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Numerical Stability Analysis of Drilled Wells in Maroun Oilfield

Mohammadreza Zare-Reisabadi[1*], Mohammad Parvazdavani[1], Hosein Sharifi[2]

[1] Research Institute of Petroleum Industry, Tehran, Iran
[2] National Iranian Oil Company, Tehran, Iran

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Abstract

Wellbore stability is one of the critical issues in successes of drilling operation. Instability is one of the major problems encountered during drilling, with an estimation cost exceeding hundreds of million dollars worldwide each year. To access the stability of borehole, the stress generated around the wellbore after drilling should be compared with strength of the formation. Mud weight must be determined so that provides sufficient borehole support to counteract the stress resulting from creation of wellbore.

This paper presents a numerical mechanical wellbore stability analysis in Asmari formation of Maroun oil field, which is one of the depleted Iranian fields. This formation consists of different layers with different lithologies. The drilled wells in this formation are suffering from wellbore instability problems during overbalanced drilling in some of Asmari layers. Therefore it is essential to investigate wellbore stability analysis and choose the optimum mud weight window. By mechanical properties from well-logs data analysis and using FLAC software, an elasto-plastic model was combined with a finite-explicit code to evaluate the stability problem. Based on yielding zone theory any by doing this numerical analysis, optimum Equivalent Circulating Density (ECD) was predicted. Results of study revealed that using an elasto-plastic constitutive model would be suitable to analyze mechanical wellbore stability in Asmari formation of Maroun field.

Keywords: Wellbore Stability; Numerical Modeling; Equivalent Circulating Density; Yielding Zone.

1. Introduction

Maintaining a stable borehole is one of the main problems encountered in drilling, whether a well is being drilled with overbalanced or underbalanced drilling techniques. Wellbore instability can lead to higher than necessary drilling cost. While drilling, wellbore instability is mainly function of how the rock surroundings of a well responds to the stress concentration induced around the wellbore wall. If the rock is stronger than the induced stresses, then the borehole will be stable. If not, rock yielding and possible rock collapse, detachment or convergence will occur [1]. The stability of wellbore during drilling is generally maintained by mud weight, which exerts a radial compression stress on the wellbore wall.

Quantitative analysis of wellbore stability is based on mechanical aspects. It requires the information of new stresses, strains and pore pressure in the rock mass around the wellbore after the well has been drilled. The new stresses around the wellbore can be determined from the application of the principles of continuum mechanics. A careful study and interpretation of these values allow the evaluation of the stability. During overbalanced and underbalanced drilling situation, the bottomhole-circulating pressure and direction of well are the controllable variables. The main objective of stability analysis is to study the probable instability of wellbore by computing the redistributed stress situation and comparing with an adopted failure criterion [2].

Parameters that affect the wellbore stability are either under our control or not. Uncontrollable factors are in-situ stress regime, direction of in-situ principal stresses, pore pressure, rock strength parameters and strength anisotropy (presence of bedding plane in formations). Controllable factors are well trajectory and mud weight and its rheological properties. Perhaps, the strongest tool in engineers' hands in controlling the stability of the well is the drilling mud and its properties. The drilling mud has to compensate for the lost support which was provided by the removed rock [3]. This has lead to the definition of safe mud weight window concept; it is also called equivalent circulating density (ECD). The safe mud weight window is determined by the failure criteria and the stability model used in the analysis. Using different failure criteria can lead to totally different mud weight windows [4].

In order to evaluate the potential for wellbore stability a realistic constitutive model must be used to compute the stresses and strains around a borehole. Out of the numerous published models, the linear elastic model (LEM) is the most common approach. This is due to its simplicity and less required input parameters compared to other models. However, using these simple models in some cases underpredicts the wellbore stable ECD. The LEM based models do not adequately explain the fact that, in many cases the borehole remains stable even if the stress concentration around the borehole exceeds the strength of the formation. Alternatively, elasto-plastic models offer the ability to assess the mechanical integrity of a borehole more realistically. Westergaard [5] published one of the early works contributing to the knowledge of stress distribution around a borehole, in which an elasto-plastic model was developed. Afterwards, elasto-plastic model was used widely in different works [6-9].

