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14. ABSTRACT Shear bands are a critical factor in the response of granular materials, such as soils, rocks, and concrete. The objective of this research is to develop methods for accurately predicting the onset and propagation of deformation bands in granular media under extreme environments by developing an efficient multiscale simulation framework. The goal is to bridge continuum scale methods with the existing discrete methods to obtain an accurate multiscale model that can be used to predict and model shear band inception and propagation in granular media. Fundamental understanding of granular mechanics under shear banding will pave the way to tackling more challenging phenomena such as projectile penetration and blasting.						
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MULTISCALE PREDICTION AND SIMULATION OF LOCALIZATION BANDING IN GRANULAR MEDIA

FA9550-08-1-0192

José E. Andrade
Division of Engineering and Applied Science
California Institute of Technology, CA

Ted Belytschko
Department of Mechanical Engineering
Northwestern University, Evanston, IL

Abstract

Shear bands are a critical factor in the response of granular materials, such as soils, rocks, and concrete. The objective of this research is to develop methods for accurately predicting the onset and propagation of deformation bands in granular media under extreme environments by developing an efficient multiscale simulation framework. The goal is to bridge continuum scale methods with the existing discrete methods to obtain an accurate multiscale model that can be used to predict and model shear band inception and propagation in granular media. Fundamental understanding of granular mechanics under shear banding will pave the way to tackling more challenging phenomena such as projectile penetration and blasting.

Status/Progress

A key component for the success of the multiscale scheme is the ability to extract the continuum behavior directly from the granular scale. To achieve this goal, a number of objectives have been successfully achieved: 1. The design and implementation of a semi-concurrent multiscale scheme to extract material behavior from the granular scale and pass it onto the continuum scale [1], 2. The creation of a novel semi-implicit return mapping algorithm to enable the semi-concurrent multiscale computations [2], 3. Development of constitutive models capable of capturing rate effects [3], 4. Design and implementation of parallel algorithms to perform multi-unit cell calculations [4, 6]. In addition to these achievements, final efforts focused on crucial aspects dealing with the development of a new hierarchical multiscale method amenable to direct linkage with experimental and numerical granular kinematics [6], and the development of multiscale failure modeling methods linking assumed enhanced strain (AES) finite elements [5] with discrete element calculations. In this final report for this project, we focus on the overall achievements.

Perhaps the two most important achievements in this project were: 1) development of the first predictive (validated) multiscale method for failure modeling in granular materials and 2) multiscale enhancement of existing failure modeling techniques such as Assumed Enhanced Strains (AES) to accurately model multiscale failure in granular solids. These

achievements enabled us to accomplish the goals proposed for this project, which are shown pictorially in Figure 1.

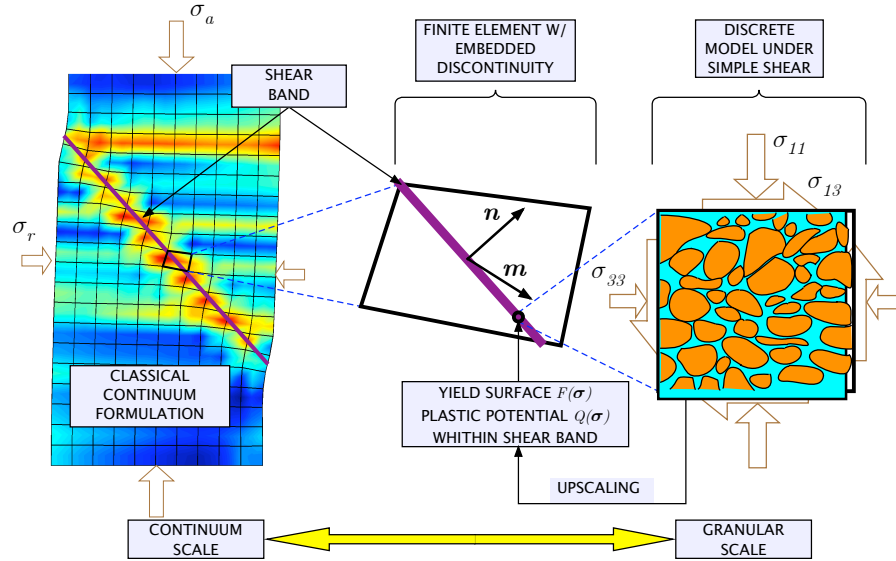


Figure 1. Schematic of proposed research and its main goal: to enhance elements with embedded discontinuities within a multiscale framework connecting continuum and granular scales.

To showcase the aforementioned achievements, we will focus on the last publication conceived during this project [5]. In this paper, we developed a new Assumed Enhanced Strain (AES) technique, using an original formulation proposed in [7]. The original formulation enriched elements but could not describe plasticity inside shear bands accurately. Our new method accesses the granular scale to enhance the constitutive description at the AES continuum level. Figure 2 shows an example of simulations performed using discrete mechanics and compared with simulations using the AES multiscale technique.

