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Geotechnical investigation and testing — Laboratory testing of soil —

Part 11: Determination of permeability by constant and falling head

Reconnaissance et essais géotechniques — Essais de sol au laboratoire —

Partie 11: Détermination de la perméabilité au perméamètre à charge constante ou variable

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Foreword

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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 17892-11:2004) 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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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 is intended for use in earthworks and foundation engineering. It specifies laboratory test methods to establish the coefficient of permeability of water through water-saturated soils. In the proposed laboratory tests soil specimens are subjected to a flow of water passing through the specimen. The water pressure conditions and volume of water passing through the specimens are measured for evaluation of the permeability.

The results obtained serve to calculate groundwater flow and to assess the permeability of man-made impervious layers and filter layers.

2 Normative references

The following referenced document is 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 1997-2, *Eurocode 7 - Geotechnical design — Part 2: Ground investigation and testing.*

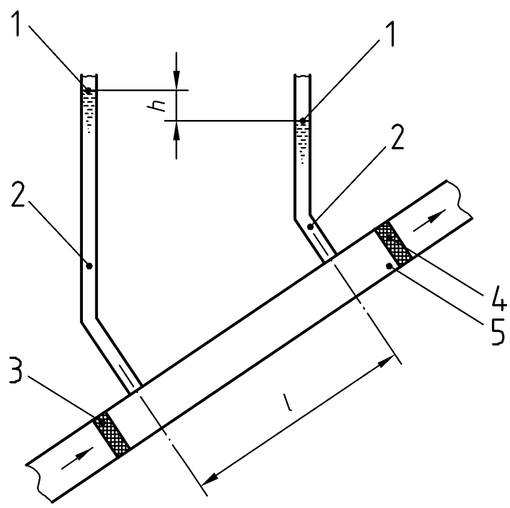
3 Terms and definitions

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

3.1
flow rate
Q
quantity of water passing through a specimen per unit time, t

3.2
discharge velocity
v
rate of flow of water per unit area of soil (including particles and voids) normal to the direction of flow

3.3
hydraulic gradient
i
ratio of the difference in total head of water (head loss), h, between two gland points, to the length of the flow path, l (distance between the gland points measured in the direction of flow, see Figure 1)



Key

1 Standpipe head
2 Standpipe
3 Filter block
4 Filter block
5 Specimen

Figure 1 — Water flow in a soil specimen

3.4
undisturbed sample
normally a sample of quality class 1 or at least 2 according to prEN 1997-2

3.5
coefficient of permeability
k
in accordance with Darcy's law for laminar flow, the coefficient of permeability of a water-saturated soil, k, is the ratio of the discharge velocity, v, to the hydraulic gradient, i

NOTE For partly saturated soil, the coefficient of permeability is always smaller than for fully water-saturated soil due to turbulence caused by air voids and non-function of .capillary action.

4 Test procedure

4.1 General requirements

4.1.1 Grading, particle structure and volume

Grading and particle structure shall not alter while measuring the permeability. Consolidation and swelling should substantially be completed before the measurements are done.

In clay swelling and consolidation cannot completely be avoided unless provisions are made to prevent it. Therefore, the height of the specimen should be locked or the load regulated to prevent changes in height. The height of the specimen should be recorded and any significant change in height should be accounted for, both in terms of expelled water and in change of seepage path.

4.1.2 Properties of water

The water used for testing shall not wash out constituents of the specimen, deposit any dissolved or suspended matter in it or alterthe colloidal state of the soil.

As far as possible, water similar in type to the pore water shall be used, de-aired tap water generally being adequate. Where necessary (e.g. where marine sediments are to be tested), the water shall be treated or obtained from a given source so that the natural conditions can be reliably reproduced.

