Transportation Research Board

81st Annual Meeting

Pre-Meeting Workshop:

Doctoral Student Research in Transportation Geotechnics

Sunday, January 13, 2002, 1:30 – 4pm
Hall B3
Marriott Wardman Park Hotel
Washington, DC

Sponsored by TRB A2 Sections on Soil Mechanics, Geology and Properties of Earth Materials, and Geomaterials

Transportation Research Board – 81st Annual Meeting
Pre-Meeting Workshop
Doctoral Student Research in Transportation Geotechnics

Moderator: Deborah J. Goodings, University of Maryland

Presentations:

1. **Three-dimensional Behavior of Kaolin Clay with Random and Dispersed Fabric using True Triaxial Testing**
   Amit Prashant **--** *University of Tennessee*

2. **Three-Dimensional Static and Dynamic Behavior of Clay with Random and Dispersed Fabric Using Combined Axial-Torsional Testing**
   Han Lin -- *University of Tennessee*

3. **Seismic Compression of Fills and Embankments**
   Patrick M. Smith -- *University of California, Los Angeles*

4. **Uncertainties and Bias in Ground Motion Estimates at Soil Sites**
   Mehmet Bora Baturay -- *University of California, Los Angeles*

5. **Analysis & Design of Concrete Pavement Systems Using Artificial Neural Networks**
   Halil Ceylan -- *University of Illinois at Urbana-Champaign*

6. **Coupled Heat and Moisture Flow Analysis of Unsaturated Subgrade Soil**
   Suknam Kim -- *University of Toledo*

7. **Fundamental Behavior of the Steel-Grout Interface of a Drilled and Grouted Pile**
   David R. Baroi -- *Texas A&M University*

8. **Electrokinetically Enhanced Reduction of [Cr(VI)] in Contaminated Soils**
   Antionette Weeks – *Lehigh University*

1. Three-dimensional Behavior of Kaolin Clay with Random and Dispersed Fabric using True Triaxial Testing

Many boundary value problems in geotechnical engineering involve soil elements that are subjected to generalized stress paths with varying intermediate principal stress ratio. The objective of the present research is to evaluate the effect of intermediate principal stress and the initial micro-fabric (geometric arrangement of clay platelets) of cohesive soil on the 3D stress-strain, pore pressure, and shear strength behavior.

In order to study this behavior of clay from normally consolidated to over-consolidated state of stress, series of True Triaxial Tests were performed on cubical specimens of Kaolin clay. The true triaxial testing device developed for this study applies three mutually perpendicular principal stresses on cubical soil specimens using flexible membrane boundaries. A constant rate of strain (0.05 %/min) is applied in major principal direction and the intermediate principal stress is then applied through a feedback control system using adaptable Proportional-Integral-Differential (PID) algorithm. This setup is connected to a computer though a data acquisition system and software is developed to store the stress and deformation information, in addition to real time feedback control.

The three dimensional test results for kaolin clay specimens with initially random micro-fabric are completed to date. The test data are compared with the predictions from existing popular constitutive models with varying yield and failure surfaces. Experiments on cubical specimens with dispersed micro-fabric for various b-values are in progress. The impact of this project will be to establish a unified theory for cohesive soil that accounts for the effect of micro-fabric in a generalized three-dimensional state of stress.

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2. Three-Dimensional Static and Dynamic Behavior of Clay with Random and Dispersed Fabric Using Combined Axial-Torsional Testing

A Combined Axial-Torsional Testing system was developed to investigate the effect of rotation of major principal stress on the three-dimensional mechanical behavior of Kaolin day. Uniform and reproducible cohesive specimens having a specimen shape of a hollow cylinder were obtained using a two stage slurry consolidation technique. Precise stress-paths (triaxial compression to pure torsional shear to triaxial extension), corresponding to the rotation of the major principal stress axis, were achieved by using Proportional-Integral-Differential feedback control technique. Kaolin Clay specimens with varying initial micro-fabric are being tested respectively under a variety of stress paths under undrained conditions. Digital imaging technique is also being used to investigate the potential of strain localization and its impact on the interpretation of test results.

