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Standard Test Method for Shrinkage Factors of Soils by the Wax Method[1]

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INTRODUCTION

Given the concern that mercury is a hazardous substance, this test method is offered as an alternative to Test Method D 427, which is used to determine the shrinkage limit and other shrinkage factors of soils using mercury (see Caution statement in Test Method D 427). Since this test method has been performed by only a few organizations to date, others are encouraged to perform both test methods and to report their findings to Subcommittee D18.03. (See Appendix X1 for a rationale of this test method.)

1. Scope

1.1 This test method covers the procedure for determining the shrinkage limit of soils.

1.2 The data obtained using this test method may also be used to calculate shrinkage ratio, volumetric shrinkage, and linear shrinkage.

1.3 This test method is applicable only for cohesive soils.

1.4 Since this test method is performed only on that portion of a soil which passes the No. 40 (425-μm) sieve, the relative consistency of this portion of the soil to the properties of the sample as a whole must be considered when using these procedures to evaluate the properties of a soil.

1.5 The shrinkage limit along with the liquid limit and plastic limit of soils are often collectively referred to as the Atterberg limits in recognition of their formation by Swedish soil scientist, A. Atterberg. These limits distinguish the boundaries of the several consistency states of cohesive soils.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific safety hazards, see Section 7, Note 1, and Note X1.1.

2. Referenced Documents

2.1 *ASTM Standards:*

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[2]

D 75 Practice for Sampling Aggregates[3]

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes[4]

D 427 Test Method for Shrinkage Factors of Soil by the Mercury Method[4]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]

D 854 Test Method for Specific Gravity of Soils[4]

D 2726 Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens[3]

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[4]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil, Rock, and Related Construction Materials[5]

E 1 Specification for ASTM Thermometers[6]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[7]

3. Terminology

3.1 *Definitions*—All definitions are in accordance with Terminology D 653.

4. Summary of Test Method

4.1 The moisture content of a pat of wet soil is determined. Then the moisture-content loss to dry the soil to a constant volume is determined and subtracted from the initial moisture content to calculate the shrinkage limit. The volume of the dry soil pat is determined from its mass in air and its indicated

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

[5] *Annual Book of ASTM Standards*, Vol 04.09.

[6] *Annual Book of ASTM Standards*, Vol 14.03.

[7] *Annual Book of ASTM Standards*, Vol 14.02.

mass when submerged in water. A coating of wax is used to prevent water absorption by the dry soil pat.

5. Significance and Use

5.1 The term shrinkage limit, expressed as a moisture content in percent, represents the amount of water required just to fill all of the voids of a given cohesive soil at its minimum void ratio obtained by ovendrying. The shrinkage limit can be used to evaluate the shrinkage potential, crack development potential, and swell potential of earthwork involving cohesive soils.

6. Apparatus

6.1 *Balance or Scale*—A balance or scale having a minimum capacity of 500 g and meeting the requirements of Specification D 4753 for a balance of 0.01-g readability. The balance or scale shall be equipped with suitable apparatus for suspending the soil specimen in water from the center of the platform or pan.

6.2 *Dish, Shrinkage*—A circular porcelain or monel metal milk dish having a flat bottom about 40 to 45 mm in diameter and about 12 to 15 mm deep.

6.3 *Drying Oven*—An oven, thermostatically controlled, preferably of the forced draft type, and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

6.4 *Mortar and Pestle*—Mortar, iron or porcelain, about 125 to 150-mm diameter with rubber tipped pestle.

6.5 *Spatula*—A spatula or pill knife having a blade about 100 mm long by about 20 mm wide.

6.6 *Straightedge*—A stiff metal straightedge of convenient length. The scraping edge must be beveled if it is thicker than 3 mm.

6.7 *Sieve*—U.S.A. Standard series No. 40 (425-µm) sieve conforming to the requirements of Specification E 11.

6.8 *Microcrystalline Wax*—Sufficient quantity to cover the soil pat.

6.9 *Sewing Thread*—Fine thread to hold the specimen to dip into the wax.

