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Structural analysis of the unstable rock slope area at Stampa above Flåm, Norway

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The unstable rock slope area around Stampa in Flåmsdalen is one of the largest actively deforming rockslide areas in Western Norway (Domaas et al., 2002). It covers an area of up to 11 km^2 that extends 7 km N-S and 2 km W-E and shows signs of active and postglacial gravitational deformation. As the consequence of a failure could be high, an intensive investigation program was requested. Part of this are detailed structural field mapping, a differential GPS survey, as well as the generation of a detailed topographic model based on airborne laser scanning (ALS) data and several terrestrial laser scanning (TLS) surveys.

The structural analysis of the three different sources of structural data (ALS, TLS and field measurements) revealed 3 main joint sets with the following mean orientations: (J1) 078/83, (J2) 021/89 and (J3) 116/82. These joint sets are very constant in orientation and appearance over the whole unstable area. Several open fractures (up to 300 m long and 10 m wide), which are visible on the DEM and in the field, developed along those main sets or a combination of two of them. The foliation is strongly folded with varying types of folding, ranging from cm-scale crenulation folds to larger amplitude (meter-scale) open folds, but with a constant horizontal fold axis. Despite this complex folding pattern, the foliation develops preferentially planes dipping shallowly to moderately towards the fjord. There is a change in mean foliation observed, which let together with major structures and observed deformation patterns, to a subdivision of different parts of the unstable area that seem to deform independently and show different stages of deformation.

The northern part of the unstable area shows the most advanced stage of deformation. In this region are the biggest open fractures located, which developed along J1 and J3, as well as two nearly freestanding blocks with the highest measured movement rates. J3 and J1 define back and lateral scarp of this two blocks with volumes of 160 000 and 55 000 m^3 respectively. The foliation is on average dipping around 20-30° towards W and could thus act as a basal sliding plane. A change in dip and dip direction of the foliation (dipping 30-40° towards SW) marks the central part of the unstable slope. There are only smaller open fractures (up to 50 m long and 5 m wide), but big ground depressions have developed along J1 and J3 (up to 700 m long and 10 m wide). In the southern part of the study area big ground depressions have developed along the foliation and can be traced up to 3 km on the high resolution DEM. This region is characterized by an up to 200 m high, west-facing cliff with very high rockfall activity. However, signs for gravitational deformation behind the cliff are fewer and less developed than in the other regions.

This subdivision can be confirmed by the deformation pattern obtained from GPS measurements. With the dGPS analyses we have registered movement of 19 measurement points for up to four 1-years-measurement intervals. Movement rates and directions vary significantly from year to year. Hence the yearly average of the cumulative movement after 4 years of monitoring are reported here. Average movement rates range from 1 to 17 mm per year, of which three monitoring points show an average yearly movement above 10 mm per year. Two of those points are close to each other in the northern part of the monitored area of the unstable slopes. They are located on the smaller, almost completely detached blocks. The third point is located on a big boulder of an old rockslide deposit on the lower part of the slope. The interpretation of the movement of this boulder is ambiguous, as it is not evident if the boulder moves by itself or as part of the entire boulder deposit. Close to the cliff of the

central part of the instability the dGPS survey indicates movement rates in between 5 and 10 mm per year. In this sector the limiting structures are not fully developed yet. The GPS points with movement rates below 5 mm per year are situated further away from this cliff edge and in the southern part of the unstable area. Limiting structures in this part are even less developed. However, ground depressions indicate blocks with volumes of up to 80 Mio m^3.

References:

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