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DaDyn-RS: a tool for the time-dependent simulation of damage, fluid pressure and long-term instability in alpine rock slopes

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Large mountain slopes in alpine environments undergo a complex long-term evolution from glacial to postglacial environments, through a transient period of paraglacial readjustment. During and after this transition, the interplay among rock strength, topographic relief, and morpho-climatic drivers varying in space and time can lead to the development of different types of slope instability, from sudden catastrophic failures to large, slow, long-lasting yet potentially catastrophic rockslides. Understanding the long-term evolution of large rock slopes requires accounting for the time-dependence of deglaciation unloading, permeability and fluid pressure distribution, displacements and failure mechanisms. In turn, this is related to a convincing description of rock mass damage processes and to their transition from a sub-critical (progressive failure) to a critical (catastrophic failure) character. Although mechanisms of damage occurrence in rocks have been extensively studied in the laboratory, the description of time-dependent damage under gravitational load and variable external actions remains difficult.

In this perspective, starting from a time-dependent model conceived for laboratory rock deformation, we developed Dadyn-RS, a tool to simulate the long-term evolution of real, large rock slopes. Dadyn-RS is a 2D, FEM model programmed in Matlab, which combines damage and time-to-failure laws to reproduce both diffused damage and strain localization meanwhile tracking long-term slope displacements from primary to tertiary creep stages. We implemented in the model the ability to account for rock mass heterogeneity and property upscaling, time-dependent deglaciation, as well as damage-dependent fluid pressure occurrence and stress corrosion.

We first tested DaDyn-RS performance on synthetic case studies, to investigate the effect of the different model parameters on the mechanisms and timing of long-term slope behavior. The model reproduces complex interactions between topography, deglaciation rate, mechanical properties and fluid pressure occurrence, resulting in different kinematics, damage patterns and timing of slope instabilities. We assessed the role of groundwater on slope damage and deformation mechanisms by introducing time-dependent pressure cycling within simulations. Then, we applied DaDyn-RS to real slopes located in the Italian Central Alps, affected by an active rockslide and a Deep Seated Gravitational Slope Deformation, respectively. From Last Glacial Maximum to present conditions, our model allows reproducing in an explicitly time-dependent framework the progressive development of damage-induced permeability, strain localization and shear band differentiation at different times between the Lateglacial period and the Mid-Holocene climatic transition. Different mechanisms and timings characterize different styles of slope deformations, consistently with available dating constraints. DaDyn-RS is able to account for different long-term slope dynamics, from slow creep to the delayed transition to fast-moving rockslides.