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13. ABSTRACT *(Maximum 200 words)*

The main research objective is to investigate the microscopic origins of shear band instability in particulate media. Our methodology combines computational micromechanics, laboratory experiments, and continuum mechanics. The particular research objective are (1) to improve the existing methods of computational micromechanics, (2) to examine the formation of shear bands, (3) to investigate the effects of grain rotation on shear strength and shear bands, (4) to study liquefaction instability, and (5) to explore the micro-macro mechanics transition relevant to material instability. Stereophotogrammetry was found to yield an accurate measurement of the motion of a large number of particles of idealized granular media. The stereo-technique was capable of determining not only the displacement and rotation of particles, but also their relative penetration. This optical technique was found to be more accurate than the present computer vision methods being processed, are to be used to re-examine the findings about the effects of higher-order continua on the response of granular media, and are therefore instrumental to understand the instability phenomena in granular media.

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A Micromechanical Investigation of Instability in Particulate Media

Principal Investigator: J. P. Bardet

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TABLE CONTENTS

1. Objectives of Research Effort

The main research objective is to investigate the microscopic origins of shear band instability in particulate media. Our methodology combines computational micromechanics, laboratory experiments, and continuum mechanics. The particular research objectives are (1) to improve the existing methods of computational micromechanics, (2) to examine the formation of shear bands, (3) to investigate the effects of grain rotation on shear strength and shear bands, (4) to study liquefaction instability, and (5) to explore the micro-macro mechanics transition relevant to material instability.

2. Status of Research Effort

The third and final year of the research project was dedicated to the development of experimental facilities and methods in order to support the previously obtained analytical and numerical findings on strain localization in idealized granular media. The research activity included (1) the construction of the experimental setup for loading specimens of idealized granular media in the laboratory, and (2) the stereophotogrammetric measurement of the displacement and rotation of particles. Most of this research was conducted at the University of Southern California, with the exception of the stereophotogrammetric measurements which were carried out at the Joseph Fourier University, in Grenoble, France. Stereophotogrammetry was found to yield an accurate measurement of the motion of a large number of particles of idealized granular media. The stereo-technique was capable of determining not only the displacement and rotation of particles, but also their relative penetration. This optical technique was found to be more accurate than the present computer vision methods based on cross-correlation techniques. These accurate experimental results, which are still being processed, are to be used to re-examine the findings about the effects of higher-order continua on the response of granular media, and are therefore instrumental to understand the instability phenomena in granular media.

3. Accomplishment and New findings

a. Accomplishment

Computer simulations of idealized granular media have been extensively used to investigate the mechanical behavior of real granular media (e. g., Bardet and Proubet, 1992; and Bardet, 1994). However, most computer simulations have physical and numerical limita-

tions, which raise legitimate concerns about the validity of their conclusions (e. g., Bardet and Proubet. 1991). The present research relies on an experimental technique, namely stereophotogrammetry (Desrues. 1984). to measure the motion of a large number of particles subjected to axial compression in the laboratory. Stereophotogrammetry is used to track the motion of about one thousand particles whose similar shapes make them difficult to distinguish using ordinary visual techniques. Figure 1 shows the experimental setup and a sample of idealized granular material axially loaded in the laboratory. and Fig. 2 shows the corresponding stress-strain response.

As shown in Fig. 3. stereophotogrammetry represents the motion of particles as a three-dimensional false relief. Particle rotations appear as slanted disks. and discontinuous displacements as cliffs. Clusters of particles translating uniformly appear as flat plateaus, and rotating clusters as slanted plateaus.

Stereophotogrammetry was found to measure accurately the motion of a large number of particles of idealized granular media. It determines not only the displacement and rotation of particles, but also their relative penetration. Figure 4 shows the displacement and rotation of particles between Steps B3 and B4 in Fig. 2. The displacement vectors and rotations clearly exhibit strain localization. and confirm the concentration of particle rotation within shear bands.

Based on these accurate experimental results, one can re-examine the conclusions of previous investigations which were largely based on computer simulations (Bardet and Proubet. 1992; and Bardet. 1994), including the structures of persistent shear bands, the volumetric response inside and outside shear bands, the concentration of particle rotation with localized deformation. the distribution of contact orientation. and rolling and sliding contacts.

