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THE JOHN A. BLUME EARTHQUAKE ENGINEERING CENTER

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING, STANFORD UNIVERSITY

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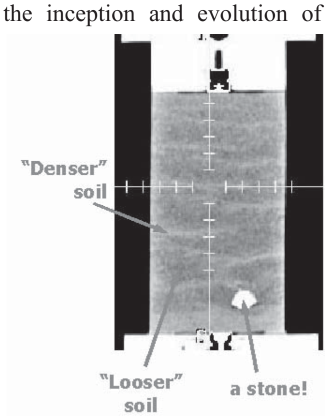
New Projects on Strain Localization Research

Two new research projects begin this year on strain localization in geomaterials, both under the direction of Prof. Ronaldo Borja. The first project is titled "Collaborative research: Experimental imaging-finite element modeling of strain localization in granular soils" in collaboration with Assistant Professor Amy Rechenmacher of Johns Hopkins University, funded by the Civil and Mechanical Systems Division of National Science Foundation. In this research, the Johns Hopkins group will utilize advanced imaging techniques commonly used in medical science to describe quantitatively the spatial density variation in soil specimens, while the Stanford group will use these measurements as input into a mesoscale finite element model for understanding the inception and evolution of shear bands. The second project is titled "Three-invariant non-coaxial plasticity modeling and its implications on the localization properties of rocks" funded by the Division of Chemical Sciences, Geosciences, and Biological Sciences, Department of Energy. The project aims at investigating the microstructural effects on the localization properties of rocks, as well as modeling the propagation of the ensuing deformation bands through these materials. The DOE project has energy-related applications in tune with the Civil and Environmental Engineering Department's current thrust on engineering for sustainability.



X-ray computer tomography (X-ray CT) scan of a soil specimen for input into a strain localization finite element model.

AUTUMN 2003 GRADUATES

The following students graduated in the Autumn quarter with a Master's Degree in Civil and Environmental Engineering. From the Structural Engineering and Geomechanics Program: **Chu-Jen Chang** and **Seemant Saxena** (KPFF-LA); and from the Design-Construction Integration Program: **Walter Baudier. Mehmet Burak Tuncer** (KPFF-LA) received his Engineer's Degree from Structural Engineering. **Luis Ibarra** (Southwest Research Institute) received his Ph.D. in Structural Engineering and **Chao Li** (Weidlinger Associates) received his Ph.D. in Geomechanics.

Alumni, Affiliates and Friends of the Blume Center are encouraged to send news items about yourselves to earthquake@ce.stanford.edu for inclusion in the next newsletter.

BLUME CENTER NEWS

Prof. Helmut Krawinkler took one of his frequent (and always enjoyable) trips to Japan in mid September to give a talk on collapse safety at a symposium in Tokyo in honor of Professor Otani and to give a presentation on seismic demands at the 5th US-Japan Workshop for Performance-Based Engineering for RC Structures. **Prof. Sarah Billington** also attended the workshop and symposium.

In September, **Dr. Renate Fruchter** visited Obayashi Corporation for a one week pilot experiment using the RECALL technology developed by Dr. Fruchter and her research team in the PBL Lab at Stanford. RECALL was used in one of Obayashi Corp projects to link experts in the Tokyo headquarters and the engineering team on a construction site in Mizunamy, and to facilitate and capture in real time problem solving and alternative exploration.

Prof. Greg Deierlein invited presentations on Performance Based Earthquake Engineering at the Southern California Earthquake Center's annual meeting (Sept. -8-9, 2003) and the University of Illinois on Nov. 17.

Prof. Anne Kiremidjian attended the International Symposium on Structural Health Monitoring held at Stanford September 14-17 and the First International Conference on Structural Health Monitoring held in Tokyo, Japan November 13-16. She presented joint papers with her students and other colleagues at both meetings

Prof. Ronaldo Borja delivered a keynote entitled "Conservation laws for three-phase partially saturated granular media" at the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) International Conference on Partially Saturated Soils held at Bauhaus-Universitat in Weimar, Germany, September 18-19, 2003.

Prof. Greg Deierlein presented an invited paper on "Framework for Structural Fire Engineering and Design Methods" at an SFPE-NIST workshop held in Baltimore (Oct. 2-3, 2003) to develop a National R&D Roadmap for Fire Safety Design and Retrofit of Structures.

