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Soil quality — Determination of hydraulic conductivity of saturated porous materials using a rigid-wall permeameter

Qualité du sol — Détermination de la conductivité hydraulique de matériaux poreux saturés à l'aide d'un perméamètre à paroi rigide

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 17312 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 5, *Physical methods*.

Introduction

The rate of water flow through the soil is of considerable importance in many aspects of agricultural and urban life. The entry of water into soil, the movement of water to plant roots, the flow of water to drains and wells, and the evaporation of water from the soil surface are but a few of the obvious situations in which the rate of water flow plays an important role. Also, in cases of soil pollution and polluted groundwater, prediction of the rate of movement of soil water is of great importance to obtain knowledge about the spreading of pollutants.

The soil properties that determine the behaviour of soil water flow systems are the hydraulic conductivity and water-retention characteristics. The hydraulic conductivity of soil is a measure of its ability to transmit water. The water-retention characteristics are an expression of its ability to store water. These properties determine the response of a soil/water system to imposed boundary conditions.

Soil quality — Determination of hydraulic conductivity of saturated porous materials using a rigid-wall permeameter

WARNING — This International Standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this International Standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1 Scope

This International Standard specifies the determination of the hydraulic conductivity of granular soils (e.g. sand and gravel) using a constant-head method involving a rigid-wall permeameter to measure the laminar flow of water. The procedure establishes representative values of the hydraulic conductivity of granular soils that can occur in natural deposits as placed in embankments, or when used as base courses under pavements.

In order to limit consolidation influences during testing, this procedure is applicable only to disturbed granular soils containing not more than 10 % soil passing a 75-µm sieve.

This procedure is applicable to the measurement of hydraulic conductivity of compacted samples of sands and gravels containing little or no silt, where flow along the rigid wall of the permeameter has no practical implications on the test results. This International Standard is not applicable to silt and clay, where seepage/flow at the boundaries is not acceptable.

2 Terms and definitions

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

2.1
compaction
densification of a soil by means of mechanical manipulation

2.2
dry bulk density
ρ_d
mass per volume of dry soil

NOTE It is expressed in kilograms per cubic metre (kg/m^3).

2.3
hydraulic conductivity
k
rate of discharge of water under laminar flow conditions through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions (20 °C)

2.4
hydraulic gradient
change in total hydraulic head of water per unit distance of flow

2.5
pore volume of flow
cumulative quantity (volume) of flow into a test specimen divided by the volume of voids in the specimen

2.6
vacuum
negative pressure
degree of rarefaction below atmospheric pressure

3 Fundamental test conditions

The following ideal test conditions are prerequisites for the laminar flow of water through granular soils under constant-head conditions:

— continuity of flow with no soil volume change during a test;

— flow with the soil voids saturated with water and no air bubbles in the soil voids;

— flow in steady state with no changes in hydraulic gradient; and

— direct proportionality of flow velocity to hydraulic gradients below certain values (see Figure 3), at which turbulent flow starts.

All other types of flow involving partial saturation of soil voids, turbulent flow, and unsteady-state flow are transient in character and yield variable and time-dependent hydraulic conductivity; therefore, they require special test conditions and procedures.

4 Apparatus

4.1 Permeameters (see Figure 1)**,** having specimen cylinders with minimum diameters approximately 8 or 12 times the maximum particle size in accordance with Table 1.

The permeameter should be fitted with:

a) a porous disk or suitable reinforced screen at the bottom with a hydraulic conductivity greater than that of the soil specimen, but with openings sufficiently small (not larger than 10 % finer size) to prevent loss of particles;

b) manometer tube outlets for measuring the loss of head, h (= $h_1 - h_2$), over a length, l (see Figure 1), which shall be equivalent to at least the diameter of the cylinder;

c) a porous disk or suitable reinforced screen with a spring attached to the top, or any other device, for applying a light spring pressure of 22 N to 45 N total load when the top plate is attached in place. This will maintain the placement density and volume of soil without significant change during saturation of the specimen and hydraulic conductivity testing to satisfy the requirement specified in Clause 3.

