Soil-Cement INFORMATION

Soil-Cement for Water Control: Laboratory Tests

ONE of the key factors that accounts for the successful use of soil-cement in the paving and water resources fields is careful predetermination of engineering control factors in the laboratory and their application during construction.

The composition of soils varies considerably, and these variations affect the manner in which the soils 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. These tests determine the three fundamental requirements for soil-cement:

1. The minimum cement content needed to harden the soil adequately.
2. The proper moisture content.
3. The density to which the soil-cement must be compacted.

Detailed test methods for determining these control factors were approved by the American Society for Testing and Materials in 1944 and by the American Association of State Highway and Transportation Officials in 1945. After 13 years of successful use, the test methods were revised by ASTM* and AASHTO in 1957 to incorporate the information and experience gained during that period. These test methods are:

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

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

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

The dependability of the standard tests has been proved by the outstanding service records of soil-cement pavements and slope protection. As noted on page 18, cement content to be used in soil-cement for water control is somewhat higher than for paving.

Invaluable as the standard tests are, they require considerable time to obtain the factors needed for construction. To reduce this time the Portland Cement Association has developed a special short-cut test method for determining cement factors for sandy soils.

*Available for a nominal charge from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

GENERAL DISCUSSION OF ASTM AND SHORT-CUT TESTS

ASTM 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.

While soil, cement, and water are being mixed, a distinct change is taking place in the mixture. Apparently a base exchange phenomenon is occurring. The soil becomes coagulated, which causes an increase in internal friction. 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 takes place during damp-mixing. These effects

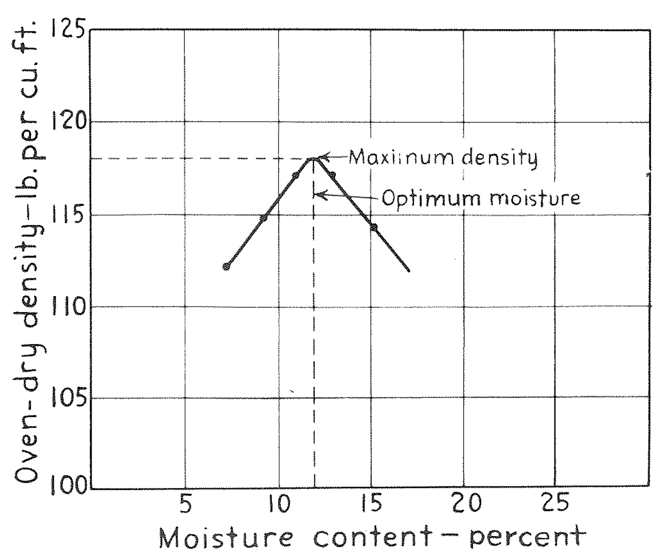


Fig. 1. Typical moisture-density curve.

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 on the soil-cement mixture are made in the laboratory 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 damp-mixing, with soil-cement taken directly from the area being constructed. Details of the moisture-density test are given starting on page 4.

ASTM Freeze-Thaw and Wet-Dry Tests

The freeze-thaw and wet-dry tests were designed to reproduce in the laboratory the moisture and temperature changes in soils. They measure the effect of internal volume changes produced by changes in moisture and temperature. Thus the tests determine whether the soil-cement will stay hard, or whether it will expand and contract excessively and soften with moisture variations and alternate freezing and thawing—conditions that produce disastrous results in untreated soil.

The freeze-thaw and wet-dry tests determine the minimum cement content required to produce a structural material that will resist volume changes produced by changes in moisture and temperature. Since moisture and temperature changes occur in varying degrees in all climatic and geographic areas, use of both the freeze-thaw and wet-dry tests assures that an adequately hardened, durable material is produced for any climatic area.

The procedures used in the freeze-thaw and wet-dry tests are given starting on page 9.

Short-Cut Test Method for Sandy Soils

Short-cut test procedures have been developed 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 used 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 can be completed in about one week.

While these procedures do not always give the minimum cement factor that can be used, they almost always provide a safe cement factor generally close to that indicated by standard ASTM-AASHTO wet-dry and freeze-thaw tests. The procedure can be made even more accurate by modifying the charts, using data from local soils.

The short-cut test method is described in detail starting on page 22.

Soil-Cement Test Data Correlation in Determining Cement Factors for Sandy Soils, Highway Research Board Bulletin 69, 1952. Also, *Expanded Short-Cut Test Methods for Determining Cement Factors for Sandy Soils*, Highway Research Board Bulletin 198, 1958.

SELECTION OF CEMENT CONTENTS FOR TESTS

The following information will aid the laboratory engineer in determining the cement factors to investigate in the standard laboratory tests.

Table 1 gives the cement requirements to use in the moisture-density test with subsurface soils of the various Unified and AASHTO soil groups. Topsoils may contain organic or other material detrimental to cement reaction and often require higher cement factors. For most topsoils the cement content in Table 1 should be increased 4 percentage points if the soil is dark grey to grey, and 6 percentage points if the soil is black. It is usually not necessary to increase the cement factor for a brown or red topsoil.

After the moisture-density test has been completed and the maximum density determined, the cement contents to investigate in the freeze-thaw and wet-dry tests

Table 1. Cement Contents for Use in Moisture-Density Test *(not for use in design)*

AASHTO soil group*	ASTM (Unified) soil group**	Cement content, percent by weight
A-1-a	GW, GP, SW, SP	5
A-1-b	SW, SP, GM, SM, GP	6
A-2	GM, SM, GC, SC	7
A-3	SP	9
A-4	ML, OL, CL, SM, SC	10
A-5	OH, MH, ML, OL	10

*Charts and tables for use in classifying soils by the American Association of State Highway and Transportation Officials Soil Classification System (AASHTO M145) are given in Portland Cement Association's *Soil Primer*, EB007S. Data for A-6 and A-7 soils are not included in this table since these soils have not been used for soil-cement slope protection. They usually require higher cement factors than granular soils, cannot be adequately mixed in a central plant, and are more dependent on weather conditions during construction.

**Possible Unified soil group comparable to the AASHTO soil group. Charts and tables to classify soils by the Unified system are also given in the *Soil Primer*.

are selected. Table 2, which considers the maximum density of the soil-cement mixture and other properties of the soil, can be used to determine the median cement content. Since three cement contents usually are investigated, test specimens are molded at the cement content determined from Table 2 and at cement contents 2 percentage points above and below that cement factor.* In case of topsoils, the cement factors should be increased as discussed in the preceding paragraph.

To further aid in selecting cement contents for the freeze-thaw and wet-dry tests and to determine how well the soil is reacting with cement, it is helpful to save half of the last moisture-density test specimen and place it in an atmosphere of high humidity for inspection daily. This half specimen, called the "tail-end" specimen (see Fig. 2), is obtained during the usual procedure of cutting the last specimen of the moisture-density test in half vertically (details are given on page 5) so that a representative moisture sample can be taken. The tail-end specimen is inspected daily by "picking" with a sharp-pointed instrument such as a dull ice pick and by sharply "clicking" the specimen against a hard object such as concrete.

In the pick test the specimen is held in one hand and the ice pick is lightly jabbed into the specimen from a distance of 2 or 3 in. If the specimen resists this light picking, the force of impact is increased until the pick is striking the specimen with considerable force. Specimens that are hardening satisfactorily will definitely resist the penetration of the pick, whereas specimens that are not hardening properly will have little resistance.

In the click test the tail-end specimen and hard object are held about 4 in. apart, one in each hand. They then are clicked together a number of times. If the tail-end specimen is hardening satisfactorily, a ringing or solid tone will be produced. A dull or "punky" sound indicates the tail-end specimen is not hardening satisfactorily.

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. If the specimen has not hardened in about four days, the median cement content to investigate in the freeze-

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

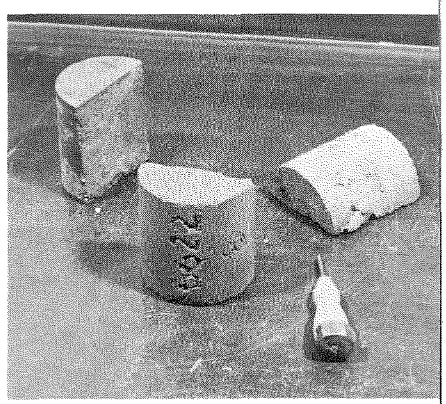
Table 3. Cement Contents for Use in Testing Miscellaneous Materials

Type of miscellaneous material	Cement content, percent by weight	
	Moisture-density test	Freeze-thaw and wet-dry tests
Shell soils	7	5-7-9
Limestone screenings	5	3-4-5-7
Red dog	8	6-8-10
Shale or disintegrated shale	10	8-10-12
Caliche	7	5-7-9
Cinders	8	6-8-10
Chert	8	6-8-10
Chat	7	5-7-9
Marl	11	9-11-13
Scoria containing material retained on the No. 4 sieve	11	9-11-13
Scoria not containing material retained on the No. 4 sieve	7	5-7-9
Air-cooled slag	7	5-7-9
Water-cooled slag	12	10-12-14

Table 2. Median Cement Content for Freeze-Thaw and Wet-Dry Tests

Material retained on No. 4 sieve, percent	Material smaller than 0.05 mm., percent	Maximum density, lb. per cu.ft.					
		105-109	110-114	115-119	120-124	125-129	130 or more
		Cement content, percent by weight					
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

Fig. 2. Soil-cement specimens saved from tail-end of moisture-density test are inspected daily to determine the rate of hardening of the soil-cement mixture.



thaw and wet-dry tests (determined from Table 2) should be increased.

A number of miscellaneous materials such as caliche, chert, cinders, scoria, shale, etc., have been used successfully in soil-cement pavement construction. If these materials are being considered for soil-cement slope protection, Table 3 can be used to determine the cement contents to use in the laboratory tests.

The cement contents given in Tables 1, 2, and 3 can be converted to the indicated cement requirement for construction of slope protection by increasing them by 2 percentage points. Thus, work on the plans and specifications can proceed while laboratory tests are under way, with the understanding that the recommended cement content based on final test data may differ slightly from the indicated value.

DETAILS OF STANDARD TESTS

Proportioning Cement

In soil-cement testing, cement quantities are proportioned on a weight basis in terms of percent of total oven-dry soil. At the completion of tests, the recommended cement content by weight may be converted to the equivalent cement content by volume for field construction. Proportioning on a volume basis for field construction is in terms of percent 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 layer being constructed is 6 in. thick, 1 sq.yd. contains $3 \times 3 \times \frac{1}{2} \times 0.10 \times 94$, or 42.3 lb. of cement.

Preparing Soil for Testing

About 75 lb. of soil is sufficient to run a complete series of 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 a drying apparatus that limits the temperature of the sample to 140 deg.F. (60 deg.C.). 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 to 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.

*Canadian bags of cement weight 80 lb.

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 later incorporated, in a saturated and surface-dry condition, with 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 2 in. in the original total sample.

Moisture-Density Test (ASTM D558 or AASHTO T134)

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.

Method for Soils with Material Retained on No. 4 Sieve

To facilitate discussions of the moisture-density test and molding test specimens, illustrations of calculations are included. Assume that a brown, C horizon, A-1-a(0) or SP soil is to be tested. As shown on the summary data sheet, Fig. 19, page 20, the soil contains 30 percent material retained on the No. 4 sieve that has an absorption** of 2.0 percent. From Table 1, 5 percent by weight will be used in the moisture-density test.

Detailed calculations can be made to determine the quantity of soil needed for a 4- or 5-point moisture-density test. However, to simplify calculations 11.0 lb. of oven-dry soil is generally used for soil-cement mixtures that contain material retained on the No. 4 sieve, and this amount will be used in this illustration.

Since the soil in this illustration contains 30 percent material retained on the No. 4 sieve, 11.0×0.30, or 3.30 lb., of oven-dry coarse material is required. It is added in a saturated, surface-dry condition;† therefore, 3.30×1.02, or 3.37 lb., of saturated, surface-dry coarse material is weighed out. (The material retained on the No. 4 sieve in this example has an absorption of 2 percent.) Since the specimen is only 4 in. in diameter, it is necessary to set a maximum size of material that may be used. A maximum size of ¾ in. has been selected, since material up to this size can be handled readily in the laboratory. Should material larger than ¾ in. occur in the field sample, it is replaced in the specimen with

**As determined in accordance with ASTM C127, using the following formula: absorption, percent, equals

$$\frac{\text{saturated surface-dry weight} - \text{oven-dry weight}}{\text{oven-dry weight}} \times 100.$$

†The material retained on the No. 4 sieve is prepared by soaking it in water overnight and then surface-drying it immediately before it is added to the rest of the material.

an equivalent dry weight of the No. 4 to ¾-in. material.

