

Australian Standard®

AS 1289.6.4.2:2016

Methods of testing soils for engineering purposes

Method 6.4.2: Soil strength and consolidation tests—Determination of compressive strength of a soil—Compressive strength of a saturated specimen tested in undrained triaxial compression with measurement of pore water pressure

PREFACE

This Standard was prepared by Standards Australia Committee CE-009, Testing of Soils for Engineering Purposes, to supersede AS 1289.6.4.2—1998.

The objective of this Standard is to set out the method for performing isotropically consolidated undrained (CIU) triaxial tests.

This revision is motivated by improvements in the equipment, instrumentation and computer control capabilities of recent triaxial test apparatus. More emphasis is placed on minimizing sample disturbance during specimen preparation as research since the last revision has emphasized the importance of minimal disturbance on soil strength and stiffness.

This revision describes the procedure for a single stage test. It doesn't preclude multi-stage tests, however the determination of c' and ϕ has been removed. This revision also brings the Standard more in line with other international Standards.

METHOD

1 SCOPE

This Standard sets out a test procedure applicable to cohesive soils and a method for determining the compressive strength of a specimen of soil in a triaxial compression apparatus under conditions in which the cell pressure is maintained constant (see Appendix B1).

A typical test will involve a stage in which an all-round pressure is applied following which the sample is allowed to drain, a saturation stage in which pressures are increased to minimize the amount of air within the specimen, and a shearing stage performed at a constant rate of axial deformation. During the shearing stage, drainage of water from the specimen is prevented so that there is no change in the total water content of the specimen. The pore pressure is monitored throughout the test. The test described is limited to specimens in the form of right cylinders with height to diameter ratio of $2 \pm 2\%$.

The test method is limited to soil materials that can be trimmed to produce right circular cylinders that maintain their shape when unsupported. Undrained triaxial compression tests can be performed on materials which cannot stand unsupported however, special techniques are required for the specimen preparation, and differences in test procedure from this Standard may be required, for which information can be obtained from the reference sources (see Appendix B1).

The specific conditions of the test procedure, including the saturation procedure and the effective consolidation pressure, are specified by a geotechnical engineer who is responsible for ensuring the test method is appropriate for the data required.

Interpretation of the results to determine cohesion parameters and friction angles is beyond the Scope of this Standard. Guidance is provided in the reference sources given in Appendix B1.

2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS

1289 Methods of testing soils for engineering purposes

1289.2.1.1 Method 2.1.1: Soil moisture content tests—Determination of the moisture content of a soil—Oven drying method (standard method)

Bishop and Henkel, The Measurement of Soil Properties in the Triaxial Test

Head, K.H. and Epps, Roger, *Manual of Soil Laboratory Testing: Volume 2 Permeability, Shear Strength and Compressibility Tests*, 3rd ed, Taylor & Francis, U.K., 2011

Head, K.H. and Epps, Roger, *Manual of Soil Laboratory Testing: Volume 3 Effective Stress Tests*, 3rd ed, Whittles Publishing, U.K., 2014

3 DEFINITIONS

3.1 Sample

The soil submitted to the laboratory for testing.

3.2 Specimen

The portion of the sample upon which the test is performed.

4 APPARATUS

The following apparatus is required and shall be operated in a room in which the temperature is maintained at a constant level of $21 \pm 2^\circ\text{C}$:

- (a) A triaxial test cell of dimensions appropriate to the size of the specimen, suitable for use with water as cell fluid and capable of withstanding a pressure of 1700 kPa. The cell shall be provided with a means of applying additional axial compressive load to the specimen through a loading ram.

The cell shall include a base pedestal of the same diameter as the test specimen. Where the base pedestal is not integral with the cell base it shall be secured to the cell base so that the pedestal is level and axially aligned with the loading ram.

