Center for Geotechnical Practice and Research
2007 Annual Meeting
Wednesday, February 28, 2007

Solitude Conference Room – Skelton Conference Center
Virginia Tech Campus Blacksburg, Virginia

Meeting Agenda

8:00	AM	Continental Breakfast in Meeting Room
8:30	AM	Welcome, Self Introductions – CGPR
8:40	AM	Summary Report on CGPR Activities – CGPR
9:00	AM	Business Plan Committee Report – Aaron Zdinak and others
10:00	AM	Break
10:15	AM	Graduate Student Presentations of On-Going Research at Virginia Tech
12:00	PM	Lunch (Served in adjoining portion of Skelton Conference Center)
1:00	PM	New CGPR Initiatives Forum
3:00	PM	Coffee Break in Meeting Room
3:30	PM	Evaluation and Ranking CGPR Programs Initiatives
4:30	PM	Adjourn

Evening Program
Latham Ballroom B – Inn at Virginia Tech and Skelton Conference Center

5:30	PM	Reception/Poster Session with Geotechnical Graduate Students
7:00	PM	Dinner – Members/Faculty/Graduate Students

Emergence of Intelligent Compaction in U.S. Practice

Student: Michael McGuire

Faculty Supervisor: George Filz (filz@vt.edu)
Tom Brandon (tbrandon@vt.edu)

Sponsor: Virginia Tech, CGPR

Start/Completion Dates: August 2005 / February 2006

Project Background

The standard approach to specifying compaction of soils in the U.S. is to use end result specifications that require a minimum relative compaction or density together with a range of acceptable water contents. The prevailing methods of field testing are the nuclear density gauge and the sand cone density test. These tests are usually performed on a relatively infrequent basis. Such an approach has proven reliable through decades of experience, although successful implementation depends on near full-time observation by an experienced inspector. Increasingly, however, many state transportation agencies are finding it harder to provide adequate oversight due to budgetary restrictions, loss of experienced inspectors, and competing demands on the remaining inspectors' time. Furthermore, there is increasing political and financial pressure to deliver transportation projects faster, with higher quality, and at lower cost.

In response to this problem, the FHWA and many state DOTs are pursuing alternative methods to design, construct, and verify the quality of compacted fills, subgrades, and pavements. Continuous Compaction Control (CCC) and Intelligent Compaction (IC) are technologies that are frequently used in Europe and Asia to construct compacted fills, subgrades, and pavements with greater efficiency, quality, and more complete documentation than is provided using the traditional approach of inspection and spot-testing. CCC technology uses data collected from compactor-mounted instruments to evaluate the level of compaction and the operation of the compaction equipment. IC equipment uses the data from compactor-mounted instruments, along with the CCC measurements, to adjust the operation of the compactor to maximize the compaction efficiency.

Over the next several years, it is expected that AASHTO will adopt a Mechanistic-Empirical (M-E) approach for the design of subgrade and pavement surfacing materials. For unbound subgrade, subbase, and base materials, the most important input parameter is the resilient modulus, M_r. It is likely that the use of the resilient modulus for design and acceptance testing in the field will invite the widespread use of alternative in-situ testing methods, such as IC/CCC technology.

Alternative specifications and project contracts are also being considered to address the needs for higher quality and greater construction efficiency. Performance specifications are one such alternative that rely on measurements of performance indicators to establish an acceptable quality level of the finished product measured over the course of a warrantee period. A study conducted by McGuire and Filz (2005) developed and conceptually evaluated six approaches, including performance specifications, for specifying embankment and subgrade compaction.

The implementation of IC/CCC technology is well-suited for projects using performance specifications and/or a M-E design methodology. IC/CCC technology has the ability to rapidly evaluate and document the stiffness and uniformity of the entire area of each compacted lift. It is also possible for compactor-derived output values or stiffness measurements to be correlated to commonly used soil parameters

Project Objective and Contents

The objective of this project is to generate comprehensive reference materials intended for engineers, construction industry professionals, and academics within the U.S. on the subject of intelligent compaction and continuous compaction control. This project includes a review the existing body of literature on IC and CCC and discussion with experts. The report produced for this project presents IC/CCC technology in the following four parts:

- Part I. Overview and Background
- Part II. Equipment Manufacturers and the Emergence of IC/CCC Technology
- Part III. Development of Theory and Equipment
- Part IV. Implementation in the United States

A searchable comprehensive electronic bibliography listing 142 sources of information about intelligent compaction and continuous compaction control is also provided as a supplement to the report. The bibliography contains 43 searchable summaries of the sources.

The final report will be distributed to CGPR members soon.

Probabilistic Procedures for Post-Liquefaction Stability Analysis of Embankment Dams and Foundations

Student: Morgan A. Eddy

Faculty Advisor: Dr. Marte S. Gutierrez(magutier@vt.edu)

Sponsors: United States Bureau of Reclamation

Start/Completion Date: April 2004/February 2007

Project Background

Liquefaction of cohesionless soil deposits can have extremely detrimental effects on the stability of embankments, natural soil slopes, and mine tailings dams. The residual or liquefied shear strength of the liquefiable soils is an important parameter when evaluating stability of sloping ground. Current procedures for estimating the liquefied shear strength are based on extensive laboratory testing programs or from the back-analysis of failures where liquefaction was involved and in-situ data was available. All available procedures utilize deterministic methods for estimation and selection of the liquefied shear strength. Over the past decade, there has been an increasing trend towards analyzing geotechnical problems using probability and reliability. This study presents procedures for assessing the liquefied shear strength of cohesionless soil deposits within a risk-based framework. Probabilistic slope stability procedures using Monte Carlo Simulations and the Hasofer-Lind reliability index are developed to incorporate uncertainties associated with geometrical and material parameters, and in situ data.

Project Objectives

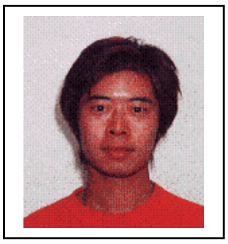
- Re-evaluate and expand the available databases of flow liquefaction and lateral spreading
- Develop reliability-based procedures for back-analysis of liquefaction cases
- Produce new probabilistic liquefied shear strength criteria
- Demonstrate the use of the new procedures within the USBR seismic risk framework
- Address several controversial questions regarding the liquefied shear strength

Results

The existing databases of liquefaction instability failure have been compiled and additional cases from recent earthquakes including the 1993 Kushiro-oki Earthquake, 1996 Hyogoken-Nambu Earthquake, and the 1999 Kocaeli/Izmit Earthquake have been included. Back-analysis of the liquefied shear strength is performed using several slope stability models and Monte Carlo simulations. Figure 1 presents results from the back-analysis of thirty-eight cases of liquefaction instability. Reliability calculations are then performed to determine the probability of failure, P_F, for each case based on the best-fit equation shown in Fig. 1. The results of the reliability analysis are shown in Figure 2. Figure 2 can be used in three ways; 1) with a given *FFD* (flow failure demand) and minimum SPT blowcount the

P_F can be estimated, 2) with a given *FFD* and P_F the minimum required SPT blowcount can be estimated, or 3) with a given minimum SPT blowcount and P_F the liquefied shear strength can be estimated.

SOIL AND SITE CHARACTERIZATION USING ELECTROMAGNETIC WAVES



Student:	Ning Liu
Faculty Supervisor:	James K. Mitchell (jkm@vt.edu)
Sponsor:	Charles Edward Via. Fellowship
Start/Completion Dates:	November 2004 / May 2007

Project Background

Many investigations concerning soil electromagnetic properties have been made over the past several decades. The investigations showed that soil electromagnetic properties have potential for determination of several soil engineering properties. Electrical conductivity, dielectric permittivity and their changes over 1 MHz to 1 GHz frequency range (dielectric dispersion) are especially useful in deducing soil engineering properties. However, how to correctly interpret the dielectric spectra in this frequency range and relate them to soil engineering properties remain largely unsolved. In addition, apparatus that can be readily used in the field to measure soil electromagnetic properties over this frequency range are still limited.

Project Objectives

The primary objectives of this research include: (1) develop a convenient and economic way for dielectric spectrum measurement in the laboratory and in the field; (2) investigate the strengths and limitations of dielectric spectrum measurements as a basis for soil property characterization.
The specific targets of this research project include the following:
(1) obtain the electromagnetic spectrum of natural and artificial soils over the frequency range from 1MHz to 1GHz using time domain reflectometry (TDR); (2) develop a suitable models to analyze the dielectric permittivity and electrical conductivity over the above frequency range; (3) evaluate how well the EM waves can be used to estimate such fundamental soil parameters as the specific surface area (SSA), water content, plasticity and pore fluid chemistry; (4) Investigate the relationships between soil EM properties and such engineering properties as hydraulic conductivity, compressibility and residual shear strength.

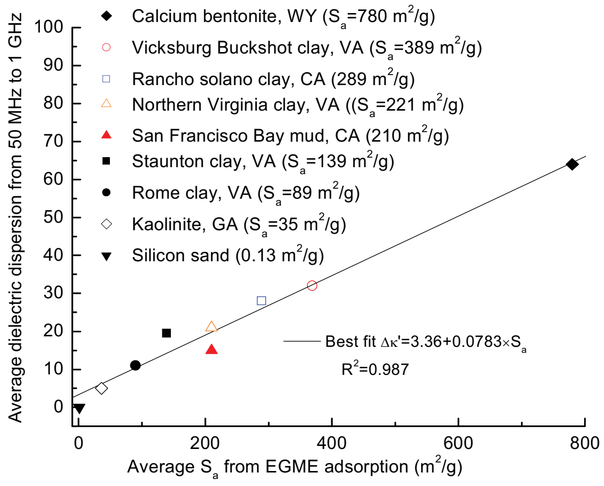
Approaches

To fulfill these objectives, the following tasks have been performed.
(1) Development of a physically based model that provides a means of investigating the combined effects of important polarization mechanisms on soil electromagnetic properties, and a means of relating the electromagnetic properties of a soil to its fines content, clay mineralogy, anisotropy, water content, degree of flocculation and pore fluid chemistry;
(2) Verification of the theoretical model by measuring the frequency-domain dielectric spectra of saturated silicon sand, kaolinite, bentonite and bentonite-silicon flour mixtures.
(3) Proposal of a practically applicable method to determine the volumetric water content and specific surface area of a soil simultaneously from its dielectric spectrum;
(4) Verification of the proposed method by measuring the specific surface areas of eight soils using the ethylene glycol monoethyle ether (EGME) adsorption method.
(5) Deduction of the wide-frequency electromagnetic properties of a soil by measuring its responses to a step pulse voltage using time domain reflectometry (TDR).
(6) Establishment of the correlations between the specific surface area and residual friction angle, compressibility, coefficient of consolidation and hydraulic conductivity.

Some Conclusions

1. *Mechanism of dielectric dispersion behavior*

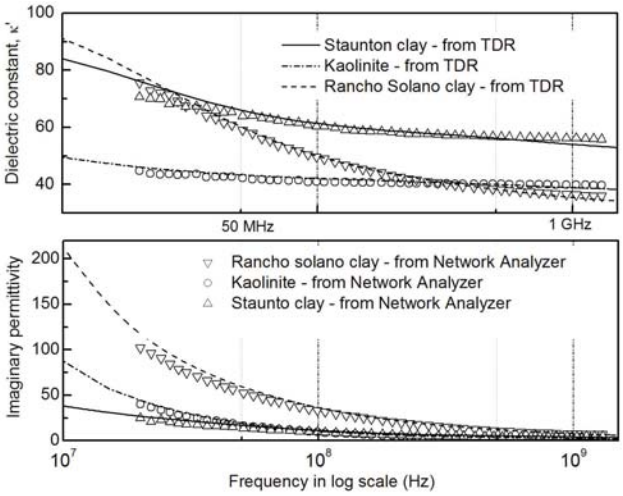
Typical soils encountered in engineering practices contain sand, silt and clay. Over the 1 MHz to 1 GHz frequency range, the dielectric permittivity of sand-water mixtures is essentially frequency-independent regardless of the pore fluid chemistry. In contrast, soils containing clay minerals usually exhibit a dielectric dispersion behavior over this frequency range. Interfacial polarization is identified as the most important mechanism contributing to the dielectric dispersion behavior and it is primarily induced by the difference between clay particles and bulk pore fluid in electrical conductivity. The clay particles are electromagnetically anisotropic and their maximum electrical conductivity is determined by the total specific surface area and surface conductance of the clay mineral. Given the fact that the surface conductance varies in a narrow range for common clay minerals, the specific surface area is identified as the most important factor determining the electrical conductivity of clay particles and governing the dielectric dispersion behavior of fine-grained soils.



2. *A simplified method to determine total specific surface area and water content*

A new approach is proposed to simultaneously determine the total specific surface area and volumetric water content of soils from the dielectric constant at 1 GHz and dielectric dispersion magnitude from 50 MHz to 1 GHz. A linear correlation between the total specific surface area determined by the EGME adsorption method and the dielectric dispersion magnitude over the 50 MHz to 1 GHz frequency range is established based on the experimental results on nine soils as shown in the figure on the left.

3. *Frequency domain analysis of TDR time domain records*



Time domain reflectometry (TDR) is more and more frequently used in the field to measure soil volumetric water content and bulk electrical conductivity. The TDR waveform essentially traces the responses of a soil to an input step voltage as a function of time. More information can be derived from TDR time domain records because both the input step pulse and the measured waveform can be transformed to sinusoidal electromagnetic waves over a wide frequency range. As a result, soil electromagnetic properties at each frequency can be deduced from its TDR time domain records using Fast Fourier Transform (FFT) techniques. The comparison between the TDR-converted and directly measured dielectric spectra show that the TDR has sufficient precision to determine the dielectric spectrum over the 50 MHz to 1 GHz frequency range.

Rapid Stabilization of Soft Clay Soils

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Sponsors: Air Force Research Laboratory
Via Foundation
Start/Completion Dates: March 2003 / May 2009

Project Background

For decades, traditional stabilizers such as cement and lime have been added and mixed into weak soils to improve site conditions. Even though cement and lime are still among the most effective stabilizers in use today, recent developments in technology and materials indicate that non-traditional stabilizers might be more effective. These new non-traditional stabilizers could be used alone or in addition to cement and lime.

Project Objectives

The purpose of this research is to increase the strength of soft clay soils within 72 hours for contingency airfields. The soft clay soils are assumed to have an initial California Bearing Ratio (CBR) of 2 in the field, which represents a soft and weak subgrade condition. After treatment, the stabilized clay must sustain aircraft traffic from C-17s and C-130s. Because of weight limitations on transport to remote airfield sites, the design will consist of stabilized soil alone, a light-weight aluminum mat overlying stabilized soil, or crushed-aggregate overlying stabilized soil, although the latter option depends on available resources near the airfield. In addition, the results of this research are intended to serve as the basis for determining the required type of treatment based on soil composition and mineralogy.

Research Accomplished

- **Stabilizer Study**

  A study of stabilizer effectiveness that consisted of treating clays with similar dosage rates of different stabilizers was performed first, using unconfined compressive strength (UCS) tests to evaluate the strength and toughness of the mixtures. UCS tests were chosen to evaluate the effectiveness of the stabilizers because a large number of samples could be prepared and tested quickly due to small sample sizes of 2 inches in diameter and 4 inches in height.

  To compare stabilizer effectiveness for each soil, water contents for each soil was adjusted to produce the same initial untreated strength, as represented by an initial CBR of 2. After achieving the appropriate water content, different stabilizers were mixed into the soils, samples were compacted using standard Proctor effort, and UCS tests were run.

  In this research, stabilizers were categorized as either primary or secondary stabilizers, where primary stabilizers were the major or only stabilizer, and secondary stabilizers were sometimes used in addition to the primary stabilizers. Primary stabilizers included Type III cement, Type I/II cement, microfine cement, quicklime, calcium carbide, sodium silicate, and fibers. Secondary stabilizers included fibers, sodium silicate, super absorbent polymers, superplasticizers, and accelerators. Fiber material types included polypropylene, nylon, and poly(vinyl) alcohol.

- **Dosage Rate and Treatment Study**

  Using the most effective stabilizers determined from the stabilizer study, another study was performed to determine appropriate treatments to achieve adequate performance characteristics for a potential underlying subbase layer and top base layer of a pavement design section. To accomplish this, clay was treated with different treatments at various dosage rates for each layer, and the treatment was considered to be successful when the treated soil satisfied the layer strength requirements determined from the Pavement-Transportation Computer Assisted Structural Engineering (PCASE) program. Strength was evaluated with both UCS and CBR tests at corresponding dosage rates in this study, so that strength could be quickly evaluated with UCS tests and then correlated to CBR values for pavement design.

- **Pavement Design**

  Pavement design charts for various aircraft loading conditions were generated using PCASE, which was developed by the Engineering Research and Development Center to determine ranges of required strength and thickness for an underlying subbase layer and a top base layer, such as stabilized soil, crushed-aggregate, or aluminum matting.

Key Findings

The results of the stabilizer study showed that traditional stabilizers like cement and lime, as well as calcium carbide, were most effective in stabilizing the soil, while most of the other nontraditional stabilizers were not as effective. In addition, fiber reinforcement was also found to be effective, as a result of the fibers' ability to increase toughness of untreated and chemically treated soil. However, fiber reinforcement was found to decrease the strength of chemically treated soil, if the fibers were too large or did not disperse well throughout the soil.

Regardless of stabilizer and treatment type, the dosage rate and treatment study established a linear relationship between CBR and UCS values. By comparing this correlation to previously published correlations, several factors were identified that seem to influence the correlations between UCS and CBR values, such as curing time, sample soaking, compaction energy, soil type, etc.

Based on the dosage rate and treatment study strength results, stabilizing soil with an initial CBR value of 2 for a potential subbase and/or base layer in an unsurfaced, aggregate-surfaced, or matted airfield should be possible. For a potential subbase layer, treating a soft soil with 2% to 5% pelletized quicklime achieved CBR values up to 30, which satisfies the required CBR values determined from PCASE for most loading conditions. For a potential base layer, treating a soil with 3% pelletized quicklime, 1% RSC15 fibers, and 11% Type III cement exceeded the required CBR value of 80.

Even though most of the layer strength requirements can be satisfied, the layer thickness requirements determined from PCASE may be difficult to achieve in some cases. While the base layer has a small required minimum thickness of 6 inches, the subbase layer may require a thickness ranging anywhere from 0 to 65 inches for all the loading conditions considered in this research. However, newly developed construction equipment by the J. H. Becker Company should be able to mix stabilizers into soil down to approximately six feet deep, which would satisfy any of the required subbase layer thickness requirements. Once the stabilizer is mixed into the soil, construction equipment such as the Rapid Impact Compactor (RIC), should be able to compact the stabilized soil to a depth of six feet.

A full discussion of this research can be found at: http://scholar.lib.vt.edu/theses/available/etd-12062006-190050/.

Levee Underseepage, Filters in Dams, and Seepage Monitoring

Students: Matthew Sleep, Chris Meehan, Emily Navin
Faculty Advisor: J. Michael Duncan (jmd@vt.edu)
Sponsor: United States Army Corps of Engineers
Start/Completion Date: August 2006/August 2007

Project Background

Three projects have been completed for the United States Army Corps of Engineers (USACE). These projects consist of a revision to EM 1110-2-1913 the Design and Construction of Levees, an update to the current CGPR Filter Workbook, and a report detailing seepage monitoring practices and techniques.

Project Objectives

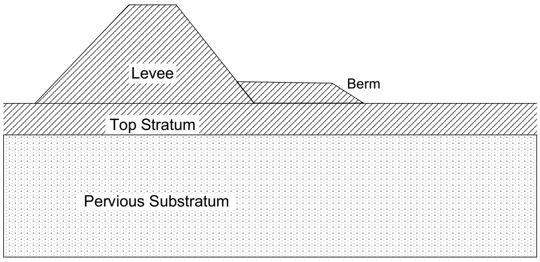
The revisions to The Corps Engineering Manual on Design and Construction of Levees (EM 1110-2-1913) focused on updating guidance for design and construction of seepage berms. Seepage berms protect levees from erosion and piping due to underseepage. The revisions reflect recent changes in Corps design practice, and new recommendations with regard to factor of safety criteria based on uncertainties in site conditions and consequences of failure.

Three federal agencies, the Corps of Engineers (USACE), the Natural Resources Conservation Service (NRCS) and the Bureau of Reclamation (USBR) each have slightly different filter criteria. To make it convenient to apply all of these criteria for filter design, the existing Excel Filter Workbook was updated to include the NRCS criteria. The new manual that accompanies the Excel workbook also includes guidance for filter installation.

In response to a request from FEMA to the U. S. Army Corps of Engineers Research and Development Center in Vicksburg, a draft report has been prepared summarizing desirable practices for seepage monitoring.

Approach and Results

Levee Underseepage



EM 1110-2-1913 was updated to include the changes from ETL 1110-2-569. The limiting berm dimension of 300 to 400 feet in length was removed. Also more guidance is given on the minimum investigation required for levee design. This guidance then corresponds to new factors of safety against erosion and piping at both the toe of the levee and the toe of the berm, if one is required. The proposed factors of safety are similar to the factors of safety used in the CGPR Engineering Manual for Slope Stability Studies. The factors of safety are functions of both consequence and uncertainty instead of using a single factor of safety for all conditions. A shift was also made to use factors of safety instead of relying on hydraulic gradient as the basis for safety criteria. Using factor of safety as opposed to hydraulic gradient is more logical because it also includes the unit weight of the material subject to upward seepage from the foundation.

Also as a part of this research, the equations presented in EM 1110-2-1913 were incorporated into a seepage berm design spreadsheet. This spreadsheet uses the equations from EM 1110-2-

1913, for a simplified two-layer system, to calculate the factor of safety at the toe of a levee against erosion and piping. Then, depending on the calculated factor of safety, a seepage berm or other remedial measure may be needed. The spreadsheet allows the user to calculate the dimensions of a required seepage berm, or to input dimensions and calculate the factor of safety.

Filter Workbook

The previous edition of the Filter Workbook included only the USACE and the USBR filter criteria. The updated workbook also contains the criteria of the NRCS. To create an easily understandable output, the workbook was split into three sections, one for each agency. As with the previous workbook, the user enters gradations for the base material and candidate filter on one sheet, and the information is automatically transferred to each sheet, where it is determined if the candidate filter meets each agency's criteria. The user's manual for the Filter Workbook was also updated to include guidance on the construction of filters using information from the different agency's filter criteria and other published sources. This inclusion creates a more comprehensive document for filter design. Included as guidance for construction are the following:

- Avoiding Segregation
- Achieving Adequate Compaction
- Using Durable Materials
- Using Materials That Are Not Subject To Cementation
- Avoiding Contamination of the Filter by Adjacent Materials
- Using Large Enough Filter Zones So that Windows are Avoided and Continuity of The Filter Zones is Assured

Seepage Monitoring

Seepage monitoring is an essential means of protecting a dam from failure due to erosion and piping. While monitoring may not offer physical protection, knowing if and when a dam is deteriorating due to erosion and piping is an important aspect of incorporating successful repairs or modifications. A report was written summarizing the state of practice in seepage monitoring. The most important aspect of seepage monitoring is visual inspection. Included in the report are several examples of current state dam safety office visual inspection checklists which can be very helpful for dam owners. Also discussed are instrumentation, geophysical methods, and how to handle data from these types of measurements. Because failure due to erosion and piping is often rapid once distress is noted, having an effective monitoring plan is essential to a dam safety program. This document can aid in that capacity.

Stability of Levees on Deep-Mixed Foundations

Student: Tiffany E. Adams

Faculty Advisor: George Filz (filz@vt.edu)

Sponsors: National Science Foundation,
U.S. Army Corps of Engineers

Start/Completion Date: May 2006/Jan 2009

Project Background

Increasing interest in using deep-mixing methods (DMM) to improve the foundation of levees constructed on soft ground is driven by the need to reduce levee footprints and environmental impacts and to allow for more rapid construction. Suitable methods for analysis and design of these systems are needed to insure that the DMM technology is properly applied.

Previous research on the stability of roadway embankments on DMM columns indicated that numerical analyses were preferable over limit equilibrium analyses due to their ability to capture column failure modes other than shearing, such as bending and tilting. This research recommended the use of continuous shear walls instead of individual columns to limit the potential for bending or tilting failure of the columns.

Foundation shear walls can be completed using specialized equipment for multiple-axis mixing or by overlapping single-axis DMM columns. Weak joints can develop in the walls wherever there is insufficient overlap between adjacent installations. Depending on the prevalence and strength of these joints, complex failure mechanisms, such as racking, can occur.

Project Objectives

The overall objective is to develop recommendations for the design of levees founded on DMM shear walls. The goal is to determine if numerical methods are necessary to accurately asses the stability of these systems and to provide recommendations for modeling weak joints within the shear walls. Three-dimensional numerical analyses will be performed to investigate the potential for localized stress concentrations due to three-dimensional effects as well as the potential for extrusion failure between the shear walls.

Approach

Stability analyses were completed for a 14-foot high levee constructed over an improved foundation consisting of a 35-foot wide and 40-foot deep zone of continuous dry-mixed single-axis DMM columns. This configuration was based on a project recently completed by the U.S. Army Corps of Engineers. The cross-sectional geometry and material properties were provided by the Corps.

Limit equilibrium stability analyses using Spencer's method were completed for a wide range of potential failure surfaces, including a shallow failure surface downstream of the DMM columns and a deep failure surface beneath the columns. Numerical analyses were completed using the finite difference computer code FLAC. Vertical joints were included in the DMM improved zone in order to model potential weak joints between columns. The analyses were completed for a joint strength corresponding to a condition of no overlap between columns (i.e., the strength of the native soil) and for a strength corresponding to a condition of full overlap.

Results

When the strength assigned to the weak joints corresponded to full overlap, the numerical analyses resulted in similar computed factors of safety to those calculated using limit equilibrium analyses. However, when the strength assigned to the weak joints corresponded to no overlap between columns at five locations, the results of the numerical analyses show racking of the columns and predict lower factors of safety than those calculated using limit equilibrium analyses. The computed factors of safety are summarized in Table 1 and the deep failure surfaces are shown in Figure 1.

Table 1. Computed Factors of Safety

	Factor of Safety	
Analysis Case	**Limit Equilibrium**	**Numerical Analysis**
Full Overlap Between Columns		
Shallow Failure Surface	1.36	1.33
Deep Failure Surface*	1.53	1.51
No Overlap Between Columns		
Deep Failure Surface*	1.53	1.37

* "Deep Failure Surface" refers to failure surfaces which involved the DMM columns, either by inducing racking of the columns or by passing beneath the columns.

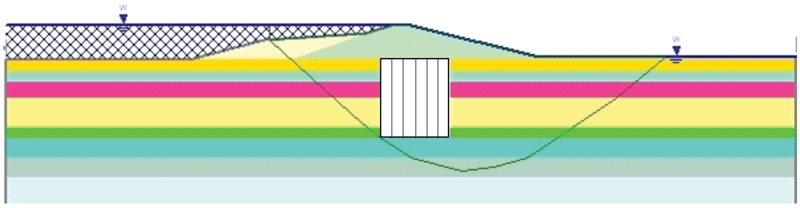


Figure 1a. Limit Equilibrium Failure Surface (FS=1.53)

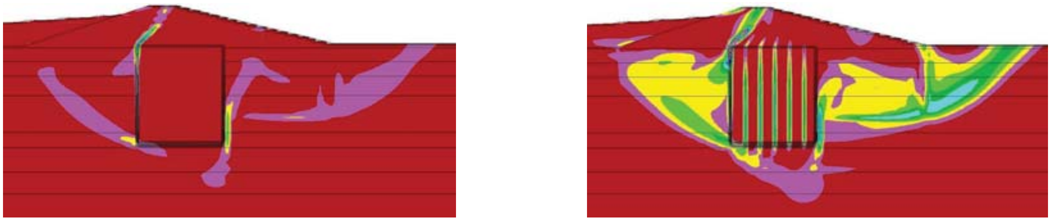


Figure 1b. Numerical Analysis Failure Surface, Full Overlap of Columns (FS=1.51)

Figure 1c. Numerical Analysis Failure Surface, No Overlap of Columns (FS=1.37)

Figure 1. Deep Failure Surfaces

Future Research

- Analyses will be completed for a range of overlap strengths to investigate the variation in factor of safety for different percentages of full overlap distance and to determine if a correlation can be made between the overlap efficiency and the occurrence of failure within the improved zone (e.g., racking or bending of the columns).
- Three-dimensional analyses will be completed to study the effects of stress-concentrations and assess the potential for extrusion failure between the shear walls.
- Reliability analyses will be performed.

Drained Triaxial Compression Test on 21b and #57 Gravels

Post-Doctoral staff: Wenxing Jian and Youngjin Park

Students: Genevieve Smith, Todd Griffith,
Jessa Corton and Esther Ryan

Faculty Supervisors: Mike Duncan (jmd@vt.edu)
Tom Brandon (tbrandon@vt.edu)

Sponsor: CGPR and Hayward Baker

Start/Completion Date: January, 2005 / March, 2007

Project Background

A study to evaluate drained friction angles for 21b and #57 gravels was requested by the members of the CGPR at the 2005 annual meeting, and the study was supported by CGPR base funding, and supplemental funding by Hayward Baker. The testing was performed at the W.C. English Geotechnical Engineering Laboratory at Virginia Tech.

Project Objectives

Measure values of ϕ for 21b and #57 gravels over a range of densities and confining pressures.

Tested Materials

Four types of gravels were tested: 21b limestone, 21b granite, #57 limestone, and #57 phyllite. The 21b and #57 limestone gravels were obtained from the Acco Stone quarry in Blacksburg, Virginia. The 21b granite gravels and #57 phyllite gravels were obtained from the Luck Stone crushed aggregate plants in Rockville and Charlottesville, Virginia. Photographs of the four materials are shown in figure 1.

(a) 21b limestone (from Blacksburg)

(b) 21b granite (from Rockville)

(c) #57 limestone (from Blacksburg)

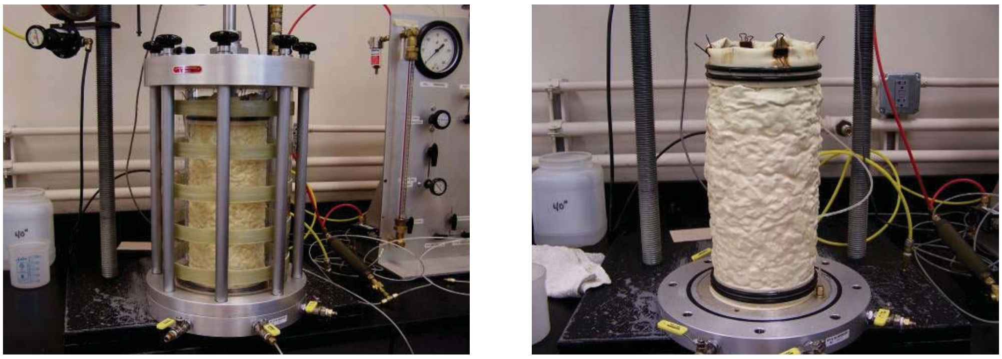
(d) #57 phyllite (from Charlottesville)

Figure 1 Photographs of materials tested

Test procedures

To form a triaxial test specimen, two rubber membranes with a thickness of 0.0125 inches and 0.025 inches were used. The material was placed inside the forming jacket in twelve 1-inch layers. The weight of the material placed in each layer was controlled so that the density of the test sample would be at the desired high or low test density. Formed samples were carefully seated into the triaxial device with automated stress-path system. Figure 2 shows the test procedures. Eight tests of 21b low density gravels, seven tests of 21b high density gravels and 19 tests of #57 low and high density gravels were performed under various confining pressures, varying from 3.9 psi to 30.5 psi.

