ROCKFALL FRAGMENTATION ANALYSIS: VILANOVA DE BANAT CASE STUDY

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Fragmentation is a critical mechanism for the calculation of the trajectories of the blocks and the impact energies, for the assessment of the potential damage and for the design of protective structures, although few rockfall models account for it. In this contribution we present an application of the trajectory simulation tool RockGIS, which explicitly accounts for fragmentation, to a recent rockfall event occurred near Vilanova de Banat (Spain). All parameters of the model controlling the kinematics of the propagation and fragmentation have been calibrated in order to reproduce the number of fragments generated and trajectories followed by the blocks. Several performance criteria have been considered and simulations with and without accounting for fragmentation have been performed to assess their influence. The results considering fragmentation show a reasonable matching with the observations in the field.

Keywords: rockfall, fragmentation, GIS, rockfall simulation

INTRODUCTION

A rockfall is a mass instability process frequently observed in road cuts, open pit mines and quarries, steep slopes and cliffs. It is frequently observed that the detached rock mass becomes fragmented due to the impacts upon the slope surface. However, accounting for this phenomenon in rockfall models is not trivial. In this work we have modelled the fragmentary rockfall of Vilanova de Banat using RockGIS tool, which incorporates the fragmentation. First, an overview of the model is presented. Then, we describe all data available from different previous studies of Vilanova de Banat site and the calibration process. Finally, the results of some simulations considering or not fragmentation are shown and discussed.

ROCKGIS MODEL

RockGIS is a GIS-Based model that simulates stochastically the fragmentation of rockfalls, based on a lumped mass approach [1]. The model requires as main input data a digital surface model, the soil type coverage map and the release coordinates for triggering the movement of the blocks. In RockGIS, the fragmentation initiates by the disaggregation of the detached rock mass through the pre-existing discontinuities. An energy threshold is defined in order to determine whether a block break or not at each impact upon the ground surface. The distribution of the initial mass between the set of newly generated broken rock fragments is carried out stochastically following a power law since it has been proved to represent reasonably the phenomena in several real scale tests [2]. The output velocities of the new rock fragments are

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distributed within a cone and the remaining energy after breakage is distributed proportionally to the mass of each fragment. Finally, all fragments generated propagate downslope and the process continues iteratively until all fragments stop.

VILANOVA DE BANAT ROCKFALL

In November 2011 a fragmental rockfall event occurred on a limestone cliff in the Cadí Sierra, Eastern Pyrenees near the village Vilanova de Banat. A field inventory carried out by [3] estimated the initial detached mass to be 10,000 m³. This mass became substantially fragmented, generating a Young Debris Cover (YDC) extending over an area of approximately 30,000m². Many Large Scattered Blocks (LSB) propagated far beyond the YDC. In [3] the Rockfall Block Size Distribution (RBSD) was extrapolated from the measurements in representative sampling plots within the YDC. All the LSB were measured one by one. The input to our models is the In Situ Block Size Distribution (IBSD) of the detached rock mass, which was obtained in [3] by applying a Discrete Fracture Network to the missing volume of the rockfall source. The rockfall deposit is shown in Fig. 1c while the measured ISBD and RBSD are shown in Fig. 2.

CALIBRATION AND VALIDATION

The model requires the calibration of both the runout of the resultant blocks and the spatial distribution of the volumes of fragments generated by both disaggregation and breakage during their propagation. As this is a coupled process which is controlled by several parameters, a set of performance criteria to be met by the simulation have been defined. The criteria include: position of the centre of gravity of the whole block distribution, histogram of the runout of the blocks, extent and boundaries of the young debris cover over the slope surface, lateral dispersion of trajectories, total number of blocks generated after fragmentation, volume distribution of the generated fragments, the number of blocks and volume passages past a reference line and the maximum runout distance. We tested several sets of parameters varying each parameter using fixed intervals. Finally, the set of parameters fitting better the field data according the mentioned performance criteria was selected.

RESULTS

In this contribution we used all data collected in [3,4] to perform trajectory simulations considering and without considering fragmentation in RockGIS. Each block of the ISBD is released in a randomly chosen point inside the estimated detachment area. As all the propagation process is stochastic, 5 simulations in each case where performed to check the variability of the results.

