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Geotechnical investigation and testing — Geohydraulic testing —

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

Reconnaissance et essais géotechniques — Essais géohydrauliques — Partie 6: Essais de perméabilité à l'eau dans un forage en tube fermé

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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 22282-6 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*

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Geotechnical investigation and testing — Geohydraulic testing —

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

1 Scope

This part of ISO 22282 specifies requirements for the determination of the local permeability in soils and rocks below or above the groundwater table in a closed system by the water permeability tests as part of the geotechnical investigation services according to EN 1997-1 and EN 1997-2.

The tests are used to determine the permeability coefficient k in low permeability soil and rock lower than 10^{-8} m/s. It can also be used to determine the transmissivity T and the storage coefficient S.

NOTE The water pressure test in rock is covered by ISO 22282-3.

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, *Geotechnical investigation and testing — Geohydraulic tests — Part 1: General rules*

ISO 22475-1, *Geotechnical investigation and testing — Sampling method 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 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
C_{app}	apparent compressibility of the measurement device	Pa^{-1}
C_w	compressibility of the water	Pa^{-1}
F	shape factor	—
g	acceleration due to gravity	$m.s^{-2}$
h	hydraulic head	m
h_{st}	pre-test stabilized hydraulic head	m
k	permeability coefficient	$m.s^{-1}$
k_{20}	permeability coefficient at a temperature of 20 °C	$m.s^{-1}$
L	height of the cavity	m
p	pressure	Pa
Q	flow rate	$m^3.s^{-1}$
r_c	radius of the measurement cavity and of the borehole	m
S	storage coefficient	—
T	transmissivity ($T = k\,L$)	$m^2.s^{-1}$
t	time	s
V	volume	m^3
V_w	volume of water submitted to pressure pulse	m^3
z_c	height of the middle of the cavity in relation to the natural land	m
z_{capt}	height of the pressure sensor in relation to the natural land	m
η	dynamic viscosity of the water	Pa.s
ρ_w	density of the water	$kg.m^{-3}$
Δh_0	variation in initial hydraulic head	m
ΔV_0	variation in initial volume	m^3
Δp_0	variation in initial pressure	Pa

4 Equipment

The basic equipment consists of the following parts (see also the example in Figure 1):

— pump or pressure source capable of injecting or removing water to the water-filled system to produce a pressure pulse in the test interval;

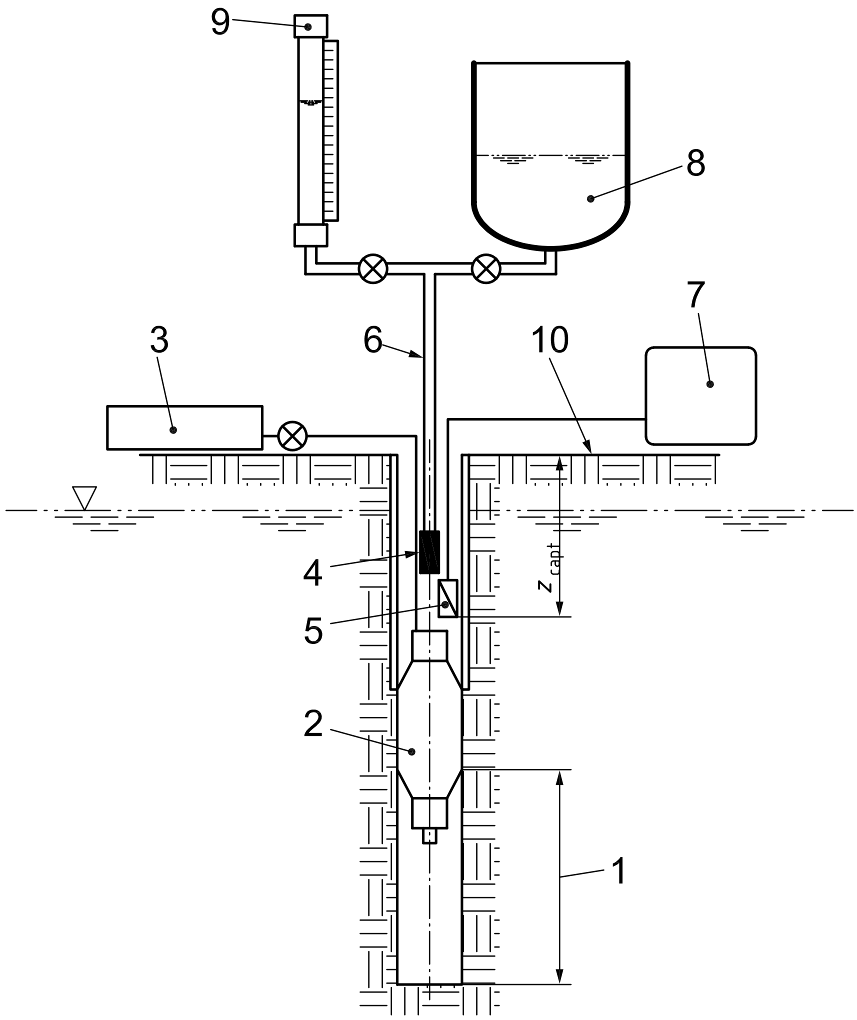
— pipes;

