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Multi-scale modelling of granular pile collapse by using material point method and discrete element method

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Abstract

Granular debris flows are often observed in mountainous areas in Southwestern China. The process is accompanied with large deformation and the evident transitions between solid- and fluid-like states bring difficulties in proposing a unified phenomenological constitutive model. In this study, a hierarchical multi-scale modelling scheme is developed, and is applied to simulate a granular pile collapse. The macroscopic behavior is modelled by using material point method (MPM), which is suitable for large deformation treatment, while the constitution relation at each material point is extracted from discrete element method (DEM) modelling. This MPM/DEM multi-scale modelling strategy abandons any constitutive assumptions as required in MPM, and facilitates effective cross-scale interpretation and understanding of granular flow behavior. It provides a potential approach to simulate large deformation of granular materials when their constitute relations are hard to be derived explicitly.

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1. Introduction

Granular materials are important constituents in many industrial processes and geophysical phenomena. Understanding the evolution of internal structures of granular flows would certainly be of considerable helps when describing and predicting natural geophysical hazards, particularly the frequent granular-type debris flows that occur in the mountainous areas of Southwestern China [1]. Within the framework of continuum mechanics, it is hard to establish a unified constitutive model for granular media because they can behave like solids or fluids [2]. Various phenomenological parameters would also be introduced with no physical meaning or difficult to calculate [3]. Discrete element method (DEM) tracks all individual particles within their discrete nature, providing rich information at the microscopic level of the granular material. Since all the particles are modeled in their real sizes, the simulation time is consuming and it is currently unrealistic for DEM to model real engineering.

Clearly, investigating the mechanical behaviors of granular material from the microscale and macroscale views respectively are on two distinct modeling approaches. Multiscale modelling approach provides a feasible solution

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to fully utilize the advantages of these two methods. There are approximately three main schemes for multiscale modelling. Firstly, we extract the kinematics of grains from DEM to continuum mechanics, such as the evolution of frictional resistance and dilatancy (or internal plastic variables), which are known to be key variables in the macroscopic description of granular materials. Note that a phenomenological model is still needed in this solution [4]. Secondly, bridging scale method decomposes the computational domain into the coarse region and the fine scale region. The previous region covering the whole medium is simulated with FEM, while the later region limited to a localized zone is numerically simulated with DEM. The displacements of particles are interpolated into the nodes of FEM and a layer of virtual interfacial particles in the macroscopic region are assumedly generated to impose the interfacial condition applied to the DEM region [5,6]. Thus, the realistic mechanical responses, particularly the progressive localized failure process, and the micro-structure evolutions can be captured using less unknown variables than modelling with DEM. Recently, a new hierarchical multiscale technique has been proposed. In this strategy, the boundary value problem is solved by FEM on the macroscale, whereas the constitution relation is derived from DEM modelling at each integration point of the FEM [3,7].

Considering that FEM is difficult to model behaviors involving large deformations due to mesh distortion, we extend the hierarchy multiscale modelling scheme using MPM and DEM. The paper is organized as follows. The next section presents the details of modelling scheme including algorithms of both MPM and DEM, and the coupling method of MPM and DEM. By using the MPM/DEM method, Section 3 shows the simulated example of the collapse process of a granular pile . The summary is given in Section 4.

2. Modelling scheme

As shown in figure 1, MPM is used for macroscale modelling and DEM is adopted for microscale modelling. Each material point is a representative volume element (RVE) consisting of granular packing. The deformation information obtained by MPM is applied to the RVE as boundary conditions, while the Cauchy's stress calculated by DEM is reflected to MPM for the next step.

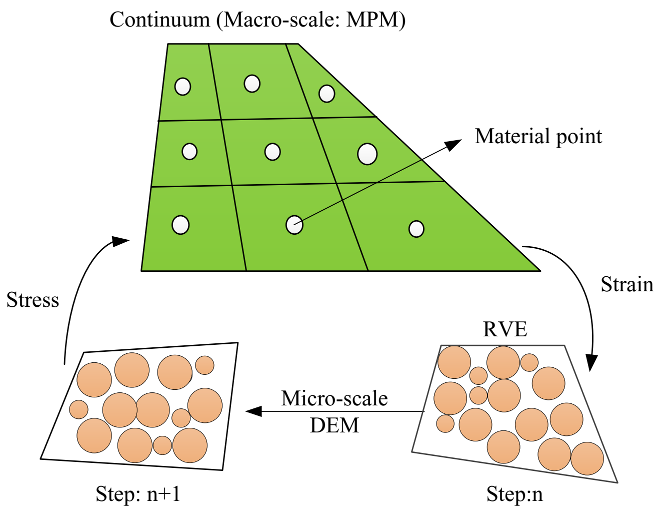

Fig. 1. Schematic of hierarchy multiscale modelling scheme.

2.1. *Algorithm of MPM*

MPM, as a mesh-free method, combines the Lagrangian description and Eulerian description. As shown in figure 2, (a) the material points carrying all the physical variables, such as mass and momentum, are linked with the background grid, (b) according the second law of Newton, the grid nodes update their positions and other kinetics, (c) these updated information of nodes are interpolated to the material points, and (d) in the next step, a new mesh would be adopted.