



# Standard Test Method for Unconfined Compressive Strength of Cohesive Soil<sup>1</sup>

This standard is issued under the fixed designation D 2166; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope \*

1.1 This test method covers the determination of the unconfined compressive strength of cohesive soil in the undisturbed, remolded, or compacted condition, using strain-controlled application of the axial load.

1.2 This test method provides an approximate value of the strength of cohesive soils in terms of total stresses.

1.3 This test method is applicable only to cohesive materials which will not expel or bleed water (water expelled from the soil due to deformation or compaction) during the loading portion of the test and which will retain intrinsic strength after removal of confining pressures, such as clays or cemented soils. Dry and crumbly soils, fissured or varved materials, silts, peats, and sands cannot be tested with this method to obtain valid unconfined compression strength values.

NOTE 1—The determination of the unconsolidated, undrained strength of cohesive soils with lateral confinement is covered by Test Method D 2850.

1.4 This test method is not a substitute for Test Method D 2850.

1.5 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.5.1 The procedures used to specify how data are collected/recorded and calculated in this test method are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to commensurate with these considerations. It is beyond the scope of this test method to consider significant digits used in analysis methods for engineering design.

1.6 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate.

1.7 *This standard does not purport to address all of the safety problems, 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.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

D 422 Test Method for Particle-Size Analysis of Soils<sup>2</sup>

D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>

D 854 Test Method for Specific Gravity of Soil Solids by Water Pycnometer<sup>2</sup>

D 1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes<sup>2</sup>

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass<sup>2</sup>

D 2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)<sup>2</sup>

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)<sup>2</sup>

D 2850 Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression<sup>2</sup>

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design Construction<sup>2</sup>

D 4220 Practices for Preserving and Transporting Soil Samples<sup>2</sup>

D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils<sup>2</sup>

D 6026 Practice for Using Significant Digits in Geotechnical Data<sup>3</sup>

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods<sup>4</sup>

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method<sup>4</sup>

## 3. Terminology

3.1 *Definitions:* Refer to Terminology D 653 for standard definitions of terms.

### 3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *unconfined compressive strength ( $q_u$ )*—the compressive stress at which an unconfined cylindrical specimen of soil

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 04.08.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 04.09.

<sup>4</sup> *Annual Book of ASTM Standards*, Vol 14.02.

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

will fail in a simple compression test. In this test method, unconfined compressive strength is taken as the maximum load attained per unit area or the load per unit area at 15 % axial strain, whichever is secured first during the performance of a test.

3.2.2 *shear strength* ( $s_u$ )—for unconfined compressive strength test specimens, the shear strength is calculated to be  $\frac{1}{2}$  of the compressive stress at failure, as defined in 3.2.1.

#### 4. Significance and Use

4.1 The primary purpose of the unconfined compression test is to quickly obtain the approximate compressive strength of soils that possess sufficient cohesion to permit testing in the unconfined state.

4.2 Samples of soils having slickensided or fissured structure, samples of some types of loess, very soft clays, dry and crumbly soils and varved materials, or samples containing significant portions of silt or sand, or both (all of which usually exhibit cohesive properties), frequently display higher shear strengths when tested in accordance with Test Method D 2850. Also, unsaturated soils will usually exhibit different shear strengths when tested in accordance with Test Method D 2850.

4.3 If both an undisturbed and a remolded test are performed on the same sample, the sensitivity of the material can be determined. This method of determining sensitivity is suitable only for soils that can retain a stable specimen shape in the remolded state.

NOTE 2—For soils that will not retain a stable shape, a vane shear test or Test Method D 2850 can be used to determine sensitivity.

NOTE 3—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing/sampling/inspection. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

#### 5. Apparatus

5.1 *Compression Device*—The compression device may be a platform weighing scale equipped with a screw-jack-activated load yoke, a hydraulic loading device, or any other compression device with sufficient capacity and control to provide the rate of loading prescribed in 7.1. For soil with an unconfined compressive strength of less than 100 kPa (1.0 ton/ft<sup>2</sup>) the compression device shall be capable of measuring the compressive stress to within 1 kPa (0.01 ton/ft<sup>2</sup>). For soil with an unconfined compressive strength of 100 kPa (1.0 ton/ft<sup>2</sup>) or greater, the compression device shall be capable of measuring the compressive stress to the nearest 5 kPa (0.05 ton/ft<sup>2</sup>).

5.2 *Sample Extruder*, capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube, at a uniform rate, and with negligible disturbance of the sample. Conditions at the time of sample removal may dictate the direction of removal, but the principal concern is to keep the degree of disturbance negligible.

