Research Posters
Stabilization and Control of Clay Swelling Using Plant Extracted Silicate Solution

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Introduction

• Swelling soils cause billions of USD in damage to light construction and pavement structures every year.
• Hypothesis: Sodium silicate can act as a dispersing agent modifying edge-charge reversal, ion exchange, and/or pH of expansive clays.
• Preliminary results show significant reduction in swelling potential of clay.
• This study presents preliminary procedures needed to optimize gelification of bio-based sodium silicate solution extracted from rice husk ash.
• Work plan includes: a) Optimization of the amount of silica extracted from rice husk; b) Controlling gelation time to facilitate/control field application; c) Large scale testing of untreated/treated specimens to evaluate the level of swelling mitigation.

Silica Gel Extraction from Rice Husk Ash

• Mix 10g ash with 60 ml 1 N NaOH.
• Boil at 100°C.
• Stir at 400 rpm for 1 hour.
• Sodium silicate solution is obtained.
• Silica gel is obtained by adding HCl.
• The process of obtaining the gel consists of:
  (1) Releasing silicic acid:
  \[ Na_2SiO_3 + H_2O + 2HCl = Si(OH)_4 + 2NaCl \]
  (2) Polymerization of silicic acid:

Gelation Time - Spectrophotometry

• Gelation time is pH-dependent.
• Gelation time can be measured as a function of color absorbance.

Conclusions

• Optimal temperature/time resulted to be 600°C/2 hours
• It was possible to extract 97% of silica from rice husk ash in the form of sodium silicate solution
• The solution was gelified in order to treat expansive soils.
• A colorimetry method was developed for measuring gelation time.

Acknowledgement

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Enzyme Induce Carbonate Precipitation (EICP) for Soil Improvement
Abdullah Almajed, Postdoctoral Research Assistant, Advisor: Prof. Edward Kavazanjian, Jr.
Arizona State University

**Background**

EICP: Carbonate precipitation via hydrolysis of Urea catalyzed by Urease enzyme (Ureolysis)

\[
\text{CO(NH}_2\text{)}_2(aq) + 2H_2O + \text{CaCl}_2(aq) \rightarrow \text{CaCO}_3(s) + 2\text{NH}_4\text{Cl}(aq)
\]

**Sources of Urease:**
- Microbial
- Agricultural
  - Jack-bean plant: best known and most studied
  - Many other agricultural products, including waste vegetation

**EICP Applications**

**Mix-and-compact**
- Embankments
- Roadway subgrades

**Percolation, injection**
- Bearing capacity, settlement control
- Vertical columns
- Inclined columns (soil nails)

**Recent Advances**

**Materials and Methods**

**Methods**
- Mix and Compact

**Materials**
- Added powdered milk (“organic stabilizer”)

**Results**

**Mix and Compact**
- Similar strength to percolation or injection

**Powdered Milk**
- Focused precipitation at contacts
  - Significantly higher strength with one treatment cycle
  - Less effort to bio-cement soil
  - Less substrate needed
  - Less by-product produced

**Acknowledgment**

This material is based upon work supported in part by the National Science Foundation (NSF) under NSF CA No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the NSF.

**Relationship between UCS vs CaCO\(_3\)**

**SEM Images**

(A) CaCO\(_3\) at inter-particle contact points,
(B) Inter-particle cementation,
(C) Broken CaCO\(_3\) at inter-particle contact,
(D) CaCO3 spread on the surface texture of the sand. (EICP w/o fresh milk)

**Current Work**

- Field site identification and characterization
- Investigate the effect of soil type
- Investigate the effect of gradation size on cementation
Electrokinetic Subsurface Transport for Soil Remediation and Mineral Precipitation:

The Influence of Electrokinetic Bioremediation on Subsurface Microbial Communities in Pilot-scale Treatment of a PCE Contaminated Site

Megan Altizer, Anca G. Delgado, Rosa Krajmalnik-Brown, César Torres (Arizona State University), James Wang, Evan Cox (Geosyntec Consultants)

Background

In situ bioremediation of chlorinated contaminants via bioaugmentation is an effective remedial strategy. However, success can be hindered at sites with complex geology and low-permeability soils. In situ electrokinetic-enhanced bioremediation (EK-Bio) is an alternative that can improve transport of required bioaugmentation amendments at these challenging sites. Geosyntec Consultants has demonstrated the effectiveness of this technology from the laboratory to full-scale applications.

Objective: Our aim was to investigate the effect of EK-Bio on native microbial communities’ structures and functions using next generation sequencing (NGS) techniques, yielding information about the long-term changes in microbial ecology and soil health as well as potential strategies for optimizing the technology.

Methods

Geosyntec Consultants completed a pilot test of EK-Bio at a site in Jacksonville, FL contaminated with perchloroethylene (PCE). The contaminant source was 6-8m below the ground surface in a clay soil under an active parking lot. An EK-Bio system was constructed with 9 electrode wells to apply direct current and 8 supply wells to deliver bioaugmentation amendments. Groundwater samples were collected from monitoring wells during active system operation and several months after operation ceased. DNA was extracted from these samples with the Zymo Universal DNA kit, and 16S rRNA gene amplicons were sequenced with Illumina Miseq.

Results

After treatment, PCE concentrations decreased by >80%. Sequencing results revealed an enrichment in the treatment zone of PCB/chloro-organic pesticide degrading Betaproteobacteria (>65%), metal and chlorinated solvent reducing Delta-proteobacteria (>24%) and sulfate reducing Deltaproteobacteria (>17%).

Alpha diversity (mean local species diversity) of the samples from the treatment zone increased from that in samples from up-gradient background and down-gradient locations.

Conclusions

• Some microorganisms were enriched due to the PCE contamination, while other enrichments may be correlated with changes in soil geochemistry associated with EK-Bio. This result suggests future applications should carefully consider site geochemistry (e.g., high nitrate or sulfate concentrations) which may create a more competitive microbial environment.
• The application of EK-Bio at this site resulted in increased microbial diversity in the treatment zone and, thus, improved soil microbiota health supporting the objective of enhanced in situ bioremediation.
Numerical modeling of earthworm excavation: a micromechanics perspective

Student: Rodrigo Borela • Advisor: Dr. David Frost
School of Civil and Environmental Engineering • Georgia Institute of Technology

Thrust: Cross-cutting Use case: Tunneling and subsurface exploration Stage: Fundamental Knowledge

Abstract
Current excavation techniques utilizing tunnel boring machines (TBM) suffer from slow advance rates, due to extended intermittent stops to build reactive supports for the pushing operation. In contrast, earthworms use a series of synchronized movements which allow nearly continuous motion at significantly faster rates. In this study, we evaluate the mechanisms employed by such animals, through a set of 3D discrete element simulations (DEM). The results reveal the micromechanical implications of the method and provide directions for developing enabling technologies.

Earthworm locomotion
Earthworms are segmented organisms filled with coelomic fluid. Locomotion is achieved through the antagonistic action of two muscle groups in individual segments. As circumferential muscles relax, longitudinal muscles contract, causing segments to shorten and expand radially, creating anchor points. Conversely, as longitudinal muscles relax, circumferential muscles contract, the coelomic fluid is pressurized and the segment protrudes longitudinally. (Quillin, 1999). This sequential mechanism produces a peristaltic motion that propagates in the opposite direction of movement.

Peristaltic motion modeling
In addition to the underlying simulations involving the separate mechanisms, preliminary modeling of peristaltic wave propagation has been conducted on a cylinder fixed in the vertical direction (no downward displacement). The peristalsis in the following figure was modeled as a sinusoidal wave propagating upwards. Initial results indicate that as the ring expands into the ground it generates reactive forces which would serve as reactive supports for propelling the worm body. The constriction allows the body to lose touch with the granular matrix, therefore eliminating the frictional resistance, reducing the burrowing energy consumption.

Miniature device prototype
Based on the initial lessons learned from this set of simulations, a first prototype that simulates the peristaltic motion was designed and 3D printed. It consists of a shell with free hanging pieces and an axle which is powered by a microcontroller. 3D printing allows fast improvement of the design before the heavy manufacturing stage.

Concluding remarks
The success obtained in the preliminary models suggests the approach to be fitting for the problem being analyzed. Currently a parametric study is being conducted to obtain additional insight into the behavior in a range of ground conditions. This knowledge will serve as the basis to optimize the design of the propelling system for a self-mobile sensor and self-burrowing device.

References
Wikimedia Commons, the free media repository. 14 Mar 2015, 08:26 UTC. 9 Oct 2017.
Tree Root Inspired Foundations and Retaining Systems

Students: Matthew Burrall, Kyle Doughty, Lin Huang
Faculty: Drs. Jason T. DeLong, Daniel Wilson, Alejandro Martinez

Motivation
Tree root systems are nonlinear, branched, natural foundation systems that develop anchorage efficiently in a variety of growing and loading conditions. This project is focused on developing foundation designs based on lessons learned through study of root system, architecture, and anchorage.

Test Setup and Measurements
- Uplift force – 10000 lb load cell
- Trunk and ground displacements – 12 string potentiometers mounted on a unistrut reference frame
- Ground and trunk accelerations – 12 ICP 50G accelerometers
- Photogrammetry for 3D mapping of deformation surface
- Air spading to expose extended root system
- Lidar scans of extracted root systems
- Mini-cone (tip and sleeve measurements)
- Soil sampling for density and moisture content

Pullout Curves

Ground Deformation Models
Two Nikon D3200 DSLR Cameras were mounted on a dolly and pushed around a circular, lift radius track, with pictures taken at each 5 degree mark for each pullout increment (approximately 1 inch of vertical displacement).

Lidar Scans
Dr. Brian Bailey, from the UC Davis Plant Science Department, with graduate student Miguel H. Ochoa, produced point clouds of the extracted root systems using a ground-based lidar apparatus for the purpose of mapping of root 3D structure.

Collaborators and Acknowledgements
The help of fellow students, UC Davis Center for Geotechnical Modeling (CGM) staff, and collaborators from Plant Science is greatly appreciated.

Drs. Astrid Volder, Jason T. DeLong, Bruce Campbell

Follow-up Measurements
- Finish processing soil samples
- Collect root samples from adjacent trees and perform tensile tests
- Perform excavations on remaining holes to assess distribution of root cross-sectional area close to trunk

Next Steps for Analysis
- Analyze accelerometer records to study root breakage sequencing (the timing and spatial distribution versus the root diameter, compared for the different rootstocks)
- Analyze ground displacements to assess the extent of soil engagement around the root bulb
- Analyze root architectural characteristics
Upscaled Modeling of Microbially Induced Calcite Precipitation: Effects of Bio-cementation on Liquefaction Triggering of Sand

Jason T. DeJong, Ross W. Boulanger, Michael G. Gomez, & Dan Wilson

Motivation
Use Microbially Induced Calcite Precipitation (MICP) to understand the effect of cementation on the liquefaction triggering of sands.
- Increase liquefaction resistance of loose sands
- Examine the effect of bio-cementation on the cyclic strength, cone penetration resistance ($q_c$), and shear wave velocity ($V_s$).
- Hypothesize that results may be applicable to aged sands

Test Plan
A series of tests on MICP treated Ottawa sand will be conducted at 80g using the 1m radius centrifuge at the UCD Center for Geotechnical Modeling, an NSF NEERI Equipment Site.
- Measure acceleration, pore pressures, $V_s$, and settlement
- Perform bottom-up treatment to create different cementation levels in different models
- Subject models to a sequence of sinusoidal shaking events with increasing amplitude until liquefaction is triggered
- Obtain $V_s$, and $q_c$, measurements before shaking, after initial triggering, and after liquefaction has ceased
- Inverse analysis of accelerometer data to obtain shear strain and CSR time series

Preliminary Results
An Ottawa MICP treated model with a relative density ($D_r$) of ~40% was treated to a 1g $V_s$ of ~170m/s. Two treatments were needed to reach the target $V_s$. The model was spun at 80g and subjected to a total of 17 sinusoidal shaking events.

Summary of Preliminary Results
Bio-cementation technology and centrifuge tests will be utilized to understand how cementation affects liquefaction triggering of loose sands.
- The MICP treated model had a higher cyclic strength than a non-treated model with a similar $D_r$ and shaking sequence.
- The $V_s$ and $q_c$ decreased after initial triggering and then increased after subsequent shaking events.
This study will deploy numerical simulations to optimize the geometry and flow-loop configuration of ground heat exchangers.

Proposed work

Objective

• Learning from vascular systems and phase changing mechanisms in nature to improve the performance of ground heat exchangers.

Bio-Inspired mechanisms

• Vasoconstriction vs vasodilation and phase changing mechanisms.

Main challenges

• High initial cost of installation.
• Uncertainty of the backfill and the ground in the short and long term:
  • Short-term (hours to months) - fluid-temperature anomalies.
  • Long-term (years) - heating or cooling of the reservoir.

Introduction

• In 2013, approximately 21% of the total CO₂ emissions in the U.S was related to residential energy usage (EPA 2013).
• Accounting for all the American households, the cost of energy used to heat and cool spaces reaches approximately $82 billion per year (EIA 2011). Hence, it is imperative to develop more and more efficient energy systems.
• Ground heat exchangers have helped mitigate such environmental and economic problem; however, their current design needs to be optimized. Underground closed-loop piping systems use heat transfer to extract heat from the soil.

References


Figure 1. Ground heat exchanger arrangement (Johnston et al., 2011).

Figure 2. Illustration of bio-thermal regulation. (a) Vasoconstriction and vasodilation mechanism (Xilaxo, 2016). (b) Selective temperature control (Pearson, 2004).

Figure 3. Heat recovery systems. (a) Loop patterns (Comsol Multiphysics, 2014). (b) Single vs double loop in vertical heat exchangers (Ozudogru et al., 2014).

Figure 4. Preliminary simulation results. (a) Ground temperature evolution. (b) Output temperature at different flow rates.
Microbial Metabolic Exploration from Extreme Environments

Microbial metabolic reactions under extreme alkaline conditions

Sofia Esquivel-Elizondo, Alta Howells, Everett Shock, Rosa Krajmalnik-Brown (ASU)

**BACKGROUND**

High pH (>11) in the Oman Ophiolite (see pictures) is driven by serpentinization, a subsurface water-rock reaction. The serpentinization-reacted waters (SRW) are reduced, H₂-rich, and low in Si. SRW come up to the surface, resulting in CO₂ precipitation into carbonate minerals. The disequilibrium created when SRW mix with surrounding surface water (~pH 8) is important for CO₂ precipitation and dissolution and has the potential to fuel microbial metabolisms involved in the production/consumption of CO₂: CO and CH₄ oxidation and CH₄ production (methanogenesis).

**ACHIEVEMENTS**

We generated fundamental knowledge to understand microbial metabolic reactions that occur under hyperalkaline conditions (pH > 11) and that are involved in carbonate precipitation.

We enriched for microorganisms involved in CO metabolism from hyperalkaline sites and other natural environments.

**METHODS**

Oman Sameil Ophiolite (26 samples)
- Energetic calculations
- High throughput sequencing
- Bioinformatic analysis
- Enrichment cultures with CO

CO-enrichments were compared to others from natural environments
Introduction
Adobe is one of the oldest building techniques, found in historic landmarks and traditional dwellings (Fig. 1) as well as in modern construction on all continents. Traditional adobe consists of laying sun-dried mud (earth) bricks in courses with mud mortar. Traditional adobe making uses locally available soils, requires little energy and water, and generates no waste. However, adobe strength characteristics can be highly affected by moisture. Unreinforced adobe masonry is also very susceptible to seismic loading.

