New drilling methods for the conductor casing operations

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Nové vŕtacie metódy pre prevádzača zapúzdrenia operácii

The necessity to apply casing to wells drilled in loose rock strata have recently created conditions for the modernization of old solutions and the development of new drilling technologies. The newest World's design and technological solutions for rotary, rotary-percussion and percussion drillings are presented in the paper with a further development directions indicated. An emphasis is put on the comparison of frequently diversified technologies basing on the concurrent drilling and the casing operations. In the course of an analysis of distribution of forces acting on the casing, the strength conditions were specified to enable a proper selection of physical properties and geometrical parameters of pipes. An exemplary calculation indicates that axial forces and torque have an influence on the selection of the outer diameter of casing made of various materials.

Key words: *Overburden drilling, casing operations*

Introduction

When drilling the oil wells, considerable problems with tripping casing to rather loose Quaternary strata may be encountered. The so-called conductor casing has to be applied. This casing is frequently 340-760 mm (13 3/8 ÷ 30") of diameter and some tens of meters of length. This is a first casing which secures the well against sliding of the surface loose material (sand, gravel). The conductor casing is also necessitated by the need of intaking the drilling mud during the first stage of drilling. The casing is tripped to a depth where the compact layer appears. Then the whole section and the bottom of the well are cemented. To minimize the problems with drilling and casing in the near-surface rock strata, new drilling technologies have been worked out. Among the newest solutions presently applied throughout the World are technologies lying in concurrent drilling and casing operations [2, 3, 4]. These technologies reduce the time of drilling and the risk of lost ductibility of the well.

Division of concurrent drilling and casing methods

Depending on the type of drilled rocks and the destination of the well, a number of concurrent drilling and casing systems were worked out. Presently used world's engineering drilling technologies of concurrent drilling and casing differ in the way of drilling, the type of drive on the drilling tools and casing, the type of bits, their design, technology and the trajectory of the well's axis [4].

In view of the presented division criteria and analysis of the presently applied world's solutions, the following concurrent drilling and casing systems can be distinguished:

- with a lost bit,
- with casing and a wire line bit,
- with a downhole hammer and pushing casing,
- with a downhole hammer and pulling casing,
- rotary drilling with a concurrent rotation of the string and casing.

Determining geometrical parameters of casing for concurrent drilling and casing operations

During concurrent drilling and casing operations it is crucial to determine a minimal torque value and a load generated by the rig. Depending on the applied drilling method, they will be transmitted to the string and the bit, and also to the casing. The selection principles of the string and mechanical parameters of drilling technology with various types of bits are presented in the literature [1]. When selecting necessary technological parameters for casing for the concurrent drilling and casing operation, the methodics presented in [4] is proposed.

When casing down to tens of meters, the steel or cast iron pipes are usually used. The present material solutions enable polymerconcrete, vitrified clay, HDPE or GRP to be used.

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(Recenzovaná a revidovaná verzia dodaná 6. 10. 2006)

When designing the casing, first, the size of end-diameter of the borehole is assumed; then the inner and outer diameters of the casing are being selected (for exploitation, technical, and guide pipes), as well as bit diameters. One of the design criteria is the clearance between the casing and the bit.

The minimal inner diameter of conductor casing is a derivative of the assumed end-diameter of the borehole, number of casing pipes, and the diameter of the applied bits. In practice, its minimal value can be calculated from the formula:

$$D_W = D_S + k_W \tag{1}$$

The size of the external diameter of the conductor casing will depend on the applied technology (here: concurrent drilling and casing).

Depending on the casing disposal technology, the following impacts can be distinguished:

a, axial force on casing (pushing or pulling of casing to the borehole),

b, axial force on casing with simultaneous rotation of the casing column.

