INTERNATIONAL STANDARD

ISO 22282-2

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Geotechnical investigation and testing — Geohydraulic testing —

Part 2: **Water permeability tests in a borehole using open systems**

Reconnaissance et essais géotechniques — Essais géohydrauliques — Partie 2: Essais de perméabilité à l'eau dans un forage en tube ouvert

Reference number
ISO 22282-2:2012(E)

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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.

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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.

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.

ISO 22282-2 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical investigation and testing*, in collaboration with Technical Committee ISO/TC 182, *Geotechnics*, Subcommittee SC 1, *Geotechnical investigation and testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

ISO 22282 consists of the following parts, under the general title *Geotechnical investigation and testing — Geohydraulic testing*:

— *Part 1: General rules*

— *Part 2: Water permeability tests in a borehole using open systems*

— *Part 3: Water pressure tests in rock*

— *Part 4: Pumping tests*

— *Part 5: Infiltrometer tests*

— *Part 6: Water permeability tests in a borehole using closed systems*

Geotechnical investigation and testing — Geohydraulic testing —

Part 2: **Water permeability tests in a borehole using open systems**

1 Scope

This part of ISO 22282 specifies requirements for the determination of the local permeability in soils and rocks below and above groundwater level in an open hole by water permeability tests as part of the geotechnical investigation services according to EN 1997-1 and EN 1997-2.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 14689-1, *Geotechnical investigation and testing — Identification and classification of rock — Part 1: Identification and description*

ISO 22282-1: 2011, *Geotechnical investigation and testing — Geohydraulic testing — Part 1: General rules*

ISO 22475-1, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for execution*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22475-1 and ISO 22282-1 apply.

3.2 Symbols

For the purposes of this document, the symbols given in Table 1 apply.

Table 1 — Symbols

Symbol	Designation	Unit
A_c	area of the inner cross-section of the casing	m^2
A_r	area of the water surface in the reservoir	m^2
D	borehole diameter, diameter of the test section	m
F	shape factor	m
h	hydraulic head of the test	m
h_1, h_2, h_3	applied hydraulic heads	m
h_o	distance of the water level from the ground level	m
Δh	change in hydraulic head	m
k	permeability coefficient	m/s
k_{fs}	field saturated permeability coefficient	m/s
L	length (height) of the test section	m
Q	flow rate	m^3/s
r	radius	–
S	storage coefficient	–
T	transmissivity	–
t_i	time needed to reach the equilibrium	s
t	time	s
t_o	time at start of test	s
$\dot{V}$	volume flow rate	

4 Test principle

The test is based on the assumption that the test section is isolated and located above or below the groundwater surface.

The results can vary depending on the test type chosen (water withdrawal or injection) according to the purpose of the test.

Three test methods are available:

a) Constant flow rate test method (suitable for k-value greater than 10^{-6} m/s)

This test consists of producing a change in hydraulic head in a section of a borehole by injecting or withdrawing a constant flow rate. The change in hydraulic head is measured against time.

b) Variable head test method (suitable for k-value between 10^{-6} m/s and 10^{-9} m/s)

This test consists of producing an instant change in hydraulic head in a section of a borehole. The change in hydraulic head is measured against time.

c) Constant head test method (suitable for k-value between 10^{-4} m/s and 10^{-7} m/s)

This test consists of maintaining a constant hydraulic head in a section of a borehole. The flow rate is measured against time.

5 Equipment

In addition to a casing or a piezometer, the following equipment is necessary:

a) water supply or plain rod for the falling head test;

b) pump or bail system for the rising head test;

c) device to determine the flow rate with an accuracy of 5 % of the measuring range for constant head and constant flow;

d) device to maintain the flow rate for constant flow;

e) perforated tube and/or filter material (for filter criteria see ISO 22282-1);

f) device to measure the water level in the casing or piezometer with an accuracy of 0,01 m;

g) a time measuring and/or recording device, reading in s.

All the equipment and measuring devices shall be calibrated according to their use, either periodically or before they are used.

6 Test procedure

6.1 Preparation of a test section

6.1.1 General

The test section shall be prepared in accordance with ISO 22282-1: 2011, Annex A.

6.1.2 Preparation of a test section in non-stable soil and rock below the groundwater surface

Drilling shall be executed with the use of a casing. After drilling the test section and cleaning the borehole, the test section shall be prepared according to one of these three alternatives (see Figure 1):

a) A perforated tube that is closed by a perforated or closed disc at the bottom shall be installed through the casing tube in the test section [Figure 1 a)]. After that the casing tube shall be withdrawn by the length L shortly above the upper end of the perforated section.

NOTE If the bottom of the boreholes cannot be cleaned, a full disc can be used at the bottom of the tube. In this case a specific shape factor is used (see ISO 22282-1).

b) Before withdrawing the casing tube, an appropriate filter material shall be filled into the test section. After that the casing tube shall be withdrawn up to the upper edge of the filter [Figure 1 b)].

c) Open end test: the test is performed at the bottom of the casing through the open section of diameter D [Figure 1 c)].

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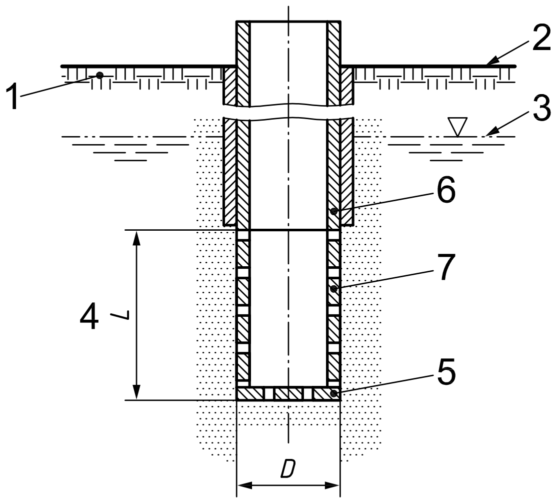
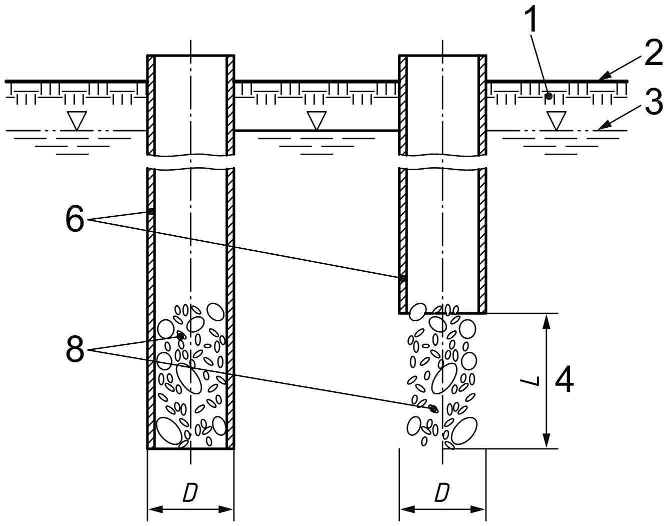


