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Geotechnical investigation and testing — Laboratory testing of soil —

Part 10: Direct shear tests

Reconnaissance et essais géotechniques — Essais de sol au laboratoire —

Partie 10: Essai de cisaillement direct

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Foreword

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ISO/TS 17892-10 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 17892-10:2004) 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 11: Determination of permeability by constant and falling head*

— *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 laboratory test methods to establish the effective shear strength parameter for soils within the scope of the geotechnical investigations according to prEN 1997-1 and -2.

The test method consists of placing the test specimen in the direct shear device, applying a pre-determined normal stress, providing for draining (and wetting if required) of the test specimen, or both, consolidating the specimen under normal stress, unlocking the frames that hold the specimen, and displacing one frame horizontally with respect to the other at a constant rate of shear-deformation and measuring the shearing force, and horizontal displacements as the specimen is sheared. Shearing is applied slowly enough to allow excess pore pressures to dissipate by drainage so that effective stresses are equal to total stresses.

Direct shear tests are used in earthworks and foundation engineering for the determination of the effective shear strength of soils.

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)*

3 Terms and definitions

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

3.1
direct shear test
test whereby a square or circular prism or annular specimen of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a pressure applied normal to that plane

3.2
shearbox test
direct shear test whereby a specimen is placed in a rigid container (shearbox) which is square or circular and divided horizontally into two halves.

NOTE Shearing is applied by displacing the two halves of the shearbox relative to each other (see Figure 1)

3.3
ring shear test
direct shear test whereby an annular specimen is subjected to rotational shear while subjected to vertical stress (see Figure 2)

3.4
friction angle
φ'
angle of friction, as determined from effective stresses

3.5
cohesion
c'
cohesion intercept, as determined from effective stresses

4 Equipment

4.1 Shearbox

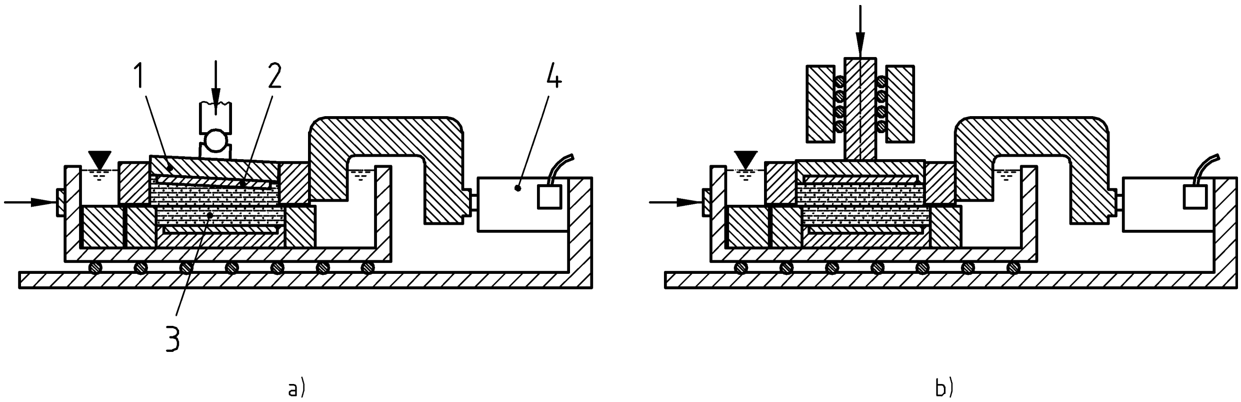
4.1.1 The shearbox shall be square or circular in plan and divided horizontally into two rigid halves which prevent horizontal deformation of the specimen.

4.1.2 Arrangements shall be provided for locking the two halves of the shearbox securely together while the specimen is being placed, and for lifting the upper half of the box from the lower half by a small controlled vertical displacement without tilt, after applying vertical load to the specimen.

4.1.3 The arrangement shall be such that when released one half of the shearbox shall be able to move exactly parallel to the other half.

4.1.4 The loading cap shall be 0,5 mm smaller in plan than the internal dimensions of the shearbox and be rigid enough to transmit the vertical load uniformly to the specimen.

4.1.5 The loading cap should preferably be guided by a bearing to prevent tilting during shear.



Key

a conventional device

b parallel controlled device

1 loading pad

2 porous plate

3 soil specimen

4 force transducer

Figure 1 — Schematic drawing of a conventional and a parallel controlled shearbox

4.1.6 During testing, the shear box shall be placed in an outer container (the carriage), such that the test specimen is submerged under water during the test.

4.1.7 The carriage shall be supported on the bed of the machine by a low-friction bearing which allows movement in the longitudinal direction only.