Denotations:

$\sigma_1, \sigma_2, \sigma_3$ – axial stress, [N/m^2],
$\tau_{1,2}, \tau_{2,3}, \tau_{3,1}$ – static stress, [N/m^2],
μ_i – Poisson coefficient of i-th geotechnical layer, [-],
ρ_m – density of casing material, [kg/m^3],
$\rho_{pł}$ – density of drilling mud, [kg/m^3],
σ_{zr} – counterpart stress (reduced), [N/m^2],
D_w – inner diameter of casing, [m],
D_z – outer diameter of casing, [m],
f – coefficienct of bit friction against rocks, [-],
F_G – weight of casing, [N],
f_i – coefficient of friction between the i-th geotechnical layer and casing, [-],
F_T – friction force of casing against the borehole wall,[N],
F_W – pushing or pulling force, [N],
g – acceleration of gravity, [m/s^2],
h_k – thickness of k-th geotechnical layer, [m],
k_W – magnitude of inner clearance between the bit diameter and the inner casing column through which the bit is driven, [m],
L – length of casing, [m],
M – torque, [Nm],
N – number of drilled geotechnical layers, [-],
N_i – side force on casing from the i-th geotechnical layer, [N],
P_{zi} – pressure of formation fluids filling the i-th geotechnical layer, [Pa],
Re_m – yield of casing material, [Pa].

Axial force on casing

The pushing or pulling force (F_W) value, needed to dispose the casing in the borehole, should be calculated from the following dependence:

$$F_W = F_T - F_G \tag{2}$$

The weight of the casing should be calculated from the formula:

$$F_G = \frac{\pi}{4}\rho_m g L (D_z^2 - D_w^2)\left(1 - \frac{\rho_{pł}}{\rho_m}\right) \tag{3}$$

The friction force of the casing against the borehole walls should be calculated from the dependence:

$$F_T = \sum_{i=1}^{N} f_i N_i \tag{4}$$

The value of the side force, coming from a single geotechnical layer, depends on the geostatic pressure value in the given layer, the Poisson coefficient and the pressure of the formation water filling the layer:

$$N_i = \frac{\mu_i}{1-\mu_i} g \sum_{k=1}^{N} \rho_k h_k - \frac{1-2\mu_i}{1-\mu_i} P_{zi} \tag{5}$$

Accounting for the presented formulae, a minimal value of the axial force (pushing or pulling) needed for disposing of the casing, should be calculated from:

$$F_W = \sum_{i=1}^{N} f_i \left(\frac{\mu_i}{1-\mu_i} g \sum_{k=1}^{N} \rho_k h_k - \frac{1-2\mu_i}{1-\mu_i} P_{zi} \right) - \frac{\pi}{4} g \rho_m L (D_z^2 - D_w^2) \left(1 - \frac{\rho_{pł}}{\rho_m} \right) \tag{6}$$

When the F_W value turns out to be less than zero, the casing shall gravitationally move in the borehole.

Having assumed the following strength condition:

$$\frac{4F_W}{\pi\left(D_z^2 - D_w^2\right)} < Re_m \tag{7}$$

we obtain an equation for determining the minimal value of external diameter:

$$D_z > \sqrt{D_w^2 + \frac{4\sum_{i=1}^{N} f_i \left(\frac{\mu_i}{1-\mu_i} g \sum_{k=1}^{N} \rho_k h_k - \frac{1-2\mu_i}{1-\mu_i} P_{zi} \right)}{\pi Re_m + \frac{\pi}{4} g \rho_m L \left(1 - \frac{\rho_{pł}}{\rho_m} \right)}} \tag{8}$$

Axial force on the casing with a concurrent drilling and casing

Some of the applied technologies require imposing axial force with a simultaneous rotation of the casing. In such a case the torque (M) transmitted from the bit on the casing has to be accounted for.

