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POSSIBILITIES OF USING INCLINED BOREHOLES IN SHALLOW DRILLING

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Abstract: The article presents the possibilities of using inclined boreholes. Three cases were considered: backfill boreholes, hydrogeological boreholes, and borehole heat exchangers. The advantages and disadvantages of these solutions are described. In the case of an inclined backfill borehole, the time required for backfill material injection is minimized. In the case of an inclined hydrogeological borehole, the active filter area is increased, improving efficiency. In the case of inclined borehole heat exchangers, the unit power exchange with the rock mass is increased by increasing the length of the borehole in the layer with the best thermal conductivity.

Keywords: inclined boreholes, injection boreholes, hydrogeological boreholes, borehole heat exchangers, Geothermal Radial Drilling

1. Introduction

Drilling boreholes are made for various engineering purposes, ranging from exploratory drilling, through production drilling, to drilling for geotechnical, geoengineering, and construction applications, as well as various types of mining applications. Most frequently, wells are made vertically. Drilling boreholes can be classified according to various factors, including purpose, depth, diameter, etc. Taking into account the final drilling depth, a distinction is made between shallow, deep, and super-deep wells [1]. Of course, there are no clear definitions of numerical values since different authors, also due to the purpose of the boreholes, give different depths in an ambiguous way. The authors of this study propose classifying shallow boreholes as wells with a final depth of up to 200–250 m.

In recent years, there has been significant development in shallow drilling, primarily due to the need to eliminate gaps and collapses caused by mining activities or due to the development of renewable energy sources, which include the provision of geothermal energy using borehole heat exchangers. There has also been increased interest in hydrogeological drilling. Currently, all such drilling is performed as vertical wells. An exception is a special type of borehole heat exchanger made using Geothermal Radial Drilling (GRD) technology. This technique involves drilling several angled boreholes from a single point. The fundamental principles were established by Tracto-Technik in the late 1970s, they were the ones who gave it that name [2, 3].

In 2006, the company introduced an advanced system incorporating intelligent technologies for this type of installation. The process utilizes a specialized drilling machine designed for creating these boreholes. The drilled wells are typically inclined and range from 40 to 60 meters in length. What sets GRD apart from traditional drilling techniques is the requirement to build a launch chamber, usually 1 to 2 meters deep. Drilling is typically carried out at angles between 30 and 65 degrees [4, 5]. Such an installation is located in research field C of the Geoenergetics Laboratory (Faculty Drilling, Oil and Gas, AGH University of Krakow). In addition, some of the first borehole heat exchangers in the form of inclined boreholes were drilled from research fields in the Geoenergetics Lab [6].

Currently, directional drilling is most commonly used in deep drilling and trenchless techniques. Directional holes are described by additional data not usually found in vertical boreholes. Measured Depth – this is the depth of a given point in the hole measured along the length of the drill string. True Vertical Depth – this is the depth of a given point in the hole measured vertically to the reference level. Dog Leg Severity – this is the increase in the curvature of the hole per unit of distance. Of course, only the basic concepts are given here. There are many trajectories for directional wells in deep drilling. The main ones are J-type and S-type. You can read more about horizontal directional drilling and deep directional drilling trajectory in [7–11].

Due to their complexity and the necessary lengths of the wells, they are not directly applicable in shallow drilling. Horizontal directional drilling also belongs to the category of directional drilling. This modern technology (classified as a trenchless technology) involves performing horizontal directional drilling. Horizontal directional drilling enables various types of installations (water pipes, gas pipes, power lines) to be carried out using the trenchless method wherever it is impossible to dig an open trench for pipes or cables. Therefore, it is very important to transfer the experience gained there to shallow drilling.

