JME

Journal of Mining & Environment,
Vol.7, No.1, 2016, 37-46.
DOI: 10.22044/jme.2016.457

Development of a mechanical earth model in an Iranian off-shore gas field

E. Bozorgi[1], D. Javani[2*] and M. Rastegarnia[3]

1. Islamic Azad University, Science and Research Campus, Tehran, Iran
2. Imam Khomeini International University, Ghazvin, Iran
3. School of Mining, Petroleum & Geophysics Engineering, Shahrood University of Technology, Shahrood, Iran

Received 9 November 2014; received in revised form 21 May 2015; accepted 24 June 2015
**Corresponding author: javani.dariush@gmail.com (D. Javani).*

Abstract

Wellbore instability is a quite common event during drilling, and causes many problems such as stuck pipe and lost circulation. It is primarily due to the inadequate understanding of the rock properties, pore pressure, and earth stress environment prior to well construction. This study aims to use the existing relevant logs, drilling, and other data from offset wells to construct a precise mechanical earth model (MEM) describing the pore pressure, stress magnitudes and orientations, and formation mechanical properties of South Pars Gas field. Since the core test data, MDT/XPT data, and LOT/XLOT data were not available to calibrate the developed model, each component of the model was determined using a range of existing methods and relations, and then the wellbore instability was analyzed based on the developed MEM and the Mogi-Coulomb failure criterion. The predicted incidents such as the lost circulation and tight hole were then compared with the caliper log and reported drilling events to determine the consistency of the model. Since the stability analysis based on the developed MEM had the most agreement with the caliper log and reported drilling events, the equations presented by Eaton and Zoback had good estimations of the pore pressure and rock strengths. Also the estimated horizontal stresses were precise enough to enable the constructed MEM to predict the wellbore instabilities. The stress regime in the field of study was strike-slip, which is frequently specified in the industrial technical reports of the studied field. Finally, it was concluded that the Mogi-Coulomb failure criterion minimized the conservative nature of the mud pressure prediction due to the consideration the strengthening effect of the intermediate stress.

Keywords: *Mechanical Earth Model, Wellbore Instability, Drilling Operation, Mogi-Coulomb Failure Criterion.*

1. Introduction

The wellbore stability maintenance is a crucial step during drilling a well for oil and gas production. The wellbore instability problems may cause increase in the wellbore's drilling costs; delay in drilling the wellbore, and, in severe conditions, wellbore abandonment. It has been estimated that at least 10% of the average well budget is used on unplanned operations resulting from the wellbore instability. These costs may approach one billion dollars per year worldwide [1]. The simplest constitutive model for describing the behavior of rocks is linear elastic, which is the foundation for all the aspects of rock mechanics. This theory is based upon the concepts of stress and strain, which are related to the simple Hook's law. Two parameters are required for describing the elastic response of a material: Young's modulus and Poisson's ratio. The solution to a given problem, considering the elasticity theory, consists of determination of the stress, strain, and displacement components. Bradley [2] and Fjaer et al. [3], among others, have presented analytical equations to compute the stresses around boreholes. They have assumed a state of plane strain. The derivation of the stress solution has been in the work presented by Jaeger and Cook [4], and the final equations have been given by Bradley [2] and Fjaer et al. [3].

When the formation rock is subjected to sufficiently large stresses, a kind of failure occurs. In this work, we considered two types of failures: shear failure and tensile failure. The most common shear failure criteria are Mohr-Coulomb and Mogi-Coulomb.

In the present work, firstly, an MEM was constructed using the existing relevant logs, drilling, and other data from the offset well, and then the wellbore instability was analyzed based upon the developed model and the Mogi-Coulomb failure criterion. Finally, the results obtained were compared with the caliper log and reported incidents such as the lost circulation in order to validate the developed model.

2. Mechanical earth model development

Development of a mechanical earth model (MEM) is essential for making the best use of field geomechanics information. MEM is a description of the strengths, stresses, and pressures as a function of depth, referenced to a stratigraphic column. Once an MEM is constructed, it can be used to estimate and predict the best possible methods for safely drilling and completing in both a single borehole and field development. A typical flow chart for the key MEM steps is shown in Figure 1.

Figure 1. Basic workflow in MEM construction process.

2.1. Calculation of elastic parameters

The rock elastic properties represent the basic inputs to the estimation of rock strength and in-situ stresses, which can be later refined and calibrated to the other available information. Assuming elastic isotropy, DSI, dipole sonic measurements (i.e. compressional Δt_C and shear slowness Δt_S) and bulk density (ρ_b) from well logs were used together with the following equations to calculate the dynamic elastic moduli:

$$G_{dyn} = (13474.45)\frac{\rho_b}{(\Delta t_s)^2} \quad (1)$$

$$K_{dyn} = (13474.45)\frac{\rho_b}{(\Delta t_s)^2} - \frac{4}{3}G_{dyn} \quad (2)$$

$$E_{dyn} = 2G(1+\vartheta) \quad (3)$$

$$\vartheta_{dyn} = \frac{\frac{1}{2}(\frac{\Delta t_s}{\Delta t_c})^2 - 1}{(\frac{\Delta t_s}{\Delta t_c})^2 - 1} \quad (4)$$

However, these dynamic properties are systematically different from the equivalent static values that are typically needed for the subsequent geomechanics modeling and stress analysis, with dynamic Young’s modulus often being 2 to 3 times larger than the equivalent static Young’s modulus [5, 6]. Many authors [3, 7- 9] have presented relations between the static and dynamic Young’s modulus in carbonates. Based upon the Zoback’s findings [10], the static Young’s modulus is approximately 0.4 times of the dynamic Young’s modulus, and, therefore, Wang’s equation [8] can be used to determine the static Young’s modulus:

$$E_s = 0.414E_d - 1.15 \quad (5)$$

Figures 2 and 3 show the dynamic and static elastic moduli, respectively.

