MULTISCALE FRAMEWORK FOR MODELING MECHANICAL BEHAVIOR OF GRANULAR MATERIALS

Xuxin Tu and José E. Andrade
Department of Civil and Environmental Engineering,
Northwestern University, 2145 Sheridan Road, Evanston, IL 60208

INTRODUCTION

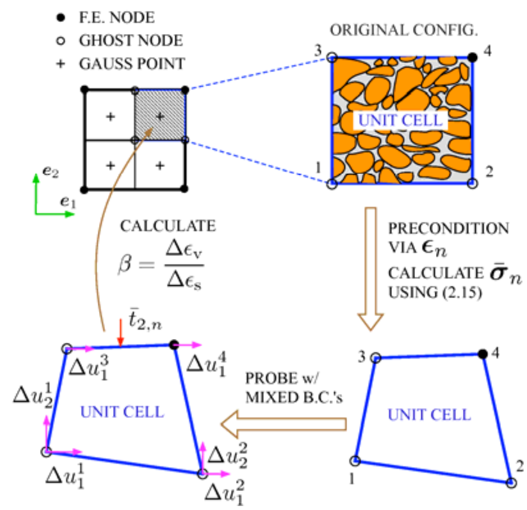
Granular matter is ubiquitous and appears in a plethora of presentations including sands, sandstones, concrete, pharmaceutical pills and nanoparticles. The macroscopic response of granular matter is governed by relative particle rolling and sliding, fabric rearrangement, force chain forming and breaking, bond breakage or grain crushing under extreme conditions, etc. Conventionally, these complex yet crucial microscopic features are smeared into plasticity models that have been widely used for modeling granular materials. These continuum-based models are capable of capturing many important features of granular materials. However, they generally are subject to two limitations. First, most plasticity models are phenomenological, meaning that the devised constitutive relations are based on limited observations and thus are short of general applicability. Second, due to the lack of a fundamental scale length, these continuum-based models easily lose their strength when simulation involves strain localization and discontinuities, commonly encountered in post-failure behavior of granular materials.

The aforementioned issues can be effectively addressed using microscale models. For granular materials, the discrete element method (DEM) has been widely used (1). Like most microscale models, DEM is computationally expensive and most granular systems are far too large to permit a complete DEM description. To make such problems computationally tractable, the microscale model must be applied to the area of highest concern, e.g., deformation band or fracture front. The remainder of the domain, which is less critical, should be modeled using a continuum-based (macroscale) method with less computational effort, e.g., plasticity models and FEM. This multiscale approach has been under constant development for modeling metals and composites. Up to now, however, an effective multiscale framework is still in need for simulating granular matter, partially due to the complexity of the material.

FRAMEWORK

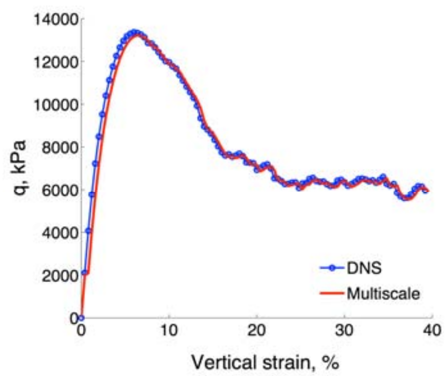
Here we present a multiscale framework for granular materials (2). Without loss of generality, FEM is chosen as the global solver, a Drucker-Prager plasticity model serves as the macroscale model and DEM serves as the microscale model. However, the framework is not limited to any of these components. The key is how to link the macroscale with the microscale. In some other multiscale approaches, the microscale model is used to update stresses directly, literally replacing a conventional constitutive law. Since the response of the microscale model is typically nonsmooth, this approach generally suffers from convergence problem in an implicit FEM solver (3). In our framework, the microscale model is only employed to update the key parameters involved in the macroscale model. For granular materials, it has been shown that the friction resistance and dilatancy are key parameters that govern the overall mechanical response (2). The direct extraction of them from the underlying micromechanics effectively bypasses the phenomenology of the macroscale model.

The following figure presents a schematic illustrating how to extract the key parameters from grain scale. More details are given in (2).



RESULTS

The following figure shows an example wherein the stress-strain responses computed from the direct numerical simulation (DNS) and the multiscale computation are compared (3). It is clear that the multiscale method is able to faithfully recover the underlying microscale model, despite the presence of the nonsmooth behavior.



The proposed method is amenable to coupling with discrete microscale models, as well as high-fidelity experiments. It has been applied to a variety of loading conditions, ranging from triaxial compression to triaxial extension to plane strain to full-blown boundary value problems where shear banding is observed (2).

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ACKNOWLEDGMENTS

Support for this work was provided in part by NSF grant number CMMI-0726908 and AFOSR grant number FA9550-08-1-1092 to Northwestern University. This support is gratefully acknowledged.