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Structural changes in granular materials: The case of irregular polygonal particles

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Abstract

This paper presents a series of numerical simulations of biaxial tests performed on assemblies of two-dimensional irregular polygonal particles. Each sample is prepared with a technique similar to dry pluviation. Different aspect ratios (1–3) are considered and the behavior of granular samples is analyzed from both a global and a local point of view. More precisely, the influence of the particle aspect ratio on both inherent (initial) and induced anisotropy is investigated. New internal variables which are related to the orientation of particles are proposed. They give new insight into the specific mechanisms that control the behavior of irregular polygonal materials. Associated to global variables, they demonstrate the existence of a *critical state* irrespective of the investigated aspect ratios. However, for materials with higher aspect ratios (2 and 3), their inherent anisotropy prevents any extensive reorganization, this means that, within the range of usual strains considered in civil engineering, the particle reorientation remains in progress and considerable deformations are required to reach the critical state.

Keywords: Granular material; Polygonal particle; Aspect ratio; Biaxial test; Anisotropy; Internal state; Critical state

1. Introduction

The constitutive modelling of granular materials remains an open issue because it has proved difficult to define relevant macroscopical variables that capture the evolution of the internal state accurately. This difficulty is essentially related to the discontinuous nature of such materials and to the great changes that may affect their internal structure. Another difficulty arises as experimental tests cannot generally provide suf-

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ficient information about the internal state of samples. This deficiency generates a bias that may prevent a good understanding and modelling of phenomena. Discrete numerical simulations of granular materials seem of great interest in this respect, as they provide information at the grain scale level throughout the loading process. They will eventually give clues to define clear internal variables for modelling.

Many analyzes dedicated to the study of two-dimensional granular materials by means of a discrete element method (DEM) have been published in the literature, but most of them have been performed on simulated samples with materials composed of either cylindrical particles (Cundall and Strack, 1979; Thornton and Barnes, 1986; Dedecker et al., 2000; Radjaï et al., 2004; Cambou et al., 2004), isotropic-shaped polygons (Mirghasemi et al., 2002; Nouguier-Lehon et al., 2003) or elliptical particles (Rothenburg and Bathurst, 1992; Rothenburg and Kruyt, 2004). Isotropic shapes give rise to specific internal states and a global material behavior which is not generally in good agreement with natural materials like sands, gravels or rocks (low peak friction angle value, low dilatancy rates,...). This bias is introduced by perfect roundness (that characterizes how smooth or sharp the edges of the particles are) and cylindricity (extrapolation of sphericity in two-dimensional context). Nevertheless, some studies have thrown valuable insight onto the mechanisms of the creation of induced anisotropy (Rothenburg and Bathurst, 1989). On the other hand, elliptical particles are only representative of a class of actual granular materials. However, they have proved to be a more realistic way to idealize the description of granular material. For example, Rothenburg and Bathurst (1992) simulated biaxial tests performed on elliptical shaped particles from an isotropic state. They investigated the influence of particle aspect ratio on the initial state (density, coordination number) and the way induced anisotropy was generated. Qualitative and quantitative relationships were obtained but specific behavior of particles with a higher aspect ratio remained difficult to explain. Moreover, when the phenomena involved in the shear bands of real sands are investigated (Oda and Kazama, 1998), it seems that rotational stiffness at contacts play a major role in strength development in granular materials. This aspect cannot be reflected using elliptical smooth particles. Consequently, in DEM, the use of particles that can develop edge-to-edge contacts seems to be a more appropriate way to model the behavior of a large amount of actual angular soils.

This paper analyzes materials composed of two-dimensional irregular polygonal particles having different aspect ratios, which corresponds to a realistic representation of a large class of real materials considered in civil engineering. Biaxial tests are simulated for different samples generated by dry pluviation of grains within a box. Each sample contains particles whose shapes belong to a group of aspect ratios (1, 1.5, 2 or 3). We investigate the role of inherent anisotropy for each sample by considering different loading directions with respect to bedding. The behavior of granular materials is presented from both a local and a global point of view. Internal variables are introduced to trace the evolution of anisotropy, and considerations with respect to the critical state are derived.

2. Conditions for the numerical simulations

2.1. Numerical context

In this paper, we present some results from two-dimensional distinct element numerical simulations performed with a program based on the *Contact Dynamics* method (Jean, 1995, 1999; Moreau, 1994, 1999). This method, initiated by Cundall and Strack (1979) for granular modelling, consists in computing the evolution of large systems of bodies using time discretization. The constituents of the granular medium are assumed to be rigid grains interacting with each other by contact, with friction or not. At each time step, the position and the velocity of each grain is computed by solving the dynamics equation, taking into account the contact forces between particles and the boundary conditions. Two principal features are peculiar to the *Contact Dynamics* method: firstly, the non-interpenetrability constraints and the Coulomb dry friction law