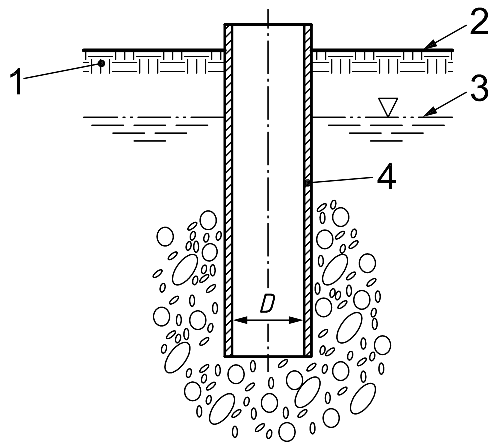
a) With perforated tube



b) With filter material

Key

1 ground
2 top surface
3 water table
4 test section
5 perforated or closed disc
6 casing
7 perforated tube
8 filter pack
L length of the test section
D diameter of the test section



c) Open end test

Key

1 ground
2 top surface
3 water table
4 casing
D diameter of the test section

Figure 1 — Test section in non-stable soil and rock

6.1.3 Preparation of a test section in stable soil and rock

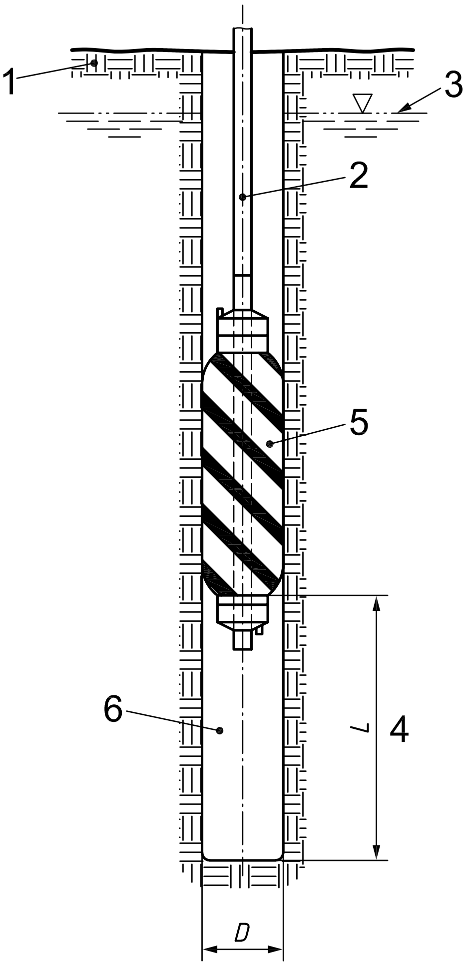
After drilling the test section and cleaning the borehole, the test section shall be prepared according to one of the following alternatives (see Figure 2):

a) A packer is inflated above the test section [Figure 2 a)]. A perforated tube can be used below the packer.

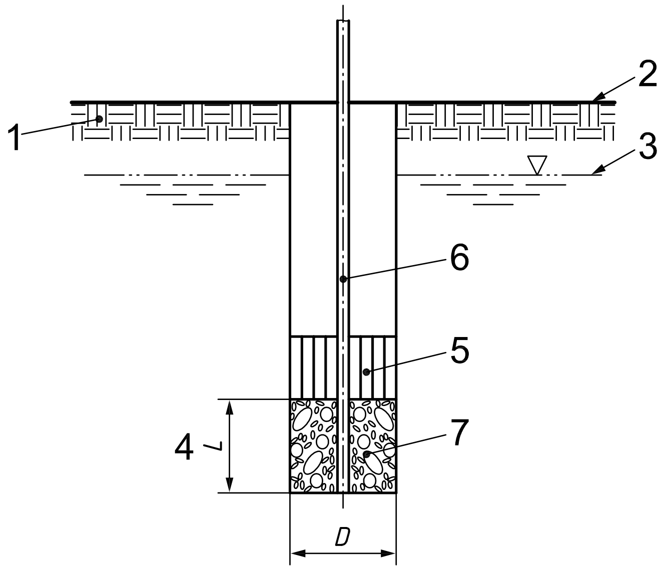
b) In a temporary open piezometer, a perforated tube shall be used in the test section. An appropriate filter material shall fill the space between the tube and the borehole wall into the test section. A sealing plug shall be installed above the filter pack [Figure 2 b)].

c) Before withdrawing the casing tube, an appropriate filter material shall be filled into the test section. After that the casing tube shall be withdrawn up to the upper edge of the test section [Figure 2 c)].

d) The same preparation as in c), but without filter material [Figure 2 d)].



a) With packer



b) Temporary piezometer

Key

1 ground

2 measuring tube

3 water table

4 test section

5 packer

6 cavity

L length of the test section

D diameter of the test section

Key

1 ground

2 top surface

3 water table

4 test section

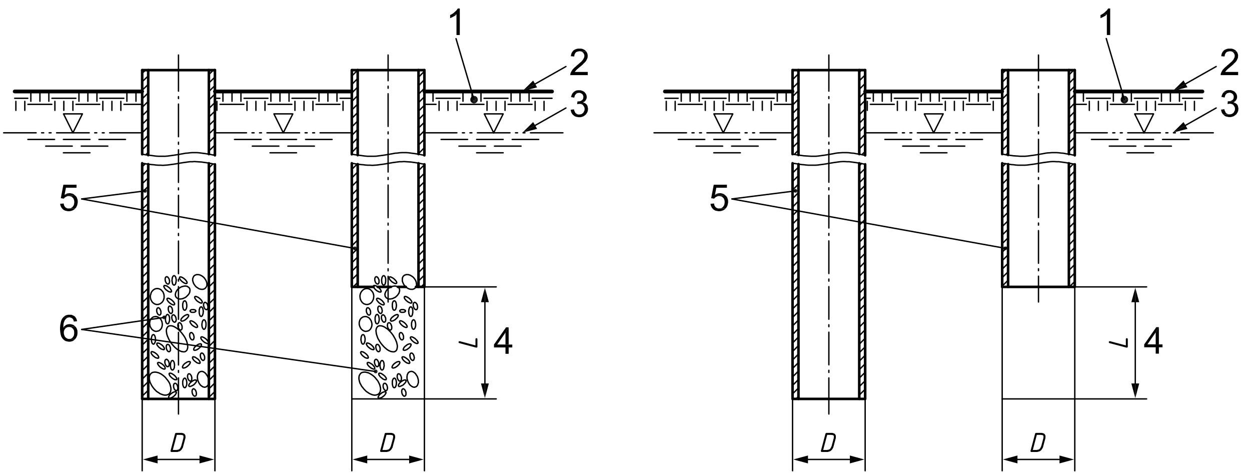
5 sealing plug

6 measuring tube

7 filter pack

L length of the test section

D diameter of the test section



c) With filter material **d) Without filter material**

Key

1 ground
2 top surface
3 water table
4 test section
5 casing
6 filter material
L length of the test section
D diameter of the test section

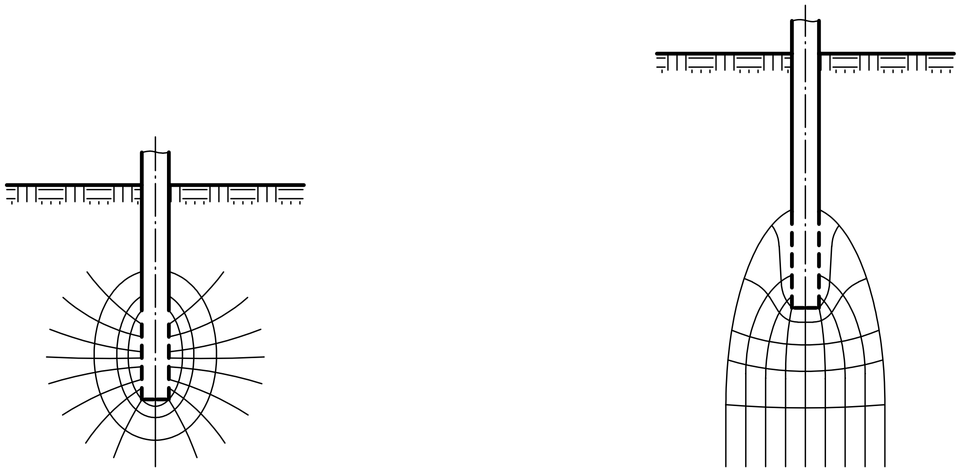
Figure 2 — Example of test section in stable soil and rock

6.1.4 Preparation of the test section in unsaturated conditions

Measurement of permeability in unsaturated soils is made by injecting water into the test section.

During infiltration created by the permeability test, a field-saturated condition develops around the test section. Full saturation does not occur due to entrapped air remaining in the soil or provided by the injected fluid. This may reduce the permeability measured in the field.

When testing unsaturated coarse soils (typically gravels and sands), the flow of water is not spherical or ellipsoidal as observed below water table in homogeneous soils (Figure 3). The flow net is affected by gravity and shall be described by specific equations such as those provided in B.5.



a) **Saturated conditions** b) **Unsaturated conditions**

Figure 3 — Water flow in coarse soils

In low permeability soils (silts and clays) the effect of suction at the wetting front can affect the test results, particularly if the initial saturation of the soil is low. In order to avoid or limit the effect of suction, the soil around the test section should be pre-saturated prior to proper permeability measurement. This phase creates a saturated bulb around the test section wall. The equations used to compute the test data in saturated conditions may be used.

