Dissipative Discrete Element Model Applied to Rock Avalanches

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Abstract. In order to improve the numerical modelling of rock avalanches and to provide information concerning the physical phenomena underlying this type of granular flow, a discrete element model is used to investigate the collective behaviour of granular masses propagating down a slope. The numerical model aims at improving the understanding of rock avalanches by providing both valuable information about the shape of the granular deposit, and relevant data about the kinematics of the flow. The simulations consist in the launch, fall, and deposition of a granular mass constituted of small bricks, along a planar slope having a sharp change of gradient. Sizes and shapes of the particles are investigated in order to assess their influences on the kinematics of the flow and on the dimensions and shape of the granular deposit.

Keywords: Discrete modelling, Rock avalanches, Particle size, Particle shape, Energy dissipation.
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INTRODUCTION

Rock avalanches are a significant concern for the development of mountain areas. A reliable prediction of depositional areas from avalanches is thus needed. Discrete modeling is a very convenient tool for this purpose, for a number of reasons : (i) it allows the modeling of a free-surface granular flow without the need of postulating a material rheology or kinematical assumptions, (ii) it makes it possible to introduce realistic shapes and/or sizes of the rock particles, and (iii) it provides access to some physical quantities (such as the individual particles kinematics) which are out-of-reach of common experimental measurements.

In this communication, we propose a parametric study of an idealized rock avalanche. The simulations are based on a small-scale experiment (Manzella and Labiouse 2009) which consisted in releasing an apparent volume of 40 litres of small bricks (roughly 30mm long) on a slope and to observe its flow and further deposition on a horizontal plane. The layout of this experiment is proposed in Fig. 1. In a previous work by the present authors (Richefeu et al. 2012), a discrete modeling of this experiment was performed and appeared to reproduce rather well the experimental measurements, both in terms of flow velocity and of size and shape of the granular deposit. This good correspondence was considered as a valuable result for several reasons :

1. Despite the complexity of the phenomena involved in such a flow, a rather simple contact model with only four parameters was used to account only for the dissipative phenomena that occur during inter-particles or slope-particle frictions and collisions. This contact law is provided in Fig. 2, and detailed in Richefeu et al. 2012.

2. The eight parameters (four for inter-particles contacts and four for slope-particle contacts) of the contact law were measured by an accurate back-analysis procedure of ballistic measurements performed on additional experiments involving single impacts, instead of fitting these parameters on the simulation of the whole event (Richefeu et al. 2012).

3. Much attention was paid to the particles geometries, using the framework of spheropolyedra (see insert in Fig. 1) in the discrete modeling. It was thus demonstrated that this kind of flow may be satisfactorily assessed by focusing on accurate particle shapes and on simple dissipative phenomena at the contact level, the parameters controlling these phenomena being very easily obtained by simple ballistic lab tests.

In Mollon et al. 2012, we proposed several methods of post-processing and applied them to several simulations of granular flow in the same framework, with varying contact parameters, slope angles, and slope macro-scale rugosities. These post-processing algorithms aimed at investigating some physical variables, such as the amount and nature of the dissipated energy, velocity and angular velocity fields, bulk density of the flow, etc.

In this communication, we continue this parametric study, focusing on the sizes and shapes of the particles but keeping constant the contact parameters, the material amount, the initial bulk density, and the slope characteristics.

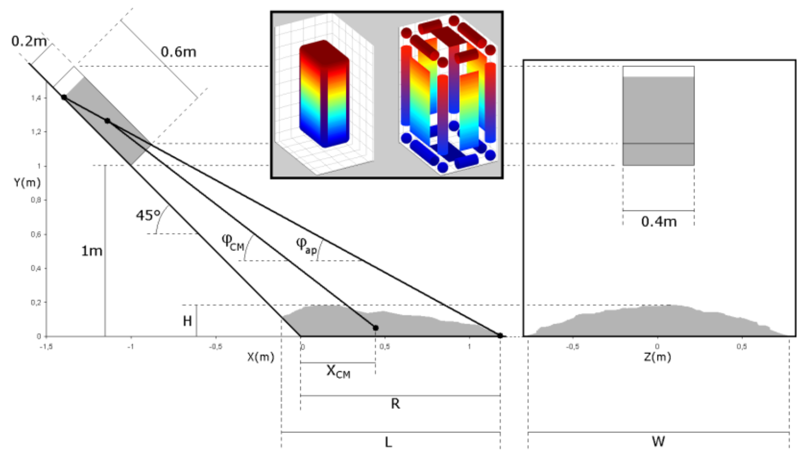

FIGURE 1. Layout of the experiment reproduced in simulations ; Insert : spheropolyedron framework applied to brick shape.

