Purdue Geotechnical Society Workshop, Friday April 11, 2025

Engineering the Ground: From Fundamentals to Applications

PRESENTATION ABSTRACTS

For more information on their presentations and related projects, please contact the presenters via email.

MORNING SESSION

Keynote Lecture by Raymond Franz, *Keller North America*
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PROJECT EXPERIENCES: WERE THE FUNDAMENTALS AND APPLICATIONS ALIGNED?

Several projects from the speaker's career will be reviewed for consideration. Examples will be presented that are intended to illustrate the successful, and unsuccessful, alignment of geotechnical fundamentals with project execution.
Our mandate as civil engineers is to provide solutions that safely and predictably meet the needs of society while stewarding precious resources.

In geotechnical engineering, when we align appropriate investment in understanding geotechnical risk factors with appropriate mitigation measures, performance can be predictable and economical.

When we do not ensure fundamentals and applications are properly connected, poor performance and /or squandered resources can result.
The presentation is intended to utilize case studies to provoke thoughtful reflection on your own approach to geotechnical analysis, design and construction for satisfactory outcomes.

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US 421 SLOPE STABILIZATION ON PINE MOUNTAIN USING A PERMANENT ROCK ANCHORED TIEBACK RETAINING WALL

Transportation infrastructure in the mountainous terrain of southeastern Kentucky is vulnerable to geohazards such as slope failures, rockfalls and bridge washouts as the result of major rainfall events. In February 2019, heavy rainfall triggered several geohazards, including a slope failure on US 421 near the base of Pine Mountain in southeastern Kentucky. The Kentucky Transportation Cabinet (KYTC) worked with the Federal Highway Administration (FHWA) to develop a mitigation method that would be eligible for FHWA Emergency Relief (ER) funding. If the slope failure and/or repair operations had resulted in the closure of US 421 a detour of around 50 miles [80 km] would have been required.

The KYTC Geotechnical Branch performed a subsurface exploration, tested soil and bedrock samples, monitored slope displacements and groundwater levels, and performed engineering analyses. KYTC subsequently estimated that the sliding mass was approximately 800 feet [244 m] by 700 feet [213 m] horizontally with an elevation difference of about 300 feet [91 m] and had a maximum thickness on the order of 45 feet [14 m]. KYTC and FHWA agreed that a permanent rock anchor tieback retaining wall with soldier piles anchored into bedrock would be acceptable to stabilize the slope. The design relied on soil arching between the soldier piles and horizonal drains to lower the groundwater table. This method allowed KYTC to maintain traffic and avoid a detour during stabilization efforts.

Construction contract documents included geotechnical data, wall geometry, design loads, and performance-based specifications that required a qualified specialty contractor to design and construct a permanent rock anchored tieback retaining wall to stabilize the slope. KYTC administered the construction contract for the approximately $6 million project that was constructed in 2021 and 2022.

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REDEVELOPING TORONTO'S WATERFRONT: A MULTI-DISCIPLINARY CASE STUDY

The City of Toronto is reshaping and revitalizing its waterfront in one of the largest ongoing urban redevelopment projects in North America. The 800-acre Port Lands Flood Protection redevelopment includes naturalizing a kilometer-long stretch at the mouth of the Don River, which has become a source of flooding as the city has built around it. Constructing a new river valley involves multi-staged excavations up to 7 meters below Lake Ontario in alluvial sediments that have been impacted by historical industrial use.

The presentation will provide an overview and touch on several geotechnical aspects of the project, including: over a mile of secant pile, slurry wall, and diaphragm cutoff walls, extending up to 140 feet below ground surface; the geoenvironmental barrier beneath the new river that prevents migration of impacted sediments and improves water quality; improvements to flood resilience and sustainability; and challenges related to construction, sequencing, and logistics.

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USE OF WICKING GEOTEXTILE TO DEHYDRATE ROAD EMBANKMENT UNDER UNSATURATED CONDITIONS

A pavement structure is often built with soils compacted at their optimum moisture contents. The surface soils are exposed to the surrounding atmospheric environment with relative humidity of less than 90%. Such a relative humidity corresponds to a suction value of 14 MPa. All soils become air-dry under such high suction and have very low permeability (nearly impermeable) to transport water from inside to outside. In the meantime, the soils inside the pavement structure tend to reach equilibrium with the ground water table through capillary rise. When surface soils are air-dry and have cracks, they have high permeability for water infiltration. As a result, the soils inside the pavement structure are often wet or have tendency to become wet with time. Increase in soil moisture content often means deteriorating performance. Research indicates when moisture contents of the soil increase from 3.3% to 6%, the resilient moduli for Alaska D-1 materials are at least reduced 50%.

