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Geotechnical investigation and testing — Laboratory testing of soil —

Part 11: **Permeability tests**

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

Partie 11: Essais de perméabilité

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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 17892-11:2004, which has been technically revised. It also incorporates the Technical Corrigendum ISO/TS 17892-11:2004/Cor 1:2006.

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

— the document has been restructured with general revision of text and figures and addition of specimen preparation procedures;

— types of apparatus have been included for rigid wall permeameters, both cylindrical and oedometer ring equipment, and flexible wall permeameters;

— permeability measurement by constant head, falling head and constant flow conditions has been included;

— normative Annex A on calibration, maintenance and checks has been added.

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 coefficient of permeability of soils 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 is not anticipated. It is based on international practice (see Reference [1]).

The permeability test is carried out on a cylindrical test specimen that is either confined laterally by a rigid container or by a flexible membrane. The specimen is subjected to differential hydraulic head and the water flow is measured under either a constant or falling head. The results are used to determine the coefficient of permeability of the soil specimen. Tests can be carried out on undisturbed, remoulded, compacted or reconstituted specimens.

The calculation of the coefficient of permeability assumes the application of Darcy's law for laminar flow of water under saturated conditions.

It is possible that the size of the specimen does not adequately represent the fabric features present in field conditions.

Geotechnical investigation and testing — Laboratory testing of soil —

Part 11: Permeability tests

1 Scope

This document specifies methods for the laboratory determination of the water flow characteristics in soil.

This document is applicable to the laboratory determination of the coefficient of permeability of soil within the scope of geotechnical investigations.

NOTE This document fulfils the requirements of the determination of the coefficient of permeability of soils in the laboratory 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 386, *Liquid-in-glass laboratory thermometers — Principles of design, construction and use*

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:

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

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

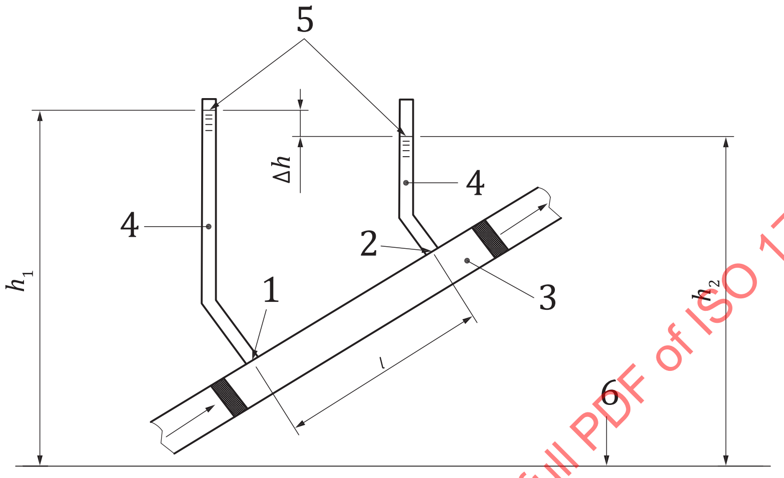
3.1
permeameter
apparatus (cell) containing the test specimen in a permeability test

3.2
flow rate
volume of water passing through a specimen per unit time

3.3
discharge velocity
rate of flow of water per unit cross-sectional area of specimen in the direction of flow

3.4
hydraulic gradient
ratio of the difference in elevation head of water (head loss) between two points, to the length of the flow path (distance between the points measured in the direction of flow)

Note 1 to entry: In Figure 1 the hydraulic gradient is $i = \Delta h/l$.



Key

1 measurement point 1
2 measurement point 2
3 specimen
4 standpipe
5 standpipe head
6 datum

Figure 1 — Water flow in a soil specimen

3.5
coefficient of permeability
ratio of the *discharge velocity* (3.3) to the *hydraulic gradient* (3.4)

Note 1 to entry: The coefficient of permeability is in accordance with Darcy's law for laminar flow.

