INTERNATIONAL STANDARD

ISO 22282-3

First edition
2012-06-01

Geotechnical investigation and testing — Geohydraulic testing —

Part 3: Water pressure tests in rock

Reconnaissance et essais géotechniques — Essais géohydrauliques — Partie 3: Essais de pression d'eau dans des roches

Reference number
ISO 22282-3:2012(E)

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 22282-3 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*

Copyrighted material licensed to Dublin Institute of Technology by SAI Global (www.saiglobal.com), downloaded on 12 Jul 12 by Ann McSweeney.
No further reproduction or distribution is permitted. Uncontrolled when printed.

Geotechnical investigation and testing — Geohydraulic testing —

Part 3:
Water pressure tests in rock

1 Scope

This part of ISO 22282 specifies the requirements for water pressures tests (WPT) carried out in boreholes drilled into rock as part of geotechnical investigation and testing according to EN 1997-1 and EN 1997-2.

The tests are used to investigate the following:

— hydraulic properties of the rock mass, which are mainly governed by discontinuities;

— absorption capacity of the rock mass;

— tightness of the rock mass;

— effectiveness of grouting;

— geomechanical behaviour, e.g. hydrofracturing, hydrojacking.

Many effects of the geohydraulic tests are not only influenced by the ground itself, but stem from the testing procedure. Historically, the water pressure test was evaluated based on the assumption that the stationary behaviour was achieved. Recent advances in geohydraulics have shown that transient phenomena are often present. This part of ISO 22282 attempts to address the limitations of certain testing procedures without restricting the required equipment too stringently.

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

ISO 22282-1, *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 of 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 and the following apply.

3.1.1
water flow rate
Q
quantity of water that flows through the test equipment under certain test conditions per time unit

3.1.2
water take
w
water flow Q related to the effective test pressure p_T

3.1.3
single pressure step test
test with only one pressure step

NOTE This test is normally used to check the tightness of the rock or the tightening measures.

3.1.4
multiple pressure step test
test with more than one pressure step

NOTE This test is normally used to investigate the water take and the behaviour of the discontinuities, e.g hydrojacking, hydrofracturing, erosion and clogging.

3.1.5
steady state condition
test phase during which both pressure and flow rate are constant

3.1.6
Lugeon
unit of permeability

NOTE 1 lugeon unit equals 1 litre of water taken per metre of test length, per minute, at 10 bars pressure.

3.1.7
hydrofracturing
formation of new discontinuities by injection

3.1.8
hydrojacking
dilation of discontinuities by injection

3.1.9
flow meter
device used to measure the volume of water usage

3.2 Symbols

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

Table 1 — Symbols

Symbol	Designation	Unit
D	diameter of the test section	m
d	diameter of the pipe	m
g	gravity	m/s^2
h	hydraulic head	m
K	absolute permeability	m^2
k	permeability coefficient	m/s
L	length	m
L_p	length of the packer	m
m	slope	—
N	number of discontinuities	—
p	pressure	MPa
p_A	pressure above packer	MPa
p_B	pressure below packer	MPa
p_M	pressure at the top of the borehole	MPa
p_R	pressure loss	MPa
p_T	effective test pressure	MPa
p_p	pressure at the top of the hole (p_M)	MPa
p_0	press-in pressure	MPa
Δp	pressure loss between the pump and the test section	MPa
Q	flow rate	m^3/s
R	calculated radius of investigation	m
r_0	radius of the borehole	m
S	storage coefficient	—
T	transmissivity	m^2/s
t	time	—
W_m	mean width of joints	m
w	water take	m^3/s
α	shape coefficient of the test section	—
γ	density	kg/m^3
η	dynamic viscosity of the fluid	N s/m^2
ρ	water density	kg/m^3

4 Equipment

4.1 General

According to Figure 1 water shall be pumped into a test section of a borehole closed by one or more packers to determine the relationship between pressure and water take.

Depending on the type of testing, a single packer or double packer assembly is used (see Figure 1).

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

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

— pump, including water supply;

— pipes;

— single or double packer;

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

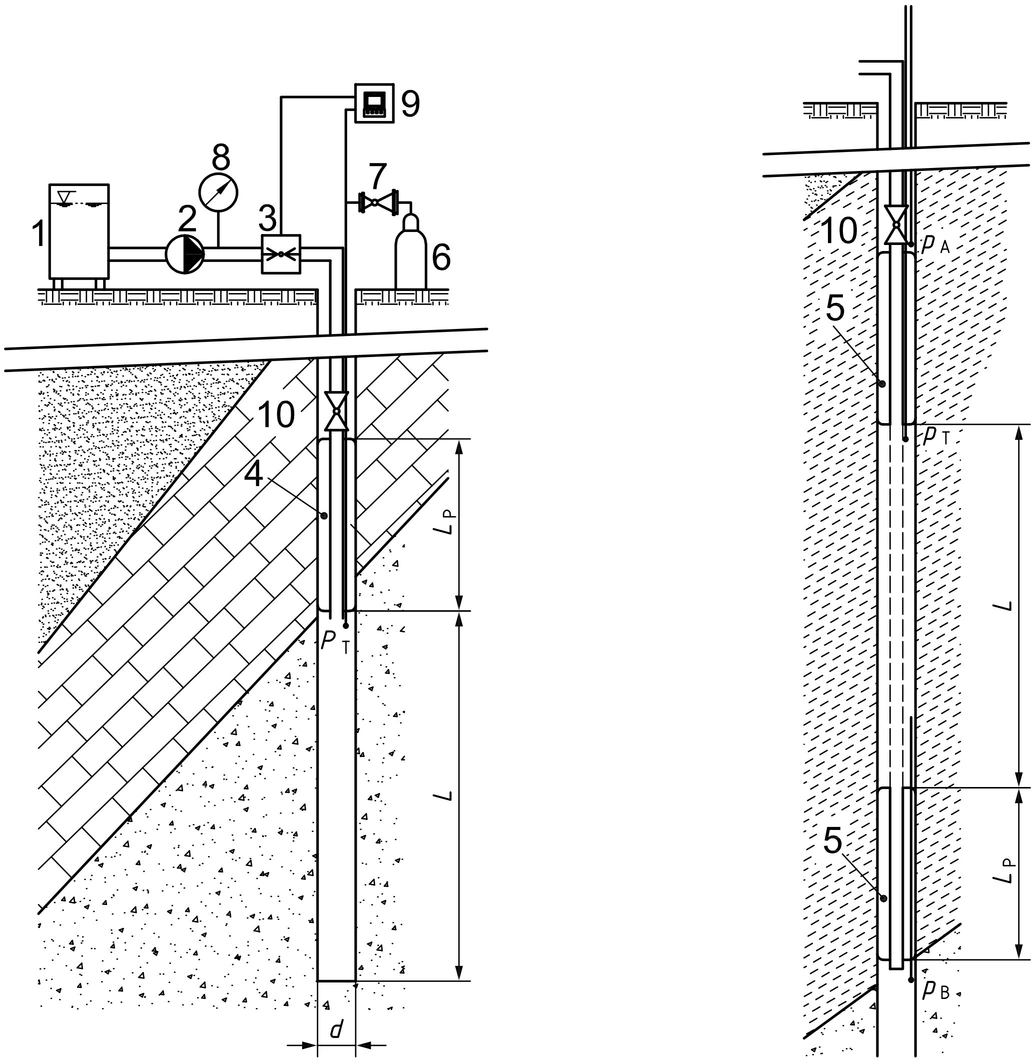
— pressure measuring device;

— measurements in test section with pressure transducer;

— control measurements at the surface with manometer;

— flow meter;

— data recording system.



a) With single packer

b) With double packer

Key

1 reservoir
2 pump
3 flow meter
4 single packer, inflatable
5 double packer, inflatable
6 compressed gas bottle
7 controller to regulate pressure inflating packers
8 manometer
9 data recording unit
10 shut-in valve
L length of test section
L_p length of packer
p_T effective test pressure
p_A pressure in borehole above packer (optional)
p_B pressure below double packer in borehole (optional)

Figure 1 — Example of equipment and set-up of water pressure test using single packer and double packer

The function of manometers and flow meters used shall be verified before each test. In cases of manual recording, two manometers and two flow meters of different ranges shall be installed. In cases of automatic recording, a visual control shall be available.