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COASTAL GROUND IMPROVEMENT VIA ELECTRODEPOSITION

Coastal areas suffer from the disappearance of beaches and the disintegration of civil infrastructure due to soil erosion. Current approaches to mitigate soil erosion suffer from drawbacks, calling for new solutions. This paper summarizes the results of a research program developed at Northwestern University to explore the largely uncharted feasibility of utilizing mild electric stimulations to precipitate naturally dissolved minerals in the pore water of soils into solid forms for cementation. This work shows that such an approach, widely known as electrodeposition, can instantaneously trigger binding mineral precipitations in the structure of soils wetted by ion-rich solutions. The application of electrodeposition to marine soils wetted by seawater enables the precipitation of solid minerals of calcium carbonate and magnesium hydroxide that turn these soils into soft rocks. Utilizing this electrochemical phenomenon through yet-to-be-developed technologies promises to offer a valuable alternative or complementary process to support existing ground improvement methods.

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LOCKED AND LOADED: *AB INITIO* EXPERIMENTS ON COHESIVE INCLUSIONS IN GRANULAR MEDIA

One of the most common techniques employed in ground improvement is the addition of cements or cohering agents to soft clays or low relative density sands in order to enhance their strength and stiffness. Typically cementing agents such as ordinary Portland cement, lime, gypsum etc have all been used for improvement of soil strength. While optimal design strategies have evolved predominantly based on macro / continuum scale experiments an understanding of the microscale.

It is well documented that the amount of cohesion, confining pressure, and void ratio / density control the ensemble mechanical response of any cohesive-granular material. However, at the microstructural scale – the particle arrangement (fabric) and the cohesive bonds control the behavior. The results of a series of photoleastimetry experiments which were performed to investigate the microstructural manifestations of this artificially introduced cementation between particles will be presented. In this series of photoelasticity experiments we carefully parse the influence of fabric and the amount of interparticle cohesion. The fabric influence was controlled by recreating the exact same fabric for all the experiments (i.e. locking in the fabric), enabling a critical examination of the influence of interparticle cementation on the ensemble. A series of biaxial experiments were performed on these model cohesive granular materials with cohesive diads placed in random locations throughout the ensemble. These cohesive diads show interesting properties and act as sinks to force chains. This locked in fabric allows a clear delineation of changes in several other microstructural facets such as coordination number, particle fabric etc. The experiments reveal very interesting facets of the landscape of force propagation in the presence of cohesion, and provides extraordinary insights into the microstructure of composite soils, and sedimentary rocks. It also provides an ab-initio understanding of the stress-force fabric relations in materials such as cemented sands.

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BIO-CEMENTATION OF SANDS: A GRANULAR PERSPECTIVE

Bio-cementation is a promising method for the mitigation of liquefaction in loose saturated sands. In this improvement process a bacterium that can be found naturally in soil deposits is fed urea. The bacterium consumes and breaks down the urea to form ammonium and carbonate. In the presence of calcium, calcium carbonate will precipitate and act as a cementitious agent to solidify the deposit. The precipitate increases the particles' surface roughness and contact area, resulting in improvement of engineering properties of soil such as stiffness and shear strength.

A new approach for modeling bio-cemented sands using the discrete element method (DEM) is presented. Strings of calcite 'particles' are used to bond sand grains via glued contact points. The scheme prevents sliding and separation and transmits moment at cemented sand-sand contacts. Bonds break gradually depending on the geometry of the stress transmission through the assembly. During de-cementation, fragments of calcite are generated, occupy the pore space, and continue to affect overall system response. Calibration of the numerical model to the laboratory results of triaxial tests of Ottawa 50-70 sand and bio-cemented Ottawa 50-70 sand is done using a new membrane model. This membrane model uses a simple algorithm of an array of independently controlled walls and is computationally efficient. We will show that the calcite contributes to the load transmission within a bio-cemented sand specimen at a microscale level.

