QUANTITATIVE ROCKFALL HAZARD ASSESSMENT AT THE MONT SAINT-EYNARD (FRENCH ALPS)

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A methodology is proposed for quantitative assessment of impact frequency on an element at risk located on a slope under a rock cliff, from the volumetric retreat rate of the cliff, the distribution of the block volumes and the simulation of the block trajectories. The volumetric retreat rate is derived from diachronic terrestrial laser scanning and integration of a power law distribution of the rockfall volume. The frequency and the size of the falling blocks are determined from the power law distribution of the block volume, which is derived from a survey of the blocks fallen on the slope. Finally, the impact frequency is obtained from the simulation of block falls occurring during a given period, using the computer program Rockyfor3D. The method is applied to the Mont Saint-Eynard cliff, which overhangs the Grenoble urban area.

Keywords: rockfall, hazard, cliff, retreat rate, block size distribution, impact frequency

INTRODUCTION

A methodology for impact frequency assessment is applied to the Mont Saint-Eynard cliffs, which overhang the Grenoble urban area (Fig. 1). The lower cliff is 240m high, separated from the 120 m high upper cliff by a ledge covered with forest. The upper cliff consists of massive limestone (bed thickness >1 m) while the lower cliff consists of fractured thin bedded (10–50 cm) limestone. The bedding planes dip inside the cliff. This anaclinal configuration, completed by subvertical fractures, produces overhanging compartments falling mainly by toppling.

Fig. 1 The Mont Saint-Eynard limestone cliff (left); the 1500 m^3 rockfall (middle); orthophoto of some blocks of the 1500 m3 rockfall.(right).

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VOLUMETRIC RETREAT RATE OF THE CLIFF

The volumetric retreat rate of the cliff has been estimated by integrating the volume-frequency relation for the rockfalls occurring yearly in the cliff [1]. The volume-frequency relation has been obtained from a TLS (Terrestrial Laser Scanner) survey of the cliff during 3 years, which allowed to detect 344 rockfalls bigger than 0.05 m^3 [2]. It is described by a power law:

$$F = A\ V^{-B} \qquad (1)$$

Where F is the frequency of rockfalls bigger than V and A the frequency of rockfalls bigger than 1 m^3. For the integration, a maximal possible rockfall volume V_{max} must be fixed, which can be much bigger than the maximal observed volume. The volumetric retreat rate is [1]:

$$W = V_{max}^{(1-B)}\ A/(1-B) \qquad (2)$$

Methods for the determination of the maximum credible rockfall volume in a cliff have been presented in [3]. If one assumes that the power law is valid for the whole volume range, the smallest volumes (which have not been observed) are also taken into account. For he Mont Saint-Eynard, $A = 10^{-4}.m^{-2}.year^{-1}$, B = 0.75 and a maximal volume of 10^6 m^3 has been considered. The retreat rate obtained is 0.012 $m.year^{-1}$. The rockfall frequency in the upper cliff is much lower than in the lower one [4], so the former has been neglected in this analysis.

DISTRIBUTION OF THE BLOCK VOLUMES

The distribution of the volumes of the blocks released when a rock compartment falls from a rock cliff can be obtained by measuring the volumes of the blocks deposited during a recent rockfall [5-11]. Haas [6], Hantz et al. [7,10] and Ruiz et al. [9,11] have shown that it is well fitted by a power law with a scaling exponent (b) varying from 0.6 to 1.3:

$$n = a\ v^{-b} \qquad (3)$$

Where n is the number of blocks with volume higher than v and a is the number of blocks bigger than 1 m^3. Fig. 2 shows the distribution of the block volumes observed on a recent 1500 m^3 rockfall occurred in the Mont Saint-Eynard (Fig. 1). It has been obtained from a drone photographic survey [12] (Fig. 1). Assuming the scaling exponent depends only on the rock mass structure, the value obtained from a single rockfall can be considered representative of the whole homogenous cliff and Equation (3) represents also the volume distribution of all the blocks falling yearly from the cliff. The volumetric retreat rate (W) can then be derived by integrating the volume in Equation (3):

$$W = v_{max}^{(1-b)}\ a_y/(1-b) \qquad (4)$$

Where a_y is the number of blocks bigger than 1 m^3 falling yearly from the cliff and v_{max} is the maximal possible volume of a block. It has to be estimated from the observation of the rock cliff. Knowing W, v_{max} and b, a_y can be derived from Equation (4). Hence the distribution of the volumes of the blocks which fall yearly is known and can be used as input data in the simulation of the trajectories. For the Mont Saint-Eynard, assuming a maximal volume of an individual block (v_{max}) of 63 m^3, a value of 1.1 10^{-3} $year^{-1}.m^{-2}$ has been obtained for a_y.

