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Geotechnical investigation and testing — Laboratory testing of soil —

Part 8: Unconsolidated undrained triaxial test

Reconnaissance et essais géotechniques — Essais de sol au laboratoire —

Partie 8: Essai triaxial non consolidé non drainé

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Foreword

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ISO/TS 17892-8 was prepared by the European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC 182, *Geotechnics*, Subcommittee SC 1, *Geotechnical investigation and testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this document, read "...this European pre-Standard..." to mean "...this Technical Specification...".

ISO 17892 consists of the following parts, under the general title *Geotechnical investigation and testing — Laboratory testing of soil*:

— *Part 1: Determination of water content*

— *Part 2: Determination of density of fine-grained soil*

— *Part 3: Determination of particle density — Pycnometer method*

— *Part 4: Determination of particle size distribution*

— *Part 5: Incremental loading oedometer test*

— *Part 6: Fall cone test*

— *Part 7: Unconfined compression test on fine-grained soil*

— *Part 8: Unconsolidated undrained triaxial test*

— *Part 9: Consolidated triaxial compression tests on water-saturated soil*

— *Part 10: Direct shear tests*

— *Part 11: Determination of permeability by constant and falling head*

— *Part 12: Determination of the Atterberg limits*

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Foreword

This document (CEN ISO/TS 17892-8:2004) has been prepared by Technical Committee CEN/TC 341 "Geotechnical investigation and testing", the secretariat of which is held by DIN, in collaboration with Technical Committee ISO/TC 182 "Geotechnics".

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this Technical Specification: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

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- *Part 12: Determination of Atterberg limits*

Introduction

This document covers areas in the international field of geotechnical engineering never previously standardised. 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 [1]).

1 Scope

This document specifies the test method for the determination of the compressive strength of a cylindrical, water-saturated specimen of undisturbed or remoulded cohesive soil when first subjected to an isotropic stress without allowing any drainage from the specimen, and thereafter sheared under undrained conditions within the scope of the geotechnical investigations according to prEN 1997-1 and -2.

NOTE "Water-saturated" refers to the in-situ condition. The material tested need not necessarily be saturated at all stages during the laboratory testing.

2 Normative references

The following referenced documents are indispensable for the application 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.

prEN 1997-1, *Eurocode 7: Geotechnical design - Part 1: General rules*

prEN 1997-2, *Eurocode 7: Geotechnical design — Part 2: Ground investigation and testing.*

CEN ISO/TS 17892-1, *Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content (ISO/TS 17892-1:2004) .*

CEN ISO/TS 17892-2, *Geotechnical investigation and testing — Laboratory testing of soil — Part 2: Determination of density of fine grained soil (ISO/TS 17892-2:2004).*

CEN ISO/TS 17892-3, *Geotechnical investigation and testing — Laboratory testing of soils — Part 3: Determination of density of soild particles — Pycnometer method (ISO/TS 17892-3:2004)*.

3 Terms and definitions

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

3.1
failure
stress of strain condition at which failure takes place

3.2
cohesive soils
soils that behave as if they were actually cohesive, e.g. clay and clayey soils

NOTE Most soils in this group behave cohesively due to negative pore pressure and friction, and not due to cohesion.

3.3
undisturbed sample
normally sample of quality class 1 according to prEN 1997-2

NOTE If no specification for the failure state is given, failure may be considered to occur at the peak deviator stress.

4 Symbols

ε_1 vertical strain during shearing.

σ_3 minor principal stress or cell pressure.

