CONTROLLED HORIZONTAL CORE DRILLING TECHNIQUE - AN ADDITIONAL METHOD FOR THE UNDERGROUND EXPLORATION OF THE GORLEBEN SALT DOME BY MEANS OF LONG BOREHOLES

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ABSTRACT

The Gorleben salt dome has to be proved suitable as repository for radioactive waste by a comprehensive underground exploration program. An essential part of this program involves about 100 km of direction-stabilized horizontal cored boreholes with a length up to about 1500 m.

It was the goal of an R&D project to prove the merit of the direction-stabilized horizontal core drilling technique and to develop it for long boreholes for practical operation.

A horizontal drilling program of about 7000 m was performed in a potash mine in Northern Germany. The program objective was to keep the course of the borehole within a tolerance cylinder 5 m in diameter. Oriented cores not less than 40 mm in diameter, a core recovery of 95% per core run, and an increasing efficiency of the wire-line drilling method should be achieved by extending the usable length of the inner core barrel.

The R&D project yielded the following results:

- Control of the vertical borehole course was generally possible with a precision of $\pm$2.50 m deviation from the ideal position by means of appropriate stablizer placement near the bit.
- Steering of the horizontal borehole course was managed applying a clockwise or anticlockwise rotating drill string. Thus, systematic effects caused by the vertical control mechanism were used for correcting the horizontal course of the borehole. A precision of $\pm$2.50 m deviation from the ideal horizontal position was not always attained, but at least the final horizontal deviations could be limited to 1-2% of the final length of the borehole.
- An essential help for the vertical and horizontal navigation of the borehole course was the consistent application of the data unit for recording drilling parameters. It was therefore possible to analyze the influence of weight on bit and rotational speed on the course of the borehole with respect to stabilizer placements and geology.
- The maximal length of a borehole was 1522 m.

An efficient drilling method that allows successful steering of the borehole course in horizontal and vertical direction under operational conditions has been developed.

INTRODUCTION

In the course of the investigation of the Gorleben salt dome for ascertaining its suitability for the final disposal of radioactive waste, the exploration of the salt dome by means of horizontal core drilling from an underground site is envisaged, among other methods.

In accordance with the current status of the planning, the intention is to drill two exploratory shafts 7.5 m in diameter. From these shafts, in turn, prospect entries are to be driven within a depth range from 800 to 900 m. From the drifts, in turn, horizontal, directed coring operations are to be conducted over as long a distance as possible for further exploration of the salt dome.

A developmental project entitled "Controlled Horizontal Core Drilling Technique - An Additional Method for the Underground Exploration of the Gorleben Salt Dome by Long Boreholes", conducted by DBE, had the following objectives:

- Continuing development of control techniques for horizontal core drilling with the application of the wireline coring process for the correction of deviations in the vertical and horizontal directions,
- attainment of a borehole length up to 1500 m with the use of this technique, and
- testing for continuous orientation of the cores with high core recovery.

REQUIREMENTS

The execution of the project is subject to the following requirements:

- use of conventional drilling equipment and logging technology for facilitating operation by the drilling crew,
- achieving a core recovery of at least 95% for each core run, in order to investigate the stratigraphic sequence without interruption,
- use of wireline coring strings of size H (core diameter about 64 mm) for attaining superior core quality and long drilled distances,

- orientation of the cores for determining the spatial position of the strata,

- fivefold stabilization of the drill string in accordance with the analytical model[1] for improving directional stability,

- surveying of the borehole course at regular intervals during the drilling operation, in order to permit reliable navigation,

- continuous measurement and storage of the drilling parameters for analyzing the directional course of the borehole and monitoring the success of the corrective measures implemented,

- optimization of the length of the inner core barrel for practical purposes[2].

An endeavor was made to keep the directional course of the borehole within a "tolerance cylinder" 5 m in diameter over its entire length and directional changes within a limit of 0.5° per 10 m of length.

TEST PROGRAM

The input parameters were to be kept constant. Drill strings with clockwise and counterclockwise rotation and different positions of a maximum of five stabilizers over the foremost 20 m of the drill string, as well as variation of the bit thrust and rotational speed, were to be selectively applied, in order to exert an influence on the vertical and horizontal course of the borehole.

A survey of the test program is presented in Fig. 1.

TEST PROCEDURE

The drilling operations associated with the developmental project have been conducted in a potash mine by the SAARBERG-INTERPLAN GmbH on behalf of the Deutsche Gesellschaft zum Bau und Betrieb von Endlagern für Abfallstoffe mbH (DBE). The analytical work was performed at the Institute of Petroleum Engineering at the Technical University of Clausthal.