4.1.8 To achieve a uniform distribution of the shear stresses over the plan of the specimen rough porous filter plates shall cover the upper and the lower surface of the specimen. The porous plates shall be of a material which does not react chemically with the pore water or the soil. Their porosity shall prevent intrusions of soil into the pores, but shall allow free drainage of water throughout the test. Therefore the permeability of the porous platens shall be at least 10 times the permeability of the specimen.

4.1.9 Typical arrangements for a conventional and a parallel controlled shearbox are shown in Figure 1.

NOTE A parallel controlled shear box allows a correct simulation of in-situ shearing when shear planes occur. Investigations show that with cohesive soils the friction angle φ is up to 4° smaller and with non-cohesive soils it is up to 6° higher in a parallel controlled shearbox than in a conventional apparatus.

4.2 Ring shear apparatus

4.2.1 The apparatus shall be constructed such that shearing forces are purely torsional.

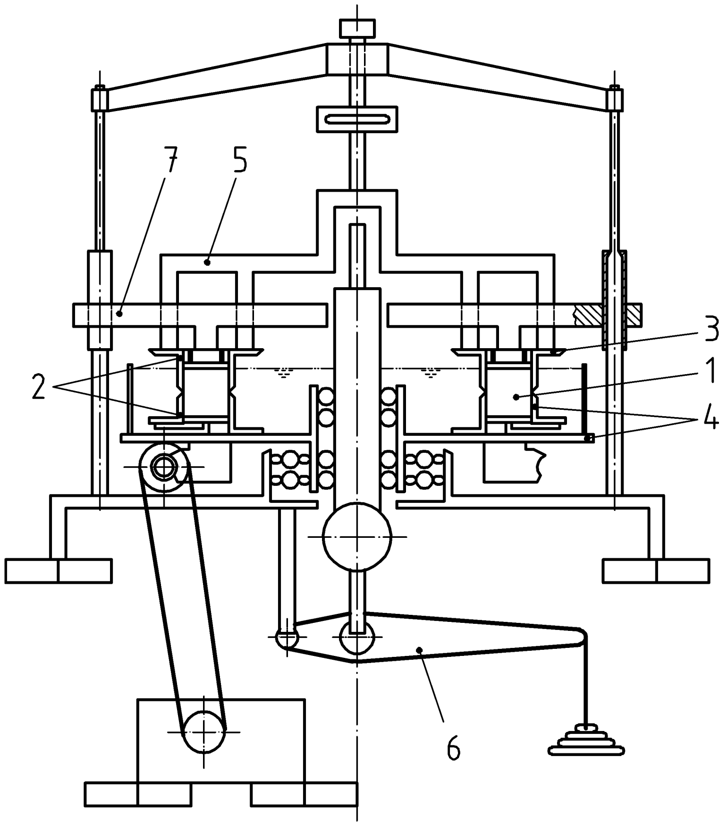
4.2.2 The soil container rings shall be of sufficient stiffness to prevent radial deformation of the specimen.

4.2.3 The soil container rings shall be integrated in a water bath which allows the specimen to be submerged during the test.

4.2.4 The upper and lower rings shall be fitted with porous platens having the same properties as those in the shear box (see 4.1.8).

4.2.5 The ring shear apparatus shall contain a device for application of vertical (normal) stresses.

4.2.6 A typical arrangement for a ring shear apparatus is shown in Figure 2.



Key

1 specimen

2 filter stones

3 upper circular frame (fixed)

4 lower circular frame (rotating)

5 bearing to lift upper circular frame

6 loading lever for normal stress

7 loading and measurement of torque

Figure 2 — Example of a ring shear apparatus

4.3 Loading system

4.3.1 The normal load shall be kept constant during shearing.

4.3.2 Shearing must be achieved by continuous horizontal or torsional displacement.

4.3.3 If only the peak shear stress is to be determined shearing can also be done by constant increase of the shear load.

4.3.4 Shearbox equipment shall allow a minimum horizontal displacement of 20 % of the length or diameter of the specimen.

4.3.5 Ring shear equipment shall allow a travel by torsion of 30 mm.

4.4 Measurement of forces and displacements

4.4.1 Force

The vertical force shall be measured with an accuracy of 3 %, or within 2,5 N, whichever is the greater. If the friction between both halves of the apparatus is higher than 3 % of the shear force at failure, a suitable correction to the shear force shall be applied.

4.4.2 Displacements

The horizontal and vertical displacements shall be measured with an accuracy of 0,02 mm and 0,002 mm respectively.