OVERVIEW OF THE SIMULATIONS

Five DEM simulations are analyzed in this communication. All of them are based on the layout which is provided in Fig. 1 and detailed in Richefeu et al. 2012. For each simulation, an apparent volume of 40 litres of granular material (composed of small bricks) is first poured randomly in a starting box by gravitational deposition, in order to reach a constant solid fraction of 65%. This starting box is then rotated and moved to the relevant position on the slope, and the avalanche flow is triggered by deleting its lower face. The contact parameters are the same as the ones used in our previous studies (Richefeu et al. 2012, Mollon et al. 2012, see Fig. 2).

The only differences between the five simulations are the size and shapes of the particles, and their total number (this number being chosen in order to keep a constant volume of matter between the simulations). The bricks used in the five simulations are presented in Fig. 3, with their dimensions and their number. More specifically, simulation A is actually the one corresponding exactly to the original experimentation published by Manzella and Labiouse 2009. This simulation was described with many details in our previous work (Mollon et al. 2012), and is used here as a reference. Simulations B and C use bricks with the same proportions, but with volumes respectively multiplied and divided by 8. They are thus intended to point out the influence of particles sizes on the flow. Simulations D and E use particles with slightly different shapes : In simulation D they exhibit a flatness but no elongation, and in simulation E they are perfectly cubic. The computation times run from a few hours (case B) to several weeks (case C), for a simulated time of roughly two seconds.

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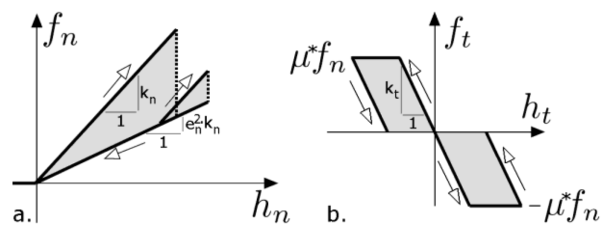

FIGURE 2. Contact law used in the simulations (energy dissipations in grey) ; a. Normal contact law (dissipation is triggered by a smaller unloading stiffness) ; b. Tangential contact law (classical Coulomb friction). f_n and f_t are the normal and tangential contact forces, h_n is the normal interpenetration distance, h_t is the relative tangential displacement, k_n and k_t are the normal and tangential contact stiffnesses, e_n^2 is the normal disspation coefficient, and μ^* is the friction coefficient.

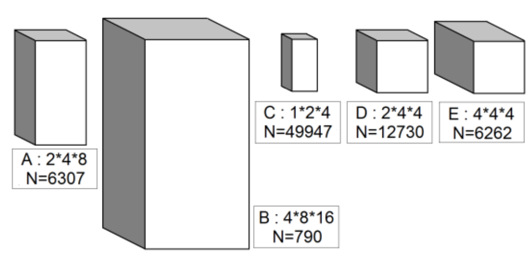

FIGURE 3. Bricks corresponding to simulations A to E. Dimensions (Depth*Width*Length) are provided in terms of a unit length equal to 8mm. Number N of particles are also indicated for each simulation.

ANALYSIS OF THE DEPOSITS

Several quantities obtained by post-processing the simulated granular deposits are provided in Fig. 4 for the five simulations : fahrböshung (φ_{ap}, see Fig. 1), travel angle (φ_{cm}, see Fig. 1), and deposit dimensions.

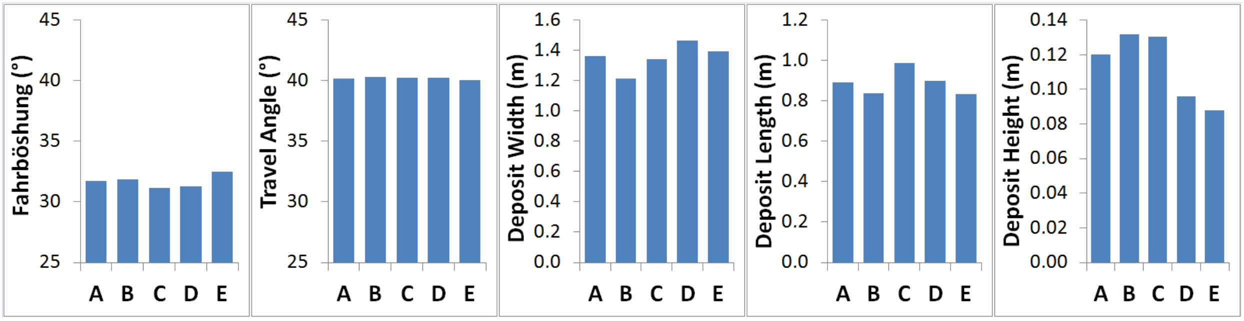

FIGURE 4. Geometrical characteristics of the deposits obtained at the end of the five simulations.

