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CADANAV: Methodology of rockfall hazard mapping.

Jaboyedoff Michel (1)(2), Labiouse Vincent (2)

(1) Quanterra, Lausanne, Switzerland, michel.jaboyedoff@quanterra.org
(2) Rock Mechanics Laboratory, Swiss Federal Institute of Technology Lausanne, Switzerland, vincent.labiouse@epfl.ch

Because of large inhabited areas and valuable objects at risk located in mountainous areas potentially endangered by rockfalls, there is a need of rockfall hazard mapping in the Swiss Alps and Pre-Alps. In the framework of a project entitled CADANAV for the Canton of Vaud and the cantonal fire insurance establishment of Vaud (ECA), the Rock Mechanics Laboratory of EPFL put forward a methodology of rockfall hazard mapping (Jaboyedoff and Labiouse, 2002) compatible with the 1997 Swiss federal guidelines for land-use planning in landslide-prone areas (Lateltin, 1997; Raetzo et al. 2002).

The suggested hazard mapping method depends on the required level of detail: (i) quick identification of areas potentially endangered by rockfalls at regional or valley scale, (ii) hazard assessment and detailed delineation of the areas at risk at local scale.

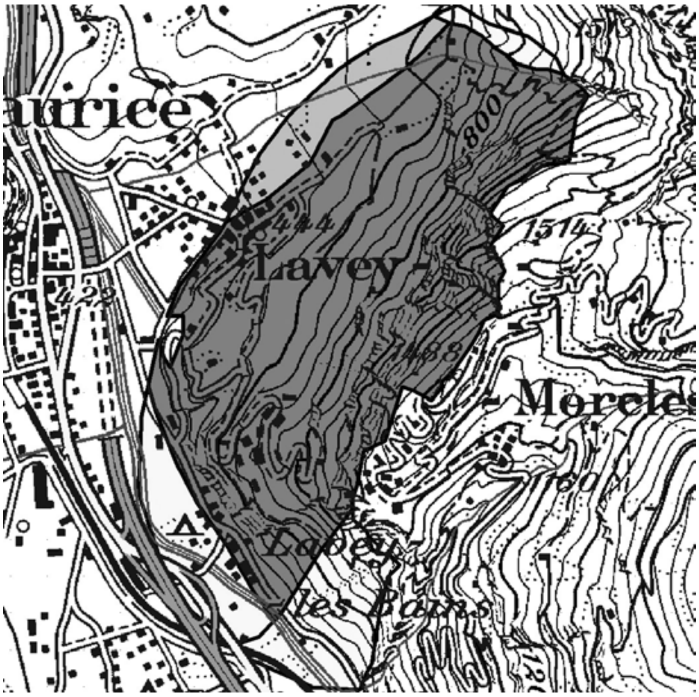

Figure 1: Example of preliminary hazard mapping at the indicative level for a zone above Lavey-Village, Vaud. The darker grey corresponds to the proved run-out zone (1) and the lighter one to the highly unlikely zone (4).

The objectives at regional or valley scale are the early detection of conflicts between land-use and rockfall hazard as well as the identification, from a simple risk analysis, of the zones where detailed investigations are first required. Geographic information system (GIS) data allow the detection of potential instabilities from steep slopes and cliff areas, and the preliminary estimation of potential run-out areas by means of a so-called cone method, which models rockfalls as the sliding or rolling of a mass on a sloping surface with an apparent friction angle (Evans and Hungr, 1993; Jaboyedoff and Labiouse, 2003). Complementing these computer results by information about rockfall activity (aerial pictures, register of events, historical documents and quick field surveys), four different run-out zones are distinguished and delineated: (1) the proved run-out zone, where blocks are observed; (2) the inferred run-out zone, computed with the cone model, but where no boulder is observed; (3) the potential zone, which is probably not reachable by blocks even if it is difficult to prove it (e.g. high reverse slope or near-vertical source above a flat relief); (4) highly unlikely run-out zone, due to artefacts of the cone method such as the overestimation of the lateral extent of the zones that can be endangered by rockfalls. Figure 1 shows an example of preliminary hazard mapping for a zone above Lavey-Village, Vaud.