The following technical equipment has been employed:

Drilling rig:	Electrohydraulic drilling rig of type B1A with carriage-mounted power swivel for a rig of type B2A (rated input power: 110 kW), supplied by the Wirth Co.
Drill pipe:	Drill pipe for wireline coring of size H, with clockwise or counter-clockwise rotation, as well as matching Stratapax core bits, diamond reamers, and stabilizers with bladeshaped rib structures, from the LONGYEAR Co.
Shut-off equipment:	Annular preventers, kelly cocks, and conductor pipes from the ITAG Co.
Slush pump:	Oil well triplex plunger pump, type C-323, from the ITAG Co.
Drilling Fluid:	Waste brine with a high concentration of $MgCl_2$, without further additives
Recording of drilling parameters:	Explosion-proof drilling data acquisition unit from the PETTENPOHL Co., for the display and storage of the following drilling parameters: drilling speed, weight on bit, torque, rotational speed, flow rate and pressure of drilling fluid over the course of the borehole

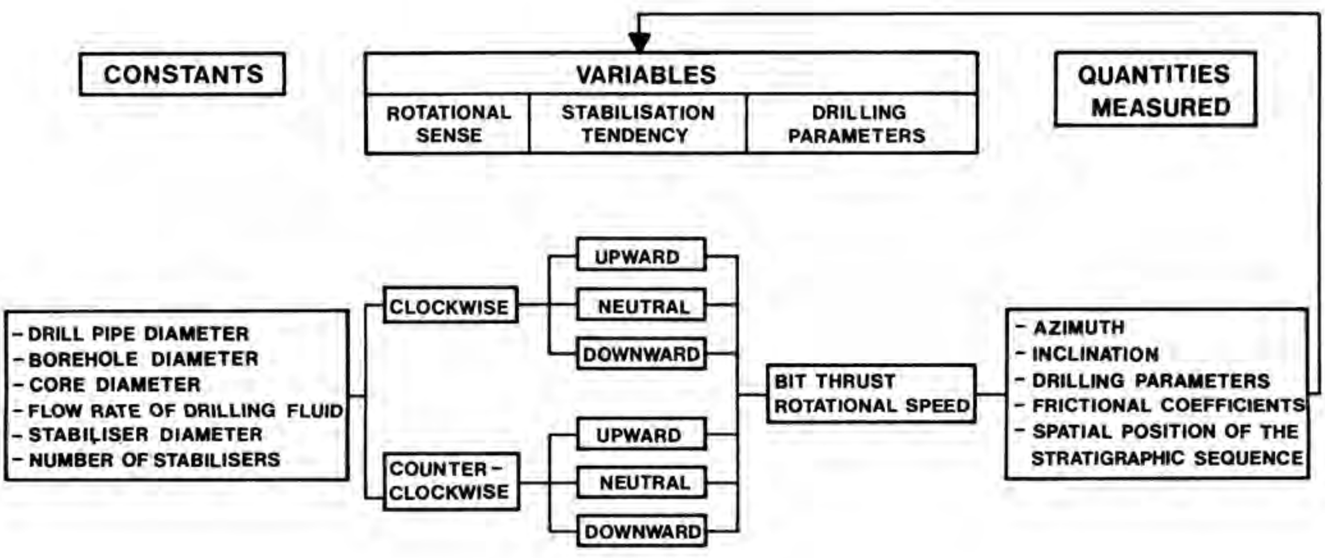

Fig. 1. Test Program.

Measuring equipment:	- Surveying of the borehole course during the drilling operation by means of single-shot tool and, in part, final borehole measurement by means of multishot tool with 10^0 compass and pendulum for horizontal application, with a measuring accuracy of $\pm 0.1^0$ for the pendulum, and 1^0 for the compass, from the EASTMAN INTERNATIONAL CO.
	- Orientation of the core by means of a core orientation tool supplied by the EASTMAN INSTRUMENTS CO.
	- Further safety devices, as specified by the mining authorities.

The drilling program comprised eight horizontal boreholes for coring purposes, with a total drilled distance of just about 7000 m. The longest distance drilled for an individual borehole amounted to 1522 m.

The boreholes penetrated preponderantly Staßfurt salt; Leine salt, hard salt, anhydrite and grey salt clay were encountered in only a few cases. Hence, the geological conditions can be viewed as relatively homogeneous.

RESULTS

An analytical model has been applied for ascertaining the position of the stabilizers in the vicinity of the core bit.