3.6
degree of saturation
ratio of the volume of water to the volume of voids

4 Symbols

A	cross-sectional area of specimen in the direction of flow
a	cross-sectional area of standpipe
a_{in}	cross-sectional area of inlet pipe
a_{out}	cross-sectional area of outlet pipe
B	pore pressure coefficient
D	diameter of the specimen

h_1	total head of water above datum at measurement point 1
h_2	total head of water above datum at measurement point 2
Δh	difference in head of water between measurement point 1 and 2
Δh_{t1}	head of water above outlet elevation at time t_1
Δh_{t2}	head of water above outlet elevation at time t_2
l	distance between measuring points 1 and 2 in the direction of flow
k	coefficient of permeability
k_T	coefficient of permeability corrected to temperature
Q	flow rate
v	discharge velocity
i	hydraulic gradient
S	degree of saturation
$\Delta \sigma_c$	increment of cell pressure
Δt	increment of time between two readings
Δu	change in pore pressure due increment of cell pressure
α	correction factor for temperature
T	temperature

5 Apparatus

5.1 General

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

The permeability test arrangement requires a container for the specimen (the permeameter) which may have either rigid or flexible walls and a system for applying and measuring water pressures to either or both ends of the specimen. Schematics of some typical arrangements are shown in Figures 2 to 4.

5.2 Permeameters

5.2.1 General

The minimum internal dimension (height and diameter) of the permeameter shall be at least six times the maximum particle size of the specimen.

5.2.2 Rigid wall permeameters

5.2.2.1 General

Rigid wall permeameters shall be made of corrosion-resistant materials of sufficient rigidity to resist deformation during the test. The inlet and outlet arrangements shall be of sufficient flow capacity to not influence the test results. Hydrophobic coating can be used on the inside of the permeameter, mould or ring to prevent channels and cavities that can cause bypass seepage along the surface. This coating can consist of silicon grease, petroleum jelly coated with bentonite powder or other suitable lubricant.

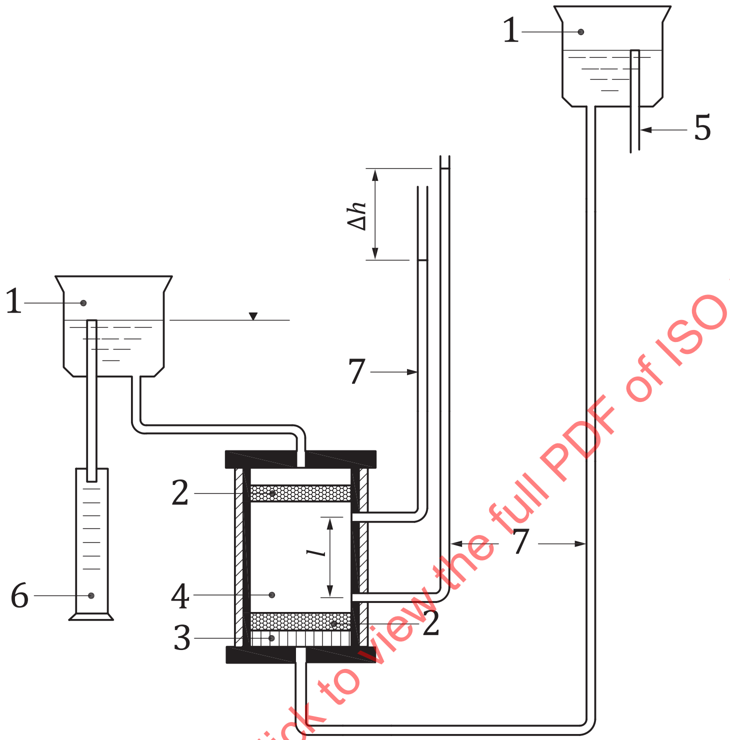
5.2.2.2 Cylindrical permeameter

A cylindrical permeameter comprises a cylindrical mould fitted with porous discs on a top-plate and baseplate. The plates are mounted with watertight seals and equipped with valves where water inlet and outlet can be connected.

Two or more fitted glands can be provided for connecting manometer tubes/standpipes along the length of the cylinder.

If required a piston that goes through the top plate and can be locked with a watertight seal at the vertical position where it is in contact with the top porous disc, should be provided to maintain the specimen height during the test.

A typical arrangement for a permeability test in a cylindrical rigid wall permeameter is shown in Figure 2.