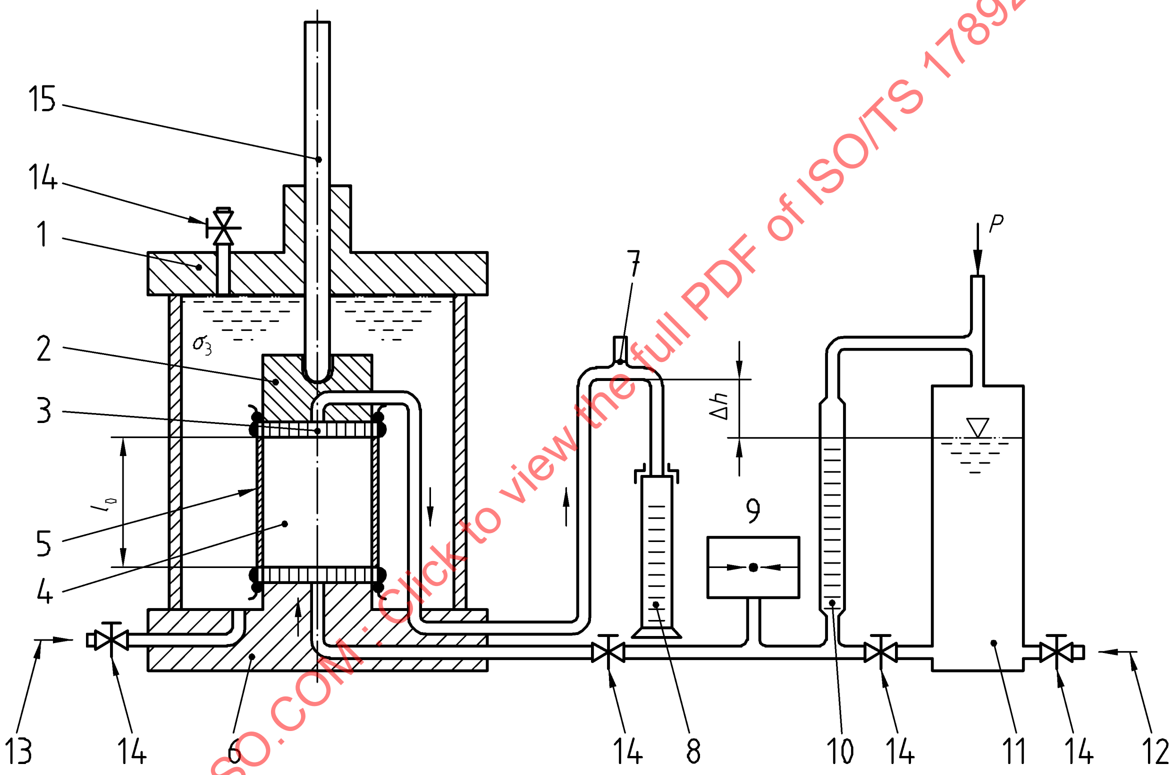
4.1.3 Degree of saturation

4.1.3.1 The specimen shall remain saturated during the measurement of the permeability.

4.1.3.2 Saturation of the specimen can be achieved by applying a back pressure u_0 (as specified in Table 1), which is produced by subjecting the pore water in the specimen to a hydrostatic pressure which shall be maintained throughout the test. This may be accomplished using the test arrangement shown in Figure 2.

Table 1 — Back pressure as function of initial saturation

Initial saturation S_r %	Back pressure u_0 kN/m^2
100	0
95	300
90	600
85	900



Key

1 Top plate
2 Cell top with spiral groove
3 Filter block with k greater than or equal to ten times that of the specimen
4 Specimen
5 Rubber membrane with O-rings
6 Pedestal
7 Glass tube with vent opening less than 1 mm in diameter
8 Graduated glass cylinder or volume change sensor
9 Pressure gauge
10 Burette to determine the quantity of inflowing water
11 Vessel containing pressurized de-aired water
12 Supply of de-aired water
13 Inlet for cell water and cell pressure, σ_3
14 Valve
15 Piston for applying anisotropic load to the specimen
l_0 Specimen height (= length of seepage path)
p Pressure to produce hydraulic gradient

In tests with back pressure, the pressure in the vent opening (7) should be raised to correspond to the back-pressure u_0 and the pressure p raised to $p + u_0$.

Figure 2 — Example for test arrangement for triaxial cell test

At full saturation, the quantities of water entering and leaving a specimen shall be equal, with constant pressure and constant hydraulic gradient being assumed.

Disturbed specimens are normally not fully saturated with water, the same applying to specimens in which the pore water pressure dropped as the specimen was taken, thus releasing dissolved gas. Air dissolved in the water passing through the specimen may be retained in the specimen and thus reduce the latter's permeability.