5.3 *Deformation Indicator*—The deformation indicator

shall be a dial indicator graduated to 0.03 mm (0.001 in.) or better and having a travel range of at least 20 % of the length of the test specimen, or some other measuring device, such as an electronic deformation measuring device, meeting these requirements.

5.4 *Dial Comparator*, or other suitable device, for measuring the physical dimensions of the specimen to within 0.1 % of the measured dimension.

NOTE 4—Vernier calipers are not recommended for soft specimens, which will deform as the calipers are set on the specimen.

5.5 *Timer*—A timing device indicating the elapsed testing time to the nearest second shall be used for establishing the rate of strain application prescribed in 7.1.

5.6 *Balance*—The balance used to weigh specimens shall determine the mass of the specimen to within 0.1 % of its total mass.

5.7 *Equipment*, as specified in Test Method D 2216.

5.8 *Miscellaneous Apparatus*, including specimen trimming and carving tools, remolding apparatus, remove the water content cans, and data sheets, as required.

#### 6. Preparation of Test Specimens

6.1 *Specimen Size*—Specimens shall have a minimum diameter of 30 mm (1.3 in.) and the largest particle contained within the test specimen shall be smaller than one tenth 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 one sixth of the specimen diameter. If, after completion of a test on an undisturbed specimen, it is found, based on visual observation, that larger particles than permitted are present, indicate this information in the remarks section of the report of test data (Note 5). The height-to-diameter ratio shall be between 2 and 2.5. Determine the average height and diameter of the test specimen using the apparatus specified in 5.4. Take a minimum of three height measurements (120° apart), and at least three diameter measurements at the quarter points of the height.

NOTE 5—If large soil particles are found in the specimen after testing, a particle-size analysis performed in accordance with Method D 422 may be performed to confirm the visual observation and the results provided with the test report.

6.2 *Undisturbed Specimens*—Prepare undisturbed specimens from large undisturbed samples or from samples secured in accordance with Practice D 1587 and preserved and transported in accordance with the practices for Group C samples in Practices D 4220. Tube specimens may be tested without trimming except for the squaring of ends, if conditions of the sample justify this procedure. Handle specimens carefully to prevent disturbance, changes in cross section, or loss of water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut it off in small sections to facilitate removal of the specimen without disturbance. Prepare carved specimens without disturbance, and whenever possible, in a humidity-controlled room. Make every effort to prevent any change in water content of the soil. Specimens shall be of uniform circular cross section with ends perpendicular to the longitudinal axis of the specimen. When carving or trimming, remove

any small pebbles or shells encountered. Carefully fill voids on the surface of the specimen with remolded soil obtained from the trimmings. When pebbles or crumbling result in excessive irregularity at the ends, cap the specimen with a minimum thickness of plaster of paris, hydrostone, or similar material. When sample condition permits, a vertical lathe that will accommodate the total sample may be used as an aid in carving the specimen to the required diameter. Where prevention of the development of appreciable capillary forces is deemed important, seal the specimen with a rubber membrane, thin plastic coatings, or with a coating of grease or sprayed plastic immediately after preparation and during the entire testing cycle. Determine the mass and dimensions of the test specimen. If the specimen is to be capped, its mass and dimensions should be determined before capping. If the entire test specimen is not to be used for determination of water content, secure a representative sample of trimmings for this purpose, placing them immediately in a covered container. The water content determination shall be performed in accordance with Test Method D 2216.

**6.3 Remolded Specimens**—Specimens may be prepared either from a failed undisturbed specimen or from a disturbed sample, providing it is representative of the failed undisturbed specimen. In the case of failed undisturbed specimens, wrap the material in a thin rubber membrane and work the material thoroughly with the fingers to assure complete remolding. Avoid entrapping air in the specimen. Exercise care to obtain a uniform density, to remold to the same void ratio as the undisturbed specimen, and to preserve the natural water content of the soil. Form the disturbed material into a mold of circular cross section having dimensions meeting the requirements of 6.1. After removal from the mold, determine the mass and dimensions of the test specimens.

**6.4 Compacted Specimens**—Specimens shall be prepared to the predetermined water content and density prescribed by the individual assigning the test (Note 6). After a specimen is formed, trim the ends perpendicular to the longitudinal axis, remove from the mold, and determine the mass and dimensions of the test specimen.

NOTE 6—Experience indicates that it is difficult to compact, handle, and obtain valid results with specimens that have a degree of saturation that is greater than 90 %.

