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Borehole insitu stress stability analysis of RBS-9 field utilizing the inversion technique

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Abstract. The main objective of this paper is to perform an insitu stress model and borehole stability evaluation of 9 wells with limited data available in the RBS-9 field. In this paper, the Inversion technique is utilized to perform an analysis of the insitu stresses around RBS-9 wells. The analyses of results are used together with data form each well to calculate fracture and collapse pressures for the wells. The Inversion technique was used to find the maximum and minimum horizontal stresses. The stresses were also found for the whole well and for the places around each casing shoe. The RBS-9 field stresses were found to be anisotropic. Gathering the insitu stress analysis with data form each well led to the calculation of fracture and collapse pressure for the wells.
The fracturing pressure obtained from the model became unrealistically large for some wells, and too low for other wells. The cause for this may be data inconsistency due to collection from many different sources. Also, a geological uncertainty related to the faults and tectonic forces present represents a factor.

Keywords: Wellbore stability, inversion technique, insitu stress model, fracture and collapse calculations.

1. Introduction

Borehole instability is defined as an undesirable condition of an open hole interval that does not maintain its gauge size and shape and/or its structural integrity [1,2,3,4]. The causes are classified into three categories [1,2,3,4]: Mechanical (due to insitu stresses), Erosion (due to fluid circulation), and Chemical (due to interaction of borehole fluid with the formation).

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Borehole instability causes problems in drilling operations and design procedures. Instability problems can result in non-productive time and sometimes also loss of equipment which means additional non-productive costs. Instability problems can appear in both vertical and horizontal well. Long extended reach deviated wells are specially known for having instability problems. Wells stability evaluation represents a rock mechanics problem which means prediction of a rock's response to mechanical loading [1, 2, 3, 5]. Some special circumstances that make evaluation of stability problematic [1, 2, 3, 5]:

- The drill bit may be several thousand of meters away and there are no methods available for direct observation of what is happening.
- There may be large variations in formation stresses, and insitu stresses are not measured systematically.
- There are large variations in the material properties of the formations. Coring costs are high, and only limited amounts of material are available for rock mechanics testing. Coring in layers above the reservoir is normally accidental.
- Many forces act on the formation around the wellbore: mud chemistry, redistribution of stresses, temperature changes etc.

In this paper, an insitu stress model is developed in order to simulate and analyze wells stability of RBS-9 field with limited data available to build that model. In this model, the stress state and stresses in a wellbore are detailed. Additionally, all failure criterions are presented while the different fracturing data and the methods for normalizing the fracturing data are also discussed. The inversion technique is presented, which will be used to find the maximum and minimum horizontal stresses. Theory about borehole stability is presented for vertical and deviated wells with the different equations required for determining borehole fracturing and collapse. Finally, modelling of the insitu stress RBS-9 field is done and verified, and the fracture and collapse calculations are performed.

2. Insitu stresses determination

Yi [6] built the geomechanical earth model (GEM) to predict wellbore stability using the following equations to determine insitu stresses:

$$\boldsymbol{\sigma_v = \int_0^H \rho_b(h)dh} \tag{1}$$

$$\boldsymbol{\sigma_h = \frac{\upsilon}{1-\upsilon}\left(\sigma_v - \alpha_b P_p\right) + \alpha_b P_p} \tag{2}$$

where

σ_v= Overburden stress, psi
σ_h= Minimum horizontal stress, psi
ρ_b= Bulk density for rock, lb/ft.^{3}
h= depth, ft.
υ= Possion's ratio
α_b= Biot Coefficient
P_p= Pore pressure, psi

Maximum horizontal stress magnitude and orientation can be determined from the inversion of calibration of borehole failure such as breakouts, washouts, drilling induced fractures and drilling problems [6]. Additionally, wellbore stability models used for horizontal and deviated wells based on insitu stresses equations are presented by Yi [6], Khaksar [7], and Mohiuddin [8]. The role of rock strength criteria in wellbore stability and trajectory optimization is presented by Chabook [9].