The top cap shall be the same diameter as the test specimen and its mass will be such that the vertical stress due to the top cap shall not exceed 1% of the maximum deviator stress or 1 kPa, whichever is the greater. The top cap shall have either—

- (i) a central seating which will not transmit moment (a ball and cone assembly is suitable) to receive the loading ram; or
- (ii) a means of creating a rigid connection with the loading ram. In this case an internal load cell shall be used to measure the axial load.

Both base pedestal and top cap shall include porous discs in contact with the specimen. The porous discs shall be made of silicon carbide, aluminium oxide, sintered bronze or other materials which are not attacked by soil or soil moisture. The discs shall be sufficiently rigid to withstand the pressures applied without changes in physical properties. The discs shall be sufficiently fine so that soil will not extrude into the pores, but shall be sufficiently coarse so as to have permeability appreciably greater than the soil sample. The coefficient of permeability of the porous discs shall be greater than 10^{-6} m/s for clayey materials and greater than 10^{-4} m/s for silty materials. Filter paper discs may be placed between the soil specimen and the porous discs to prevent intrusion of fine soil particles. Any filter paper so used should be at least as permeable as the porous discs when subjected to the applied deviator stress (a hard high grade filter paper, such as Grade No. 54, is recommended).

The base pedestal and top cap shall both be capable of permitting drainage from the ends of the specimen to outside the cell. Suitable valves shall be provided to allow back pressure to be applied and change in volume to be measured from either one or both ends. The hydraulic line from either the base pedestal or the top cap shall be capable of being connected to a pore pressure measurement system and closed off beyond the pore pressure measurement take-off.

- (b) Apparatus for applying, maintaining and measuring the desired pressure in the water within the cell to an accuracy of ± 2 kPa.
- (c) An A grade machine capable of applying axial compression to the specimen at convenient speeds. A speed of application in the range 0.0005 to 5 mm/min is normally satisfactory. The machine shall be capable of applying an axial deformation of approximately one-third of the height of the specimen.
- (d) Apparatus for measuring the additional axial load on the specimen to an accuracy of 0.5% of the axial load at failure or ± 2 N, whichever is the greater. This level of accuracy can best be achieved by the use of a load measuring device within the triaxial cell. If such a device is used it shall be insensitive to non-axial loads and the cell pressure, or capable of correction to allow for any influence of the cell pressure. If an external axial load measuring device is used it is important to ensure that friction between the piston and the sealing bushing does not influence the results. The alignment of the loading ram shall be such that it passes vertically through the bushing and no significant lateral loads are generated by its connection to the loading machine.
- (e) Apparatus for measuring the axial deformation of the specimen to 0.01 ± 0.005 mm, together with an adjustable reference point attached to the cell.
- (f) Apparatus for measuring the pore pressure in the specimen with an accuracy of ± 2 kPa. The volume change (ΔV in cubic millimetres) in the pore pressure measuring system shall be not more than that given by the following equation:

$$\frac{\Delta V}{V \times u} = 0.5 \times 10^{-6}, \text{ in } m^2/kN \quad \dots 4(1)$$

where

V = volume of the specimen, in cubic millimetres

u = pore pressure, in kilopascals

- (g) Apparatus for measuring volume change to an accuracy of $\pm 0.01\%$ of the specimen volume or $\pm 10 \text{ mm}^3$, whichever is the greater.
- (h) The devices used to measure axial load, pore pressure, volume change and displacement should be capable of recording data automatically at regular intervals throughout the test.

- (i) Apparatus for applying back pressure to the specimen to an accuracy of ± 2 kPa or $\pm 0.5\%$, whichever is the greater. The control of this pressure shall be separate from the cell pressure.