4.2 Constant-head filter tank, to supply water and remove most of the air from tap water.

The tank shall be fitted with suitable control valves to maintain conditions described in Clause 3.

De-aerated water may be used if preferred.

4.3 Large funnels, fitted with special cylindrical spouts of 25 mm diameter for particles of maximum size 9,5 mm, and 13 mm diameter for particles of maximum size 2,00 mm.

The length of the funnel spout shall be greater than the full length of the hydraulic conductivity chamber, and at least 150 mm.

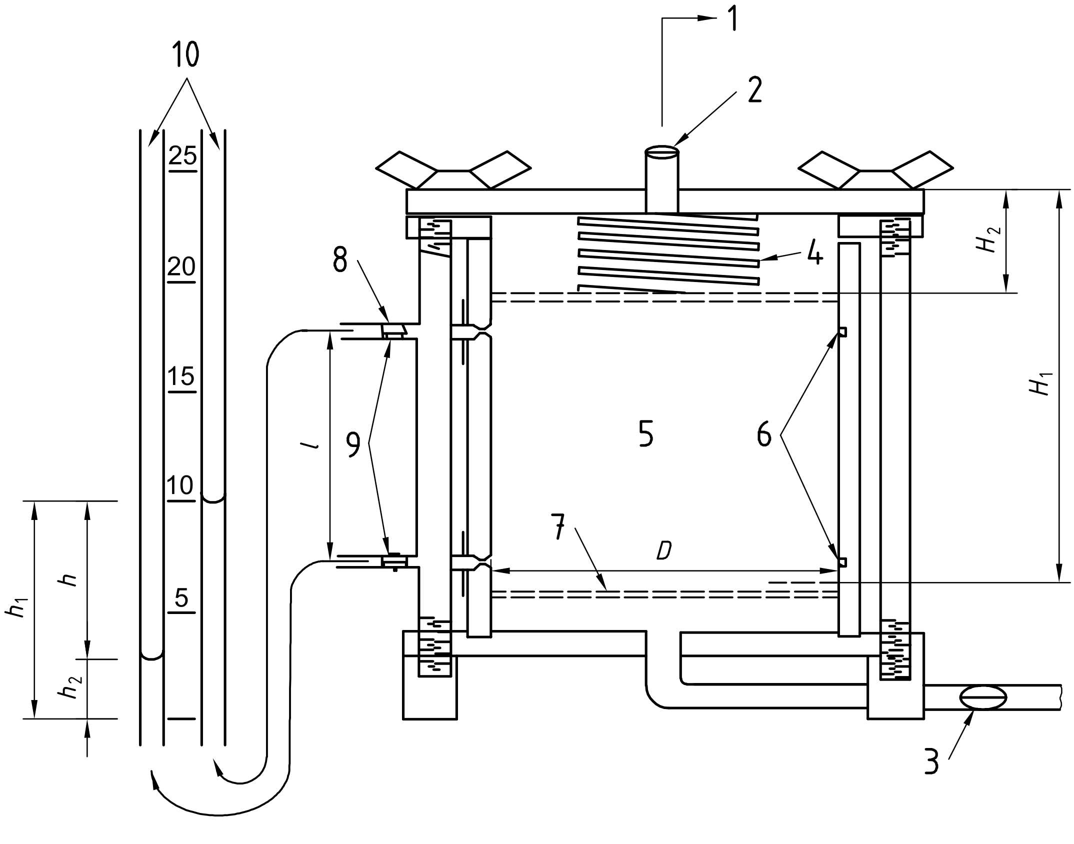
4.4 Specimen compaction equipment (optional):

a) a vibrating tamper fitted with a tamping foot 51 mm in diameter;

b) a sliding tamper with a tamping foot 51 mm in diameter,

c) a rod for sliding weights of 100 g (for sands) to 1 kg (for soils with large gravel content), having an adjustable drop height of 102 mm for sands and 203 mm for soils with large gravel content.