3. Circular wellbore stresses

Before drilling a hole, a rock formation is loaded on all sides, and has uniform stresses in all directions. This situation is then called insitu stress state. When a hole is drilled in the middle of the rock formation region, the stress state around the hole will change due to the new geometrical element. The stress state around the hole is called a stress concentration. The two categories of stresses appeared due to changing condition are insitu/rock stresses and stresses around the hole. The Kirsch equations [2,3,10] and their derivatives are the most important equations related to applied rock mechanics. The Kirsch equations [2,3,10] are:

$$\left.\begin{aligned}
\sigma_r &= \frac{1}{2}(\sigma_x+\sigma_y)\left(1-\frac{a^2}{r^2}\right)+\frac{1}{2}(\sigma_x-\sigma_y)\left(1+3\,\frac{a^4}{r^4}-4\frac{a^2}{r^2}\right)\cos 2\theta+\tau_{xy}\left(1+3\,\frac{a^4}{r^4}-4\frac{a^2}{r^2}\right)\sin 2\theta+\frac{a^2}{r^2}\\
\sigma_\theta &= \frac{1}{2}(\sigma_x+\sigma_y)\left(1+\frac{a^2}{r^2}\right)+\frac{1}{2}(\sigma_x-\sigma_y)\left(1+3\,\frac{a^4}{r^4}\right)\cos 2\theta+\tau_{xy}\left(1+3\,\frac{a^4}{r^4}\right)\sin 2\theta+\frac{a^2}{r^2}\\
\sigma_z &= \sigma_{zz}-2\nu(\sigma_x-\sigma_y)\,\frac{a^2}{r^2}\cos 2\theta-4\nu\,\tau_{xy}\,\frac{a^2}{r^2}\sin 2\theta\\
\tau_{r\theta} &= \left\{\frac{1}{2}(\sigma_x-\sigma_y)\sin 2\theta+\tau_{xy}\cos 2\theta\right\}\left(1-3\frac{a^4}{r^4}+2\frac{a^2}{r^2}\right)\\
\tau_{rz} &= \left\{\tau_{xz}\cos\theta+\tau_{yz}\sin\theta\right\}\left(1-\frac{a^2}{r^2}\right)\\
\tau_{rz} &= \left\{-\tau_{xz}\cos\theta+\tau_{yz}\sin\theta\right\}\left(1+\frac{a^2}{r^2}\right)
\end{aligned}\right\}\quad (3)$$

where a = *radius of the hole*

r = *position radially outwards from the center*

θ = *angle with the direction of the maximum horizontal stress*

Y = Poisson's ratio

Now there is an expression for the borehole wall, or the stress state in the adjacent formation. At the borehole wall (r = a), the equations are reduced to:

$$\left.\begin{aligned}
&\textbf{Radial stress: } \sigma_r = P_w\\
&\textbf{Tangential stress: } \sigma_\theta = \sigma_x+\sigma_y+P_w-2\gamma(\sigma_x-\sigma_y)\cos(2\theta)-4\tau_{xy}\sin(2\theta)\\
&\textbf{Axial stress, plane strain: } \sigma_z = \sigma_{zz}-2\gamma(\sigma_x-\sigma_y)\cos(2\theta)-4\mu\tau_{xy}\sin(2\theta)\\
&\textbf{Axial stress, plane stress: } \sigma_z = \sigma_{zz}\\
&\textbf{Shear stress: } \sigma_{\theta z} = 2(\tau_{yz}\cos\theta-\tau_{yz}\sin\theta),\ \tau_{rz} = \tau_{r\theta}
\end{aligned}\right\}\quad (4)$$

