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Installation of the Gudrun platform on the Norwegian continental shelf

The Gudrun platform, which was officially opened on 19 August, is the first new Statoil-operated platform on the Norwegian continental shelf since Kristin in 2005.
(See also report on page OG 120)

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OIL GAS EUROPEAN MAGAZINE
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In this issue: **Buyers' Guide** for the Petroleum Industry

Contents

Analytical Research and Experimental Tests on the Technology for Drilling Small Diameter Channels with small Radius of Curvature

By I. LYAGOV, N. VASILEV, M. REICH and M. MEZZETTI*

Abstract

This article presents a novel approach to stimulate wells by using a slim short radius directional BHA to drill small directional wells from the production well into the reservoir. The hardware was designed, built and tested on a test stand using concrete blocks to represent the formation. The paper was prepared in cooperation between the universities of St. Petersburg and Freiberg.

Introduction

Maintaining production volume at a high level involves the maximum use of the opportunities of each well. The application of technologies of intensifying well productivity, such as hydraulic fracturing, acid treatment, thermal stimulation, etc. is not always possible due to a number of geological and technological reasons. However, each of these methods may have negative effects on the reservoir properties. The effectiveness of these methods, the impact on the producing zone is often limited by an insufficiently reliable hydrodynamic connection between the well and the producing formation, which may be caused, for example by deterioration of reservoir properties over time, the lack of rock permeability, reservoir heterogeneity or insufficient length of perforations [1].

A new technology, known as "Perfodrill", has been designed to increase the perforation production flow rates and increase the capacity of injection wells (by increasing the filtration area into the producing zone), reduce water cut (by reducing the drawdown), as well as improving the turnaround time for the well operation (by increasing the flow efficiency of the producing zone) [2].

Figure 1 shows a diagram with the possibilities that could be achieved with the Perfodrill technology for single and multiple perforations.

In this article a short description of the Perfodrill system will be given. Additionally, the analytical and experimental research as well as some of the improvements to the Perfodrill bottom hole assembly (BHA) after experiments on the special test rig will be presented.

1 Development Description: Design and Operation

The first stage of the technology involves the casing removal in order to put the Perfodrill equipment in place. The Perfodrill layout, including a bit, an orientation tool, a whipstock and anchors for fixation, is shown in Figure 2.

After installation of Perfodrill, a special gel is injected into the well and then a cement plug is placed where the casing used to be. This plug is drilled through with the bit and then the extra long channels can be drilled [1, 2, 3]. Perfodrill could be applied for drilling one-, two-, or multiple well configurations. The device consists of the pushing device, coupled with the overflow valve on the top and at the bottom and positioned in the tube housing assembly, a guide adapter connected through a hydro-mechanical power loader, a flexible tube with a curved two- piece positive displacement motor with a 4 to 8° bent housing angle and the bit (Fig. 2). At the bottom the Perfodrill is connected to a whipstock with an angle of 4 to 11 °. The anchor works as a support at the bottom of the hole [2]. The Perfodrill specifications are presented in Table 1.

In the compact layout, Perfodrill offers the possibility of multi-shot position surveys (autonomous action principle), the measuring system can be included in the BHA. The use of the system offers a variety of operational advantages:

