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Rockfall simulations in Gothenburg, southwestern Sweden

Rockfalls are a type of mass movement that occurs when one or several boulders detach from a cliff or a steep slope. Depending on the location, the size of the falling blocks and their velocity, they can represent a serious threat to the surroundings. In some parts of Sweden, it is common to find residential or recreational infrastructure near steep slopes due to the generally high strength of the rocks, which provides a good foundation for construction. A national risk evaluation and detailed documentation related to this natural hazard is, however, lacking.

A first step to address this problem is to map the areas under possible threat of rockfalls, by considering two fundamental aspects: i) identification of the areas where blocks may lose support and start moving downslope (source areas). ii) estimation of the extent of the blocks' trajectories until they finally stop (runout zones).

Potential rockfall source areas can be outlined using statistical calculations, whereas runout zones can be simulated using modelling software. CONEFALL and RockyFor3D are computer programs that offer the possibility to estimate the vertical and horizontal extent of the runout zones for a specific rockfall source. These programs can generate simple models that are based on literature studies, or realistic results based on evaluation of the slope characteristics in the area of interest (for example, the size and shape of the blocks, the type of soil and rock, and the presence of trees on the slope).

This study was performed in the northeastern part of the Gothenburg municipality, focusing on Fjällbo park, a popular climbing area where cliffs can reach more than 90 meters in height. In this area, large accumulations of blocks under the cliffs evidence both historic and recent rockfalls. The most recent one occurred in 2017 after a pillar of approximately 150 Ton detached from the rock wall. This rockfall destroyed a renowned climbing route and impacted near a hiking trail transited by locals and visitors; moreover, a growing residential area is situated approximately 40 to 50 m from the base of the cliffs.

For the Fjällbo area and its surroundings, according to statistical calculations, the slope angle threshold above which all angles are considered potential rockfall sources is 40°-42°. Simple rockfall simulations for these potential source areas show that the vertical extent of the runout zones is dependent on the height of the cliffs, and their lateral extent is overestimated by the software but can be fixed by performing fieldwork or observations from aerial photographs of the area. On the other hand, realistic rockfall simulations show that the block shape affects the lateral extent of runout zones, block mass controls the energy dissipation and deacceleration of the blocks. Similarly, the bouncing behavior of the blocks on the surface is mostly controlled by the type of soil or rock, and by the obstacles encountered on the way (their distribution and their sizes). And lastly, these simulations indicate that forests act as protective agents, as they may stop the falling blocks; however, the protection efficacy depends mainly on the density of the forest.

The inclusion of a verification point (the 2017 rockfall in Fjällbo in this study) offers a great opportunity to evaluate the applicability and accuracy of the models when replicating the environmental conditions of the previous rockfall (Fig. 1) and allows us to suggest that the methodologies for potential rockfall source detection, as well as the runout zone estimations obtained with CONEFALL and RockyFor3D models, serve as a foundation for further and more detailed risk assessment.

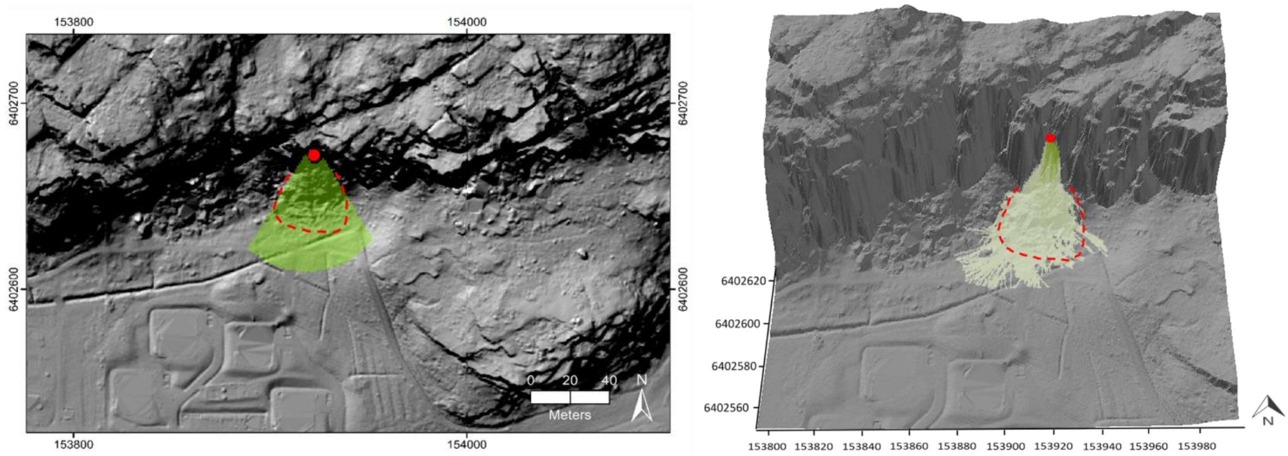

Figure 1. To the left: Simple simulation performed with CONEFALL. To the right: Realistic simulation performed with RockyFor3D. In both cases, the yellow area corresponds to the simulated runout zone, the red dot represents to the location of the source area, and the red dashed line corresponds to the actual extent of the 2017 rockfall in Fjällbo.

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