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A Comprehensive Approach to In-Situ Stress Estimation in Subsurface Energy Structures using Numerical Simulation and Machine Learning

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The objective of this research is to establish a consistent relationship between nonlinear numerical simulations and the obtained results for use in inverse analysis. We simulate the shape of breakouts, taking into account inelastic deformation of high-porosity limestone, using developed finite element methods under various in-situ conditions. Subsequently, the dataset is employed to train four machine learning algorithms, as well as white-box algorithms, in order to determine the relationship between in-situ stress and breakout shape.
This study employs a two-phase approach through inverse analysis to determine in-situ stress. In the initial phase, we utilize nonlinear elastoplastic finite element modeling to generate a dataset. This dataset serves as the training data for a machine learning (ML) algorithm designed to establish a predictive correlation between in-situ stress and borehole breakout measurements. In the second phase, the trained ML algorithm is applied to estimate the equivalent in-situ stress based on provided borehole breakout measurements. To investigate in-situ stress from borehole breakouts and construct robust correlations, we employ a combination of four black-box algorithms and three white-box algorithms.
A numerical simulation has been performed to determine the geometry of borehole breakouts under various in situ stress levels and taking into account plastic deformations. The breakout cross-section's non-circular shape can be modeled using an elastoplastic model that was created using the finite element approach. This shape fluctuates as the breakout develops until it stabilizes. The depth of the breakouts rises until a stable state, just like in earlier models based on the elastic assumptions. The width of the breakouts, however, does not change as the breakouts develop. The growth of the breakout is stopped by taking into account inelastic deformations, which also gives the chance to model the V-shaped type breakouts seen in both field and laboratory data. According to laboratory research, disregarding plastic deformations in very porous and weak rocks results in an incorrect understanding of the relationship between in situ stress and rock failure state.
To determine the correlation between in situ stress and breakout shape, four machine learning techniques and three whitebox algorithms have been applied to the data set generated from numerical tests. To calculate the in situ stress from breakout shapes, trained algorithms were put through an inverse analysis. The XGBoost and GP algorithms mean square error (RMSE) of 0.419541, 0.9977and a determination coefficient (R2) of 0.99565 and 0.97564 outperform others in terms of accuracy and suitability.
The novelty of the proposed approach lies in its consideration of inelastic deformation for estimating in-situ stresses, which is a crucial factor in the failure of high-porosity and unconsolidated rocks. Additionally, it involves establishing a relationship for estimating in-situ stresses through a combination of machine learning and numerical simulation.

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References

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