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Geotechnical investigation and testing — Geothermal testing — Determination of thermal conductivity of soil and rock using a borehole heat exchanger

Reconnaissance et essais géotechniques — Essais géothermiques — Détermination de la conductivité thermique des sols et des roches dans les sondes géothermiques

Reference number
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Contents

Page

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

ISO 17628 was prepared by European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical investigation and testing*, in collaboration with ISO Technical Committee ISO/TC 182, *Geotechnics*, Subcommittee SC 1, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Geotechnical investigation and testing — Geothermal testing — Determination of thermal conductivity of soil and rock using a borehole heat exchanger

1 Scope

This International Standard specifies requirements for the Geothermal Response Test (GRT). This test comprises the *in situ* determination of the thermal conductivity in saturated and unsaturated soil and rock in a heat exchanger installed in a borehole. For this test, liquid heat transfer media not subjected to phase changes are used.

The thermal conductivity is an important parameter used in the design of thermal storage and thermal exchange systems.

A Geothermal Response Test measures the temperature response to a thermal energy forcing of a borehole heat exchanger (BHE) or the extraction of thermal energy from a borehole. The temperature response is related to the thermal parameters of the ground and borehole filling material, such as thermal conductivity and borehole resistivity, and is therefore used to obtain estimated or derived values of these parameters.

This International Standard applies to heat exchangers installed in vertical or inclined boreholes with length up to e.g. 400 m and with a diameter of up to 200 mm.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 22475-1, *Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for execution*

EN 16228-1, *Drilling and foundation equipment - Safety - Part 1: Common requirements*

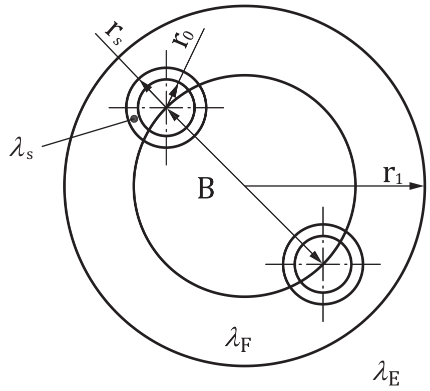
EN 16228-2, *Drilling and foundation equipment - Safety - Part 2: Mobile drill rigs for civil and geotechnical engineering, quarrying and mining*

3 Terms and definitions

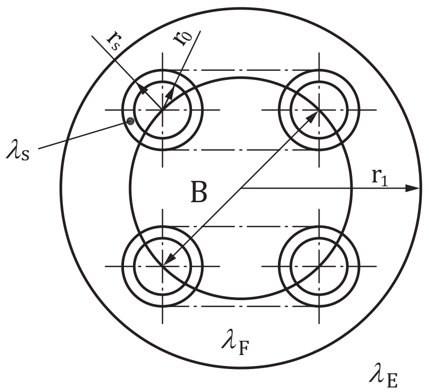
For the purposes of this document, the terms and definitions given in ISO 22475-1 and the following apply.

3.1
borehole heat exchanger
BHE
one or two U-tubes or one coaxial tube in a borehole through which the exchanger fluid circulates

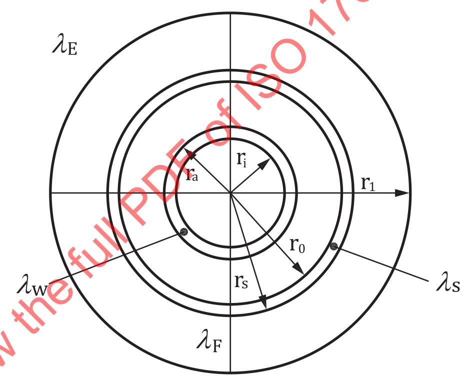
Note 1 to entry: See Figure 1 and Figure 2.