The static value for the Biot's constant was assumed to be 1.0 for all the formations and rock types considered [11].

2.2. Calculation of rock strength

Rock strength refers to the ability of a rock to bear the in-situ stress environment around the wellbore. Unconfined compressive strength (UCS) is one of the most widely used rock strength parameters. It is typically computed by log measurements. Several empirical equations exist for calculating UCS from the log data. Most of them use the rock elastic moduli (Young's modulus, shear modulus), porosity, and other formation properties. In this work, UCS was calculated based on the empirical relation presented by Militzer [12], and Zoback [10] (table 1). Zoback's equation had good estimations for limestone and dolomite, and, therefore, was used in the MEM development in this field. Figure 4 shows the calculated values for UCS in reservoir.

Tensile strength of the formation was used to evaluate the tensile failure of the borehole due to the stress concentration. The tensile strength of a rock is usually in the order of 1/12 to 1/8 of its UCS [10].

Table 1. Empirical relation to calculate UCS in carbonates.

UCS, MPa	Comments	Reference
$UCS = (\frac{7682}{\Delta t})^{1.82} / 145$	Carbonates	Militzer, 1973 [12].
$UCS = 0.4067E^{0.51}$	Limestone with 10<UCS<300 MPa	Zoback, 2007 [10].
$UCS = 2.4E^{0.34}$	Dolomite with 60<UCS<100 MPa	Zoback, 2007 [10].

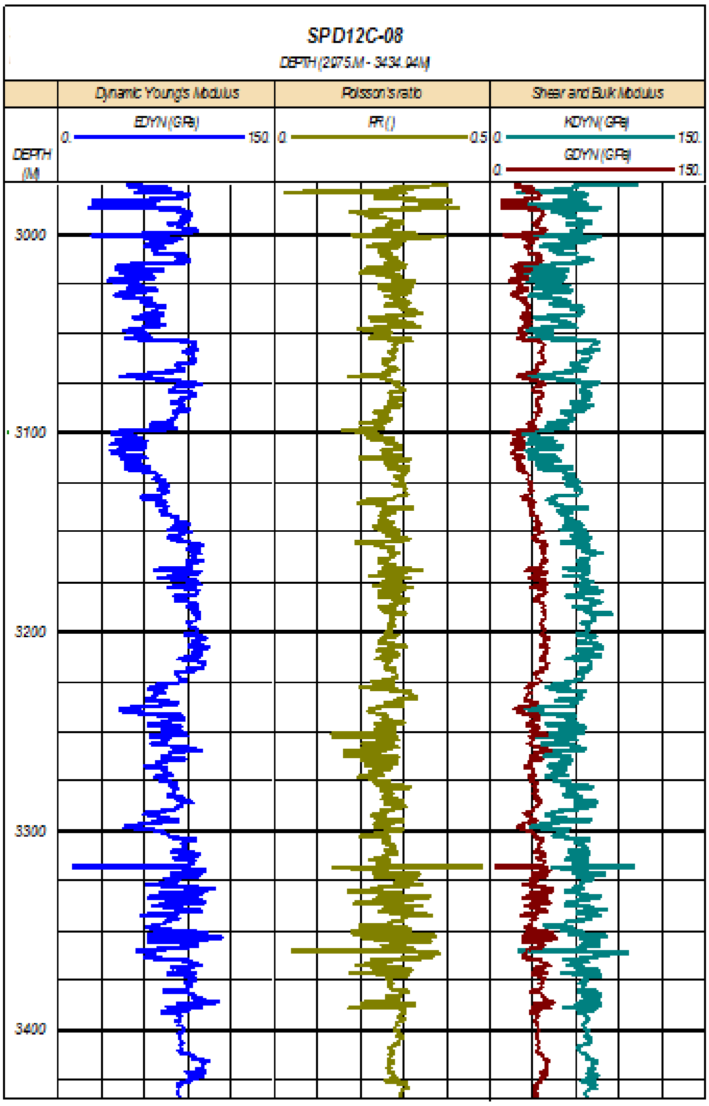

Figure 2. Dynamic elastic moduli.

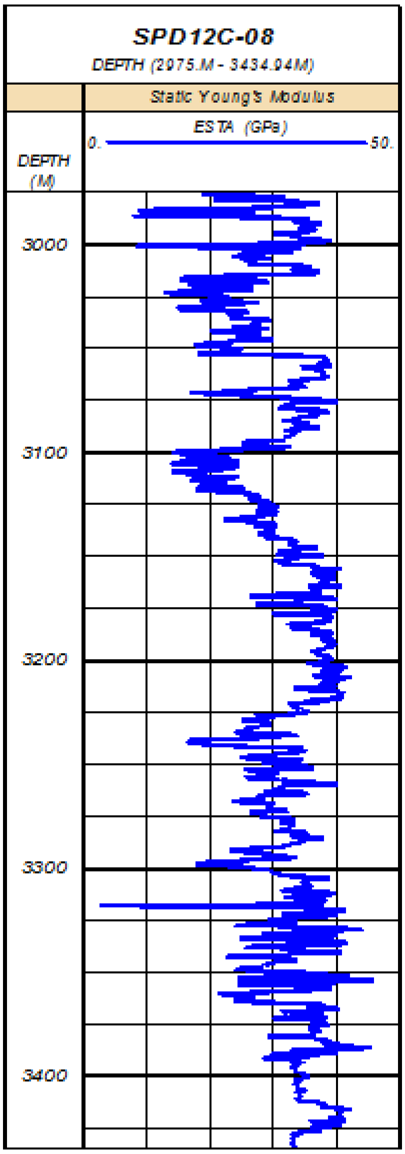

Figure 3. Static Young's modulus.