3.1. Cartesian Stresses in three dimensions

In the oil field industry, it is known that there are three principle insitu stresses, the vertical or overburden stress (σ_v), and the maximum and minimum horizontal stresses (σ_H and σ_h). The input stresses are the insitu stresses σ_v, σ_H and σ_h. Since the Kirsch equations [2,3,10] assumes horizontal and vertical direction, and the borehole may be in any orientation, these stresses should therefore be transformed into Cartesian system x, y and z and represented as stresses σ_x, σ_y and σ_z. The following equations define all transformed stress components:

$$\left.\begin{aligned}
\sigma_x &= \left(\sigma_H \cos^2\varphi + \sigma_h \sin^2\varphi\right)\cos^2\gamma + \sigma_v \sin^2\gamma \\
\sigma_y &= \left(\sigma_H \sin^2\varphi + \sigma_h \cos^2\varphi\right) \\
\sigma_{zz} &= \left(\sigma_H \cos^2\varphi + \sigma_h \sin^2\varphi\right)\sin^2\gamma + \sigma_v \cos^2\gamma \\
\tau_{yz} &= \frac{1}{2}(\sigma_h - \sigma_H)\sin(2\varphi)\sin\gamma \\
\tau_{xz} &= \frac{1}{2}\left(\sigma_H \cos^2\varphi + \sigma_h \sin^2\varphi - \sigma_v\right)\sin(2\gamma) \\
\tau_{xy} &= \frac{1}{2}(\sigma_h - \sigma_H)\sin(2\varphi)\cos\gamma
\end{aligned}\right\} \quad (5)$$

where γ = the borehole inclination from vertical,

ϕ= the geographical azimuth and the borehole position from the x-axis, θ.

All equations required to analyze failures of boreholes are now defined.

4. Rock failure criteria

Rock failure criteria identify, clearly and definitely, stress conditions at failure. Common rock failure criteria as shown in Table (1) can be classified based on two main characteristics (linear or nonlinear form and considering the effect of intermediate principal stress on the rock strength). More details and discussion are presented by Rahimi [10].

Table 1. Common rock failure criteria

Failure Criterion Name	Failure Criterion Formula
Mohr-Coulomb	$\tau = \mu\sigma + C \quad , \quad \mu = \tan\emptyset$
Mogi-Coulomb	$\tau_{oct} = a + b\,\sigma_{m,2}$ $\sigma_{m,2} = \frac{1}{3}(\sigma_1 + \sigma_3),$ $\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2}$ $a = \frac{2\sqrt{2}}{3}\frac{C_0}{q+1}, \quad b = \frac{2\sqrt{2}}{3}\frac{q-1}{q+1}$

Failure Criterion Name	Failure Criterion Formula
Tresca	$\frac{(\sigma_1 + \sigma_3)}{2} = C = \tau_{max}$, $\frac{C_0}{2} = C$
Von Mises	$\sqrt{J_2} = \sqrt{\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2}{6}} = \frac{C_0}{3}$
Drucker-Prager	$\sqrt{J_2} = k + \alpha J_1$, $J_1 = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$
Hoek-Brown	$\sigma_1 = \sigma_3 + \sqrt{m C_0 \sigma_3 + s C_0^2}$
Modified Lade	$\frac{I''^3_1}{I''_3} = \eta_1 + 27$ $I''_1 = (\sigma_1 + S) + (\sigma_2 + S) + (\sigma_3 + S)$ $I''_3 = (\sigma_1 + S).(\sigma_2 + S).(\sigma_3 + S)$
Modified Wiebols-Cook	$\sqrt{J_2} = A + B J_1 + CJ_1{}^2$
Griffith	$(\sigma_1 - \sigma_3)^2 = 8 T_0(\sigma_1 + \sigma_3)$ $\sigma_3 = -T_0$ IF $(\sigma_1 + 3\sigma_3) < 0$, and $T_0 = \frac{C_0}{8}$
Modified Griffith	$\sigma_1 \left[\sqrt{\mu^2 + 1} - \mu\right] - \sigma_3 \left[\sqrt{\mu^2 + 1} + \mu\right] = 4T_O$ $4T_O = \frac{4}{\sqrt{\mu^2 + 1} - \mu}$
Murrel	$(\sigma_1 - \sigma_3)^2 + (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 = 24\, T_O(\sigma_1 + \sigma_2 + \sigma_3)$
Stassi d'Alia	$(\sigma_1 - \sigma_3)^2 + (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 = 2(C_o - T_o)(\sigma_1 + \sigma_2 + \sigma_3) + 2\, C_o T_o$

5. Fracturing data determination

There are several ways to determine the formation fracturing pressure. Among these are Leak-Off test (LOT), Extended Leak-off test (ELOT) and Formation Integrity test (FIT). Extended Leak-off test yields the best estimate of the insitu stress. LOT may yield satisfactory results, whereas FIT only provides a vague indication [1,4,12].

