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Geotechnical investigation and testing — Laboratory testing of soil —

Part 8: Unconsolidated undrained triaxial test

Reconnaissance et essais géotechniques — Essais de laboratoire sur les sols —

Partie 8: Essai triaxial non consolidé non drainé

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical investigation and testing*, in collaboration with ISO Technical Committee TC 182, *Geotechnics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition of ISO 17892-8 cancels and replaces ISO/TS 17892-8:2004 and ISO/TS 17892-8:2004/Cor.1:2006.

A list of all the parts in the ISO 17892 series can be found on the ISO website.

Introduction

This document covers areas in the international field of geotechnical engineering never previously standardized. It is intended that this document presents broad good practice throughout the world and significant differences with national documents is not anticipated. It is based on international practice (see Reference [1]).

Geotechnical investigation and testing — Laboratory testing of soil —

Part 8: Unconsolidated undrained triaxial test

1 Scope

This document specifies a method for unconsolidated undrained triaxial compression tests.

This document is applicable to the laboratory determination of undrained triaxial shear strength under compression loading within the scope of geotechnical investigations.

The cylindrical specimen, which can comprise undisturbed, re-compacted, remoulded or reconstituted soil, is subjected to an isotropic stress under undrained conditions and thereafter is sheared under undrained conditions. The test allows the determination of shear strength and stress-strain relationships in terms of total stresses.

Non-standard procedures such as tests with the measurement of pore pressure or tests with filter drains are not covered in this document.

NOTE This document fulfils the requirements of unconsolidated undrained triaxial compression tests for geotechnical investigation and testing in accordance with EN 1997-1 and EN 1997-2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14688-1, *Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description*

ISO 17892-1, *Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content*

ISO 17892-2, *Geotechnical investigation and testing — Laboratory testing of soil — Part 2: Determination of bulk density*

ISO 17892-3, *Geotechnical investigation and testing — Laboratory testing of soil — Part 3: Determination of particle density*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
cell pressure
pressure applied to the cell fluid

3.2
deviator stress
difference between the applied vertical total stress and the horizontal total stress at the mid height of the specimen

3.3
undrained shear strength
equal to one half of the deviator stress at failure in the unconsolidated undrained triaxial compression test

3.4
failure
stress or strain condition at which one of the following criteria are met:

— peak deviator stress;

— a specified deformation criterion if a peak deviator stress has not been achieved, e.g., 15 % vertical strain.

4 Symbols

A_i initial cross-sectional area of the specimen

A_{cor} cross-sectional area of the specimen during shear

a cross-sectional area of the piston if an external load cell is used

c_u undrained shear strength

D_m initial internal diameter of membrane (before it is placed on the specimen)

E_m elastic modulus for the membrane, measured in tension

f factor relating the vertical strain to the specimen volumetric strain

H_s initial height of the specimen prior to shearing ($=H_i$-ΔH_i)

H_i Initial height of specimen after preparation

h distance from the top of the top cap to the mid height of the specimen

P vertical load reading

t_m initial thickness of the unstressed membrane

V_i initial volume of the specimen after preparation

W gravity force acting on the sum of the deadweight hanger (if used), the piston, the top cap and one half of the soil specimen

