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Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils[1]

This standard is issued under the fixed designation D 2850; 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 (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 This test method covers determination of the strength and stress-strain relationships of a cylindrical specimen of either undisturbed or remolded cohesive soil. Specimens are subjected to a confining fluid pressure in a triaxial chamber. No drainage of the specimen is permitted during the test. The specimen is sheared in compression without drainage at a constant rate of axial deformation (strain controlled).

1.2 This test method provides data for determining undrained strength properties and stress-strain relations for soils. This test method provides for the measurement of the total stresses applied to the specimen, that is, the stresses are not corrected for pore-water pressure.

NOTE 1—The determination of the unconfined compressive strength of cohesive soils is covered by Test Method D 2166.

NOTE 2—The determination of the consolidated, undrained strength of cohesive soils with pore pressure measurement is covered by Test Method D 4767.

1.3 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units and given in parentheses are approximate.

1.4 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 422 Method for Particle-Size Analysis of Soils[2]
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]
D 854 Test Method for Specific Gravity of Soils[2]
D 1587 Method for Thin-Walled Tube Sampling of Soils[2]
D 2166 Test Methods for Unconfined Compressive Strength of Cohesive Soil[2]
D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[2]
D 2487 Classification of Soils for Engineering Purposes[2]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[2]
D 3740 Practice for Evaluation of Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction[2]
D 4220 Practices for Preserving and Transporting Soil Samples[2]
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[2]
D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Testing Soil and Rock, and Related Construction Materials[2]
D 4767 Test Method for Consolidated-Undrained Triaxial Compression Test on Cohesive Soils[2]

3. Terminology

3.1 Definitions—The definitions of terms used in this test method shall be in accordance with Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *failure*—the stress condition at failure for a test specimen. Failure is often taken to correspond to the maximum principal stress difference (deviator stress) attained or the principal stress difference (deviator stress) at 15 % axial strain, whichever is obtained first during the performance of a test.

3.2.2 *unconsolidated-undrained compressive strength*—the value of the principal stress difference (deviator stress) at failure.

4. Significance and Use

4.1 In this test method, the compressive strength of a soil is determined in terms of the total stress, therefore, the resulting strength depends on the pressure developed in the pore fluid during loading. In this test method, fluid flow is not permitted from or into the soil specimen as the load is applied, therefore the resulting pore pressure, and hence strength, differs from that developed in the case where drainage can occur.

4.2 If the test specimens are 100 % saturated, consolidation cannot occur when the confining pressure is applied nor during the shear portion of the test since drainage is not permitted. Therefore, if several specimens of the same material are tested, and if they are all at approximately the same water content and void ratio when they are tested, they will have approximately the same undrained shear strength. The Mohr failure envelope

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

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

will usually be a horizontal straight line over the entire range of confining stresses applied to the specimens if the specimens are fully saturated.

4.3 If the test specimens are partially saturated or compacted specimens, where the degree of saturation is less than 100 %, consolidation may occur when the confining pressure is applied and during shear, even though drainage is not permitted. Therefore, if several partially saturated specimens of the same material are tested at different confining stresses, they will not have the same undrained shear strength. Thus, the Mohr failure envelope for unconsolidated undrained triaxial tests on partially saturated soils is usually curved.

4.4 The unconsolidated undrained triaxial strength is applicable to situations where the loads are assumed to take place so rapidly that there is insufficient time for the induced pore-water pressure to dissipate and for consolidation to occur during the loading period (that is, drainage does not occur).

4.5 Compressive strengths determined using this procedure may not apply in cases where the loading conditions in the field differ significantly from those used in this test method.

NOTE 3—Notwithstanding the statements on precision and bias contained in this test method: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies which meet the criteria of Practice D 3740 are generally considered capable of competent testing. Users of this test method are cautioned that compliance with Practice D 3740 does not ensure reliable testing. Reliable testing depends on several factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Axial Loading Device*—The axial loading device may be screw jack driven by an electric motor through a geared transmission, a hydraulic loading device, or any other compression device with sufficient capacity and control to provide the rate of loading prescribed in 7.5. The rate of advance of the loading device should not deviate by more than ±5 % from the selected value. Vibrations due to the operation of the loading device shall be sufficiently small to not cause dimensional changes in the specimen.

NOTE 4—A loading device may be said to provide sufficiently small vibrations if there are no visible ripples in a glass of water placed on the loading platen when the device is operating at the speed at which the test is performed.