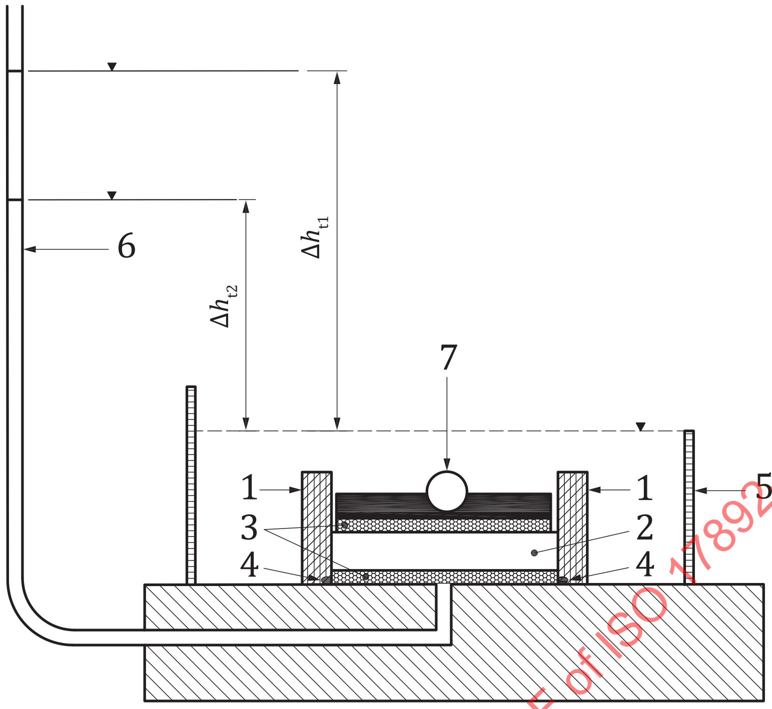
Key

1 reservoir
2 porous disc
3 perforated base plate
4 specimen
5 overflow
6 measuring cylinder
7 standpipe

Figure 2 — Example arrangement for a constant head test in a cylindrical rigid wall permeameter

5.2.2.3 Oedometer ring permeameter

An oedometer ring permeameter comprises an oedometer ring that holds the specimen in an oedometer used for compression tests. A typical arrangement for a permeability test in an oedometer ring permeameter is shown in Figure 3.



Key

1 oedometer ring
2 specimen
3 porous disc
4 water seal
5 reservoir
6 standpipe
7 vertical load and displacement measurement device

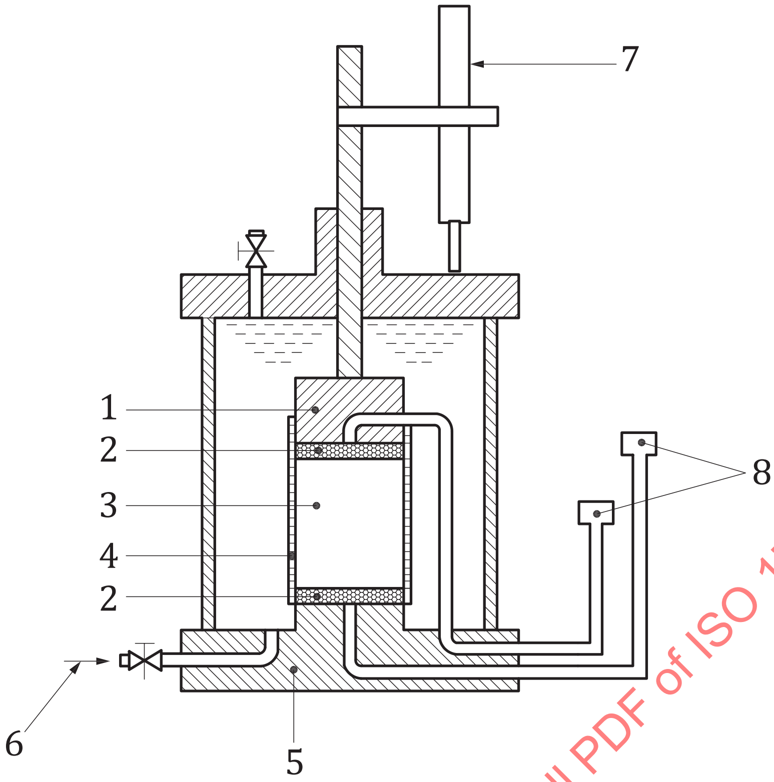
Figure 3 — Example arrangement for a falling head test in an oedometer cell permeameter

5.2.3 Flexible wall permeameter

5.2.3.1 General

A flexible wall permeameter can be used where the soil specimen is to be tested under specific effective stress conditions and/or where back pressure will be used to fully saturate the specimen. The test can be performed in a standard triaxial apparatus. It needs to have a cell that can be pressurised, a base pedestal and top cap with porous discs and connectors to the water flow measurement system and a membrane that seals the surface of the specimen.

