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STRESS STATE ANALYSIS IN ASPECT OF WELLBORE DRILLING DIRECTION

ANALIZA ROZKŁADU NAPRĘŻEŃ W ASPEKCIE KIERUNKU WIERCENIA OTWORU

Drilling directional wells challenges designers. Apart from known problems until now they face exact description of stress distribution in near wellbore region issue. Paper presents analysis of stress state taking into account drilling direction. The transposed in-situ stress state relative to the borehole coordinate system (Cartesian borehole coordinate system) and the total stress component at the borehole wall (cylindrical coordinate system) exhibits cyclic behaviour with respect to drilling direction of borehole. It allows to find optimal wellbore path.

Keywords: directional drilling, stress state, wellbore path

Wiercenie otworów kierunkowych stanowi duże wyzwanie dla projektantów. Poza problemami typowymi obecnie staja oni w obliczu zagadnienia dokładnego opisu rozkładu naprężeń w strefie przyotworowej. Artykuł przedstawia analizę stanu naprężeń w aspekcie kierunku wiercenia. Rozkład naprężeń transponowany do układu odniesienia związanego z otworem wiertniczym (kartezjański układ współrzędnych zgodny z kierunkiem otworu wiertniczego) oraz składowe naprężenia na ścianie otworu wiertniczego (w cylindrycznym układzie odniesienia) wykazują cykliczną zmienność zależną od kierunku wiercenia. Pozwala to na określenie optymalnej trajektorii osi otworu wiertniczego.

Słowa kluczowe: wiercenie kierunkowe, rozkład naprężeń, trajektoria otworu wiertniczego

1. Introduction

Drilling directional wellbore requires understanding many additional factors like stress field variation with azimuth and inclination change. Bradley is acknowledging as a person that introduces geomechanics to the drilling industries in seventies (Cheatam et al., 1984). From that time, industry and services has rapidly developed in new wellbore drilling as well as in utilizing

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wells in challenging areas (Gonet et al., 2012; Nagy et al., 2011; Śliwa et al., 2003). Maintaining a stable well is of primary importance during drilling. For this reason describtion of stress state in the near wellbore region is key problem. Drilling process will result in perturbation of insitu stress state. What consequently requires methods to keep stable wellbore wall. Hole collapse and solid particle influx into mud must be prevented (Aadnoy, 2005). Wellbore stability requires a proper balance between the uncontrollable factors of earth stress, rock strength, and pore pressure, and the controllable factors of wellbore fluid pressure and mud chemical composition (Jones, 1996). There are many factors that influence the stress state of a wellbore. Some of these operational and technically induced factors can be regulated and controlled to obtain the desired results. Other factors like the formation strata and lithology of the environment are uncontrollable. During the initial operation stage, certain operating parameters take precedence over others. The most important is hydrostatic pressure, which can be managed by adding weighting material like barite. Another are wellbore inclination and azimuth, which can be optimised during the project stage.

2. Stress Model

Undisturbed stress field was assumed to be typical for non tectonic regions. It can be described by vertical stress, maximum horizontal stress and minimum horizontal stress. Wellbore deviation in this paper is described by the drilling azimuth of borehole (α) with respect to σ_H and the borehole inclination (β). In a given stress equations, α, β angles where substituted and the stresses computed were graphed with respect to varying α and β. Values held as constant are assumed values from the data table (Table 1) for mathematical simplicity.

TABLE 1

Assumed Data Table used in the calculations

Vertical Stress,σ_v (Mpa)	115,00
Maximum horizontal stress, σ_H (Mpa)	99,78
Minimum horizontal stress, σ_h (Mpa)	91,25
Poisson's ration, v	0,30
Pore Pressure, P_o (Mpa)	30,20
Hydrostatic Pressure, P_h (Mpa)	46,40

Equations denotes in-situ stresses as σ_1, σ_2, σ_3 and transforming these into stress components with the z axis aligned with the wellbore axis give stresses σ_x, σ_y ,σ_z, τ_{xy}, τ_{xz} and τ_{yz}. Boundary conditions at the hole are $\sigma_r = P_w$ (the wellbore pressure) and $\tau_{r\theta} = \tau_{rz} = 0$ (Kang et al., 2009). Impermeable mudcake was assumed.

It is commonly assumed that when a vertical well is drilled, the in-situ stress around the wellbore includes three mutually orthogonal principal stresses. That is the vertical stress, σ_v the maximum horizontal stress, σ_H and the minimum horizontal stress, σ_h. However for the inclined borehole, the in-situ stress needs to be converted to a new co-ordinate system where one axis is in the borehole axial direction (Li et al., 2010). Therefore the in-situ stress (or far field stress) for an inclined wellbore can be expressed by Eq. 1-3.

