

Geomechanical Modeling and Comparison of Different Methods for Calculating Rock Failure Criteria and Pore Pressure in a Hydrocarbon Field in Southwestern Iran

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Abstract

Given the importance of geomechanics and reservoir petrophysics in the oil and gas industry, the current study presents a comprehensive analysis of borehole wall stability based on the integration of geomechanical-petrophysical studies through the construction of a one-dimensional geomechanical well model. The focus is on comparing various methods for calculating rock failure criteria and pore pressure parameters. To achieve this, the elastic and strength parameters of the studied formation were first determined using well logs and empirical relationships derived from laboratory studies. Subsequently, pore pressure was estimated by two methods – compressibility (drilling-explosion) and Eaton. A comparison of these two methods with RFT test data indicated that the compressibility method provides higher accuracy than the Eaton method. Next, by estimating the in-situ and induced stresses in the studied well, the lower and upper limits of the safe mud weight window were calculated using the Mohr-Coulomb, Hoek-Brown, and Mogi-Coulomb criteria. Comparison of the results from these three methods revealed that the Mohr-Coulomb criterion offers greater accuracy and behaves more conservatively compared to the Hoek-Brown and Mogi-Coulomb approaches.

Keywords: *Geomechanical Model, Pore Pressure, Mohr-Coulomb Criterion, Hoek-Brown Criterion, Mogi-Coulomb Criterion*

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Extended Abstract:

1. Introduction

Constructing a geomechanical model throughout the lifetime of a reservoir can not only ensure optimal production, but also prevent the imposition of excessive operational costs. Comprehensive knowledge of the stress conditions prior to production and their temporal variations plays a crucial role in achieving safe and economical hydrocarbon production and underground storage (Zoback et al., 1985). Subsurface stresses affect various aspects, such as borehole wall stability, caprock integrity, and variations in rock properties resulting from induced stresses, altogether affecting upstream engineering operations. Therefore, determining the magnitude and orientation of the principal in-situ stresses during the process of one-dimensional wellbore geomechanical modeling – both prior to drilling and during or after the operation – is of paramount importance. Typically, the construction of a geomechanical model relies on well logs, and the model is calibrated using core samples and downhole tests. Numerous studies have been conducted on one-dimensional geomechanical modeling. Kolawole et al. (2018) developed a geomechanical model to predict and assess borehole wall instability using well logs in a field located in the eastern part of the Pannonian Basin in Hungary (Kolawole et al., 2018). Ikamil et al. (2018) examined borehole stability and compared the Mohr–Coulomb, Modified Lade, and Mogi–Coulomb failure criteria (Ikamil et al., 2018). Ezati et al. (2020) performed borehole stability analysis through geomechanical modeling for the carbonate Sarvak reservoir in three wells of an oil field located in the Abadan Plain, southwestern Iran, by calculating elastic and strength parameters, pore pressure, and determining the safe mud weight window (Ezati et al., 2020). Almasi and Mohsenipour (2022) analyzed the drilling mud window and borehole stability using both analytical and numerical methods (Almasi and Mohsenipour, 2022). Ammarloo et al. (2025) developed a one-dimensional geomechanical model in an oil field in southwestern Iran, in which the magnitude and direction of in-situ stresses were determined using the corresponding well logs (Ammarloo et al., 2025). Accordingly, considering the importance of geomechanics and reservoir petrophysics in the oil and gas industry, this study conducts a comprehensive analysis of borehole wall stability based on the integration of geomechanical–petrophysical studies through the construction of a one-dimensional geomechanical model. The study further compares various calculation methods for rock failure criteria and presents a flowchart of different indirect approaches for estimating pore pressure using well log data.

2. Materials and methods

The present research was conducted on the Asmari reservoir, which serves as the main hydrocarbon producer in one of the oil fields located in southwestern Iran (Motiei, 1993). For conducting this study, a complete set of conventional well logs from well A of the mentioned field, along with the results of RFT pore pressure tests at 16 points, was used to validate the estimated pore pressure data. To achieve this, in the studied reservoir, the elastic and strength parameters of the formation were first determined using well logs and empirical relationships developed from laboratory studies. Then, considering the high cost of direct pore pressure measurement tools, pore pressure was estimated by two indirect methods – the Compressibility (or Drilling-Explosion) method and the Eaton method – for the studied reservoir. Subsequently, through estimating the in-situ and induced stresses in the examined well, the lower and upper limits of the safe mud weight window were calculated using the Mohr-Coulomb, Hoek-Brown, and Mogi-Coulomb failure criteria.