5.1. Normalizing of the Fracture Data

It is known that the leak-off data vary for no obvious reasons. This is due to other lateral variation and anisotropy in the insitu stress field. Therefore, the normalization process is to reduce the spread in the raw data and discover hidden trends. The two most often used normalization methods are to normalize for different borehole inclinations and to use the compaction model [3,11,13]. These two models are presented in the following sections.

5.1.1. Normalizing for different borehole inclination

The fracture gradient in terms of stresses on the borehole wall with the assumption from Aadoy & Chenevert [14] is expressed as follows [3,11,13]:

$$P_{wf} = 3\sigma_y - \sigma_x - P_o \tag{6}$$

$$\sigma_x = \sigma_a cos^2\gamma + \sigma_v sin^2\gamma \tag{7}$$

$$\sigma_y = \sigma_a \tag{8}$$

Therefore, the fracture gradient for any inclination is:

$$P_w = 2\sigma_a - P_o - (\sigma_v - \sigma_a)sin^2\gamma \tag{9}$$

The fracture gradient for a vertical hole after comparison with fracture data for inclined boreholes is:

$$P_{wf}(0) = P_{wf}(\gamma) - (\sigma_v - \sigma_a)sin^2\gamma \tag{10}$$

The fracturing of a vertical hole after eliminating the average horizontal stress σ_a is:

$$P_{wf}(0) = P_{wf}(\gamma) - \frac{(\sigma_v - \frac{1}{2}P_o)sin^2\gamma}{1 + \frac{1}{2}sin^2\gamma} \tag{11}$$

5.1.2. The compaction model

The compaction model is a method to estimate changes in the fracturing pressures due to the depletion of pore pressure in a reservoir. Aadnoy [13,15] has delivered a simple model with reference to pore pressure history. The effect over time of a change in pore pressure on the fracturing pressure is given by:

$$\Delta P_{wf} = \Delta P_o \frac{1-3\nu}{1-\nu} \tag{12}$$

where

ΔP_{wf} = *the corresponding change in fracturing pressure,*
ΔP_o = *the change is pore pressure*

6. The inversion technique

If the field is an anisotropic field, the best way of modeling the field from fracturing data is to use the inversion technique. The inversion technique is a unique modeling method developed by Aadnoy [3,11,13,15]. The technique uses leak-off data to predict stresses in the formation, and also predicts fracturing pressures for new wells. The field data used as input for the method includes the leak off pressure, depth, pore pressure, overburden stress, inclination and azimuth for each data point. The following procedures relate to the inversion technique [3,11,13,15]:

I. Using Aadnoy & Chenevert equation [14] derived from the Kirsch equations to express the fracture pressure of a borehole when $\sigma_x > \sigma_y$, assuming no shear stresses at the borehole wall.

$$\boldsymbol{P_{wf} = 3\sigma_y - \sigma_x - P_o + \sigma_t \quad for\ \sigma_y = \sigma_x} \tag{13}$$

II. Replacing the two normal stresses by transformation equations to obtain:

$$\boldsymbol{\sigma_x = \left(\sigma_H\, cos^2\varphi + \sigma_h\, sin^2\varphi\right) cos^2\gamma + \sigma_v\, sin^2\gamma} \tag{14}$$

$$\boldsymbol{\sigma_y = \left(\sigma_H\, sin^2\varphi + \sigma_h\, cos^2\varphi\right)} \tag{15}$$

III. Combining results in:

$$\boldsymbol{\frac{\sigma_{wf} + P_o}{\sigma_v} + sin^2\gamma = \left(3\, sin^2\varphi + cos^2\varphi\ \ sin^2\gamma\right) \frac{\sigma_k}{\sigma_v} + (3\, cos^2\varphi + + sin^2\varphi\, cos^2\gamma)\ \frac{\sigma_l}{\sigma_v}} \tag{16}$$

