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Quantification of rotational and toppling movements of unstable rock slopes based on discontinuity orientations

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Large unstable rock slopes have often a complex displacement pattern that is composed of several blocks moving in different directions with different velocities and that is often a combination between translational and rotational displacements or toppling. Translational displacements can be measured by many monitoring techniques (dGNSS, total station, extensometer, InSAR, terrestrial laser scanning and many more), while rotational movements and toppling are more complicated to detect (tiltmeter, inclinometer, terrestrial laser scanning). The goal of this study is to quantify the total rotational movement of unstable rock slopes based on the differences in orientation of the main discontinuity sets between the moving block and its (relatively) stable surroundings.

This analysis assumes that the orientations of the discontinuity sets in the unstable slope matched those of the surroundings before the displacement and that differences are directly related to rotational movement. After having identified pairs of discontinuities that are found both on the instability and its surroundings, the rotation angles leading from the initial to the final orientation of the discontinuities can be computed. This is achieved by varying the rotation angles in the three coordinate system axes with the goal to minimize the differences between the pairs of discontinuities.

We applied this rotation analysis to several unstable rock slopes in Norway and based the discontinuity analysis on high-resolution terrestrial laser scanning data. The example of an unstable block at Stampa (Flåm, western Norway) with a volume of 280'000 m^3 shows a total rotational displacement of 4.1° in downslope direction. This rotation is consistent with a toppling movement along one of the major discontinuities forming the back-scarp, but toppling by 4.1° cannot fully explain the opening of the 20 to 30 m wide graben between the back-scarp and the instability. The remaining part of the total observed displacement can be caused by either sliding in a combined slide-topple failure mechanism, which involves sliding along one or multiple sliding surfaces and toppling. Alternatively, the total width of the graben can also be only apparent and be caused by partial collapses along the back-scarp and the rear-facing wall of the unstable block.

This study provides an interesting and novel tool to quantify the rotational and toppling components of unstable rock slopes based on the discontinuity orientation. By this it helps to improve the understanding of rock slope instabilities and their complex deformation pattern and mechanism. Thereby, this study can give useful input for creating reliable scenarios for rock slope instabilities and contribute to their hazard or susceptibility assessment.