Investigating the Stability of the Wellbore Walls Stability and its Analysis and Interpretation in Over Balanced and Balanced Drilling with FLAC Software

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Abstract - The most important challenge in oil engineering is to reach the oil layer without drilling problem. Despite the drilling problems, a very good strategy with regard to geomechanical modeling is required to achieve the optimum mud pressure for safe drilling with respect to the pore pressure. The lack of accurate prediction of pore pressure and wellbore stability analysis results in problems such as well blowing, wellbore wall fractures, and so on. Wellbore wall instability increases the duration of drilling operation, increases costs and sometimes leads to the abandonment of the well before reaching the target point. During drilling, because of the relationship between the mud pressure and the main stresses, a field called induced stress is created that calculating the stresses it is very important to determine the types of wellbore wall fractures. Accordingly using geomechanical analysis and the values of horizontal stress and pore pressure, the optimal mud pressure was obtained. In this study, geomechanical modeling was performed and using single-axial compressive strength, it was determined that the soft formation material is clay and sand. The fault regime in the formation was defined as strike-slip fault. Finally, using the drilling mud window, the minimum mud pressure level of 60-80 MPa and the maximum drilling mud pressure that the formation can tolerate was introduced as 95-115 MPa. Then, after applying the drilling mud pressure with which the well was drilled, and FLAC software it was revealed that in the over-balanced drilling, no falling occurs in the well, however, some levels of collapse is predicted on the walls in the balanced drilling.

Keywords: Wellbore wall, Pore pressure, Induced stress, Geomechanics

1. Introduction

Reservoir geomechanical studies and modeling are carried out to obtain a successful strategy for reservoir development. Geomechanics is very important in the oil and gas industry[1]. In order to realize geomechanical studies, a precise geomechanical model must first be defined initially. In these studies, many parameters, including wellbore wall stability, hydraulic fracture operations and sand production management … are studied and evaluated[2].A comprehensive geomechanical model of the reservoir includes tensile and pore pressure status as a function of depth, rock characteristics such as rock deformation including modulus of elasticity and rock strength parameters such as single-axial compressive strength, tensile strength and internal angle of friction of the rock. Given the depth of the reservoir in the development of fields, in many areas, the nature and location of drilling wells put a huge challenge against the oil industry [3].

A study was conducted on the problems of instability of wells in a sand reservoir in Saudi Arabia. The researchers identified the reasons for the instability of wells with the statistical studies and the construction of the geomechanical model and predicted the safe mud weight window for drilling in this formation [4].

In another field study in Oman, a study was conducted to construct a geomechanical model with respect to factors affecting the pressure of a carbonate formation, and this model predicted the rate of subsidence in the future [5]. The researchers used the geomechanical model and identified the best route to drill deep wells in a gas field in Saudi Arabia to obtain in situ stress. Since in the sloping wells, the location of the drainage is a function of the well path and the stresses on the wellbore wall, by identifying the drainage characteristics, they determined the amount of in situ stress, effective rock strength and the direction of stresses in the formation [6].

The instability of the well was studied in the Chilean Formation of Nahr Omar in Oman. They used a comprehensive geomechanical model to investigate the instability of the wellbore wall. The minimum mud weights and uniaxial compressive strength required to prevent the well fracture in azimuths and slopes were presented [7].

In another study, using the shear wave velocity chart of Bangestan reservoir in the wellhead No. 20 of the Kupal field, the possibility of constructing a geomechanical model with greater accuracy has been investigated. The pore pressure gradient in the Bangestan reservoir is measured by the RFT test information. By plotting regression of the density graph from the reservoir to the ground, the overpressure points in this reservoir are detectable. For fractured carbonate formations, including the Bangestan reservoir, the horizontal pressure value will be at least close to the mud loss pressure [8].

There are many problems in the long path between the reservoir and the ground in the world, most of which are caused by the physical-mechanical unbalanced conditions of the formations. Today, oil geomechanics are the key to analyze and overcome such problems. Geomechanical modeling will help in assessing possible risks in future drilling of the wells. Nowadays, different methods of numerical modeling, such as the finite difference method in the analysis of continuous, discontinuous, and quasi-continuous behavior, are widely used along with analytical models. The FLAC2D geomechanical modeling engine is used to simulate the fracture conditions in samples.