(a) Forming jacket with membrane (b) Sample ready for testing



(c) Sample in triaxial cell (d) Sample after testing

Figure 2 Photographs of testing specimen and facilities

Results

Figure 3 shows the relationship between measured friction angles and confining pressures normalized with atmospheric pressure (σ_3/p_a). The friction angles of 21b low density, 21b high density, and #57 high and low density gravels decrease linearly with the increase of σ_3/p_a. The friction angles of 21b high density gravels are 8-12 degrees greater than those of 21b low density gravels. The friction angles of #57 high and low density gravels are almost the same, and the values are in the middle between those of 21b low density gravels and 21b high density gravels.

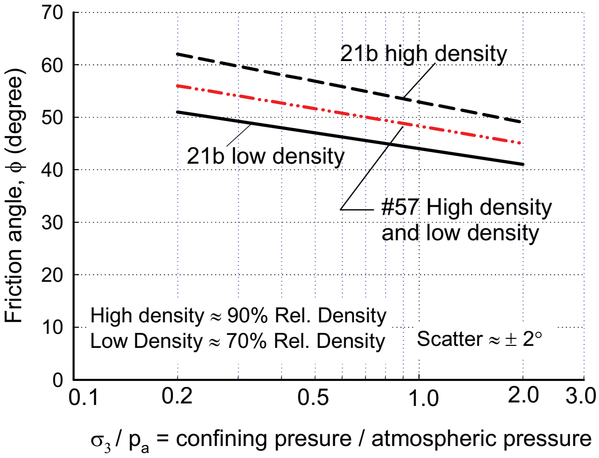


Figure 3 Variations of ϕ with σ_3/p_a for tested gravels

Remote Measurement of Fracture Data

Students: Jeramy Bruyn Decker, Brian Badillo, Justin Sommerville

Faculty Supervisor: Dr. Joseph Dove, Dr. Matthew Mauldon

Sponsor: National Science Foundation

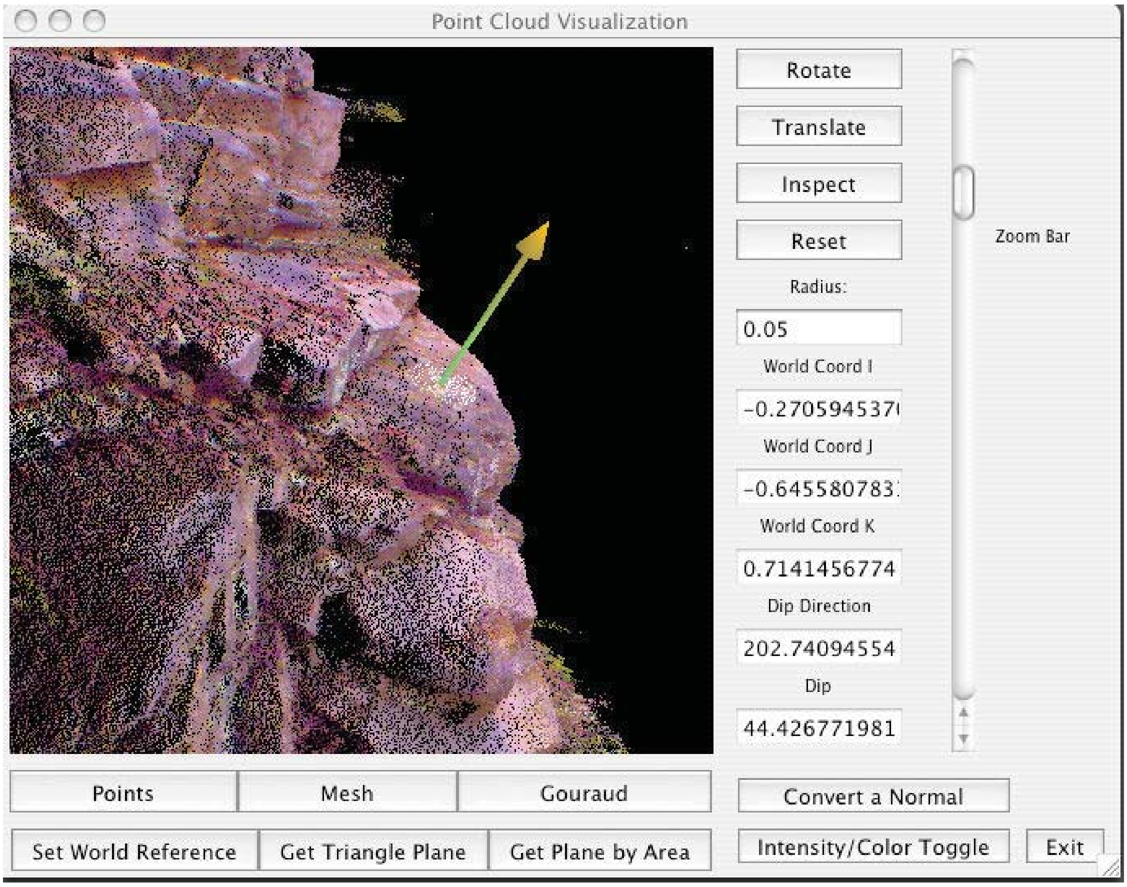
Start/Completion Dates: August 2003 / May 2007

Research Objective

This research project is a component of a larger research project called AMADEUS. Dr. Marte Gutierrez heads up the team which also includes: Dr. Joseph Dove, Dr. Erik Westman, Dr, Doug Bowman, Sotirios Vardakos, and Andrew Ray.

Preliminary joint data, such as orientation and spacing, are derived from field measurements taken from outcrops and/or boreholes. In the tunneling process, these preliminary measurements are used to assess the rock type, rock strength, rock behavior and to build fracture models of the rock mass. As tunnel excavation advances, more joint data can be measured. This research is developing new methods and tools to obtain imaging data in the tunnel that can be measured and visualized remotely. The research is also utilizing state of the art 3d visualization tools (e.g, VE, Stereo Imaging) to enhance the visualization image data.

Figure 1: LIDAR point cloud data from tunnel in Eggleston, VA being viewed in a fully immersive 3d environment within VT's CAVE.



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World Coord I: -0.270594537
World Coord J: -0.645580783
World Coord K: 0.7141456774
Dip Direction: 202.74094554
Dip: 44.426771981

Figure 2: Interface for *gVT* developed to analyze LIDAR data.

Approach

- Use of LIDAR and digital cameras.
- Development of custom software to analyze imaging data
- Comparison of field measured data with remotely measured data

Outcomes to date

- Custom software—*gVT*
- Visualization techniques developed to view LIDAR and stereo photography in 3d environment.
- Field study performed using LIDAR, digitial stereo images, and field measurements to test data collection techniques and field measurements vs. remote measurements.

Future Outcomes

- Further assessment of field data collected.
- Further enhancement of *gVT*

Development of a Simplified Laboratory Filter Test

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Sponsors:	USBR
Start/Completion Date:	December 2005/December 2007

Project Background

The filter zone is one of the most important components of embankment dams. They are constructed not only to protect the core materials during steady state seepage, but they also must perform satisfactory in the event of cracking due to seismic events. Although considerable efforts have been made by several organizations to develop procedures to determine the suitability of filters in embankment dams, scant research has been conducted regarding the ability of filters against collapse during static or seismic loading. In the past, several laboratory testing methods were developed to evaluate filter performance. However, most of them are either difficult to conduct or expensive. Therefore, it is necessary to develop a simplified laboratory test method in order to evaluate the suitability of filters to function effectively in an embankment dam.

Project Objectives

The objectives of this research were to (1) study the performance of filters during earthquakes and static loading, and (2) develop a simplified and less expensive filter test method.

Approach

The following describes the specific task items for collecting and analyzing the data, and developing the methods for laboratory filter tests:

- Desk study on the mineralogy, gradation, and placement condition of filter and core materials in USBR dams in order to establish a range of conditions to be simulated in the experimental testing program.
- Literature review, survey, and investigation through available reports on the depth and causes of cracking that have occurred in dams worldwide. This study will help to determine the depth of cracks and approximate range of overburden pressure that should be simulated during the experimental program.
- Literature review of the chemical and biological causes of cementation of granular soil, and obtaining case histories on the cementation in granular filters. The study will mainly focus on the favorable conditions for the development of cementation in filters. This will give an idea about the background necessary for the testing program in terms of materials and methods to be involved during experimental study.

- Experimental study on cracked filters using the laboratory testing devices developed at Virginia Tech to investigate the amount and plasticity index of fines on the performance of cracked filters. This will be useful to quantify the acceptable range of filter materials in terms of engineering properties.
- Experimental study on the self-healing ability of broadly graded filters. This will determine the potential conditions for those broadly graded filter materials to have self-healing and self-filtering capability without effective filters downstream.
- Development of simplified index test methods to assess potential filter performance. This will help to determine whether a candidate material is acceptable or not, using simple tests that can be performed at laboratories that do not have the specialized devices developed at Virginia Tech.

Research Progress

The following work has been completed within the first year of the project:

- Summarization of the gradation and mineralogy of the embankment materials at the existing USBR dams has been completed for the desk study and was submitted for review.
- Summarization of the depth and causes of cracking that has occurred in the dams worldwide has been completed for the literature review and was submitted for review.
- Summarization of the causes and case records of cementation in granular materials has been completed for the desk study and was submitted for review.
- A soil slump test has been developed to fulfill the requirements of the simplified index test. Testing of 21B gravel began in August of 2006 and was completed in January of 2007. A preliminary report summarizing the findings has been submitted with a detailed report to follow.
- Presently, dam filter materials are being tested with the soil slump test.

Future Research Activities

Research activities that are being planned for the remaining study period are as follows:

- Continuation of testing filter material for acceptability using the soil slump test.
- Summarization of the results obtained from the soil slump test in a detailed report.
- Investigation on the effect of amount and plasticity of fines on the performance of cracked filters using a 4-inch diameter filter test device created at Virginia Tech.
- Investigation on the self-healing ability of broadly graded filters using a 4-inch diameter filter test device created at Virginia Tech.

Engineering Manual for Organic Soils and Peat

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Sponsors: CGPR
Start/Completion Date: April 2003/ May 2007

Project Background

Organic soils and peat pose a variety of engineering challenges. The steps to working with organic soils and peat on a job site include: classifying the soil, assessing possible problems, assigning engineering properties and developing a mitigation plan. As land in desirable areas becomes less and less available, it is often necessary to construct in areas that have traditionally been avoided due to poor soil conditions. The Engineering Manual for Organic Soils and Peat will bring together and summarize published data for use by design professionals faced with sites containing organic soils and peat.

Project Objectives

The objectives of this research were to (1) collect and compile data on classification and engineering properties of organic soils and peat (2) compile and discuss mitigation methods for organic soils and peat, based on case histories.

Characterization

Classification of organic soils and peat is accomplished initially in the field using visual-manual techniques. Laboratory testing (ASTM D2974) is conducted to determine the quantity of organic material in a soil. NAVFAC DM 7.1 classifies organic soils according to the following:

Organic Content		Soil Classification
75% or more	→	Peat
30% to 75%	→	Peaty Organic Soil
5% to 30%	→	Organic Soil
1% to 5%	→	Soil with Organic Content
Less than 1%	→	Inorganic

Engineering Problems

Once identified on site, organic soils and peat pose multiple engineering challenges. First, the deposits of organic soils and peat are generally not uniform, and can change significantly over short distances. Organic soils and peat often have large void ratios and great water uptake and holding potential. The soils tend to exhibit large primary and secondary settlements. Primary settlement will occur relatively quickly in comparison to inorganic clay; however secondary settlement is often a significant portion of the total settlement in organic soils and peat.

In addition to large settlements, organic soils and peat often have low strengths. The undrained strength ratio for organic soils and peat is not significantly different from inorganic clays; however the effective vertical stress on the soil is usually significantly less because the soils have lower unit weight values. Another major engineering problem with organic soils and peat is potential corrosivity. Organic soils and peat tend to be highly acidic, with substantial cation exchange potential.

Mitigation Techniques

When organic soils and peat are encountered mitigation techniques need to be considered carefully. In locations where it is possible, avoiding the soil and building in a more suitable area is the first option. Other common techniques are to excavate and replace the undesirable soil, or to bypass the soil layer with deep foundations such as drilled shafts or piles. Preloading the soil to induce settlement along with applying admixtures to improve material properties, such as lime to reduce corrosivity, are also used to mitigate engineering problems with organic soils and peat.

Fully-Coupled Staggered Solution of Fluid Flow Behavior in Porous Media Based on the Biot's Theory

Student: Imsoo Lee

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Sponsors: American Chemical Society

Start/Completion Date: August 2004/August 2007

Project Background

Many physical phenomena can be explained by geomechanics-fluid flow coupling such as soil consolidation, hydrocarbon production, and contaminant transport. Therefore, there is a strong interest in the modeling of fluid flow behavior in deformable porous medium that takes into account geomechanical effects.

Project Objectives

This research focuses on developing a staggered solution technique for fully-coupled problem of fluid flow and deformation in porous media based on Biot's theory. The solution technique will be implemented to enable a geomechanical finite element code to be fully coupled with various types of finite element and finite difference fluid flow simulators. The main goal is to permit the rigorous implementation of geomechanical effects and existing fluid flow codes. The validity of the staggered technique will be demonstration by their use and application to idealized problems with analytical solutions (e.g., Mandel-Cryer problem) and to realistic field problems (e.g., subsidence in the Ekofisk oil field).

Approach

There are various ways to achieve couple between geomechanics field and fluid-flow field. In general, coupling can be categorized to three forms such as one-way coupled, iterative-coupled, and fully-coupled approach. The fully-coupled approach is based on the Biot's theory which has become a powerful framework for modeling three-dimensional fluid flow in deformable porous media in soil and rock mechanics. The fully-coupled is the most rigorous approach and produces the most correct results, however, it requires large computational efforts because it solves the geomechanics and the fluid-flow unkowns simultaneously and monolithically. Due to this limitation of the fully-coupled approach, most researches have focused on the iterative coupling. In the iterative coupling, porosity and the rock compressibility are used as key parameters of coupling between the fluid flow and geomechanics. However, most of the iterative coupling approaches assume that the porosity (or volumetric strain) change is caused by the mean effective stress alone. This is not necessarily true because deviatoric stresses also cause volumetric strain, and porosity can change even at constant effective mean stress conditions, as is well known in soil mechanics.

Instead of using a scalar compressibility matrix, a full compressibility matrix is used, which is calculated by diagonalization of the full tensorial compressibility matrix. The diagonalization process reduces the tensorial compressibility matrix to its principal components. Pore pressures are then calculated using the updated full compressibility matrix in the fluid diffusion equation, and this information is passed to the geomechanics code for the stress calculations. Due to the staggered characteristic, the proposed algorithm can be used in pre-developed fluid-flow simulation and geomechanics codes by providing a rigorous coupling between the two codes consistent with Biot's theory. Additionally, the proposed procedure does not require massive programming and computational efforts. Analytical solution and fully-coupled numerical solution of the Mandel's problem are used for the validation of the algorithm.

Results

- Finite Element Code for the fully-coupled and monolithic solution based on the Biot's theory was built.
- The code was validated using Mandel's problem and the rigidity effects of the surrounding material on the porous medium has been researched.
- 3D Geomechanical code was built based on linear elastic theory.
- Finite Element and Finite Difference code for the transient fluid flow code were built.
- Coupling algorithm was applied to the simple FE and FD flow codes.

Future Work

- Apply the developed coupling algorithm using an existing conventional reservoir simulator (e.g. BOAST).
- Implement other types of constitutive models (e.g. elasto-plastic, chalk) in the geomechanical code.
- Analyze a case history (e.g. Ekofisk).

Long-Term Performance of Seepage Barriers in Dams

Student: John D. Rice
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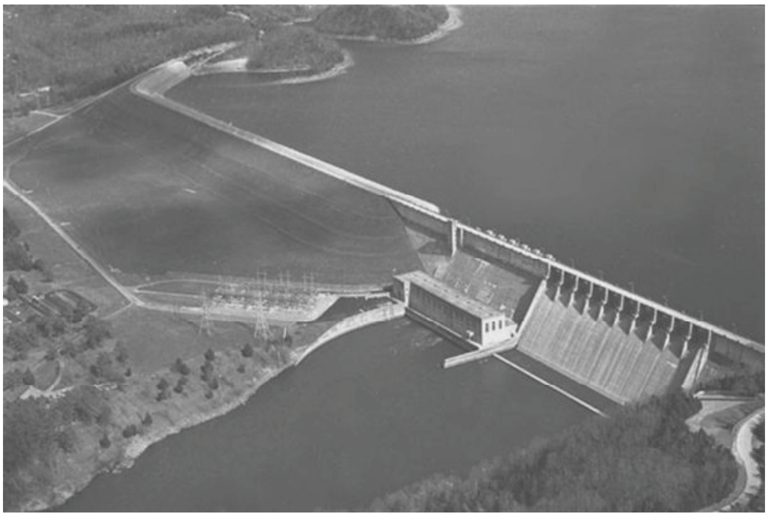
Sponsors: U.S. Bureau of Reclamation, CGPR
Start/Completion Date: August 2004/ August 2007

Project Background

It has usually been assumed that the installation of cutoff barriers result in permanent mitigation of seepage problems through embankment dams and foundations. Over the past two years, we have collected published literature, construction documents, and long-term performance data from a large number of dams that have had seepage barriers in place for over 10 years. While most of these dams appear to be performing as expected, some have not. The most extreme example of unsatisfactory performance observed is Wolf Creek Dam in Kentucky, where a concrete diaphragm wall was installed between 1975 and 1979. Seepage problems at Wolf Creek Dam have redeveloped over the past 25 years to levels equal to or exceeding those observed prior to installation of the barrier. Recent assessments of the renewed seepage have prompted the U.S. Army Corps of Engineers to lower the pool, resulting in an expected annual financial impact of over $50 million due to reduced hydropower production and losses to recreation business.



Wolf Creek Dam (USACE Photo)

The poor performance of Wolf Creek Dam after seepage barrier construction was obviously not anticipated and serves as an example of incomplete understanding of the distress-causing mechanisms that are unique to dams with seepage barriers. This study aims to identify these mechanisms and develop greater understanding of how they work, when they can be expected to occur, and how designs can be improved to prevent them from occurring.

Data Collection and Assessment

The collected data is being reviewed and analyzed to identify situations in which seepage barriers are not performing as expected. This information includes original dam design and construction reports, reports of seepage incidents, seepage barrier design reports, and most importantly, long term performance data.

Identification of Distress Mechanisms

The primary mechanisms associated with the addition of a seepage barrier in a dam can be tied to a single basic factor: the buildup of hydraulic pressure behind the barrier and the resulting increase in hydraulic gradient across and around the barrier. The differential water pressures on the barrier cause it to deflect, and this deflection may lead to cracking. The increased hydraulic gradients increase the potential for internal erosion and piping through and around the barrier.

We have identified four general distress mechanisms that represent different ways in which the existence of a seepage barrier in a dam can affect the behavior of the dam:

1. Leaks through seepage barrier**.**
2. Erosion of soil through bedrock joints.
3. Erosion of solution void infill.
4. Internal instability of foundation soils.

These four mechanisms are not necessarily the only mechanisms to be considered in assessing the effects that a seepage barrier has on a dam's performance. Rather, these failure modes are intended as examples of potential failure modes for dams with seepage barriers. Other failure modes are also no doubt possible depending on detailed characteristics of particular dams and foundations, and should be evaluated thoroughly.

Analyses

We are currently performing analyses to enhance our understanding of the distress mechanisms discussed above. Two categories of analyses, each with its own purpose, will be performed for this study:

1. Analyses performed on models of specific dams from our data base to assess the performance of the barrier with respect to its intended purpose.
2. Analyses of hypothetical dam configurations in order to increase our understanding of the situations where the distress mechanisms discussed above are likely to occur. These analyses will look at various dam/seepage barrier configurations and specific portions of the seepage barrier and surrounding soil.

Both categories will consist of finite element deformation analyses and two- and three-dimensional finite element seepage analyses.

Outcome

The end products of this research will be better understanding of seepage barrier performance and tools that can be used by engineers and dam owners to improve procedures for design, monitoring and assessment of performance of seepage barriers. We feel that the results of this study will be especially useful in improving risk assessment studies for dams with seepage barriers.

Distinct Element Modeling Simulations of the February 17, 2006 Leyte, Philippines, Rockslide

Students:	Naya Asprouda (naya@vt.edu)
Faculty Advisors:	Dr. Marte S. Gutierrez
Sponsor:	National Science Foundation
Start/Completion Date:	August 2006 / May 2007

Project Background:

This projects investigates the massive rockslide which occurred on February 17, 2006 in the island of Leyte, Philippines. The rockslide is considered to be one of the largest and most catastrophic in the last few decades. The nearby village of Guinsaugon, located at the foot of Mt. Cabac, was completely inundated and 1,328 persons of the 1,857 persons that populated the village were reported missing and presumed dead. The village of Guinsaugon was completely covered by approximately 30m of soft and unstable debris causing great difficulties to the rescue teams. The nature of the debris and the continuous rain prevented heavy machinery from being able to approach and operate in the area, and thus rescue operations were carried out manually.

The area was subject to heavy rainfall during the month of February 2006, averaging at approximately five times the average amount of rain during rainy seasons. The excessive rainfall was attributed both to the weather phenomenon in the Pacific Ocean known as La Niña, as well as to the presence of an inversion zone in Southern Leyte island. Additionally, four minor earthquakes occurred the same morning prior to the slide. Two of these earthquakes occurred along the PFZ fault, which later on was identified as one of the slide surfaces, and were of a significant magnitude approximately Mb=4.5. The influence of both the heavy rainfall and earthquakes on the triggering of the slide has not yet been proven.

Project Objectives:

The main objective of this project is to investigate the underlying causes of the massive rockslide which occurred in February 17, 2006 in the island of Leyte, Philippines. The rockslide and debris flow is modeled using a distinct element code, 3DEC. The objective of the use of numerical simulations is to use back-analysis and realistic 3D geometry of the sliding wedge in order to better understand the mechanisms responsible for the rockslide.

Work Completed:

Dr. Marte S. Gutierrez led a U.S. Reconnaissance Team to the rockslide location both in June and November 2006 in order to collect data on the geometry of the scarp as well as the geology of the area. Additionally, witness accounts were taken which will be used in verifying the reliability of the results of the numerical analyses by comparison to the actual behavior of the slide.

- 3DEC digital elevation model has been developed using digitized topographic maps prior to the slide.
- The three major failure surfaces forming the sliding wedge, which were identified at the site during the U.S. Reconnaissance Teams visits, have also been modeled on the 3DEC digital elevation model
- In order to determine the triggering mechanism of the slide, several models were created and analyzed in 3DEC. First, back-analysis was used to estimate the angle of internal friction of the failure surfaces, and the results were then compared to laboratory results from samples taken at the site.
- Literature review has been performed in order to get a better understanding of the circumstances under which the slide occurred.

Future Work

- Determine and analyze the triggering mechanism of the slide by hydraulically pressurizing the fault and applying horizontal ground accelerations equal to those produced by the earthquakes the morning of the incident.
- Further refine the model and the geometry in order to be able to analyze the debris flow more accurately and compare it to the actual behavior of the debris during and shortly after the slide.

A Guide to the Settlement of Valley Fills

Student:	Andrew Bursey
Faculty Advisor:	J. Michael Duncan (jmd@vt.edu)
Sponsor:	CGPR
Start/Completion Date:	March 2006/August 2006

Background

Successful construction on valley fills requires consideration of settlements caused by secondary compression, wetting, and earthquakes. Settlements in valley fills are deep-seated, and largely independent of surface loading. Variations in fill depth or fill density may contribute to large and damaging differential settlements. The magnitude of settlement to be expected in these fills, and the effectiveness of various measures to reduce settlement, can be estimated based on case history data.

Objectives

The objective of this research was to survey case histories and previous research to produce a practical guide to the causes of valley fill settlements, approaches for evaluating their potential magnitude, and methods for mitigating their effects.

Approach

A large body of literature was reviewed. Among others, principal references included:

- Sowers et al. (1965), "Compressibility of broken rock and the settlement of rockfills"
- Brandon et al. (1990), "Hydrocompression settlement of deep fills"
- Charles and Watts (2001), *Building on fill: geotechnical aspects, 2nd edition*
- Stewart et al. (2001), "Seismic performance of hillside fills"

Results

Segregation occurs in all fills, making exploration and characterization difficult. In the case of end-dumped fills, segregation may contribute to differential settlements. Fill thickness has large bearing on settlement magnitude. Causes of settlement in valley fills include secondary compression, wetting, and earthquake shaking. Significant secondary compression may continue long after placement occurs, particularly in clay and rock fills. Sluicing, once thought beneficial in densifying rock fills, increases the rate of secondary compression. Wetting due to irrigation or subsurface flow may trigger accelerated settlement rates well into the service life of a fill, resulting in unexpected damage. Earthquake shaking has lead to significant fill settlements in a broad spectrum of soil types.

Full-scale field tests and experience show that the location of structures on fills is an important factor in the amount of damage that results from settlement. Buried valley topography is useful for evaluating fill thickness variations, but is often unavailable. Densification of valley fills reduces settlements, but densification to adequate depth is frequently not possible. The study is described in CGPR Report #41, *Settlement of Valley Fills*, which has been distributed to members.

Technology Demonstration of Rapid Stabilization of Soft Clay Soils

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Sponsor: Air Force Research Laboratory

Start/Completion Dates: March 2003 / May 2009

Project Objectives

This research is part of a larger project, for which the overall objective is to stabilize soft clay, obtaining a strength gain within 72 hours that will be sufficient to support contingency airfields. A key element of this research is the application of lime-mixing technology developed by the J. H. Becker Construction Co. They have demonstrated the ability to mix lime to depths of 6 ft in one pass with specially designed equipment.

Test Location

Figure 1 presents Craney Island, identified as a potential field test location for this project. Located in Portsmouth, Virginia, Craney Island is composed mainly of dredge materials, resulting in very soft site soils. This site, owned by the U.S. Army Corps of Engineers, is currently undeveloped and it is used as a dredge material management area.

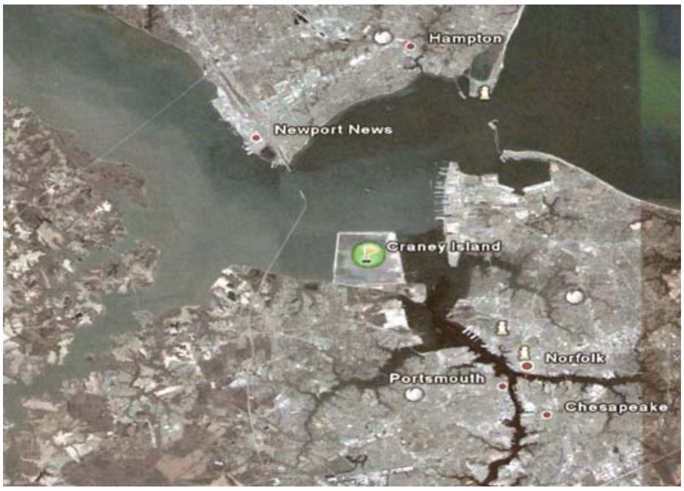

Figure 1 – Aerial view of Craney Island

Technology Demonstration

A preliminary site investigation and laboratory study will determine the existing soil properties and determine the optimum lime content. During the field construction, the J.H. Becker Construction Co. will stabilize a 0.5 to 1.0 acre test area using quicklime to a depth of 3 to 6 feet at the specified dosage rate. We anticipate using both Rapid Impact Compaction (RIC) and a Caterpillar 815 to compact the treated soil. An additional in situ and laboratory testing program will be conducted to measure the properties and depth of the treated soil.

Research Expectations

- Introduce specialized lime mixing technology into the area of contingency airfield construction.

Fracture Modeling for Hard Rock Tunneling

Student: Jeramy Bruyn Decker

Faculty Supervisor: Dr. Matthew Mauldon

Sponsor: National Science Foundation

Start/Completion Dates: August 2003 / May 2007

Research Objective

This research project is a component of a larger research project called AMADEUS. Dr. Marte Gutierrez heads up the team which also includes: Dr. Joseph Dove, Dr. Erik Westman, Dr, Doug Bowman, Sotirios Vardakos, and Andrew Ray.

Preliminary joint data, such as orientation and spacing, are derived from field measurements taken from outcrops and/or boreholes. In the tunneling process, these preliminary measurements are used to assess the rock type, rock strength, rock behavior and to build fracture models of the rock mass. As tunnel excavation advances, more joint data can be measured. This research is developing new methods to build and update in real-time stochastic fracture models, using preliminary data along with new data as the tunnel is advanced.

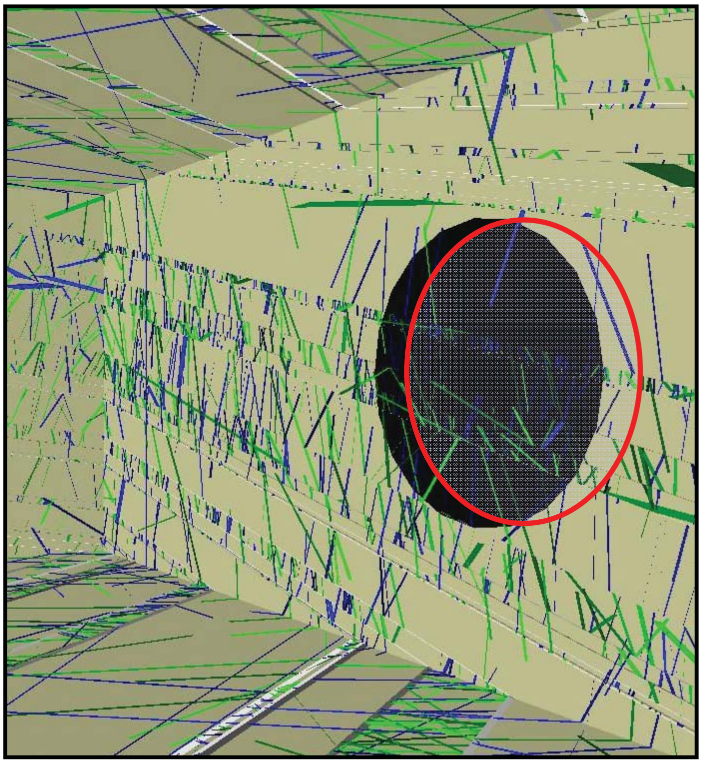

Figure: Virtually excavated fracture model with a virtual circular sampling area.

Approach

- Development of stochastic fracture models using FracMan and custom software.
- Utilization of custom software and 3d visualization techniques to create trace maps remotely
- Updating of fracture models using newly obtained data as tunnel is advanced.
- Development of new statistical tools to estimate fracture shape and size, and testing of these tools using Monte Carlo simulations and field data

Outcomes to date

- Virtual fracture models created with the ability to excavate virtual tunnels.
- Distribution-independent stereological estimators derived for trace density and mean trace length.
- Kaplan-Meier based method utilized to create nearly unbiased trace length PDF's.
- Differential Evolution algorithm used to infer shape and size of rectangular fractures from censored trace data on two or more nonparallel planes.
- Field study performed within existing tunnel test developed statistical tools.

Future Outcomes

- Further assessment of field data collected.

Revised Reliability Manual

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Esther Ryan

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Faculty Supervisor: Michael Duncan (jmd@vt.edu)

Sponsor: CGPR

Start/Completion Dates: August 2006 / May 2007

Project Background

The reliability manual was published in 1999 for use by CGPR members. Since that time CGPR members found that the manual is difficult to follow. In addition, new methods have emerged to assess the reliability of engineering projects.

Project Objectives

Update the manual with state of the art reliability methods.Revise the structure of the reliability manual to make the manual easier to use by including step by step instructions.

Approach

The main modifications to the manual are:

- Explain the basic concepts in simple terms – “The language of statistics and probability”; this new chapter was developed to introduce engineers to the terminology associated with statistic and probability.