All devices shall be calibrated in accordance with ISO 22282-1. The pressure loss of the system shall be assessed.

4.2 Pump and supply

A pressure controlled pump shall be suitable to produce the pressure required by the local conditions.

NOTE A controlled pump typically has an output capacity of up to 150 l/min. A pump of 1,5 MPa is usually suitable.

In order to provide an oscillation-free water flow and pressure, a pump with an oscillation pressure of maximum ± 3 % or a pressure damper that is constant within ± 3 % shall be used.

The water shall be pumped through a flexible pressure hose or a pipe system to the test section.

4.3 Flow meter

The measuring range of the flow meters used shall be adapted to the quantity of water (water flow) Q expected to be absorbed. It may be necessary to install two flow meters covering different measuring ranges:

— if Q_{max} reaches the order of 100 l/min, a flow of 2 l/min shall be identifiable;

— if Q_{max} reaches the order of 10 l/min, a flow of 0,5 l/min shall be identifiable.

The accuracy of the flow meter shall be better than 3 % of the measuring range.

4.4 Packers

The effective length of the packer sleeve shall be at least 10 times the diameter of the borehole and at least 0,5 m. The pressure to expand the packer shall be at least 30 % higher than the maximum test pressure expected.

5 Test procedure

5.1 Test preparation

Before the water pressure test is carried out, the basic requirements according to ISO 22282-1 shall be considered.

In addition to the requirements in ISO 22282-1, the following test requirements shall be given:

— purpose of the test (e.g. estimation of permeability or groutablity);

— depth and sequence of test section;

— length of test section;

— application of testing pressure;

— number and duration of pressure stages, as ascending and descending pressure steps;

— maximum pressure allowable during the test.

After drilling, the borehole shall be cleaned by flushing prior to the execution of the test.

NOTE Drilling and flushing for cleaning of the borehole influences the groundwater in the rock mass.

The pressure in the test section shall be measured and recorded before starting the test while the packer is set and the water supply pipe is closed.

5.2 Test execution

During the test, readings shall be taken and recorded of the pressure p and the quantity of water (water flow) Q flowing through the flow meter over a certain time (Figure 2).

Pressure and flow rate shall be simultaneously adapted to the value of the pressure step.

A substantial increase of the flow rate compared to the pressure may be an indication of hydrofracturing or hydrojacking. A reduced increase of the flow rate compared to the pressure may indicate turbulent flow in the rock surrounding the boring.

The data shall be taken during each pressure step until the steady state condition is reached for both the pressure p and the water flow Q, i.e. the pressure and the water flow remain constant. Each step shall last at least 10 min. Where steady state conditions are not reached within 10 min, the measurements may be stopped when the variation is less than 5 % per minute or after 30 min.

The reading and recording of the data can be done either manually or automatically.

If automatic recording is used, the data shall be recorded at least every 5 s. If manual recording is used, the data shall be recorded at least every minute.

Manual readings generally require steady state conditions which can be reached after 10 min of water flow per pressure step.

For manual readings at the surface the length of the pipe shall be less than 30 m below the manometer in order to make a reasonable correction of the pressure loss in the pipe system.

If pressure transducers are used, an additional manometer at the surface should be used for checking.

Direct measurements in the test section should be done to avoid additional corrections.

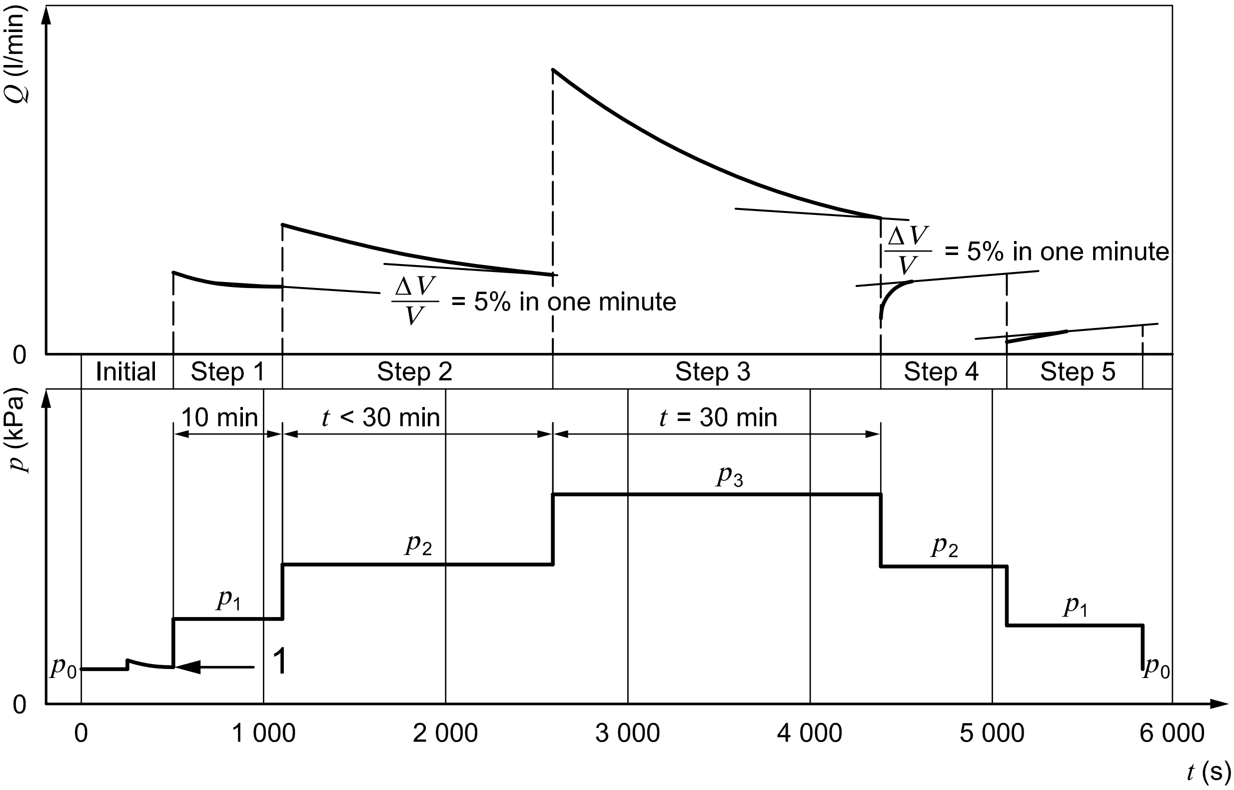
Leakages around and/or along the packer(s) can be detected by installation of pressure transducers above the upper packer (and below the lower packer). Changes in water pressure may indicate leakages.

Leakages around and/or along the packer shall be minimized. Examples of actions that can be taken are:

— applying a drilling technique producing a smooth and uniform surface of the borehole wall and constant borehole diameter;

— using a suitable flexible material for the packer sleeve allowing a tight contact with the borehole wall;

— using longer packer sleeves depending on the local conditions in case of a tight net of open joints.



Key

1 pressure in ground

Figure 2 — Example of a record of pressure and flow rate of a multi-stage water pressure test

The results of a water pressure test are the recorded pressure p and the water flow Q as a function of time.

Moreover, the recorded pressure p and the water flow Q shall be plotted on a graph (see Annex B).

The test results can be used for evaluating the permeability and groutability with steady state conditions (see Annex C) and transient conditions (see Annex D).

6 Reports

6.1 Field report

6.1.1 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 identification and description of rock according to ISO 14689-1;

e) installation record according to 6.1.2;

f) calibration record according to ISO 22282-1;

g) record of measured values and test results according to 6.1.3.