The duration of the saturation phase depends on the permeability of the soil in the test section (Figure 4). The total amount of infiltrated water during the saturation phase shall be recorded.

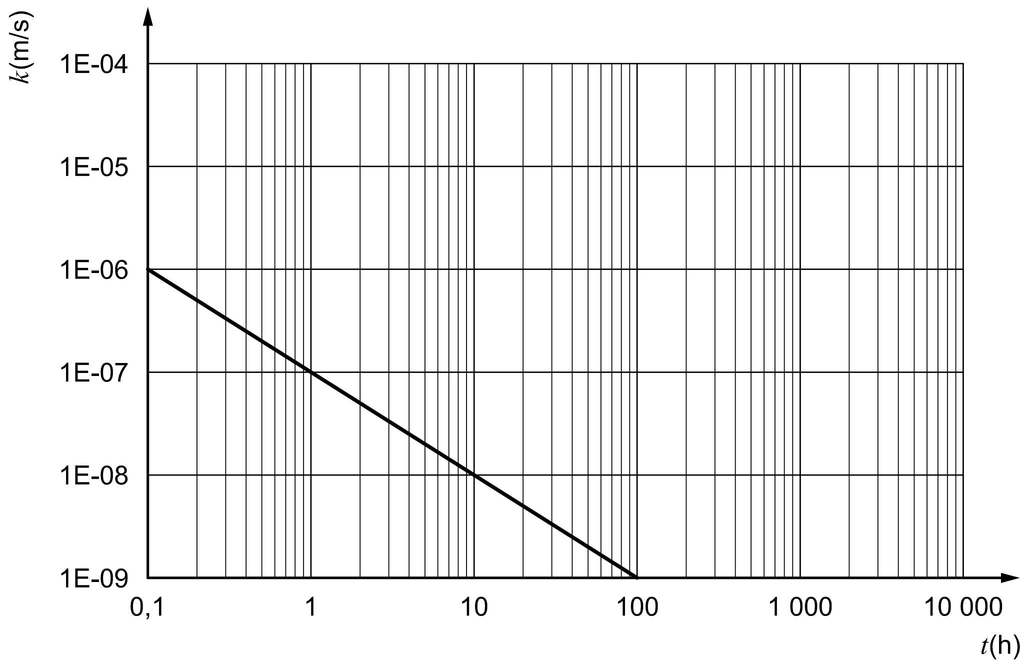


Figure 4 — Recommended duration of saturation phase

6.2 Conducting the test

6.2.1 General

All test methods can be executed as multi-step tests applying different hydraulic heads or flow rates.

6.2.2 Constant flow rate test method

The constant flow rate test method is generally suitable for k-values greater than 10^{-6} m/s.

Before starting the test, the water level shall be measured in the annular space or measuring tube after stabilization.

A flow rate shall be chosen which shall allow a variation of the water level in the tube of at least 10 cm during the first minute in order to obtain a significant change in level between two measuring steps.

NOTE In a usual shape of the test section (e.g. $D = 10$ cm and $L = 100$ cm), a variation of 10 cm with a flow rate of 100 l/min corresponds to a range of permeability of approximately 10^{-3} m/s. If the borehole is emptied (respectively filled) with a smaller flow rate (approximately 1 l/min), the permeability is less than 10^{-6} m/s.

Before beginning the test, the water level shall have reached the static water level at rest.

The defined flow rate shall be applied and maintained.

The water level shall be measured at least every minute until 20 min have elapsed and then at least every 5 min until the end of the flow-phase.

The test can be ended when the water level is stabilized in the measuring tube, i.e. three consecutive measures which do not vary more than 1 cm or after 60 min.

When the water flow is stopped, the recovery of the water level shall be measured. The measurement shall start a maximum of 30 s after the water flow stopped and shall be continued at least every following minute until the half time of the duration of the flow-phase or until the initial water level has been reached.

6.2.3 Variable head test method

The variable head test method is generally suitable for k-values between 10^{-6} m/s and 10^{-9} m/s.

Before starting the test, the water level shall be measured in the annular space or measuring tube after stabilization.

The water level in the borehole or measuring tube shall be changed by injecting or withdrawing water. The measurements of the water level shall begin immediately from the start of the test.

The measurement intervals shall be defined according to the range of permeability. The test can be ended when 75 % of the water level recovery is obtained.

6.2.4 Constant head test method

The constant head test method is generally suitable for k-values between 10^{-4} m/s and 10^{-7} m/s.

Before starting the test, the water level shall be measured in the annular space or measuring tube after stabilization.

The constant head test requires the supply or withdrawal of water. A constant hydraulic head increment (injection or withdrawal) shall be applied to the test section. The amount of infiltrated or extracted water shall be monitored against time until steady-state flow is obtained.

7 Test results

7.1 Constant flow rate test method

The results of a constant flow rate test are the changes of hydraulic head versus time (Figure 5).

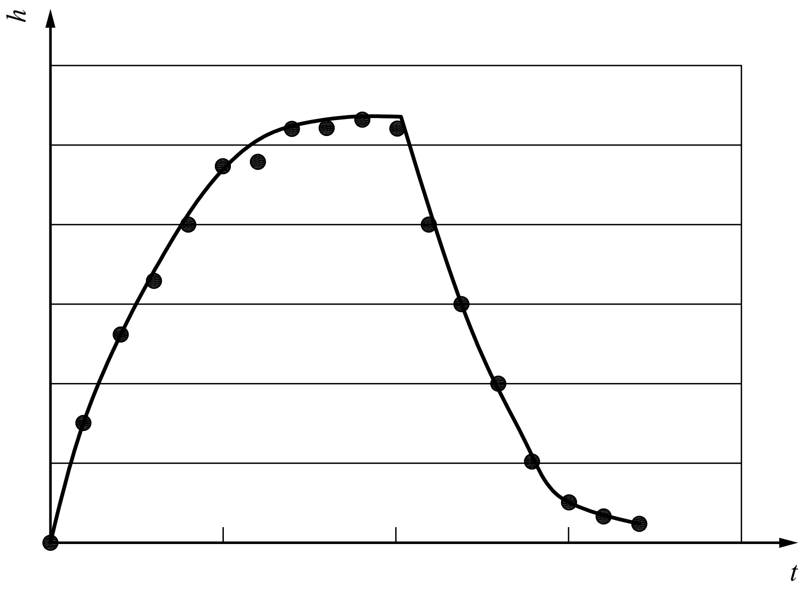


Figure 5 — Example of test results of a constant flow rate test

7.2 Variable head test method

The results of a variable head test are the changes of hydraulic head versus time (Figure 6).

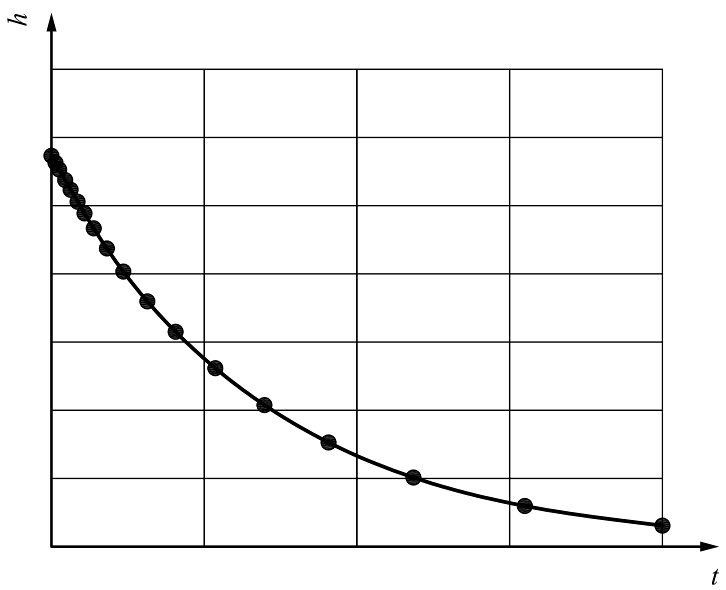


Figure 6 — Example of test results of a variable head test

7.3 Constant head test method

The results of a constant head test are the changes of volume or rate of water flow versus time (Figure 5).