Based on the phenomenological evidence, evaluation and modification of existing constitutive models will be performed to represent the measured test data. This research will have significant impact on the three dimensional constitutive behavior of cohesive soil from both the experimental and the modeling points of view.

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3. Seismic Compression of Fills and Embankments

Permanent deformations in compacted fills and embankments due to earthquakes result principally from the accumulation of volumetric strain, a process that is referred to as seismic compression. The current state of practice for evaluation of seismic compression in fills uses procedures based upon the test results of Seed and his co-workers for clean sands. These procedures use various methods to obtain the amplitude and number of cycles of cyclic shear strain induced in the soil at various depths, and then relate volumetric strain to shear strain based on the relative density of the sand. The resulting volumetric strains are then integrated through the fill to estimate the amount of seismic compression settlement.

The primary objective of this research is to develop deterministic guidelines for seismic compression analysis and to perform a pilot study on the implementation of the deterministic analysis procedure into a probabilistic framework. To achieve this objective, a comprehensive laboratory-testing program has been conducted to investigate several key factors controlling the accumulation of volumetric strain in compacted unsaturated soils. In addition, numerical analyses will be performed to develop simplified procedures for the evaluation of cyclic shear strain amplitudes in two-dimensional fill geometries.

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Technical publications from this research

- Stewart, J. and Smith, P. (1998). "Ground deformation in constructed ground," Award No. Z-19-2-133-96 Pacific Earthquake Engineering Research Center, PEER
- Whang, D., Bray, J.D., Stewart, J.P., Reimer, M.F., and Smith, P.M., (in review). "Characterization of seismic compression of some compacted fills, " ASTM Geotechnical Testing Journal
- Whang, D., Reimer, M.F., Bray, J.D., Stewart, J.P., and Smith, P.M., (2000). "Characterization of seismic-compression of some compacted fills," in Advances in Unsaturated Geotechnics, ASCE Geotech. Special Publication No. 99, C.D. Shackelford, S.L. Houston, and N-Y. Chang (eds.), 180-194.
- Stewart, J.P., Bray, J.D., McMahon, D.J., Smith, P.M., and Kropp, A.L. (2001). "Seismic Performance of Hillside Fills" ASCE Geotechnical Journal

4. Uncertainties and Bias in Ground Motion Estimates at Soil Sites

For a given seismic source, ground motions at soil sites can be estimated using either soil attenuation relationships, or ground response analyses with input otions scaled to match specified spectral ordinates from rock attenuation relationships. When engineers perform ground response analyses, it is with the expectation that accounting for nonlinear sediment response will improve the accuracy and reduce the uncertainty in estimated ground motions. This research will investigate the benefits of performing ground response analyses as a function of geotechnical site condition and the level of shaking. Both equivalent linear and fully nonlinear analysis procedures will be considered in this assessment.

This research will utilize large databases of strong motion recordings in shallow crustal regions and borehole locations to identify strong motions sites that can be geotechnically well characterized for ground response analysis. For each of these sites, ground motions will be estimated by three procedures: (1) soil attenuation relations, (2) equivalent linear ground response analysis, and (3) fully nonlinear ground response analysis.

Residuals between recorded and estimated motions will be calculated to elucidate trends in the results of each ground motion estimation procedure across geotechnical site categories. Outcomes of the research will include guidelines on the geotechnical and seismological conditions for which ground response analyses can be justified, and recommendations on how such analyses should be performed (both from the standpoint of input motion selection and analysis method).

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Technical publications from this research

- Stewart, J.P. and Baturay, M.B. (2001). "Uncertainties and residuals in ground motion estimates at soil sites," Proc. 4th Int. Conf. Recent Advances in Geotech. Eqk. Engrg. Soil Dyn., San Diego, CA. Paper 3.14.

