Non-Invasive, Photochromic-Tracer Studies of Particulate Suspensions and Granular Media

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The subject research is being carried out by the research group of the P.I., including the efforts of a Postdoctoral Research Engineer, Dr. Florence Cantelaube, who recently received her Ph.D. in Physics from the University of Rennes, France, and an undergraduate Laboratory Assistant, Mr. Ben King, a Senior majoring in Chemical Engineering, at UCSD. Both are supported by grants other than the subject AASERT award.

Efforts are being made to identify an AASERT Graduate Fellow during the upcoming academic year 1996-97. We have achieved almost perfectly transparent dispersions of photochromic glass particles in ZnCl solutions are currently developing optics to focus a UV beam in the dispersion. Also, efforts are being made to dope polymeric beads with an organic (pyrospyran) dye.
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Mechanics, Transport Properties and Statistical Physics
of Granular Media and Geomaterials

Submitted
to

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SUMMARY

This is a summary of research performed under the subject AFOSR grant on the micromechanics, continuum mechanics and transport properties of granular media and geomaterials. It has involved the development of new theoretical models of microstructure, numerical simulation of granular assemblages, and experimental observation on model systems. The overall goal of the work is to provide a sound microstructural basis for understanding continuum behavior and elucidating structurally and geologically important phenomena such as the propagation of acoustic and seismic waves, the quasi-static yield of granular media, the structural stability of soils and their liquefaction, and the non-invasive testing of geomaterials.

The three and one half year effort has involved the Principal Investigator, a postdoctoral research associate, one Ph.D. research assistant and various M.S. research assistants supported in part by the AFOSR grant. This has involved the development and application of an improved computer simulation for idealized granular assemblages to the prediction of dilatancy, scalar conductivity and yield surfaces, continuing development of experimental methods for granular media, and the inception of related work on continuum-mechanical mixture theories for fluid-particle systems and porous media.

RESEARCH ACTIVITY AND OBJECTIVES

The specific research activities and goals of the research are summarized here:

(1) Micromechanical Analysis of Granular Media and Geomaterials

The research has involved a continuing effort to apply various analytical methods, such as discrete-element and network representations, together with standard homogenization techniques, such as effective-medium or self-consistent techniques, to infer continuum response from microstructure and micromechanics. The goal is understanding and modelling of the quasi-static mechanical response and transport properties of granular media and fractured or jointed geomaterials.

(2) Large-scale Numerical Simulations of the Quasi-Static Mechanics of Granular Assemblages

This effort is aimed at applications of a computational method developed earlier in this research program. A major objective is to investigate the effects of evolving particle-contact topology on dilatancy and on other mechanical and transport properties in frictional-elastic particle assemblages. A related goal is to simulate the plastic response of such assemblages in complex loading paths, as a guide to the development of continuum plasticity theory for granular media and geomaterials.

(3) Development of Experimental Methods

Part of the current effort has involved the development and application of a novel test cell for conductive granular materials which allows one to monitor stress and electrical conductivity simultaneously. Also, as part of an effort launched under a companion AFOSR AASERT Fellowship award, we have worked on the development of transparent, refractive-index matched fluid-particle dispersions with UV-excitable photochromic-dye doped particles, to permit non-invasive study of the kinematics in fully 3D granular assemblages and particulate suspensions.

ACCOMPLISHMENTS AND PROGRESS

Research Accomplishments

Following is a summary of the major research accomplishments to date, together with a listing of publications, related activities and personnel:
(1) Numerical Simulation and Theoretical Analysis of Reynolds Dilatancy and Plastic Yielding in Idealized Granular Assemblages

A new method has been developed for the computer simulation of the quasi-static mechanics and conductivity of frictional-elastic sphere assemblages, the subject of several reports, conference presentations and publications cited below [J2,C2,C3,R1,R2,T1,T4,T11]. As discussed there, the simulations show quite good agreement with experiments on an idealized granular medium consisting of a stainless steel ball bearing assemblage. As a recent effort over the past few months, the above computer simulation has been applied to the calculation of yield surface evolution for assemblages of rigid frictional spheres subject to elementary proportional loading histories, including uniaxial compression, pure shear (planar uniaxial compression), and equi-biaxial compression (uniaxial extension), as well as simple shear. We have investigated the effects of initial density (void ratio), polydispersity (unequal sphere sizes), intergranular friction and total plastic strain. Remarkably, the simulations indicate an asymptotic approach to the empirical Lade-Duncan yield surface of soil-mechanics at plastic strains of only a few (ca. 5) percent. Also, it is found [T12, T13] that the purely theoretical kinematic estimate of dilatancy based on a network model proposed by one of us [C1, T2,T3] for the limit of zero friction provides a reasonable upper bound for the uniaxial strength of frictionless, monodisperse assemblages. In a publication now in preparation [J5], we show how these findings may point the way to a rational, semi-theoretical predictive scheme for the plastic yield strength of granular media, based on relatively simple modifications of the classical Rowe stress-dilatancy model for rigid particle assemblages.