— single or double packer;

— shut-off valve in the pipe above the test section;

— pressure measuring and recording device in test section;

— data acquisition system.



Key

1 test section
2 inflatable packer
3 packer inflation device
4 isolating valve (bottom valve)
5 pressure and water temperature device
6 hydraulic delivery pipe
7 pressure and water temperature indicating and recording device
8 water reservoir
9 device for application of pressure pulse and measurement of compressibility
10 ground level

Figure 1 — Test equipment — Example

5 Test procedure

5.1 General

The principle of water permeability tests in a borehole using closed systems is based on an instantaneous change of the hydraulic head in a test section. The dissipation of imposed head is recorded as a function of time.

According to Figure 1, a volume of water is pressurized on a test section of a borehole closed off by one or more packers in order to determine dissipation of pressure with time.

The test can be carried out in a borehole of any orientation and diameter. The test section may be located above or below the groundwater level.

5.2 Installation of equipment

The test rod or tubing shall be installed into the borehole with the valve open.

The packer(s) shall be inflated or the sealing plug shall be installed.

5.3 Determination of the pre-test stabilized hydraulic head

5.3.1 Below water table

Below groundwater table, an initial measurement of the initial hydraulic head in the soil or rock to be tested shall be conducted:

— starting the recording system of the pressure in the test section;

— closing the isolating valve;

— monitoring the pressure, until the state of equilibrium is reached.

Monitoring shall be continued until the head variation Δh is less than 10 % of variation in initial head.

5.3.2 Above water table

In the case of a test in initially unsaturated soil, the soil around the test section shall be initially saturated before applying the pressure pulse. This saturation results in a major reduction of the suction in the vicinity of the test section.

The recommended value for the constant hydraulic head for this phase is approximately 1 m of water with respect to the ground level. The volume infiltrated during this phase shall be estimated and indicated in the test report. The duration of the infiltration phase depends largely on the permeability of the soil. Table 1 indicates the minimum duration of the saturation phase for various permeability ranges.

Table 2 — Duration of saturation phase and permeability ranges

Permeability coefficient k (m/s)		
$1,10^{-8}$	$1,10^{-9}$	$1,10^{-10}$
Duration of saturation phase (hours)		
3	10	20

After the saturation phase, stabilized hydraulic head is determined according to 5.3.1.

5.3.3 Application of the pressure pulse

With the isolating valve still in the closed position, the pressure variation shall be adjusted above the valve to be produced within the test section.

The amplitude of the pressure pulse shall be limited in order to avoid all risks of hydraulic fracturing of the soil within the test section. The hydraulic head increment above ground level shall be less than 30 % of the depth of the test section.

The pressure in the test section shall be measured and recorded every second.

The isolating valve shall be opened for 2 s to allow the pressure to apply in the whole system, and then it shall be closed.