- Production rate or injection capacity resp. is

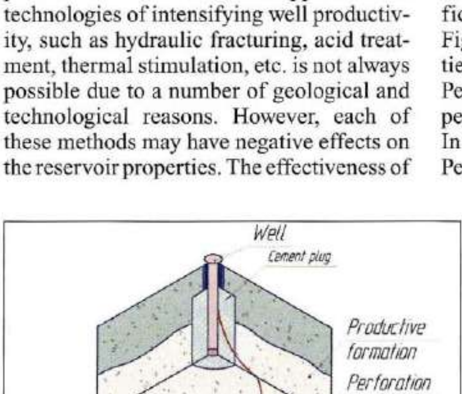

Fig. 1 Arrangement of perforations and their radial projection

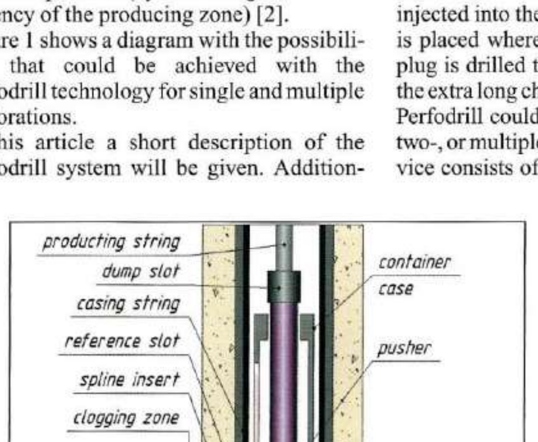

Fig. 2 Perfodrill layout

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Table 1 **Perfodrill specifications**

Bit diameter	56–58 mm
Borehole deviation	5–9 m
Borehole diameter	140 mm
Perforation length (in the first stage of the project)	10–15 m
The number of perforation channels on a single layer	up to 4
Radius of curvature	5–13 m
Build rate	2.8–5.5 °/m
BHA length (layout assembly)	35–43 m
Whipstock angle	4–11 °
WOB (weight on bit)	600–800 kg
Flow Rate (Triplex Pump 03.01 PT-50D2)	1.5–2 l/s
Torque on the PDM D-43.5\6.42.010	70–110 Nm
Engine speed	90–180 rpm
Pressure drop in the system	4–8 MPa
Axial load on the bit	2–6 kN

increased due to the larger effective filtration area

- The water cut is reduced due to the reduced differential pressure during production
- Reducing the deterioration rate of the reservoir properties increases the service life of wells.

The Perfodrill system was developed on the basis of RF patents No. 2213195, 2213197, 2124125, 2147699 and 2284402. It has passed field tests and therefore it can provide technical reference that includes more basic operational and technical characteristics compared to other technologies known to be used in the producing zone [1, 2, 3].

2 Analytical Research of the Perfodrill BHA

A three dimensional model of the Perfodrill BHA was developed with the software package ANSYS. The model of the BHA has an overall length of 2 m and is positioned with a given inclination.

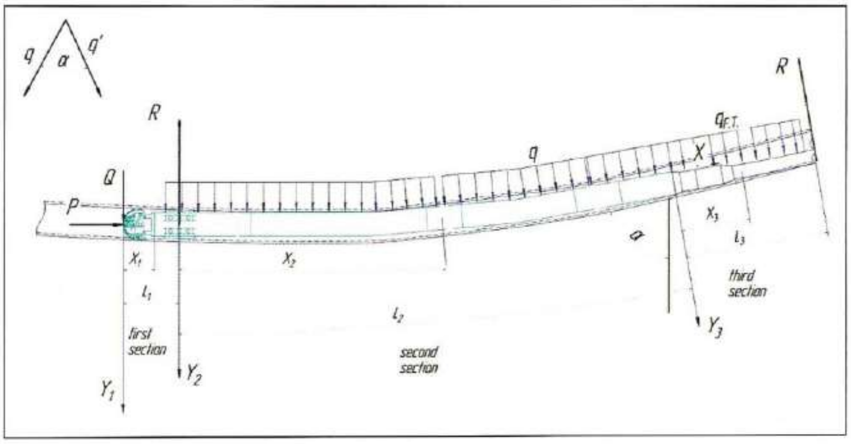

Fig. 3 Diagram of the forces acting on an inclined BHA

Prior to running the strength analysis in ANSYS, it is required to perform a static strength analysis. The finite element method (FEM) in ANSYS allows solving a wide range of physical problems mathematically formulated as a system of differential equations. This method can be used for the analysis of the stress state in complex structures. Before working with ANSYS, it is necessary to study the elastic stress condition layout of the positive displacement motor (PDM) in an inclined hole section, as shown in Figure 3. The differential equation of the bent axis of the Perfodrill system (according to the three moment theorem [4, 5]) will have the following form:

1st stage:

$$E_1 \cdot I_1 \cdot \frac{d^2y}{dx^2} = -P \cdot y + Q \cdot x + \frac{q_1 x^2}{2} \qquad (1)$$

