ASSESSMENT OF ROCK FALL HAZARD AND RISK ON A TRAIL UNDER A LIMESTONE CLIFF

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INTRODUCTION

The rock fall hazard may be defined as the probability of a rock fall of a given magnitude (or kinetic energy) reaching the element at risk (reach probability). It can be expressed as the probability of detachment (or failure probability) times the probability of the rock mass reaching the element given that it detaches from the rock wall (propagation probability).
This paper describes a new method for a quantitative assessment of rock fall hazard for trails or roads located at (or near) the foot of a rock wall. In that case, the propagation probability is 1, and the reach probability is given by the failure probability for rock masses the height of which is sufficient for the rock fall having a minimal kinetic energy when reaching the foot of the cliff. The lower limit of the cliff area to be considered thus depends on the size of the rock fall. For a given point at the foot of the cliff, the lateral limits also depend on the size of the rock fall. Then one must consider the failure frequency in a cliff area the size of which depends on the size of the rock fall.
The method proposed is based on the spatial-temporal (normalized) rock fall frequency, which is given by a power law (Hantz et al., 2003), and on the relation between the volume and the width of the falling compartments, which depends on the internal structure of the rock wall (Frayssines and Hantz, 2006). For a plane rock wall, an analytical solution is given which allows determining the reach frequency of a given point with a minimal kinetic energy, for a wide continuous range of volume.
In the case of a fix element at risk, the method presented allows estimating the order of magnitude of the reach frequency in the cases where it is not possible to distinguish particularly hazardous sections of the wall. When the element at risk is moving (a hiker or a vehicle for example), its reach frequency during the time it covers the whole wall, is not affected by the variations of the failure frequency along the wall (the most hazardous sections are compensated by the least ones).
The method has been applied to the hiking track which stretches over 1 km along the base of the Saint-Eynard calcareous cliff, near Grenoble. From the rock fall hazard, the individual and the societal risks have been estimated and compared to some risk acceptability criteria.

SPATIAL-TEMPORAL ROCK FALL FREQUENCY

Many works have shown that the relation between rock fall frequency and volume is well fitted by a power law (general review by Picarelli et al., 2005). For a given rock wall, the number of rock falls per unit of time (frequency = F), with volume greater than V (in m^3) is given by:

$$F = \alpha V^{-b} \qquad (1)$$

where α = number of rock falls, per unit of time, with volume greater than 1 m^3; and b another constant. For the Grenoble calcarous cliffs (French Alps), the rock fall frequency has been estimated from an inventory carried out by a forest service (RTM 38) and completed by the Grenoble University. The spatial temporal rock fall frequency (F_{st}) is the number of rock falls per unit of time and per unit of wall area, with a volume greater than a given value V (in m^3), expressed by:

$$F_{st} = aV^{-b} \qquad (2)$$

where a = number of rock falls, per unit of time and area, with volume greater than 1 m^3

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ROCK FALL FREQUENCY AFFECTING A CLIFF PROFILE

In a general formulation, the relationship between the volume (V) and the width (w) of the fallen compartments may be written:

$$V = kw^3 \tag{3}$$

where k is a shape factor, which equals 0.5 for the calcareous cliffs of the Grenoble area.
For a given cliff profile, the integrated frequency of the rock falls the volume of which is between V_{min} and V_{max} is given by:

$$F_f = \frac{3abhk^{-\frac{1}{3}}}{(3b-1)}\left(V_{min}^{(\frac{1}{3}-b)} - V_{max}^{(\frac{1}{3}-b)}\right) \tag{4}$$

where h is the cliff height.

REACH FREQUENCY WITH A MINIMAL ENERGY

The reach frequency with a minimal energy E_0, for an element at risk with a width v, is given by:

$$F_r = F_f - \frac{3abk^{-\frac{1}{3}}E_0}{\gamma(3b+2)}\left(V_{min}^{-b-\frac{2}{3}} - V_{max}^{-b-\frac{2}{3}}\right) - \frac{abvE_0}{\gamma(b+2)}\left(V_{min}^{-b-1} - V_{max}^{-b-1}\right) \tag{5}$$

with $V_{min} = E_0 / \gamma H$ (6)

F_f is given by Eq. (4), γ is the specific weight of the rock.

APPLICATION TO A HIKING TRACK

The height of the cliff is about 150 m. The width of a hiker was set to 0,5 m. The minimal energy considered to kill a hiker (0.025 kJ) was derived from climbing helmet tests. According to the uncertainties affecting a and b, the reach frequency was determined with an uncertainty factor of 10. The central value is 2.3 x 10^{-2} events per year, which gives a return period of 44 years.
Assuming that a pedestrian wearing a helmet is killed if he is affected by a fall whose energy is higher than 0.025 kJ, a hiker who takes the trail once a year, assuming it takes one hour, increases his yearly death probability of about 10^{-6}. The individual risk of about 10^{-6} corresponds to the broadly acceptable limit given by the Health and Safety Executive (UK) for land use planning around industries. As higher risks are usually accepted from naturally occurring landslides than from engineered slopes, this individual risk can be considered as acceptable.
In terms of societal risk, considering that about one thousand of hikers take this trail each year, the expectancy of the annual number of deaths is about 10^{-3}. HKSAR (Hong Kong Special Administrative Region) has published interim risk guidelines especially for natural slopes. The societal risk of about 10^{-3} corresponds to the limit between the unacceptable risk and the tolerable risk.

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