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Long-term conditioning of deep-seated rockslides in deglaciated valleys: the Spriana case study

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Deep-seated rockslides in alpine valleys evolve over long time under the action of multiple triggers. Early Warning based on monitoring is often the only effective approach to cope with these landslides, but it requires an improved understanding of mechanisms interplaying over long time. Deep-seated rockslides are often characterized by long-term “creep” and seasonal displacement components, contributing to measured displacement patterns which are often modelled as rockslide responses to hydrologic perturbations. Although this hydro-mechanical modelling approach fits the behaviour of disrupted rockslide masses with well-developed shear zones, it is often insufficient to explain the initial onset and the long-term components of creep movements of deep-seated rockslides. This outlines the need to link long-term evolution of rock slopes and their sensitivity to triggers.

We discuss the Spriana rockslide, affecting the steep left-hand flank of Val Malenco (italian Central Alps). Documented instabilities date back to 1912, whereas the rockslide underwent major acceleration stages in 1960 and 1977-78 and later minor reactivations. We reviewed a large amount of data collected since 1978 by extensive geotechnical site investigation (borehole drilling, exploratory adits, and seismic refraction) and monitoring activities (ground surface and deep displacements, pore pressures) motivated by potential catastrophic collapse threatening the city of Sondrio area. We performed rock mass characterization based on laboratory studies on intact rock samples, field surveys and drillcore logging. These data allowed re-evaluating the geological model of the Spriana rockslide, which is a compound slide of up to 50 Mm^3 of slope debris and fractured gneiss, with multiple shear failure zones up to 90 m deep. Two main scarps developed in different stages, suggesting progressive failure processes. The rockslide creeps at slow rates of 0.4-3 cm/a, and undergoes acceleration stages (weeks to months) during increased water recharge periods. Heavily fractured rock masses occur below rockslide base up to 150 m in depth, suggesting extensive rock mass damage pre-dating rockslide onset. Groundwater monitoring shows that this fractured layer hosts a perched water table characterized by annual fluctuations up to 3 m.

To gain insights in the long-term slope evolution we performed 2D Finite-Element multi-stage stress-strain and seepage modelling, accounting for post-LGM deglaciation, damage and related changes in slope strength and hydrology. Results validated using investigation data show that rockslide onset would have been unlikely without the strong preconditioning of long-term damage related to deglaciation. This led to a two-layer hydro-mechanical slope differentiation, with a fractured upper layer hosting a perched water table that favoured rockslide onset. Once structured, the rockslide became more sensitive to short-term hydrologic triggers, with displacement rates increasing in response to groundwater recharge related to critical values of antecedent (7 to 30 days) rainfall. Our results outline the importance of accounting for long-term slope evolution when dealing with rockslides evolving over 10^2-10^3 year timescales, and point to the need of modelling approaches able to relate changing hydro-mechanical properties of slopes to long-term damage processes.