4.5 Vacuum pump or water-tap aspirator, for evacuating and for saturating soil specimens under full vacuum (see Figure 2).



Key

1	to constant head filter tank	6	manometer grooves
2	inlet valve	7	porous disk
3	outlet valve	8	valve
4	spring	9	manometer outlets
5	soil specimen	10	manometer tubes

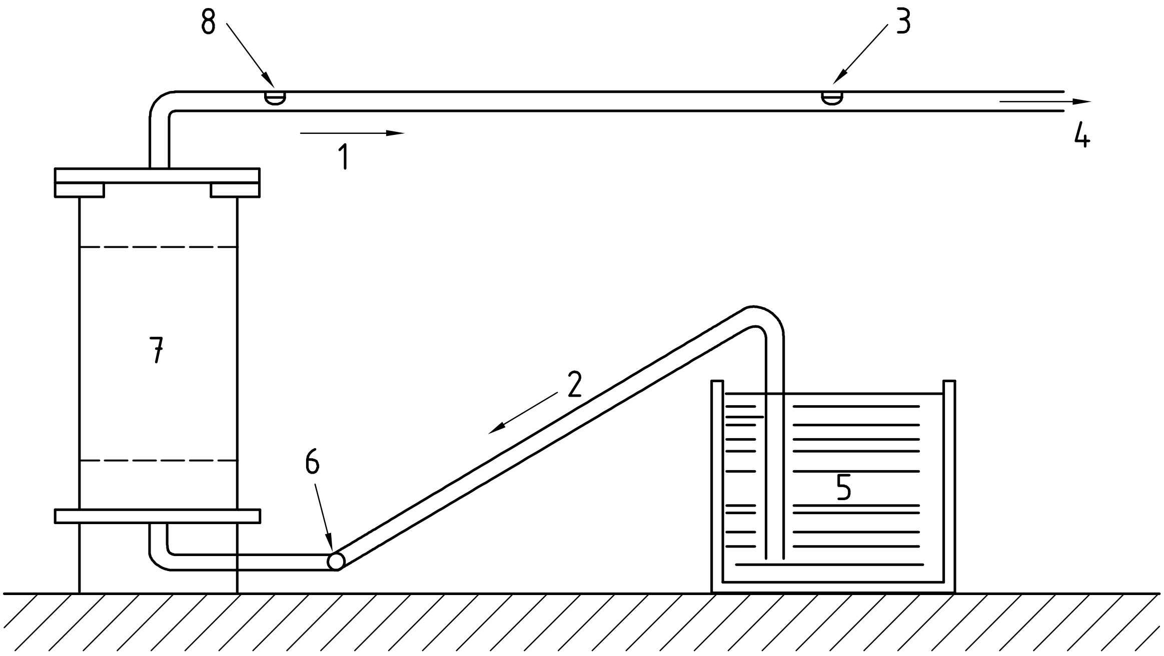
h_1 Manometer reading, inlet

h_2 Manometer reading, outlet

H_1 Distance from upper surface of the top plate of the cylinder to the top of the upper porous plate temporarily placed on the lower porous plate

H_2 Distance from upper surface of the top plate of the cylinder to the top of the upper porous plate in place on top of the sample

Figure 1 — Constant-head permeameter



Key

1 flow out
2 flow in
3 valve
4 vacuum
5 water
6 outlet valve
7 soil
8 inlet valve

Figure 2 — Device for evacuating and saturating specimen

4.6 Manometer tubes, with metric scales for measuring head.

4.7 Balance, of 2 kg capacity, sensitive to ±1 g.

4.8 Scoop, with a capacity of about 100 g of soil.

4.9 Miscellaneous apparatus

Thermometers, clock with sweep-second hand, 250-ml graduated cylinder, quart jar, mixing pan, etc. shall be available as needed.

5 Sample

A representative sample of air-dried granular soil, containing less than 10 % of material passing the 75-μm sieve and equal to an amount sufficient to satisfy the requirements below, shall be selected by the method of quartering.