3. Discussion and Results

In the present study, a comprehensive analysis of borehole wall stability was carried out through combining geomechanical and petrophysical studies through the construction of a one-dimensional geomechanical well model, with an emphasis on comparing various methods for calculating rock failure criteria and pore pressure parameters. In the first stage, the elastic parameters (Al-Qahtani & Zillur, 2001), strength parameters (Gholami et al., 2015), and stress magnitudes were calculated based on poroelastic equations (Ammarloo et al., 2025). To this end, the combination of the shear wave velocity (DTS), compressional wave velocity (DTC), and density log (RHOB) was employed to determine the elastic constants of the reservoir rock. Subsequently, the uniaxial compressive strength (UCS), tensile strength (T), and internal friction angle (ϕ) were calculated, too. Next, the pore pressure was estimated using two methods – the Compressibility (or Drilling-Explosion) and Eaton methods – and compared with the RFT test data. The curve of the estimated pore pressure values obtained from the Compressibility (Drilling-Explosion) method showed good agreement with the measured data. On the other hand, it was observed that the curve derived from the Eaton method exhibited significant fluctuations within the studied interval of this well that appeared unreasonable when compared with the relatively linear trend of the measured values. Hence, the Compressibility (Drilling-Explosion) method is recommended for estimating pore pressure in similar zones. The key factor determining the accuracy of this method lies in how the pore compressibility coefficient (C_p) is determined. Typically, this parameter is derived from laboratory results, and its value is strongly dependent on rock porosity, which can, in turn, be reliably estimated from porosity data using established empirical correlations. Ultimately, according to the induced stresses generated during drilling operations, the safe mud weight window was obtained using rock failure criteria (Al-Ajmi & Zimmerman, 2006).

4. Conclusion

In the studied well, comparison of the applied failure criteria revealed that the Mohr–Coulomb criterion provides more accurate and reliable results for determining the optimal mud pressure range than the Hoek–Brown and Mogi–Coulomb criteria. According to the caliper log data, which identified several collapsed intervals, it was determined that the studied formation contains numerous zones prone to instability. Based on the final model, the range predicted by the Mohr–Coulomb criterion predominantly falls within the collapse zone, whereas the other two criteria do not depict the wellbore condition with the same degree of accuracy. Consequently, it can be concluded that the Mohr–Coulomb failure criterion provides a more precise estimation of the safe mud weight window.

References:

- Almasi, A. and Mohsenipour, A., 2022. Determining the mud window, geomechanical model (MEM), and well wall stability analysis, using analytical and numerical methods in one of the wells in Iran's southwest fields. *Advanced Applied Geology*, 12(1), pp.1-11
- Alkamil, E.H., Abbood, H.R., Flori, R.E. and Eckert, A., 2018. Case study of wellbore stability evaluation for the Mishrif Formation, Iraq. *Journal of Petroleum Science and Engineering*, 164, pp.663-674.
- Atashbari, V. and Tingay, M., 2012, April. Pore pressure prediction in carbonate reservoirs. In *SPE Latin America and Caribbean petroleum engineering conference* (pp. SPE-150835). SPE.
- Abalioglu, I., Legarre, H., Garland, C., Sallier, B., Gao, J., van Galen, M., Chou, Q., Neil, B., Soroush, H.,

