this cement factor based on the minus No. 4 soil to the cement factor based on the total soil. This is quickly done as follows: cement content by weight of total soil = cement content by weight of minus No. 4 soil x $\frac{(100 - \% \text{ plus No. } 4)}{100}$. This cement content by weight usually is then converted[5] to a volume basis for field construction by using Figure 9. (B) If the average strength value falls below the curve of Figure 7, the indicated cement factor obtained in

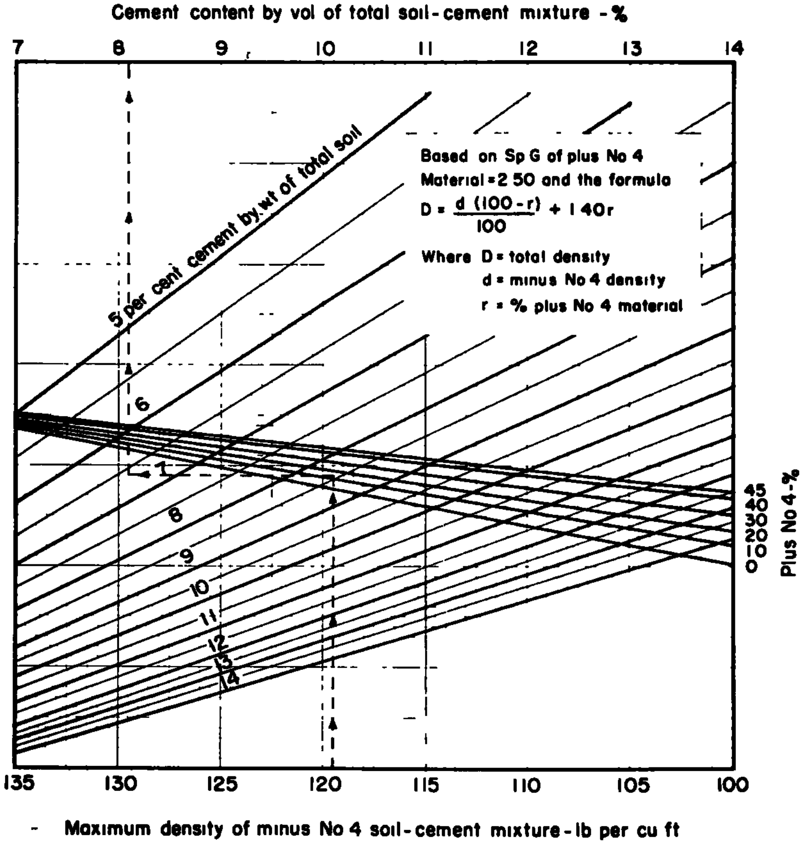

Figure 9. Relation of cement content by weight of total soil to cement content by volume of total compacted soil-cement mixture.

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[4] 2-in. diameter by 2-in. high specimens or 4-in. diameter by 4.6-in. high specimens may be molded using minus No. 4 soil-cement material. The 2-in. specimens shall be submerged in water one hour before testing and the 4-in. specimens four hours.

[5] The formula, $D = \frac{d(100 - r)}{100} + 1.40\ r$, used to develop Figure 9 is based on formula given in "Laboratory Compaction Tests of Coarse-Graded Paving and Embankment Materials", Highway Research Board Proceedings of the Thirty-Second Annual Meeting, 1953.

Step 2 is probably too low. Additional testing following the modified ASTM-AASHO test procedures is needed to establish the cement requirement for the soil. Generally, however, only two freeze-thaw specimens will be needed; one at the cement content by weight indicated as adequate in Step 4(A) based on the total soil and one at a cement content two percentage points higher.

