Geophysical Research Abstracts
Vol. 13, EGU2011-2546, 2011
EGU General Assembly 2011

Thermo-mechanical forcing of seasonal rock slope deformation at Randa (Switzerland)

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Thermo-elastic effects are generally considered to be of minor importance in the study of mechanisms driving large slope instabilities, and are often disregarded. Here we present a case study of the current rock slope instability above the village Randa (Switzerland), where thermo-mechanical coupling is the primary mechanism controlling slope movement. Long-term monitoring has revealed that ∼6 million m3 of crystalline rock remains unstable following two catastrophic failures in 1991, moving at rates up to 30 mm/yr with a strong seasonal deformation pattern. An abrupt increase of displacement rate occurs in early winter during cooling of the near-surface rock mass, while subsequent deceleration occurs each year after snowmelt as the rock begins to warm. This temporal behaviour was measured with both vibrating wire inclinometers and fiber optic strain sensors at different depths down to 68 m, as well as at the surface with crack extensometers and geodetic monitoring. Such behaviour is opposite to that reported for most slope instabilities, where higher displacement rates occur after snowmelt due to increased water pressure. Piezometric pressure in boreholes shows dry conditions down to 120 m depth and a small perched groundwater body. The absence of water seepage from the unstable rock mass also indicates nearly drained conditions, which is not unexpected for the highly fractured rock mass and ridge topography. With 2D numerical models, we demonstrate that thermo-mechanical effects can drive deep slope deformation and may also force movements at the Randa instability. We show that near-surface thermo-elastic stresses can penetrate to depths well below the thermally active layer in a stiff rock mass and in the presence of strong topography. While stresses within the thermally active layer can reach up to 1 MPa, induced stress changes at depths up to 100 m are on the order of 10-100 kPa. If discontinuities are critically stressed, i.e. sufficiently close to failure, these small stress changes can induce slip and thus drive progressive slope deformation. For the Randa instability, numerical models were able to reproduce the order of magnitude of observed displacement rates and seasonal amplitudes by applying only thermal forcing. We conclude that a considerable amount of discontinuities are critically stressed at Randa, which leads to high sensitivity of the rock mass to thermo-mechanical stresses changes at depth.