There are also other methods to saturate specimens. It can be done e.g. by flushing the specimen with water or by replacing the air in the dry specimen by CO_2 before filling the specimen with water. Bubbles of CO_2 can more easily be solved in water.

4.1.4 Hydraulic gradient

For testing purposes, the hydraulic gradient may be selected to satisfy practical considerations as long as the flow characteristics given by the gradient complies with Darcy's law. In case of doubt whether the test conditions comply with Darcy's law the hydraulic gradient has to be varied to check it. Where the flow is not linear, the hydraulic gradient in the laboratory shall approximate that in the field.

NOTE The flow behaviour of coarse-grained soil deviates from laminar flow as described by Darcy's law, if the hydraulic gradient exceeds a certain level, i.e. the discharge velocity increases non-linearly with increasing hydraulic gradient due to the influence of inertial forces. For fine-grained soil the discharge velocity decreases non-linearly with decreasing hydraulic gradient when passing a certain lower level.

4.1.5 Temperature

4.1.5.1 Testing shall be carried out at approximately constant ambient temperature (± 2 °C), with which the temperature of the specimen and water shall be in equilibrium. The temperature shall be measured and recorded.

4.1.5.2 To obtain reproducible results, the value of k as determined in the test shall be converted to a reference temperature of 10 °C using the following empirical equation (1) from Poiseuille:

$$k_{10} = \alpha \times k_{\mathrm{T}} \tag{1}$$

$$\alpha = \frac{1,359}{1 + 0,0337 \times T + 0,00022 \times T^2} \tag{2}$$

where

T is the water temperature (°C) throughout the test;

k_{T} is the coefficient of permeability at ambient temperature (m/s);

α is a correction factor, to be calculated or taken from Table 2. For intermediate values linear interpolation is allowed.

A reference temperature of 10 °C equals the average temperature of groundwater. A different temperature may be used where required.

Table 2 — Correction factor α to allow for the viscosity of water

Temperature T [°C]	5	10	15	20	25
Correction factor α [–]	1,158	1,000	0,874	0,771	0,686

4.1.6 Specimen dimensions

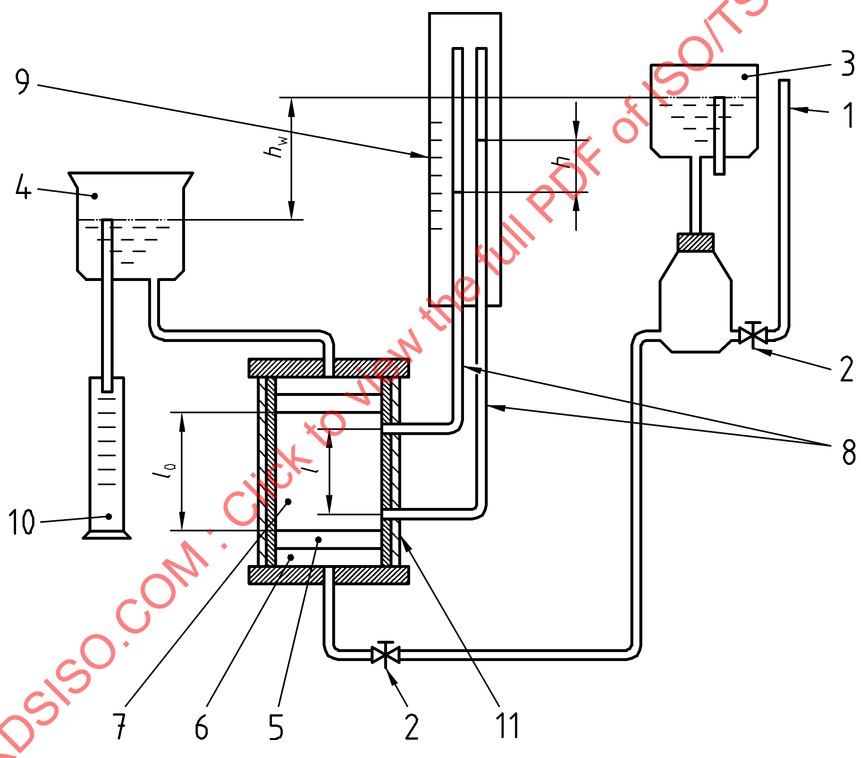
4.1.6.1 Specimen diameter and height shall be selected so as to prevent any inhomogeneities influencing the test results.