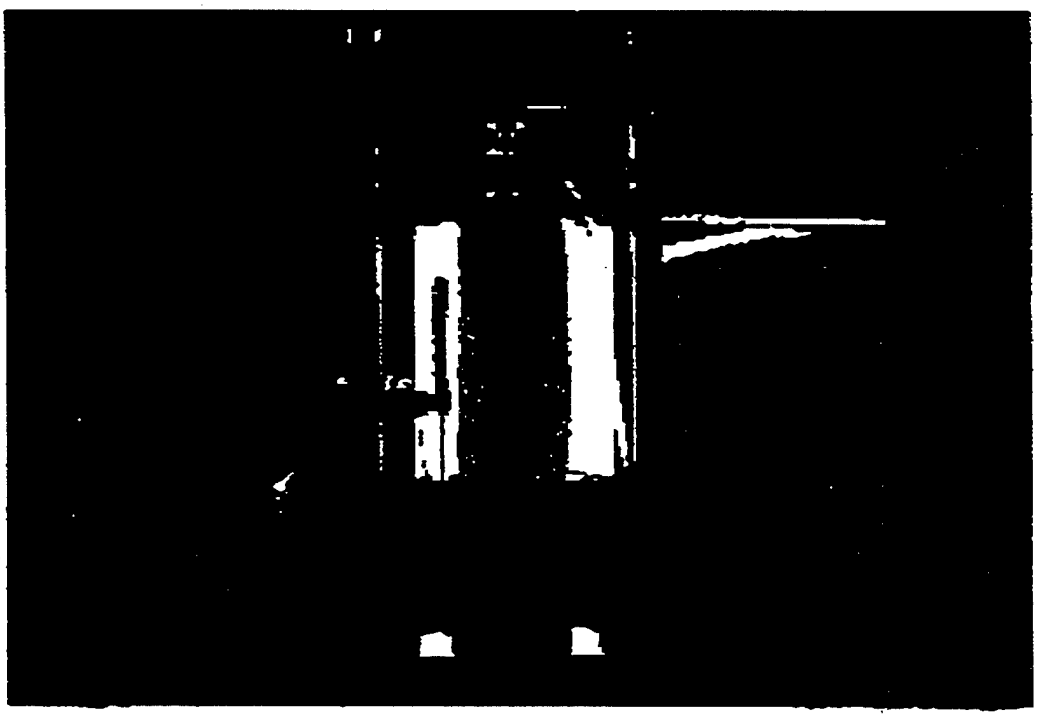

Figure 1. Experimental setup for axial compression of idealized granular materials.

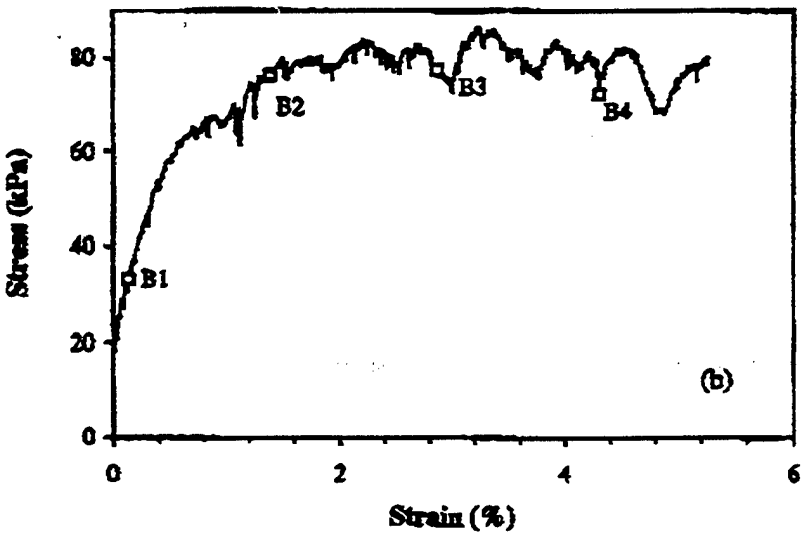

Figure 2. Axial stress-strain response of sample of idealized granular material.

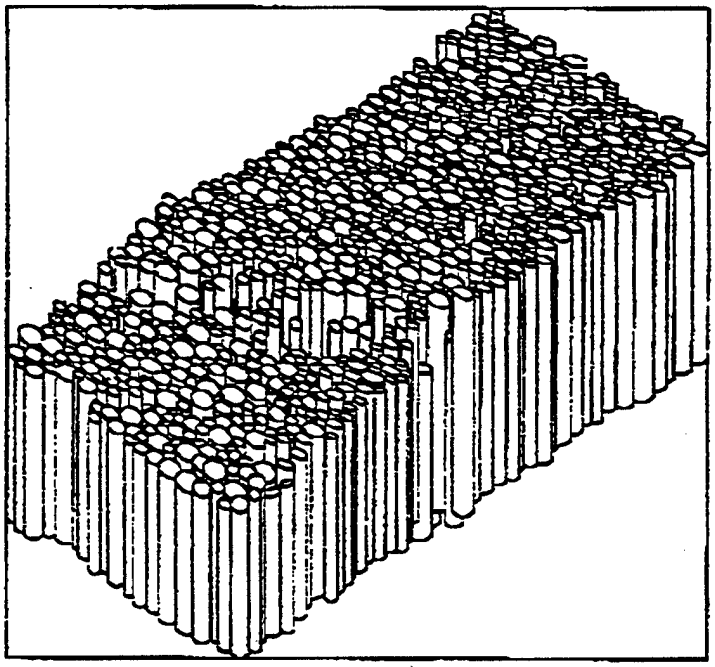

Figure 3. Displacement and rotation of particles visualized by stereophotogrammetry.