A sieve analysis shall be made on a representative sample of the complete soil prior to the hydraulic conductivity test. Any particles larger than 19 mm shall be separated out by sieving. This oversize material shall not be used for the hydraulic conductivity test, but the percentage of oversize material shall be recorded.

In order to establish representative values of hydraulic conductivity for the range that may exist in the situation being investigated, samples of the fine, average and coarse soils should be obtained for testing.

From the material from which the oversize portion has been removed, select, by the method of quartering, a sample for testing equal to an amount approximately twice that required for filling the permeameter chamber.

6 Preparation of specimen

6.1 General

The size of permeameter to be used shall be as specified in Table 1.

Make the following initial measurements, in centimetres or square centimetres, and record on the data sheet (Table 2): the inside diameter, D, of the permeameter; the length, l, between manometer outlets; the depth, H_1, measured at four symmetrically spaced points from the upper surface of the top plate of the hydraulic conductivity cylinder to the top of the upper porous stone or screen temporarily placed on the lower porous plate or screen. This automatically deducts the thickness of the upper porous plate or screen from the height measurements used to determine the volume of soil placed in the hydraulic conductivity cylinder. Use a duplicate top plate containing four large symmetrically spaced openings through which the necessary measurements can be made to determine the average value for H_1. Calculate the cross-sectional area, A, of the specimen.

Take a small portion of the sample selected as prescribed in Clause 5 for water content determinations. Record the mass of the remaining air-dried sample, m_1, for unit mass determinations.

Table 1 — Cylinder diameter

Dimensions in millimetres

Maximum particle size lies between sieve openings of	Minimum cylinder diameter			
	Less than 35 % of total soil retained on sieve opening of		More than 35 % of total soil retained on sieve opening of	
	2,00	9,5	2,00	9,5
2,00 and 9,5	76	—	114	—
9,5 and 19,0	—	152	—	229

Using one of the following procedures, place the prepared soil in uniform thin layers approximately equal in thickness after compaction to the maximum particle size, but not less than approximately 15 mm.

a) For soils having a maximum particle size of 9,5 mm or less, place the appropriate size funnel, as specified in 4.3, in the hydraulic conductivity device with the spout in contact with the lower porous plate or screen, or previously formed layer, and fill the funnel with sufficient soil to form a layer, taking soil from different areas of the sample in the pan. Lift the funnel by 15 mm, or approximately thickness of the unconsolidated layer to be formed, and spread the soil with a slow spiral motion, working from the perimeter of the device toward the centre, so that a uniform layer is formed. Remix the soil in the pan for each successive layer to reduce segregation caused by taking soil from the pan.

b) For soils having a maximum particle size greater than 9,5 mm, spread the soil from a scoop. Uniform spreading can be obtained by sliding a scoopful of soil in a nearly horizontal position down along the inside surface of the device to the bottom or to the formed layer, then tilting the scoop and drawing it toward the centre with a single slow motion; this allows the soil to run smoothly from the scoop in a windrow without segregation. Turn the hydraulic conductivity cylinder sufficiently for the next scoopful, thus progressing around the inside perimeter to form a uniform compacted layer of a thickness equal to the maximum particle size.

Compact successive layers of soil to the desired dry density by appropriate procedures, as follows, to a height of about 2 cm above the upper manometer outlet.

6.2 Minimum dry bulk density

Continue placing layers of soil in succession by procedure 6.1 a) or 6.1 b) until the device is filled to the correct level.

6.3 Maximum dry bulk density

6.3.1 Compaction by vibrating tamper

Compact each layer of soil thoroughly with the vibrating tamper, distributing a light tamping action uniformly over the surface of the layer in a regular pattern. The pressure of contact and the length of time of the vibrating action at each spot should not cause soil to escape from beneath the edges of the tamping foot, thus tending to loosen the layer. Make a sufficient number of coverages to produce maximum dry density, as evidenced by practically no visible motion of surface particles adjacent to the edges of the tamping foot.