4.1.6.2 The ratio of maximum particle size to specimen diameter or length shall be not less than 1 : 5 for non-uniform and 1 : 10 for uniform soils.

4.1.6.3 For cohesive (fine-grained) soil, the cross-sectional area of the specimen A shall be not less than 1000 mm^2 and for coarse-grained soil, not less than 2000 mm^2, unless the test equipment requires the use of larger specimens (see 4.4.4).

4.1.7 Measurement of standpipe heads

4.1.7.1 For permeable to highly permeable soil specimens, the difference in head shall not be measured between the specimen ends but only across the length of that part of the specimen through which the water is flowing (see Figure 3), in order to prevent any loss of head and to prevent the result being affected by interference effects at the specimen ends.



Key

1 Inlet for de-aired water
2 Pinch cock or ball valve
3 Inlet reservoir
4 Outlet reservoir
5 Filter
6 Perforated plate with wire gauze
7 Specimen
8 Piezometric tubes
9 Graduated scale
10 Graduated cylinder
11 Cell
h Difference in piezometric heads
h_w Difference in head in inlet and outlet reservoirs
l Length of seepage path
l_0 Specimen height

Figure 3 — Example for a test arrangement for constant head permeameter test

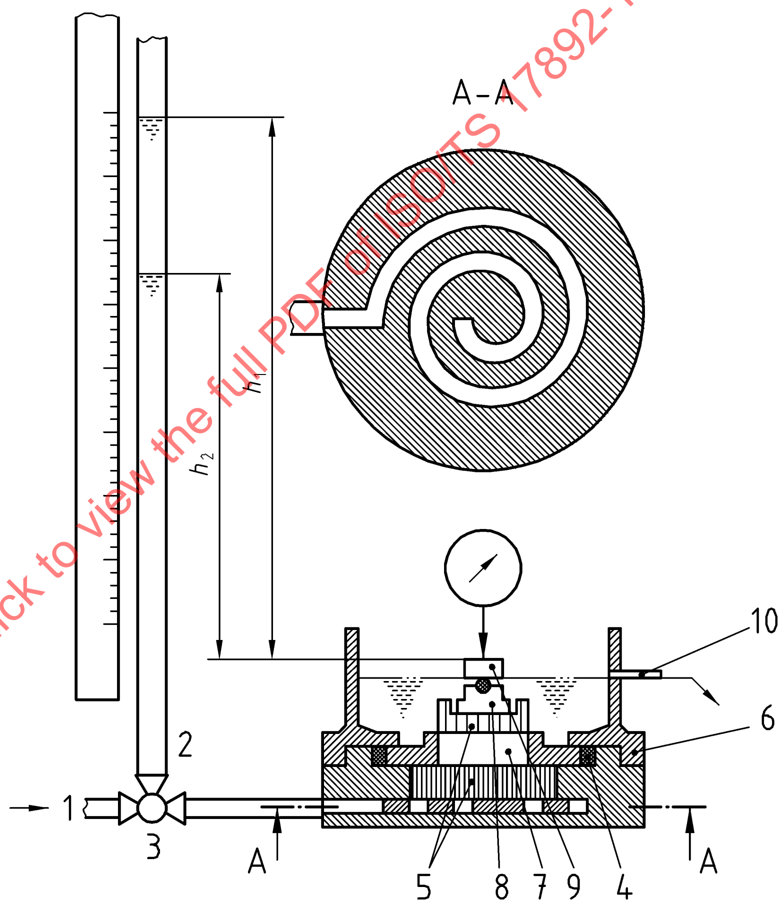
4.1.7.2 Standpipes (piezometric tubes) shall have an internal diameter of 3 mm to 4 mm and be located at a minimum of 15 mm from the top and bottom ends of the specimen. The end of the tube entering the specimen shall be protected by a wire gauze against blockage. In the case of soil with low permeability, the loss of head between the standpipes and cell is small enough to be ignored so that the difference in head between inlet and outlet may be regarded as being equal to the difference in head across the specimen.

4.1.8 Measurement of water flow

4.1.8.1 The quantity of water flowing through the specimen shall be measured at steady-state flow conditions.

4.1.8.2 In constant head tests with large quantities of water passing through the specimen, the overflow at the outlet end shall be measured.