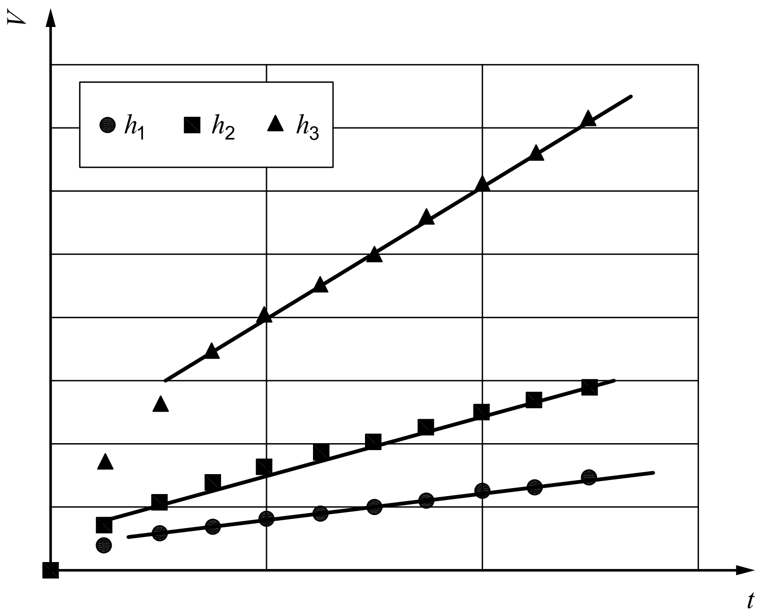


Figure 7 — Example of test results of a constant head test for different hydraulic heads (multi-step test) ($h_3 > h_2 > h_1$)

8 Reports

8.1 Field report

8.1.1 General

At the project site, a field report shall be completed. This field report shall consist of the following, if applicable:

a) summary log according to ISO 22475-1;

b) drilling record according to ISO 22475-1;

c) sampling record according to ISO 22475-1;

d) calibration record according to ISO 22282-1;

e) record of measured values and test results according to 8.1.2.

All field investigations shall be reported such that third persons are able to check and understand the results.

8.1.2 Record of measured values and test results

The record of measured values and test results shall contain the following data, if applicable (see Annex A).

a) General information:

   1) name of the enterprise performing the test;

   2) reference to this International Standard, e.g. ISO 22282-2:2012;

   3) name of the client;

4) name and number of project;

5) name and signature of the test operator.

b) Information on the location of the test:

1) date and number of test;

2) number of borehole;

3) place within or which is nearest;

4) position and elevation of borehole x, y, z;

c) Information on the used equipment:

1) inner and outer diameter of the casing and the filter tube;

2) type of filter;

3) isolation device.

d) Information on the test procedure:

1) type of test with reference to this part of ISO 22282;

2) borehole inclination/orientation;

3) drilling method;

4) test results;

5) medium depth of the test section;

6) length and diameter of the test section;

7) details of any unusual event or observation during the test;

8) comments on observations or performed checks of importance for the interpretation;

e) Additional information:

1) weather conditions during the test;

2) identification and description of soil and rock according to ISO 14688-1 and ISO 14689-1;

3) hydrogeological conditions.

8.2 Test report

The test report shall include the following essential information:

a) the field report (in original and/or computerized form);

b) a graphical presentation of the test results and the recorded values of the hydraulic head or the flow rate (or the volume) versus time, for every step of hydraulic head applied when relevant;

c) any corrections in the presented data;

d) any limitations of the data (e.g. irrelevant, insufficient, inaccurate and adverse test results);

e) name and signature of the responsible expert.

Annex A
(informative)

Example of record of measured values and test results

Water permeability tests in a borehole using open systems according to ISO 22282-2							
Name of the enterprise				Name of the client			
Name/No. of the project				Location			
Test method				Test No.		Date	
Drilling method				Static hydraulic head			
Borehole No.		Position X		Position Y		Elevation	
Type of filter		Isolation device		Diameter of filter tube			
Test section diameter		Upper level		Lower level		Length	
Time	**Flow rate** $\dot{V}$	**Hydraulic head** h	**Head changes** Δh	**Time**	**Flow rate** $\dot{V}$	**Hydraulic head** h	**Head changes** Δh
Remarks and additional information							
Name and signature of the test operator							

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Annex B
(informative)

Interpretation of test results

B.1 General

The interpretation of the tests includes the determination of the permeability coefficient k (in m/s). This coefficient can deviate from the large scale k-value and may not be used for the dimensioning of significant lowering of the groundwater level. In the close-up range of a limitation of an aquifer, the proposed equation for the calculation of k, as described in Reference [4], has to be adjusted.

B.2 Constant rate test method

The permeability coefficient shall be calculated according to Equation (B.1) when steady state is reached:

$$k = \frac{Q}{F \cdot h} \tag{B.1}$$

where

k is the permeability coefficient;

Q is the constant flow rate;

F is the shape factor calculated according to ISO 22282-1;

h is the stabilized hydraulic head at steady state.

The graph of the various flow rates can be plotted as a function of the hydraulic head when more than one flow rate is applied successively (see B.3).

Radial flow is recognized if the data in plot dh versus log(dt) form a straight line. Spherical flow is recognized if the data in plot dh versus 1/SQRT(dt) form a straight line.

The data collected during the transient phase may also be interpreted from the following equation:

$$h(t) = \left(\frac{Q}{S} - \frac{dh}{dt} \right) \cdot \frac{A}{k \cdot F} \tag{B.2}$$

where A is the cross-section surface area of the measuring tube.

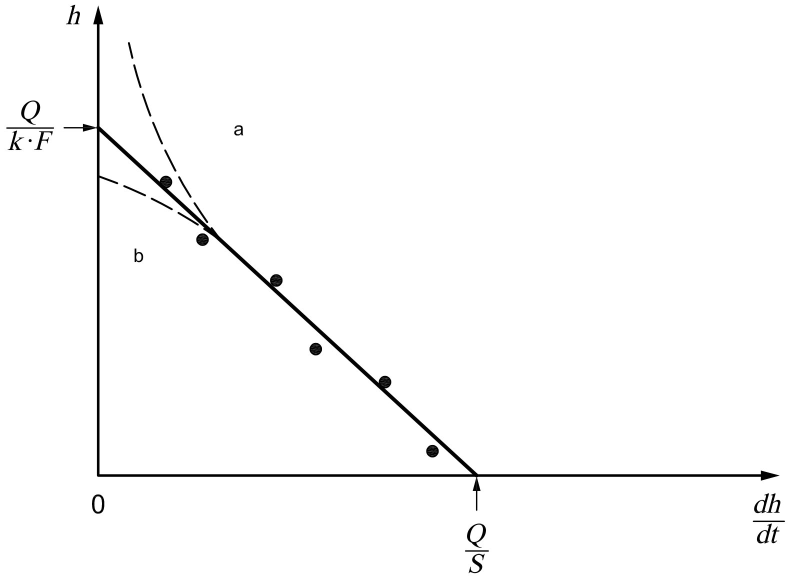
The data are plotted by computing the hydraulic head $h(t)$ versus dh/dt during the flow rate phase and during the static level recovering phase (Figure B.1).

The curve obtained from the flow rate phase is a straight line passing through the following points:

($dh/dt = 0$, $h = Q/k\,F$)

($dh/dt = Q/S$, $h = 0$)

This allows the calculation of k.



Key

a Clogging.

b Washing.

Figure B.1 — Plotting of hydraulic head *h* versus *dh*/*dt*

B.3 Constant head test method

The permeability coefficient k shall be calculated according to Equation (B.3):

$$k = \frac{Q}{F \cdot h} \tag{B.3}$$

where

Q is the steady state water flow rate;

F is the shape factor according to ISO 22282-1;

h is the hydraulic head of the test.

Radial flow is recognized if the data in plot 1/q versus log(dt) form a straight line. Spherical flow is recognized if the data in plot q versus 1/SQRT(dt) form a straight line.

