

NUMERICAL MODELING OF ROCK SLOPE INSTABILITY USING A PHASE-FIELD MATERIAL POINT METHOD

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Abstract

Rockfalls are a significant natural hazard in mountain regions, posing substantial risks to infrastructure and human safety. A central difficulty in assessing these hazards lies in the inherently limited ability to characterize large rock masses. In this context, numerical modeling plays a key role in linking observable surface behavior with the underlying mechanisms driving instability, allowing measurable signs of deformation and fracturing to be interpreted in terms of the mechanical behavior within the rock mass.

In this context, a phase-field Material Point Method approach [1] is adopted for the simulation of slope failure triggering, with particular emphasis on fracture propagation in rock masses leading to rockfall events. The phase-field method [2] is adopted to represent fracture without the need for explicit crack tracking. Material degradation is described by a continuous scalar field ranging from 1 (intact material) to 0 (fully fractured material). This variable is governed by an additional partial differential equation, coupled with the balance of momentum in a nonlinear system, enabling the consistent simulation of crack initiation and evolution.

The resulting governing equations are discretized using the Material Point Method [3], in which the continuum is represented by Lagrangian particles moving on an Eulerian background grid. The proposed formulation offers significant flexibility in handling complex geometries and heterogeneous materials, which are typical of natural slopes. Furthermore, MPM is particularly well suited for problems involving large deformations, making the framework also suitable for the simulation of the subsequent runout phase, into a unified methodological framework.

The characteristics of the proposed phase-field MPM approach are illustrated through applications to real case studies located in the municipality of Lecco (Italy).

Keywords: Phase-Field, MPM, slope instability

References

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