γ unit weight of the cell fluid

ΔH_i height change prior to shearing

ΔH_s height change during shearing

$(\Delta\sigma_v)_m$ correction to vertical total stress due to the membrane

ε_v vertical strain

$(\varepsilon_v)_m$ vertical strain of the membrane

σ_c cell pressure at the mid height of the specimen

σ_h horizontal total stress at the mid height of the specimen

σ_v vertical total stress at the mid height of the specimen

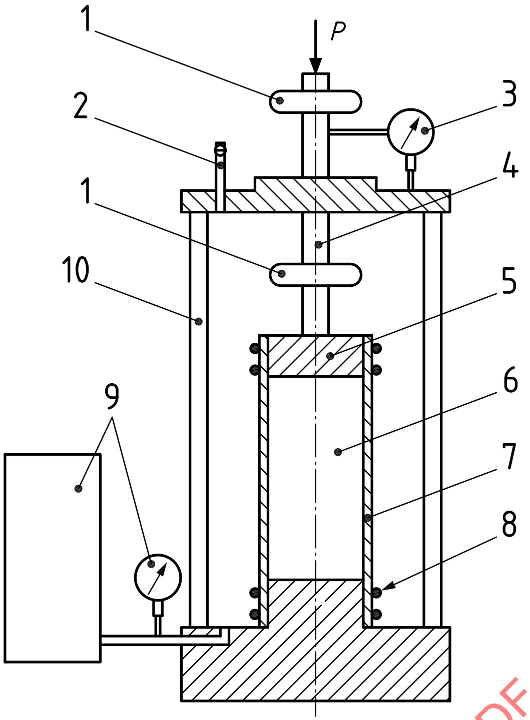
ΔV specimen volume change (with reduction in volume being a positive numerical value)

5 Apparatus

5.1 General

The apparatus shall undergo regular maintenance, checks and calibration as specified in Annex A.

A schematic diagram of a typical apparatus for triaxial compression testing is shown in Figure 1.



Key

1 alternative positions for load measuring device
2 air bleed
3 vertical displacement measuring device
4 piston
5 top cap
6 soil specimen
7 rubber membrane
8 O-rings
9 device for control and measurement of cell pressure
10 triaxial cell
P vertical load

Figure 1 — Schematic diagram of a typical unconsolidated undrained triaxial apparatus

5.2 Triaxial cell

5.2.1 The triaxial cell shall be able to withstand the applied cell pressure without leakage of cell fluid out of the cell. Transparent cells should be used where possible.

5.2.2 The sealing bushing and piston guide shall be designed such that the piston runs smoothly with minimal friction and maintains alignment.

5.2.3 The material of the top cap and the pedestal and the connection between the top cap and the piston shall be such that their deformations are negligible compared to the deformations of the soil specimen.

5.2.4 The diameter of the top cap and of the pedestal should normally be equal to the diameter of the specimen. Specimens with diameters smaller than the diameter of the end caps may be tested provided cavities under the membrane at the ends of the specimen can be avoided.

5.2.5 The vertical stress applied to the specimen due to the weight of the top cap should not exceed 2 % of the estimated undrained shear strength of the specimen or 1 kPa, whichever is the greater.

5.3 Confining membrane

5.3.1 The soil specimen shall be confined by an elastic membrane which effectively prevents the cell fluid from penetrating into the specimen.

NOTE Membranes with an elastic modulus of around 1 400 kPa have been found to be suitable.

5.3.2 A confining membrane that gives a correction on the estimated undrained shear strength of less than 10 % at failure should be used (see 7.4).

If rubber membranes are used, membranes with following properties should be used:

— unstretched diameter between 95 % and 100 % of specimen (after being stored in water);

— thickness not exceeding 1 % of the specimen diameter.

5.3.3 O-rings or similar, used to seal the confining membrane to the top and to the pedestal, shall have dimensions and elastic properties such that the confining membrane is firmly sealed to the top cap and to the pedestal.

5.4 Cell pressure system

The device for applying the cell pressure shall be capable of maintaining a stable pressure within 1 kPa or 1 % of the absolute pressure, whichever is the greater.

5.5 Load frame

5.5.1 The load frame shall be able to provide a range of rates of vertical strain as required for the test (see 6.4.1). The actual rate applied shall not fluctuate more than 10 % of the intended value. The movement of the platen shall be smooth without vibration such that fluctuations do not occur in the test results.

5.5.2 The stroke of the load frame shall be more than that required for the test. A value of 30 % of the specimen height is normally suitable.

5.6 Measuring devices

5.6.1 Load measuring device

The accuracy of the vertical load measuring device, in the range 20 % to 100 % of the capacity of the device, shall be 1 N or 1 % of the actual value, whichever is greater. The device should be insensitive to changes in horizontal forces or bending moments, and to changes in temperature or cell pressure during a test, unless the performance is sufficiently stable that the effect can be corrected.

