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Mechanics of granular and polycrystalline solids

Influence of the morphology of slope and blocks on the energy dissipations in a rock avalanche

Influence de la morphologie de la pente et des blocs sur les modes de dissipation d'énergie dans une avalanche rocheuse

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A B S T R A C T

A discrete element model was used to determine the influence of block shape and surface topography on energy dissipative modes occurring during rockfalls or avalanches. By using realistic shapes of particles and a specific contact law able to represent the main dissipation phenomena at the contact-rebound point, we analyze the contribution of tangential and collisional effects within the granular material or at the base of the flow. It was shown that the particle shape and the slope geometry have a major influence on the energy dissipative modes and need to be accounted for in numerical models.

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R É S U M É

Les modes de dissipations énergétiques lors de la propagation d'avalanches de roches sont étudiés à l'aide d'un modéle numérique aux éléments discrets. En utilisant des formes de blocs réalistes et une loi de contact spécifique permettant de prendre en considération les principaux phénomènes dissipatifs qui surviennent lors d'un impact, il nous a été possible d'analyser les différents modes de dissipation, par frottement et par chocs, qui se développent au sein du matériau granulaire ou à la base de l'écoulement. Il est montré que la forme des particules et la géométrie de la pente ont une influence majeure sur les modes de dissipation d'énergie et doivent être pris en compte dans les modèles numériques pour une meilleure prédiction de la propagation des avalanches rocheuses.

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1. Introduction

Rock avalanches are among the most frequent and unpredictable natural events that need to be taken into account to define the risks in the mountainous infrastructures. The complexity of the interacting mechanisms involved during the flow has a great influence on the morphology of the deposit and on the propagation distance of a rock mass. The nature of the

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flow patterns and the mode of interaction between blocks strongly depend on the shape, size, and number of blocks as well as the geometry of the surface topography. The influence of these parameters on the kinematics of the flow and on the amounts of energy dissipated at the base and within the moving granular mass is one of the key points that must be raised in order to predict satisfactorily the propagation and deposition areas of the granular mass.

Usually, the trajectory of individual block and the position of the stop zone are approximated using softwares based on mass-point mechanics for which the energy dissipation at each contact depends on damping and frictional coefficients [1–3]. Small avalanches may be studied with a probabilistic approach of the precedent trajectory methods [4,5], but energy dissipation is modeled through restitution coefficients, defined in normal or/and tangential directions, which may be expressed either with velocity ratios or kinetic energy ratios [6,2,7–10]. Some authors have shown that the kinetic of the impact depends strongly on the substrate nature related to soft or hard contacts [11,12,1,3], on the shape of the blocks and on the impact angle [6,10,13,14]. So, different values and definitions of the restitution coefficient are proposed in the literature, leading in some cases (transformation of rotational energy into translation energy for example) to unphysical values greater than the unity limit [15].

Larger avalanches are generally modeled with fluid-like engineering softwares based on the assumption of a shallow water fluid behavior. This type of hypothesis leads to a smoothing of the internal fluid phenomena such as re-circulation or velocity fluctuations. The frictional dissipative mechanisms are generally located at the basal interaction between fluid and substrate, or averaged in the fluid [16–19]. The parameters are obtained from laboratory studies [20,17,21] or more often from back-analysis of real cases.

Nevertheless, none of these two types of model is completely satisfactory, specifically for medium volume avalanches where interactions between particles cannot be ignored while the mass is discontinuous in some place. In fact, the complex collective behavior between particles such as collision, friction, transfers of translation velocity to rotational velocity are not represented with the mass center point mechanics trajectory. Besides, the shallow-water continuous model, although commonly used in the communities of stakeholders and researchers, cannot account for some mechanical effects, especially at the change in slope geometries, without adding numerical specific ingredients [19,22].

In this context, the discrete element modeling offers an interesting alternative to the continuous approaches as, using specific assumptions on the constitutive contact law and real representation of the block shapes, they seem to be more relevant in modeling medium and small volumes of rock avalanches [23–29]. The contact law between particles becomes a factor of importance in this case. In general, the classical elastic laws with friction are used [30,31,27] and some dissipation parameters may be added as in Walton's laws [32,33]. The particles' shape may be taken into account by using polygons [31], spheres, clumps of spheres, ellipsoids, spheropolyhedrons [34].

The model proposed here is able to take into account realistic block shapes [35] and is based on the definition of specific interaction laws that make physical parameters easily assessable by means of a simple laboratory experiment of block launch retro-analysis [36]. Each block is modeled by a spheropolyhedron, which is the shape resulting from the sweeping of a sphere onto the surface of a polyhedron [37]. This makes it possible to obtain realistic shapes, to optimize the contact detection algorithm and to minimize the time calculation. The contact model, described in the following section, is tested and validated with laboratory experiments performed at EPFL [38], which consist in the release of an assembly of small bricks on a bi-plane. Then, the model is used to highlight the energy dissipation mechanisms occurring along the slope, especially the influence of the blocks shape (bricks and cubes), the undulation of the slope, and the effect of the slope transition between the two planes.

2. Contact law and calibration of parameters

The quality of a numerical model is partly linked to its ability to reproduce and predict a physical phenomenon and secondly to the ease with which the user is able to identify the parameters. The contact model that we used to simulate the dissipative mechanisms occurring during an impact between two solids is deliberately minimalist and defined by four parameters that can be easily identified by laboratory tests ($e_{\rm n}^2$, μ, $k_{\rm n}$ and $k_{\rm t}$).

The parameter $e_{\rm n}^2$ reflects the amount of energy restored in the direction perpendicular to the contact plane at each cycle of loading/unloading of the contact. In the case of a vertical drop of a particle on a horizontal plane, this coefficient is the ratio between the height of rebound of the particle and the height of the initial drop. A value of 1 corresponds to a perfectly elastic collision and a value close to 0 refers to a completely dissipative contact. As shown by many authors, this coefficient depends on the impact velocity and on the impact angle [39,40,42–44]. In the laboratory experiments presented in this paper, the range of normal velocities at collision is relatively narrow. This makes the parameter $e_{\rm n}^2$ nearly constant, in fact [41]. Actually, this parameter integrates a very complex set of mechanisms that are difficult to identify (damage, plastification, elastic wave, heat generation, etc.). From this point of view, the chosen behavior law does not include the actual mechanisms of energy dissipation, but allow in a comprehensive manner, by using a simplified contact law, to access to the amount of energy dissipated during impact.

The parameter μ is a coefficient that introduces energy dissipation in the tangential direction to the contact plane. Upon contact between two rigid bodies, this parameter is the dynamic friction coefficient. For a contact between a boulder and loose soil, this coefficient incorporates, in addition to frictional forces, the abutment force and the shear strength of the soil of the impacted area. However, it behaves exactly like a classical Coulomb friction coefficient.

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