



Designation: D5102/D5102M – 22

Standard Test Methods for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures¹

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1. Scope*

1.1 This test method covers procedures for preparing, curing, and testing laboratory-compacted specimens of soil-lime and other lime-treated materials (**Note 1**) for determining unconfined compressive strength. Depending on the diameter to height ratio, two procedures for determining the unconfined compressive strength of compacted soil-lime mixtures have been developed for specimens prepared at the maximum unit weight and optimum water content, or for specimens prepared at other target unit weight and water content levels. Other applications are given in Section 5 on Significance and Use.

NOTE 1—Lime-based products other than commercial quicklime and hydrated lime are also used in the lime treatment of fine-grained cohesive soils. Lime kiln dust (LKD) is collected from the kiln exhaust gases by cyclone, electrostatic, or baghouse-type collection systems. Some lime producers hydrate various blends of LKD plus quicklime to produce a lime-based product.

1.2 Cored specimens of soil-lime should be tested in accordance with Test Methods **D2166/D2166M**.

1.3 Two alternative procedures are provided:

1.3.1 Procedure A describes procedures for preparing and testing compacted soil-lime specimens having height-to-diameter ratios between 2.00 and 2.50. This test method provides the standard measure of compressive strength.

1.3.2 Procedure B describes procedures for preparing and testing compacted soil-lime specimens using Test Methods **D698** compaction equipment and molds commonly available in most soil testing laboratories. Procedure B is considered to provide relative measures of individual specimens in a suite of test specimens rather than standard compressive strength values. Because of the lesser height-to-diameter ratio (1.15) of the cylinders, compressive strength determined by Procedure B will normally be greater than that by Procedure A.

1.3.3 Results of unconfined compressive strength tests using Procedure B should not be directly compared to those obtained using Procedure A.

¹ These test methods are under the jurisdiction of ASTM Committee **D18** on Soil and Rock and is the direct responsibility of Subcommittee **D18.15** on Stabilization With Admixtures.

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1.4 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice **D6026**.

1.4.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.5 Lime is not an effective stabilizing agent for all soils. Some soil components such as sulfates, phosphates, organics, etc. can adversely affect soil-lime reactions and may affect the test results using this method.

1.6 **Units**—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.6.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs. The rationalized slug unit is not given, unless dynamic ($F = ma$) calculations are involved.

1.6.2 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft³ shall not be regarded as non-conformance with this standard.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use. For specific precautionary statements, see Section 8.*

*A Summary of Changes section appears at the end of this standard

1.8 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 ASTM Standards:²

- C51** Terminology Relating to Lime and Limestone (as Used by the Industry)
- C977** Specification for Quicklime and Hydrated Lime for Soil Stabilization
- D653** Terminology Relating to Soil, Rock, and Contained Fluids
- D698** Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))
- D2166/D2166M** Test Method for Unconfined Compressive Strength of Cohesive Soil
- D2216** Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- D2488** Practice for Description and Identification of Soils (Visual-Manual Procedures)
- D3551** Practice for Laboratory Preparation of Soil-Lime Mixtures Using Mechanical Mixer
- D3740** Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- D4753** Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing
- D6026** Practice for Using Significant Digits and Data Records in Geotechnical Data

3. Terminology

3.1 Definitions:

3.1.1 Refer to Terminology **D653** for terms relating to soil and Definitions **C51** for terms relating to lime and limestone.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *unconfined compressive strength of soil-lime* (q_u), n —the compressive stress at which an unconfined cylindrical specimen of soil-lime will fail in an axial compression test.

3.2.1.1 *Discussion*—In this test method, unconfined compressive strength is either the maximum axial load/force attained per unit area or the load/force per unit area at 5 % axial strain, whichever occurs first during performance of a test.

3.2.2 *carbonation, n*—partial or complete transformation of calcium hydroxide or magnesium hydroxide (or both) to carbonate phases due to reaction with carbon dioxide.

3.2.2.1 *Discussion*—Carbonation may take place during manufacture and storage of lime, laboratory mixing, curing and testing of soil-lime mixtures, construction, and service. Car-

bonation will reduce the effectiveness of the lime in producing desired soil-lime reactions.