2. Field of Study

Maroun is located approximately 50 kilometers southeast of Ahwaz in southwestern Iran (Figure 1). The field is elliptical in shape, and is approximately 65 kilometers long and 8 kilometers wide. It is situated in a belt of northwest-southeast trending fields, which underlie the plains between the Persian Gulf and the Zagros Mountains. The nearest field, Aghajari, is less than two kilometers from Maroun's southeastern edge. Structurally, Maroun is a symmetric anticline typical of many large Iranian fields. The steepest flank is on the southwest side where dips reach 60°-70°. In contrast, the northeast flank appears to be gentler, with dips rarely exceeding 45° [10].

Figure 1. Location of Maroun between neighborhood oilfields [10]

Within the Zagros area, the regional structural grain is oriented northwest-southeast. Large scale structural elements in the area formed in response to regional compression created by the Arabian Plate colliding with the Iranian Plateau. Deformation produced by the collision resulted in the formation of a northern most "crush zone", a south flanking "imbricate zone" and a southern most "simply-folded" zone which contains the Maroun Field.

Lithologically, Asmari reservoir in Maroun Field is predominantly a carbonate unit composed of an alternating sequence of dolomites, limestones and limey shales. Essentially Asmari is composed of compact limestone, dolomite limestone and occasional shale band, The high production rates from diffractively dense limestone matrix and also the high circulation losses encountered while drilling are due to the present of a system of interconnecting fissures. In Maroun field, there is a major change in faces within Asmari.

3. Wellbore Stability Analysis

By wellbore stability modeling, one means that using available constitutive models and strength criteria, the current situation of the wellbore under existing in-situ stresses and rock properties as well as drilling parameters, be simulated and its state of stability be assessed. Here we have used a finite explicit code named FLAC for conducting wellbore stability simulation. An elasto-plastic Mohr-Coulomb failure criteria model is used for assessing state of instability with respect to different ECDs.

The Mohr-coulomb shear-failure model is one of the most widely used models for evaluating borehole collapse. This failure criterion proposes that shear failure takes place when the shear stress on some plane overcomes both the natural cohesion of the rock plus the frictional force that opposes motion along the failure plane. This model neglects the intermediate principal stress [11].

$$\tau = c + \sigma_n \tan \qquad (1)$$

where σn is the normal stress acting on the failure c is the cohesion of the material and φ is the angle of internal friction.

The Asmari formation was divided into four lithologies (achieved from geological unit) that they have almost similar characteristics. These lithologies contain carbonate, carbonate-marl, sandstone and inter-bedded shale (figure 2).

Data that are needed for wellbore stability analysis for both subzones are summarized in Table 1. Elastic properties that are needed consist of shear modulus, bulk modulus, Young's modulus and Poisson's ratio which are derived from laboratory rock strength measurement. In addition the internal friction angle and cohesion also are measured by rock mechanic tests. *USC* is the uniaxial compressive strength (USC), which can be related to the cohesion and the angle of internal friction by [11]:

$$USC = (2c\cos\phi)\,/\,(1-\sin\phi) \qquad (2)$$

True Tensile strength can be obtained from UCS [12]:

$$T = USC/10 \qquad (3)$$

To get an accurate magnitude for overburden stress, one can use the integration method using density log data as used by [13]. It can be expressed as:

$$\sigma_v = \int_0^h \rho g dh \qquad (4)$$

where, σ_v is vertical stress, ρ is density, g is acceleration due to gravity and h is depth.

In the cases where the density logs are not available, the overburden gradient can be assumed to be 1 to 1.1 *psi/ft.* the overburden stress was estimated to be 83.5 MPa in zone of interest.

Horizontal in-situ stresses are generally different in magnitude, but they may be, sometimes, equal. The in-situ stress regime is one of most critical factors that affect the stability of the borehole. Magnitudes of in-situ horizontal stresses may be estimated using mini-frac test or leak-off test (LOT) data. Unfortunately there is no horizontal stress measurement in the Maroun oilfield. In the case where none of these tests are conducted in the interval under analysis, formulations can be used to determine the magnitude of these stresses as follows [14]:

$$\sigma_{Hmin} = \frac{\nu}{1-\nu}\left(\sigma_v - \alpha P_f\right) + \alpha P_f \qquad (5)$$

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$$\sigma_{Hmax} = \frac{\sigma_{Hmin}+\sigma_v}{2} \quad (6)$$

where v is Poisson's ratio, Pf is pore pressure and α is Biot constant.

Pore pressure was recorded to be 28 MPa from RFT test analysis and the minimum horizontal and maximum horizontal stresses was determined to be 51.3 and 67.4MPa in zone of interest respectively.

