OPINION PAPER

International Workshop on the Uncertainties in Nonlinear Soil Properties and their Impact on Modeling Dynamic Soil Response

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Introduction and Perspective

The growing number of papers in the Geotechnical Engineering literature advocating probabilistic approaches to analysis and design (e.g. Phoon et al., 2000, Duncan, 2000) indicates the community's increasing interest in finding ways to manage the effects of uncertainties in soil property characterization on geotechnical modeling, analysis and design. While current advances in scientific computing and sensing have contributed to substantial gains in bio- and nano-technologies, the prudent combination of these advances with probabilistic methods should serve to significantly improve our ability to understand and manage soil property uncertainty.

The ability to correctly quantify and interpret *elemental* soil response forms a first, crucial step toward extrapolating predictability to field-scale problems. The mechanistic characterization of soils in the form of constitutive models is essentially an encapsulation of controlled experimental measurements into a format that is conducive to extrapolation beyond the specific conditions that existed during calibration. Generally, soil constitutive models are calibrated from boundary measurements on laboratory soil specimens which are assumed to be homogeneous: characterization is then relegated to an average homogenized material, one that is "equivalent" to the actual heterogeneous one. While this approach has served mechanics well, it has not permitted the development of material models that are capable of reproducing the heterogeneity and variability typically observed in soils (e.g. Gilbert and Marcuson, 1988 and Rechenmacher, 2004). In spite of advanced testing and sensing equipment, and use of carefully executed laboratory procedures, non-elemental and non-homogeneous soil behavior still is observed.

One effect of laboratory-scale material variability on model development and performance can be demonstrated in reference to the solution of the theoretical bifurcation problem. Because of the assumption of homogeneous deformation and material properties prior to localization, an elemental model is unable to predict the exact location of a shear band in a specimen (theoretically, an infinite number of shear bands could form). Practically, one location needs to be *chosen* a priori (e.g. Borja, 2000). Similarly, that the "International Workshop on the Uncertainties in Nonlinear Soil Properties and their Impact on Modeling Dynamic Soil Response" has been conceived evidences the importance of this subject to the Soil Dynamics community as well.

Current Research Efforts

By exploiting experimental techniques that measure the full-field of deformations of soil specimens, thus fully characterizing the non-uniformity of response, improved soil model calibrations that accommodate this ever-present heterogeneity may be obtained. The author is involved in the development of an improved method for model calibration in which image-based displacement measurements of deforming surfaces of triaxial specimens are assimilated into finite element predictive models of soil behavior (Rechenmacher, 2004; Ghanem et al., 2003 and Rechenmacher et al., 2003). The discrepancy between predicted and measured displaced shapes serves to define an objective function to be minimized in an associated optimization process. This combination of digital imagery and inverse analysis can then delineate a heterogeneous structure of soil specimens formed under controlled laboratory conditions. The method has performed successfully in conjunction with linear soil models, and is currently being extended to non-linear models. The next step is to describe the observed variability within a probabilistic context.

The author additionally is involved in an experimental/numerical collaboration between The Johns Hopkins University (JHU) and Stanford University, to assess the effects of laboratory soil specimen heterogeneities on numerical predictions of bifurcation. The research utilizes X-Ray Computed Tomography (X-Ray CT) technology to delineate heterogeneities in laboratory soil specimens. Figure 1 shows typical CT measurements through a cross-section of a reconstituted sand specimen. Density variations within the soil are manifested in different levels of gray in the image (the white "blob" near the bottom is an implanted stone). It is clear that, in spite of careful preparation procedures, this "controlled" laboratory specimen is quite variable. The assumption that "elements", such as this, from which model parameters are derived, are homogeneous, no doubt impacts model predictability and performance.

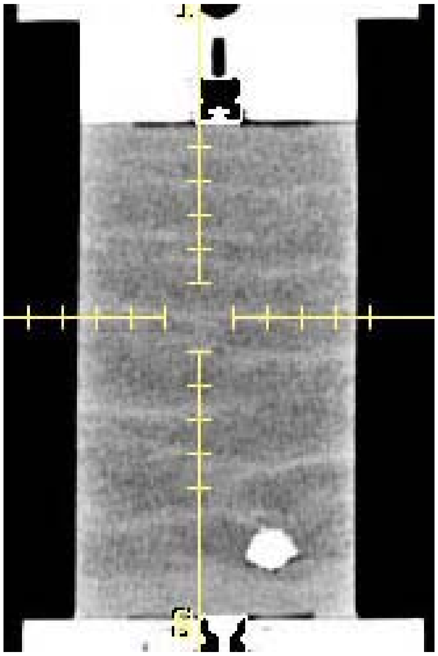

Figure 1. Data from X-ray CT measurements on a reconstituted sand specimen

Contributions to Workshop

The author is gaining experience in the quantification of soil heterogeneitites and assessment of their impact on static and pseudo-static model development and performance. Her efforts could no doubt provide insight toward delineating approaches for managing uncertainties in characterization of soil properties as applied to dynamic problems.

The use of boundary feedback techniques in development of the above-described model calibration procedure may be seen as directly applicable to a performance-based design framework (BO Session #2). While imaging-based feedback data are currently being used, the method can likely be extended for use with other, dynamic-based sensing and measuring techniques.

The management of soil material variability and heterogeneity naturally lends itself to probabilistic methods. The author's experience in applying probabilistic methods to characterizing soil heterogeneity may contribute to the development of advanced dynamic models, new model forms, and associated needs for new testing methods (BO sessions #5 and #7).

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