ESTIMATION OF FALLEN BLOCK VOLUME-FREQUENCY LAW FOR RISK ANALYSIS: AN EXAMPLE

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Quantitative rockfall risk assessment is a powerful tool for land planning and the structural design of rockfall protection systems. In this sense, one of the most critical and discussed aspects is the definition of a design block. In the present paper, a method for formulating a block volume frequency relationship is proposed. Two inputs are necessary: a list of observed falling block events and the results of a detailed survey at the foot of the cliff. An example illustrating the calculations is proposed.

Keywords: rock block size, frequency law, statistics

INTRODUCTION

Modern design Codes aim at guaranteeing the structural safety during buildings' expected life [1]. The expected life of a building depends on the class of consequence of the activities performed in it. Thus, for many natural hazards, say earthquake or strong winds, Building Codes establish a link between the magnitude of the forces exerted by the natural phenomenon and the corresponding return period. The present paper summarizes the methods and findings recently published in NHESS [2], consisting in a novel approach for building a block volume-frequency law for rockfall risk analysis. Such input is required for a probabilistic risk assessment [3]. The approach is in some points similar to the solution found by [4] for hydrological problems with reduced data sets.

BUILDING THE FREQUENCY LAW CURVE

The steps required for the derivation of a block volume-frequency relationship with a reduced number of available data are proposed in the following. The methodology is based on the following hypothesis: temporal occurrences of the falling block events are considered separately from the deposit volumes distribution in a representative area where the rockfall phenomenon occurs. Although a detailed explanation and discussion of the methodology is proposed in [2],[5], the procedure can be summarized in the following steps.

(1) Surveying: the required data for deriving the frequency law are the catalogue of the events, $\mathcal{C}$, i.e., a catalogue containing the size of the falling block and the corresponding temporal information (date), and a list of measured volumes, $\mathcal{F}$, that may have fallen down at any time. Both $\mathcal{C}$ and $\mathcal{F}$ must relate to the same representative area. The representative area is defined as the portion of deposit beyond a defined line, in which the hazard is computed. We consider the foot of the slope as a representative area;

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(2) Definition of the threshold volume: the catalogue of the events $\mathcal{C}$ contains all the recorded events gathered in a time window of temporal length, t. Since the recording of the events is related to *in-situ* observations after the occurrence, events involving small rock blocks are not always recorded. Therefore, there is the possibility that the catalogue $\mathcal{C}$ contains only a part of these small events. This fact was considered in the proposed analysis with the introduction of a threshold volume, V_t, defined as the minimum size of a fallen block that has always been observed and recorded (after its occurrence).

(3) Creation of the reduced data sets: once the threshold volume V_t is determined, the catalogue of the events and the list of measured blocks are split in two parts. In both data sets, the volumes smaller than V_t are not considered. The remaining constitute the so-called reduced catalogue, $\mathcal{C}^\star$, and the reduced list, $\mathcal{F}^\star$. The temporal length t is increased to $t^\star$ accounting for the fact that the decision of monitoring a rockfall prone slope usually begins after the occurrence of an event larger than the threshold volume;

(4) Choice of the probabilistic models: two probabilistic models (p.m.) are chosen. One should be able to describe the temporal occurrences of the events of the reduced catalogue; the other the distribution of the surveyed volumes. The hypothesis of Poisson point process is adopted for the former p.m., thus a Poisson distribution is considered for the occurrence of the falling blocks. The probability of occurrence of n events during the observation period $t^\star$ is

$$p(n) = \frac{e^{-\lambda t^\star}(\lambda t^\star)^n}{n!} \quad , \tag{1}$$

where λ is the occurrence parameter to be determined. A Generalized Pareto Distribution (GPD) is adopted for the latter. Evidences of power laws (GPD is a power-like probability distribution) are present in literature for fragmentation processes [6]. The cumulative distribution function of volume v is

$$F_V(V) = 1 - \left(1 + \xi \frac{v-\mu}{\sigma}\right)^{-\frac{1}{\xi}} \quad , \tag{2}$$

where σ, ξ and μ are the scale, shape and location parameters, respectively.

(5) Evaluation of the parameters of the distribution: the estimate of the four parameters can be obtained through maximum likelihood method from the reduced data sets. Poisson distribution parameter is equal to the ratio between the number of observed events larger than the threshold volume and $t^\star$.

Following that, the volume $v(T)$ of a block corresponding to a return period T is

$$v(T) = \mu + \left[(\lambda T)^\xi - 1\right]\frac{\sigma}{\xi} \quad . \tag{3}$$

and the return period, $T(v)$, corresponding to a volume v is

$$T(v) = \frac{1}{\lambda}\left(1 + \xi\frac{v-\mu}{\sigma}\right)^{1/\xi} \quad . \tag{4}$$

A CASE STUDY

The test is located in Aosta Valley (Northwestern Italian Alps) at an altitude ranging from 1630 m to 1800 m a.s.l. The study area is composed of greenschist facies deposits (metabasites and metamorphosed gabbro) with the foliation plane N 160/80. Large rock blocks are present at the base of the cliff, proving an intense rockfall activity in the past. Recent events have been recorded since 2010. Since this year, risk analyses have been performed and three falling blocks were observed in three different events. The observed size was larger than 0.5 m^3. An onsite survey was performed in order to define the distribution of the fallen blocks in a representative area at the foot of the cliff following the procedure reported in [7]. Block sizes are grouped into size classes in a geometric progression following $\sqrt{2}$ with volume, as reported in the plot of Fig. 2(a). The volume of the measured blocks ranges from 0.008 m^3 to 60 m^3.