5 Specimen

5.1 Type and number of specimen

5.1.1 Direct shear tests shall be performed with homogeneous specimen which are either cut from undisturbed samples (quality class 1 according to prEN 1997-2) or prepared from soil material so that they reproduce the relevant in-situ conditions as closely as possible.

5.1.2 Normally three similar specimens shall be prepared from an undisturbed or reconstituted cohesive sample, for testing under three different normal pressures.

5.1.3 Non-cohesive samples shall be large enough to provide three separate specimens, to avoid having to re-use the same material.

5.1.4 When shear strength of cohesionless (coarse-grained) material is to be determined as a function of the void ratio e a minimum of 5 tests with constant normal stress σ' and different initial void ratios e_0 should be performed.

5.2 Dimensions of specimen

5.2.1 Shearbox apparatus

5.2.1.1 In a shearbox with a square specimen the minimum width a shall be 60 mm. For cylindrical specimen the minimum diameter D shall be 70 mm.

5.2.1.2 The minimum height of the specimen shall be not less than 10 mm. The largest grain size in the specimen shall not be greater than 1/5 times the specimen height.

5.2.1.3 The ratio of height to width or height to diameter H/a or H/D shall not exceed 1/3.

5.2.2 Ring shear apparatus

5.2.2.1 The minimum outer diameter shall be D_a = 90 mm.

5.2.2.2 The minimum ratio of inner diameter to outer diameter shall be D_i/D_a = 0,5.

5.2.2.3 The minimum height of the specimen shall be not less than 10mm. The largest grain size in the specimen shall not be greater than 1/5 times the specimen height.

5.2.2.4 The ratio of height to width of the annulus shall be $H/((D_a - D_i)/2) \leq 1$.

5.3 Preparation of specimen

5.3.1 During the preparation of the specimen the upper and lower halves of the shearbox or the ring shear apparatus must be fixed to avoid any displacement of the two parts relative to each other. To prevent shear stresses on the inside faces and friction between the two halves of the shear box, a thin coating of silicone grease or petroleum jelly may be applied to the inside faces of the shearbox or the circular frame and to the surfaces of contact between the two halves of the box or circular frame respectively.

5.3.2 The specimen shall be cut, trimmed and placed into the shear apparatus with a technique to minimise its disturbance and loss or gain of moisture.

5.3.3 Specimen of reconstituted soil material shall be prepared homogeneously in such a way that the relevant in-situ conditions are reproduced as closely as possible – i. e. density, water content and soil structure.

5.3.4 The specimen shall be weighed to the nearest 0,01 g.

6 Test procedure

6.1 General

The consolidation stresses shall be specified.

6.2 Consolidation

6.2.1 The vertical (normal) stress σ shall be applied smoothly and as rapidly as possible.

NOTE The vertical stress is identical to the specified consolidation stress.

6.2.2 The timer shall be started immediately after application of the load, and the vertical deformation shall be recorded at suitable intervals of time. The selected time intervals shall allow a graph to be drawn of vertical deformation as ordinate, against square-root of elapsed time as abscissa. A plot with a logarithmic scale of time may also be made.

6.2.3 The readings shall be continued until the plotted readings indicate that primary consolidation is complete. Dry sand or free-draining saturated sand consolidates very rapidly, therefore consolidation readings are not necessary for these materials and a rapid test is appropriate.

6.2.4 The square-root time plot shall be used to extend the approximately linear portion of the graph (which normally lies between just after zero time to about 50 % of primary consolidation) downwards (see Figure 3).

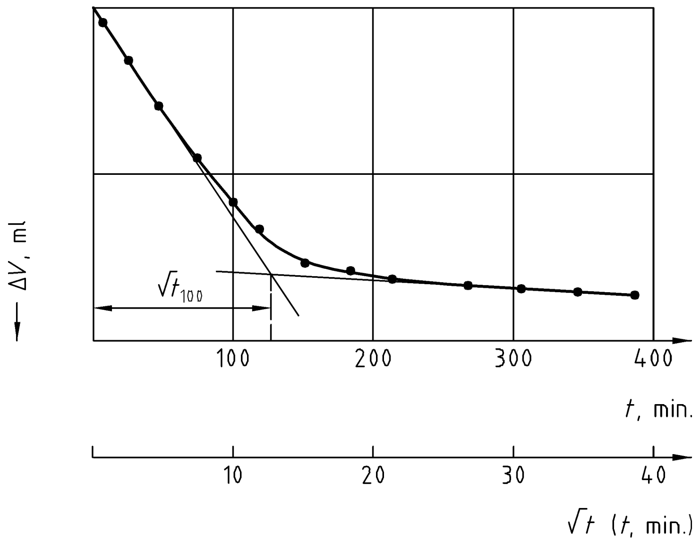


Figure 3 — Example of time-settlement-curve to determine the time for primary consolidation

6.2.5 The intersection of this line with the line through the final points on the curve of primary consolidation which is almost horizontal, shall be determined and the value ($\sqrt{t_{100}}$) on the square-root time axis shall be read off.

