Consequences assessment of large rock slopes failures in Norway

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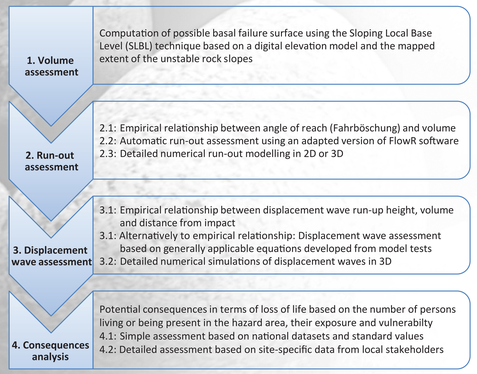
GOALS

- Generation of a methodology for the assessment of consequences of large rock slope failures in Norway.
- Combination of the consequences assessment with a qualitative hazard assessment to classify risk according to the hazard and risk classification system for unstable rock slopes (Hermanns et al. 2012).
- Prioritization of follow-up activities, such as more detailed investigations, periodic displacement measurements, permanent monitoring and early-warning.

WORKFLOW

The proposed method for consequence assessment comprises four main steps (Fig. 1) with different levels of detail according to the mapping approach of the Geological Survey of Norway (NGU) (Fig. 2).



↑ *Figure 1: Workflow for the consequences assessment (step 3 is only required if a lake or fjord is hit by a rock avalanche). Landslide dams are excluded from this assessment, since they do not lead to immediate casualties.*

→ *Figure 2: Approach for mapping of unstable rock slopes at NGU with detailed investigations focusing on potential medium- to high-risk sites. The consequences assessment follows also different levels of details (numbers refer to Fig. 1).*

1. VOLUME ASSESSMENT

The Sloping Local Base Level (SLBL) technique (Jaboyedoff et al. 2004) computes a second-order curved surface based on a digital elevation model and the mapped extent of the unstable rock slope.

This surface represents the possible basal sliding surface and its curvature can be adapted to local geological and structural conditions (Fig. 3).

The elevation difference between this surface and the topographic surface yields the volume.

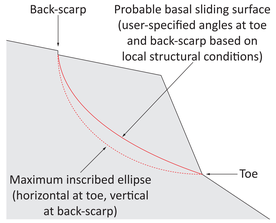
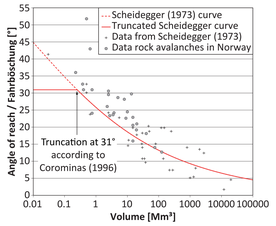


Figure 3: Example cross-section of an unstable rock slope with the maximum inscribed ellipse and the probable sliding surface using user-specified angles.

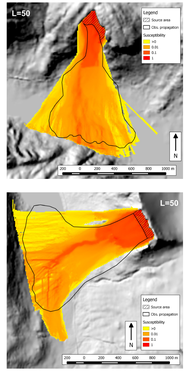
2. RUN-OUT ASSESSMENT

2.1 Empirical relationship

The angle of reach of a rock avalanche usually decreases with increasing volume (Scheidegger 1973; Corominas 1996). The best-fit curve from Scheidegger (1973) appears to be a conservative relation for Norway, as >90% of past rock avalanches in Norway have shorter run-out distance than predicted by the curve (Fig. 4). For volumes smaller than ca. 250 000 m³ a fixed angle of 31° is used (Corominas 1996).



→ *Figure 4: Empirical relation between angle of reach and volume. Norwegian events have generally shorter run-out than Scheideggers best-fit curve.*



→ *Figure 5: Run-out assessment of two prehistoric rock avalanches in Norway using FlowR. Extent of mapped deposits as black lines.*

2.2 Automatic run-out assessment

The volume-dependent angle of reach is used for the run-out assessment of rock avalanches using the FlowR software with a digital elevation model (Horton et al. 2014).

The software is widely used for debris flows and is adapted here for rock avalanches, including the potential to ascend opposing slopes. This is achieved by introducing a memory effect for each propagation path, which simulates the inertia of a rock avalanche, i.e. the tendency to keep the direction (Fig. 5). This run-out assessment in FlowR does however not take into account terrain roughness, terrain types or entrainment etc.

2.3 Detailed run-out analysis

More detailed numerical run-out modelling – using for example DAN3D (McDougall & Hungr 2005) or similar software tools – may be required if the uncertainties on the possible consequences are high (see Fig. 2).

3. DISPLACEMENT WAVE ASSESSMENT

3.1 Empirical relationship & generally applicable equations

An empirical power-law relation of wave run-up height as a function of rock avalanche volume and distance from impact location are derived from a national and international inventory of landslide-triggered displacement waves (Fig. 6). Uncertainties are very high at present and additional parameters (slope angle at run-up, propagation angle from impact) need to be taken into account.

Alternatively, generally applicable equations derived from model tests (Heller et al. 2009) are used to compute run-up heights at several locations around the affected water body.

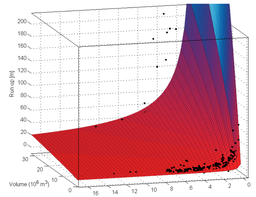


Figure 6: Fitted 3D power-law of run-up height vs. volume and distance from impact (6 events, 289 run-up registrations).

3.2 Numerical simulation of displacement waves

More detailed numerical simulation of displacement waves – using for example GloBouss and DpWaves models (Harbitz et al. 2014) or similar software tools – may be required if the uncertainties on the possible consequences are high (see Fig. 3).

4. CONSEQUENCES ANALYSIS

The population exposed in the rock avalanche run-out area and in the run-up area of a possible displacement wave is assessed taking into account different population groups:

- Inhabitants
- Persons in critical infrastructure (e.g. hospitals & other emergency services)
- Persons in schools and kindergartens
- Persons at work, in shops etc.
- Tourists, persons on ferries

Exposure levels for each population group are defined and vulnerability values are set for the rock avalanche run-out area (100%) and the displacement wave run-up area (70%). Exposure and vulnerability are included in the final estimation of potential life losses caused by a catastrophic failure of an unstable rock slope.

CONCLUSIONS

The proposed methodology for the consequences assessment of unstable rock slopes in Norway will be used as part of mapping program of unstable rock slopes.

The consequences are combined to a qualitative hazard assessment to classify risk. Follow-up activities can then be prioritized based on the risk level and with a standard approach for all unstable rock slopes in Norway.

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