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Analysis of gravitational hazards and risks along the Axen traffic lines (Central Switzerland)

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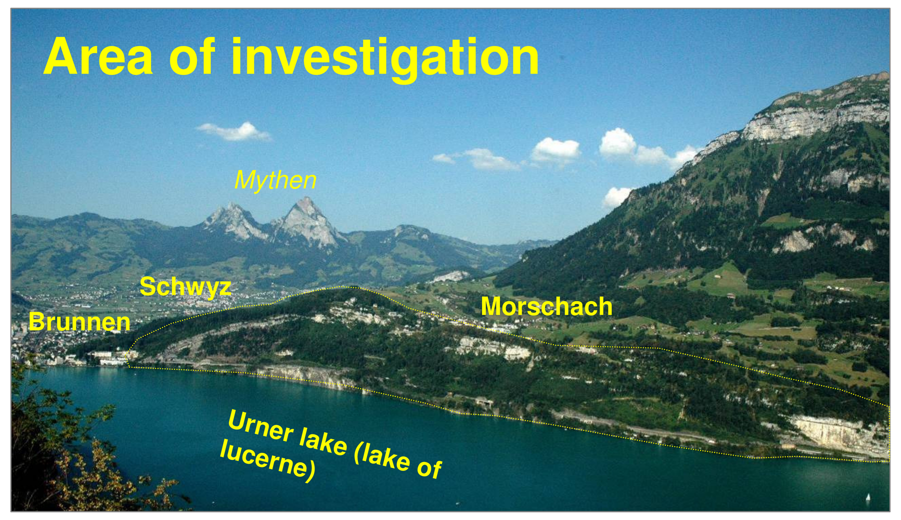
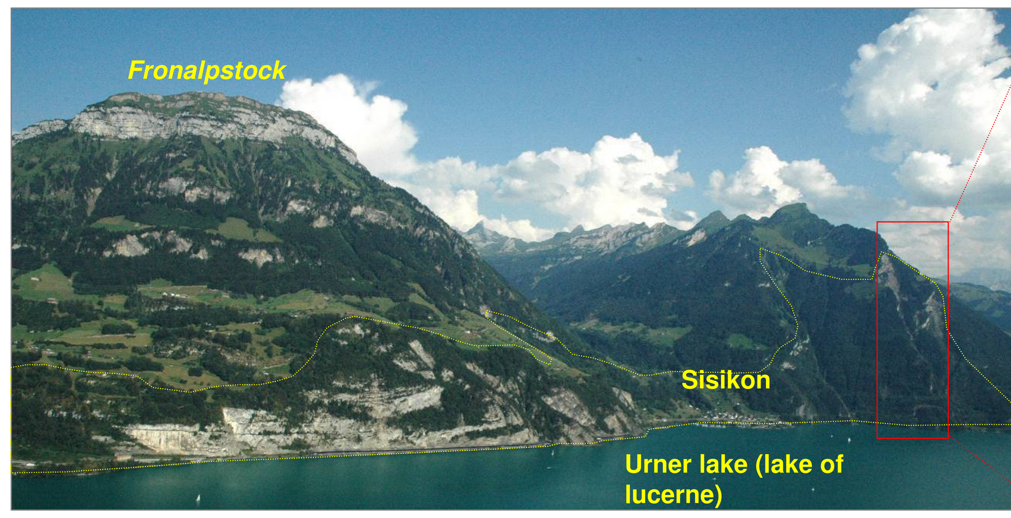
Initial Position

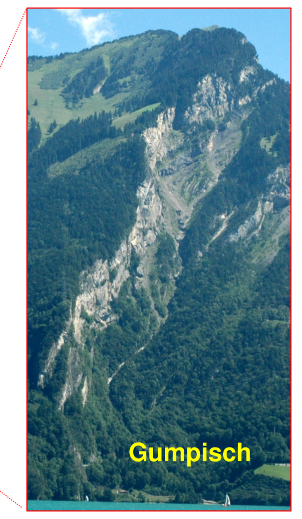
The national highway A4 as well as the Gotthard railway line (N-S transit-line) are passing along the eastern shore of the Urnersee (southern part of Lake of Lucerne) often below steep rocky cliffs. Both infrastructures are highly exposed to gravitational natural hazards, principally rockfall, avalanches and debris flows. The record of occurred events is extending from frequent rockfalls up to rockslides of 6'000 m3 (1932). Despite of existing rockfall galleries and additional protective measures (e.g. rockfall barriers), statistically every second year a potentially harmful rockfall event has to be expected.