5.2 *Axial Load-Measuring Device*—The axial load-measuring device shall be a load ring, electronic load cell, hydraulic load cell, or any other load-measuring device capable of measuring the axial load to an accuracy of 1 % of the axial load at failure and may be a part of the axial loading device.

5.3 *Triaxial Compression Chamber*—The triaxial chamber shall consist of a top plate and a baseplate separated by a cylinder. The cylinder may be constructed of any material capable of withstanding the applied pressure. It is desirable to use a transparent material or have a cylinder provided with viewing ports so the behavior of the specimen may be observed. The top plate shall have a vent valve such that air can be forced out of the chamber as it is filled. The base plate shall have an inlet through which the pressure liquid is supplied to the chamber.

5.4 *Axial Load Piston*—The piston passing through the top of the chamber and its seal must be designed so the variation in axial load due to friction does not exceed 0.1 % of the axial load at failure as measured in 8.4.1.3 and so there is negligible lateral bending of the piston during loading.

NOTE 5—The use of two linear ball bushings to guide the piston is recommended to minimize friction and maintain alignment.

NOTE 6—A minimum piston diameter of one sixth the specimen diameter has been used successfully in many laboratories to minimize lateral bending.

5.5 *Pressure Control Device*—The chamber pressure control device shall be capable of applying and controlling the chamber pressure to within ±2 kPa (0.25 psi) for pressures less than 200 kPa (28 psi) and to within ±1 % for pressures greater than 200 kPa (28 psi). This device may consist of a reservoir connected to the triaxial chamber and partially filled with the chamber fluid (usually water), with the upper part of the reservoir connected to a compressed gas supply; the gas pressure being controlled by a pressure regulator and measured by a pressure gage, electronic pressure transducer, or any other device capable of measuring to the prescribed tolerance. However, a hydraulic system pressurized by deadweight acting on a piston or any other pressure-maintaining and measurement device capable of applying and controlling the chamber pressure to the tolerance prescribed in this section may be used.

5.6 *Specimen Cap and Base*—An impermeable rigid cap and base shall be used to prevent drainage of the specimen. The specimen cap and base shall be constructed of a noncorrosive impermeable material, and each shall have a circular plane surface of contact with the specimen and a circular cross section. The weight of the specimen cap shall produce an axial stress on the specimen of less than 1 kN/m^2. The diameter of the cap and base shall be equal to the initial diameter of the specimen. The specimen base shall be connected to the triaxial compression chamber to prevent lateral motion or tilting and the specimen cap shall be designed such that eccentricity of the piston to cap contact relative to the vertical axis of the specimen does not exceed 1.3 mm (0.05 in.). The end of the piston and specimen cap contact area shall be designed so that tilting of the specimen cap during the test is minimal. The cylindrical surface of the specimen base and cap that contacts the membrane to form a seal shall be smooth and free of scratches.

5.7 *Deformation Indicator*—The vertical deformation of the specimen shall be measured with an accuracy of at least 0.03 % of the specimen height. The deformation indicator shall have a range of at least 20 % of the height of the specimen, and may be a dial indicator, linear variable differential transformer (LVDT), extensiometer or other measuring device meeting the requirements for accuracy and range.

5.8 *Rubber Membrane*—The rubber membrane used to encase the specimen shall provide reliable protection against leakage. Membranes shall be carefully inspected prior to use, and if any flaws or pinholes are evident, the membrane shall be discarded. To offer minimum restraint to the specimen, the unstretched membrane diameter shall be between 90 and 95 % of that of the specimen. The membrane thickness shall not exceed 1 % of the diameter of the specimen. The membrane shall be sealed to the specimen base and cap with rubber

O-rings for which the unstressed inside diameter is between 75 and 85 % of the diameter of the cap and base or by any method that will produce a positive seal. An equation for correcting the principal stress difference (deviator stress) for the effect of the stiffness of the membrane is given in 8.6.

5.9 *Sample Extruder*—The sample extruder shall be capable of extruding the soil core from the sampling tube in the same direction of travel in which the sample entered the tube and with minimum disturbance of the sample. If the soil core is not extruded vertically, care should be taken to avoid bending stresses on the core due to gravity. Conditions at the time of sample removal may dictate the direction of removal, but the principal concern is to keep the degree of disturbance minimal.

5.10 *Specimen Size Measurement Devices*— Devices used to measure the height and diameter of the specimen shall be capable of measuring the desired dimension to within 0.1 % of its actual length and shall be constructed such that their use will not disturb the specimen.

