THE ROCKRISK PROJECT: ROCKFALL RISK QUANTIFICATION AND PREVENTION

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Rockfalls are frequent instability processes in road cuts, open pit mines and quarries, steep slopes and cliffs. The orientation and persistence of joints within the rock mass define the size of the kinematically unstable rock volumes and determine the way how the detached mass becomes fragmented upon the impact on the ground surface. Knowledge of the size and trajectory of the blocks resulting from fragmentation is critical for calculating the impact probability and intensity, the vulnerability the exposed elements and the performance of protection structures. In this contribution we summarise the main goals and achievements of the RockRisk project. We focused on the characterization of the rockfall fragmentation by means of the analysis of the fracture pattern of intact rock masses, the development of a fragmentation model and its integration into rockfall propagation analysis. The ultimate goal of the project is to quantify risk due to rockfalls and develop tools for the improvement of prevention and for protection from its occurrence.

Keywords: Rock falls, fragmentation, vulnerability, quantitative risk assessment, digital photogrammetry, LiDAR

1. INTRODUCTION

The RockRisk project aims at quantifying the risk induced by rockfalls and to provide tools to improve its prevention and mitigation. The project has three work packages: (a) the spatially explicit determination of rock volumes kinematically unstable and characterization of the rock mass fracture pattern using high resolution remote techniques such as: Terrestrial Laser Scanner (TLS) and terrestrial or aerial digital photogrammetry; (b) definition of fragmentation laws using data collected from recent rockfall events and real-scale tests. Incorporation of the fragmentation mechanism in rockfall propagation models and in the calculation of impact energies; (c) Quantitative risk assessment, by developing of methods for quantifying the vulnerability of different types of masonry structures and buildings against rockfalls and the preparation of fragility curves.

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2. CHARACTERIZING DETACHABLE ROCK MASSES AND FRAGMENTATION

The initial rockfall volume is a required input parameter of the trajectographic analysis. The detached mass may be either a single block or a rock mass containing discontinuities. The impact on the ground may cause the disaggregation of the rock mass and breakage of the blocks, thus producing new rock fragments. Although, fragmentation has been frequently observed in rockfalls this phenomenon is rarely considered in the rockfall analysis.

Fragmentation of a rock mass may result from the division of detached volume by either the breakage of the rock pieces, the disaggregation of joint-determined blocks, or both. The analysis of fragmentation requires considering the In-Situ Block Size Distribution (IBSD) of the detached mass at the cliff face. Due to the frequent lack of accessibility of the rockfall sources that difficult the direct measurement of joints, a 3D Digital Surface Model (DSM) of the rock wall is generated with digital photogrammetry and then the fracture pattern is extracted using the software Rhinoceros [1].

The volume distributions of the fragments of several rockfall events and from real scale tests can be fitted to power laws [2 & 3]. However, the scaling factors or exponents of the tails range between 0.5 and 1.3 and that the scaling factors are an expression of the intensity of the fragmentation process. The highest exponents are found in the rockfalls showing high height of fall and mobilised volume. Large exponents mean a substantial reduction of the particle size and implicitly the breakage of large blocks.

We have developed a rockfall fractal fragmentation model (RFFM) that generates rockfall block size distribution (RBSD) from the volume of the initial detached mass and its fracture pattern (IBSD) [1]. This model is based on a generic fractal fragmentation model of Perfect that considers a cubic block of unit length which is broken into small pieces according to a power law. The size distribution of the elements in a fractal system is given by:

$$(1/b^i) = k[1/b^i]^{-Df} \; ; \; i=0,1,2,\ldots\infty$$

Where N (1 / b^i) is the number of elements at the level "i" of the hierarchy; "k" is the number of initiators of unit length; "b" is a scaling factor > 1; and D_f is the fractal dimension of fragmentation, which can be defined as:

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$$D_f = 3 + \frac{log[P(1/b^i)]}{log[b]}$$

Where P (1 / b^i) or P_f is the probability of fracture that determines the proportion of the original block that breaks and generates new fragments. The fractal fragmentation model has been adapted for the case of the rockfall. First, instead of k initial volumes of unit length, the IBSD is used as input, classifying it in bins. Second, not all the blocks of the IBSD break upon impact on the ground. To consider this, a survival rate, Sr, representing the proportion of blocks that do not break is defined.