a) single U-tube



b) double U-tube

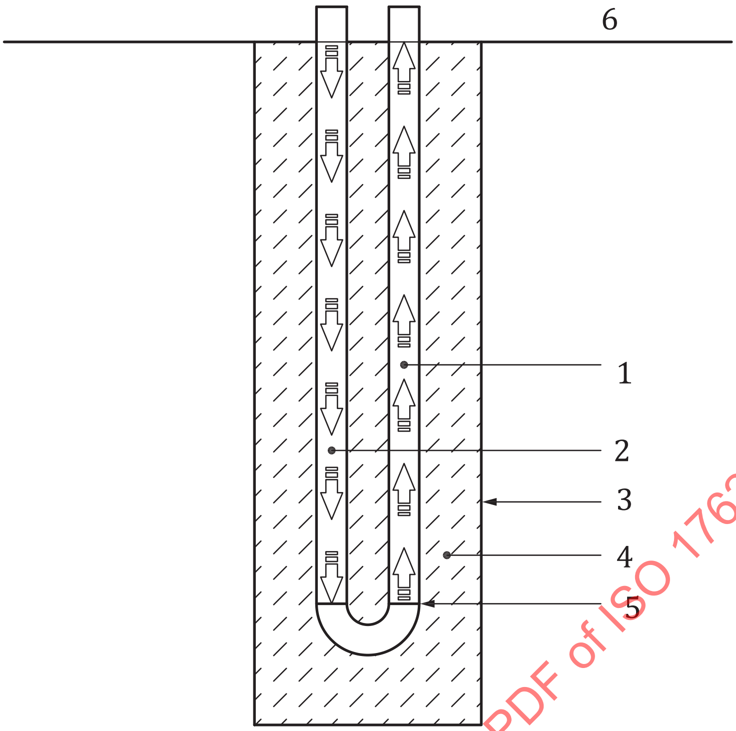


c) coaxial tube

Key

r_1	borehole radius
r_i	inner radius
r_a	outer radius
r_o	inner radius of the outer tube
r_s	outer radius of the outer tube
λ_F	thermal conductivity of the annular space filling
λ_W	thermal conductivity of the inner borehole tube
λ_s	thermal conductivity of the outer borehole tube
λ_E	thermal conductivity of the ground
B	tube spacing

Figure 1 — Cross-section of examples of borehole heat exchanger tubes



Key

1 heat exchanger outlet
2 heat exchanger inlet
3 borehole wall
4 annular space filling
5 connection
6 ground level

Figure 2 — Example of a borehole heat exchanger including annular space filling

3.2
geothermal response test
test to obtain the thermal conductivity

4 Symbols and abbreviations

Table 1 — List of symbols and abbreviations

Symbol	Designation	Unit
A	total cross sectional area of a conducting surface	m^2
B	tube spacing	m
H	length of the borehole heat exchanger	m
k	slope	
m	mass of a substance	kg
ρc_p	volume related thermal capacity	$J/m^3/K$
Q	heat supply	W
r_0	borehole radius	m
r_i	inner radius	m

Table 1 *(continued)*

Symbol	Designation	Unit
r_a	outer radius	m
r_o	inner radius of the outer tube	m
r_s	outer radius of the outer tube	m
Re	Reynold's number	
R_b	borehole resistance	
T	temperature	°C
T_0	undisturbed ground temperature	°C
T_f	fluid temperature at time t	°C
t_1	minimum test duration	
x	thickness of the conducting surface separating two different temperatures	m
λ	thermal conductivity	W/m/K
λ_E	thermal conductivity of the ground	W/m/K
λ_{eff}	effective thermal conductivity	W/m/K
λ_{est}	estimated thermal conductivity	W/m/K
λ_F	thermal conductivity of the annular space filling	W/m/K
λ_s	thermal conductivity of the outer borehole tube	W/m/K
λ_w	thermal conductivity of the inner borehole tube	W/m/K

5 Installation of borehole heat exchangers

5.1 Drilling rigs and ancillary equipment

5.1.1 General

The drilling equipment selected shall be of the appropriate size and type in order to produce the required quality.

5.1.2 Requirements for the drilling rigs and equipment

Drilling rigs with appropriate stability, power, and equipment such as drill rods, casing, core barrels, and bits shall be selected in order that the required depth and stability of the borehole can be achieved.

The drilling rig and equipment shall allow all drilling functions to be adjusted accurately.

When specified, the following drilling parameters should be measured and recorded against depth:

a) penetration rate (m/min);

b) drilled length (m);

c) flushing medium recovery rate (l/min);

d) azimuth and inclination (degree);

e) borehole diameter (mm);

f) casing and casing length (m);

g) flush medium.

5.2 Borehole heat exchangers, filling, and annular space filling materials

5.2.1 Borehole heat exchanger material

The material of the borehole heat exchanger tubes and bottom concerning the following shall be selected related to the purpose and the design:

a) quality;

b) durability;

c) corrosion;

d) thermal resistance;

e) impact resistance;

f) hydraulic resistance;

g) compressive strength;

h) resistance to deformation;

i) safety, related to contamination of the ground and ground water;

j) dimensions (diameter, wall thickness, and distance).

Plastic tubes shall have the quality of at least PE 100 black pipe for non-potable underground use and should be made of the same material as the borehole heat exchanger which will be installed for the later BHE-array.

Tube spacers shall be attached to U-tubes in order to avoid thermal shortcuts. The minimum spacer distance shall be at least 2 m.

Beginning at the bottom of the borehole heat exchanger, the tubes shall possess length marks every meter in numerical order starting at zero and increasing to the end of the tubes to check the installed length at all times.

5.2.2 Heat transfer fluid of the borehole heat exchanger tubes

The heat transfer fluid of the borehole heat exchanger tubes shall fulfil the requirements of the test design and the environmental regulations.

Water or de-ionized water should be used because of its good hydrodynamic properties and it does not endanger the ground and the groundwater, if a leakage of the borehole heat exchanger occurs.

The specific thermal capacity of the heat transfer fluid shall be known.