2. Results

The realization of the above-described examples of vertical wells in the form of inclined wells can bring many benefits. An inclined injection well (backfill well) is recommended for chambers or gaps intended for stabilizing that are located under heavily urbanized areas. It is also recommended to make diagonal backfill boreholes in order to provide greater apparent thickness of the chamber or cavity in relation to a vertical hole. This results in an increase in the length of the perforated section of the pipe used to inject the backfill material. A similar solution is proposed for groundwater access. Compared to a vertical borehole, this technological solution will increase the surface area of the well's filtration zone cylinder, thus increasing the surface area of water inflow to the well (the so-called apparent thickness). Similarly, in the case of borehole heat exchangers installed in a borehole to obtain low-temperature heat, the use of an inclined borehole design can bring economic benefits by making a longer part of the borehole in a layer with the highest possible thermal conductivity, which will increase the amount of heat exchanged between the rock mass and the heat carrier circulating in the exchanger pipes.

The increase in the length of the inclined borehole (Fig. 1) will be the same for each case described in this paper and will depend on the angle at which the inclined well is made.

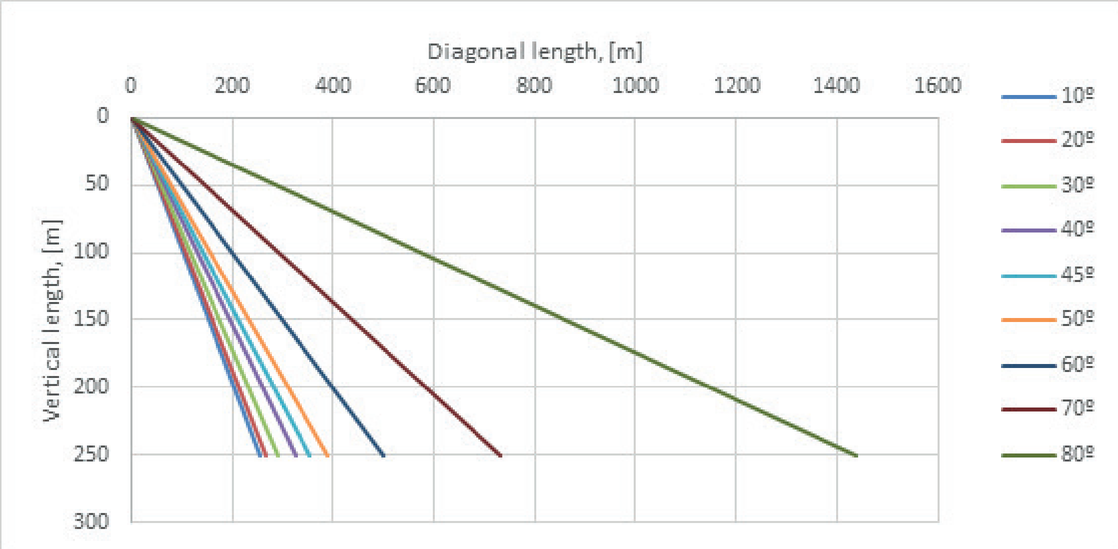

Fig. 1. Comparison of the length of a vertical borehole and an inclined borehole drilled at a defined angle

2.1. Injection boreholes (backfill boreholes)

Backfill boreholes are specially designed technical boreholes used to transport backfill material (usually a mixture of sand, ash, hydraulic grout, or brine) from the surface to voids created by mining operations. Their main purpose is to fill underground excavations and stabilize the rock mass, which minimizes the risk of subsidence and surface deformation and improves the safety of infrastructure facilities located in post-mining areas. In areas designated for construction, the presence of voids resulting from previous mineral extraction activities often requires remedial actions to ensure ground stability. The intensification of geological resource exploitation has contributed to the reactivation of subsidence and collapse phenomena. To address these challenges, drilling techniques are increasingly employed for the backfilling of underground cavities and discontinuities in the rock mass. Through the use of specially designed boreholes, backfilling materials can be efficiently transported from the surface directly to the targeted voids or post-mining chambers. The design parameters of these boreholes are typically determined based on the lithological profile of the subsurface and established drilling standards. Literature reports indicate that steel casing pipes with diameters ranging from 12 inches to 18 inches are most commonly used for this purpose. However, variations exist – for instance, some boreholes, such as the TP-25 well in the Wieliczka Salt Mine, utilize initial casing diameters exceeding 20 inches, whereas final segments may be reduced significantly, down to 6 5/8 inches for effective backfill transport [12, 13].