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

6.1.2 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 sensor;

e) flow rate measuring unit;

f) checking;

g) initial water pressure in the test section;

h) name and signature of the test operator.

6.1.3 Record 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) borehole inclination/orientation;

h) drilling method;

i) depth of top of test section;

j) depth of bottom of test section;

k) type of test with reference to this International Standard, i.e. ISO 22282-3;

l) weather conditions during the test;

m) elevation of the packer(s);

n) pressure used to inflate the packer(s);

o) test pressure as a function of time;

p) flow meter readings as a function of time;

q) flow rate as a function of time;

r) total water consumption;

s) length of the test section L;

t) time and duration of the test;

u) initial and final piezometric head in the test section;

v) pressure at the top of the hole p_M;

w) details of any unusual event or observations during the test;

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

y) name and signature of the test operator.

6.2 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) any corrections in the presented data;

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

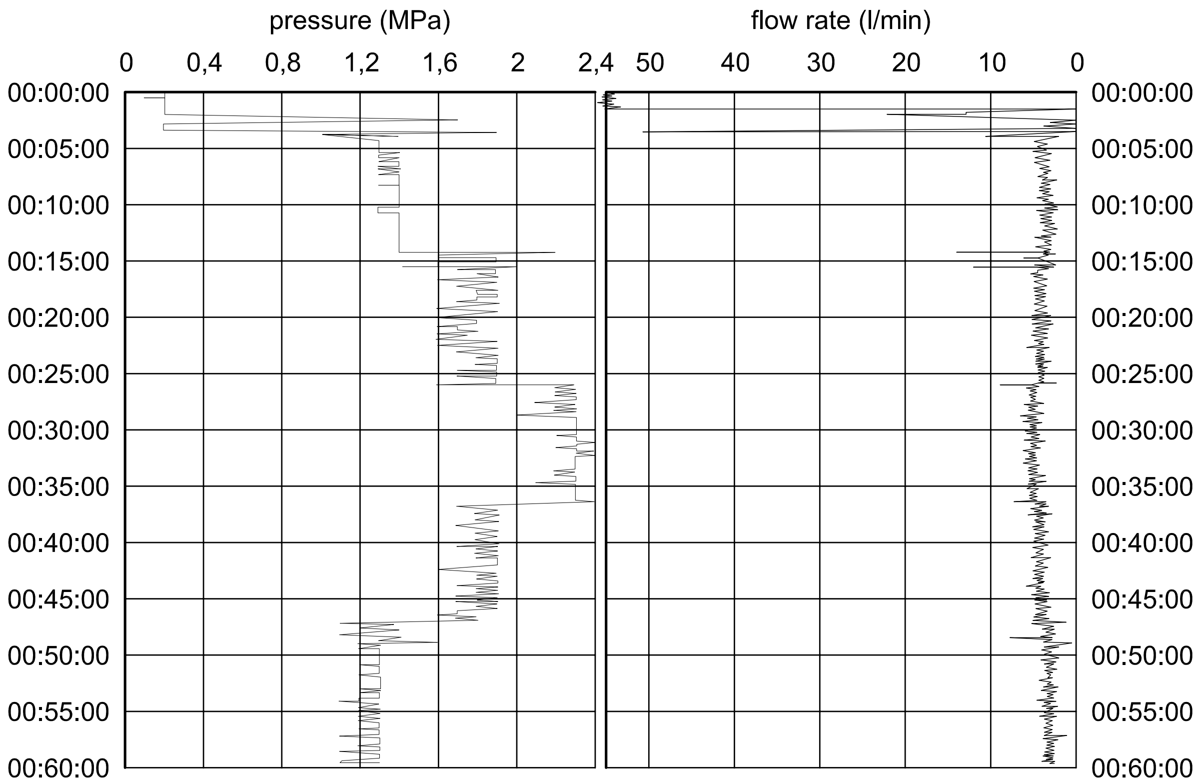
e) name and signature of the responsible expert.

Copyrighted material licensed to Dublin Institute of Technology by SAI Global (www.saiglobal.com), downloaded on 12 Jul 12 by Ann McSweeney.
No further reproduction or distribution is permitted. Uncontrolled when printed.

Annex A
(informative)

Record of measured values and test results of the water pressure test

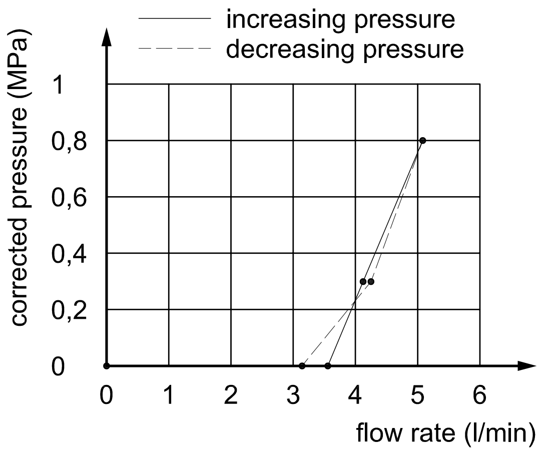
Report Water pressure test according to ISO 22282-3		(*Name of the enterprise*)	
Project		Client	
Location		Water surface	
Position (X/Y/Z)		Test section above	
Date		Test section below	
Borehole		Borehole diameter	
Test duration		Length of the packer	
Depth of the sensor		Rock type	

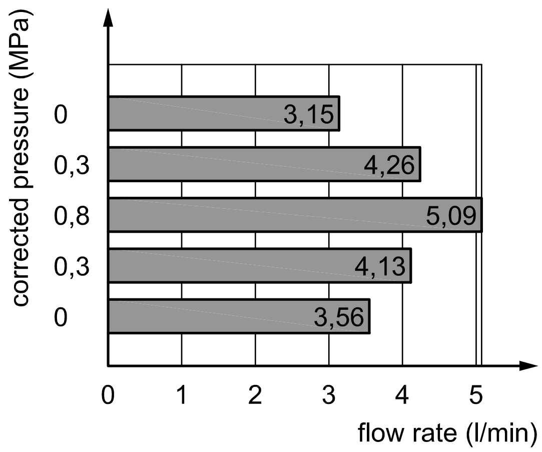


<u>*Comments*</u>

Report Water pressure test according to ISO 22282-3		(*Name of the enterprise*)	
Project		Client	
Location		Water surface	
Position (X/Y/Z)		Test section above	
Date		Test section below	
Borehole		Borehole diameter	
Test duration		Length of the packer	
Depth of the sensor		Rock type	

Measured Pressure (MPa)	**Duration (hh:mm:ss)**	**Water level (m)**	**Volume start (l)**	**Volume end (l)**	**Flow rate (l/min)**	**Pressure loss (MPa)**	**Corrected pressure (MPa)**	**Flow rate/ length of test section**





Comments

Results			
Flow rate at 1 MPa (l/min)		LUGEON	
Length of test section (m)			
Pressure (MPa)	Permeability coefficient (m/s)	Pressure (MPa)	Permeability coefficient (m/s)

Annex B
(informative)

Interpretation of test results

B.1 Methods of interpretation

Water pressure testing in civil engineering has developed primarily in an empirical way, mostly assuming steady state conditions. For the design of waste repositories and petroleum exploration, mathematically and physically more rigorous approaches have developed for testing of permeability as well as hydraulic fracturing of rock or hydraulic jacking of discontinuities. Also, the availability of economic pressure transducers and automated data acquisition systems has led to further development of the testing procedures. This part of ISO 22282 does not claim to be a textbook, however, with a brief review and comparison of the testing methods, attempts to indicate some shortcomings. The multi-step test may show some influence from the different stages proper, in particular during the ascending phase when the earlier stages have not reached complete steady state.

With the multi-step test the behaviour of the ground to water flow and pressure can be tested in a “trial-and-error” procedure. Many phenomena can also be detected with single-stage tests, in particular by also observing the changes in flow during application of the pressure or vice versa.