5. Analysis & Design of Concrete Pavement Systems Using Artificial Neural Networks

Artificial neural networks (ANNs) are valuable computational tools that are increasingly being used to solve resource-intensive complex problems as an alternative to using more traditional techniques. In recent successful applications, the use of ANNs was introduced for the analysis of jointed concrete pavement responses under mechanical and climatic loadings. ILLI-SLAB finite element program, extensively tested and validated for over two decades, has been used as the primary analysis tool for the solution of concrete slab responses under multi-wheel gear and temperature loadings. ANN models then trained with the results of the ILLI-SLAB solutions have been found to be viable alternatives to analyze concrete pavements. The trained ANN models are capable of predicting critical pavement responses (maximum strains, stresses and deflections) with very low average absolute errors of those obtained directly from ILLI-SLAB analyses.

These models based on factorials of finite element runs offer an attractive alternative to the direct use of finite element analysis for determining the critical pavement responses in mechanistic-empirical design. Such use of ANN models enables pavement engineers to easily and quickly incorporate current sophisticated finite element approach into routine practical design. In addition, comprehensive ANN models trained for the different conditions of gear loading only, temperature loading only, and the simultaneous temperature and gear loading cases along with the models that can handle any possible gear loading with the use of principle of superposition. Developed ANN models would aid pavement engineers in the investigation of "what if" scenarios before making a final design decision in a relatively very short amount of time (several thousand analyses can be performed in one second using today's typically available personal computers).

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Technical publications from this research:

- Ceylan, H., Tutumluer, E., and Barenberg, E.J. (2000). "Effects of Simultaneous Temperature and Gear Loading on the Response of Concrete Airfield Pavements Serving the Boeing B-

777 Aircraft." Proceedings of the 26th ASCE International Air Transportation Conference, 2020 Vision of Air Transportation: Emerging Issues and Innovative Solutions, pp. 25-44, San Francisco, California, June 18-21, 2000.

- Ceylan, H., Tutumluer, E., and Barenberg, E.J. (2000). "Neural Network Modeling of Slabs Under Simultaneous Aircraft and Temperature Loading." 14th ASCE Engineering Mechanics Division Conference, Austin, Texas, May 21-24, 2000.
- Ceylan, H., Tutumluer, E., and Barenberg, E.J. (2000). "Artificial Neural Networks for Analyzing Concrete Airfield Pavements Serving the Boeing B-777 Aircraft." Journal of the Transportation Research Board, Transportation Research Record 1684, pp. 110-117.
- Ceylan, H., Tutumluer, E., and Barenberg, E.J. (1999). "Neural Network Modeling of Concrete Airfield Pavements." 13th ASCE Engineering Mechanics Conference, The Johns Hopkins University, Baltimore, MD, June 13-16, 1999.
- Ceylan, H., Tutumluer, E., and Barenberg, E.J. (1998). "Artificial Neural Networks as Design Tools in Concrete Airfield Pavement Design." Proceedings of the 25th ASCE International Air Transportation Conference, Airport Facilities: Innovations for the Next Century, pp. 447-465, The University of Texas at Austin, Austin, Texas, June 14-19, 1998.

6. Coupled Heat and Moisture Flow Analysis of Unsaturated Subgrade Soil

Heat flow and moisture flow in unsaturated soils have been recognized as coupled processes with complex interactions within them. Soils within pavement systems are usually in unsaturated state and are affected by climatic factors. A finite element program to analyze the coupled heat and moisture flow in unsaturated subgrade soils was developed for this research.

The coupled heat and moisture flow analysis requires two known relationships, the soil-water characteristic curve and permeability function. Two sets of equations are used selectively in the model. One set consists of the equations by Gardner (1958) and the other the equations by Fredlund and Xing (1994) and Fredlund et al. (1994). The model can solve one-dimensional and two-dimensional problems for flow in pavement systems. The model predicts not only the change of temperature and water content, but also frost heave with time. The simulation predictions by the model are compared with the results by other models for model verification and with field data from the Strategic Highway Research Program (SHRP) testing program. This research discusses the program development, and the capabilities of the program for modeling two-dimensional flow below pavements.