The stress acting alone the x axis in a borehole Cartesian coordinate system is given by:

$$\sigma_x = \cos^2 \beta \left(\sigma_H \cos^2 \alpha + \sigma_h \sin^2 \alpha\right) + \sigma_v \sin^2 \beta \tag{1}$$

where:

σ_H — is the maximum horizontal stress,
σ_h — is the minimum horizontal stress,
α — is the drilling azimuth of borehole with respect to σ_H,
β — is the borehole inclination,
σ_v — is the vertical stress.

The stress acting alone the y axis in a borehole Cartesian coordinate system is given by:

$$\sigma_y = \sigma_H \sin^2 \alpha + \sigma_h \cos^2 \alpha \tag{2}$$

The stress acting alone the z axis in a borehole Cartesian coordinate system is given by:

$$\sigma_z = \sin^2 \beta \left(\sigma_H \cos^2 \alpha + \sigma_h \sin^2 \alpha\right) + \sigma_v \cos^2 \beta \tag{3}$$

As represented in Fig. 1, the in-situ principal stresses obtained using Eq. 1 and 3 are plotted.

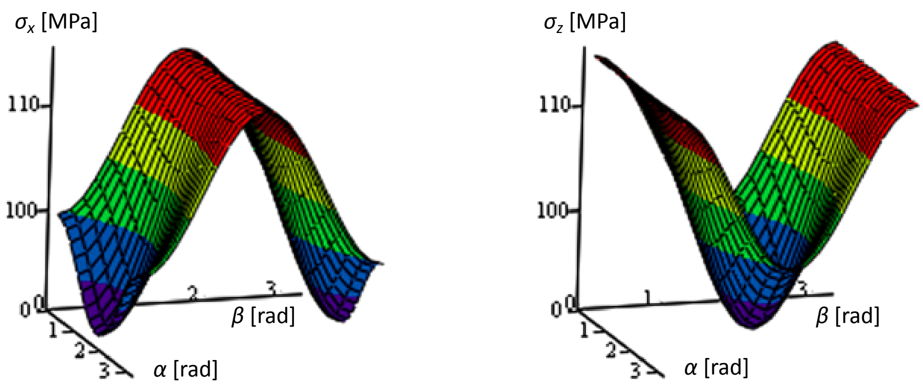

Fig. 1. Transformed in-situ Stress vs. Wellbore Inclination and Azimuth, Graph in Cartesian Co-ordinate

For given well it can be analysed how stresses vary by holding α constant for example 20°. At $\beta = 0$, σ_x is 98,8MPa and σ_z is 115 MPa. σ_z has opposing trend to σ_x as β increase. σ_x reach the maximum value 115 MPa at $\beta = 90°$ and does not depend on α. σ_z has minimum turning point at $a = \beta = 90^{o}$ with the stress values of 91,25 MPa.

From Fig. 1 it can be concluded that, by varying β, it affects the stress state of the wellbore. An optimal point (stress) for these stresses with varying β can be indentified prior to drilling for best stability result.

The graph in Fig. 2 is generated when α is varied from 0° through to 180°, the three Cartesian coordinate stresses σ_x, σ_y, σ_z all exhibits cyclic behavior. According to Fig. 1 and 2 the initial

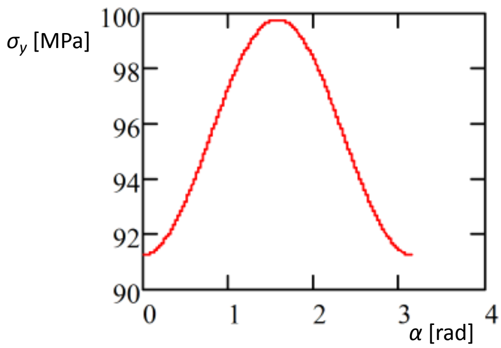

Fig. 2. Transformed in-situ Stress vs. α

stress value when α = 0 are different for all three stresses with σ_y having the lowest stress of 91,25 MPa. Varying α has distinguishable effect on the borehole stress regime as shown in Fig. 2.

In-situ shear stress component in a borehole Cartesian coordinate system that acts in the direction of y axis is given by:

$$\tau_{xy} = \cos\beta \sin\alpha \cos\alpha \left(\sigma_h - \sigma_H\right) \tag{4}$$

than in the direction of z axis is given by:

$$\tau_{yz} = \sin\beta \sin\alpha \cos\alpha \left(\sigma_h - \sigma_H\right) \tag{5}$$

and in the direction of z axis is given by:

$$\tau_{xz} = \sin\beta \cos\beta \left(\sigma_H \cos^2\alpha + \sigma_h \sin^2\alpha - \sigma_v\right) \tag{6}$$

The shear stress graphs in Fig. 3 are plotted using Eq. 4, 5 and 6. Stresses τ_{xy} and τ_{yz} display some local extremes. τ_{xz} is completely different from the two former. At α = 45° and β = 180°, τ_{xy} has one of the highest stress value of 4.265 MPa. The common thing about all these graphs is that, shear stresses are rather low values.

