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Design and construction of backfilled and grouted borehole heat exchangers

Planung und Bau von Erdwärmesonden

Conception et construction de sondes géothermiques verticales comblées et remplies de coulis

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Design and construction of backfilled and grouted borehole heat exchangers

Conception et construction de sondes géothermiques verticales comblées et remplies de coulis

Planung und Bau von Erdwärmesonden

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Contents

Page

European foreword 6
1 Scope 7
2 Normative references 7
3 Terms and definitions 8
4 Geological and environmental aspects 10
4.1 General 10
4.2 Geological and hydrogeological risks 11
4.2.1 Artesian aquifers 11
4.2.2 Stacked aquifers with different groundwater potential 11
4.2.3 Groundwater and soil chemistry 11
4.2.4 Gas occurrence 11
4.2.5 Ground stability 11
4.2.6 Contrasting geological sequence (Alternated bedding) 12
4.2.7 Karst geology 12
4.2.8 Frost susceptibility 13
4.2.9 Groundwater protection area 13
4.3 Anthropogenic risks and constraints 13
4.4 Environmental aspects 13
4.4.1 General 13
4.4.2 Influence on groundwater 13
4.4.3 Environmental impact due to construction works 14
5 System description 15
5.1 General 15
5.2 Borehole heat exchanger 15
5.3 Horizontal piping 17
5.4 Manifolds 17

5.5 Thermal plant 18
6 Materials 18
6.1 General properties 18
6.2 Materials 18
6.2.1 Polymeric materials 18
6.2.2 Connection methods 20
6.2.3 Metallic materials 21
6.3 Heat transfer fluid 21
6.4 Backfilling materials 22
6.4.1 General 22
6.4.2 Grouting material 22
6.4.3 Other backfilling materials requirements 23
6.5 Component selection criteria 23
6.5.1 General 23
6.5.2 BHE loops 23
6.5.3 Horizontal pipes 24
6.5.4 Manifolds 24
6.5.5 Heat transfer fluid 24
7 Design 24
7.1 Steps of design 24
7.2 Sizing 25
7.2.1 General 25
7.2.2 General methodology 26
7.2.3 Thermal properties of the ground 29
7.2.4 Thermal Response Test (TRT) 30
7.2.5 Calculation and modelling procedure 37
7.2.6 Simulation 38
7.2.7 Hydraulic design 39

8 Construction 40
8.1 General 40
8.2 Site preparation and planning 40
8.3 Drilling 41
8.3.1 General 41
8.3.2 Drilling diameter 41
8.3.3 Drilling fluid 41
8.3.4 Monitoring and documentation of the drilling process 41
8.4 Borehole heat exchanger loop 42
8.5 Borehole heat exchanger loop installation 42
8.6 Backfilling and grouting procedure 43
8.6.1 General 43
8.6.2 Grouting procedure 43
8.6.3 Other backfilling procedure 44
8.7 Horizontal piping 44
8.8 Testing and checking of BHE – Leakage, flow, grouting, geophysical measurements 45
8.9 Manifolds 45
9 Start-up 46
9.1 General 46
9.2 Heat transfer fluid 46
9.3 Filling of the system 46
9.4 Drying of new buildings 46
9.5 Commissioning 46
9.6 Documentation 47
10 Operation, monitoring and maintenance 47
10.1 Operation 47
10.2 Monitoring 47
10.2.1 General 47

10.2.2 Temperature 48

10.2.3 Pressure 48

10.2.4 Flow rate 48

10.3 Maintenance 48

11 Renovation 49

12 Decommissioning 49

12.1 General 49

12.2 Heat transfer fluid 49

12.3 Borehole heat exchangers 49

12.3.1 Backfilled boreholes 49

12.4 Horizontal pipes 50

12.5 Documentation 50

Annex A (informative) Insulation of horizontal piping 51

Annex B (informative) Example simulation time 52

B.1 General 52

B.2 Single house, unbalanced energy design 52

B.3 Field of 30 houses with an unbalanced design 53

B.4 Field with 400 houses with an unbalanced design 54

B.5 Conclusion 54

Annex C (informative) Commissioning checklist 55

Annex D (informative) Examples of thermal conductivity and volumetric - heat capacity of the underground 57

Annex E (informative) Main drilling methods 59

Bibliography 61

European foreword

This document (EN 17522:2023) has been prepared by Technical Committee CEN/TC 451 “Water wells and borehole heat exchangers”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2023, and conflicting national standards shall be withdrawn at the latest by October 2023.