- Qutob, H. and Mahli, Z., 2011, September. The Role of Geomechanics in Diagnosing Drilling Hazards and Providing Solutions to the Northern Iraq Fields. In SPE Middle East Oil and Gas Show and Conference (pp. SPE-142022). SPE.
- Ammarloo, H., Zoughy, P., Mehraban, L. F., & Amiri, M. (2025). Evaluation of empirical relationships in carbonates by developing a 1D mechanical earth model in an oil field in Southwestern Iran. *Results in Engineering*, 26, 104799.
- Al-Qahtani, M.Y. and Zillur, R., 2001, March. A mathematical algorithm for modeling geomechanical rock properties of the Khuff and Pre-Khuff reservoirs in Ghawar field. In SPE Middle East Oil and Gas Show and Conference (pp. SPE-68194). SPE
- Al-Ajmi, A.M. and Zimmerman, R.W., 2006. Stability analysis of vertical boreholes using the Mogi–Coulomb failure criterion. *International journal of rock mechanics and mining sciences*, 43(8), pp.1200-1211.
- Azim, S.A., Mukherjee, P., Al-Anezi, S.A., Al-Otaibi, B., Al-Saad, B., Perumalla, S., Araujo, E. and Babbington, J.F., 2011, October. Using Integrated Geomechanical Study To Resolve Expensive Wellbore Instability Problems While Drilling Through Zubair Shale/Sand Sequence of Kuwait: A Case Study. In SPE/IADC Middle East Drilling Technology Conference and Exhibition (pp. SPE-148049). SPE.
- Bowers, G.L. (1995). Pore pressure estimation from velocity data: accounting for over pressure mechanisms besides under compaction, *SPE Drill & Compl* 10 (02): 89-95, doi.org/10.2118/27488-PA.
- Brown, E.T. and Hoek, E., 1980. *Underground excavations in rock*. CRC Press.
- Eaton, B.A., 1969. Fracture gradient prediction and its application in oilfield operations. *Journal of petroleum technology*, 21(10), pp.1353-1360.
- Eaton, B.A., 1976. Graphical method predicts geopressures worldwide. *World Oil*; (United States), 183(1).
- Fischer, K. and Henk, A., 2013. A workflow for building and calibrating 3-D geomechanical models &ndash a case study for a gas reservoir in the North German Basin. *Solid Earth*, 4(2), pp.347-355.
- Gholami, R., Moradzadeh, A., Rasouli, V., Hanachi, J., 2014. *Journal of Rock Mechanics and Geotechnical Engineering* Practical application of failure criteria in determining safe mud weight windows in drilling operations. *Rock Mech. Geotech. Eng.* 6, 13–25.
- Ghalibaf Mohammadabadi, H., Hafezi Moghaddas, N., Lashkaripour, A., Gholami, R., and Talebi, H., 2022. Estimation of Geomechanical Parameters, In-Situ Stress Analysis, and Determination of the Optimal Mud Weight Window Using Machine Learning Algorithms, *Journal of Petroleum Geomechanics*, pp. 1-28
- Herwanger, J., 2014, April. Seismic geomechanics: how to build and calibrate geomechanical models using 3D and 4D seismic data. In fourth EAGE CO2 geological storage workshop (pp. cp-439). European Association of Geoscientists & Engineers.
- Hoek, E., Brown, E.T., 1988. The Hoek-Brown failure criterion—a 1988 update. In: *Proceedings of the 15th Canadian Rock Mechanics Symposium*. Toronto, Canada: Proc. 15th Can. Rock Mech. Symp, University of Toronto, pp. 31–38.
- James, G.A. and Wynd, J.G., 1965. Stratigraphic nomenclature of Iranian oil consortium agreement area. *AAPG bulletin*, 49(12), pp.2182-2245.
- Jahan Mohammadi, H., Mosadegh, H., Azzadeh, M., Sarkheil, H., and Mohammadinia, M., 2023. Determination of Safe Mud Weight Window and Optimal Drilling Path in the Gadvan Formation Using Rock Failure Criteria in a Hydrocarbon Field in Southwestern Iran, *Journal of Petroleum Geomechanics*, pp. 61–80.
- Khamehchi, A. & Abbasi, M., 2022. One-Dimensional Geomechanical Modeling and Hydraulic Fracture Simulation in One of the Sarajeh Wells for Production Enhancement (A Case Study), *The 4th National Conference on Petroleum Geomechanics, Innovation and Technology*, Tehran.
- Kolawole, O., Federer-Kovács, G. and Szabó, I., 2018, June. Formation susceptibility to wellbore instability and sand production in the Pannonian Basin, Hungary. In *ARMA US Rock Mechanics/Geomechanics Symposium* (pp. ARMA-2018). ARMA.
- Motiei, E. 1993. "Geology of Iran, Zagros stratigraphy", Tehran, Geological Survey, First Edition.

- Mansourizadeh, M., Jamshidian, M., Bazargan, P. and Mohammadzadeh, O., 2016. Wellbore stability analysis and breakout pressure prediction in vertical and deviated boreholes using failure criteria—A case study. *Journal of Petroleum Science and Engineering*, 145, pp.482-492.
- Mohiuddin, M.A., Awal, M.R., Abdulraheem, A. and Khan, K., 2001, March. A new diagnostic approach to identify the causes of borehole instability problems in an offshore Arabian field. In *SPE Middle East Oil and Gas Show and Conference* (pp. SPE-68095). SPE
- Radwan, A.E., Abdelghany, W.K. and Elkhawaga, M.A., 2021. Present-day in-situ stresses in Southern Gulf of Suez, Egypt: Insights for stress rotation in an extensional rift basin. *Journal of Structural Geology*, 147, p.104334.
- Ramjohn, R., Gan, T. and Sarfare, M., 2018, June. 3D Geomechanical Modeling for Wellbore Stability Analysis: Starfish, ECMA, Trinidad and Tobago. In *SPE Trinidad and Tobago Section Energy Resources Conference?* (p. D031S027R002). SPE.
- Sarem, M. & Ebrahimabadi, A., 2022. Geomechanical Design of the Shadegan Oil Field for Modeling and Planning ERD Wells in the Bangestan Formations, *Journal of Petroleum Geomechanics*.
- Saadatnia, N., Sharghi, Y., Moghaddasi, J., and Ezati, M., 2022. Geomechanical Modeling and Caprock Integrity Assessment for a Major Carbonate Field in Southwestern Iran, *Journal of Petroleum Geomechanics*.
- Seyed Sajjadi, Sh. & Aghighi, M., 2014. Construction and Analysis of the Geomechanical Model of the Bangestan Reservoir in the Kopal Field, *Journal of Mining Engineering*, pp. 21-34.
- Zoback, M.D., Moos, D., Mastin, L. and Anderson, R.N., 1985. Well bore breakouts and in situ stress. *Journal of Geophysical Research: Solid Earth*, 90(B7), pp.5523-5530.