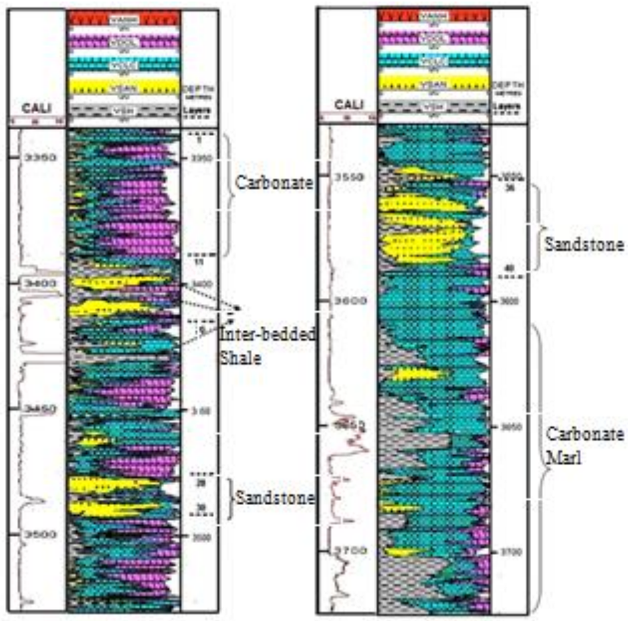

Figure2. Different section of Asmari formation

Table 1. Input parameter for wellbore stability analysis.

Lithology	Carbonate	Carbonate-Marl	Sandstone	Shale
Poisson's Ratio	0.295	0.277	0.238	0.313
Young's modulus, (Gpa)	48.3	36.3	25.6	15.3
Bulk modulus, (Gpa)	40.5	26.1	20.5	17
Shear modulus, (Gpa	18.4	14.9	10.6	8.1
Tensile strength, (Mpa)	10.3	8.3	9.7	6.1
Internal friction angle (Degree)	38	34	39	32
Cohesion,(Mpa)	24.5	22.2	23	16.7

4. Results and discussion

FLAC is a two-dimensional explicit finite difference program for engineering mechanics computation which is developed by Itasca consulting group. The created model for this problem is a plane-strain model with the plane of analysis oriented normal to the axis of the hole. By using gridding the finite difference zoning has been created. As the figure 3 indicate this mesh is radically symmetric with increasing zone size away from the hole. The grid contains 10000 zones, 100 zones in the radial direction and 100 zones on the circumference. According to the equations of stresses in hollow cylinder [15] and figure 4, at $\frac{r}{R} \geq 6$ the alteration of the stress is negligible, therefore stress deviation is also insignificant, and so r should be equal or greater than 6R (R is borehole radius). The origin of the system is located at the center of the hole and the radius of inner boundary R is 0.7m. The block length, L, is equal to 10m from the center of the hole; it means that r equals 7R. The Y-axis has been fixed in X direction and X-axis has been fixed in Y-direction as boundary.

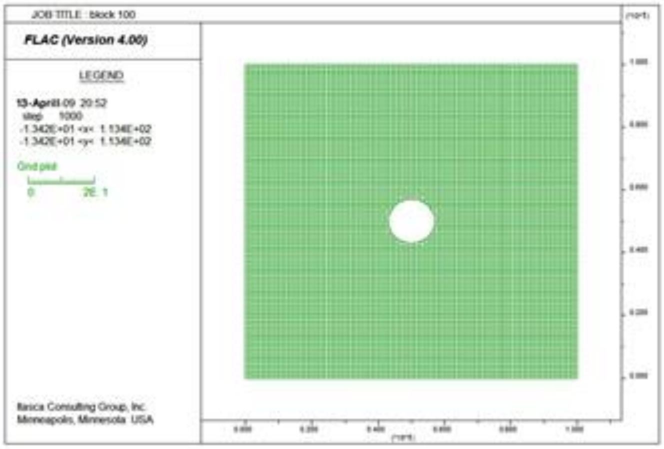

Figure 3. FLAC model created for a hole

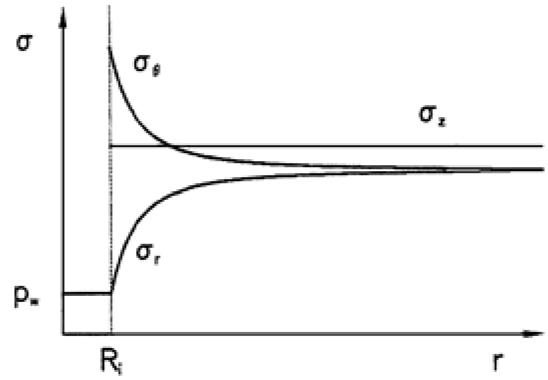

Figure 4. Stresses around a wellbore in a linear elastic formation [15]

Then the rock mechanics parameters are inputted to the model and in-situ stresses applied. After that a hole (wellbore) is drilled into the model and different mud pressures are applied and the model is run.