The RFFM has been implemented in an Excel worksheet, allowing the adjustment of the model parameters and generating a range of rock fragments distribution. The model input is the IBSD. The model parameters "Sr", "P_f" and "b", control the intensity of fragmentation and the resultant RBSD. The model generates the RBSD through the iterative adjustment of the model parameters. Real-case inventories are used to calibrate the model for different scenarios. The Excel file is freely available in the tool tab at https://rockrisk.upc.edu/en

Finally, a method simulating the volume and number of fragments of rockfall events, based on the size distribution of blocks deposited at the talus slope, has also been developed [4]

3. ADDING FRAGMENTATION TO THE ROCKFALL SIMULATION

In the project we have developed RockGIS, a GIS-Based tool that simulates stochastically the fragmentation of the rockfall, based on a lumped mass approach [5]

The model requires as input data a digital surface model with the release points of the rockfall, the volume of the detached mass and its IBSD, the land use coverage map and the model parameters. In RockGIS, the fragmentation initiates with the disaggregation of the detached rock mass through the pre-existing discontinuities just before the impact with the ground. An energy threshold is defined in order to determine whether the impacting blocks break or not. The conservation of energy during the impact is written as follows:

$$E_k^{bi} = E_k^{ai} + E_d + E_b$$

Where E_k^{bi} is the kinetic energy before impact, E_d is the energy dissipated in the impact with the ground, E_b is the energy dissipated due to the breakage process and E_k^{ai} is the sum of the kinetic energy of the fragments. The main hypothesis of the model is that the energy loss from the impact of the block with the ground and the energy released by the breakage of the block are considered uncoupled processes. Thus the breakage of the block will take place after the computation of the rebound velocity, independently of the rebound model used. The distribution of the initial mass between a set of newly generated rock fragments is carried out stochastically following a power law. This criterion has been support by the results of the rockfall inventories and real scale tests. The trajectories of the new rock fragments are distributed within a cone while the remaining energy after breakage is distributed proportionally to the mass of each fragment. Finally, all fragments generated are simulated as new rockfalls and the process continues iteratively until all fragments stop their propagation. The fragmentation model has been calibrated and tested with real cases.

4. VULNERABILITY OF BUILDINGS DUE TO ROCK BLOCK IMPACTS

Vulnerability has been often analysed using empirical and/or judgmental approaches that do not provide objective and quantitative information on the expected damage and do not take into consideration the kinematical characteristics of the rock block impact. Moreover, differentiation between different structural typologies is seldom made. These are limiting the application of these approaches for damage prediction.

Our research group has developed analytical methodologies for evaluating the vulnerability of reinforced concrete buildings impacted by rockfalls. These approaches incorporate the kinematic properties of the block, their size and the probability of impact on key structural elements for the stability of a building. The obtained vulnerability is expressed in quantitative terms and can be directly integrated into the QRA using fragility curves. In Rockrisk an analytical procedure to evaluate the damage caused by blocks impacting on different masonry typologies, which are typical structures of buildings in rural and mountainous areas [6]. This methodology takes into consideration the characteristics of the exterior walls of a building (e.g. natural stone or brick walls) for the assessment of the damage due to a rock block impact.

The procedure comprises three stages: (i) Determination of the rockfall impact actions which are applied to a masonry structure, in terms of external forces, using the Particle Finite Element method; (ii) Evaluation of the mechanical properties, modelling of the masonry structure, and calculation of the internal stresses, using the finite element method; (iii) Assessment of the damage due to the rockfall actions, applying a failure criterion adapted to masonries, and calculation of the damage in terms of the percentage of the damaged wall surface. An Excel tool, called RockDamage, has been developed for the automatic calculation of fragility curves for masonry walls and is freely available in the tool tab at https://rockrisk.upc.edu/en

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