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EFFECT OF DISCONTINUITIES ON THE SURVIVAL PROBABILITY OF SPHERICAL BLOCKS UPON IMPACT

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ABSTRACT

The fragmentation of rocks upon impact is a complex and not well-understood phenomenon. To model this fragmentation accurately, the first question to address is whether a falling block will fragment upon impact. This can be determined if the survival probability of the rock, i.e. the probability that the rock block does not fragment, is known. However, predicting this probability is challenging, as no existing model or method can accurately forecast the survival probability of natural rocks. Recently, the authors have developed a model that can predict the survival probability of brittle rocks under collinear impact, building on a preliminary breakthrough for brittle spheres. However, natural blocks may contain discontinuities, which can increase the probability of fragmentation occurring not only due to breakage but also due to the disaggregation of the rocks along these discontinuities. The present work introduces an experimental campaign in which fully persistent and filled discontinuities were inserted into mortar spheres. The angle of the discontinuities with respect to the impact surface, as well as the impact velocity, was varied to obtain an experimental survival probability for blocks with discontinuities. The results were compared with the survival probability of intact blocks, showing how the discontinuities significantly reduce the range of energy required to break the spherical block.

1 INTRODUCTION

Rockfalls are particularly dangerous among landslide hazards, posing risks to people, structures, and infrastructure Understanding and predicting these events is crucial for effective risk management. Forecasting block trajectories and their kinematic parameters is essential for implementing mitigation measures (Volkwein et al., 2011). Rockfall events often involve fragmentation, where rock blocks break into pieces or disaggregate along fractures (Corominas et al., 2017). Despite its prevalence, the fragmentation process in rockfalls is not fully understood. Studies have shown that factors like block shape, impact angle, discontinuities, impact velocity, and soil characteristics influence fragmentation patterns (Giacomini et al., 2008; Wang and Tonon, 2011). While existing models provide insights, a universal fragmentation model and comprehensive predictive trajectory model are still lacking. Current models require site-specific parameters and handle post-impact kinematics stochastically, highlighting gaps in knowledge and the need for further research (Marchelli and De Biagi, 2019; Matas et al., 2020; Lanfranconi et al., 2024).

Guccione et al. (2021a) proposed a model that can predict the fragmentation survival probability (SP) of brittle homogeneous spheres upon impact from the input parameters of both block and slope material resulting from statistical analysis of Brazilian test and unconfined compressive tests. However, this prediction model is not valid if the sphere contains defects or, more specifically, preexisting discontinuities. In this paper, an extensive campaign of drop tests on artificial rocks of simple shape (spheres) with discontinuities is presented to investigate the experimental survival probability of these specimens and compare it with the prediction model of homogeneous spheres.

2 EXPERIMENTAL METHODS

For this study, two types of sphere specimens with discontinuities were made: containing 1 discontinuity (1Dsc) (Figure 1a) or 3 discontinuities (3Dsc) (Figure 1b). The spheres were cast in 3Dsc-printed moulds (Figure 1c) and glued together to create discontinuities. A total of 182 and 202, 1Dsc and 3Dsc specimens were created, respectively. Both the matrix (sphere) and discontinuity were made using mortar of different mass proportions. The mortar for the matrix is made of silica sand, Portland cement, hydrated lime, and water (3:1:0.25:1 by mass), and included a cement accelerant (2% by weight of cement weight) for faster curing. Material characterization tests (Brazilian tests (BT), unconfined compressive tests (UCS), and toughness tests) following ISRM standards were conducted for each batch. To simulate rock discontinuities, a weaker mortar type (3.5:0.8:1:1.2 by mass) was used. All specimens were cured for 2 weeks in a humid environment and 4 weeks in an oven at 40°C before testing. The mass of the specimen is about 1kg. Results of material characterization of both materials are reported in Table 1.

The two series of drop tests (1Dsc and 3Dsc) were performed using a specifically designed setup to study the fragmentation of blocks upon impact, developed by Guccione et al. (2021b). The setup allows the release of the blocks (in freefall) from height up to 5.1 m (equivalent impact velocity of 10 m/s). The impacted material is an instrumented concrete slab to simulate an impact against hard rock. More details about the setup as well as the characteristics of the slab can be found in Guccione et al. (2021b). Four impact velocities were used: 4, 5, 6, and 7 m/s for 1Dsc and 1.5, 3, 4 and 5 m/s for 3Dsc. Different orientations (θ) of the discontinuities with respect to the impacted surface (slab) were considered (Figure 1c). The "impact position" θ were grouped into 9 categories (one every 10°): 0-10°, 11-20°, 21-30°, 31-40°, 41-50°, 51-60°, 61-70°, 71-80°, and 81-90°. To ensure a good representation of all possible θ, at least 5 drop tests were conducted for each category, with a total number of tests for each impact velocity equal to 50. The exception was for 4 m/s of 1Dsc where, due to a manufacturing issue, only 25 samples were used. Note that the spheres were dropped without rotation. The SP is obtained from the following equation:

$$SP = \left(1 - \frac{N_f}{N}\right) \cdot 100 \tag{1}$$

where N is the total number of drop tests and N_f represents the number of tests that result in fragmentation (or desegregation). The SP can be described in terms of either impact velocity or impact kinetic energy. The impact velocity (or impact kinetic energy) at which there is a 37% probability of survival is referred to as the critical impact velocity (v_{crit}) (or critical kinetic energy). According to experimental evidence provided by the authors, the survival probability of brittle spheres in drop tests can be approximated as a linear function (Guccione et al. 2021a).

Table 1: Material characterization of the matrix and discontinuity material.

Parameter	Unit	Matrix	Discontinuity
Unconfinement Compression Strength (from UCS) σ_y	MPa	16.69	8.51
Secant Young Modulus (from UCS) Y_b^s	MPa	2021*	1316
Tangent Young Modulus (from UCS) Y_b^t	MPa	3385	2082
Poisson ratio (from UCS) ν_b **	-	0.20*	0.20
Diameter of specimen used for BT d	m	0.053*	0.053
Height of specimen used for BT h	m	0.029*	0.029
Tensile Strength (from BT)	MPa	2.11	1.05
Critical Force (from BT) F_{BT}^{cr}	N	5398*	2801
Weibull shape F factor (from BT) m_{BT-F}	-	7.29*	5.19
Critical Work (from BT) W_{BT}^{cr}	J	1.372*	0.707
Weibull shape W factor (from BT) m_{BT-W}	-	3.75*	4.02
Mode I fracture toughness (from toughness tests) K_{Ic}	MPa ·m$^{1/2}$	0.350	0.181
* Impact for prediction model of SP for homogeneous sphere (Guccione et al. 2021a). ** assumed.			

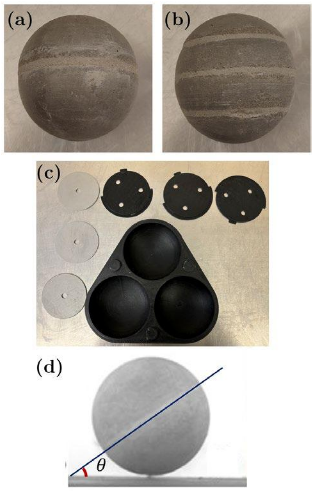

Figure 1: (a) Sphere with 1Dsc; (b) Sphere with 3Dsc. (c) Moulds used to cast the spheres. (d) Angle between discontinuity in impacting surface

3 RESULTS

Figure 2 reports the experimental SP (expressed in terms of impact velocity) for both 1Dsc and 3Dsc. Each point represents at least 50 tests, with the exception of impact velocity 4 m/s where only 25 drop tests were performed. The Linear interpolation of the experimental data for both series of drop tests is also shown in the figure. The experimental SPs are compared in the same figure with the predicted SP of homogeneous spheres of the same diameter (100 mm). Note that the input parameters of the block material for the predicted SP are reported in Table 1. For conciseness, the input parameters of the slope (concrete slab here) are not reported here but it can be found in Guccione et al. (2021a).

By comparing the three SPs, it is clear how the presence of preexisting defects (1Dsc) and the number of these defects (1Dsc vs 3Dsc) on the block influence the probability of fragmentation occurring. Clearly, less kinetic energy is required to observe fragmentation of blocks with discontinuities (compared to a block of the same dimension but without defects). The v_{crit} are 6.0 m/s and 3.7 m/s for 1Dsc and 3Dsc, respectively. These are about 20% and 50% less than that of the homogeneous blocks (7.3 m/s). The fragmentation (both for breakage of the intact material or disaggregation along the discontinuities) of blocks with 3D can start being observed at an impact velocity > 0.2 m/s (SP = 100%), particularly for θ > 45°. This is more than 95% less than the value for 1Dsc (2.0 m/s) or homogeneous blocks (5.6 m/s). Finally, it is interesting to note that the two experimental SPs look parallel. This is probably due to similar characteristics (in strength) of the discontinuities. The shift of the SP is given by the fact that 3Dsc has more defects compared to 1Dsc, therefore it is more likely to break compared to the blocks containing a single defect.

