A NOVEL PROBABILISTIC ROCKFALL MODEL INCORPORATING FRAGMENTATION: INSIGHTS FROM AN ALPINE CASE STUDY

Maddalena Marchelli[1]

[1] Department of Environment, Land and Infrastructure Engineering (DIATI), Politecnico di Torino, Turin, Italy

OBJECTIVES

Rockfall occurrences on fractured alpine slopes present critical challenges for infrastructure safety, yet conventional trajectory models often overlook fragmentation or simplify it with empirical approaches, resulting in underestimated hazard footprints. The author recently developed a probabilistic 2D lumped-mass model and a trajectory code (RockFRAG) that explicitly incorporates fragmentation as a core component. The framework considers impact energy, block geometry, and rock mass conditions, including joint orientation, and computes fragment trajectories using stochastic velocity vectors rather than empirical assumptions [1], and has been calibrated through controlled laboratory impact tests [2].

In the present work, the model is applied to a real case study in the Aosta Valley (Italy) to demonstrate the practical implications of fragmentation for hazard assessment and risk management. The analysis compares fragmented and non-fragmented conditions and evaluates how neglecting fragmentation affects runout predictions and the required performance of protective structures. Incorporating fragmentation is shown to be essential not only for correctly estimating the probability of block or fragment arrival but also for capturing the full range of potential damage, especially when multiple fragments follow different trajectories. Neglecting fragmentation can therefore lead to substantial misjudgements in both the optimal location of protective measures and in their performance. These aspects are critical for public authorities when defining risk thresholds, designing mitigation strategies, and prioritizing interventions.

STUDY SITE DESCRIPTION

- Settlement area in the Aosta Valley (Italy) with steep slopes and high rockfall exposure, posing severe risk to residents and infrastructure.
- Variations in fracture density control the likelihood and mode of fragmentation.
- Historical rockfall events and field observations support calibration and validation of the model.
- The probabilistic model with fragmentation predicts different runouts and higher trajectories, influencing protective-measure required performance, placement, and residual risk.

MAIN RESULTS AND CONCLUSIONS

- Fragmentation increases runout variability and impacts frequency vs. intact-block assumption.
- Geo-structural variability strongly influences fragmentation probability and fragments trajectories.
- Neglecting fragmentation can lead to inaccurate estimation of residual risk and inadequate protective performance: when rebounds occur almost normal to the surface, energy dissipation increases and may stop many fragments, but it can also generate a few very high trajectories.
- A probabilistic approach that accounts for fragmentation is key to capturing hazard variability and supporting informed decisions on mitigation strategies, priorities and resource allocation.

REFERENCES

[1] M. Marchelli (2026). A new probabilistic rockfall trajectory model incorporating fragmentation, rock mass quality and block shape variability. International Journal of Rock Mechanics and Mining Sciences, 206, 106624

[2] M. Marchelli, D.E. Guccione, A. Giacomini, O. Buzzi, (2025). Fragmentation Patterns and Trajectories During Rockfall: Analysis of the Influence of Discontinuities and Impact Conditions Through Drop Tests. Rock Mechanics and Rock Engineering, 1-33.