Or in short form:

$$\mathbf{P' = a\ \frac{\sigma_k}{\sigma_v} + b\ \frac{\sigma_l}{\sigma_v}} \tag{17}$$

IV. Constructing a system of equations that in matrix from look like the above equation:

$$\begin{bmatrix}\mathbf{P_1}\\ \mathbf{P_2}\\ \mathbf{P_3}\\ \dots\\ \dots\\ \mathbf{P_n}\end{bmatrix} = \begin{bmatrix}\mathbf{a_1, b_1}\\ \mathbf{a_2, b_2}\\ \mathbf{a_3, b_3}\\ \dots\\ \dots\\ \mathbf{a_n, b_n}\end{bmatrix} + \begin{bmatrix}\boldsymbol{\sigma_k/\sigma_v}\\ \boldsymbol{\sigma_l/\sigma_v}\end{bmatrix} \quad \text{or} \quad [P'] = [A][\sigma] \tag{18}$$

V. Solving the above system to obtain the error between the model and the measurement is

$$\mathbf{[\mathit{e}] = [\mathit{A}][\sigma] - [\mathit{P}']} \tag{19}$$

VI. Minimizing this error by using the least squares method as follows:

$$\mathbf{[\mathit{e}^2] = [\mathit{e}]^T[\mathit{e}]} \quad \text{or} \quad \mathbf{\frac{\partial e^2}{\partial[\sigma]} = 0} \tag{20}$$

VII. Performing the analysis shown above, the insitu stresses are calculated by:

$$\mathbf{[\sigma] = \{[A]^T[A]\}^{-1}\, [A]^T\, [\mathit{P}']} \tag{21}$$

7. Wellbore Stability Determination

7.1. General methodology of analysis of borehole stability problems

The general methodology for borehole stability analysis is presented for both fracturing and collapse by Robert [4]. This is valid for all stress states (normal, strike-slip, and reverse) and for all borehole orientations. The methodology procedures [4] are:

1. Calculate the stresses in the direction of the borehole.
2. Insert this data into the borehole stress equations.

3. Determine the point on the borehole wall where failure will occur.
4. Implement a failure model.
5. Compute borehole pressure at failure.

7.2. Borehole fracturing

It is important to avoid fracturing during the drilling phase due to the high costs of the drilling mud and inability to "repair" fractures. The borehole will fracture when the rock stress changes from compression to tension. The general fracturing equation which is valid for fractures in all directions and for anisotropic stresses is presented by Aadnoy [3,11,13,15] as follows:

$$P_w = \sigma_x + \sigma_y - 2(\sigma_x - \sigma_y)\cos(2\theta) - \frac{\tau_{\theta z}^2}{\sigma_z - \sigma_t - P_o} - P_o - \sigma_t \quad (22)$$

Another general case in which the fracture may not arise in the direction of the x or y axis because of shear effects is solved by differentiating the above equation to define the external conditions. For simplicity, a plane stress case is assumed therefore the result becomes:

$$\frac{dP_w}{d\theta} = 0 \rightarrow \tan(2\theta) = 2\frac{\tau_{xy}\,(\sigma_z - \sigma_t - P_o) - \tau_{xz}\tau_{yz}}{(\sigma_x - \sigma_y)(\sigma_z - \sigma_t - P_o) - \tau_{xz}^2 - \tau_{yz}^2} \quad (23)$$

Since the normal stresses are usually much larger than the shear stresses, the second order shear stress components can therefore be negligible, so the equation is reduced to:

$$\tan(2\theta) = \frac{2\tau_{xy}}{(\sigma_x - \sigma_y)} \quad (24)$$

Assuming the rock has zero tensile strength because the rock may contain cracks and fissures, the fracture equations become:

$$P_w = 3\sigma_x + \sigma_y - P_o - \sigma_t \qquad \text{for } \sigma_x < \sigma_y \text{ , and } \theta = 90^o \quad (25)$$

$$P_w = 3\sigma_y + \sigma_x - P_o - \sigma_t \qquad \text{for } \sigma_y < \sigma_x \text{ , and } \theta = 0^o \quad (26)$$