B.2 Interpretation of water pressure tests by pressure flow diagrams

During a water pressure test, the pressure and flow rate develop certain patterns that can be attributed to the behaviour of the flow in the ground. The flow rate is plotted as a function of the pressure steps (see Figure B.1). The procedure was proposed initially by Houlsby (1976, 1985, 1990) and was applied by Steiner et. al. (2006) to a dam project.

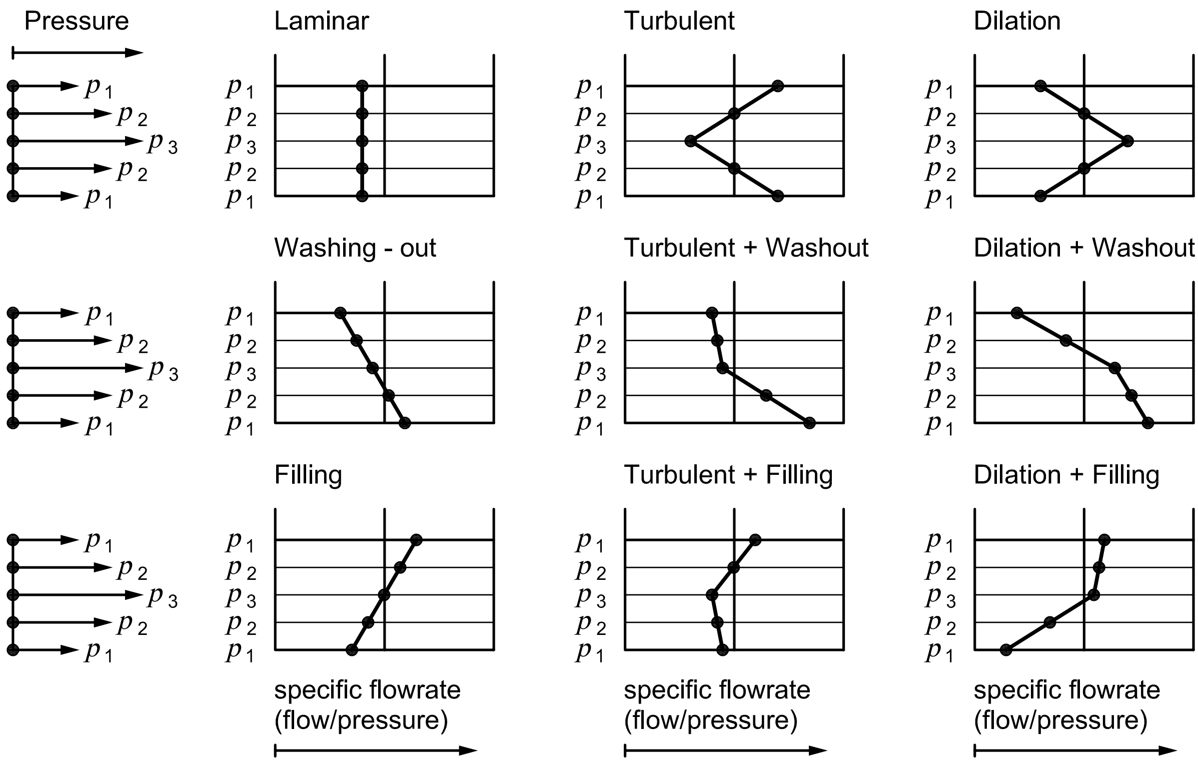


Figure B.1 — Pressure flow diagrams for multi-step tests

Properly executed and evaluated water pressure yields explainable p/Q-diagrams. Examples are given in Figure B.2.

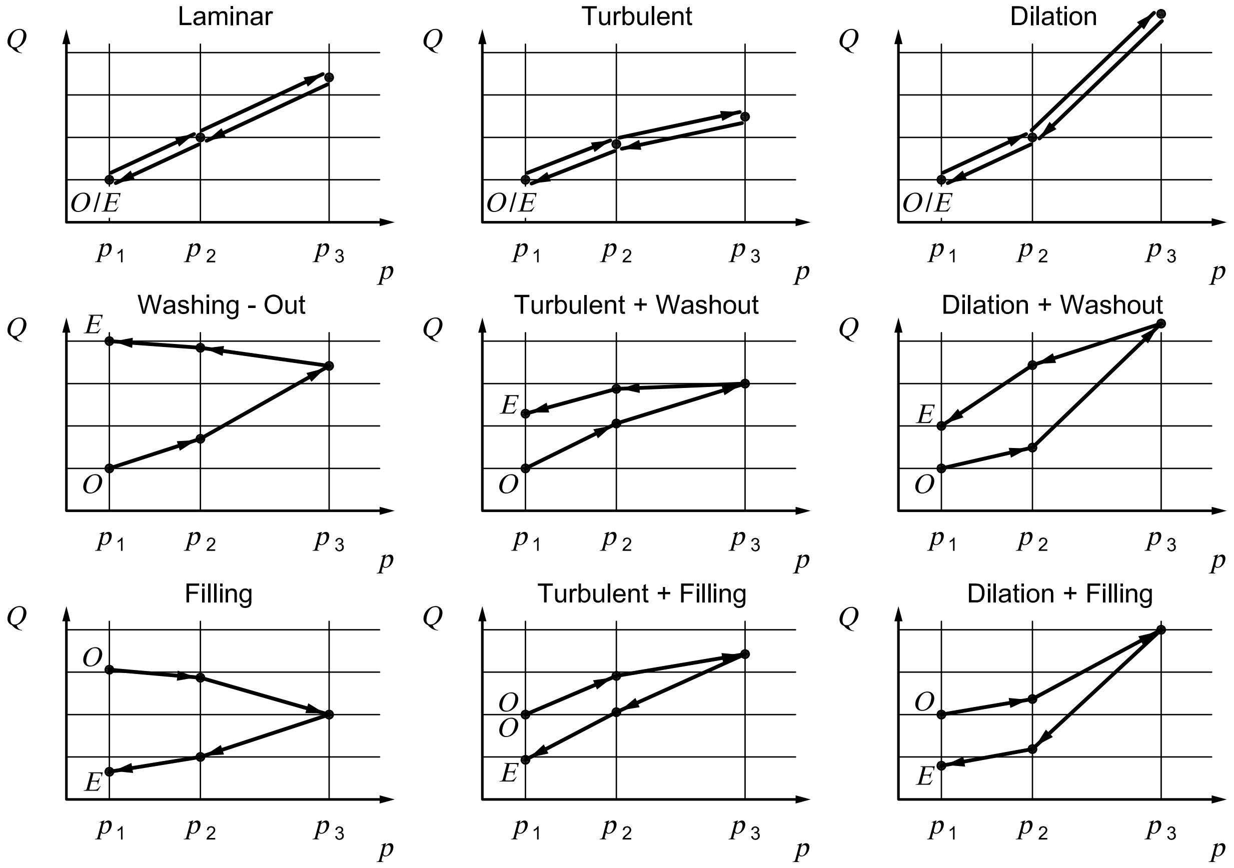


Figure B.2 — Variety of p/Q-diagram types

B.3 Examples of water pressure tests with continuous monitoring and conclusions

B.3.1 Water pressure test in strongly discontinuous rock

This multi-stage water pressure test was carried out in strongly discontinuous limestone. The applied pressure steps were small, in the order of one to two metres. The flow and pressure versus time and a p/Q diagram are shown in Figure B.3.

