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Fabric controls on the failure mode of strongly deformed metamorphic rocks: investigation, modelling, and impact on rock-slope stability

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The strength and deformability of anisotropic, folded metamorphic rocks strongly depend on rock mineralogy and microstructure. Although a large body of literature exists on the effects of single planar anisotropy on rock strength, fabric controls on the failure mode of rocks which underwent severe ductile deformation (e.g. crenulation folding) are poorly understood and difficult to generalize. In order to fill this gap, we studied the mechanical behaviour of gneisses (Monte Canale unit) and phyllites (Ambria Unit) from the Italian Central Alps and Southern Alps. Rock petrography and fabric were characterised through standard optical microscopy and XRD techniques. About 60 gneiss samples and 40 phyllite samples from available drill cores were prepared and tested under uniaxial and triaxial (multistage) compression, and indirect tension (Brazilian) tests. Laboratory tests allowed reconstructing the stress-strain behaviour and the main mechanical properties of intact rock, as well as observing the fracture pattern of tested samples. Rock samples revealed low and scattered values of unconfined compressive strength (UCS) and Young's modulus. Rock samples broke according to four failure modes, from the well-known shear failure along foliation to the development of centimetre-scale brittle shear zones, both at low and high confining pressure. Moreover, no clear dependence of rock strength on the foliation direction could be identified. Fracture patterns were thus further investigated through X-ray Computed Tomography imaging, performed at different resolutions (MicroCT: 40-60 μm; medical CT: 625 μm), and micro-structural analysis of thin sections. Investigation results suggest that the failure of strongly deformed metamorphic rocks is controlled by the occurrence of multiple anisotropies related to micro-fabric, not always characterised by clear meso-scale expression, including crenulation folding, shape preferred orientation, intracrystalline deformation microstructure. Different failure modes dominate depending on the geometrical arrangement of both foliation and fold axial surfaces, in turn affecting the values of rock strength and deformability. The relationships among rock fabric, failure mode, mechanical properties, and their constraints, were further investigated by Finite Difference numerical modelling of experiments performed under uniaxial compression. Modelling results provided a satisfactory account of laboratory test results and gave further insights through parametric modeling. Possible impact of different strongly deformed rock fabric on rock mass properties and large-scale rock slope stability were also illustrated by parametric stability modelling.