A criterion based on size of yielded zone was used in analyzing the risk of borehole instability. Since the yielded zone will be susceptible to spalling due to pressure surges during trips, the larger this zone is the greater the likelihood that instability-related problems will occur [1]. A parameter often used as a borehole instability risk indicator is the Normalized Yielded Zone Area (NYZA), which is the cross-sectional area of the yielded rock around the borehole divided by the area of the original borehole (Figure 5). Experience has indicated that the onset of borehole instability problems is often associated with NYZAs greater than 1.0, although the critical value for this parameter undoubtedly varies depending on the setting and other factors such as well inclination and hole cleaning capacity [16-17]. Figure 6, shows a sample of yielded zone area determination in model. The red points are failed points by shear failure.

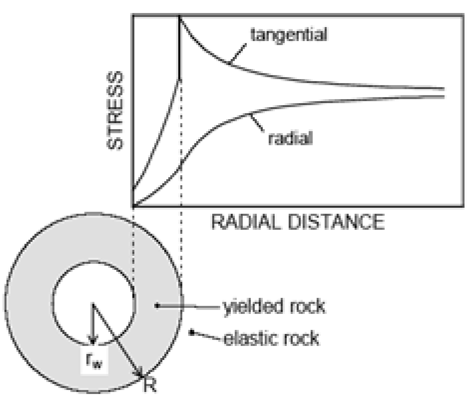

Figure5. Development of yielded zone

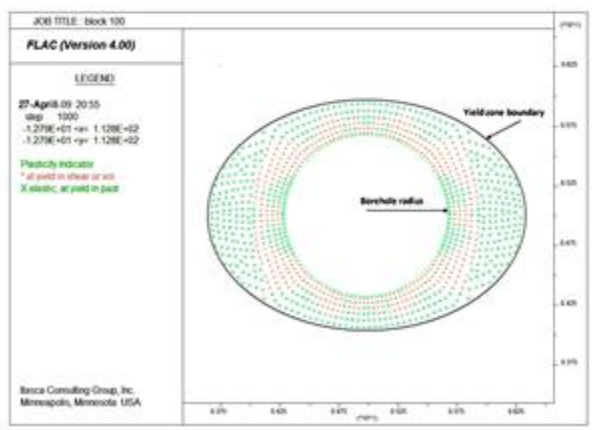

Figure 6. Predicting yielding zone in FLAC

Because maximum overburden stress is in deepest layer, for stability analysis of every lithology we consider deepest layer of each lithology. By applying different ECDs, the model is run for each lithologies and the trend of NYZA changes with different ECDs is estimated. This trend is shown in figures 7, figure 8, figure 9 and figure 10 in shale, carbonate-marl, carbonate and sandstone respectively. As mentioned previously, ECD is safe when NYZA is less than one. These figures indicate that with increasing ECD the NYZA will decrease and we will have more stable wellbore. As figures 6-9 indicate the safe ECD in shale is 65.5 pcf, it is

59 pcf for carbonate-marl, 50.6 pcf for carbonate and 53 pcf for sandstone. Actual used ECD in Asmari formation was same through the formation, and its average was 58 pcf.

In the case of inter-bedded shale, the actual used ECD was more than calculated in the simulation; therefore the occurrence of breakout is likely, which some instability were reported in daily drilling report of shale sections. However, in order to prevent these instabilities it is recommended to use calculated ECD 65.5 pcf, in shale sections of Asmari formation. In the case of carbonate-marl, the actual ECD, was very close to the calculated one, 59 pcf, therefore in this state the actual ECD is near to critical NYZA and well is possible to be unstable. In order to increase the safety, actual ECD should be increased. In the case of carbonate and sandstone sections the actual used ECD (58 pcf), were upper the calculated ECD in these two layers. Therefore as it is expected no serious instability was reported during drilling of carbonate and sandstone layers.