4.1.8.3 Where the quantities of water passing through the specimen are small, measurement shall be carried out using piezometric tubes (see Figure 4) or capillary tubes, due consideration being given to the possibility of evaporation falsifying the results. This may be avoided by increasing the hydraulic gradient, provided this is not inconsistent with the other conditions described in 4.1.4.



Key

1 Inlet for de-aired water

2 Detachable piezometric tube of cross-sectional area *a*

3 Three-way cock

4 Rubber seal

5 Filter blocks

6 Specimen holder

7 Specimen with height l_0

8 Top plate

9 Device to apply vertical load, with compression gauge

10 Container (with overflow to produce constant head)

h_1 Water head at start of measurement

h_2 Water head at time t

Figure 4 — Example for a test arrangement for compression permeameter test

4.1.8.4 In falling head tests, the volume of water passing through the specimen is equal to the internal volume of the standpipe as defined by the difference in level of two consecutive readings.

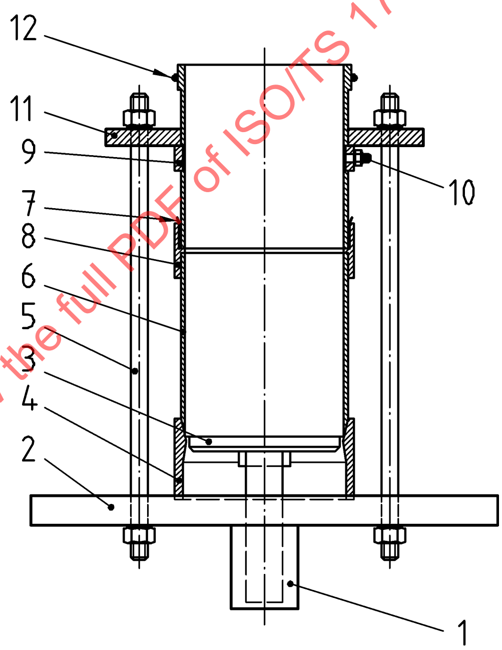
NOTE The water flow can be regarded as steady if, at a constant head, the quantity of water entering the specimen and that leaving it per unit time remains constant.

4.1.9 Prevention of bypass seepage

4.1.9.1 Bypass seepage due to small stones and other foreign matter embedded in specimens and cavities between the specimen and the wall of the cell or test mould shall be prevented as it suggests a higher permeability than is in fact is the case. Any such channels and cavities shall be filled, for example with material from the sample, bentonite or silicone grease.

4.1.9.2 If seepage along the wall cannot be prevented due to the presence of coarse constituents in coarse-grained material, it is recommended that the core cutter be lined with a solid material having a low melting point (e.g. paraffin wax) or before the specimen is taken, so that the gap between specimen and cutter wall is sealed by heating once the specimen has been taken. The sealant shall not penetrate into the specimen. This is to be checked after the test.

In the case of specimens of cohesive (fine-grained) material, seepage can be prevented by placing them in a mould with an internal diameter a few millimetres larger than the specimen diameter, the gap being filled by pouring a sealing compound. An apparatus as shown in Figure 5 may be used to introduce such specimens into a mould lined with a tubular latex membrane. While inserting the specimen, the membrane shall be held in place by exhausting the mould. The internal diameter of the mould shall be larger than that of the core cutter by more than twice the thickness of the membrane. In the test, the membrane shall be pressed against the specimen with a pressure 20 % above the maximum pore water pressure, this pressure being applied via water since latex is not airtight. Silicone grease between two membranes may also be used to prevent air passing through the membrane. Test arrangements as shown in Figure 2 may be used to prevent undue seepage along the walls where cohesive (fine-grained) material is to be tested.



Key

1 Jack
2 Baseplate
3 Piston
4 Centring tube
5 Tie rods
6 Core cutter with sample
7 Tubular rubber membrane
8 Intermediate collar
9 Mould for permeability test
10 Pressurizing/depressurizing nozzle
11 Clamping plate
12 O-ring

Figure 5 — Apparatus for enclosing a specimen in a rubber membrane

4.1.10 Stresses in the specimen

4.1.10.1 To determine the effect of the void ratio on permeability, highly compressible specimens shall be tested at the relevant stress level.