- Add new reliability method - “Hasofer Lind”. Recent studies prove that the Hasofer Lind method produces the best results compared to the accurate Monte Carlo method, as shown in Figure 1.

- Use only simple normal distribution. This allows us to avoid the complexity of the lognormal distribution in reliability analysis. Recent work shows that the simple normal distribution gives accurate results.

- Provide step by step procedures on how to use the “Taylor Series Method” and the “Hasofer Lind Method”

- Provide guidance on choosing the coefficients of variation. An experienced engineer can easily make a good estimate of average geotechnical parameters, but estimating coefficients of variation is a less familiar process.

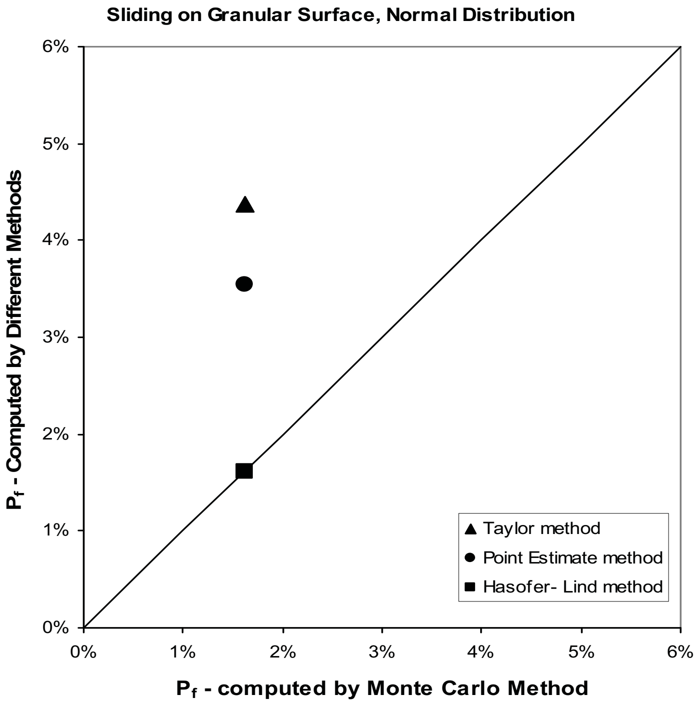

Figure 1: Comparison of values of P_f for sliding mode of a retaining wall.

Downdrag and Dragloads on Piles Subject to Negative Skin Friction

Student:	Mike Greenfield
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Sponsors:	CGPR
Start/Completion Date:	August 2006/May 2007

Project Background

Piles in clay strata will often settle less than the clay, especially when additional consolidation of the clay is induced by fills, drains, or even pile driving. This differential settlement causes negative skin friction which results in additional loads and settlement in piles and pile groups. The additional settlement is commonly called downdrag while the additional force created from negative skin friction is called dragload. These phenomenon are generally well known, but there is little consensus on how to analyze and design for these conditions.

Project Objectives

The objective of this report is to determine the current state-of-practice for analyzing and designing for piles and pile groups experiencing negative skin friction. The result will be a report and worksheet by which practicing engineers can identify downdrag conditions, estimate material property values, then analyze and design piles with respect to downdrag and dragloads.

Results

The literature review identified several methods by which one can calculate downdrag and dragloads in single piles. Four of these methods will be explained in the manual. These four methods encompass a range of possibilities for analyzing single piles, from quick and simple estimates to more rigorous models that include multiple subsurface characteristics. All four methods use fully mobilized skin friction on the shaft, and three of the methods use fully mobilized toe resistance.

In addition to the four methods selected from the literature review, two new methods were developed to allow for partially mobilized skin and toe resistance, which is a better model for piles bearing on rock or other extremely stiff layers.

To calculate downdrag and dragload in pile groups, finite element analyses are often used because of the complexity of the situation and the lack of field data for full pile groups. The report will present published reduction factors for dragloads in pile groups from finite element analyses. Two of the methods described previously account for group settlement using load-spread methods.

As an to aid practicing engineers, a Microsoft Excel® Workbook has been developed that calculates downdrag and dragloads for all of the methods described previously. In the Workbook, the user can select or unselect methods to use depending on the available subsurface information. The Workbook will then run the selected methods, and output the results in tabular form and as a graphical display of settlement versus depth and axial pile load versus depth.

Continued Research

The remainder of the research is twofold:

(1) Compare the methods with case histories and determine the best way to estimate material property values. At the time of this summary, it is clear that properly estimated material properties is more important than the complexity of the method one uses. A comparison of several case studies with results from the Excel® Workbook is currently underway.

(2) Develop design criteria to accommodate for negative skin friction. The literature review resulted in numerous methods of designing piles with respect to negative skin friction. More investigation is required to determine which method will work best from a practical standpoint.

Soil and Rock Modulus Correlations for Geotechnical Engineering

Student:	Andrew Bursey
Faculty Advisor:	J. Michael Duncan (jmd@vt.edu)
Sponsor:	CGPR
Start/Completion Date:	September 2006/February 2007

Background

Correlations between soil modulus and in situ or laboratory test results are useful in geotechnical engineering, and many have been published. Variations among them are large because of differences in type of modulus, stress state, and strain magnitude. In order to select and use the appropriate correlation, an understanding of these differences, and of the factors that control soil stiffness is necessary.

Experience shows that in situ testing to obtain rock mass modulus is difficult, and the area tested is frequently too small to be representative. Consequently, estimates of rock modulus based on in situ tests tend to exhibit large scatter. Relationships between rock mass classification systems and rock mass modulus have been developed to overcome this shortcoming.

Objectives

The objective of this research was to produce a practical guide to understanding soil and rock moduli, and to provide guidance for estimating soil and rock modulus values based on the results of in situ and laboratory tests, and rock mass classification systems.

Approach

The literature was surveyed to compile soil and rock modulus correlations and review relevant case histories. The manual emphasizes the importance of identifying clearly the type of modulus used, and the strain level to which it applies. When this is done, the scatter among the various correlations is reduced very significantly.

Results

A practical guide to stress-strain parameters, their interrelationships, and the factors that control soil and rock stiffness was developed. Selected correlations between in situ and laboratory test results and soil moduli are compiled in the report, and references are provided for more in-depth study. A matrix relating test type, soil type, and modulus type is included to aid in selecting the best correlation for the purpose at hand. Methods for estimating rock mass modulus based on rock mass classification systems are discussed. References to the most widely used rock mass classification systems and methods of estimating rock mass modulus are provided, including links to Everett Hoek's on-line tools, which are available at no cost.

This study is described in CGPR Report #43, *Soil and Rock Modulus Correlations for Geotechnical Engineering*, recently completed.

LEACHING OF LIME-TREATED SOIL

Students: Jaime M. Colby and Jessa D. Corton

Faculty Advisors: George Filz (filz@vt.edu)
Thomas L. Brandon (tbrandon@vt.edu)

Sponsors: J.H. Becker Company, Inc.

Start/Completion Date: May 2006/ February 2007

Project Background

Lime treatment of soil is a popular modification/stabilization technique for soft soils, especially clays and certain silts. As viable ground available for development decreases and treatment technology improves, lime treatment is being utilized for a variety of purposes beyond pavement subgrade stabilization, such as treatment of borrow material for structural fill. When stabilized soil is used in applications without an impermeable cover, the long-term effects of leaching due to infiltrating precipitation on the engineering properties of the treated soil becomes a concern.

Project Objective

The purpose of this research is to investigate whether leaching has the potential to degrade the engineering properties of lime-treated soil. This research investigates the effects of leaching on specimens of a marine clay from northern Virginia mixed at different lime treatment levels.

Procedure

A literature review was performed on the limited studies currently available and their findings regarding on the effects of leaching on lime-treated soils. Using these studies as a guide, the marine clay was characterized by a series of tests and then mixed with four different lime contents: 0.5%, 2%, 4%, and 6%. Characterization of the lime-treated marine clay was then analyzed by a similar set of testing. The treated soils were compacted into permeameters and leached for a duration of 45 days or until a total water volume of 200 liters passed through the system. Upon conclusion of leaching, the soil underwent characterization testing similar to that performed on the pre-leaching soil.

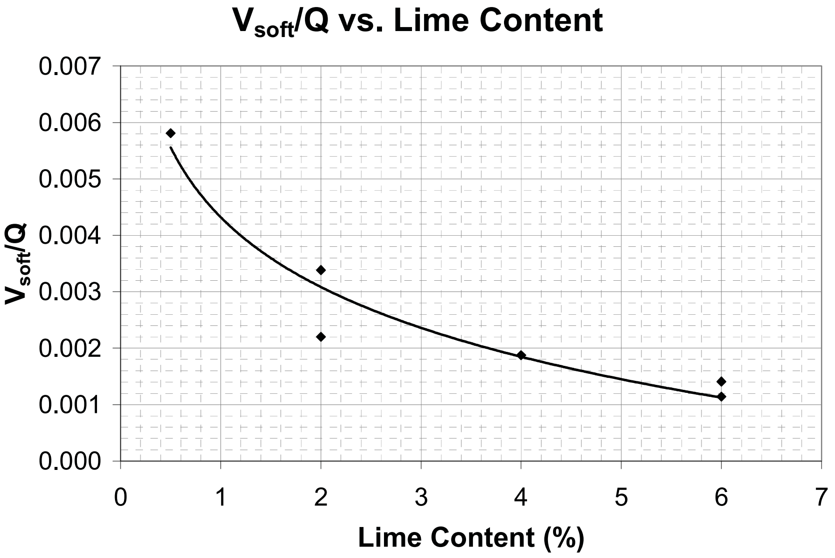
Results

After leaching, hard and soft zones were found within each specimen. These two zones were separated and classified according to the applicable ASTM standards. When compared to their pre-leaching equivalent, it was discovered that the plasticity index increased in the soil from pre-leaching to post-leaching conditions. Plasticity index was also found to increase from the post-leaching hard to soft soil zones. Characterization testing also revealed that the average grain-size decreased for both the post-leaching hard and soft soil zones.

Lime Content (%)	Plasticity Index		
	Pre-leaching	Post-leaching Hard	Post-leaching Soft
0	28	---	---
0.5	18	20	20
2	11	28	40
4	NP	18	37
6	NP	ND	34

Soil	Percent Passing No. 200
Untreated	90.9
Pre-leaching	66.9
Post-leaching Hard	76.3
Post-leaching Soft	91.9

A relationship between the softened volume of the lime-treated material, V_{soft}, normalized by the volume of water passed through a specimen, Q, and the lime content was established. The relationship shows that the sample softening relative to the quantity of water leached through the specimen is less significant as lime content increases. Developing a correlation allows the prediction of the stabilized soil's degradation according to water volume and lime content for this specific soil.



Geotechnical Specifications of Little League Ballfields

Student: Timothy M. Moore
Faculty Advisor: Thomas L. Brandon (tbrandon@vt.edu)
Sponsors: USDA-Agricultural Research Service
Start/Completion Date: November 2006/December 2007

Project Background

A grouping of eight soccer fields were built for a YMCA organization in Beckley, WV. The land for these fields was donated by a large-scale mining outfit in the area, and was un-mined terrain. The mining company also volunteered its equipment and labor to construct the field. The fields in their current condition have received numerous complaints due to their lack of turf growth, hardness, and high-occurrence of injuries. More land has been donated across the street from these fields in the same sports complex, and the town of Beckley has decided to build baseball fields in this location. This plot of land is also un-mined terrain, but the owners and town want to avoid the poor performance of soccer fields.

Project Objectives

The objectives of this research is to (1) establish a set of geotechnical recommendations for the construction phase of the project, (2) provide limited quality control measures to ensure the recommended specifications are followed, (3) construct and monitor long-term research plots adjoining the ballfields, and (4) examine and relate the application of current ASTM and geotechnical specifications in respect to ballfields.

Approach

The Annual Book of ASTM Standards for 2006 was reviewed to extract any current specifications that may relate to impact/shock attenuation of natural ground surfaces, compaction specifications/recommendations of sports fields/playgrounds, or compaction specifications for promoting turf growth while avoiding differential settlement. These specifications will then be used to compile a set of geotechnical recommendations for the ballfield construction phase. Quality control measures will be put in place to randomly ensure proper accordance with these recommendations. The research plots will become an entirely different phase of the project, where three plots will be constructed at different levels of compaction (80%, 85%, and 90% of the standard Proctor density). Each of these three plots will have the same set of varying soil/turf treatments, to provide a set of variables that can be monitored long term. The success of the varying treatments in the varying compaction levels, and the level of differential settlement of the plots will be examined throughout the life of the research plots. Through the quality control phase of the construction and the long-term monitoring of the research plots, various ASTM specifications will be examined by applying them to ballfield construction.

Work Completed

- **Research and Review of current ASTM specifications.** Review of current ASTM standards and specifications is almost complete, and those that have possible relevance to this project are being noted.

- **Development Phase of Geotechnical Ballfield Recommendations.** At this point, development of the specifications for the ballfield construction has begun. Since there are not many ASTM specifications for the geotechnical engineering aspect of ballfield construction, specifications from similar projects will be altered and applied using the best engineering judgment and experience possible. Over the course of the long-term research, these specifications will be remolded as better information is formulated.

Areas for Further Research

- Develop a complete set of geotechnical recommendations for the ballfield construction phase.
- Develop a quality control plan to ensure proper accordance with these specifications.
- Examine the application of current ASTM specifications to the research plots and relate them to the construction of ballfields.

Central and Eastern United States (CEUS): Seismic Implications

Student: Morgan A. Eddy, MS, EIT (meddy@vt.edu)

Faculty Advisor: James R. Martin, PhD, PE (jrm@vt.edu)

Sponsors: Earthquake Engineering Center for the
Southeastern United States (ECSUS)

Start/Completion Date: Summer 2006 / Summer 2007

Project Background

Recently, numerous states as well as the Department of Defense have adopted the International Building Code (IBC2000, 2003). In the Central and Eastern US (CEUS), this new building code has introduced more stringent seismic considerations of constructed facilities and lifelines. The code is a combination of recent US regional model codes and relies mainly on provisions and standards that were initially developed in the western US. As a result, it appears that in some cases the code may not be directly applicable to some CEUS regions due to geologic conditions and other seismological factors that are different than those for which the code was developed. Accordingly, the main objectives of this research are to provide general outlines for performing a seismic analysis per the IBC 2003, address the CEUS unaccounted geologic conditions and perform site response analyses of CEUS sites to assess implications of the IBC 2003. Two CEUS sites were selected to provide a range of results that demonstrate the issues described: Charleston and Columbia, South Carolina. These sites are of increased importance from a seismic standpoint because of the historical "1886 Charleston, SC" earthquake (Moment Magnitude, M_w 7.0-7.3).

Response Spectra

To interpret the results of this study, a general understanding of response spectra is necessary. Response spectra represent the response of various structures to an earthquake. The response can be measured in terms of acceleration, velocity, or displacement plotted against the period of the structure. The period of a structure depends on the geometry and material properties. In general, the period of structures constructed in the United States is approximately equivalent to the number of stories divided by ten. Figure 1 contains two response spectra: a jagged spectrum labeled "Earthquake Spectra" and a spectrum labeled "Capped & Smoothed IBC 2003 Design Spectrum." The jagged spectrum corresponds to one particular earthquake, represented by the time series shown in the bottom left corner of Figure 1. The "Earthquake Spectrum" is obtained by shaking buildings of various periods (illustrated in Figure 1 by the short building, tall building, and suspension bridge), recording the maximum responses, and plotting the values against period. The IBC 2003 design spectrum is capped for economy and smoothed for computational convenience and developed from site information. The IBC 2003 design spectrum represents all possible sources of seismic hazard rather than one particular earthquake; this spectrum is used to design the structure to prevent loss of life.

IBC 2003 Assumptions

IBC 2003 design spectra are constructed using the USGS Seismic Hazard Maps. Spectral values obtained from the USGS maps are used to "anchor" the IBC 2003 design spectra. The CEUS portions of the USGS maps were developed using a generalized rock site with a smoothed velocity profile shown in Figure 2. To account for various site conditions, the spectral values are adjusted for average soil properties in the top thirty meters of the site profile. However, the IBC 2003 does not account for several geologic conditions found in CEUS, these include: very hard rock, deep-soft sediment wedge (i.e. Charleston, SC), and soft-rock close to the ground surface (i.e. Columbia, SC). Figure 2 contains velocity profiles for Charleston and Columbia, SC, showing the difference between the IBC 2003 assumption and actual site conditions. To assess the implications of these geologic conditions, site response analyses were performed using the "1886 Charleston, SC" earthquake.

Implications of IBC 2003

1. Charleston, SC: The IBC 2003 spectrum is conservative in low period range and unconservative in high period range because of the sharp stiffness contrast and the deep sediment wedge (Figure 3).
2. Columbia, SC: The IBC 2003 spectrum is unconservative over a broad period range because of soft soil deposits atop soft rock close to the ground surface (Figure 4).
3. Computed site amplification factors indicate a need for modification to the existing factors suggested by the building code.

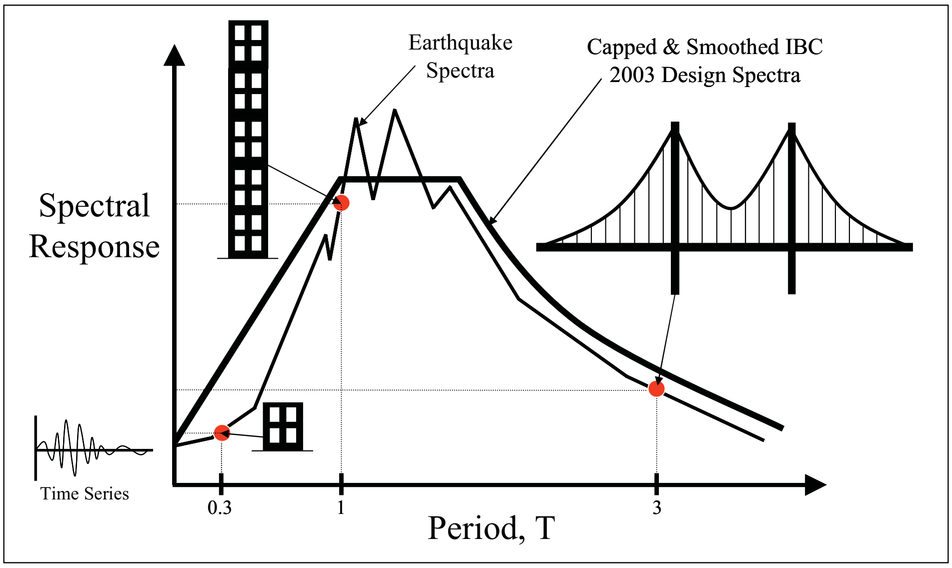


Figure 2 – General definition of response spectra

Emergence of Intelligent Compaction in U.S. Practice

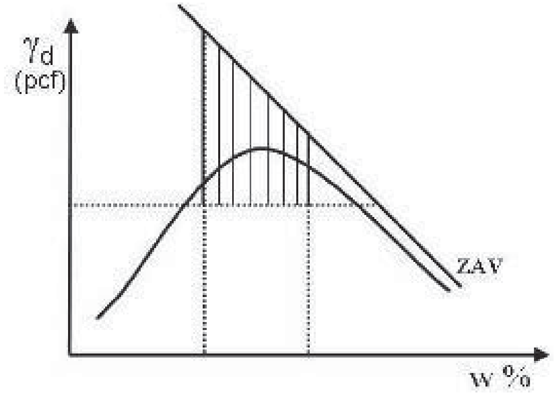
Start: August 2005 End: February 2006

Report Available: February 2007

- Student: Michael McGuire
- Supervisors: George Filz and Tom Brandon
- Sponsors: Virginia Tech CGPR

Objective: Compile and summarize comprehensive reference materials on intelligent compaction and continuous compaction control.

Problems With Traditional Method of Assessing Compaction Quality



- Very low testing frequency
- Even with high testing frequency, only very small percentage of total compacted volume tested
- Sampling bias

- Inspection budgets strained under rising labor and benefits costs.
- Many experienced inspectors are retiring.
- Visual inspection of compaction is often undervalued.

IC/CCC Technology

www.geodynamik.com

<u>Continuous Compaction Control (CCC):</u> compactor integrated technology that collects data in real time over the entire compacted area regarding the state of soil compaction.

<u>Intelligent Compaction (IC):</u> refers to the capability of a compactor to automatically adjust its operation based on data from the CCC system.

Overview of IC/CCC Technology

- Depending on the system, compactor-derived compaction measurements can be:
  - Unit less values that reflect the stiffness of the compacted material in a relative sense.
  - Calculated values of the actual stiffness or modulus of the compacted material (sands and gravels only).

- CCC output values can be correlated to other soil parameter values (e.g. density for a particular water content) or be used directly for acceptance.

- CCC output values are stored along with GPS coordinates in on-board *Compaction Documentation Systems (CDS)* to create a permanent record of the compaction process.

Using IC/CCC Technology for Assessment of Compaction

A contractor QC program can benefit from IC/CCC technology.

- Continuous and instantaneous measurements of compaction over the entire roller pattern provides documentation of compaction and eliminates unnecessary roller passes.
- Correlation with traditional field tests increases the effectiveness of infrequent spot-testing.
- Statistical analysis (min, max, mean, std. dev.) of CCC output values can evaluate the uniformity of the compacted area and identify localized soft/weak zones.
- IC equipment adjusts the compactor operation to maximize compaction efficiency to reduce the number of roller passes, prevent aggregate crushing, and increase equipment life .

Probabilistic Procedures for Post-Liquefaction Stability Analysis of Embankment Dams and Foundations

Start: April 2004 End: February 2007

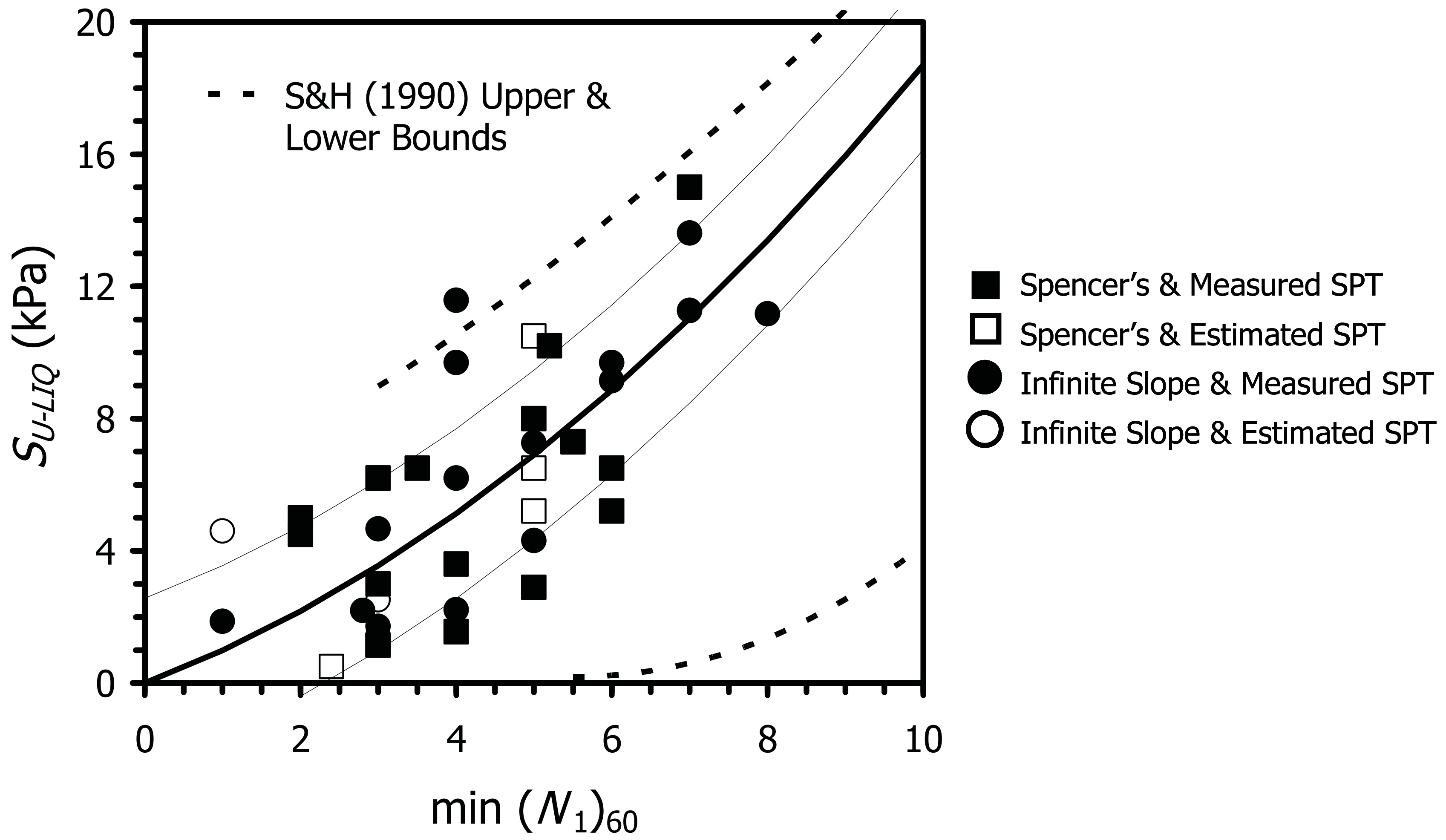
- Student: Morgan Eddy
- Supervisor: Dr. Marte Gutierrez
- Sponsors: USBR

<u>Objectives</u>

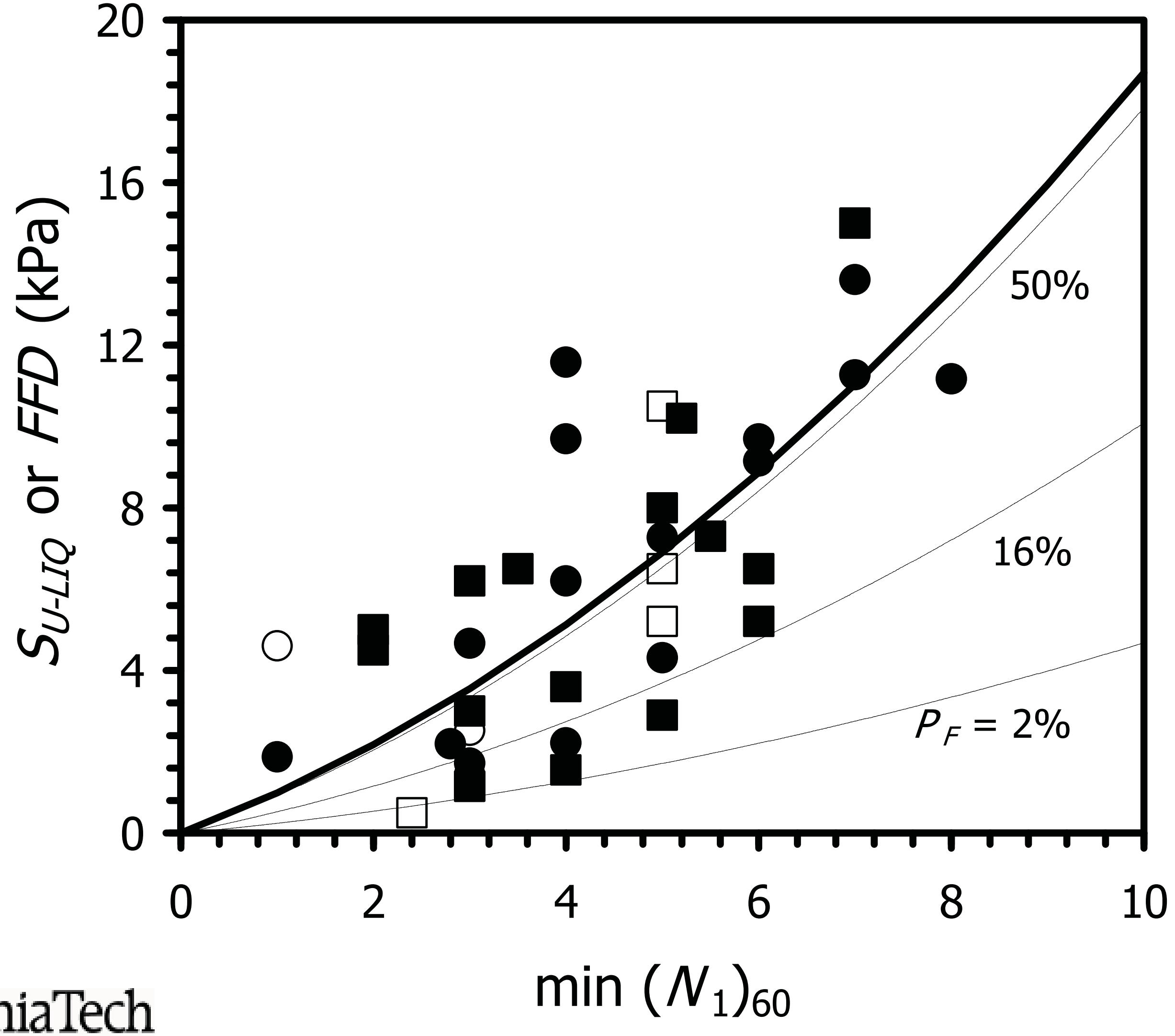
  - Re-evaluate and expand available databases
  - Develop reliability-based back-analysis procedures
  - Produce probabilistic liquefied shear strength criteria
  - Demonstrate new procedures within USBR seismic risk scheme


(a)
(b)
(c)
N
(d)

Liquefied Shear Strength Relationship



Probabilistic Criteria



Conclusions

- Additional cases from recent earthquakes have been added to the existing database of failures
- Monte Carlo Simulations and the First-Order Reliability Method are used to analyze the failures
- Simplified charts have been developed using Bayesian Mapping to provide relations between SPT blowcount, liquefied shear strength (or *FFD*), and probability of failure

SOIL AND SITE CHARACTERIZATION USING ELECTROMAGNETIC WAVES

Start: November 2004 End: May 2007

- Student: Ning Liu
- Supervisor: James K. Mitchell
- Sponsor: Charles Edward Via. Fellowship

  NSF IGERT Program

Objectives – use electromagnetic waves to evaluate:

- Water content, specific surface area, pore water chemistry
- Strength, compressibility, hydraulic conductivity

Soil Components and Structure

Theoretical equations and empirical correlations

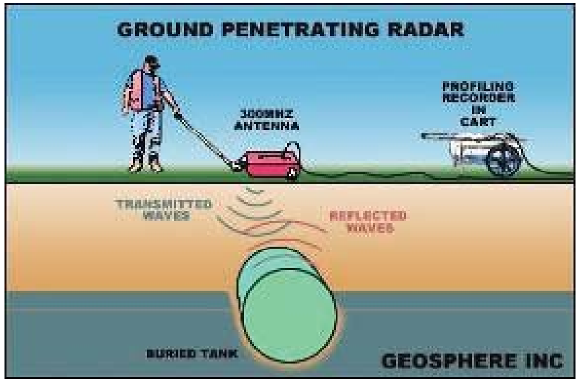
Soil Engineering Properties

- Strength
- Fluid flow properties
- Stress-deformation properties

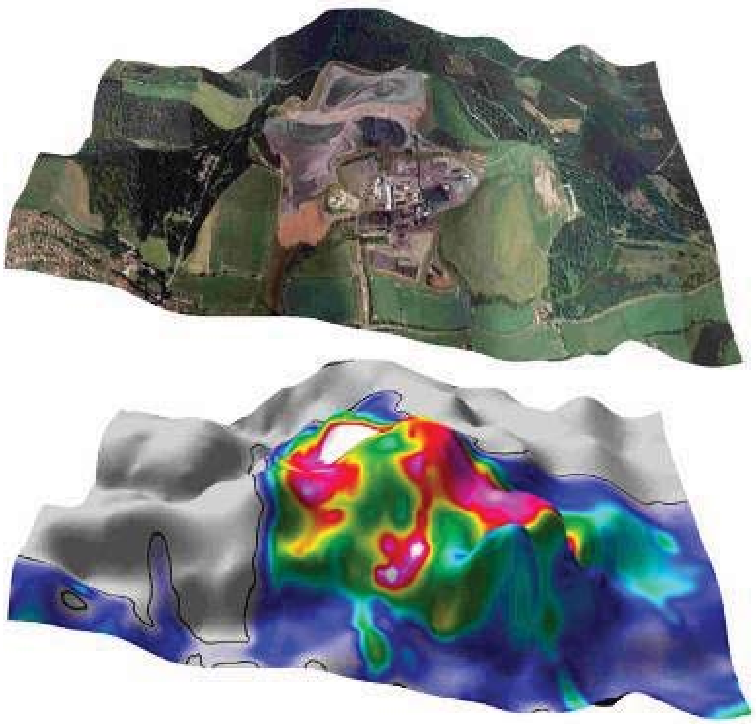
?