AFTERNOON SESSION

Keynote Lecture by Chadi El Mohtar, *University of Texas, Austin*
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EXPLORING GROUT TESTING LIMITATIONS AND OPPORTUNITIES FOR ENHANCING GROUND IMPROVEMENT IMPLEMENTATIONS

Grouting has been widely used for decades as a cost-effective ground improvement technology, enabling geotechnical engineers to strengthen soils and effectively control groundwater flow. While grouting can be a highly valuable solution, the success of a project depends heavily on the design of an appropriate grouting program. A well-planned approach can mean the difference between a successful outcome and costly, ad-hoc repairs.

However, current grout design practices often fall short of providing a robust objective design. Geotechnical investigations are rarely tailored specifically for grouting, and final designs frequently rely on a mix of rules of thumb, index tests, outdated charts, and past project experiences. Many of these index tests were originally developed for other fields and were never intended for materials with the unique properties of grout.

This presentation explores recent research on grout characterization testing, highlighting potential biases and limitations associated with these methods and opportunities for enhancing ground improvement implementations.

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DYNAMIC COMPACTION: A PROVEN GROUND IMPROVEMENT ALTERNATIVE FOR LANDFILL MATERIALS

During the past 40 years, ground improvement has become an important tool for the geotechnical community, as the number of sites with suitable bearing soils become fewer and farther between. Similarly, as time moves on, more and more sites come into focus for development that have received any number of various landfill materials, be it municipal solid waste (MSW) from households, construction and demolition (C&D) debris from construction activities, or simply soil materials exported from another site. As a result, the challenges to engineers and contractors to design and construct new developments within budget and on time continue to increase.

Dynamic compaction is a ground improvement technique that has been used more frequently to improve in-place landfill materials to a point where vertical construction can proceed without excessive long-term settlements. On sites where dynamic compaction is used, alternative methods of post-improvement evaluation have become more common, given the number of below-grade obstructions at a site that typically prohibit standard drilling approaches. Embankment load testing, plate load testing, and where applicable, post-improvement drilling are all techniques that have been used successfully to evaluate the effectiveness of dynamic compaction programs, as outlined by the three case studies discussed herein.

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INDIGENOUS BACTERIA-DRIVEN SOIL STABILIZATION: A BIOINSPIRED MICROBIALLY INDUCED CALCITE PRECIPITATION APPROACH FOR EXPANSIVE SUBGRADES

Microbially Induced Calcite Precipitation (MICP) has gained significant attention as a bioinspired technique for improving soil properties, particularly in mitigating challenges posed by expansive clays. This study explores the potential of biostimulated MICP for enhancing the engineering properties and long-term durability of clayey soils under freeze–thaw conditions, which are critical for road pavement applications.

Comprehensive macroscopic and microscopic analyses are conducted on untreated and biostimulated clayey soils to evaluate the treatment's efficacy. The investigation includes assessments of plasticity, mineralogical composition, chemical characteristics, and strength properties. Unconfined compressive and split tensile strength tests are performed on biocemented specimens, alongside chemical analyses such as pH, electrical conductivity, and calcite content, to understand the transformation in soil properties.

To examine durability, biocemented specimens are subjected to repeated freeze–thaw cycles (2, 4, 6, 8, and 10 cycles), monitoring the evolution of strength and chemical characteristics at each stage. Microstructural analysis further elucidates the role of calcite distribution and structural modifications induced by MICP. The results reveal that biostimulated MICP significantly increases calcite content, achieving up to a 205% improvement, which directly enhances soil strength. The uniform distribution of calcite contributes to consistent biocementation, ensuring durability under freeze–thaw cycles. This study highlights the potential of MICP as a sustainable solution for soil stabilization, offering improved strength and durability without disrupting the natural soil ecosystem. The findings underscore its applicability in road pavements and other geotechnical engineering projects, addressing challenges related to expansive soils and freeze–thaw conditions. This investigation contributes essential knowledge toward the practical implementation of biostimulated MICP in civil engineering projects, offering sustainable solutions for soil improvement in the field of geotechnical engineering.