Backfill boreholes made as inclined wells will significantly reduce the time needed to pump backfill material. In special cases of highly urbanized surface development, they will allow backfilling to be carried out from an area not located directly above the chamber being backfilled. In addition, the advantage of using backfill materials is that they reduce rock mass deformation caused by deposit exploitation, thereby protecting the surface and the levels and deposits above. Occasionally, some backfill boreholes serve as water inflow routes to the mine, and in order to limit this adverse effect, all such holes should be sealed after fulfilling their technological purpose. To achieve insulation around the holes, additional sealing of the rock mass should be designed using the hole injection method carried out from the surface. To achieve isolation around the holes, additional sealing of the rock mass should be designed using the hole injection method carried out from the surface [12].

2.2. Hydrogeological boreholes

Hydrogeological boreholes, designed to access aquifers, are mainly constructed as vertical structures. Initially, hydrogeological boreholes were constructed using the percussion method, which involved drilling a borehole with a smaller diameter and then widening it to the required final diameter. The circular method was used next. These holes require human strength, so it is only possible to drill in this way in very soft and soft rocks. At the same time, manual drilling of holes is characterized by low technical and economic drilling indicators. In the first half of the 20th century, this method was replaced by rotary drilling, performed as large-diameter boreholes, i.e., boreholes with a diameter of more than 0.5 m [14]. The increased profitability of rotary technology compared to the percussion method was achieved thanks to significant advances in drilling using reverse circulation drilling mud. Hydrogeological boreholes are mainly drilled using clay drilling mud, often natural. The development of drilling technology and techniques has made it possible to access groundwater using boreholes drilled using the rotary method with normal mud circulation. This is mainly due to the possibility of reducing the final diameter determined by the well equipment (submersible pump, outer diameter of the filter column, etc.). An important aspect of hydrogeological drilling is therefore a thorough lithological survey. This allows for the elimination of possible "missed boreholes" which, after the column with the filter has been inserted, do not guarantee good well performance. As stated earlier, the efficiency is determined on the basis of a test pumping. The radius of the depression cone is determined, which extends from the axis of the hydrogeological borehole to a distance where no drop in the water table in the borehole is observed during water extraction. In the process of rotary drilling with mud, depending on the rate of penetration, the type of drill bit, flow character and the type of mud, the operation of the mud pumps, and the mud cleaning system from cuttings, the pressure of the mud on the bottom and the wall of the borehole can vary significantly of the drilling fluid to the bottom and walls of the borehole. The pressure in the borehole reaches different values in different phases of drilling operations. In addition, poorly selected drilling fluid for drilling through aquifers or improperly chemically treated may lead to the sedimentation of solid particles from it, and under the influence of the pressure difference between the mud column in the hole and the reservoir water, these particles may be pressed into the pores and cracks of the rock, clogging them [14].

Inclined boreholes significantly improve the technical and technological indicators as well as the economics of the work described in the study. Accessing aquifers through an inclined bore will increase the active surface area of the filter, thereby increasing the water inflow to the filter column. The increase in water inflow to the completed well will directly affect the dynamic water table of the well, which will settle at a higher level. Each inclined well made to access groundwater will be characterized by an increased length of the active filter surface. It is recommended to select the casing and drill bit diameters in accordance with API standards, depending on the geological conditions encountered. The dimensions of the filters are determined primarily on the basis of the designed capacity of the well and the geological and hydraulic conditions of the aquifer. The length of the filter should be as long as possible, as it directly affects the flow of water from the aquifer into the production column.

