ANALYSIS OF GRAVITATIONAL HAZARDS AND RISKS ALONG THE AXEN TRAFFIC LINES (CENTRAL SWITZERLAND)

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The A4 national highway and the Gotthard railway line (european 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 natural hazards, principally rockfall, debris flows and snow avalanches. The record of occurred events is exhaustive. It is extending from frequent rockfalls up to rockslides of 6'000 m^3 (1932). Since the construction of rockfall galleries in 1968 (Fig. 1), direct hits on the road by low energy events could be minimized. But despite galleries and additional protective measures (e.g. rockfall barriers), statistically every second year a potentially harmful rockfall event has to be expected. Traffic is rather heavy. Every 5-6 minutes a train is passing with 169 persons on an average or with cargo. The daily highway traffic is totalizing 11'800 cars, trucks or buses.

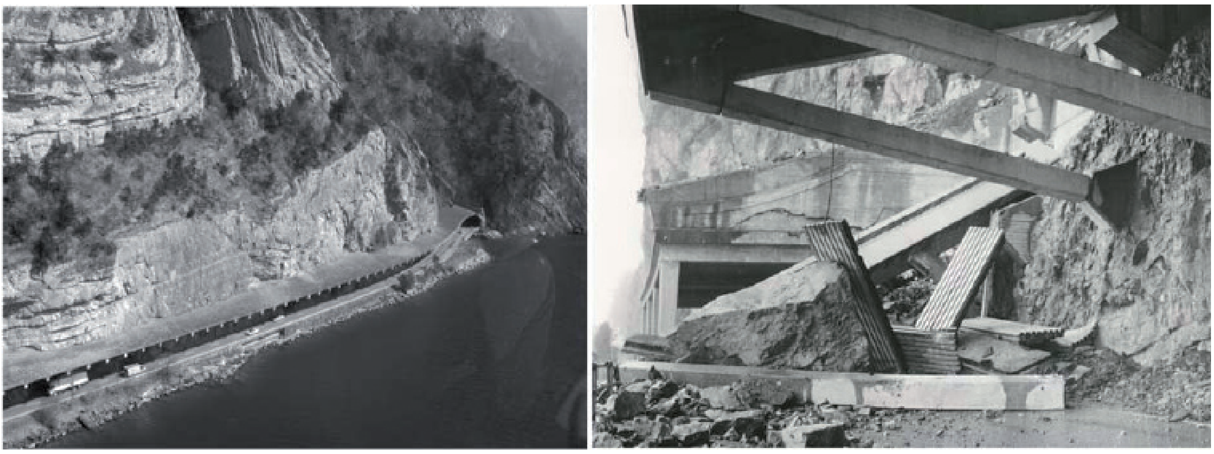

Fig. 1: Part of the Axen national highway with rockfall protection gallery (left). Gallery destroyed by rockfall event (500-600 m^3) in 1970 (right).

Although the last fatal casualty is dated back to 1956, authorities are fully aware of presumably high risks along the approximately 8 km long section between Brunnen and Gumpisch (site south of Flüelen). In order to accurately assess hazards and risks, the authorities of the cantons of Schwyz and Uri, the SBB railway company and federal authorities started a two-phase project, that should focus on the following subjects: Present gravitational hazard potential (Phase 1); present collective and individual risks; evaluation of measures to be taken to reduce existing risks to an acceptable level, considering the principles of cost-efficiency (Phase 2).

Within phase 1, detailed field work was carried out. Concerning rockfall hazard, the steep slopes and cliffs have been analysed intensively, including roping down a great number of profiles.

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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 (size and geometry of falling blocks) for different return periods (3, 10, 30, 100, 300 years) of rockfall events have been determined, based on visual source rock characterization (i.e. lithology, bedding, joints, spacing of joints, decomposition, failure mechanisms, registered events or observed traces). The field observations were registered on standardized forms as well as on maps and photographs. For all scenarios, rockfall-energies have been determined by 2D-modelling. Referred to the highway, almost 5.4 km (65%) are exposed to rockfall. Some of its sections are threatened simultaneously by up to 4 different source areas. Even the galleries (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. This corresponds to events of a return period of 10-30 years. Events with a return period of 30-100 years mostly exceed energies of 300 kJ, and on a length of roughly 1.5 km energies of 3’000 kJ. Maximal energies are beyond the limit of 10’000 kJ. The risk profile of the railway is slightly better, because the tracks are situated either in tunnels or they are “sheltered” by the highway.

Other hazards (debris flows, snow avalanches and landslides) have been assessed by thorough analysis of the relevant catchment areas and transit zones, as well as by 3D-modelling. Compared to rockfall events, these hazards are of minor significance (relatively rare, and – in the case of snow avalanches – predictable). An exception is given by the Dornibach location, where debris flows can hit the traffic lines and interrupt them for days (e.g. event of August 2005).

Within phase 2, 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). The first outcome of analysis indicates, that the individual risk (probability of fatal casualty per year) is near (railway) or even below (highway) the threshold of risk, that is considered to be acceptable in Switzerland (i.e. $1 \cdot 10^{-5}$ to $1 \cdot 10^{-6}$). This can be attributed to the already existing protective measures (e.g. galleries, rockfall barriers). Highway and railway risk profiles differ essentially from each other. Whereas highway traffic is over long distances threatened by rockfall (65% of the total risk for persons), the railway risk hotspot can be linked with debris flows at the Dornibach ravine (90% of the total risk). In respect to the currently acceptable risk situation it is assumed, that further technical protective measures will hardly be cost-efficient. An exception is given by the debris flow protection measures at the Dornibach ravine, where the risk can be reduced substantially. Regarding different types of construction, cost-efficiency varies there roughly between CHF 45’000 and CHF 109’000 per prevented fatal casualty/year. These values are considerably below the threshold of CHF 5 millions, that is supposed to be the upper limit of very cost-efficient measures. As the current rockfall risk along the highway is caused to nearly 66% by rare to very rare events of high intensities, it has to be deduced, that no technical measures for risk attenuation will meet the requirements of cost-efficiency. Thus, risk management has to focus primarily on the monitoring of critical rock masses by means of early warning systems and periodic visual controls.

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.

Keywords: Hazard assessment, risk analysis, acceptable risk, protective measures