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MITIGATION OF EMBANKMENT FILL SLOPE MOVEMENT ON THAW-SENSITIVE PERMAFROST AT LOST CREEK ALONG THE TRANS-ALASKA PIPELINE SYSTEM

This presentation will focus on the design and performance of the Lost Creek Thermal Improvements project, which addressed slope movement and landslide risk at a site along the Trans-Alaska Pipeline System. The pipeline at Lost Creek traverses a north facing slope with discontinuous, warm permafrost underlain by a frozen peat bog. This peat layer contains a shear zone that moves as the permafrost degrades, causing the pipeline's vertical support members to tilt, which required expensive maintenance. The presentation will describe the design process for a system of vertical passive thermosyphons (FSHPs) and woodchip surface insulation to cool the permafrost and mitigate these risks. The use of 3D finite element thermal modeling to optimize the design of the FSHPs and insulation layout will be described. The presentation will conclude with a summary the system performance to date as measured by in situ thermistor strings and inclinometers, and a comparison of measured temperatures versus model predictions

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TWO- AND THREE-DIMENSIONAL FINITE ELEMENT FREEZING BEHAVIOR OF COMPLEX FROZEN SOIL GEOMETRIES

Artificial ground freezing (AGF) is often a ground improvement method of choice for situations when geometries of subsurface structures are complex, excavation depth is well below the ground water table, and soil conditions are favorable for soil freezing. Two-dimensional finite element thermal analysis of representative cross sections is the common industry procedure for AGF operations. However, using three-dimensional finite element programs to perform thermal design simulations may have advantages, particularly when dealing with complex frozen geometries. Three-dimensional models could be used to validate two-dimensional model results, help refine freezing pipe alignments for optimal development of the frozen barrier and provide higher accuracy when estimating energy consumption.

This presentation will review a subway tunnel project where AGF ground improvement was used to stabilize soils for the construction of a crossway passage. After a brief introduction of AGF methods and project overview, this presentation will compare three-dimensional transient thermal modeling results to a two-dimensional thermal design analysis results and actual performance data obtained during construction. The modeled geometry is an inner-city crossway-passage between two separate tunnel segments connected in coarse grained soils below the water table. The programs used for two-/and three-dimensional thermal modeling are GEOSLOPE – Temp/W and ABAQUS/Standard, respectively. Both models evaluate the artificial development of a frozen soil barrier around the structure's geometry in reference to technical aspects such as temperature and structural thickness, as well as economic impacts, such as energy consumption and required project duration based on temperature development. The thermal results of the finite element models were compared to data obtained in-situ during the construction project.

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THE UNINTEDED CONSEQUENCES OF SOIL FREEZING: DEATH, DESTRUCTION AND IMPACTS OF EXPLOSIONS CAUSED BY LEAKING GAS PIPELINES

Natural gas explosions resulting from leaky pipelines pose significant risks to public safety in the United States. On average, about 125,000 residential gas leaks and 4,200 gas-ignited home fires occur annually, with nearly 300 causing explosions leading to property damage, severe injuries, or fatalities. While geotechnical engineers often focused on the impacts of freezing on soil compressibility and strength, or the resulting decrease in permeability from reductions in effective soil porosity, not as much attention has been paid to the impact that soil freezing has had on the migration patterns of gas releases that occur in the subsurface. In this presentation, a case history will be used to illustrate a ‘failure’ analysis that determined the cause of a devastating explosion that destroyed a residential home, killing one of its family members. The analysis methodology used a combination of analytical solutions to recreate the behavior of the gas migration into the home: 1) the classic freezing Stefan problem, 2) a new analytical solution for the migration of gas away from a punctured pipeline under pressure, and 3) an air mixing model that allowed for the concentration of the gas to build up to explosive levels over time as it entered the pervious basement wall.

The explosion was ultimately linked to a faulty natural gas pipeline that had developed a small but persistent leak after excavation occurred near the pipeline. Over time, gas accumulated in the surrounding soil, and when the ground froze, it created a seal, shutting off the vertical migration of the gas and enhancing its horizontal displacement toward and into the house. The investigation into this incident used a combination of physical evidence, forensic analysis, and expert testimony to prove the cause of the explosion. The predicted gas concentrations and timing of the explosion by the analysis provided conclusive evidence of a leak from the pipeline, and resulted in a substantial financial settlement by the responsible parties.