2. Research Method

2.1. Calculation of elastic parameters in dynamic and static modes

The geomechanical parameters of the reservoir are derived from dynamic studies using the acoustic log graphs (including pressure and shear waves' passage time) and density log graphs. By measuring the properties, geomechanical parameters of the formation (modulus of elasticity of the reservoir rock in dynamic mode) are obtained [9].

Because the changes in rock-related geomechanics are slowly, dynamic computing should be converted into static computations, therefore, the following experimental relationships are used to convert the modulus of elasticity from the dynamic to static mode.

Table 1- Equations for modulus of elasticity in dynamic and static modes

Rock Properties	Dynamicmodulus	Static modulus
Young's modulus	$E_d = \dfrac{\rho_b [3 - 4(\frac{\Delta t_c}{\Delta t_s})^2]}{\Delta t_s^2 - \Delta t_c^2}$	$E_s = 0/4145 E_d - 1/0593$
Shear modulus	$G_d = \dfrac{\rho_b}{\Delta t_s^2}$	$G_s = \dfrac{E_s}{2(1+\upsilon_s)}$
Volumetric module	$K_d = \rho_b (\dfrac{1}{\Delta t_c^2} - \dfrac{4}{3\Delta t_s^2})$	$K_s = \dfrac{E_s}{3(1-2\upsilon_s)}$
Poisson ratio	$\upsilon = \dfrac{1}{2}(\dfrac{\Delta t_s^2 - 2\Delta t_c^2}{\Delta t_s^2 - \Delta t_c^2})$	

Where, ρ_b is the rock density, Δt_s is the duration of the pressure waves passage and Δt_c is the duration of the shear waves passage. In these relations, the time of pressure and shear wave's passage is in microsecond per foot and density is in grams per cubic centimeter. The Poisson's coefficient is not different in dynamic and static modes and does not require any particular conversion. In this section, the important thing is that there are many relations to convert the dynamic into static moduli.

2.2. Calculating rock strength parameters

In this step, the uniaxial compressive strength parameter of the reservoir rock is obtained using formula (1). There are many relations to calculate the uniaxial compressive strength [10].

1) $UCS = 143/8 \exp(-6/95 * \phi)$

2.3. Determining in situ stresses

One of the important input parameters in the failure criteria is the in situ stress. Vertical stress (σ_v) is one of the principal stresses and maximum (σ_H) and maximum (σ_h) horizontal stresses are the other two main stresses. Vertical stress is obtained by the rock density integral from the surface to the desired depth as follows: The value of this stress is obtained by the bulk density graph [6]:

2) $\sigma_v = \int_0^z \rho g dz \cong \overline{\rho} g z$

Where, σ_v is the vertical stress g is the acceleration of gravity and z is the depth from the surface.

The minimum and maximum horizontal stresses are determined by the pro elastic relations as follows:

3) $$\sigma_h = \frac{v}{1-v}\sigma_v - \frac{v}{1-v}\alpha P_p + \alpha P_p + \frac{E_{sta}}{1-v^2}\varepsilon_y + \frac{vE_{sta}}{1-v^2}\varepsilon_x$$

4) $$\sigma_H = \frac{v}{1-v}\sigma_v - \frac{v}{1-v}\alpha P_p + \alpha P_p + \frac{E_{sta}}{1-v^2}\varepsilon_x + \frac{vE_{sta}}{1-v^2}\varepsilon_y$$

Where, υ is the Poisson coefficient, α is the Biot factor, P_p is the pore pressure, E is the static Young's modulus and ε_x and ε_y are the strain is at the minimum and maximum horizontal stress levels that can be either tensile or compressive.

After obtaining the above parameters, they should be compared with the relationship that Anderson proposed in 1951 to describe the in situ stresses based on the relative values between the horizontal and vertical stresses. He suggested that the stress regimes in the normal, reverse and strike slip faults are $\sigma_v \geq \sigma_H \geq \sigma_h$, $\sigma_H \geq \sigma_h \geq \sigma_v$ and $\sigma_H \geq \sigma_v \geq \sigma_h$ respectively. The difference between the in situ stresses and the course of the drilling path have different effects on each other, that is, the stability of the wellbore wall during the drilling is strongly dependent on the stress regime. To select optimal drilling, it is necessary to follow a direction in which the difference between the fracture and rupture failure is maximum. In this case, the drilling mud's weight range will be higher in safe state, which is known as Hydrostatic Tension [11],[12].

