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# Rockfall source characterization at high rock walls in complex geological settings by photogrammetry, structural analysis and DFN techniques

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Rockfall quantitative risk analysis in areas impended by high, subvertical cliffs remains a challenge, due to the difficult definition of potential rockfall sources, event magnitude scenarios and related probabilities. For this reasons, rockfall analyses traditionally focus on modelling the runout component of rockfall processes, whereas rock-fall source identification, mapping and characterization (block size distribution and susceptibility) are over-simplified in most practical applications, especially when structurally complex rock masses are involved. We integrated field and remote survey and rock mass modelling techniques to characterize rock masses and detect rockfall source in complex geo-structural settings. We focused on a test site located at Valmadrera, near Lecco (Southern Alps, Italy), where cliffs up to 600 m high impend on a narrow strip of Lake Como shore. The massive carbonates forming the cliff (Dolomia Principale Fm), normally characterized by brittle structural associations due to their high strength and stiffness, are here involved in an ENE-trending, S-verging kilometre-scale syncline. Brittle mechanisms associated to folding strongly controlled the nature of discontinuities (bedding slip, strike-slip faults, tensile fractures) and their attributes (spacing and size), as well as the spatial variability of bedding attitude and fracture intensity, with individual block sizes up to 15 m3. We carried out a high-resolution terrestrial photogrammetric survey from distances ranging from 1500 m (11 camera stations from the opposite lake shore, 265 pictures) to 150 m (28 camera stations along N-S directed boat routes, 200 pictures), using RTK GNSS measurements for camera station geo-referencing. Data processing by Structure-from-Motion techniques resulted in detailed long-range (1500 m) and medium-range (150 to 800 m) point clouds covering the entire slope with maximum surface point densities exceeding 50 pts/m2. Point clouds allowed a detailed reconstruction of 3D topography, fold mapping and characterization of orientation, intensity and size of slope-scale discontinuities. Due to the structural complexity, interpretation of discontinuity features associated to different fold sectors (i.e. limbs and hinge zone) required a detailed field description of small-scale structural features including slickensides, veins and joint associations, impossible to be detected in point clouds. This information allowed generating Discrete Fracture Network models in FracmanTM, which provided a robust description of rock mass structure, accounting for the controls of slope-scale folding processes on rock mass structure. Block size distributions and locations of potentially unstable blocks were derived from the DFN model of the cliff, providing valuable input to the definition of realistic scenarios for rockfall modeling and quantitative risk analysis.