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A HIERARCHICAL MUTLSCALE APPROACH FOR GRANULAR MEDIA

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The behaviour of granular media is difficult to characterize. Conventional continuum approaches have to assume complicated constitutive models involving model parameters without clear physical meanings and/or difficult to calibrate. While the phenomenological nature of these approaches has been a major drawback, the more fundamental reason lies in their neglect of the underlying microstructural mechanisms originated from the discrete particle scale. Micromechanics-based methodologies, particularly those based on Discrete Element Method (DEM), can help to take into account the particle-level information. They are however unable to provide adequate predictions for practical engineering problems due to excessive computational cost.

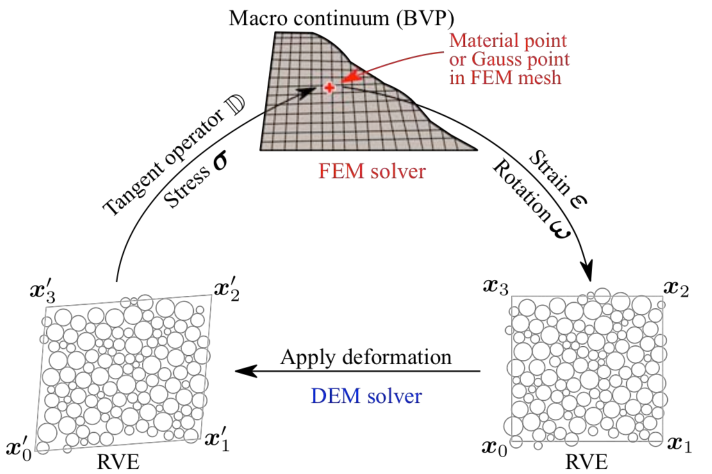

Figure 1. Illustration of the solution procedure of the hierarchical multiscale modelling approach for granular media

In this study, we propose a hierarchical multiscale approach by coupling Finite Element Method (FEM) and DEM to model the boundary value problems (BVPs) of granular media. We discretize the macro-scale domain of a BVP into a FEM mesh, and attach to each Gauss integration point a DEM assembly serving as the representative volume element (RVE). The DEM assembly receives the global deformation from FEM at the specific Gauss point as input boundary conditions and is solved to derive the constitutive relation at the material point required to advance the FEM computation. The multiscale scheme is illustrated in Figure 1. Since the DEM computation employ simple physically-based contact models and Coulomb's friction law and the FEM does not need any constitutive relation, the hierarchical multiscale scheme totally avoids the phenomenological assumptions as conventional FEM does. The approach has been successfully implemented, calibrated and benchmarked against single element tests of sand. We have also implemented effective distributed parallel computing algorithms to enhance its predictive efficiency in solving large scale BVPs.

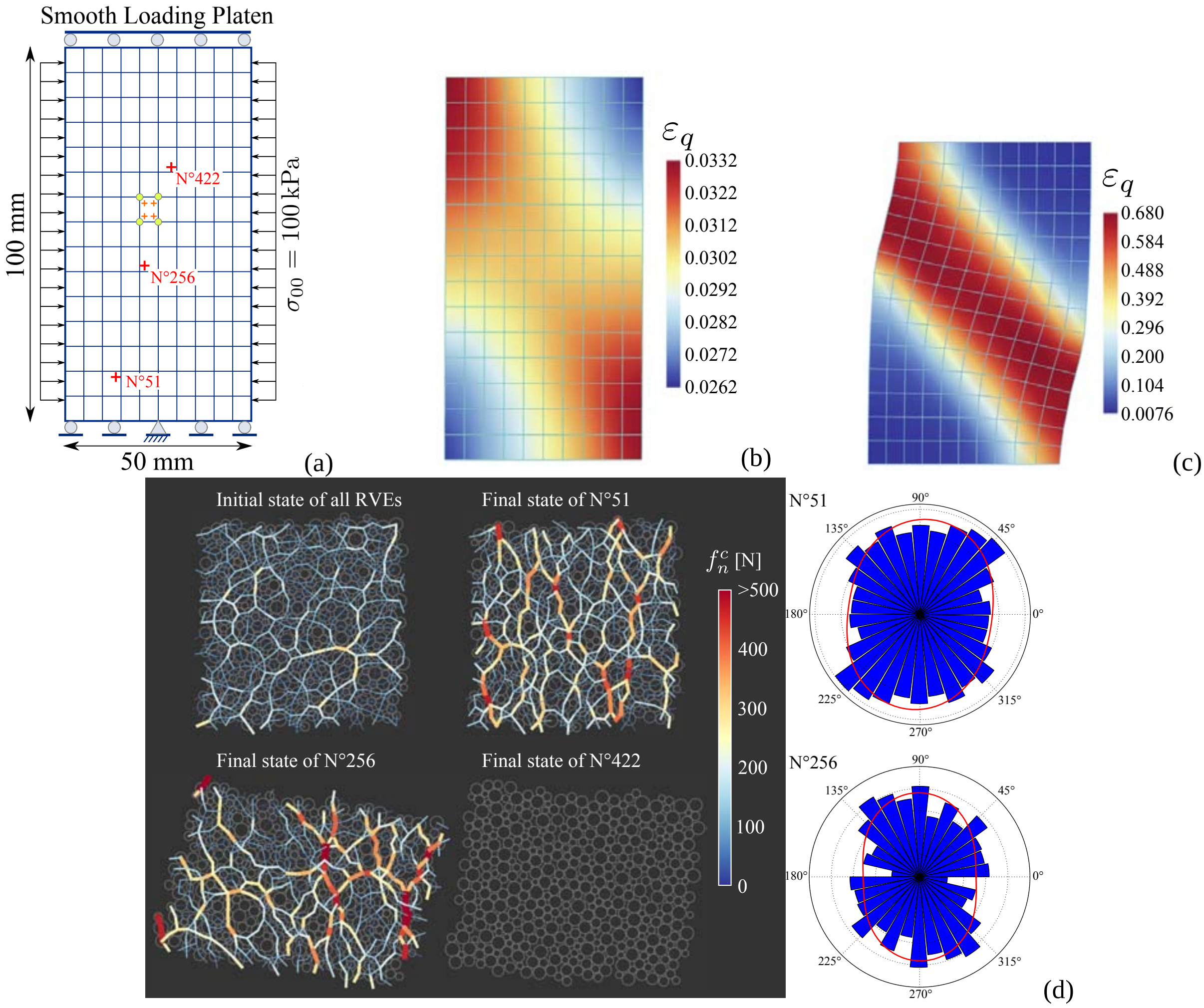

Figure 2. (a) FEM mesh and boundary conditions of a sand sample subjected to monotonic biaxial shear; Accumulated deviatoric strain contours at (b) peak stress state ($\epsilon_y = 1.6\%$) and (c) final state ($\epsilon_y = 10\%$); (d) Internal contact force networks and fabric anisotropy at the initial and final states for different Gauss points.

The proposed multiscale approach has been first applied to the simulation of a sand sample under monotonic biaxial compression (see Fig. 2a). The multiscale simulation captures an obvious shear band localization (Figs. 2b & 2c) at symmetric boundary and loading conditions which otherwise is impossible for conventional models, and meanwhile provides detailed microstructural information for different material points in the sample for insightful analysis (Fig. 2d). The proposed method is further compared with existing studies [1-3].

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