The graph of the infiltrated or extracted water amount can be plotted as a function of the hydraulic head h by the reiteration of the test with three different hydraulic heads h_1, h_2, and h_3 (see Figure B.2). If the test is carried out correctly, the plotted pairs of data are located on a straight line. If the last points are located on an upwards curved graph, it can mean that fine particles were washed out. If a clogging has occurred during the test, the last points are located on a downwards curved graph.

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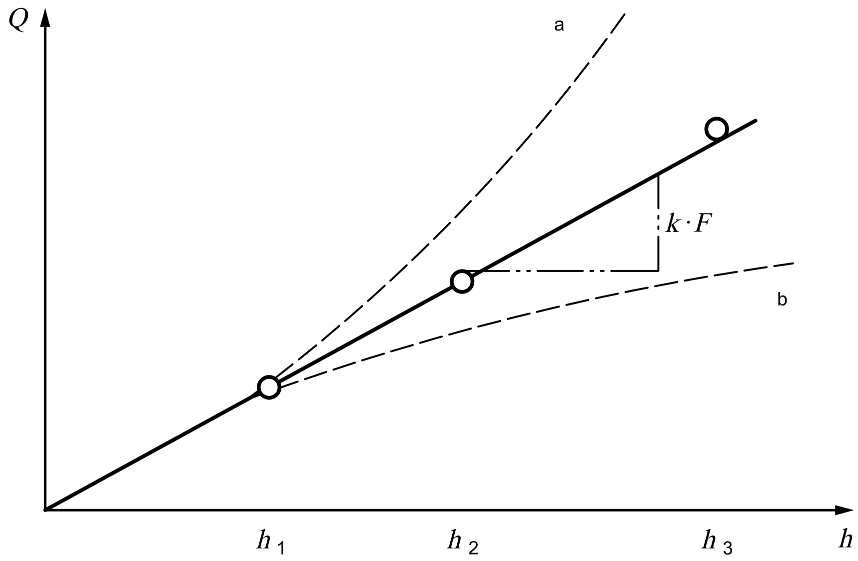

Key

a Clogging.

b Washing.

Figure B.2 — Infiltrated water amount depending on the pressure difference

B.4 Variable head test method

B.4.1 Velocity graph method

By convention, the equation for open cased variable head borehole tests is:

$$\ln\left[\frac{h_o}{h(t)}\right]=\frac{k\cdot F\left(t-t_o\right)}{S} \quad \text{(B.4)}$$

where

h_o and $h(t)$ are the hydraulic heads measured respectively at the times t_o and t;

S is the known actual internal cross-section of the liaison tube in which the measurement is carried out;

F is the shape factor calculated according to ISO 22282-1.

The plotting of $\ln[h_o/h(t)]$ versus elapsed time gives a straight line of slope α equal to $k{\cdot}F/S$ (Figure B.3). k is calculated directly by Equation (B.5):

$$k=\alpha\cdot S/F \quad \text{(B.5)}$$

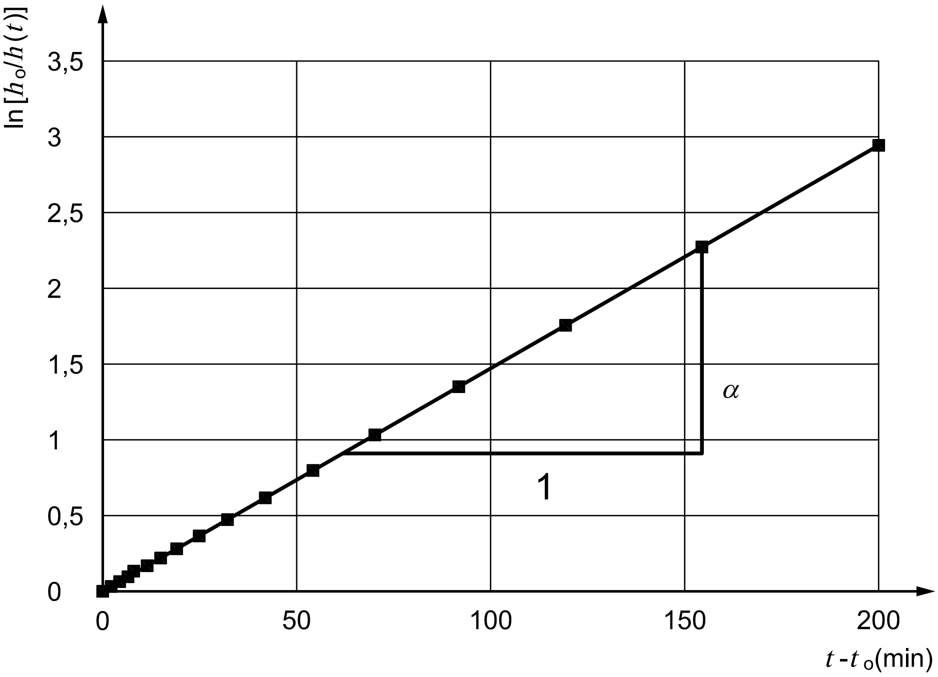

Figure B.3 — Representation of the head variation $h(t)$ as a function of the elapsed time t in ratio chart form

In some cases, the relationship between ln[$h_o/h(t)$] and (t-t_o) is not a straight line (Figure B.4). It is necessary to plot the velocities dh/dt, calculated on each measurement step dt, as a function of the average hydraulic head variation h during the time step dt (Figure B.5). Where the test points are aligned, the straight line intercepts the h axis at a value h_{st} corresponding to the corrective term on the estimation of the initial static level.

The corrected values of $h(t)$, designated $h_{cor}(t)$, are obtained by applying the following correction:

$$h_{cor},(t) = h(t) - h_{st} \qquad \text{(B.6)}$$

The plotting of the corrected h_{cor} values as a function of time gives a straight line which allows the characterization of the theoretical slope α. The value of k is calculated as previously (Figure B.6).