Research Goal and Objectives
The main goal is to develop and propose enhancements to the traditional adobe construction inspired in biological principles, processes, and materials to increase its resilience against weather and natural hazards while preserving its inherent sustainable, economic, and easy-to-do aspects.

Research objectives:
- Improve material properties of adobe using natural fibers (Fig. 2)
- Explore bio-inspired fiber reinforcement in adobe walls and foundations to improve resilience against moisture and lateral loads
- Study moisture and temperature variation within adobe walls

Experimental Work - Ongoing

Material testing:
- Jute
- Palm leaf
- Straw
- Sisal
- No fibers

Future work
- Continue studying material properties of fiber-reinforced earth bricks and natural fibers
- Assess effects of fiber reinforcement and moisture using DIC (Collaboration with UT Tyler)
- Assess scale effects (bricks and walls)
- Study soil fabric and spatial distribution of fibers in soil mixtures
- Explore other potential applications of fiber-soil mixtures
- Complete quarter-scale adobe wall testing
- Instrument / monitor historic building
- Model system components using finite element method

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Microbial Ecology of Stimulated Ureolytic Biocementation: Culture Collection Coverage of Stimulated MICP Communities

Charles M. R. Graddy, University of California, Davis
Advisors: Douglas C. Nelson & Jason T. DeJong

Background

- Stimulated ureolytic microbially induced calcite precipitation (MICP) uses enriched native microbial communities to mitigate liquefaction risk and improve soil properties.
- It minimizes environmental impact relative to conventional geotechnical methods.
- The process can be further optimized to reduce material use and duration.
- Microbes, of the ureolytic and competitive categories, may be identified.
- Culture-independent genetic techniques generate hypotheses that are difficult to validate outside of live cultures.
- Our extensive culture collection is an important resource for understanding the microbial physiology and routes for increasingly efficient stimulation of MICP.
- Ideally, the culture collection contains representatives of all organisms in the stimulated community for hypothesis testing and metabolic experimentation.

Methods

- Bacterial isolates were collected in pure cultures from three stimulated ureolytic MICP experiments.
- Pure cultures had their 16S RNA genes PCR purified and sequenced.
- Full length 16S rRNA genes were cloned out of column pore fluid and into plasmid sequencing vectors for isolation.

Conclusions

- Composition dynamics show similar general trends in time, but the culture-independent methods reveal a new clade in mature cementation communities.
- Lysinibacilli may be more important than previously expected.
- The culture collection doesn’t capture the overall diversity but it does represent the prevalent microbes. All isolates should be represented in 16S genes, so there is significantly more fruitful sequencing to be done.
- The isolate collection appears to be sufficient to validate hypotheses for the prevalent organisms in stimulated ureolytic MICP.

Future Research

- Finish sequencing isolates and experimental samples.
- Engage collaborators for genome sequencing of recurrent microbes, high-throughput amplicon, and metagenome sequencing.
- Analyze the prevalent strains’ physiology and test performance in soil columns, i.e., how organic, urea, and calcium affect crystal morphology and material performance.
- Explore putative urea hydrolysis energy generation in Sporosarcina and isolates that may help explain their enrichment success.

Acknowledgments

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Biofilm Enabled Permeability Reduction in Sands

Jordan A. Greer; Charles M.R. Graddy; Rebecca Parales; Jason DeJong; Douglas Nelson (UC Davis)
Ziqi Chen; Zhuhui Chen; Mary J.S. Roth; Laurie F. Caslake (Lafayette)

Background and Motivation
Biofilms demonstrate potential as a short term ground improvement technology for geotechnical projects where water seepage control and/or dewatering requirements exist.

Biofilms are bacterial communities that form a gel-like substance made of bacteria, secreted polymers and captured organic/inorganic material.

Reducing the permeability of sands using biofilm is less hazardous and more sustainable than traditional methods such as grouting and the injection of chemicals.

Possible applications:
- Erosion control
- Temporary dewatering systems
- Localized seepage control

Results

Column Test #2 Results:
- 100 fold permeability reduction in Columns 1 & 3
- No decrease in permeability of control column
- Hypothesized that system is oxygen limited
- Observed clogging in outlets

Column Test #3 Results:
- In furanone treated columns, k immediately decreased
- In both the control and nutrient columns, k increased
- Observed fine transportation through column
- Nutrient concentration of influent was less than anticipated
- After dissection and cleaning the inlet and outlet there was a decrease in k

Possible applications:
- Erosion control
- Temporary dewatering systems
- Localized seepage control

Future Work

Column Test 4
- Test is set-up and ready to start
- Smaller columns with focus on use of the most efficient nutrient formula

Experimental Procedure
- Create protocol for sampling and quantifying biofilm in column
- Understand the limiting factor in spatial distribution

Up-scaling
- Increase understanding of biogeochemical factors
- Explore bench scale models with 2D-0 flow regimes

Acknowledgements
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Microbially Enhanced Iron-Modified Zeolite Permeable Reactive Barrier

Neda Halalsheh, Ph.D. Student and Audrey Smith, M.S. Student
Faculty Advisors: Dr. Lambis Papelis and Dr. Paola Bandini, New Mexico State University

Introduction
Iron modified zeolites are used to develop a permeable reactive barrier (PRB) to treat groundwater contaminated by oxyanions of selenium (selenite and selenate) and arsenic (arsenite and arsenate). The PRB is further enhanced by the incorporation of microbial communities to optimize oxyanion oxidation state and enhance the retention of mobile oxyanions. Batch and column sorption experiments with selenium and arsenic oxyanions of both oxidation states are being conducted in the presence and absence of microbial activity.

Materials and Methods
- Zeolite Preparation
  - Natural Zeolite (NZ)
  - Sodium Pre-treated Zeolite (SPZ)
  - Iron-Modified Zeolite (IMZ)
  - Sodium Pre-treated Iron-Modified Zeolite (SPIMZ)
- Zeolite Characterization

Column Setup

Arsenic Retention

Selenium Retention

Future Work
Future work will include column experiments in the presence of microbes to investigate their effect on sorption affinity and ability to reduce selenium and oxidize arsenic to maximize oxyanion retention by iron-modified zeolites.

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Microbiologically Induced Desaturation and Precipitation (MIDP) via Denitrification under Centrifugal Loading
Caitlyn Hall, Edward Kavazanjian, Jr., Bruce Rittmann, & Leon van Paassen

Earthquake-Induced Liquefaction Hazards
- Structures are at risk of bearing failure and flow slides by earthquake-induced liquefaction
- Engineering challenge: develop a cost-effective, sustainable solution for existing facilities

MIDP for Liquefaction Mitigation
- Biobased solution: mitigate liquefaction using microbiologically induced desaturation and precipitation (MIDP) via denitrification
- Dampen pore pressure by biogenic gas production
- Precipitate calcium carbonate to improve soil strength, stiffness, and dilatancy

MIDP by Denitrification Soil Improvement Mechanisms
- Biotic processes: denitrification

Centrifuge Experimental Methods
80g 1 m-arm Centrifuge Testing at the Center for Geotechnical Modelling at UC Davis
Objective: Investigate desaturation via denitrification at simulated field depth in bioaugmented sand

Numerical Predictions of Centrifuge Model
Scaling the Soil Model to Centrifuge Prototype

Preliminary 1g Experimental Results
- After 48 hours: 8-10% desaturation by liquid volume displaced
- After 60 hours: Desaturation reduced p-wave reception, no precipitation visible
One treatment flush has the potential to reach adequate degree of desaturation for liquefaction mitigation at 1 g

Future Work
- Develop predictive biogeochemical model of reactant consumption and product generation
- Run 8 centrifuge trials with different sand grain sizes and relative densities

Acknowledgments
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EICP Treatment of Soil by Using Urease Enzyme Extracted from Watermelon Seeds

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1Graduate Research Assistant (E-mail: njavadi@asu.edu), 2Post-Doctoral, 3Professor, Assistant Professor, Arizona State University

Introduction

- In Enzyme Induced Carbonate Precipitation (EICP), free urease enzyme is used to precipitate carbonate minerals and improve soil properties.
- Free urease enzyme is only available at reagent grade and is expensive.

Research Motivation

- Need to lower the cost of free urease.
- Extraction from urease-rich agricultural wastes may offer a cost-effective and sustainable solution.

Objective

- Extract urease enzyme from watermelon seeds for use in EICP for soil improvement.

Materials and Methods

Crude After 1st Acetone Fractionation After 2nd Acetone Fractionation

Soil treatment column

- Spectrometer was used to measure the urease activity.

Results

<table>
<thead>
<tr>
<th></th>
<th>Watermelon seeds</th>
<th>Crude</th>
<th>First fractionation</th>
<th>Second fractionation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our results (U/ml)</td>
<td>242</td>
<td>338</td>
<td>611</td>
<td></td>
</tr>
<tr>
<td>Literature (U/ml)</td>
<td>180</td>
<td>542.8</td>
<td>1040</td>
<td></td>
</tr>
</tbody>
</table>

(Prakash and Upadhyay 2003)

SDS_PAGE data representing protein bands in (a) watermelon seeds crude extract, (b), after first acetone fractionation, (c) after second acetone fractionation, and (d) type III Jack bean urease from Sigma

EDX analysis of the specified zone on the particle from the treated soil.

Conclusions

A simple method of blending, filtration, and acetone fractionation can be applied to extract and purify urease from watermelon seeds and used to induce carbonate precipitation in soil

Acknowledgment

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Impact of microbial motility on subsurface flows
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Introduction
- The overall project objective is to understand the functional diversity of microbial communities at 1-2 km subsurface and their effects on interfacial interactions, multiphase flow processes, and biogeochemical properties of geomaterials at elevated pressure and temperature conditions.
- This study in particular is to investigate the impact of microbial motility on subsurface flows.
- This study presents the growth characteristics of Escherichia coli (E. coli) under various temperature and pressure conditions, and also investigates the decrease in fluid viscosity due to the presence of E. coli.

Materials and Methods
- Growth of E. coli at subsurface condition
- Fluid viscosity measurement

Results and Discussions
- Growth of E. coli at subsurface condition
- Preliminary test for viscosity measurement

Summary and Future study
- E. coli grows faster at the optimum condition of 37°C and 1 atm, but still shows activity under outer range of temperature and pressure.
- Preliminary study for the viscosity measurement shows constant pressure at each shear rate, however, the results could not make confident viscosity value.
- Case studies of viscosity measurement experiment with various conditions need to be conducted, and way to consider subsurface condition in viscosity measurement need to be considered.
- This project is critically relevant to geological carbon sequestration, enhanced geothermal systems, and subsurface hydrocarbon recovery, and is expected to provide a mechanistic understanding of how bacterial motility impacts fluid viscosity at subsurface conditions.

Growth of E. coli at subsurface condition

Fluid viscosity measurement

Hagen-Poiseuille equation

\[ \Delta P = \frac{8\mu L Q}{\pi R^4} \]

\( \mu \): fluid dynamic viscosity
\( L \): pipe length
\( Q \): flow rate
\( R \): pipe radius

Experimental conditions
- Supernatants: nutrient medium, buffered solution, deionized water
- Bacterial concentration
- Shear rate

Preliminary test for viscosity measurement

- Supernatants: buffered solution (phosphate buffer saline 1X)
- No bacterial injection
- Shear rate: 2.83 sec\(^{-1}\) (500 µL/hr flux), 1.13 sec\(^{-1}\) (200 µL/hr flux)
- Tube length and radium: 30 cm / 0.03125 in
- Initial pressure with vacant tube: 0.1246 inH\(_2\)O

Fig 4. preliminary test result of viscosity measurement at shear rate of 2.83 and 1.13 sec\(^{-1}\)
Hybrid Bio-Inspired Geoprobe
Sheldon John (M.S. Student), Russell Buehling (U.R. Student-EE); Cyrena Ridgeway (U.R. Student-CE)
Faculty advisor: Dr. Douglas D. Cortes, New Mexico State University

Introduction
Geotechnical in-situ testing is critical for the assessment of subsurface layering and soil properties for civil infrastructure applications. Available test devices sample the ground through straight vertical soundings and require large surface equipment to drive them into the ground. These features limit the ability of geotechnical engineers to collect subsurface information underneath existing infrastructures and in remote inaccessible locations. Using nature as inspiration, specifically plant roots and earthworms, this project seeks to develop a new generation of in-situ test devices capable of overcoming the limitations of available technology while also providing an unprecedented access to underground 3D motion and sensing.

Plant root-inspired propulsion system
The root-inspired propulsion mechanism mimics root growth by continuously depositing a filament near the tip of the probe. Sadeghi et al. (2014) created a plantoid robot capable of transforming the rotational movement of an electrical motor into axial movement though the deposition of a filament near the tip of the robot. Our version of the root-inspired probe is designed with a high torque variable speed electrical motor and a hollow rotating shaft. The shaft serves as a port from the tip to the surface and allows for pressurization and depressurization of the tip. Thus, soft body evolutionary adaptations from the earthworm can be incorporated into the root-inspired propulsion system.

Results
Early tests conducted as part of an REU project over the summer (2017) showed that the pressurization of the balloon can decrease the penetration resistance of the cone. As the balloon inflates, vertical force chains are bent away from the cone tip. This arching of forces is expected to decrease the effective stress near the tip of the cone and reduce the penetration force necessary to advance the probe. The research team is currently exploring the effects of balloon size, shape, pressure, and distance from the tip on the penetration resistance.

Acknowledgement:
This material is based upon work primarily supported by the National Science Foundation (NSF) under NSF Award Number EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s), and do not necessarily reflect those of the NSF.

Reference:
Production of complex organic compounds and hydrogen via microbial metabolic chain elongation (MCE) in soils

Sayalee M. Joshi1,2, Samuel Aguiar1, Aide Robles2,3, Anca G. Delgado2,3

1School for Engineering of Matter, Transport and Energy; 2Biodesign Swette Center for Environmental Biotechnology; 3School of Sustainable Engineering and the Built Environment

Background and Objectives
Microbial metabolic chain elongation (MCE) is a process through which microorganisms grow and obtain energy from converting simple substrates like acetate, ethanol, or other C2/C3 compounds into larger fatty acids, such as hexanoate or octanoate:

Ex. Reaction: \( \text{CH}_3\text{COO}^- + 3\text{CH}_3\text{CH}_2\text{OH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{COO}^- + 3\text{H}_2\text{O} \)

The concept of MCE has not been discussed as a major contributor of organics in soils and has not been considered as a possible pathway affecting soil bioremediation approaches. The objectives of the project are (i) to assess the extent and ubiquity of MCE, (ii) to understand the fundamental mechanism behind the MCE pathway, (iii) to explore and enrich microbial communities responsible to MCE and to isolate chain elongators, and (iv) explore MCE for remediation of oxidized contaminants.

Materials and Methods
Experiments were performed in soil microcosms (25 g soil and 75 mL reduced anaerobic, buffered, mineral medium).

