Key results of the Swiss wide natural hazard risk assessment on national roads

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ABSTRACT
Since 2008, the Federal roads office FEDRO is owner and manager of all national roads in Switzerland, which comprise the highways as well as most of the mountain passes of key importance. As a result, Swiss-wide, standardized information on natural hazards that threaten national roads (highways) was not available. The FEDRO therefore decided to initiate a four year project aiming at quantifying and mapping all risks due to natural hazards threatening Swiss national roads. This paper presents the methodology used in this project and presents a summary of the monetarised risks of the evaluated road sections. The natural hazards that are assessed are snow avalanches, rock- and icefall, flooding, debris flows, landslides (permanent, spontaneous and slope type debris flows) and collapse dolines. Risk hot spots mainly occur due to road closure related to rockfall or bank erosion. Damage to infrastructure represents generally only up to 20 % of the total calculated risk; person risks add up to 8 % of the total risk.

KEYWORDS
risk evaluation; natural hazards, road management, hazard assessment

INTRODUCTION
Snow avalanches, landslides and flooding repeatedly pose a threat to Alpine regions (e.g., BUWAL 1999; Rudolf-Miklau et al. 2006; Bezzola and Hegg 2007). To reduce the risk posed by these hazards, about 775 million CHF is yearly invested in hazard prevention, by the Swiss Confederation, cantons, communes and privates (PLANAT, 2007). Protection against flooding and debris flows takes up 54% of this amount, 25% is used for landslides and rockfall prevention, and 21% for prevention of snow avalanches. Nevertheless, a 100% safety cannot be guaranteed. Examples such as the rockfall event of June 2006 on the Gotthard highway, the road destructing flooding and landsliding events in August 2005 or the numerous snow avalanches in the winter of 1999 show that road infrastructure and its users are susceptible to the impact of natural hazards.

Since January 2008, the federal roads office (FEDRO) is responsible for the Swiss national road network (highways and the main alpine passes). Before then, the national roads were managed by Cantonal road services. As a result, Swiss-wide, standardized information on the type, frequency, intensity and location of natural hazards that threaten national roads, as well

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as the costs of required protective measures, was not available. The FEDRO therefore decided to initiate a Swiss wide project, called "natural hazards on national roads – NHNR" with the technical support of the Federal Office for the Environment (FOEN), aiming at quantifying and mapping all risks due to natural hazards threatening Swiss national road network (total length = 1892 km). At the moment of writing, 75% of the national road network, including all alpine national roads, has been analysed, which allows to assess and evaluate the importance of natural hazard related risks on national roads. This paper will present the methodology used in the project and presents a summary of the monetarised risks of the evaluated road sections.

METHODOLOGY

The detailed project methodology of the project NHNR can be found online (FEDRO, 2012). This methodology describes in detail the following 4 main parts: 1) hazard assessment, 2) risk analysis, 3) risk evaluation and 4) planning of protective measures. As such the methodology defines the natural hazards to be studied, the study perimeter, the standards to be used, the risk equations, and parameter values to be used, as well as the products to be delivered. The project steering committee decided not to prescribe models for simulating the different natural hazards to be assessed, but rather to define the required products in detail, in order to guarantee a maximum transparency and traceability of the methods, models and assumptions used.

For this project, the national road network has been split in road sections of 30 – 70 km. On each of these sections, the following natural hazards (if present), also called gravitational natural hazards, have to be assessed:

– snow avalanches
– rock- and icefall, rock avalanches
– flooding and debris flows
– landslides (permanent, spontaneous and slope type debris flows)
– collapse dolines

The field and modeling studies needed for the hazard and risk analysis are being done by consortiums of collaborating geotechnical bureaus. In general, each consortium consists of an interdisciplinary project leader with experience in natural hazards, an avalanche expert, one or two geological experts, a hydraulic engineering/flooding expert and a risk analysis expert. On average, they need approximately one and a half year to complete the natural hazard assessment per road section. The risk analysis is subsequently finalised within three months.

We used hazard indication maps based on the projects Aquaprotect (FOEN, 2015a) and SilvaProtect-CH (FOEN, 2015b) to determine which hazards had to be studied in detail in which area. To obtain a homogeneous and comparable dataset for the entire Swiss national road network, 4 return period scenarios (0 – 10 yrs, 10 – 30 yrs, 30 – 100 yrs, 100 – 300 yrs and intensity classes low, medium and high) have to be defined for each the potential hazard source area. The so called damage potential perimeter that is to be taken into account is the area covered by the highway with a 10 m buffer, as well as surrounding facilities (e.g., parking places, technical tunnel installations, …). The risk analysis is carried out on one or two lines that represent the road axes and on surrounding facilities.