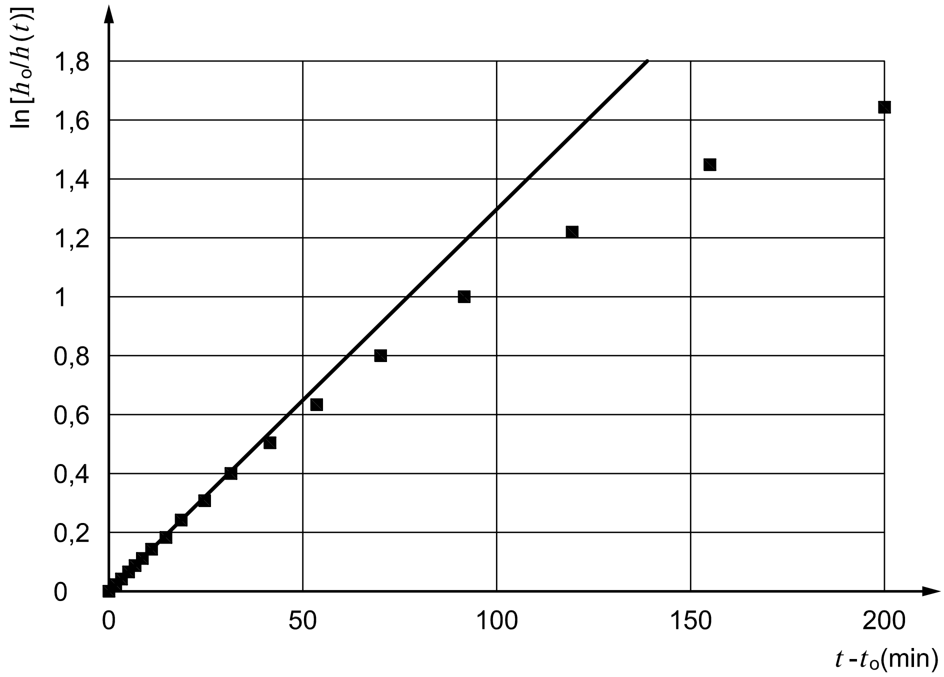

Figure B.4 — Non-linear relationship between ln[$h_o/h(t)$] **and the time**

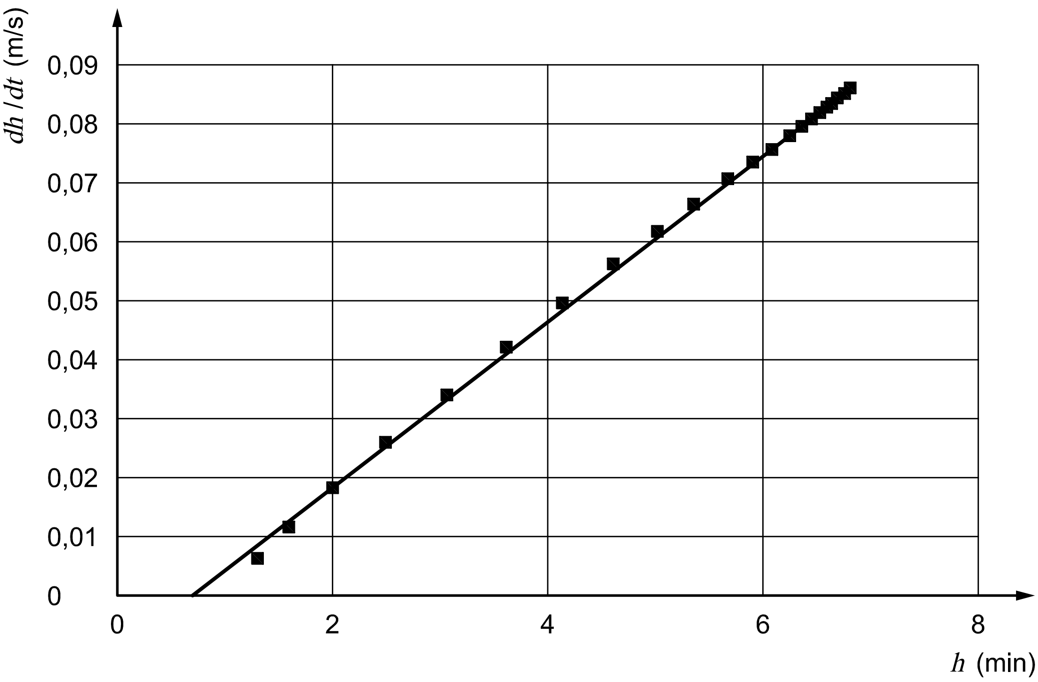

Figure B.5 — Representation of the time-dependent head variation velocity

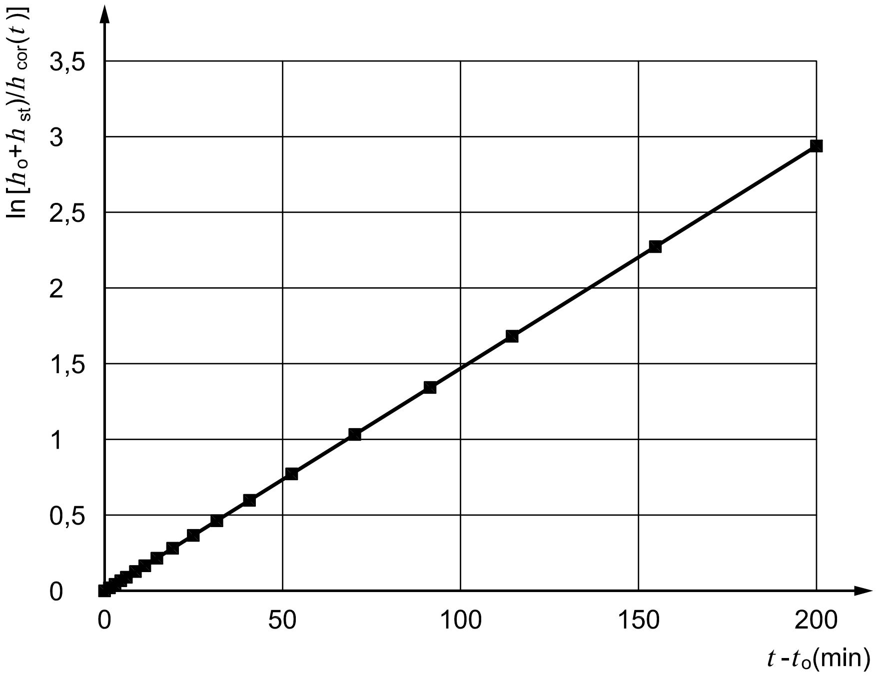

Figure B.6 — Representation of the time-dependent corrected hydraulic head $h_{cor}(t)$, ratio chart

B.4.2 Hvorslev method

The Hvorslev method can be applied only below the water table. The following equation applies to the data:

$$k = \frac{r^2 \cdot \ln\left(L/R\right)}{2 \cdot L \cdot t_o} \quad \text{(B.7)}$$

where

- k is the coefficient of permeability (m/s);
- r is the radius of the measuring tube (m);
- R is the radius of the test section (m);
- L is the length of the test section (m);
- t_o is the time it takes for the water level to rise or fall to 37 percent of the initial change in head (s).

The data are plotted by computing the ratio h/h_o and plotting that versus time on semi-logarithmic paper, as shown in Figure B.7.

The previous equation is one of many formulas presented by Hvorslev for differing piezometer geometry and aquifer conditions and can be applied for most piezometer designs where the length is typically quite a bit greater than that of the radius of the well screen. For other conditions, the original publication should be consulted (see Bibliography).

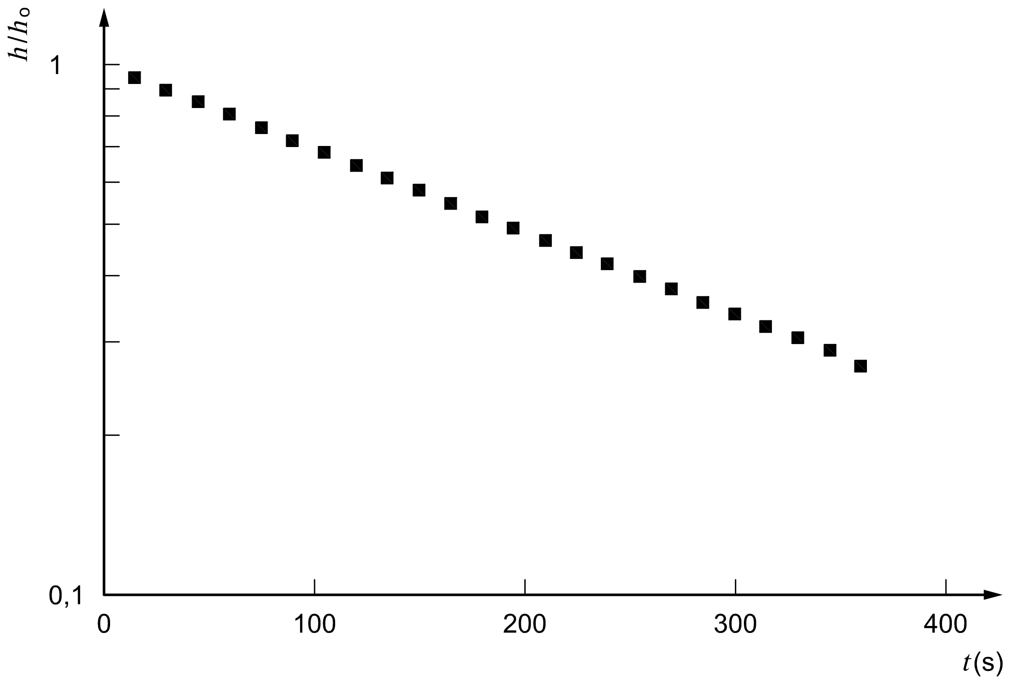

Figure B.7 — Plot of h/h_o versus time according to Hvorslev method (1951)

B.4.3 Cooper-Bredehoeft-Papadopoulos method

This test method describes the analytical procedure for analysing data collected during an instantaneous head test using an overdamped well. The analytical procedure consists of analysing the recovery of water level in the well following the change in water level induced in the well.

Assumptions of the solution of Cooper et al method:

— The head change in the control well is instantaneous at time $t = 0$.

— The well is of finite diameter and fully penetrates the aquifer.

— The flow in the nonleaky aquifer is radial.