If the effective confining pressure is less than 50 kPa the difference between the cell and back pressures shall be measured to an accuracy of ± 1 kPa. A differential pressure transducer is recommended for this purpose.
- (j) Seamless rubber membrane in the form of a tube, open at both ends, of internal diameter equal to the specimen diameter and of length approximately 50 mm greater than the height of the specimen. The membrane thickness should be selected having regard to the size, strength and nature of the soil to be tested. A thickness of 0.25 mm to 0.4 mm is normally satisfactory.
- (k) Membrane stretcher to suit the size of the specimen.
- (l) Rubber rings of circular cross-section and internal diameter smaller than the diameter of the end caps.
- (m) Sampling tubes with a sharp cutting edge at the inner surface or a soil lathe for preparing test specimens of the required diameter directly from a block sample in the laboratory.
- (n) Sample extruder.
- (o) Trimming device, e.g. split mould or mitre box and wire saw for obtaining plane ends normal to the axis of cylindrical specimens.
- (p) Mould or formers and auxiliary apparatus, for preparing remoulded specimens.
- (q) Apparatus for the determination of moisture content as described in AS 1289.2.1.1.
- (r) A balance of appropriate capacity to measure the mass of the wet specimen.

5 PREPARATION OF SPECIMENS

Procedures for the preparation of test specimens vary considerably in detail but the aim is to produce specimens of required dimensions while minimizing the disturbance and changes to moisture content. The diameter of the specimen is to be selected having regard to the character of the soil and the maximum size of particles present in the sample. The diameter should not be less than 38 mm.

The preparation of specimens shall be as follows:

- (a) Obtain from a sample a subsample of the desired diameter in one of the following ways:
 - (i) Extrusion from a thin-walled sample tube having the same diameter as that desired. In this case special care is required to extract an undisturbed test specimen as significant compression within the sample tube may occur on pushing the sample. The height of the sample before and after extrusion shall be recorded.
 - (ii) Splitting of a thin-walled sample tube having the same diameter as that desired. This is required if the sample cannot be extracted by pushing. In this case disturbance may occur due to stress relief resulting in extensive micro-fracturing. Any visible disturbance shall be recorded.
 - (iii) After extraction of a subsample from a thin-walled tube of a larger diameter than desired, a lightly oiled thin-walled tube having the desired specimen dimensions may be pushed into the subsample by progressively and carefully trimming the specimen ahead of the cutting face.

- (iv) From a block sample, gently trim a soil cylinder using a soil lathe to provide a test specimen of the required dimensions.
- (v) From a disturbed sample, compact a specimen to the desired moisture/density condition in a split mould or former. The minimum diameter should be at least 5 times the diameter of the largest particle if the soil is well graded, or at least 10 times the diameter of the largest particle if the soil has a uniform grading.
- (b) Place the subsample obtained by Step (a)(i), Step (a)(ii) or Step (a)(iv), in the trimming device and prepare the ends, plane and parallel, to provide a test specimen of the required height. For subsamples obtained by Step (a)(iii) and Step (a)(v), trim the ends before removing from the mould or former.

Where large particles are lost from the trimmed surfaces the surface voids shall be filled with remoulded soil having the same moisture content.

6 PREPARATION

The preparation shall be as follows (see Paragraph B2):

- (a) Take a photograph of the specimen.
- (b) Measure and record the height and diameter to 0.2 mm and the mass of the sample to an accuracy of $\pm 0.2\%$.
- (c) Determine the moisture content of trimmings obtained during the sample preparation following AS 1289.2.1.1.
- (d) Ensure that all connecting drainage lines are filled with de-aired water (see Paragraph B4) taking special care to ensure that there are no air bubbles in the fluid lines between the specimen and apparatus for measuring pore pressures and water supply for saturation.
- (e) If the soil is a stiff clay the porous discs should be placed on the base pedestal and top cap dry, to avoid the clay softening and swelling. Otherwise saturate the porous discs by either boiling or vacuum impregnation. Place the porous discs and filter paper above and below the specimen. Place the specimen on the base pedestal and put the top cap on top of the specimen.
- (f) If filter paper radial drainage is to be used this needs to be placed on the specimen. It is important that filter paper strips not cover more than 50% of the specimen to minimize the effects of the strips on the test response.
- (g) Using the membrane stretcher, place the rubber membrane around the specimen and seal the membrane to the pedestal and end cap by means of rubber rings. Connect a line from the top cap to the cell base or other exit point.
- (h) Assemble the cell with the loading ram initially clear of the top cap of the specimen and place the cell containing the specimen in the loading machine.
- (i) Connect all remaining pressure control and pressure measurement lines to appropriate apparatus, taking care to exclude air.
- (j) Fill the cell with potable water. The cell and pore pressure zero readings shall be taken when the water level in the cell is at the mid-height of the specimen.
- (k) After the cell is filled, bring the loading ram into contact with the top cap. In doing this care is required to ensure the axial load does not exceed a load equivalent to an axial stress of 3 kPa. When the ram is in contact the reading of the axial displacement recording device shall be recorded.