The use of antifreeze additives shall be justified. If used, the annular space filling has to be adapted to freezing and thawing conditions in order to avoid cracks.

The design shall take into account the minimum temperature of the heat transfer fluid.

5.2.3 Annular space filling material

The annular space filling material shall provide the thermal transport from the ground to the borehole heat exchanger and vice versa. It shall seal the borehole to the ground level to prevent contaminants from entering and aquifers that might have been penetrated. The filling material shall ensure a durable, physically and chemically stable incorporation of the borehole heat exchanger in the ground. It shall be suited for all the respective deployment temperatures.

The filling material shall be selected according to expected thermal conductivity of the surrounding ground and ground water.

Thermally improved filling materials with a thermal conductivity of > 2 W/mK should be used.

The material shall be chemically harmless for the environment and health.

5.3 General requirements prior to installation

5.3.1 Requirements on the drilling and installation site

Drilling points shall be marked on the site before drilling commences. Their location and elevation shall be surveyed correctly and in accordance with site conditions and entered in a site plan on completion of the installation.

Drilling and installation sites shall be investigated with respect to relevant hazards, underground utilities, former or current underground mining activities, natural cavities, and unexpected, unexploded ordnance and, if necessary, appropriate actions have to be taken. Installation locations on contaminated ground have to be dealt with by special procedures.

The environmental impact of drilling and installation shall be considered. Special principles have to be applied in

— water supply areas,

— areas with artesian or confined groundwater conditions,

— areas with multiple aquifers, and

— grounds with swellable or collapsible rocks or soils.

The distance to existing buildings should be at least 2 m; the stability may not be jeopardized.

5.3.2 Selection of drilling techniques and installation methods

The techniques and methods for drilling and installation shall be selected according to the purpose of the borehole heat exchanger in relation to the expected geological and hydrogeological conditions.

If installation in unstable ground is necessary, stable or stabilized boreholes are required using casings or suitable flushing media.

Sampling techniques, sample transportation, and storage procedures shall be selected according to ISO 22475-1 on the basis of the required sample quality class.

The knowledge of the geological and hydrogeological conditions is necessary for the interpretation of the results of the Geothermal response test and for the selection of the annular space filling material.

5.3.3 Preliminary information needed before starting drilling and installation

The following preliminary information shall be available before starting drilling and installation:

a) location of the planned borehole heat exchanger;

b) requirements on numbering of boreholes;

c) identification and planned depths of boreholes based on the outline design;

d) orientation, inclination, and acceptable deviations in boreholes;

e) installation plan of the borehole heat exchanger including the annular space filling;

f) tolerances of borehole depth and installation length;

g) expected geology and hydrogeology;

h) space requirements, accessibility of the drilling site, transport routes;

i) environmental and safety risks associated with, e.g. flushing media or additives intended to be used as well as regulations for their use;

j) possible risks, e.g. underground and overhead services, traffic, unexpected and unexploded ordnance, contamination;

k) preparation of the disposal of drilling mud and cuttings;

l) supply of auxiliary materials, water and energy;

m) sampling method and sampling category intended;

n) sample handling, storage, and transport intended according to ISO 22475-1;

o) requirements concerning planned measurements in the borehole heat exchanger;

p) required accuracy and uncertainty of measurements;

q) frequency of measurements;

r) *in situ* tests intended;

s) site reinstatement;

t) environmental care;

u) emergency arrangements;

v) clarification of necessary permissions;

w) name of contact person;

x) planned flow of information.

5.3.4 Environmental requirements

Regarding nuisance and environmental protection, for each particular situation, the respective national standards, specifications or statutory requirements or respective international standards shall be applied.

5.3.5 Safety requirements

Regarding safety on the site and safety of the working practices, the respective national standards, specifications or statutory requirements or respective international standards shall be applied.

Drill rigs shall be in accordance with EN 16228-1 and EN 16228-2.

Every borehole shall be fenced or temporarily capped in a safe manner until the installation has been finished.

5.4 Execution

5.4.1 Drilling

The drilling methods have to be selected according to the expected geology and hydrogeology. In the case that the borehole is not stable, it shall be stabilized by a supporting liquid (e.g. bentonite suspension) or by casing.

NOTE In suitable soils, a push-in technique can be used instead of drilling. Where required, the inclination of the casing and the borehole can be checked by an inclinometer measurement.

A possibility for sampling of cuttings shall be provided. If more than one drill rig is working at the same site, the rigs shall keep a sufficient distance from another to minimize the interaction during drilling and grouting.

5.4.2 Installation of borehole heat exchangers

The borehole heat exchanger shall be prefabricated to avoid welding at the installation site. It shall have a pressure test certificate. Mechanical damages during transport, storage, and installation shall be avoided.