Soil Electromagnetic Properties

- Non-destructive
- Suitable for remote sensing
- Suitable for automation



Ground Penetration Radar



Air-borne electromagnetic survey

Electromagnetic Measurements - From Theory to Practice

- A model to relate the EM property of a soil to:
  - Porosity, clay percentage, clay mineralogy, anisotropy, flocculation
  - Pore fluid chemistry, temperature

- A simple method to determine:
  - Volumetric water content
  - Total specific surface area
  - Pore fluid salt concentration

- An economical and convenient tool for in-situ EM property measurements
  - Time domain reflectometry (TDR)

- Relationships between soil EM properties and Engineering properties :
  - Residual shear strength
  - Compressibility
  - Hydraulic conductivity

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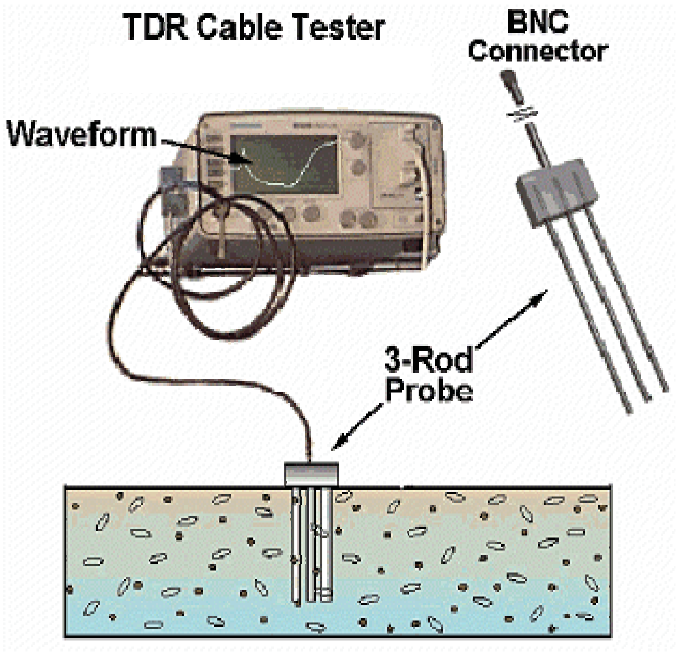
A method to determine total specific surface area and water content from dielectric spectrum

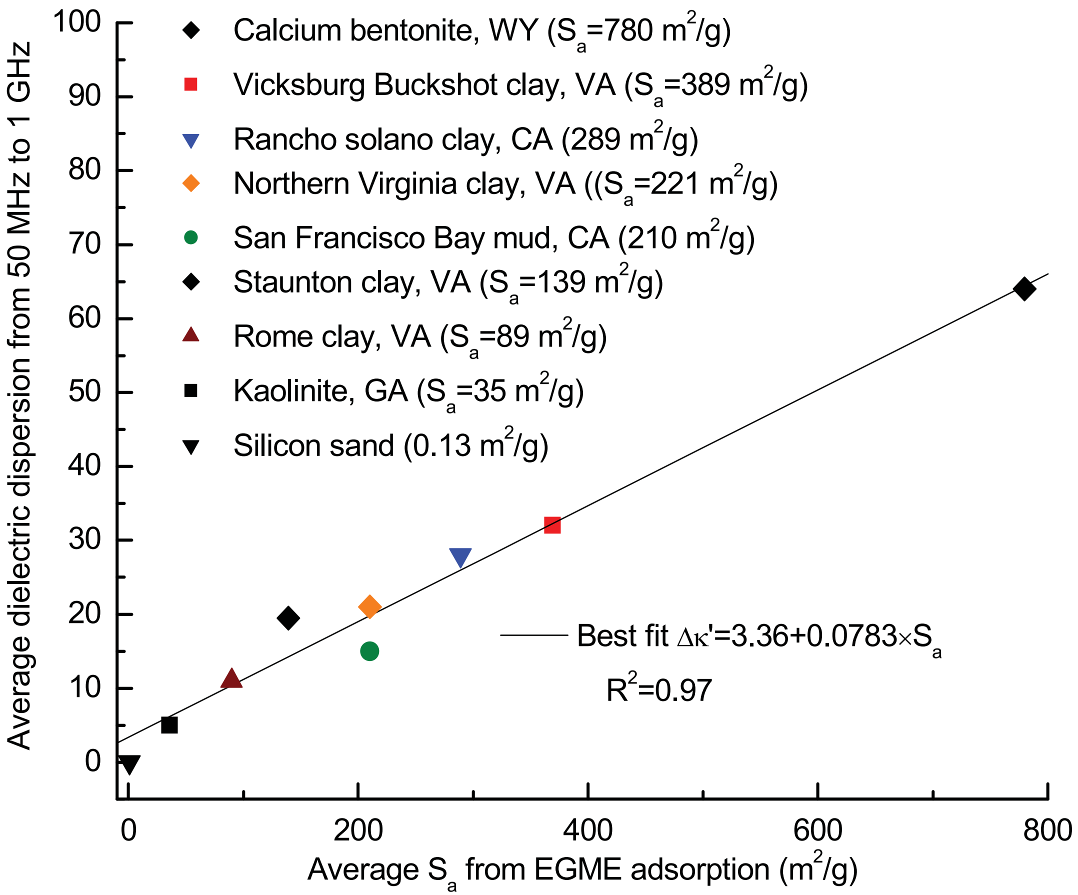


TDR100 System:

Cost: \$3.6 K

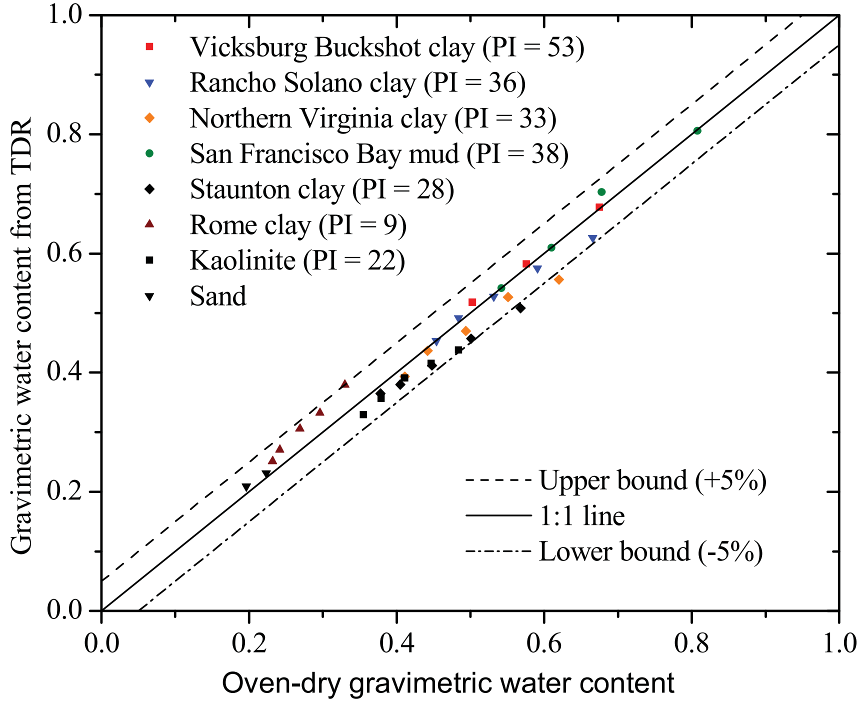
Weight: 2 Pounds

Power: Rechargeable battery

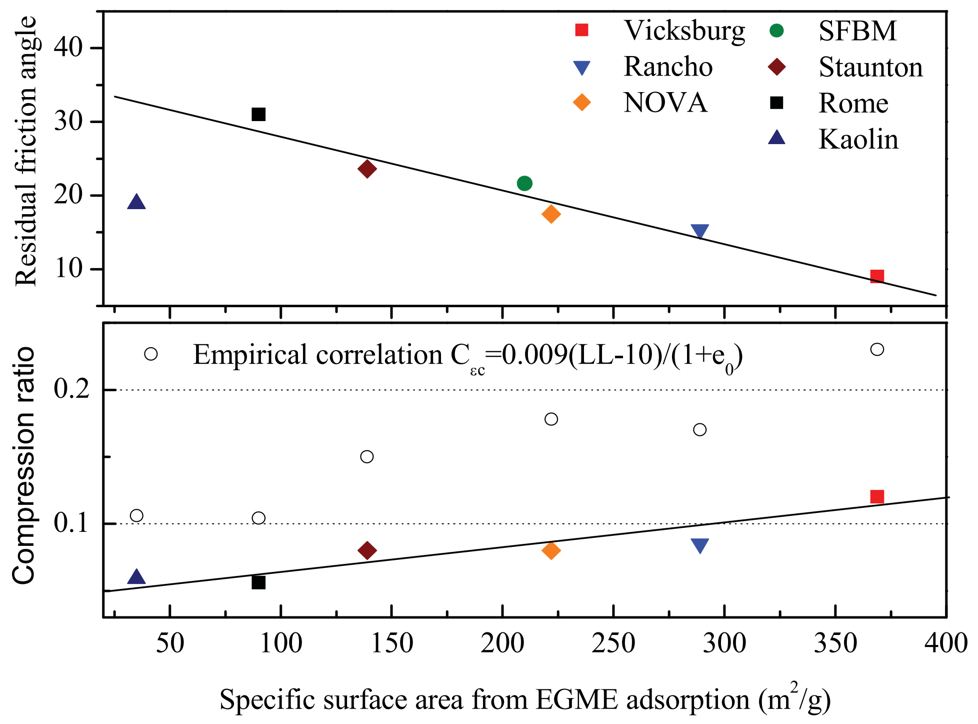


EM Property Measurement – Specific Surface Area, water content – Engineering Properties

Water content determination



Residual shear strength and compressibility



Rapid Stabilization of Soft Clay Soils

Start: March 2003 End: May 2009

- Students: Susan Rafalko & Liselle Vega
- Supervisors: Thomas L. Brandon, George M. Filz, & James K. Mitchell
- Sponsors: Air Force Research Laboratory

Purpose – To increase the strength of a soft clay soil (CBR = 2) to support C-17s & C-130s within 72 hours

C-17: Globemaster III (Photo from AFCESA/CES “ETL 97-9”)

Objectives

- Evaluate effectiveness of stabilizers using:
  - UCS tests
  - Toughness
- Evaluate dosage rates using:
  - UCS tests
  - CBR tests
- Develop guidance for pavement design

Stabilizers Tested

- Single Treatment
  - Portland cement
    - Type I/II
    - Type III
  - Quicklime
  - Microfine cement
  - Calcium carbide
  - Sodium silicate
  - Fibers
    - Fibrillated polypropylene
    - Nylon
    - Poly(vinyl) alcohol
- Combination Treatments
  - Fibers
    - Type I/II cement
    - Type III cement
    - Calcium carbide
  - Sodium silicate
    - Quicklime
    - Calcium carbide
  - Super absorbent polymers & calcium carbide
  - Accelerators & Type III cement
  - Superplasticizers
    - Microfine cement
    - Type III cement

Key Findings: Laboratory Testing

- Stabilizer effectiveness
  - –Traditional stabilizers were most effective
  - –Calcium carbide performed similar to quicklime
  - –Other stabilizers were relatively ineffective
  - –Fibers increased toughness
  - –Fiber shape influenced strength
- CBR vs. UCS correlation
  - –Approximate linear relationship
  - –Relationship not dependent on treatment type

Key Findings: Pavement Design

- Layer strength
  - –Base layer: minimum CBR value of 80
    - •Achieved with 3% pelletized quicklime, 11% Type III cement, & 1% PVA fibers
  - –Subbase layer: up to a CBR value of 30
    - •Achieved with 2% to 4% pelletized quicklime
- Layer thickness
  - –Base layer: minimum of 6 inches
  - –Subbase layer: between 0 to 65 inches

Levee Underseepage, Filter Design and Installation, and Seepage Monitoring

Start: January 2006 End: August 2007

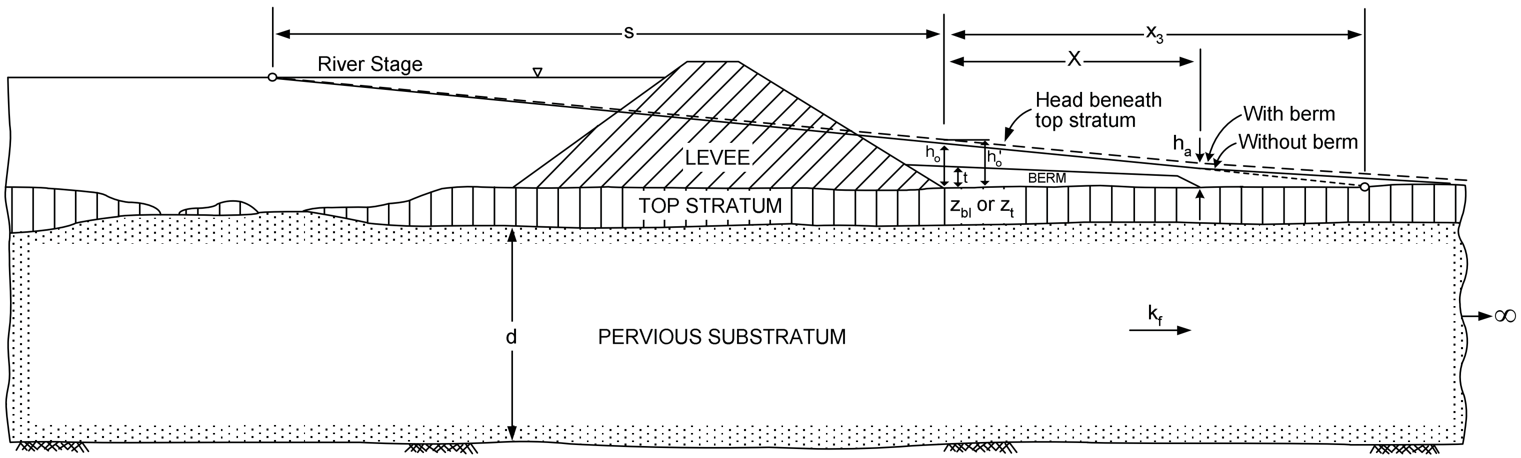
- Student: Matthew Sleep, Chris Meehan, Emily Navin
- Supervisor: Dr. J. Michael Duncan
- Sponsor: U. S. Army Corps of Engineers

Objectives

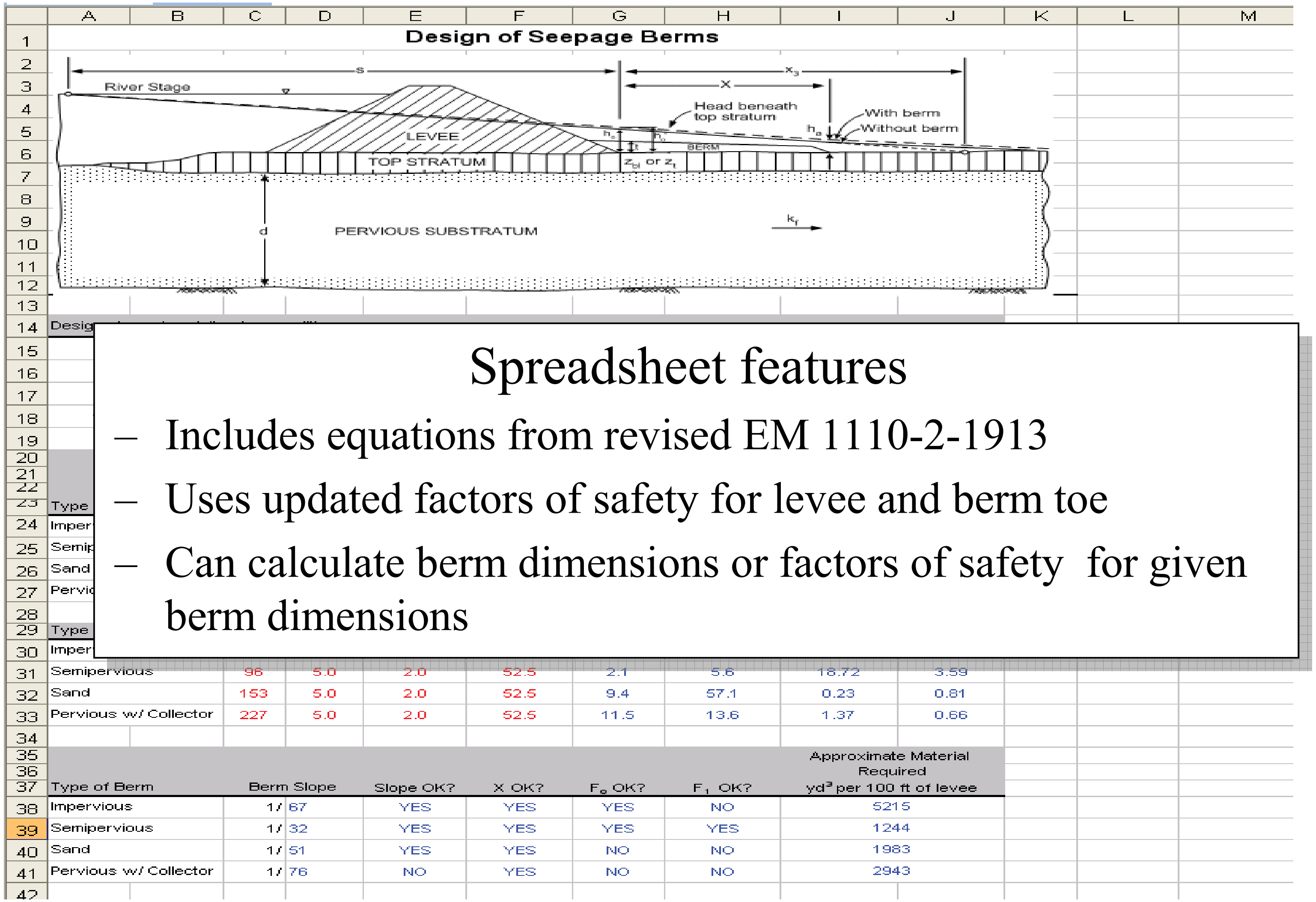
- Update Corps EM 1110-2-1913 Design and Construction of Levees
- Update CGPR Filter Design Workbook and filter installation guidelines
- Develop draft seepage monitoring guidelines for FEMA

Update Corps EM 1110-2-1913 –
“Design and Construction of Levees”

- Incorporate changes reflected in Corps ETL 1110-2-569
- Update guidance on seepage berm design
- Incorporate new factors of safety criteria



Seepage Berm Design Spreadsheet for Corps



Design of Seepage Berms

Semipervious	96	5.0	2.0	52.5	2.1	5.6	18.72	3.59
Sand	153	5.0	2.0	52.5	9.4	57.1	0.23	0.81
Pervious w/ Collector	227	5.0	2.0	52.5	11.5	13.6	1.37	0.66

Type of Berm	Berm Slope	Slope OK?	X OK?	F_o OK?	F_1 OK?	Approximate Material Required yd³ per 100 ft of levee
Impervious	1/ 67	YES	YES	YES	NO	5215
Semipervious	1/ 32	YES	YES	YES	YES	1244
Sand	1/ 51	YES	YES	NO	NO	1983
Pervious w/ Collector	1/ 76	NO	YES	NO	NO	2943

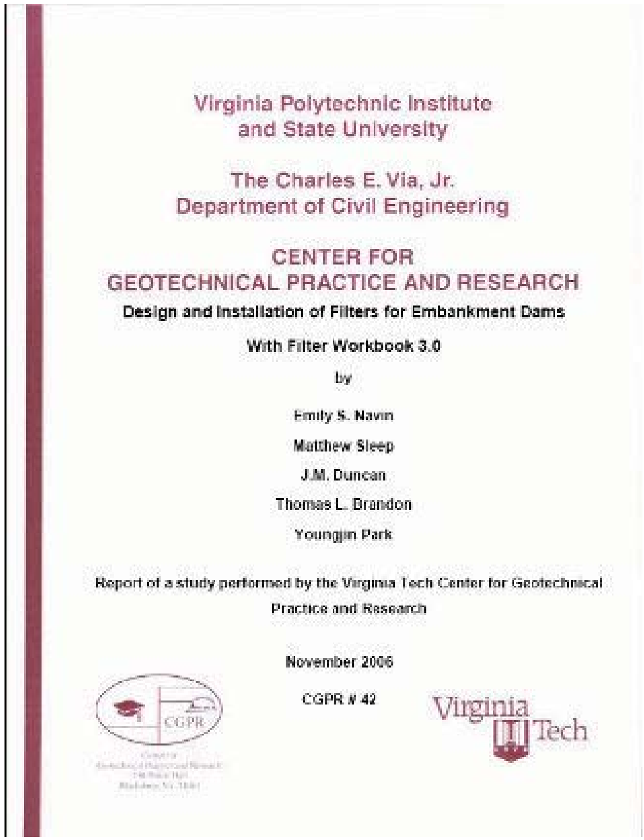
Spreadsheet features

- Includes equations from revised EM 1110-2-1913
- Uses updated factors of safety for levee and berm toe
- Can calculate berm dimensions or factors of safety for given berm dimensions

Update CGPR Filter Design Manual

- Add NRCS criteria to filter workbook
- Add guidance for filter installation

1. Segregation
2. Compaction
3. Cementation
4. Durability
5. Width
6. Contamination



Virginia Polytechnic Institute
and State University

The Charles E. Via, Jr.
Department of Civil Engineering

CENTER FOR
GEOTECHNICAL PRACTICE AND RESEARCH

Design and Installation of Filters for Embankment Dams

With Filter Workbook 3.0

by

Emily S. Navin

Matthew Sleep

J.M. Duncan

Thomas L. Brandon

Youngjin Park

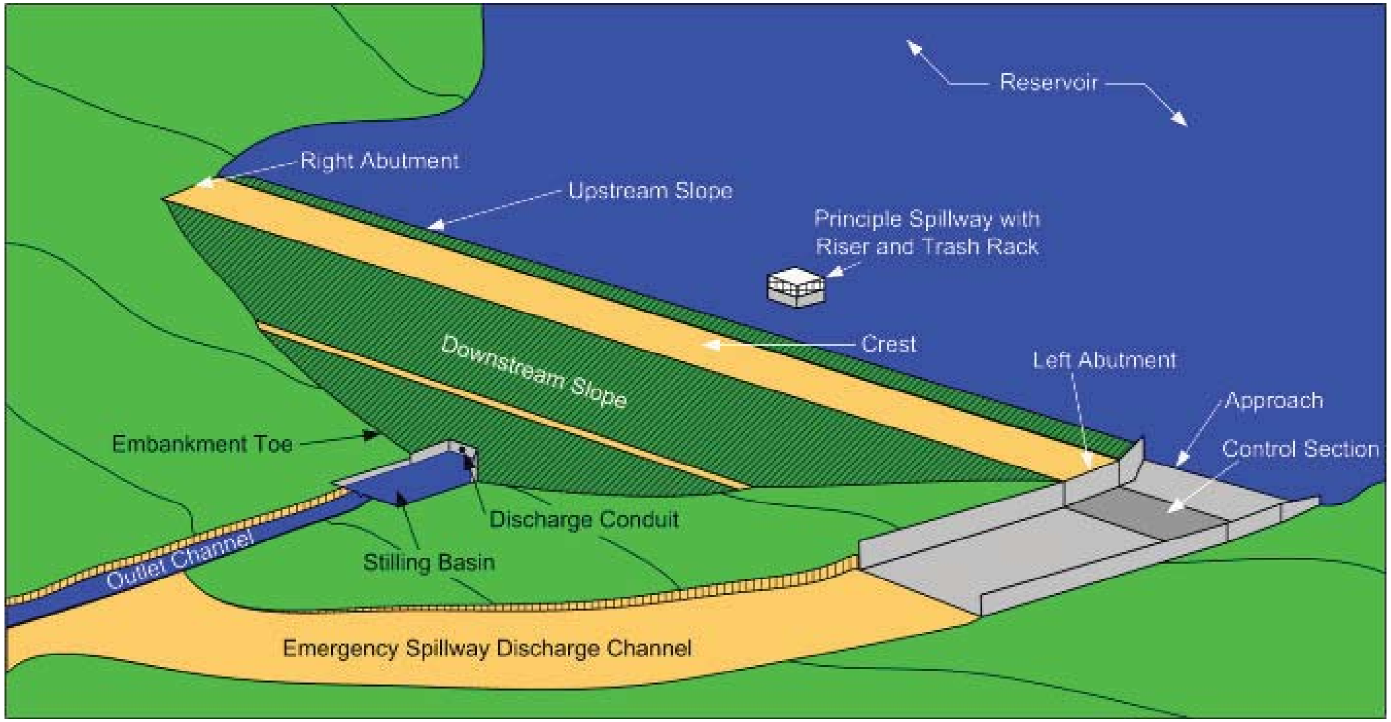
Report of a study performed by the Virginia Tech Center for Geotechnical Practice and Research

November 2006

CGPR # 42

Seepage Monitoring Guidelines for FEMA

- Visual Inspection
- Instrumentation
- Assessment of Consequences



Levee Stability on Deep-Mixed Foundations

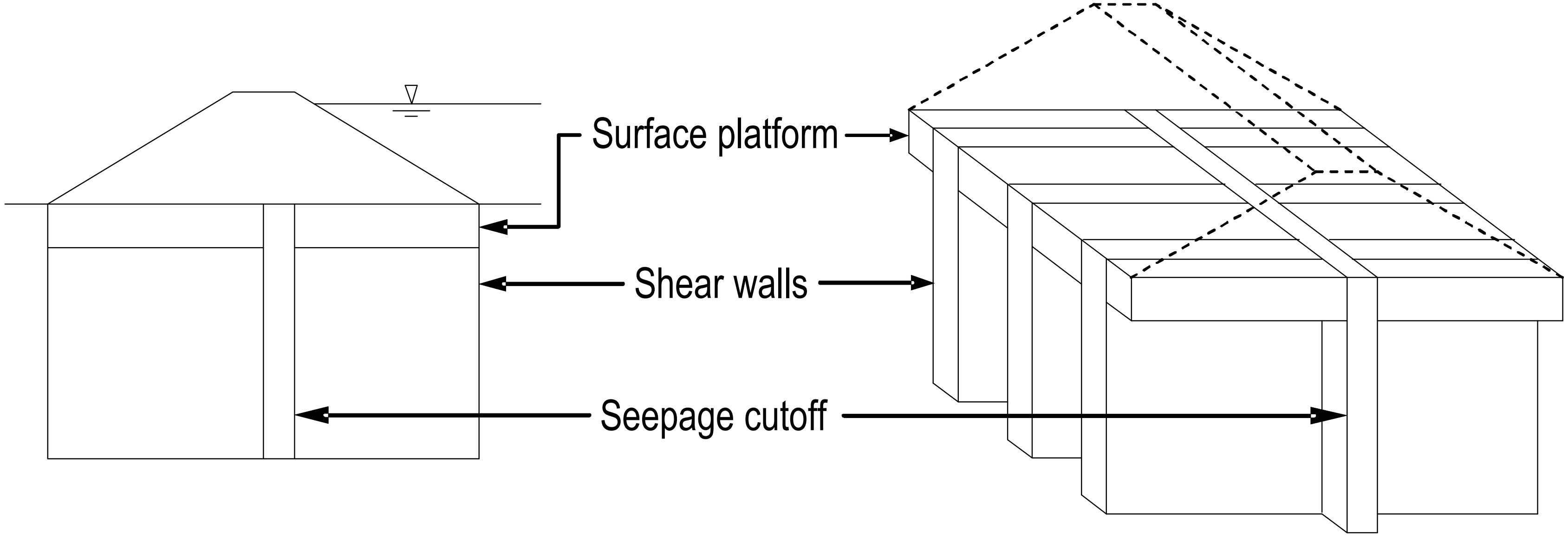
Start: May 2006 End: Jan 2009

- Student: Tiffany Adams
- Supervisor: Dr. George Filz
- Sponsors: National Science Foundation/
  U.S. Army Corps of Engineers

Objectives

– Provide recommendations for design of levee structures on shear walls constructed using deep-mixing methods.

