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Geotechnical investigation and testing — Laboratory testing of soil —

Part 10: **Direct shear tests**

Reconnaissance et essais géotechniques — Essais de laboratoire des sols —

Partie 10: Essai de cisaillement direct

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of 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 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 ISO/TC 182, *Geotechnics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This first edition cancels and replaces ISO/TS 17892-10:2004, which has been technically revised. It also incorporates the Technical Corrigendum ISO/TS 17892-10:2004/Cor 1:2006.

The main changes compared to the previous edition are as follows:

— general revision of the text and figures and addition of specimen preparation procedures;

— inclusion of two types of ring shear apparatus; Type A wherein failure occurs at the depth in the specimen defined by the split specimen container and Type B wherein the location of the failure surface is not defined by the apparatus;

— addition of Annex A on calibration, maintenance and checks;

— addition of Annex B on additional calculations for effective strength parameters.

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

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document provides laboratory test methods for the determination of the effective shear strength of soils by direct shear within the international field of geotechnical engineering.

The tests have not previously been standardized internationally. It is intended that this document presents broad good practice and significant differences with national documents are not anticipated. It is based on international practice (see Reference [1]).

This document specifies two methods for the determination of the effective shear strength of soils under consolidated drained conditions using either a shearbox or a ring shear device.

The shearbox test is generally used for the determination of peak effective shear strength parameters of soils. The ring shear test is generally used for the determination of residual effective shear strength parameters of fine grained soils. Residual effective shear strength parameters can also be obtained from shearbox tests and peak effective shear strength parameters can also be obtained from ring shear tests.

The test method consists of placing the test specimen in the direct shear device, applying a pre-determined vertical stress, providing for draining (and wetting if required) of the test specimen, consolidating the specimen under vertical stress and then shearing the specimen. This shearing is imposed by displacing one part horizontally, relatively with respect to the other part of the specimen at a constant rate of shear-deformation. The shearing force and the horizontal and vertical displacements are measured 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.

Geotechnical investigation and testing — Laboratory testing of soil —

Part 10:
Direct shear tests

1 Scope

This document specifies two laboratory test methods for the determination of the effective shear strength of soils under consolidated drained conditions using either a shearbox or a ring shear device.

This document is applicable to the laboratory determination of effective shear strength parameters for soils in direct shear within the scope of geotechnical investigations.

The tests included in this document are for undisturbed, remoulded, re-compacted or reconstituted soils. The procedure describes the requirements of a determination of the shear resistance of a specimen under a single vertical (normal) stress. Generally three or more similar specimens from one soil are prepared for shearing under three or more different vertical pressures to allow the shear strength parameters to be determined in accordance with Annex B.

Special procedures for preparation and testing the specimen, such as staged loading and pre-shearing or for interface tests between soils and other materials, are not covered in the procedure of this document.

NOTE This document fulfils the requirements of the determination of the drained shear strength of soils in direct shear 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 17892-1, *Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content*

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

ISO 386, *Liquid-in-glass laboratory thermometers — Principles of design, construction and use*

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:

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

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

3.1
direct shear test
test whereby a specimen of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a vertical stress applied normal to that plane

3.2
shearbox test
direct shear test (3.1) whereby a specimen is placed in a rigid square or circular container (shear box) and shearing is applied by linear displacement of one half of the shear box relative to the other

Note 1 to entry: See Figure 1.

3.3
ring shear test
direct shear test (3.1) whereby an annular specimen is subjected to shear induced by rotation of one half of the specimen relative to the other while subjected to vertical stress applied normal to the *failure* (3.4) plane

Note 1 to entry: See Figures 2 and 3.

3.4
failure
stress or strain condition at which either peak horizontal shear stress is achieved or a specified deformation criterion is achieved, if a peak horizontal shear stress is not observed

3.5
pore pressure
pressure of water in the voids within the soil specimen

3.6
primary consolidation
process whereby the void ratio of a specimen decreases as a result of an increase in the effective stress due to a decrease in the excess *pore pressure* (3.5) under a constant total applied load

Note 1 to entry: Time-dependent volume change during primary consolidation is primarily controlled by drainage conditions.

4 Symbols

D_a	outer diameter of specimen container rings
D_i	inner diameter of specimen container rings
D_m	mean diameter of specimen container rings
R_i	inner radius of the container rings
R_a	outer radius of the container rings
H	height of annulus in the specimen container rings or shear box
t_c	time value from vertical displacement versus root time plot
t_f	calculated minimum time to failure during shear stage
v_{max}	maximum allowable rate of shear displacement
s_{rs}	horizontal shear deformation during ring shear
s_f	estimated horizontal shear deformation at failure
r	mean radius of the specimen in the ring shear test
θ	angular displacement during the ring shear test
θ_{max}	maximum rate of angular displacement in the ring shear test
ρ	initial bulk density of specimen