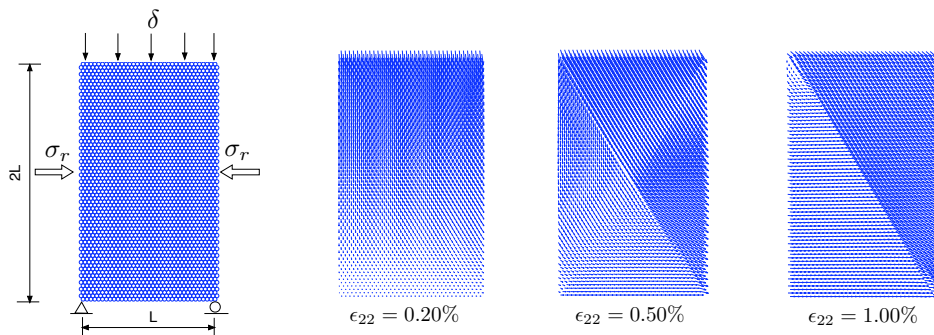


Figure 2. Sample (left) composed of regularly packed granular materials under plane strain compression. A shear band develops when vertical strain is about 0.5%, with this shear band dominating the process for the duration of the discrete element simulation.

We used our proposed AES technique to simulate the aforementioned sample of granular material under the same boundary conditions. Figure 3 shows the results using a triangular irregular mesh enhanced with AES elements that have multiscale capabilities to describe the constitutive response based on the grain scale mechanics. This figure also shows a comparison between the global stress-strain responses between the multiscale AES and the direct numerical simulation using discrete mechanics (DEM). Clearly, the method is able to capture the most salient features related to overall strength of the sample and the topology of the shear band.

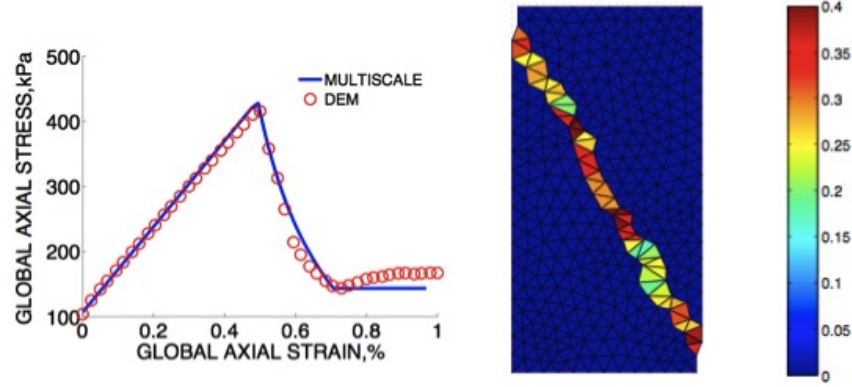


Figure 3. Results comparing multiscale AES with direct simulations using discrete mechanics (DEM).

Finally, we have shown that the method can be validated using actual experiments. This is the first method of its kind to be ever compared with actual physical experiments. In reference [5], we compare the multiscale AES method with physical experiments on sands where a dominant shear band was observed. Micromechanical information measured during the test was used to construct the hierarchical multiscale AES calculation. Figure 4 shows the results of the multiscale AES prediction compared with experimental data. It can be seen that the method clearly captures the macroscopic response of the sample accurately.

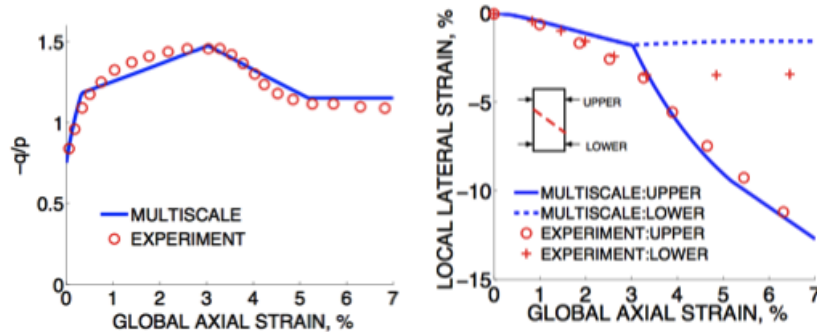


Figure 4. Comparisons of multiscale AES with physical experiments where a dominant shear band was observed.

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Personnel Supported During Duration of Grant

J. E. Andrade	Associate Professor, Caltech, Pasadena, CA
T. Belytschko	Professor, Northwestern University, Evanston, IL
X. Tu	Post-Doctoral Fellow, Northwestern University, Evanston, IL
C. F. Avila	Post-Doctoral Fellow, Caltech, Pasadena, CA
Q. Chen	Ph.D. Candidate, Northwestern University, Evanston, IL

Publications

- J. E. Andrade. Predictive framework for multiscale computations in granular media. In B. A. Schrefler and U. Perego, editors, *WCCM8 and ECCOMAS 2008*, Venice, Italy, in CD ROM (2008).
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Honors & Awards Received

- ASCE's Arthur Casagrande Professional Development Award, 2011
- AFOSR Young Investigator (YIP) Award, 2010
- NSF CAREER Award, CMMI Division, 2010
- Natural National Science Foundation Young Researcher Fellowship, China, 2009
- U.S. National Academy of Engineering Frontiers of Engineering Symposium, participant, Albuquerque, NM (2008)
- USNC/TAM Fellowship, International Congress in Theoretical & Applied Mechanics, Adelaide, Australia (2008)
- USACM Fellowship, 8th World Congress in Computational Mechanics, Venice, Italy (2008)

AFRL Point of Contact

William L. Cooper, PhD
Air Force Research Laboratory
AFRL/RWMW

Transitions

None.

New Discoveries

Discovered efficient and accurate numerical algorithms for multiscale analysis of failure in granular solids. Discovered a set of parameters that are key in capturing the behavior of granular materials under plastic deformation. These discoveries are relevant and easily transferable to other solid materials where multiscale deformation and failure takes place.