Fig. 1 shows the locations stopped blocks in two of the simulations runs: not considering (Fig. 1a) and considering block breakage (Fig. 1b). The size of the circles is proportional to the volume of the blocks. The distances between the observed and simulated centre of gravity of the fragments (c.o.g) are 1.57, 1.18, 2.82, 2.36 and 5.67 meters for simulations 1 to 5, respectively. The simulations without fragmentation show an average excessive distance of 79m for the modelled c.o.g.

For the proper visualization of the spatial distribution of the simulated blocks, a set of polygons defining specific percentages of the total number of simulated blocks has been plotted. Fig. 1c shows the results of this procedure in the fragmentation case overlaid with the field data. It is observed that the YDC boundary is quite similar to the contour of the polygon containing 80% of the simulated blocks.

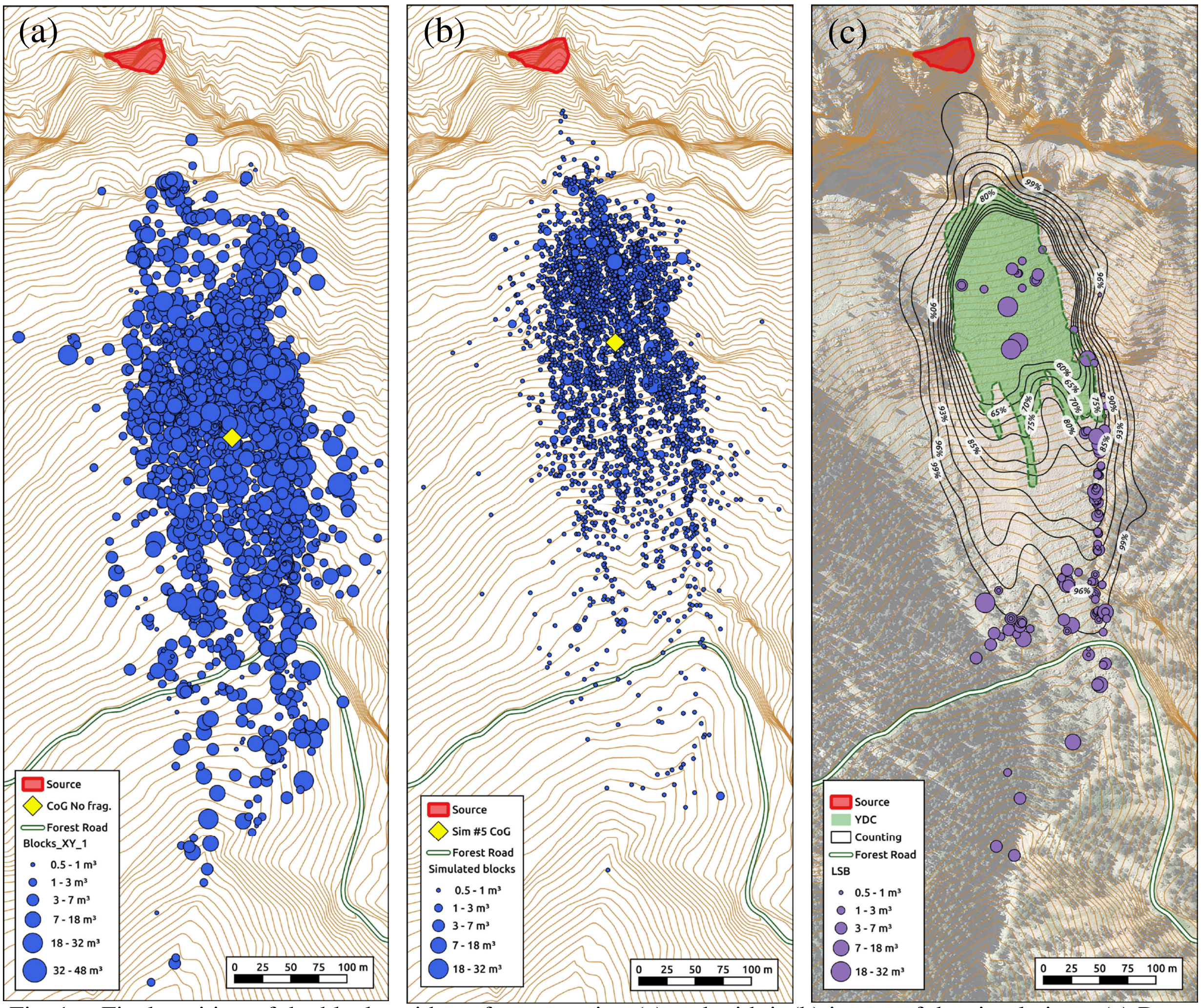

Fig. 1 Final position of the blocks without fragmentation (a) and with it (b) in one of the simulations. (c) Density map of the accumulated blocks of the simulation with fragmentation superposed with the field YDC and LSB measured in the field, [modified from 1].