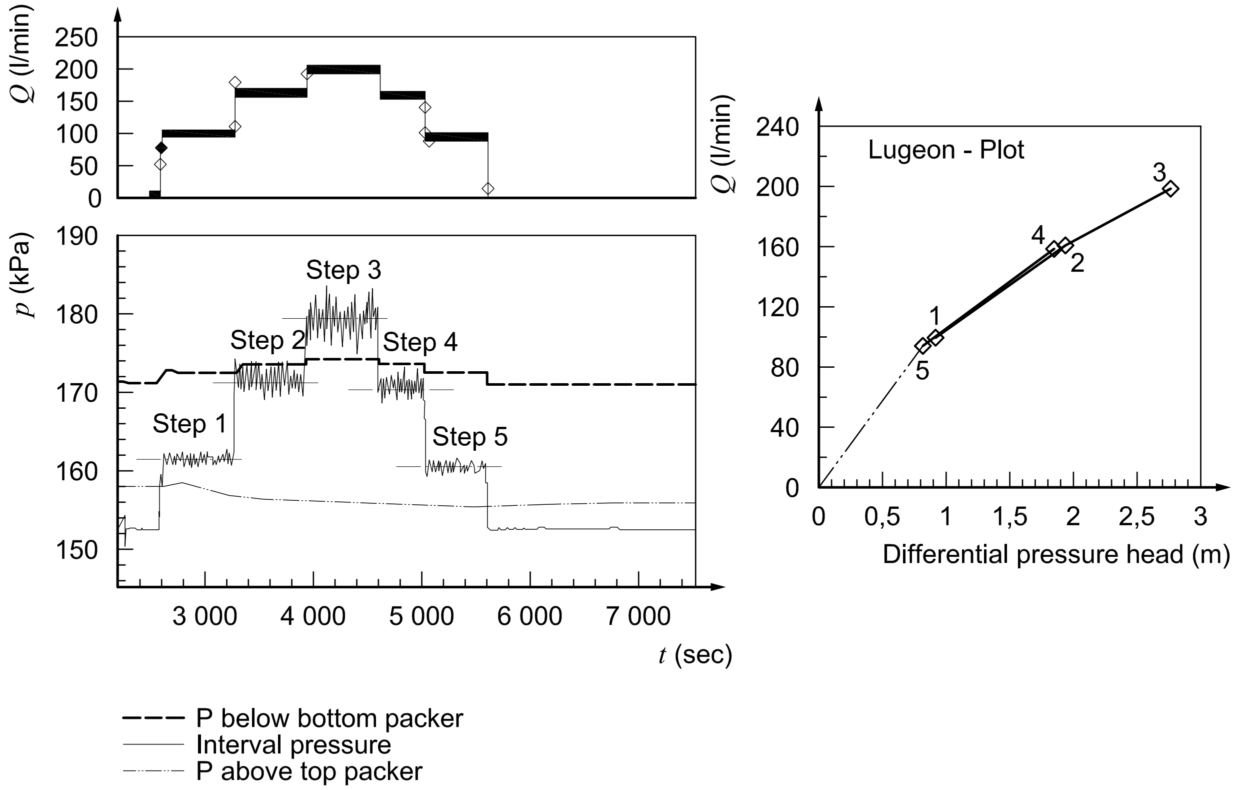


Figure B.3 — Water pressure test in strongly discontinuous rock

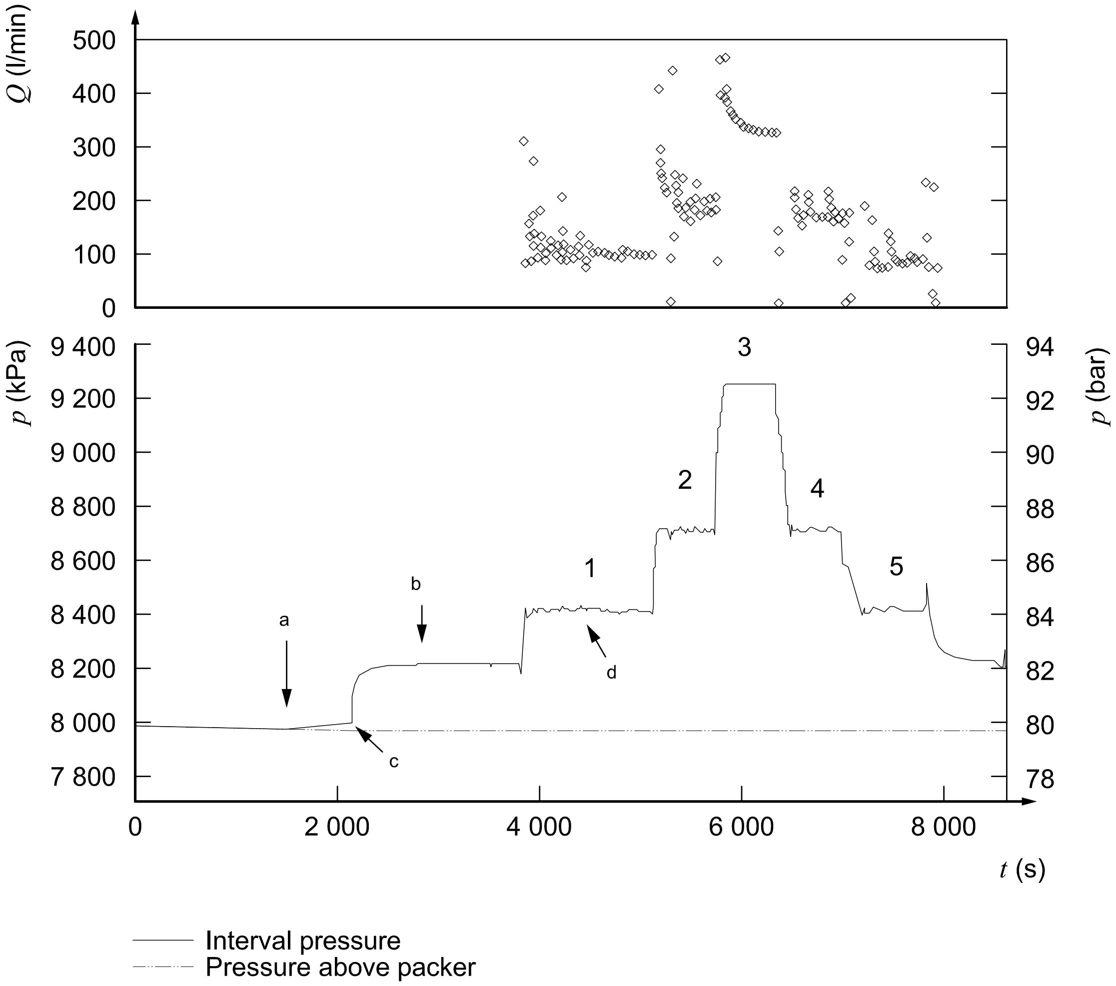
Table B.1 — Evaluation of water pressure tests in strongly discontinuous rock

Pressure stage	Δh m of water	Flow rate l/min	Computed Lugeon	Computed k-value (m/s)
1	0,9	90	10,000	$1,5 \cdot 10^{-3}$
2	2,0	160	8,000	$1,1 \cdot 10^{-3}$
3	2,7	200	7,400	$1,0 \cdot 10^{-3}$

The pump and piping system arrive at their limit with a flow rate of 200 l/min with a maximum applied pressure of only 2,7 m. The flow rate did not increase linearly with pressure. With the higher flow rate, more resistance in the ground developed by more turbulent flow. This is called pseudo skin. Around the well, higher resistance (pseudo-skin) has developed.

B.3.2 Water pressure test in less pervious rock

In Figure B.4 the results of a modified water pressure test are presented (Fisch & Ziegler, 2001). At the beginning of the test the pressure in the test section was determined. If the ambient pressure would not have been determined the test would have been carried out with a first pressure stage corresponding to the at rest hydraulic potential, thus resulting in practically no flow. The first pressure stage was carried out with an extended time (30 min). This allows for a transient evaluation of the pressure flow relation.



Key

a Packer expansion.

b Initial pressure recovery.

c Shut-in.

d Extended duration of first injection period.