2.4. Determining the pressure range in fracture and shear

At the time of drilling, the connection between the mud pressure and principal stresses results in the formation of a stress field called the induced stress field. Calculation of the induced stress is very important in geomechanical evaluation and determination of types of wellbore wall fractures. In order to determine the pressure range in tensile and shear fracture, the tangential, axial and radial induced stresses that are created after well drilling due to the concentration of stress in the rock mass are calculated as follows:

5) $$\sigma_{\theta\theta} = 3\sigma_H - \sigma_h - P_w - P_p$$

6) $$\sigma_{zz} = \sigma_v + 2\upsilon(\sigma_H - \sigma_h) - P_p$$

7) $$\sigma_{rr} = P_w - P_p$$

Where, the applied mud pressure to a well can be calculated only by having the weight of mud and depth at different depths. In these relations, the radial induced stress is perpendicular to the wellbore wall and the tangential induced stress is perpendicular to the radial and axial induced stresses, or in other words around the wellbore wall.

2.5. Analysis of the stability of the wellbore wall

Using the parameters calculated in the previous sections, one could analyze the stability of the wellbore wall according to Fig. 1. In geomechanical analysis, the mud safe window can also be obtained based on the minimum horizontal and pore pressure obtained from the above relations at different depths of the drilling. This range of mud pressure allows preventing the wellbore wall drainage as well as the hydraulic fracture in the entire depth of drilling. In addition, with attention to this range of mud pressure, it is possible to prevent the entry of formation fluid into the wellbore wall and mud loss of the entire formation. Finally, it is possible to prevent problems caused by the instability of the wellbore wall, such as pipe clogging, fishing, uniformity of the wellbore wall, poor cementing and bypass.

In drilling wells in different formations, two major methods of balanced and over-balanced drilling are used. In the balanced and over-balanced drilling methods, the drilling mud pressure is less than the pore pressure and more than the pore pressure of the formation respectively. It should be noted that in normal conditions and without mud pressure, the pore pressure of the formation creates fluid flow into the well. If the balanced drilling method is used, fluid flow into the well will still be present. Typically, in balanced drilling, the mud pressure is about 0.69 to 1.38 MPa, and in the case of over-balanced drilling, the mud pressure is more than the pore pressure based on the same amount.

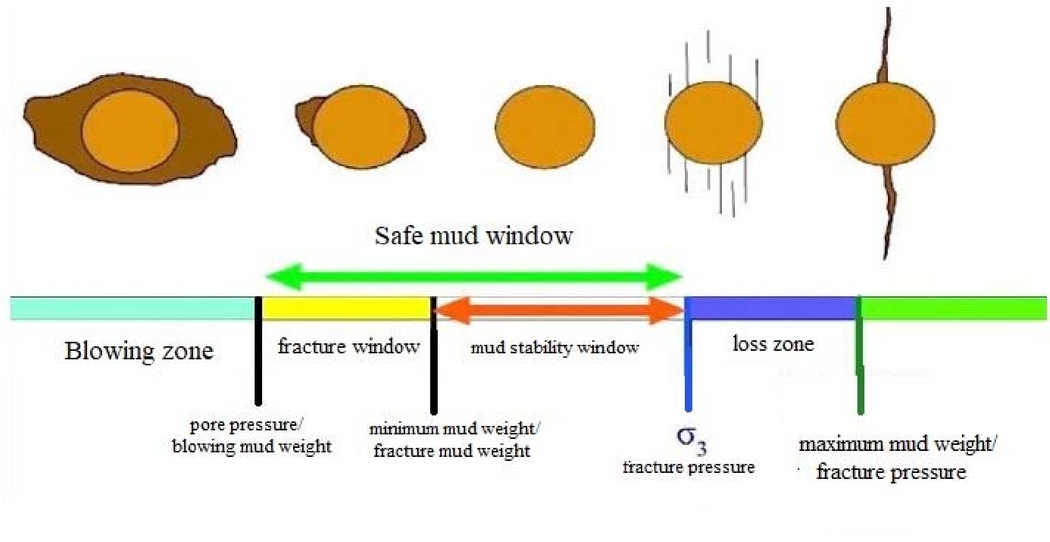

Figure 1- safe and unsafe sections in wellbore wall stability

3. Conclusion

The initial charts required to compute the mechanical parameters of the reservoir are gamma ray, density, porosity, acoustic, pressure and shear charts as shown in Fig. 2.