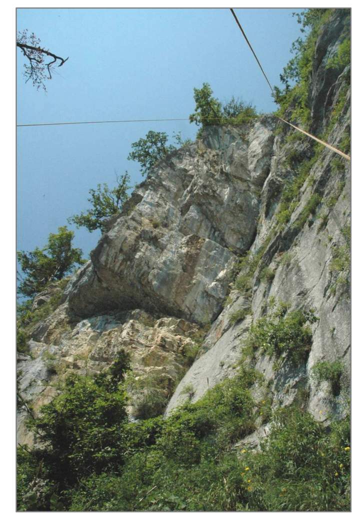
In order to accurately assess hazards and risks along the 10 km long section, the authorities of Schwyz and Uri, the SBB transport company and federal authorities initiated a two-phase project.

Area of investigation









Phase 1: Hazard Analysis

Field investigations: The steep slopes and cliffs have been analysed intensively in the field (fig. 1), including roping down a great number of profiles.

Scenarios: Since lithologies, tectonization (especially structures of brittle deformation), weathering and exposition vary substantially, 58 individual source areas for rockfall processes have been identified. For each area, scenarios for different return periods (3, 10, 30, 100, 300 years) of rockfall events have been determined, based on source rock characterization.

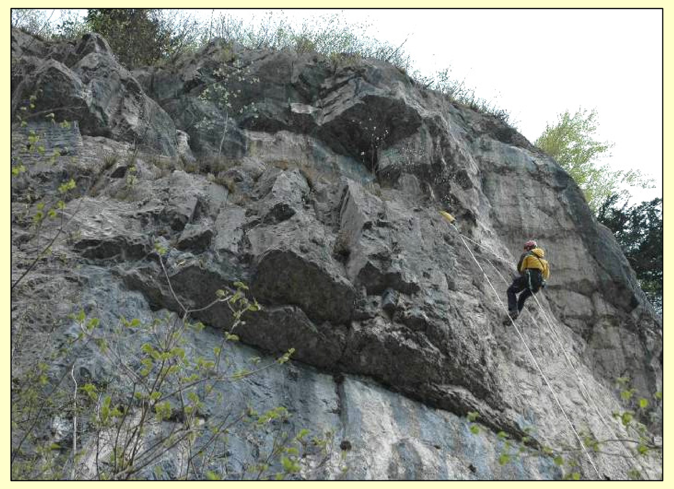


Fig. 1: Field investigations, evaluation of an instable rock mass.

A total of 500 numerical 2D rockfall simulations (fig. 2) were conducted in 44 slope profiles, according to the different block volumes expected as well as to the different release zones. To deal with the high computational effort, a batch procedure for the simulation run as well as pre- and post-processing tools were applied. For this, the used software Rockfall 6.1 was slightly modified.