The borehole heat exchanger tubes shall be filled with water and pressure-tight capped before installation. It shall be predetermined whether an additional weight is required at the bottom of the borehole heat exchanger tubes. The density of the flushing media, if used, shall be checked to ensure its compliance with the selected predetermined weight. The borehole heat exchanger shall be held back initially when placed into the borehole to avoid it from sliding in too quickly. The tubes cannot be pushed from the ground level. The tubes can only be drawn in a straight position by a suitable device that applies any force directly at the bottom of the borehole heat exchanger. The meter marks on the tubes shall be reported.

In circumstances where the borehole is dry, the BHE tube should not be filled with water until after installation.

The tremie pipes for filling the annular space should be placed together with borehole heat exchanger in the borehole considering the dimensions of the left space. Several tremie pipes can be required depending on the borehole depth to ensure continuous grouting. The number and lengths of the tremie pipes shall have been defined by the design in advance. The tremie pipes shall be clearly marked, i.e. the depth or length of the respective tremie pipe shall be recognizable at the ground level.

During prolonged frost periods, the tubes can also be filled with an antifreeze fluid that is compatible with ground array design.

The installation shall be recorded according to 7.1.2.

5.4.3 Annular space filling

After the installation of the borehole heat exchanger, the annular space shall be filled with materials whose permeability after hardening is equal or less than that of the surrounding ground, e.g. in order to stabilize the borehole, to provide a good thermal transfer, and to prevent contamination and connections between aquifers and vertical drainage along the borehole heat exchanger tubes.

The grout shall be placed by means of a tremie lowered to the bottom of the borehole. The tremie should remain in the borehole. If it is removed, this should not happen until the infill material flows out at the surface with a density equal to the density at which it was injected. The injection operation shall be continued during removal.

If there is an influence of the ground and groundwater conditions on the filling process, special technical requirements for filling shall be specified in advance. Voids shall not occur during the placement of the filling material in the borehole.

Due to certain conditions, e.g. hydrogeological and geological conditions, more than one grouting tube can be required to ensure the filling of the annular space from the bottom to the top.

When withdrawing the grouting tube, the outlet shall always be below the current filled level to prevent entrapped air. A grouting tube that remains in the borehole shall remain filled with suspension.

The annular space shall be infilled, consolidated, and capped in such a manner that there will be no subsequent depression at ground level due to the settlement to the infill material. After one or two days, the level of annular space filling shall be checked. Any depressions shall be equalized.

The properties and the preparation of the filling material shall be recorded.

The filling amount shall be recorded and continuously compared to the target quantity. If there are any differences, appropriate measures shall be resolved.

While withdrawing the casing, if used, the borehole heat exchanger tubes may not be damaged.

The annular space filling shall be recorded according to 7.1.3.

After the annular space has been filled, a functional test according to 5.4.4 on the fluid-filled tubes shall be carried out.

5.4.4 Functional testing

The functional test of the water-filled borehole heat exchanger consists of a flow test and a pressure test. The pressure test shall be carried out under the following conditions:

a) the test equipment and the heat exchanger shall be completely de-aired;

b) the tube temperatures shall be in the permissible range; the test equipment, the head of the heat exchanger and the supply pipes, if used, have to be in the shade;

c) anti-freeze measures shall be applied, if the temperature is below 0 °C.

The pressure test shall be carried out in different stages (see Table 2).

Table 2 — Course of the pressure test

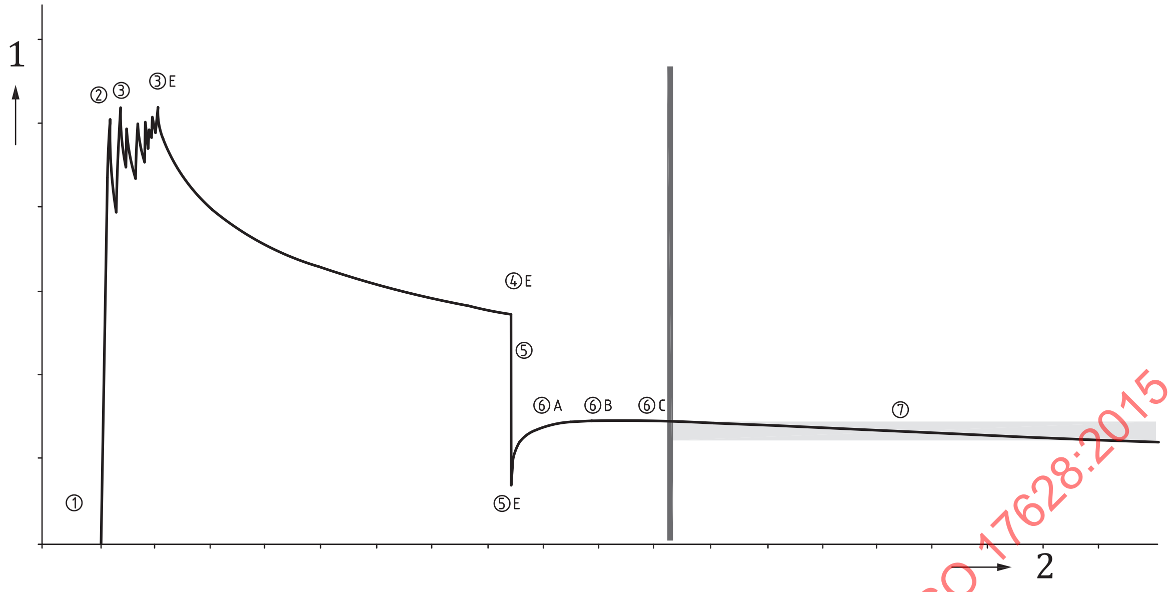
Stage	Description	Duration
1	**Decompression** Only a small differential pressure is built up during the installation of the heat exchanger tubes and the flow test. Therefore, the decompression stage can be omitted unless a retesting is required.	
2	**Pressure building-up** The pressure has to be quickly built up to 8 bar and then reduce to 4 bar.	Less than 10 min
3	**Pressure retaining** The pressure has to be kept to 4 bar. The minimal pressure may not be lower than 10 bar during this stage. The pressure loss at the time 3E shall be recorded (see Figure 3).	20 min
4	**Off-time** The pressure at the time 4E shall be recorded (see Figure 3). The pressure loss between the times 3E to 4E shall be less than 20 %.	60 min
5	**Pressure relief** The water shall be discharged in the test array to lower the pressure for 2 bar. The amount and the pressure at the time 5E shall be recorded (see Figure 3). The amount of water may not be larger than as indicated in Table 3. If the amount is larger, air is present in the BHE tube and the pressure test shall be repeated including the decompression stage (stage 1).	