Group II Soils

Seven percent cement by volume, based on the total mixture, is automatically the indicated cement factor for these soils for soil-cement construction.[6]

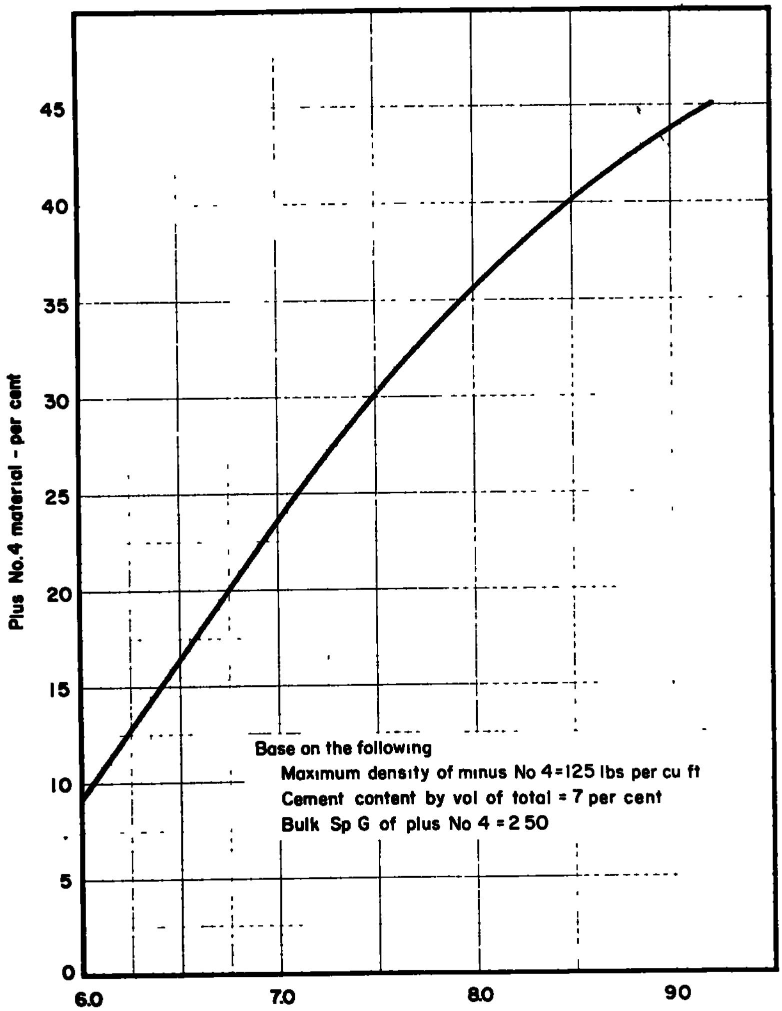

Figure 10. Cement content by weight of minus No. 4 soil for moisture-density test of Group II soils.

[6] Seven percent of portland cement by volume was the minimum recommended for these soils. It is quite probable that tests with lower cement contents would have shown adequate hardening in some cases with less cement. In past years the recommendation of a minimum of 7 percent cement was considered necessary to insure quality construction. More recently considerable soil-cement has been satisfactorily constructed with cement factors well below 7 percent. Modern construction equipment plus job know-how has made quality construction easier.

Step 1: Determine by test the maximum density and optimum moisture content for a mixture of the minus No. 4 soil and portland cement. The cement content by weight of minus No. 4 soil to be used in the test can be determined from Figure 10 by using the percentage of plus No. 4 material in the original soil sample.