In those isolated cases where material that is retained on the No. 4 sieve and passes the 2-in. sieve is also retained on the ¾-in. sieve, the material shall be crushed, and that portion then passing the ¾-in. sieve and retained on the No. 4 sieve is used in the proper dry-weight proportions.

The required amount of oven-dry soil passing the No. 4 sieve is 11.0 — 3.30, or 7.70 lb. The hygroscopic* moisture content of this material has been determined by test to be 1 percent. Thus, 7.70 × 1.010, or 7.78 lb., of air-dry material is weighed out.

The quantity of cement required is 11.0 × 0.05, or 0.55 lb., which is 0.55 × 454, or 250 g.

To reduce laboratory calculations, quantities of saturated, surface-dry material retained on the No. 4 sieve, of air-dry soil passing the No. 4 sieve, and of cement needed to run a moisture-density test with soils that contain material retained on the No. 4 sieve may be obtained from Tables 4, 5, and 6.

When performing the test, the air-dry soil passing the No. 4 sieve (7.78 lb. in this example) is first weighed out. The required cement (250 g.) is added to the pulverized soil and the two are thoroughly mixed to uniform color. A quantity of water sufficient to dampen the mixture to a degree approximately 4 to 6 percentage points below the estimated optimum moisture content is then thoroughly incorporated.

The saturated, surface-dry material retained on the No. 4 sieve (3.37 lb. in this example) is added next and intimately mixed in.

The soil-cement mixture is then immediately compacted in the mold in three layers of approximately equal thickness, to give a total compacted depth of about 5 in.** Each layer is compacted by 25 uniformly spaced blows of a 5.5-lb. rammer with a 2-in.-diameter striking face dropping free from a height of 12 in. above the final elevation of each compacted layer. During compaction, the mold rests on a uniform, rigid foundation that weighs approximately 200 lb.

After compaction, the collar on the mold is removed and excess compacted soil-cement is carefully trimmed level with the top of the mold with a knife and straightedge. During this trimming operation all particles that extend above the top of the mold are removed. This may cause some irregularities in the surface of the specimen, which can be corrected by hand-tamping fine material into these irregularities and leveling the specimen again with a straightedge.

The compacted specimen and mold are then weighed and the tare of the mold is subtracted to give the wet weight of the specimen. The specimen is removed from the mold and sliced vertically through the center. A representative 750-g. sample of the material is taken from the full height of one of the cut faces, weighed immediately, and placed in an oven to dry at 230 deg.F. (110 deg.C.) for at least 12 hours or to constant weight to permit determination of the moisture content.

The remaining soil-cement mixture is then broken up to pass a ¾-in. sieve. All lumps made up of particles larger than the No. 4 sieve are broken up again to pass a No. 4 sieve. Sufficient water to increase the moisture content of the mixture by approximately 2 percentage points is added and thoroughly mixed with the soil-cement.† The moistened soil-cement mixture is again compacted in the mold as previously described, and the procedure is repeated for each increment of water until the wet weight of the compacted soil-cement mixture decreases or until the specimen becomes spongy.

*The hygroscopic moisture content may be defined as the moisture content of the material as used in testing. This is determined by completely oven-drying a small representative portion of the total soil sample after the total soil sample has been partially dried to a friable state.

**Dimensions and tolerances for the 1/30-cu.ft. mold and sleeve rammer are given in ASTM D558, Moisture-Density Relations of Soil-Cement Mixtures. A mechanically operated rammer is also permitted if it is calibrated using ASTM D2168, Method for Calibration of Mechanical Laboratory Soil Compactors.

†When a moisture-density test is being performed on fragile materials that tend to crush or break down under the weight of the rammer, a separate batch of soil-cement is used for each trial.

Fig. 3. The quantity of soil-cement to be placed in the mold for each of the three equal compacted layers can be easily judged with a scoop.

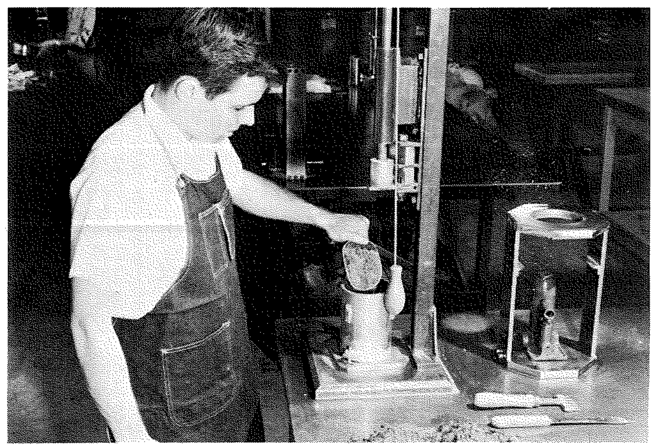


Fig. 4. Taking moisture sample from center plane of specimen during moisture-density test.

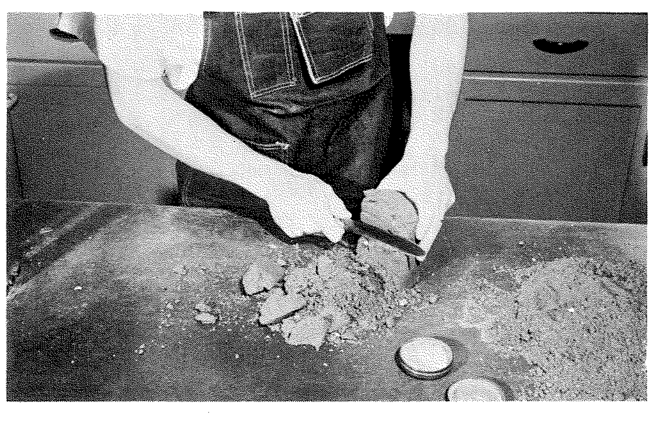


Table 4. Quantities of Material Retained on the No. 4 Sieve for 11.0-Lb. Batch of Total Soil for Use in Moisture-Density Test

Material retained on No. 4 sieve, percent	Oven-dry material retained on No. 4 sieve, lb.	Absorption of material retained on No. 4 sieve, percent									
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
		Saturated, surface-dry material retained on No. 4 sieve, lb.									
5	0.55	0.55	0.56	0.56	0.56	0.56	0.57	0.57	0.57	0.57	0.58
6	0.66	0.66	0.67	0.67	0.67	0.68	0.68	0.68	0.69	0.69	0.69
7	0.77	0.77	0.78	0.78	0.79	0.79	0.79	0.80	0.80	0.80	0.81
8	0.88	0.88	0.89	0.89	0.90	0.90	0.91	0.91	0.92	0.92	0.92
9	0.99	0.99	1.00	1.00	1.01	1.01	1.02	1.02	1.03	1.03	1.04
10	1.10	1.11	1.11	1.12	1.12	1.13	1.13	1.14	1.14	1.15	1.16
11	1.21	1.22	1.22	1.23	1.23	1.24	1.25	1.25	1.26	1.26	1.27
12	1.32	1.33	1.33	1.34	1.35	1.35	1.36	1.37	1.37	1.38	1.39
13	1.43	1.44	1.44	1.45	1.46	1.47	1.47	1.48	1.49	1.49	1.50
14	1.54	1.55	1.56	1.56	1.57	1.58	1.59	1.59	1.60	1.61	1.62
15	1.65	1.66	1.67	1.67	1.68	1.69	1.70	1.71	1.72	1.72	1.73
16	1.76	1.77	1.78	1.79	1.80	1.80	1.81	1.82	1.83	1.84	1.85
17	1.87	1.88	1.89	1.90	1.91	1.92	1.93	1.94	1.94	1.95	1.96
18	1.98	1.99	2.00	2.01	2.02	2.03	2.04	2.05	2.06	2.07	2.08
19	2.09	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17	2.18	2.19
20	2.20	2.21	2.22	2.23	2.24	2.26	2.27	2.28	2.29	2.30	2.31
21	2.31	2.32	2.33	2.34	2.36	2.37	2.38	2.39	2.40	2.41	2.43
22	2.42	2.43	2.44	2.46	2.47	2.48	2.49	2.50	2.52	2.53	2.54
23	2.53	2.54	2.56	2.57	2.58	2.59	2.61	2.62	2.63	2.64	2.66
24	2.64	2.65	2.67	2.68	2.69	2.71	2.72	2.73	2.75	2.76	2.77
25	2.75	2.76	2.78	2.79	2.81	2.82	2.83	2.85	2.86	2.87	2.89
26	2.86	2.87	2.89	2.90	2.92	2.93	2.95	2.96	2.97	2.99	3.00
27	2.97	2.98	3.00	3.01	3.03	3.04	3.06	3.07	3.09	3.10	3.12
28	3.08	3.10	3.11	3.13	3.14	3.16	3.17	3.19	3.20	3.22	3.23
29	3.19	3.21	3.22	3.24	3.25	3.27	3.29	3.30	3.32	3.33	3.35
30	3.30	3.32	3.33	3.35	3.37	3.38	3.40	3.42	3.43	3.45	3.47
31	3.41	3.43	3.44	3.46	3.48	3.50	3.51	3.53	3.55	3.56	3.58
32	3.52	3.54	3.56	3.57	3.59	3.61	3.63	3.64	3.66	3.68	3.70
33	3.63	3.65	3.67	3.68	3.70	3.72	3.74	3.76	3.78	3.79	3.81
34	3.74	3.76	3.78	3.80	3.81	3.83	3.85	3.87	3.89	3.91	3.93
35	3.85	3.87	3.89	3.91	3.93	3.95	3.97	3.98	4.00	4.02	4.04
36	3.96	3.98	4.00	4.02	4.04	4.06	4.08	4.10	4.12	4.14	4.16
37	4.07	4.09	4.11	4.13	4.15	4.17	4.19	4.21	4.23	4.25	4.27
38	4.18	4.20	4.22	4.24	4.26	4.28	4.31	4.33	4.35	4.37	4.39
39	4.29	4.31	4.33	4.35	4.38	4.40	4.42	4.44	4.46	4.48	4.50
40	4.40	4.42	4.44	4.47	4.49	4.51	4.53	4.55	4.58	4.60	4.62
41	4.51	4.53	4.56	4.58	4.60	4.62	4.65	4.67	4.69	4.71	4.74
42	4.62	4.64	4.67	4.69	4.71	4.74	4.76	4.78	4.80	4.83	4.85
43	4.73	4.75	4.78	4.80	4.82	4.85	4.87	4.90	4.92	4.94	4.97
44	4.84	4.86	4.89	4.91	4.94	4.96	4.99	5.01	5.03	5.06	5.08
45	4.95	4.97	5.00	5.02	5.05	5.07	5.10	5.12	5.15	5.17	5.20

Table 5. Quantities of Air-Dry Soil Passing No. 4 Sieve for 11.0-Lb. Batch of Total Oven-Dry Soil for Use in Moisture-Density Test