Figure B.4 — Multi-stage water pressure test with measurements of initial pressure and extended measurement interval (example)

The complete recordings of pressure and flow versus time for the various stages of the multi-stage test show smaller flow rates for the descending stages with respect to the corresponding ascending ones. This effect is not due to increasing skin effect, i.e. a clogging of the discontinuities; rather it is due to a transient flow regime. The earlier pressure steps had not reached a steady state and influence the decrementing pressure steps.

B.3.3 Limits of interpretation

The interpretation of the water pressure test is based mainly on continuum assumption or at least the assumption that the features are equally distributed over the test section or the section of interpretation.

The hydraulic conductivity is governed by the opening of discontinuities and their distribution. The hydraulic conductivity and the transmissivity are not a material property, but depend on the geometry of interpretation. For example, if we assume a rock with a set of discontinuities of 0,1 m (100 mm) width the result is different by an order of magnitude, if the test section is 0,1, 1,0, or 10 m long and the remaining section is assumed as impervious. The relative hydraulic conductivity is 1 for a test section of 0,1 m, one tenth for 1 m and one hundredth for 10 m long test section. The distribution of discontinuities and their opening width are important parameters and have to be considered in the interpretation.

Annex C
(informative)

Evaluation of test results assuming stationary conditions

The permeability of a set of joints can be determined if the orientation of the borehole is approximately perpendicular to that set of joints and a radially symmetrical flow around the borehole can be assumed. For the evaluation, a laminar, stationary flow is assumed. The evaluation of the test results shown in Figure C.1 shall be based on the pair of parameters Q/p_0 on the tangent. The mean permeability of the rock mass k in the plane of the set of joints i cut vertically by the borehole can be determined by Equation (C.1):

$$k_i = \frac{Q}{2 \cdot L \cdot h \cdot \pi} \cdot \ln \frac{R}{r_o} \tag{C.1}$$

where

- L is the length of the test section (m);
- R is the calculated radius of investigation (influence) of the test (m) (for practical purposes: 10 m $\leq R \leq$ 100 m);
- r_o is the radius of the borehole (m);
- k_i is the permeability of rock mass calculated in m/s;
- Q is the flow rate at the end of the test expressed in m^3/s;
- h is p_0/γ_w = hydraulic head in test section (m);
- p_o is the injection pressure (MPa);
- γ_w is the density of water.

Equation (C.1) is from Rissler (1984) and corresponds to the equation in Earth Manual (USBR, 1990).

Copyrighted material licensed to Dublin Institute of Technology by SAI Global (www.saiglobal.com), downloaded on 12 Jul 12 by Ann McSweeney.
No further reproduction or distribution is permitted. Uncontrolled when printed.

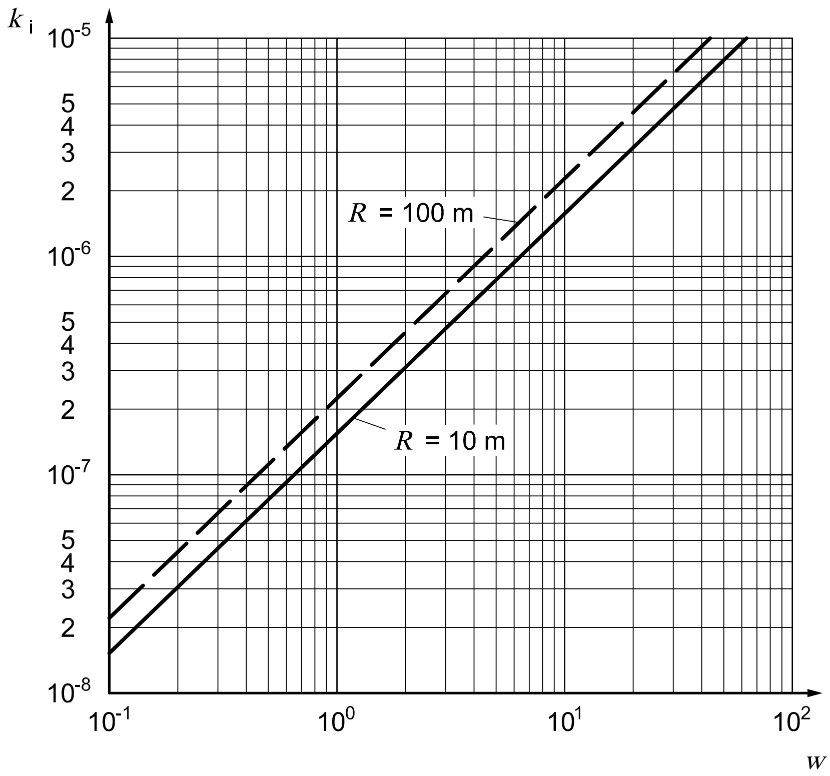


Figure C.1 — Examples of the relationship between k_i in m/s **and water take w in** l/[min × m × (1,0 MPa)]

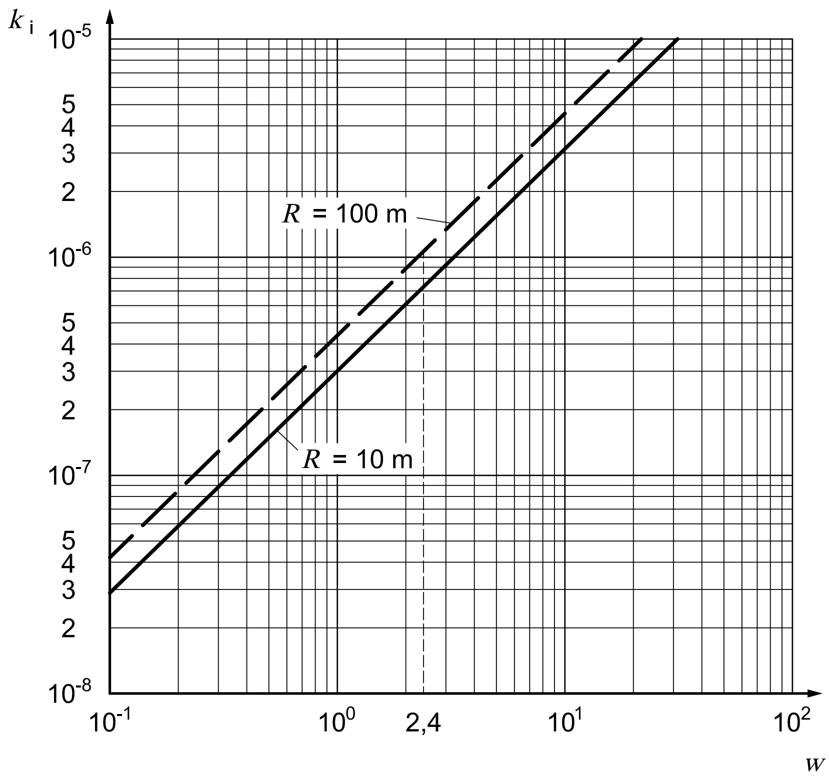


Figure C.2 — Examples of the relationship between k_i in m/s **and water take w in** l/[min × m × (0,5 MPa)]

When the dimensions l/min for Q and 1,0 MPa or 0,5 MPa for p_o normally used in the field are applied, k_i (in m/s) for p_o in 1,0 MPa is:

$$k_i = \frac{10^{-6}}{12\pi} \cdot \ln\frac{R}{r_o} \cdot \frac{Q}{d \cdot p_o} = \frac{10^{-6}}{12\pi} \cdot \ln\frac{R}{r_o} \cdot w \tag{C.2}$$

and for p_o in 5 MPa:

$$k_i = \frac{5 \cdot 10^{-5}}{12\pi} \cdot \ln\frac{R}{r_o} \cdot \frac{Q}{d \cdot p_o} = \frac{5 \cdot 10^{-5}}{12\pi} \cdot \ln\frac{R}{r_o} \cdot w \tag{C.3}$$

As the borehole radius used hardly affects the result, the graphs in Figures C.1 and C.2 may be used for the evaluation of a medium borehole diameter (2 r_o = 76,2 mm). Figure C.1 applies for a water take w in l/[min × m × (1,0 MPa)] and Figure C.2 for a water take w in l/[min · m · (0,5 MPa)].