ρ_d	initial dry density of specimen
ρ_s	particle density
H_0	initial height of the specimen
w_0	initial water content
m_0	initial mass of specimen
m_d	final dry mass of specimen
e	void ratio
e_0	initial void ratio
S_r	initial degree of saturation
ρ_w	water density
ΔH	change in specimen height from the initial zero reading
τ	shear stress on the surface of shear
τ_R	residual shear strength
σ_v	vertical stress on the surface of shear
P	horizontal shear force
N	vertical force
φ'	angle of effective shearing resistance
φ'_R	residual angle of effective shearing resistance
c'	effective cohesion intercept
A	initial plan area of specimen
M_t	moment (torque) applied to the specimen in the ring shear

5 Apparatus

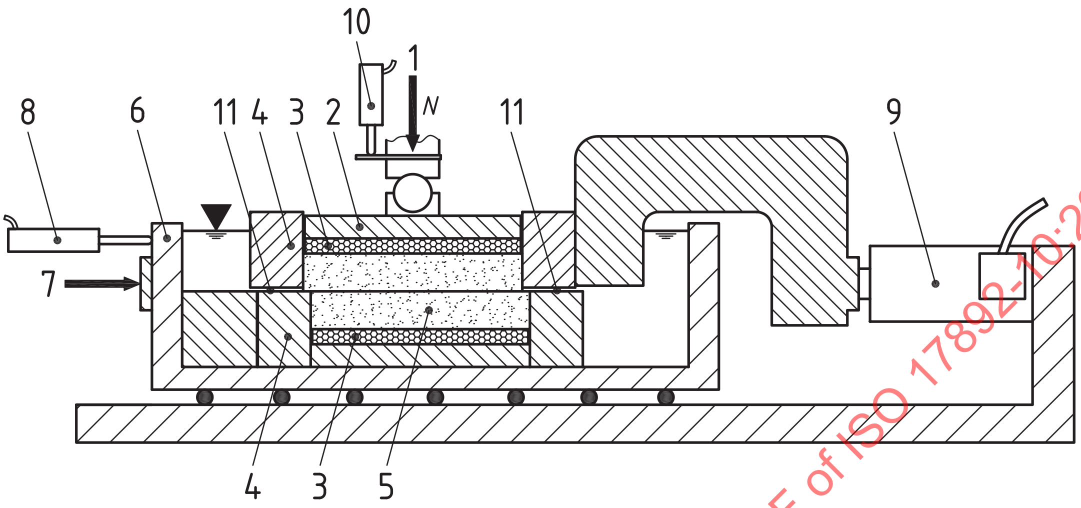
5.1 General

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

5.2 Shear devices

5.2.1 Shearbox test apparatus

5.2.1.1 A typical shearbox apparatus is shown schematically in Figure 1.



Key

1 (device to apply) vertical force, *N*
2 loading cap to apply vertical force
3 porous discs or shear friction plates
4 upper and lower part of the shear box
5 soil specimen
6 outer container (carriage)
7 device to apply (a constant rate of) horizontal displacement
8 device for measurement of horizontal displacement
9 device for measurement of horizontal force
10 device for measurement of vertical displacement
11 gap between upper and lower parts of shear box to prevent friction

Figure 1 — Schematic drawing of a typical shearbox

5.2.1.2 The frame, the outer container (carriage), the shearbox and internal components shall be made of corrosion resistant materials of sufficient rigidity to resist distortion and deformation during the test.

5.2.1.3 The outer container (carriage) should allow testing to be carried out with the specimen and porous discs or shear friction plates submerged under water.

5.2.1.4 The outer container (carriage) shall be supported on the frame by a low-friction bearing which allows movement in the horizontal direction only.

5.2.1.5 The shear box shall be square or circular in plan and divided horizontally into two rigid halves. The design of the shear box shall fulfil the following requirements:

— The design shall allow the two halves of the shear box to be locked securely together. Once locked together they shall form a square or circular prism with a smooth internal surface.

— The design shall allow the upper half to be lifted relative to the lower half prior to shear by a small, controlled vertical displacement without tilt.

— The arrangement shall be such that when lifted, one half of the shear box shall be able to move smoothly and parallel to the other half.

— The square shear box should be designed for a square specimen with a minimum width of 50 mm. The circular shear box should be designed for a specimen with a minimum diameter of 50 mm.

— In both cases the shear box should be designed for a specimen with a minimum initial height of 20 mm or not less than 6 times the maximum particle size diameter, whichever is larger.

— The ratio of the specimen width or diameter to height should not be less than 2,5.

5.2.1.6 Porous discs or shear friction plates shall cover the upper and lower surfaces of the specimen:

— They shall allow free drainage of water, while preventing intrusion of soil particles into their pores. The upper and lower surfaces shall be plane, clean and undamaged. They shall be made of corrosion-resistant materials of negligible compressibility under the maximum stress likely to be applied during the test and shall be strong enough to prevent breakage under load.

— They should be sufficiently rough to provide an interlock with the sample but without causing localised stress concentrations.