The variation in volume ΔV_0 corresponding to the variation in pressure Δp_0 of the fluid in the measurement system and in the test section shall be recorded. The values of the compressibility parameters, ΔV_0 and Δp_0, shall be noted and used for the estimation of the compressibility of the whole system.

5.3.4 Measurement of the pressure change within the test section

The change in the excess pressure $\Delta p(t)$ produced in the system until $\Delta p(t)/\Delta p_0 \leq 0{,}10$ shall be recorded.

Before stopping the measurements, a second determination of the compressibility parameters shall be carried out as follows:

— with the isolating valve still in the closed position, a new pressure variation Δp_0 shall be adjusted to the test section;

— the isolating valve shall be opened for 2 s to allow the pressure to apply in the whole system, and then it shall be closed;

— the new variation in volume ΔV_0 corresponding to the new variation in pressure shall be determined by reading or recording;

— the compressibility coefficient shall be calculated from the parameters determined before and after the test (see Clause 6).

6 Test results

The test results are:

— the pressure as a function of time,

— the variation of volume at application of the pressure pulse at the beginning and at the end of the test.

7 Reports

7.1 Field report

7.1.1 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) record of installation of wells and piezometers according to ISO 22475-1;

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

f) installation record according to 7.1.2;

g) calibration record according to ISO 22282-1;

h) record of measured values and test results according to 7.1.3

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

7.1.2 Installation record

The installation record shall be attached to the summary log and include the following essential information, if applicable:

a) type of equipment;

b) packers (including inflation method);

c) pumps;

d) pressure sensors;

e) volume measuring device;

f) dates and times of test;

g) groundwater levels;

h) name and signature of the test operator.

7.1.3 Records of measured values and test results

The record of measured values and test results shall be attached to the summary log and include the following essential information, if applicable (see also Annex A):

a) name of the enterprise performing the test;

b) name of the client;

c) test date;

d) name and number of project;

e) number of borehole;

f) position and elevation of borehole;

g) diameter of the casing;

h) drilling method and drilling fluid used;

i) test depth;

j) length of the test section;

k) type of test with reference to this International Standard, i.e. ISO 22282-6;

l) weather conditions during the test;

m) elevation of the packer(s);

n) groundwater surface;

o) duration of saturation phase when relevant;

p) stabilized hydraulic head h_0;

q) test pressure as a function of time;

r) variation of volume and pressure for compressibility determination;

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

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

u) name and signature of the test operator.

7.2 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;

c) quality evaluation of the test execution and test results for the intended purpose of 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.

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Annex A
(informative)

Example of the record of measured values and test results

Water permeability tests in a borehole using closed systems according to ISO 22282-6							
Name of the enterprise				Date of test			
Name of the client				Name and number of the project			
Test method				Name of the borehole			
Climate condition during the test				Location of the project			
Still groundwater surface				Position and elevation of the borehole			
Still pressure				Diameter of the casing			
Test depth				Drilling method			
Elevation of the packer(s)				Soil and rock type			
Length of test section							
Pressure and time course							
Pressure/ head	Time	Pressure/ head	Time	Pressure/ head	Time	Pressure/ head	Time
Details of any unusual event or observation during the test							
Comments on observations or performed checks of importance for the interpretation:							
Name and signature of the test operator							

Annex B
(informative)

Interpretation of test results

B.1 Determination of compressibility coefficient

C_{app} is the apparent compressibility coefficient of the system obtained from:

$$C_{app} = \frac{\Delta V}{\Delta p} \cdot \frac{1}{V_w} \quad \text{namely} \quad C_{app} \cdot V_w = \frac{\Delta V_0}{\Delta p_0} \tag{B.1}$$

The product of $C_{app}.V_w$ is therefore measured directly, by determination of ΔV_0 and of the corresponding Δp_0, at the end of the last pressure pulse. It is this term which intervenes in the expression of α and β.