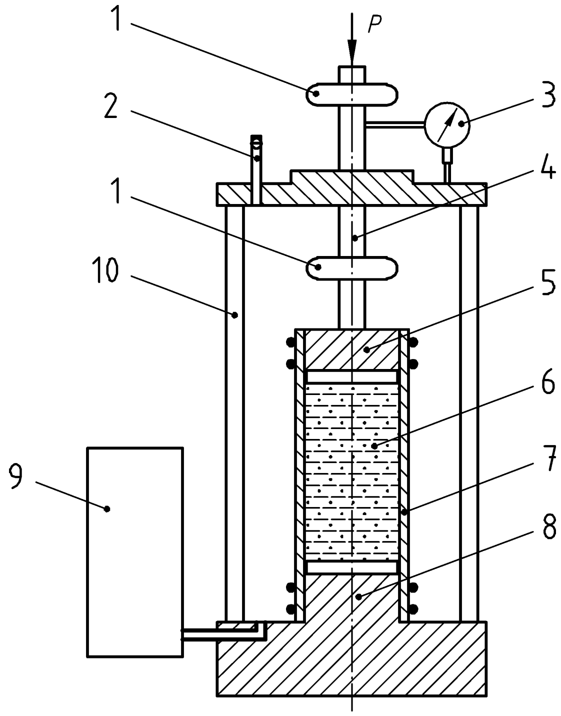
σ major principal stress or vertical stress.

$\sigma_1 - \sigma_3$ deviator stress.

5 Equipment

5.1 General

A schematic diagram of an apparatus for triaxial testing is shown in Figure 1. The requirements for an apparatus are given in the following sections.



Key

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

Figure 1 — Example of a triaxial test unit

5.2 Triaxial cell

5.2.1 The triaxial cell shall be able to withstand the cell pressure without significant leakage of cell fluid out of the cell.

NOTE A cell with a maximum cell pressure of 1500 kPa will be sufficient for nearly all cases. Transparent cells are recommended.

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

5.2.3 The testing procedure, the accuracy of the load measuring device, the design of the piston, its sealing and guide and the design of the connection between the piston and the top cap shall be such that the load at failure is known within ± 3 % or within ± 1 N, whichever is the greater (see NOTE).

The laboratory shall ensure that this accuracy can be achieved with the worst possible combination of vertical and horizontal force and bending moment acting at that end of the piston that sticks into the triaxial cell. If the load measuring device is situated outside the triaxial cell (see Figure 1), it shall be ensured that the friction between the piston and it's sealing bushing is low enough or repeatable enough to permit the failure load to be determined with the required accuracy.

NOTE Smooth running of the piston when subjected to no horizontal load and no cell pressure is no guarantee that this is the case.

If the load measuring device is situated inside the triaxial cell, it shall be ensured that the device is sufficiently insensitive to horizontal forces and/or bending moments to achieve the required accuracy. The influence of the cell pressure on the load cell, if any, shall be sufficiently repeatable to be corrected for.

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

5.2.5 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.

5.2.6 The vertical stress applied on the specimen due to the weight of the top cap may not exceed 3 % of the unconfined compressive strength (compressive strength is equal to two times the 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. If rubber membranes are used, membranes with following properties should be used:

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

— thickness not exceeding about 1 % of the specimen diameter;

— elastic modulus (measured in tension) not exceeding 1600 kPA.

5.3.2 Confining membranes that give a correction on the deviator stress (σ_1 - σ_3) of more than 10 % at failure should not be used.

5.3.3 If O-rings are used to seal the confining membrane to the top cap and to the pedestal, their dimensions and elastic properties shall be such that the confining membrane is firmly sealed to the top cap and to the pedestal.

5.4 Cell pressure device

5.4.1 The device for maintaining the cell pressure constant shall be accurate enough to keep the required cell pressure constant within ± 2 % or ± 1,0 kPa, whichever is greater.

5.4.2 The tubings between the triaxial cell and the cell pressure sensor shall be wide enough to ensure negligible pressure difference between these two components.

5.5 Loading press

5.5.1 The loading press shall be able to provide the rates of vertical strain according to 6.5. The actual rate may not deviate more than ± 10 % from the required value. The movement of the press shall be smooth without fluctuations or vibrations.

NOTE A loading press with a maximum load capacity of 10 kN and which is able to advance the piston with rates varying from about 0,5 mm to about 3 mm per minute with a minimum of four different advance rates is considered to be sufficient for most testing.