Assuming a maximum and minimum normal stress to the borehole wall and the shear stresses have vanished, the general fracture equation becomes:

$$P_w = 3\sigma_{min} + \sigma_{max} - P_o - \sigma_t \quad (27)$$

7.3. Borehole collapse

Borehole collapse is the other main failure mechanism of boreholes. Collapse is a wellbore instability problem which occurs at low borehole pressures. At low borehole pressures the tangential stress becomes large. The maximum principal stress, which is dominated by the tangential stress, and the minimum principal stress are given by [2,11,13,15]:

$$\sigma_1 = \frac{1}{2}(\sigma_\theta + \sigma_z) + \frac{1}{2}\sqrt{(\sigma_\theta + \sigma_z)^2 + 4\,\tau_{\theta z}^2} \text{ and } \sigma_3 = P_w \quad (28)$$

The borehole pressure causing the highest tangential stress is expressed at certain conditions as follows:

$$P_1 = 3\sigma_y + \sigma_x - P_w \qquad \text{for } \sigma_x < \sigma_y \text{ , and } \theta = 90^o \quad (29)$$

$$P_1 = 3\sigma_x + \sigma_y - P_w \qquad for\ \sigma_y < \sigma_x \text{ , } and\ \theta = 0^o \quad (30)$$

These equations indicate that the borehole collapse will initiate in the direction of the least stress [14]. The expressions for the minimum and maximum principal stresses are available. A failure criterion is also needed to calculate the critical pressure for the general case of borehole collapse.

7.4. Stability in highly inclined boreholes

The stability conditions in a deviated well will be worse than in a vertical well. This is also true for the stress layers. The vertical stress has an increasing normal stress to the wellbore as the deviation angle increase, and the mud weight stability range decreases. The fracturing pressure generally decreases with increased hole inclination [7,8,14,16]. This appears in the curves generated by Aadnoy & Chenevert [14] for a vertical and a horizontal wellbore. On the other hand, when the wellbore is rotated from a vertical to a horizontal position, the analysis shows that the borehole becomes more sensitive towards collapse. An increase of the borehole pressure reduces the stress state away from the failure envelope. Therefore, a higher mud weight improves wellbore stability. If the mud weight becomes too high, it will move towards the fracturing curve and tensile failure will occur [7,8,14,16]. According to Aadnoy & Chenevert [14], the increase of the insitu stress field with depth causes the well to become more sensitive towards collapse at greater depths. From studies where Mohr-Coulomb criteria have been used as a basis, it has been concluded that the borehole becomes more susceptible toward collapse the greater the inclination [11].

8. RBS-9 Field

The RBS-9 field was discovered in 2006 by drilling 9 wells. The company has determined after several RBS-9 reservoir analyses to redevelop RBS-9 as this decision is technically feasible and economically viable. Therefore, an insitu stress modeling and analysis for this field should be performed in order to optimize the next drilled wells. However, only limited data are available for this field. Collecting data from 9 wells which include casing setting points and their pore pressure, LOT data, overburden pressure, and casing sizes are shown in Fig. (1). Wells inclination and azimuth are shown in Fig. (2).

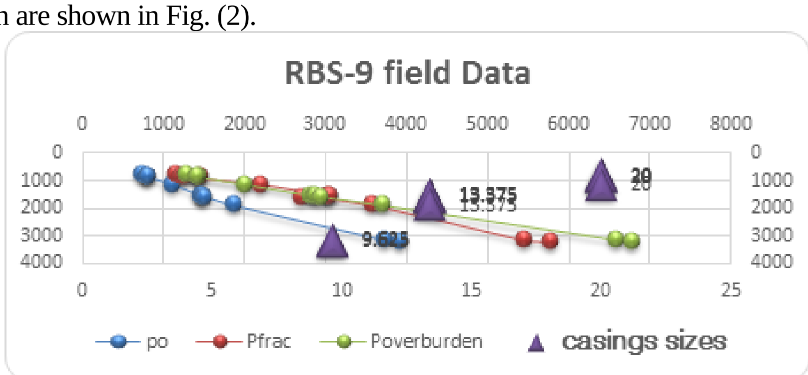

Fig. 1. RBS-9 field data.

