Geophysical Research Abstracts
Vol. 14, EGU2012-11617, 2012
EGU General Assembly 2012

Kink zone localization, structurally-controlled instability, and large-scale rock slope failure at the Mt. Gorsa porphyry quarry (Trentino, Italy)

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Rock slope failure is controlled by rock mass strength and anisotropy, and by slope-scale persistent fractures with different spacing, eventually resulting in complex mechanisms as large-scale flexural toppling, block toppling, and kink band slumping. Despite these mechanisms have been studied, their interplay in large rock slope failure is often difficult to ascertain in complex geological settings. We studied the 250 m high porphyry quarry slopes of Mt. Gorsa (Trentino, Italy). Two slopes facing to N and E are carved in Permian rhyolithic ignimbrites, providing spectacular exposures of the inherited geological structure. Despite the strong intact rock, rock mass has a complex structure due to the occurrence of thermal cooling joints, persistent tectonic fractures, and joint sets. Evidence of ongoing displacement of the northern quarry face in 2003 motivated geotechnical and geophysical site investigation, and the initiation of displacement monitoring activities. GB-InSAR measurements using a LiSALab system captured large-scale slope dilation involving 400.000 m3. Further GB-InSAR measurements have been carried out since 2010.
In order to understand the mechanisms governing large-scale deformation and failure of the northern slope, we carried out a comprehensive field and modelling study exploiting terrestrial photo mapping, field structural analysis and discontinuity surveys at different locations. On the northern face, 190 Geological Strength Index (GSI) surveys along benches, DEM structural analysis (COLTOP3D), and analysis of GB-InSAR data were carried out, and relationships among rock mass quality, 2003 landslide extent, and measured displacements established. Data show that slope instability is locally constrained by close and persistent cooling joints steeply dipping to the south (K1), persistent fault surfaces moderately dipping to the NNW (K2), and joint sets steeply dipping to NE and WNW (K3 and K4). NNW-dipping, top-to-N kink bands up to 2m wide also occur at depth and are exposed on the eastern slope. Close to the northern quarry face, structurally-controlled instabilities (sliding, flexural toppling, block toppling) occur inside individual kinematic domains ranging from tens to thousands cubic meters, leading to significant rock mass degradation (GSI < 35-40) and to disintegrated and weathered rock masses in areas undergoing largest displacements.
We investigated the links between local structurally-controlled failure and large-scale rock slope failure using different Finite-Element modelling approaches implemented in the softwares Phase2 v.8 (Rocscience Inc.) and ELFEN (Rockfield Inc.). Performed modelling tasks include: continuum models (Phase, ELFEN), continuum-based jointed rock models (Phase), and hybrid continuum-discrete models (ELFEN). A continuum-based SSR (Shear Strength reduction) back-analysis of the 2003 instability, calibrated on landslide geometry and GB-InSAR displacements, shows that reduced rock mass properties (GSI < 35-40) observed where local-scale structurally-controlled instability occurs, were a pre-requisite for the 2003 global slope instability. Jointed rock and hybrid models suggest that slope excavation results in shear strain localisation along inherited fault surfaces and newly-formed kink bands at different depths. At depths less than some tens of meters, these interact with K1 resulting in step-path failure surfaces, sliding and toppling. Globally, these processes result in dilation and rock mass damage, which in turn promote the required conditions for global slope failure.