

Three dimensional particle based modelling of frictional behaviour in shear zones

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Abstract

Three dimensional numerical simulations were conducted by particle based modelling of fracture, flow and comminution of rock to investigate frictional behaviour in shear zones. As the model can simulate the process of fault formations from solid rock mass and the process of flow in the shear zones with gouge layers straightforwardly, frictional behaviour under complex topology of shear layers with gouge materials are naturally represented without artificial prescription. The potential of this model is illustrated by means of a simulation of a tri-axial compression test of rock. Then, a fault formation and frictional behaviour in resultant shear zones can be studied using this model.

Introduction

Fault zones in the Earth consist of materials with varying physical properties. Fault formation process generates significant amounts of structural irregularities, material discontinuities in rock bodies and wear products, such as gouge and breccia. Under large displacement at high stress level, fault zones further evolves by comminution and progressive granulation. Thus, frictional response response in shear zones is not unique but progressive which associated with microstructures evolution and localized shear band formation [1]. A numerical model capable of describing this progressive microstructures evolution should be developed to understand the complex frictional behaviour at macroscopic level. Mora and Place [2] proposed the Lattice Solid Model to investigate the physical processes underlying earthquakes from microstructural point of view coupling with thermal effect due to the friction.

The types of microstructures that form during shear, and the mechanical properties of the gouge, do appear to be strongly influenced by particle size and its distribution [3], [4]. However, previous studies have shown that microstructures depend not only the size but also the shape of the constituent particles [5]. Sakaguchi and Mühlhaus [6] and Mora and Place [2] proposed macro-particles systems, which micro-particles are bonded in a regular triangular lattice with elastic spring to form a highly irregular shape.

Another important fact is that almost all of 3D particle packings are amorphous in sharp contrast to the situation in 2D, where the most packings are polycrystalline [5]. That means three dimensional analysis is unavoidable.

Therefore, we have been developing a three dimensional particle based model to simulate fault formation and frictional behaviour in shear zone straightforwardly depicted in Figure(1).

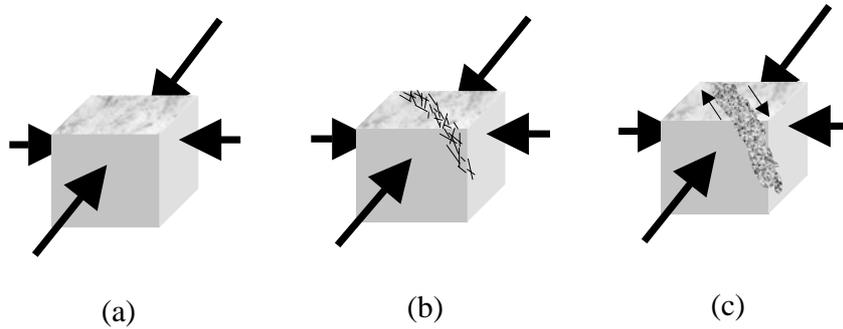


Figure 1: Schematic diagram of fault formation and frictional behaviour in shear zone

DEM model simulating a triaxial compression test

The discrete element method offers the opportunity to study the behaviour of virtual materials, virtual granulates in particular, under the perfectly controlled conditions of the numerical experiment (*e.g.* [7],[8]). The adjustment of the properties of the virtual materials to the properties of a real geo-material is performed conveniently by comparing real and simulated triaxial compression tests. For this purpose, we have established a virtual triaxial compression testing procedure.

The sample specimen can be generated in 3D either by a radius growth strategy for spherical particles or, as described earlier, by generating macro-particles for irregular shaped particles. Both methods can produce isotropic packing with controlled particle size distribution and initial void space.

The virtual specimen is initially isotropically consolidated at a specified, constant confining pressure. During consolidation the radial and vertical displacements at the cylinder and top and bottom surfaces respectively of the specimen are kept uniform by servo control mechanism (Figure 2(a) and (b)). During the actual compression test the axial displacement (Figure 3) at the top surface is increased at constant confining pressure. During this phase the displacement control at the cylinder surfaces is replaced by membrane boundary elements which support the constant confining pressure during monotonically increasing axial compression (Figure 3).

