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Impact of dry granular flows on a rigid wall: discrete and continuum approach

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Abstract

Numerical simulations of impacts of granular flows with structures are complex because they have to take into account large deformations, large strain rates and interactions with boundaries or structures. Moreover, the material response is governed by interactions between grains, which leads to a complex rheology. Discrete methods (DEM), which apply a micromechanical approach, appears very well suited to this purpose, but they can hardly deal with large-scale problems. In contrasts, continuum methods can handle large granular volumes because they use a macroscopic approach in which the material behaviour is described by a constitutive model. The aim of this paper it to compare the results obtained by a discrete and a continuum approach in simulating the impact of a dry granular flow on a rigid wall. The problem is simulated with a DEM code and with a software based on the Material Point Method.

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Keywords: granular flow; MPM; DEM; impact forces

1. Introduction

Granular flows have been classified as one of the most hazardous landslides due to their high velocities and impact forces, the long run-out distance and the poor predictability. Protective structures, such as retaining walls, fences, and dams, can be installed to slow down or stop granular flows from affecting adjacent infrastructures and residential communities. The impact forces exerted by a granular flow are computed with simplified methods. A numerical tool

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able to capture the key features of these phenomena would be useful in the design of structures that can withstand snow and rock avalanches as well as high-speed landslides. Most studies of dry granular flows in the context of geo-hazards focused on flow models for predicting the run-out distance, velocity, and other variables. The understanding of the impact process and the evolution of the static and dynamic force components are still quite limited.

Numerical simulations of granular flows are complex because they have to take into account large deformations, large strain rates, interactions with boundaries or structures, and collisional interactions between grains, which leads to a complex constitutive behavior of the material. Various numerical techniques have been used for analyzing the inception or the propagation of a landslide, but only a few are suitable for studying the whole process as well as the impact against structures. These include Discrete Element Methods (DEM) [1], and continuum-based Lagrangian meshless methods [2–4].

DEM applies a micromechanical approach (single soil grains are simulated). The interactions between grains is taken into account realistically, but the knowledge of the contact parameters, their link to macroscopic quantities and the effect of considering grain-shapes different than spherical can be difficult to determine. The computational cost is very high, thus simulations of real-scale events may be ineffective. For this reason, continuum-based methods are often preferred. They apply a macroscopic approach, in which the behavior of the granular mass is described by the constitutive model. Lagrangian meshless methods can simulate small and large deformations of big soil masses with a limited computational cost. Amongst them, the Material Point Method (MPM) appears to be particularly promising and it is preferred in this study.

The aim of this paper is to compare the results obtained with a discrete and a continuum approach in simulating the impact of a granular flow on a rigid structure. In this work, we consider a set of laboratory tests reported by [5]; in which a cubical sample of dry granular material is instantly released from the top of an inclined slope, it flows down the channel and hits a rigid wall on which impact forces are measured. Two reference tests have been selected varying the chute inclination ($\theta = 30°$ and $\theta = 40°$). The problem is simulated using DEM (discrete approach) and MPM (continuum approach). The considered problem is very complex; an exhaustive comparison between the two methods, covering all the similarities and dissimilarities, exceeds the purpose of this paper, which wants to give only an insight to the problem.

2. DEM model

The Discrete Element Method is used to simulate the behavior of granular materials in several fields: from geotechnics, to material science and process engineering. It explicitly solves the dynamic of discrete interacting particles by assuming a micromechanical constitutive model at the contacts. In our case the basic contact model has been used: the normal contact is ruled by a linear elastic spring coupled with a dashpot while a frictional slider, a dashpot and a linear spring is used in tangential direction [6]. Frictional parameters have been selected on the base of the measurements given in [5]. Linear elastic stiffness parameters at the contact have been chosen according to the calibration performed in [7]. Damping coefficient has been computed on the base of restitution coefficients provided in the same publication. Grain-size used in simulations is similar to the experimental tests and has been obtained linearizing the grain size distribution around a mean value $d_{50} = 14.1$ mm (finest and coarsest particles were neglected). It is worth to note that microscopic friction coefficient is not the real one because the shape of each grain was simplified with a sphere that is free to rotate. Some preliminary tests have shown that its effect on the result is quite negligible, and the macroscopic friction angle was then adopted. The parameters used in DEM simulations are listed in Table 1.

Table 1. Material parameters used in DEM simulations.

Grain density (ρ_s)	2650 kg/m^3	Interparticle friction angle (φ)	53°
Porosity (n)	0.48	Mean diameter (d_{50})	14.1 mm
Normal contact stiffness (k_n)	400 kN/m	Basal friction coefficient (μ_b)	0.466
Tangential contact stiffness (k_s)	100 kN/m	Retaining wall friction coefficient ($\mu_{w,r}$)	0.384
Norm. and tangential viscous damping coeff. (c)	0.3	Lateral wall friction coeff. ($\mu_{w,l}$)	0.268
Grain-size ratio d_{min}/d_{max}	2		