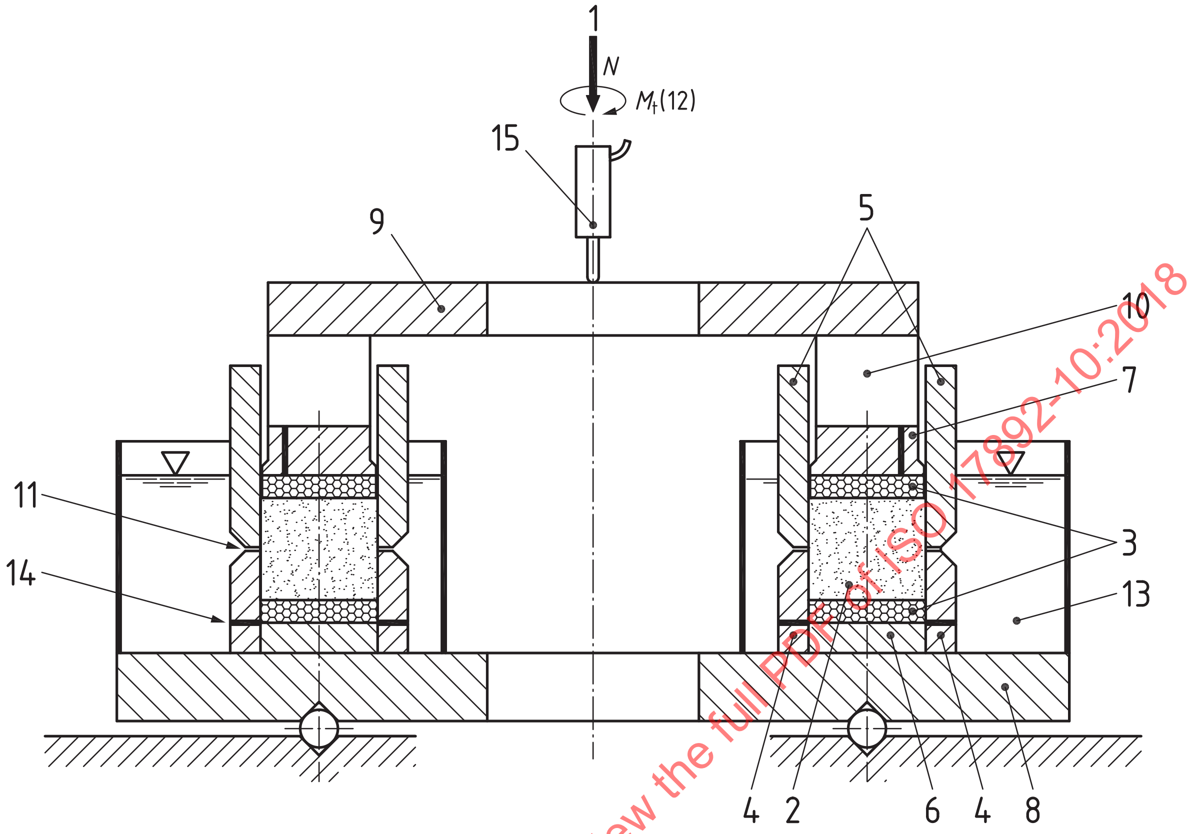
— They shall be smaller in plan than the internal dimensions of the shear box in order to prevent binding to the walls but large enough to prevent extrusion of the specimen.

5.2.1.7 The loading cap shall be smaller in plan than the internal dimensions of the shear box such that the loading cap can tilt without jamming and be rigid and sufficiently large so as to transmit the vertical load uniformly to the specimen.

5.2.1.8 The loading cap and base shall have grooves or perforations to allow free drainage of water from the porous discs.

5.2.2 Ring shear apparatus

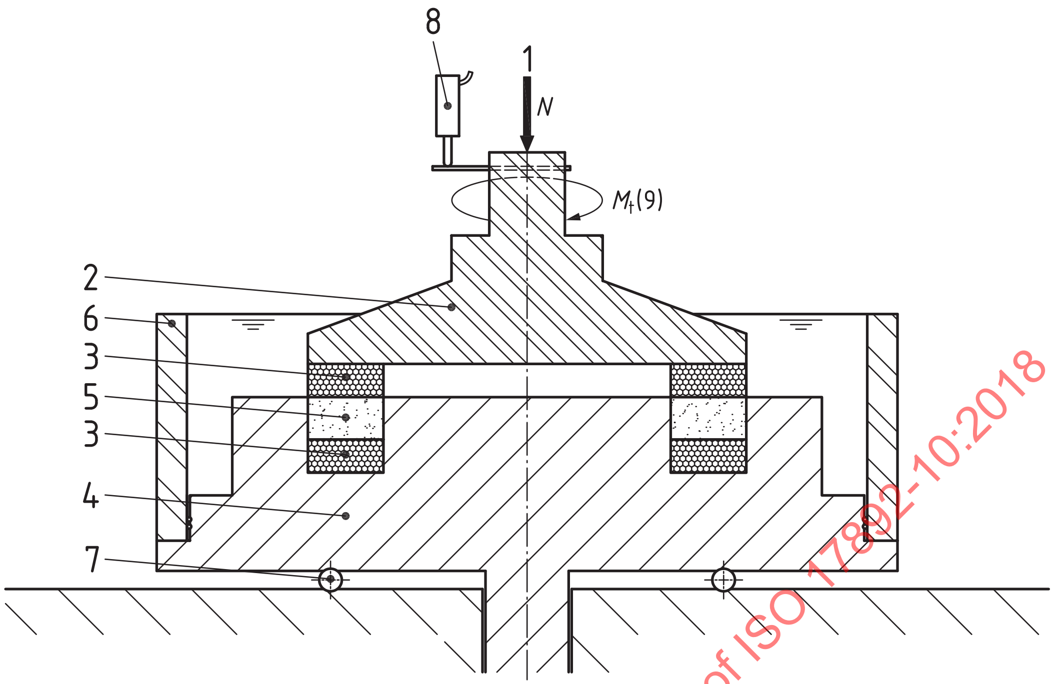
5.2.2.1 The apparatus shall be constructed such that shearing forces are purely rotational. Typical arrangements for ring shear apparatus are shown in Figures 2 and 3. Figure 2 shows a typical arrangement for a ring shear test with a split specimen container such that failure occurs at the depth defined by the split container (Type A). Figure 3 shows a typical arrangement for a ring shear test with a solid specimen container where the location of the failure surface is not defined by the apparatus (Type B).