Table 2 *(continued)*

Stage	Description	Duration
6	**Contraction** The heat exchanger tube contracts. The pressure is increasing again. The pressure shall be recorded in 10 min intervals (see 6A, 6B, and 6C of Figure 3). The pressure may not decrease from 6A to 6B and 6 C, i.e. it should slightly increase or stay constant. If there is pressure loss, the heat exchanger or test equipment is leaking. In this case, the test equipment and the connections shall be checked first. Then, each single BHE tube shall be checked. The decompression stage shall be considered (stage 1). A pressure loss of more than 0,1 bar relative to the maximum is not acceptable if the pressure is recorded by electronic pressure transducers (noise).	30 min

Table 3 — Acceptable water volume for the pressure relief of 2 bar (see also Table 2, stage 5)

Maximum water volume for usual heat exchanger tubes			
Tube diameter 32 mm		**Tube diameter 40 mm**	
Tube length m	**Volume** l	**Tube length** m	**Volume** l
50	0,308	102	0,951
60	0,370	127	1,184
70	0,432	140	1,306
80	0,493	152	1,418
90	0,55	165	1,539
100	0,617	175	1,632
112	0,691	185	1,725
125	0,771	200	1,865
137	0,845	225	2,098
150	0,925	250	2,331
175	1,079	300	2,798
200	1,234	350	3,264
Supply pipe			
Length m	**Tube diameter 32 mm**	**Tube diameter 40 mm**	**Tube diameter 50 mm**
5	0,008	0,012	0,018
10	0,015	0,023	0,037
15	0,023	0,035	0,055
20	0,031	0,047	0,073
25	0,039	0,058	0,092
30	0,046	0,070	0,110
35	0,054	0,082	0,129
40	0,062	0,093	0,147
45	0,069	0,105	0,165
50	0,077	0,117	0,184
55	0,085	0,128	0,202
60	0,093	0,140	0,220



Key

1	pressure in bar
2	time in minutes
①,②,③ ..	steps

Figure 3 — Example of a pressure test

5.4.5 Site reinstatement

When the installation of the borehole heat exchanger and the tests are completed, it is of the utmost importance that the site is restored and no hazards are left which would be of potential harm to the public, the environment, or animals.

If the borehole heat exchanger shall be used for later production, the water in the tubes shall be evacuated down to 2 m from the ground surface and the tubes shall be capped and protected by heat fusion. The BHE tube tails shall be protected by a lockable iron cast cover.

If the borehole shall be abandoned, the tubes should be filled up with grout and the borehole shall be excavated to an appropriate depth. The BHE tube tails shall be cut and fitted with caps heat fused. The excavation shall be backfilled as required.

The site should be left in a safe, clean, and tidy state.

6 Geothermal response testing

6.1 General

The knowledge of ground thermal properties is a requirement for the design of borehole heat exchangers. The most important parameter is the thermal conductivity of the ground.

The thermal contact of the borehole wall, the tubes, and the heat transfer fluid inside the tubes are controlled by the following:

a) tube material;

b) thickness of the tube wall;

c) tube size and configuration;

d) spacing of tubes;

e) properties of the fluid inside the tubes;

f) flow rate of the fluid;

g) borehole diameter;

h) annular space filling.

