Dynamic Analyses of Rock Avalanche Focusing on the Effects of Block Size and Block Shape Based on Discontinuous Deformation Analysis

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1. Introduction

Rock avalanches are massive, extremely rapid, far-reaching landslides originating from the abrupt rockfalls and rockslides. Rock avalanches involve the disintegration of initially intact rock masses during descent, creating highly fragmented debris that spreads over vast areas within minutes. Their travel velocities can exceed 10 meters per second, leading to widespread destruction and posing a significant threat to both people and infrastructure. Heim's observation in 1932 revealed that as the volume of a rock avalanche increases, its mobility also increases. This phenomenon was characterized by plotting the ratio of its pre-fall height to the farthest horizontal runout distance (H/L). However, the complex nature of the dynamic processes and the challenges in observing or replicating rock avalanches have resulted in a limited understanding of the behavior and deformation patterns of rock avalanches from experiments and field studies. Consequently, the scientific literature still contains ongoing challenges on this topic. In this study, we employ the 3D Discontinuous Deformation Analysis (3D DDA) to simulate multi-block rockfalls, with the aim of analyzing the impacts of the block size, and block shape on runout distance, collision frequency, and the H/L ratio of rock avalanche.

2. Method and numerical models

Numerical modelling methods can overcome some of these limitations in experimental and field studies and provide a more feasible method for simulating rock avalanches. Among these numerical methods, 3D DDA is a powerful technique for modelling the movement of rockfall. In this study, to unravel the dynamic behaviors of rockfall, dynamic analyses of multi-block rockfall models with the same volume but different block sizes or rock shapes are conducted using 3D DDA.

Table 1. Parameters in muti-block rockfall model.

Parameter	Rock Mass	Base Block
Density (kg/m^3)	2500	/
Poisson's ratio	0.2	0.2
Young's modulus E (GPa)	1.0	1.0
Friction ϕ (°) Model for size/shape	25/30	25/15
COR	0.925~0.928	0.925~0.928

Figure 1 and Figure 2 demonstrates the geometry parameters of rockfall model and the definition of the models' name, respectively. The size of rockfall model for block shape analysis is magnified by a factor of two. The differences in runout distance, velocity, and the H/L ratio during the movement are discussed.

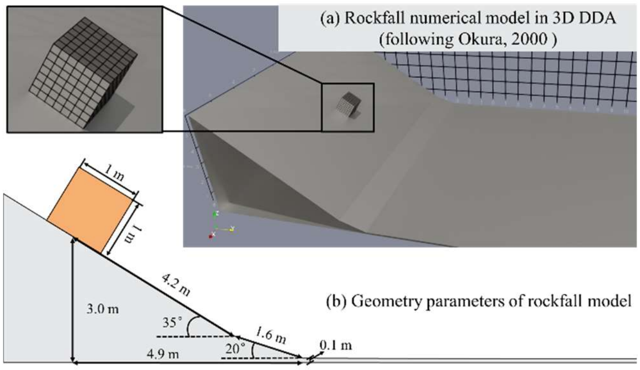

Figure 1. (a) Rockfall numerical model (volume is 1 m^3) in 3D DDA (Okura et al., 2000) and (b) geometry parameters of rockfall model.

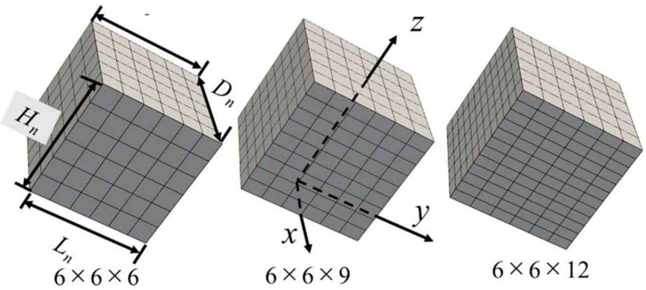

Figure 2. Number of pieces in L_n×D_n×H_n sides for block shape analysis (volume is 8 m^3).