Dr. Renate Fruchter was a guest lecturer for one week at Bauhaus University, Weimar Germany, in October sponsored by the DAAD (German Scholar Exchange Assoc.) where she gave a series of lectures on AEC Global Teamwork

Dr. Renate Fruchter visited KTH in Stockholm Sweden at the end of October to discuss their continued participation in the AEC Global Teamwork course CEE222 offered at Stanford, and met with executives from Skanska Teknik to discuss their engagement as industry mentors in the AEC Global Teamwork course.

Prof. Greg Deierlein and Ph.D. Candidate **Paul Cordova** presented a paper on "PSUEDO-DYNAMIC TEST OF FULL-SCALE RCS FRAME" during a symposium on composite steel-concrete structures held at the National Center for Research in Earthquake Engineering (NCREE) of Taiwan on Oct. 8-9, 2003.

From Oct. 31 to Nov. 5, **Prof.** *continued on page 4*

RESEARCH SPOTLIGHT

Instability and Localization of Deformation Using Three-Invariant Plasticity Models

Kossi Medji Sama and Ronaldo I. Borja

Motivation

Failure in geomaterials (soils, rocks, concrete) generally falls within two broad categories: diffuse and localized. The diffuse type of collapse corresponds to a bulk loss of strength in the region of interest and includes phenomena such as soil liquefaction. Localized failure, on the other hand, manifests itself through the appearance of surfaces of discontinuity, which may induce collapse. Landslides fall within this latter category. Related to this latter type of failure is the notion of strain localization, which refers to the formation of tabular regions of intense deformation, generally called deformation bands (see [1] and [2]).

In recent years, laboratory experiments have revealed that the cross-sections of yield and plastic potential surfaces is not circular as implied by two-invariant constitutive laws such as the Drucker-Prager and Cam-clay models. Instead, they are rounded triangular at low pressures and circular at higher pressures so that all three stress invariants must be used for proper representation of isotropic elastoplastic response of geomaterials. Furthermore, the assumption of infinitesimal strains commonly used in practice is not justified in situations where the strain levels are high. Discrepancies between small and large deformation theories appear not only in the stress-strain curves but also in the predicted stability properties of the material.

The purpose of this research is to study the impact of the adoption of three-invariant models and finite deformation theory on the mathematical characterization of stability as well as on the formulation of conditions for the onset of strain localization in an elastoplastic geomaterial. See [3,4] for additional details and references.

Computational Framework

In the case of classical time-independent plasticity at infinitesimal strains, the rate form of the constitutive law reads: $\dot{\boldsymbol{\sigma}} = \mathbb{C} : \dot{\boldsymbol{\varepsilon}}$, where C is the continuum tangent operator. Sufficient conditions for the onset of diffuse instability and strain localization are given respectively by:

$\det[\mathrm{sym}(\mathbb{C})] = 0$ and $\det[\boldsymbol{Q}] = 0$, $Q_{ij} = n_k C_{ikjl} n_l$,

where the operator sym (·) extracts the symmetric part of a tensor and n is the unit normal to the deformation band. The critical unit normal corresponds to the orientation that minimizes the determinant of the so-called acoustic tensor $\boldsymbol{Q}$ The presence of the continuum tangent moduli (C_{ijkl}) in the criteria underscores the important role played by the constitutive model. As for the stress integration process, an efficient algorithm, cast in principal stress space, has been proposed and shown to perform well for isotropic three-invariant models at both small and large strains [5].

Selected Results

Consider the two-invariant Drucker-Prager (DP) and the three-invariant Matsuoka-Nakai (MN) plasticity models (Figure 1). These two constitutive laws are applicable to dilatant/frictional materials and, in spite of their simplicity, display all the features we wish to highlight. While the MN cross-section passes through all the corners of the Mohr-Coulomb (MC) surface, the DP cross-section passes through either the inner or tension corners or the outer or compression corners (Figure 2). The abbreviations DP (T) and DP (C) are used to denote the Drucker-Prager circles passing through the tension and compression corners of the MC surface, respectively.

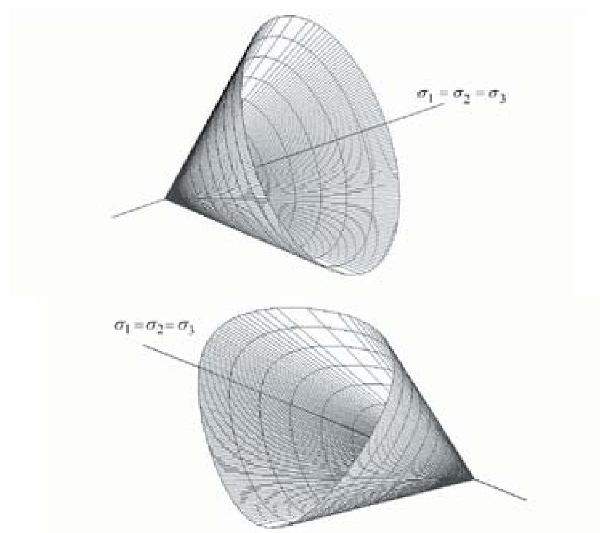


Figure 1. Yield surfaces for Drucker-Prager (top) and Matsuoka-Nakai (bottom) plasticity models.