5.5.2 The stroke of the loading press shall be at least 30 % of the specimen height.

5.6 Measuring devices

5.6.1 Vertical load

The accuracy of the vertical load sensor shall be compatible with the accuracy by which it is required that the failure load shall be known (see 5.2.3).

5.6.2 All pressure

5.6.2.1 The cell pressure measuring device shall be sufficiently accurate to permit the cell pressure to be known within ± 2 % or within ± 1,0 kPa whichever is the greater. The device shall give the correct pressure at a level approximately equal to the level of half the height of the specimen.

5.6.3 vertical compression

The vertical compression of the specimen is usually determined by measuring the distance the piston travels relative to the base pedestal. The distance travelled by the piston shall be measured with an accuracy better than ± 0,10 % of the initial specimen height. The compression sensor, with the applied reading equipment, shall be readable to ± 0,015 % of the initial specimen height. Possible false compression due to cell pressure change shall be accounted for if compression measurements are performed in the stage prior to shearing.

5.7 Ancillary apparatus

The ancillary apparatus consists of:

— Equipment for determination of water content according to CEN ISO/TC 17892-1;

— equipment for determination of density of cohesive (fine-grained) soil, linear method according to CEN ISO/TC 17892 -2;

— specimen trimming and carving tools, membrane and O-ring expanders.

6 Test procedure

6.1 General requirements and equipment preparation

6.1.1 Test specimens shall be cylindrical with diameter not less than 35 mm and height from 1,85 to 2,25 times the diameter. The largest particle size may not exceed 1/6 of the specimen diameter.

6.1.2 The specimen height and diameter shall be measured or evaluated in such a way that their average values are known within ± 0,1 mm. The mass of the specimen shall be measured to within ± 0,1 %.

6.1.3 Care shall be taken to maintain the water content of the specimen during the preparation process. If the process for some reason is interrupted, the specimen shall be carefully wrapped in plastic foil. Air circulation around the specimen shall be avoided.

6.1.4 The confining membrane shall be checked for leakage before each test, for example by subjecting it to a small air pressure on the inside and looking for air bubbles when immersing it in water. The membrane shall be dry on the inside before being placed onto the soil specimen. If rubber membranes are used, they should be stored in water at least 24 hours before being used because dry membranes tend to adsorb water.

6.1.5 If the test is performed in a triaxial cell with drainage tubes, the drainage tubes shall be saturated with water, shut off, and covered with impervious platens.

6.1.6 If the vertical load is measured outside the triaxial cell, it shall be checked prior to each test that the piston runs smoothly, and if a rotating bushing is used, it shall be checked during each test, by direct observation of the bushing, preferably at high loads, that it really rotates.

6.1.7 To fill the cell, a liquid shall be used which does not significantly penetrate the membrane enclosing the specimen or absorb a significant amount of water from the specimen through the membrane. De-aired water is generally found to meet these requirements.

6.2 Preparation of undisturbed specimens

6.2.1 Disturbed material near the ends of a sample should not be used for triaxial testing.

6.2.2 Extreme care shall be taken to avoid, as much as possible, deforming the specimen during the mounting process. Very soft specimens (undrained shear strength < 12,5 kPa) may have to be mounted without touching the specimen by hand at any stage during the preparation.

6.2.3 The end surfaces shall be as plane and perpendicular to the longitudinal axis as possible. The angle between each end surface and the longitudinal axis may not deviate from a right angle by more than ± 0,6°. Grooves and holes in the ends and sides of the specimen shall be filled with remoulded material if they cannot be removed by further trimming and if new specimens cannot be trimmed. Grooves and holes in the ends greater than 1/10 of the specimen diameter shall be filled in with a material that hardens with time and which does not release water to the specimen.

6.3 Preparation of remoulded specimens

6.3.1 Unless specified otherwise, remoulded specimens may be prepared by remoulding undisturbed material at its natural water content, without significantly changing the water content. After remoulding it shall be kneaded, still without changing the water content, into a mould with the same internal dimensions as the required remoulded specimen. Care shall be taken to avoid entrapping air.