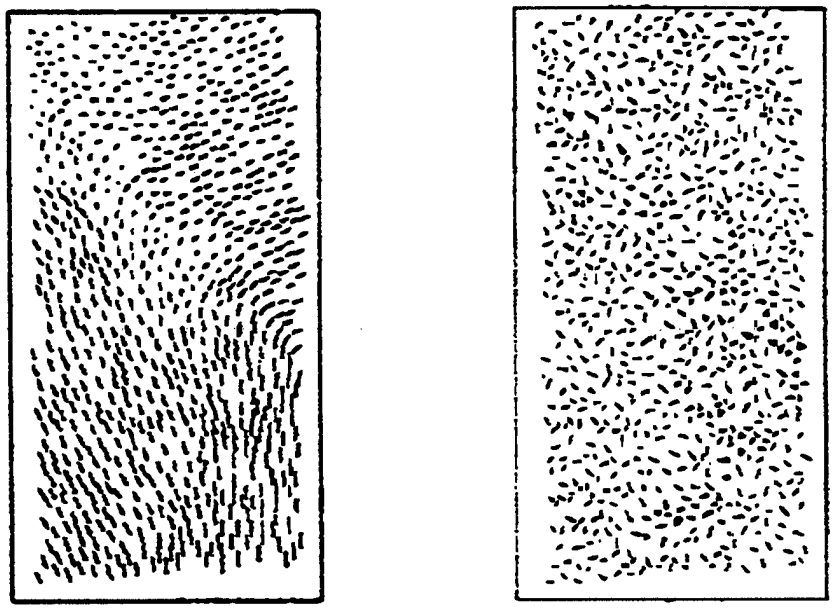

Figure 4. Motion of 1000 particles between steps B3 and B4 of Fig. 2 as determined from stereophotogrammetry: (a) displacement and (b) rotation of particles.

b. References

1. Bardet, J. P., and Proubet, J., 1991, "An adaptative relaxation technique for the statics of granular materials," *Computers and Structures*, Vol. 39, pp. 221-229.

2. Bardet, J. P., and Proubet J., 1992, "A numerical investigation of the structure of persistent shear bands in granular media." *Géotechnique*, Vol. 41, pp. 599-613.

3. Bardet, J. P., 1994, "Observations on the effects of particle rotations on the failure of idealized granular materials," *Mechanics of Materials*, Vol. 18, pp. 159-182.

4. Desrues, J., 1984, "Localization de la déformation plastique dans les matériaux granulaires," Thèse d'état, Université Joseph Fourier, Grenoble, France.

c. Relevance to Air Force's mission

This experimental investigation is relevant to the Air Force's mission. It is useful to understand the behavior of granular materials in airfield pavement. The application of stereophotogrammetry for displacement measurement is not only useful to track the displacement of material particles in the laboratory, but is also applicable to measure the deformation and damage to larger facilities (e.g., airfields) after being subjected to explosions. From the point of view of resolution and accuracy, the optical technique used in this investigation is still ten times higher than that of existing computer vision systems based on cross-correlation techniques. However, in view of the rapid and recent progress in high resolution digital cameras, there is great potential in combining the advantages of stereophotogrammetry and computer vision.

4. Personnel Supported

There are two persons working on this project. The principal investigator – J.P. Bardet – is assisted by one undergraduate student -- Julie Young, a senior in Civil Engineering at the University of Southern California. Julie is a US citizen. She is supported by an AASERT grant (F49620-95-1-0420) which extends the present grant.

5. Publications

1. Bardet, J. P., J. Young and J. Desrues," Stereophotogrammetric Investigation of the Kinematics of Idealized Granular Media," to be submitted to Géotechnique.

6. Interactions/Transitions

a) The research results will be presented at forthcoming international conferences.

b) No consultative and advisory functions to AF or DoD laboratory to report.

c) No transitions to report.

7. Papers Presented at Meetings and Conferences

The research results will be presented at forthcoming international conferences.

8. New Discoveries, Inventions, or Patent Disclosures

None to report.