2.3. Calculation of pore pressure

The predicted pore pressure is one of the key parameters involved for constraining the in-situ stress state in the study field that is implemented in an integrated wellbore stability model. The normal trend method [13], Holbrook method [14], and explicit method [15] are commonly used in the oil industry for the pore pressure prediction. The Eaton method was used in this work. It is essential to determine the normal pore pressure trend line, normal trend of compaction, and Eaton exponent [13] to utilize the Eaton normal trend method for a pore pressure prediction. The Eaton method can be described as the following equation:

$$\frac{P}{D}=\frac{S}{D}-(\frac{S}{D}-(\frac{P}{D})_n)(\frac{\Delta t_n}{\Delta t_o})^{\alpha} \quad (6)$$

where D is the depth. P and S are the pore pressure and overburden stress, respectively. Δt_n and Δt_o are the normal and real transit time of sonic wave in the formation, respectively. Also α is the Eaton's alpha exponent, which has been reported to be equal to 3.0. The predicted pore pressure profile is shown in Figure 6.

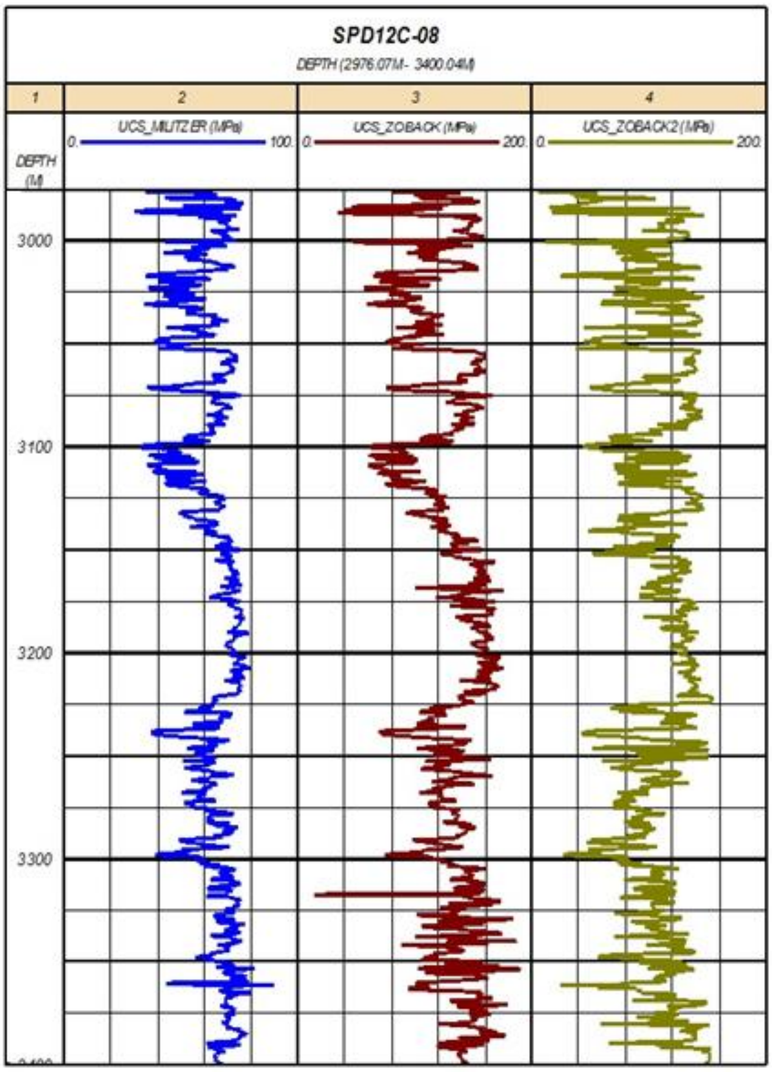

Figure 4. Estimated UCS in reservoir section using Militzer and Zoback's equations for limestone and dolomite respectively.

2.4. Calculation of in-situ stress

The in-situ stress magnitudes and orientations play very important roles in a geomechanical analysis, and they are the most basic parameter inputs in investigation of the wellbore stability. For more details for calculation of the in-situ stress magnitudes, please refer to Amadei and Stephansson [16] and Haimson and Cornet [17].

Whilst formation density can be obtained using wire-line logs or core density, only bulk density logs were used in this work. The values for the vertical stresses (σ_V) were computed by integrating the formation bulk density (ρ_b) from surface to TD using the following equation:

$$\sigma_v = \int_0^z \rho(z)gdz = \bar{\rho}gz \quad (7)$$

where ρ is the rock density.

When characterizing the horizontal stress, the first step consists of determining its orientation. Stress direction analysis is a critical part of any geomechanics study. Identifying the stress direction and magnitude allows improving a well trajectory design so that the wellbore instability can be minimized. Several methods are available for identifying the stress direction including the borehole breakout orientation, hydraulic fracture orientation, and shear sonic anisotropy.