The required input data are:

- the angle of inclination of the borehole,
- the borehole diameter,
- the core diameter,
- the outer and inner diameter of the drill pipe,
- the outer and inner diameter of the outer core barrel,
- the length of the core barrel,
- the intended thrust on the core bit (net thrust), and
- the density of the drilling fluid.

In combination with the stabilizers, whose configuration is to be determined, these parameters exert a decisive influence on the tilt angle between the borehole axis and drill pipe axis, which is caused by the bending curve (bending of the drill pipe in the vicinity of the core bit). An optimal placement of the stabilizers for achieving directional stability (maintenance of a constant borehole inclination and azimuth) is realized when the tilt angle (and thus the angle of the resultant) approaches zero. By means of intentional deviation from the value "zero", desired deflections from a straight course of the borehole are achieved; that is, a tilt angle, whose extent is to be adjusted, is utilized for deliberate deviation of the borehole.

Control of the borehole course was achieved by means of various configurations of the first two stabilizers behind the reamer. The positions of the remaining three stabilizers was thereby always kept constant at the calculated distances of about 9, 15, and 21 m from the core bit. By means of these measures, the vertical course of the borehole was kept within the required tolerance range of ±2.50 m.

Influence was exerted on the horizontal course of the borehole through the use of drill pipe with clockwise or counterclockwise rotation, as the case required. The horizontal course of the borehole is considerably affected by the magnitude of the difference between the axial and radial cutting forces acting on the bit. The specified tolerance requirement of ± 2.50 m in the horizontal plane has been satisfied in the preponderant majority of cases. As a result of this measure, the necessity of employing downhole motors with a bent sub for altering the direction in the horizontal plane, with the associated high cost, is avoided.

The influence exerted on the borehole course through variation of bit thrust and rotational speed constitutes a secondary measure for delaying a round trip for repositioning the first two stabilizers behind the core bit.

The horizontal course of the borehole is also decidedly influenced by the design of the core bit. The use of a data unit with digital display as an aid for controlling the course of the borehole is important, since the maintenance of the optimal drilling data can thus be very effectively monitored. A survey of the measures best suited for controlling the course of the borehole is presented in Table I; these measures most effectively fulfil the intended control requirements. An example of the successful application of the control measures presented in Table I is illustrated in Fig. 2, in which the vertical and horizontal courses of a borehole are plotted. The deviations of the boreholes from the specified axes are compiled in Table II.

As far as improvements in effectivity are concerned, the following results have been achieved:

- long coring runs have been realized by optimizing the length of the inner core barrel at 15.84 m,

- through the intensive use of a data unit, a nearly uninterrupted documentation of the following drilling parameters has been realized: weight on bit, rotational speed, torque, drilling speed, flow rate and pressure of drilling speed, flow rate and pressure of drilling fluid over the length of the borehole. The data unit provides considerable assistance to the rig operator in reaching decisions concerning the alteration of bit thrust and rotational speed, since information on the actual values of the drilling data are continually indicated on the display. In combination with geological information and plotting of the borehole course, the data unit constitutes an important tool in reaching decisions for adopting appropriate control measures.

Finally, it should be remarked that the drilling crew has executed the surveying of the borehole course, the orientation of the cores, the operation of the unit for the acquisition of drilling data, and the control of the borehole course largely independently. This fact constitutes a proof of the operational maturity of the control method applied.

TABLE I

Measures adopted for controlling the course of the borehole

CASE	DEVIATION FROM SPECIFIED AXIS	INTENDED CONTROL	CONTROL MEASURES: ROTA-TIONAL SENSE	CONTROL MEASURES: STABILISER CONFIGURATION IN M	CONTROL MEASURES: DRILLING PARAMETERS F_A in daN	CONTROL MEASURES: DRILLING PARAMETERS n in min^{-1}	RESULT OF THE CONTROL MEASURES in °/30m
1		V H		1,44 C+R 9,08 2,34	> 500	> 250	V: −0,3 H:+0,2 V: −0,3 H:−0,2
2		V H		1,60 C+R 9,08 2,50	~500	> 250	V: −0,2 H:+0,1 NOT TESTED
3		V H		1,30 C+R 9,08 0,40	~500	> 250	V: +0,6 H:±0 NOT TESTED
4		V H		1,44 C+R 9,08 2,34	~500	< 250	V: +0,1 H:+0,3
5		V H		1,45 C+R 9,08 2,35	~500	< 250	V: − 0,3 H:−0,2
6		V H		C+R 9,08 5,34 0,40	> 500	< 250	V: +0,8 H:+0,5
7		V H		C+R 9,08 5,35 0,41	> 500	< 250	V: +1,1 H:−0,5
8		V H		2,50 C+R 9,08 3,40	> 500	< 250	V: −1,0 H:−0,4
9		V H		2,51 C+R 9,08 3,41	> 500	< 250	V: −1,2 H:−0,5