Levees Built on DMM Shear Walls



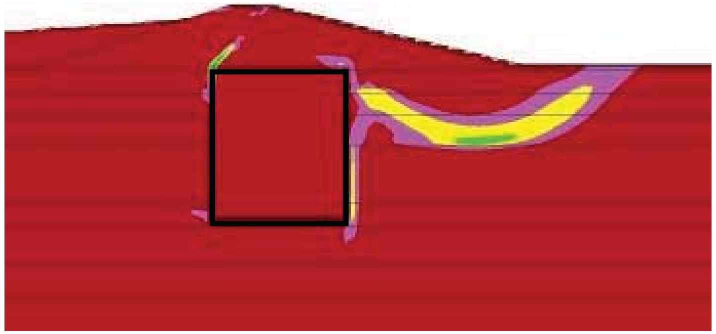
Surface platform

Shear walls

Seepage cutoff

Full Overlap at all Locations

FS = 1.33



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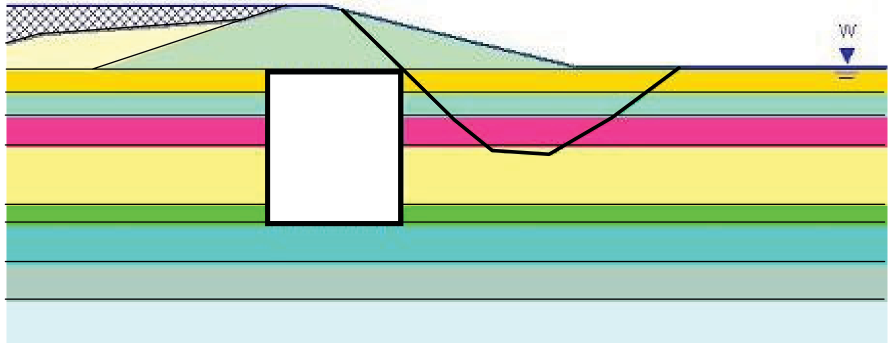
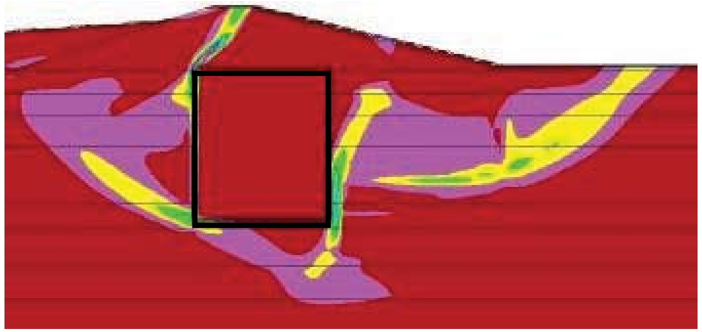
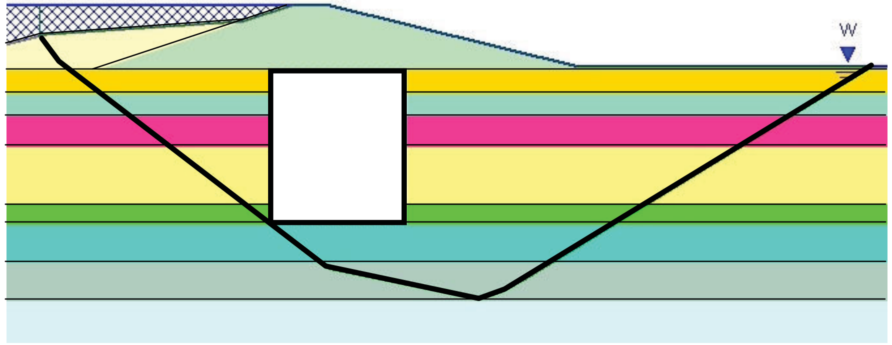


FS = 1.51



FS = 1.53



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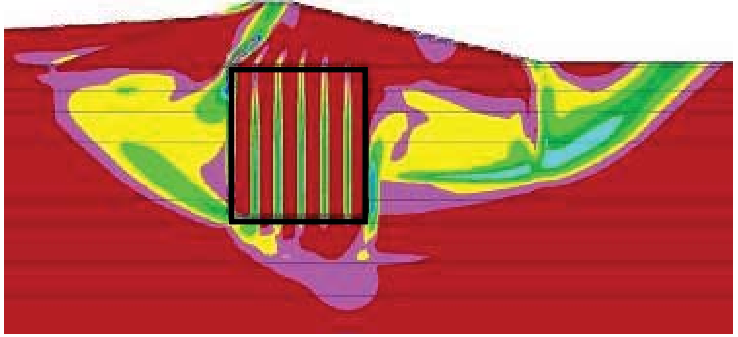
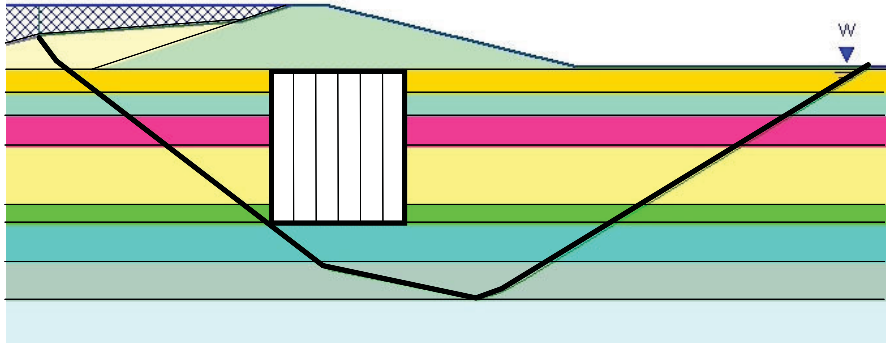
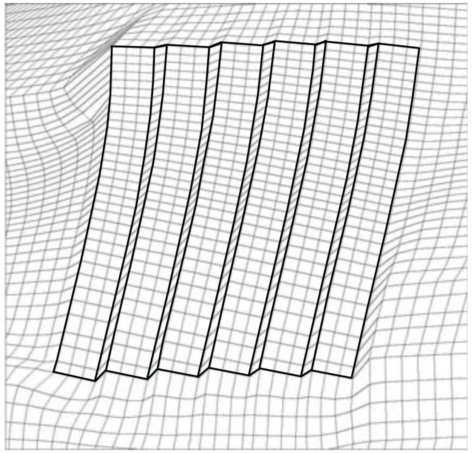
No Overlap at 5 Locations

FS = 1.37



FS = 1.53

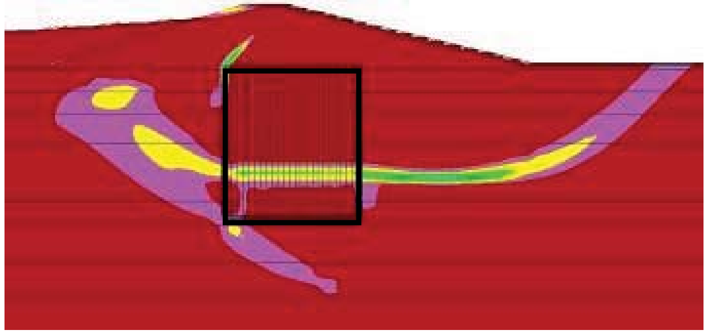




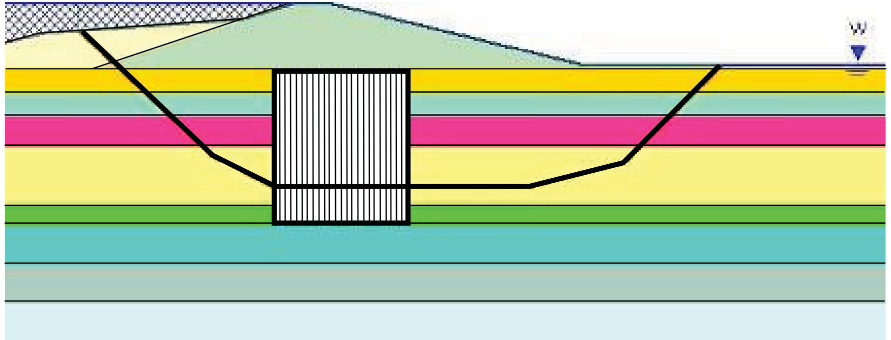
Column Deformations
(Magnified 5x)

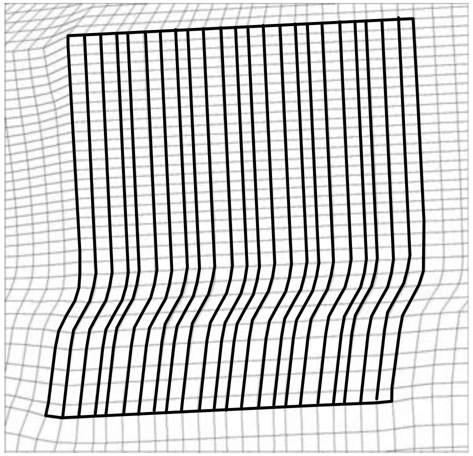
No Overlap at all Locations

FS = 1.21



FS = 2.88





Column Deformations
(Magnified 5x)

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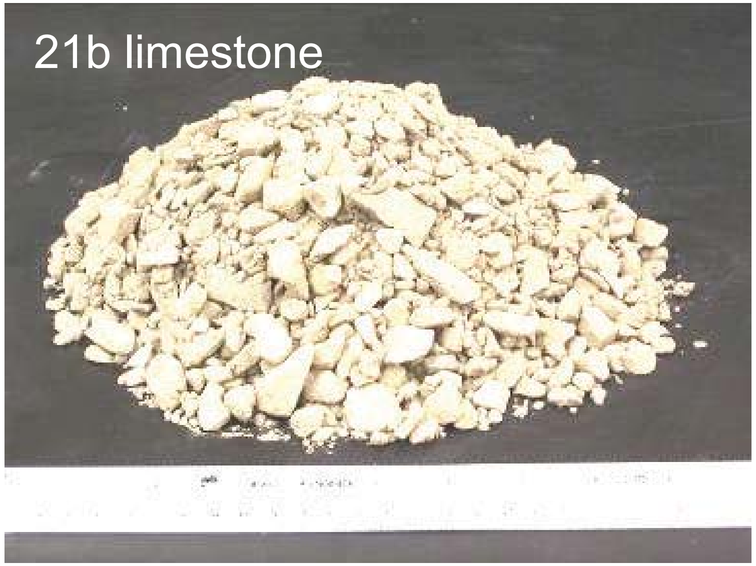
Drained Triaxial Compression test on 21b and #57 Gravels

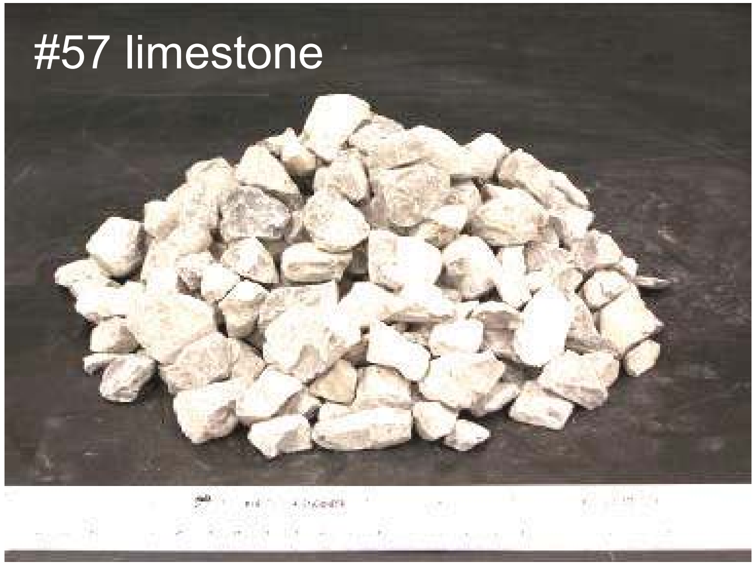
- Start: January 2005 End: March 2007
- Post-Doctoral staff: Wenxing Jian and Youngjin Park
- Students: Genevieve Smith, Todd Griffith, Jessa Corton, and Esther Ryan
- Supervisors: Mike Duncan and Tom Brandon
- Sponsor: CGPR and Hayward Baker

Objective

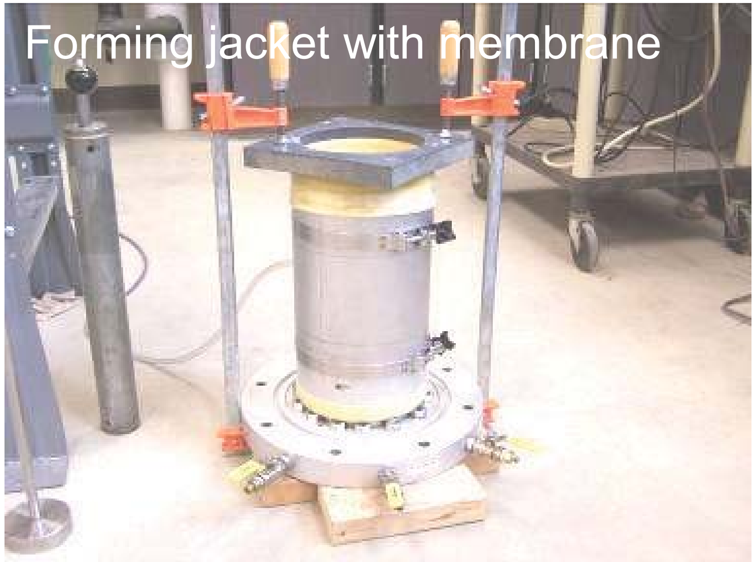
- Measure values of ϕ for
  - 21b gravels – limestone and granite
  - #57 gravels – Limestone and phyllite

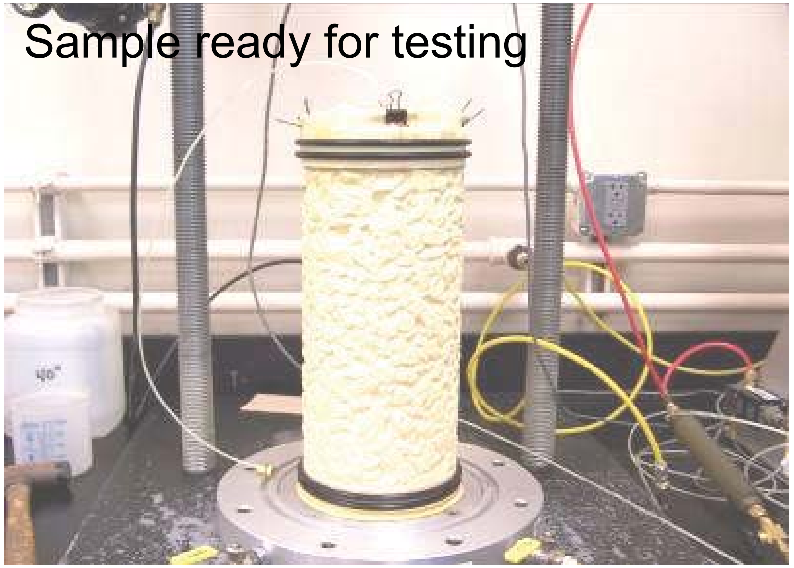
Tested Materials

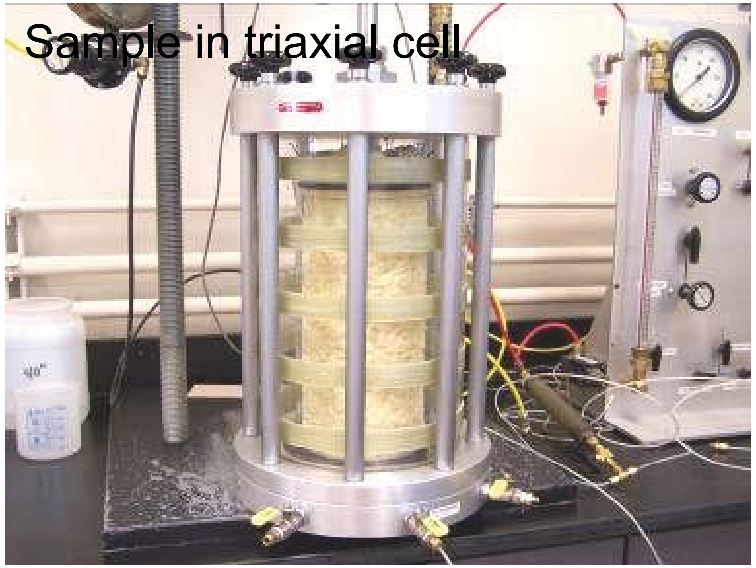


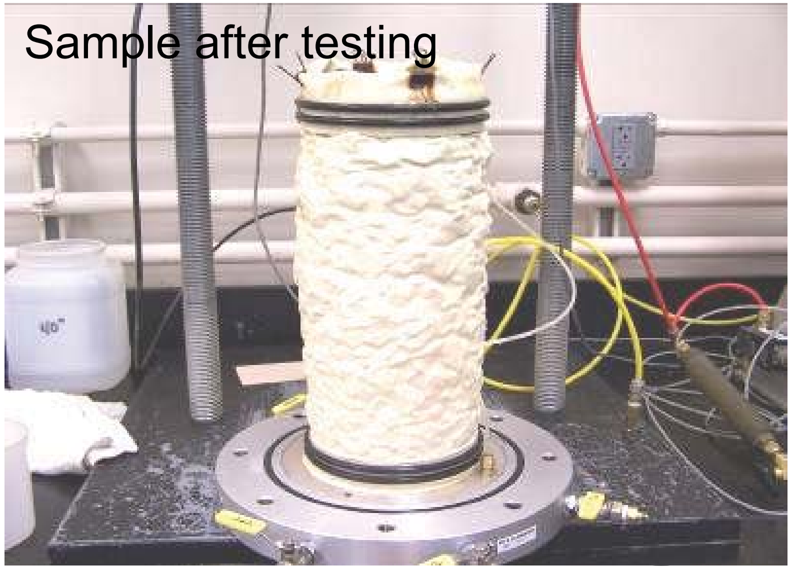


Test Procedures

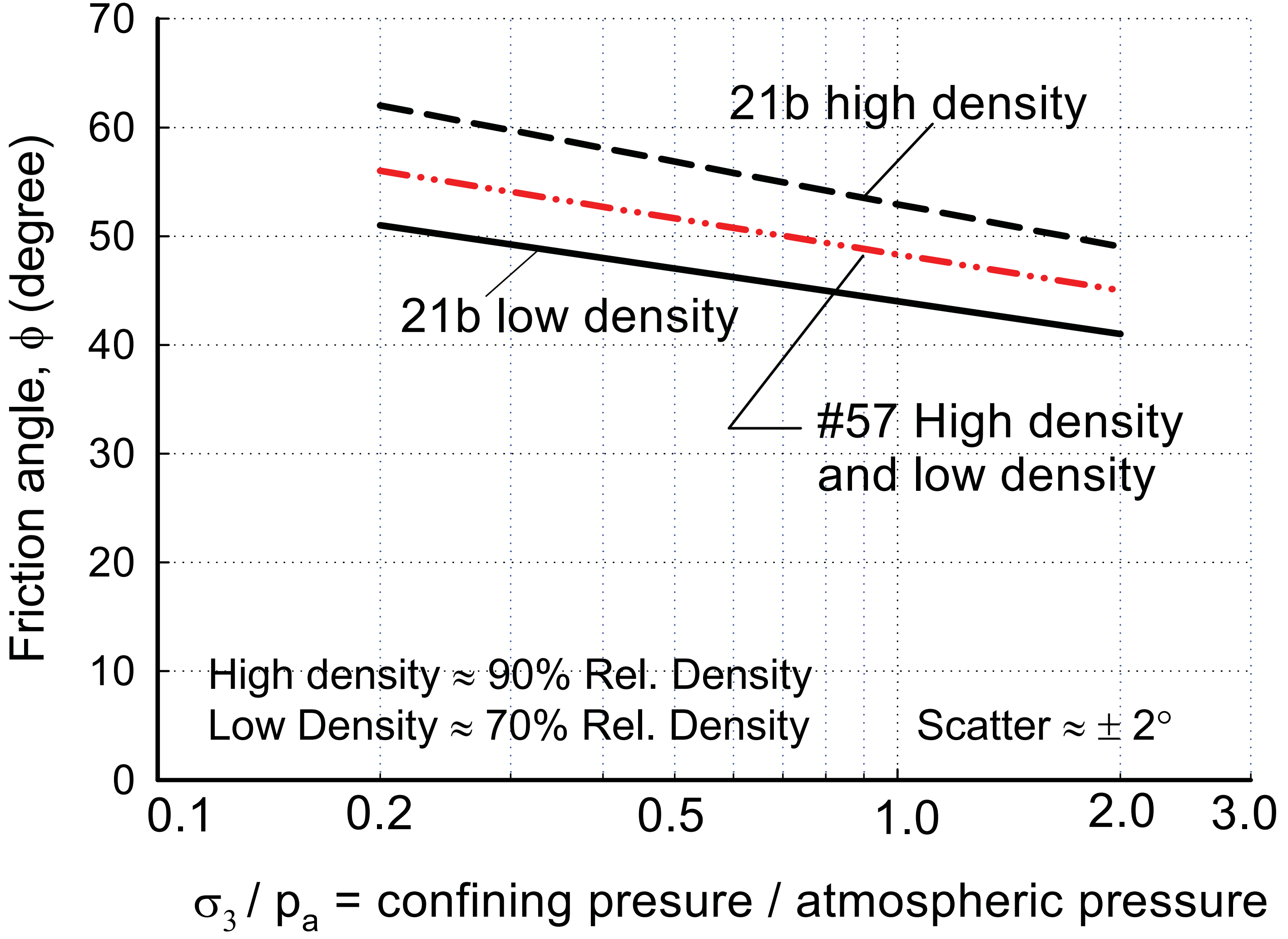

Forming jacket with membrane


Sample ready for testing


Sample in triaxial cell


Sample after testing

Results


Friction angle, ϕ (degree)
70
60
50
40
30
20
10
0
0.1
0.2
0.5
1.0
2.0
3.0
21b high density
21b low density
#57 High density and low density
High density ≈ 90% Rel. Density
Low Density ≈ 70% Rel. Density
Scatter ≈ ± 2°
σ3 / pa = confining presure / atmospheric pressure

Remote Measurement of Fracture Data

Start: August 2003 End: May 2007

- Student: Jeramy Decker, Brian Badillo, Justin Sommerville
- Supervisors: Joseph Dove, Matthew Mauldon, Marte Gutierrez
- Sponsors: National Science Foundation

Objective

– Develop methods and tools to collect, analyze and utilize imaging data during tunnel excavation

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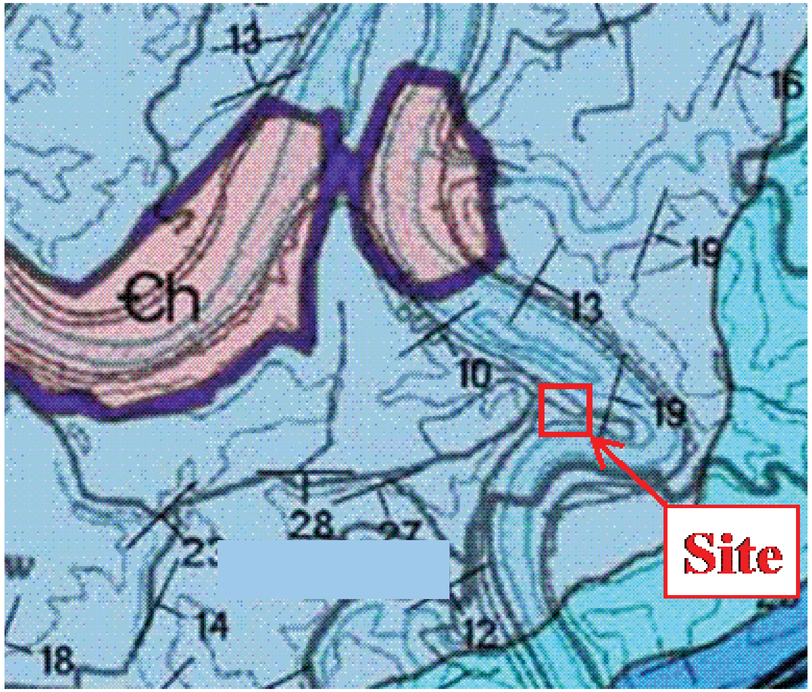
Field study: Abandoned Railroad Tunnel.

Outline:

- Site geology
- Technologies
- Results

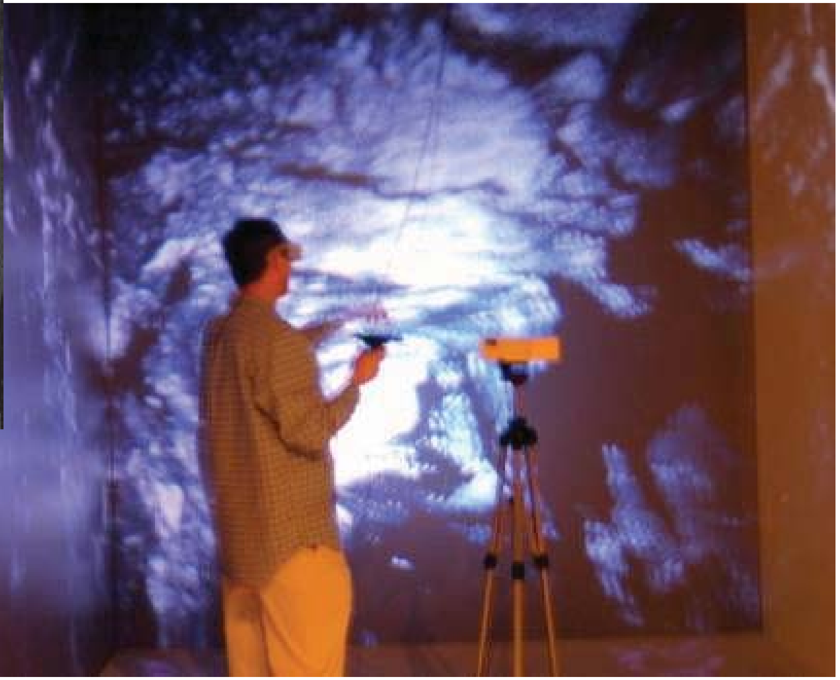
Copper Ridge Formation (Cambrian): Dolomite Ꞓcr



Field measurements, LiDAR and digital stereo photography used to obtain data

3D visualization of imaging data

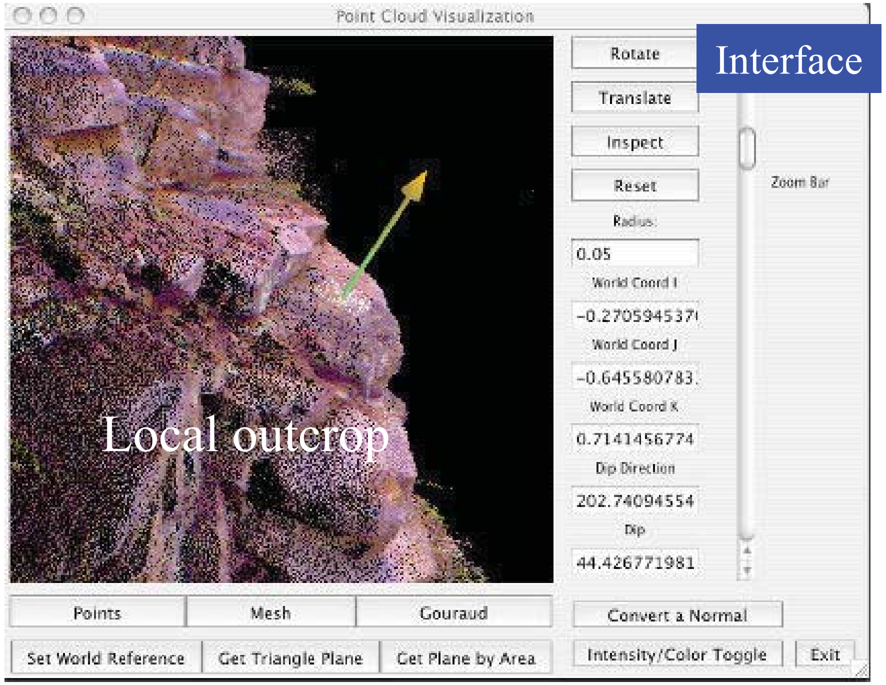
Tunnel



CAVE at VT

gVT– geotechnical Visualization Tools

– new software for visualizing and using LiDAR-based data



Radius: 0.05

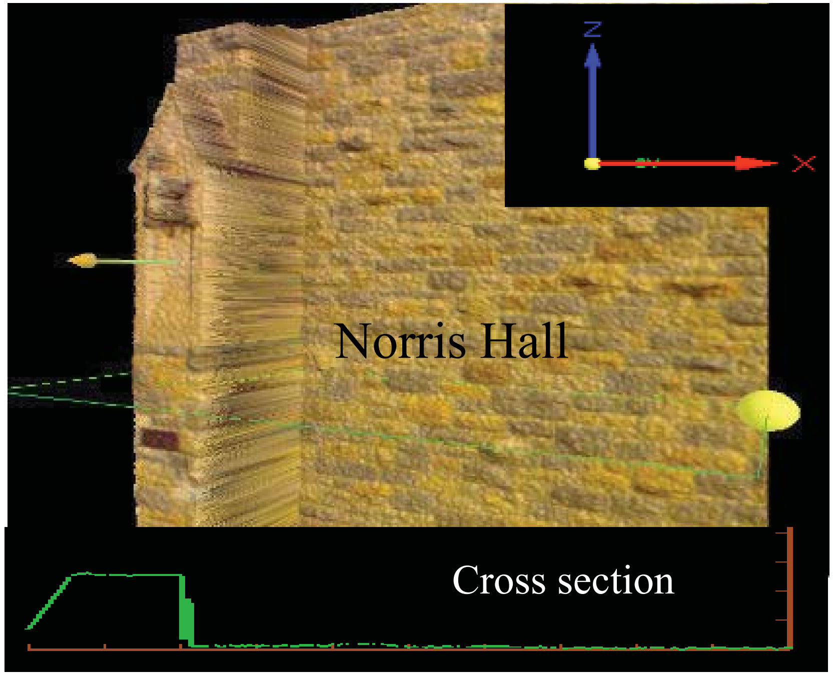
World Coord I: -0.270594537

World Coord J: -0.645580783

World Coord K: 0.7141456774

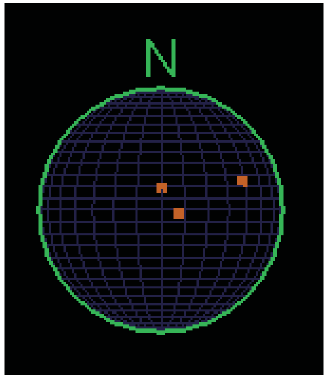
Dip Direction: 202.74094554

Dip: 44.426771981



Potential Industry Benefits

- Improved field personnel safety
- Project cost savings by digitally recording site conditions for later use in the office.
- Supplement to site investigation data



Stereonet

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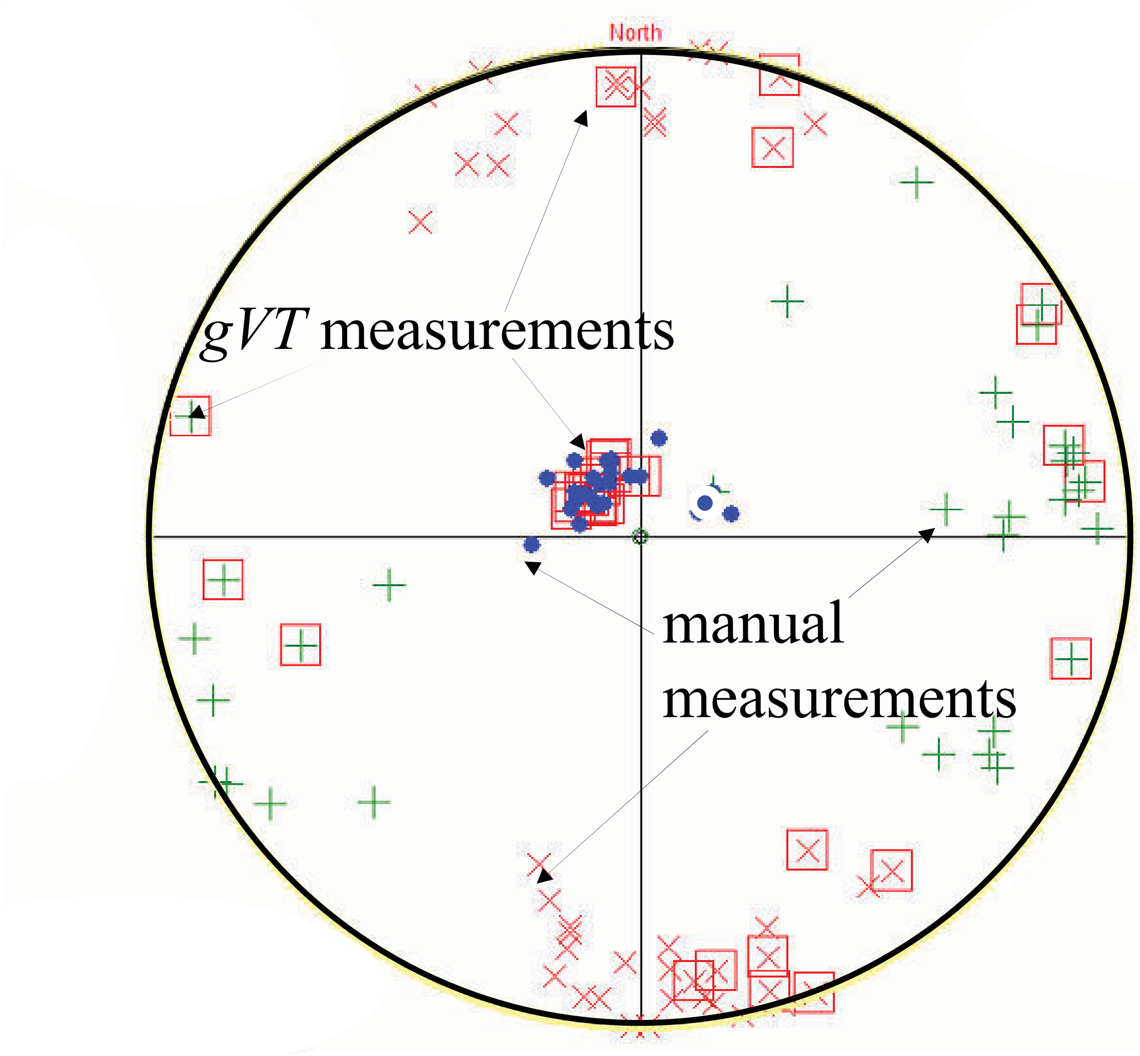
Results from *gVT* agree well with hand measurements



gVT measurements

manual
measurements

Development of Simplified Laboratory Filter Test

Start: December 2005 End: December 2007

- Students: Andrew Bolton, Manuel Ochoa, Binod Tiwari
- Supervisor: Dr. Thomas L. Brandon, Dr. J. Michael Duncan,
  Dr. James K. Mitchell
- Sponsors: USBR

Objectives

- Study the performance of filters that have developed cracks
- Develop a simplified and less expensive filter test method.