6.2.6 The value of t_{100} shall be calculated.

6.2.7 The minimum time to failure, i. e. to mobilisation of maximum shear resistance by the specimen t_f shall be calculated according to equation (1):

$$t_f = 12{,}7 \times t_{100} \tag{1}$$

NOTE 1 The factor 12,7 relating t_f to t_{100} is derived from consolidation theory to ensure that no more than 5% of the pore pressure remains in the specimen when failure is reached.

NOTE 2 This test does not permit the derivation of a reliable value of coefficient of consolidation c_v.

6.2.8 The maximum rate of shear displacement shall be determined according to equation (2):

$$v = s_f / t_f \tag{2}$$

where

v is the maximum allowable rate of shear displacement;

s_f is the estimated horizontal shear deformation at failure;

t_f is the time to failure.

6.2.9 For saturated fine-grained (cohesive) soils, the maximum rate of displacement shall not exceed the rate determined in 6.2.8. For coarse-grained (cohesionless) soils the rate of displacement shall not exceed 0,5 mm/min.

6.3 Shearing

6.3.1 Before shearing, the two halves of the shearbox or the circular frames shall be disconnected to give a clearance, which shall be enough to prevent friction during the test, but shall not permit extrusion of the soil between them. For fine-grained soils a clearance or 0,5 mm is usually sufficient. For sandy soils it should not exceed about 1 mm.

6.3.2 The specimen shall be sheared at a constant rate (strain controlled) by displacing one of the two halves of the shearbox or the circular loading cap relative to the other half.

6.3.3 During the shearing the displacement, the height change and the shear force or the torsion shall be determined such that at least 20 readings are taken up to the maximum load, i. e. peak shear strength. Intervals of horizontal displacement of 0,1 mm often meet this requirement. For brittle specimens such as dense sand, sets of data should be recorded at frequent intervals of force, instead of displacement, to ensure that enough readings are taken.

6.3.4 If only the peak shear stress is to be determined, shearing may be done by continuous loading (stress controlled).

6.3.5 The test can be terminated when:

— the strain at peak load is clearly exceeded, or

— when the horizontal displacement has reached 20 % of the diameter or the width of the specimen.

6.3.6 To determine the residual shear strength τ_R the following termination criteria apply:

— for shearbox testing, when, after repeated reversal of the shearing direction, no further decrease of the shearing resistance can be measured between two subsequent shear stages.

— for ring shear testing, the movable circular ring is turned continuously until no further decrease in shear resistance is measured. The rate of horizontal displacement may be increased to the three- to tenfold after reaching the maximum shear load.

6.3.7 The specimen shall be transferred from the shear apparatus box to a small tray, taking care not to lose any soil.

6.3.8 The specimen shall be weighed, then dried. The final water content of the specimen shall be determined in accordance with CEN ISO/TS 17892-1.

7 Test results

7.1 Water content

The initial water content shall be calculated in accordance with CEN ISO/TS 17892-1 from the initial mass m_o of the specimen and the final dry mass m_d of the specimen, both masses in grams.

7.2 Initial dry density

The initial dry density ρ_d shall be calculated in accordance with equation (3):

$$\rho_d = \frac{m_d}{A \times H_0} \tag{3}$$

where

A is the plan area of the specimen;

H_0 is the initial height of the specimen.

NOTE For an undisturbed specimen trimmed in the specimen cutter, H_o is equal to the height of the cutter.

7.3 Initial bulk density

The initial bulk density ρ shall be calculated according to equation (4):

$$\rho = \frac{m_0}{A \times H_0} \tag{4}$$

7.4 Initial void ratio

The initial void ratio e_0 (if required) shall be calculated according to equation (5):

$$e_0 = \frac{\rho_s}{\rho_d} - 1 \tag{5}$$

where

ρ_s is particle density.

7.5 Initial degree of saturation

The initial degree of saturation S_{RO} (if required) shall be calculated according to equation (6):

$$S_{RO} = \frac{w_0 \times \rho_s}{e_o \times \rho_w} \quad (6)$$

7.6 Void ratio during testing

The void ratio e shall be calculated at the end of the consolidation stage and at the end of shearing (if required) according to equation (7):

$$e = e_0 - \frac{\Delta H}{H_0}(1 + e_0) \quad (7)$$

where

ΔH is the calculated change in height (vertical deformation) of the specimen from the initial zero reading.