+V, +H ≙ Deviation from the specified axis viewed in the direction of drilling

V ≙ Side view of the vertical borehole course

H ≙ Top view of the horizontal borehole course

V ≙ vertical plane (+V ≙ upward deviation)

H ≙ horizontal plane (+H ≙ deviation to the right)

C+R ≙ Core bit and reamer

≙ Stabiliser

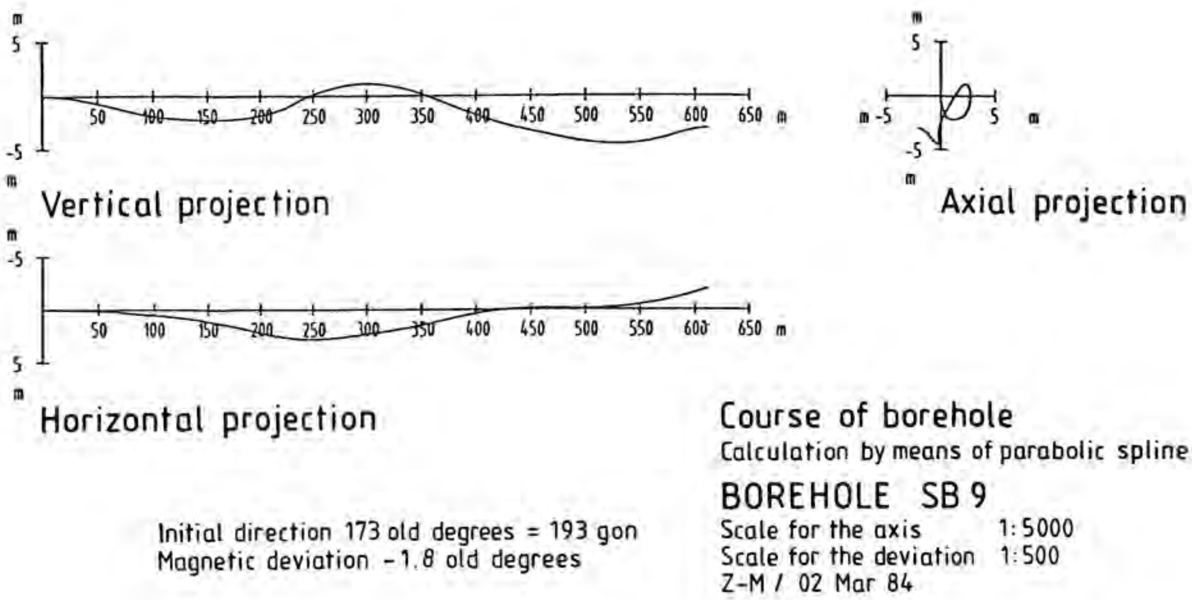

Fig. 2. Vertical and horizontal course of the borehole SB 9.

TABLE II

Deviations of the Borehole From Their Specified Oxes

Borehole	Final length achieved, on the basis of drill pipe	Last measured point, as referred to the specified axis	Absolute deviation for final point measured			
			horizontal		vertical	
	in m	in m	in m	in %	in m	in %
SB 1	338,90	337,86	- 1,26	0,37	+2,01	0,60
SB 4	1521,65	1515,02	+ 8,22	0,54	+0,68	0,05
SB 3	1411,65	1408,09	+25,01	1,78	+0,84	0,06
SB 2	987,80	958,73	+13,65	1,43	+0,13	0,01
SB 8	987,50	984,00	-54,89	5,58	+1,32	0,13
SB 9	627,80	611,67	- 2,00	0,33	-2,97	0,49
SB 7	195,20	175,33	- 2,03	1,16	-2,89	1,65
SB 10	923,20	921,91	-19,04	2,07	+2,07	0,23

Deviation of borehole viewed in direction of drilling:

+: horizontal deviation to the right, vertical deviation upward

-: horizontal deviation to the left, vertical deviation downward

PROSPECTS

The developmental project thus executed has proved that horizontal boreholes in salt rock can be controlled vertically and horizontally by appropriate positioning of stabilizers and the use of clockwise and counterclockwise drill strings in the sections concerned.

The technique of directed horizontal core drilling for exploring a salt dome over long distance has been developed to operational maturity. An efficient drilling system has thus evolved; this system allows effective control of the borehole course in the horizontal and vertical planes under operating conditions, with an expected arbitrary frequency of repetition.

REFERENCES

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