Substrates tested in semi batch cycles:
- 100 mM Acetate (C2) + 100 mM Ethanol (C2)
- 100 mM Acetate (C2) + 88 mM Hydrogen
- 100 mM Ethanol (C2) + 88 mM Hydrogen
- 100 mM Ethanol (C2)

Serial dilution for isolation of chain-elongating microorganisms

Chemical analyses:
- Fatty acids and alcohols were analyzed on the high pressure/performance liquid chromatography (HPLC)
- Hydrogen gas on Gas chromatography with a thermal conductivity detector (GC TCD).
- DNA analysis by Illumina Miseq.

Ongoing and future work
- Analyzing different substrate combinations (methanol, propionate) to get off numbered (C5) valerate, (C7) heptanoate fatty acids and various experimental conditions.
- Performing serial dilution and agar plating of enriched microbial cultures to obtain isolates performing MCE.
- Determining favorable microbial growth conditions and MCE reaction kinetics under continuous flow-through conditions, simulating conditions similar to in-situ.
- Testing bioremediation processes that involve organic and inorganic carbon.

Key Findings
- MCE is an ubiquitous process in soil.
- Products included fatty acids, butyrate (C4), caproate (C6), butanol (C4 alcohol), and hydrogen gas.
- MCE shows potential as a novel remediation of oxidized contaminants in the soil and groundwater.
Precipitation of calcium carbonate via urea hydrolysis process in soil pores
- CaCl₂, urea and a source of urease enzyme (microorganisms or free urease) are introduced into soil
- Enzymatic and Microbially Induced Carbonate Precipitation (EICP & MICP)
- Precipitation can result in particle binding, particle surface roughening, and pore filling
- Improvement in mechanical properties

Quality of Precipitation
- Morphology
- Agglomeration
- Location

Does precipitation quality change at different conditions?
Does different precipitation quality influence mechanical properties of the treated soil?

Variation in Quality of Precipitation
Granular vs. needle shape precipitates under naked eyes

Effect of Precipitation Quality on Mechanical Properties
- Bigger ΔVs /CaCO₃ % in MICP-treated sand at lower precipitation rate
- Higher strength at less amount of precipitation when precipitation occurs mainly at contact point

Conclusion
Mineralogical considerations should be included when mechanical properties of biologically cemented sand is investigated.

Acknowledgement
Work described herein was supported by the National Science Foundation Geomechanics and Geosystems Engineering and Engineering Research Center programs under grants numbered CMMI-0850182 and ERC-1449501. The authors are grateful for this support. Any opinions or positions expressed in this article are the authors only, and do not reflect any opinions or positions of the NSF.
Pore-scale Investigation of Biogenic Gas Distribution:
The Effect of Gas Production Rate

Daehyun Kim       Caitlyn Hall       Nariman Mahabadi       Advisor: Leon van Paassen

Overall Research Goals

- Investigation of the biogenic gas production in porous media through denitrifying microbial activity
- Objective of these microfluidic chip experiments is to evaluate how the gas production rate affects the gas distribution

Experimental Details

- Micromodel
  - Artificial microfluidic chip simulating homogeneous porous media
  - Including 377 of circular grains with diameter of 800μm
  - Pore throat size: 40μm ~ 140μm

- Experimental Setting Up
  - Designed for optical observation of phases changes in the micromodel

Preliminary Research - CO₂ Gas Production

- Testing Procedure
  - CO₂ gas is dissolved into water under the pressure
  - Solution of dissolved CO₂ gas is injected into the micromodel
  - CO₂ gas is generated by pressure release at two different rates

- Results
  - Case 1: Fast pressure release: -600 kPa/min
  - Nucleation throughout the system and high final gas saturation

- Case 2: Slow pressure release: -10 kPa/min
  - Limited nucleation points, but fully displacement of the liquid phase

Biogenic Gas Production via Denitrification

- Testing Procedure
  - Substrate solution with denitrifying bacterial is injected into the micromodel
  - Biogenic gas (N₂) production via bacterial activity is monitored

- Biogenic Gas Production
  - Degree of Saturation over Time as Gas Bubble Forms

- Extracted Gas Phase by Image Processing

Conclusions

Biogenic gas production through denitrification is relatively slow. The rate of gas production affects the nucleation, migration, distribution and final saturation of the gas phase.

Acknowledgement

This material is based upon work supported in part by the National Science Foundation (NSF) under NSF CA No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the NSF.
Upscaled Modeling of Microbially Induced Calcite Precipitation: Developing a Constitutive Model for Treated Sands

Maya El Kortbawi, University of California, Davis
Advisors: Katerina Ziotopoulou and Jason T. DeJong

PROJECT OVERVIEW (COMMENCED 08/2017)

Problem Statement: Treatment of loose sands by means of microbially induced calcite precipitation (MICP) has been shown to improve their liquefaction susceptibility by increasing their resistance to liquefaction. A broad range of lab testing data provide evidence of this behavior as well as information on the response of MICP treated sands post-triggering (e.g., shear strain of 3% for a strain-based liquefaction criterion). In the micro-scale, when MICP treated soils are cyclically loaded (e.g., earthquakes) they experience a progressive collapse of the cementation bonds that developed during the treatment process. In the macro-scale, the damage accumulated post-triggering is experienced as lateral deformations of level or sloping ground deposits, or post-shaking reconsolidation strains than in turn greatly affect infrastructure. To date, we understand how MICP affects the strength and deformation characteristics of sands, but we are lacking a quantitative predictive framework for the mechanical response of such materials, that will allow for better design and prediction of their behavior in the field.

Objectives: To develop a constitutive model for MICP-treated (biocemented) sands that can incorporate the effects of cementation and the cyclic response and associated deformations into finite element/difference modeling of geotechnical systems, and perform numerical simulations of centrifuge tests and future field trials. The overall objective is to take the critical steps necessary for field deployment in the near future. These results will be applicable to both biocemented as well as naturally cemented and aged soils, the latter of which is challenging to characterize in practice.

METHODS AND SYNERGY

This project will utilize the extensive testing data available from other projects within CBBG, to understand the response of MICP treated soils (stiffness degradation as cementation bonds are disrupted, constant stress-ratio induced damage) in order to formulate and implement developments in the framework...

BASELINE FRAMEWORK: PM4SAND V3 (BOULANGER AND ZIOTOPOULOU 2015)

It follows the basic framework of the critical-state compatible, stress-ratio controlled, bounding surface plasticity model of Dafalias & Manzari (2004). The bounding surface plasticity framework is adopted for the constitutive modeling of MICP treated sands: a well-established constitutive framework, capable of capturing the effects of cyclic loading & associated development of plastic strains and damage accumulation in granular materials. Most notably, when incorporating the effects of fabric (Dafalias and Manzari 2004, Boulanger and Ziotopoulou 2015), the framework is capable of capturing the progressive damage accumulation as well as the variable contractiveness and dilatancy of liquefiable sands.

Candidate Developments:
1. Greater elastic range
2. Bounding surface accounting for cohesion
3. CSL that accounts for material degradation
4. Plastic modulus degradation
5. Fabric tracking damage
6. Adding cap to account for breakage
Introduction
Microbially induced calcite precipitation (MICP) is an environmentally friendly ground improvement technique that has been actively studied for over a decade. The formation of calcite (CaCO₃), driven by urea hydrolysis in the pore space/grain contact of coarse-grained soils, increases strength and stiffness, and decreases the hydraulic conductivity of soils. However, several issues remain in the long-term application of MICP, including supplying oxygen, temperature- and pressure-dependent ureolytic activity, and ensuring uniform calcite precipitation throughout the target treatment zone. Precipitation of calcite from solution is driven in large part by nucleation mechanics, which is primarily bio-mediated heterogeneous nucleation at sites on the surface of soils or adhered bacteria surface (De Jong et al. 2006). Therefore, it is hypothesized that an increase in the number of nucleation sites may effectively increase the rate of calcite deposition, the uniformity of calcite formation throughout the coarse medium, and the total amount of calcite deposition, even though the process does not increase urease activity.

Colloidal Facilitation of Microbial Induced Calcite Precipitation
Junghwoon Lee, Jong Muk Won, Susan Burns
School of Civil and Environmental Engineering, Georgia Institute of Technology

Colloidal Particles
- Range from ~1 nm to 10 μm
- Can be suspended due to electrical forces and are mobile in porous media
- Clay colloids are inorganic colloids (<2 μm)
- Can deposit in or transport through porous media, depending on geochemistry of the pore fluid
- Polydispersed, aggregate, sensitive to surface charge

MICP Tests in Sand/Silt Mixtures
Preliminary tests: sand (100%) versus sand (80%)/silt (20%)
- Soil mixture percentages by volume
- Increased shear wave velocity when silt is present as a component in the soil mixture
- True for biotic and abiotic experiments
- Impact of ageing and fine-grained deposition to be quantified

Colloid Transport
Retention profile and hydraulic conductivity as a function of colloidal aggregation, straining, and deposition
- Colloids can play a role as possible nucleation between sand particle contacts
- Challenges include distribution of colloids as a function of geochemistry, and selection of optimal colloidal size, shape, and type

Work Plan
- Soil-column tests to quantify impact of solution chemistry on transport / retention behavior of colloidal and bacterial transport
- Soil-column tests to study the impact of injection of colloidal suspensions on the uniformity of calcite precipitation
- Qualitative microscale analysis using SEM to provide the spatial distribution of calcite at the grain scale
- Quantitative TOC analysis to provide the spatial distribution of calcite at the macroscale
Desaturation via Biogenic Gas Formation and Migration: Micro and Mesoscale Experiments

Nariman Mahabadi, Caitlyn Hall, Leon van Paassen

Introduction
Desaturation by biogenic gas production has potential to be used as a ground improvement method to mitigate earthquake-induced liquefaction. Even a small amount of gas bubbles is sufficient to reduce pore fluid bulk stiffness and increase the cyclic resistance of the soil. However, soil heterogeneity may affect the distribution of the gas, and the consequent hydro-mechanical response when exposed to cyclic loading. In this study micro and mesoscale experiments were performed to investigate the behavior of gas bubbles during formation, and migration in soils. The results show that the biogenic gas production rate and pore scale characteristics of the soil significantly affect the distribution and migration patterns of biogenic gas bubbles.

Microscale Experiment
- Microfluidic Chip is used to visualize gas bubble formation and migration in pore space (pore size =285 µm, throat size=140 µm)
- Efferdent (sodium perborate) and cold water is injected into the microchip to generate micro-size oxygen gas bubbles
- Different gas bubble migration mechanisms were detected:
  - Nucleation and Expansion
  - Movement (Biggest Tubes)
  - Movement (Blocked Tubes)
  - Separation (Snap off)
  - Snake Movement
  - Bubble Merging
  - Pushing

Mesoscale Experiment
- A transparent acrylic chamber (25 cm x 25 cm x 1 cm) was filled with Ottawa-2030 and F60 sands
- The substrate solution containing denitrifying bacteria was injected into the cell
- Gas was formed at the base and gradually migrated upward
- Fine grained sand inclusions act as a capillary barriers blocking upward migration of the gas
- The degree of saturation was determined by measuring the volume of expelled liquid:

<table>
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<th>Day</th>
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<th>S=99.5%</th>
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<th>S=94.1%</th>
<th>S=91.5%</th>
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</tbody>
</table>

Conclusion
The biogenic gas production rate, soil heterogeneity and pore scale characteristics of the soil such as pore size and connectivity significantly affect the distribution, expansion and migration patterns of biogenic gas bubbles in porous media.

Future Plan
- Investigation in Hydro-mechanical effects of gas production
- Effect of biogenic gas production rate on gas distribution
- Effect of Temperature-Pressure conditions on gas distribution
- Validate the results with pore scale numerical simulations
- Pressure measurement during the test

Acknowledgment: This material is based upon work supported in part by the National Science Foundation (NSF) under NSF CA No. EEC-1449591. Any opinions, findings and conclusions expressed in this material are those of the author(s) and do not necessarily reflect those of the NSF.
Abstract

Fibrous root system-inspired anchors incorporate the uplift anchorage properties of the root systems of monocotyledons (e.g., grains and grasses) into conventional anchor elements, such as tiebacks, soil nails, and anchor piles. For this research, the role of root system geometry and soil conditions on the pullout behavior, namely the pullout capacity, displacement at the maximum force, and secant pullout stiffness, is investigated experimentally. Additionally, the results serve as a means to calibrate a numerical model for the further study of the root, soil, and root-soil interface properties affecting pullout behavior.

Fibrous Root Systems

Definition: group of roots branching from a single point near the stem

Study Selection: architecture thought to contain evidence of adaptive traits and plastic responses to improve anchorage resistance to uplift forces

Fibrous Root System Analogs

Analogs are created as representative models of fibrous root systems. Thereby, consistent, and complete control of the properties of root system analogs is achieved, which allows for more robust insight into pullout behavior. 2 types of analogs are used in the 1st round of testing:

1) 3D Printed Models, fabricated from ABS plastic. The geometric properties are varied.
2) Unwound Polyethylene Rope. The topological branching order and depth are varied.

Experimental Equipment and Procedure

Loading Device
- Displacement rate controlled load frame
- 3 jaw chuck attachment grip

Instrumentation
- Load cell to measure force
- LVDT to measure displacement
- Data Acquisition and power supply to obtain readings and provide excitation voltage, respectively

Procedure
- Attach analog to 3 jaw chuck
- At a zero elevation step, fill soil box with F110 sand
- Tap soil box with mallet to achieve desired
- At a displacement rate of 10mm/min, lift analog from soil

Data Analysis: Pullout Tests

Root Geometry Factors
Effect of Depth

Effect of Branch Length

Effect of Number of Branches

Effect of Branching Order

Soil Factors
Effect of Relative Density

Results and Conclusions

- Larger pullout capacity values are to be expected with increased depth, number of branches, topological order, and to a lesser extent, branch length.
- Displacement at pullout capacity and the secant pullout stiffness is critical for strain/displacement capability in the design of anchors; the trends, while not remarkably clear, suggest that stiffer analog possess more and shorter branches.
- Larger displacements occur before maximum pullout capacity is reached at greater depths, and for analogs with longer and fewer branches.

Numerical Modelling

A numerical model of root analog pullout is implemented in FLAC3D, a 3D finite difference software. After initial calibration with experimental pullout data, a host of parametric studies are performed to further validate and extend the experimental results of the factors affecting root analog pullout behavior.
Enzyme-Induced Carbonate Precipitation (EICP): Bio-cemented Soil Columns

Kimberly Martin, PE; Rachel Adam; Dion Shurley; Dr. Edward Kavazanjian, Jr, PhD, PE, GE, D.GE, NAE

Objective
- Construct bio-cemented columns for ground improvement using EICP

Motivation
- Provide non-disruptive ground improvement
- Reduce Portland cement consumption

Current Research
- Use laboratory tank tests to:
  - Determine if un-enhanced EICP solution is sufficient to control treatment zone
  - Evaluate benefits of enhanced viscosity of EICP solution in laboratory tank tests

Methods
- General approach (Figs. 1-2)
  - Fluviate soil into tank until depth (152mm) of injection tube is reached
  - Place injection tube into soil
  - Fluviate top of tank
  - Mix EICP solution and inject within two minutes of mixing
  - Extract column after 24 hours and test qualitatively for strength
- Viscosity Enhancement Trial (Fig. 3)
  - Measure viscosity-enhanced EICP solution flow rate through soil for:
    - Various concentrations of xanthan
    - Various time delays of application after mixing
  - Determine optimum concentration based on injection rate, gel time, and cementation time

Results
- Viscosity enhancement required
- Un-enhanced EICP solution drained out of targeted treatment zone (Fig. 4)
- Enhanced EICP solution cemented a treatment zone consistent with targeted zone and at sufficient strength (Fig. 5)

Next Steps
- Test in saturated condition
- Test finer-grained sand
**Combined Biotic and Abiotic Reduction of Trichloroethene and Perchlorate**

Srivatsan Mohana Rangan,¹ Anca G. Delgado,¹ Rosa Krajmalnik-Brown,**¹

¹School of Sustainable Engineering & the Built Environment, Arizona State University, Tempe, AZ, United States

**Objectives**

- Utilize Zero-Valent Iron (ZVI) to induce anaerobic conditions for bioremediations of contaminants: Trichloroethene (TCE) and Perchlorate (ClO₄⁻).
- The challenges of combined abiotic reduction by ZVI and microbial reduction of TCE and ClO₄⁻ for remediation of aquifers are not well understood.

