Microbiological Improvement of the Physical Properties of Soil

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CONTRIBUTIONS OF JAMES K. MITCHELL (1)

- Clay Fabric and Compacted Soil Properties
- Rate Process Theory and Stress-Strain-Time Behavior
- Electro-Osmosis and Chemical Osmotic Effects
- Clay Sensitivity and Bonding, Effective Stress and Strength
- Lunar Soil Mechanics
- Waste Fills

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CONTRIBUTIONS OF JAMES K. MITCHELL (2)

- Soil Liquefaction
- Stone Column Performance
- Aging in Clay and Sands
- CPT Interpretation
- Reinforced Soil Systems
- Soil Improvement by Blasting
- Seismic Risk Mitigation
CONTRIBUTIONS OF JAMES K. MITCHELL (3)

• BioGeotechnical Engineering

Biological Considerations in Geotechnical Engineering

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BioGeotechnical Improvement Processes that Operate on a Geological Time Scale

- Cementation of Granular Soils
  - Carbonate Cementation
  - Transformation of Sand to Sandstone

- Mineral Transformations
  - Smectite to Illite at High Temperature and Pressure

- Formation of the Desert “Varnish” (Crust)
BioGeotechnical Processes that Cause Adverse Effects in Engineering Time Frames

- Clogging of Drainage Systems in Dams, Landfills, and Waste Dumps
- Clogging of Water Treatment Plant Filters
- Fouling of Well Screens
- Formation of Mineral Scale on Pipes
The BioGeotechnical Challenge

• Accelerate beneficial processes to occur in a time frame of interest and/or
• Induce adverse processes in a context where the effect is beneficial
BioGeotechnical Improvement Processes and Applications

- Mineral Precipitation
  - Bearing Capacity, Settlement Control, Liquefaction Mitigation, Excavation Stability, Tunneling, *Carbon Sequestration* (?)

- Mineral Transformation
  - Soil Expansion Potential, Slope Stability

- Biopolymer and Biofilm Growth
  - Seepage Control, Subsurface Barriers, Corrosion, Erosion Control
Application of Microbiological Mineral Precipitation Processes to Engineering

• Advantages
  – Non-destructive, Non-Disruptive
  – Sustainable
  – Cost Effective

• Challenges
  – Understanding the Complex Processes
    Geo….., Chem……, Micro….., Hydro…..
  – May Need to Develop Site Specific Approaches
Precipitation Mechanisms

• Carbonate Precipitation
  – Hydrolysis of urea
  – Oxidation of organic compounds by sulfate-reducing bacteria
  – Oxidation of organic compounds by denitrifying bacteria
  – Oxidation of organic compounds consisting of carbon and nitrogen in a well-buffered media
  – Oxidation of nitrogen-rich organic compounds in unbuffered media
  – Microbial fermentation of volatile fatty acids
  – Removal of CO$_2$ from bicarbonate-containing solutions
ASU Denitrification Experiments

• First-stage experiments (complete)
  – Proof of Concept and Basis for Biogeochemical Models for Optimization Studies
  – *Pseudomonas denitrificans* (ATCC 13867)
  – 150 ml and 2.0 L Batch Reactors with Liquid Media
  – Periodic Sampling to Monitor pH, alkalinity, \([\text{NO}_3^-]\), \([\text{NO}_2^-]\), \([\text{Ca}^{2+}]\), and Headspace Gas Composition (\(\text{O}_2\) and \(\text{CO}_2\))
  – Studies on Effect of Electron Donor Type, Nutrient Limitations, Salt concentration.
ASU Denitrification Experiments

- Second-stage experiments (in progress)
  - Soil Column Experiments with ASTM 20/30 Ottawa sand
  - Steady-state Flow through Sand Column
  - Periodic Sampling to Monitor pH, alkalinity, $[\text{NO}_3^-]$, $[\text{NO}_2^-]$, and $[\text{Ca}^{2+}]$
  - Continuous Monitoring of Shear Wave Velocity using Bender Elements
Mineral Transformation

• Smectite (Montmorillonite) to Illite (Kim et al., 2004)
  – May Just be Reduction of Fe$^{3+}$ to Fe$^{2+}$ in Iron-Rich Clays (e.g. Nontronite)

Effect of ex-situ treatment with *Shewanella oneidensis* on swelling clay (Fowler, 2008)
In situ Improvement by Mineral Transformation

- Potential Pore Size Constraints

Comparative sizes of microorganisms and soil particles (Mitchell and Santamarina, 2005)

Considerations:
- Pore Size at the Wetting Front in Expansive Clays
- Use of Starved Bacteria and Nano Bacteria
Biopolymer Improvement

- Permeability Reduction – Bonnie Silt Compacted with Xanthan Gum (Karimi et al., 1998)
Biopolymer Improvement

• Martin et al. (1996): Bonnie Silt Compacted with Xanthan Gum in Triaxial Compression
Biopolymer Improvement

- **Corrosion Protection**
  - Significant increase in corrosion of steel and aluminum when protective biofilm was suppressed (Ruo et al., 2004)

- **Erosion Control**
  - Desert crusts develop due to photosynthetic biopolymer growth (Garcia-Pichel, 2002)
Important Issues to Consider

- Permanence/Reversability of Microbial Processes
  - Reversibility may be Beneficial
- Stimulating Microbes In Situ vs. Introducing Microbes to the Environment
- The Need to Add Nutrients and Source Minerals
- Delivery of Necessary Microbes and Nutrients
- Energy Consumption
- Environmental Impacts / Unanticipated Side Effects
- Public Acceptance
Conclusions

• Many Potential Applications of BioGeotechnical Processes for Soil Improvement
• Much Work to be Done to Realize this Potential
THANK YOU

• To the Audience
  – for Your Attention

• To Jim Mitchell
  - for Being Jim