In the specific conditions of the proposed simulations, it appears from the results of Fig. 4 that neither the particle size nor the particle shape seem to have a major influence on the fahrböshung and on the travel angle (which are of primary interest for the geophysics community). Fahrböshung is roughly equal to 32° for the five cases (slightly larger for the cubic bricks, for which the shape is somehow closer to a sphere), and the travel angle is very close to 40° for all the cases.

The deposit size horizontal dimensions are a bit more dependent on the particles sizes and shapes. Larger particles (case B) lead to a less extended deposit (both in width and length), while smaller particles (case C) increase the deposit length by roughly 12% with respect to the reference case A. Besides, particles with smaller elongation (case D) and smaller flatness (case E) tend to increase the deposit width. It also clearly appears that these shapes lead to much less high deposits (deposits heights are close to 120mm for cases A to C, and close to 90mm for cases D and E), which tends to indicate that elongation and flatness of the particles act as restrictions to the lateral spreading of the granular mass.

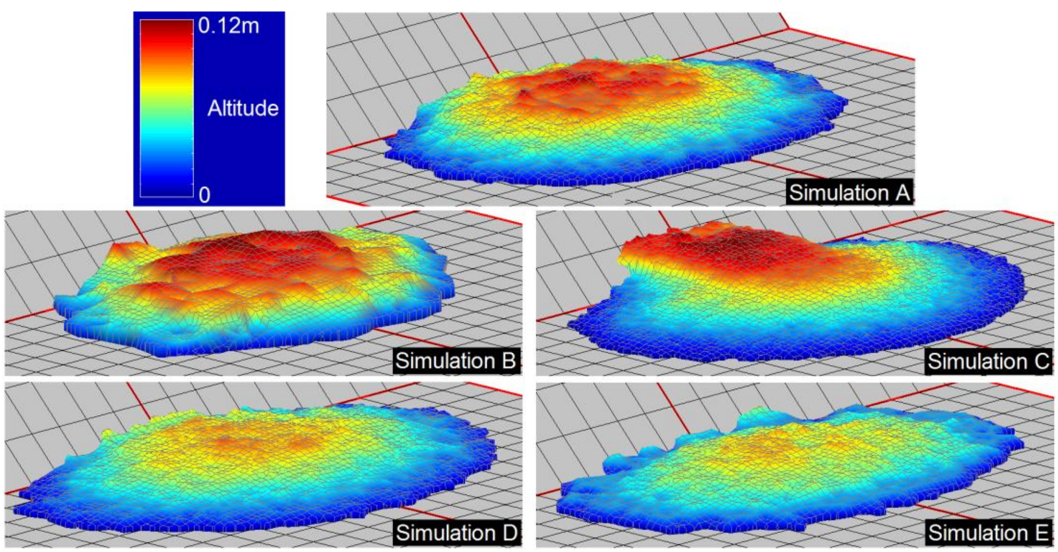

FIGURE 5. Non-convex envelopes of granular deposits. Color indicates altitude.

Fig. 5 represents the non-convex envelopes of the five deposits, as obtained after applying a post-processing algorithm described in details in Mollon et al. 2012. This figure confirms the results of Fig. 4. Deposits B and C are respectively less and more extended than the others, and deposits D and E are flatter and lower than the others. Besides these quantitative observations, it also clearly appears that particle size has a significant influence on the deposit shape. Indeed, deposit B seems more "compact" with rather steep slopes on its contour, while deposit C exhibits a planar surface on the top, surrounded by soft slopes up to the ground surface. One explanation may be that simulation B is composed by a much smaller number of particles (roughly 64 times less), and may not have the sufficient "degree of freedom" to form the shape of Deposit C. Deposits D and E have similar shapes to the reference case A, being only flatter.

FLOW KINEMATICS

Figs. 6 and 7 show respectively velocity and rotational velocity fields obtained by an interpolation technique described in Mollon et al. 2012. These fields are plotted in the symmetry planes of the five simulations at a simulated time t=1s.