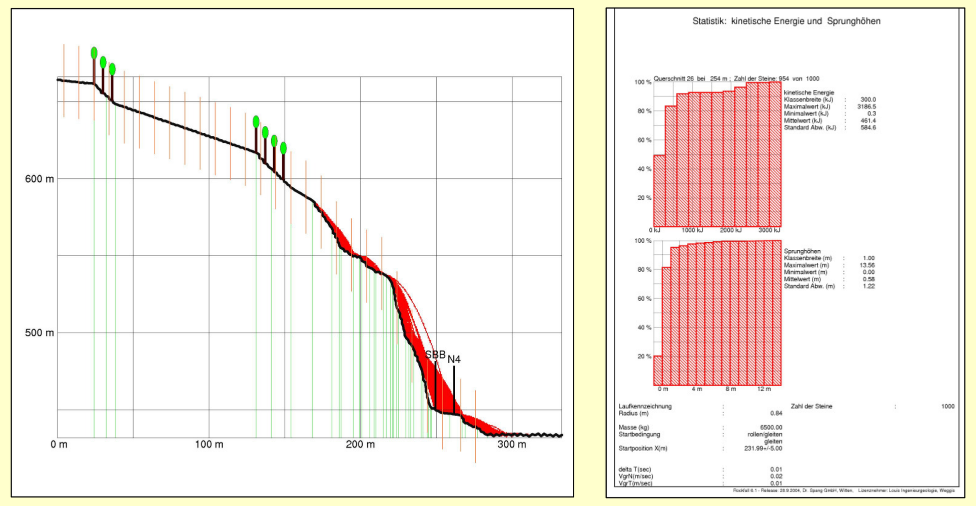


Fig. 2: 2D- rockfall simulation with statistical analysis of kinetic energy and jump height of the blocks (site: „Oelberg“).

Fig. 3: *Left:* 2005, Dornibach, debris flow covers highway and railroad. *Right:* 1970, Rockfall gallery destroyed by rockfall event (500-600 m3).

74 **past events** (fig. 3) had been mapped and analyzed in detail. The **existing mitigation measures** (e.g. galleries, fig. 7) and protection structures had been evaluated concerning their efficiency in respect to the different scenarios and had been accounted in the determination of impact.

The rockfall exposure as well as the exposure to debris flow and avalanches were illustrated with **intensity maps** per scenario (fig. 4).

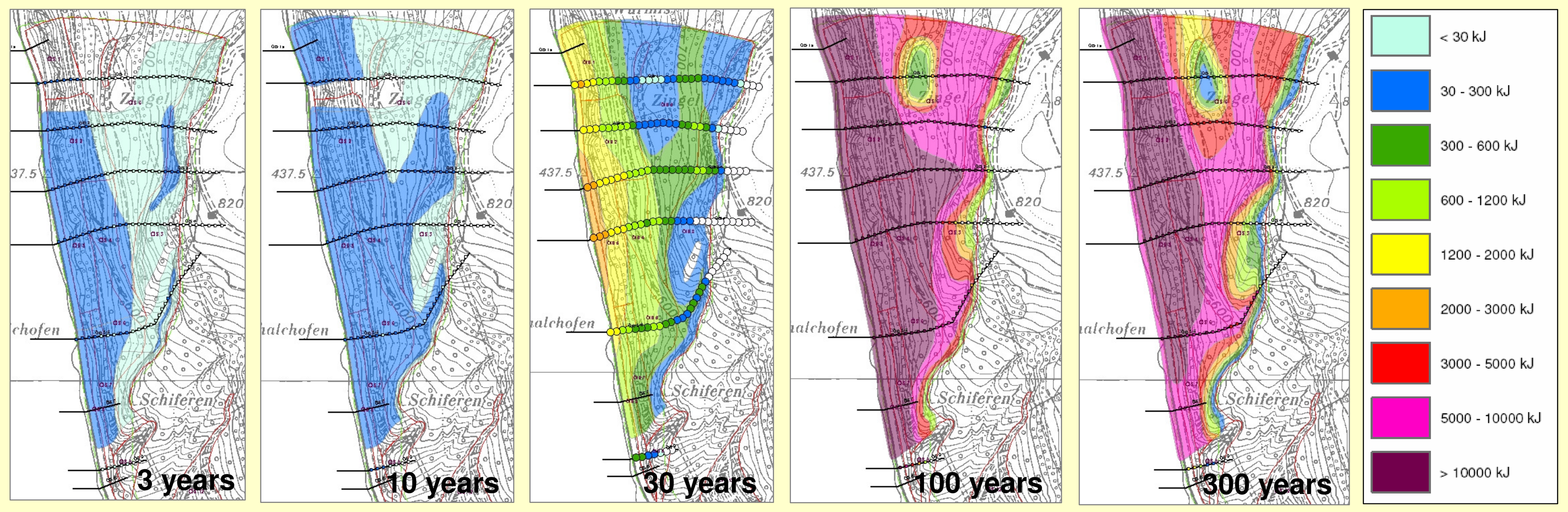


Fig. 4: Sequence of rockfall intensities at 5 given scenarios from an isolated source area (Site: Oelberg-Schieferenegg). The maps had been drawn according to the 2D rockfall simulation results (circles alon the profile lines).