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1 Scope

This document covers standardization in the field of geological and environmental aspects, design, construction, operation, monitoring, maintenance and decommissioning of grouted borehole heat exchangers for uses in geothermal energy systems.

This document is only applicable for backfilled and grouted boreholes, it is not applicable for groundwater-filled boreholes.

Direct expansion and thermal syphon techniques are excluded from this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

EN 1057, *Copper and copper alloys — Seamless, round copper tubes for water and gas in sanitary and heating applications*

EN 1254-2, *Copper and copper alloys —Plumbing fittings — Part 2: Compression fittings for use with copper tubes*

EN 1254-3, *Copper and copper alloys — Plumbing fittings — Part 3: Compression fittings for use with plastics and multilayer pipes*

EN 1254-7, *Copper and copper alloys — Plumbing fittings — Part 7: Press fittings for use with metallic tubes*

EN 1254-8, *Copper and copper alloys — Plumbing fittings — Part 8: Press fittings for use with plastics and multilayer pipes*

EN 1965-2, *Structural adhesives — Corrosion — Part 2: Determination and classification of corrosion to a brass substrate*

EN 10216-5, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 5: Stainless steel tubes*

EN 12201-1:2011, *Plastics piping systems for water supply, and for drainage and sewerage under pressure — Polyethylene (PE) — Part 1: General*

EN 12201-2, *Plastics piping systems for water supply, and for drainage and sewerage under pressure — Polyethylene (PE) — Part 2: Pipes*

EN 12201-3, *Plastics piping systems for water supply, and for drainage and sewerage under pressure — Polyethylene (PE) — Part 3: Fittings*

EN 12201-5, *Plastics piping systems for water supply, and for drainage and sewerage under pressure — Polyethylene (PE) — Part 5: Fitness for purpose of the system*

EN 12449, *Copper and copper alloys — Seamless, round tubes for general purposes*

EN ISO 15875-1, *Plastics piping systems for hot and cold water installations — Crosslinked polyethylene (PE-X) — Part 1: General (ISO 15875-1)*

EN ISO 15494, *Plastics piping systems for industrial applications — Polybutene (PB), polyethylene (PE), polyethylene of raised temperature resistance (PE-RT), crosslinked polyethylene (PE-X), polypropylene (PP) — Metric series for specifications for components and the system (ISO 15494)*

EN ISO 22391-1, *Plastics piping systems for hot and cold water installations — Polyethylene of raised temperature resistance (PE-RT) — Part 1: General (ISO 22391-1)*

EN 12168, *Copper and copper alloys — Hollow rod for free machining purposes*

EN ISO 1127, *Stainless steel tubes — Dimensions, tolerances and conventional masses per unit length (ISO 1127)*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
aquifer
water-bearing geological layer comprising permeable rock, fractures or unconsolidated materials (gravel, sand, or silt)

Note 1 to entry: an aquifer can be fully or partly saturated.

Note 2 to entry: its upper limit is called the "top of the aquifer" and its base is called the "bottom of the aquifer"

3.2
aquitard
body of rock or stratum of sediment that restricts but does not prevent the flow of groundwater from one aquifer to another

3.3
backfill
material used for refilling any borehole or trench, except groundwater

3.4
borehole heat exchanger
BHE
consists of vertical or inclined boreholes with a loop, to circulate a heat transfer fluid and a borehole backfill

3.5
borehole heat exchanger field
BHE field
area with several BHEs that are connected in the same hydraulic circulation system

3.6
borehole heat exchanger loop
BHE loop
pipe system in the borehole, which contains the fluid for heat transfer

3.7
borehole heat exchanger system
BHE system
the BHE system consists in four subsystems (Figure 1):

1) borehole heat exchanger;

2) horizontal piping;

3) manifold;

4) thermal plant (technical room) with all installation except heat pump

Note 1 to entry: the borehole heat exchanger system is considered as a unit including the entire borehole heat exchanger field

3.8
effective borehole thermal resistance
effective thermal resistance between the mean temperature at the wall of the borehole and the mean fluid temperature for thermally quasi-steady-state conditions in the borehole

Note 1 to entry: "borehole thermal resistance" always refers to the effective borehole thermal resistance

3.9
effective thermal conductivity
thermal conductivity determined by a thermal response test as effective value over the entire length of the borehole heat exchanger

Note 1 to entry: implicit allowance also is made for unrecognized influencing factors, e.g. groundwater flow, as long as the heat transport can still be regarded as heat conduction