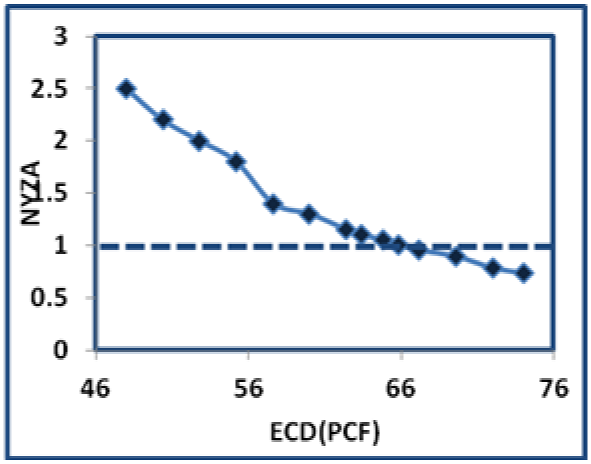

Figure 7. NYZA versus ECD in shale layers

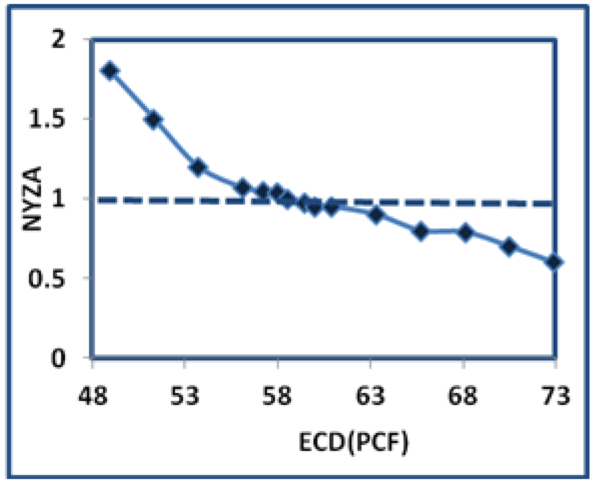

Figure 8. NYZA versus ECD in Carbonate-Marl layers

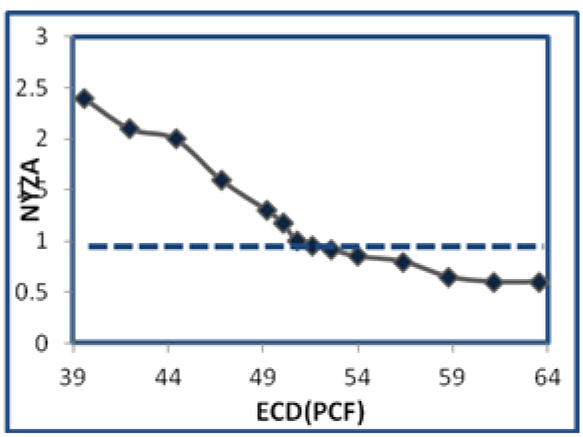

Figure9. NYZA versus ECD in Carbonate layers

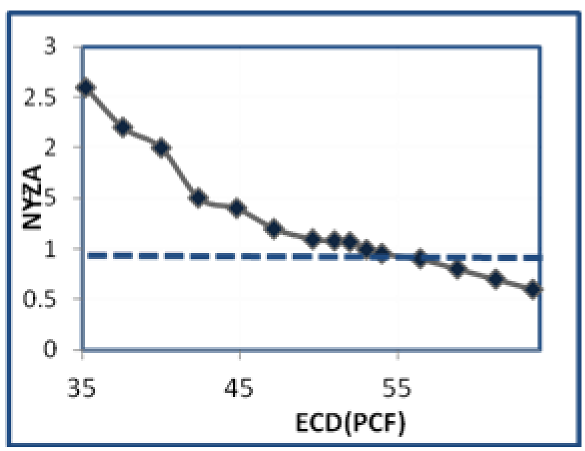

Figure 10. NYZA versus ECD in sandstone layers

5. Conclusions

An elasto-plastic model combined with a finite explicit code was used for mechanical wellbore stability analysis in Asmari formation of Maroun oil field. Based on the results and comparison with actual field data, an elasto-plastic model gives good predictions for wellbore stability in this formation. The safe ECD was calculated in each layers of Asmari formation; comparing the actual ECD with the calculated safe ECD in a drilled well reveals that the instability problems in shale sections was because of using unsafe ECD during drilling. In the cases of carbonate and sandstone layers actual used ECD was upper than the minimum ECD, therefore no instabilities were reported.

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* *Corresponding Author: mr.zare.r@gmail.com*