Some Results:

1. 5.4 km (65%) of the highway is exposed to rockfall.
2. The rockfall galeries (approx. 1.3 km total length) are providing limited protection, since the structure itself can be seriously damaged or fail by hits exceeding approximately 300 kJ.
3. High kinetic energies are expected with return periods of 10-30 years already. Maximal energies are beyond the limit of 10'000 kJ.

➔**The applicability of active protective measures is restricted due to technical and financial feasibility.**

Phase 2: Risk Analysis

Methods: Risks have been determined relating to the expected number of casualties and losses. For that purpose, hundreds of event trees have been calculated. For the 28 (street) and 9 (railway) relevant sections, risk was calculated for different scenarios of impact (e.g. intensities of rockfall events) and the courses of event (direct hit, collision with accumulated debris, collision with oncoming traffic, derailing etc. See fig. 5)).

In a further step, possible mitigation measures were evaluated concerning their cost-effiency and the cost/benefit value respectively.

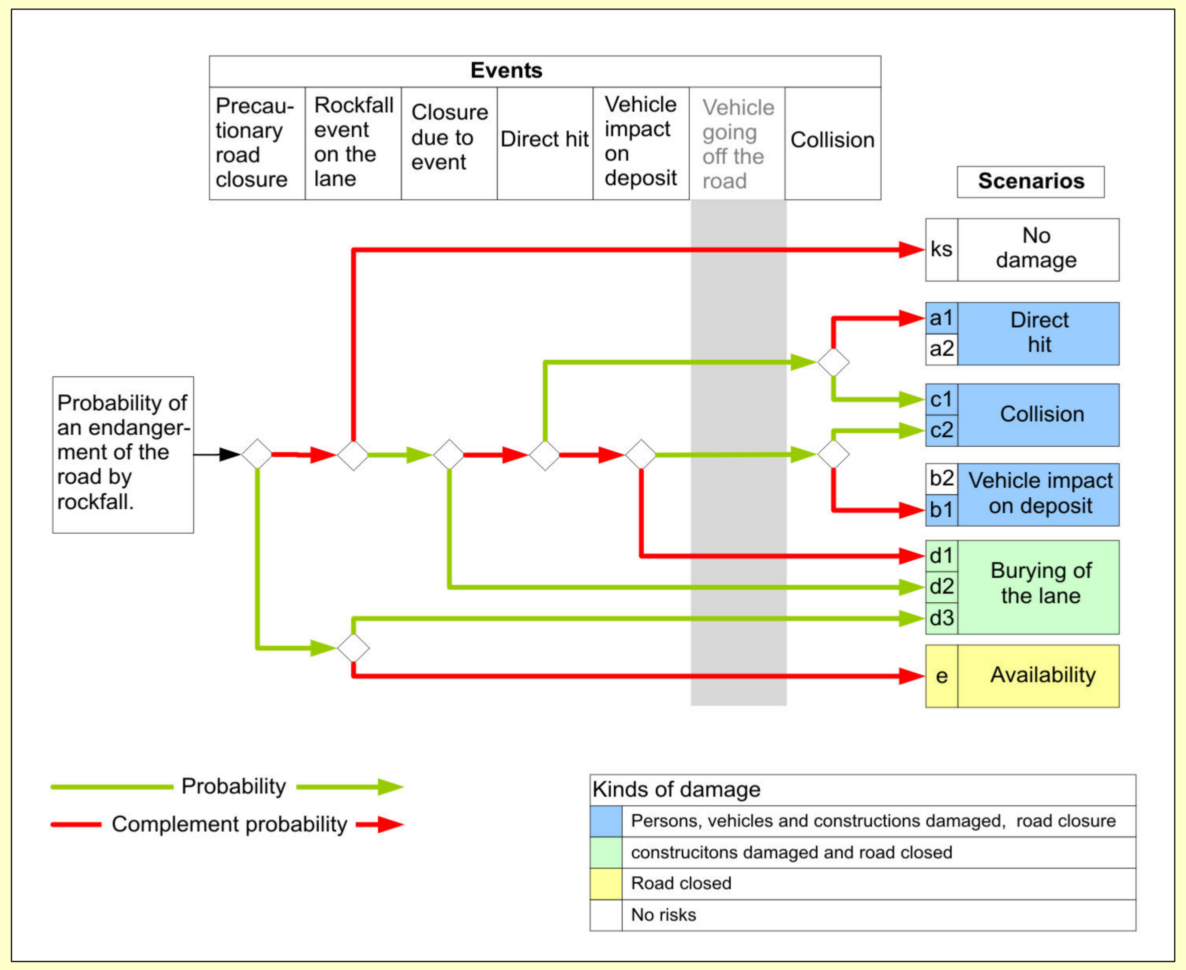


Fig. 5: „Event-tree“ for the highway.

Results:

- Individual risk is near (railway) or even below (highway) the treshhold of risk.