Key

1 (device to apply) vertical force, transmitted through (10) and (7) to the specimen
2 specimen
3 porous discs or shear friction plates
4 lower circular frame (lower soil container ring)
5 upper circular frame (upper soil container ring)
6 base ring
7 loading ring (with drainage opening)
8 base plate, which is rotated by a driving gear, together with the lower circular frame (4) and the base ring (6)
9 top plate to apply the vertical load *N* to the loading ring by radially distributed ridged blocks (10)
10 rigid blocks to transmit the load to the loading ring
11 gap between upper and lower circular frame to allow for rotation of the one relative to the other
12 device to measure torque, M_t
13 outer container (water bath)
14 drainage openings
15 device for measurement of vertical displacement

Figure 2 — Example of a Type A ring shear apparatus



Key

1 (device to apply) vertical force, transmitted through (2) to the specimen
2 loading cap, centred on the lower cell (4) by means of a centring pin, with a torsion beam to measure torque M_t
3 porous discs or shear friction plates
4 lower part of cell which is rotated by a driving gear
5 specimen
6 outer container (water bath)
7 ball race
8 device for measurement of relative vertical displacement
9 device to measure torque, M_t

Figure 3 — Example of a Type B ring shear apparatus

5.2.2.2 The soil container rings, outer container and internal components shall be made of corrosion-resistant materials of sufficient rigidity to resist distortion during the test.

5.2.2.3 The outer container (water bath) in which the soil container rings are integrated should allow the specimen and porous discs or shear friction plates to be submerged during the test.

5.2.2.4 The design of the soil container (rings) shall fulfil the following requirements:

— the minimum outer diameter of the soil container (D_a) should be 70 mm;

— the minimum ratio of inner diameter to outer diameter of the container (D_i/D_a) should be 0,6;

— the minimum height of the specimen annulus shall be 5 mm;

— the ratio of height to width of the annulus H / [(D_a – D_i) / 2] shall be equal to or less than 1;

— the upper and lower rings shall be fitted with porous discs or shear friction plates.

5.2.2.5 The porous discs or shear friction plates shall comply with 5.2.1.6.

5.3 Loading-devices

5.3.1 The vertical loading system shall maintain the required vertical load constant during consolidation and shearing. The vertical loading system may consist of physical weights and a lever system, or a mechanical, hydraulic, pneumatic or electro-mechanical device. If a hanger system is used to apply the vertical load the weight of the hanger shall be known and allowed for. The vertical stress applied to the specimen shall be accurate to at least 1 % of the intended stress or 1 kPa whichever is greater.

5.3.2 The shearbox apparatus and loading device shall allow a minimum linear, horizontal displacement of 15 % of the length or diameter of the specimen. The apparatus shall allow the rate of displacement to be maintained within 10 % of the intended rate and slow enough to allow dissipation of pore water pressures during shear.

NOTE Displacement rates varying from about 0,005 mm/min to about 1 mm/min have been found to be sufficient for most testing.

5.3.3 Ring shear apparatus and loading device shall allow an unlimited horizontal travel by rotation. The apparatus shall allow the rate of displacement to be maintained constant and slow enough to allow dissipation of pore water pressures during shear.

NOTE Rotation rates of 0,05°/min or greater have been found to be sufficient for a large range of soils.

5.4 Measuring devices

5.4.1 Load measuring devices

The vertical load measuring device shall have an accuracy of 1 % of the actual value, or within 5 N, whichever is the greater value.

The horizontal load measuring device in the shearbox test shall have an accuracy of 1 % of the shear force at failure, or within 2,5 N, whichever is the greater value.

