Accepted Manuscript

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Matthew R. Kuhn, Ali Daouadji

PII: S0022-5096(17)30972-9
DOI: 10.1016/j.jmps.2018.02.019
Reference: MPS 3293

To appear in: *Journal of the Mechanics and Physics of Solids*

Received date: 28 October 2017
Revised date: 24 February 2018
Accepted date: 28 February 2018

Please cite this article as: Matthew R. Kuhn, Ali Daouadji, Quasi-static Incremental Behavior of Granular Materials: Elastic–Plastic Coupling and Micro-scale Dissipation, *Journal of the Mechanics and Physics of Solids* (2018), doi: 10.1016/j.jmps.2018.02.019

Quasi-static Incremental Behavior of Granular Materials: Elastic–Plastic Coupling and Micro-scale Dissipation

Matthew R. Kuhn[a,*], Ali Daouadji[b]

[a] Br. Godfrey Vassallo Prof. of Engrg., Donald P. Shiley School of Engrg., Univ. of Portland, 5000 N. Willamette Blvd., Portland, OR, USA 97231
[b] University of Lyon, INSA-Lyon, GEOMAS, F-69621, France

Abstract

The paper addresses a common assumption of elastoplastic modeling: that the recoverable, elastic strain increment is unaffected by alterations of the elastic moduli that accompany loading. This assumption is found to be false for a granular material, and discrete element (DEM) simulations demonstrate that granular materials are coupled materials at both micro- and macro-scales. Elasto-plastic coupling at the macro-scale is placed in the context of thermomechanics framework of Tomasz Hueckel and Hans Ziegler, in which the elastic moduli are altered by irreversible processes during loading. This complex behavior is explored for multi-directional loading probes that follow an initial monotonic loading. An advanced DEM model is used in the study, with non-convex non-spherical particles and two different contact models: a conventional linear-frictional model and an exact implementation of the Hertz-like Cattaneo–Mindlin model. Orthotropic true-triaxial probes were used in the study (i.e., no direct shear strain), with tiny strain increments of 2×10^{-6}. At the micro-scale, contact movements were monitored during small increments of loading and load-reversal, and results show that these movements are not reversed by a reversal of strain direction, and some contacts that were sliding during a loading increment continue to slide during reversal. The probes show that the coupled part of a strain increment, the difference between the recoverable (elastic) increment and its reversible part, must be considered when partitioning strain increments into elastic and plastic parts. Small increments of irreversible (and plastic) strain and contact slipping and frictional dissipation occur for all directions of loading, and an elastic domain, if it exists at all, is smaller than the strain increment used in the simulations.

Keywords: Granular material, plasticity, incremental response, stiffness, discrete element method

1. Introduction

We use discrete element (DEM) simulations to address the micro-scale nature of elastic and plastic deformation in granular materials, and to determine possible coupling of the

*Corresponding to: Donald P. Shiley School of Engineering, University of Portland, 5000 N. Willamette Blvd., Portland, OR, 97203, USA. Email: kuhn@up.edu

Email addresses: kuhn@up.edu (Matthew R. Kuhn), ali.daouadji@insa-lyon.fr (Ali Daouadji)