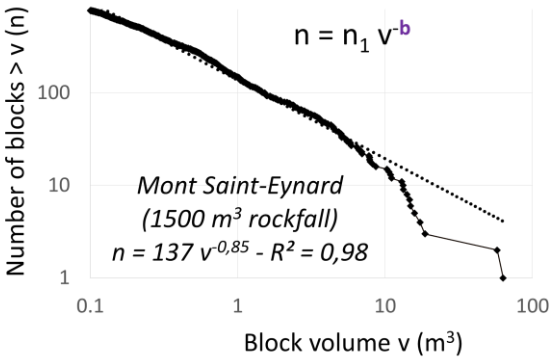

Fig. 2 Distribution of the block volumes observed on a rockfall deposit.

SIMULATION OF THE BLOCK TRAJECTORIES

From the distribution obtained above, the trajectories of all the blocks which fall during a chosen time length can be simulated to determine the impact frequency on each pixel of the slope. A probabilistic modelling has been used with the software Rockyfor3D [13]. The length of the simulated period (1000 years) has been chosen so that a sufficient number of blocks start from each pixel of the DEM (455 blocks > 0.1 m^3 per 5x5m pixel). The contour lines corresponding to different impact frequencies has then been drawn, as shown in Fig. 3. The mean kinetic energy (and different percentiles) can also be given as well as the mean flying height (and different percentiles).

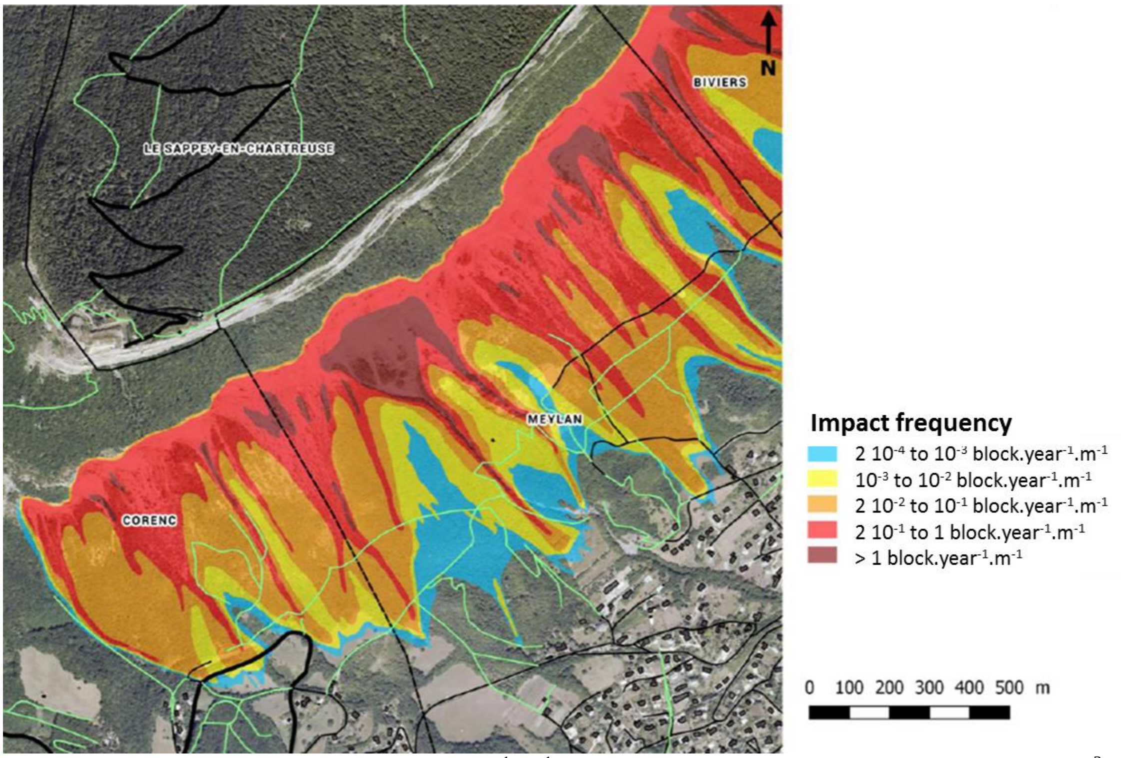

Fig. 3 Annual impact frequency ($block.year^{-1}.m^{-1}$) under the Mont Saint-Eynard for volume > 0.1 m^3.

CONCLUSION

A quantitative approach for rockfall hazard assessment is increasingly used. A methodology is proposed for quantitative assessment of rockfall impact frequency, which consist in: (a) estimating the volumetric retreat rate of the cliff (taking into account the extrem events); (b) dividing this volume into individual blocks (using a power law distribution for the block volumes); (c) simulating the trajectories of the blocks falling during a given period. The application of the method needs the knowledge of the rockfall volume-frequency relation and the distribution of the individual block volumes. It makes it possible to quantify the natural risk, and the residual risk after mitigation measures have been taken.

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