6.2 Test equipment

The test equipment consists of the following parts:

— a heating or cooling device;

— a circulation pump;

— data recording devices (the power supply, the inflow and return temperature, the ambient temperature, the flow rate);

— sensors to measure temperature and flow rate;

— thermal insulation.

The test equipment is connected to the borehole exchanger tubes.

The test equipment shall provide a constant power heating or cooling source for the duration of the geothermal response test. It should be possible adjusting different load or cooling steps. The circulation pump shall permit the adjustment of the circulating water amount. Security devices against overheating, flow problems, etc. should be envisaged.

The temperatures and flow rates shall be measured and recorded with sensors with appropriate degree of accuracy and the thermal performance calculated from the results.

The data recording device and the connecting pipes to the borehole heat exchanger tubes shall be insulated in order to minimize the heat exchange with the atmosphere. The connections should generally be as short as possible. The borehole heat exchanger tubes, the connecting pipes, and the testing device itself shall be filled with a heat exchanger fluid, preferably water, and shall be fully deaeratable; for example, by air valves installed at the top of the borehole heat exchangers or at the highest elevated point of the testing equipment.

The test equipment shall be capable of providing turbulent flow ($Re > 2500$) to supply an appropriate heat rate. The heat rate supplied to the heat ground exchanger should be 40 W/m to 80 W/m of borehole, with lower rates corresponding to lower conductivity formations. Lower heat rates shall be sufficient enough to provide a differential BHE tube temperature of 3 °C to 5 °C.

6.3 Test procedure

The test shall not be commenced earlier as 5 d after the filling of the annular space of the borehole heat exchangers and the thermal disturbances are faded.

Delays of longer than 5 d can be required where air-flush drilling has been carried out, as this introduces hot air into the formation, or where cemented grouts are used since the setting of cement is an exothermic reaction. Measurements should be taken until equilibrium has been reached.

The initial temperature of the ground shall be measured before starting the test. The temperature can be measured as follows:

a) measuring the temperature profile in the borehole heat exchanger tubes or in the annular space of open boreholes without circulation of the heat transfer fluid, each two meters down to the total depth;

b) the temperature shall be recorded during exactly one cycle of the fluid to measure the undisturbed initial temperature of the ground as accurately as possible.

The heat transfer fluid heated to a certain temperature shall be evenly pumped through the borehole heat exchanger tubes. The temperature change compared to the initial temperature should be measured as closely as possible to the subsequent operating temperature. The heating or cooling shall be as even as possible.

The temperature shall be recorded over time at the inflow and at the outlet of the borehole heat exchanger tubes. The recording shall start when engaging the circulation pump.

The temperature should be measured and recorded with a temporal resolution of several seconds at point B.

The heater can be engaged after measuring the initial temperature.

The flow through the borehole heat exchanger tubes should be turbulent.

The test shall be carried out with constant power input until the measure thermal conductivity converges to a constant value. The definite test duration shall conform to

— the dimension and design of the borehole heat exchanger (borehole diameter, annular space fill material, etc.), and

— the constancy of the heating and cooling.

The minimum test duration until the actual beginning of the determination of the thermal conductivity of the ground can be calculated according to Formula (1):

$$t_1 = \frac{5{r_0}^2}{\alpha} \qquad (1)$$

where

$\alpha = \frac{\lambda_{est}}{\rho\, c_p}$;

r_0 is the radius of the borehole (m);

