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Full Length Article

# High-resolution photogrammetry to measure physical aperture of two separated rock fracture surfaces

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ABSTRACT

Photogrammetry, reconstructing three-dimensional (3D) models from overlapping two-dimensional (2D) photos, finds application in rock mechanics and rock engineering to extract geometrical details of reconstructed objects, for example rock fractures. Fracture properties are important for determining the mechanical stability, permeability, strength, and shear behavior of the rock mass. Photogrammetry can be used to reconstruct detailed 3D models of two separated rock fracture surfaces to characterize fracture roughness and physical aperture, which controls the fluid flow, hydromechanical and shear behavior of the rock mass. This research aimed to determine the optimal number of scale bars required to produce high-precision 3D models of a fracture surface. A workflow has been developed to define the physical aperture of a fracture using photogrammetry. Three blocks of Kuru granite (25 cm × 25 cm × 10 cm) with an artificially induced fracture, were investigated. For scaling 3D models, 321 markers were used as ground control points (GCPs) with predefined distances on each block. When the samples were well-matched in their original positions, the entire block was photographed. Coordinate data of the GCPs were extracted from the 3D model of the blocks. Each half was surveyed separately and georeferenced by GCPs and merged into the same coordinate system. Two fracture surfaces were extracted from the 3D models and the vertical distance between the two surfaces was digitally calculated as physical aperture. Accuracy assessment of the photogrammetric reconstruction showed a 20–30 μm digital control distance accuracy when compared to known distances defined between markers. To attain this accuracy, the study found that at least 200 scale bars were required. Furthermore, photogrammetry was employed to measure changes in aperture under normal stresses. The results obtained from this approach were found to be in good agreement with those obtained using linear variable displacement transducers (LVDTs), with differences ranging from 1 μm to 8 μm.



## 1. Introduction

Rock mass is a complex material consisting of intact rock and discontinuities characterized by its geometrical, physical, and mechanical properties. The discontinuities can be fractures, bedding planes, or any other type of plane that separates the rock into distinct blocks. Discontinuities control the behavior of the rock mass in many ways, such as hydraulic conductivity, strength, and deformation behavior (Hudson and Harrison, 1997). In civil engineering, repositories for hazardous waste disposal, hydrogen storage, or $CO_2$ sequestration are located in deep underground excavations, where the rock mass acts as a barrier to prevent leakage. To assess the long-term performance of these repositories, it is crucial to understand the intact rock and fracture properties (Birkholzer et al., 2019; Guo et al., 2023).

Geometrical properties of discontinuities include physical aperture, roughness, orientation, spacing, persistence, size, and shape (Zhang, 2016; Zheng et al., 2022a). Measuring these properties accurately is essential for understanding fracture behavior in different conditions (Zheng et al., 2022b; Zhang et al., 2023). Roughness and physical aperture significantly influence a single fracture's hydromechanical behavior (Tatone and Grasselli, 2012; Luo et al., 2016; Vogler et al., 2017; Chen et al., 2021). Stress distribution, deformation, shear behavior and conductivity of the rock mass are affected by properties of fractures. Asperities could be

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