4.1.10.2 Where a back pressure is applied or where the direction of flow is upward, the application of an external static load is required to establish equilibrium conditions.

4.1.11 Classes of permeability tests

4.1.11.1 According to the reliability with which the full saturation of the specimen and steady-state of flow is ensured i.e. how closely the test models the conditions in situ the permeability tests can be classified as presented in Table 3.

Table 3 — Classes of permeability tests

Class of quality	Controlled degree of saturation?	Controlled steady-state flow condition?
1	yes	yes
2	no	yes
	yes	no
3	no	no

4.1.12 Choice of test arrangement

4.1.12.1 The test arrangement shall be selected as a function of the type of soil to be tested (see Table 4). In doing so, it shall be checked whether it is necessary to determine the permeability coefficient at a controlled full saturation with laminar flow, or whether it is sufficient to determine the coefficient without laminar flow being controlled.

Table 4 — Example for test arrangement as a function of soil type

Soil type	Apparatus			Means of measuring hydraulic gradient			Means of measuring water volume[a]				
	Test mould	Compression permeameter	Triaxial cell	Two or more piezometric tubes	One piezometric tube	Pressure system	Measuring cylinder	Piezometric tube or burette	Capillary tube	Specimen under stress	Specimen saturated
Clay, silt	(×)			×	×	×	(×)	×	–	(×)	–
		×		–	×	–	–	×	–	×	–
			×	–	–	×	–	(×)	×	×	×
Fine sand	×			×	×	–	×	×	–	–	–
			×	–	–	×	×	–	–	×	×
Medium and coarse sand	×			×	×	–	×	×	–	–	–
			×	–	–	×	×	–	–	×	(×)
Sand-gravel mixture	×			×	(×)	–	×	(×)	–	–	–
			×	–	–	–	×	–	–	×	×
Sand-clay mixture	(×)			×	×	×	(×)	×	–	(×)	–
		×		–	×	–	–	×	–	×	–
			×	–	×	×	(×)	×	×	×	×
Gravel-sand-clay mixture	(×)			–	×	×	(×)	×	–	–	–
			×	–	–	×	(×)	–	×	×	×

[a] equivalent electronic systems with balances, pumps or pressure transducers may also be used

× = suitable (×) = suitable with reservations – = not suitable

4.2 Falling head

4.2.1 Apparatus

The following apparatus is required (see Figure 4):

a) de-aired water supply unit;

b) reservoir for de-aired water;

c) core sampling or cutting equipment;

d) steel straightedge;

e) compression permeameter (with piezometric tube and loading device).

4.2.2 Test arrangement

4.2.2.1 The permeameter used shall be one working on the compression principle and to which a piezometric tube shall be connected so as to permit upward flow.

4.2.2.2 The piezometric tube shall be calibrated to allow the volume to be measured accurately, its diameter being chosen as a function of the permeability of the specimen (e.g. d = 4 mm for $k = 10^{-10}$ m/s). The tube should be weighed before and after the test.

4.2.2.3 The filter blocks in the permeameter shall be sufficiently permeable (i.e. k shall exceed 10^{-6} m/s), their permeability being checked at regular intervals, taking the possible influence of valves and connecting tubing into account. The permeability of the filter block shall be at least 10 times bigger than the permeability of the sample.

4.2.2.4 Any trapped air shall be removed from the apparatus by filling de-aired water via feeding pipes into the chamber designed to accommodate the lower filter block. The filter block itself shall be de-aired by boiling in water and then fitted into the chamber filled with water.

4.2.3 Soil type and specimen dimensions

4.2.3.1 The method described below is suitable for fine-grained soil, especially for clay and silt.

4.2.3.2 The minimum diameter of the specimen shall be 50 mm, and the minimum height 20 mm.

4.2.4 Specimen preparation

4.2.4.1 If the permeability of an undisturbed sample is to be determined, a specimen shall be taken from the sample using a sampling ring.

4.2.4.2 Disturbed sample material (e.g. manmade fill material) shall be compacted to the required density using the Proctor test apparatus, for example. A specimen shall then be taken as described above and tested in the permeameter.

4.2.4.3 Depending on the construction of the apparatus, the ring shall either be introduced directly into the apparatus, or the specimen shall be pressed out of the ring into a specimen holder which must first be removed from the apparatus. The end faces shall be carefully levelled off, without producing undue cavities. The specimen holder shall then be introduced into the permeameter and a rubber ring pressed into place.