Wellbore breakout generally occurs in the minimum principal stress direction around the wellbore, where the stress concentration is the highest. In a vertical well, the minimum principal stress direction corresponds to the direction of the minimum horizontal stress. Therefore, the borehole breakout direction in a vertical wellbore indicates the direction of the minimum horizontal stress. Wellbore breakout direction can be identified using the image logs or by analyzing the oriented multi-arm caliper data.

Hydraulic fractures generally occur in the maximum principal stress direction around the wellbore, where the hoop stress is tensional. In a vertical well, the maximum principal stress direction corresponds to the direction of the maximum horizontal stress. Therefore, the hydraulic fracture direction in a vertical wellbore indicates the direction of the maximum horizontal stress. The drilling induced hydraulic fracture direction can be identified using the image logs.

Stress magnitudes including those of in-situ stresses in rocks cannot be explicitly measured, and can only be modeled or inferred from measurement of deformation, strain, and pressure. However, there are a number of fundamental conditions in mechanics that must be honored. They constrain the magnitudes and directions of the principal stresses σ_1, σ_2, and σ_3 in a solid body (including the stresses in the ground).

Of the two horizontal stresses, the magnitude of σ_h is more straightforward to determine if it happens to be the in-situ minimum stress σ_3, and is therefore less than the overburden stress. With mini-frac or extended leak-off test, indirect measurements of σ_3 (and, therefore, σ_h) can be obtained with a reasonable accuracy. In contrast to the minimum horizontal stress, it is not possible to make a direct measurement of the maximum horizontal stress magnitude (σ_H). However, it can be inferred with reasonable accuracy using additional constraints from stress polygons, as discussed later.

In a passive basin, if a rock is assumed to be a semi-infinite isotropic medium subjected to gravitational loading and no horizontal strain, the two horizontal stresses are equal in magnitude. They can be estimated [18] from the pore pressure P_p, overburden stress σ_V, Biot's coefficient, α, and static Poisson's ratios, ν, using the following uniaxial strain poro-elastic equation:

$$\sigma_h = \frac{\vartheta}{1-\vartheta}(\sigma_v - \alpha P_p) + \alpha P_p \qquad (8)$$

In a tectonically-active basin, the tectonic stresses and strains arise from the tectonic plate movements. If tectonic strains are applied to rock formations, they add a stress component to an elastic rock. The poro-elastic horizontal strain model, discussed by Bratton (1999), takes the tectonic strains into account, and, therefore, accommodates the anisotropic horizontal stresses.

$$\sigma_h = \frac{\vartheta}{1-\vartheta}(\sigma_v - \alpha P_p) + \alpha P_p + \frac{E}{1-\vartheta^2}\varepsilon_x + \frac{E\vartheta}{1-\vartheta^2}\varepsilon_y \qquad (9)$$

$$\sigma_H = \frac{\vartheta}{1-\vartheta}(\sigma_v - \alpha P_p) + \alpha P_p + \frac{E}{1-\vartheta^2}\varepsilon_y + \frac{E\vartheta}{1-\vartheta^2}\varepsilon_x \qquad (10)$$

Here, the two horizontal strains ε_x and ε_y may be compressional (i.e. for tectonic compression) or extensional (i.e. to represent lateral spreading), and can be treated simply as the calibration factors that can be adjusted to best-match the stress estimates to minimum horizontal stress measurement or specific modes of rock failure seen on the image logs, etc. In this study, the minimum horizontal stress was estimated through Equation 9, and then calibrated through the reported lost circulations during drilling.

Maximum horizontal stress was first determined using Equation 10. The results obtained were then constrained through a stress polygon [10]. The stress polygon is based upon the Anderson's faulting theory and Coulomb frictional theory [19]. To determine the maximum horizontal stress using the stress polygon, vertical stress, pore pressure, minimum horizontal stress, and unconfined compressive strength were needed [20]. Figure 5 shows the stress polygon at a depth of 3000 m, in which the required parameters in terms of MPa were P_p = 38, S_h = 77 ± 3, UCS = 82.87, and S_v = 70. Using this stress polygon resulted in a maximum horizontal stress of 115 MPa.

Based on the aforementioned methods, the three in-situ stresses and pore pressure were calculated and presented in Figure 6 for the studied well.

In figure 6, $\sigma_H > \sigma_v > \sigma_h$, and therefore, based on the Anderson's frictional faulting theory, the faulting regime in our case was strike-slip, which has been frequently specified in the industrial technical reports for the studied field [21].

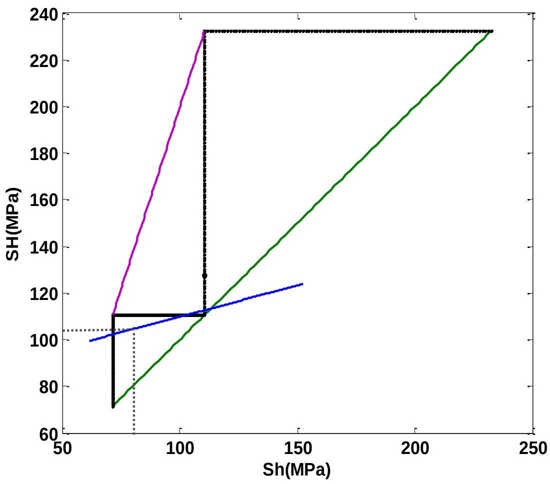

Figure 5. Stress polygon at depth of 3000 m.

