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Research paper

Advanced continuous drilling for depth-dependent mechanical properties mapping in graded rocks

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ABSTRACT

Accurate rock property assessment is crucial for successful engineering projects in sectors such as water management, power generation, transportation, resource extraction, and mining. This study explores the potential of continuous drilling as a semi-destructive technique for evaluating the mechanical properties of functionally graded rocks altered by weathering and acid treatment. Conventional methods often miss subtle property changes caused by environmental factors, but continuous drilling provides real-time data on parameters like torque and thrust force, enabling depth-dependent property mapping. Experiments were conducted on composite and acid-treated Asmari limestone samples using a custom portable drilling machine. The device, equipped with a T-shaped chisel bit, maintained constant penetration and rotation speeds, capturing changes in thrust and torque as the drill progressed. Tests on composite samples demonstrated sensitivity to shifts between different rock types, highlighting the method's ability to detect interfaces and structural weaknesses. Field tests confirmed its ability to measure gradual changes due to weathering. Acid-treated limestone exposed to hydrochloric acid showed a significant reduction in mechanical properties: UCS decreased by up to 45%, internal friction angle reduced by 8 degrees, and cohesion dropped by 35% from surface to core. Porosity increased with acid exposure, ranging from 24.3% in the outermost layer to 9.3% in deeper layers. These findings align with existing research on acid-induced degradation of carbonate rocks. Continuous drilling offers a valuable, real-time method for assessing depth-dependent rock properties, enhancing understanding of rock stability and weathering for applications in conservation and modeling.

1. Introduction

For successful engineering applications and accurate assessments of geological hazards within rock masses, a thorough understanding of their mechanical properties is necessary. This includes precise measurement of key parameters such as unconfined compressive strength, internal friction angle, cohesion, and elastic modulus, all of which are critical for designing safe and efficient structures in mining, civil construction, and geological investigations [1–3]. Recent advancements in rock engineering and engineering geology have led to the development of indirect and non-destructive methods for rock property estimation, offering less invasive alternatives to traditional destructive testing [4–6]. Despite the advances in rock property testing, significant gaps remain in assessing functionally graded rocks, particularly in capturing continuous property transitions within the rock. Conventional methods, such as uniaxial compressive strength (UCS) tests, provide averaged properties over large volumes and fail to detect subtle variations, especially in chemically altered or weathered rocks. Furthermore, existing non-destructive testing methods like rebound hammers or sonic testing struggle to monitor changes at different depths or under varying environmental conditions, making them less effective for heterogeneous materials [7,8].

Among the others, using operational drilling data such as torque, thrust force, penetration rate, and rotation speed are an effective method for assessing rock strength [9–12]. This method is applicable to small-scale laboratory testing using portable drilling equipment [13–18], as well as large-scale, in-situ geological assessments using advanced rotary drilling machine equipped with electronic control systems [19–25]. Notably, this technique extends beyond rocks and can estimate the strength of other materials such as concrete [26,27] and cementitious mortars [28,29]. A primary advantage of this approach over other non-destructive testing methods lies in its ability to provide

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