All the in-situ stress states with respect to borehole coordinate system in Cartesian coordinate system are used here to calculate the total stress state of the wellbore in the cylindrical coordinate system (r, θ, z) as shown in Eq. 7, 8, 9, and 10. The total normal stresses and shear stresses at the wellbore wall for a deviated borehole in polar system are defined by the theses equations.

Radial stress and effective minimum principal stress is given by:

$$\sigma_r = P_h - P_o = P_w \tag{7}$$

where:

P_w — is the wellbore pressure,
P_o — is the pore pressure,
P_h — is the hydrostatic pressure.

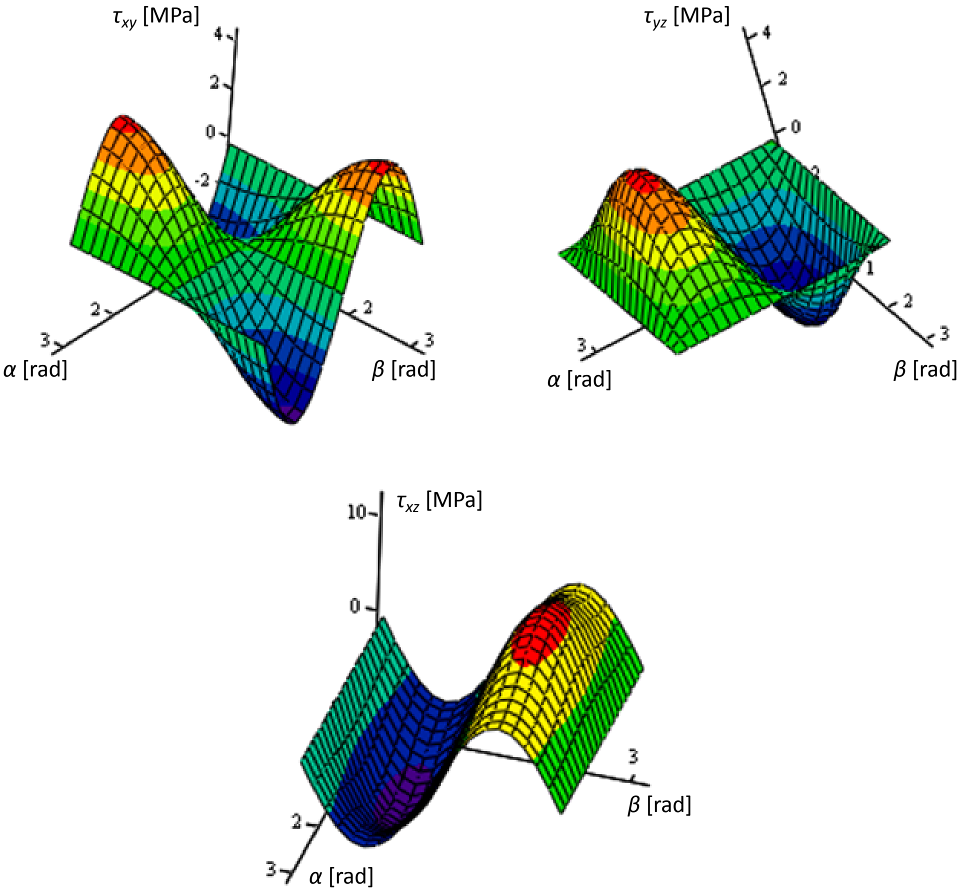

Fig. 3. Shear Stress vs. Wellbore Inclination and Azimuth graph

The tangential stress (hoop stress) is given by:

$$\sigma_\theta = (\sigma_x + \sigma_y) - 2(\sigma_x - \sigma_y)\cos 2\theta - 4\tau_{xy}\sin 2\theta - (P_h - P_o) \tag{8}$$

Where θ is the orientation angle around the wellbore. The axial stress in a cylindrical co-ordinate system is given by:

$$\sigma_{z'} = \sigma_z - 2v\left((\sigma_x - \sigma_y)\cos 2\theta + 2\tau_{xy}\sin 2\theta\right) \tag{9}$$

where σ_z is the axial stress in the Cartesian co-ordinate system and v is the Poisson's ratio.

The effective shear stress component is given by:

$$\tau_{\theta z'} = 2(\tau_{yz}\cos\theta - \tau_{xz}\sin\theta) \tag{10}$$

3. Conclusions

To avoid borehole collapse the most preferable is drilling in the direction of the minimum stress.

The drilling azimuth of borehole and the borehole inclination plays key part in wellbore stability problem.

Wellbore angles for the highest and the lowest stress can be clearly determined graphically.

Plotting all the in-situ stresses, shear stress and stresses related to borehole cylindrical coordinate system, the optimal wellbore stress can be established. Therefore prior to drilling, it would be important to establish optimal path in advance before the actual drilling is commenced.

Standard mud selection process besides pore and fracture gradient should also include wellbore path data.

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