Annex D
(informative)

Evaluation of constant head and constant rate tests

D.1 General principle

Injection and withdrawal tests with constant applied pressure or constant flow rates are used with packer tests. A constant head corresponds to the first stage of a multi-stage test. Constant rate tests usually require a shorter observation time than constant head tests, since wellbore storage effects only have an influence during a few seconds or fractions of a second. The pressure in the test section remains constant thereafter.

D.2 Constant head tests

With the Jacob-Lohman (1952) method the inverse flow rates are plotted versus log time starting with initiating the constant head test (Figure D.1)

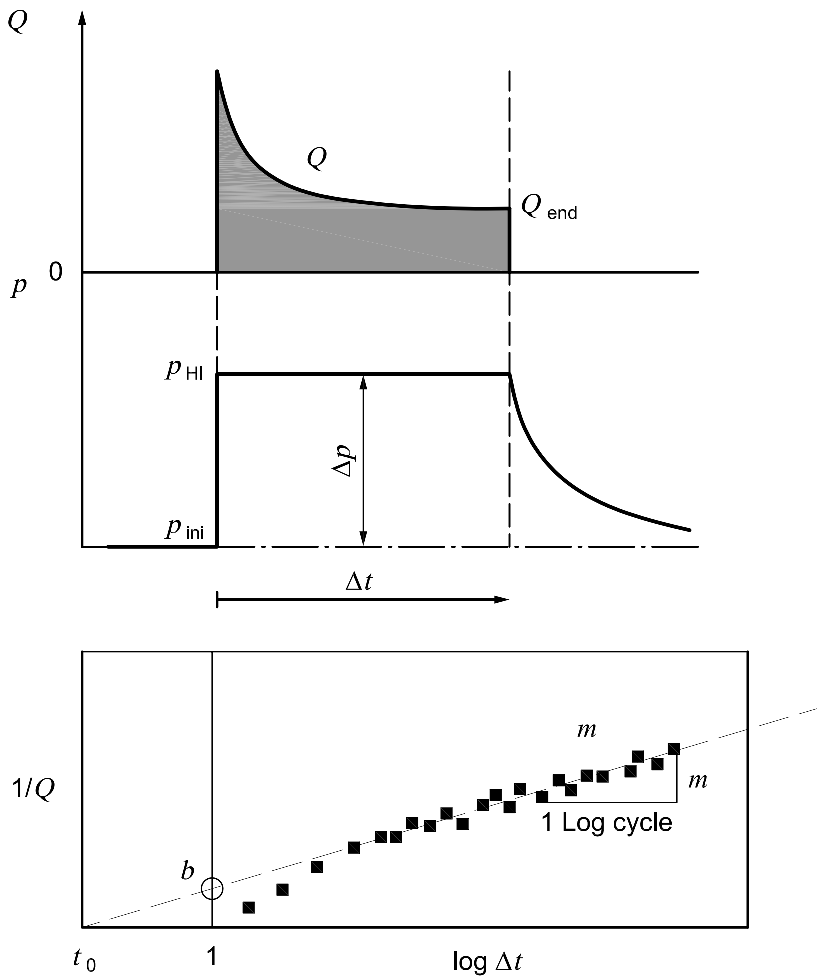


Figure D.1 — Semi-logarithmic plot of constant head test

Table D.1 — Equations for constant head and slope of straight line

$T = \frac{0{,}183}{" \; h \cdot m}$	[m²/s]	Transmissivity
$S = \frac{2{,}25 \cdot T \cdot t_o}{r_w^2}$	[-]	Storage coefficient
$t_o = 10^{-b/m}$	[s]	Intersection with time axis for 1/q = 0
$t_D = \frac{T \cdot \Delta t}{r_o^2 \cdot S}$	[-]	Dimensionless time

where

- Q is the flow rate [m³/s];
- m is the slope of the fitted line [m pressure head/log-cycle];
- r_o is the radius of well or borehole;
- t_o is the time on the abscissa ($\Delta h = 0$) with the fitted line;
- b is the Δh - value of the intersection of the values ($t = 1$, log $\Delta t = 0$) with the fitted line.

D.3 Constant rate tests

The changes of pressure head from the start of the constant rate test are plotted versus logarithm of time. The slope m of the straight line part of the test data is determined. From flow rate and the slope m the transmissivity and other parameters are computed (Table D.3).

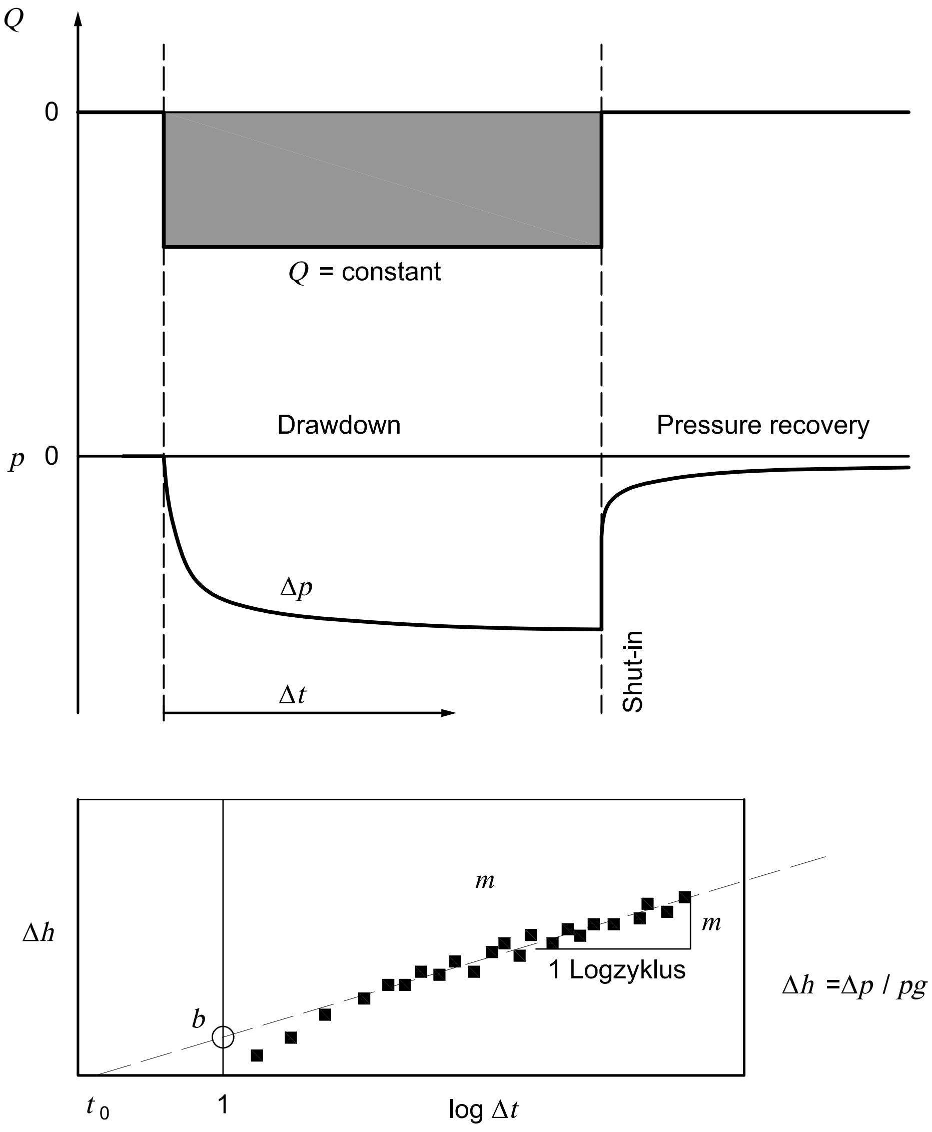


Figure D.2 — Semi-log plot for constant-rate test

Table D.2 — Equations for constant rate and slope of straight line

$T = \frac{2{,}30 \cdot Q}{4 \cdot \pi \cdot m} = \frac{0{,}183 \cdot Q}{m}$	[m²/s]	Transmissivity
$S = \frac{2.25 \cdot T \cdot t_o}{r_o^2}$	[-]	Storage coefficient
$t_o = 10^{-b/m}$	[s]	Intersection with time axis for $\Delta h = 0$
$t_D = \frac{T \cdot \Delta t}{r_o^2 \cdot S}$	[-]	Dimensionless time

where

Q is the flow rate [m³/s];

m is the slope of the fitted line [m pressure head/log-cycle];

r_o is the radius of well or boring;

t_o is the time on the abscissa ($\Delta h = 0$) with the fitted line;

b is the Δh - value of the intersection of the values ($t = 1$, log $\Delta t = 0$) with the fitted line.