2nd stage:

$$E_1 \cdot I_1 \cdot \frac{d^2y_1}{dx_1^2} = -P \cdot y_2 + Q \cdot (l_1 + x_2) - R \cdot x_2 + \frac{q_T x_2^2}{2} + \frac{q_T l_1^2}{2} + q_T l_1 x_2 \qquad (2)$$

3rd stage:

$$E_2 \cdot I_2 \cdot \frac{d^2y_3}{dx_3^2} = -P \cdot y_3 + Q \cdot (l_1 + l_2 + x_2) - R \cdot (l_2 + x_3) + q_1 l_1 l_2 + q_1 l_1 x_3 + \frac{q_1 l_1^2}{2} + \frac{q_1 l_2^2}{2} + q_1 l_2 x_3 + \frac{q_2 x_3^2}{3} \qquad (3)$$

with:

P	axial load on the bit, $P = 6000\ N$
Q	deflecting force, N
$E_n \cdot I_n$	perfodrill bending stiffness,
q_n	the transverse component of the perfodrill components weight per unit length, N/m
R_n	the reaction of the borehole wall, N
*n	suffix indicating the section in the BHA
l_1	the distance from the bit to the stabilizer, m
l_2	distance from stabilizer to the connection, m
l_3	the distance from the top connection to the flexible tube, point of contact with the bore-h ole wall, m.

The following boundary conditions are used for eqs. (1) through (3)