Material retained on No. 4 sieve, percent	Oven-dry material passing No. 4 sieve, lb.	Hygroscopic moisture content of material passing No. 4 sieve, percent									
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
		Air-dry material passing No. 4 sieve, lb.									
5	10.45	10.50	10.55	10.61	10.66	10.71	10.76	10.82	10.87	10.92	10.97
6	10.34	10.39	10.44	10.50	10.55	10.60	10.65	10.70	10.75	10.81	10.86
7	10.23	10.28	10.33	10.38	10.43	10.49	10.54	10.59	10.64	10.69	10.74
8	10.12	10.17	10.22	10.27	10.32	10.37	10.42	10.47	10.52	10.58	10.63
9	10.01	10.06	10.11	10.16	10.21	10.26	10.31	10.36	10.41	10.46	10.51
10	9.90	9.95	10.00	10.05	10.10	10.15	10.20	10.25	10.30	10.35	10.40
11	9.79	9.84	9.89	9.94	9.99	10.03	10.08	10.13	10.18	10.23	10.28
12	9.68	9.73	9.78	9.83	9.87	9.92	9.97	10.02	10.07	10.12	10.16
13	9.57	9.62	9.67	9.71	9.76	9.81	9.86	9.90	9.95	10.00	10.05
14	9.46	9.51	9.55	9.60	9.65	9.70	9.74	9.79	9.84	9.89	9.93
15	9.35	9.40	9.44	9.49	9.54	9.58	9.63	9.68	9.72	9.77	9.82
16	9.24	9.29	9.33	9.38	9.42	9.47	9.52	9.56	9.61	9.66	9.70
17	9.13	9.18	9.22	9.27	9.31	9.36	9.40	9.45	9.50	9.54	9.59
18	9.02	9.07	9.11	9.16	9.20	9.25	9.29	9.34	9.38	9.43	9.47
19	8.91	8.95	9.00	9.04	9.09	9.13	9.18	9.22	9.27	9.31	9.36
20	8.80	8.84	8.89	8.93	8.98	9.02	9.06	9.11	9.15	9.20	9.24
21	8.69	8.73	8.78	8.82	8.86	8.91	8.95	8.99	9.04	9.08	9.12
22	8.58	8.62	8.67	8.71	8.75	8.79	8.84	8.88	8.92	8.97	9.01
23	8.47	8.51	8.55	8.60	8.64	8.68	8.72	8.77	8.81	8.85	8.89
24	8.36	8.40	8.44	8.49	8.53	8.57	8.61	8.65	8.69	8.74	8.78
25	8.25	8.29	8.33	8.37	8.42	8.46	8.50	8.54	8.58	8.62	8.66
26	8.14	8.18	8.22	8.26	8.30	8.34	8.38	8.42	8.47	8.51	8.55
27	8.03	8.07	8.11	8.15	8.19	8.23	8.27	8.31	8.35	8.39	8.43
28	7.92	7.96	8.00	8.04	8.08	8.12	8.16	8.20	8.24	8.28	8.32
29	7.81	7.85	7.89	7.93	7.97	8.01	8.04	8.08	8.12	8.16	8.20
30	7.70	7.74	7.78	7.82	7.85	7.89	7.93	7.97	8.01	8.05	8.09
31	7.59	7.63	7.67	7.70	7.74	7.78	7.82	7.86	7.89	7.93	7.97
32	7.48	7.52	7.55	7.59	7.63	7.67	7.70	7.74	7.78	7.82	7.85
33	7.37	7.41	7.44	7.48	7.52	7.55	7.59	7.63	7.66	7.70	7.74
34	7.26	7.30	7.33	7.37	7.41	7.44	7.48	7.51	7.55	7.59	7.62
35	7.15	7.19	7.22	7.26	7.29	7.33	7.36	7.40	7.44	7.47	7.51
36	7.04	7.08	7.11	7.15	7.18	7.22	7.25	7.29	7.32	7.36	7.39
37	6.93	6.96	7.00	7.03	7.07	7.10	7.14	7.17	7.21	7.24	7.28
38	6.82	6.85	6.89	6.92	6.96	6.99	7.02	7.06	7.09	7.13	7.16
39	6.71	6.74	6.78	6.81	6.84	6.88	6.91	6.94	6.98	7.01	7.05
40	6.60	6.63	6.67	6.70	6.73	6.77	6.80	6.83	6.86	6.90	6.93
41	6.49	6.52	6.55	6.59	6.62	6.65	6.68	6.72	6.75	6.78	6.81
42	6.38	6.41	6.44	6.48	6.51	6.54	6.57	6.60	6.64	6.67	6.70
43	6.27	6.30	6.33	6.36	6.40	6.43	6.46	6.49	6.52	6.55	6.58
44	6.16	6.19	6.22	6.25	6.28	6.31	6.34	6.38	6.41	6.44	6.47
45	6.05	6.08	6.11	6.14	6.17	6.20	6.23	6.26	6.29	6.32	6.35

Table 6. Quantities of Cement for Running Moisture-Density Test

Cement content, percent by weight	6.0-lb. batch of soil passing No. 4 sieve		11.0-lb. batch of total soil	
	Cement, lb.	Cement, g.	Cement, lb.	Cement, g.
3	0.18	82	0.33	150
4	0.24	109	0.44	200
5	0.30	136	0.55	250
6	0.36	163	0.66	300
7	0.42	191	0.77	350
8	0.48	218	0.88	400
9	0.54	245	0.99	449
10	0.60	272	1.10	499
11	0.66	300	1.21	549
12	0.72	327	1.32	599
13	0.78	354	1.43	649
14	0.84	381	1.54	699
15	0.90	409	1.65	749
16	0.96	436	1.76	799

With coarse, sandy soils that contain very few fines, the compacting action may force a portion of the water downward and out of the mold. This loss makes it difficult to obtain a decrease in density. Loss of water can be prevented by sealing the point of contact between the bottom of the mold and the base plate with petroleum jelly or some similar material. Due to the migration of water in these coarse soils, it is difficult to obtain a representative moisture sample after compaction. This may be overcome by taking the moisture sample from the soil-cement mix before compaction.

As discussed on page 3, considerable information can be obtained by saving half of the last specimen made on the wet side of optimum moisture. This tail-end specimen is stored in the moist room and inspected daily to determine the rate of hardening.

The moisture content and oven-dry weight of the soil-cement mixture as compacted in each trial are calculated as follows:

$$w = \frac{A - B}{B - C} \times 100, \text{ and}$$

$$W = \frac{W_1}{w + 100} \times 100,$$

where

w = moisture content of specimen, percent;
A = weight of moisture can and wet soil-cement;
B = weight of moisture can and dry soil-cement;
C = weight of moisture can;
W = dry weight of compacted soil-cement, pounds per cubic foot;
W_1 = wet weight of compacted soil-cement, pounds per cubic foot.

After calculating the moisture content and corresponding oven-dry weight (density) of the compacted soil-cement for each test made on the mixture, the densities are plotted as ordinates and the corresponding moisture contents as abscissas. By connecting the plotted points with a smooth line, a curve is produced as in Fig. 1. The moisture content at which maximum density is obtained is called the "optimum moisture content" of the soil-cement mixture. The oven-dry weight per cubic foot of the mixture at optimum moisture content is called the "maximum density." This maximum density and optimum moisture content are used for design of wet-dry and freeze-thaw test specimens.

Method for Soils with Material Not Retained on No. 4 Sieve

The moisture-density relations of soil-cement mixtures for soils that do not contain material retained on the No. 4 sieve are determined in essentially the same manner as that just described for soils containing this material. However, the handling of the coarse material and calculations relating thereto are not required.

Six pounds of oven-dry soil is adequate for running the test with mixtures that do not contain material retained on the No. 4 sieve. Quantities of cement and air-dry soil needed can be conveniently obtained from Tables 6 and 7.

In performing the test, the necessary quantity of air-dry soil is first weighed out. The cement is added to the pulverized soil and the two are thoroughly mixed to uniform color. A quantity of water sufficient to dampen the mixture to approximately 4 to 6 percentage points below the estimated optimum moisture is then incorporated. The soil-cement mixture is then immediately compacted in the mold as described on page 5, and the procedure repeated until there is a decrease in the wet weight of the compacted soil-cement mixture or until the specimen becomes spongy.

A 100-g. moisture sample will suffice.

Calculations of moisture content and corresponding oven-dry weight (density) of the compacted soil-cement for each test made on the mixture and plotting of the moisture-density curve are the same as those for soils containing material retained on the No. 4 sieve.

Table 7. Quantities of Air-Dry Soil Passing No. 4 Sieve for 6.0-Lb. Batch of Oven-Dry Soil for Use in Moisture-Density Test

Hygroscopic moisture content, percent	Air-dry soil, lb.
0.5	6.03
1.0	6.06
1.5	6.09
2.0	6.12
2.5	6.15
3.0	6.18
3.5	6.21
4.0	6.24
4.5	6.27
5.0	6.30

Freeze-Thaw and Wet-Dry Tests

Designing Test Specimens

After the maximum density and optimum moisture content of the soil-cement mixture have been determined, specimens at different cement contents are molded for the wet-dry and freeze-thaw tests. These tests will determine the minimum amount of cement required to harden the soil properly. The test specimens are molded at the optimum moisture content determined from the moisture-density test with the same compaction equipment. The density of the test specimens will therefore be comparable to the maximum density obtained in the moisture-density test and to the density that will be obtained during construction.

The cement contents to be investigated in the freeze-thaw and wet-dry tests will depend on the type of soil being tested. Tables 2 and 3 on page 3 can be used as a guide. Also, as discussed on page 3, the condition of the moisture-density tail-end specimen can be used to aid in selecting cement contents for testing. Three cement contents, in an ascending order of 2 percentage points difference,* are usually selected.

Two specimens may be molded at each cement content, one for testing in the freeze-thaw test and one for the wet-dry test. However, experience has shown that the freeze-thaw test is generally the critical test except for soil-cement mixtures that contain relatively large amounts of clay. Therefore, time and work can be saved by molding only one wet-dry test specimen—generally at the median cement content.

Calculations for Soils with Material Retained on No. 4 Sieve

Assume that the moisture-density relations obtained for the A-1-a(0) or SP soil at 5 percent cement by weight are 129.5 lb. per cubic foot maximum density at 9.2 percent optimum moisture. The soil contains 30 percent material retained on the No. 4 sieve, and this material has an absorption of 2 percent. The hygroscopic moisture content of the soil passing the No. 4 sieve is 1 percent.

From Table 2, the median cement content for freeze-thaw and wet-dry test specimens is 5 percent. Specimens will be molded at 3, 4, 5, and 7 percent cement by weight.

The amount of soil required for one specimen is first calculated. In making these computations, the quantity of soil that is required for molding a specimen having the median cement content is first computed; this quantity of soil is then used for molding all specimens. Of course the cement quantities and water quantities vary for specimens that contain different percentages of cement. In this example the median cement content is 5 percent, and the following calculations will be those required to mold a test specimen at that cement content.

*If the median cement is 5 percent or less, it is good practice to use 1 percentage point increments in the low cement content range.

The maximum density of the soil-cement mixture being illustrated is 129.5 lb. per cubic foot, and a cubic foot contains $\frac{129.5}{1.05}$, or 123.33 lb. of soil. The amount of oven-dry soil needed for one specimen (1/30 cu.ft.) is $\frac{123.33}{30}$, or 4.11 lb. This amount is increased by 1/10 (0.41 lb.) to provide soil for manipulation and by 1.65 lb. (750 g.) for a moisture sample. (Increasing soil quantities by 1/10 gives sufficient soil to provide a specimen 5 in. in height before the collar of the mold is removed. The excess soil-cement is then trimmed from the top to give a specimen the exact height of the mold.) Thus the total soil required per specimen is equal to 4.11 + 0.41 + 1.65, or 6.17 lb.

Since the soil in this illustration contains 30 percent material retained on the No. 4 sieve, 6.17 × 0.30, or 1.85 lb., of this oven-dry material is required for one specimen. It is added in a saturated, surface-dry condition; therefore, 1.85 × 1.020, or 1.89 lb., of saturated, surface-dry material is weighed out. (The material retained on the No. 4 sieve has an absorption factor of 2 percent.)

The amount of oven-dry soil passing the No. 4 sieve required for one specimen is 6.17 − 1.85, or 4.32 lb. The hygroscopic moisture content of this soil is 1 percent. Thus 4.32 × 1.010, or 4.36 lb., of air-dry soil is weighed out.

These quantities of material retained on and passing the No. 4 sieve will be used for molding each specimen.

The quantity of cement required for molding a specimen that contains 5 percent cement by weight is 6.17 × 0.05, or 0.309 lb., which is 0.309 × 454, or 140 g.

The water required to bring the soil-cement mixture to its optimum moisture content equals the weight of total oven-dry soil plus the weight of cement multiplied by the optimum moisture content: (6.17 + 0.309) × 0.092 × 454 = 271 g., or 271 cc (1 g. of water is equal to 1 cc); minus the amount of water already in the voids of the saturated, surface-dry material retained on the No. 4 sieve: 1.85 × 0.02 × 454, or 17 cc; minus the hygroscopic moisture in the soil passing the No. 4 sieve: 4.32 × 0.01 × 454, or 20 cc; plus an extra amount for evaporation loss during mixing, which is assumed in this case as 1 percent of the weight of soil passing the No. 4 sieve plus cement: (4.32 + 0.309) × 0.01 × 454, or 21 cc. The total quantity of water to add for accurate control equals 271 − 17 − 20 + 21, or 255 cc net water.

The above calculations are tabulated on Form Sheet No. 6, Fig. 5.

Calculations for Soils with Material Not Retained on No. 4 Sieve

The calculations of batch quantities for soils that do not contain material retained on the No. 4 sieve are essentially the same as those just described for soils containing this material. However, calculations relating to the coarse material are not required.

Soil-Cement Laboratory, Form Sheet No. 6

DESIGN AND MOLDING WET-DRY AND FREEZE-THAW TEST SPECIMENS

DATA ON SOIL NO. 1

Maximum Density 129.5 lb. per cu. ft.

Optimum Moisture 9.2 %

Material Retained on No. 4 Sieve
30 % Absorption 2.0 %

Material Passing No. 4 Sieve
Hygroscopic Moisture 1.0 %

QUANTITIES FOR MOLDING SPECIMENS

Total Oven-dry Soil 6.17 lb.