2.3. Borehole heat exchangers

Low-temperature energy can be used for heating and heating-cooling purposes by using a heat pump system with borehole heat exchangers. This is one of the most popular methods of extracting heat from the rock mass. The rock mass is a good heat reservoir. The heat can come from solar or geothermal energy, or it can also be anthropogenic heat. Correct drilling of the borehole is very important for the precise operation of geothermal heat pump systems with borehole heat exchangers. A very important element of this process is the selection of the appropriate drilling method. Borehole heat exchangers are most often made using one of two methods [15–17]: the rotary method or the percussion-rotary method. The drilling of a borehole and the installation of heat exchanger pipes in it consists of a series of steps, the correct execution of which guarantees the achievement of the intended goal. Boreholes are most frequently drilled using the rotary method with normal mud circulation. In many cases, cutting drills are used to drill rocks, and native or bentonite clay mud is used to remove drill cuttings from the bottom of the well to the surface. The individual stages of drilling a borehole consist of assembling the drilling rig, preparing the mud system and drilling mud, installing the initial casing string, drilling rock, crane operations with the drill string, and the cementing process [6].

The correct design and construction of installations based on borehole heat exchangers requires a complex approach involving a number of key stages. First, it is necessary to assess the thermal potential of the rock mass, which allows the energy efficiency of the planned installation to be determined. Next, an analysis of the techniques and technologies used for drilling holes and their adaptation to the function of heat exchangers in various geological conditions is carried out, which allows the drilling method to be adapted to local geological conditions. Another important stage is the selection of the appropriate design of borehole heat exchangers, including the composition of sealing grouts, which guarantee adequate sealing of the borehole exchanger and prevent water migration between different aquifers. To predict the behavior of the installation during operation, modeling of borehole heat exchangers is performed, and on this basis, the parameters of their operation technology are optimized to increase the energy efficiency and durability of the entire system. Borehole heat exchangers installed in inclined wells will be characterized by increased apparent thickness in layers with the highest possible thermal conductivity. This will have a positive effect on the total power exchanged with the rock mass. The efficiency of the entire heating or heating-cooling system based on borehole heat exchangers will therefore increase.

3. Conclusions

– Backfill boreholes can be drilled as vertical and inclined wells from the surface or from underground mine levels. Inclined backfill wells may be drilled in the following cases: a) when vertical drilling is not possible, b) when drilling from underground mine levels is necessary, c) in order to reduce the time needed to inject the backfill materials.
– Hydrogeological boreholes (exploratory, production, research, absorption, observation, dewatering) can be drilled as vertical and inclined boreholes. Inclined hydrogeological wells can be drilled: a) when vertical drilling is not possible, b) when dewatering from underground mine levels is necessary, and c) to improve performance parameters (water flow). Cases a and b are independent of the investor's decision. In case c, the decision to drill inclined will enable a higher flow of the production well.
– Drilling inclined through an aquifer increases the surface area of groundwater inflow into the borehole. Using a longer filter (active part) increases the rate of flow at the same depression, measured vertically. Drilling a hydrogeological borehole in an inclined borehole is more difficult than in a vertical borehole. The difficulty and possibility of complications increase with the increase in the angle between the borehole axis and the vertical direction.
– Borehole heat exchangers (single U-tubes, multi-U-tubes, centric, etc.) can be drilled as vertical and inclined wells. Inclined drilling of borehole heat exchangers can be performed in the following cases: a) when vertical drilling is not possible, b) when there is not enough space on the surface for the required number of vertical heat exchangers, c) when heat storage is available under infrastructure facilities, d) when drilling from inside buildings, e) to improve functional parameters (heating capacity).
– The use of inclined wells will lead to benefits in each of the cases described and will have a positive impact on the efficiency of hydrogeological drilling, the amount of energy exchanged with the rock mass in the case of borehole heat exchangers, and the time required to inject backfill material into the chamber or gap left by mining operations.

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