NOTE 7—Circumferential measuring tapes are recommended over calipers for measuring the diameter.

5.11 *Timer*—A timing device indicating the elapsed testing time to the nearest 1 s shall be used for establishing the rate of strain application prescribed in 7.5.

5.12 *Balances*—A balance or scale conforming to the requirements of Specification D 4753 readable (with no estimation) to 0.1 % of the test mass, or better.

5.13 *Miscellaneous Apparatus*—Specimen trimming and carving tools including a wire saw, steel straightedge, miter box and vertical trimming lathe, apparatus for preparing compacted specimens, remolding apparatus, water content cans, and data sheets shall be provided as required.

6. Test Specimens

6.1 *Specimen Size*—Specimens shall be cylindrical and have a minimum diameter of 3.3 cm (1.3 in.). The height-to-diameter ratio shall be between 2 and 2.5. The largest particle size shall be smaller than one sixth the specimen diameter. If, after completion of a test, it is found based on visual observation that oversize particles are present, indicate this information in the report of test data (see 9.1.12).

NOTE 8—If oversize particles are found in the specimen after testing, a particle-size analysis may be performed in accordance with Test Method D 422 to confirm the visual observation and the results provided with the test report (see 9.1.4).

6.2 *Undisturbed Specimens*—Prepare undisturbed specimens from large undisturbed samples or from samples secured in accordance with Practice D 1587 or other acceptable undisturbed tube sampling procedures. Samples shall be preserved and transported in accordance with the practices for Group C samples in Practices D 4220. Specimens obtained by tube sampling may be tested without trimming except for cutting the end surfaces plane and perpendicular to the longitudinal axis of the specimen, provided soil characteristics are such that no significant disturbance results from sampling. Handle specimens carefully to minimize disturbance, changes in cross section, or change in water content. If compression or any type of noticeable disturbance would be caused by the extrusion device, split the sample tube lengthwise or cut the tube in suitable sections to facilitate removal of the specimen with minimum disturbance. Prepare trimmed specimens, in an environment such as a controlled high-humidity room where soil water content change is minimized. Where removal of pebbles or crumbling resulting from trimming causes voids on the surface of the specimen, carefully fill the voids with remolded soil obtained from the trimmings. When the sample condition permits, a vertical trimming lathe may be used to reduce the specimen to the required diameter. After obtaining the required diameter, place the specimen in a miter box and cut the specimen to the final height with a wire saw or other suitable device. Trim the surfaces with the steel straightedge. Perform one or more water content determinations on material trimmed from the specimen in accordance with Test Method D 2216. Determine the mass and dimensions of the specimen using the devices described in 5.11 and 5.9. A minimum of three height measurements (120° apart) and at least three diameter measurements at the quarter points of the height shall be made to determine the average height and diameter of the specimen.

6.3 *Compacted Specimens*—Soil required for compacted specimens shall be thoroughly mixed with sufficient water to produce the desired water content. If water is added to the soil, store the material in a covered container for at least 16 h prior to compaction. Compacted specimens may be prepared by compacting material in at least six layers using a split mold of circular cross section having dimensions meeting the requirements enumerated in 6.1. Specimens may be compacted to the desired density by either: (*1*) kneading or tamping each layer until the accumulative mass of the soil placed in the mold is compacted to a known volume; or (*2*) by adjusting the number of layers, the number of tamps per layer, and the force per tamp. The top of each layer shall be sacrified prior to the addition of material for the next layer. The tamper used to compact the material shall have diameter equal to or less than one half the diameter of the mold. After a specimen is formed, with the ends perpendicular to the longitudinal axis, remove the mold and determine the mass and dimensions of the specimen using the devices described in 5.11 and 5.9. Perform one or more water content determinations on excess material used to prepare the specimen in accordance with Test Method D 2216.

NOTE 9—It is common for the unit weight of the specimen after removal from the mold to be less than the value based on the volume of the mold. This occurs as a result of the specimen swelling after removal of the lateral confinement due to the mold.

7. Procedure

7.1 Place the membrane on the membrane expander or, if it is to be rolled onto the specimen, place the membrane onto the cap or base. Place the specimen on the base. Place the rubber membrane around the specimen and seal it at the cap and base with O-rings or other positive seals at each end. A thin coating of silicon grease on the vertical surfaces of the cap or base will aid in sealing the membrane.

