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Research article

Wellbore Stability Analysis Using Ground Reaction Curve and Mohr-Coulomb Failure Criterion

Amir Mohammad Ahmari[1], Abolfazl Abdollahipour[1*], Alireza Kargar[1]

1- Dept. of Mining Engineering, Colleges of Technology, University of Tehran, Tehran, Iran

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Keywords

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English Extended Abstract

Summary

This research adapts the ground reaction curve (GRC) method, traditionally used in tunnel engineering, to analyze wellbore stability and determine the optimal drilling fluid weight in oil and gas operations. The objectives are to assess wellbore stability under varying conditions and establish a safe drilling fluid pressure window. The methodology employs analytical solutions based on the Mohr-Coulomb failure criterion and numerical modeling using FLAC software. Results demonstrate that parameters such as pore pressure, in-situ stress ratios, and wellbore radius influence wellbore convergence, with the numerical GRC method providing a larger safe drilling fluid pressure window compared to the analytical approach, potentially enhancing drilling efficiency and reducing operational risks.

Introduction

Wellbore stability is increasingly critical in the oil and gas industry as drilling operations target complex geological formations to meet rising energy demands. Conventional analytical methods for determining safe drilling fluid weights often rely on simplifying assumptions that may not fully address the challenges posed by these environments. This study introduces a novel approach by adapting the ground reaction curve (GRC), a concept from tunnel engineering, to wellbore stability analysis. The GRC relates internal pressure to radial displacement, offering a framework to evaluate rock mass behavior under varying conditions. Pertinent literature highlights diverse approaches to wellbore stability, including elastoplastic and poroelastic models, and failure criteria such as Mohr-Coulomb, Mogi-Coulomb, and Hoek-Brown [1-2]. Building on these foundations, this research employs two methods: an analytical approach using the Mohr-Coulomb criterion with Kirsch equations to calculate stress distributions and critical pressures, and a numerical approach using FLAC software to simulate wellbore excavation and generate the GRC. The study investigates the effects of pore pressure, stress anisotropy, and wellbore radius on stability. The main findings indicate that the numerical method yields a broader safe drilling fluid pressure window, offering potential operational advantages over the analytical method.

Methodology and Approaches

The methodology integrates analytical and numerical techniques to assess wellbore stability. Analytically, stress distributions around the wellbore are computed using the Kirsch equations, which describe radial and tangential stresses as functions of drilling fluid pressure, in-situ stresses, and Poisson's ratio. The Mohr-Coulomb failure criterion is then applied to determine the minimum pressure preventing shear failure (collapse) and the maximum pressure avoiding tensile failure (fracturing), establishing the safe pressure window. Numerically, the FLAC software (version 8) simulates wellbore excavation in a two-dimensional

*Corresponding author: E-mail: abdollahipour@ut.ac.ir

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model under hydrostatic and anisotropic stress fields. The GRC is generated by monitoring radial displacement as internal pressure varies. The lower limit of the safe pressure window is identified when the wellbore stabilizes (e.g., at 75% of in-situ stress in the hydrostatic case), while the upper limit is determined by minimizing the plastic zone around the wellbore (e.g., at 42 MPa). The study also examines the sensitivity of the GRC to pore pressure, stress ratios, and wellbore radius, with parameters detailed in the original paper's Table 1. This dual approach provides a comprehensive stability analysis, with sufficient detail to replicate the methods or refer to cited works [3-4].

Results and Conclusions

The GRC analysis shows that increased pore pressure, stress anisotropy, and wellbore radius amplify convergence. Table 1 compares the safe drilling fluid pressure windows from both methods in a hydrostatic field ($\sigma H = \sigma h = 30$ MPa). The numerical GRC method consistently provides a larger window across conditions, enhancing drilling flexibility. Fig. 1 visually contrasts these windows, confirming that the numerical GRC method generally provides a larger safe range across conditions, enhancing drilling flexibility. This principle suggests that integrating displacement-based numerical analysis with failure-based analytical methods improves stability assessment. An exception occurs in specific hydrostatic cases where the numerical window narrows slightly, possibly due to differing criteria emphasis. Theoretically, this approach refines wellbore mechanics understanding; practically, it suggests cost and risk reductions. Validation with field data remains necessary. The study concludes that the GRC method is a promising tool for optimizing drilling fluid design, recommending further testing across diverse formations.

Table 1. Safe Drilling Fluid Pressure Windows (Hydrostatic Field)

Method	Lower Limit (MPa)	Upper Limit (MPa)	Window Size (MPa)
Analytical (Mohr-Coulomb)	17.69	42.6	24.91
Numerical (GRC)	22.5	42.0	19.5

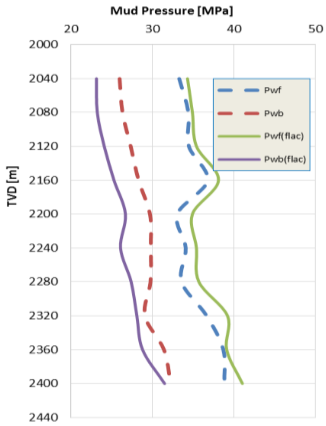

Fig. 1. Changes in Drilling Fluid Window in Analytical and Numerical Methods

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