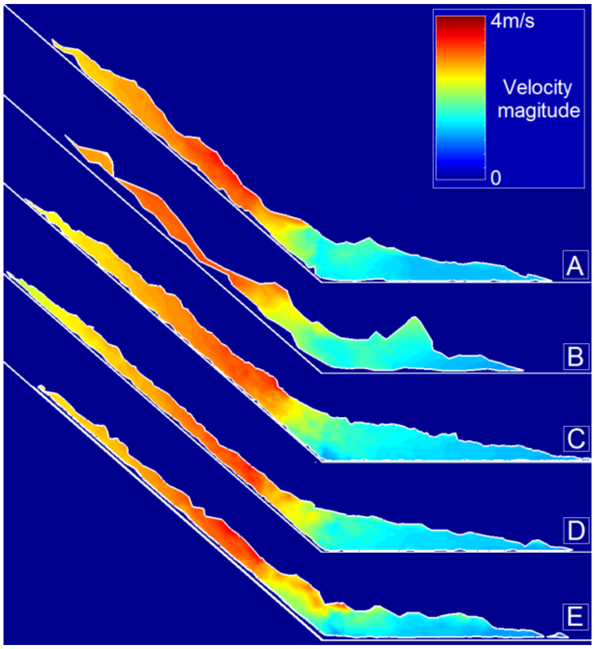

FIGURE 6. Velocity fields in the symmetry plane of the five simulations at t=1s after release (Profile B is rather inaccurate due to the large size of the particles).

Fig. 6 clearly shows that the kinematics of the flow are not affected a lot by the particles sizes and shapes considered in the proposed simulations. Flow is very regular, velocity magnitude is roughly constant in a plane normal to the slope, and no vertical velocity gradient develops. The granular mass is not sheared, and the flow regime is mostly based on basal slip, as already shown in Mollon et al. 2012. This is confirmed by Fig. 7, which shows that rotations of particles are very rare, except in the neighborhood of the transition between the slope and the horizontal plane. However, it would appear that rotation is even more restrained for large particles (Case B), while the zone of perturbation induced by the slope transition seems larger in case of particles with smaller size (Case C) or with no elongation (Case D) and no flatness (Case E). This more important perturbation of the flow may be the reason of the larger lateral spreading of the deposits of cases C to E as observed in Fig. 5.

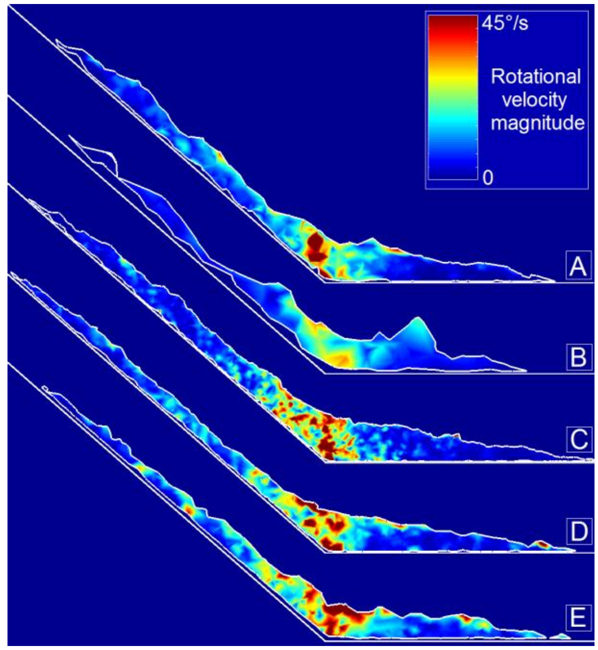

FIGURE 7. Rotational velocity fields in the symmetry plane of the five simulations at t=1s after release.

CONCLUSION

This communication deals with the free-surface flow of a granular mass composed of angular particles on a perfectly planar surface, as an idealization of a rock avalanche. Several particles sizes and shapes are tested, and their influence on the flow kinematics appears limited. This is probably related to the perfect flatness of the slope, which induces a slip regime of the flow without shear. The assumption of contact parameters independent from the particle size and shape may also be questionable. Our future studies will be dedicated to extending this analysis to slopes exhibiting a macro-scale rugosity, as started in Mollon et al. 2012. In such conditions, a larger influence of the sizes and shapes of the particles is expected because of the shearing of the flow that may be induced by a larger adhesion of the particles to the slope. One may also expect to have much different results when exploring particle shapes differing from the "bricks" class.

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