$\frac{129.5}{1.05} \div 30 = 4.11$
+0.41
+1.65
6.17

Material Retained on No. 4 Sieve
Oven-dry 1.85 lb.
Saturated, Surface Dry 1.89 lb. *

Material Passing No. 4 Sieve
Oven-dry 4.32 lb.
Air-dry 4.36 lb. *

Cement Content by wt. %	Cement Content Batch lb.	Cement Content Batch grams *	Total Oven-dry soil + cement, lb.	Mat'l. pass. No. 4 + cement, lb.	Water for batch: Theo. cc.	Abs. mat'l. ret. on No.4, cc.	Hygro. moist., mat'l. pass. No. 4, cc.	Evaporation %	Evaporation cc.	Net cc. *
3.0	.185	84	6.36	4.51	266	17	20	1	20.	249
4.0	.247	112	6.42	4.57	268	17	20	1	21	252
5.0	.309	140	6.48	4.63	271	17	20	1	21	255
7.0	.432	196	6.60	4.75	276	17	20	1	22	261

*To be weighed out for molding specimens

DATA FROM MOLDED SPECIMENS

Tare 8.50 Operator ________ Date ________

Cement content % by wt.	Wet wt. spec. plus mold, lb.	Wet wt. spec. lb.	Can No.	Wet soil + can gr.	Dry soil + can gr.	Wt. can gr.	Moisture loss gr.	Dry wt. soil gr.	Moisture %	Density lb. per cu. ft.
F-3.0	13.17	4.67							9.0	128.5
F-4.0	13.18	4.68							9.0	128.8
W-5.0	13.19	4.69							9.1	129.0
F-5.0	13.18	4.68							9.0	128.8
F-7.0	13.19	4.69							8.9	129.2

Fig. 5. Calculations for wet-dry and freeze-thaw test specimens for soils containing material retained on the No. 4 sieve. Soil No. 1.

DESIGN AND MOLDING WET-DRY AND FREEZE-THAW TEST SPECIMENS

DATA ON SOIL NO. 2

Maximum Density 121.0 lb. per cu. ft.

Optimum Moisture 10.5 %

Material Retained on No. 4 Sieve
— % Absorption — %

Material Passing No. 4 Sieve
Hygroscopic Moisture 1.3 %

QUANTITIES FOR MOLDING SPECIMENS

Total Oven-dry Soil 4.37 lb. 121.0/1.05 ÷ 30 = 3.77 + 0.38 + 0.22 = 4.37

Material Retained on No. 4 Sieve
Oven-dry — lb.
Saturated, Surface Dry — lb.*

Material Passing No. 4 Sieve
Oven-dry 4.37 lb.
Air-dry 4.43 lb.*

Cement Content			Total Oven-dry soil + cement, lb.	Mat'l. pass. No. 4 + cement, lb.	Water for batch					
by wt. %	Batch lb.	Batch grams *			Theo. cc.	Abs. mat'l. ret. on No.4, cc.	Hygro. moist., mat'l. pass. No. 4, cc.	Evaporation %	Evaporation cc.	Net cc. *
5.0	.219	99		4.59	219	—	26	1	21	214
7.0	.306	139		4.68	223	—	26	1	21	218
9.0	.393	178		4.76	227	—	26	1	22	223

*To be weighed out for molding specimens

DATA FROM MOLDED SPECIMENS

Tare 8.50 Operator ______ Date ______

Cement content % by wt.	Wet wt. spec. plus mold, lb.	Wet wt. spec. lb.	Moisture Determination: Can No.	Wet soil + can gr.	Dry soil + can gr.	Wt. can gr.	Moisture loss gr.	Dry wt. soil gr.	Moisture %	Density lb. per cu. ft.
F-5.0	12.93	4.43							10.8	119.9
W-7.0	12.95	4.45							10.7	120.6
F-7.0	12.94	4.44							10.8	120.2
F-9.0	12.95	4.45							10.6	120.7

Fig. 6. Calculations for wet-dry and freeze-thaw test specimens for soils not containing material retained on the No. 4 sieve. Soil No. 2.

To illustrate the calculations, assume that a soil-cement mixture has a maximum density of 121.0 lb. per cubic foot and an optimum moisture content of 10.5 percent. The hygroscopic moisture content of the soil is 1.3 percent. Test specimens will be molded at 5, 7, and 9 percent by weight. The following calculations are those required for a 7 percent test specimen, the median cement content.

The maximum density of the soil-cement mixture being illustrated is 121.0 lb. per cubic foot, and a cubic foot contains $\frac{121.0}{1.07}$, or 113.08 lb. of soil. The amount of oven-dry soil needed for one specimen (1/30 cu.ft.) is $\frac{113.08}{30}$, or 3.77 lb. This amount is increased by 1/10 (0.38 lb.) to provide soil for manipulation and by 0.22 lb. (100 g.) for a moisture sample. Thus the oven-dry soil required for one specimen is equal to 3.77 + 0.38 + 0.22, or 4.37 lb. The hygroscopic moisture content of the soil is 1.3 percent. Thus the air-dry soil required is 4.37 × 1.013, or 4.43 lb. This quantity of soil is used for molding specimens of all cement contents.

The quantity of cement required for molding a specimen containing 7 percent cement by weight is 4.37 × 0.07, or 0.306 lb., which is 0.306 × 454, or 139 g.

The water required to bring the soil-cement mixture to its optimum moisture content equals the oven-dry weight of soil plus the weight of cement multiplied by the optimum moisture content: (4.37 + 0.306) × 0.105 × 454, or 223 cc; minus the hygroscopic moisture in the soil: 4.37 × 0.013 × 454, or 26 cc; plus an extra amount for evaporation loss (1 percent assumed in this example): (4.37 + 0.306) × 0.010 × 454, or 21 cc. The total quantity of water to add for accurate control equals 223 − 26 + 21, or 218 cc net water.

The above calculations are tabulated on Form Sheet No. 6, Fig. 6.

Molding Test Specimens

Method for Soils with Material Retained on No. 4 Sieve

The designed quantities of air-dry soil passing the No. 4 sieve (4.36 lb. in this example) and cement (140 g. for a 5 percent specimen) are weighed out and mixed together. The designed quantity of water (255 cc) is added, and mixing is continued until the mixture is of uniform color.

The designed quantity of saturated, surface-dry material retained on the No. 4 sieve (1.89 lb.) is then added and uniformly mixed with the soil-cement-water mixture. (The material retained on the No. 4 sieve is prepared by being soaked in water overnight and then surface-dried immediately before being added.)

The soil-cement mixture is then compacted with the same compaction equipment used to make the moisture-density test and in the same manner, except that as the soil-cement mixture for each layer is placed in the mold, a knife blade is used to spade along the inside of the mold before compaction to obtain uniform distribution of the material retained on the No. 4 sieve. Also, the top surfaces of the first and second compacted layers are scarified to remove smooth compaction planes. Particular attention must be given to this scarifying operation to ensure adequate bond between layers. At the time the second layer of the specimen is being placed, a 750-g. representative sample for moisture determination is taken from the batch.

After the third layer has been compacted, the collar of the mold is removed and the surface of the specimen is leveled with a straightedge. All particles that extend above the top level of the mold are removed. This may cause some irregularities in the surface of the specimen, which should be corrected by hand-tamping fine material into these irregularities and leveling the specimen again with a straightedge.

The weight of the molded specimen is obtained and used in conjunction with the moisture determination to compute the dry weight (density) of the molded specimen. It is then carefully removed from the mold. Laboratory equipment for this purpose is shown in Fig. 9.

After the specimens are molded they are placed in an atmosphere of nearly 100 percent humidity to permit cement hydration for 7 days before wet-dry and freeze-thaw tests are started. If the soil is very sandy and the specimens are fragile at the time of molding, they may need to be placed on specimen carriers for safe handling.

Method for Soils with Material Not Retained on No. 4 Sieve

The procedure for molding freeze-thaw and wet-dry test specimens with soils that do not contain material retained on the No. 4 sieve is essentially the same as that just described for soils that contain this material, except that handling of the coarse material is not required, and it is not necessary to spade along the inside of the mold. It is very important, however, that the top surfaces of the first and second compacted layers be scarified to remove smooth compaction planes.

A 100-g. moisture sample is taken at the time the second layer is being placed. The weight of the molded specimen is obtained and the specimen is placed in an atmosphere of high humidity for 7 days, as previously described.

Checking Molded Specimens

As specimens are molded, data are entered on Form Sheet No. 6, as illustrated in Figs. 5 and 6. A portion of the sheet is provided for check calculations of the molded specimens.

As an illustration, assume that the 5 percent cement specimen previously designed for the soil containing material retained on the No. 4 sieve has been molded and the following data have been obtained:

Wet weight of specimen = 4.68 lb.
Moisture content of specimen = 9 percent

The cement content of the specimen is 5 percent by weight as designed and the moisture content is 9 percent as determined from the moisture sample. The dry

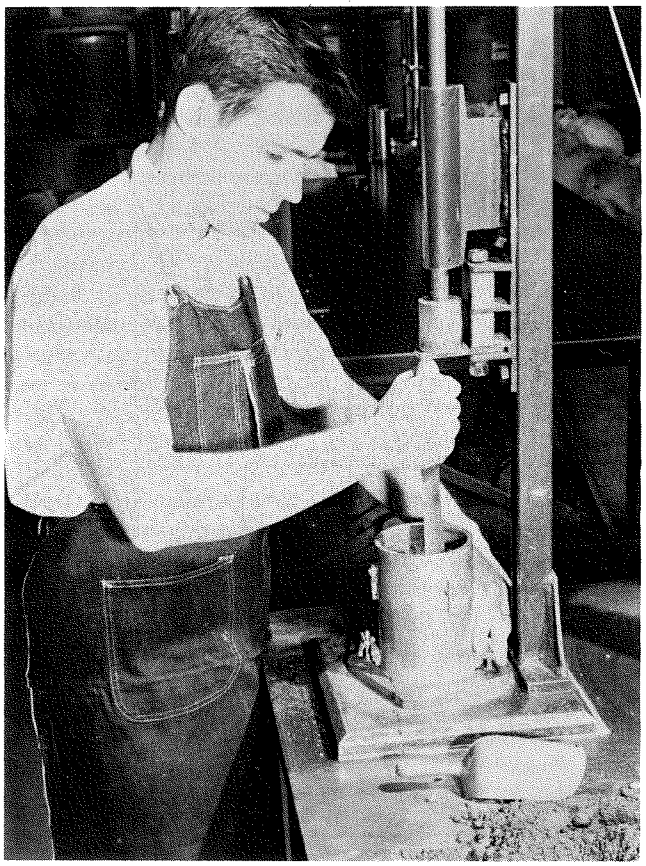


Fig. 7. Spading along inside of mold with knife blade to obtain uniform distribution of material retained on the No. 4 sieve.

density of the specimen is $\frac{4.68 \times 30}{1.090}$, or 128.8 lb. per cubic foot. The theoretical values were 129.5 lb. per cubic foot oven-dry density and 9.2 percent moisture.

TOLERANCES

The objective when molding soil-cement test specimens is to obtain specimens with the designed theoretical moisture content and density. However, for practical considerations some variation must be permitted.

For routine testing, the following tolerances are used to determine whether the test specimens are satisfactorily molded or whether they should be remolded:

Moisture content: plus or minus 1 percentage point.

Density: plus or minus 3 lb. per cubic foot.

Conducting Freeze-Thaw Test (ASTM D560 or AASHTO T136)

At the end of the 7-day storage period in an atmosphere of high humidity, water-saturated felt pads about ½ in. thick, blotters, or similar absorptive material are placed between the specimens and specimen carriers, and the assembly is placed in a refrigerator with a constant temperature not warmer than −10 deg.F. (−23 deg.C.) for 24 hours and then removed.

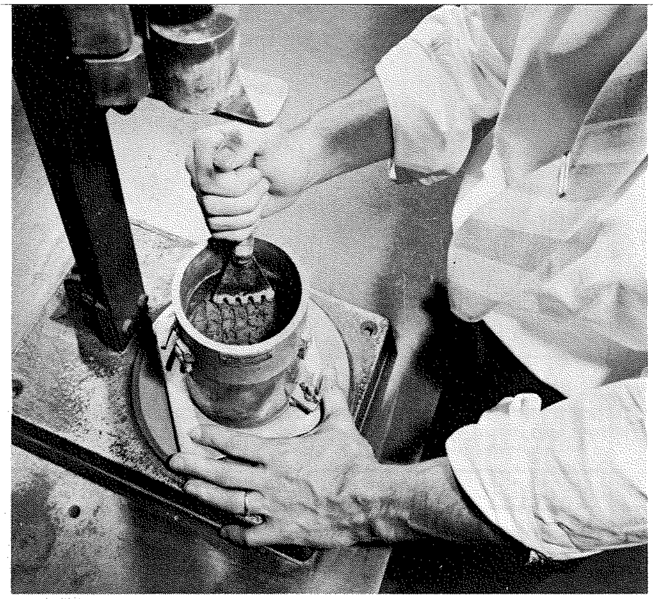


Fig. 8. Scarifying top of first and second compacted layers to remove smooth compaction planes.