The risk calculation is finally done by an internet based risk calculation tool called RoadRisk (www.roadrisk.ch). This tool is WebGIS-based (Fig. 1) and intersects the intensity maps of all studied natural hazards for the defined return periods with the damage potential. The underlying attributes of the intensity polygons and the road axes allow the calculation of the following risk types:
- Direct impact (Risk direct impact),
- Collision with deposits on the road or with cars that are impacted by natural hazards (Risk collision),
- Damage to infrastructure (Risk infra damage),
- Precautionary road closure (Risk pre-closure),
- Road closure after an event (Risk post-closure).

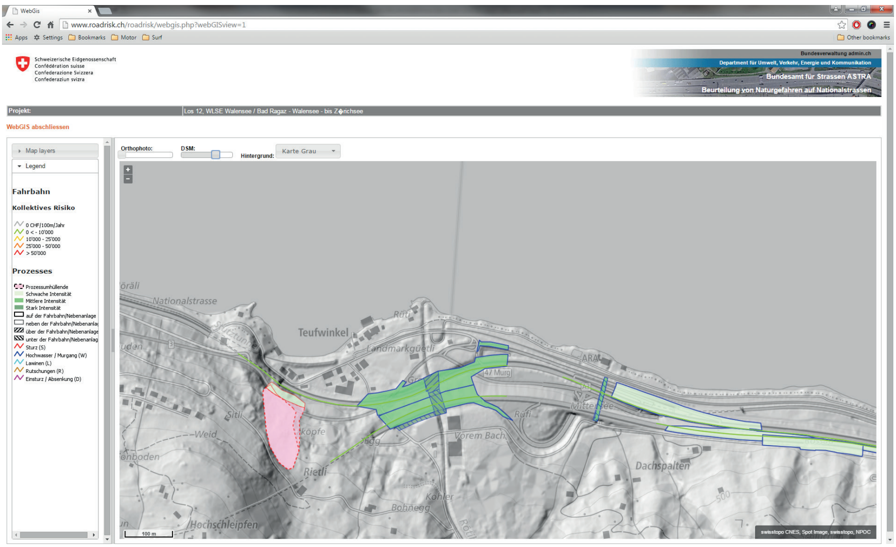

Figure 1: A screen shot of the internet tool RoadRisk.

Casualties are expressed in costs using a value of 5 million CHF per human life. Variables required for calculating person risks (direct impact and collision risk) are:
- the probability of the a precautionary road closure during the hazard event.
- the mean daily traffic.

– the mean occupancy rate per vehicle (= 1.76 person per vehicle).
– the maximum driving speed per road section.
– the occurrence probability of traffic jams.
– the lethality of the people in a car being impacted as function of
– the type of hazard process and its intensity.

The main variables for calculating the risks of infrastructure damages and road closure are infrastructure construction costs (defined by the FEDRO), as well as the daily costs for road closure (varying between 150’000 and 4’000’000 CHF/day, after Erath 2011) and the estimated duration of the road closure. As mentioned before, all risk calculation algorithms can be found in FEDRO (2012).

RESULTS

The results of the 22 completed national road sections show that the sum of the yearly expected damage due to gravitational natural hazards can add up to several 100’000 CHF/year, and in extreme cases up to several millions CHF/year per road section. Fig. 2 shows a summary of the risk hot spots on the completed road sections.

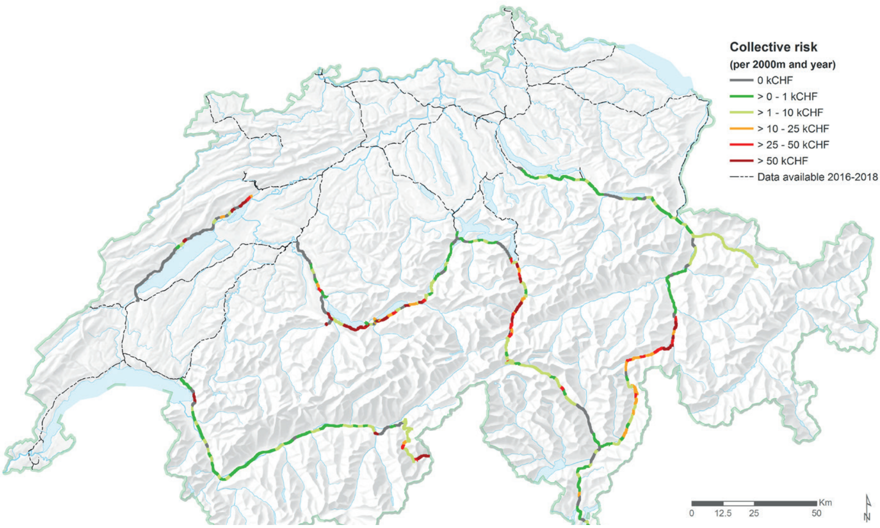

Figure 2: Overview of the risk hot spots on the national road sections that have been analysed between September 2008 and August 2015.