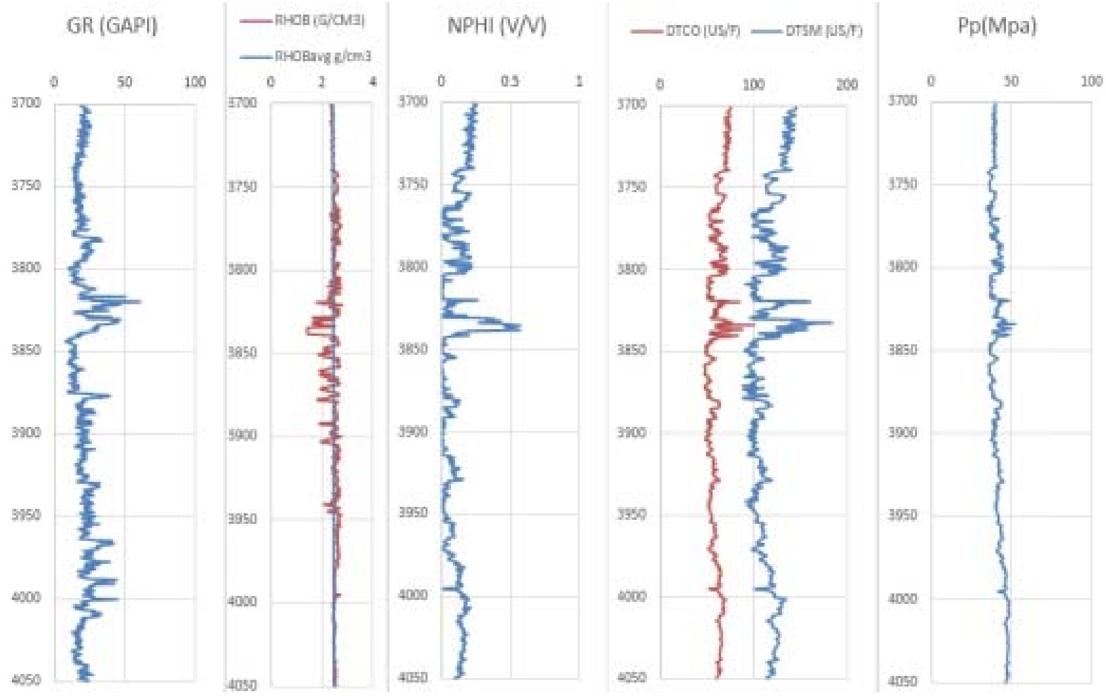

Figure 2- Charts obtained from the well in the studied reservoir in terms of depth

In the first column, gamma ray is shown at various depths. Gamma ray is important for the wellbore lithology. In general, where this chart has more values, it can be indicative of an increase in shale amount. In the second column, two mass density charts are presented and in the third column neutron chart is given. In general, when the density diagram is located at the right of the neutron chart, the rock material is dolomite. When the density diagram is placed at left of the neutron chart, the formation is sandstone and when the two graphs are roughly matched, the formation is limestone. In this figure, the density diagram is located on the right side of the neutron curve, which indicates the probability of dolomite in the formation. The fourth column also shows the acoustic waves in pressure and shear modes. In Fig. 3, the dynamic and static elastic parameters of the studied reservoir are shown.