7 SATURATION

It is required that the specimen shall be back pressure saturated to ensure near total saturation, and the following procedure shall be adopted:

- (a) Apply an initial saturation pressure of 10 kPa to 15 kPa to the specimen. (Higher values, up to the estimated in-situ effective stress, may be required for very stiff clays that are expected to swell when water is provided.) In no circumstances shall the initial cell pressure be higher than the final effective cell pressure (the difference between the cell and back pressure) specified for the shear test. Record the initial reading of the volume change measuring apparatus. Then allow the specimen to drain from both ends and consolidate while maintaining a zero back pressure. Readings of volume change with time shall be taken at regular intervals until reaching equilibrium with no further change of volume. The coefficient of consolidation (c_v) can be calculated if required at this point following the procedure in Appendix A.

For more permeable materials with low initial degrees of saturation the process of allowing the specimen to reach equilibrium under the initial saturation pressure is not appropriate. In this case de-aired water may be permeated through the specimen after applying the initial saturation pressure of 10 kPa to 20 kPa. During permeation the water pressure at the base of the specimen shall be at least 5 kPa less than the applied cell pressure and shall be no greater than 10 kPa, and the top drain shall be open to the atmosphere. Permeation shall continue until no further air bubbles are observed coming from the top drain or for a maximum of 2 h. When permeation is completed drainage from top and bottom of the specimen shall be connected to the back pressure device which should maintain a zero back pressure.

- (b) The next part of the saturation process involves simultaneously increasing both the cell pressure and the back pressure. A final back pressure of 300 kPa to 600 kPa would be suitable for most soils. The rate at which the pressures are increased shall be sufficiently slow to allow pore pressure equalization.

To achieve these objectives, the cell and back pressure shall be raised at a steady rate of <5 kPa/min while maintaining the original difference in cell and back pressure. This procedure is designed to ensure that the effective stress on the specimen during the saturation stage shall not exceed that which is to be applied during the shearing stage.

Once the final back pressure is reached the specimen shall be allowed to saturate in this condition for not less than 12 h with longer time periods required for stiffer soils. A back pressure of around 900 kPa may be required for effective saturation in some soils to ensure the air in the specimen is dissolved. If the specimen is initially nearly saturated then much lower cell and back pressures may be used.

- (c) Check the effectiveness of the saturation process by closing off all drainage taps, increasing the cell pressure by Δc (where Δc should be between 20 kPa to 50 kPa) and measuring the consequent change in the pore pressure, Δu . The value of Δu shall be measured within 15 minutes of raising the cell pressure to avoid the value being unduly affected by undrained creep.

The resultant of $\Delta u/\Delta c$ shall not be less than 0.95. Where $\Delta u/\Delta c$ is less than 0.95, continue to increase the cell and back pressures in the sequence given in Step (b) and allowing it to stand for a further 12 h, maintaining the original value of excess cell pressure until $\Delta u/\Delta c$ is ≥ 0.95 .

In very stiff soils it is impossible to achieve $\Delta u/\Delta c \geq 0.95$ even when the soil is fully saturated. For these soils the back pressure may be raised to the maximum value considering the limiting capacity of the cell and other equipment.

- (d) At the end of the saturation stage bring the loading ram in contact with the specimen to measure the specimen height and determine any changes during saturation. Follow the procedure in Clause 6(j).