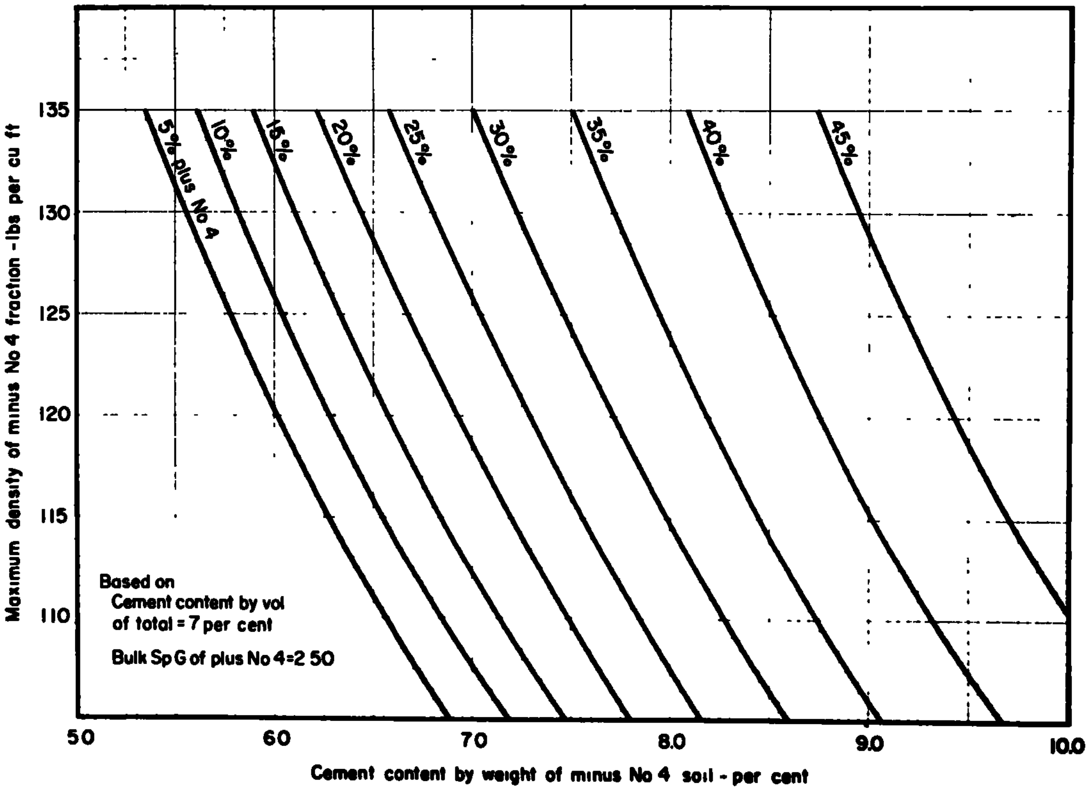

Figure 11. Cement content by weight of minus No. 4 soil for compressive strength specimens of Group II soils.

Step 2: (A) Mold compressive strength specimens[7] in triplicate at maximum density and optimum moisture using minus No. 4 soil and the cement content obtained from Figure 11 by using the maximum density obtained in Step 1 and the percentage of plus No. 4 material. (B) Determine the average compressive strength of the specimens after 7-day's moist room curing.

Step 3: (A) On Figure 12 plot the average compressive strength value obtained in Step 2. If this value falls above the line shown, 7 percent cement by volume of the total soil-cement mixture is adequate for soil-cement construction. If the point falls well above the line it is likely that less than 7 percent cement would be satisfactory. This could be checked by conducting modified standard tests at lower cement contents. (B) If the average strength falls below the line of Figure 12, 7 percent cement by volume of the total mixture is probably not adequate. In this case it is necessary to conduct the modified ASTM-AASHO tests. Generally, however, only two freeze-thaw specimens will be adequate; one at 7 percent cement and one at 9 percent.

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 test-

[7] Two-inch-diameter by 2-inch-height specimens or 4-inch-diameter by 4.6-inch-height specimens may be molded using minus No. 4 soil-cement material. The 2-inch specimens shall be submerged in water for an hour before testing and the 4-inch specimens for four hours.

ing is not feasible or practical.[8] It involves molding and inspecting visually several specimens covering a wide range of cement contents, for example: 10, 14 and 18 percent. After at least a day or two of hardening while kept moist the specimens are inspected by "picking" using a sharp-pointed instrument and by sharply "clicking" each specimen against a hard object such as concrete to determine the relative hardness. If a specimen cannot be penetrated more than 1/8 to 1/4 inch by "picking" and 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 cement content adequate to harden the soil.