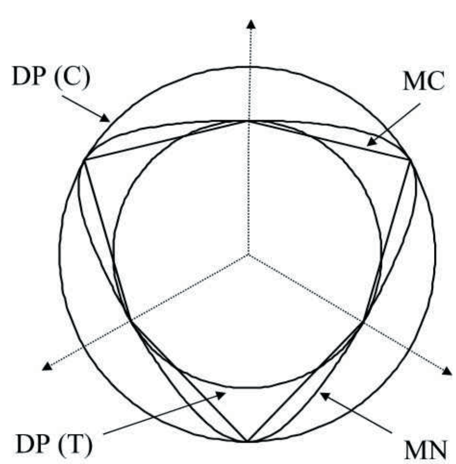


Figure 2. Octahedral sections for the Mohr-Coulomb (MC),

Matsuoka-Nakai (MN), and Drucker-Prager (DP) models.

Consider now a loading path consisting of two steps: (a) conventional triaxial compression from an initial confining pressure of 50 KPa up to the onset of plastic yielding; (b) a shearing phase consisting of an applied shear strain increment with in-plane normal stresses kept constant and zero out-of-plane strains. The purpose of the plane strain shearing phase is to allow for rotation of principal stress directions as the deformation progresses. This is in contrast with the usual triaxial test where the principal stress directions are fixed throughout the loading process. The material parameters are as follows: Young's modulus: 100 MPa, Poisson's ratio: 0.2, friction angle: 30^{o}, dilatancy angle: 15^{o} (18^{o} for DP (C)). The results presented here pertain to the shearing phase (b) in the case where the material is allowed to isotropically harden/soften with accumulated plastic strain.

Figure 3 reveals that the MN model predicts the onset of a shear band (vanishing of the determinant of the acoustic tensor) at an earlier stage than that of the DP models. This observation is to be contrasted with the fact that MN and DP (C) models would predict almost identical results in triaxial tests.

The evolution of the criteria for diffuse instability is plotted in Figure 4. As in the case of localization, the MN model is more susceptible to this type of instability than the corresponding DP models. In addition, we also observe that the amount of strain required to reach localization is larger than that required to trigger diffuse instability. Thus, localized failure may not be the most critical collapse mechanism in this situation.

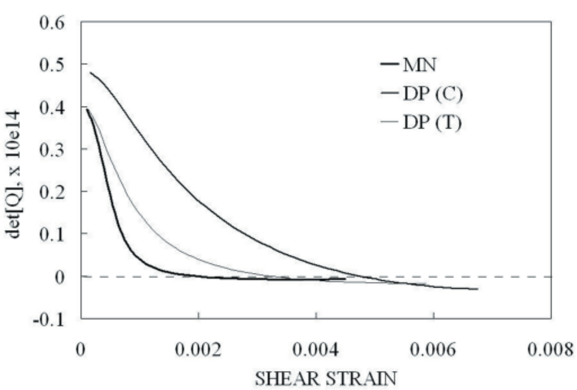


Figure 3. Evolution of the localization criterion.

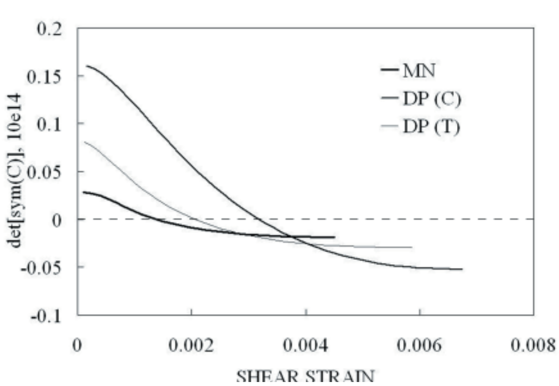


Figure 4. Evolution of the stability criterion.