## 7. Procedure

7.1 Place the specimen in the loading device so that it is centered on the bottom platen. Adjust the loading device carefully so that the upper platen just makes contact with the specimen. Zero the deformation indicator. Apply the load so as to produce an axial strain at a rate of 1/2 to 2 %/min. Record load, deformation, and time values at sufficient intervals to define the shape of the stress-strain curve (usually 10 to 15 points are sufficient). The rate of strain should be chosen so that the time to failure does not exceed about 15 min (Note 7). Continue loading until the load values decrease with increasing strain, or until 15 % strain is reached. The rate of strain used for testing sealed specimens may be decreased if deemed desirable for better test results. Indicate the rate of strain in the report of the test data, as required in 9.1.7. Determine the water content of the test specimen using the entire specimen, unless repre-

sentative trimmings are obtained for this purpose, as in the case of undisturbed specimens. Indicate on the test report whether the water content sample was obtained before or after the shear test, as required in 9.1.2.

NOTE 7—Softer materials that will exhibit larger deformation at failure should be tested at a higher rate of strain. Conversely, stiff or brittle materials that will exhibit small deformations at failure should be tested at a lower rate of strain.

7.2 Make a sketch, or take a photo, of the test specimen at failure showing the slope angle of the failure surface if the angle is measurable.

7.3 A copy of an example data sheet is included in Appendix X1. Any data sheet can be used, provided the form contains all the required data.

## 8. Calculation

8.1 Calculate the axial strain,  $\epsilon_1$ , to the nearest 0.1 %, for a given applied load, as follows:

$$\epsilon_1 = \Delta L / L_0$$

where:

$\Delta L$  = length change of specimen as read from deformation indicator, mm (in.), and

$L_0$  = initial length of test specimen, mm (in).

8.2 Calculate the average cross-sectional area,  $A$ , for a given applied load, as follows:

$$A = A_0 / (1 - \epsilon_1)$$

where:

$A_0$  = initial average cross-sectional area of the specimen, mm<sup>2</sup>(in.<sup>2</sup>), and

$\epsilon_1$  = axial strain for the given load, %.

8.3 Calculate the compressive stress,  $\sigma_c$ , to three significant figures, or nearest 1 kPa (0.01 ton/ft<sup>2</sup>), for a given applied load, as follows:

$$\sigma_c = (P/A)$$

where:

$P$  = given applied load, kPa (ton/ft<sup>2</sup>),

$A$  = corresponding average cross-sectional area mm<sup>2</sup>(in.<sup>2</sup>).

8.4 *Graph*—If desired, a graph showing the relationship between compressive stress (ordinate) and axial strain (abscissa) may be plotted. Select the maximum value of compressive stress, or the compressive stress at 15 % axial strain, whichever is secured first, and report as the unconfined compressive strength,  $q_u$ . Whenever it is considered necessary for proper interpretation, include the graph of the stress-strain data as part of the data reported.

8.5 If the undisturbed and remolded compressive strengths are remolded, determine the sensitivity,  $S_T$ , is calculated as follows:

$$S_T = \frac{q_u \text{ (undisturbed specimen)}}{q_u \text{ (remolded specimen)}}$$

## 9. Report

9.1 The report should include the following:

9.1.1 Identification and visual description of the specimen, including soil classification, symbol, and whether the specimen

is undisturbed, remolded, compacted, etc. Also include specimen identifying information, such as project, location, boring number, sample number, depth, etc. Visual descriptions shall be made in accordance with Practice D 2488,

9.1.2 Initial dry density and water content (specify if the water content specimen was obtained before or after shear, and whether from trimmings or the entire specimen),

9.1.3 Degree of saturation (Note 8), if computed,

NOTE 8—The specific gravity determined in accordance with Test Method D 854 is required for calculation of the degree of saturation.

9.1.4 Unconfined compressive strength and shear strength,

9.1.5 Average height and diameter of specimen,

9.1.6 Height-to-diameter ratio,

9.1.7 Average rate of strain to failure, %,

9.1.8 Strain at failure, %,

9.1.9 Liquid and plastic limits, if determined, in accordance with Test Method D 4318,

9.1.10 Failure sketch or photo,

9.1.11 Stress-strain graph, if prepared,

9.1.12 Sensitivity, if determined,

9.1.13 Particle size analysis, if determined, in accordance with Method D 422, and

9.1.14 *Remarks*—Note any unusual conditions or other data that would be considered necessary to properly interpret the results obtained, for example, slickensides, stratification, shells, pebbles, roots, or brittleness, the type of failure (that is, bulge, diagonal shear, etc.).

## 10. Precision and Bias

10.1 *Precision*—Criteria for judging the acceptability of test results obtained by this test method on rigid polyurethane foam (density about 0.09 g/cm<sup>3</sup>) is given in Table 1. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.<sup>5</sup> The precision estimates will vary with the material/soil type being tested, and judgement is required when applying these estimates to soil.