**Methods**

**Results & Findings: Simulated Injection Zone Conditions: ZVI microcosms**

- Bench scale semi-batch microcosms with soil and groundwater - Superfund site aquifer materials.
- Conditions representing an injection zone of ZVI and a downstream zone containing Fe(II) derived from ZVI oxidation.
- Microcosms – 25 g soil, 75 mL groundwater + amendments
- Amendments: Lactate/EVO, Phosphate, Yeast extract
- Microbial cultures containing Dehalococcoides mccartyi – Z A R A -10 (from ASU) and SDC-9 (commercially available)

**Microcosms**

- Rapid dechlorination of TCE to ethene & ethane by ZVI made TCE unavailable for dechlorinating bacteria
- ZVI inhibited perchlorate reducing bacteria
- H₂ generated by ZVI enriched methanogenesis and sulfate reduction in the presence of bioaugmentation cultures
- High concentration of ZVI (16.5 g/L) inhibits dechlorinating bacteria and perchlorate reducing bacteria enriching competing H₂ consuming processes

**Simulated Downstream Zone Conditions: Fe(II) microcosms**

- In the presence of Fe(II), bioaugmentation cultures showed incomplete TCE dechlorination with accumulation of cis-DCE and VC (TCE dechlorination daughter products) after 56 days.
- perchlorate reduction rate was faster in the absence of additional iron species
- In the absence of additional iron species (ZVI or Fe(II)), complete TCE dechlorination to benign product ethene was observed.

**Conclusions**

- Anaerobic conditions were achieved using ZVI
- ZVI inhibited microbial reduction of TCE and perchlorate reduction.
- Fe(II) released due to ZVI oxidation lead to incomplete TCE reduction and accumulation of toxic TCE daughter products.
Influence of Steady State Pore Pressure on Biogas Desaturation

Juan Paez, M.S. Student
Edward Kavazanjian, Research advisor
Arizona State University

Introduction
- Soil Liquefaction induced by earthquakes is a serious geologic hazard
- Current methods of mitigating liquefaction under existing facilities are expensive and difficult to implement
- Microbially induced desaturation and precipitation (MIDP) appears to be a promising alternative.
- Desaturation can be induced by biogas generation via denitrification.

Objective
- Understand the effects of steady state pore pressure on biogas desaturation

Method
- Soil Columns are prepared in triaxial cells using Ottawa 20-30 crystal silica sand.
- Columns are saturated with a denitrifying microbial solution.
- Initial back pressure 20 kpa with cell pressure of 70 kpa.
  - Desaturation monitored based upon expelled fluid
- Pore and cell pressure will be increased by 50 kpa
- Fluid pushed back into specimen will be measured.

Results

Conclusion
- The project is in preliminary stages
- Will also investigate effect of steady state pore pressure on initial desaturation rate, amount

Acknowledgement
This material is based upon work supported by the National Science Foundation (NSF) under NSF CA No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the NSF.
Snakeskin-Inspired Anisotropic Surfaces: Prescribing Frictioal Interactions at Soil-Structure Interfaces

Sophia Palumbo, M.S. Student, UC Davis
Advisor: Alejandro Martinez

Motivation

Applying geometric principles of snakeskin, this research seeks to develop multifunctional systems with anisotropic surfaces. This development has important implications on infrastructure elements loaded in opposing directions during installation and service life.

Background

The frictional interactions between the underbody scales of snakeskin (i.e. ventral scales) and soils are dictated by their surface roughness and other geometrical attributes. Ventral scales mobilize high frictional resistances when soil is sheared against them (i.e. cranial direction) in order to generate reaction for locomotion. On the other hand, a smaller frictional resistance is mobilized when soil is sheared along them (i.e. caudal direction) in order to minimize friction during forward movement.

Results: Direct Interface Shear

- Two-way cyclic shear tests with specimens of target Dv = 80% under an effective stress of 75 kPa
- Shearing surface geometries consist of one of three ventral profile geometries (Table 1)
- Surface asperities, or “scales” varied in scale height, length, and angles

![Figure 5: Experimental workflow](image)

Table 1. Average roughness (R̄), maximum roughness (R̄), and schematics of tested profiles with an average scale height of 0.3 mm and scale length of 12 mm

<table>
<thead>
<tr>
<th>Surface</th>
<th>R̄ (μm)</th>
<th>R̄ (μm)</th>
<th>Profile Schematic</th>
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<tr>
<td>Profile 2</td>
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<tr>
<td>Profile 3</td>
<td>91</td>
<td>425</td>
<td><img src="image" alt="Profile 3" /></td>
</tr>
</tbody>
</table>

![Figure 6: Profile 3 shear-stress displacement plot (a), and vertical displacement (b)](image)

![Figure 7: Profile 3 residual shear stresses for constant length, (a), and height (b)](image)

![Figure 8: Normalized residual frictional anisotropy, shearing cranial flow, for surfaces of constant length and height](image)

\[ A_{\text{Res}} = \frac{\tau_{\text{CR}} - \tau_{\text{CC}}}{\tau_{\text{CR}} + \tau_{\text{CC}}} \]

\[ A_{\text{Res}} = \text{normalized residual frictional anisotropy} \]

\[ \tau_{\text{CR}} = \text{residual shear stress, shearing cranial direction} \]

\[ \tau_{\text{CC}} = \text{residual shear stress, shearing caudal direction} \]

![Figure 9: Schematic of interface shear testing configuration](image)

Results: Anisotropic Shear Stress

![Figure 10: Normalized residual frictional anisotropy, shearing cranial flow, for surfaces of constant length and height](image)

Future Work

- Continue cyclic interface shear tests to evaluate geometric features of profiles and boundary conditions that optimize the anisotropic stress response
- Investigate localized soil-structure interface frictional interactions with particle image velocimetry (PIV)
- Scale up interface shear tests via pile load tests with bioinspired snake surface at the UC Davis centrifuge

Acknowledgments

This material is based upon work primarily supported by the Engineering Research Center Program of the National Science Foundation under NSF Cooperative Agreement No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the National Science Foundation.
Root-inspired Vascular System for Pile Foundations

Jose N. Pasillas (M.S. graduate), Jason Alcantar (M.S. student), and Seyed A. Aleali (Ph.D. student)

Faculty Advisors: Dr. Paola Bandini, and Dr. Craig Newton, New Mexico State University

Introduction
Driven pile foundations in granular soils without a strong bearing layer are often designed based on the development of shaft friction resistance. When strong bearing material is deep, the length of the driven pile has to be increased to accommodate the required load capacity because it relies mostly on shaft friction. The nature of reinforced concrete, along with construction and installation techniques, make this type of foundation somewhat expensive. The ultimate goal of this research is to develop cost-effective and sustainable bio-inspired soil improvement and foundation methods. The research team currently focuses on integrating a root-inspired "vascular system" into a pile foundation for improvement of the soil around and below the pile to achieve greater pile capacity in unsaturated sandy soils.

Bio-inspiration
The research seeks to adapt functions of the root system to deep foundations for the purpose of improving the ground around and/or below the pile and increasing pile capacity. The biological analog is the vascular system of plants, which is composed of tubular-type tissue (xylem and phloem) (Figures 1 and 2). Roots not only absorb water and nutrients, but also produce and secrete mucigel, which is a hydrated polysaccharide that has vital roles such as:
- preventing the growth of roots from competing plants,
- lubricating the root so that it can easily penetrate the soil,
- increasing soil-root contact to aid water and nutrient absorption,
- protecting the root by preventing desiccation,
- aiding the establishment of symbiotic bacteria in the soil that help protect the plant from disease.

Research approach
The research proposes achieving ground improvement around and below the pile tip after pile installation. Increasing the sand strength through soil particle cementation at the pile tip may lead to increasing the pile resistance and, consequently, reducing the required pile length. Potential benefits include savings in terms of concrete volume, and driving time and energy.

Root analog:
Components of vascular pile system:
- Tubular tissue: conduit system to deliver grout or fluids
- Mucigel secretion: Grout or soil improving mechanism
- Pressure flow: Transportation and injection system

Approach to design and test lab-scale proof-of-concept experiment:
- Design and test bench-scale prototype
- Determine feasibility of various gouts and sands
- Identify important variables

Major barriers: constructability, reproducibility, and quality control

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Experimental work - completed
The experimental work completed includes:
- Design and construction of bench-scale test system prototype
- Pressurized injection through vascular system built into the pile
- Assessment of permeation and compaction grouting techniques

| Table 1: Materials used in testing |

<table>
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<th>Material</th>
<th>Mix Design</th>
<th>Saturated Density (kN/m³)</th>
<th>Unconfined compressive strength (kPa)</th>
<th>Application</th>
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</tr>
<tr>
<td>Type of Sand</td>
<td>Mix Design</td>
<td>Saturated Density (kN/m³)</td>
<td>Unconfined compressive strength (kPa)</td>
<td>Application</td>
</tr>
</tbody>
</table>

Figure 1. Vascular system of roots (Source: Gwen Barnett, slideplayer.com)

Figure 2. Stained cross section of root tip (Source: slideplayer.com)

Figure 3. Cementation of sands: A) Ottawa 20/30 sand (OS1), B) Stucco sand (SS), C) Concrete sand (CS)

Figure 4. Unconfined compression of EICP-treated OS1 columns

Figure 4. Excavation sequence of EICP-treated elements in test box

Experimental work - ongoing
- Assessment of EICP feasibility for permeation grouting in local sands (Figure 5)
- Development of delivery mechanisms

Future work
- Continue benchtop scale testing
- Provide working prototype as a proof-of-concept
- Modify setup for field-scale prototype
- Based on bench-scale results, design a small-scale pilot test and seek industrial partner collaboration
- Work on other bio-inspired concepts
- Collaborate with expert in plant physiology
Design and calibrate a pressure controlled and a displacement controlled prototype of bio-inspired probes capable to measure anisotropic stress states and stiffness and strength parameters of the soil (G, ν, ϕ, ψ).

Natural systems perform tunneling with outstanding efficiency by adapting continuously to the local stress state, deforming the soil mass; thus integrating design and construction. We will test two different approaches, inspired by:

**Roots:** which grow by expanding radially depressurizing the tip, and pushing forward.

- Pressure controlled.

**Earthworms:** which burrow by contracting longitudinally their segments while keeping their volume constant, thus increasing their diameter.

- Displacement controlled.

**Goal**

Design a bio-inspired probe capable of measuring in real time the stress state and the mechanical properties of granular soils before and/or during tunnel construction.

**Fundamental Knowledge**

Cavity expansion theory in anisotropic, drained conditions. Pressure and displacement controlled. Validation by finite elements method and CT scanning to measure soil response.

**Bio-Inspiration**

**Enabling technology**

Design and calibrate a pressure controlled and a displacement controlled prototype of bio-inspired probes capable to measure anisotropic stress states and stiffness and strength parameters of the soil (G, ν, ϕ, ψ).

**System Integration**

Physical scale modeling of prototypes, recreating stress state and dimensions using centrifuge testing. Development of software and controllers for the autonomous operation of the device.

Potential large scale testing in partnership with industry.
Life Cycle Sustainability Assessment of Geotechnical Systems

Advisors: Alissa Kendall & Jason T. DeLong

Motivation
Geotechnical infrastructure projects consume large quantities of energy and resources, and can have significant impacts on the environment.
- Missed opportunity to reduce environmental impacts at low cost in the planning stage of a project or in the research and development stage of new technologies.
- Goal: To develop a robust methodology to encourage efforts to optimize geotechnical design considering environmental impacts, cost, safety, and performance.

Framework
The sustainability assessment framework includes environmental life cycle assessment (ELCA), life cycle cost analysis (LCCA), and social life cycle assessment (SLCA).
- ELCA characterizes, quantifies, and interprets materials and energy flows in, and emissions and waste flows out of a defined system over its entire life cycle (from "cradle-to-grave").
- LCCA evaluates all relevant costs associated with the system over the equivalent defined boundary and life cycle.
- SLCA analyzes the life cycle social impacts to key stakeholders. However, social indicators are less developed and not widely used.

Background
A critical literature review was performed to investigate the state-of-the-practice for life cycle-based environmental assessments of geotechnical systems. Studies were evaluated in a parametric analysis against standardized ELCA methods.

Real Project Application
Five ground improvement methods were considered for the measure island redevelopment project:
- Deep soil mixing (DSM)
- Vibro replacement (VR)
- Vibro compaction (VC)
- Deep dynamic compaction (DDC)
- Earthquake drains (EED)

Methods:
- Functional unit: 25,000 m³ of soil.
- Performance criterion: UCS of 1 – 2.5 MPa for liquefaction mitigation.
- Equipment/vehicle use estimates and anticipated project costs provided by Haywark Baker.

Sensitivity Analysis:
- To evaluate the assumptions regarding materials selection and transport distances.
- (a) Global Warming Potential for DSM
- (b) Global Warming Potential for VC
- (c) Global Warming Potential for VR
- (d) Global Warming Potential for DDC
- (e) Global Warming Potential for EED

Technology Development Application
Goals:
- To guide the R&D on microbially induced calcite precipitation (MICP)
- To optimize the MICP bio-cementation technology for field deployment considering environmental impacts.
- To compare the environmental impacts of MICP to those of similar conventional ground improvement methods.

Methods:
- Functional unit: 1 m³ of soil.
- Performance criterion: UCS of 1 – 2.5 MPa for liquefaction mitigation.
- System boundary: preliminary LCA focuses on impacts from materials used only.
- Conventional technologies: jet and chemical grouting.

Results:
- Relative contributions of calcium chloride and water to total impacts are substantial.
- Uncertainty of MICP material quantities is significant to impacts.
- Importance of evaluating a suite of environmental impacts.

Research Plans for Year 3
- UC LCA Questionnaire and Evaluation Statement for all CBBG projects
- Continued development of streamlined quantitative ELCA model for projects
- Collaboration with industry to develop benchmarks for conventional technologies
- Collection of damage cost estimates for pollutants of interest
- Critical literature review on environmental sustainability indicators
- Continued development of MICP ELCA model and evaluation of waste product scenarios for treatment

Acknowledgements
Funding is provided by the National Science Foundation and the Center for Bio-mediated Bio-inspired Geotechnics.
Abstract

Bioreactor landfills are a proven strategy to enhance biomethanation within solid waste. However, this strategy can be limited by both biogeotechnical and economic constraints. Here, we sought to exploit anaerobic corrosion of an elemental metal (e.g. manganese, or Mn⁰), which was augmented to non-methanogenic solid waste microcosms. We demonstrate that in appropriate dosages of exogenous Mn⁰, excess molecular hydrogen (H₂) can be produced as a byproduct of Mn⁰ oxidation and act as a substrate in microbial metabolism, favoring enhanced methanogenesis.

