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Optimization of massive countermeasure design in complex rockfall settings

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Rockfall protection is a major need in areas impended by subvertical rockwalls with complex 3D morphology and little or no talus to provide natural rockfall attenuation. The design of massive embankments, usually required to ensure such protection, is particularly difficult in complex rockfall settings, due to: widespread occurrence of rockfall sources; difficult characterization of size distribution and location of unstable volumes; variability of failure mechanisms; spatial scattering of rockfall trajectories; high expected kinetic energies. Moreover, rockwalls in complex lithological and structural settings are often prone to mass falls related to rock mass sector collapses. All these issues may hamper a safe application of classic embankment analysis approaches, using empirical rules or 2D-based height/energy statistics, and point to the need of integrated analyses of rock slope instability and rockfall runout in 3D.

We explore the potential of combining advanced rock mass characterisation techniques and 3D rockfall modelling to support challenging countermeasure design at a site near Lecco (Southern Alps, Italy). Here subvertical cliffs up to 600 m high impend on a narrow (< 150 m) strip of flat land along the Como Lake shore. Rock is thickly bedded limestone (Dolomia Principale Fm) involved in a ENE-trending, S-verging kilometre-scale anticline fold. The spatial variability of bedding attitude and fracture intensity is strongly controlled by the geological structure, with individual block sizes varying in the range 0.2-15 m^3. This results in spatially variable rockfall susceptibility and mechanisms, from single block falls to mass falls. Several rockfall events occurred between 1981 and 2010 motivated the design of slope benching and a massive embankment.

To support reliable design verification and optimization we performed a 3D assessment of both rock slope instability and rockfall runout. We characterised fracture patterns and rock mass quality associated to different sectors of the folded structure (i.e. limb and hinge zones) in the field and by the structural analysis of point clouds derived by Terrestrial Laser Scanning and Digital Photogrammetry. This allowed characterising block size/shape distributions and the expected (local and global) failure mechanisms for different slope sectors. This information provided improved spatially-distributed inputs to 3D rockfall runout modelling, performed using the Hy_STONE rockfall simulator and explicitly integrating the countermeasure design geometry into a HRDEM. We calibrated modelling parameters by the back analysis of previous rockfalls and performed predictive simulations accounting for different landslide size scenarios. Countermeasure design was verified according to the spatial pattern, height and overpassing probability of expected trajectories, allowing the evaluation of three "countermeasure efficiency descriptors" to be used for design optimisation scenarios.