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Research paper

Drilling-based rock strength estimation: A validated model for Mohr-Coulomb and a new theoretical-empirical approach for Hoek-Brown parameters

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ABSTRACT

Conventional methods for determining the strength properties of rock are often costly and time-consuming. This research presents an innovative approach using operational drilling data for the continuous, real-time estimation of rock strength parameters for both the Mohr-Coulomb and Hoek-Brown failure criteria. The study evaluates a theoretical model for Mohr-Coulomb parameters and introduces a new theoretical-empirical model to estimate Hoek-Brown constants. These models were validated against conventional laboratory tests on ten different rock types, including sedimentary, metamorphic, and igneous varieties. The results demonstrate that the models can effectively estimate the strength properties for both failure criteria. A key finding is the introduction of a dimensionless ratio of bit diameter to rock grain size (D/d), which was shown to be a critical factor governing the accuracy of the Mohr-Coulomb parameter estimation; estimation error decreases significantly as the D/d ratio increases. Furthermore, the newly developed model accurately estimated the Hoek-Brown criterion constants, showing excellent agreement between the drilling-derived intrinsic specific energy and the uniaxial compressive strength values from conventional tests. This work provides a robust framework for more efficient rock strength characterization in various engineering applications.

1. Introduction

Due to the heterogeneity and anisotropic behavior of the mechanical properties of rocks, evaluating their variation is very important. Different testing methods have been developed to measure the strength and elastic properties of rocks, including conventional uniaxial or triaxial compressive tests and indirect non-destructive tests such as Schmidt hammer, point load, and scratch tests. However, it is generally costly and time-consuming to measure the strength and deformability of rocks using conventional methods. Moreover, taking representative rock samples with standard dimensions in direct assessment is challenging or even impossible under complex engineering and geological conditions [1–3].

Therefore, using operational drilling data, such as torque, thrust, penetration rate, and drill rotation speed, has emerged as one of the indirect and semi-destructive methods developed in recent years. This method is used on a small scale in the laboratory to estimate the strength of rock samples [4–7]. Additionally, large-scale drilling rigs equipped with electronic control systems can be used to estimate the strength of formations and rock masses at different depths [8–16]. The strength of another material, such as concrete [17,18] and cement mortars [19,20] were estimated by the drilling method. A significant advantage of this method over other indirect methods is the ability to estimate rock strength parameters during drilling continuously. A servo-controlled drilling machine is facilitated to continuously monitor the drilling parameters which could be correlated to gradual changes in the mechanical properties of rock from the surface to the depth [21–23]. This technique allows the machine to detect changes in rock composition and hardness and adjust the drilling parameters accordingly. This way, a continuous record of physical and mechanical changes can be obtained from the surface to the depths [24–27].

The mechanical properties of materials are estimated using drilling data from two empirical and theoretical methods. In empirical methods, the minimum thrust force required at a constant penetration rate and rotational speed is measured and considered as drilling resistance [28, 29]. In this case, weathered or altered zone in rocks or other building

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