Closure

The selected simulations presented above have shown that three-invariant plasticity models exhibit a greater susceptibility to diffuse and localized failures, particularly when the principal stress directions vary during loading. It is important to note that three-invariant plasticity models were originally proposed to more closely match experimental stress-strain curves under true triaxial conditions. The results of this research demonstrate that the adoption of these models has far-reaching implications for stability. In particular, some of the discrepancies between numerical results and experimental observations of strain localization could be alleviated by the adoption of the more accurate three-invariant models. In addition, stability analysis based on two-invariant models and/or infinitesimal strains may be non-conservative and therefore lead to unsafe design considerations. Along with other enhancements such as vertex effects, three-invariant models cast within a fully nonlinear framework constitute a step towards better mathematical representations of material behavior.

Acknowledgments

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References

[1] R.I. Borja, A. Aydin (2004). Computational modeling of deformation bands in granular media, I: Geological and mathematical framework, Computer Methods in Applied Mechanics and Engineering, in press.

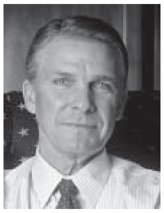
[2] R.I. Borja (2004). Computational modeling of deformation bands in granular media, II: Numerical simulations, Computer Methods in Applied Mechanics and Engineering, in press.

[3] K.M. Sama (2004). Localization properties of three-invariant plasticity models at finite strain. Ph.D. Dissertation, Stanford University, Stanford, California.

[4] K.M. Sama, R.I. Borja (2004). Conditions for stability and localization of deformation in geomaterials using three-invariant plasticity models, International Journal for Numerical and Analytical Methods in Geomechanics, in review.

[5] R.I. Borja, K.M. Sama, P.F. Sanz (2003). On the numerical integration of three-invariant elastoplastic constitutive models, Computer Methods in Applied Mechanics and Engineering, Vol. 192, Nos. 9-10, pp. 1227-1258.

SHAH FAMILY LECTURE ANNOUNCED



James Witt of James Lee Witt Associates, LLC has been named at the Shah Family Distinguished Lecturer 2004. The lecture will be on April 21 at 4:15pm in Kresge Auditorium at Stanford University. Witt served as director of FEMA during the Clinton Administration, during which he is widely credited with effective reorganization of the agency to provide post-disaster assistance. For more information, please contact Kim Vonner at kvonner@stanford.edu or (650) 723-4121.

BLUME CENTER HOSTS SEMINAR SERIES

On November 10 and 18, the Blume Center hosted a two-part seminar by Mary Comerio (Professor of Architecture, UC Berkeley) and William Holmes (Executive Principal, Rutherford and Chekene, Engineers) to examine lessons from a recent effort to assess and improve the seismic performance of UC Berkeley campus. Sitting astride the Hayward Fault, the UC Berkeley campus faces risks that are similar in many respects to those at Stanford. Drawing from studies conducted as part of a massive seismic retrofit program of the Berkeley campus, Comerio and Holmes dealt with a broad range of issues ranging from seismic risk and prioritization of seismic retrofit for existing (seismically deficient) buildings to examining innovative design solutions for protecting valuable contents in high-tech laboratories. Beyond the technical engineering details, both speakers stressed the importance of engaging key stakeholders in the process (university administration, building users, etc.) and translating the seismic performance into measures of safety, economics, and downtime that stakeholders can understand.

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Krawinkler was on a lecture tour in Korea, at the invitation of KEERC, the Korean Earthquake Engineering Center. He gave seminars on performance-based earthquake engineering, collapse of structures, and near-fault ground motion effects.

In November, **Dr. Renate Fruchter** presented two papers at the ASCE Computing in Civil Engineering Conference in conjunction with the ASCE Annual Convention: "Innovation in Engaging Learning and Global Teamwork Experiences" by Renate Fruchter, and "Turning A/E/C Knowledge into Working Knowledge" by Renate Fruchter, Peter Demian, Zhen Yin, and Greg Luth.

Prof. Ronnie Borja attended a Community Workshop on Computational Simulation and Visualization Environment for NEES held at the University of Kansas, Lawrence Campus, on December 1-2, 2003.

Profs. Greg Deierlein and **Anne Kiremidjian** co-chaired sessions at the PEER-MCEER-MAE Tri-Centers Annual Meeting on Geographically Distributed Network Systems, held in Las Vegas, Dec. 11-12, 2003.

PUBLISHED PAPERS

Kesner, KE, and Billington, SL, (2003) Experimental Response of Precast Infill Panel Connections and Panels Made With DFRCC,J. Advanced Concrete Technology, 1(3): 1-7.

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