Results

Conclusions/Future Directions

Methods

- Headspace gas from MSW microcosms was upgraded "in situ" utilizing H₂ generated from anaerobic oxidation of Mn⁰ (Fig. 2a, Fig. 3, Fig. 4, Fig. 6)
- Acetoclastic methanogenesis was overtaken by hydrogenotrophic methanogenesis as the predominant methanogenesis pathway, as evidenced through ¹³C stable isotopic variation (Fig. 7)
- Enhancement of biomethanation likely also attributed to circumneutral pH development (Fig. 2b, Fig. 4)
- [Low] and [Mid] treatments' manganous (Mn²⁺) stability relative to the [High] reveals pH control is dominant Mn⁰ oxidation byproducts (Fig. 5)
Abstract
Harvester ants' nest structure
Chambers' interaction
Conclusion Remarks
References

Harvester ants' nest structure

According to Tschinkel (2004), a nest has two main components: "descending shafts" and "horizontal chambers". Chamber heights and shaft widths are fairly constant around 1 to 2 cm and are independent of the chamber area.

Chambers' interaction

The color-coded results below show the normalized displacement of particles after creating elliptical and rectangular cavities inside a container including 100,000 particles ranging from 1 to 2 mm. DEM simulations were performed using PFC Suite Version 5.0 software, and pre- and post-analysis studies were performed using MATLAB.

Conclusion Remarks

- Chamber geometry plays a key role in the stability of chambers.
- Chamber interactions were examined at the particle level using discrete element modeling.
- Depth and height of chambers are defined based on actual "class 0" nest and used in simulation.
- Rectangular and elliptical chambers were compared with each other and shown that elliptical chambers provide more stable structure than rectangular ones.
- The color-coded results show normal force magnitude and angle, respectively, for elliptical and rectangular chambers. Normal force chains are shown in the intuitive polar plots considering two different regions around the chambers.

References

Background

Microbially Induced Calcite Precipitation (MICP) is an environmentally-conscious and economically-promising alternative to traditional ground improvement techniques, which oftentimes use high mechanical energy and energy-intensive materials. The biogeochemical process is made possible by ureolytic bacteria which hydrolyze urea to produce carbonate and ammonium. If this is completed in the presence of calcium, calcium carbonate can be precipitated thereby coating and bonding soil particles.

MICP reactions that ranged from calcium to ammonium centered on the ureolytic bacteria which hydrolyze urea to produce carbonate and ammonium. If this is completed in the presence of calcium, calcium carbonate can be precipitated thereby coating and bonding soil particles. The process is made possible by ureolytic bacteria which hydrolyze urea to produce carbonate and ammonium.

Experimental Set-Up

Five identical soil columns were prepared with Concrete Sand and treated with solutions containing urea to calcium ratios of 1:5.1, 1:2.5, 1:3, 1:3.75:1, 1:5.1:1, 1:7.5:1:5.1:1, 1:10:1. These formulas resulted in MICP reactions that ranged from calcium to ammonium.

Experimental Set-Up

Five identical soil columns were prepared with Concrete Sand and treated with solutions containing urea to calcium ratios of 1:5.1, 1:2.5, 1:3, 1:3.75:1, 1:5.1:1, 1:7.5:1:5.1:1, 1:10:1. These formulas resulted in MICP reactions that ranged from calcium to ammonium.

Results

Experiment 1: Solution pH adjustment to 9.0 was attempted to limit changes in microbial communities. However, pH and calcite data suggests lower ureolysis than observed in previous experiments, especially in carbonate limited columns. A possible explanation is the absence of daily pH fluctuations from 7.5 to 9.0 and limited ammonia and hydroxide production. Further investigation of the effect of changes in reaction chemistry on ureolytic activity and stimulated microbial communities should be performed.

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Experiment 2: We attempted to look at differences between ureolytic isolates with large differences in cell-specific enzyme kinetics. However, potential differences in injection concentrations of bacteria, multiple augmentations, and differences in cell affinities for soil particle surfaces resulted in bulk ureolytic activities that did not match anticipated results. Additional investigations are needed to understand the effect of strain specific properties.

Experiment 2: We attempted to look at differences between ureolytic isolates with large differences in cell-specific enzyme kinetics. However, potential differences in injection concentrations of bacteria, multiple augmentations, and differences in cell affinities for soil particle surfaces resulted in bulk ureolytic activities that did not match anticipated results. Additional investigations are needed to understand the effect of strain specific properties.

Conclusions

In Year 3, optimization work will continue and a large-scale bio-cementation experiment will be performed to:

- Demonstrate MICP with lower-impact industry-grade reagents and waste products;
- Achieve uniform improvement at the meter scale;
- Improve our assessment of the life cycle impacts associated with stimulated ureolytic microorganisms;
- Evaluate larger well-to-well spacings to be used in future field-scale applications.

Develop and demonstrate strategies for MICP by-product removal (including NH4+, NO3−, and NO2−).

Acknowledgments

I would like to thank my advisors, Jason T. De Jong and Michael G. Gomez, for their constant support and guidance. I would also like to thank Charles Grady, Gabby Hernandez, and Kazuyuki Hayashi for their help with the above experiments. Lastly, I would like to thank NSF and CBBG for funding this project (EEC 1449501).
Objective:
Development of a transient computational model for the variability of hydraulic properties for granular soils treated with denitrifying MIDP.

Envisioned Application in Practice:
Predicting hydraulic properties to optimize field application of MIDP.

Project Objectives:
Injection of a solution containing calcium acetate and calcium nitrate inoculated with denitrifying bacteria into a saturated or dry sand to induce production of nitrogen gas and precipitation of calcium carbonate.

Work Tasks:
- Monitoring transient changes in moisture, hydraulic conductivity, carbonate precipitation, gas production, fluid viscosity and suction potential using a large 2D tank set-up.
- Developing computation model to predict fluids flow behavior that account for changing pore scale characteristics of porous media due to carbonate precipitation and internal gas generation in addition to unsaturated fluid flow.

Unsaturated Fluid Flow through Granular Soils Treated with Microbial Induced Desaturation and Precipitation (MIDP)

Elizabeth G. Stallings, M.S., PE, Edward Kavazanjian, Ph.D., PE, Claudia Zapata, Ph.D., Leon van Paassen, Ph.D.

MIDP:

\[
\frac{1}{2.6} Ca(C_2H_3O_2)_2 + \frac{1.6}{2.6} Ca(NO_3)_2 \rightarrow 1CaCO_3 + \frac{1.6}{2.6} N_2 + \frac{1.4}{2.6} CO_2
\]

(van Paassen et al. 2010)

Injection of Microbial Solution and Substrates

This material is based upon work primarily supported by the National Science Foundation (NSF) under NSF Award Number EEC-1449501. Any opinions, findings and conclusions, or recommendations expressed in this material are those of the author(s), and do not necessarily reflect those of the NSF.
Problem: EICP crust is too thin for conventional strength assessment

Solution: Evaluate EICP crust strength using inverse analysis of penetration tests

Approach: Using FLAC™ finite difference code and advanced constitutive model, vary soil properties to match numerical prediction to vertical displacement of the penetration probe

Soil Type: Arizona Mine Tailings (Poorly Graded Silty)

Test Parameters:
- 1.5” deep, 9” diameter pie pan
- EICP crust to be sprayed on soil
- Steel ¼” diameter flat probe
- Constant loading rate: 0.051 mm/min

Initial FLAC™ Inverse Analysis
1. Use elasto-plastic model for sand
2. Use Mohr-Coulomb failure criteria
3. Initial sand properties from lab tests
4. Axi-symmetric numerical model
5. Lateral boundary at closest distance to pan edge
6. Vary soil moduli to get best agreement

Initial Results: No crust

Issues:
- Maximum displacement possible with FLAC™ model limited (probably due to mesh discretization).
- Elasto-plastic model not suitable for crust

Future Work:
- Apply FLAC™ w/ more sophisticated (plastic hardening) constitutive equation to model treated specimens

Acknowledgement
This material is based upon work supported by the National Science Foundation (NSF) under NSF CA No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the NSF.
Geotechnics of Bio-locomotion and Self-excavating Systems (Experimental Work)

Student: Karie Yamamoto
Advisor: Dr. J. David Frost
School of Civil and Environmental Engineering

Abstract
Ants use about 0.1% of the energy used by tunnel boring machines to excavate equivalent volumes of soil. Thus, the excavation behavior of ants and their nests provide inspiration when studying tunnel stability and subsurface excavation methods. This paper presents an experimental study of the excavation behavior of ants and the effect of particle size on the nest structure and stability of the nests.

Background & Energy Comparison
Studying the excavation behavior and nest structures of ants provides an interesting opportunity to apply the solution-driven approach to bio-innovation from a geotechnical engineering perspective. The authors are interested in the process of discovering energy efficient methods or techniques for tunneling through soils.

Ant Excavation Behavior
Ants use about 0.1% of the energy used by the most efficient tunnel boring machine as seen in the table. These digging techniques are utilized differently when the particle size differs. Large particles involve a pulling mode where ants grasp the particle in their mandible and pull it out from the rest of the substrate. For small particles, the particles can be compressed in a pellet and then carried away.

Experimental Setup
The 2-Dimensional experiments take place in an acrylic chamber where the lower half is filled with a substrate and the upper half allows space for the ants to deposit the excavated substrate. The configurations of substrates are comprised of F110 and OS 20/30 mix and in various layers in a binary mix.

Thrust: Cross-Cutting
Use Case: Tunneling and Subsurface Excavation
Stage: Fundamental Knowledge

Conclusion Remarks
- Based on the initial tests with the homogeneous substrate, the effort to excavate the smaller particles is less than to excavate the larger particles because larger pellets can be formed for removal.
- Observe the effect of the different substrates on the geometry of the tunnel structure.
- Use MATLAB to find the distance between the chambers and the length of tunnels.
- Connect the results from the experiments to the numerical simulations of tunnel stability.

References
DEM Simulations of the Mechanical Behavior of Bio-cemented Sands

Pu Yang, Ed Kavazanjian, Narayanan Neithalath
School of Sustainable Engineering and the Built Environment,
Arizona State University, Tempe, AZ

- Discrete Element Method (DEM)
  - Widely used to simulate behaviors of granular materials
  - Particle-scale modeling
  - Individual motion and inter-particle interactions

- Bio-cemented sand
  - Enhanced soil capacity
  - Environmentally friendly methods

- Undrained Triaxial Compression
  - Multiple boundary conditions
  - Varying cementation levels
  - 3D visualizations of force chain networks and shear bands

- Unconfined Test
  - Ultra-high cementation level
  - Ultra-high strength

- Liquefaction (ongoing)
  - Direct simple shear
  - Cyclic direct simple shear
  - Centrifuge test (large-scale simulation with TACC)

- Future Goals
  - Multi-phase packing
  - XRT image
  - 3D distributions of phase properties
Education and Outreach Posters
**Active Strategies to Reduce Barriers to Entry for Women in Civil Engineering**

Colleen E. Bronner, University of California, Davis

<table>
<thead>
<tr>
<th>Motivation</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>The percentage of women in engineering has remained at approximately 20 percent for the past two decades. There are numerous barriers to girls and women in engineering, including:</td>
<td>To address these barriers, our team is implementing and assessing a range of activities to remove or reduce barriers to women in civil engineering using the following strategies:</td>
</tr>
<tr>
<td>• Barrier 1: Societal stereotypes about engineers and engineering;</td>
<td>• Promote formal and informal interactions of K-12 students with civil engineering students;</td>
</tr>
<tr>
<td>• Barrier 2: Lack of awareness by teachers, parents, and other adult role models about implicit biases towards girls and women in engineering fields;</td>
<td>• Demonstrate societal benefits of civil engineering;</td>
</tr>
<tr>
<td>• Barrier 3: Lack of awareness by girls and K-12 teachers about what a civil engineer does and their contributions to society;</td>
<td>• Develop engaging education modules that demonstrate types of design and research projects civil engineers work on;</td>
</tr>
<tr>
<td>• Barrier 4: Lower self-efficacy levels by girls and other underrepresented groups with respect to their abilities in engineering; and</td>
<td>• Educate K-12 teachers and future engineering educators about implicit bias, stereotype threat, and other barriers limiting diversity in engineering;</td>
</tr>
<tr>
<td>• Barrier 5: Limited evaluation on ability of outreach programs to recruit women into engineering.</td>
<td>• Train future engineering educators in fundamentals of pedagogy; and</td>
</tr>
<tr>
<td></td>
<td>• Disseminate lessons learned and developed curriculum to other ERCs, engineering educators, and other interested parties.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activities</th>
<th>Preliminary Results &amp; Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Components</td>
<td>Camp/Academy</td>
</tr>
<tr>
<td>• Graduate course in engineering education</td>
<td>• Recruitment strategies for targeting students from less affluent areas</td>
</tr>
<tr>
<td>• Develop educational modules inspired by CBBG research</td>
<td>• Students sharing lessons learned with family</td>
</tr>
<tr>
<td>• Annual teacher workshop</td>
<td>• Multiple students participating more actively in summer academies than in school</td>
</tr>
<tr>
<td>• Summer camp for girls in grades 3-5</td>
<td>• Concepts that are most difficult to grasp (e.g., a life cycle can apply to something not alive)</td>
</tr>
<tr>
<td>• Engineering academy for girls in grades 7-9</td>
<td>• Characterization of civil engineers expands during week-long workshops</td>
</tr>
<tr>
<td>• K-12 class visits to UC Davis</td>
<td>• Middle school girls connect to impostor syndrome lesson</td>
</tr>
<tr>
<td>• Large community outreach events</td>
<td>Teachers Workshops</td>
</tr>
<tr>
<td>• Development of appropriate assessment tools</td>
<td>• Challenges with applying modules and content shared during the workshop (e.g., limited supplies, lack of confidence)</td>
</tr>
<tr>
<td></td>
<td>• Desired characteristics and format of education modules</td>
</tr>
<tr>
<td></td>
<td>• Perceptions on Civil Engineering before and after the workshop</td>
</tr>
<tr>
<td></td>
<td>• Perceived challenges to meeting engineering components of next generation science standards (e.g., limited teacher professional development)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Year 3 Future Plans</th>
<th>Acknowledgements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of Educational Modules and Outreach Activities</td>
<td>This material is based upon work supported by the National Science Foundation (NSF) under NSF Award Number EEC-1449501. Any opinions, findings and conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the NSF. A big thank you to all the CBBG graduate and undergraduate students who have helped run outreach activities listed above, especially Matthew Burrall, Charlie Grady, Jordan Greer, Jenna Kelmar, Annie Kirkwood, Vivian Le, Alena Raymond, and Sophia Palumbo.</td>
</tr>
<tr>
<td>• Develop new educational modules (e.g., bio-mediation module)</td>
<td></td>
</tr>
<tr>
<td>• Edit and pilot educational modules started in Year 1 and Year 2</td>
<td></td>
</tr>
<tr>
<td>Evaluation of Educational Modules and Outreach Activities</td>
<td></td>
</tr>
<tr>
<td>• Visits to local middle schools in nearby school districts</td>
<td></td>
</tr>
<tr>
<td>• Middle school teachers bringing classes to UC Davis to interact with civil engineering undergraduate and graduate students</td>
<td></td>
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<tr>
<td>• Sustainable Engineering Academy for young women in grades 7 through 9</td>
<td></td>
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<tr>
<td></td>
<td>Revisions of assessment tools and procedures</td>
</tr>
<tr>
<td>Preparing Current &amp; Future Educators</td>
<td></td>
</tr>
<tr>
<td>• Graduate course on engineering education and instructional design</td>
<td></td>
</tr>
<tr>
<td>• Sustainable Engineering for Middle School Teachers Workshop</td>
<td></td>
</tr>
</tbody>
</table>
A New Approach to Collaboration:
A partnership between the CBBG and a liberal arts college
Laurie F. Caslake* and Mary J.S. Roth

*Department of Biology, Lafayette College, **Department of Civil and Environmental Engineering, Lafayette College

Research Goals

- Determine the feasibility of a sustainable ground improvement approach to reducing the permeability of soils by establishing a biofilm formed by native bacteria (bio-stimulation) throughout a 100 cm column of sand.
- Advance the application of biofilm forming bacteria as a soil treatment method: reduction of permeability has applications with respect to mitigating hazards caused by seepage (e.g., failure of contaminant containment systems, dams, and levees) in a cost-effective and environmentally sustainable way.