3.10
fluid return
flow from the BHE

3.11
fluid supply
flow to the BHE

3.12
g-functions
the G-functions are dimensionless functions describing the relation between temperature change, load and time for a specific BHE configuration, derived from more complex numerical or analytical solutions

3.13
ground source heat pump system with BHE
BHE GSHPS
BHE system including the horizontal piping, manifolds, the heat pump and circulation pump

3.14
grout
backfilling material for sealing of boreholes composed of clay and/or cement and additional components (rock powder, etc.). Solid materials especially in case of cementous grouts shall be mixed with water forming a pumpable slurry

3.15
heat transfer fluid
HTF
liquid fluid circulated through the BHE loop for the heat transport

3.16
injection pipe
tremie pipe or permanent grout injection pipe

3.17
shank spacing
distance between the centres of the U-pipes

3.18
slurry
liquid grout mixture at the time of mixing

3.19
thermal plant
heating/ including the heat pump installation

3.20
tremie pipe
grout injection pipe

3.21
COP
Coefficient Of Performance
ratio of the useful heating power to the electric power of a heat pump

3.22
EER
Energy Efficiency Ratio
ratio of the useful cooling power to the electric power of a chiller

4 Geological and environmental aspects

4.1 General

The designer shall check whether the location of the planned installation is situated in any areas defined in spatial planning documents. These could be areas of special protection of natural resources (water protection, nature protection) or areas of specific risks (endangered areas, landslides, contaminated sites, etc.).

It shall be checked whether there are hydrogeological conditions (artesian aquifers, shallow groundwater table, perched groundwater, etc.) that could require special consideration or even impact or risk assessments.

The designer shall assess whether the available geological and hydrogeological information is sufficient for the project in question.

4.2 Geological and hydrogeological risks

4.2.1 Artesian aquifers

When the drilling penetrates an artesian aquifer, the groundwater level rises above ground level and can overflow uncontrollably at the wellhead. The use of improper drilling techniques or equipment selection can result in uncontrolled upwelling and pressure loss. This represents the main risks when artesian aquifers are penetrated.

Drilling in the artesian aquifer is a risk. Special specifications regarding drilling methods and BHE construction shall be implemented.

4.2.2 Stacked aquifers with different groundwater potential

Drilling through sealing layers between aquifers could result in leakage from one aquifer to another and result in impact on chemical characteristics of groundwater or hydraulic conditions. This could also cause an undesired drop or increase of groundwater level in one or more aquifers. Consequences could be decreased productivity of water sources or deteriorated formation conditions.

Groundwater flow conditions and qualities can also be affected adversely where drilling penetrates two or more groundwater layers. In this case, the possibility of uncontrolled water exchange between the individual aquifers via the borehole needs to be taken into account. A hydraulic short circuit shall be avoided for groundwater protection reasons, especially where one of the penetrated layers contains highly mineralized or contaminated groundwater.

If drilling would cross through several aquifers, at least the aquitards shall be sealed.

4.2.3 Groundwater and soil chemistry

The chemical composition of the groundwater (high sulphate concentration, low pH, high salinity, etc.) could adversely affect the sealing properties and stability of the backfilling.

Drilling or excavating near springs or wells could adversely affect the mineralogical composition of groundwater.

4.2.4 Gas occurrence

Under certain geological conditions, gas of geogenic origin can accumulate in cavities and trap structures in the subsurface. When drilling in these areas, the gas could leak uncontrollably through the borehole and pose a safety risk (toxic or explosive gases) or an environmental risk (greenhouse gases). Gas deposits could occur in areas with volcanic activity or above geological layers containing coal, peat, hydrocarbons, sulphides, etc. If the risk of drilling gas at the project site is known or can be predicted based on geological research, appropriate safety measures (e.g. explosion protection and well control measures such as an annular seal and diverter, special backfill material) are required or the drilling depth should be limited or the drilling should be terminated.

Gas (e.g. CO_2) can migrate by diffusion processes into the PE-HD BHE-loop. This can disrupt the operation of the heat pump.