B.2 Determination of k, T and S with Cooper, Bredehoeft and Papadopulos method[3][5][6]

The following assumptions are made:

— the aquifer has an apparently unlimited superficial extent;

— the aquifer is homogeneous, isotropic (i.e. its permeability is the same for all directions), and of constant depth thickness;

— the confined and/or free groundwater surface is nearly horizontal;

— the pressure pulse causes no deformations in the ground or the test equipment;

— Darcy's law applies (laminar flow).

The hydraulic head variation within the test section during the test is expressed by:

$$\Delta h(t) = \Delta h_o \cdot \mathrm{F}\,(\alpha, \beta)$$

where

Δh_o	is the head variation applied at the start of the test;
F (α, β)	is given in the form of nomograms (Figures B.1 and B.2) or analytically.

with

$$\alpha = S.\frac{\pi \quad r_c^2}{V_w \; C^* \; \rho_w \quad g} \tag{B.2}$$

$$\beta = T.t.\frac{\pi}{V_w \; C^* \; \rho_w \quad g}$$

B.3 Determination of S and T

B.3.1 Graphical method

— Plot on a ratio chart the variation of $\Delta h(t)/\Delta h_0$ as a function of the time t, at a scale similar to that of the nomogram of Figure B.1;

— superpose by horizontal translation (parallel to the axis of abscises), until a good concordance is obtained between the test curve and one of the theoretical curves of the nomogram.

The best-fit curve allows the determination of α, either by taking the value corresponding to the curve, or by interpolating the values relative to two neighbouring curves. The value of S is then derived from this:

$$S = \alpha \frac{C^* V_w \rho_w g}{\pi r_c^2} \tag{B.4}$$

If the value found for α is greater than 0,1, the nomogram of Figure B.2 should be used for which $\Delta h(t)/\Delta h_0$ is plotted as a function of the product $\alpha\beta$.

— for the previous best-fit, a couple of values (t, β) are noted, namely one value of t on the test graph, and the corresponding value of β on the theoretical graph. These two values allow the calculation of the transmissivity T:

$$T = \frac{\beta}{t} \frac{C^* V_w \rho_w g}{\pi} \tag{B.5}$$

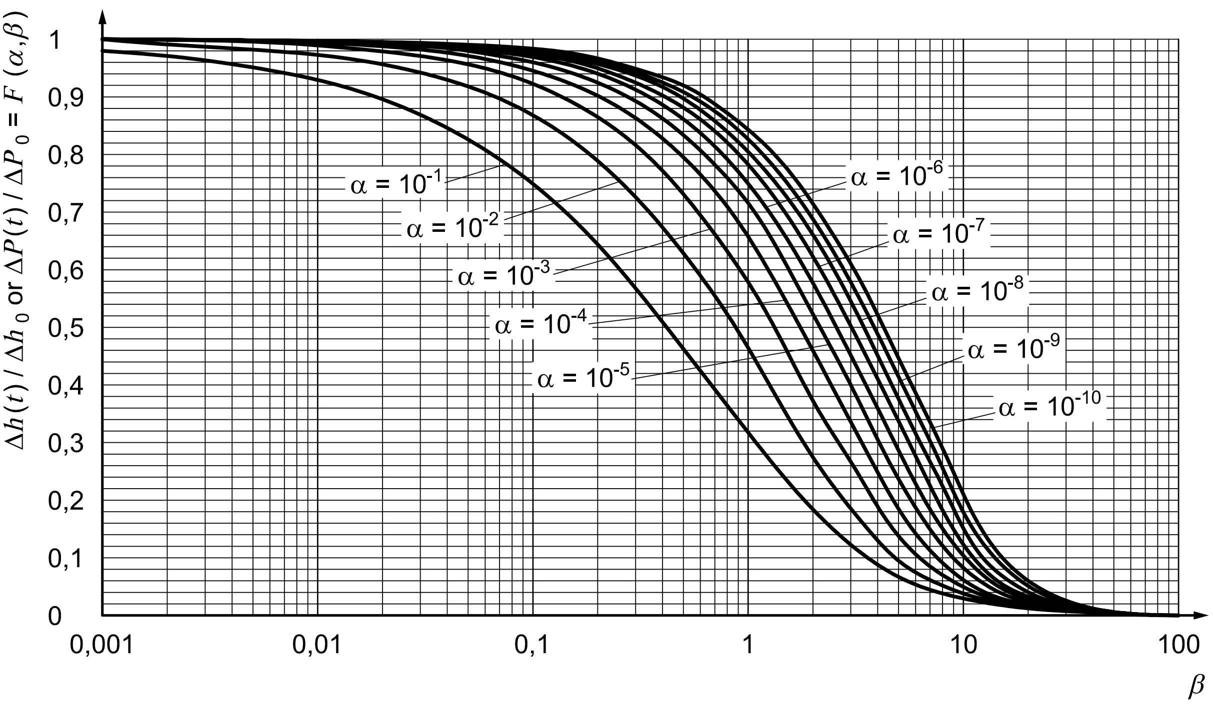


Figure B.1 — Curves of development of the variation in hydraulic head within the cavity as a function of α and β, for $\alpha \leq 0,1$

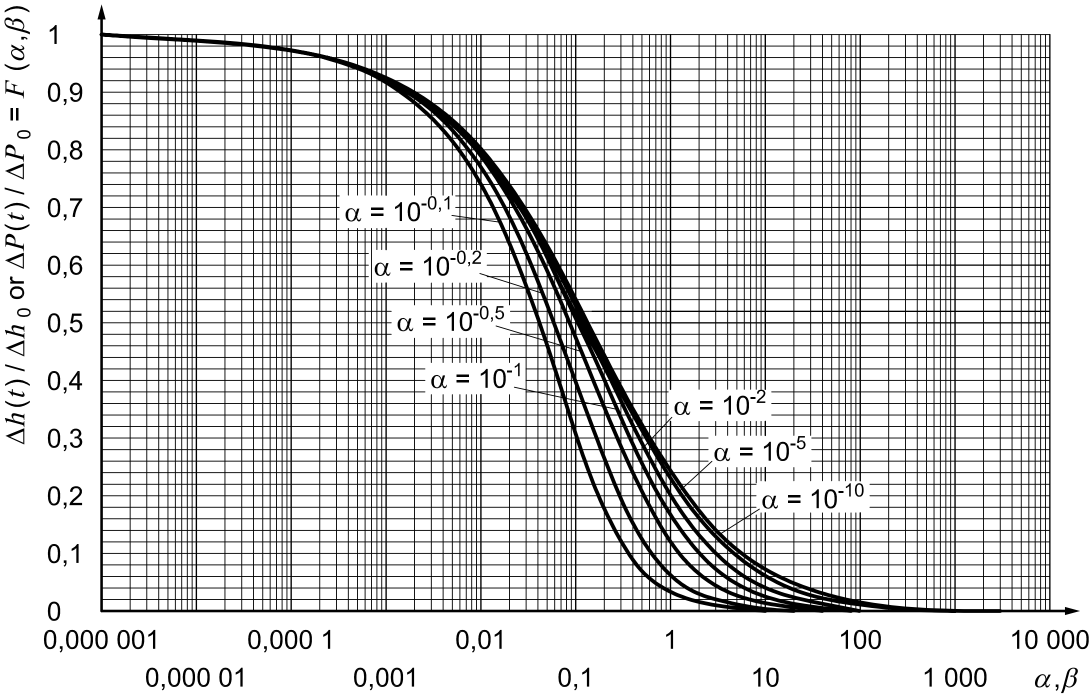


Figure B.2 — Curves of development of the variation in hydraulic head within the cavity as a function of α, β, for 0,1 ≤ α ≤ 10

B.3.2 Analytical method

B.3.2.1 General

The function F (α,β) is expressed by:

$$F(\alpha,\beta) = \frac{8\alpha}{\pi^2} \cdot \int_0^\infty \left(\exp\left(\frac{-\beta u^2}{\pi^2}\right) / \left[u \,.\, \Delta(u) \right] \right) du \tag{B.6}$$

with

$$\Delta(u) = \left[uJ_0(u) - 2\alpha J_1(u) \right]^2 + \left[uY_0(u) - 2\alpha Y_1(u) \right] \tag{B.7}$$

where

J_0, J_1, Y_0 and Y_1 are Bessel functions of order 0 and 1, respectively of the first and second type.