Fig. 9. Apparatus for removing soil-cement specimens from the mold.

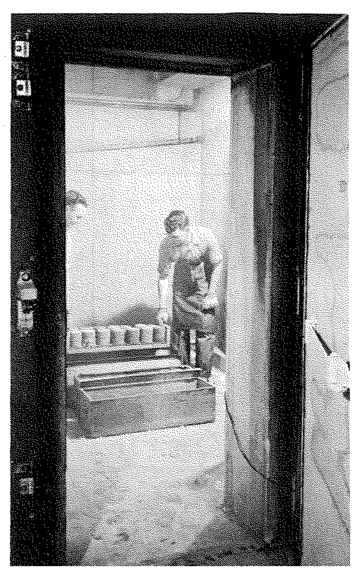


Fig. 10. First portion of freeze-thaw test cycle consists of 24 hours' freezing at a temperature not warmer than —10 deg.F.

Soil-Cement Laboratory, Form Sheet No. 8

FREEZING-THAWING TEST OF COMPACTED SOIL-CEMENT MIXTURES

Soil No. /   Date Molded________

Cement content, % by wt.	3.0	4.0	5.0	7.0
Initial moisture content, %	9.0	9.0	9.0	8.9
Initial calculated oven-dry wt.,lb.	4.28	4.29	4.29	4.31
Final oven-dry wt.,lb.*	0.00	3.08	3.59	4.12
Final corrected oven-dry wt.,lb.**	0.00	3.05	3.55	4.05
Soil-cement loss, %	100	29	17	6

*After 12 cycles of testing and after drying to constant wt. at 110° C.
**After correcting for water of hydration. (______%)

SCHEDULE FOR SPECIMENS DURING TEST

Date	Remove from moist room & brush	Cycles completed	Place in refrigerator, -10°F.	Date	Remove from refrig. & place in moist room	Remarks
4/13	X	start of test	10 AM	4/14	10 AM	
4/15	9 AM	1	10 AM	4/16	10 AM	
4/17	9 AM	2	10 AM	4/19	10 AM	held in refrig. on Sunday
4/20	✓	3	✓	4/21	✓	
4/22	✓	4	✓	4/23	✓	
4/24	✓	5	✓	4/26	✓	held in refrig. on Sunday
4/27	✓	6	✓	4/28	✓	
4/29	✓	7	✓	4/30	✓	
5/1	✓	8	✓	5/3	✓	held in refrig. on Sunday
5/4	✓	9	✓	5/5	✓	
5/6	✓	10	✓	5/7	✓	
5/8	✓	11	✓	5/10	✓	held in refrig. on Sunday
5/11	✓	12	X	X	X	

Fig. 11. Data for calculating soil-cement losses and schedule for handling freeze-thaw specimens during test.

Next, the assembly is placed to thaw in the moist room or in suitable covered containers at a temperature of 70 deg.F. (21 deg.C.) and a relative humidity of 100 percent for 23 hours and then removed. Free water is made available to the absorbent pads to permit the specimens to absorb water by capillary action during the thawing period.

The specimens are then given two firm strokes on all areas with a wire scratch brush* to remove all material loosened during the freeze-thaw cycles. These strokes, corresponding to approximately 3-lb. force,** are applied to the full height and width of the specimen. Approximately 18 to 20 vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end.

After being brushed at the end of each thawing period, the specimens are turned over end for end before they are replaced on the water-saturated pads.

Some specimens made of fine sands or silty and clayey soils may scale on sides and ends, particularly after about the sixth cycle of test. This scale should be removed with a sharp-pointed instrument such as an ice pick, since the regular brushing may not be effective.

The procedure described in the preceding paragraphs constitutes one cycle (48 hours) of freezing and thawing. The specimens are then replaced in the refrigerator and the freezing-thawing continued for 12 cycles.

If it is not possible to run the cycles continuously—for example, because of weekends or holidays—the specimens should be held in the freezing cabinet during the layover period.

After 12 cycles of test the specimens are dried to constant weight at 230 deg.F. (110 deg.C.) and weighed to determine their oven-dry weights.

Conducting Wet-Dry Test (ASTM D559 or AASHTO T135)

At the end of the 7-day storage period in an atmosphere of high humidity, the specimens are submerged in tap water at room temperature for a period of 5 hours and then removed. The specimens are next placed in an oven at 160 deg.F. (71 deg.C.) for 42 hours and removed.

The specimens are then brushed in the same manner as just described for the freeze-thaw test.

The procedure described in the preceding paragraphs constitutes one cycle (48 hours) of wetting and drying. The specimens are then again submerged in water and the wetting-drying continued for 12 cycles.

If it is not possible to run the cycles continuously—for example, because of weekends or holidays—the

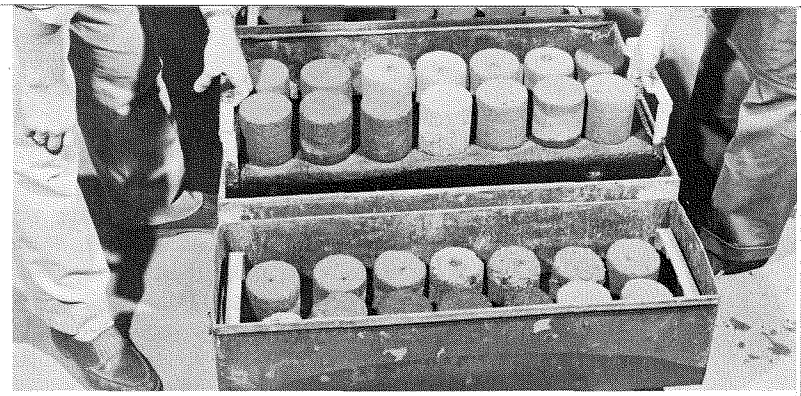


Fig. 12. During the thawing portion of the freeze-thaw test the specimens are in contact with saturated absorbent pads that supply water for the specimens to absorb by capillary action.

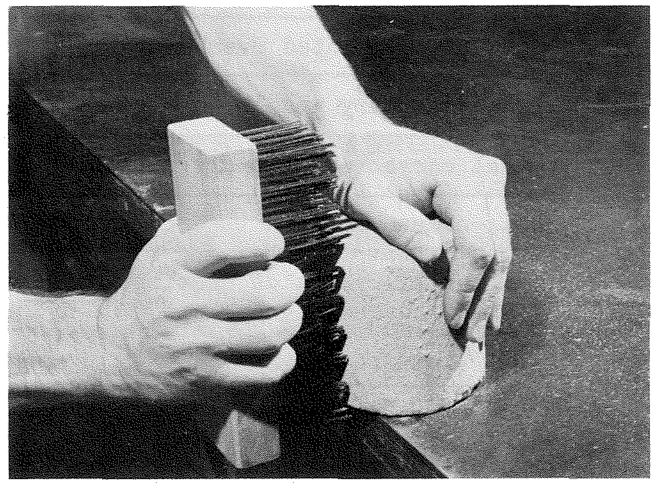
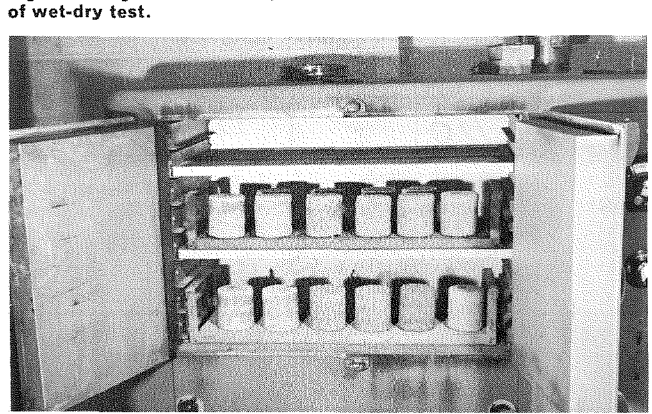


Fig. 13. Soil-cement specimens are given two firm strokes on all areas with a wire scratch brush after each cycle of freezing and thawing or wetting and drying.

Fig. 14. Wet-dry test specimens are immersed in water for 5 hours of each cycle.

Fig. 15. Forty-two hours' drying at 160 deg.F. completes one cycle of wet-dry test.



*Wire brushes for use in the freeze-thaw and wet-dry tests consist of 2x1/16-in. flat No. 26 gage wire bristles assembled in 50 groups of 10 bristles each and mounted to form 5 longitudinal rows and 10 transverse rows of bristle groups on a 7½x2½-in. hardwood block (see Fig. 13).

**This force is measured as follows: Clamp a specimen in a vertical position on the edge of a platform scale and set the scale at zero. Apply vertical brushing strokes to the specimen and note the force necessary to register approximately 3 lb.

Soil-Cement Laboratory, Form Sheet No.7

WETTING-DRYING TEST OF COMPACTED SOIL-CEMENT MIXTURES

Soil No. 1 Date Molded ____

Cement content, % by wt.		5.0	
Initial moisture content, %		9.1	
Initial calculated oven-dry wt., lb.		4.30	
Final oven-dry wt., lb.*		4.02	
Final corrected oven-dry wt., lb.**		3.97	
Soil-cement loss, %		8	

*After 12 cycles of testing and after drying to constant wt. at 110° C.
**After correcting for water of hydration. (____%)

SCHEDULE FOR SPECIMENS DURING TEST

Date	Remove from oven & brush	Cycles completed	Place to soak	Place in oven 160°F.	Remarks
4/13	X	start of test	10 AM	3 PM	
4/15	9 AM	1	10 AM	3 PM	
4/17	9 AM	2	10 AM	3 PM	
4/19	✓	3	✓	✓	
4/21	✓	4	✓	✓	
4/23	✓	5	✓	✓	
4/26	✓	6	✓	✓	held over in oven on Sunday
4/28	✓	7	✓	✓	
4/30	✓	8	✓	✓	
5/3	✓	9	✓	✓	held over in oven on Sunday
5/5	✓	10	✓	✓	
5/7	✓	11	✓	✓	
5/10	✓	12	X	X	held over in oven on Sunday

Fig. 16. Data for calculating soil-cement losses and typical schedule for handling wet-dry specimens during test.

specimens should be held in the oven during the layover period.

After 12 cycles of tests the specimens are dried to constant weight at 230 deg.F. (110 deg.C.) and weighed to determine their oven-dry weights.

Calculating Soil-Cement Loss of Specimens

The weight of soil-cement specimens dried out at 230 deg.F. (110 deg.C.) includes some water used for cement hydration that cannot be driven off at this temperature, and the oven-dry weight of the specimen must be corrected for this retained water. The percent water of hydration is approximately equal to $\frac{1}{4}$ of the percent cement in the specimen. For example, a specimen containing 8 percent cement by weight would retain about 8/4 or 2 percent water. The oven-dry weight of the specimen is corrected for this water of hydration. Corrected oven-dry weight equals

$$\frac{\text{oven-dry weight after drying at 230 deg.F. (at 110 deg.C.)}}{\left(\text{percent water of hydration retained in specimen}\right) + 100} \times 100.$$

The soil-cement loss of the specimen is then calculated as a percentage of the original oven-dry weight. Soil-cement loss, percent, equals

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

To illustrate the calculation of soil-cement losses, assume that the oven-dry weight of the wet-dry test specimen molded with the A-1-a (0) soil previously illustrated is 4.02 lb. after 12 cycles of testing and after drying to constant weight at 230 deg.F.

The original calculated oven-dry weight of the specimen was 4.30 lb. The percent of water of hydration for this 5 percent cement specimen is 5/4 or 1.2 percent. The final oven-dry weight corrected for the retained water is $\frac{4.02}{101.2} \times 100$, or 3.97 lb. The soil-cement loss is then $\frac{4.30 - 3.97}{4.30} \times 100$, or 7.7 percent. Since soil-cement losses are usually reported to the nearest whole number, the 7.7 percent would be considered 8 percent. The above calculations and a typical schedule for handling the freeze-thaw and wet-dry test specimens during testing are given in Figs. 11 and 16.

Inspecting Specimens During Test

Visual inspections of test specimens are generally made every three cycles of test by subjecting them to "picking" and "clicking" as discussed on page 3. This will furnish information on the condition of the specimens as testing progresses and will permit a check on the estimated cement requirement. It also will determine whether an adequate number of cement contents are being investigated. For instance, if test specimens are molded at 8, 10, and 12 percent cement by weight, and if after six cycles of test the 8 percent cement specimens are very hard and have low soil-cement losses, it is advisable to mold specimens containing 6 percent cement by weight in order to determine the most economical cement content that will adequately harden the soil. The other extreme will occur when the 12 percent cement specimens are inadequately hardened. It is then necessary to mold test specimens containing 14 and 16 percent cement by weight to determine a satisfactory cement content.