The integral expression in the solution given in Equation (B.8) cannot be evaluated analytically. A graphical solution for determination of transmissivity and coefficient of storage can be made using a set of type curves as illustrated in Figure B.8.

$$h=\frac{2h_o}{\pi}\int_0^\infty\left[\left[\exp\left(-\beta u^2/\alpha\right)\left[J_o(ur/r_w)\left[uY_o(u)-2\alpha Y_1(u)\right]-Y_o(ur/r_w)\left[uJ_o(u)-2\alpha Y_1(u)\right]\right]/\Delta(u)\right]\right]\cdot du \quad \text{(B.8)}$$

where

$$\alpha = r_w{}^2 S/r_c{}^2 \quad \text{(B.9)}$$

$$\beta = Tt/r_c{}^2 \quad \text{(B.10)}$$

$$\Delta(u)=\left[uJ_o(u)-2\alpha J_1(u)\right]^2+\left[uY_o(u)-2\alpha Y_1(u)\right]^2 \quad \text{(B.11)}$$

r_w is the radius of the well;

r_c is the radius of the casing;

S is the storage coefficient.

Prepare a semi-logarithmic plot of a set of type curves of values of F(β,α), h/h_o, on the arithmetic scale, as a function of β, on the logarithmic scale.

Prepare a semi-logarithmic plot of the same scale as that of the type-curve. Plot the water level data in the control well, expressed as a fraction, h/h_o, on the arithmetic scale, versus time, t, on the logarithmic scale.

Overlay the data plot on the set of type curve (Figure B.8) plots and, with the arithmetic axes coincident, shift the data plot to match one curve or an interpolated curve of the type curve set. A match point for β, t, and α is picked from the two graphs.

Using the coordinates of the match line, determine the transmissivity and storage coefficient from the following equations:

$$T = \beta r_c^2 / t \qquad \text{(B.12)}$$

and

$$S = \alpha r_c^2 / r_w^2 \qquad \text{(B.13)}$$

Permeability coefficient is then calculated from:

$$k = T/L \qquad \text{(B.14)}$$

where

T is the transmissivity;

L is the length of the test section.

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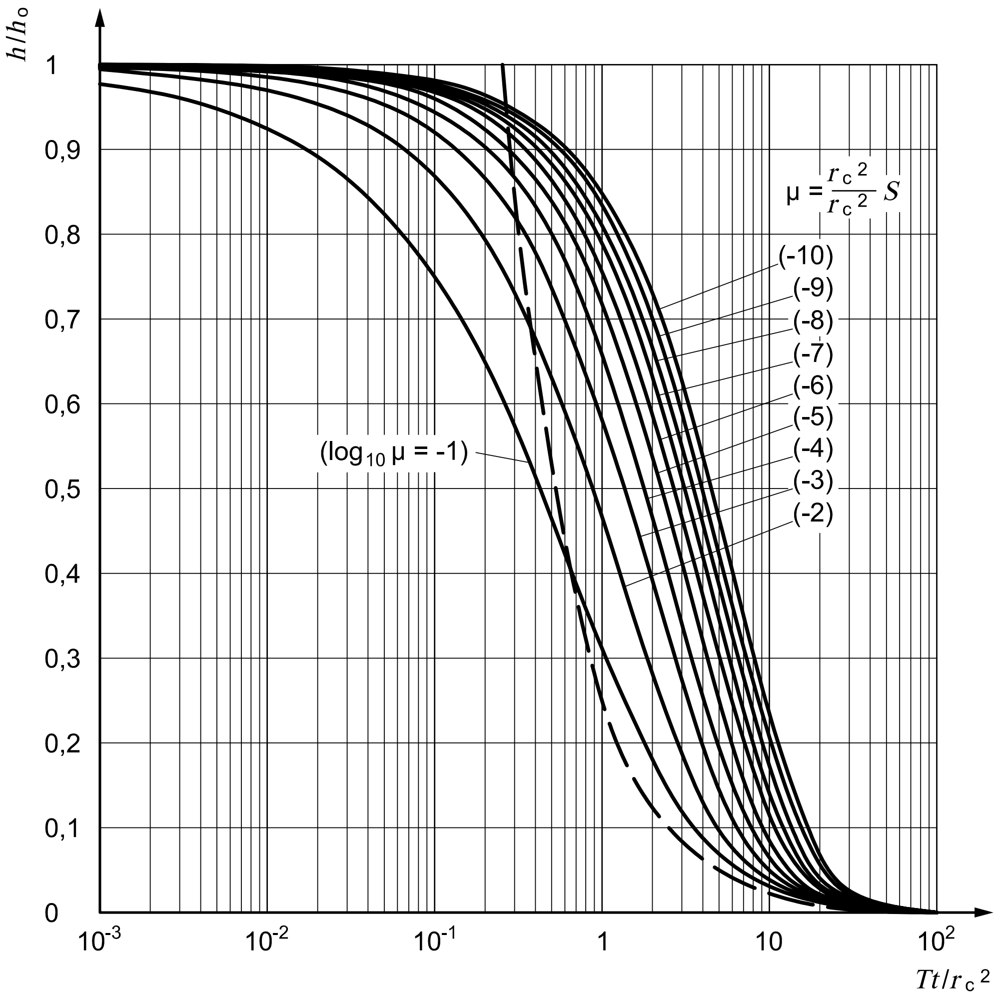


Figure B.8 — Type curves for slug test in a well of finite diameter

B.4.4 Bouwer and Rice method

This method can be performed on open boreholes or screened wells. The well can be fully of partially penetrating the tested formation. Although the test was originally developed for unconfined aquifers, it can be used in confined aquifers if the top of the well screen is some distance below the bottom of the confining layer.

The geometry of the borehole for the Bouwer and Rice test is shown in Figure B.9. In this diagram the parameter r_c is the radius of the well casing in which the water level is changing and R is the radius of the gravel pack or developed area around the well screen.

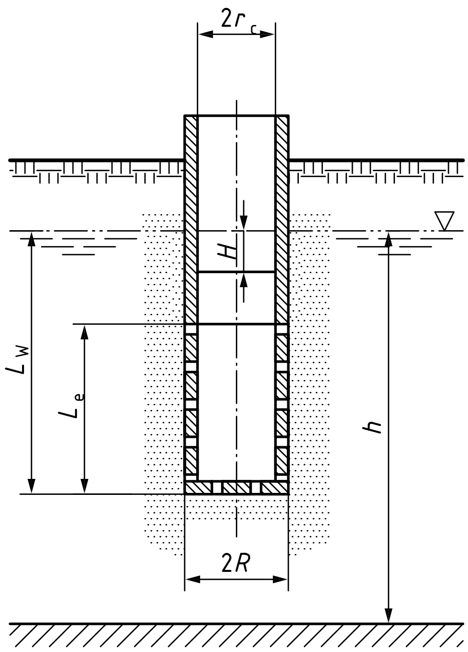


Figure B.9 — Geometry and symbols for the Bouwer and Rice method

The Bouwer and Rice equation is:

$$k = \frac{r^2 \cdot \ln\left(R_e/R\right)}{2 \cdot L} \cdot \frac{1}{t} \cdot \ln\left(\frac{h_o}{h_t}\right) \tag{B.15}$$

where

- k is the permeability coefficient (m/s);
- r is the radius of the measuring tube or the well casing (m);
- R is the radius of the test section (m);
- R_e is the effective radial distance over which induced head is dissipated (m);
- L is the length of the test section through which water can enter (m);
- h_o is the drawdown at time $t = 0$ (m);
- h_t is the drawdown at time t (m);
- t is the time since $h = h_o$ (s).

The effective distance over which the induced head is dissipated, R_e, is also the distance away from the well that the average value of k is being measured. However, there is no way to know what value of R_e is for a given well. Bouwer and Rice have presented a method of estimating the dimensionless ratio $\ln(R_e/R)$.

If L_w is less than h, the saturated thickness of the aquifer, then

$$\ln \frac{R_e}{R} = \left[\frac{1.1}{\ln(L_w/R)} + \frac{A + B \cdot \ln\left[(h - L_w)/R\right]}{L/R} \right]^{-1} \tag{B.16}$$

If L_w is equal to h, then

$$\ln \frac{R_e}{R} = \left[\frac{1.1}{\ln(L_w/R)} + \frac{C}{L/R} \right]^{-1} \tag{B.17}$$

where A, B et C are dimensionless numbers that can be found from Figure B.10, where they are plotted as a function of L/R.