4.2.5 Test execution

4.2.5.1 The specimen shall be consolidated by subjecting it to a stress acting vertically and applied via a top plate (see Figure 4). To maintain equilibrium, this stress shall be higher than the additional hydrostatic pressure acting on the specimen in the test. The pore water flowing out of the specimen through the lower filter block shall run off freely.

4.2.5.2 A variable hydraulic gradient is produced by a column of water in a standpipe (or piezometric tube), the level in which falls during the test.

4.2.5.3 For determining the permeability, the water head in the tube shall be measured at given intervals (see 4.2.5.5).

4.2.5.4 Evaporation, if any, shall be taken into account.

NOTE Completion of consolidation and/or swelling is indicated by a constancy of reading on the compression gauge.

4.2.5.5 If the water column falls rapidly, it may be more appropriate, to record the rate of fall of the meniscus against the scale marks on the tube.

In the case of tubes with a smaller diameter, very small quantities of water can be measured directly with the tube if it is calibrated. Therefore, the test arrangement illustrated in Figure 4 is particularly suitable for fine-grained soil.

4.3 Constant head test in the permeameter

4.3.1 Apparatus

The following apparatus is required:

a) de-aired water supply unit;

b) tamping rod;

c) permeameter cell;

d) piezometric tubes or transducers;

e) graduated cylinders with perforated lid;

f) inlet and outlet reservoirs, capable of maintaining the inlet and outlet head, respectively;

g) sponge rubber or similar material.

4.3.2 Test arrangement

4.3.2.1 The water shall be passed from the de-aired water supply unit through a transparent flexible tube to the inlet reservoir and from there to the permeameter cell, the inflow to the reservoir being controlled by a pinch cock or a ball valve (see Figure 3, and 4.3.2.4 and 4.3.4.2).

4.3.2.2 Prior to the preparation of the specimen the apparatus shall be vented.

4.3.2.3 The quantity of water passing through the specimen shall be controlled by adjusting the difference in head between inlet and outlet reservoirs. At least two piezometric tubes shall be fitted to the cell.

4.3.2.4 Use of pinch cocks or ball valves is required to prevent sudden changes in cross section of the tubing, which could result in the formation of air bubbles.

For soil with a coefficient of permeability exceeding 10^{-2} m/s, a device is required that ensures an adequate continuous supply of de-aired water to the apparatus. De-airing of the water may either be effected by spraying it under high vacuum pressure or by allowing it to percolate through a fine sand filter. Where tests extend over longer periods, the air thus trapped in the filter shall be removed at regular intervals.

4.3.3 Soil type and specimen dimensions

4.3.3.1 The following method is suitable for coarse-grained soil, such as sand, gravel and sand-gravel mixtures. The minimum specimen dimensions shall be as specified in 4.1.6.

4.3.4 Specimen preparation

4.3.4.1 Dried and homogenized soil shall be placed in the cell, in layers, sufficiently thin to prevent segregation of material. Any concentration of coarse particles shall be avoided. Where the material is to have a particular density, the quantity of material needed for one layer shall be determined by weighing and the material compacted by applying a uniform pressure or by tamping it down to the required thickness. Prior marking of the desired thickness on the cell wall will facilitate this process.

4.3.4.2 If necessary, a 15 mm thick layer of filter material shall be placed on the perforated plate (with wire gauze) at the base of the cell.

4.3.4.3 Other preparation methods are allowed, provided care is taken to provide specimen homogeneity.

4.3.4.4 When testing gravel of uniform particle size, the inner cell wall shall be lined with sponge rubber or a similar material to prevent seepage along the cell wall.

If necessary, a 15 mm thick filter layer shall be placed on top of the specimen. The wire gauze together with the perforated plate shall then be fitted and the top plate fastened to the cell.

4.3.5 Test execution

4.3.5.1 After the specimen has been introduced and the tubes are fitted to the cell the flow to the cell shall be carefully opened, allowing the water level in the specimen to rise slowly without entrapping air in the voids. To remove the small quantities of air inevitably entrapped in the specimen, the de-aired water shall be allowed to pass through the specimen for a certain period (see 4.3.5.6).

