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Evaluating failure mechanisms of fractured rock pillars by rock mass characterization, DFN and FEM modelling

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The deformation and ultimate stability of rock pillars is a major issue in underground mining, particularly in abandoned mines where rehabilitation for storage or cultural heritage uses is planned. Pillar design have been traditionally based on empirical methods considering simple geometry and homogeneous material. Nevertheless, pillar stability can be influenced by several factors, including pillar slenderness and irregularity, intact rock fabric and strength, fracture network properties and related rock mass property up-scaling, and weathering. In this perspective, we set up a complete workflow to evaluate the strength and failure mode of real pillars in fractured rock, including: laboratory testing, discontinuity characterization by field and remote survey techniques, Discrete Fracture Networks and numerical modelling.
We considered two case studies in different lithological settings, namely: a 3m high pillar in bedded limestone and a 8m high pillar in a Messinian gypsum formation (H/D ratio: 1.1). We performed laboratory uniaxial compression tests on intact rock specimens to characterize their strength, deformability and stress-strain behavior, and direct shear tests on natural discontinuities to evaluate their frictional and stiffness properties. We characterized discontinuities and their attributes (orientation and statistical clustering, spacing, geometry, roughness) by field surveys and analysis of virtual outcrops derived from very high resolution laser scanning (TLS) and Structure-from-Motion photogrammetry. For each fracture set, we performed fracture mapping and circular window analyses to quantify fracture intensity and trace length distributions, providing input data for Discrete Fracture Network model calibration and generation. DFN models provided realistic representation of fracture networks for the final numerical model stage.
We set up series of 2D Finite-Element numerical compression tests (displacement control) on full-size pillars with simplified or realistic geometry and made, respectively, of: a) intact rock (model calibration vs. laboratory data); b) equivalent continuum rock mass (material properties upscaled for rock mass structure); c) intact rock cut by fracture networks derived from DFN models (pseudo-discontinuum model with explicit fractures). Our results allowed to characterize the progressive failure modes of studied pillars in realistic conditions, depending on the combination of intact rock (rock bridges) and fracture properties, and to set the basis of pillar stability criteria accounting for a wide spectrum of geomechanical controls.