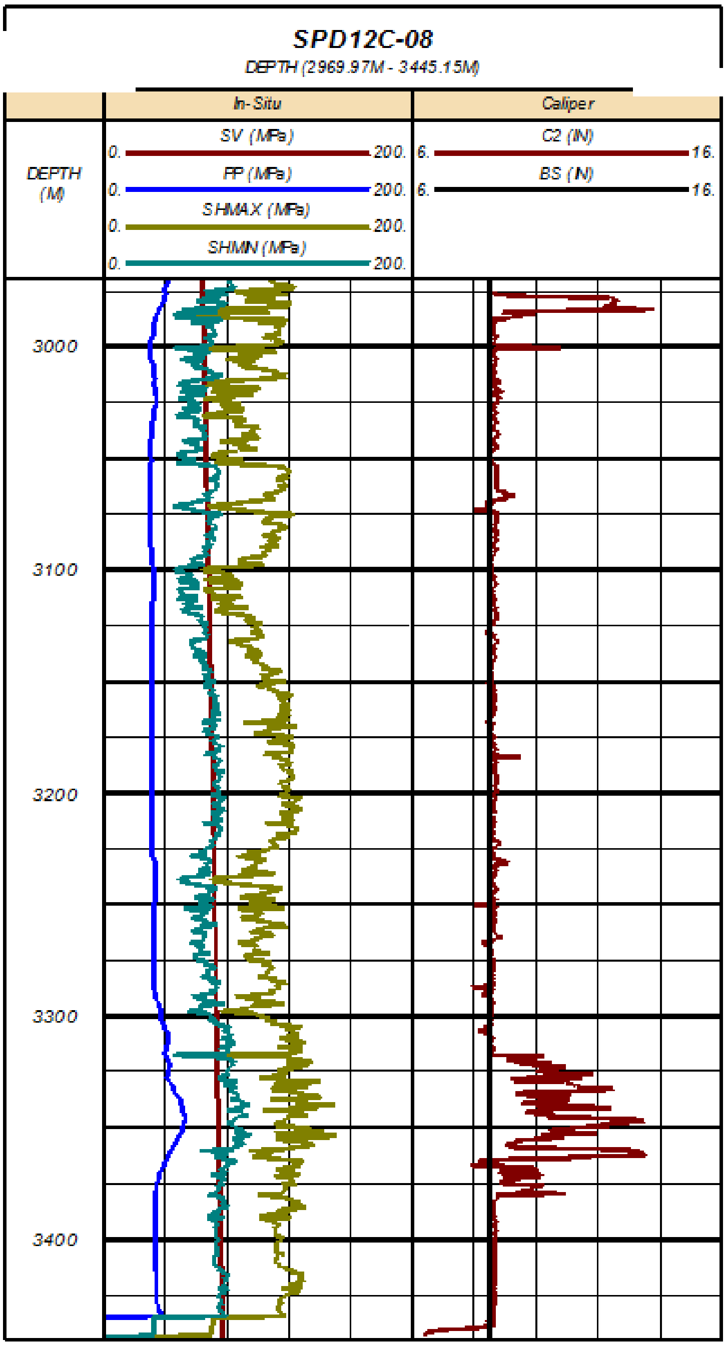

Figure 6. In-situ stresses and pore pressure *vs.* caliper.

3. Wellbore stability analysis

3.1. Stress distribution around wellbores

For an inclined borehole, the near-wellbore stress can be obtained by modifying the Kirsch's solution for the state of stress surrounding a circular hole in an infinite elastic plate. Based on the cylindrical coordinates, the Kirsch's equations refer to the stress distribution at the wellbore of a vertical borehole with unequal far field stress that can be obtained from Equation 11 [22]:

$$\begin{aligned}
&\sigma_{rr} = P_w \\
&\sigma_{\theta\theta} = \sigma_{xx} + \sigma_{yy} - 2\left(\sigma_{xx} - \sigma_{yy}\right)\cos 2\theta - 4\sigma_{xy} \sin 2\theta - P_w \\
&\sigma_{zz} = \sigma_v - 2\nu\left[\left(\sigma_{xx} - \sigma_{yy}\right)\cos 2\theta - 2\sigma_{xy} \sin 2\theta\right] \\
&\sigma_{r\theta} = 0 \\
&\sigma_{\theta z} = 2\left(-\sigma_{xz} \sin\theta + \sigma_{yz} \cos\theta\right) \\
&\sigma_{rz} = 0
\end{aligned} \qquad (11)$$

Figure 7 shows an estimation of the stress distribution around the wellbore at a depth of

3350 m. It shows the compressive stress concentration in the direction of σ_{hmin}, which leads to wellbore breakouts in the direction of minimum horizontal stress. On the other hand, the tensile-induced fractures occur perpendicular to the minimum horizontal stress due to the tensile stress concentration in the direction of maximum horizontal stress.