3. Results and discussions

The effect of block size on the H/L ratio, denoted as f, is investigated, as shown in Figure 3. It is observed that f decreases with an increasing number of sides (equivalently, a decrease in block size), indicating a longer runout distance. As for f_g, it decreases with the increasing size number when size number is lower than 3 and then increases when the size number is larger than 3. Additionally, simulations reveal that the back-to-front relative positions of the blocks remain largely consistent with the downflow direction during movement. Moreover, blocks initially located in the middle part tend to experience more collisions throughout the rockfall process.

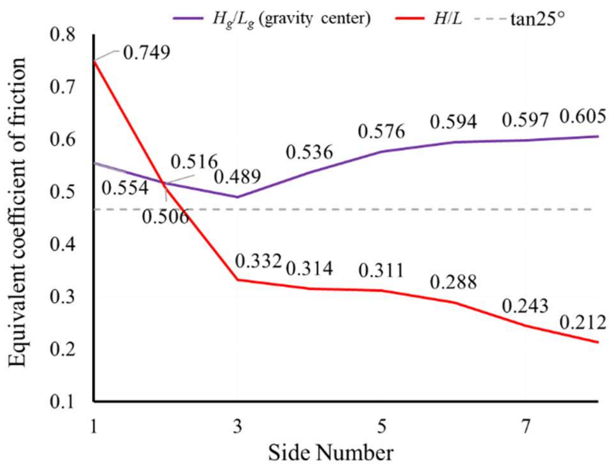

Figure 3. Relation curves of equivalent coefficient of friction $f = H/L$ and gravity-center $f_g = H_g/L_g$ with respect to side number.

In the analysis of a rockfall model with varying block shapes, simulations were conducted for models with dimensions 6×6×6, 9×6×6, 12×6×6, 6×9×6, 6×12×6, 6×6×9, and 6×6×12, corresponding to aspect ratios of 1:1:1, 3:2:2, 2:1:1, 2:3:2, 1:2:1, 2:2:3, and 1:1:2, respectively. The results, presented in Figure 4, reveal that as the number of slices in each side direction (L_n, D_n, and H_n defined in figure 2) increase, the equivalent coefficient of friction f decreases rapidly while the equivalent coefficient of friction at gravity center f_g shows a slight decrease. Moreover, the simulations indicate that the width and height of each block have a more significant impact on the value of f compared to length.

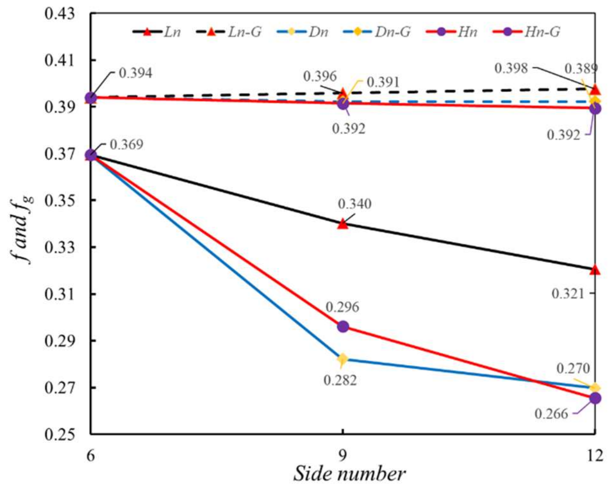

Figure 4. Relation curves of $f = H/L$ and r $f_g = H_g/L_g$ with respect to slice number in each direction of side.

Summary

The effects of block size and shape on the rock avalanche were studied by simulating the muti-block rockfall models based on 3D DDA. It was found that:

1) With the decrease of block size, f decreases, indicating a longer runout distance.
2) f_g decreases with the increasing size number when size number is lower than 3 and then increases when the size number is larger than 3.
3) Blocks initially located at middle part experience more collisions during the rockfall process.
4) f decreases rapidly while f_g decreases slightly with the decreasing length, width and heigh of block.

Acknowledgments

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References

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