NOTE Evaporation during the remoulding process may be minimized by wrapping the material in a thin rubber membrane or in a plastic bag, and working the soil thoroughly with the fingers to assure complete remoulding.

6.4 Stage prior to shearing

6.4.1 The specified cell pressure shall be applied to the specimen.

6.4.2 Shearing shall start about 10 minutes after application of the cell pressure.

6.4.3 The vertical compression due to application of cell pressure ΔH_C should be measured. This can be done if the piston is kept in contact with the top cap, for example by adding dead weights, when applying the cell pressure.

6.5 Shearing

6.5.1 During shearing, the cell pressure shall be kept constant and the specimen loaded to failure by compressing the specimen in the vertical direction at a constant rate.

6.5.2 The rate of strain during testing shall be in the range of 0,5 % to 2 % per minute. The lowest rates should be selected for specimens with the lowest failure strains.

6.5.3 The following variables shall be recorded during shearing:

— vertical load;

— vertical compression;

— total cell pressure.

6.5.4 Readings shall be taken on all measuring devices at intervals such that stress-strain curves can be obtained from the readings. As a minimum, 15 readings shall be taken prior to failure, and thereafter at every 1 % vertical strain. For brittle materials readings shall be taken more frequently around failure than during the rest of the test.

6.5.5 The strain at which the test shall be stopped, should be. If no such specification is given, the test may be stopped when the axial strain reaches 15 % or exceeds, by 5 %, the strain at peak deviator stress, whichever its earlier.

6.6 Dismounting

6.6.1 The deviator load shall be removed and the cell pressure shall be reduced to zero.

6.6.2 As quickly as possible, the specimen shall be removed from the triaxial cell and the membrane shall be stripped off.

6.6.3 A rough sketch or photograph of the specimen indicating the failure planes shall be taken.

6.6.4 The whole specimen shall be weighed and immediately afterwards a representative part shall be selected and the water content shall be determined.

6.6.5 The specimen shall be broken into pieces and the soil shall be described. If there are particles greater than permitted this shall be noted (see 6.1.1). Particle size distribution and plastic and liquid limits on material that is not dried, should be determined for at least one triaxial test specimen of each type of material included in the investigation.

7 Test results

7.1 Bulk density, dry density and water content

The initial water content and the bulk density shall be calculated from initial measurements of height, diameter and mass of the specimen and from final weighings. Initial void ratio (or initial porosity) and initial degree of saturation based on a measured or estimated particle density should be calculated.

7.2 Stage prior to shearing

If the height change of the specimen prior to shearing is determined, the volume change may be calculated from equation (1):

$$\Delta V = \Delta H_\mathrm{C} \times 3 \times \frac{V_\mathrm{i}}{H_\mathrm{i}} \qquad (1)$$

where

ΔV is the volume change;

ΔH_C is the height change;

V_i is the initial volume of specimen;

H_i is the initial height of the specimen.

7.3 Shearing

7.3.1 Average area of specimen:

$$A = \frac{V_\mathrm{i} - \Delta V}{H_\mathrm{i} - \Delta H_C - \Delta H} \qquad (2)$$

7.3.2 Deviator stress:

$$\sigma_1 - \sigma_3 = \frac{P + K - a \times \sigma_3}{A} - \left(\Delta\sigma_1\right)_m \qquad (3)$$

7.3.3 Vertical strain:

$$\varepsilon_1 = \frac{\Delta H}{H_\mathrm{i} - \Delta H_C} \qquad (4)$$

where

ΔV is the volume change prior to shearing;

P is the vertical load (= load on top of piston);

a is the area of piston;

K is the W – [$(A - a)h$ x y] where W is gravity force acting on deadweight hanger (if used), piston, top cap, one half of the soil specimen and so on, is unit weight of cell fluid and h is distance from top of top cap to mid-height of specimen

σ_3 is the cell pressure.

$(\Delta\sigma_1)_m$ is the correction on vertical total stress due to membrane restraint.