A typical arrangement for a permeability test in a flexible wall permeameter is shown in Figure 4.



Key

1 top cap
2 porous disc
3 specimen
4 membrane
5 pedestal
6 cell pressure
7 displacement measurement device
8 pressure control and volume measurement device

Figure 4 — Example arrangement for a flexible wall permeameter

5.2.3.2 Membranes

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 they shall have an un-stretched diameter between 95 % and 100 % of the specimen diameter. The membranes are sealed with O-rings on the pedestal and top cap.

5.2.3.3 Cell pressure system

The devices for applying pressure to the cell and to the back pressure system shall be capable of maintaining a stable pressure within 1 kPa or 1 % of the absolute pressure, whichever is greater. The total cell pressure used shall be greater than the sum of the back pressure and the inlet pressure applied.

5.2.3.4 Cell pressure fluid

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 in the period of time it takes to perform the permeability test.

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

5.3 Porous discs

The specimen is contained between porous discs at both ends of the specimen. The porous discs shall be of corrosion-resistant material and 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. Filter paper may be used to prevent soil particles from clogging the porous discs. The permeability of the discs together with the filter paper, if used, shall be at least one order of magnitude higher than the permeability of the specimen tested.

5.4 Permeant water properties

Water of a similar chemistry to the pore water should be used if the soil is susceptible to the chemistry of the water. If the chemistry of the pore water is unknown, tap water should be used as its chemistry is more likely to be similar to ground water than distilled water would be. The water shall be de-aired.

5.5 Measurement and control devices

5.5.1 Elevation head

The water elevation head can be measured as the difference in height of the water source and the water outlet.

Electronic differential or absolute pressure transducers can also be used to determine the elevation head applied. Differential transducers may be preferred when high back pressures are applied,

If a rigid wall permeameter is used it is preferable to measure the pressure (elevation head) difference at glands along the length of the specimen, due to potential loss in pressure over tubes, valves and filter discs. The corresponding flow lengths are the distances between the glands along the side of the specimen which shall be determined to an accuracy of 1 %.

5.5.2 Displacement and volume measuring devices

If the specimen height or cross-sectional area can change significantly during the test and affect the calculation of permeability, measuring devices are required to measure the dimensional changes of the specimen during the test.

5.5.3 Flow volume measurement device

The volume of water passing through the specimen can be measured on graduated tubes or from the weight of expelled water. If measurements are taken over a long period of time, evaporation of water from these tubes or water receptacles should be prevented to avoid errors in the measured flow volumes.

The flow rate may also be measured by inserting an air bubble into both the inlet and outlet tubes, of known diameter and measuring the travel time of the air bubbles corresponding to the flow volume. The diameter of the tubes shall be checked at the pressure used for the flow measurement.

If digital pressure/volume controllers are used the change in volume and pressure can be automatically recorded.

The time between water volume measurements can be measured by a stopwatch or a data-logging system.

The measurement duration shall be sufficient to determine the flow volume within an accuracy of 10 %.

5.6 Ancillary apparatus

The ancillary apparatus consists of:

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

— compaction equipment (e.g. Proctor compactor, gyratory compactors or tamping rods).

6 Test procedure

6.1 General requirements

6.1.1 Saturation

The degree of saturation has a great impact on the measured permeability. A completely saturated specimen gives the highest value of measured permeability. It is not always possible to ensure full saturation during the test due to equipment or soil condition, so the degree of saturation should be calculated and reported for each test. Unless a clay specimen is known to be saturated, back pressure should be used to saturate the specimen.

6.1.2 Hydraulic gradient

The hydraulic gradient shall be sufficiently low to ensure laminar flow conditions and to prevent material transport within the specimen and high enough to ensure exceeding the threshold gradient. The more permeable the soil, the lower the hydraulic gradient that should be used. The values in Table 1 have been found to be helpful when choosing the hydraulic gradient. Stable conditions can be confirmed by measuring the coefficient of permeability for the same specimen at different hydraulic gradients.