It is proposed that the value of equivalents of compressive and torsional stresses on the casing was calculated on the assumption of highest non-dilatational strain energy.

$$\sigma_{zr}^2 = \frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 + 6\left(\tau_{1,2}^2 + \tau_{2,3}^2 + \tau_{3,1}^2\right)\right] \tag{9}$$

By analyzing the uniaxial state of stresses in casings, the following is obtained:

$$\sigma_{zr} = \sqrt{\sigma^2 + 3\tau^2} \tag{10}$$

Should values of equivalent stresses be lower than the yield of the casing material, and assuming the following dependences:

$$\sigma = \frac{4F_W}{\pi\left(D_z^2 - D_w^2\right)} \tag{11}$$

$$\tau = \frac{16MD_z}{\pi\left(D_z^4 - D_w^4\right)} \tag{12}$$

By assuming a strength condition:

$$\sigma_{zr} < Re_m \tag{13}$$

and by accounting for (10), (11), (12), a selection condition is obtained for physical properties and geometric parameters of casing, if the casing was moved (a simultaneous rotation and drilling of the rock mass).

$$\sqrt{\left(\frac{4F_W}{\pi\left(D_z^2 - D_w^2\right)}\right)^2 + 3\left(\frac{16MD_z}{\pi\left(D_z^4 - D_w^4\right)}\right)^2} < Re_m \tag{14}$$

The minimal outer diameter value can be calculated from the dependence:

$$aD_z^8 - bD_z^4 - cD_z^2 - d > 0 \tag{15}$$

where:

$$a = Re_m^2 \tag{16}$$

$$b = \frac{16F_w^2}{\pi^2} + 2Re_m^2 D_w^4 \quad (17)$$

$$c = \frac{32F_w^2 D_w^2 + 2304M^2}{\pi^2} \quad (18)$$

$$d = \frac{16F_w^2 D_w^4}{\pi^2} - Re_m^2 D_w^8 \quad (19)$$

Having analyzed the course of the function:

$$g(D_z) = aD_z^8 - bD_z^4 - cD_z^2 - d \quad (20)$$

intervals where it is positive are defined. Accounting for the condition $D_z > D_w$, equation (20) is numerically solved. The searched minimal D_z meets the condition $g'(D_z)>0$.

Exemplary calculations

Basing on these dependences, exemplary calculations were made for outer diameters of the conductor casing.

The dependence of minimal outer diameter of axial force and torque for the low density polyethylene LDPE (Re=20 MPa) casing of inner diameter Dw=300 mm is presented in Fig. 1.

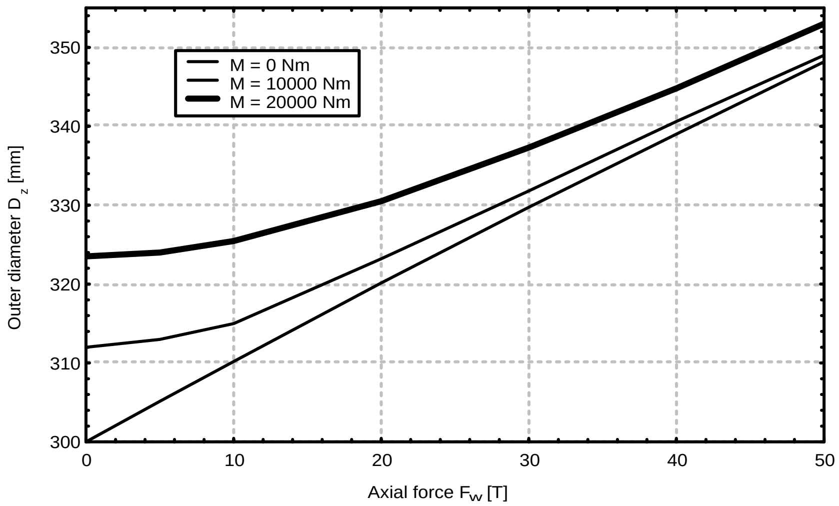

Fig. 1. Minimal outer diameter vs. axial force and torque for low density polyethylene LDPE (Re=20 MPa) casing of inner diameter Dw=300 mm.