The expression for K given above and equation (2) 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 device is hanging over the piston, without being in contact with it. Other arrangements and/or procedures may require modifications of the expression for K and of equation (3):

7.4 Corrections for elastic membrane

7.4.1 General

If not more accurate expressions are required, equation (6) shall be used to compute the membrane correction.

7.4.2 Correction to total vertical stress:

$$(\Delta\sigma_1)_m = \frac{4 \times t \times E}{D_\mathrm{i}} (\varepsilon_1)_m \qquad (6)$$

where

t is the initial thickness of membrane;

E is the elastic modulus for membrane, measured in tension;

D_i is the initial diameter of membrane (diameter before it is placed on specimen);

$(\varepsilon_1)m$ is the vertical strain of membrane (expressed as a ratio).

NOTE Equation (6) for computation of the membrane correction is based on the assumptions that the specimen deforms as a cylinder and that no slippage takes place between the membrane and the specimen. Equations based on such assumptions on the deviator stress may give somewhat too high membrane correction if the membrane wrinkles and considerably too low correction if the specimen deforms along a single shear-plane (even if the membrane wrinkles).

8 Test report

The test report shall affirm that the test was carried out in accordance with CEN ISO/TS 17892-3 and shall include the following:

a) identification of the sample (material) being tested, e.g. drilling number, sample number, sample depth, test number etc.:

b) description of tested material, including, when determined, liquid limit, plastic limit, and size of sand-, silt- and clay fractions;

c) procedure used for the preparation of specimens;

d) initial and final water content (i.e. water content after dismounting);

e) initial bulk density (cohesive soils) or dry density (non-cohesive soils);

f) initial void ratio or porosity, when determined;

g) data from the stage prior to shearing:

- value of cell pressure applied;
- vertical strain prior to shearing if measured;

h) following data at failure:

- the failure criterion adopted;
- $\frac{\sigma_1 - \sigma_3}{2}$ *or* $\sigma_1 - \sigma_3$;
- drawing or photo showing the type of failure (degree of bulging, dominating failure planes and so on);

i) type of equipment used, including the type of connection used between the piston and the top cap (between pedestal and piston if the piston is at the bottom of the cell). The information shall be accompanied by a principal drawing where information is given about how much the top cap is allowed to tilt and/or move horizontally during the test:

j) description of deviations from the procedures prescribed in this document;

k) other information required for proper interpretation of the test results.

Items a) and b) shall be repeated on all pages of the report.

All data reported in a numerical format shall have at least three significant digits.

It is further recommended to include in the report the in-situ effective overburden stress, and the in-situ preconsolidation stress.

The laboratory shall maintain records of all data. These shall be made available for inspection if required.

The stress paths should be marked with values of ε_1, for example at ε_1 = 0,2 %; 0,5 %; 1,0 %; 2,0 %; 5 % and 10 %.

Water contents, porosities and so on and all strains, (but not void ratios), should be reported as percentages. In equations these parameters should be considered as dimensionless ratios.

NOTE The value of $(\sigma_1 - \sigma_3)/2$ at failure for undrained tests is usually called 'undrained shear strength' and should according to the list of symbols published by ISSMFE be denoted c_u.However, the symbol s_u (already used in some countries) is recommended to make it clear that the undrained shear strength is basically not due to actual cohesion, but mainly due to friction and effective stresses.

Bibliography

[1] DIN, ISSMGE (Eds.) (1998): Recommendations of the ISSMGE for geotechnical laboratory testing; (in English, German and French); Berlin, Wien, Zürich (Beuth Verlag).

[2] ISO (1995), Guide to the expression of uncertainty in measurement; Geneva.

[3] CEN ISO/TS 17892-4, *Geotechnical investigation and testing — Laboratory testing — Part 4: Determination of particle size distribution.*

[4] CEN ISO/TS 17892-5, *Geotechnical investigation and testing — Laboratory testing of soil — Part 5: Incremental loading oedometer test.*

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