Logic Model for Grant

<table>
<thead>
<tr>
<th>Inputs/Resources</th>
<th>Strategies</th>
<th>Outcomes/Outputs</th>
<th>Long-Term Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lafayette College</td>
<td>Conduct research</td>
<td>Research publications and presentations</td>
<td>Contributions to knowledge regarding engineering applications of biofilm formation in soil</td>
</tr>
<tr>
<td>Lafayette College (LC)</td>
<td>Recruit, involve, and mentor undergraduates</td>
<td>LC faculty development beyond grant funding</td>
<td>Workforce development</td>
</tr>
<tr>
<td>CBBG</td>
<td>Coordinate and collaborate (LC and CBBG) through regular video conference calls</td>
<td>Initiating new research</td>
<td>Short-term through students involved in project</td>
</tr>
<tr>
<td>CBBG researchers’ collaboration efforts and time</td>
<td>Undergraduate students to participate in REU training and summer research at CBBG universities</td>
<td>Developing summer students involved in project</td>
<td></td>
</tr>
<tr>
<td>Video conferencing coordination</td>
<td>Graduate students to participate in REU training and summer research at CBBG universities</td>
<td>Exchange students to conduct research at LC and CBBG</td>
<td></td>
</tr>
<tr>
<td>Summer training and housing logistics for LC students</td>
<td>LC faculty researchers to participate in CBBG meetings and in‐venue research at CBBG universities</td>
<td>EXCEL (Grant No. 1632963)</td>
<td></td>
</tr>
<tr>
<td>Participation of LC students in summer research</td>
<td>Exposure CBBG graduate students and researchers to research opportunities at LC</td>
<td>Contestants to NSF and Engineering applications of biofilm formation in soil</td>
<td></td>
</tr>
</tbody>
</table>

Collaboration Goals

Create a partnership between a strictly undergraduate institution, Lafayette College (LC), and an NSF-funded Engineering Research Center (ERC), the CBBG

Collaboration Structure

- Conduct research as described in proposal
- Recruit and involve students in research
- Select two students to participate in summer CBBG REU program activities
- Integrate LC undergraduate students in the CBBG REU summer program activities
- Hand all financial aspects of the collaboration related to LC faculty and students
- Integrate LC undergraduate students in the CBBG REU summer program activities
- Provide logistical support regarding accommodations for LC students visiting CBBG

Results (1st Year)

Research

- Unable to replicate permeability decreases reported by others
- Developed and implemented equipment modifications to support permeability testing involving biofilm
- Involved 4 undergraduate students during 2016-17 (3 female, 1 male; 3 biologists, 3 civil engineers)
- Involved 5 undergraduate students during 2017-18 (4 female, 1 male; 2 biologists, 3 civil engineers)

Collaboration

- Participation in approximately 16 video conference calls
- LC researchers participated in CBBG mid-year meeting, summer research collaboration, as well as CBBG annual meeting
- Shared equipment designs and equipment
- Two LC students (2 females, 1 biologist, 1 civil engineer) participated in summer research at ASU and UCSD
- Collaborated with CBBG researchers during summer 2017 in preliminary testing using quartz sensing inhibitor to control biofilm formation

This material is based upon work supported by the National Science Foundation under Grant No. 1632963 and under National Science Foundation Cooperative Agreement No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the National Science Foundation. This work has also been supported by Lafayette College.
Research Experience for Teachers (RET) Posters
Reductive Dechlorination of TCE and Perchlorate by two Bioaugmentation Cultures in the Absence of Soil

Natalie Aragon, Micah Sandys, Quin Thacker, Srivatsan Mohana Rangan, Sayalee Joshi, Anca Delgado, Dr. Rosa Krajmalnik-Brown

RET Program 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background Rationale & Research Objectives

• Does adding microbial cultures contribute to reductive dechlorination of TCE and perchlorate or is the native soil microbes present responsible?
• Assess microbial cultures in TCE and Perchlorate which are ground water contaminants using GC.
• Collect data as results come in for dechlorination using IC at the tool for measuring our cultures.

Methods & Materials

• Set up a batch of serum bottles with 100mL of liquid with 20mL of headspace.
• Samples are taken every few days gas chromatography to track concentrations of TCE, DCE, VC, Ethene, and Methanefor
• Liquid sampling is taken for IC to track perchlorate.

Experimental Results

• SDC-9 and Zara-10 cultures did not produce any Perchlorate reduction.
• Zara-10 cultures stalled the SDC-9 production of Ethene.
• The SDC-9 production of Ethene occurred quickly between day 0 and day 8.

Classroom lesson

• B How can we reclaim the land with the contamination?
• Students were given a list of supplies to design their own research using the engineering process as a guide.

They made plans and put their plans into action.

Results

Over a period of ten days students observed, took pictures, and measured what happened with their test conditions.

Charts, Graphs and results were created. Then we discussed experimental data.

Students were surprised with their results. Many of the microorganism infused plants did not fare well. The cucumber and potato plants had the best results with the microorganisms and oil. They decided that further testing is needed. My students also want to test other microorganisms to see if that makes a difference.
Research Objectives
• Investigate the affect of enzyme induced carbonate precipitation on liquefaction mitigation (EICP)

Background
• Liquefaction occurs when an increase in pore-water pressure during an earthquake causes the soil to liquefy.
• As a result, liquefaction presents an significant civil concern to costal communities.

Conclusions
• EICP presents a viable mitigation solution for liquefaction related issues.
• Further questions for investigation include:
  • (1) How can we minimize the undesirable effects of introducing ammonia into soils?
  • (2) How can we reduce the amount of urease enzyme required for usage in the EICP mitigation technique?
  • (3) How can we develop viable methods for introduction of EICP into civic spaces with established infrastructure?

Geotechnical Engineering In the K-12 Classroom

Lesson Objectives
• Students will perform a controlled investigation to determine the best engineering solution to a complex problem.

Lesson Implementation
• Students: designed a controlled investigation to study possible solutions to a real world problem.
• Collaborated with their classmates to develop testable hypotheses.
• Reported the results of their experiment.

Student Outcomes
• Students used the results of their experiment to ask new questions leading to the development of their own experiments.
• Provided overwhelmingly supportive qualitative feedback.
• Linked in class learning to global events.
Fugitive Dust Mitigation for the 7-12 Classroom

Steven Clemens; Miriam Woolley; Dr. Ed Kavazanjian

Research Experience for Teachers 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale

- 3,000 square-miles of area in Maricopa and Pinal Counties have been designated a nonattainment area, because it does not meet the federal air quality standards for particulates smaller than ten microns in diameter PM$_{10}$. (Arizona D.O.T.)

- The best available method for construction companies to control fugitive dust is the use of water trucks at construction sites. This requires multiple applications per day.

- Enzyme Induced Calcium Precipitate (EICP) is a method used to stabilize the crust of soil and mitigate the level of fugitive dust.

Research Objectives

- Develop a formula that is cost effective and scalable for use at construction sites and other high traffic areas that will mitigate the abundance of fugitive dust.

- Create a lesson for the 7th -12th grade classroom that mimics the research of EICP mitigation for fugitive dust control.

Experimental Method and Results

- Students will complete research via experimentation to mimic the process that is being conducted at Engineering Research Centers. Specifically, students will understand the process of soil stabilization and fugitive dust mitigation and then propose an alternate formula that engineers could use that is cost effective.

- Students developed multiple formulas for EICP mimicry. The strongest formula (stabilized crust) was a mixture of Elmer's Glue and Calcium Chloride. Students created research posters based on their findings in the laboratory.
Rain Check: Effects of rain on soil crusts produced by dust suppressants

Renée C. Elder, Miriam Woolley, Edward Kavazanjian

Background

Fugitive dust, dust from sources such as construction sites that become entrained in the lower atmosphere due to wind, or other agitation, e.g., driving over loose soil, etc., is a public health problem that has put Maricopa County, AZ in nonattainment status. That is, it is in violation of the Environmental Protection Agency’s National Ambient Air Quality Standards, i.e., Limit: PM_{2.5} 24-hour level = 150 μg/m³. Consequences of exposure to high concentrations of particulate matter <10μm can result in compromised lung and heart health especially to sensitive populations, e.g., those with existing respiratory and health problems.

Currently the best available dust suppressing method is to spray the surface with water. This practice is unsustainable in semi-arid and arid climates. Thus, chemical dust suppressants that could potentially be applied with less frequency and yield a longer lasting effect have been considered. However, it is worth considering, what happens to the crust formed by chemical dust suppressants after a rain event? Is the soil essentially washed of the material holding it in place?

Experimental Design

Step 1: Two sets of pans of soil were sprayed with 50mL of one of the following solutions to each pan in each set with one pan left of plain dry soil, i.e., it is not treated with a suppressant, in each set.

Dust Suppressants:
- Salts
- Magnesium Chloride [MgCl₂]
- Calcium Chloride [CaCl₂]
- Enzyme Induced Carbonate Precipitation (EICP)
- EICP + Polymer [xanthan gum]

Step 2: Each pan of one set was sprayed with 500 mL over an hour to induce drainage through the bottom. The pans were covered to limited evaporation from the surface. The pans were left to dry in the lab, then, to reduce capillary action, they were put in a 105 °C oven for several days.

Step 3: Several tests to assess the strength of the soils’ crusts before and after the “rain” were done, and the results were graphed.

Results

Step 1: Two sets of pans of soil were sprayed with 50mL of one of the following solutions to each pan in each set with one pan left of plain dry soil, i.e., it is not treated with a suppressant, in each set.

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Step 3: Several tests to assess the strength of the soils’ crusts before and after the “rain” were done, and the results were graphed.

Conclusions

It is clear that all the crusts became more resistant to penetration after the “rain”, opposing the idea that the suppressant solution would percolate through the soil and draining out of the pan when wetted. Moreover, soil pans treated with EICP resulted in similar penetration resistance than the two salt suppressants. Though more testing is necessary to explain these results, the following could be attributive possibilities:

1. Pre-existing salts in the soil: could explain why the untreated soil had such greater resistance, quite similar to that of the treated soils, after the “rain” event across all tests
2. Capillary action: although soils were left to dry out, it is possible water adhesion affected the results

Lesson: Soil Classification

Summary of Lesson:
- Introduce Geotechnics, soil, soil classification
- Playing with soil!
  - Virtual soil classification
- Students touched the soil, looked at it underneath magnifying glasses, smelled it, and tested plasticity with water.

Science with soil!
- Sieve analysis
- Grain size distribution
- Compute coefficients
- Determine true soil type

Students compared their visual classification to the scientifically derived classification.

This lesson was performed in a college level course. The students enjoyed the hands-on activity.
Research Experience for Teachers

Sieve Analysis: What size is my soil?

Lesson Objective

- Students will be able to sieve a sample of soil using the scientific method to analyze the particles that are within a sample.

Lesson Implementation

- Students utilizing the scientific method to analyze particle size
- Students hypothesis the type of particles in their sample
- Student conduct a sieve analysis and mass each individual sieve

Lesson Outcomes

- Students draw conclusions about sieve analysis procedures
- Students inquire the use of each particle size
- Students will apply learning to construct their own soil columns for an intended project

Background

- Darcy’s Law calculates permeability
- Soil mechanics defines and assesses all solid properties
- Microbial bridge soil grains allowing for soil improvement
- Injecting micro-organism change the mechanical and hydraulic properties of soil.

Research Conclusions

- Evidence of gas demonstrates micro-organisms survival in soil column.
- Sensors need to be calibrated individually
- Future investigation of different sensors may be beneficial to project

Michelle Gerrick, Brianna Stephens, Elizabeth Stalling, Dr. Claudia Zapata, Dr. Ed Kavazanjian

Research Objective

- Testing to identify a method for determining the unsaturated permeability in a soil column as calcium carbonate precipitation occurs.
Background & Rationale
- Portland cement concrete is the most widely used infrastructural material.
- Concrete durability gains through the use of supplementary materials.
- Biodeposition in the form of microbial induced or enzyme-induced carbonate precipitation could possibly help in reduction of pore size in concrete.
- Therefore, biodeposition can be effective as a means of surface treatment to increase the durability of existing infrastructure.

Research Objectives
- To create a suitable paste which meets the requirement for a specific application in a particular geographic location.

The following scenarios were specified:
A. Crosswalk in May
B. Bridge girder in February
C. Bridge deck in Colorado in December
D. Sidewalk in October
E. Concrete canoe

Explore the effect of EICP to increase the durability of the designed concrete specimens.

Mix Designs

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<td>15</td>
<td>10</td>
<td>10</td>
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<tr>
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<td>1.6, 1.55, 1.4</td>
<td>1.6, 1.9, 2</td>
<td>0</td>
</tr>
</tbody>
</table>

Lesson Implementation
- **Title:** Understanding Cementation- Optimal Water Content
  Implemented on September 25–26, 2017
- **Learning Objective:** Students will be able to identify factors that influence optimal concrete design mixtures.
- **Learning Activity:** Students engaged in a lab experience to explore the question, how do we know when a cement mixture is optimal?

Students developed three mix designs where the amount of concrete (g) was the independent variable. Additives such as sand (g) and water (mL) acted as dependent variables.

Each design was allowed to set over night. The next day, students collected, graphed, and analyzed their results regarding the characteristics of the design mixtures. Student teams determined what an optimal cement mix design meant.

Student Learning
- In reference to the Common Core State Standards, students were able to extend their understanding of mathematical practices:
  - Use appropriate tools strategically (5)
  - Attend to precision (6)
- Students carried out an investigation using a scientific method.
- Students engaged in meaningful discourse using tier three vocabulary and content specific writing.
- Students used their new learning to carry out the design thinking process in order to solve a concrete dam design problem.
What’s Shakin’?
A CBBG-Inspired 8th Grade Lesson

Susan M. Rumann, Ph.D.; Steven Batchelder; Kimberly K. Martin; Dion Shurley; Dr. Edward Kavazajian

Background & Rationale

- Investigate the affect of enzyme induced carbonate precipitation on liquefaction mitigation (EICP)
- Examine earthquake induced liquefactions effect in a real world context.
- Expose female and minority students to all disciplines of engineering

Research Objectives

- CBBG research objective is to induce carbonate precipitation at the base to reinforce a structure.
- Instructional objective is that students will be able to construct a written response explaining liquefaction.