3.2.3 See Section 7 on Reagents and Materials.

4. Summary of Test Method

4.1 Dependent on design criteria, a predetermined number of compacted soil-lime specimens are prepared for each specified lime content (the ratio, expressed as a percentage, of (a) the dry (as received/packaged) mass of lime to (b) the dry mass of soil), unit weight, and water content so unconfined compression testing can be performed on laboratory cured specimens of specified ages. In many instances, single or preferably duplicate specimens are tested following a 28 and 90-day curing period at room temperature. In some cases, however, a curing period of 7 days at room temperature or accelerated curing conditions may be necessary.

4.2 The amount of soil, lime, and water required for the specimen is determined. The soil-lime-water mixture is compacted in a mold to the desired initial specimen conditions (moist/dry unit weight and molding water content).

4.3 After removal from the mold, specimens are cured for a specified number of days.

4.4 Following the curing period, the soil-lime specimens are loaded in compression to failure. Maximum load or load at 5 % axial strain is used to calculate unconfined compressive strength.

5. Significance and Use

5.1 Compression testing of soil-lime specimens is performed to determine unconfined compressive strength of the cured soil-lime-water mixture to determine the suitability of the mixture for uses such as in pavement bases and subbases, stabilized subgrades, and structural fills.

5.2 Compressive strength data are used in soil-lime mix design procedures: (a) to determine if a soil will achieve a significant strength increase with the addition of lime; (b) to group soil-lime mixtures into strength classes; (c) to study the effects of variables such as lime percentage, unit weight, water content, curing time, curing temperature, etc.; and (d) to estimate other engineering properties of soil-lime mixtures.

5.3 Lime is generally classified as calcitic or dolomitic. Usually in soil stabilization, high-calcium lime [CaO] or dolomitic lime [CaO + MgO] are used. The lime is transformed from oxide to hydroxide form [[Ca(OH)₂ or [Ca(OH)₂ + Mg(OH)₂]] by the addition of water in the soil, a slurry tank, or at a manufacturing facility. Lime may increase the strength of cohesive soil. The type of lime in combination with soil type influences the resulting compressive strength.

NOTE 2—The agency performing this test method can be evaluated in accordance with Practice **D3740**. Notwithstanding statements on precision and bias contained in this method: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facility used. Agencies that meet the criteria of Practice **D3740** are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with Practice **D3740** does not, in itself, ensure reliable testing. Reliable testing depends on many factors; Practice **D3740** provides a

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

means of evaluating some of these factors.

6. Apparatus

6.1 Balance or Scale:

6.1.1 *Specimen Masses*—A balance or scale which will measure masses to four significant digits and conforming to the requirements of either Class GP2 or GP5 in Guide D4753.

6.1.1.1 The minimum capacity requirement for Procedure A is typically 1000 g; while for Procedure B it is typically 20 000 g.

6.1.2 *Water Content Masses*—A balance or scale which will enable water content determinations to be determined to the nearest 0.1 % and conforming to the requirements of either Class GP1, GP2 or GP5 in Guide D4753. The type of class required depends upon the size of the water content specimen and its water content.

6.1.2.1 To meet this requirement, masses less than about 400 g have to be measured to 4 significant digits; while larger masses to three significant digits.

6.2 *Specimen Dimension Measurement Devices*, dial comparators, calipers, circumferential tape or other suitable devices for measuring the height and diameter of the specimen to three significant digits.

6.2.1 If densities/unit weights are required to four significant digits (density to nearest 0.001 Mg/m^3 or unit weight to nearest 0.1 lbf/ft^3), then the specimen dimensions have to be measured to four significant digits.

6.3 Specimen Molds:

6.3.1 *Procedure A*, molds having sufficient capacity to provide specimens with length-to-diameter ratios between 2.00 and 2.50. Molds shall have a minimum inside diameter (ID) of 50 mm [2.0 in.]. Split molds may be used. The mold shall have an extension collar assembly made of rigid metal and constructed so it can be securely attached to and detached from the mold.

6.3.2 *Procedure B*, molds with extension collars conforming to the requirements of Test Methods D698.

6.4 *Tamping Rod or Compaction Hammer*, tamping rod or compaction hammer suitable for mold size and preparation of specimen at desired unit weight.