6.10 *Water*, Distilled.

6.11 *Water Bath*—Of sufficient size to allow the soil pat to be submerged when determining mass in water.

6.12 *Wax Warmer*—Sufficient temperature control to avoid overheating.

6.13 *Thermometer (optional)*—A thermometer, 0 to 50°C range, 0.5° gradations, conforming to the requirements of Specification E 1.

6.14 *Glass or Clear Plastic Plate*, used for calibrating the shrinkage dish, about 80 by 80 mm, about 5 mm thick.

6.15 *Petroleum Base Lubricant*, used in calibrating the shrinkage dish.

6.16 *Liquid Limit Device and Grooving Tool*, as described in Test Method D 4318.

7. Safety Hazards

7.1 Wax melting equipment or hot wax may burn unprotected skin. Overheated wax may burst into flames; therefore, extreme care should be taken when working with hot wax. Do not use an open flame device to heat wax.

8. Sampling

8.1 Take samples from any location that satisfies testing needs. However, use Practices C 702 and D 75, as well as Guide D 420, as guides for selecting and preserving samples from various types of sampling operations.

8.2 Where sampling operations have preserved the natural stratification of a sample, keep the various strata separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construction, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.3 Where data from this test method are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible.

8.4 Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the No. 40 (425-µm) sieve. Mix samples thoroughly in a pan with a spatula or scoop and scoop a representative portion from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration and Standardization

9.1 Calibrate each shrinkage dish used in accordance with Annex A1. Since the dishes may have different volumes, each dish must be permanently identified.

9.2 The specific gravity (or density) of the microcrystalline wax must be known in advance. This can usually be obtained from the manufacturer. If not, determine the specific gravity in accordance with Test Method D 2726. In either case, the specific gravity value should be checked initially and then periodically.

9.3 Maintain the water bath, testing apparatus, and the laboratory environment at about the same temperature while performing this procedure.

10. Preparation of Test Specimen

10.1 Prepare the test specimen in accordance with the directions in Test Method D 4318, using either the wet or dry preparation, except that the moisture content of the soil is adjusted to a consistency that would require about ten blows of the liquid limit device to close the groove along a distance of 13 mm. The amount of water required may exceed the liquid limit by as much as 10 percentage points.

11. Procedure

11.1 Select a shrinkage dish and record its identification designation and its volume. The volume of the shrinkage dish is used as the volume of the wet soil pat. Lightly grease the inside of the shrinkage dish.

11.2 Determine the mass of the greased shrinkage dish and record the value as the mass of the empty shrinkage dish.

11.3 Place, in the center of the dish, an amount of the wetted soil equal to about one-third the volume of the dish and cause the soil to flow to the edges by tapping the dish on a firm surface cushioned by several layers of blotting paper or similar material. Add an amount of soil approximately equal to the first portion, and tap the dish until the soil is thoroughly compacted and all included air has been brought to the surface. Add more

soil and continue the tapping until the dish is completely filled and excess soil stands out about its edge. Strike off the excess soil with a straightedge and wipe off all soil adhering to the outside of the dish.

11.4 Determine the mass of the dish immediately after it is filled and record the struck measure value as the mass of dish plus wet soil.

11.5 Allow the soil pat to dry in air until the color of the pat turns from dark to light. Oven dry the pat to constant mass at 110 ± 5°C. Determine and record the mass of dish plus dry soil.

11.5.1 Drying the soil pat in air may produce cracking of the soil due to rapid moisture losses in dry climates. If this problem is encountered, it may be necessary to dry the soil in a humidity controlled environment. In this case, it may take from 1 to 2 weeks for the color of the soil to turn from dark to light.

11.6 Determine the volume of the dry soil pat as follows:

11.6.1 Securely tie the sewing thread around the soil pat.

11.6.2 Immerse the dry pat of soil in molten wax, holding the dry pat with the sewing thread, completely coating the pat. Do not allow air bubbles to develop in the wax coating. If air bubbles are present, use a sharp object to cut out the bubble; refill the hole with wax.

