Numerical Modeling of Brittle Fracture and Step-path Failure: From Laboratory to Rock Slope Scale

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Recent research indicates that brittle fracture and step-path failure are important considerations in both natural high-mountain and engineered rock slopes, particularly large open pits. Newly developed techniques for field survey and numerical modeling of brittle fracture and step-path failure are presented in this research in an attempt to overcome many of the limitations of traditional approaches. Research primarily focuses on the numerical simulation of brittle fracture and step-path failure at both the laboratory and large slope scale, and the application of LiDAR and digital-imaging techniques in the field characterization of brittle fracture.

Boundary element, finite element, discrete element (UDEC Voronoi) and hybrid FEM/DEM (with fracture) codes are all used in an attempt to realistically simulate laboratory step-path brittle fracture. The selected numerical approaches are constrained through comparison of simulated fracture coalescence patterns with published physical model experiments. The limitations and advantages of the varied numerical techniques are critically discussed. The combined utility of a diverse suite of data interpretation methods is shown to aid in the identification of brittle fracture initiation and propagation.

Simulation of brittle fracture propagation using both the hybrid FEM/DEM code ELFEN and the FEM code PHASE2 is presented for a conceptual large open pit slope with the specific objective of investigating the relationship between intact rock bridge width and the potential for toe breakout. A major high mountain rock slope failure, the Randa rockslide, is used to demonstrate the potential of the hybrid code ELFEN in modelling the influence of discontinuity persistence and step-path failure on progressive rock slope instability. The research demonstrates the importance of considering the integrated roles of intact rock fracture, step-path geometry and persistence when considering the failure mechanisms of high-mountain and major surface mine slopes.

The importance of characterizing three dimensional step-path failure modes in the field and the subsequent simulation using a three dimensional distinct element code are illustrated. A variety of block movement modes (i.e. translation, rotation, buckling and toppling) are shown to be highly sensitive to joint orientation, joint spacing, the assumed joint friction angle, and acting boundary constraints (toe support/excavation.).

The insights gained from this research provide a major contribution toward our understanding of the limitations and advantages of varying numerical approaches in the simulation of brittle fractures and step-path failure. Simulating brittle fracture from the laboratory to the field scale shows not only the importance of brittle fracture at all scales but provides increased confidence in our numerical tools for future modelling of large rock slopes. The critical need to further characterize brittle fracture and step-paths in the field is demonstrated using a preliminary program of LiDAR imaging. It is hoped that by examining the process of brittle fracture and step-path failure using state-of-the-art numerical codes and field characterization methods, this thesis, will provide a foundation for improved hazard assessment and rock slope design.