COMPRESSIVE-STRENGTH TESTS

Compressive-strength tests are generally made as supplementary to the freeze-thaw and wet-dry tests. Compressive-strength test specimens are commonly broken in compression at ages of 2, 7, and 28 days. They are stored at room temperature in an atmosphere of approximately 100 percent humidity until the day of testing and are then broken in compression after being soaked in water for 4 hours. A rate of application of load of approximately 20 psi per second should be used.

The specimens are molded at cement contents covering the range of cement factors being investigated in the freeze-thaw and wet-dry tests. Specimens of 4-in. and 2-in. diameter are most commonly used. Other size specimens, such as those 2.8 in. in diameter and 5.6 in. high,* may also be practical. Since compressive-strength test data are not used for design purposes but only to determine the rate of hardening and whether the soil is reacting normally, the size of the specimens is not too important.

Four-Inch-Diameter Specimens

The 4-in.-diameter, 4.6-in.-high specimens are generally molded with the same compaction equipment used to make the moisture-density test and to mold wet-dry and freeze-thaw test specimens. They are molded at the optimum moisture content, determined from the moisture-density test, and contain the percent of material retained on the No. 4 sieve that occurs in the soil sample. The calculations required and the procedure for molding are the same as those described for wet-dry and freeze-thaw test specimens. These specimens are capped and soaked in water for 4 hours before they are broken.

*Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory, ASTM D1632, and Compressive Strength of Molded Soil-Cement Cylinders, ASTM D1633.

Two-Inch-Diameter Specimens

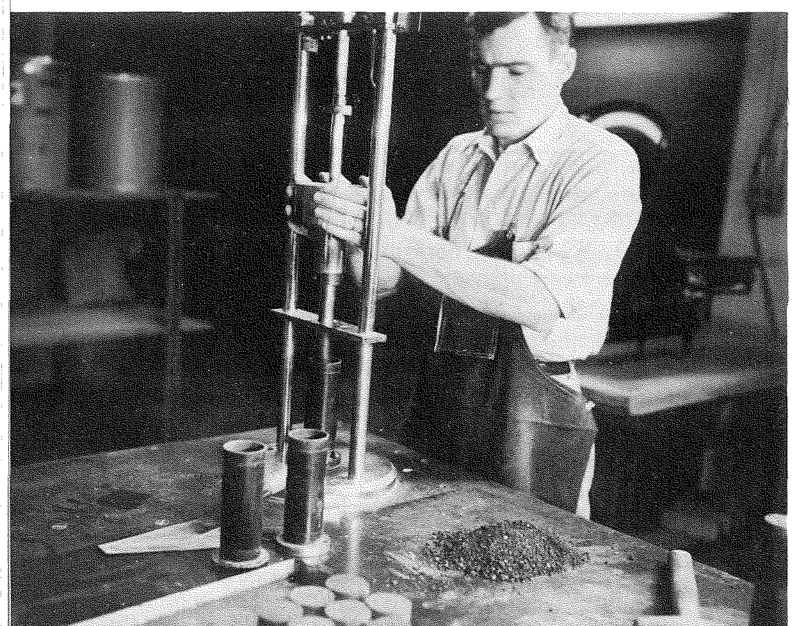
Specimens 2 in. in diameter and 2 in. in height can be molded in the machine shown in Fig. 17 when the soil does not contain material retained on the No. 4 sieve. These specimens are soaked in water for 1 hour before they are tested. A designed quantity of soil-cement at optimum moisture is weighed out and compacted to a height of exactly 2 in. Force of compaction is applied by the double-piston method in which force is applied to the top piston but both top and bottom pistons are left free to move during compaction. The quantity of soil-cement weighed out and placed in the machine is such that the specimens have the designed density.

These 2-in.-diameter, 2-in.-high specimens can also be molded in a hydraulic testing machine, using molds similar to those shown in Fig. 17. Hydraulic testing machines will shut off automatically when a certain distance is reached between the head and the compression block. This automatic shutoff can be used to control the 2-in. height of the specimen merely by making the base-plate thickness of the mold 2 in. less than the space between the head and the compression block of the machine at the time of shutoff.

Analysis of Data

The influence of cement in producing compressive strength in compacted soil-cement mixtures can be analyzed from two viewpoints. The cement influence will be evidenced by increases in strength with increases in age and by increases in strength with increases in cement content. The 7-day compressive strengths of saturated specimens at the minimum cement content that produces adequately hardened soil-cement will generally be between 300 and 800 psi.

Fig. 17. Molding 2-in. compressive-strength test specimens.



Compressive-strength tests are also used to check soils previously tested. When the field data indicate that a soil has the same texture and is from the same U.S. Department of Agriculture soil series and horizon as a previously tested soil, compressive strengths should be about the same.

ESTABLISHMENT OF CEMENT FACTORS FOR CONSTRUCTION

The principal requirement of a hardened soil-cement mixture is that it withstand exposure to the elements. Thus the primary basis of design of soil-cement mixtures is the cement content required to produce a mixture that will withstand the stresses induced by the wet-dry and freeze-thaw tests. The service record of projects in use proves the reliability both of the results based upon these tests and of the criteria given below.

The following criteria for soil-cement pavement base construction are based on considerable laboratory test data, on the performance of many pavement base projects in service, and on the information obtained from the outdoor exposure of several thousand specimens. The use of these criteria will provide the minimum cement content required to produce hard, durable soil-cement suitable for pavement base course construction of the highest quality.

1. Soil-cement losses during 12 cycles of either the wet-dry test or freeze-thaw test shall conform to the following limits:
   - Soil Groups A-1, A-2-4, A-2-5, and A-3, not over 14 percent;
   - Soil Groups A-2-6, A-2-7, A-4, and A-5, not over 10 percent;
   - Soil Groups A-6 and A-7, not over 7 percent.
2. Compressive strengths should increase both with age and with increases in cement content in the ranges of cement content producing results that meet requirement 1.

The cement content determined as adequate for pavement, using the above criteria, will be adequate for soil-cement slope protection that is 5 ft. or more below the minimum pool elevation. For soil-cement that is higher than that elevation the cement content should be increased 2 percentage points. If it is necessary to use a soil containing more than 50 percent fines, the cement content increase required for erosion resistance is 4 percentage points.

The magnitude of the soil-cement losses is applicable only when two or more cement contents have been investigated. This makes it possible to determine the decrease in loss caused by an increase in cement content. For instance, assume that wet-dry and freeze-thaw test specimens were molded with an A-2-4(0) soil at cement contents of 5, 7, and 9 percent and that the soil-cement losses for these specimens were 70, 14, and 5 percent, respectively. In this case, 8 percent cement would be recommended for a pavement base (10 percent for slope protection) because of the critical reaction of less than 7 percent cement contents with this particular soil. On the other hand, if the losses for these specimens were 19, 13, and 6 percent, and if the compressive strengths were satisfactorily increasing with cement content and with age, it would be satisfactory to recommend 7 percent cement for a pavement base (9 percent for slope protection) because the cement reaction with the soil is not critical in that particular range.

It is the practice in most laboratories to inspect individual specimens for hardness during the wet-dry and freeze-thaw tests and also at the completion of tests. The specimens are rapped together or picked with an ice pick to determine if they are thoroughly hardened. Recommendations are then made both on the basis of soil-cement-loss data and visual inspection. Good soil-cement specimens are hard and stable even when wet.

If it is desired to convert the recommended cement content by weight to the equivalent cement content by volume, this conversion can be made by using Fig.

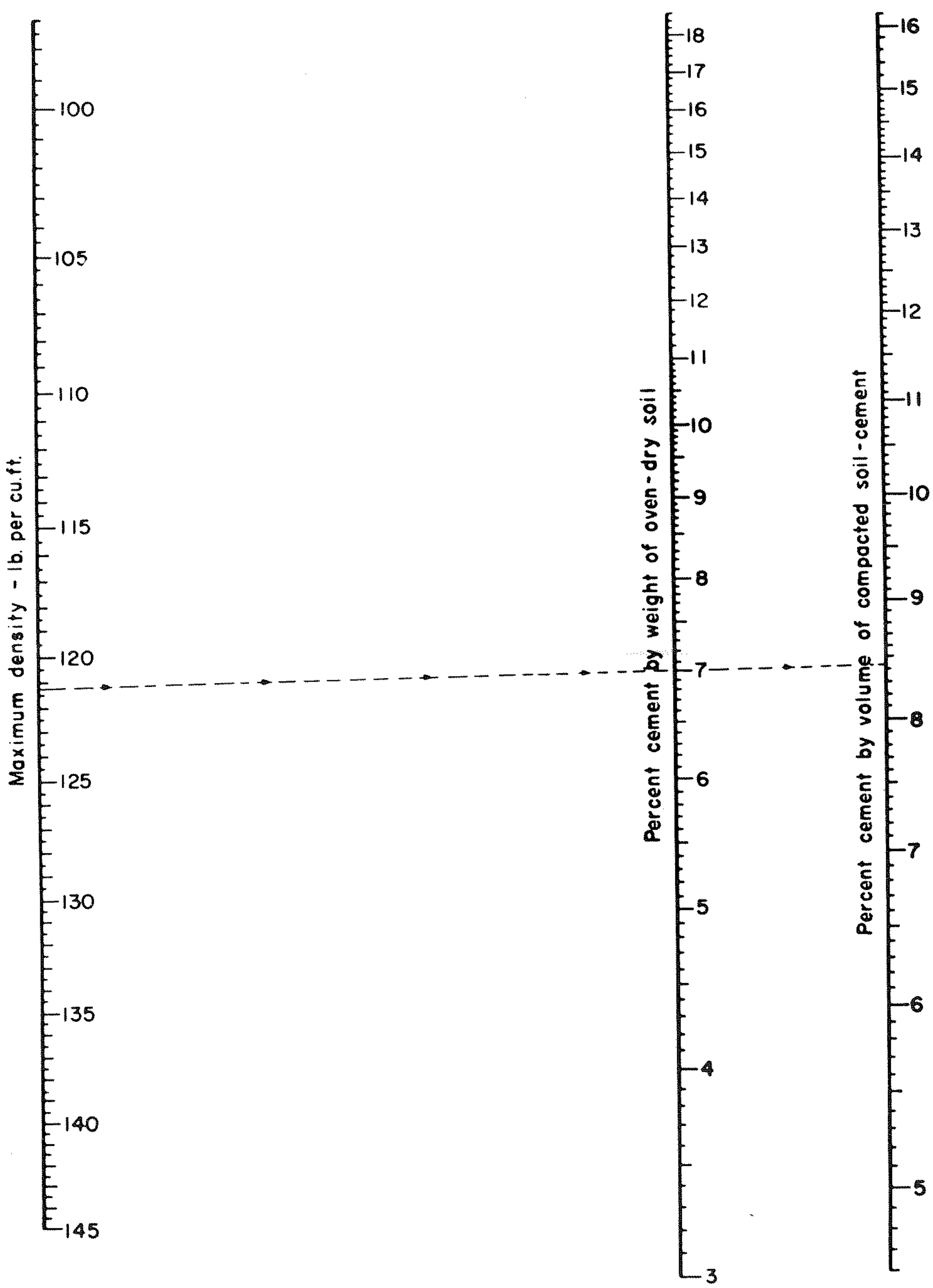


Fig. 18. Relation of cement content by weight of oven-dry soil to cement content by volume of compacted soil-cement mixture.

Soil-Cement Laboratory, Form Sheet No. 13

Date tests completed ____

SUMMARY OF TESTS ON SOIL CEMENT MIXTURES
PORTLAND CEMENT ASSOCIATION

State ____ Project ____

PCA Soil No. 1

County ____

Field Project No. ____

Sampling location ____

GRADATION

	Soil mortar	Total sample
Per cent passing		
2-in. sieve		100
¾-in. sieve		92
No. 4 sieve (4.76 mm.)		70
No. 10 sieve (2.00 mm.)	100	49
No. 18 sieve (1.00 mm.)	76	37
No. 35 sieve (0.50 mm.)	53	26
No. 40 sieve (0.42 mm.)	49	24
No. 60 sieve (0.25 mm.)	37	18
No. 140 sieve (0.105mm.)	16	8
No. 200 sieve (0.074mm.)	8	4
Per cent smaller than		
0.05 mm.	4	2
0.005mm.	2	1
0.002mm.	2	1

U.S. DEPT. OF AGRICULTURE SOIL CLASSIFICATION

Soil series ____
Soil horizon "C"
Textural class Gravelly Coarse Sand
Color of moist soil Brown

PHYSICAL TEST CONSTANTS
L. L. NP
P. I. NP

AASHTO SOIL CLASSIFICATION
A-1-a(0)

Unified Class = SP

COMPRESSIVE STRENGTH, psi*

Cement content, % by wt.	Age when tested, days: two	seven	twenty-eight
3.0	61	123	168
5.0	264	445	596
7.0	402	661	800

*Specimens saturated in water before testing

DATA FROM WET-DRY AND FREEZE-THAW SPECIMENS

Cement content % by wt.	Total soil-cement loss, %: Wet-Dry	Freeze-Thaw
3.0	–	100
4.0	–	29
5.0	8	17
7.0	–	6

MATERIAL RETAINED ON NO. 4 SIEVE

Absorption, % 2.0
Bulk sp. gravity 2.55

RECOMMENDATIONS

Recommended cement content 9.5(1) % by volume (7.4 % by weight)
which is 6.70 lb. per sq. yd. per inch of compacted thickness.