Table 1 — Guidelines for maximum recommended hydraulic gradient

Permeability (m/s)	Recommended maximum hydraulic gradient
$>10^{-5}$	1
10^{-5} to 10^{-6}	2
10^{-6} to 10^{-7}	5
10^{-7} to 10^{-8}	10
10^{-8} to 10^{-9}	20
$<10^{-9}$	30 or greater

6.1.3 Water temperature

The viscosity of water changes with temperature and affects the measured permeability. The temperature at which the test was performed shall be recorded.

6.2 Specimen preparation

6.2.1 General

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

6.2.1.2 Examine 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. Highly disturbed samples will not provide meaningful results and should not be tested.

6.2.1.3 Specimens may be prepared directly within a cylindrical permeameter or from previously fabricated or undisturbed tube or block samples for the oedometer or flexible wall permeameters.

6.2.1.4 The maximum particle size should not exceed $1/6^{th}$ of the minimum internal dimension of the permeameter. If larger particles are present a larger permeameter should be used or the larger particles should be removed and the proportion removed shall be reported. If larger particles are found after completion of the test, their presence shall be noted in the report.

6.2.1.5 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.

6.2.2 Rigid wall permeameter

6.2.2.1 Disturbed samples shall be prepared by compacting the soil into the permeameter or compaction mould either at the required water content under the application of the appropriate compaction effort, or to achieve the specified dry density.

6.2.2.2 Samples prepared in a compaction mould shall be prepared at the required specimen diameter and extruded.

6.2.2.3 Block or tube samples shall be placed on to the trimming or tube sample extrusion apparatus, the cutter shall be fitted into the permeameter or 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.

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

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

6.2.2.6 The sample shall be cut off underneath the permeameter or mould to remove the cutter and contained soil.

6.2.2.7 Each end of the specimen shall be trimmed in turn using appropriate tools to cut away excess soil a little at a time.

6.2.2.8 Immediately after preparation the mass of the specimen shall be determined to an accuracy of 0,1 % or 0,01 g whichever value is greater.

6.2.2.9 For a rigid wall permeameter, the specimen area is taken as the inside cross-sectional area of the permeameter. The height of the specimen shall be determined to an accuracy of 0,5 mm or 1 % whichever value is greater.

6.2.2.10 Complete the assembly of the permeameter.

6.2.3 Flexible wall permeameter

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

6.2.3.2 The soil specimen end surfaces shall be plane and perpendicular to the longitudinal axis in accordance with ISO 17892-2. Grooves and holes in the ends and sides of the specimen should be removed by further trimming or a new specimen selected if available. Otherwise, fill grooves or holes not exceeding 1/6th of the specimen diameter with remoulded sample material.

6.2.3.3 Specimens may be prepared in the laboratory by compacting the material in layers into a split mould with the rubber membrane mounted inside. Water mixed into the material should be given time before the compaction to equalize over the whole soil mass.

6.2.3.4 Measure the specimen height, diameter and mass in accordance with ISO 17892-2 by linear measurement.

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

6.2.3.6 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.

6.2.3.7 Complete the assembly of the flexible wall permeameter.

6.3 Test preparation

6.3.1 Cylindrical permeameter

6.3.1.1 If the permeameter is equipped with manometer tubes, their valves shall be closed during the equipment and specimen saturation process.

6.3.1.2 The permeameter water inlet shall be connected to a de-aired water supply with a low hydraulic gradient just sufficient to allow the water to slowly percolate through the specimen. If a vacuum source is available it may be connected to the outlet before the inlet valve is opened. When vacuum is used the inlet valve shall be opened slowly to prevent turbulent flow conditions and specimen disturbance.

6.3.1.3 When the specimen and permeameter have been adequately saturated, open the connections to the manometer tubes and apply the inlet and outlet pressures.

6.3.2 Oedometer ring

6.3.2.1 The oedometer ring containing the specimen shall be placed in position on the apparatus.

6.3.2.2 A small seating pressure shall be applied to the specimen not exceeding 3 kPa (in addition to the stress due to the weight of the top cap and porous disc) to ensure proper contact between the loading system and the soil. Care shall be taken to assemble the top cap and load frame such that the load is applied axially without imposing tilt of the top cap.

6.3.2.3 The deformation measuring apparatus shall be secured in position and the initial reading corresponding to zero deformation shall be recorded.