7.7 Shear stress

From each set of data obtained during the shear test the shear stress on the surface of shear τ shall be calculated according to equation (8):

$$\tau = \frac{P}{A} \quad (8)$$

where

P is the horizontal shear force;

A is the initial plan area of the specimen.

NOTE The continual change in the area of contact in the shear box is not normally taken into account.

7.8 Cumulative vertical deformation

The cumulative vertical deformation shall be calculated for each set of readings relative to the datum corresponding to the initial specimen height.

7.9 Effective strength parameters

From the third graph of 7.10.1 or 7.10.2 the best straight line fit (if possible) shall be determined. The slope gives the friction angle φ', and the intercept gives the cohesion c'. The slope of the residual strength envelope gives the residual friction angle φ'_R. (The residual cohesion $c_R \approx 0$). Peak and residual strength relationships may show non-linearity, and their interpretation requires further consideration.

7.10 Plotting

7.10.1 Single test testing

For each specimen of a set of single-test tests the following graphs shall be plotted:

— shear stress τ as ordinate against horizontal displacement as abscissa;

— change in height (vertical deformation) of the specimen as ordinates against horizontal displacement as abscissa. If preferred the changes in height may be plotted in terms of void ratio;

— from each shear test, the value of the peak shear stress τ_f as ordinate against the corresponding consolidation stress, σ as abscissa, both to the same linear scale.

To determine the friction angle φ' as a function of void ratio, the shear strength versus initial void ratio shall be plotted for tests performed at different initial void ratios but at the same consolidation stress. From the best straight line fit through the points, the shear strength can be determined for any void ratio. Using Coulombs diagram and assuming c' = 0, the friction angle can be determined (Figure 4).

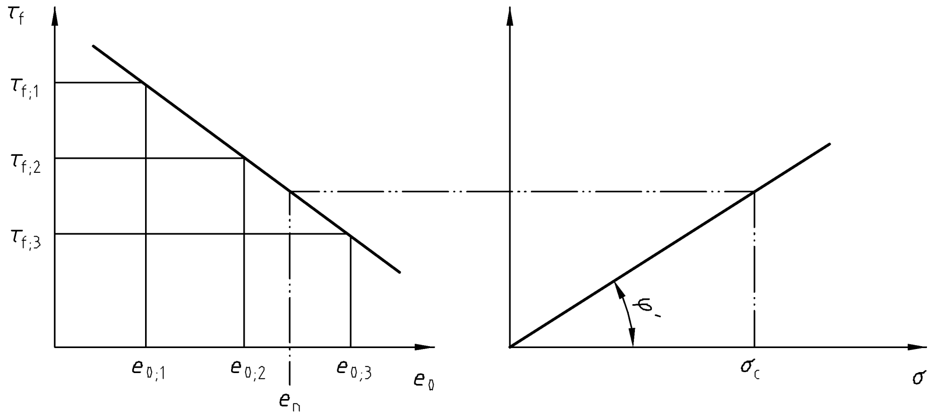


Figure 4 — Determination of the friction angle φ' as a function of the void ratio *e*

7.10.2 Multi-reversal tests

For each specimen of a set of multi-reversal tests the following graphs shall be plotted:

— Shear stress τ as ordinate, against forward displacement as abscissa, for each shearing test in succession;

— change in height (vertical deformation) of the specimen as ordinate, against forward movement as abscissa, if required;

From each shear test, the value of the peak shear stress τ_f and residual shear strength τ_r as ordinate against the corresponding consolidation stress, σ as abscissa, both to the same linear scale.

8 Test report

The test report shall state that the test was carried out in accordance with this document. It shall contain the following information:

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

b) location and orientation of the test specimen in the original sample;

c) method of preparation of specimen, and whether undisturbed, remoulded or recompacted;

d) statement of the method used, i. e. apparatus and application of strain reversal;

e) initial dimensions of the specimens;

f) initial moisture content, bulk density, and dry density;

g) particle density, indicating whether measured or assumed;

h) initial void ratio and degree of saturation, if required;

i) tabulated values for each specimen of the applied normal stress, maximum shear stress, and corresponding horizontal displacement;

j) when determined, the residual shear stress, the number of traverses, and the travel per traverse;

k) rate or rates of horizontal displacement;

l) whether the specimens were tested dry or submerged;

m) graphical plots of settlement against square root time for each specimen, if relevant;

n) graphical plots as described in 7.10;

o) friction angle φ', to the nearest 0,5°, and cohesion c', to two significant digits, at peak shear strength;

p) the residual friction angle φ'_R, when determined.

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.

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