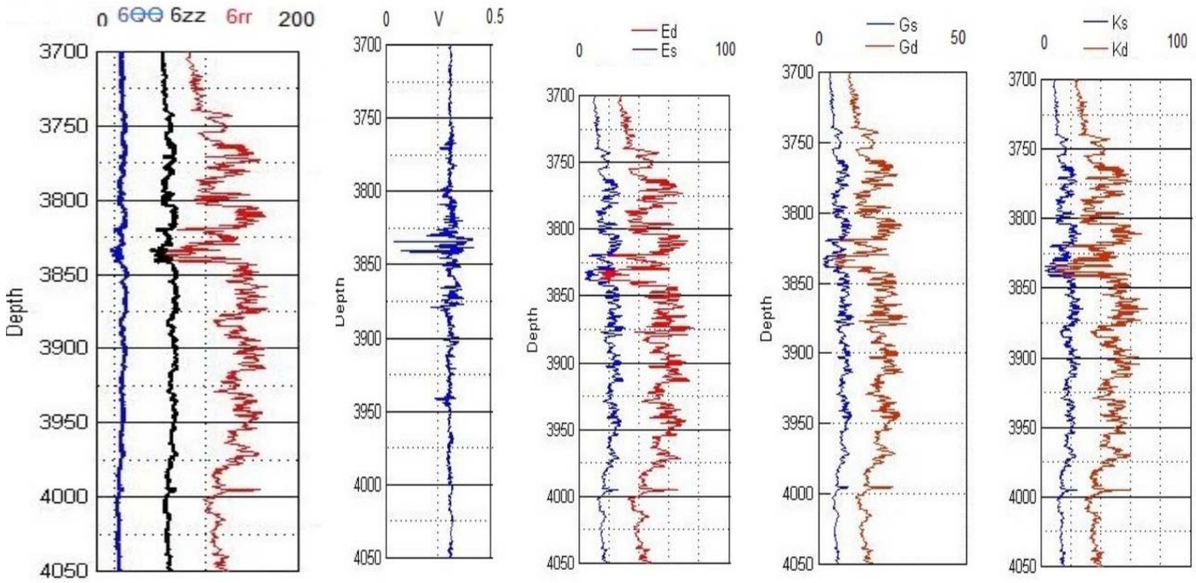

Figure 3- Dynamic and static moduli (four right charts) and axial, tangential and radial induced stresses in depth (left chart)

Table 2 Maximum, average and minimum elastic parameters of the reservoir rock in GPa

Coefficients	Maximum	Average	Minimum
Poisson coefficient (v)	0.42	0.30	0.045
Young's dynamic coefficient (Ed)	70.39	39.75	12.12
Young's static coefficient (Ed)	29.58	17.69	4.39
Dynamic shear coefficient (Gd)	31.88	17.01	4.70
Static shear coefficient (Gd)	13.12	7.68	1.50
Dynamic volume coefficient (Kd)	75.32	41.65	7.87
Atatic volume coefficient (Kd)	28.42	16.30	2.75

Based on Fig. 3, the TCYL model (radial tensile fracture) is obtained according to the induced stresses of the SWBO shear fracture model and the tensile fracture model. The minimum and maximum permissible mod pressures were determined by the Mohr-Coulomb criterion. Then, according to the obtained results, the safe mud window was obtained and this range of mud pressure allows us to prevent the wellbore wall leakage, hydraulic fracture and drilling mud loss to the formation in the entire depth of drilling in the reservoir rock. In Table 3, the input parameters for the software obtained in the above steps are summarized.

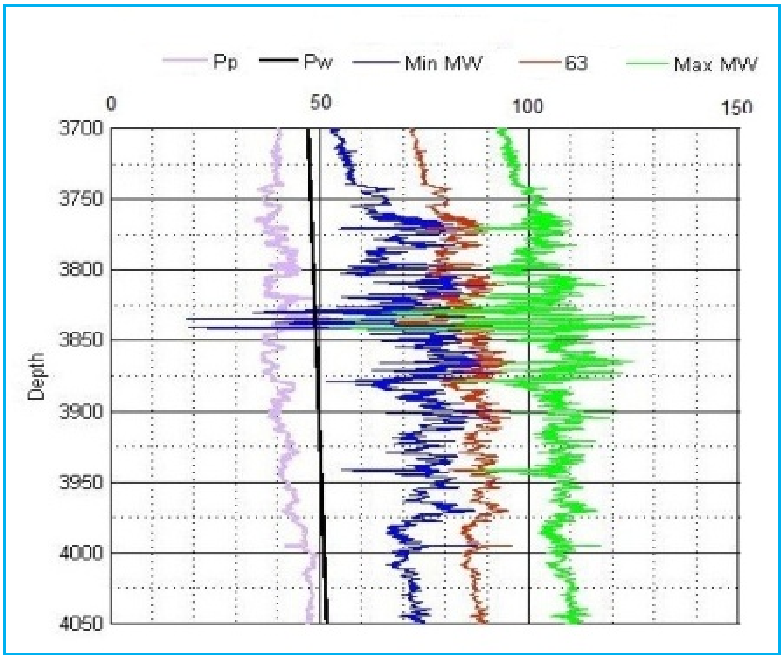

Figure 4- safe and unsafe sections in wellbore wall instability in terms of depth