NOTE Load measurement devices both above and below the specimen can allow the side friction to be evaluated.

5.4.2 Torque measuring devices

Torque measurement devices shall have an accuracy of 1 % of the actual value, or within 0,1 Nm, whichever is the greater value.

5.4.3 Displacement measuring devices

The vertical linear displacements measurement device:

— The range of the device shall be suitable to measure and display displacements of up to 20 % of the initial height of the specimen.

— The device shall have a resolution of at least 0,02 % of the initial height of the specimen and an accuracy of at least 0,2 % of the initial height of the specimen or 0,02 mm, whichever is the greater value.

The horizontal linear displacements measurement device:

— In the shearbox apparatus the horizontal linear displacements shall be measured with an accuracy of 0,1 % of the specimen length in the direction of shear or 0,02 mm, whichever is the greater value.

— In the ring shear apparatus the angular displacement shall be measured with an accuracy of 1° or better.

5.5 Ancillary apparatus

The ancillary apparatus consists of:

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

— 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 is the greater value;

— tools and equipment for mixing and compacting or pre-consolidating the specimen, if applicable.

Tap water may be used to fill the outer container, but water with a similar chemistry as the specimen pore water should be specified for the test when the results may be affected.

6 Test procedure

6.1 General requirements

6.1.1 Test specimens may be prepared from undisturbed, remoulded, recompacted or reconstituted samples. However, for the determination of residual strength in the ring shear test, remoulded or reconstituted specimens are generally used.

6.1.2 The largest grain size in the specimen should not be greater than 1/6 of the specimen height and if particles greater than 1/10 of the specimen height are present this shall be reported.

6.2 Preparation of specimen

6.2.1 General requirements and selection of the preparation method

6.2.1.1 Depending on the type of sample the specimen shall be fabricated, cut or trimmed as described below, so that it can be mounted in the apparatus with the minimum of disturbance.

6.2.1.2 Specimens shall have a minimum initial height of 20 mm for the shearbox test and 5 mm for the ring shear test.

6.2.1.3 The specimen surfaces shall be plane and perpendicular.

6.2.1.4 Take care to maintain the water content of the specimen during the preparation process. If the process is interrupted for more than a few minutes, the specimen shall be protected, e.g. by carefully wrapping in plastic foil.

6.2.2 General requirements for preparation of specimens from undisturbed samples

6.2.2.1 Specimens may be prepared by trimming from either block samples or from tube samples or by extrusion of tube samples into a mould with a cutting edge. The mould and cutter should be either square or circular to suit the specimen shape and size required for the test.

6.2.2.2 Examine undisturbed samples prior to testing and select the least disturbed material for the test. If significant disturbance is apparent in the specimen this should be recorded in the test report.

6.2.2.3 Take care to avoid deforming the specimen during cutting and trimming.

6.2.2.4 After removal of the cutter or after extrusion, the ends shall be trimmed by cutting away a little of soil at a time. The ends shall be checked to be flat and flush with each end of the ring or mould.

6.2.2.5 Any grooves or holes in the surface of the specimen should be removed by further trimming or a new specimen should be selected if available. Otherwise, fill grooves or holes not exceeding 1/6 of the specimen height with remoulded sample material and record the action taken. Specimens with voids or holes larger than this should not be used.

6.2.3 Trimming from extruded or block samples

6.2.3.1 A horizontal flat surface shall be prepared on the sample of a size larger than the diameter of the cutter and mould.

6.2.3.2 The sample shall be placed on to the trimming apparatus, the cutter shall be fitted into the mould and the cutting edge shall be lowered on to the prepared surface. The cutter should be centred on the sample, unless visible discontinuities or disturbance suggests that a better quality specimen can be cut off-centre.

6.2.3.3 The cutter and mould shall be steadily pushed into the sample until it is filled with soil with an excess protruding from the top. Soil cuttings shall be removed so that advance of the cutter and mould is not impeded.

6.2.3.4 With stiff soils the sample shall be trimmed in advance of the cutter to about 1 mm or 2 mm larger than the internal cutter dimension so that the cutting edge removes the remaining thin layer.

6.2.3.5 The sample shall be cut off underneath the cutter to remove the mould and contained soil to allow trimming of the ends of the specimen.

6.2.4 Extrusion from a tube of diameter larger than the mould and cutter

6.2.4.1 The sampling tube shall be mounted in the extrusion device and secured.

6.2.4.2 Any disturbed soil shall be extruded from the end of the tube and the surface of the soil remaining in the tube shall be trimmed flat.

6.2.4.3 The sample shall be extruded through the cutter and mould whilst checking that the excess soil can be removed easily and does not impede the extrusion process.

6.2.4.4 The sample shall be cut off underneath the cutter to remove the mould and contained soil to allow trimming of the ends of the specimen.

6.2.5 Preparation of laboratory fabricated specimens

6.2.5.1 For samples fabricated of fine grained soils, the water mixed into the material should be allowed to equalise for at least 16 h before compaction.