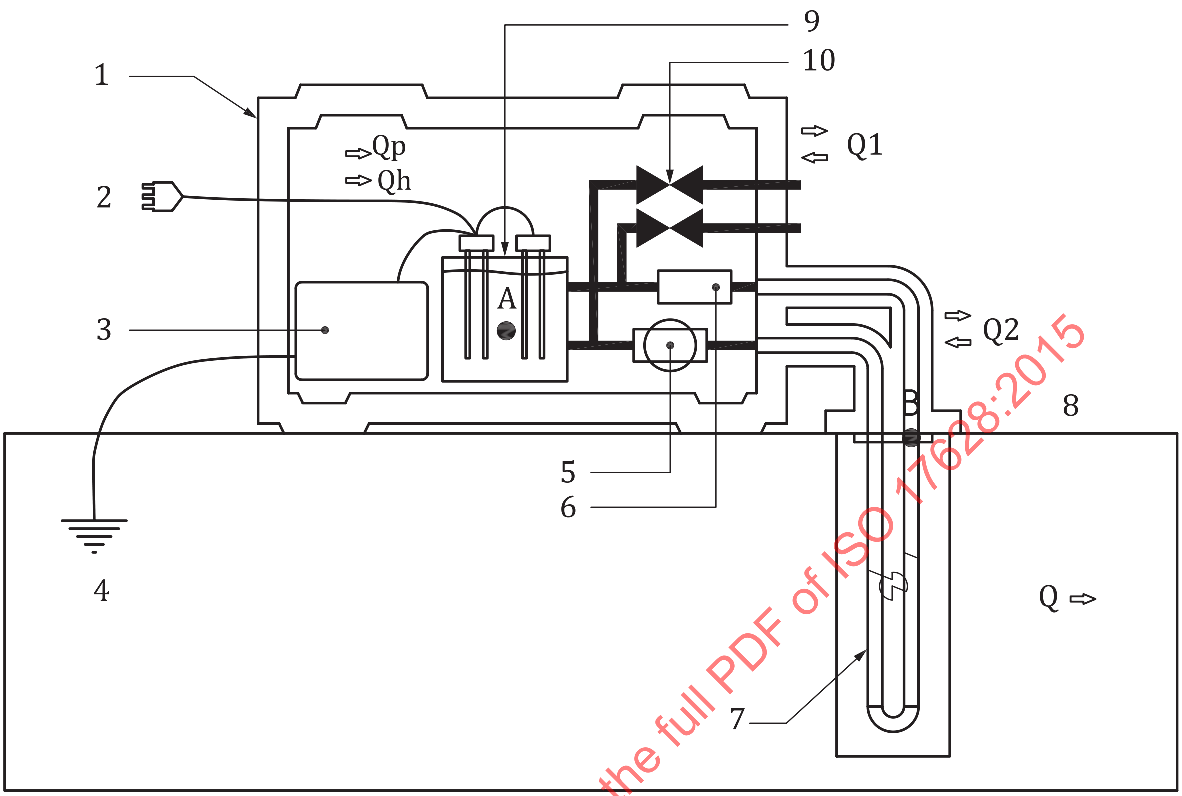
λ_{est} is the estimated thermal conductivity (W/m/K);

ρc_p is the volume related thermal capacity (J/m³/K).

The duration of the test shall be based on the convergence of the measured thermal conductivity and a constant value and shall remain after the estimated period to overcome borehole resistance as calculated by Formula (1). The minimum test duration shall be extended where grouts with < 1,3 W/m/K are used.

The measuring duration shall be extended, if clear temperature fluctuations are recognizable, in order to compensate the variation statistically.

Moreover, the ambient conditions shall be recorded.



Key

Q heat flow

Q1, Q2 heat flow exchange to ambient air

Qp heat flow of the pump

Qh heat flow of the heating

A, B measuring points

1 insulation

2 electrical connection

3 data acquisition

4 earth spike to reduce interference on data recording (grounding)

5 pump

6 temperature probes and flow meter

7 standard ground heat exchanger drilled to expected BHE tube depth at site

8 ground level

9 water tank with heating elements

10 purge valves

Figure 4 — Schematic example of a geothermal response test showing possible heat flows

6.4 Test results

The test results of the Geothermal response test are

— the inflow temperature at the top of the borehole heat exchanger over time, and

— the outlet temperature at the top of the borehole heat exchanger over time.

6.5 Evaluation of the test results

The test results can be evaluated by the following methods:

— determination by approximation of the line source theory;

— parameter estimation with numerical and analytical models;

— evaluation according to the cylinder theory, if applicable.

NOTE Both methods assume conductive heat transport.

The approximation of the line source theory can be applied, if after the initial period, the temperature graph results in a straight line using a logarithmic time axis or have such periodical variations which balance during test duration. The initial period is about 10 h to 15 h and it can be determined according to Formula (1). The evaluation shall be repeated with an initial time re-calculated according to Formula (1), when the result of the calculated thermal conductivity strongly deviates from the estimated thermal conductivity.

The slope k of the temperature graph shall be determined for calculating the effective thermal conductivity according to Formula (2):

$$\lambda_{\mathrm{eff}} = \frac{Q}{k \cdot 4 \cdot \pi \cdot H} \tag{2}$$

The thermal borehole resistance R_{b} can be calculated according to Formula (3):

$$R_{\mathrm{b}} = \frac{H}{Q} \cdot \left(T_{\mathrm{f}} - T_0\right) - \frac{1}{4\pi\lambda} \cdot \left(\ln(t) + \ln\left(\frac{4\alpha}{r_0{}^2}\right) - 0{,}577\,2\right) \tag{3}$$

The values of k and R_{b} should be iteratively varied until the modelled temperature response matches the measured temperature response as closely as possible.

A mathematical simulation model is used for the parameter determination with numerical simulation. The parameters for the thermal conductivity of the ground and for the thermal borehole resistance (or the thermal conductivity of the annular space filling) shall be varied as long as the actually measured temperature graph is obtained.

7 Report

7.1 Field report

At the project site, for each borehole, etc., 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 soil and rock according to ISO 22475-1;

e) record of the installation of the heat exchanger tubes (see 7.1.1);

f) annular space filling record (see 7.1.1);

g) checking record (see 7.1.3);

h) record of measured values and test results (see 7.1.4).