The membrane elements (Figure 2(c)) are defined by particles which are initially positioned loosely around the cylinder surface and are arranged in a lattice of equal sided triangles. The triangles are connected by linear elastic springs. Contact during loading between the membrane particles and the specimen particles are detected and considered by standard discrete element contact detection techniques. The results presented here are snapshots of work in progress. The virtual servo control, the membrane elements, all work very well, however during the simulation the stiffness of the membrane was vastly overestimated (by

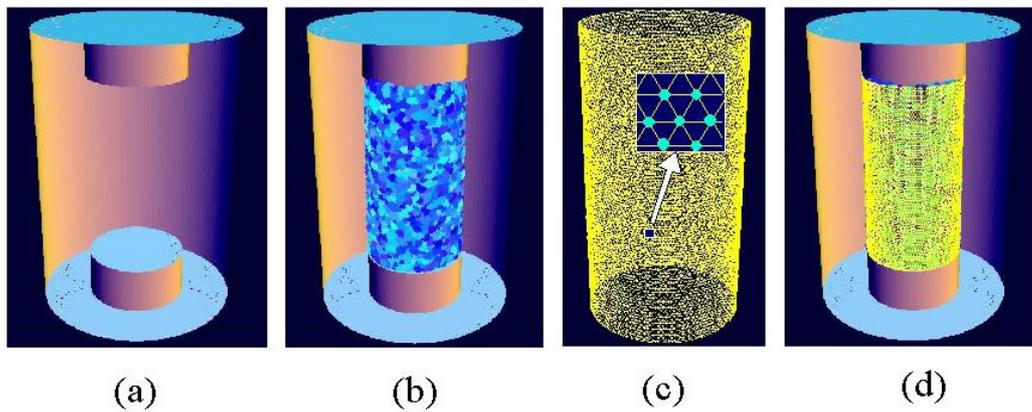


Figure 2: Setup of virtual triaxial compression test. (a) Triaxial compression cell and platen, (b) Specimen under consolidation at isotropic confining pressure, (c) Membrane particles, (d) Specimen covered by membrane.

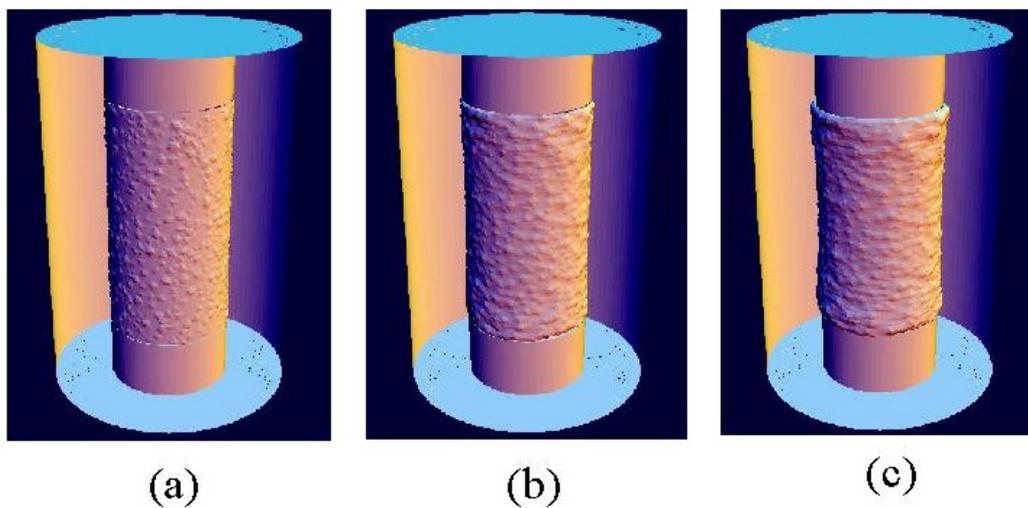


Figure 3: Surface deformation represented by membrane elements. (a) Initial, (b) 1% axial strain, (c) 3% axial strain.

about 10 times) so that the results correspond more what one would expect in an oedometer test (Figure 4) rather than a triaxial compression test. A re-run of these calculations will be presented shortly. Nevertheless the overall deformation pattern looks remarkably realistic. Note the wrinkles appearing with progressive deformation on the membrane surface.

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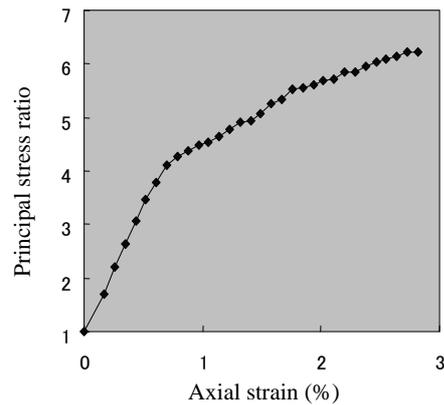


Figure 4: Principal stress ratio *v.s.* axial strain.

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