6.2.5.2 If the specimen is to be fabricated within the specimen container, weigh the empty shearbox, shear ring or container, including porous discs (if appropriate) to the nearest 0,01 g or 0,1 % of the total mass, whichever is the greater value, as required to subsequently determine the initial mass of the specimen.

6.2.5.3 Specimens may be prepared in the laboratory by compacting the soil in layers into the shear box. Compacted specimens should be prepared by adding soil in layers and compacting the soil at a specified water content and dry density, or by compaction under the application of a specified compaction effort. The top of each layer shall be scarified before adding material for the next layer. Reconstituted specimens of sand may be prepared by pluvial compaction in air or under water. Reconstituted specimens of fine grained soils may be prepared by consolidation of a material prepared at suitable water content, to a specified consolidation stress prior to the test.

6.2.5.4 Remoulded specimens may be prepared for testing in the ring shear apparatus by kneading the sample into the annulus between the specimen container rings using a small spatula and levelling off the top surface. If necessary, any oversize particles should be removed before remoulding. Reconstituted specimens of fine grained soils may also be prepared in the ring shear apparatus by consolidation of a material prepared at suitable water content, to a specified consolidation stress prior to the test.

6.2.5.5 Test specimens may also be prepared in a suitable mould other than the shear box or soil container of the ring shear apparatus (e.g. a compaction mould). Compaction may be performed either at the required water content under the application of the appropriate compaction effort, or to achieve the specified dry density. Reconstituted specimens of fine grained soils may be consolidated prior to the test to a specified consolidation stress. The sample can then be extruded from the mould and the test specimen shall be prepared in accordance with 6.2.2.

6.2.5.6 Care should be taken that layer interfaces do not coincide with the shear plane defined by the apparatus.

6.3 Measurements before testing

6.3.1 Weigh the shear box or ring shear container (including the porous discs if appropriate) containing the specimen, or cutting ring containing the specimen, to the nearest 0,01 g or 0,1 % of the total mass, whichever is the greater value, as required to determine the initial mass of the specimen, m_0.

6.3.2 Determine the initial height, H_0 of the specimen and the dimensions required to calculate the plan area, A of the specimen. The dimensions of the cutting ring or those of the shear apparatus container should be used if appropriate, depending on the preparation method of the specimen. The dimensions of the ring or container shall be measured to the nearest 0,1 mm.

6.3.3 The water content of the specimen shall be obtained in accordance with ISO 17892-1, from excess representative adjacent material.

6.4 Equipment preparation

6.4.1 During installation of the specimen into the shearbox the upper and lower parts of the shearbox shall be fixed to avoid any displacement of the two parts relative to each other.

6.4.2 To reduce shear stresses on the inside faces and friction between the two halves of the shear box during the shear phase, a thin coating of silicone grease or petroleum jelly may be applied to the inside faces of the shearbox or the ring and to the surfaces of contact between the two halves of the box or ring.

6.4.3 If the specimen was not prepared in the shearbox or container ring, fit the prepared specimen into the shearing apparatus by pushing it gently from the cutting ring into the box or ring. Weigh the empty cutting ring (including any particles left on the side surfaces) to the nearest 0,01 g or 0,1 % of the total mass, whichever is the greater value, to allow calculation of the initial mass of the specimen, m_0.

6.4.4 If wet porous discs are used, free water shall be allowed to drain from them and excess surface water shall be removed before placing or using them in the shearbox or shear ring. The porous discs shall be clean and not clogged.

6.4.5 Assemble the apparatus, align and take zero readings for the displacement measuring devices and the load measuring devices.

6.5 Consolidation

6.5.1 The consolidation stress shall be defined taking into account the nature of the soil, the presumed in situ stress history and the parameters that are requested from the test.

6.5.2 When testing compressible soils the vertical consolidation load may be applied in several intermediate increments to avoid extrusion of the soil. If consolidation reduces the thickness of a reconstituted specimen in the ring shear test by more than 10 % for the Type B ring shear device, further soil should be added and consolidation should be repeated.

6.5.3 Unless testing a dry specimen, water shall be introduced to the outer container to a level at which the top porous disc or plate is submerged. For soils that readily absorb water (e.g. stiff clays), the specimen may be mounted with dry porous discs (or shear friction plates) and the water may then be added whilst applying a vertical stress high enough to inhibit swelling.

6.5.4 Carefully apply the required load without jolting, within a period of 2 s. Alternatively a jacking system may be used to support the lever arm while weights are added to the hanger. At the same instant the timer shall be started.

6.5.5 Record the vertical displacement at suitable time intervals. 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.

6.5.6 Continue to take readings of the vertical displacement until the plotted readings indicate that primary consolidation is complete. Dry sand or free-draining saturated sand consolidates very rapidly, therefore timed consolidation readings are not necessary for these materials.

6.5.7 Determine the maximum rate of shear displacement:

6.5.7.1 A plot of vertical displacement, *d,* versus the square root time may be used to estimate the value of t_c for use in determining the time to failure for the direct shear test (see Figure 4).