6.5 *Test Specimen Extruder*, an extruder is required if split molds are not used. The device shall consist of a piston, jack, and frame or similar equipment suitable for extruding specimens from the mold.

6.6 *Containers*, suitable plastic airtight, moisture proof containers for sealing and storing specimens after compaction. The containers should be rigid to protect the specimens from disturbance during handling.

6.7 *Miscellaneous Equipment*, tools such as spatulas, knives, straightedge, trowels, scoops, etc., for use in preparing specimens.

6.8 *Temperature Controlled Room or Cabinet*, a room or cabinet capable of maintaining a temperature of $23 \pm 2^\circ\text{C}$ [$73 \pm 4^\circ\text{F}$] for curing soil-lime specimens. A moist room can be used but is not required.

6.9 *Timer*, a timing device to indicate the elapsed testing time to the nearest second for establishing the rate of strain application prescribed in 13.2.

6.10 *Compression Device and Load/Force Indicator*, the compression device may be any device with sufficient capacity and control to provide a constant rate of deformation to meet the requirements of 13.2. The device shall be equipped so the compressive load is applied to the specimen without producing eccentric loading conditions. When the compression device is set to advance at a specified rate, the actual rate shall not deviate from the required value by more than $\pm 20\%$, with the change in rate being gradual, not stick-slip (Note 3).

NOTE 3—The loading conditions of most loading frames with multiple gear-drive settings vary more than expected; that is, more than about $\pm 10\%$.

6.10.1 The load/force indicator shall have a direct readability of at least three significant digits at failure, with a minimum full range accuracy of 0.25 %.

6.11 *Deformation Indicator*, the deformation indicator (mechanical or electronic) shall have a minimum readability (without interpolation) of 0.02 mm [0.001 in.] and have a travel range sufficient to measure 6 % axial strain (see 14.2).

7. Reagents and Materials

7.1 *Hydrated Lime*—Lime that is predominantly calcium hydroxide [$\text{Ca}(\text{OH})_2$] or a mixture of $\text{Ca}(\text{OH})_2$ and magnesium oxide (MgO) or magnesium hydroxide [$\text{Mg}(\text{OH})_2$], or both. Only fresh lime meeting the requirements of Specification C977 may be used. Bagged lime must be kept sealed because of the tendency for the lime to undergo carbonation.

7.2 *Quicklime*—Lime which is predominantly calcium oxide (CaO) or CaO in association with MgO. Only fresh lime meeting the requirements of Specification C977 may be used. Bagged lime must be kept sealed because of the tendency for the lime to combine with CO_2 in air.

7.3 *Tapwater*—Tapwater that is free of acids, alkalies, and oils and is suitable for drinking shall be used for wetting the soil.

8. Safety Hazards

8.1 Lime chemically reacts with water and can become hot. Appropriate safety equipment, such as gloves, protective eyewear, respirator, and plastic apron should be worn when handling lime.

9. Technical Hazards

9.1 Perform compaction as quickly as possible after the curing period to minimize additional lime carbonation and unrecorded moisture loss.

9.2 When compacting specimens, tamping should be uniform and consistent over the surface of each layer, and scarify between layers.

9.3 Handle compacted soil-lime specimens so as to prevent disturbance or changes in cross section or loss of moisture.

9.4 Lime can react with some metals such as aluminum and zinc. Therefore, aluminum foil and metal pans and containers

consisting of aluminum and zinc shall not be used for storing lime, curing a soil-lime mixture(s), or curing a soil-lime compacted specimen(s).

10. Test Specimens

10.1 *Specimen Size*—Specimens shall have a minimum diameter of 50 mm [2.0 in.], and the largest particle contained within the test specimen shall be smaller than $\frac{1}{10}$ of the specimen diameter. For specimens having a diameter of 72 mm [2.8 in.] or larger, the largest particle size shall be smaller than $\frac{1}{6}$ of the specimen diameter.

10.2 Calculate the quantity of soil, lime, and water required for one specimen and the total quantities of each needed to prepare the required number of test specimens at each prescribed lime content, percent of maximum dry unit weight, and water content. The values of maximum dry unit weight and optimum water content are determined in accordance with Test Methods D698. The initial water content of soil, as determined using Test Method D2216, is used to calculate the additional water required to bring the soil-lime mixture to the desired water contents. Approximately 10 % more material than calculated should be prepared to ensure that enough material is available.