The most prominent risks are due to road closure in areas that are strongly affected by rock-fall or bank erosion/underscouring (cf. the damaged highway viaduct in canton Uri in 1987). Figure 2 also shows that high risks on natural roads due to natural hazard in Switzerland do not occur in alpine terrain only. An example is the risk hot-spot west of the city of Biel (on the N5 parallel to lake Biel), which is related to high frequency rockfall from a Jura-type limestone cliff and a relative high mean daily traffic (~15'500 vehicles per day). A typical risk hot-spot is the double highway viaduct of Chillon, close to Montreux at the eastern side of Lake Geneva. Although the occurrence probability if low, the pillars of this viaduct can be heavily damaged by falling blocks with volumes of 5m^3, which would lead to a road closure of several months. The lack of suitable detour possibilities leads to a high risk of road closure after an event.

Details of the expected damages (Fig. 3) show that direct damage to infrastructure represents generally only adds up to 16% of the total potential damages, but can reach up to 40% for some individual hazard sources. Looking at the sums of the expected damage values of the road sections that are currently finished, road closure after an event represents 69%, precautionary road closure 7%. Person risks (casualties) are mostly to be expected due to falling rocks, rock avalanches, debris flows and dense snow avalanches, which add up to 8% of the total risk.

The results show that rockfall is responsible for 31% of the total calculated risk, bank erosion for 17%, flooding for 14%, snow avalanches for 13%, landslides for 9%, rock avalanches for

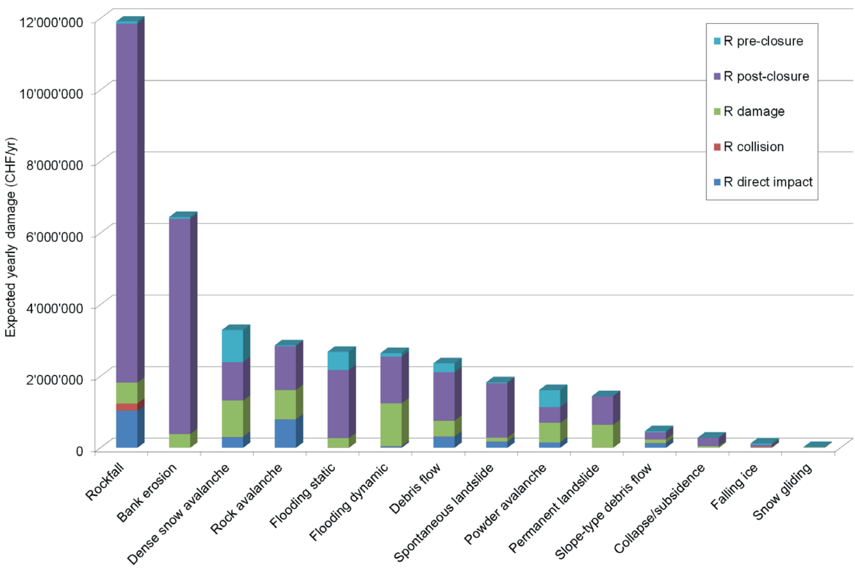

Figure 3: Risk details per hazard and damage type for all analysed road sections.

8%, debris flows for 6%, and slope-type debris flows for 1%. Finally, subsidence processes due to doline collapse, falling ice and snow gliding account for 0.7% resp. 0.3% and 0.1%. When calculating the expected number of casualties per year caused by rockfall (incl. rock mass falls) on national roads, by dividing the total of the rockfall related person risks by 5 million CHF, the result is 0.25 casualties per year. In the last thirty years, rockfall caused 0.13 casualties per year on average. The total expected number of casualties per year caused by all gravitational natural hazards on national roads is 0.6

CONCLUSIONS

The currently available results of the project NHNR show that rockfall and bank erosion are mainly responsible for the expected damage due to natural hazards on national roads in Switzerland. A large part of this is due to road closure after hazard events.
The threshold for the individual risk of death due to natural hazards defined by the FEDRO is $1 * 10^{-5}$. If an individual would pass all currently evaluated endangered national road sections every day, his or her individual risk of death would be $1 * 10^{-4}$. In the meantime, the project results regarding the number of casualties seem to be too pessimistic in comparison to reality of the last thirty years.

The currently known total sum of expected yearly damage by natural hazards on national roads (~40 million CHF per year) are equal to 15% of the mean yearly amount for the prevention of gravitational hazards invested by the Swiss confederation between 2000 and 2005 (PLANAT, 2007). This amount covers risk prevention on all roads, railways, residential areas and other critical infrastructure. At present, the mentioned expected yearly damage justifies continuous investments in risk reduction on national roads.

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