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Deformation and stabilisation mechanisms of slow rock slides in crystalline bedrock

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Deep-seated rock slides are slope instabilities which are characterised by deformation along one or several shear zones where most of the measured total slope displacement localizes. Generally, a high danger potential is given when rock slides fail in a rapid manner characterised by very high sliding velocities and/or when they develop into long run-out rock avalanches. However several field surveys and deformation monitoring data show that numerous deep-seated rock slides do not fail in a high velocity regime. In fact, many slides creep downwards at rates of some centimetres per year or even less and do not show any evidence for non-reversible acceleration in the past or in the future. Furthermore some of these slope instabilities are actually inactive (dormant) or have even reached a stabilised final state. Deformation monitoring on active rock slides show that acceleration phases characterised by velocities up to meters per day can occur. The trigger for these phases can be manifold and include heavy rainfall, snow melt, water level fluctuations of reservoirs at the slope foot, changes in the slope's equilibrium state due to antecedent slow creeping processes, changes in the material behaviour within the sliding zone, erosion along the foot of the slope, etc. Whereas the role of these triggers in promoting phases of acceleration are generally understood, the same can not be said regarding the kinematics and dynamic processes/mechanisms by which rock slide masses re-stabilise once the trigger impetus has been removed. In the context of this study the term "stabilisation" is used for rock slides which decelerate from high velocities to slow base activities or even stop moving after a certain amount of displacement.

Given that reliable rock slide forecasts require the fundamental understanding of possible slope stabilisation mechanisms this study focuses on field-based and numerically obtained key-properties which influence the long-term slope deformation behaviour. On a regional scale several valleys located in amphibolites, ortho- and paragneisses of the Ötztal-Stubai crystalline basement (i.e. Kaunertal, Pitztal, Ötztal, Lüsenstal, all located in North Tyrol, Austria) were investigated. Therefore geological and morphological basis data were compiled and re-evaluated, remote sensing methods (i.e. airborne laser scanning terrain models and orthofotos) applied and field mapping campaigns performed. On a local scale several rock slides were investigated and analysed in high detail with regard to their lithological and structural inventory, geometry of sliding masses and -zones, failure mechanisms, kinematics and temporal deformation characteristics. Field data clearly show that competent rock masses, e.g. orthogneisses and amphibolites, are affected by rapid failure events and therefore are characterised by "brittle" rock mass behaviour. In contrast, the majority of the slowly moving and "self-stabilising" rock slides are located totally or partly in mica-rich incompetent crystalline rock masses, e.g. paragneisses and micaschists, and are characterised by moderately dipping sliding zones. Apart from a causal lithological influence, numerous field observations demonstrate a major influence of pre-existing geological structures on the formation and deformation behaviour of these rock slides.

The nature of rock slides implies that the temporal deformation behaviour is primarily dominated by two key-features of the sliding zone i.e. the mechanical properties (shear strain strengthening or weakening) and the effective in-situ stresses. The in-situ stresses along a sliding zone are influenced by the geometry of both the sliding mass and sliding zone, the internal deformation of the sliding mass and the pore pressures. All these properties can vary during progressive shear displacements. Especially large shear displacements in the range of tens to hundreds of metres along a distinct sliding zone can cause significant in-situ stress changes which in turn may influence the slope deformation behaviour and stabilisation mechanisms. In order to study these processes for selected case studies in paragneissic rock masses the impact of the sliding mass geometry and sliding zone shape on the in-situ stresses has been investigated by applying the discrete element method. This numerical approach enables the simulation of large shear displacements and complex block assembly interactions.

Results show that slope stabilisation can be achieved when the dip angle of the sliding zone flattens downslope. In this case and after a certain amount of displacement the lower part of the rock slide mass reaches stable slope conditions (shear strength of the sliding zone material exceeds the shear stress acting on the sliding zone) and acts as a resisting mass for the still unstable upper part of the slope. Furthermore numerical models show that secondary slides at the lower part of the slope have a similar effect. In both case cases the observed slope stabilisation can be clearly attributed to the formation of natural buttressing masses at the toe.