6.3.2.4 The permeability test can be performed both as a standalone test and as part of an incremental oedometer test. The sequence of stresses to be applied to the specimen should be defined taking into account the nature of the soil, the presumed in situ stress history and the parameters that are required from the test. The stress applied during the permeability test shall take into account the change in effective stress produced by the hydraulic head. The effective stress should be adequate to prevent swelling. Permeability measurements can only be taken when the soil specimen is fairly stable, after primary consolidation is complete at the required consolidation stress.

6.3.2.5 Take readings of displacement and volume change measurement devices on completion of the consolidation stage.

6.3.2.6 Apply the inlet pressure required for the permeability test.

6.3.3 Flexible wall permeameter

6.3.3.1 Take initial readings of displacement and volume change measurement devices.

6.3.3.2 Saturation

6.3.3.2.1 In the flexible wall permeameter adequate saturation of the specimen may be achieved either by:

- the application of increments of cell pressure with closed drainage, with resulting increase in pore water pressure, or
- the application of increments of both cell and back pressure with open drainage.

The selection of the method of saturation shall ensure that the effective stresses within the specimen are not raised to a level that affects behaviour during the permeability measurement.

The effective stress should be adequate to prevent swelling.

6.3.3.2.2 The effective stresses acting on the specimen during saturation shall not exceed the specified effective stresses for the test.

6.3.3.2.3 If performing saturation with closed drainage, the following should also be met:

- the observed increase in back pressure during increments of cell pressure should be at least 90 % of the corresponding increase in cell pressure;
- for effective consolidation stresses below 20 kPa the difference in the increment of cell and back pressure should be kept below 2 kPa.

If these criteria cannot be met, saturation using open drainage should be considered.

If applying back pressure using open drainage, the change in effective stress should be not greater than 5 kPa during saturation.

6.3.3.3 Saturation checks

6.3.3.3.1 Saturation by back pressure should be checked by measuring the B-value. To perform the check, close the drainage to the specimen, increase the cell pressure by an isotropic increment ($\Delta\sigma_c$) and record the corresponding increase in pore pressure (Δu). The value of the isotropic increment needs to be carefully chosen, reflecting the nature of the sample and the intended final effective stresses required on the sample, but increments between 10 kPa and 100 kPa are often found to be appropriate.

6.3.3.3.2 Calculate the *B*-value according to Formula (1):

$$B = \frac{\Delta u}{\Delta \sigma_c} \tag{1}$$

6.3.3.3.3 Saturation should be considered complete when a *B*-value of at least 0,95 is achieved. If the *B*-value is less than 0,95, further increments of cell pressure, or cell and back pressure (6.3.3.2) shall be applied and the *B*-value re-measured (6.3.3.3). If during repeated increments the *B*-value shows no significant increase, the saturation stage may be considered complete.

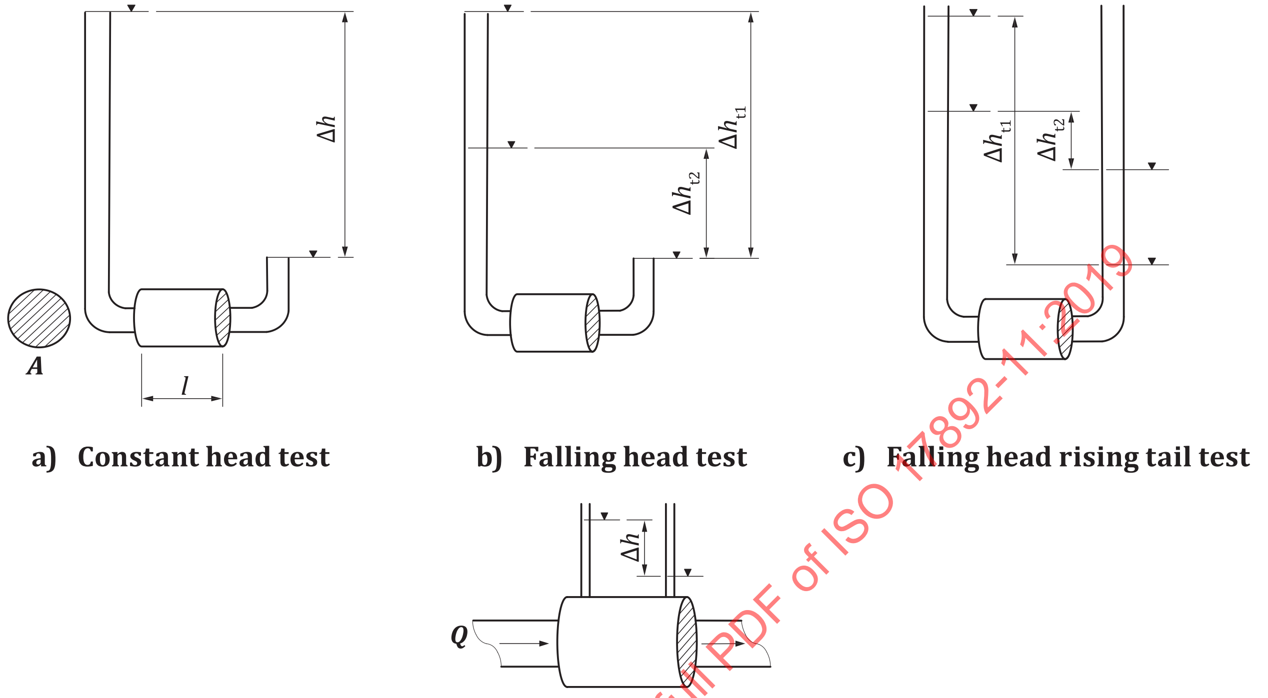
6.3.3.4 Take readings of displacement and volume change measurement devices. Adjust the cell pressure until the difference between the total cell pressure and the total pore pressure becomes equal to the specified effective stress. The choice of effective stress shall take into account the increased elevation (pressure) head during the permeability test. Permeability measurements can only be taken when the soil specimen is fairly stable, after primary consolidation is complete at a specific consolidation stress increment.