The value of h_t as a function of t is plotted on semi-logarithmic paper, with h_t on the logarithmic axis. The data pairs will fall on a straight line from small values of time and large values of head.

The value $(1/t)\ln(h_o/h_t)$ may be obtained from two points picked on the straight line portion of the graph. At one point the values are h_1 and t_1 and at the other points the values are h_2 and t_2. Under these conditions:

$$\frac{1}{t} \cdot \ln\left(\frac{h_o}{h_t}\right) = \frac{1}{(t2 - t1)} \cdot \ln\left(\frac{h_1}{h_2}\right) \tag{B.18}$$

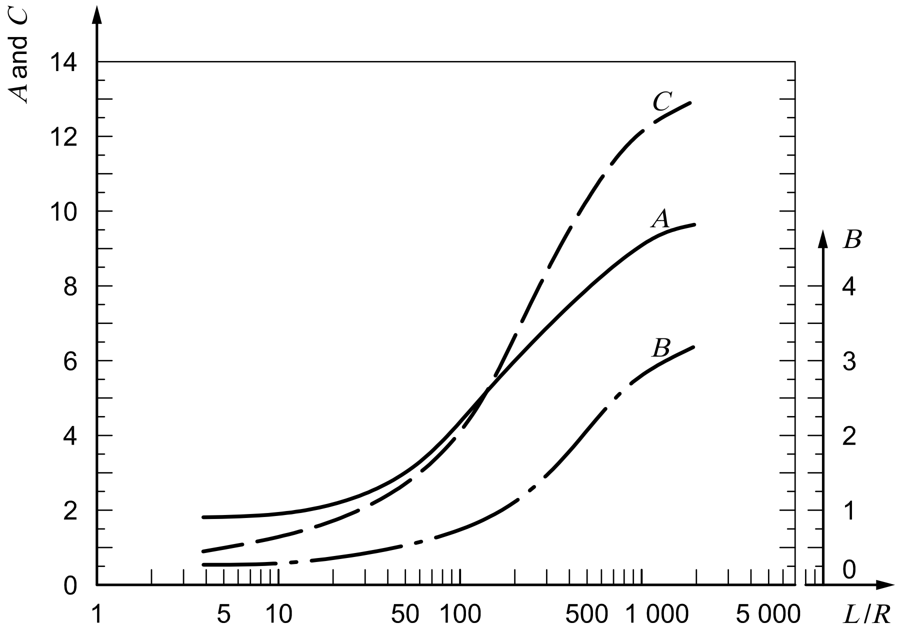


Figure B.10 — Dimensionless parameters *A*, *B* versus *L*/*R*

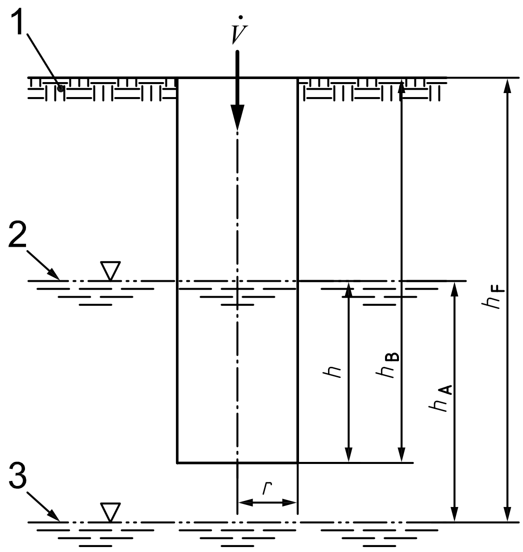
B.5 Unsaturated soil conditions

Test results of constant head tests carried out in unsaturated soils may be interpreted if the following requirements are fulfilled:

— stationary flow conditions during the test;

— $h/r > 10$;

— hydrogeological conditions according to Figures B.11 and B.12.



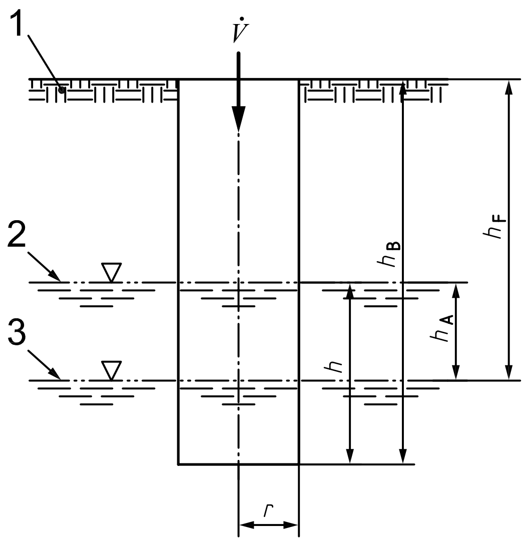
Key

1 ground surface

2 raised water surface

3 unconfined water surface

Figure B.11 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface below borehole bottom)



Key

1 ground surface

2 raised water surface

3 unconfined water surface

Figure B.12 — Hydrogeological conditions for a constant head test in unsaturated soils (unconfined groundwater surface above borehole bottom)

According to the hydrogeological test conditions there are three equations:

for $h_A > 3\ h$, unconfined groundwater surface in greater depth below the borehole bottom:

$$k_f = 0{,}159 \cdot \frac{\dot{V}}{h^2} \cdot \left[\ln\left(\frac{h}{r} + \sqrt{\left(\frac{h}{r}\right)^2 + 1} \right) - 1 \right] \quad \text{(B.19)}$$

for $h \le h_A \le 3\ h$, unconfined groundwater surface in lower depth below the borehole bottom:

$$k_f = 0{,}159 \cdot \frac{\dot{V}}{h^2} \cdot \frac{\ln\left(\frac{h}{r}\right)}{0{,}1667 + \frac{h_A}{3 \cdot h}} \quad \text{(B.20)}$$

for $h_A < h$, unconfined groundwater surface above the borehole bottom:

$$k_f = 0{,}159 \cdot \frac{\dot{V}}{h^2} \cdot \frac{\ln\left(\frac{h}{r}\right)}{\frac{h_A}{h} - 0{,}5 \cdot \left(\frac{h_A}{h}\right)^2} \quad \text{(B.21)}$$

where

k_f is the permeability coefficient;

$\dot{V}$ is the infiltration rate (flow rate);

h is the hydraulic head in the borehole;

r is the radius of the borehole;

h_F is the depth of the unconfined groundwater surface;

h_B is the depth of the borehole;

h_A is the distance of the elevated water surface to the unconfined groundwater surface:

$h_F = h_A + h_B - h$.

Bibliography

[1] EN 1997-1, *Eurocode 7: Geotechnical design — Part 1: General rules*

[2] EN 1997-2, *Eurocode 7: Geotechnical design — Part 2: Ground investigation and testing*

[3] CASSAN, M. (2005): Les essais de perméabilité sur site dans la reconnaissance des sols, nouvelle édition, Presses de l'école nationale des Ponts et Chaussées, Paris

[4] BOUWER, H. and RICE, R.C. (1976): A slug test for determining hydraulic conductivity of unconfined aquifers with completely penetrating wells, *Water Resources Research*, Vol. 12, No. 3, pp. 423-428

[5] FETTER, C.W. (1994): *Applied Hydrogeology*, Third Edition, New Jersey: Prentice Hall, Englewood Cliffs, 691 p.

[6] COOPER, H.H., BREDEHOEFT, J.D., and PAPADOPOULOS, I.S. (1967): Response of a finite diameter well to an instantaneous change of water, *Water Resources Research*, Vol. 3, No. 1, pp. 263-269

[7] HVORSLEV, M.J. (1951): *Time lag and soil permeability in groundwater observation*, U.S. Army, Corps of Engineers, Waterways Experiment Station, Vicksburg MS., Bull. 36

[8] US Department of the Interior (1990): *Earth Manual, Part 2, A Water Resources Technical Publication. Procedure for constant-head hydraulic conductivity tests in single drill holes* (USBR 7310-89)

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