The capacity of the load measuring device should be chosen so that the failure load is at least 20 % of its capacity.

NOTE Class 1 load measuring devices to ISO 7500-1 meet this accuracy requirement.

5.6.2 Pressure measuring device

The cell pressure measuring device shall be sufficiently accurate to permit the determination of total cell pressure to 1 kPa or 0,5 % of the full range of the device, whichever value is the greater.

5.6.3 Vertical displacement measuring device

The device for measuring the change in height of the specimen shall be accurate to 0,1 mm or to 0,1 % of the initial specimen height, whichever value is the greater.

5.7 Cell pressure fluids

The cell fluid should be selected such that it does not significantly penetrate through the membrane into the specimen nor extract pore water from the specimen through the membrane during the duration of the test. The cell fluid should be stabilized to the same temperature as the test location.

NOTE De-aired water is generally found to meet these requirements.

5.8 Ancillary apparatus

The ancillary apparatus consists of:

— balance, accuracy 0,01 g or 0,1 % of the weighed mass, whichever value is the greater,

— timer readable to 1 s;

— maximum/minimum thermometer readable to 1 °C;

— apparatus for determination of water content;

The apparatus for the specimen preparation consists of:

— cutting and trimming tools (e.g. a sharp knife, wire saw, spatula, cutting ring, soil lathe);

— steel straight edge, with a maximum deviation from straight of 0,1 % of its length;

— try-square or a jig (e.g. a mitre box) or split mould to ensure that flatness shall be accurate to within 0,5 % of each dimension and that right-angles are within 0,5° of true;

— callipers, either analogue or digital, readable to 0,1 mm or 0,1 % of the measured length, whichever value is the greater.

6 Test procedure

6.1 General requirements and equipment preparation

6.1.1 The test specimen shall be cylindrical with a diameter not less than 34 mm and a height from 1,8 to 2,5 times the diameter. The largest particle size should not exceed 1/6 of the specimen diameter.

6.1.2 Confining membranes should be immersed in water for at least 24 h before being used. The membranes shall be free of excess surface water on the inside before being placed onto the soil specimen.

6.1.3 Prior to each test check that there is no visible sign of damage to any of the equipment and that the piston runs smoothly

6.1.4 If leakage of water from the cell or any water line is observed at any time during the test, the effect of the leak on the test result shall be evaluated and if detrimental the test may be judged invalid.

6.2 Preparation of specimens

The following procedures shall apply to undisturbed, re-compacted, remoulded or reconstituted samples.

6.2.1 Examine undisturbed samples prior to testing. If significant disturbance is apparent in the specimen this should be recorded in the test report. Highly disturbed samples will not provide meaningful results and should not be tested.

6.2.2 Take care to maintain the water content of the specimen during the preparation process. If the process is interrupted, the specimen shall be protected so that the water content does not change. Air circulation around the specimen shall be avoided.

6.2.3 Cut and trim the specimen to the required dimensions. Take care to avoid deforming the specimen during the cutting and trimming process.

6.2.4 The soil specimen end surfaces shall be plane and perpendicular to the longitudinal axis in accordance with ISO 17892-2. Remove grooves and holes in the ends and sides of the specimen by further trimming or by selecting a new specimen if available. Otherwise, fill grooves or holes not exceeding 1/6 of the specimen diameter with remoulded sample material. Grooves and holes in the ends may be filled with a material that hardens with time and which does not release or absorb water.

6.2.5 Specimens may be prepared in the laboratory by reconstituting the material in a mould with or without the rubber membrane mounted inside. Water mixed into the material shall be given time for at least 16 h before compaction to equalize throughout the soil mass.

6.2.6 Measure the specimen height, diameter and mass immediately prior to test in accordance with ISO 17892-2 by linear measurement.