Table 3- The mechanical properties of the studied reservoir and strength parameters of the pore fluid and the values of environmental stress, pore pressure and mud pressure

Feature	Value	Unit	Feature	Value	Unit
Tensile strength	3.95	MPa	Horizontal stress	83.54	MPa
Friction angle	40	Degree	Vertical stress	92.52	MPa
Adhesion	21.5	MPa	Pore pressure of the formation	43.71	MPa
Porosity	0.16		Mud pressure in over-balanced drilling	49.87	MPa
Internal permeability	525	Milidarcy	Mud pressure in balanced drilling	40.36	MPa
Bbulk density	2446	Kg/m3			

3.1. Balanced and over-balanced drilling

The mechanical analysis mode was activated in the presence of fluid flow and a 50/50 mesh grid was used to model the well cross section. In this figure, the elastoplasticity of the adjacent zones is visible.

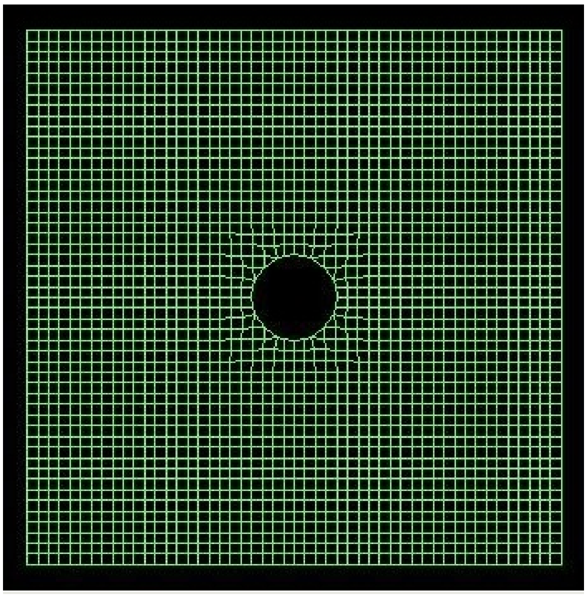

Figure 5- model elementation

In the over-balanced drilling, the pressure of the injected fluid (drilling mud) is greater than the pore pressure of the formation, so the flow of mud can penetrate the rock layer. The penetration flow into the formation vectors are introduced in Fig. 6 (right). The vectors of the figure represent the flow of mud from the well into the formation. As the distance from the well increases, the rate of mud permeation into the formation should be applied. It is observed in this figure that as the distance from the well increases, the vectors shorten, which confirms this issue.

In balanced drilling, the drilling mud pressure is considered smaller than the pore pressure, and there is a probability that the formation fluid will penetrate into the oil well. The penetrated flow vectors are presented in Fig. 6 (left). The vectors on the shape represent the flow of mud from the inside of the rock layer due to the lower mud pressure than the pore pressure into the well.