- Highway risks are caused to 66% by rare or very rare rockfall events of high intensities.
- The railway risk hotspot can be linked with debris flow in the dornibach ravine (90% of total risk; fig. 3).
- Due to the high impact intensities no technical measures for risk attenuation will meet the requirements of cost-efficiency.
- Therefore the risk management has to focus primarly on the monitoring of critical rock masses by means of early warning systems and periodic visual controls.

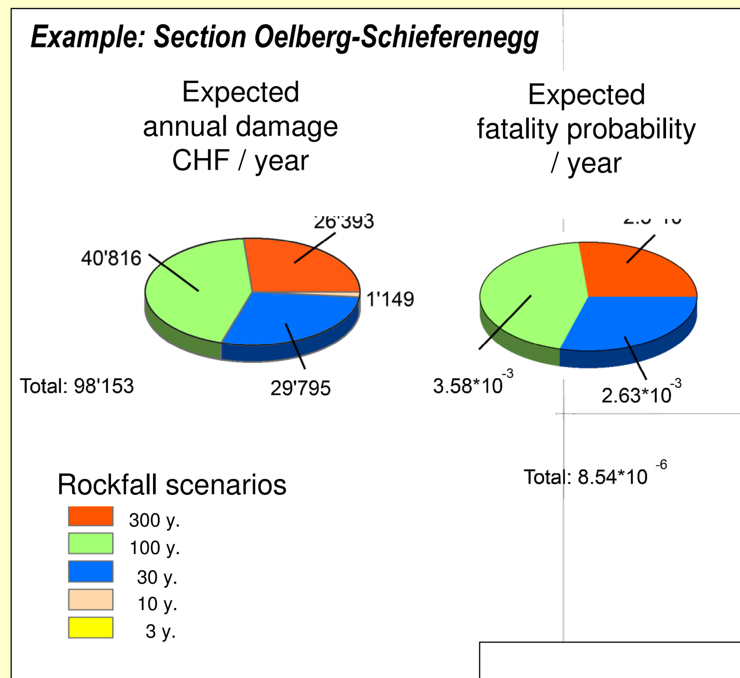


Fig. 6: Example of the expected annual damage and fatality probability in the section Oelberg-Schieferenegg (highway).

Fig. 7: Steep rock cliff over the 800 m long gallery between Oelberg and Schieferenegg.

Conclusion

Detailed hazard and risk analysis are indispensable procedures to apply in complex systems. They provide full context information, that would presumably not be gained from a sectoral or local approach. They yield the relevant data for a goal-oriented use of limited resources.

Fig. 8: Instable Rock mass (ca. 100 m3) directly over the railroad track.

Literature

IG Louis/Bart/Imper, Gefahrenanalyse Axen Januar 2007

IG Louis/Bart/Imper, Risikoanalyse Axen Januar 2008

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