Tests on Soils Identified by Soil Series. A most helpful tool for the engineer in reducing soil-cement test work is the Department of Agriculture soil classification system[9]. In this classification system, soils are subdivided into groups called soil series. Soils of a certain series have similar characteristics of subsoil (B horizon), parent material (C horizon), climate, age and vegetation. Large areas may be covered by soils of the same series. It is important to identify soils by series name in soil-cement work because it has been found that soils of the same 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, no further tests for that particular soil series are needed regardless of where it is encountered. Thus by identifying the soil series, testing can be sharply reduced or eliminated altogether for large areas. An increasing number of engineers are making use of this system of classification to reduce their soil-cement testing work.[10]

As a further aid along this line, the Portland Cement Association has underway a project to determine the cement requirements of the major soil series occurring in various areas of the United States. This involves obtaining representative samples of each horizon of each of the significant series in the area under study and determining the required cement content in the laboratory. When these soil series are encountered

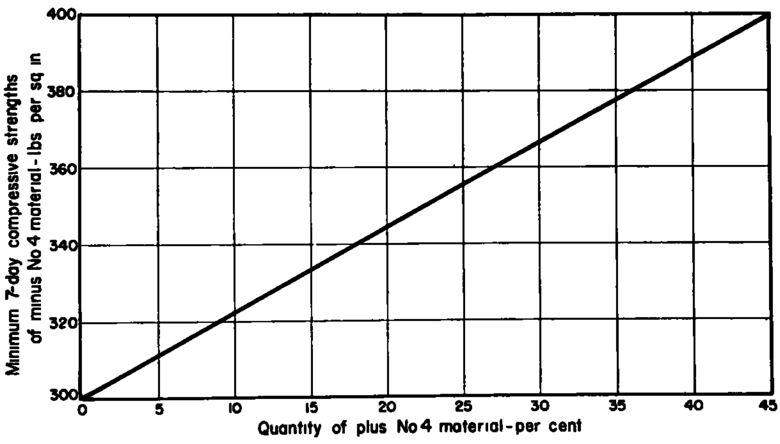

Figure 12. Minimum 7-day compressive strengths required for Group II soils at cement contents equivalent to 7 percent by volume of total mixture.

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[8] Details of this are given in "Suggestions for Emergency Soil-Cement Testing and Construction" available free in the United States and Canada upon request to the Portland Cement Association.

[9] The Department of Agriculture soil classification system is described in PCA Soil Primer published by the Portland Cement Association, available free in the United States and Canada.

[10] "The Use of Agricultural Soil Maps in Making Soil Surveys" by L. D. Hicks, Chief Soils Engineer, North Carolina State Highway Commission Engineering Use of Agricultural Soil Maps. Highway Research Board Bulletin No. 22, October 1949, p. 108.

and accurately identified on future soil-cement projects, detailed testing will not be required.

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, etc.

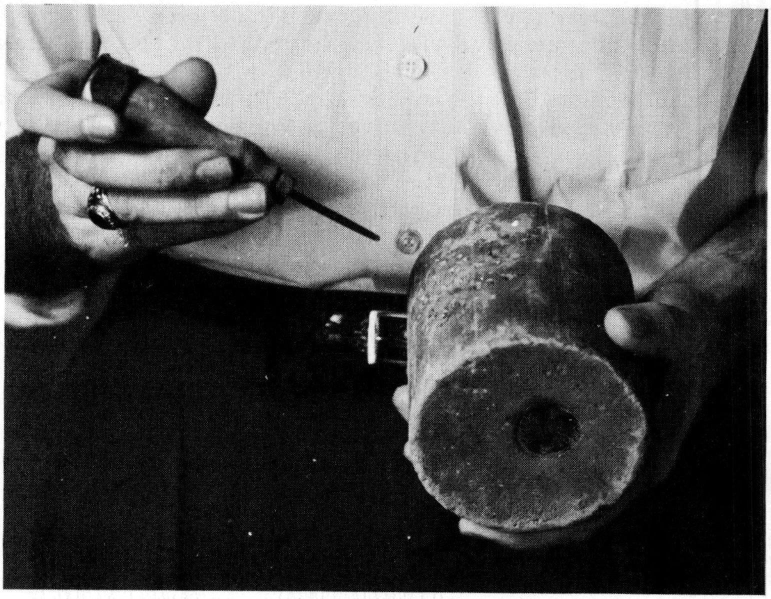

Figure 13. The "pick" test.