Experimental Results

- Concentration of ECIP solution introduced to the soil caused various levels of soil solidification.
- Use of quarry sand resulted in a variation in soil solidification is less constant.
- Question for further investigation: How does soil behave under multiple cycle loading conditions?

Conclusions

- An EICP solution is a potential resource for liquefaction related issues.
- Students developed an awareness of various disciplines of engineering.
- Students advanced their understanding of earthquake-induced liquefaction.
- Instructional support in Design Thinking facilitates scientific inquiry.
Experimental Design

- Contaminants in ground water:
  - Trichloroethylene (TCE) is a known carcinogen
  - Perchlorate (ClO₄⁻) has harmful effects on pregnant women and toddlers
- Experiment included seeing if bacteria that are able to do chain elongation can clean water.
- Long Term Application: Have the ability to clean up contaminated ground water and create a biofuel simultaneously.

Lesson Plan Design and Implementation

The lesson is designed to be a 3 day mini unit.
Day 1- Introduce bioinspired products by playing matching game. Students match product with the animal that inspired that product. Introduce As You See It activity.

Day 2- Students begin designing their own bioinspired product.

Day 3- Students present product to class, similar presentation to the TV show Shark Tank.

Experiment Results

- Shows a decrease in TCE when both Acetate and Ethanol are used as electron donors.
- Shows a slight decrease in Perchlorate levels over the 20 day.

Testing Methods and Setup Materials

Gas Chromatography (Trichloroethylene degradation)
Ion Chromatography (Perchlorate)
High Pressure Liquid Chromatography (Microbial Chain Elongation)
Anaerobic Chamber (Oxygen < 30ppm)
Measure Headspace with frictionless syringe

Student Examples

- Using snake venom to cure diseases
- A new way to live and reduce urban sprawl inspired by a butterfly
- A film that can make cars communicate by changing color

The Answers are All Around You
A CBBG-Inspired High School Lesson

Micah Sandys, Quinn Thacker, Natalie Aragon, Sri Rangan, Sayalee Joshi, Dr. Anca Delgado

In order to see full results for both TCE and Perchlorate reduction, a longer duration of testing is required.
Bioremediation: Microbes Facilitate Chain Elongation & Degradation of TCE!
Quinn Thacker; Micah Sandys; Natalie Aragon; Dr. Anca Delgado; Srivatsan Mohana Rangan; Sayalee Joshi; Megan Altizer; Aatikah Mouti; Dr. Rosa Krajmalnik-Brown
Research Experience for Teachers (RET) Program 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

1. Background & Rationale
- Microbes in subsurface soils are capable of degrading chemicals of longer carbon chains.
- Reaction includes hydrogen gas production—Is it useful in sustaining dechlorination of trichloroethylene (TCE) and perchlorate reduction?
  - TCE → DCE → Vinyl Cl → Ethene
  - From Bad carcinogens to Good!

2. Research Objective
- What are optimal conditions for microbes to grow acetate to a longer carbon chain? How long?
- How fast can they reduce TCE to ethene?

3. Methods & Materials
- Condition changes: types of bacteria plus substrates and temperature.
- We use calculations, data analysis from various instrumentation: GC, IC and HPLC as well as incubators.

4. Experimental Results
- Introduce bioremediation/biomimicry
- Concentration calculations & graphing
- Pre- and post assessments
- Results: Students gained in knowledge
- Commit to work on a community issue

5. Instructional Objectives & Results
- Chains grew from 2 to 6 carbons
- Substantial Hydrogen production
- TCE reduced to less harmful ethene
- Future: Study if ethanol can propel carbon chain elongation
- Students gained in knowledge
- Students to work on selected issues

6. Conclusions
Acknowledgements
This material is based upon work primarily supported by the Engineering Research Center Program of the National Science Foundation under NSF Cooperative Agreement No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the National Science Foundation.
Research Experience for Undergraduates (REU) Posters
Microbially Enhanced Iron-Modified Zeolite Permeable Reactive Barrier

Taliya Anwar (REU); Neda Halalsheh Ph.D; Dr. Paola Bandini; Dr. Lambis Papelis
Research Experience for Undergraduates 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background/Objective
Exploring the ability of microorganisms to enhance the use of iron-coated zeolites as permeable reactive barriers (PRB) for the remediation of sites contaminated with anions of concerns, such as arsenic and selenium.

Methods and Materials
Zeolite Preparation
Four different types of zeolites were prepared to study the percent sorption of two oxidation states of Selenium (Selenite +4, Selenate +6). Natural Zeolite (without any modification), sodium pretreated zeolite, iron modified zeolite, and iron modified sodium pretreated zeolite.

Batch Sorption Experiment
Batch sorption experiment were conducted using zeolite type to determine the most effective medium for removal of Selenium oxyanions.

Results
Selenium Sorption as a function of Non-Iron-Modified Zeolites Type and Oxidation State

Selenite Sorption as a function of Zeolite Type

Conclusion
We worked with four different types of zeolites. The percentage sorption of selenite increased up to 90% with coated zeolites as compared to natural zeolite which was 10%.

Future Work
Future work will include further zeolite modification optimization and initiation of batch sorption experiments incorporating microbial communities. Of particular interest is the ability of microorganisms to alter the oxidation state of oxyanions.

Acknowledgements
This material is based upon work primarily supported by the Engineering Research Center Program of the National Science Foundation under NSF Cooperative Agreement No. EEC-1449501. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the National Science Foundation.
Methods for Uniform Biofilm Distribution

Zhui Chen1, Ziqi Chen2, Charles M.R. Graddy3, Mary J.S. Roth2, Douglas C. Nelson1, Laurie F. Caslake1, Rebecca E. Parales1

1Department of Biology, Lafayette College
2Department of Civil and Environmental Engineering, Lafayette College
3Department of Microbiology and Molecular Genetics, University of California, Davis

Uniform Biofilm Distribution
- During the development of biofilm in soil, one of the most concerning issues is the uniformity of distribution.
- Two facilitating factors were tested: quorum sensing signal quenching enzyme aiiA, and quorum sensing receptor inhibitor furanone c-56.
- The plausibility of each method was tested at the micro titer plate scale.

Mechanisms of methods
- A lactonase called aiiA, can cut off quorum sensing(QS), a signaling process for biofilm formation, thus inhibiting the initial accumulation of QS signals at single points in soil.
- A chemical called furanone c-56, was reported to inhibit the biofilm formation. It was hypothesized that this chemical binds to receptors thus competing with the biofilm formation signaling molecules.

Methods & Materials
Extraction of aiiA
- Overnight culture of E. coli strain with plasmid containing overexpressed aiiA gene fused to maltose-binding protein.
- Eluted with amylose resin column (Figure 1).
- Stored as frozen protein pellets at -80°C.

96-well microtiter plate experiment
- Pseudomonas aeruginosa was used as model organism to test the effect of aiiA and furanone c-56.
- Wells were inoculated with bacteria and chemical (aiiA or c-56), incubated for 2 d at 28°C, stained with 0.1% crystal violet, and dried overnight.
- The dry crystal violet was dissolved with 30% acetic acid and measured spectrophotometrically. (Figure 2)

Micro titer Plate Results

Figure 2: The comparison of aiiA and furanone c-56 with increasing dosage.
- Furanone c-56 shows a more obvious impact on biofilm development in P. aeruginosa.

aiiA Extraction Results

Figure 1: SDS-PAGE result of the elution fractions from the amylose resin.
- Heavy bands in predicted size (71kDa)
- Successful elution confirmed with nanodrop.
- Enzyme Activity confirmed by activity assay on Chromobacterium violaceum.

Conclusions & Future work
- Lactonase aiiA extraction was successful and ready for further study.
- Furanone c-56 showed negative effects on biofilm development in Pseudomonas aeruginosa.
- Further study on the effect of Furanone c-56 on general soil microbial population is needed.

Acknowledgements

This work was supported by the National Science Foundation under Grant No. 1623963 and by National Science Foundation Cooperative Agreement No. EEC-1449501. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. This work has also been supported by Lafayette College.
Biofilm Induced Permeability Reduction in Soil

Ziqi Chen1; Zhihui Chen1; Jordan A. Greer1; Charles M.R. Graddy2; Rebecca Parales2; Douglas C. Nelson2; Laurie F. Caslake1; Jason T. Dejong1; and Mary J.S. Roth3
1Department of Civil Engineering, University of California, Davis, 2Department of Microbiology and genetics, University of California, Davis, 3Department of Civil and Environmental Engineering, Lafayette College, 4Department of Biology, Lafayette College

What is Biofilm?

• Biofilm are the communities formed by bacteria. Usually include gel-like substance together with captured organic/inorganic material.
• Examples of biofilm: slippery green moss, tooth plaque etc.

Permeability of Soils

• Permeability (K) is a measure of a certain type of porous material, for example, sand to allow fluids to pass through it. (Typical Sand K:0.02cm/s)

Previous Work and Objectives

• Record of 10-fold permeability reduction from previous research results and a potential of 100-fold reduction induced by biofilm.
• Reduce the overall permeability of the soil sample from facilitating the growth of bacteria uniformly through the soil.
• Stimulate future geotechnical engineering applications, including contamination seepage control and construction site dewatering.

Methodology

• Using nutrients (yeast extract, casein peptone and glucose) to facilitate the growth of bacteria.
• Bio-stimulated concrete sand
• Falling head permeability test once everyday.
• 8 columns of compacted soil

Table 1: Permeability Values of different soils

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>K (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Gravel</td>
<td>1-100</td>
</tr>
<tr>
<td>Sand Gravel</td>
<td>10^-2-10</td>
</tr>
<tr>
<td>Clean Sand</td>
<td>10^-2-1</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>10^-3-10^-1</td>
</tr>
<tr>
<td>Clay sand</td>
<td>10^-4-10^-2</td>
</tr>
</tbody>
</table>

Experimental Results

• The sectional and bulk permeability vary inside the columns. (Figure 5)
• The permeability changes the most in the top section near the feeding inlet.
• Comparison between C3 (nutrient) and C8 (Nutrient + furanone) (Figure 6,7)

Conclusions

• The growth of biofilm can potentially result in reduction of the soil permeability.
• Furanone is likely responsible for a rapid reduction in permeability.

Future Work

• Confirm the presence of biofilm in the soil by taking samples of running columns.
• Develop approaches to ensure the uniformity of the biofilm growth.

References


Acknowledgements

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Root system evaluation for foundation bio-inspiration

Caroline Colbert; Rodrigo Borela; Sangy Hanumasagar; Seth Mallet; Dr. David Frost

Research Experience for Undergraduates 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale

- Root systems play a crucial role in anchorage of plants
- Long term goals of this project include gaining insight into the anchorage mechanics of root systems in order to develop bio-inspired foundations

Research Objective

- This study concentrated on evaluating the root system strengths of various plants under a pullout force

Methods & Materials

- A load frame machine was used to test the root system strength of various plants under a pullout force
- 3D models of the root systems were generated using photogrammetry

Pullout Results

The peak of each curve represents the max pullout force for each plant tested. The pullout tests revealed a wide range of max forces for the various plants.

The max pullout force was observed to positively correlate with both mass of plant material and stem diameter at the base of the plant, which are indicators of plant/root-system development.

Photogrammetry Results

- Various factors contribute to the amount of force required to uproot a plant such as root length and horizontal spread, in addition to various soil properties, which could not be controlled due to the replanting process and potting mix characteristics
- Although we observed a correlation between the max pullout force and measured stem properties, not enough tests were performed to determine statistical relevance
- Future work will investigate the root system strengths of leek plants at various stages of development

Conclusions

- Photogrammetry was utilized to capture 3D models of root systems that were tested
- Through trial and error we developed a basic set of guidelines to capture the best images for this process
Integrating Bio-Inspired Engineering Design into Middle School Education

Jenna Kelmser; Colleen Bronner; Annie Kirkwood; Vivien Le

Research Experience for Undergraduates 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale

- The Next generation Science Standards (NGSS) specify that engineering concepts and skills are taught alongside science in K-12 education.
- Following these standards gives local educators the flexibility to design classroom learning experiences that stimulate students’ interests in science and prepares them for college, careers, and citizenship.
- K-12 teachers are unclear on how to teach engineering concepts in classrooms and have been given little guidance.
- This means that there is a need for both engineers and K-12 educators to be a part of students lives in some way. We aim to bridge that gap.

Research Objectives

- Producing valuable modules that flow along with the curriculum of eighth graders and align with the Next Generation Science Standards (NGSS).
- Provide bio-inspired engineering lessons based on current CBBG research.
- Produce a module on sustainability and bio-inspired design for geoenineers.
- Assess the capacity of lessons to engage students, teach concepts, and develop engineering skills.

Methods

- Submit curriculum on teachingengineering.org
- Research bio-inspired design and sustainability
- Use NGSS standards that apply to each topic
- Develop and include

Recommendations

- Teachers do find communicating engineering ideas difficult. It is important to understand their needs.
- Students of this age group have a very wide and differing range of knowledge. It will be important to give them options.
- Students need a “phenomenon” to catch their attention.
- Teachers need a unit plan, not just a lesson plan.

Future Plans

- Expand Curriculum to meet other standards.
- Test modules in K-12 classes.
- A review from CBGG curriculum committee as well as teachingengineering.org.
- Updating assessments and lessons.
- Giving teachers more options with lessons so that they can fine tune them to fit the needs of their specific students.
- Developing homework’s to go along with modules and activities.
- Develop an active list of CBGG research projects that is accessible to teachers.

Results

<table>
<thead>
<tr>
<th>Activity/Module</th>
<th>NGSS Standards</th>
<th>Type of Activity</th>
<th>Key Concepts</th>
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<td>Sustainability Module</td>
<td>NGSS-ESS-1</td>
<td>- Outlining the three pillars of sustainability</td>
<td>- Three Pillars of Sustainability</td>
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<td>Sustainability Activity</td>
<td>NGSS-1-2</td>
<td>- Approaching a definition of sustainability using the engineering design process of problem solving</td>
<td>- Defining terms that have many different definitions.</td>
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<tr>
<td>Bi-Inspired Design for Geoenineers Module</td>
<td>NGSS-LS-1</td>
<td>- Teaching student basics of bio-inspired design, identified examples, and thought processes of an engineer</td>
<td>- The role engineers play in development of projects that execute the environment around them.</td>
</tr>
<tr>
<td>Bi-Inspired Design for Geoenineers Activity</td>
<td>NGSS-MS</td>
<td>- Using critical thinking skills to solve a problem using bio-inspired design and the engineering design process</td>
<td>- Methods of the engineering design process, CBBG bio-inspired research.</td>
</tr>
</tbody>
</table>

Figure 1. Eighth grade girls learning about a variety of topics such as bio-inspired design at the Engineering for Sustainability Academy.

Figure 2. Students were able to use engineering problem solving methods to define sustainability from their own perspective. This included the three pillars of sustainability. (left)

Figure 3. Group Students Sophie Polumbus introducing the students to the basics bio-inspired Design.

Figure 4. A solo activity with another grad student.