The calculation requires a software programme proceeding:

— either by a semi-automatic adjustment, defining in an *a priori* manner pairs of values for T and S, and comparing the calculated theoretical curve with the test curve, both plotted on the same graph; or

— by an entirely automatic adjustment. In this latter case, it should be ascertained that the values of both T and S have a plausible physical signification taking into account the nature of the land.

The test report shall specify the references of the software (name, version and supplier). The user shall constitute a validation dossier showing the accuracy of the calculations made compared to the analytical solution.

B.3.2.2 Calculation of the permeability coefficient

The permeability coefficient k is calculated from the transmissivity T derived from the interpretation of the test data:

$$k = T / L \tag{B.8}$$

where L is the length of the test section.

B.4 Determination of k with the velocity graph method[4]

For interpreting the pulse test data, an alternative method may be used. The pulse corresponds to an increase of hydraulic head Δh and an increase of volume of water DV_w that becomes available for injection into the packed-off interval. The volume DV_w corresponds to the volume of water rising by Δh inside an imaginary small pipe of diameter D (radius r_c) such as:

$$DV_w = \Delta h\ S_{inj} = \Delta h\ \pi\ d^2 / 4 = \Delta h\ \pi\ r_c^2 \tag{B.9}$$

The mass conservation equation, at the interface between the soil and the packed-off interval, relates the flow into the soil (Q_{soil} according Darcy's law) to the flowrate in the pipe (Q_{inj}).

$$Q_{inj} = -S_{inj}\left(dh / dt\right) = Q_{soil} = F\ k\ h \tag{B.10}$$

where

F is the shape factor of the injection zone;

Δh is the applied difference in hydraulic head;

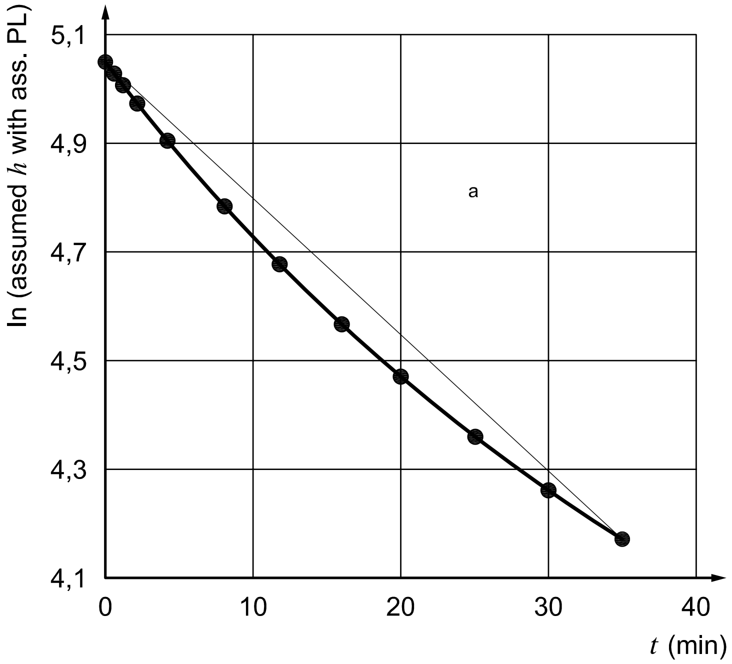
S_{inj} is the internal cross-section of the injection pipe.

Integration of Equation (B.10) yields the general equation of Hvorslev (1951):

$$\ln\left(h_1 / h_2\right) = -\left(kF / S_{inj}\right)\left(t_1 - t_2\right) = -k\left(F / S_{inj}\right)\left(t_1 - t_2\right) \tag{B.11}$$

where h_1 and h_2 are the differences in total heads at times t_1 and t_2 respectively.

