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A Material Point Method for Alpine Mass Movements

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Gravitational mass movements pose a threat to the population of numerous mountainous regions around the globe. Climate change affects these processes and their related hazards by influencing their triggering, flow and deposition mechanisms, overall increasing the number of natural catastrophes. Numerical modelling is an essential tool for the analysis and the management of such hazards: it allows the quantitative description of the runout and pressure of rapid mass movements and may contribute to better understand the effects of climate change on their size, frequency, and dynamics. Several depth-averaged models are already operational and commonly applied by practitioners and scientists. Yet, a unified model able to simulate multi-phase cascading events, including their initiation, propagation, entrainment and finally impact on structures is still missing. Hence, more detailed models are required to advance our understanding of the physics behind gravitational mass movements and ultimately to contribute improving hazard assessment and risk management.

Here, we present some preliminary results of the development of a hybrid Eulerian-Lagrangian Material Point Method (MPM) with finite strain elasto-plasticity to simulate in a unified manner: i) permafrost instabilities and failure initiation; ii) rock and ice avalanche dynamics; iii) solid-fluid interaction and phase transition from rock avalanches to debris-flows. In order to simulate the mechanical behaviour of rock and ice, we propose a Drucker-Prager softening constitutive law accounting for cohesion, internal and residual friction. We calibrate this constitutive law on the basis of state of the art laboratory experiments. The model is applied to synthetic slope geometries to evaluate their stability and investigate subsequent rock fragmentation processes. At a larger scale, dynamics simulations are compared against observations of full-scale process chains. In particular, we implement the two real-scale cases of the rock-avalanche from the Piz Cengalo (CH) and ice- and snow-avalanche from the Grandes Jorasses (IT). The 3D implementation of the model allows to accurately reproduce the initial conditions of an event and complex phenomena such as reported ballistic trajectories non adherent to the ground. Secondary releases due to the mass flow (such as snow or glacier-ice entertainment) and phase changes can be simulated realistically. We test the potential of the model in a broad range of settings and highlight the major gaps to be filled in the near future.