Rockfall frequency in different geomorphological conditions

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The knowledge of the rockfall frequency in a cliff is needed for quantitative rockfall hazard assessment (Hantz et al., 2016). It can be estimated from historical data bases (e.g. Hantz et al., 2003) or from diachronic comparison of digital cliff topographic models (e.g. Dewez et al. 2013, Guerin et al. 2014). An empirical approach is proposed to be used when historical data bases are not significant (not enough events) and diachronic digital models not available.

1 VOLUME-FREQUENCY RELATION AND EROSION RATE

It is well recognised that the frequency of the rockfalls occurring in a rock wall decreases when the volume considered increases. It has appeared that the best law for describing this decrease is a power law, which can be applied either to the temporal frequency or to the spatial-temporal frequency (number of rockfalls per year and per m^2 of cliff):

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

Where F is the frequency of rockfalls bigger than V, A is the frequency of rockfalls bigger than 1 m^3, and B is the scaling exponent, whose value is usually between 0.4 and 0.8. Note that the relation holds up to a finite value of V because there is a maximal rockfall volume (V_{max}) which depends on the size of the cliff. This maximal volume is rarely observed because its return period is usually larger than the observation period. Integrating the volume V from 0 to V_{max} (assuming $B < 1$) gives the volumetric retreat rate of the cliff (Hantz et al., 2003):

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

If the spatio-temporal frequency is used ($F_{st} = A_{st}\,V^{-B}$), Equation (2) gives the linear retreat rate (or erosion rate) of the cliff ($E = V_{max}^{(1-B)}\,A_{st} / (1-B)$). As this rate includes the biggest possible volumes, it is usually higher than the rate obtained by summing the observed volumes or measuring the retreat of the cliff crest. V_{max} is difficult to estimate, but one can note that if its uncertainty is a factor 10, the uncertainty on the erosion rate is lower (factor $10^{(1-B)}$).
The retreat rate given by Equation (2) includes very large rockfalls (flow like movements) as well as smaller rockfalls (with negligible interaction between individual particles). As the methods used to simulate the propagation of these phenomena are different, it is relevant to calculate different volumetric retreat rates using this relation (Hantz et al., 2003):

$$W = [V_2^{(1-B)} - V_1^{(1-B)}]\,AB / (1-B) \qquad (3)$$

Where W is the volumetric retreat rate due to rockfalls whose volume is between V_1 and V_2. A method to estimate the frequency of impacts due to small rockfalls is given by Hantz et al. (2016).

2 ESTIMATING THE ROCKFALL FREQUENCY PARAMETERS

Three parameters are necessary to characterize the rockfall activity of a cliff: V_{max}, B and E or A_{st}. V_{max} and B are geometrical parameters. It is reasonable to assume they depend essentially of the rock mass structure (notably discontinuities extension and spacing). A_{st} (or E) is a temporal parameter ($year^{-1}$) which reflects the activity of the processes leading to rockfalls. The processes leading to landslides (of all types) have been listed by Popescu (1994). They can be divided in 3 groups: geomorphological processes, physical and chemical processes and human processes. Effendiantz et al. (2004) have listed the processes leading to failure in rock walls. The more relevant ones have to be considered for estimating the erosion rate.

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Note that the Slope Mass Rating system (Romana, 1985) doesn't seem adequate for estimating the erosion rate, because it doesn't consider most of these processes (except groundwater action). It is useful to predict the stability of a rock cut rather than the evolution of an existing rock slope.

The rockfall frequency parameters B, A_{st} and E have been determined for different types of rock masses, geomorphological and climatic conditions (Table 1). It seems that B is lower for massive rocks (massive limestone, chalk, gneiss) than for bedded rocks (bedded limestone). This finding is in agreement with the results obtained by Hungr et al. (1999) who concluded that a B value in the order of 0.7 is characteristic in moderately to highly jointed metamorphic, igneous and strong sedimentary rocks and that a lower value, of the order of 0.4, appears appropriate for massive felsic intrusive rocks (which possibly produce a relatively greater proportion of large-magnitude, structurally controlled failures).

The erosion rate (and A_{st}) is strongly influenced by the geomorphological context: Erosion rates of some cm/year to some dm/year are obtained for coastal cliffs submitted to the waves action, while values of some tenth of mm/year to some cm/year are derived for middle mountain cliffs.

Table 1: Rockfall frequency parameters

Rock	Massive limestone (Urgonian)	Massive limestone (Urgonian)	Bedded limestone (Valaginian)	Bedded limestone (Sequanian)	Massive chalk	Massive gneiss
Site	Isère	Haute-Savoie	Gorgette	Saint-Eynard	Mesnil Val	Venosc
Cliff area (m^2)	$6.1\ 10^7$	$7.8\ 10^7$	$5.1\ 10^4$	$1.3\ 10^5$	$3.7\ 10^4$	$3.5\ 10^5$
Period length (year)	62	22	3.2	3.2	2.3	3.2
Number of rockfalls	87	45	147	344	8567	12
B	0.52	0.60	0.57	0.75	0.54	0.38
Ast ($m^{-2}.year^{-1}$)	$1.4\ 10^{-7}$	$2.2\ 10^{-7}$	$9.6\ 10^{-5}$	$9.8\ 10^{-5}$	$1.1\ 10^{-3}$	$8.4\ 10^{-6}$
Maximal volume (m^3)	10^7	10^7	10^6	10^6	10^5	10^6
Erosion rate ($m^{-1}.year^{-1}$)	0.0007	0.0004	0.085	0.012	0.48	0.07

CONCLUSION

Orders of magnitude have been proposed for the rockfall frequency parameters according to the rock mass properties and geomorphological context.

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