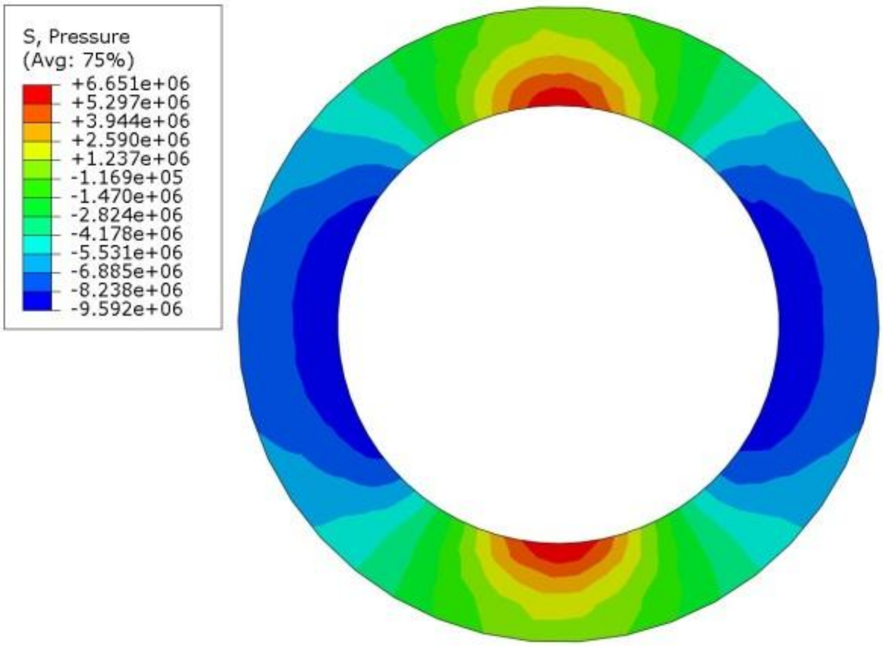

Figure 7. Stress distribution around well at depth of 3350 m.

3.2. Shear and tensile failure criterion

A main aspect of the wellbore stability analysis is the selection of an appropriate rock failure criterion. The most commonly used criterion for brittle failure of rocks is Mohr-Coulomb. As the Mohr-Coulomb criterion ignores the strengthening effect of the intermediate stress, it is expected to be too conservative in estimating the critical mud weight required to maintain the wellbore stability [23]. Recently, Al-Ajmi and Zimmerman [24] have developed the Mogi-Coulomb failure criterion, and have shown that it is reasonably accurate in modeling the polyaxial failure data from a variety of rocks. During drilling, there are two main wellbore stability problems, namely, borehole collapse and fracturing [24]. In this work, the Mogi-Coulomb failure criterion was used to analyze wellbore stability. The Mogi-Coulomb failure criterion in the τ_{oct} - $\sigma_{m,2}$ space [23] is as follows:

$$\begin{aligned} \tau_{oct} &= a + b\sigma_{m,2} \\ a &= \frac{2\sqrt{2}}{3} c\cos\varphi \\ b &= \frac{2\sqrt{2}}{3} \sin\varphi \\ \tau_{oct} &= \frac{1}{3}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_3-\sigma_1)^2+(\sigma_2-\sigma_3)^2} \end{aligned} \quad (12)$$

3.3. Failure analysis and history matching

The first step in performing a history matching consists of computing the mud weight window along the well trajectory using the stress model and the rock properties calculated for MEM. The shear and tensile failures were computed along the well trajectory using a defined mud weight and the Mogi- Coulomb failure criterion. The predicted failure occurrences (breakouts, tensile induced fractures, etc.) were then compared with the actual data from the drilling report or caliper log data. Figure 8 shows that the mud weight used leads to few breakouts and mud loss, which are obvious in caliper log, and have been mentioned in the daily drilling reports. These drilling incidents are thoroughly predicted by the developed MEM, as shown on Figure 8.

In this figure, MW is the mud weight used while drilling this well. When MW lies in the blue shaded area, the mud weight would be less than the pore pressure, and there would be a risk of kick. When MW is lower than the brown curve, there would be occurrence of breakout, as mentioned in Figure 8. When MW is higher than the green curve (minimum horizontal stress), losses may occur in the presence of natural fractures. Finally, if MW exceeds the formation breakdown gradient (red), there would be a drilling-induced fracture on the borehole wall.

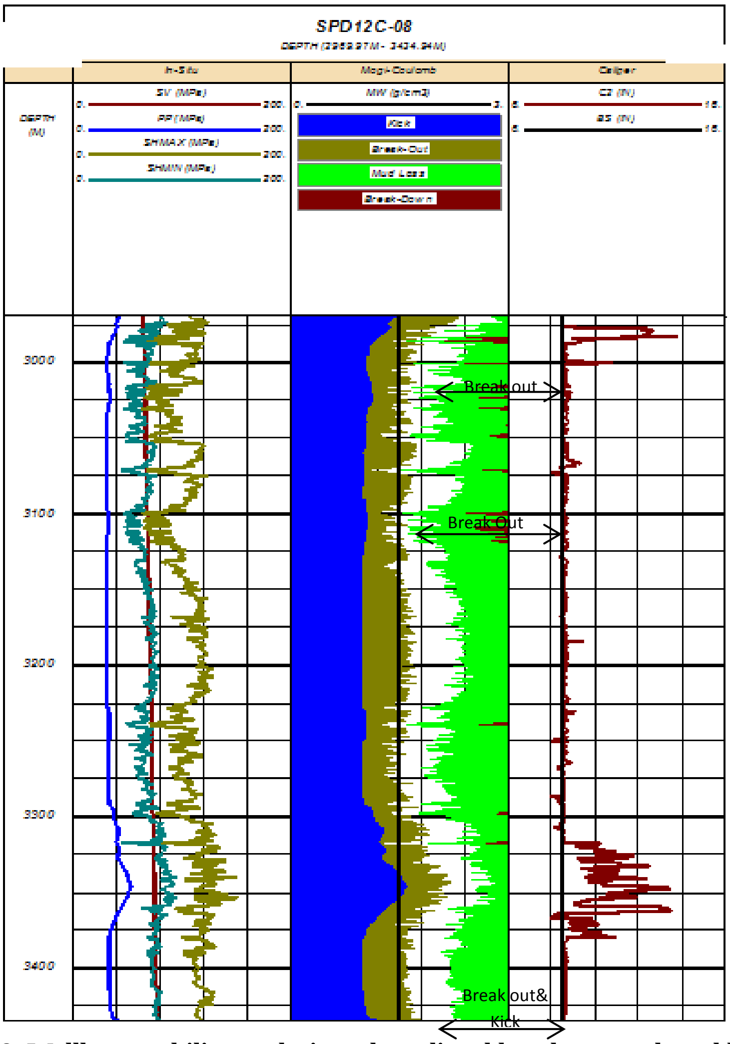

Figure 8. Wellbore stability analysis and predicted breakouts and mud losses.