Because of the particular attention paid on rockfall events reaching the foot of the cliff where a residential area is located, all the events occurred after 2010 were considered in the catalogue $\mathcal{C}$ and the reduced catalogue $\mathcal{C}^{\star}$, which are coincident. The threshold volume V_t was set equal to 0.5 m^3, i.e., the minimum size of the observed events in $\mathcal{C}$. The number of events considered in the analysis is equal to $n = 3$. The corrected temporal length of the observation period, $t^{\star}$ (computed through Eqn. (7) of ref. [2]) is equal to 7.0 years. Thus, the estimate of Poisson parameter modelling the distribution of the occurrences is equal to

$$\lambda = \frac{3}{7} = 0.4285\, yr^{-1}\,. \tag{5}$$

The reduced list $\mathcal{F}^{\star}$ was created after the survey at the foot of the cliff. The volumes smaller than 0.512 m^2 were not considered in the calculations. Referring to the plot of Fig. 2(a), the excluded block sizes are marked in red, while those that served for getting the volume-frequency law are in black. A maximum likelihood procedure has provided the following estimates of the Generalized Pareto Distribution parameters. The location parameter is equal to the threshold volume, i.e., 0.512 m^3. The scale and the shape parameter are equal to 2.2963 and 0.1955, respectively. Using the equations found at point (5) of the numbered list in the previous section, the volume corresponding to a given return period can be found. The block-volume frequency law is plot in Fig. 2(b).

CONCLUSIONS

Differently from other results found in the literature observed rockfall events [8],[9], where volume-frequency laws were from a database of observed and measured events, exclusively, the procedure herein summarized permits to build a volume-frequency law from a reduced set of observations. The computed frequency law can be used in engineering calculations (risk and design). The independency between the events described by Poisson's probabilistic models in rockfall was discussed in [10], who affirmed that the interaction between a natural hazard and anthropic elements (say, vehicles, buildings) is a rare event that can be ascribed to a Poisson process, i.e., it is random. Despite the fact that precursors of large rockfall events were observed [11],[12], the assumption of random process can be considered true for volumes larger than the threshold volume. In order to have a good estimate of the return period of the events of the reduced catalogue, it is necessary to have a consistent number of observations. The present case study considers three events in six years with $\lambda = 0.4286$ yr^{-1}. An additional (missed) event would set $\lambda = 0.5925$ yr^{-1}, implying that the volumes with 100 and 500 years return period are 12% and 9.8%, respectively, greater than the ones currently expected. Since the bounds are acceptable, the temporal sample can be considered representative. In case of a single observed event in a short observation period, the return period would be strongly underestimated [2].

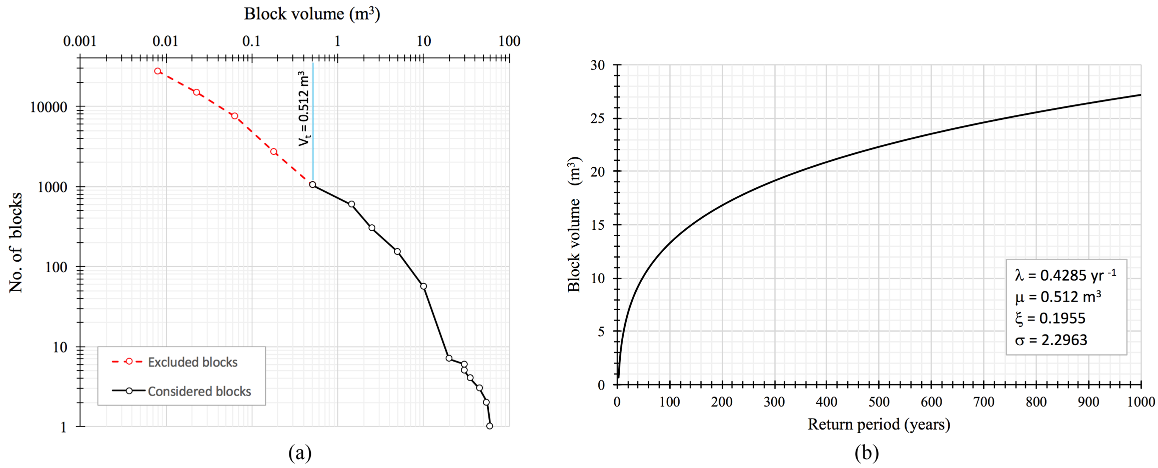

Fig. 2 In (a) the cumulative number of measured blocks versus block volume is plot. In (b) the block volume frequency law is reported

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