if $x_i = 0$, then $y_i = 0$

if $x_i = l_i$, then $y_i = r_i$

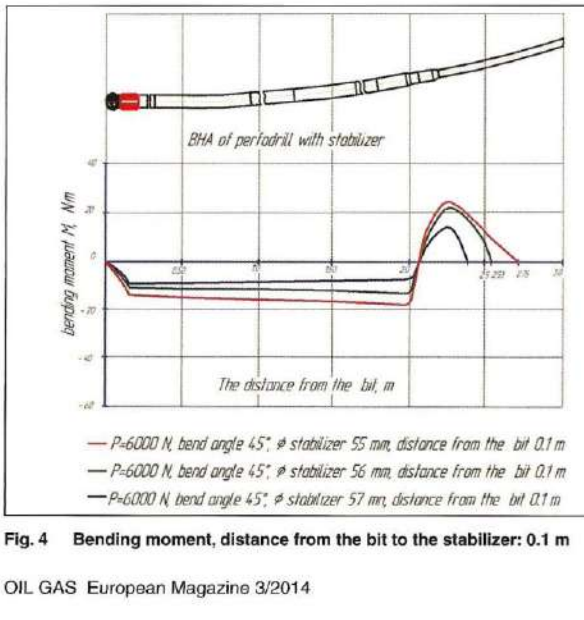

Fig. 4 Bending moment, distance from the bit to the stabilizer: 0.1 m

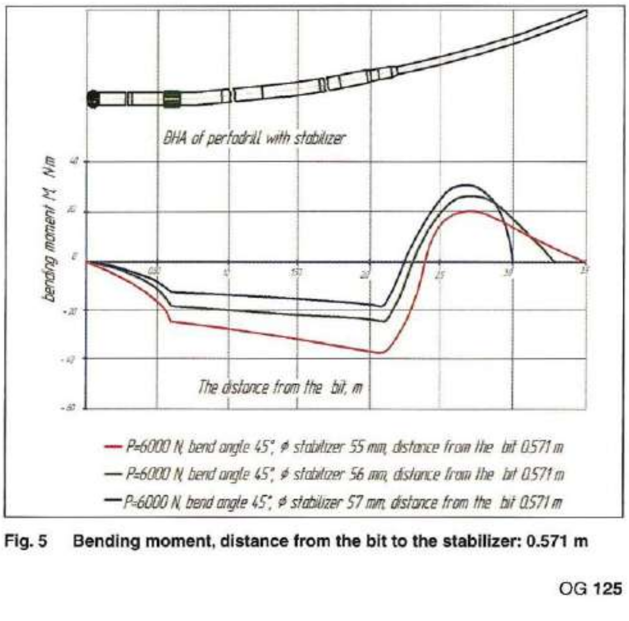

Fig. 5 Bending moment, distance from the bit to the stabilizer: 0.571 m

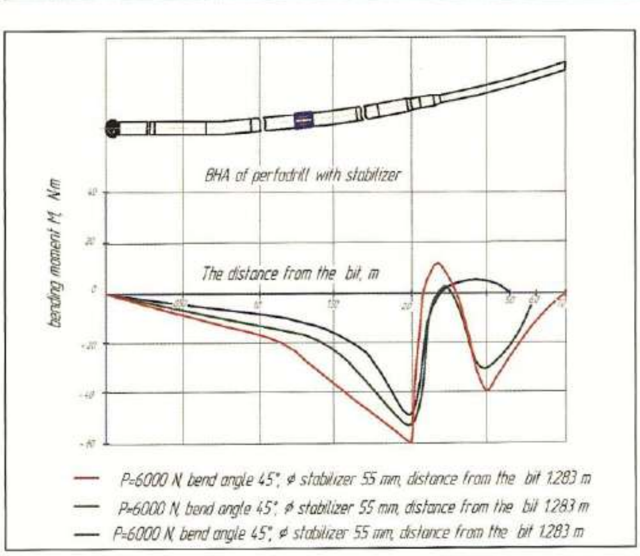

Fig. 6 Bending moment, distance from the bit to the stabilizer: 1.283 m

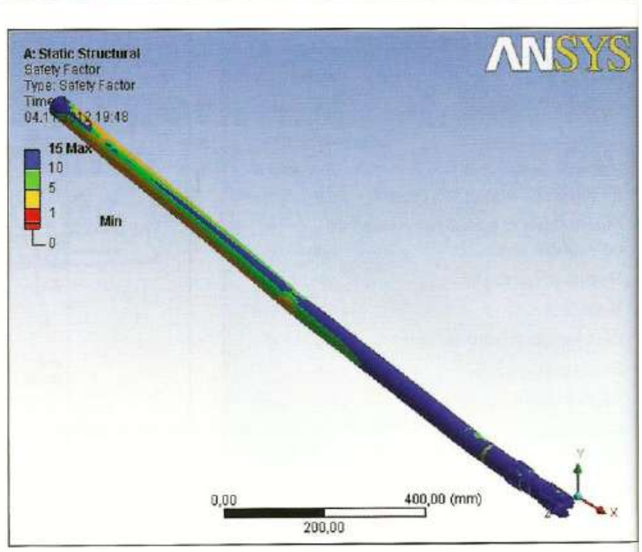

Fig. 7 Safety Factor (contingency factor)

if $x_2 = 0$, then $y_2 = r_i$

if $x_2 = 0$ and if $x_1 = l_1$, then $\frac{dy_1}{dx_1} = \frac{dy_2}{dx_2}$

if $x_2 = l_2$ and $x_3 = 0$, then $y_2 = y_3$

if $x_3 = 0$ and if $x_2 = l_2$, then $\frac{dy_2}{dx_2} = \frac{dy_3}{dx_3}$

if $x_3 = l_3$, then $\frac{dy_3}{dx_3} = 0$

if $x_3 = l_3$, then $y_3 = r_2$

if $x_3 = l_3$, then $\frac{d^2 y_3}{dx_3^2} = 0$

where:

r_w the apparent radius of the well, m.

In the resulting calculations, the bending moment curves acting on the perforations of the layout were obtained (Figs. 4–6).

Further calculations were made using a BHA model with a stabilizer of 57 mm diameter, which is located at a distance from the bit of 0.1 m. It can clearly be seen in Figure 4 that the magnitude of the bending moment is lower than in the other cases.

Having determined the loads on the BHA during operation, the modeling can begin with the program ANSYS by applying finite element methods. After the model creation, the BHA materials were specified (main tools according to materials specified by VNIIBT, steel 40 XN according to GOST 4543-71 and hard material inserts WC – 8 Co according to GOST 25395-90). Also, the BHA was meshed into finite elements, and the fixation points specified as well as the acting forces from the calculations. The safety factor can be evaluated in ANSYS according to two theories of strength. For this model, the maximum equivalent stress approach was used. It was found, that for the BHA the safety factor is always greater than 1, as shown in Figure 7. Equivalent von Mises stress on the PDM is shown in Figure 8.