10.3 Mix the soil-lime mixtures in accordance with Practice D3551. See Section 11 before compaction.

10.4 Select the proper compaction mold in accordance with the procedure to be used.

10.4.1 *Procedure A, (Specimens Having Height-to-Diameter Ratios Between 2.0 and 2.5)*—Prepare specimens by compacting material in at least three layers into a mold meeting the requirements of 6.3.1. Specimens may be compacted to the desired unit weight by either: (1) kneading, tamping, or impacting (Test Methods D698) each layer until the accumulative mass of the soil placed in the mold is compacted to a known volume, or (2) adjusting the number of layers, the number of tamps/blows per layer, and the force per tamp/blow (Note 4). The ends of the specimen should be perpendicular to the longitudinal axis. Scarify the top of each layer prior to the addition of material for the next layer. After the specimen is formed, remove the mold. Determine and record the mass of the specimen, length of the specimen, and diameter of the specimen at midheight to the number of significant digits prescribed in Section 6 (6.1 and 6.2).

NOTE 4—When comparing strength data between laboratories, the details on specimen preparation should be known, as the preparation method affects unit weight as strength is affected by the method of compaction, the compacted unit weight and the molding water content.

10.4.2 *Procedure B*—Compact specimens in accordance with the procedure given in Test Methods D698. Scarify the surfaces of the first two layers prior to adding material for the next layer. Take steps to ensure layer heights are approximately equal. After a specimen is formed and its moist/dry unit weights are determined (Test Methods D698), extrude the specimen from the mold and determine and record the mass of the specimen, length of the specimen, and diameter of the specimen at midheight. The significant digits in these measurements shall be in accordance with that prescribed in Section 6.

10.5 After the mass and dimensions of the specimen have been determined, place the specimen in an airtight, moisture proof container and allow the specimen to cure in accordance with Section 12 on curing test specimens.

11. Conditioning

11.1 Store lime in a plastic, airtight, moisture proof container to keep it dry and free from carbonation.

11.2 Store the soil in an airtight, moisture proof container to preserve the water content.

11.3 Allow the soil-water-lime mixture to mellow in an airtight, moisture-proof container as specified, before compacting.

11.3.1 A 24-h mellowing period is typical, although periods exceeding 48 h have been used for high plasticity soils.

12. Curing Specimens

12.1 Randomize the specimens for testing to ensure representative test results.

12.2 Cure compacted test specimens in an airtight, moisture proof container at a temperature of $23 \pm 2^\circ\text{C}$ [$73 \pm 4^\circ\text{F}$] for the specified curing period.

12.2.1 Any curing period may be specified, however, most commonly used curing periods are 7, 28, and 90 days.

12.2.2 The container cannot contain aluminum or zinc, see 9.4.

12.3 The test specimens should be wrapped and sealed in plastic or placed in rubber sleeves to reduce carbonation. Curing conditions different from those specified should be noted on the test data sheet/form, see Section 15.

12.3.1 When accelerated curing conditions are necessary to expedite the curing process for simulating long-term field conditions, curing temperatures in excess of 49°C [120°F] should be avoided. Research indicates that a temperature of 40°C [105°F] at various curing times is appropriate for accelerated curing without introducing pozzolanic reactive products that significantly differ from those expected during field curing.

12.3.2 A damp cloth placed within the curing container, but not in contact with the soil-lime specimen, will maintain humid conditions for curing and will prevent drying.

13. Procedure

13.1 Determine and record the mass of the specimen, see 10.4.1 or 10.4.2. If the change in mass is greater than about 2 %, re-measure and record the dimensions of the specimen, see 10.4.1 and 10.4.2.

13.2 Place the specimen in the loading device so it is centered on the bottom platen. Carefully adjust the loading device so the upper platen just makes contact with the specimen. Zero the deformation indicator. Apply the load continuously and without shock so as to produce an axial deformation rate of approximately 0.5 to 2.0 % per min. The lower rate should be selected for brittle specimens, while the higher rate for non-brittle specimens.

13.3 Record load (axial force), deformation, and time values at intervals sufficient to define the shape of the stress-strain