6.2.7 Check that the membrane to be used is free from damage that may cause leakage during the test.

6.2.8 Mount the specimen into the apparatus with the membrane and O-rings, so that it is centred with respect to the top and bottom platens. Take extreme care to avoid, as much as possible, deforming the specimen during the mounting process. Very soft specimens may have to be mounted without touching the specimen by hand at any stage during the preparation.

6.2.9 Complete the assembly of the triaxial cell.

6.3 Application of cell pressure and initial readings

6.3.1 Record the initial reading of the displacement measurement device in contact with the specimen (corresponding to the height H_i).

6.3.2 Adjust the cell pressure to the desired value relative to the mid height of the specimen and allow the specimen to stabilize prior to shearing. A period of approximately 10 min has been found to be suitable.

6.3.3 Unless otherwise specified, the cell pressure should be at least the total over-burden pressure acting on the sample in situ, subject to not exceeding the upper capacity of the equipment being used.

6.3.4 If an internal load cell is used, record the initial load cell reading and lower the piston down until it is just in contact with the specimen.

6.3.5 If an external load cell (i.e. an external load measuring device) is used, lower the piston and record the initial load cell reading while the piston is moving, prior to contact with the specimen. Continue to lower the piston until it is just in contact with the specimen.

6.3.6 The seating load applied to ensure contact between the load cell and specimen should be kept as small as possible.

6.3.7 Take an initial reading of the displacement transducer immediately prior to shearing (corresponding to the height H_S).

6.4 Shearing

6.4.1 Keep the cell pressure constant during shearing. Load the specimen to failure (shearing) by moving the piston into the triaxial cell with a constant rate of axial strain of between 0,3 % and 2 % of the specimen height per minute. In brittle materials, a strain rate towards the lower end of this range may be required to adequately define failure.

6.4.2 During shearing, record the following:

— vertical load

— vertical displacement

— cell pressure

— elapsed time

6.4.3 Select an appropriate recording frequency so that at least 15 readings should be taken prior to failure, and thereafter at least every 0,5 % vertical strain. For brittle materials, readings may need to be taken at smaller intervals of strain to define failure.

6.4.4 If the axial strain at which the test is to be stopped has not been specified, the test may be stopped when the strain reaches 15 %, or exceeds the strain at peak deviator stress by 5 %, or when the deviator stress has reduced by 20 % from the peak value, whichever occurs earlier.

6.5 Dismounting

6.5.1 Unload the piston and reduce the cell pressure to zero. Drain the cell fluid.

6.5.2 Remove the specimen from the triaxial cell as quickly as possible and remove the membrane.

6.5.3 Make a sketch of, or photograph the specimen to illustrate the mode of failure.

6.5.4 Weigh the whole specimen.

6.5.5 Cut the specimen open to allow any internal structures or inhomogeneity to be identified and recorded. If there are particles greater than 1/10 of the specimen diameter their size and approximate proportion shall be noted.

NOTE The presence of particles greater than 1/10 of the specimen diameter can affect the results. The magnitude of the effects will depend on the nature of the specimen and the quantity, location and composition of these particles.

6.5.6 Either determine the dry mass of the entire specimen, or determine the water content of a representative part of the specimen, without further delay in accordance with ISO 17892-1. If a failure surface is present, an additional water content may be taken from near the failure surface.

7 Test results

7.1 Bulk density, dry density and water content

7.1.1 Determine the water content from the final dry mass and the initial wet mass if the whole specimen has been dried. Otherwise the water content of the representative part of the specimen (6.5.6) shall be used.

7.1.2 Determine the initial bulk and dry densities from the initial measurements of specimen dimensions and mass following the linear measurement procedure in accordance with ISO 17892-2.

7.1.3 The initial void ratio and initial degree of saturation, based on a measured or estimated particle density, may be determined.

7.2 Stage prior to shearing

If any height change of the specimen prior to shearing has occurred, the volume change shall be determined from Formula (1):

$$\Delta V = \Delta H_i \times \frac{1}{f} \times \frac{V_i}{H_i} \tag{1}$$

NOTE The value of f is typically 1/3 for homogenous soils with isotropic stresses but other values may be appropriate for soils with anisotropic stresses.