Fig. 2 shows the five RBSD obtained by the RockGIS simulations considering fragmentation against the field RBSD and IBSD. The five simulation runs yield similar RBSD, which may be well fitted to the observed in the field. They nearly coincide in the domain corresponding to the power law used for distributing the mass of the fragments during breakage but differ slightly in the part of the curve representing the largest volumes. This can be explained by the stochasticity of both the process for generating the fragments and the energy threshold for triggering breakage. In a simulation, a block may break into smaller fragments than the same block in same impact conditions in other simulations. Moreover, not all blocks break and then the RBSD obtained strongly depend on the IBSD used.

DISCUSSION

The model has shown a high sensitivity of the rockfalls to the fragmentation process. The number of large blocks reaching the lowest parts of the slope is reduced significantly with the fragmentation and the whole debris mass remains close to the rock wall as shown by the locations of the centres of gravity.

Several factors affect the breakage of a block during an impact and some tests [2] have shown it cannot be characterized by a single parameter. However, the simple assumption of an energy threshold that triggers breakage has shown to be useful for modelling purposes when considering fragmentation. Moreover, using power laws to distribute the mass has proven to be a simple way of representing the breakage process.

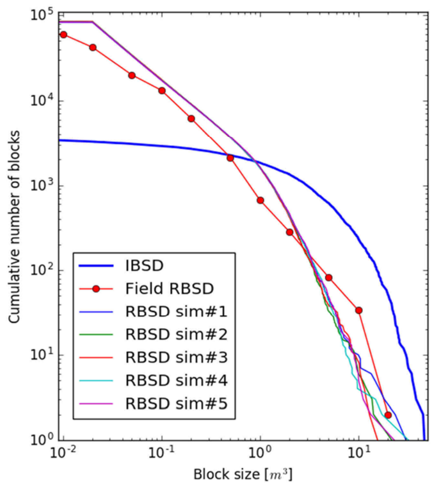

Fig. 2 RBSD obtained from five simulations in RockGIS considering fragmentation against field data RBSD.

The model uses the lumped mass approach whose restrictions are already known: it does not explicitly take into account the shape of the blocks, their rotational movement nor the relative position of the internal fractures of a block with respect to the impacting angle. Despite these limitations, the RockGIS model has been able to reproduce the study case.

The model approached the position of the centre of gravity of the field distribution with an average error of 2.72m considering fragmentation. The extend boundaries of the YDC matched the polygon containing 80% of the blocks in the performed simulations, whilst the polygon containing 96% of the blocks had an average lateral divergence of 23m.

CONCLUSION

RockGIS functions successfully and accomplishes the goal of representing the fragmentation process during a rockfall as we were able to reproduce the runout of the blocks and the RBSD measured in the Vilanova de Banat case farely well. The fulfilment of the performance criteria when adding the fragmentation parameters to the simulation makes the calibration process a delicate exercise that ends with a compromise between all the criteria.

REFERENCES

[1] MATAS G, LANTADA N, COROMINAS J, GILI JA, RUIZ-CARULLA R, PRADES A (2017). RockGIS: A GIS-based model for the analysis of fragmentation in rockfalls. Landslides. doi:10.1007/s10346-017-0818-7
[2] GILI JA, RUIZ R, MATAS G, COROMINAS J, LANTADA N, NÚÑEZ MA, MAVROULI O, BUILL F, MOYA J, PRADES A, MORENO S (2016) Experimental study on rockfall fragmentation: in situ test design and firsts results. In: Aversa S, Cascini L, Picarelli L, Scavia C (eds) Landslides and engineered slopes, 2: 983-990.
[3] RUIZ-CARULLA R, COROMINAS J, MAVROULI O (2015) A methodology to obtain the block size distribution of fragmental rockfall deposits, Landslides, 12 (4): 815-825.
[4] RUIZ-CARULLA R, COROMINAS J, MAVROULI O (2015) An empirical approach to rockfall fragmentation. EUROCK 2015 & 64th Geomechanics Colloquium, Schubert (ed): 151-156.