Background Information

- The performance of filters during steady state seepage has been studied extensively
- The ability of filters to collapse and fill cracks has been studied less
- Available test methods are difficult and expensive
- A simpler test method is needed to assess filter performance

Research Approach (Completed Items)

- Desk study summarizing the gradation and mineralogy of the embankment materials at the existing USBR dams (Completed Spring 2006)
- Literature review of the depth and causes of cracking that has occurred in dams worldwide (Completed Spring 2006)
- Literature review of chemical and biological causes of cementation of granular soil, and case histories on the cementation in granular filters (Completed Spring 2006)

Research Approach
(Present Status)

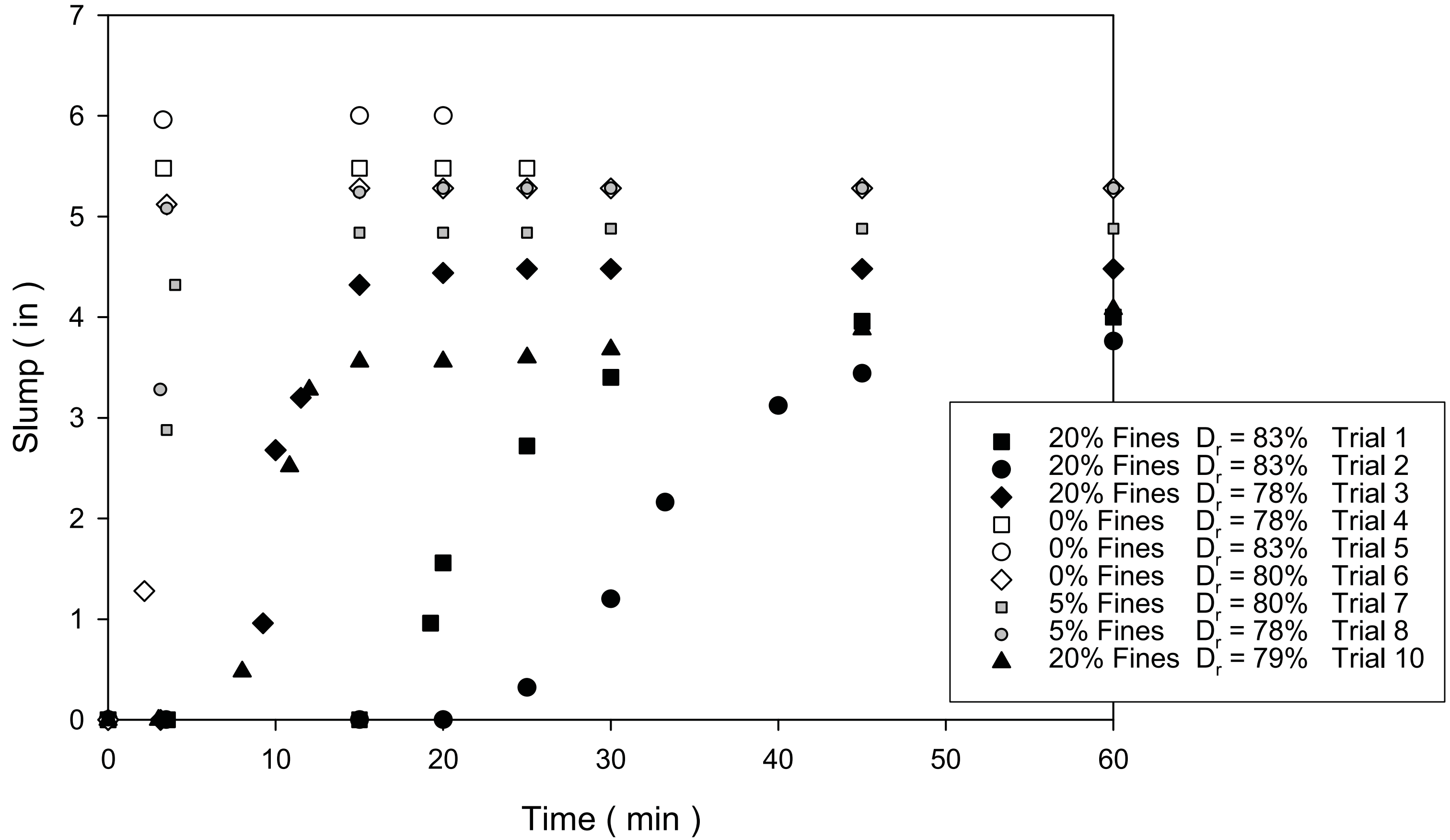
- Development of soil slump test (August 2006 to Present)

- Testing of filter materials with the soil slump test (January 2007 to present)

Soil Slump Test

Figure 1: Slump versus Time

21B Gravel, $w_c = 7\%$



Research Approach (Future Activities)

- Experimental study on cracked filters using the 4” filter test device developed at Virginia Tech (Spring 2007)
- Experimental study on the self-healing ability of broadly graded filters using the 4” filter test device developed at Virginia Tech (Summer 2007)

Engineering Manual for Organic Soils and Peat

Start: April 2003 End: May 2007

Student: Heather Hickerson

- Supervisors: George Filz, C. J. Smith, Mike Duncan
- Sponsors: CGPR

Objectives

- Collect and compile data on classification and engineering properties of organic soils and peat
- Compile and discuss mitigation methods for organic soils and peat, based on case histories

Organic Soils and Peat

Weight loss upon heating from 105°C to 440°C

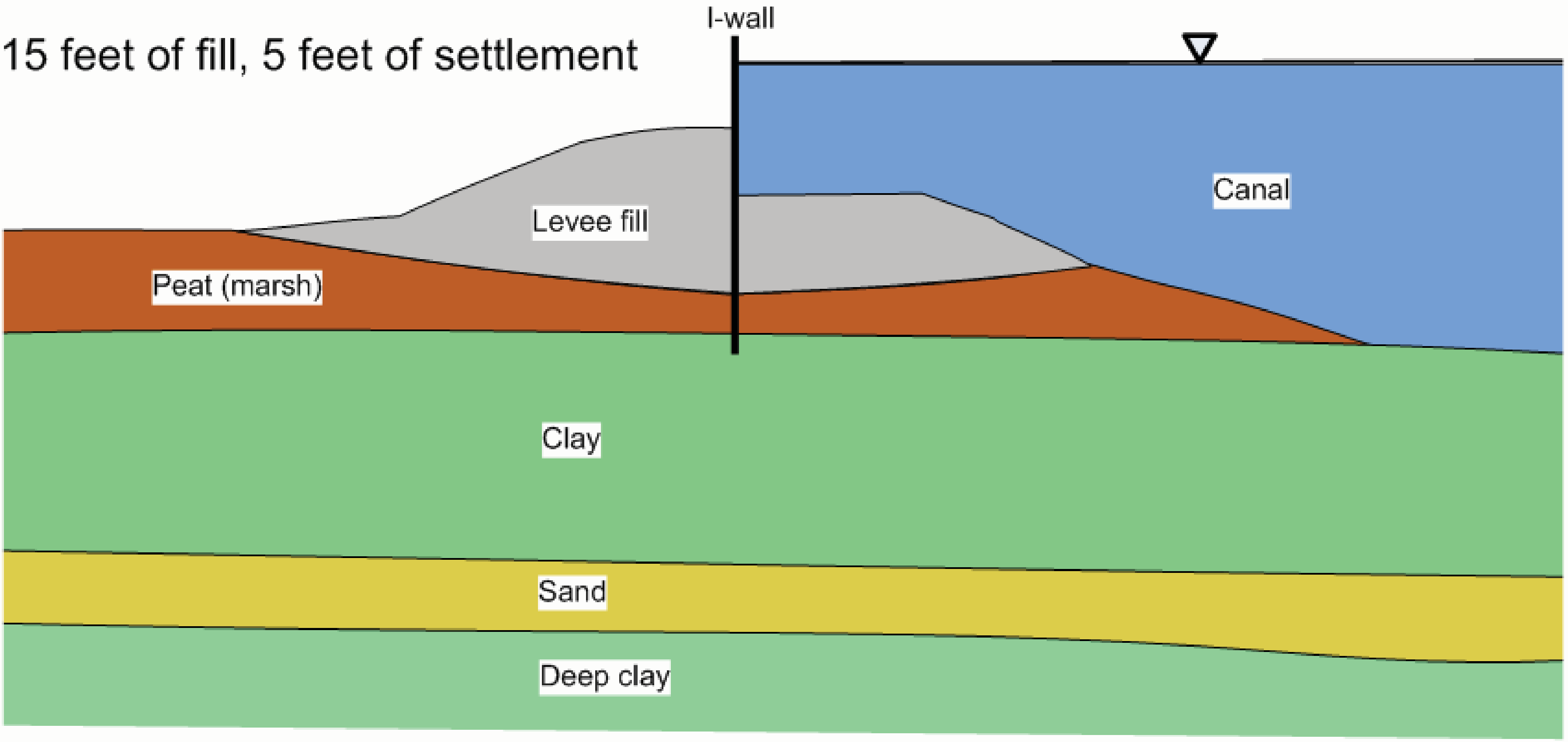
- 75% or more → Peat
- 30% to 75% → Peaty Organic Soil
- 5% to 30% → Organic Soil
- 1% to 5% → Soil with Organic Content
- Less than 1% → Inorganic

Organic Soils and Peat

Engineering Problems

- Large primary settlement
- Large secondary settlement
- Corrosivity
- Low strength

New Orleans – 17th Street Canal



15 feet of fill, 5 feet of settlement

Organic Soils and Peat

Mitigation Techniques

- Excavate and replace
- Use deep foundations – piles, drilled shafts
- Preload foundation
- Apply admixtures (lime)

Fully-Coupled Staggered Solution of Fluid Flow Behavior in Porous Media Based on the Biot's Theory

Start: August 2004 End: August 2007

- Student: Imsoo Lee
- Supervisor: Dr. Marte Gutierrez
- Sponsors: American Chemical Society

Objectives

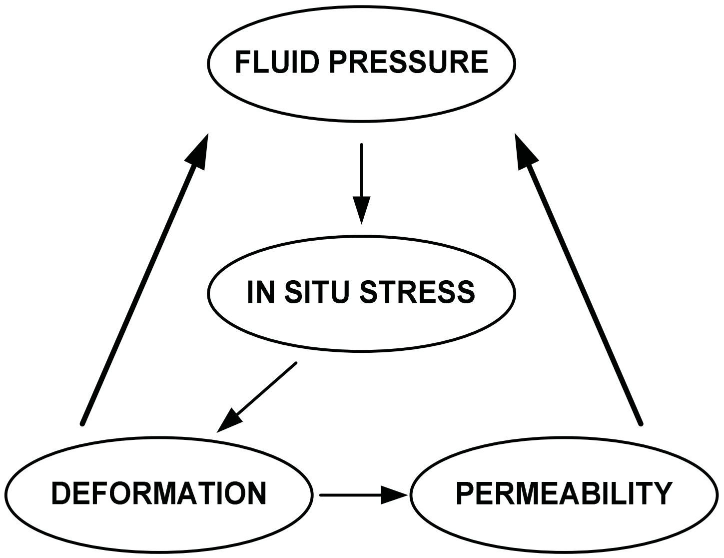
- Develop rigorous computational algorithm for coupled fluid flow and deformation processes in porous media.
- Apply the computational model to obtain better understanding of the behavior of fluid-saturated deformable porous media.

Geomechanics-Fluid Flow Coupling

- Interaction between fluid flow (pressure and flux) and the mechanical response (deformations and stresses) in fluid-saturated deformable porous media

- Neglect of Coupling Effect
  - Emphasis on the fluid flow problem
  - Oversimplification of the mechanical response through the use of “compressibility” term

- Categories of Coupling
  - One-way coupling
  - Partial coupling (stress-permeability)
  - Full coupling (deformation-flow)



The Finite Element Equation of Fully-coupled Biot's Theory

$$\begin{bmatrix} \mathbf{K_m} & \mathbf{L} \\ \mathbf{L}^T & \mathbf{S} - \Delta t \mathbf{K_c} \end{bmatrix} \begin{Bmatrix} \Delta \mathbf{u} \\ \Delta \mathbf{p} \end{Bmatrix} = \begin{Bmatrix} \Delta \mathbf{F_u} \\ \Delta \mathbf{F_p} \end{Bmatrix}$$

$\mathbf{u}$ = displacements vector
$\mathbf{p}$ = pore pressures vector
$\mathbf{K_m}$ = stiffness matrix
$\mathbf{L}$ = coupling matrix
$\mathbf{K_c}$ = conductivity matrix
$\mathbf{S}$ = compressibility matrix

- Fully-coupled fluid flow formulation

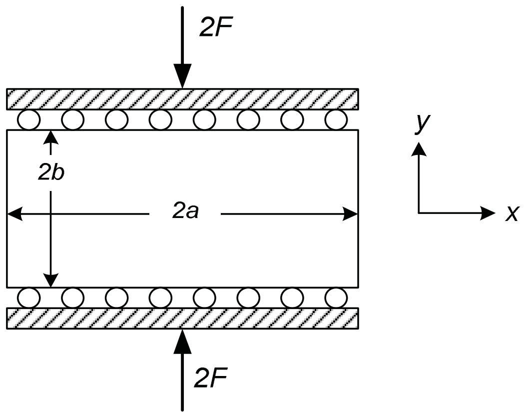
$$\left[\mathbf{L^T K_m{}^{-1} L} - \Delta t \mathbf{K_c}\right] \mathbf{P}^{n+1} = \mathbf{L^T K_m{}^{-1} L P}^n + \mathbf{L^T K_m F_u}$$

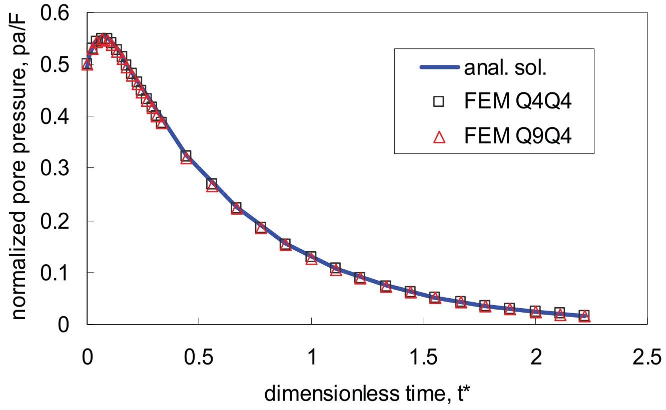
- Conventional fluid flow formulation

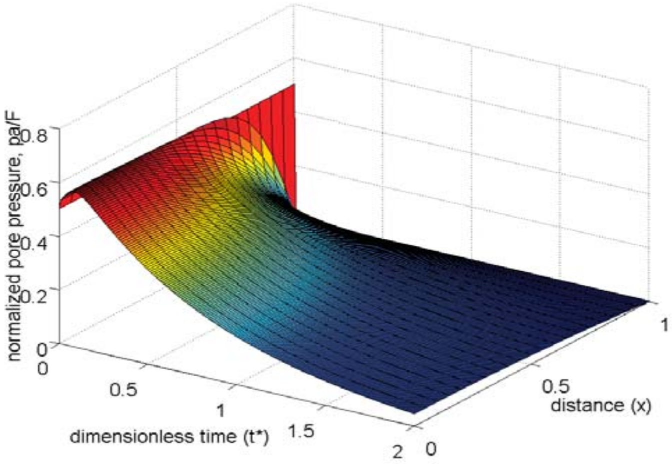
$$\left[c\mathbf{M}_m - \Delta t \mathbf{K_c}\right] \mathbf{P}^{n+1} = c\mathbf{M}_m \mathbf{P}^n$$

- Diagonalization of full compressibility matrix
  - Row sum method
  - Diagonal scaling method
  - using Eigenvalue & Eigenvector

Mandel's Problem







Future Work

- Develop efficient algorithm for the matrix diagonalization
- Apply the developed coupling algorithm using an existing conventional reservoir simulator (e.g. BOAST)
- Implement other types of constitutive models (e.g. elasto-plastic, chalk) in the geomechanical code
- Analyze a case history (e.g. Ekofisk)

Long-Term Performance of Dam Seepage Barriers

Start: August 2004 End: August 2007

- Student: John D. Rice
- Supervisor: Mike Duncan
- Sponsors: U.S. Bureau of Reclamation, CGPR

Objectives

- Identify distress mechanisms that are unique to dams with seepage barriers.
- Enhance understanding of these mechanisms.
- Develop tools for assessing risk.

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Wolf Creek Dam

Losses due to pool lowering: $53 million per year

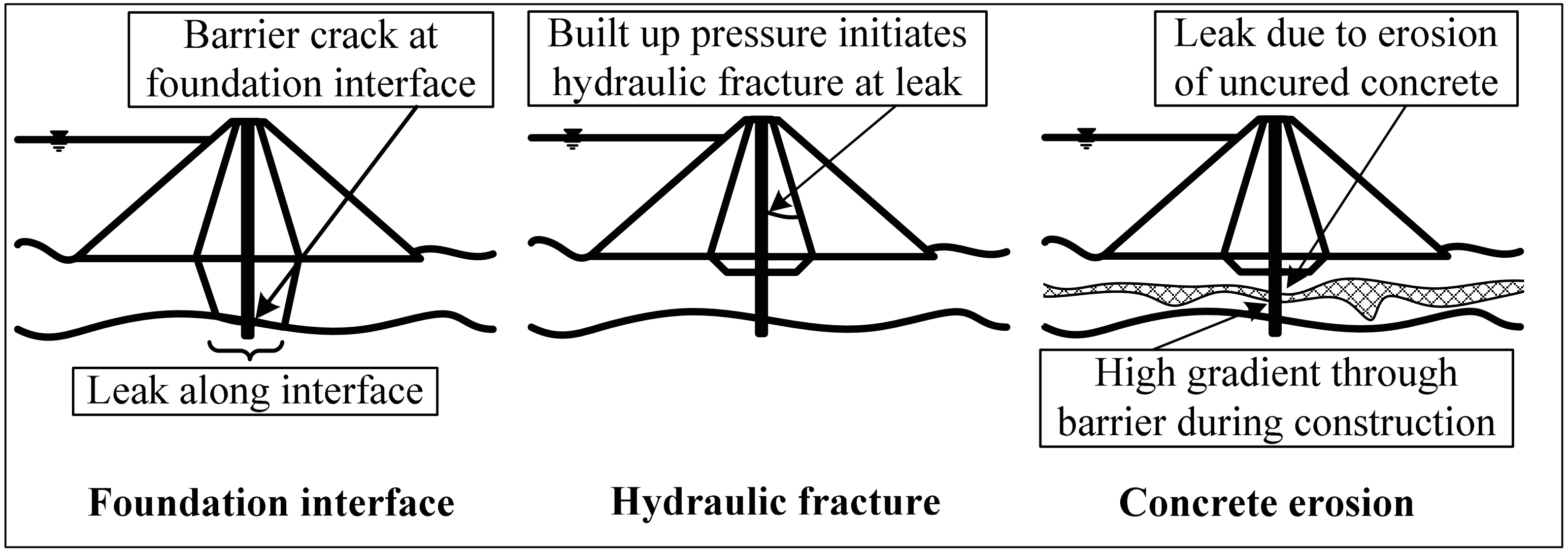
– Hydropower production	$34.2 million per year
– Recreation	$18.8 million per year

Source: USACE

Identification of Distress Mechanisms

Four types of distress mechanisms have been identified :

1. Leaks through the barriers,
2. Erosion along or through bedrock joints,
3. Erosion of solution void infill,
4. Erosion of internally unstable foundation soils.



Barrier crack at foundation interface

Leak along interface

Foundation interface

Built up pressure initiates hydraulic fracture at leak

Hydraulic fracture

Leak due to erosion of uncured concrete

High gradient through barrier during construction

Concrete erosion

Analyses

Purposes of analyses:

1. Enhance our understanding of behavior and distress mechanisms,
2. Develop tools to allow better assessment of the severity of distress mechanisms.

Types of analyses:

1. Steady seepage,
2. Soil-structure interaction.

Applicability to Risk Assessment

1. Guidance for identifying potential failure mechanisms based on case histories and distress mechanism scenarios:
2. Guidance for assessment of risk based on potential for:
   - Initiation of internal erosion
   - Continuation
   - Progression
   - Breach

DEM Simulation of the February 17, 2006, Leyte, Philippines, Rockslide

Start: August 2006 End: May 2007

- Student: Naya Asprouda
- Supervisor: Dr. Marte S. Gutierrez
- Sponsor: National Science Foundation

<u>Objective:</u>

To investigate the underlying mechanism(s) of the February 17, 2006 Leyte, Philippines, Rockslide by performing Distinct Element simulations.

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Background

February 17, 2006

- Overhanging rock detached from Mt. Cabac
- Guinsaugon village covered by as much as 30m thick soft and unstable debris, making rescue operations very difficult.
- 1,300 people reported missing

Photo from USDOD

Precursor Events

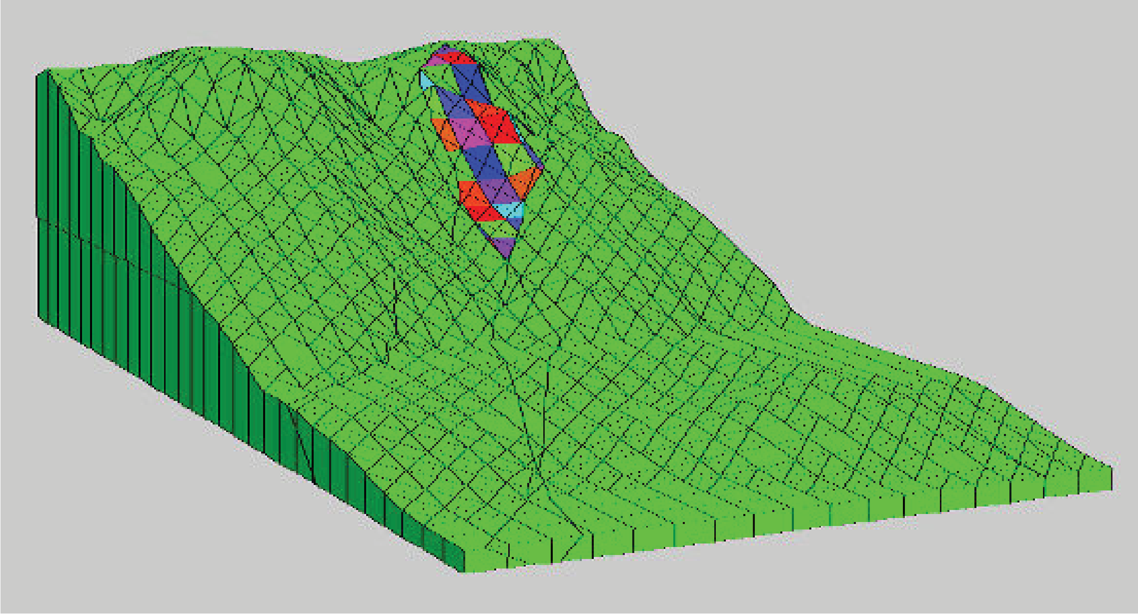
- Excessive Rainfall – five times the average amount of rain during rainy seasons in the area
  - La Niña
  - Inversion Zone in Southern Leyte
- Four minor earthquakes occurred the morning of the slide.
  - Two were of magnitude Mb≈4.5
  - Along the Philippine Fault Zone (PFZ)

Did these events influence the triggering and behavior of the slide?

Photo by M. Gutierrez

3DEC Analysis

- Digital elevation model of the area prior to the slide
- Major failure surfaces, identified during a site survey, added to the model
- Resulting “wedge” assumed rigid to limit computation time



Research Plan

- Study the effects of ground acceleration and hydraulic pressurization of the fault
- Refine model, geometry and material properties to better analyze the debris flow
- Compare results to witness accounts and actual debris behavior during and immediately after the slide.

A Guide to Settlement of Valley Fills

Start: March 2006 End: August 2006

- Student: Andrew Bursey
- Supervisor: Mike Duncan
- Sponsor: CGPR

<u>Objectives</u>

- Review case histories of valley fill settlement
- Identify principal causes of valley fill settlements
- Evaluate factors that control settlement magnitude
- Summarize methods for coping with settlement

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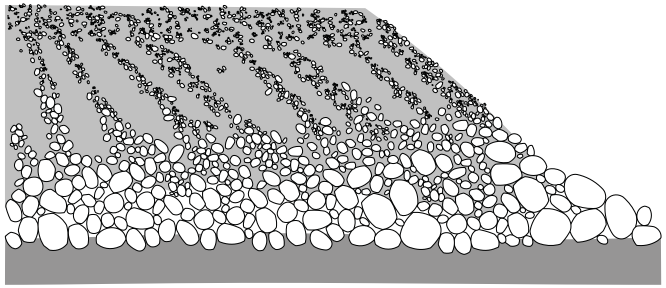
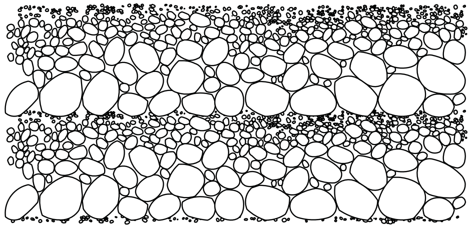
Dumping or spreading causes segregation

- Makes exploration difficult, makes fills hard to characterize
- Leads to differential settlements in end-dumped fills



End-dumped fills:

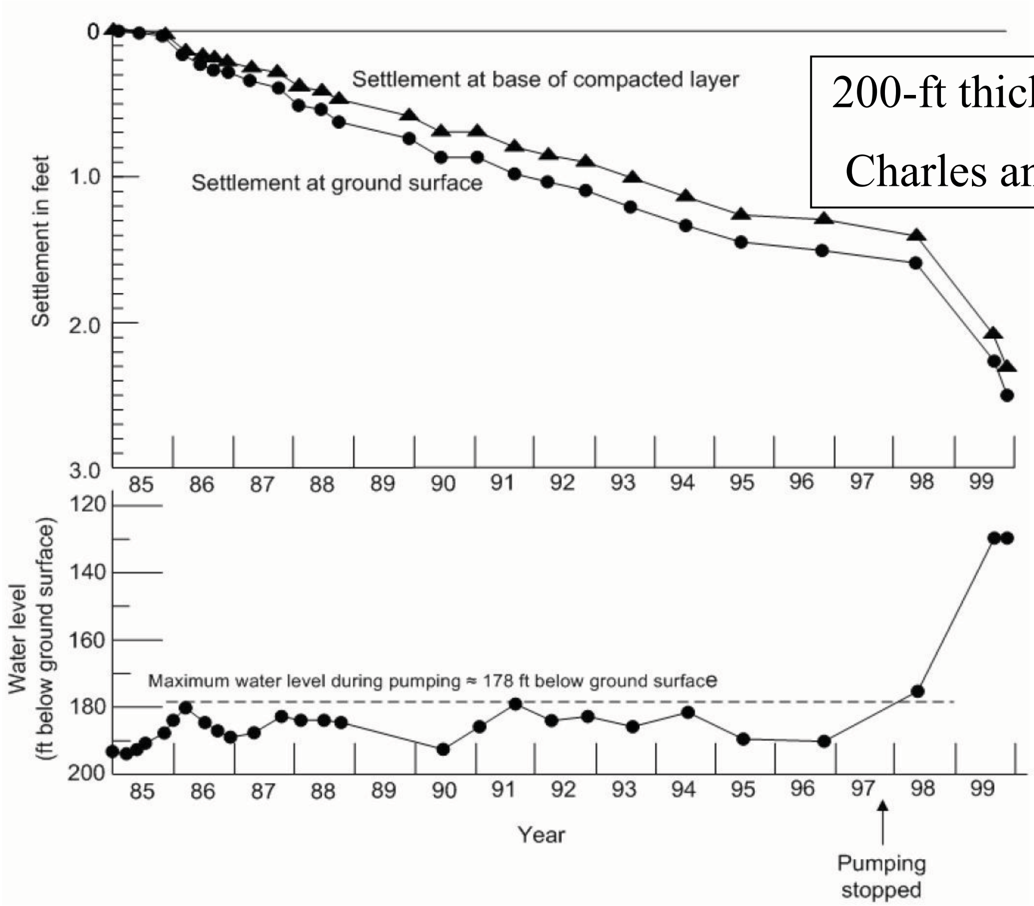
- Inclined stratification
- Coarser material at depth



Roller-compacted fills:

Coarser material at base of lift

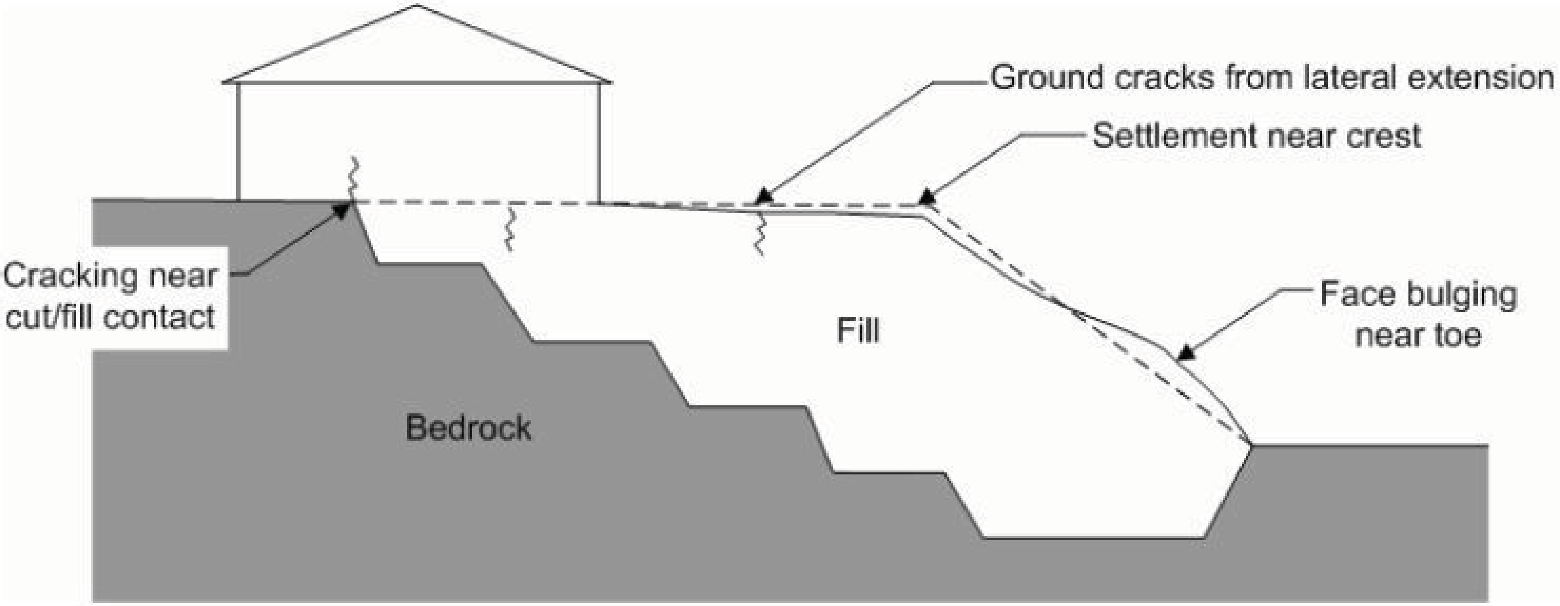
- Wetting can cause large, unexpected settlements long after fill placement completed
- A broad spectrum of fill types is susceptible



200-ft thick fill - data from Charles and Watts. (2001)

EQ shaking can induce differential settlement

- Liquefaction is not required for damaging settlements
- Variations in fill thickness and distance to free face are important factors
- Damage is usually concentrated at cut/fill transitions and near the crests of slopes



20-ft to 100-ft thick compacted fills,
data from Stewart et al. (2001)

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Dealing with valley fills

Full-scale field tests and experience show:

- Dumped rock and mixed fills are especially problematic
- Locations of structures on fills is an important factor in damage due to settlement
- Accurate topography before filling is useful for evaluating fill thickness variations, but is often unavailable
- Densification reduces settlement, but densification to adequate depth is frequently not possible
- Wetting due to irrigation or subsurface flow poses large risk well into service life of most fills

Technology Demonstration of Rapid Stabilization of Soft Clay Soils

Start: March 2003 End: May 2009

- Student: Liselle Vega-Cortés
- Supervisor: Thomas L. Brandon
  George M. Filz
  James K. Mitchell

- Sponsors: Air Force Research Laboratory

Objectives

- Stabilization of very soft materials for airfields
- Technology demonstration using lime and cement admixtures

Previous Research

- Investigated and tested mechanical, chemical, and conventional admixtures
- Determined soil properties needed for airfield design
- Developed recommendations for treatment type
    - ✓ Lime and cement admixtures

Craney Island

- 2,500 acre dredge material disposal site
- Owned by US Army Corps of Engineers
- Site soils are very soft
- Receive double of design capacity

Craney Island (Photo from http://www.nao.usace.army.mil/projects/craney/facility%20 management/AerialPhoto.html)

Craney Island

- Sampling
- Field Testing
- Laboratory Testing
- Technology Demonstration
- Monitoring

J.H. Becker Equipment (Photos provided by J.H. Becker Construction Co.)