(2) Development of Experimental Methods

A small triaxial cell, with provision for stress and electrical conductivity measurement as well as for pore liquid monitoring and control was developed. This cell has been employed in the studies discussed above on steel ball assemblages without liquid. With a view towards future studies of conductive granular material, a low-cost commercial source has been identified for low-cost, extremely hard metallic spheres, which may not be as susceptible to plastic yielding at the contact points as the steel balls employed in our current research [J2,R1,R2].

Progress on the development of the photochromic tracer technique has been somewhat sporadic. We have been able to synthesize a kind of "photochromic sand" by crushing photochromic glass (provided by the Corning Company), of the type which darkens on exposure to W (as in sunglasses, automotive sunscreens, etc.), but the darkening is rapid and impedes deep penetration of the excitation UV beam. Also, initial attempts to impregnate commercially available acrylic beads with an organic photochromic dye (a spiropyran) have not been successful, suggesting that synthesis of dye-containing beads may be necessary. At present, the P.I. is recruiting a highly qualified Ph. D. candidate to continue the work under a companion AFOSR AASERT fellowship grant.

(3) Related Studies on Fluid-Particle Systems

As independent but related research, Dr. Didwania has carried out theoretical studies of fluid-particle suspensions [J3,J4]. Also, Professor Reint de Boer, from the University of Essen, Civil Engineering, supported by the German VW Stiftung in the period September 1994-March 1995, worked with us on the foundations of continuum mixture theory with a view towards application to two-phase particle-fluid systems, including porous media, fluid-saturated granular media and fluidized particulate beds.

Personnel

Supported in part by grant:
  J.D. Goddard, Principal Investigator (1991-)
  A.K. Didwania, Research Scientist/Scholar (1992-)
  Laura Nett, Graduate Research Asst. and AFOSR AASERT Fellow (Summer 1993)
  Maria Guevara, Graduate Research Asst. and AFOSR AASERT Fellow (Fall 1993)

Other:
  Monica Orsiki, Graduate Independent-Study Student (1994; French Diplome d'Etudes Avancees completed 1994)
  Reint de Boer, Prof. Civil Eng., U. of Essen, Visiting VW Stiftung Research Scholar (9/94-3/95)
Publications*

Refereed Journals

Completed:


In Preparation:


Conference Proceedings and Book Chapters


Dissertations and Reports


* Publications tangentially related to the present research and acknowledging partial AFOSR support
Interactions

Conference Presentations


T6. (videotape presentation) "Numerical Simulation of the Micromechanics of Granular Assemblies" by X.Zhuang and J.D.Goddard, Session "Rheology in Motion", 65th Ann. Society of Rheology Meeting, Boston, October 17-21, 1993


Consultative Advisory Functions and Professional Activities of P.I., J.D. Goddard

Continuing:

Editorial Board, J. Non-Newtonian Fluid Mech. (Elsevier), 1976-

American Institute of Chemical Engineers, National Fluid Mechanics Programming Committee, 1985-


Initiated during current AFOSR Grant activity:

National Aeronautics and Space Administration, Discipline Working Group for Fluid Physics, 1992-

Chair, Session EC4, Biomechanics, 18th International Congress on Theoretical and Applied Mechanics (ICTAM), Haifa, Israel, 22-28 August 1992.

Session Chair, Suspensions (G), 11th International Congress on Rheology, Brussels, Belgium, 17-21 August 1992.


Technical Program Committee Member, 2nd International Conference on Discrete Element Methods, Sponsored by AFOSR, USBM and Intelligent Systems Laboratory, M.I.T., 18-19 March 1993.


Co-Organizer (with B.D. Coleman), workshop on material instabilities, Sacramento, CA, 7-8 October 1995 (Sponsored by the Society of Rheology, the National Science Foundation and the UCSD Institute for Mechanics and Materials).


Technical Program Committee and Session Chair, 67th Ann. Soc. of Rheology Meeting, Sacramento, CA, 8-12 October 1996


Technical Program Committee, 12th Internat. Congress Rheology, Quebec City, Canada, August 1996


Editorial Board, International Journal of Engineering Science (Elsevier), 1995-

Honors/Awards