4.3.5.2 Before the permeability test proper, the pinch cock at the base of the cell shall be closed once again. The heads in the piezometric tubes shall now be at the same level as that in the outlet reservoir. Otherwise, the piezometric tubes are not functioning properly.

4.3.5.3 Once the specimen has been de-aired and the tubes have been restored to proper function, the pinch cock at the base of the cell shall be removed and the water inflow controlled by adjusting the other pinch cock so that the water is discharged via the other cock in a steady stream. If this cannot be achieved, the difference in head between the two reservoirs shall be reduced.

4.3.5.4 To determine k, the quantity of the water collected in the graduated cylinder shall be determined, at regular intervals. Additionally, the water temperature shall be measured.

4.3.5.5 In the case of cohesionless and coarse-grained soil, testing shall be started with a very low difference in head h (see Figure 3), and repeated with a greater difference. If the ratio of water quantity to difference in head then becomes smaller, this indicates that the results are being influenced by turbulence.

4.3.5.6 Other techniques for specimen saturation are allowed.

4.3.5.7 The easiest way to achieve a constant head of the water entering the specimen is to use a vessel with overflow, into which more water is fed than passes through the specimen (see Figure 3). Higher pressures can be produced by applying compressed air via an impermeable membrane or hydraulically, via a layer of oil, for example.

The head of the water discharged is kept constant by a given back pressure, or by providing an overflow via which the water quantity to be measured is drained.

4.4 Constant head testing in the triaxial cell

4.4.1 Apparatus (see Figure 2)

The following apparatus is required:

a) de-aired water supply unit;

b) tamping rod;

c) mould for preparing specimens;

d) triaxial cell;

e) device capable of maintaining the cell pressure constant;

f) pressure system capable of maintaining pressure in the tubing, with pressure gauge.

4.4.2 Test arrangement

4.4.2.1 The test shall be carried out at a constant hydraulic gradient.

4.4.2.2 The cell shall have dimensions selected to suit the maximum particle size.

4.4.2.3 A pressure system shall be connected to the cell, through which de-aired water is supplied to the specimen, at constant pressure.

4.4.2.4 The specimen shall be enclosed in a rubber membrane, with a filter block at top and bottom. The filter blocks shall be sufficiently permeable, i.e. their coefficient of permeability shall be at least one order of magnitude higher than that of the specimen. Otherwise due corrections for pressure losses in the porous disks and tubes have to be introduced in the evaluation of the test.

4.4.2.5 The cell top and the pedestal shall each have a spiral groove or similar to permit a uniform flow of water through the specimen and to facilitate specimen de-airing.

4.4.2.6 The water flow through the specimen shall be from bottom to top, the rubber membrane being subjected to a constant cell pressure, which is greater than the inlet pressure.

4.4.2.7 The cell pressure shall be high enough to counteract the tendency of the specimen to disintegrate under the pressure of the water in the inlet zone.

4.4.2.8 In the example shown in Figure 2, the inlet pressure is generated by compressed air. The outlet head measured at item No. 7 shall be above the upper specimen face. The quantity of water flowing through the specimen is measured using a graduated cylinder or more accurately by weighing or a volume change sensor (item No. 8).

4.4.2.9 To avoid dissolving of air in the pore water-system a thin layer of paraffin oil should be provided between the air and the water of the volume change sensor (item No. 8), the burette (item No. 10) and the vessel (item No. 11).

4.4.2.10 For the volume measurement of very small quantities of water a calibrated glass capillary or transparent pressure tube with an air bubble may also be useful.

4.4.3 Preparation of apparatus

4.4.3.1 Air entrapped in the tubing shall be removed by flushing.

4.4.3.2 It shall be ensured that the filter blocks are saturated.

4.4.4 Soil type and specimen dimensions

4.4.4.1 The following method is suitable for soil with a coefficient of permeability k of less than 10^{-5} m/s.

4.4.4.2 The minimum specimen dimensions shall be as specified in 4.1.6.

4.4.5 Preparation of specimen

4.4.5.1 Undisturbed samples or core samples may be inserted in the cell after levelling off their end faces without further preparation.

4.4.5.2 Disturbed material shall be homogenised as far as possible, and placed in layers in a mould, taking care to avoid segregation of material. Where the material is to have a particular density, the quantity required for