6.3.3.5 Take readings of displacement and volume change measurement devices.

6.3.3.6 Apply the inlet and outlet pressures required for the permeability test.

6.4 Permeability measurement

6.4.1 Permeability tests may be carried out under either a constant head or a falling head. In a falling head test the outlet pressure may be maintained constant (constant tail test) or both the inlet and outlet pressures varied (the raising tail test). In the constant flow test the flow is applied directly through the specimen by a pump. These arrangements are shown schematically in Figure 5.



a) **Constant head test**

b) **Falling head test**

c) **Falling head rising tail test**

d) **Constant flow test**

Figure 5 — Alternative arrangements to generate flow for permeability measurement

6.4.2 In a constant head test both the water inlet level and the outlet level are kept constant. In a falling head test the inlet water level falls through the inlet burette or standpipe as the water flows through the specimen. This results in varying hydraulic gradient during the test.

6.4.3 The required minimum amount of the water flow or the change of the water level during each measurement shall be chosen based on the accuracy of the measurement devices used, i.e. the measurement period shall be long enough and the hydraulic gradient high enough to provide reliable and representative results.

6.4.4 If possible, the relation of the inflow rate and outflow rate should be calculated to evaluate the state of flow as this can be affected by saturation and consolidation. If the ratio between inflow and outflow is between 0,75 and 1,25, the flow conditions may be considered acceptable.

6.4.5 The presence of gas within the specimen will affect the result. If bubbles flow out from the specimen during the permeability measurement saturation should be continued and the permeability measurement repeated or their volume should be quantified and taken into account in the measurement of flow volume.

6.4.6 If the specimen height or cross-sectional area can change significantly during the test and affect the calculation of permeability, record the dimensional changes of the specimen during the test.

6.4.7 The calculated value of permeability shall be consistent over four intervals of time. If there is an increasing or decreasing trend, further measurements shall be taken until consistent results are achieved.

6.5 Dismounting

6.5.1 When the permeability measurements are finished, close the water inlet and outlet valves and disconnect the permeameter from the hydraulic pressure sources.

6.5.2 Drain the flexible wall permeameter cell (if used).

6.5.3 Dismantle the permeameter, extract the specimen and if the specimen is intact, weigh the whole specimen and if required, record its dimensions.

6.5.4 Undisturbed specimens should be cut open to allow any internal structures or inhomogeneity to be identified and recorded.

6.5.5 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 in order that the dry mass may be calculated.

7 Test results

7.1 Bulk density, dry density, water content and degree of saturation

7.1.1 Calculate the initial water content from the final dry mass and the initial wet mass of the specimen.

7.1.2 Calculate the initial bulk and dry densities from the initial measurements of specimen dimensions and mass following the linear measurement procedures in accordance with ISO 17892-2. If the specimen dimensions during the test are available, the dry density at the time of the measurement of permeability shall also be calculated.