4.2.5 Ground stability

Unstable ground could be found especially in the following geological situations:

— intensively fissured, faulted and breccia zones, provoking formation of natural or anthropogenic cavities (e.g. mine workings);

— soft fragile rocks representing unstable ground (e.g. volcanic or sedimentary rocks);

— solution or mining cavities or are extremely dangerous when the pressure or lubricant effect of the drilling fluid mobilizes surface fill deposits into the cavity resulting in a sink hole. The drilling rig, site equipment and shallow surface casing can be undermined often with fatal results and serious contamination occurs when hydrocarbons in the fuel tanks are lost into the ground. The use of augers, additional grouted surface casing or dual rotary drilling techniques (casing advance systems) can help to alleviate these risks;

— swelling, dissolving and shrinking minerals or soils;

— presence of evaporites (especially anhydrite), potentially shrinking peat or swelling clays present a risk of subsidence or swelling in the case of connection of shallow or deep aquifers with evaporitic or clay layers resulting in unsuitable or difficult drillings.

4.2.6 Contrasting geological sequence (Alternated bedding)

Geology is highly diverse, and could range from structures represented by unconsolidated sand, clay and gravel going to very complex situations including unconsolidated or consolidated sedimentary (sandstone, limestone – fissured and frequently karstified) or crystalline (metamorphic and igneous) rocks. An adequate knowledge of the geological conditions and associated hydrodynamic properties of the selected site represents the base for any BHE drilling project. An appropriate site assessment raises the probability of an efficient and long-lasting product. This also contributes to the management and protection of groundwater resources (quantity and quality) to be exploited through future projects (e.g. water wells of different purposes and configurations).

The lithological description of the geological sequence be drilled and the structural characterization of the site area are both compulsory in order to provide sufficient information for the preparation of a BHE design and provision of adequate drilling machineries and auxiliary equipment for efficient construction works; whilst avoiding, minimizing and/or controlling the potential geologic risks during drilling.

Depending on the complexity of the project and of the geological conditions, the standard set of topics to be described should refer to the following aspects (if appropriate):

— occurrence and description of the regional geologic structure(s) - sedimentary basin, folded structures and/or faults;

— the lithological (specific) description (from bottom to top or reverse) of the litho-stratigraphic units (formations, beds, layers, or horizons) to be drilled;

— occurrence and characterization of local tectonic (structural) discontinuities – faults, fissures, fractures (particularly in case of hard rocks);

— occurrence and characterization of dissolution voids and channels (in case of carbonate and evaporite rocks);

— hydrological aspects (groundwater chemistry, pH, redox potential, depth of sweet/salt level, level of phreatic groundwater, regional groundwater flow for every aquifer, hydraulic conductivity, porosity / thermal parameters);

— inventory of other users in the vicinity (groundwater extraction wells, groundwater energy wells, borehole heat exchangers).

4.2.7 Karst geology

Karstified zones can represent strong heterogeneity of the ground and risk of caverns and sink holes. High probability of occurrence of caverns leads to several risks: collapsing of borehole, subsidence of the ground, losses of drilling fluids, problems with backfilling, turbidity and solids in groundwater, unstable temperature of groundwater (too low in winter, too high in summer), hardly predictable, unreliable modelling.

Geological and hydrogeological conditions in the depth of karst area are often not sufficiently known to make a reliable prediction without additional investigation.

4.2.8 Frost susceptibility

Because the temperature of the fluid in the BHE can be below 0 °C, there could be a risk of freezing the soil causing upheaval of the horizontal pipe work and affect the sealing properties of the borehole filling and the natural sealing layers around the borehole.

The sealing grout of the borehole heat exchanger should be adapted to the actual physiochemical conditions, naturally occurring or due to operation of the system. It should not be negatively affected by freezing and should withstand a negative temperature of the heat transfer fluid that returns to the geothermal heat exchangers, keeping its physiochemical and mechanical properties intact.

4.2.9 Groundwater protection area

The risk of BHE in groundwater is the degradation of the groundwater quality.

Areas of interest to drinking water supply can be protected areas.

BHE installations in groundwater protection areas could require special authorizations. Local regulations for protected areas shall be followed.

4.3 Anthropogenic risks and constraints

Interactions between the built environment and the subsoil could impose constraints on the construction of borehole heat exchangers. Underground structures (e.g. basements, tunnels) can impact the groundwater flow.

When planning a borehole heat exchanger, the potential risks and impacts of sites should be evaluated, such as presence of:

— nature protection areas;

— unexploded ordnance;

— contaminated soil and groundwater;

— mining areas;

— areas of archaeological interest.

4.4 Environmental aspects

4.4.1 General

Environmental aspects shall be considered throughout the whole construction process.

4.4.2 Influence on groundwater

Regulations and the regional planning targets shall be complied with during planning, construction and operation of ground source heat pump systems.

Within the scope of the applicable water law and – to the extent required – mining law procedures, the desired uses should be harmonized with the water management targets with respect to the local situation by imposing usage terms.