7.2 With the specimen encased in the rubber membrane, which is sealed to the specimen cap and base and positioned in the chamber, assemble the triaxial chamber. Bring the axial load piston into contact with the specimen cap several times to permit proper seating and alignment of the piston with the cap. When the piston is brought into contact the final time, record the reading on the deformation indicator. During this procedure, take care not to apply an axial stress to the specimen exceeding approximately 0.5 % of the estimated compressive strength. If the weight of the piston is sufficient to apply an axial stress exceeding approximately 0.5 % of the estimated compressive strength, lock the piston in place above the specimen cap after checking the seating and alignment and keep locked until application of the chamber pressure.

7.3 Place the chamber in position in the axial loading device. Be careful to align the axial loading device, the axial load-measuring device, and the triaxial chamber to prevent the application of a lateral force to the piston during testing. Attach the pressure-maintaining and measurement device and fill the chamber with the confining liquid. Adjust the pressure-maintaining and measurement device to the desired chamber pressure and apply the pressure to the chamber fluid. Wait approximately 10 min after the application of chamber pressure to allow the specimen to stabilize under the chamber pressure prior to application of the axial load.

NOTE 10—In some cases the chamber will be filled and the chamber pressure applied before placement in the axial loading device.

NOTE 11—Make sure the piston is locked or held in place by the axial loading device before applying the chamber pressure.

NOTE 12—The waiting period may need to be increased for soft or partically saturated soils.

7.4 If the axial load-measuring device is located outside of the triaxial chamber, the chamber pressure will produce an upward force on the piston that will react against the axial loading device. In this case, start the test with the piston slightly above the specimen cap, and before the piston comes in contact with the specimen cap, either: (*1*) measure and record the initial piston friction and upward thrust of the piston produced by the chamber pressure and later correct the measured axial load, or (*2*) adjust the axial load-measuring device to compensate for the friction and thrust. If the axial load-measuring device is located inside the chamber, it will not be necessary to correct or compensate for the uplift force acting on the axial loading device or for piston friction. In both cases record the initial reading on the deformation indicator when the piston contacts the specimen cap.

7.5 Apply the axial load to produce axial strain at a rate of approximately 1 %/min for plastic materials and 0.3 %/min for brittle materials that achieve maximum deviator stress at approximately 3 to 6 % strain. At these rates, the elapsed time to reach maximum deviator stress will be approximately 15 to 20 min. Continue the loading to 15 % axial strain, except loading may be stopped when the deviator stress has peaked then dropped 20 % or the axial strain has reached 5 % beyond the strain at which the peak in deviator stress occurred.

7.6 Record load and deformation values at about 0.1, 0.2, 0.3, 0.4, and 0.5 % strain; then at increments of about 0.5 % strain to 3 %; and, thereafter at every 1 %. Take sufficient readings to define the stress-strain curve; hence, more frequent readings may be required in the early stages of the test and as failure is approached.

NOTE 13—Alternate intervals for the readings may be used provided sufficient points are obtained to define the stress-strain curve.

7.7 After completion of the test, remove the test specimen from the chamber. Determine the water content of the test specimen in accordance with Test Method D 2216 using the entire specimen, if possible.

7.8 Prior to placing the specimen (or portion thereof) in the oven to dry, sketch a picture or take a photograph of the specimen showing the mode of failure (shear plane, bulging, etc.).

8. Calculation

8.1 Calculate the axial strain, ϵ (expressed as a decimal), for a given applied axial load, as follows:

$$\epsilon = \Delta H/H_o \tag{1}$$

where:
ΔH = change in height of specimen as read from deformation indicator, and
H_o = initial height of test specimen minus any change in length prior to loading.

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

$$A = A_o/(1 - \epsilon) \tag{2}$$

where:
A_o = initial average cross-sectional area of the specimen, and
ϵ = axial strain for the given axial load (expressed as a decimal).

NOTE 14—In the event that the application of the chamber pressure results in a change in the specimen length, A_o, should be corrected to reflect this change in volume. Frequently, this is done by assuming that lateral strains are equal to vertical strains. The diameter after volume change would be given by $D = D_o(1 - \Delta H/H)$.

8.3 Calculate the principal stress difference (deviator stress), $\sigma_1 - \sigma_3$, for a given applied axial load as follows:

$$\sigma_1 - \sigma_3 = P/A \tag{3}$$

where:
P = measured applied axial load (corrected for uplift and piston friction, if required see 7.4), and
A = corresponding average cross-sectional area.