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7. Fundamental Behavior of the Steel-Grout Interface of a Drilled and Grouted Pile

The behavior of the steel-grout interface is dependent upon the thermal and mechanical characteristics of the two component materials. To understand the behavior at the interface, the problem was studied in two parts. The first part consisted of analyzing numerically the response of the interface when subjected to the time-temperature history of the grout hydration process. During this process, there are large temperature changes in a relatively short period of time, as well as dramatic changes in the properties of the grout. Indeed, the grout changes from a visco-plastic fluid, to a fairly compressible and porous skeletal structure of partially hydrated compounds, to a hard brittle solid. The separation of the interfaces (debonding) is a possibility during this phase. The analysis is done using a realistic time-temperature history based on scale models, material properties determined in laboratory tests, and assuming actual field conditions. Debonding of the interface can lead to significant loss of load-transfer capacity of the structure. The second part consisted of studying experimentally the strength of the interface during the post-hydration period. At this stage, the grout has gained most of its strength. Analytical models have been developed to predict the interface stresses that can occur in a drilled and grouted pile under actual field conditions. A design equation is proposed for the interface bond strength.

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8. Electrokinetically Enhanced Reduction of [Cr(VI)] in Contaminated Soils

The electrochemical reduction of [Cr(VI)] in laboratory–controlled and "field-simulated" contaminated, composite soil-water systems using electrokinetic technology has been studied. Ferrous iron, [Fe(II)], was electrokinetically introduced into the contaminated samples to reduce [Cr(VI)] to its less toxic and less mobile species of [Cr(III)]. Once reduced, the resulting [Cr(III)] species will readily adsorb onto the soil matrix; thus, promoting the possibility of becoming electrochemically stabilized within the soil medium. The results generated from this study were used to develop a model to estimate the final concentrations of the chromium species remaining within the contaminated soil medium. The proposed model, which is based on an electrochemical theory called the Nernst Equation, will rely on the relationship existing between the contaminant concentration and the measured potentials within the soil medium. A reasonable estimate for the concentration of the remaining chromium species in the contaminated soil-water medium will be obtained for each sample tested as a function of varying soil potentials using the Nernst Equation. Additionally, the optimum concentration of [Fe(II)] required to promote the reduction of [Cr(VI)] to [Cr(III)] and the most suitable duration required to facilitate the reduction will also be estimated for selected testing sequences.

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Technical publications from this research

- Weeks, A. and Pamukcu, S., 2001. Electrokinetically Enhanced Reduction of [Cr(VI)] in Contaminated Soils; XV International Conference on Soil Mechanics and Geotechnical Engineering, Istanbul, Turkey, (Submitted For Publication).
- Weeks, A. and Pamukcu, S., 1999. "Electrokinetic Modeling of the Enhanced Reduction of Cr(VI) in Porous Media" Proceedings of the 1999 Joint ACSE-CSCE Environmental Engineering Conference, Norfolk, Virginia, July 25-28, pp. 631-640.
- Weeks, A. and Pamukcu, S., 1998. "An Overview of the Reduction of Chromium in Soils" Proceedings of the National Conference on Environmental Remediation Science and Technology, Greensboro, North Carolina, September 8-10, pp. 233-242.
- Weeks, A. and Pamukcu, S., 1998. "Electrokinetically Enhanced Reduction of Cr(VI) in Porous Media" Proceedings of the Thirtieth Mid-Atlantic Industrial and Hazardous Waste Conference, Department of Civil and Environmental Engineering, Villanova University, Villanova, PA, July 12-15, pp. 41-48.

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- Pamukcu, S., Weeks, A., and Wittle, J. 1997. “Electrochemical Extraction and Containment of Selected Inorganic Species in Porous Media,” Journal of Hazardous Materials, Elsevier Publishers, Volume 55, pp. 305-318.