4. Discussion

The most effective approach used to calibrate and validate MEM is to verify the predictability of the model. Using the estimated rock properties and horizontal stresses, wellbore stability analysis shows how robust MEM is by comparing the predicted wellbore stability/instability with the drilling events, image, caliper etc. A precise MEM is formed from precise components such as pore pressure and in-situ stresses. Therefore, each component has to be verified by the existing data such as MDT/XPT, laboratory mechanical tests, and LOT/XLOT. In this study, the lack of reference data was used to determine each MEM component using few methods, and to construct few MEMs from its components. Each MEM was used to predict the wellbore stability, and was then compared with the drilling events and caliper. Comparison of the developed MEM in this study with the drilling events and caliper log demonstrated a good agreement, even though the MEM components were primarily needed for verification and calibration with the in-situ and laboratory test data.

5. Conclusions

The present paper is a summary of a comprehensive study of the wellbore stability in South Pars Gas Field as the largest gas field in the world. The SPD12C-08 well, an appraisal well in Phase 12 of South Pars Gas Field, was selected for the borehole stability analysis. An MEM was built using the interdisciplinary data sources such as well logs. Then the constructed MEM was evaluated using the wellbore failure observations, well logs, etc. The following findings were obtained.

- Since the stability analyses results obtained based on the constructed MEM had good agreement with the reported events and Caliper log, it can be concluded that the equations used to calculate the MEM components had a suitable estimation of the real data.

- The stress model indicated that the stress regime in the reservoir interval was primarily strike-slip ($\sigma_h < \sigma_v < \sigma_H$). Therefore, considering the effect of well azimuth on wellbore stability, it is recommended to plan the well azimuth between σ_h and σ_H directions.
- As the Mogi-Coulomb failure criterion considers the strengthening effect of the mean effective stress in the stability analysis, it would minimize the conservative nature of the mud pressure prediction.

References

[1]. Aadnoy, B.S. (2003). Introduction to special issue on Borehole Stability. Journal of Petroleum Science and Engineering. 38: 79-82.

[2]. Bradley, W.B. (1979). Failure of inclined boreholes. Journal of Energy Resources Technology, Transactions of the ASME. 101: 232-239.

[3]. Fjaer, E., Holt, R.M., Horsrud, P., Raaen, A.M. and Risnes, R. (1992). Petroleum related rock mechanics. Elsevier Science Publishers B.V., 515 P.

[4]. Jaeger, J.C. and Cook, N.G.W. (1979). Fundamentals of rock mechanics. Chapman and Hall, 593 P.

[5]. Plona, T.J. and Cook, J.M. (1995). Effects of stress cycles on static and dynamic Young's Moduli in Castlegate sandstone, The 35th U.S. Symposium on Rock Mechanics (USRMS), Reno, Nevada, USA, 5-7 June.

[6]. Terra Tek Inc. (1998). The difference between static and dynamic mechanical properties; TerraTek Standard Publications.

[7]. Eissa, E.A. and Kazi, A. (1988). Relation between static and dynamic Young's moduli of rocks. International Journal of Rock Mechanics and Mining Science. 25 (6): 479-482.

[8]. Wang, H.F. (2000). Theory of linear poroelasticity with applications to geomechanics and hydrogeology. Princeton, NJ, Princeton University Press, 304 P.

[9]. Jambunathan, V. (2008). Study of Mechanical Properties of Carbonates. Oklahoma, University of Oklahoma Press, 312 P.

[10]. Zoback, M. (2007). Reservoir geomechanics. New York, Cambridge University Press, 505 P.

[11]. Rafieepour, S., Jalalifar, H. and Javani, D. (2014). Drilling Optimization Based on a Geomechanical Analyses Using Probabilistic Risk Assessment, a Case Study from Off-Shore Iran. ISRM European Rock Mechanics Symposium (EUROCK 2014), Vigo, Spain, 27-29 May.

[12]. Militzer, M.A.S. (1973). Einige Beitrageder geophysics zur primadatenerfassung im Bergbau, Neue Bergbautechnik, Lipzig. 3 (1): 21-25.

[13]. Eaton, B., (1975). The equation for geo-pressure prediction from well logs. Fall Meeting of the Society of Petroleum Engineers of AIME, Dallas, Texas, USA, 28 September- 1 October

[14]. Holbrook, P., Robertson, H.A. and Hauck, M.L. (1991). Method for determining pore pressure and horizontal effective stress from overburden and effective vertical stresses. United States Patent, Patent Number: 4981037, Publication Number: US4981037 A.

[15]. Bowers, G.L. (1993). Method for estimating pore fluid pressure. United States Patent, Patent Number: 5200929, Publication Number: US5200929 A.

[16]. Aamadei, B. and Stephansson, O. (1997). Rock stress and its Measurement, New York, Chapman & Hall, 498 P.