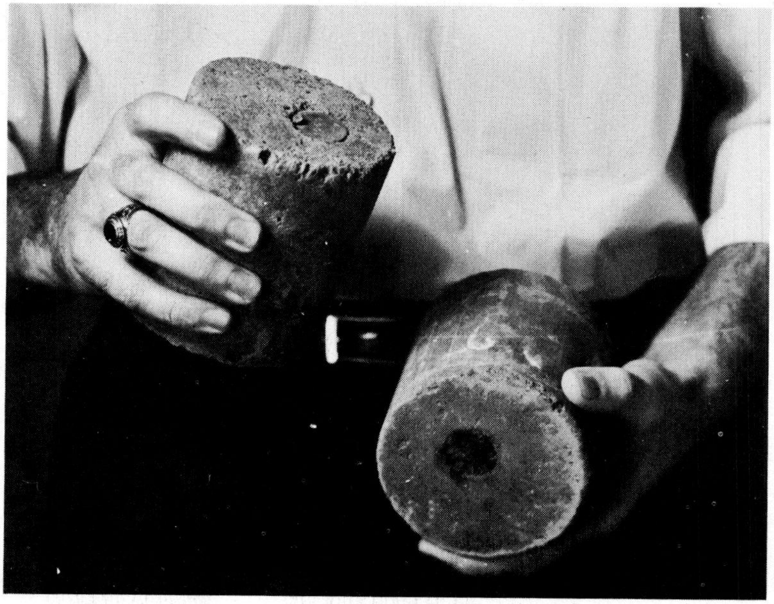

Figure 14. The "click" test.

The highway Research Board reports the status of soil mapping by the Department of Agriculture and other agencies periodically through publications sponsored by the Committee of Soil Surveying and Mapping. These periodic publications list the soil surveys completed and the new ones underway since the preceding publication was published. They keep the highway engineer abreast of the latest information on soil surveys and mapping.

The use of grain size and physical test constant test[11] are also helpful in identifying and classifying soils. These data can be used to good advantage in conjunction with the soil series identification system. They also provide additional information to permit the construction engineer to identify the various soil types on the project which were tested in the laboratory.

SUMMARY

Simplified methods of testing soil-cement to establish cement contents and other construction control factors as required for large and small jobs have been developed in the Portland Cement Association laboratories.

On major projects, when the very minimum cement factor for adequate hardening is required, modified ASTM-AASHO test procedures may be used. Use of the modified tests affords a considerable saving of time and manpower.

The modified procedures include:

1. Cement contents are expressed on a weight basis rather than by volume.
2. The moisture-density test has been modified to include plus No. 4 material. Material larger than ¾ inch however is replaced by an equal amount of No. 4-to-¾-inch material.
3. When moisture-density tests are made on materials that tend to crush or break down under blows of the compaction rammer, a separate batch of soil-cement is used for each trial.
4. Only four specimens instead of twelve are required for the wet-dry and freeze-thaw tests, since volume and moisture change specimens are not molded and only one wet-dry specimen is made.
5. The time schedule of freezing and thawing has been changed slightly to make it more accurately reflect the time actually required to handle specimens.

In addition to the modified ASTM-AASHO tests a special short-cut procedure has been evolved for determining the cement requirements of sandy soils. This procedure does not necessarily give the minimum factor that can be used.

For emergency construction and small projects where testing facilities are not available or detailed testing is not feasible, a rapid method of testing involving molding and visual inspection of specimens can be used. This method provides cement factors that are adequare but sometimes appreciably above the minimum that could be used if more detailed tests were made.

The identification of soils by the U.S. Department of Agriculture soil classification system is most helpful for reducing testing work. Soils for the same series and horizon require the same cement factor. Since many soil series cover large areas, the need for conducting soil-cement tests can be sharply reduced once the cement requirement of each horizon of a definite soil series has been determined. Up-to-date information on soil surveys and availability of soil maps is provided by the Highway Research Board's Committee on Soil Surveying and Mapping.

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[11] The soil tests, such as grain size analysis and physical test constants, which are commonly used to identify and classify soils are described in "PCA Soil Primer" published by the Portland Cement Association, available free in the United States and Canada.