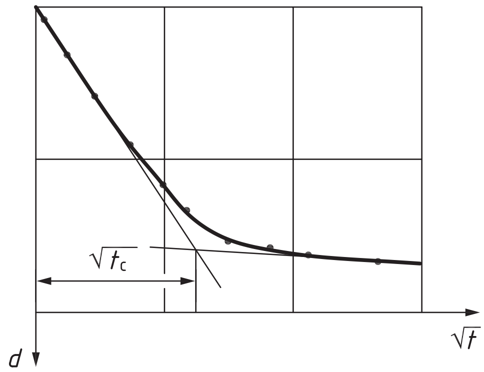


Figure 4 — Example of a time-settlement-curve to determine the time for primary consolidation

6.5.7.2 Draw the straight line of best fit to the early portion of the curve (usually within the first 50 % of compression) and extend the line to intersect the approximately horizontal line through final points on the curve of primary consolidation.

6.5.7.3 Read off the value of $\sqrt{t_c}$ corresponding to the intersection of the two lines.

6.5.7.4 Calculate the minimum time to failure, i.e. the time to mobilise the maximum shear resistance of the specimen, t_f using Formula (1):

$$t_f = 13 \times t_c \tag{1}$$

This test does not permit the derivation of a reliable value of coefficient of consolidation c_v due to uncertainty in the length of the drainage path.

NOTE Square root of time interpretation can yield erroneously fast rates of consolidation for partly saturated or very stiff materials. Other methods for estimating t_f can be used, when proved applicable to the tested material.

6.5.7.5 Estimate the horizontal shear deformation at failure s_f. In the absence of experience with the tested material a displacement of 10 mm or 10 % of the shear box length can be considered for coarse grained soils while a displacement of 1 mm or 2 % of the shear box length may be appropriate for stiff fine grained soils.

6.5.7.6 Determine the maximum allowable rate of shear displacement, v_{max} using Formula (2):

$$v_{max} = s_f / t_f \tag{2}$$

The maximum rate of angular displacement for the ring shear test, θ_{max}, expressed in degrees per minute, may be calculated using Formula (3):

$$\theta_{max} = 57{,}3\ v_{max} / r \tag{3}$$

where

v_{max} is the maximum allowable rate of shear displacement in the ring shear test (mm/min);

r is the mean radius of the specimen (mm).

The rate of displacement during drained ring shear should not exceed the maximum angular rate determined from Formula (3). The linear displacement rate in both the shear box and ring shear as determined by Formula (2), shall not exceed 1,0 mm/min.

6.6 Shearing

6.6.1 The vertical load shall be kept constant during shearing.

6.6.2 Before shearing, unlock the two halves of the shear box and slightly lift the upper half to give a clearance at the horizontal shear plane, sufficient to prevent friction during the test, but not to permit extrusion of the soil between them. This procedure should also be followed for the ring shear test if the design of the apparatus allows the upper half of the soil container to be lifted. For fine-grained soils a clearance of 0,5 mm is usually sufficient. For coarse-grained soils it should not exceed 1 mm.

6.6.3 Adjust the vertical load to the desired value required during shear to take account of the weight of the upper part of the box or soil container acting on the shear plane. Record the initial readings of the vertical and horizontal displacement gauges and the horizontal force measurement devices prior to shear.

6.6.4 Shear the specimen at a constant rate of displacement (strain controlled) no greater than that determined in 6.5.7.6, by displacing one of the two halves of the shearbox or the circular loading cap relative to the other half.

6.6.5 During the shearing stage the following readings are required, such that at least 15 readings are taken up to the maximum load, i.e. peak shear strength:

— the horizontal or angular displacement;

— the height change;

— the shear force or torque (rotational force).

Reading-Intervals of horizontal displacement of 0,5 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.

6.6.6 If only the peak shear stress is to be determined, shearing may be done by constant increase of the shear load (stress controlled).

6.6.7 The test may be stopped when either of the following criteria is reached:

— peak horizontal shear stress has been clearly achieved;

— a specified deformation, for example 15 % of the shearbox length is reached, if a peak horizontal shear stress has not been achieved.

6.6.8 The residual shear strength (τ_R) may be determined in the ring shear test as follows. After reaching the maximum shear load (if required) the rate of displacement may be increased up to tenfold. It shall then be reduced to the rate determined in accordance with 6.5.7.6 and shearing shall be continued until no further decrease in shear resistance is measured.

6.6.9 The residual shear strength may be determined in the shear box test by multi-reversal of the shear direction as follows.

6.6.9.1 After reaching the maximum shear load continue shearing until the full travel of the shear box has been reached. Return the shear box to its starting position by reversing the direction of travel. The rate of reverse displacement should be no greater than the rate of displacement to peak shearing force. If a higher rate of displacement is used the specimen shall be allowed to stand for at least 12 h to allow pore pressures to equalise.

NOTE The shear stresses during reverse travel have no significance.

6.6.9.2 Re-shear the specimen at the same displacement rate as the rate of displacement to peak shear to the full travel of the shear box.