Fracture Modeling for Hard Rock Tunneling

Start: August 2003 End: May 2007

- Student: Jeramy Decker
- Supervisors: Matthew Mauldon
- Sponsors: National Science Foundation

<u>Objectives</u>

– Develop tools to assess fracture data and use the data to develop fracture models and rock mass parameters

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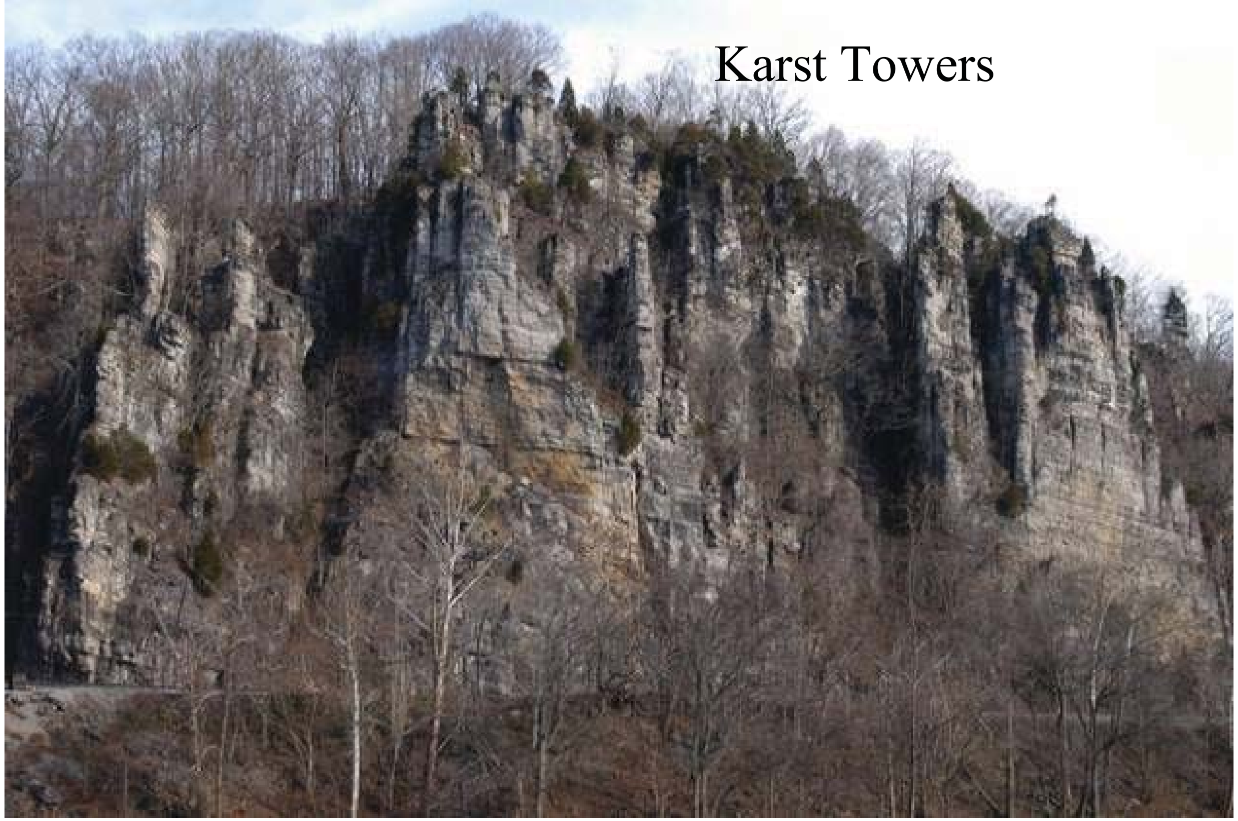
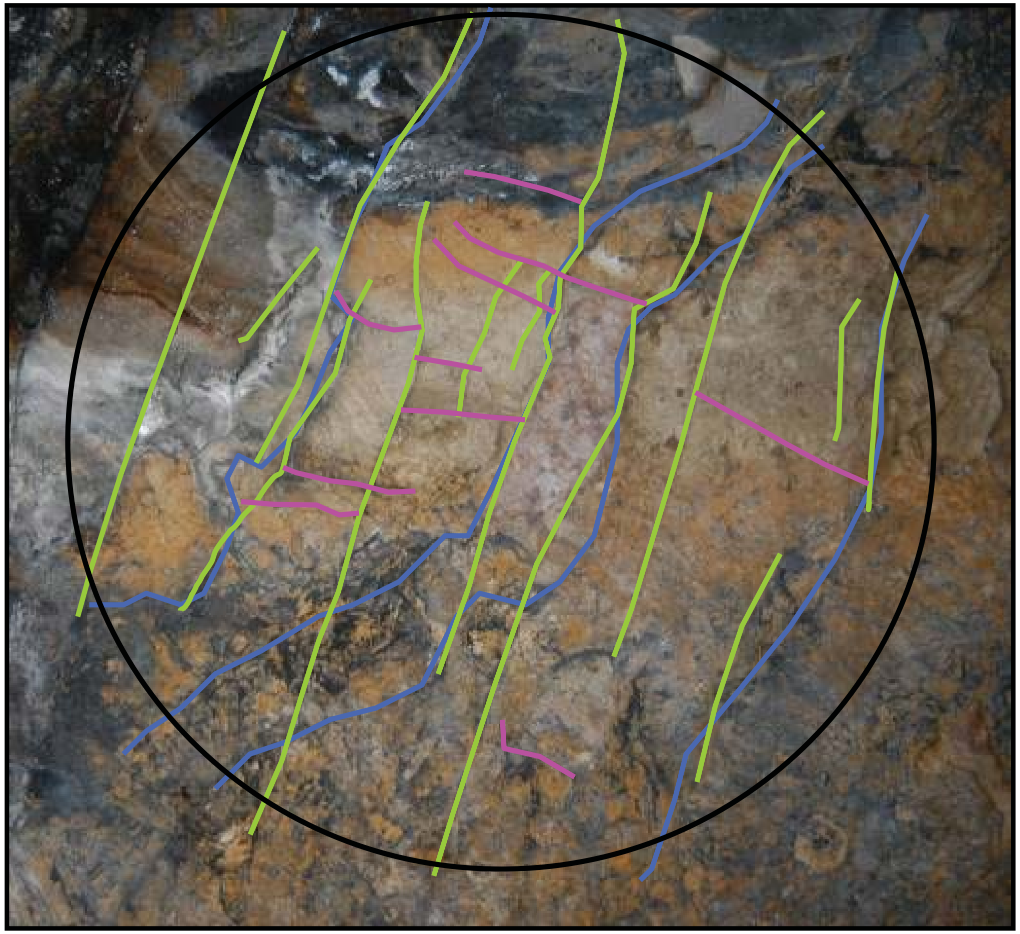
Characterization of fractures within tunnel.

Outline:

- Field observations
- Trace maps
- Statistical tools
- Fracture models


Karst Towers

Tracing fracture trace maps in lab.



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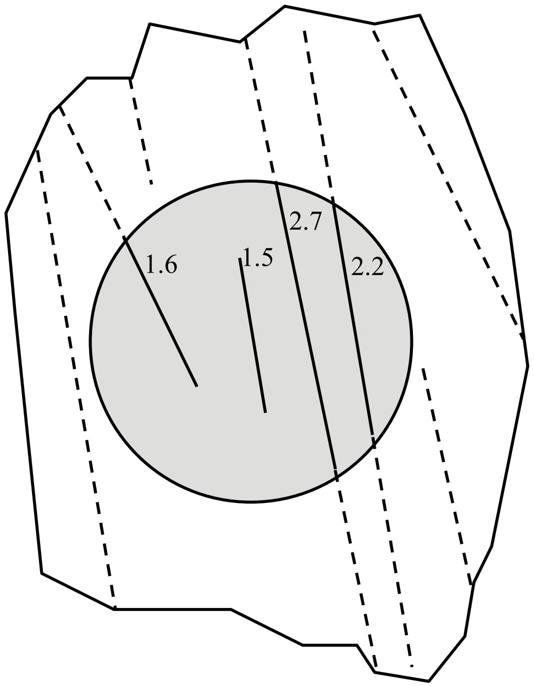
Using statistical tools to evaluate trace maps.

Stereological Estimators



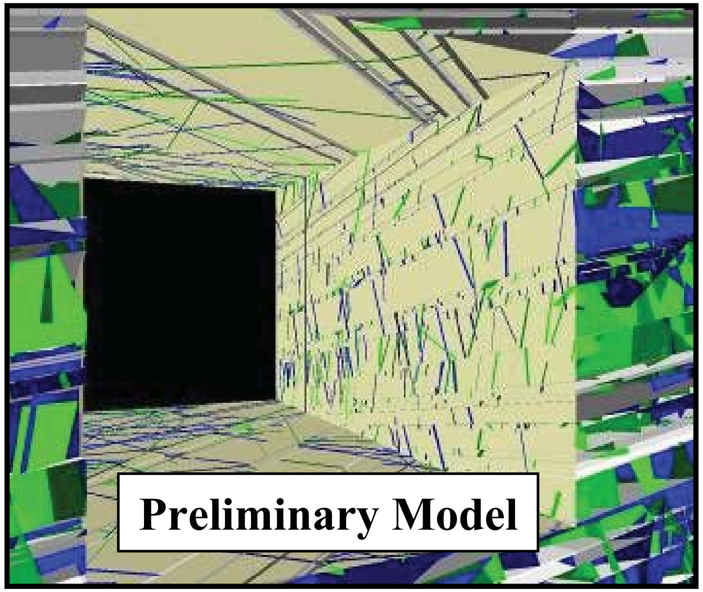
Derived stereological estimators

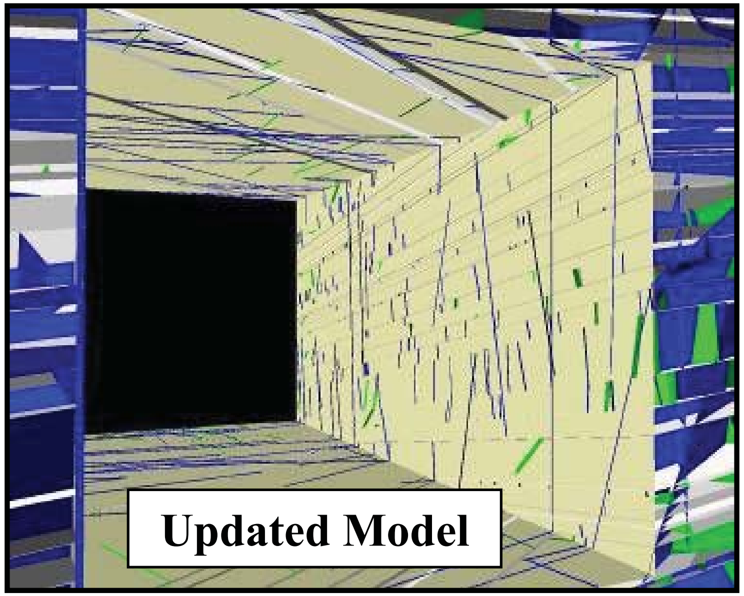
- trace density
- mean trace length

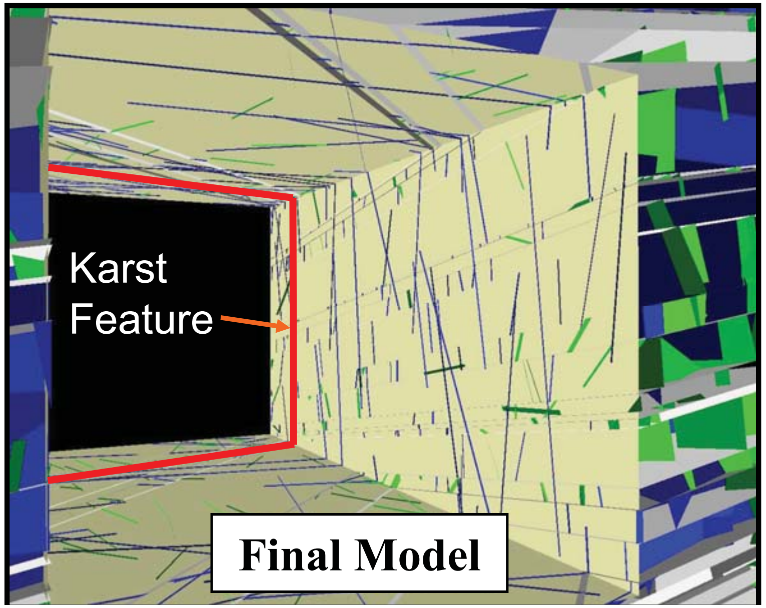
Differential Evolution

Differential Evolution algorithm utilized to infer fracture shape and size from trace data.

Verify and update fracture models based on data obtained in tunnel







Revised Reliability Manual

Start: August 2006 End: May 2007

- Students: Alfredo Arenas and Esther Ryan
- Post – Doctoral staff: Michael P. Navin
- Supervisor: Dr. J. Michael Duncan
- Sponsor: CGPR

Objectives

- To update and revise the current reliability manual to include new reliability methods and more examples

Reasons for revision of the manual

- The current manual was written 8 years ago
- CGPR members found the manual difficult to use
- New information and methods have been developed
- Many engineers have difficulty estimating coefficients of variation

Revised and Reorganized Content

- Explain the basic concepts – “The language of statistics and probability”
- Add new reliability method - “Hasofer Lind”
- Provide step by step procedure on how to use the “Taylor Series Method” and the “Hasofer Lind Method”
- Use only normal distribution – Exclude the lognormal distribution
- Provide guidance on choosing the coefficients of variation

New Chapter:
“The Language of Statistics and Probability”

Chapter Headings

– Standard Deviation

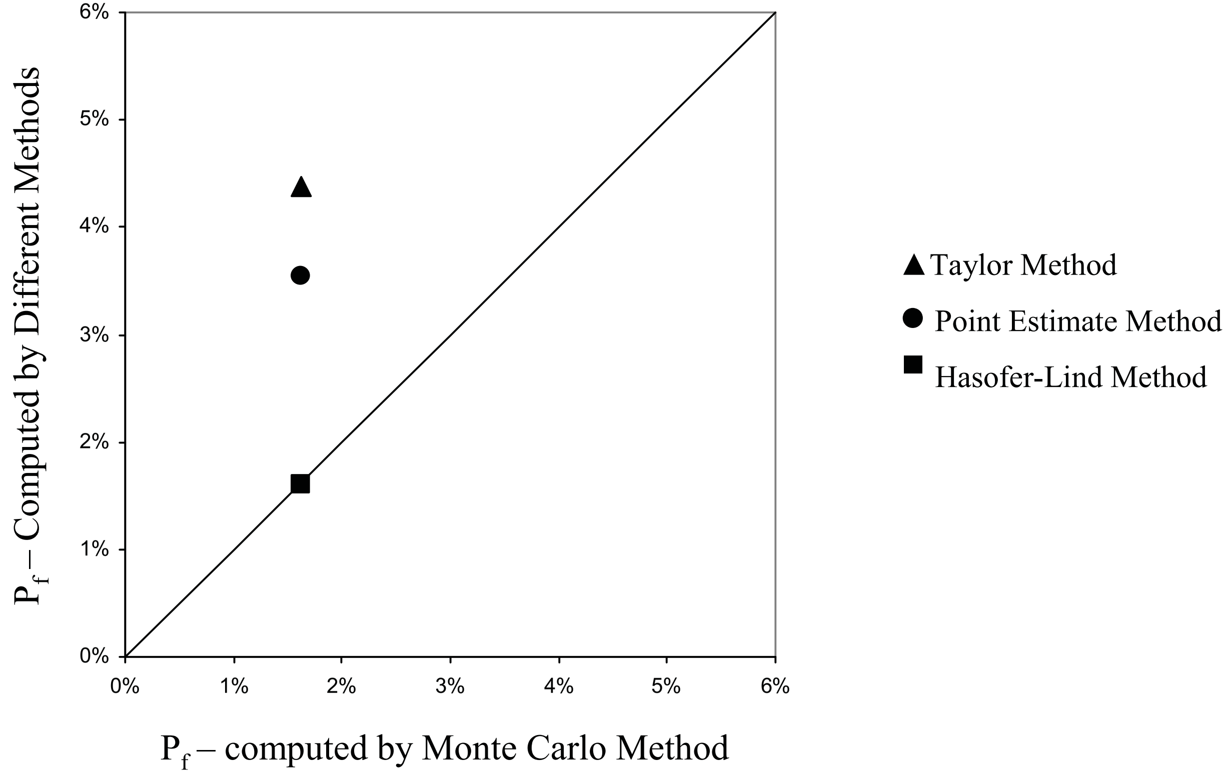
– Coefficient of Variation

– Histograms and Relative Frequency Diagrams

– Probability Density Function

– Normal and Lognormal Distribution, etc.

Hasofer Lind Method



Comparison of values of P_f for sliding mode of a retaining wall

Downdrag and Dragloads on Piles Subject to Negative Skin Friction

Start: August 2006 Projected End: May 2007

- Student: Mike Greenfield
- Supervisor: Dr. George Filz
- Sponsors: CGPR

Objectives

- Evaluate methods of analysis for use in practice
- Provide design recommendations

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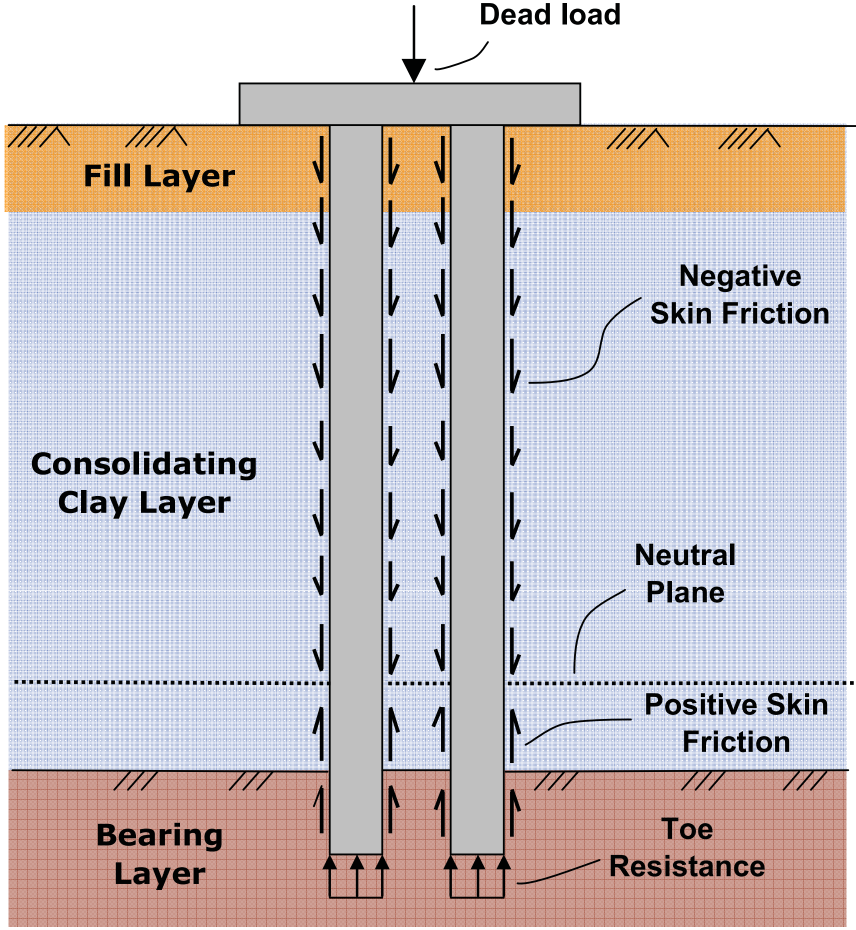
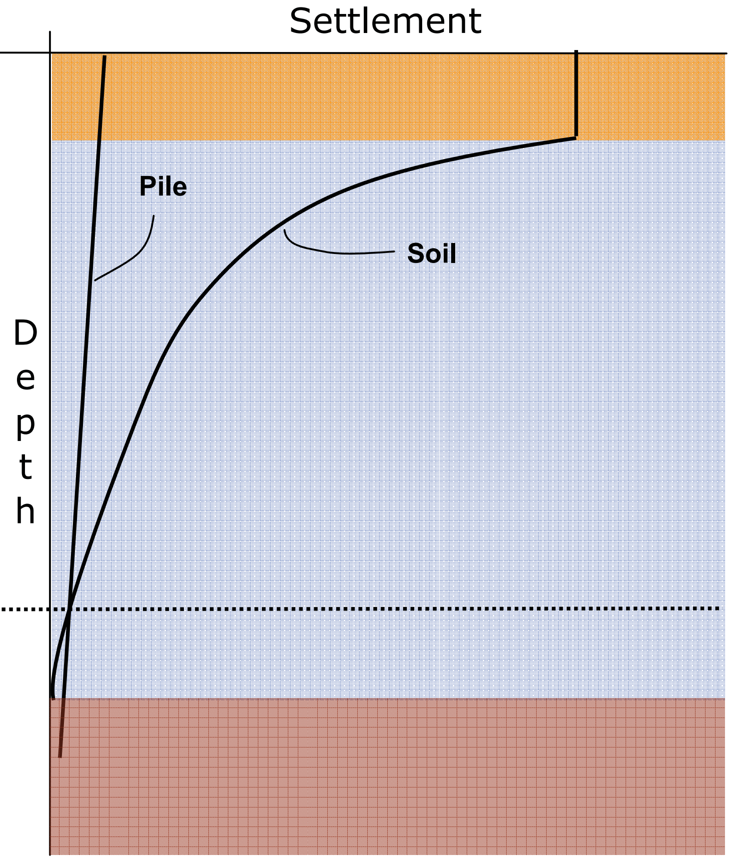
Review of Downdrag

Pile Group Diagram



Settlement Profile

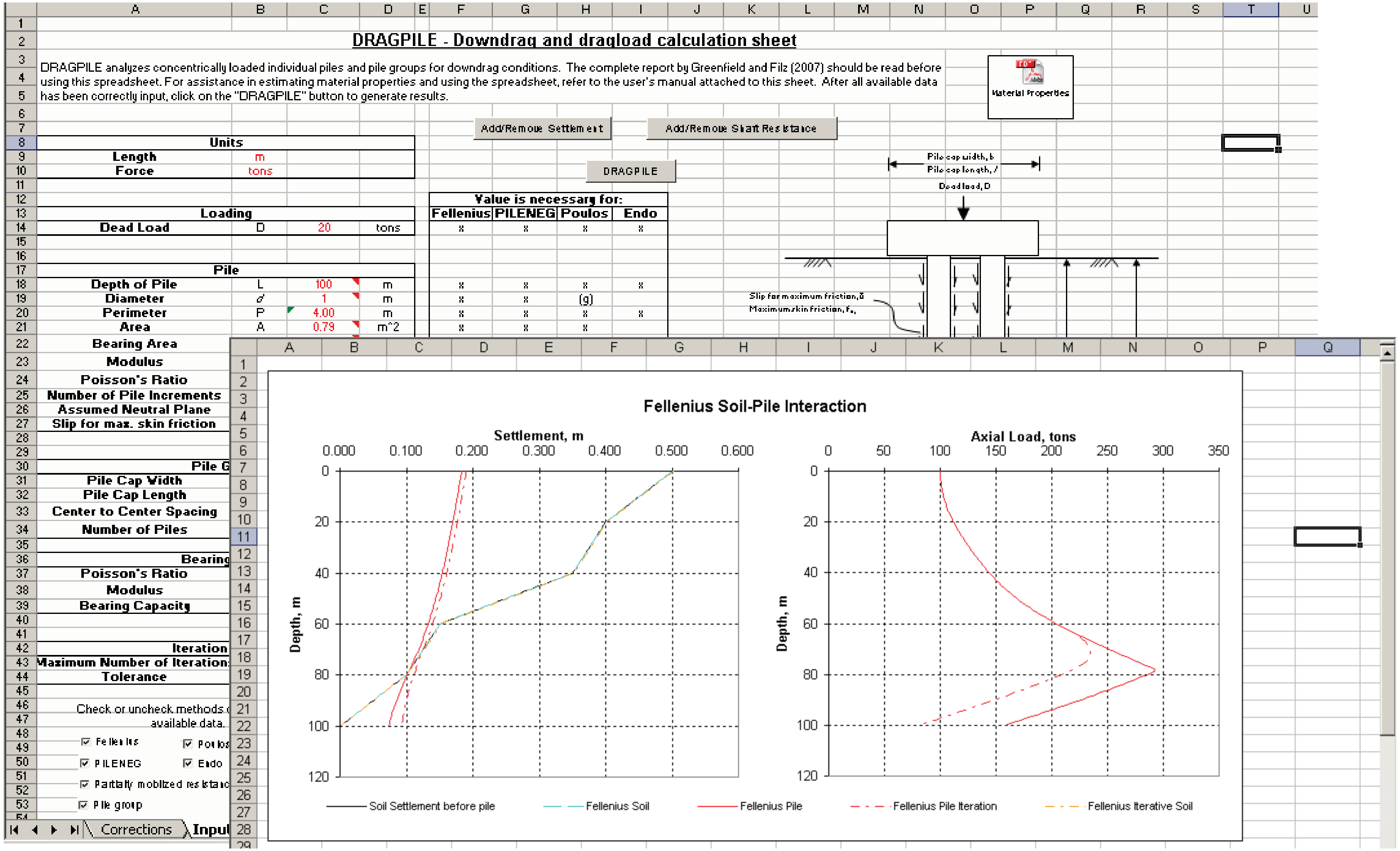


After NHI Design and Construction of Driven Pile Foundations Workshop Manual, 1996

Scope of Project

- Methods of analyzing downdrag on single piles
  - 4 practical methods
  - 2 adaptations of practical methods
  - Microsoft Excel® Worksheet - DRAGPILE
- Pile group effects
- Material property guidance
- Design criteria

DRAGPILE – screen shots



DRAGPILE - Downdrag and dragload calculation sheet

DRAGPILE analyzes concentrically loaded individual piles and pile groups for downdrag conditions. The complete report by Greenfield and Filz (2007) should be read before using this spreadsheet. For assistance in estimating material properties and using the spreadsheet, refer to the user's manual attached to this sheet. After all available data has been correctly input, click on the "DRAGPILE" button to generate results.

Units			
Length	m		
Force	tons		
Loading			
Dead Load	D	20	tons
Pile			
Depth of Pile	L	100	m
Diameter	d	1	m
Perimeter	P	4.00	m
Area	A	0.79	m^2

Value is necessary for:			
Fellenius	PILENEG	Poulos	Endo
x	x	x	x
x	x	x	x
x	x	(g)	
x	x	x	x
x	x	x	

Bearing Area
Modulus
Poisson's Ratio
Number of Pile Increments
Assumed Neutral Plane
Slip for max. skin friction

Pile G
Pile Cap Width
Pile Cap Length
Center to Center Spacing
Number of Piles

Bearing
Poisson's Ratio
Modulus
Bearing Capacity

Iteration
Maximum Number of Iteration
Tolerance

Check or uncheck methods available data.