It can therefore be concluded that the BHA withstands the stresses and strains occurring during operation.

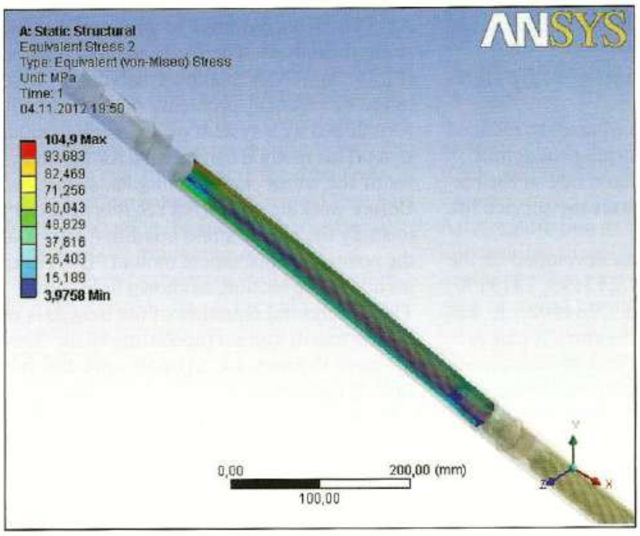

Fig. 8 Equivalent PDM rotor stress

3 Description of the Perfodrill Test Rig

Test experiments of the Perfodrill system were conducted with one stabilizer installed in the position as shown in Figure 4. The special experimental set-up that was used to test the system is shown in Figure 9.

This set-up allows testing the function of the pushing device (a horizontal version of the Perfodrill consisting of the top and bottom (no anchor) sections. The adapter includes dial gauges to measure the pressure and the axial load. Figure 10 shows the drilling process of the sixth channel [3].

The rotary unit and hydro-mechanical power loader device operate as follows: when moving the pusher tube by hand to its highest position, the thickened part is mechanically pushed out of the hydro-fixing device (differential piston on the chamfered portion of the Perfodrill guide). It then hits the other end of the piston with the smaller diameter section in the slot trap housing. The fixation of the BHA in the body takes place with a rotation of 45° while maintaining limited movement up to 70 mm. Within this process

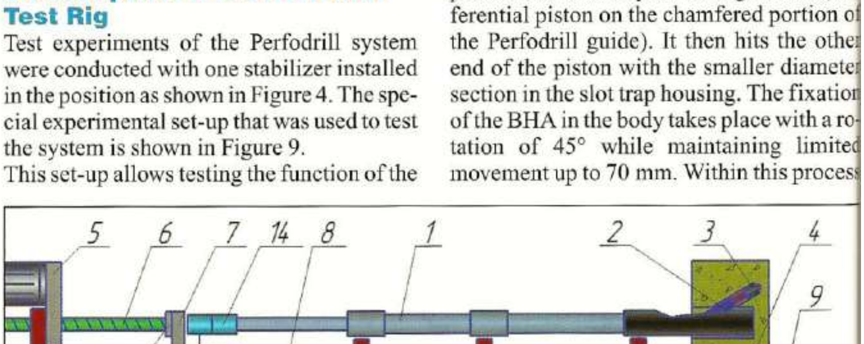

Fig. 9 Test stand components: 1–perfodrill, 2–positive displacement motor (PDM) D-43, 3–bit, 4–concrete block (1.8 m x 1.8 m x 1.6 m), 5–linear actuator drive mechanism, 6–linear actuator, 7–trolley, 8–frame, 9–drilling fluid container, 10–high-pressure hose, 11–electric gear pump, 12–pipe line for drilling fluid, 13–dynamometer, 14–guide adapter