6.6.9.3 Repeat 6.6.9.1 to 6.6.9.2 until a repeatable value of residual shear resistance is determined. Stop the test at the final forward travel of the shear box.

6.6.10 On completion of testing, if the test has been carried out on a submerged specimen, remove the water surrounding the specimen and allow the free water to drain from the porous discs or plates.

6.6.11 Remove the vertical load and transfer the shearbox or specimen container ring to a small tray and weigh, taking care not to lose any soil.

6.6.12 Dry the specimen to constant mass (m_d) or determine the water content of a representative part of the specimen, in accordance with ISO 17892-1.

7 Test results

7.1 Water content

Determine the initial mass (m_0) of the specimen from the measurements taken in 6.3 and 6.4 and then calculate the initial water content (w_0) in accordance with ISO 17892-1 from the trimmings (see 6.3.3) or from the initial mass (m_0) of the specimen and the final dry mass (m_d) of the specimen.

7.2 Initial dry density

The initial dry density ρ_d shall be calculated using Formula (4):

$$\rho_d = \frac{m_d}{A \times H_0} \tag{4}$$

If the final dry mass of the specimen cannot be determined, the initial dry density may be calculated from the initial wet mass and the initial water content of the trimmings in accordance with ISO 17892-2.

7.3 Initial bulk density

The initial bulk density, ρ, shall be calculated using Formula (5):

$$\rho = \frac{m_0}{A \times H_0} \tag{5}$$

7.4 Initial void ratio

The initial void ratio e_0 (if required) shall be calculated using Formula (6):

$$e_0 = \frac{\rho_s}{\rho_d} - 1 \quad (6)$$

7.5 Initial degree of saturation

The initial degree of saturation, S_r (if required), shall be calculated using Formula (7):

$$S_r = \frac{w_0 \times \rho_s}{e_0 \times \rho_w} \quad (7)$$

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) using Formula (8):

$$e = e_0 - \frac{\Delta H}{H_0}(1 + e_0) \quad (8)$$

7.7 Stresses and displacements

7.7.1 Shearbox

From each set of data obtained during the shearbox test the shear stress, τ and vertical stress, σ_v on the surface of shear shall be calculated using Formulae (9) and (10):

$$\tau = \frac{P}{A} \quad (9)$$

$$\sigma_v = \frac{N}{A} \quad (10)$$

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

7.7.2 Ring shear

For each set of data from the ring shear test, calculate the vertical (normal) stress, σ_v, and the shear stress, τ, on the surface of shear using Formulae (10) and (11):

$$\tau = \frac{3M_t}{2\pi \times \left(R_a{}^3 - R_i{}^3\right)} \quad (11)$$

Where the moment is measured using a torsion beam and two load cells the applied moment, M_t may be calculated using Formula (12):

$$M_t = (F_1 + F_2) \times L / 2 \quad (12)$$

where

F_1 and F_2 are the measured loads applied to the torsion beam;

L is the distance between the points of application of F_1 and F_2.

Calculate the horizontal linear shear displacement during the ring shear test, s_{rs} using Formula (13):

$$s_{rs} = (\theta \times \pi / 180) \times D_m / 2 \text{ (mm)} \quad (13)$$

Where θ is the angular displacement during the test in degrees.

7.8 Plotting

For each test the following graphs shall be plotted:

— Graph 1: shear stress, τ, as ordinate against horizontal displacement as abscissa;

— Graph 2: change in height (vertical displacement) of the specimen as ordinate against horizontal displacement as abscissa.

8 Test report

8.1 Mandatory reporting

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 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 height if present and a note that results may have been affected if any particles exceed 1/6 of the specimen height;

c) depth, location and orientation of the test specimen in the original sample;

d) method of preparation of the test specimen including any filing of voids or holes in the specimen;

e) statement of the method used, i.e. shearbox or type of ring shear;

f) initial dimensions of the specimen (mm);

g) initial water content (%);

h) initial bulk and dry density (mg/m^3);

i) tabulated values or plots of: the applied vertical stress (kPa), shear stress (kPa), and corresponding horizontal linear displacement (mm);

j) at failure:

   i) the failure criterion adopted;

   ii) the vertical stress;

   iii) the shear stress;

   iv) the horizontal linear displacement;

k) when determined, the residual shear stress from the ring shear test or from multi-reversal of the shearbox test (kPa);

l) rate or rates of horizontal displacement (mm/minute);

m) whether the specimens were tested dry or submerged;

n) graphical plots of shear stress and change in height versus horizontal linear displacement throughout the test.

8.2 Optional reporting

The following information is optional:

a) particle density, indicating whether measured or assumed (mg/m^3);

b) initial void ratio and degree of saturation (%);

c) graphical plot(s) of settlement against square root time during the consolidation process;

d) angle of shearing resistance (φ'), to the nearest 0,5°, and cohesion intercept (c' in kPa), without decimals, with the adopted failure criteria;

e) the residual angle of shearing resistance (φ'_R), to the nearest 0,5°;

f) graphical plot of shear stress against vertical (normal) stress at failure.