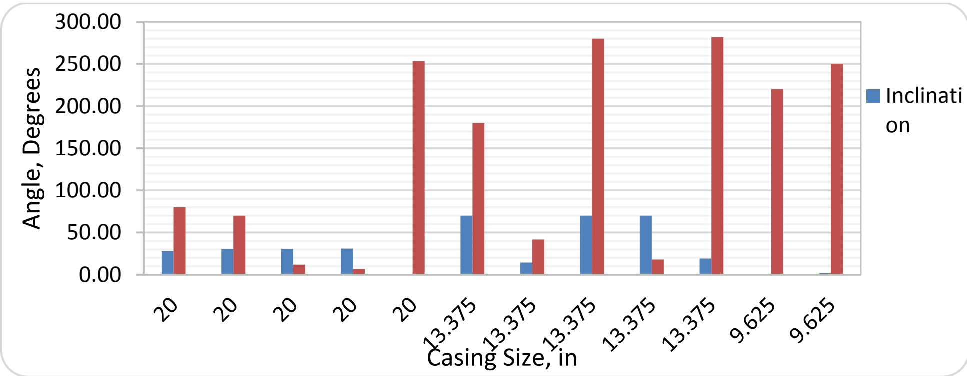

Fig. 2. RBS-9 field wells inclination and azimuth.

9. Results and discussions

It is obvious from LOT data plotted in Fig. (1) that RBS-9 field is an anisotropic stress field, which agrees with the experience that says most oil fields exhibit anisotropic stress field to some degree. The LOT data shows an increase with depth, as is expected. By performing the best-fit curve for LOT data, a better correlation used for prediction with a reasonable accuracy, is obtained. LOT data are normalized utilizing equation (11) to include the different wellbore inclination. After that the given data appeared in Fig. (1&2) combined with normalized LOT data are utilized as input for insitu stresses determination from the inversion technique (Fig. (3). Overburden and pore pressures from the formation are also used. Fig. (3) shows the maximum and minimum insitu stresses resulting from the inversion technique with percentage error (e^2)= 0 - 0.045 compared with the overburden stress. The insitu stress model shows reasonable values and trend lines for the maximum and minimum stresses. The principle insitu stresses are multiples times the overburden stress and, therefore, provide a poor comparison. This gives a good indication of an anisotropic stress field.

In order to determine fracturing and collapse pressures, insitu stress model analysis is used together with the inclination and azimuth of the wells (Fig. (2)) assuming cohesion strength 0.2 and internal friction angle 30^o. The 3D Cartesian stresses (σ_x,σ_y,σ_z) required for pressure calculations are illustrated in Fig. (4) and show good values for all wells except those of 9.625" casings due to limited data. Finally, the fracturing and collapse pressures resulted from the model are shown in Fig. (5). The fracturing pressure became unrealistically large for some wells, and too low for other wells. The cause for this may be data inconsistency due to collection from many different sources.