7.3 Shearing

7.3.1 Corrected cross-sectional area

The corrected cross-sectional area of the specimen will vary with time during the test. The cross-sectional area at any point in time shall be determined from the volume change and height change at that time according to Formula (2):

$$A_{cor} = \frac{V_i - \Delta V}{H_i - \Delta H_i - \Delta H_s} \tag{2}$$

NOTE This formula is not strictly valid after the formation of shear planes.

7.3.2 Deviator stress

Calculate the deviator stress according to Formula (3):

$$\sigma_v - \sigma_h = \frac{P + K - (a\sigma_c)}{A_{cor}} - (\Delta\sigma_v)_m \tag{3}$$

where

K is equal to the value of W – [(A – a)h . γ]

This expression for K and Formula (3) are valid when using a load measuring device that is placed outside the triaxial cell (see Figure 1) and for which zero-reading is taken when the load measuring device is un-coupled without being in contact with the specimen. The value of K may be considered as a constant for a particular specimen size and specific triaxial equipment and may be negligible for small specimens and/or light equipment.

Other arrangements and/or procedures may require modifications of the expression for K and of Formula (3).

7.3.3 Vertical strain

The vertical strain shall be determined according to Formula (4):

$$\varepsilon_v = \frac{\Delta H_s}{H_s} \tag{4}$$

7.3.4 Undrained shear strength

Determine the undrained shear strength from the maximum deviator stress according to Formula (5):

$$c_u = (\sigma_v - \sigma_h)/2 \tag{5}$$

7.4 Correction for elastic membrane

Unless more accurate expressions are required, the membrane correction shall be determined according to Formula (6):

$$(\Delta\sigma_v)_m = \frac{4 \times t_m \times E_m}{D_m}(\varepsilon_v)_m \tag{6}$$

The elastic modulus of the membrane may be measured for the material or may be provided by the manufacturer. If a latex membrane is used a value of 1 400 kPa may be assumed.

As an approximation the value of $(\varepsilon_v)_m$ may be assumed to be zero just after placing the membrane on the specimen (i.e. that there are no initial strains) and may be assumed to be equal to subsequent strains in the specimen.

NOTE Formula (6) provides only an approximation for the membrane correction based on a simple assumption of the way in which the membrane deforms during the test.

8 Test report

8.1 Mandatory reporting

The test report shall affirm that the test was carried out in accordance with this document and shall include the following:

a) identification of the specimen tested, e.g., by borehole number, sample number and sample depth and any other relevant details required, e.g., depth of specimen within a sample, method of sample selection if relevant;

b) visual description of the specimen tested including any observed features noted after testing, following the principles in ISO 14688-1 including a description of particles that exceed 1/10 of the specimen diameter if present and a note that the results may have been affected if any particles exceed 1/6 of the specimen diameter;

c) specimen type i.e. undisturbed or artificially prepared and the procedure used for the preparation of specimens;

d) initial specimen dimensions (mm);

e) specimen water content (%) and water content in the failure zone (%), if measured;

f) initial bulk density (Mg/m^3);

g) dry density (Mg/m^3);

h) cell pressure applied to the nearest kPa;

i) specimen height at start of application of deviator stress;

j) mean rate of shear in % strain per minute, or in mm/min, in either case to two significant figures;

k) undrained shear strength to the nearest kPa;

l) strain at failure to the nearest 0,1 %;

m) description, sketch and/or photograph of the specimen showing the type of failure;

n) any deviation from this procedure.

8.2 Optional reporting

The following additional information may be required:

a) degree of saturation and the particle density used (and whether the particle density was measured in accordance with ISO 17892-3, or assumed);

b) initial void ratio and the particle density used (and whether the particle density was measured in accordance with ISO 17892-3, or assumed);

c) plot of shear stress, or deviator stress, as ordinate versus vertical strain as abscissa;

d) Mohr's circle plot.