Laboratory optimum moisture content** 9.2 %

Laboratory maximum density** 129.5 lb. per cu. ft.

Tests made on total sample using ¾ in. maximum size material.

**Moisture-density test made during construction govern field control.

Remarks: (1) This recommendation for slope protection includes a 2 percentage point increase over that required for a pavement base due to exposure conditions.

Fig. 19. Summary of soil and soil-cement tests, Soil No. 1.

Soil-Cement Laboratory, Form Sheet No. 13

Date tests completed ______

SUMMARY OF TESTS ON SOIL-CEMENT MIXTURES
PORTLAND CEMENT ASSOCIATION

State ______ Project ______

PCA Soil No. 2

County ______

Field Project No. ______

Sampling location ______

GRADATION

Per cent passing	Soil mortar	Total sample
2-in. sieve		100
¾-in. sieve		100
No. 4 sieve (4.76 mm.)		100
No. 10 sieve (2.00 mm.)	100	100
No. 18 sieve (1.00 mm.)	98	98
No. 35 sieve (0.50 mm.)	87	87
No. 40 sieve (0.42 mm.)	81	81
No. 60 sieve (0.25 mm.)	43	43
No. 140 sieve (0.105mm.)	16	16
No. 200 sieve (0.074mm.)	14	14
Per cent smaller than		
0.05 mm.	13	13
0.005mm.	11	11
0.002mm.	5	5

U.S. DEPT. OF AGRICULTURE SOIL CLASSIFICATION

Soil series ______

Soil horizon "C"

Textural class Loamy Sand

Color of moist soil Brown

PHYSICAL TEST CONSTANTS

L. L. NP

P. I. NP

AASHTO SOIL CLASSIFICATION

A-2-4(0)

Unified Class: SM

COMPRESSIVE STRENGTH, psi*

Cement content, % by wt.	Age when tested, days: two	seven	twenty-eight
5.0	165	228	285
7.0	232	425	563
9.0	395	688	877

*Specimens saturated in water before testing

DATA FROM WET-DRY AND FREEZE-THAW SPECIMENS

Cement content % by wt.	Total soil-cement loss, %: Wet-Dry	Freeze-Thaw
5.0	–	34
7.0	7	13
9.0	–	5

MATERIAL RETAINED ON NO. 4 SIEVE

Absorption, % ______

Bulk sp. gravity ______

RECOMMENDATIONS

Recommended cement content 10.5(1) % by volume (8.9 % by weight) which is 7.40 lb. per sq. yd. per inch of compacted thickness.

Laboratory optimum moisture content** 10.5 %

Laboratory maximum density** 121.0 lb. per cu. ft.

Tests made on total sample using ¾ in. maximum size material.

**Moisture-density test made during construction govern field control.

Remarks: (1)This recommendation for slope protection includes a 2 percentage point increase over that required for a pavement base due to exposure conditions.

Fig. 20. Summary of soil and soil-cement tests, Soil No. 2.

18 or the following formula:

$$\text{Percent cement by volume} = \frac{D - \frac{D}{C}}{94} \times 100,$$

where

D = oven-dry density of soil-cement, pounds per cubic foot;

C = 100 + percent cement by weight of oven-dry soil, the quantity divided by 100.

The final test data report (Figs. 19 and 20) should include the following:

- —Recommended cement content for slope protection
- —Laboratory maximum density and optimum moisture content
- —Soil-cement losses from the freeze-thaw and wet-dry tests
- —Compressive strength data
- —Gradation analysis of the soil
- —Color of the soil
- —Physical test constants (liquid limit and plasticity index)
- —AASHTO and Unified (ASTM) soil classification
- —USDA soil series and horizon

The laboratory moisture-density test data are not, of course, directly applicable to field control. Moisture-density tests on representative samples taken during construction toward the end of the damp-mixing operations show the optimum moisture content of the mixture and the density to which the mix should be compacted. This procedure covers small variations in soil type and variations in optimum moisture and maximum density that result from more prolonged construction operations. However, the laboratory moisture-density test data for the soil-cement mixtures occurring on a project are sufficiently close to the field moisture-density data that they can be used for estimating equipment needs and for setting up bid items in the contract proposal.

The information on gradation, physical test constants, color, soil series, and horizon will aid the construction engineer and inspector in comparing the soils to be processed with the samples tested. This will assure the use of the proper amount of cement.

The gradation and physical test constants will also be helpful to the contractor in determining the ease of pulverization and mixing in the field and in choosing the type and weight of compaction equipment.

SHORT-CUT TEST FOR SANDY SOILS

The following short-cut test for sandy soils was developed as a result of a correlation made by the Portland Cement Association of the data obtained from ASTM-AASHTO tests of 2,438 sandy soils.* The procedures do not involve new tests or additional equipment. Instead, some tests can be eliminated by the use of charts. The only tests required are a grain-size analysis, a moisture-density test, and compressive-strength tests. Relatively small samples are needed. All tests can be completed in about a week.

The procedures can be used only with soils containing less than 50 percent material smaller than 0.05 mm. (silt and clay), less than 20 percent material smaller than 0.005 mm. (clay), and less than 45 percent material retained on the No. 4 sieve—the gradation limits for the soils that were included in the correlation used to develop the original charts. Dark grey to black soils with appreciable amounts of organic impurities were not included in the correlation and therefore cannot be tested by these procedures. This also is true of miscellaneous granular materials such as cinders, caliche, chat, chert, marl, red dog, scoria, shale, slag, etc. Moreover, the short-cut procedures cannot be used with granular soils containing material retained on the No. 4 sieve if that material has a bulk specific gravity less than 2.45.

The short-cut test procedures determine a cement requirement for pavement base construction. This cement factor may not always be the minimum cement factor that can be used with a particular sandy soil; however, it almost always is a safe cement factor, generally close to that indicated by standard ASTM-AASHTO freeze-thaw and wet-dry tests. *For soil-cement slope protection the cement requirements obtained by the short-cut test procedures are increased as indicated on page 18.*

The short-cut procedures are being widely applied by engineers and builders and may largely replace the standard tests when experience in their use is gained. The charts and procedures may be modified to conform to local climatic and soil conditions if necessary.

Step-by-Step Procedures

Short-cut test procedures involve:

1. Running a moisture-density test on a mixture of the soil and portland cement.
2. Determining the indicated portland cement requirement by the use of charts.
3. Verifying the indicated cement requirement by compressive-strength tests.

Before applying the short-cut test procedures it is necessary to determine (1) the gradation of the soil and (2) the bulk specific gravity of the material retained on the No. 4 sieve. If all the soil passes the No. 4 sieve, Method A is used. If material 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.

Note 1: Use Fig. 21 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) can be used with Fig. 22 to determine the cement content by weight to use for the test.

*See footnote giving two references on page 2.

STEP 2: Use the maximum density obtained by test in Step 1 to determine from Fig. 22 the indicated cement requirement.

STEP 3: Use the indicated cement factor obtained in Step 2 to mold compressive-strength test specimens* 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 Fig. 23, 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 pavement base construction. *For soil-cement slope protection, add cement as indicated on page 18.*

If it is desired to convert the recommended cement content by weight to the equivalent cement content by volume, the conversion can be made using Fig. 18.

Note 2: If the average compressive-strength value plots above the curve of Fig. 23, the cement content indicated in Fig. 22 is verified. Strengths at higher or lower cement contents are not determined since these data cannot be used in the procedure. In most cases the strength will be substantially higher than the minimum allowable value. This merely indicates that the soil is reacting normally. When high strengths are obtained, it is not correct to reduce the cement factor so that a strength value close to the curve in Fig. 23 is obtained. Such a

*Specimens of either 2-in. diameter and 2-in. height or 4-in. diameter and 4.6-in. height may be molded. The 2-in. specimens shall be submerged in water for 1 hour before testing and the 4-in. specimens for 4 hours. The 4-in. specimens shall be capped before testing.

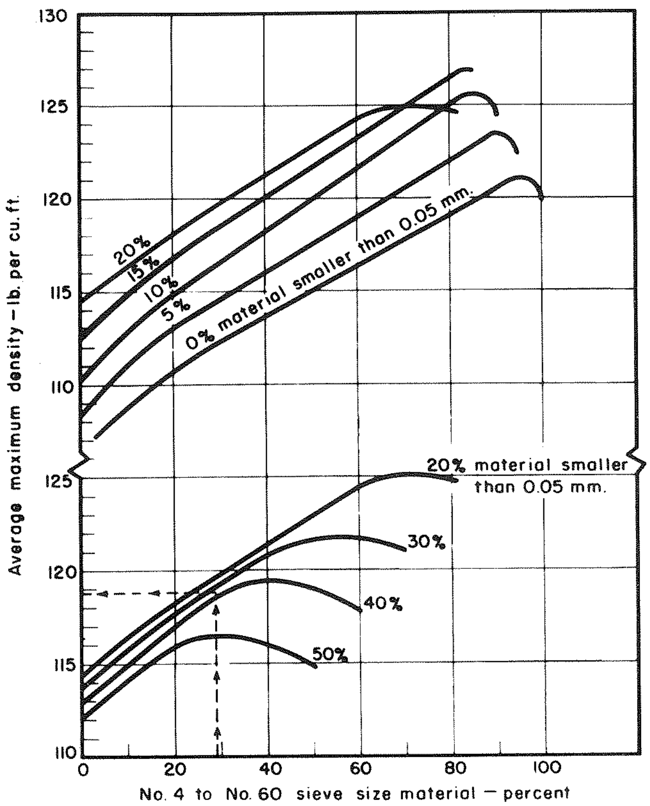


Fig. 21. Average maximum densities of soil-cement mixtures not containing material retained on the No. 4 sieve.

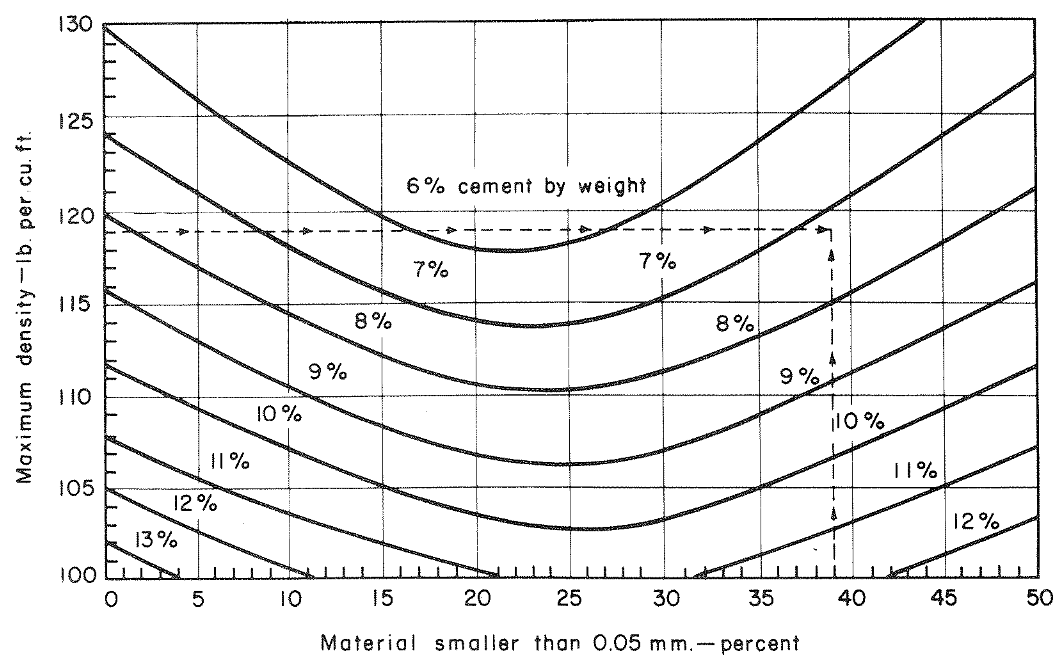


Fig. 22. Indicated cement requirements of soil-cement mixtures not containing material retained on the No. 4 sieve.