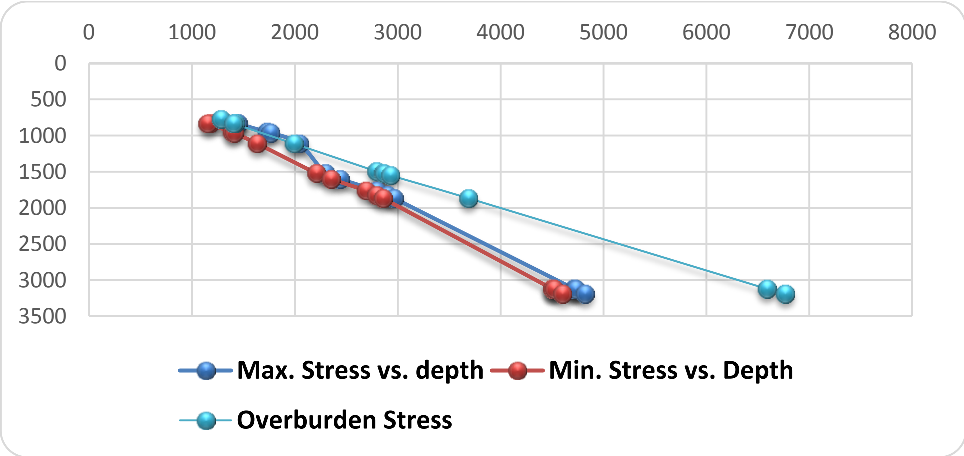

Fig. 3. RBS-9 wells insitu stress model results.

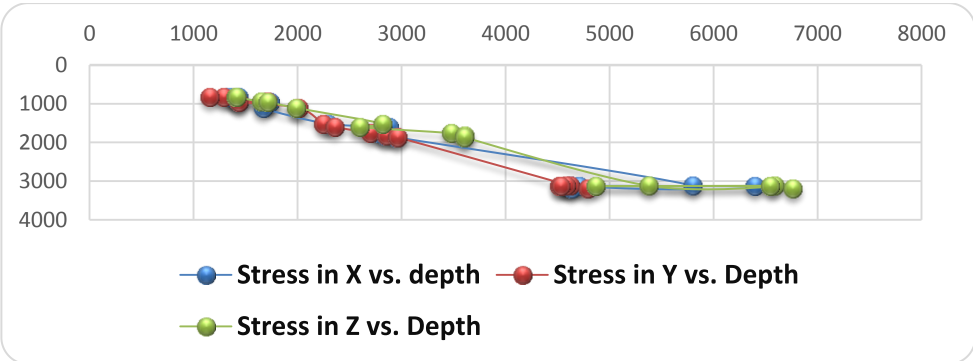

Fig. 4. RBS-9 wells normal stresses in 3D (X, Y, Z).

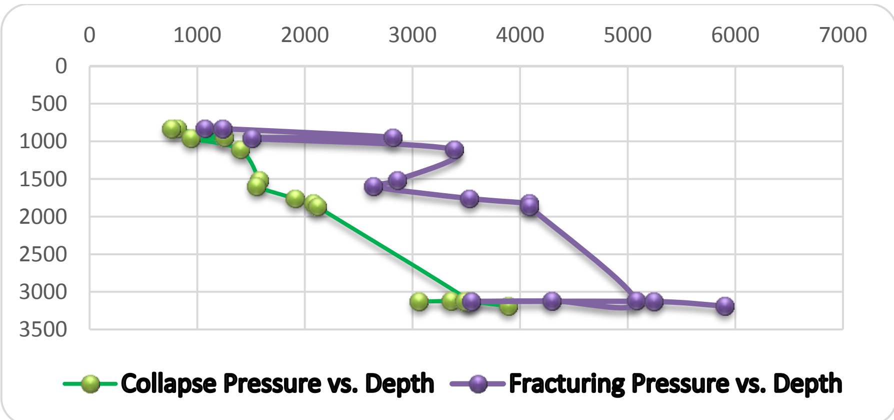

Fig. 5. RBS-9 wells collapse and fracturing pressures versus depth

10. Conclusions and recommendations

Based on the results and analysis, the following conclusions are extracted:

- A reasonable insitu stress model for RBS-9 field is obtained to predict wellbore stability although few data are available
- The limit of data from RBS-9 field wells made it difficult but not impossible to predict an accurate borehole stability evaluation.
- The insitu stress field is found to be anisotropic.
- The fracturing pressure became unrealistically large for some the wells, and too low in other wells.
- The cause may be data inconsistency due to collection from many different sources. Also, a geological uncertainty related to the faults and tectonic forces present represents a factor.
- Insitu stress model shows a reasonable results and a good comparison for RBS-9 field analysis

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