6.3.2 Compaction by sliding-weight tamper

Compact each layer of soil thoroughly by tamping blows uniformly distributed over the surface of the layer. Adjust the height of drop and give sufficient coverages to produce maximum dry density, depending on the coarseness and gravel content of the soil.

6.3.3 Compaction by other methods

Compaction may be accomplished by other approved methods, such as by vibratory packer equipment, taking care to obtain a uniform specimen without segregation of particle sizes.

6.4 Preparation of specimen for hydraulic conductivity test

Level the upper surface of the soil by placing the upper porous plate or screen in position and by rotating it gently back and forth.

Measure and record:

a) the final height of specimen, $H_1 - H_2$, by measuring the depth, H_2, from the upper surface of the perforated top plate employed to measure H_1, to the top of the upper porous plate or screen at four symmetrically spaced points, after compressing the spring lightly to seat the porous plate or screen during the measurements;

b) the final mass of air-dried soil used in the test, by weighing the remainer of soil, m_2, left in the pan.

Compute and record the unit masses and void ratio, $m_1 - m_2$, of the test specimen (see 6.1 for m_1).

Table 2 — Hydraulic conductivity test data sheet.

Test No.	**Manometer tubes**		**Head,** h	V	t	$V/A \cdot t$	h/l	**Temperature**	k
	h_1 m water	h_2 m water	$h_1 - h_2$ m	m^3	s			°C	m/s
1									
2									
3									
4									
5									
6									

Test information: ....

Test No. .... Date of test ....

Location of sample .... Date sampled .... Report ....

Boring .... Sample .... Depth ....

(a) Description of soil:

....

Materials used: ....

(b) Unit specimen determination:

Diameter, D .... m Height before, H_1 .... m Mass before, m_1 .... kg

Area, A .... m^2 Height after, H_2 .... m Mass after, m_2 .... kg

Length, l .... m Height net, $H_1 - H_2$ .... m Mass net, $m_1 - m_2$ .... kg

Moisture content (air-dried) ....

Dry bulk density, ρ_d .... kg/m^3

Void ratio, e ....

With its gasket in place, press down the top plate against the spring and attach it securely to the top of the permeameter cylinder, making an air-tight seal. This satisfies the condition described in Clause 3 of maintaining the initial density without significant volume change during the test.

Using a vacuum pump or suitable aspirator, evacuate the specimen under at least 50 cmHg for 15 min to remove air adhering to soil particles and from the voids. Follow the evacuation by a slow saturation of the specimen from the bottom upward (Figure 2) under full vacuum in order to free any remaining air in the specimen. Continued saturation of the specimen can be maintained more adequately by the use of

— de-aerated water, or

— water maintained in an in-flow temperature gradient in the specimen during the test.

Native water or water of low mineral content should be used for the test, but in any case the fluid should be described in the test data sheet. This satisfies the condition described in Clause 3 for saturation of soil voids.

NOTE Native water is the water occurring in the rock or soil *in situ*, but its use (as well as that of de-aerated water) may be a refinement not ordinarily feasible for large-scale production testing.

After the specimen has been saturated and the permeameter is full of water, close the bottom valve on the outlet tube (Figure 2) and disconnect the vacuum. Care should be taken to ensure that the hydraulic conductivity flow system and the manometer tube system are free of air and are working satisfactorily. Fill the inlet tube with water from the constant-head tank by slightly opening the valve. Then connect the inlet tube to the top of the permeameter, open the inlet valve slightly and open the manometer outlet valves slightly, to allow water to flow, thus freeing them of air. Connect the water manometer tubes to the manometer outlets and fill with water to remove the air. Close the inlet valve and open the outlet valve to allow the water in the manometer tubes to reach their stable water level under zero head.