☑ Fellenius ☑ Poulos
☑ PILENEG ☑ Endo
☑ Partially mobilized resistance
☑ Pile group

Remaining Research

- Compare methods with case histories
    - –Which methods to use in which situations?
- Develop guidance for estimating material property values
- Recommend appropriate design criteria

Soil and Rock Modulus Correlations for Geotechnical Engineering

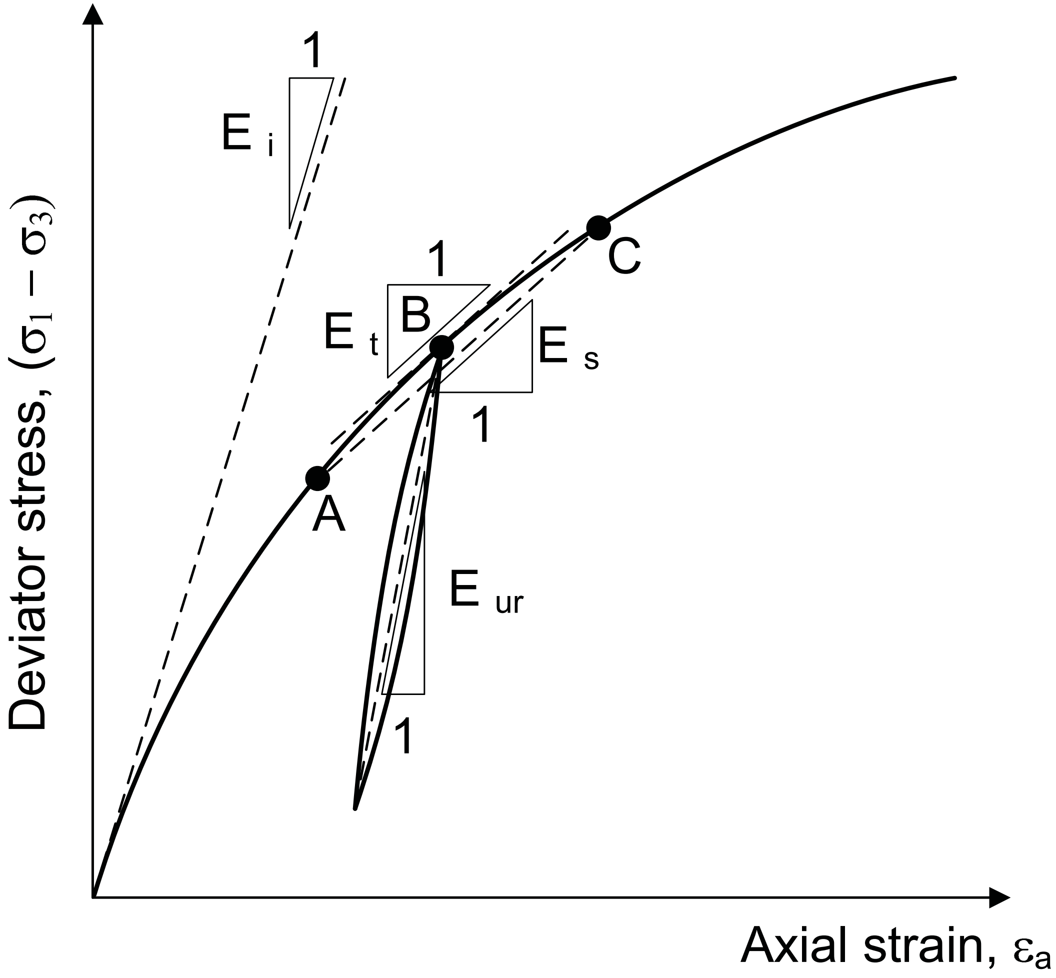
Start: September 2006 End: February 2007

- Student: Andrew Bursey
- Supervisor: Mike Duncan
- Sponsor: CGPR

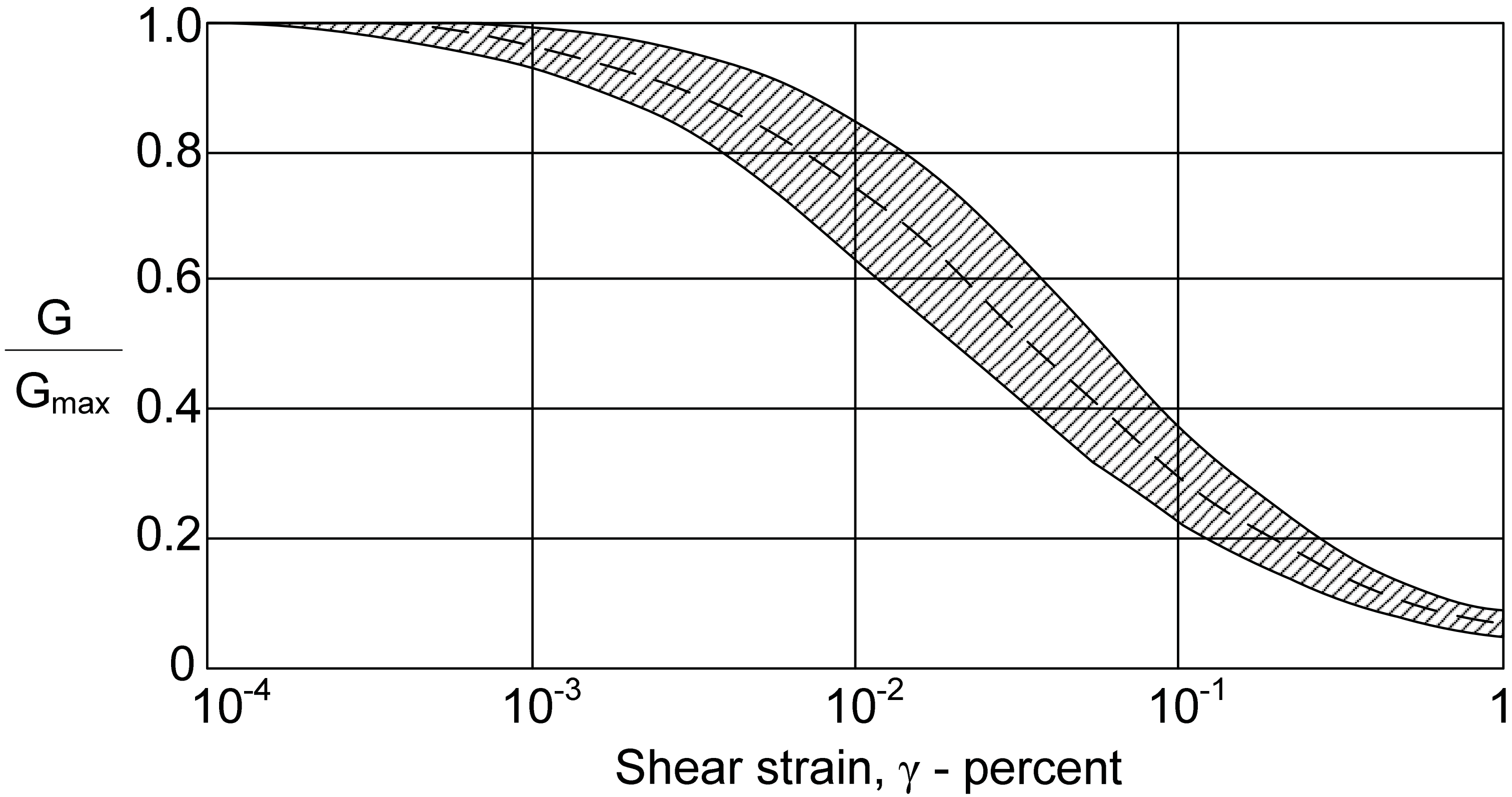
Objectives

- Define stress-strain parameters and interrelationships
- Evaluate factors that control soil stiffness
- Provide useful correlations between soil and rock mass modulus and in situ and laboratory test results, and guidance for their use

There are many ways to characterize soil stiffness



Soil stiffness decreases with increasing strain the effect is called "modulus degradation"



(Seed and Idriss, 1970)

Problems with modulus correlations

- Many correlations between modulus values and in situ or lab test results are available
- BUT, variations among them are large because of differences in
  - type of modulus (E, G, M),
  - stress state (E_i, E_t, E_s), and
  - strain magnitude (10^{-4} percent to 1 percent)

Guide to modulus correlations

Type of modulus and type of soil	**Basis for estimating modulus value**		
	SPT data	CPT data	---- Etc.
E_i for compacted (CL) clays			
M'_s for sand	**Figure 11**		
---- Etc.			

Leaching of Lime-Treated Soil

Start: May 2006 End: February 2007

- Students: Jaime Colby and Jessa Corton
- Supervisors: Dr. George Filz and Dr. Thomas Brandon
- Sponsors: J.H. Becker Company, Inc.

Primary Objective

– to determine the effects of leaching on the engineering properties of lime-treated soil.

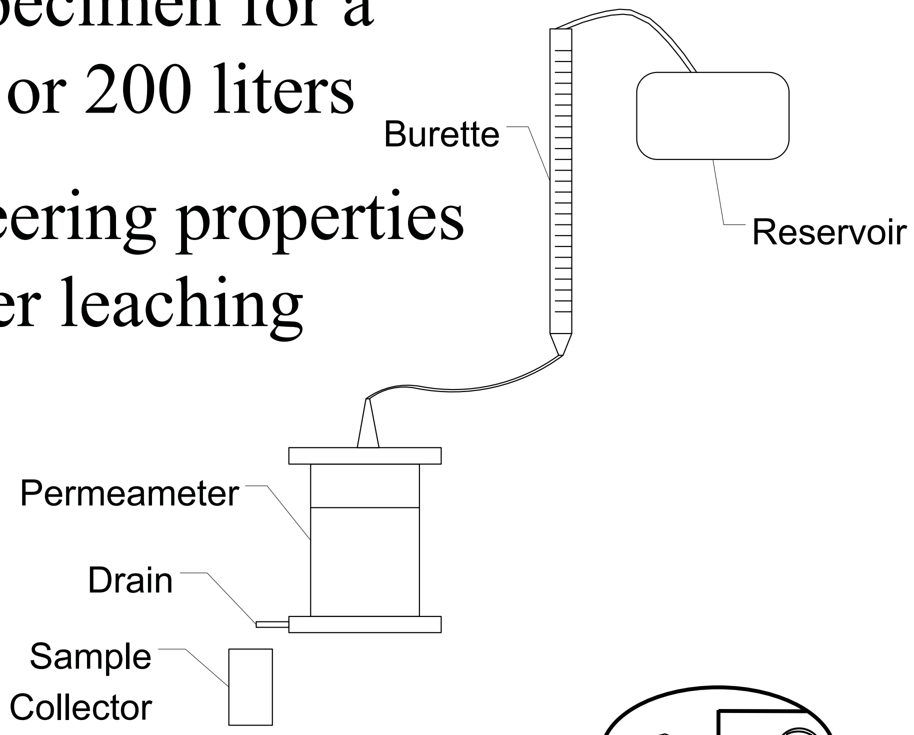
Motivation:

- Extensive and increasing use of lime for subgrade stabilization and borrow stabilization.
- Concern about long-term strength of stabilized ground due to leaching

Procedure:

- Determine the engineering properties of the treated soil before leaching
- Leach lime-treated specimen for a minimum of 45 days or 200 liters
- Determine the engineering properties of the treated soil after leaching

JC1

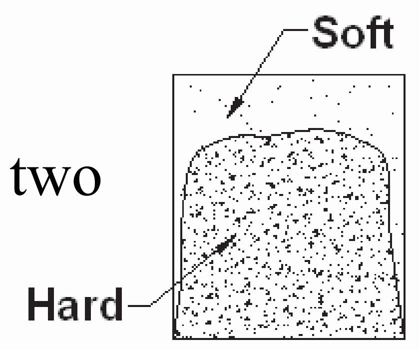


Slide 99

JC1 which includes the untreated and 0.5%, 2%, 4%, and 6% lime-treated soil.
Jessa Corton, 2/6/2007

Results:

- Post-leached specimens were found to have two different zones: hard and soft



- Plasticity index

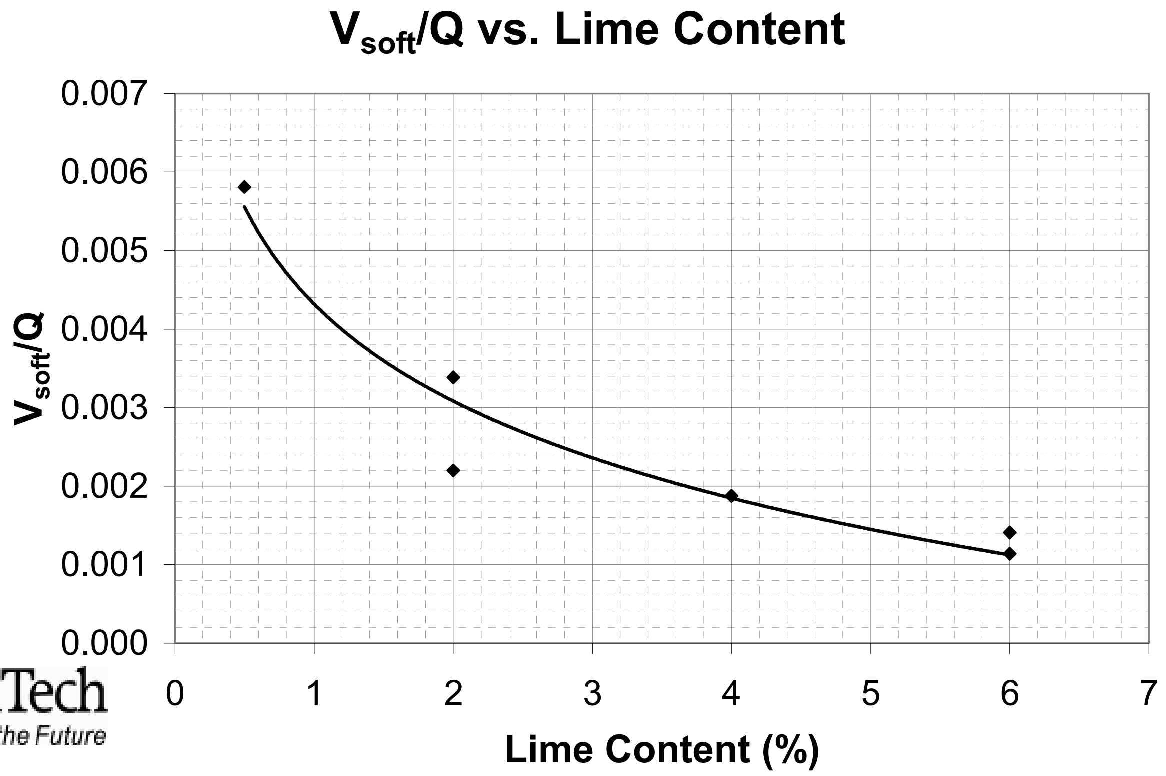
Lime Content (%)	Plasticity Index		
	Pre-leaching	Post-leaching Hard	Post-leaching Soft
0	28	---	---
0.5	18	20	20
2	11	28	40
4	NP	18	37
6	NP	ND	34

- Grain-size

Soil	Percent Passing No. 200
Untreated	90.9
Pre-leaching	66.9
Post-leaching Hard	76.3
Post-leaching Soft	91.9

Conclusions:

- Leaching has adverse effects on lime-treated soils
  - Increases plasticity
  - Reduces average grain-size
- Correlation between softened volume, V_{soft} , normalized by quantity of water, Q, versus lime content JC2



Slide 101

JC2 This research provides information about the effects of leaching on one particular lime-treated soil. It is not intended to replace laboratory testing for site specific projects utilizing lime treatment.
Jessa Corton, 2/6/2007

Geotechnical Specifications of Little League Ballfields

Start: November 2006 End: December 2007

- Student: Tim Moore
- Supervisor: Dr. Thomas L. Brandon, Dr. Naraine Persaud, Dr. Mike Goatley
- Sponsors: USDA-Agricultural Research Service (ARS)

Objectives

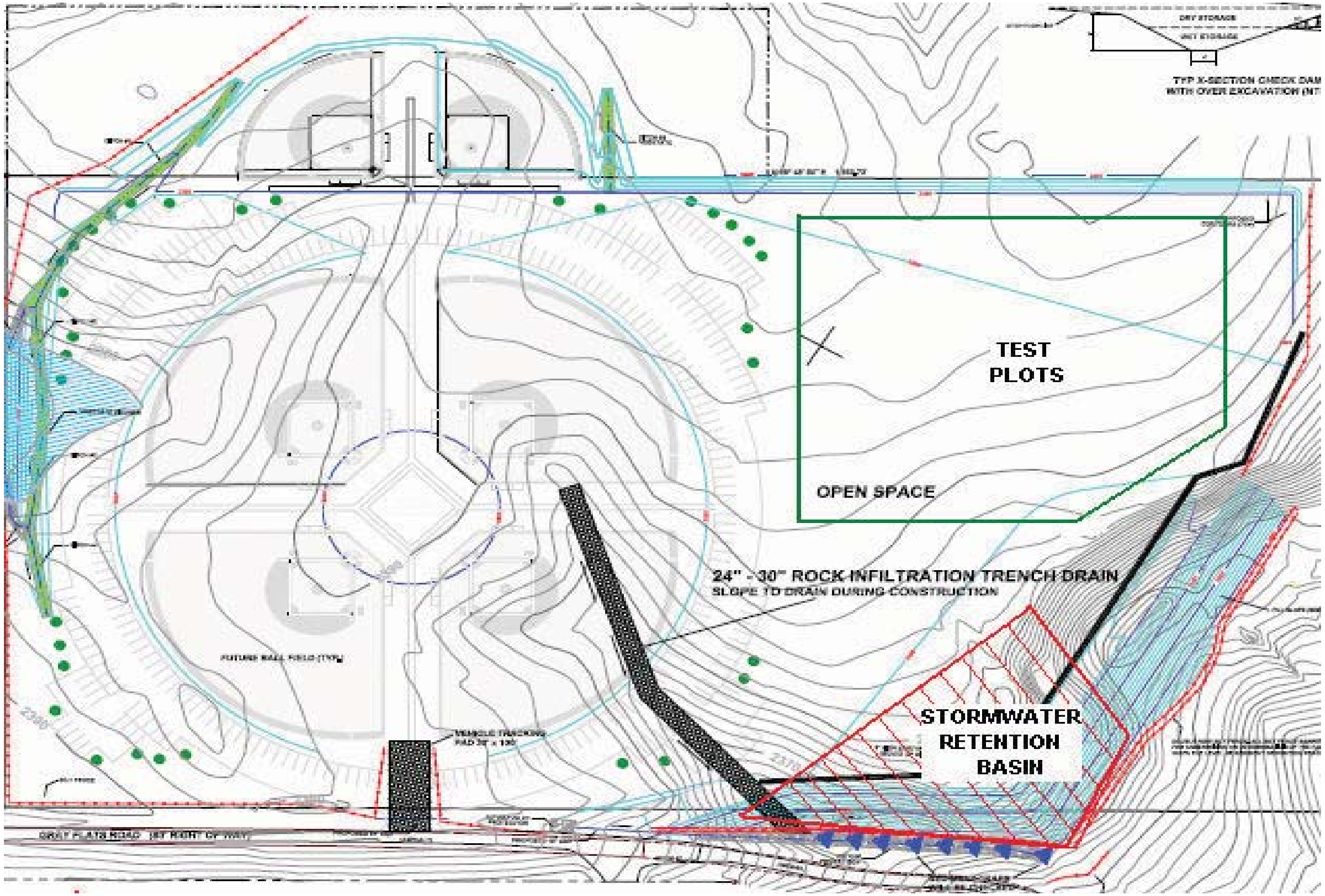
- To examine the application of current geotechnical specifications for little league ballfields
- To provide geotechnical quality control assistance during the construction of the ballfields

Little League Ballfields – Beckley, WV

Project Aspects:

- Construction of Ballfields
  - Recommend geotechnical specifications
  - Provide light quality control measures for compaction
- Research Plots
  - 3 test plots – differing compaction and soil treatments
  - Irrigated by on-site stormwater-retention basin
  - Long-term research to relate relative compaction, playability, and turf growth

Site Plan & Details



Current ASTM Specifications

- ASTM Section 15.07 – Sports Equipment and Facilities:

  - Specifications and test methods for shock-absorbing and impact-attenuation of sports field playing surfaces

- ASTM Sections 4.08 & 4.09 – Soil and Rock:

  - Specifications and test methods for relative compaction, and impact values of soils

Research Test Plot Details

- 3-plots, each with a different level of compaction (80%, 85%, & 90% of standard Proctor)
- Each plot will have different soil/turf treatments (VT CSES Dept)
- Plots will be tested using current ASTM specifications to examine their applications (compaction, shock attenuation)
- Plots will be monitored long-term for differential settlement, and turf growth
- The on-site storm water retention pond will be used to irrigate the test plots, along with the ballfields
- Graded mine spoils will be used for the subgrade of the plots to present a suitable turf growth material

Central and Eastern United States Seismic Implications

Start: Summer 2006 End: Summer 2007

- Student: Morgan Eddy
- Supervisor: Dr. James Martin
- Sponsors: ECSUS

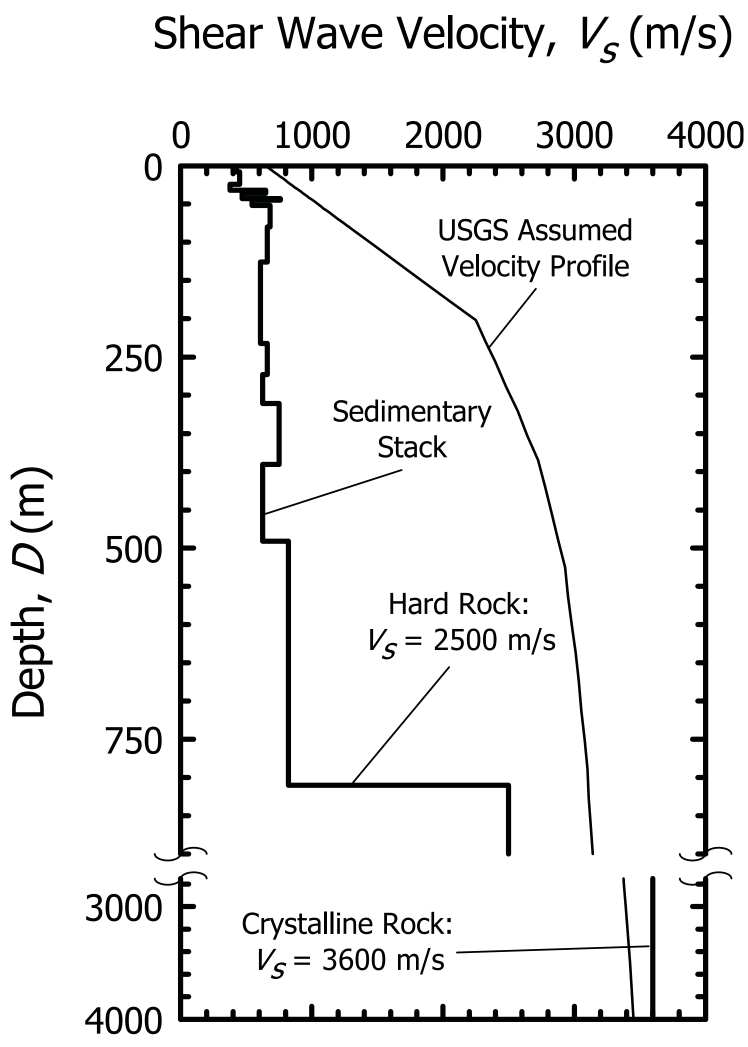
Objectives

– Investigate impact of CEUS geologic conditions on the International Building Code Seismic provisions

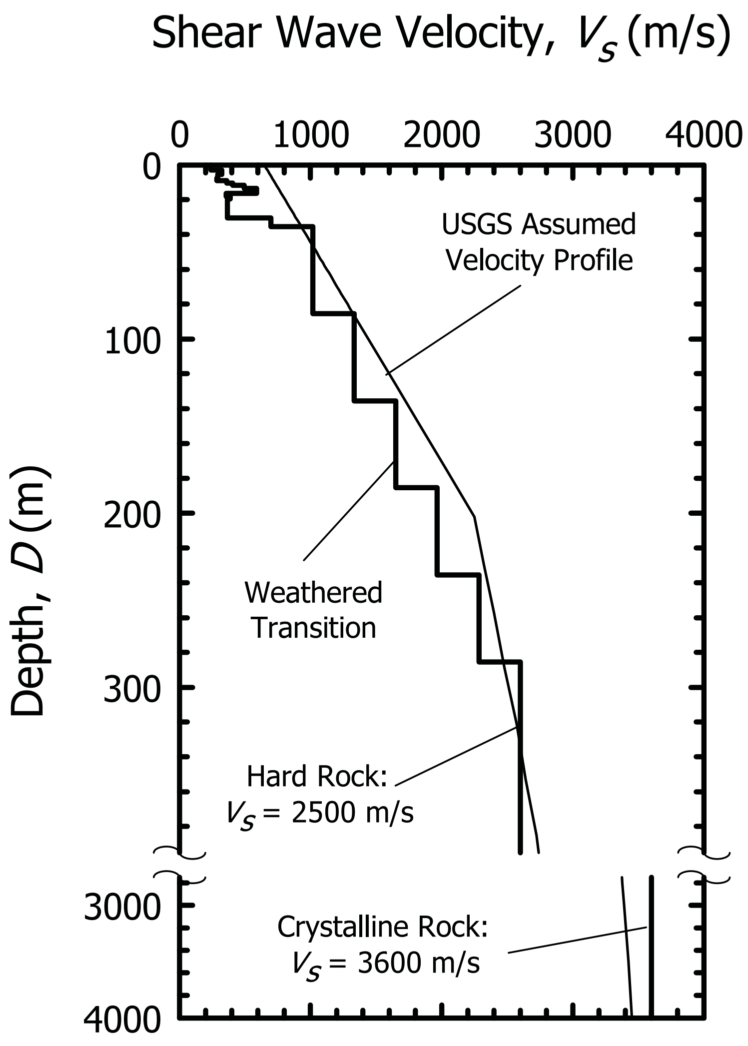
– Perform site response analyses of CEUS sites to assess implications of the IBC

– Provide recommendations for performing site response analyses of sites in the CEUS

Geologic Conditions

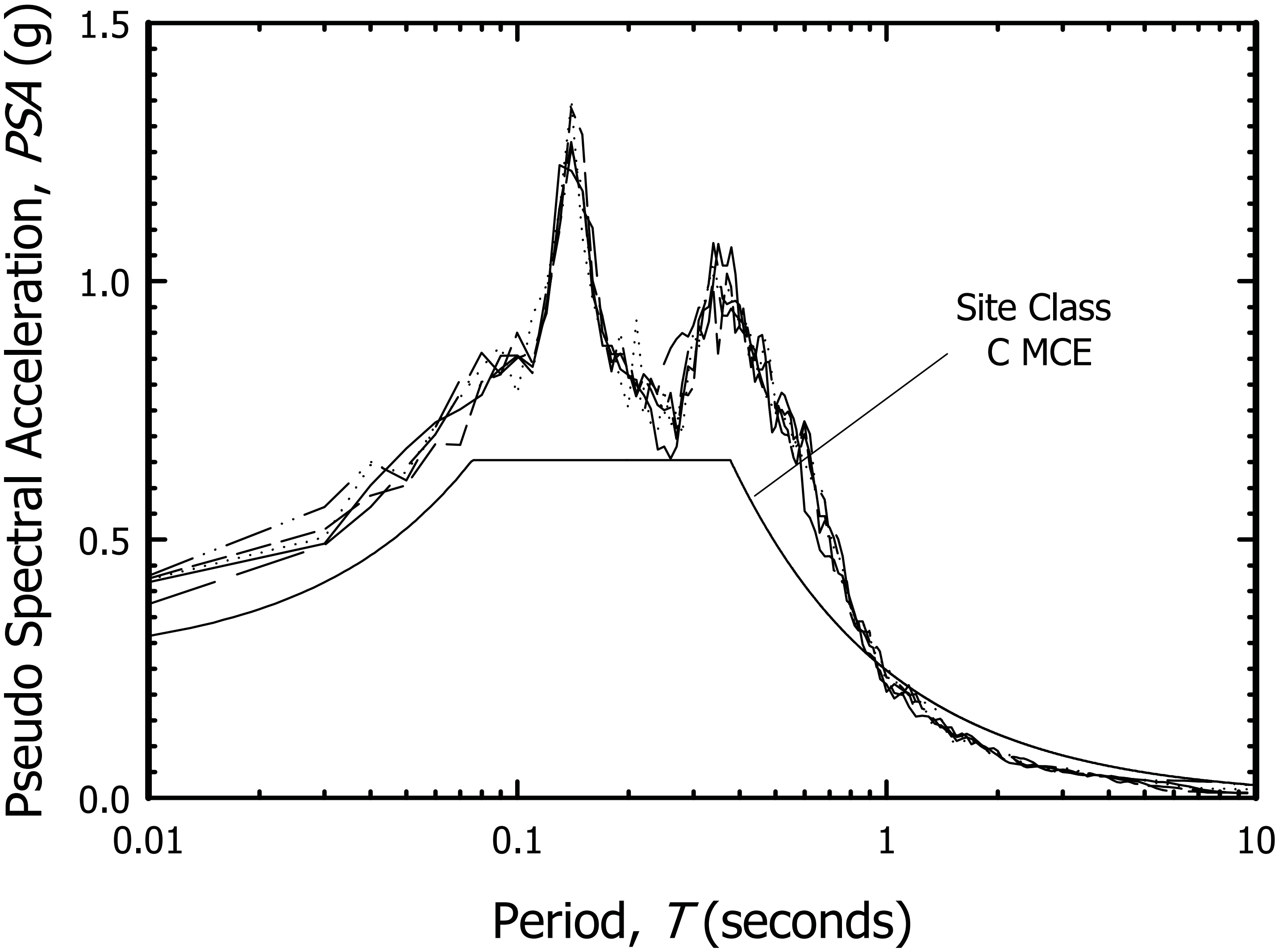


Charleston, S.C.

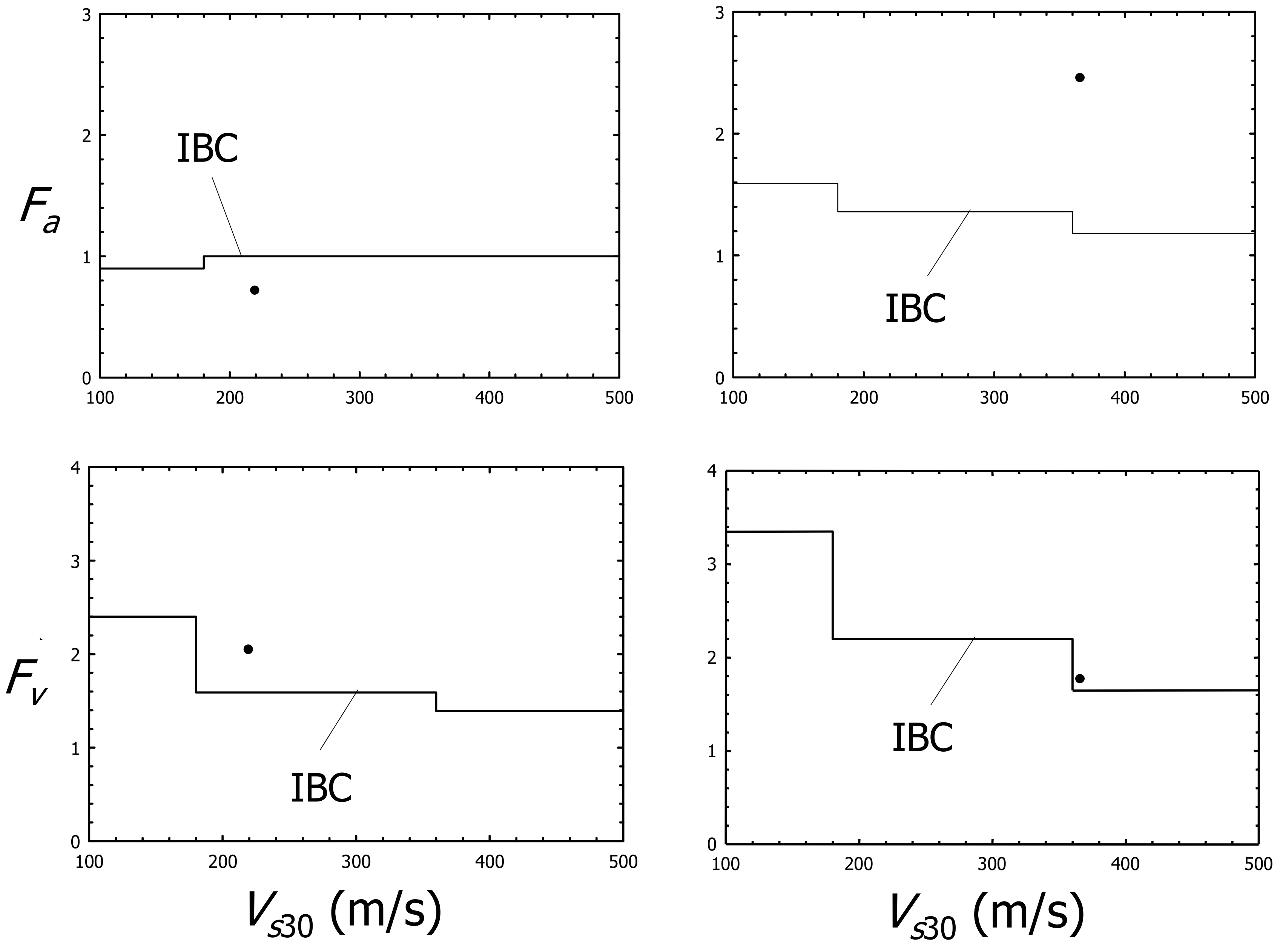


Columbia, S.C.

Response Spectra



Amplification Factors



Conclusions

- Geologic conditions found in the CEUS are not represented in the recent building codes
- Deep soil sites, such as in Charleston, can amplify long period motions above code values
- Sites where the hard rock is relatively close to the ground surface can amplify a broad range of motions above the code values
- Site amplification factors need to be adjusted to account for the conditions found in the CEUS