[17]. Haimson, B.C., and Cornet, F.H. (2003). ISRM Suggested Methods for rock stress estimation-Part 3: hydraulic fracturing (HF) and/or hydraulic testing of pre-existing fractures (HTPF). International Journal of Rock Mechanics and Mining Science. 40: 1011-1020.

[18]. Bratton, T., Bornemann, T., Li, Q., Plumb, R., Rasmus, J. and Krabbe, H. (1999). Logging-while-drilling images for geomechanical, geological and petrophysical interpretations. Proc. 40th Annual Logging Symposium, SPWLA, Oslo, Norway, 30 May-3 June.

[19]. Elyasi, A., Goshtasbi, K., Saeidi, O. and Torabi, S.R. (2014). Stress determination and geomechanical stability analysis of an oil well of Iran. Indian Academy of Science. 39 (1): 207-220.

[20]. Zoback, M.D., Barton, C.A., Brudy, M., Castillo, D.A., Finkbeiner, T., Grollimund, B.R., Moos, D.B., Peska, P., Ward, C.D. and Wiprut, D.J. (2003). Determination of stress orientation and magnitude in deep wells. International Journal of Rock Mechanics & Mining Sciences. 40: 1049-1076

[21]. Heidari, B., Younessi, A.R. and Tan, C. (2009). Wellbore Stability Study Report: SP13 Well of South Pars Gas Field. Schlumberger Data and Consulting Services, Middle East Asia.

[22]. Zhang, J., Standifird, W. B., Adesina, K. and Keane, G. (2006). Wellbore stability with consideration of pore pressure and drilling fluid interactions. The 41st U.S. Symposium on Rock Mechanics (USRMS), 17-21 June.

[23]. Al-Ajmi, A.M. and Zimmerman, R.W. (2006). Stability Analyses of Vertical Boreholes Using the Mogi-Coulomb Failure Criterion. International Journal of Rock Mechanics and Mining Science. 43: 1200-1211.

[24]. Al-Ajmi, A.M. and Zimmerman, R.W. (2005). Relationship between the parameters of the Mogi and Coulomb failure criterion. International Journal of Rock Mechanics and Mining Science. 42 (3): 431-439.

تعیین مدل ژئومکانیکی مخزن گازی پارس جنوبی

احسان بزرگی[۱]، داریوش جوانی[۲]* و مهدی رستگار نیا[۳]

۱- واحد علوم و تحقیقات، دانشگاه آزاد اسلامی تهران، ایران
۲- دانشگاه بین‌المللی امام خمینی (ره) قزوین، ایران
۳- دانشکده مهندسی معدن، نفت و ژئوفیزیک، دانشگاه صنعتی شاهرود، ایران

ارسال ۲۰۱۴/۱۱/۹، پذیرش ۲۰۱۵/۶/۲۴

* نویسنده مسئول مکاتبات: javani.dariush@gmail.com

چکیده:

ناپایداری چاه هنگام حفاری باعث بروز مشکلاتی اعم از گیر کردن لوله‌ها و هرز روی گل می‌شود که عمدتاً ناشی از درک نادرست از خواص سنگ، فشار منفذی و وضعیت تنش‌های برجای زمین قبل از شروع عملیات حفاری است. در این مطالعه سعی شده است که با استفاده از نمودارهای چاه، داده‌های حفاری و نیز اطلاعات چاه‌های مجاور، یک مدل ژئومکانیکی از میدان گازی پارس جنوبی تهیه شود که شامل مقادیر فشار منفذی، مقادیر و جهت تنش‌های برجای زمین و همچنین مشخصات مکانیکی سازندهای حفاری شده در این میدان باشد. با توجه به فقدان دسترسی به نتایج تست‌های آزمایشگاهی مغزه، داده‌های MDT/XPT و نیز داده‌های LOT/XLOT جهت کالیبره کردن مدل ساخته‌شده، هر یک از پارامترهای مورد نیاز در ساختن مدل ژئومکانیکی توسط چندین روش و رابطه موجود تخمین زده شد و سپس با استفاده از مدل ساخته شده و معیار شکست Mogi-Coulomb تحلیل ناپایداری چاه انجام گرفت. سپس ناپایداری‌ها و اتفاقاتی نظیر هرز روی گل و به هم آمدن چاه که در این مرحله تخمین زده شده بودند با داده‌های نمودار کالیپر و نیز اتفاقات گزارش‌شده در طول حفاری مورد مقایسه قرار گرفتند تا میزان قابلیت اعتماد به مدل ساخته شده بررسی شود. با توجه به اینکه تحلیل ناپایداری انجام شده بر اساس مدل ساخته شده بیشترین همخوانی را با نمودار کالیپر و اتفاقات حفاری گزارش شده داشت، نتیجه گرفته شد که روابط ایتون و زوباک تخمین قابل قبولی از فشار منفذی و مقاومت سنگ میدان مورد بررسی ارائه داده‌اند. همچنین تنش‌های افقی تخمین زده‌شده از دقت کافی برای پیش‌بینی ناپایداری‌های چاه برخوردار بوده‌اند. رژیم تنش این میدان نیز همچنان که در گزارش‌های فنی بسیاری نیز تأکید شده است از نوع گسلش امتداد لغز برآورد شد. نهایتاً نیز چنین نتیجه گرفته شد که معیار شکست Mogi-Coulomb به دلیل در نظر گرفتن نقش تنش اصلی میانگین (Sigma 2) تخمین نزدیک به واقعیت‌تری از وزن گل حفاری ارائه می‌دهد.

کلمات کلیدی: مدل ژئومکانیکی، ناپایداری چاه، عملیات حفاری، معیار شکست Mogi-Coulomb .