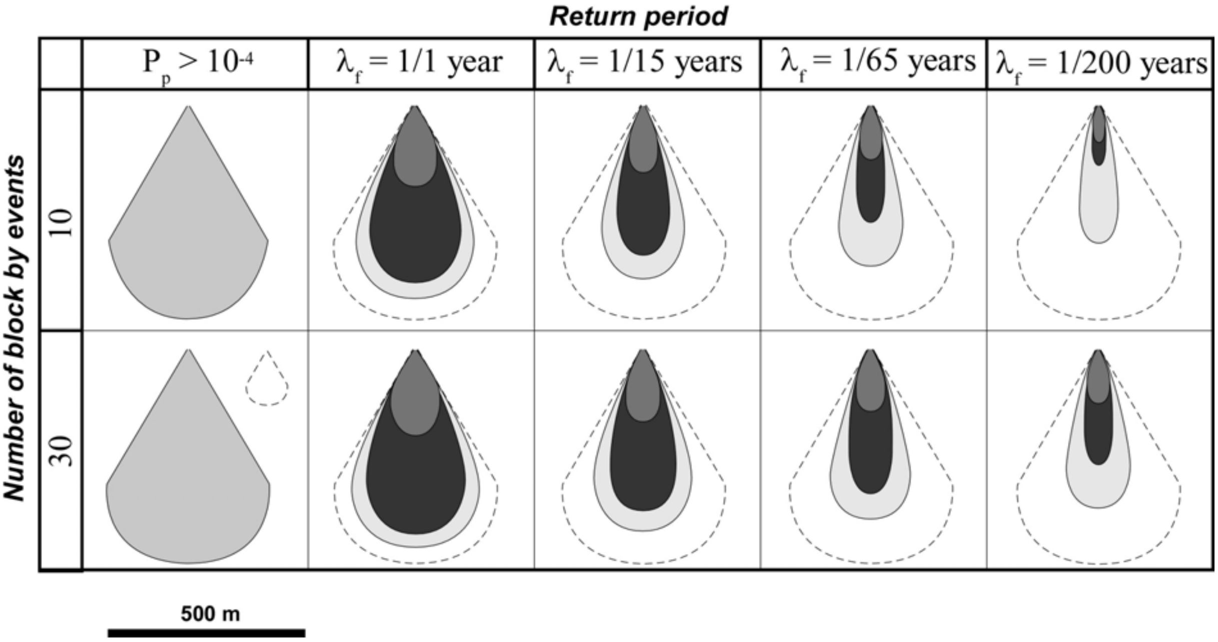

Figure 2: Schematic example of hazard mapping taking into account the return period of the rockfall event (1, 15, 65, 200 years) and the number of blocks per event (10 or 30). The three degrees of danger, commonly represented by the colours red, blue and yellow, are here symbolised respectively by dark grey (high hazard), intermediate grey (moderate hazard) and light grey (low hazard). The dashed limit reported in the graphs is provided for comparison with the mapping presented in the first column. This mapping results from the delineation that would be obtained according to the present French PPR methodology (Plan de Prévention des Risques), i.e. only based on a run-out probability criteria of $P_p = 10^{-4}$ (Besson et al., 1999).

This first hazard mapping method is too rough for the second step of the Swiss guidelines devoted to hazard assessment. Indeed, this part implies the determination of the magnitude and mean return period of events, which needs more detailed field investigations and numerical modelling (trajectory analyses). In accordance with the chart of the degrees of danger defined in the Swiss federal guidelines, a quantitative approach has been developed. It accounts for the impact energy in the exposed zone ($E < 30$ kJ: low; $30 < E < 300$ kJ: medium; $E > 300$ kJ: high) as well as for the return period (or frequency) of potential damage (block hitting an element at risk). The probability of an element at risk to be hit P_i is further calculated from $P_i = P_f \times N \times P_p$ where P_f is the probability of the occurrence of the hazardous event (likelihood of

failure), N is the number of blocks released per event, and P_p is the spatial probability of impact of the element at risk by a block (i.e. taking into account the travel path).
In many circumstances, the assessment of the probability of failure P_f in a given period and/or the average number of blocks N falling per event, is difficult and involves much uncertainty and judgement (except when register of events or historical data are available). For that reason, one should consider various scenarios and draw the corresponding hazard maps. Figure 2 provides a schematic example of hazard maps if one makes due allowance for the return period of the rockfall event (1, 15, 65, 200 years) and the number of blocks per event (10 or 30). It clearly emphasises the difference with hazard mapping methodologies only based on the run-out probability P_p, as in the present French practice (Plan de Prévention des Risques).

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