NOTE 1—**Precaution:** The melted wax and associated equipment are hot and care should be exercised to avoid burns.

11.6.3 Remove the pat of soil from the melted wax and allow the wax coating to cool.

11.6.4 Determine the mass of the wax-coated pat of soil in air and record the value as the mass in air of the dry soil and wax.

11.6.5 Determine the mass indicated when the wax-coated pat of soil is suspended from a balance while submerged in a water bath. Make sure that there are no air bubbles clinging to the surface of the wax-coated pat or thread. Record this as the mass in water of the dry soil and wax.

NOTE 2—There are other acceptable methods of determining the indicated difference of the mass of the soil pat in air and in water.

12. Calculation

12.1 Calculate the mass of the dry soil pat as follows:

$$m_s = m_d - m \tag{1}$$

where:
m_s = mass of the dry soil pat, g,
m_d = mass of the dry soil pat and shrinkage dish, g, and
m = mass of the shrinkage dish, g.

12.2 Calculate the moisture content of the soil at the time it was placed in the dish as follows:

$$w = \left[\frac{(m_w - m_d)}{m_s}\right] \times 100 \tag{2}$$

where:
w = moisture content of the soil at the time it was placed in the dish, %, and
m_w = mass of the wet soil and shrinkage dish, g.

12.3 Calculate the volume of the dry soil pat as follows:

12.3.1 Calculate the volume of the dry soil pat and wax as follows:

$$V_{d_x} = \frac{(m_{sxa} - m_{sxw})}{\rho_w} \tag{3}$$

where:
V_{d_x} = volume of dry soil pat and wax, cm^3,
m_{sxa} = mass of dry soil pat and wax in air, g,
m_{sxw} = indicated mass of dry soil pat and wax in water, g, and
ρ_w = density of water, g/cm^3.

NOTE 3—Assume density of water equal to 1.0 g/cm^3. Corrections for temperature may be used, if desired.

12.3.2 Calculate the mass of wax as follows:

$$m_x = m_{sxa} - m_s \tag{4}$$

where:
m_x = mass of wax, g.

12.3.3 Calculate the volume of wax as follows:

$$V_x = \frac{m_x}{G_x \rho_\omega} \quad \text{or} \quad \frac{m_x}{\rho_x} \tag{5}$$

where:
V_x = volume of wax, cm^3,
G_x = specific gravity of wax, and
ρ_x = density of wax, g/cm^3.

12.3.4 Calculate the volume of dry soil pat as follows:

$$V_d = V_{d_x} - V_x \tag{6}$$

where:
V_d = volume of dry soil pat, cm^3.

12.4 Calculate the shrinkage limit as follows:

$$SL = w - \left[\frac{(V - V_d)\rho_w}{m_s}\right] \times 100 \tag{7}$$

where:
SL = shrinkage limit, and
V = volume of wet soil pat (= volume of the shrinkage dish), cm^3.

12.5 If desired, calculate the shrinkage ratio as follows:

$$R = \frac{m_s}{V_d} \times \rho_w \tag{8}$$

where:
R = shrinkage ratio.

12.6 If desired, calculate the volumetric shrinkage as follows:

$$V_s = R(w_1 - SL) \tag{9}$$

where:
V_s = volumetric shrinkage, and
w_1 = some given moisture content,% .

12.7 If desired, calculate the linear shrinkage as follows:

$$L_s = 100\left[1 - \left(\frac{100}{V_s + 100}\right)^{1/3}\right] \tag{10}$$

where:
L_s = linear shrinkage.

13. Report

13.1 Report the following information:

13.1.1 Sample identifying number.

13.1.2 Any special selection process.

13.1.3 Report the shrinkage limit to the nearest whole number omitting the percent designation.

13.1.4 If desired, report the shrinkage ratio, volumetric shrinkage, and linear shrinkage.

14. Precision and Bias

14.1 *Precision*—Table 1 presents estimates of precision based on the results from the AASHTO Materials Reference Laboratory (AMRL) Proficiency Sample Program of testing conducted on Sample Numbers 113 and 114. These samples were found to be a CL material having 95.0 % fines, a liquid limit of 44, a plastic limit of 22, a shrinkage limit of 14, and a shrinkage ratio of 1.92.