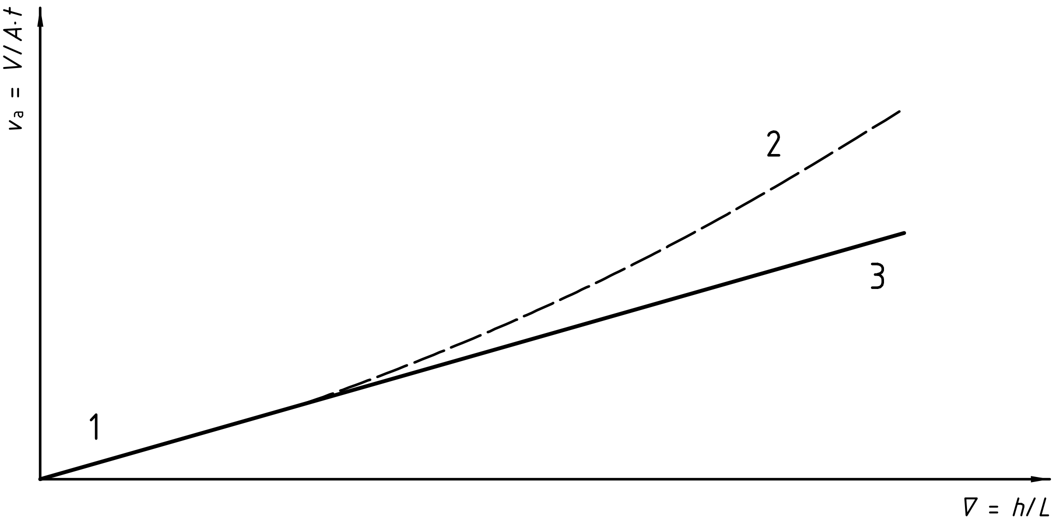
7 Procedure

Open the inlet valve from the constant head tank slightly for the first run to steady state conditions as described in Clause 3, delay measurements of quantity of flow and heat until a stable head condition without appreciable drift in water manometer tube levels is attained. Measure and record the time, t, head, h (the difference in level in the manometer tubes), volume of flow, V, and water temperature, T.

Repeat test runs at heads increasing by 0,5 cm in order to establish accurately the region of laminar flow (Figure 3) with area velocity, v_a (where $v_a = V/A \cdot t$), directly proportional to hydraulic gradient, ∇ (where $\nabla = h/l$). When departures from the linear relation become apparent, indicating the initiation of turbulent flow conditions, 1-cm intervals of head may be used to carry the test run sufficiently along the region of turbulent flow to define this region if it is significant for field conditions.

Much lower values of hydraulic gradient, h/l, are required than generally recognized, in order to ensure laminar flow conditions. The following values are suggested: loose compactness ratings, h/l from 0,2 to 0,3, and dense compactness ratings, h/l from 0,3 to 0,5, the lower values of h/l applying to coarser soils and the higher values to finer soils.

At the completion of the hydraulic conductivity test, drain the specimen and inspect it to establish whether it was essentially homogeneous and isotropic in character. Any alternating light and dark horizontal streaks or layers are evidence of segregation of fines.



Key

1 laminar flow

2 turbulent flow condition

3 linear relation

Figure 3 — Laminar, linear and turbulent flows

8 Calculation

Calculate the hydraulic conductivity, k, as follows:

$$k = V \cdot l / A \cdot t \cdot h$$

where

k is the hydraulic conductivity, in metres per second;

V is the volume of water discharged, in cubic metres;

l is the distance between manometer outlets, in metres;

A is the cross-sectional area of specimen, in square metres;

t is the total time of discharge, in seconds;

h is the difference in head on manometers, in metres.

Correct the hydraulic conductivity to that for 20 °C by multiplying k by the ratio of the viscosity of water at test temperature to the viscosity of water at 20 °C.

9 Test report

The hydraulic conductivity test report shall include the following information:

a) project, dates, sample number, location, depth and any other pertinent information;

b) grain size analysis, classification, maximum particle size, and percentage of any oversize material not used;

c) dry density, void ratio;

d) a statement of any departures from these test conditions, so the results can be evaluated and used;

e) complete test data as indicated in the laboratory form for test data (see Table 2); and

f) test curves plotting (see Figure 3) area velocity, $V/A{\cdot}t$, versus hydraulic gradient, h/l, covering the ranges of soil identification and of relative densities.

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