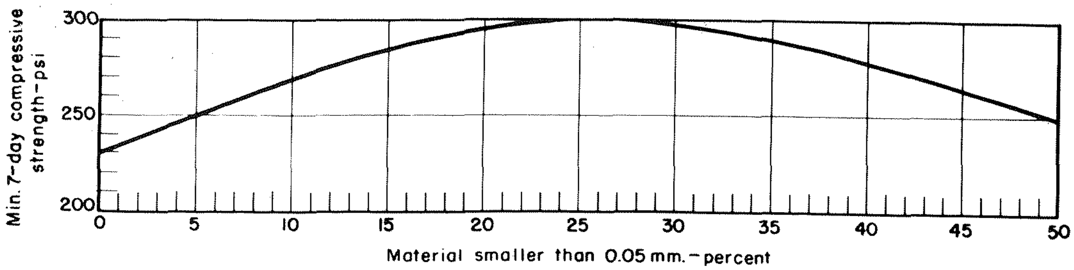


Fig. 23. Minimum 7-day compressive strengths required for soil-cement mixtures not containing material retained on the No. 4 sieve.

reduction invalidates the reliability of the procedure and will usually result in a cement content that is not sufficient to meet ASTM-AASHTO freeze-thaw and wet-dry test criteria. Although a very high compressive strength may indicate that the soil is reacting better than average, any reduction in the cement factor can only be made based on freeze-thaw tests at lower cement contents.

Note 3: If the average compressive-strength value plots below the curve of Fig. 23, the indicated cement factor obtained in Step 2 is probably too low for base construction. 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 2 percentage points higher. The specimens are then tested by ASTM-AASHTO 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.

Note 4: Use Fig. 24 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 can be used with Fig. 25 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 with 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 Fig. 25 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 test specimens* 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 Fig. 26 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 pavement base construction. *For soil-cement slope protection, add cement as indicated on page 18.*

If it is desired to convert the recommended cement content by weight to the equivalent cement content by volume, the conversion can be made using Fig. 18.

Note 5: If the average compressive-strength value equals or exceeds the minimum allowable strength obtained in Fig. 26, the cement content indicated in Fig. 25 is verified. Strengths at higher or lower cement contents are not determined since these data cannot be used in the procedure. In most cases the strength will be substantially higher than the minimum allowable value. This merely indicates that the soil is reacting normally. When high

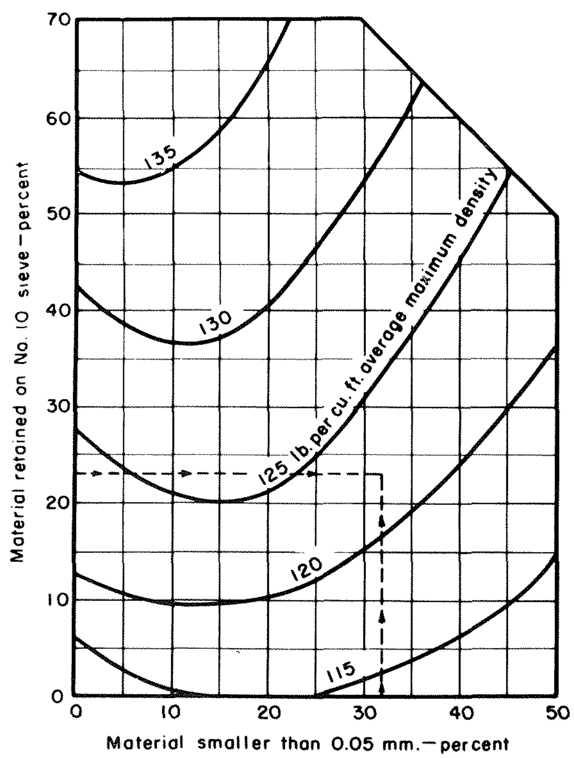


Fig. 24. Average maximum densities of soil-cement mixtures containing material retained on the No. 4 sieve.

*Specimens of 4-in. diameter and 4.6-in. height shall be molded. They shall be submerged in water for 4 hours and shall be capped before testing.

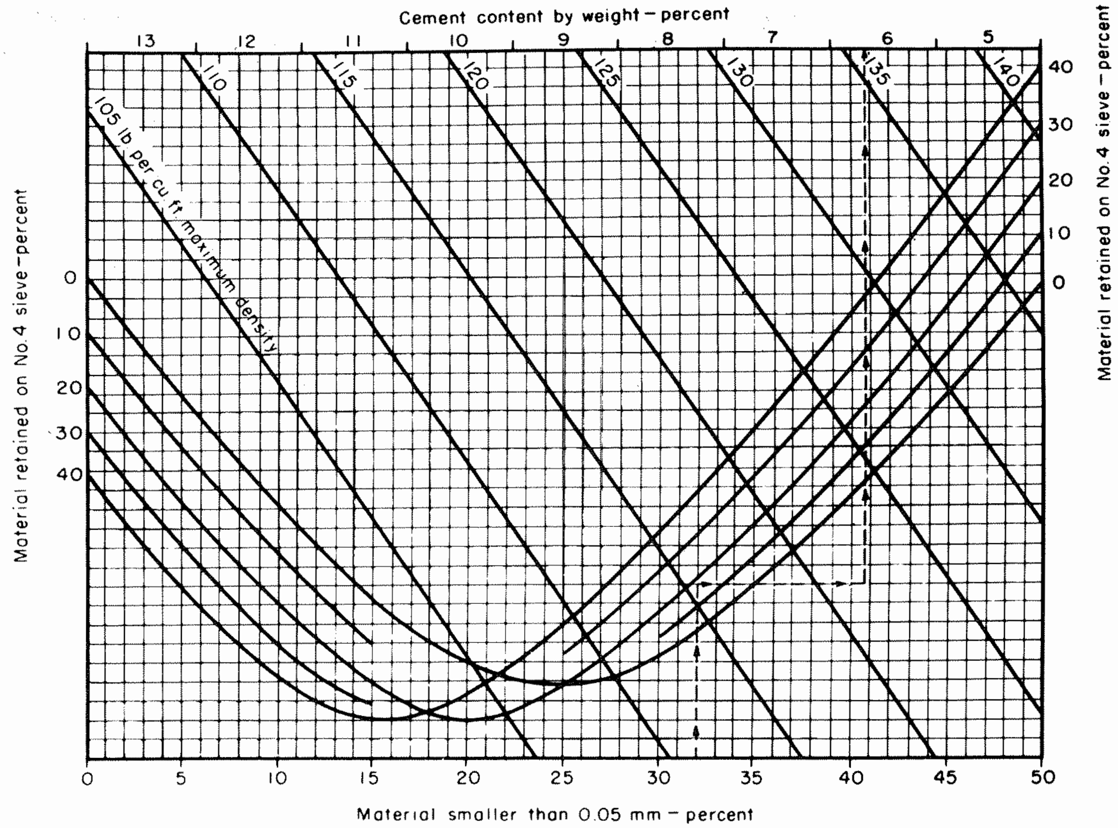


Fig. 25. Indicated cement requirements of soil-cement mixtures containing material retained on the No. 4 sieve.

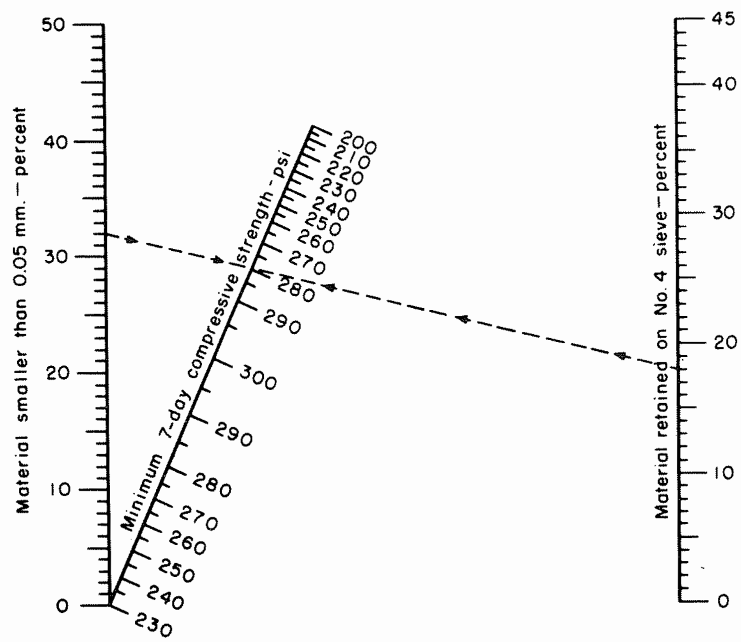


Fig. 26. Minimum 7-day compressive strengths required for soil-cement mixtures containing material retained on the No. 4 sieve.

strengths are obtained, it is not correct to reduce the cement factor so that a strength value close to the minimum allowable from Fig. 26 is obtained. Such a reduction invalidates the reliability of the procedure and will usually result in a cement content that is not sufficient to meet ASTM-AASHTO freeze-thaw and wet-dry test criteria. Although a very high compressive strength may indicate that the soil is reacting better than average, any reduction in the cement factor can only be made based on freeze-thaw tests at lower cement contents.

Note 6: 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 3 are needed.

Example

Preliminary tests determine the gradation of the soil and bulk specific gravity of the material, if any, retained on the No. 4 sieve. For this example the data obtained from these tests are tabulated below.

Gradation:
- Passing
  - No. 4 sieve . . . . 82 percent
  - No. 10 sieve . . . . 77 percent
  - No. 60 sieve . . . . 58 percent
  - No. 200 sieve . . . . 37 percent
- Smaller than
  - 0.05 mm. (silt and clay combined) . . . 32 percent
  - 0.005 mm. (clay) . . . . 13 percent

Color: Brown

Bulk specific gravity of material retained on No. 4 sieve: 2.50

Method B should be used since the soil contains material retained on the No. 4 sieve.

Step 1

From Fig. 24 the estimated maximum density of the soil-cement mixture is 122 lb. per cubic foot, since the soil contains 32 percent material smaller than 0.05 mm. and 23 percent material retained on the No. 10 sieve.

Fig. 25 is used to determine the cement content by weight to use in the moisture-density test. Since the soil contains 32 percent material smaller than 0.05 mm. and 18 percent material retained on the No. 4 sieve, and since the estimated maximum density is 122 lb. per cubic foot, 6 percent cement by weight is indicated.

Perform the moisture-density test using 6 percent cement. For this example, assume the maximum density obtained by test to be 123.2 lb. per cubic foot at 10.2 percent moisture.

Step 2

Fig. 25 indicates a cement requirement of 6 percent, using the calculated actual maximum density of 123.2 lb. per cubic foot.

Step 3

Using total material and 6 percent cement by weight, mold compressive-strength test specimens in triplicate at maximum density (123.2 lb. per cubic foot) and optimum moisture (10.2 percent).

Step 4

Determine the average 7-day compressive strength. For this example, assume the average compressive strength to be 345 psi.

Step 5

Since the soil contains 32 percent material smaller than 0.05 mm. and 18 percent material retained on the No. 4 sieve, the minimum allowable compressive strength for this soil-cement mixture is 280 psi, as shown in Fig. 26. The average compressive strength of the mixture used in this example (345 psi), as obtained in Step 4, is higher than the minimum allowable strength. Therefore, the indicated cement content of 6 percent by weight is adequate for pavement base construction. *An additional 2 percentage points of cement or a total of 8 percent cement by weight is required for slope protection construction.* Eight percent cement by weight is equivalent to 9.7 percent by volume (Fig. 18).

If the average compressive strength in Step 4 had been lower than the minimum allowable strength, say 245 psi, 6 percent cement by weight probably would not be adequate for pavement base construction. Additional testing would then have been required to establish the cement requirement for the soil. These tests would involve molding and testing freeze-thaw specimens according to ASTM-AASHTO procedures. Freeze-thaw specimens containing 6 and 8 percent cement by weight probably would be adequate in this instance.

KEY WORDS: cement content, classification, density, earth dams, embankments, erosion resistance, facings, freeze-thaw durability, laboratories, moisture content, reservoirs, slope protection, soil, soil-cement, testing, water control, wet-dry durability.

ABSTRACT: Explains in detail the standard laboratory tests required for soil-cement slope protection mix design. Step-by-step procedures are given, with sample calculations, charts, and tables. Also included are descriptions of short-cut and supplemental tests, discussion of soil properties, and illustrations of many of the test procedures.

REFERENCE: *Soil-Cement for Water Control: Laboratory Tests* (IS166.02W), Portland Cement Association, 1976.