7.1.3 Calculate the final degree of saturation, S, based on a particle density value measured in accordance with ISO 17892-3, or estimated, and the water content at the end of test (6.5.5).

7.2 Coefficient of permeability and hydraulic gradient

7.2.1 If any of the equipment used (valves, tubes, porous discs, etc.) causes a head loss that is greater than 10 % of the elevation head applied in the test, this should be corrected for. The correction can be determined by measuring the differential pressure required to flow water through the equipment without a test specimen at the same flow rate as that of the permeability test with the test specimen.

The hydraulic gradient, i, is calculated according to Formula (2).

$$i = \frac{\Delta h}{l} \quad (2)$$

7.2.2 The coefficient of permeability shall be calculated for each of the four or more test intervals and the average value calculated.

For constant head and constant flow tests the coefficient of permeability is calculated according to Formula (3).

$$k = \frac{v}{i} = \frac{Q}{A \times i} = \frac{Q \times l}{A \times \Delta h} \tag{3}$$

For a flexible wall permeameter, some consideration has to be taken for the area A used in the calculations. This could be the initial area or the calculated area at the time of the flow measurements, whichever is deemed most appropriate.

Depending on the arrangement of head and tail sources for falling head tests the coefficient of permeability is calculated according to either Formula (4) or (5).

Falling head raising tail $$k = \frac{a_{\text{in}} \times a_{\text{out}}}{\left(a_{\text{in}} + a_{\text{out}}\right)} \times \frac{l}{A \times \Delta t} \times \ln\left(\frac{\Delta h_{\text{t1}}}{\Delta h_{\text{t2}}}\right) \tag{4}$$

Falling head constant tail $$k = \frac{a_{\text{in}} \times l}{A \times \Delta \text{t}} \times \ln\left(\frac{\Delta h_{\text{t1}}}{\Delta h_{\text{t2}}}\right) \tag{5}$$

7.3 Correction for test temperature

The permeability measured in a test performed with the permeant water at temperature, T_{test} (°C), can be converted to a corresponding permeability at another temperature, T (°C) through a correction factor α according to Formulae (6) and (7).

$$k_T = k_{\text{test}} \times \alpha \tag{6}$$

where

$$\alpha = \frac{\eta_{\text{test}}}{\eta_T} \tag{7}$$

and η_T is the viscosity for water in mPa·s for a given temperature, T is from Table 2.

Table 2 — Dynamic viscosity of water

Temperature T °C	Viscosity η mPa·s
10	1,304
15	1,137
20	1,002
25	0,891
30	0,798

NOTE 1 Intermediate values can be estimated by interpolation. Alternatively, the dynamic viscosity can be calculated using the approximation:

$\eta_T = 0{,}024\ 14 \times 10^{[247{,}8\ /\ (T + 133)]}$

where T is the test temperature (ºC) in the above range.

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) type of permeameter used and whether it was a rising, falling or constant head or constant flow test;

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

c) visual description of the specimen including any observed features noted after testing, following the principles in ISO 14688-1;

d) method of preparation of the test specimen;

e) initial dimensions of the specimen;

f) initial water content (%) and a statement that it has been based on the specimen trimmings if appropriate;

g) final water content (%) and degree of saturation at the end of the test, if determined;

h) initial bulk density, initial dry density and dry density at the time of measurement of permeability, if available (Mg/m^3);

i) average coefficient of permeability;

j) consolidation stress level at which the permeability measurement was taken, if appropriate;

k) average laboratory temperature (°C) at which the test was performed;

l) source of the permeant water e.g. tap water;

m) hydraulic gradient applied during the permeability test;

n) level of back pressure and *B*-value, if used;

o) equipment head loss correction applied to the measurements, if any, and the associated flow rates;

p) deviations from the test method.

8.2 Optional reporting

The following additional information may be required:

a) flow rate and calculated coefficient of permeability for each of the test results that were used to calculate the reported average value.

b) coefficient of permeability corrected to a specific reference temperature;

c) particle density used, and whether it has been measured according to ISO 17892-3 or has been assumed;

d) initial and final void ratio;

e) inflow and outflow volumes and permeability coefficients presented as a function of time;

f) flow rates and permeability coefficients as a function of time;

g) specimen dimensions during the test, if available.