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

7.1.1 Record of the installation of the heat exchanger tubes

The record of the installation of the heat exchanger tubes shall be attached to the summary log and include the following essential information, if applicable (see also B.1):

a) General information:

   1) name of the enterprise performing the installation of the heat exchanger tubes;

   2) name of the client or representative;

   3) date of installation of the heat exchanger tubes;

   4) identification of the project;

   5) identification of the borehole;

   6) position and elevation of borehole;

   7) depth of the free groundwater surface, whenever possible;

b) Information on the used equipment:

   1) type and manufacturer of the heat exchanger tubes;

   2) dimensions of the heat exchanger tube;

   3) method of installation;

c) Information on the installation:

   1) level of the ground surface and the upper and lower end of the heat exchanger tubes;

   2) type and location of any installed measuring equipment;

d) Other information:

   1) name and signature of the qualified operator.

7.1.2 Annular space filling record

The record of the applied annular space filling shall be attached to the summary log and include the following essential information, if applicable (see also B.2):

a) name of the enterprise performing the annular space filling;

b) name of the client or representative;

c) date of annular space filling;

d) identification of the project;

e) identification of the borehole;

f) annular space filling material;

g) amount of infilled material;

h) name and signature of the qualified operator.

7.1.3 Checking record

The checking record shall be attached to the summary log and include the following essential information, if applicable (see also B.3):

a) name of the enterprise performing the checking;

b) name of the client or representative;

c) date of checking;

d) identification of the project;

e) identification of the borehole;

f) results of the checking;

g) name and signature of the checker.

7.1.4 Record of measured values and test results

The record of measured values and test results shall be digitally attached to the summary log and include the following essential information, if applicable (see also B.4):

a) inflow temperature;

b) outlet temperature;

c) thermal output;

d) test duration;

e) undisturbed temperature of the ground;

f) power applied;

g) variations of power;

h) ambient temperature.

7.1.5 Record of evaluated test results

The record of evaluated test results shall be attached to the summary log and include the following essential information, if applicable (see also B.5):

a) thermal conductivity;

b) thermal borehole resistance.

7.2 Report of the results

The report of the results shall include the following essential information, if applicable:

a) Report of the installation of borehole heat exchanger:

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

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

   3) graphical presentation of the record of the drilling parameters;

4) graphical presentation of the final record of the identification and description of soil and rock (borehole log);

5) graphical presentation of the installed borehole heat exchanger including the annular space filling;

6) name and signature of the responsible expert;

b) Report of the geothermal response test:

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

2) test evaluation (including designation of the mean effective thermal conductivity und thermal borehole resistance, evaluation method)

3) digital presentation of the results of the geothermal response test;

4) graphical presentation of the installed borehole heat exchanger combined with a borehole log;

5) name and signature of the responsible expert.

Annex A
(informative)

Example of a form for the preliminary information on the intended installation of heat exchanger

Preliminary information on the intended installation of heat exchanger		
Project		
Location		
Number of borehole		
Orientation, inclination, and acceptable deviations in boreholes		
Surveying requirements and expected geological and hydrogeological conditions		
Required accuracy and uncertainty of measurements		
Frequency of measurements		
Environmental and safety risk (associated with e.g. flushing media, suspensions)	☐yes	☐ no
	If yes, please specify	
Hazardous assessment for contaminated sites	☐ done ☐ not done ☐ not known ☐ not necessary	
Possible risks	☐ yes	☐ no
	If yes, please specify ☐ underground services, such as ☐ overhead services, such as ☐ traffic, such as ☐ unexploded ordnance ☐ contamination, such as ☐ other, such as	

Page 2	**Preliminary information**	
Planned depth of the borehole		
Sampling method(s), handling, storage, and transport		
Heat exchanger type		
Annual space filling		
Heat exchanger fluid		
Intended *in situ* testing	☐ yes	☐ no
	If yes, please specify ☐ Geothermal response test ☐ other, such as	
Borehole completion method and site reinstatement (needs, material, methods etc.)		
Environmental care		
Emergency arrangements		
Name of the contact person (client or representative)		
Flow of information		
Name of qualified operator		
Name of responsible expert		
Remarks		

Annex B
(informative)

Field reports

B.1 Record of the installation of the heat exchanger tubes

Record of heat exchanger installation			
Name of the enterprise		Name of the client	
Name of project		No. of the project	
Date of installation		Identification of the borehole	
Position of heat exchanger		Elevation of heat exchanger	m

Type	**from m**	**to m**	**Diameter**	**Material**	**Type**	**from m**	**to m**	**Diameter**	**Material**

Remarks	
Name of the qualified operator	
Signature of the qualified operator	

B.2 Annular space filling record

Annular space filling record							
Name of the enterprise				Name of the client			
Name of project				No. of the project			
Date of filling				Identification of the borehole			
Depth m		**Fill material**	**Amount** m^3	**Depth** m		**Fill material**	**Amount** m^3
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
from	to			from	to		
Remarks							
Name of the qualified operator							
Signature of the qualified operator							