TABLE 1 Table of Precision Estimates

Material and Type Index	Standard Deviation[A]	Acceptable Range of Two Results[A]
Single-Operator		
shrinkage limit	0.75	2.11
shrinkage ratio	0.017	0.048
Multilaboratory		
shrinkage limit	1.44	4.03
shrinkage ratio	0.040	0.112

[A]These numbers represent, respectively, the 1s and d2s limits as described in Practice C 670.

14.1.1 The column labeled “Acceptable Range of Two Results” quantifies the maximum difference expected between two measurements on samples of the same material under the conditions listed in the first column. These values only apply to soils which are similar to proficiency samples 113 and 114.

14.2 *Bias*—The procedure in this test method for measuring the shrinkage limit of soil has no bias because the value of the shrinkage limit can only be defined in terms of this test method.

15. Keywords

15.1 Atterberg limits; linear shrinkage; shrinkage; shrinkage limit

ANNEX

(Mandatory Information)

A1. CALIBRATION OF SHRINKAGE DISH

A1.1 Scope

A1.1.1 This annex describes the procedure for calibrating the shrinkage dish.

A1.1.2 The calibration consists of determining the volume of the shrinkage dish.

A1.2 Preparation of Apparatus

A1.2.1 The shrinkage dish, glass plate, lubricant, and water should all be at room temperature before performing the calibration procedure.

A1.3 Procedure

A1.3.1 Lightly grease the inside of the shrinkage dish and face of the glass plate. The face of the glass plate is greased to provide an adequate watertight seal while moving the dish and glass plate to the scale.

A1.3.2 Determine and record the mass of the greased dish and greased plate.

A1.3.3 Place water into the greased dish to overflowing.

A1.3.4 Remove the excess water by pressing the greased glass plate over the top of the dish. Be sure all of the air is removed from within the dish. Dry the outside of the plate and dish.

A1.3.5 Determine and record the mass of the greased dish, greased plate, and water.

A1.3.6 Calculate and record the value of the mass of water.

A1.3.7 Calculate and record the volume of the shrinkage dish.

A1.3.8 Completely clean the dish and the glass plate and repeat A1.3.1 through A1.3.7 for a second trial.

A1.3.9 If the difference in volume between the two trials is greater than 0.03 cm^3, repeat the procedure until the difference between any two trials is equal to or less than 0.03 cm^3. Average and record the results from the two trials.

A1.4 Calculation

A1.4.1 Calculate the mass of water in the shrinkage dish as follows:

$$m = m_1 - m_2 \quad \text{(A1.1)}$$

where:

m = mass of water in shrinkage dish, g,
m_1 = mass of greased dish, greased plate, and water, g, and
m_2 = mass of greased dish and greased plate, g.

A1.4.2 Calculate the volume of the shrinkage dish as follows:

$$V = \frac{m}{\rho} \quad \text{(A1.2)}$$

where:

V = volume of shrinkage dish, cm^3, and
ρ = absolute density of water, g/cm^3(use 1.000 g/cm^3, see Note 3).

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 This test method was developed by the Bureau of Reclamation as an alternate method to Test Method D 427 which uses mercury as part of the procedure. Independently, the Soil Conservation Service laboratory in Fort Worth, Texas, developed a similar procedure. Mercury is highly toxic to body tissues and can be readily absorbed into the body by way of the respiratory and digestive systems as well as directly through the skin.

X1.2 The study documenting the development and correlative data between the two test methods is described in the literature.[8]

X1.3 In Test Method D 427 the volume of the shrinkage dish is also determined by using mercury. The report referenced in X1.2 also documents the study for using water to determine the shrinkage dish volume.

[8] "Alternative Procedure for Determining the Shrinkage Limit of Soils," Report REC-ERC-86-2, Bureau of Reclamation, Denver, CO, June 1986.