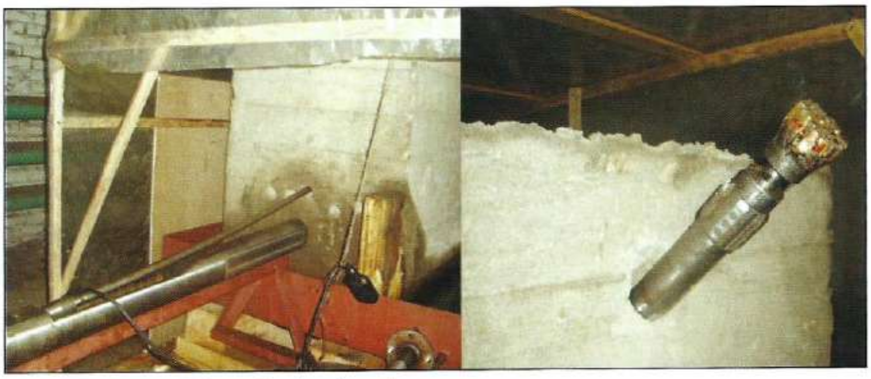

Fig. 10 Test rig for drilling perforation channels

Fig. 11 Test bits of different sizes

other connected components are also rotated. The pushrod tube acts autonomously. As the axial advance mechanism moves down under the influence of pressure, the thick part of the differential piston is forced out along the inclined section towards the guiding slot. Then the tube pusher completes rotation for another 45 degrees. Under downhole conditions, it provides spacing of each additional channel with a turn of the Perfodrill body with a 90 ° deflector.

Fig. 12 Side view of the milling operation in casing

After drilling more than 10 channels in a concrete block (2 m length each), the BHA was dismounted and a visual inspection of its basic components was performed. Further analysis showed that there was no significant wear on the bit and on other Perfodrill components.

In the next stage of the experiments the milling properties of different Perfodrill bits were investigated. For this purpose, the appropriate bits were manufactured in the USPTU (Ufa) laboratory (Fig. 11), as well as a deflecting tool with different angles. A pump station with a triplex pump (1.3 PT-50D2, maximum capacity of 2 l/s) was included in the test rig. The maximum cutting rate achieved in the concrete block was 12 m/h with a bit type PDC-56 run with a flow rate of 1.8–2.0 l/s and a pressure in the pipe of 7 MPa [6].

For milling, the DI-56 bits (Fig. 11) with impregnated pieces of hard materials of VC-6 and VC-7 (according to GOST 25395-90), for shock-free penetration into the rock or formation zone, showed the best results.

Milling out of a production string with 8 mm wall thickness with a diameter of 146 mm (Fig. 12), and drilling a lateral hole in the concrete block, was performed with a drilling rate of 0.4–0.5 m/h with axial loads of 0.2–0.3 kN and pump pressures of 5–7 MPa.

4 Evaluation of the Test Experiments

After the tests some wear was found on specific components of the BHA, especially on certain components of the bearing section. Theoretical investigations were therefore made to find ways to reduce the loads on the tool.

Using a special software at the TU Bergakademie Freiberg revealed that a fully stabilized Perfodrill BHA with two stabilizers would reduce the loads on the setup.

The optimum stabilizer placement was found to be as shown in Figure 13. Two stabilizers with 56 mm diameter each are in-

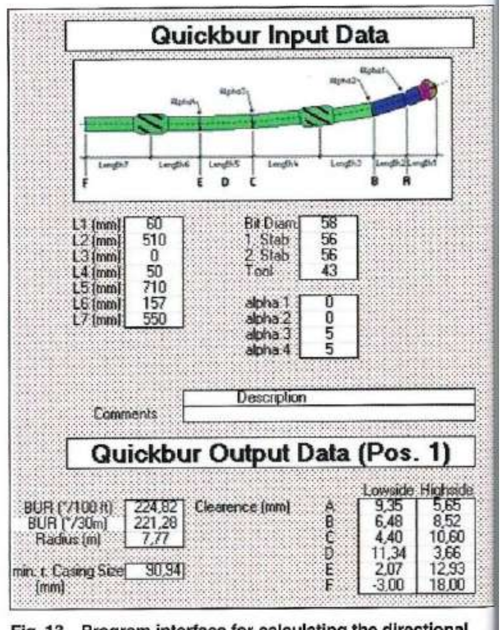

Fig. 13 Program interface for calculating the directional behavior of a directional motor of a given geometry