Figure 5. Students using the AR sandbox to model watersheds (right)

Figure 6. Other activities such as learning how to use microscopes. (below)

Figure 7. Going through the process of defining sustainability with the student. (above)
Soft Robotics and Hydrostatic Skeletons

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Research Experience for Undergraduates 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale

• Current practices for evaluating soils in situ utilize rigid and hard probes that require high penetration forces
• Softer robotic systems are less energetically intensive and more flexible
• An earthworm’s hydrostatic skeleton allows it to move through a medium with high flexibility using cyclical expansion and contraction
• Mimicking the earthworm’s hydrostatic skeleton could result in the development of new geotechnical engineering probes with unique advantages over available sampling technologies

Hypothesis

• The addition of a soft balloon, capable of transferring stresses through pressurization, to a cone penetration probe may reduce the resistance to penetration by altering the state of stresses within the vicinity of the cone tip

Research Objective(s)

• Develop a working probe that combines a soft inflatable ‘balloon’ with a rigid penetration cone
• Identify readily available polymeric materials that could be used for the soft body component of our probe.
• Create a basic test set-up that would allow controlled pressurization (inflation) and depressurization (deflation) of the probe while continuously monitoring of penetration resistance.
• Compare the results of tests with and without (control) pressurization.

Methods & Materials

• The probe is constructed of a thin, hollow steel connected to a vacuum and air compressor. The expanding mechanism is adapted from a medical balloon and is made of polyurethane
• Using a uniaxial load frame, the prototype was positioned above a container of very loose Ottawa soil, ASTM 20/30.

The protocol was run four times and resulting data was averaged. The steps of the protocol are as follows and are repeated four times for each test:
1. Probe descends downwards 10mm at a velocity of 1.75mm/s,
2. The probe ceases movement upon being displaced 10mm
3. The expansion valve is turned and the balloon inflates for 10 seconds
4. The expansion valve is turned off and the vacuum valve is turned on.
5. The vacuum valve is turned off and the prototype begins moving downward

Test Results

Conclusions

• Pressure-based soft probe reduces penetration resistance force
• Pressurization of the balloon results in an increase in force (Buoyancy effect)
• Depressurization of the balloon results in the development of tensile force.
• Changes in the distance between the balloon and the cone tip result in changes in the magnitude and variability of the measured tensile forces

Future Work

• Evaluate changes in penetration resistance at increased effective confinement
• Test sands at different initial void ratios
• Varying length of time that probe undergoes pressurized expansion
• Looking into other materials aside from polyurethane
• Extending the experimental work to numerical simulations using the discrete element method
Investigating the Effects of EICP On Vegetation

Jameson Moulis, Miriam Woolley, Nasser Hamdan, Edward Kavazanjian Jr.

Research Opportunity for Undergraduates 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale

• Vegetation is the most effective slope stabilizer
• Industry interested in vegetation-EICP interaction

Ammonium is known to cause damage in seeds and young plants, but is also a valuable fertilizer.

Research Objectives

• Hypothesis: EICP byproduct will benefit plant growth and aid in initial rooting.
• Will EICP cause a positive, negative, or neutral effect?
• All parameters and test setup need to be kept consistent (EICP solution, sunlight, water ring volume, Seed mass, etc.).

Experiments & Results

(7 mL 0.4M EICP, 0.2g Rye Grass Seed)/Cup

Day 6

Day 11

Day 15

Table 1. Dixie Cup Vegetation Experiments (Initiated 7/18/17)

<table>
<thead>
<tr>
<th>Type</th>
<th>Seeded</th>
<th>Sprayed</th>
<th>Initial Sprouting (Out of 5)</th>
<th>All cups sprouting (Out of 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EICP byproduct</td>
<td>Day 0</td>
<td>Day 0</td>
<td>Day 0</td>
<td>Day 0</td>
</tr>
<tr>
<td>EICP byproduct</td>
<td>Day 6</td>
<td>Day 6</td>
<td>Day 11 (3)</td>
<td>Day 12</td>
</tr>
<tr>
<td>EICP byproduct</td>
<td>Day 0</td>
<td>Day 0</td>
<td>Day 12 (4)</td>
<td>Day 14</td>
</tr>
<tr>
<td>EICP byproduct</td>
<td>Day 0</td>
<td>Day 0</td>
<td>Day 3 (3)</td>
<td>Day 6</td>
</tr>
<tr>
<td>EICP Control</td>
<td>Day 0</td>
<td>Day 0</td>
<td>Day 0</td>
<td>Day 0</td>
</tr>
</tbody>
</table>

Further Test Conditions

• Use growth chamber to assure consistent environmental conditions
• Till/bury seeds into soil prior to spraying
• Apply fertilizer
• Hydrogel-enhanced EICP solution to localize crust formation
• Monitor soil pH throughout testing
• Test effect on other types of vegetation
• Vary other variables

Conclusions

• We identified the variables we need to consider to effectively evaluate the relationship between EICP and vegetation.
• EICP treatment delays the germination of grass seeds and affects growth, though the exact mechanism is currently unknown.

Acknowledgements

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The Geotechnics of Ant Excavation Behavior at the Laboratory Scale

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Background & Research Objectives

• Objective: To understand the excavation techniques and tunnel complexities of harvester ants.
• Ants are very efficient excavators
• What can be learned from studying harvester ants that can be applied to geotechnical engineering?

Methods & Materials

• Chamber Dimensions: 6"x14"x1/2"
• Soil Particle Size (D50):
  - F110: 110 µm
  - Ottawa 20/30: 730 µm
• Ant Species: Pogonomyrmex barbatus
• Timelapse photography setup
• Photo Interval: 10 min
• MATLAB software for image processing

Experimental Results

Experiment 1

• Test Duration: 3 days
• Soil Type: F110
• Initial tests did not result in a complex tunnel network due to difficulty in transporting soil over vertical acrylic surfaces and a short test duration.
• Sand paper was taped to the vertical surfaces to allow for easier transportation in following tests.

Experiment 2

• Test duration: 1 week
• Soil Type: F110
• Chamber width reduced to 5/16” with cardboard insert
• Notable increase in tunnel complexity
• True 2D tunnel model not achieved
• Cardboard had inconsistent thickness
• Cardboard insert replaced with 3/16” acrylic insert in final test

Final Test

• MATLAB code used to convert timelapse images to binary images for analysis.
• Final Image of F110 test with Acrylic Insert
• Image Processing MATLAB code

Conclusions

• Significant progress in controlling test conditions
• Developed initial image processing code
• Tests with chamber width of 1/8” are currently running
• Tests with varying sand configurations is the next step

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Electrokinetic Transport of Ions and Nanoparticles in Soil

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Background & Objectives

- Electrokinetics is the application of direct current to induce in-situ transport via:
  - Electromigration – movement of ions towards an oppositely charged electrode.
  - Electroosmosis – bulk movement of a fluid due an electric field.
  - Electrophoresis – the movement of charged, dissolved or suspended particles in a pore fluid.
- In pilot studies, electrokinetics improved bioremediation of chlorinated solvents by transporting electron donors and bioaugmentation cultures throughout a contaminated site.
- Similarly, nanoscale Zero-Valent Iron (nZVI) improved bioremediation of chlorinated compounds by creating anaerobic site conditions and abiotically degrading contaminants. However, nZVI is difficult to transport in-situ.

Hypothesis: The combination of electrokinetics and nZVI will improve bioremediation by creating anaerobic conditions evenly at the site.

Objectives:
1) To confirm electrokinetic transport in the lab by measuring electromigration of nitrate ions.
2) To measure feasibility of transporting nZVI via electroosmosis.

Methods & Materials

- Electrokinetic pans

Experimental Results

Conclusions & Future Work

- Nitrate concentrations were much higher at the anode due to demonstrating electromigration.
- The nZVI tests revealed that nZVI was not transported throughout the pan, this was probably due to the fact that electroosmosis occurs at a very slow rate, much less than electromigration.
- Future work should include retesting the nZVI pans for a longer observation period and measuring nZVI with HACH kits or ion chromatography instead of ORP.
- Electrically charged surface coatings on the nZVI can also be considered to utilize electromigration instead of electroosmosis as a transport mechanism.
Bio-Inspired Enhancement of Soil Structure Interfaces

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Research Experience for Undergraduates 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale
Snakes utilize anisotropic frictional properties of their underbelly scales to move, climb trees, and interact with their environment. Snakeskin anisotropic roughness is inspiration for the improvement of geotechnical structures to increase strength and introduce multifunctionality at the soil-structure interface, thus reducing a project’s building material, construction costs, and carbon footprint.

Methods & Materials

Research Objectives
- Use a 3D scanner to scan the skin from a variety of snake specimens with differing behaviors and from various environments (ex. arboreal, aquatic, desert-dwelling)
- Create a database of snakeskin profiles
- Analyze geometric attributes (height, length, angle of elevation of scales) of the snake profile data with a MATLAB code
- Use scan data to investigate the anisotropic interface shear strength of a soil-structure interface, where the engineered surface is bio-inspired from snake skin

Experimental Results
Roughness was correlated to snake physical properties (e.g. volume), environment, and behaviors. A clear trend was observed between average roughness and specimen volume for burrowing snakes.

Conclusions
- Four distinct profile topographic patterns were associated with different snake characteristics (e.g. environment and behavior)
- Future work is focused on selecting snake profiles that will exhibit the greatest anisotropic response in direct interface shear tests, as well as expanding the snake profile database

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EICP Crust Strength

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Young Scholar Program 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale

• Fugitive dust is a significant contributor of air pollution and is common in the southwest region of the U.S. and other parts of the world.
• EICP can suppress dust with a crust
• Best Available Technology: Spraying water which can be ineffective for semi-arid regions.

Methods & Materials

Materials
• Mine Tailings Soil

Methods
Classification:
• Sieve testing
Crust Strength:
• Fall Cone (137 g cone)

• Compression testing

Conclusions

• Salt solutions offer a stronger resistance and thicker crust than EICP.
• Durability of crusts needs to be tested for better comparisons.
• We hypothesize EICP would retain strength after water erosion.

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Motivation

Liquefaction impacts:
• Niigata, Japan (1964)
• Destroyed 3,000 homes
• M 7.5
• Christchurch earthquake (2011)
• Severely damaged 15,000 homes
• Cost $10 billion in damage
• M 6.3

Background

• Key factors for liquefaction
• Low density sand
• Saturation
• Earthquakes
• Liquefaction Process:
• Earthquakes produce S waves
• Soil tries to compress, water in void space prevents compression, water pressure increases
• Shaking occurs quickly, water can’t escape which pushes soil apart
• Water cannot resist shear force so structures collapse when the foundation becomes liquid

Research Objective

• Determine number of cycles to liquefaction triggering for un cemented and cemented (improved) soil

Materials/Equipment

• Ottawa 20-30 sand conforming to ASTM C778-13 for 20-30 sand
• Round particle shape
• Poorly graded sand

Sample Preparation

Objectives:
• Reproducibly place sand at desired density (Dr~55%)
• Add water at slow, controlled flow rate (~5L/hr)

Challenges:
• Difference between emax and e_min for Ottawa Sand is small
• Injecting water at low rate without pump

Key Findings:
• Fall height of 5” during placement and some controlled shaking while dry led to consistent Dr
• Injecting water from tank was possible, but EICP clogged tubes and had to be percolated from surface

Running Shake Table

Objectives:
• Shake sample at amplitude and frequency that causes liquefaction in <10 cycles
• Determine number of cycles until liquefaction triggering
• Free water at surface
• PWP increase

Challenges:
• Too low Dr caused liquefaction at start of shaking
• Lining up cycles and PWP increase because PWP sensor has lag response and is not integrated into shake table software
• Too high of amplitude and frequency causes vertical motion and laminar box dislodged

Key Findings:
• Dr = 55%
• Uncemented soil – instant liquefaction
• Cemented soil – less cycles till liquefaction

Recommendations:
• Integrated PWP Sensor
• New EICP injection method
• Future experimentation after CBBG program ends
Biodeposition as a Surface Treatment Method to Increase Concrete Durability
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Young Scholar Program 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale
- Portland cement concrete is the most widely used infrastructure material.
- Concrete durability gains are currently accomplished through use of supplementary cementitious materials (e.g., metakaolin, silica fume, slag, fly ash, limestone).
- Biodeposition in the form of microbial induced or enzyme-induced carbonate precipitation could possibly help in reduction of pore size in concrete.
- Therefore, biodeposition can be effective as a means of surface treatment to increase the durability of existing infrastructure.

Materials, Mix Designs and Methods
- Alumino-silicates
  - Types: Metakaolin, Silica Fume
  - Benefit: Increase the reactivity of cement paste and improve particle-packing due to high fineness.
- Fillers
  - Types: Limestone
  - Benefit: Cost-effective replacement to OPC.
- Aggregate
  - Types: Coarse, Fine, Lightweight
  - Benefit: Improve load-transfer in concrete by interlocking mechanisms.
- Biodeposition
  - Types: EICP, MICP
  - Benefit: Reduces the pore size, thereby reducing permeability and increases resistance to chloride penetration.

Research Objectives
- To create a suitable paste which meets the requirement for a specific application in a particular geographic location.
- The following scenarios were specified:
  A. Cross-walk in May
  B. Bridge girder in February
  C. Bridge deck in Colorado in December
  D. Sidewalk in October
  E. Concrete Canoe
- Explore the effect of EICP to increase the durability of the designed concrete specimens.

Materials

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<td>Slag</td>
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<td>10</td>
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<td>1.2, 1.84, 1.9</td>
<td>1.6, 1.35, 1.4</td>
<td>1.6, 1.9, 1.2</td>
<td>0, 1.6, 1.5</td>
</tr>
</tbody>
</table>

Test Method
- Mini-Slump Test was used to evaluate the workability of cement pastes.
- The test procedure involves mixing the paste and pouring it out from a slump cone on a glass sheet.
- The area of spread is calculated by measuring the diameter of the slump that is formed.

Experimental Results

Conclusions and Ongoing Work
- Concrete cylinders will be cast for the five different scenarios studied.
- EICP bio-solution will be used as a surface coating on the concrete cylinders.
- The effect of biodeposition will be studied using chloride permeability testing and sorption measurements.
- The measurements will be compared against specimens without the surface coating.

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Contributors
1-Young Scholar; 2-RET; 3-Graduate Research Associate; 4-Professor
Fluid Flow Models for Microbial Induced Desaturation and Precipitation (MIDP) for Soil Improvement

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Young Scholar Program 2017, Center for Bio-Mediated & Bio-Inspired Geotechnics, Arizona State University, Tempe, AZ 85287

Background & Rationale
✧ MIDP occurs naturally & can change the geotechnical properties of a soil through cementation of the soil particles.
✧ Grain size particles dictate the rate in which matter can flow through a soil.

Research Objective(s)
✧ The goal of the project is to use a bio-mediated approach to desaturate soil for liquefaction mitigation.

Methods
✧ Permeability (K SAT device)
✧ Particle size distribution (Sieve test analysis)
✧ Soil Water Characteristic Curve
✧ Instrument tanks for MIDP
✧ Calibration of Instruments
✧ Pore pressure transducers
✧ Micro-tensiometers

Experimental Results
Particle size distribution from Sieve test using Ottawa 20-30 (in blue) and Ottawa F60 (in orange)

Materials

Conclusions
✧ Grain size distribution correlates with permeability
✧ Each of the pore pressure transducers should be calibrated individually
✧ The mixed denitrifying culture of microorganisms produces a gaseous by product

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