8.4 *Stress-Strain Curve*—Prepare a graph showing the relationship between principal stress difference (deviator stress) and axial strain, plotting deviator stress as ordinate and axial strain (in percent) as abscissa. Select the compressive strength and axial strain at failure in accordance with the definitions in 3.2.1 and 3.2.2.

8.5 *Correction for Rubber Membrane*— Assuming units are consistent, the following equation shall be used to correct the principal stress difference or deviator stress for the effect of the rubber membrane if the error in principal stress difference due to the stiffness of the membrane exceeds 5 %:

$$\Delta(\sigma_1 - \sigma_3) = 4E_m t_m \epsilon_1 / D \tag{4}$$

where:
$\Delta(\sigma_1 - \sigma_3)$ = correction to be subtracted from the measured principal stress difference,

D = $\sqrt{4A/\pi}$ = diameter of specimen,
E_m = Young's modulus for the membrane material,
t_m = thickness of the membrane, and
ϵ_1 = axial strain.

8.5.1 The Young's modulus of the membrane material may be determined by hanging a 10.0-mm wide strip of membrane over a thin rod, placing another rod along the bottom of the hanging membrane, and measuring the force per unit strain obtained by stretching the membrane. The modulus value may be computed using the following equation assuming units are consistent:

$$E_m = FL/A_m \Delta L \quad (5)$$

where:
E_m = Young's modulus of the membrane material,
F = force applied to stretch the membrane,
A_m = twice the initial thickness of the membrane multiplied by the width of the membrane strip,
L = unstretched length of the membrane, and
ΔL = change in length of the membrane due to application of F.

A typical value of E_m for latex membrane is 1400 kN/m^2.

NOTE 15—The effect of the stiffness of the membrane on the lateral stress is usually assumed to be negligible.

NOTE 16—The correction for rubber membranes is based on simplified assumptions concerning their behavior during shear. Their actual behavior is complex and there is not a consensus on more exact corrections.

8.6 Calculate the major and minor principal total stresses at failure as follows:

$$\sigma_3 = \textit{minor principal total stress} = \textit{chamber pressure, and}$$

$$\sigma_1 = \textit{major principal total stress} = \textit{deviator stress at failure plus chamber pressure}.$$

8.7 Calculate the initial degree of saturation of the test specimen using the initial mass and dimensions.

NOTE 17—The specific gravity determined in accordance with Test Method D 854 is required for calculation of the saturation. An assumed specific gravity may be used provided it is noted in the test report that an assumed value was used.

9. Report

9.1 Report the following information:

9.1.1 Identification data and visual description of specimen including soil classification and whether the specimen is undisturbed, compacted, or otherwise prepared,

9.1.2 Values of plastic limit and liquid limit, if determined, in accordance with Test Method D 4318,

9.1.3 Value of specific gravity of solids and notation if the value was determined in accordance with Test Method D 854 or assumed,

9.1.4 Particle-size analysis, if determined, in accordance with Test Method D 422,

9.1.5 Initial height and diameter of the specimen.

9.1.6 Initial specimen dry unit weight, void ratio, water content, and saturation. (Specify if the water content was obtained from cuttings, excess material, or the entire specimen.),

9.1.7 Rate of axial strain, percent per minute,

9.1.8 Axial strain at failure, percent,

9.1.9 The value of the compressive strength and the values of the minor and major principal stresses at failure, (Indicate when values have been corrected for membrane effects),

9.1.10 Stress-strain curve as described in 8.4,

9.1.11 Failure sketch or photograph of the specimen, and

9.1.12 Remarks and notations regarding any unusual conditions such as slickensides, stratification, shells, pebbles, roots, etc., or other information necessary to properly interpret the results obtained including any departures from the procedure outlined.

10. Precision and Bias

10.1 *Precision*—Data are being evaluated to determine the precision of this test method. In addition, Subcommittee D18.05 is seeking pertinent data from users of this test method.

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

11. Keywords

11.1 cohesive soil; lateral confinement; strain-controlled loading; stress-strain relationships; total stresses; unconsolidated undrained strength

SUMMARY OF CHANGES

This section identifies location of changes to this test method since the last edition.

(1) Many parts of this test method have been changed so that this standard contains wording similar to Test Method D 4767 and Test Method D 2166.

(2) Some parts of this test method have been modified to further clarify this test method. Other general improvements have been made.