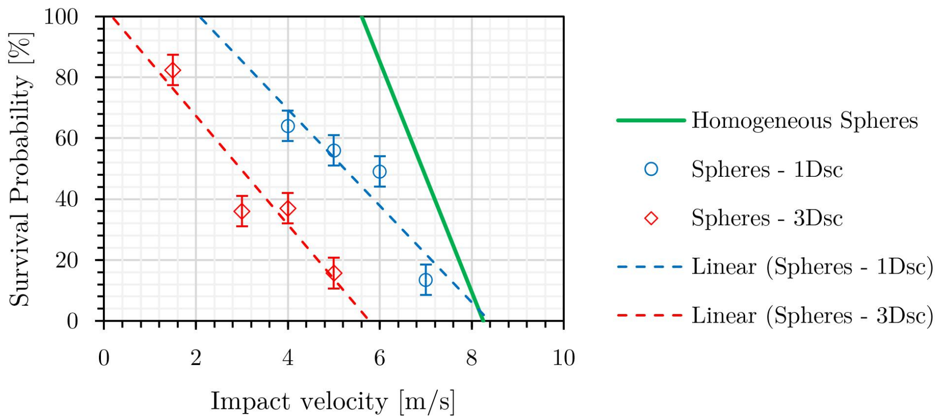

Figure 2: Comparison of experimental SP of spheres with 1Dsc and 3Dsc with predicted SP for homogeneous spheres (Guccione et al. 2021a). Symbols represent experimental data, while dashed line represent linear interpolation of the experimental results. Uncertainty in the point estimates (± 5%) is shown as error bars.

4 CONCLUSION

This paper presents the results of an experimental study focusing on the determination of the SP in drop tests of spheres with discontinuities. The results have shown how the fragmentation of blocks containing preexisting defects can occur at a much lower impact velocity compared to homogeneous blocks of the same size. Although this paper brings new insights into the significance of block defects for the SP, more research is needed. The challenge now is to be able to predict the occurrence of fragmentation considering the effect of discontinuities in an accurate yet practical manner. This is key for a more realistic rockfall assessment.

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REFERENCES

Corominas, J., Mavrouli, O. and Ruiz-Carulla, R. (2017). Rockfall occurrence and fragmentation. In *Advancing Culture of Living with Landslides: Volume 1 ISDR-ICL Sendai Partnerships 2015-2025*, Springer International Publishing, 75-97.

Giacomini, A., Buzzi, O., Renard, B. and Giani, G.P. (2009). Experimental studies on fragmentation of rock falls on impact with rock surfaces. *International Journal of Rock Mechanics and Mining Sciences*, 46(4), 708-715.

Guccione, D.E., Buzzi, O., Thoeni, K., Fityus, S. and Giacomini, A. (2021a). Predicting the fragmentation survival probability of brittle spheres upon impact from statistical distribution of material properties. *International Journal of Rock Mechanics and Mining Sciences*, 142, 104768.

Guccione, D.E., Thoeni, K., Fityus, S., Nader, F., Giacomini, A. and Buzzi, O. (2021b). An experimental setup to study the fragmentation of rocks upon impact. *Rock Mechanics and Rock Engineering*, 54(8), 4201-4223.

Lanfranconi, C., Frattini, P., Agliardi, F., Stock, G.M., Collins, B.D. and Crosta, G. (2024). Field evidence and indicators of rockfall fragmentation and implications for mobility. *Engineering Geology*, 341, 107704.

Marchelli, M. and De Biagi, V. (2019). Optimization methods for the evaluation of the parameters of a rockfall fractal fragmentation model. *Landslides*, 16(7), 1385-1396.

Matas, G., Lantada, N., Corominas, J., Gili, J., Ruiz-Carulla, R. and Prades, A. (2020). Simulation of full-scale rockfall tests with a fragmentation model. *Geosciences*, 10(5), 168.

Volkwein, A., Schellenberg, K., Labiouse, V., Agliardi, F., Berger, F., Bourrier, F., Dorren, L.K., Gerber, W. and Jaboyedoff, M. (2011). Rockfall characterisation and structural protection–a review. *Natural Hazards and Earth System Sciences*, 11(9), 2617-2651.

Wang, Y. and Tonon, F. (2011). Discrete element modeling of rock fragmentation upon impact in rock fall analysis. *Rock Mechanics and Rock Engineering*, 44, 23-35.