<sup>5</sup> Research Report RR: D18-1014 contains the data and statistical analysis used to establish these precision statements and it is available from ASTM Headquarters.

**TABLE 1 Summary of Test Results from Each Laboratory (Compressive Strength Data on Rigid Polyurethane Foam (density about 0.09 g/cm<sup>3</sup>))**

(1)	(2)	(3)	(4)	(5)
Number of Triplicate Test Laboratories	Test Parameter <sup>A</sup>	Average Value <sup>B</sup>	Standard Deviation <sup>C</sup>	Acceptable Range of Two Results <sup>D</sup>
<i>Single-Operator Results (Within-Laboratory Repeatability):</i>				
22	Strength, kPa	989	42	120
22	Strain, %	4.16	0.32	0.9
<i>Multilaboratory Results (Between-Laboratory Reproducibility):</i>				
22	Strength, kPa	989	53	150
22	Strain, %	4.16	0.35	1.0

<sup>A</sup>Strength = peak compressive stress and strain = axial strain at peak compressive stress.

<sup>B</sup>The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D 6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

<sup>C</sup>Standard deviation is calculated in accordance with Practice E 691 and is referred to as the 1s limit.

<sup>D</sup>Acceptable range of two results is referred to as the *d*2s limit. It is calculated as  $1.960\sqrt{2} \cdot 1s$ , as defined by Practice E 177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by this test method or Practice D 6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

10.1.1 The data in Table 1 are based on three replicate tests performed by each test laboratory. The single-operator and multilaboratory standard deviation shown in Table 1, Column 4, were obtained in accordance with Practice E 691. Results of two properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator *d*2s limits shown in Table 1, Column 5. For definition of *d*2s see Footnote D in Table 1. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory *d*2s limits shown in Table 1, Column 5.

10.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

## 11. Keywords

11.1 cohesive soil; sensitivity; strain-controlled loading; strength; stress-strain relationships; unconfined compression

APPENDIX

(Nonmandatory Information)

X1. Example Data Sheet

UNCONFINED COMPRESSION TEST—UI

Name \_\_\_\_\_ Date \_\_\_\_\_ Job No. \_\_\_\_\_

Location \_\_\_\_\_

Boring No. \_\_\_\_\_ Sample No. \_\_\_\_\_ Depth/Elev. \_\_\_\_\_

Description of Sample \_\_\_\_\_

\_\_\_\_\_

Proving Ring No. \_\_\_\_\_ Apparatus No. \_\_\_\_\_

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Water Content Determination

Tare No. \_\_\_\_\_

Wt. Specimen Wet + Tare \_\_\_\_\_

Wt. Specimen Dry + Tare \_\_\_\_\_

Wt. Water \_\_\_\_\_

Wt. Tare \_\_\_\_\_

Wt. Specimen Wet \_\_\_\_\_

Wt. Specimen Dry \_\_\_\_\_

Water Content in % Dry Wt.  
at 105°C \_\_\_\_\_ %

Wet Density \_\_\_\_\_

Dry Density \_\_\_\_\_

Unconfined Compressive Strength

Initial Diameter  $D_o$  \_\_\_\_\_

Initial Area  $A_o$  \_\_\_\_\_

Initial Height  $L_o$  \_\_\_\_\_

Initial Volume  $V_o$  \_\_\_\_\_

Specific Gravity \_\_\_\_\_

$$\text{Stress} = \frac{\text{Load}}{\text{Corr. Area}}$$

Test Data

$$\text{Unit Strain} = \frac{\Delta L}{L_o}$$

$$\frac{L}{D} = \frac{\text{Current Length}}{\text{Initial Diameter}}$$

$$\text{Corr. Area} = \frac{A_o}{1 - \text{Unit Strain}}$$

Elapsed Time-min	Load Dial	Axial Load	Strain Dial	Total Strain	Unit Strain	Corrected Area	Stress	

Type of Sample \_\_\_\_\_

Attach a photo or sketch of the specimen after failure to this form

Strain Rate \_\_\_\_\_ %/Min

Remarks \_\_\_\_\_

\_\_\_\_\_

## SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (98a) that may impact the use of this standard.

- (1) In the Scope section, added 1.5 and 1.5.1 that cover the application of Practice D 6026 in this test method and removed Note 2. (Renumbered the remaining subsections.)
- (2) In Referenced Documents, added Practices D 6026, E 177, and E 691 in 2.1.
- (3) In the Significance and Use section, changed Note 3 to Note 2, and added new Note 3 referencing Practice D 3740 in accordance with the policy of Committee D18. (Renumbered the remaining notes.)
- (4) The precision statement in 10.1 was changed to include data based on testing rigid polyurethane foam (density about 0.09 g/cm<sup>3</sup>).

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