The velocity graph method corresponds to the graphical exploitation and becomes a straight line (Figure B.3). It can indicate a piezometric error h_0 (Figure B.4). After correcting the h-values for the piezometric error, the graph of $\ln(h\text{-}h_0)$ becomes a straight line (Figure B.5).



[a] Curved graph due to an incorrect estimate of the piezometric level.

Figure B.3 — Graph of assumed h versus time t

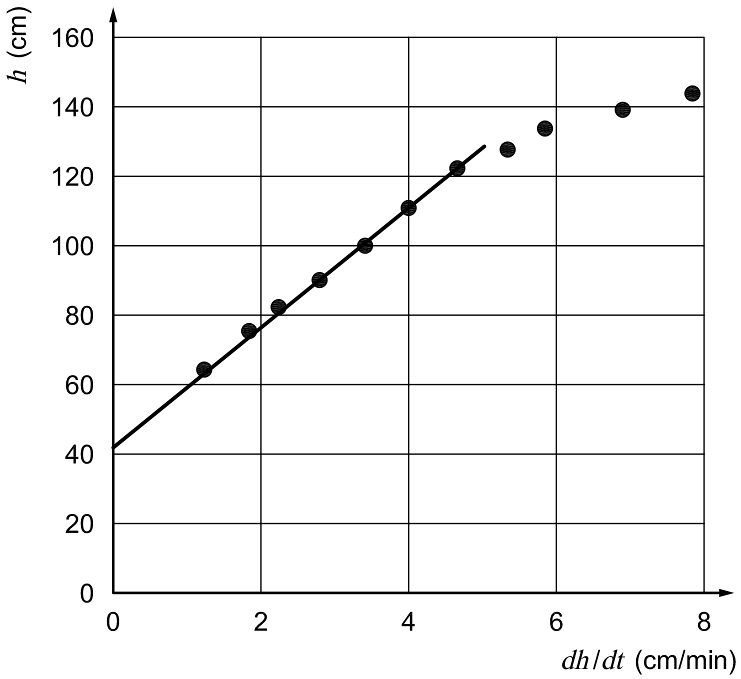
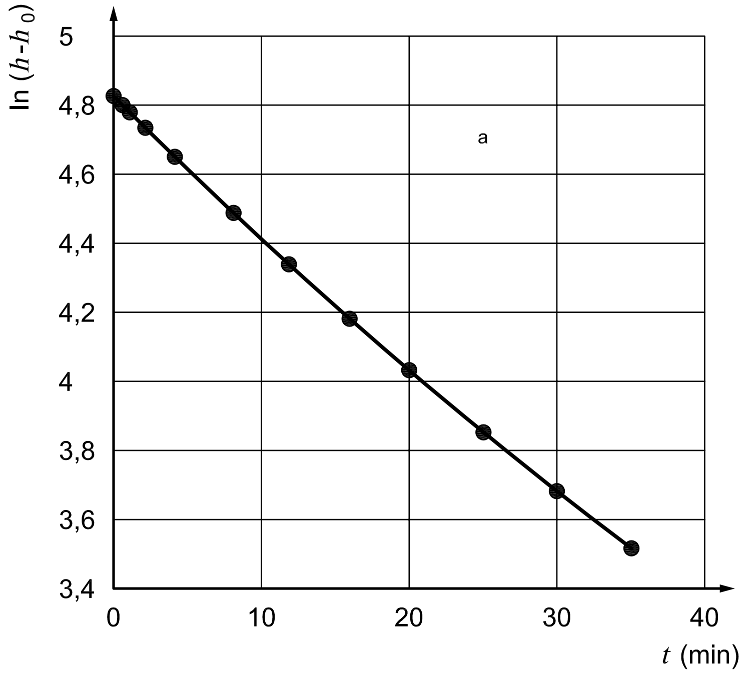


Figure B.4 — Velocity graph indicating that the estimated piezometric level is incorrect (example $h_0 = 42$ cm)



[a] Straight line after correction of the piezometric error.

Figure B.5 — Graph of real h = ass. $h - h_0$ versus t after correction for the incorrectly estimated piezometric level

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