Annex E
(informative)

Groutability

E.1 Groutability and other derived characteristics of rock masses

Basic consideration packer tests are a tool to assess the need of grouting the rock mass for dam foundations, tunnels and other rock construction for making it more impermeable. Lugeon (1933) had introduced an empirical criterion for hard rock where no grouting was necessary. This was the case when the water take was 1 l/min per metre of borehole at 10 bar (1 MPa) pressure. The International Society for Rock Mechanics has published a report by a working group that deals extensively with the topic (Widmann, Coordinator, 1995).

E.2 Characteristics of grouting and injecting materials

Grouting materials have characteristics that are different from water. Some grouts may be considered as fluids of different viscosity than water (silicates, acrylates, other chemical grouts) or they are suspended solids of various grain size suspended in water, thus also called suspensions (cement grout, microfine cement).

The basic relation between transmissivity, hydraulic conductivity and absolute permeability are given in Table E.1

Table E.1 — Relation between hydraulic characteristics for fluids

Index values	Symbol	Units	Transmissivity	Hydraulic conductivity	Absolute permeability
Transmissivity	T	m^2/s	—	$K\ L$	$(k/L)\ (\gamma/\eta)$
Hydraulic conductivity	k	m/s	T/L	—	$K\ (\gamma/\eta)$
Absolute permeability	K	m^2	$(T/L)\ (\eta/\gamma)$	$k\ (\eta/\gamma)$	—

L is the length of test section in borehole (m);

η is the dynamic viscosity of the fluid (N s/m^2);

γ is the density of the fluid(kg/m^3).

Grout and water have different viscosities. The hydraulic conductivity of the ground for grout can be evaluated with Equation (E.1) (ISRM, 1996).

$$k = \frac{T}{N \cdot W_m} \cdot \frac{\gamma_w}{\eta_w} \cdot \frac{\eta_G}{\gamma_G} \tag{E.1}$$

where

T is the transmissivity;

N is the number of discontinuities per metre;

W_m is the width of joints (m).

Indices refer to w = water, G = grout.

E.3 Effect of hydraulic jacking and fracturing

With sufficient pressure, the existing discontinuities in the rock mass may be opened or widened and the hydraulic conductivity and permeability may change substantially. During grouting it may be necessary to pass this limiting pressure in order to be able to inject some grout in the discontinuities and fill them. When releasing the grouting pressure the discontinuities will close and the ground should become more impervious. However, the rock mass must not be indiscriminately jacked or new fractures created. It is possible that another rock mass may become more pervious.

Copyrighted material licensed to Dublin Institute of Technology by SAI Global (www.saiglobal.com), downloaded on 12 Jul 12 by Ann McSweeney.
No further reproduction or distribution is permitted. Uncontrolled when printed.

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] BRASSINGTON, F.C. and WALTHALL, S. (1985): Field techniques using borehole packers in hydrogeological investigations. *Quarterly Journal of Engineering Geology*, **18**, pp. 181-193, London

[4] FISCH, H.R. & Ziegler (2001): *Alternatives Verfahren für die Durchführung von WD (Lugeon) — Tests*. Wasserwirtschaft Jg. 91, Nr. 7/8

[5] HEITFELD, K.H. and KOPPELBERG, W. (1981): *Durchlässigkeitsuntersuchungen mittels WD-Testen*. Zbl. Geol. Paläont., Teil 1, Heft 5/6, Stuttgart

[6] HOULSBY, A.C. (1976): Routine Interpretation of the Lugeon Water Test, *Quarterly Journal of Engineering Geology*, The Geol. Society, London, England, pp. 303-313

[7] HOULSBY, A.C. (1985):Cement grouting: water minimising practices. Dam Grouting, ASCE, Denver. pp 34-75

[8] HOULSBY, A.C (1990): *Construction and Design of Cement Grouting, A guide to grouting in rock foundations*, Wiley-Interscience

[9] JACOB, C.E., and LOHMAN, S.W. (1952): Nonsteady flow to a well of constant drawdown in an extensive aquifer, *Transactions, American Geophysical Union*, vol. 33, no. 4, pp. 559-569

[10] KOPPELBERG, W. (1986): Numerische und statistische Untersuchungen zur Durchlässigkeit geklüfteter geologischer Körper und ihrer Bestimmung durch Wasserdruckversuche. - Mitt. Ing.-u. Hydrogeol. Heft 23, Aachen

[11] LUGEON, M. (1933): *Barrages et Géologie*. Dunod, Paris

[12] PEARSON, R. and MONEY, M.S. (1977): Improvements in the Lugeon or Packer Permeability Test. *Quarterly Journal of Engineering Geology*, **10**, London

[13] RISSLER, P. (1984): Empfehlung Nr. 9 des Arbeitskreises 19 – Versuchstechnik Fels der Deutschen Gesellschaft für Erd- und Grundbau e.V. Wasserdruckversuch in Fels, Bautechnik 194, No. 4, S. pp. 112-117

[14] SCHETELIG, K., SCHENK, V. and HEYBERGER, W. (1978): Neues Meßverfahren für die Durchführung von Wasserabpressungen. - Veröff. 3. Nat. Tagung Felsmech.; Aachen

[15] SCHNEIDER, H.J. (1987): Durchlässigkeit von geklüftetem Fels - eine experimentelle Studie unter besonderer Berücksichtigung des Wasserabpressversuches. - Mitt. Ing.- u. Hydrogeol. 26, Aachen

[16] SNOW, D.T. (1986): Rock fracture spacing, openings, and porosities. *Proc, Am. Soc. Civ. Eng. J. Soil Mech. and Found. Div.*, American Society of Civil Engineers, **94**, 73-91, New York

[17] STEINER, W., THUT, A., FISCH, H.R.; GYSI, H.J. (2006) Geohydraulische Versuche im Fels (Geohydraulic Tests in Rock) Forschungsauftrag 2001/505 auf Antrag der Fachkommission 5 der VSS, Zürich, Report No. 1159

[18] STOBER, I. (1986): Strömungsverhalten in Festgesteinsaquiferen mit Hilfe von Pump- und Injektionsversuchen. - Geol. Jahrbuch, Reihe C, Heft 42, BGR/GLA; E. Schweizerbart'sche Verlagsbuchhandlung, Hannover, Stuttgart

[19] 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)

[20] WIDMANN, R. Coordinator, ISRM (1995): Rock Grouting, Final Report, Commission on Rock Grouting, International Society for Rock mechanics, Lisbon, *International Journal of Rock Mechanics & Geomechanics Abstracts*, Elsevier, Vol. 33, No. 8, pp. 803 -847

Copyrighted material licensed to Dublin Institute of Technology by SAI Global (www.saiglobal.com), downloaded on 12 Jul 12 by Ann McSweeney.
No further reproduction or distribution is permitted. Uncontrolled when printed.

ICS 93.020

Price based on 26 pages

Copyrighted material licensed to Dublin Institute of Technology by SAI Global (www.saiglobal.com), downloaded on 12 Jul 12 by Ann McSweeney.
No further reproduction or distribution is permitted. Uncontrolled when printed.