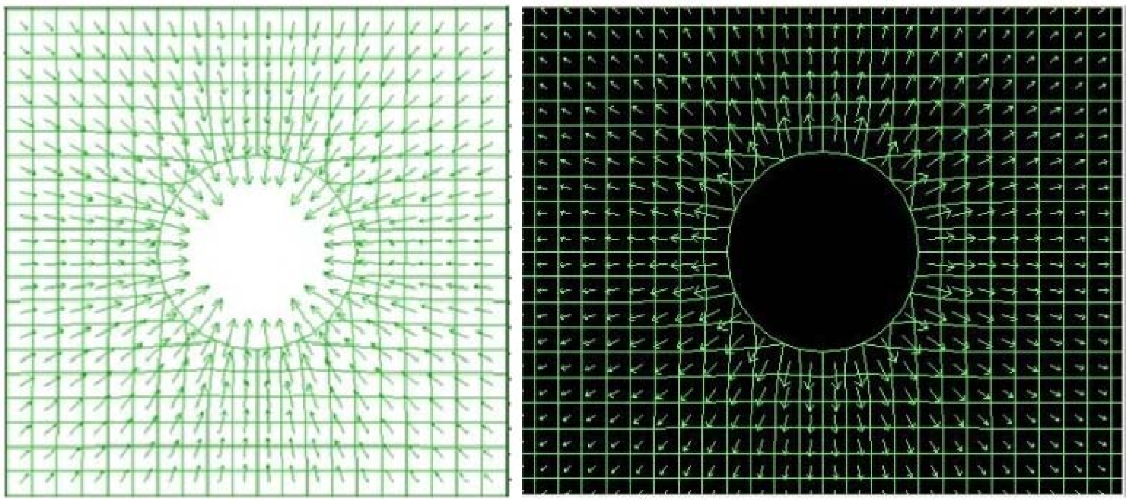

Figure 6- Permeation of mudflow vectors into the formation in over- balanced (right) and Permeation of mudflow vectors into the formation in balanced (left) modes

Due to the higher mud pressure in over- balanced drilling and the lower mud pressure in balanced drilling, the performance of the environmental materials is expected to be higher and lower in terms of safety respectively. This issue is well illustrated by the Figure.

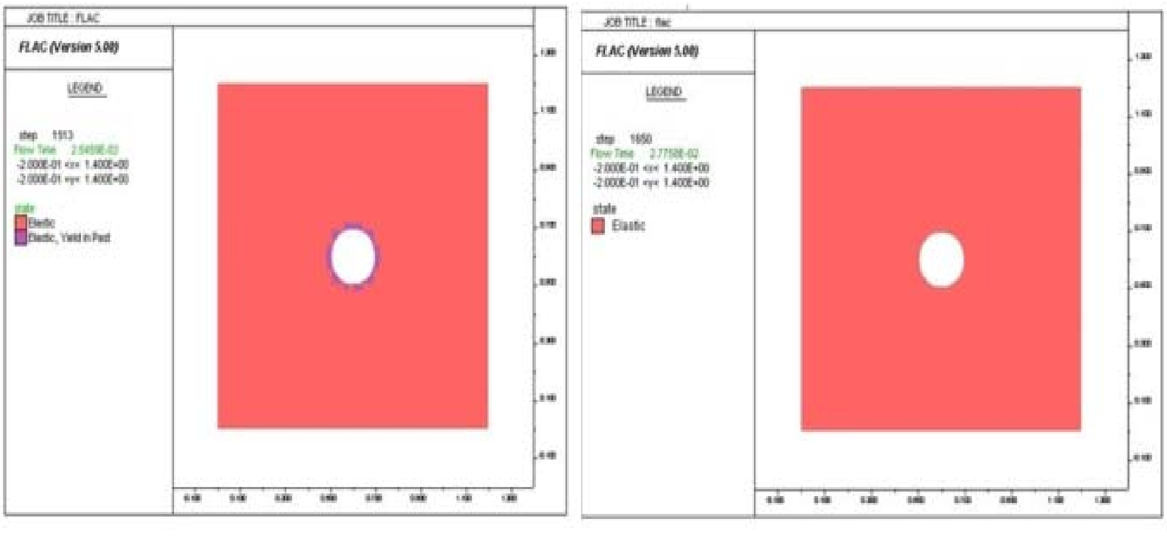

Figure 7- Elastoplasticity of rock materials during over- balanced (right) and balanced (left) drilling

Finally, the following results were obtained:

1. The depth of the studied layer is 350 meters from 3700 to 4050 meters.
2. Using gamma ray chart it is possible to estimate the amount of shale present in the formation approximately at the first glance so that, where the gamma graph shows a high value, the amount of shale increases.
3. Using the density and neutron the lithology of the formation is determined in such a way that if the density diagram is on the right of the neutron chart, the formation is dolomite. When the density diagram is placed at left of the neutron chart, the formation is sandstone and when the two graphs are roughly matched, the formation is limestone.

4. Using the induced stresses, it was determined that the model of the shear fracture is wide and the tensile fracture is radial.
5. Using the previous sections, the drilling mud window was obtained and it was determined that the minimum mud pressure is 60-80 MPa, and the maximum drilling mud pressure is 95-115 MPa.

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