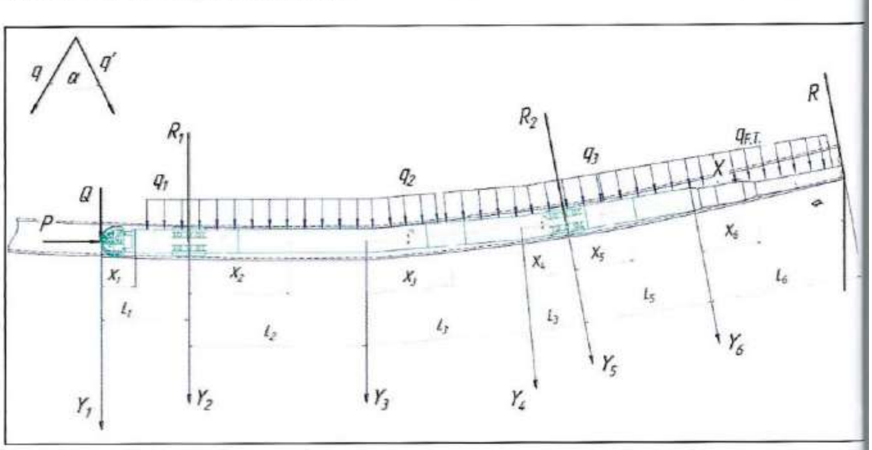

Fig. 14 Loads on the Perfodrill BHA with two stabilizers in a curved channel

stalled at distances of 0.57 m and 1.48 m resp. from the bit. As a result, it was determined that the radius of curvature to be drilled will be 7.7 m.

The loads on the assembly in the borehole were calculated using the three-moment theorem equation, see Figure 14 [4, 5].

At this stage it needs to be mentioned that the loads generated by the deflecting force Q change according to the skewing angles, when determining the transverse component of the weight per unit length, as shown in the Figure 14. The problem can be further solved, in a similar way including all boundary conditions. The bending moment on the bit is assumed to be zero.

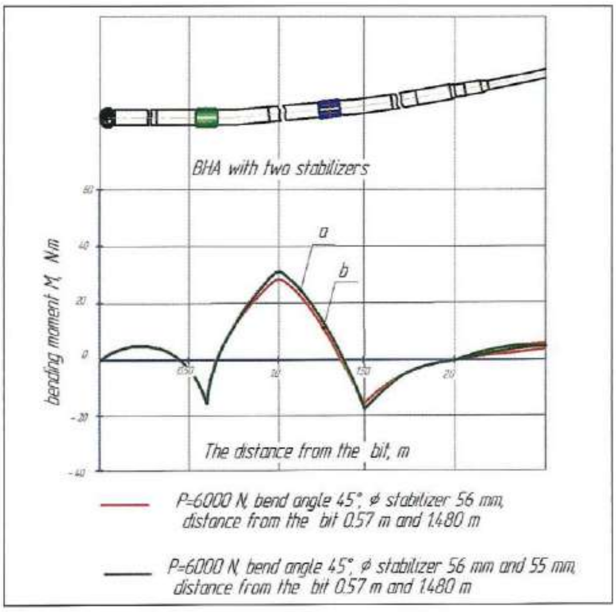

Fig. 15 Bending moment on the BHA with two stabilizers: a) first stabilizer 56 mm diameter and second stabilizer with 55 mm diameter, b) both stabilizers with 56 mm diameter

Solving the problem with MathCAD allows plotting the bending moments (Fig. 15) and comparing them with those previously obtained. It can be concluded that the use of BHA with two stabilizers raises the reliability of the drilling equipment and its service life.

Conclusions

1 Using the Perfodrill technology it was possible to drill long perforation channels (for the first stage of the project 10–15 m long) of small diameter (56–58 mm) and with a radius of curvature of 5 to 13 m on the predicted trajectory.
2 During the experiments on the test rig, channels were drilled with different types of bits, thus evaluating the possibility of working with different combinations of tools in the BHA.
3 Analytically it was determined that the highest equipment reliability for the Perfodrill is achieved by a BHA with two stabilizers.

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