NUMERICAL INVESTIGATIONS OF MICRO-STRUCTURAL PHENOMENA INSIDE SHEAR LOCALIZATION IN GRANULAR BODIES USING DEM

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Summary The paper deals with discrete simulations of micro-structural phenomena within shear localization in granular bodies. Calculations were performed with the discrete element method. Two boundary value problems with shear localization were considered: biaxial compression and active and passive earth pressure behind a retaining wall. Results were compared with corresponding experiments using a DIC technique and FE results based on a micro-polar hypoplastic constitutive model.

INTRODUCTION

Due to that micro-structural events appearing within shear zones at the level of single grains affect the macroscopic behaviour of granular materials, it is necessary to investigate them and to describe with a mechanical model. The scientific knowledge on internal coherent phenomena at the grain-scale within shear localization is still non-sufficient. The problem of buckled granular columns in dilatant shear zones in sand was indicated by Oda and Kazama [1], [2]. The nature and spatial periodicity of a nonaffine displacement field within shear zones in granular materials was investigated experimentally by Rechenmacher et al. [3]-[5] and Leśniewska and Muir Wood [6] using a DIC technique, and by Uter and Behringer [7] and Leśniewska and Muir Wood [6] using photo-elasticity, and theoretically by Tordesillas et al. [8], [9] using DEM. In turn, Alonso-Marroquin et al. [10] obtained numerically vortices appearing during shearing of an initially dense granular material. The mechanism governing the shear zone dynamics at micro-scale is still not well recognized. In addition, the material behaviour at grain-scale in contractant shear zones has not been investigated at all.

DISCRETE ELEMENT SIMULATIONS

The aim of the paper is to describe the creation mechanism of shear zones at micro-level, which are the fundamental phenomenon in granular materials. The calculations were performed with the discrete element method by using the 3D program YADE developed at University of Grenoble [11], [12], based on the called soft-particle approach (i.e. the model allows for particle deformation, modelled as an overlap of particles). Two boundary value problems with cohesionless sand including shear localization were considered: biaxial compression and active and passive earth pressure behind a retaining wall [13]. We enhanced the program by both arbitrary grain shapes by using symmetric and non-symmetric clusters composed of rigid spheres [14] and grain crushing to model more realistically the sand behaviour. Two different grain contact models were applied: a) linear elastic and b) non-linear one according to Hertz, Mindlin and Deresiewicz. Special attention was paid to the evolution of micro-structure within shear zones (during their initiation, formation and propagation) and to relationships between the self-organization of force chain networks and loaded grain contacts. Several characteristic and remarkable events occurring within shear zones such as: vortices, buckled granular columns, shear micro-bands, alternating periodic dilatant and contractant regions were systematically numerically investigated in order to determine their effect on the width and spacing of shear zones. In analyses, the effect of initial void ratio, grain size, grain size distribution, pressure level and velocity loading was taken into account.
The discrete calculations were carried out in three steps. In the first step, comprehensive simulations of quasi-static homogeneous triaxial tests were carried out to calibrate the discrete model [14]. The discrete simulation results for triaxial compression were compared with the corresponding experimental data from drained axisymmetric triaxial compression tests performed by Wu at Karlsruhe University for real sand [15]. The effect of the grain shape on strength, volume changes, elastic and dissipated energies was determined [14]. In the second step, a detailed discrete analysis of micro-structural phenomena occurring within shear zones was carried out for biaxial compression (with a single shear zone) and earth pressures behind a retaining wall (with a pattern of shear zones). The discrete results were compared with the corresponding experiments [6], [16], [17]. In the third step, comprehensive parametric studies were performed in discrete simulations in order to determine the effect of initial void ratio, mean grain size, grain distribution curve and pressure level on shear resistance and width and spacing of shear zones.
The discrete results were compared with the corresponding FE results carried out with a micro-polar hypoplastic constitutive model which is capable to realistically capture the macroscopic behaviour of granular materials by taking into account shear localization [13]. The micro-polar constitutive law takes into account the effect of density, pressure, direction of deformation rate, mean grain size, grain roughness and grain crushing on the material behaviour [18]-[20]. Due to the presence of a characteristic length in the form of a mean grain diameter, the constitutive model can describe

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the formation of shear zones: their thickness and spacing, and the related size effect. A micro-polar model makes use of rotations and couple stresses, which have clear physical meaning for granular materials. First, the rotations and couple stresses can be observed during shearing and remain negligible during homogeneous deformation. Second, the additional rotational degree of freedom of a micro-polar continuum arises naturally by mathematical homogenization of an originally discrete system of spherical grains with contact forces and contact moments. Thanks to a direct comparison between FEM and DEM [13], it is possible to calibrate more precisely both approaches to simulate shear localization in granular materials.
The discrete results were also compared with the corresponding experiments using the DIC technique [6], [17], [21]. DIC is a well-known velocity measuring non-invasive procedure, originally developed for fluid mechanics and used for the analysis of displacements in tests on soil models. It operates by tracking spatial variations of brightness within an image (divided into a mesh of patches) by comparing successive images so that displacement data can be extracted from sequences of images, and strains then calculated from gradients of measured displacements. Experiments using DIC revealed within granular mass self-organizing force chains systems, vortex structures and alternating contractancy and dilatancy regions within shear bands [6], [17].

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