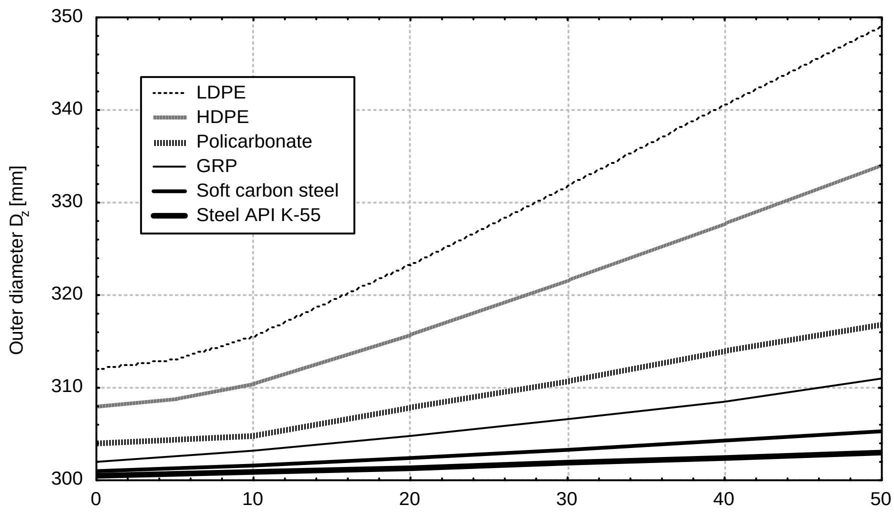

Fig. 2. Minimal outer diameter vs. axial force and material used for casing (inner diameter Dw=300 mm, torque M=10000 Nm)

Next, the influence of type of material used for casing on the minimal diameter of outer casing was analyzed. Calculations were based on the yield of various materials (Table 1).

Tab. 1. List of yield values for various casing materials.

Type of material	**Yield Re** [MPa]
Soft carbon steel	200
Standard steel St3	240
Strong steel API K-55	360
LDPE – low density polyethylene	20
HDPE – high density polyethylene	30
GRP – glass fiber-reinforced epoxy resins	100
PP- Polypropylene	35
Polycarbonate	60

The results of calculations of minimal outer diameter of conductor casing against the axial force and the material are presented in Fig. 2. Calculations were made for casing of the inner diameter D_w=300 mm, and the torque M=10000 Nm. The influence of casing material on the outer diameter of conductor casing under the axial force Fw=25 T and torque M=10000 Nm is presented in Fig. 3.

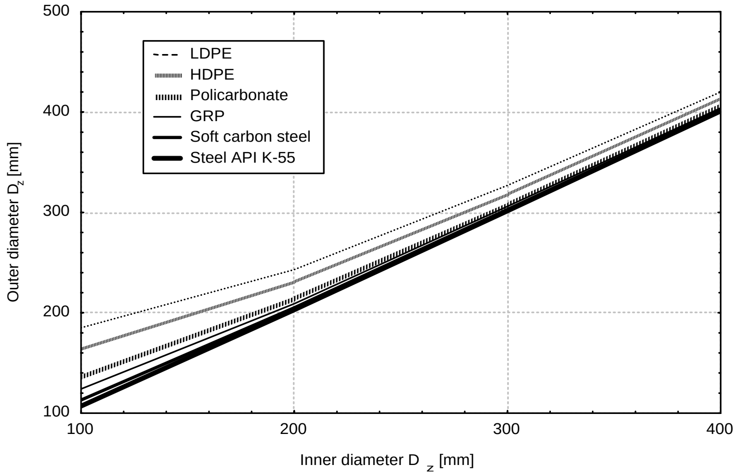

Fig. 3. Dependence of minimal outer diameter of conductor casing on the assumed inner diameter and material used for casing under the axial force Fw=25 T and the torque M=10000 Nm

Summing up

At present, the development of new drilling techniques and technologies, in that concurrent drilling and casing, has been recently observed over the world. Among the newest design solutions in this respect are: with the lost bit, with the wire line bit, with the downhole hammer and with a system of concurrent rotation of the string and casing.

The correct selection of casing depends on the applied drilling technology and the geological conditions. Formulae presented in this paper are recommended when making strength calculations for the casing.

For boreholes drilled in loose near-surface ground and rock layers, casing of non-steel material can be also used.

With the increasing axial force and torque on the casing, the thickness of casing walls should be also increased; the increase of wall thickness is bigger for lower yield casing.

Realized within Statutory Research Program
of the Faculty of Drilling, Oil and Gas, AGH-UST.

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