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EDITORIAL BOARD

Research highlights

Geotechnical Engineering Research at Purdue University

Purdue University, West Lafayette, is a public institution founded in 1869. Purdue offers more than 200 majors for undergraduates, over 69 masters and doctoral programs, and professional degrees in pharmacy and veterinary medicine. Purdue is classified as an R1 university (a "Doctoral University" with "very high research activity"). Purdue has produced 25 astronauts as of April 2019, including Neil Armstrong. Purdue has been associated with 13 Nobel Prizes. Purdue's Geotechnical Engineering program has a long tradition that is celebrated every year with two endowed lectures in honor of previous faculty members: the Lovell Lecture in the fall semester and the Leonards Lecture in the spring. The program, which is housed in the Lyles School of Civil Engineering, has a strong emphasis on doctoral-level research. The five faculty members—Professors Antonio Bobet, Monica Prezzi, Rodrigo Salgado, Marika Santagata and Joe Sinfield—are involved in research covering a broad range of areas. Research is connected to centers (listed at the end) or to individual faculty member laboratories.

Research at the Center for Offshore, Foundation and Energy Engineering (COFFEE)

Prof. Rodrigo Salgado
Co-Director of the COFFEE

Ph.D. in Civil Engineering, University of California, Berkeley, 1993

M.S., University of California, Berkeley, 1990

Civil Engineer, UGRGS, 1986

Dr. Rodrigo Salgado is the Charles Pankow Professor in Civil Engineering at Purdue University. Dr. Salgado is the author of the text *The Engineering of Foundations*

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

and the Editor in Chief of the ASCE J. of Geotech. and Geoenv. Engrg. Dr. Salgado has been the recipient of the ASCE Arthur Casagrande Award, the ASCE Huber Research Prize, the IACMAG Excellent Contributions Award, the Prakash Research Award, the Geotechnical Research Medal (2015) from the Institution of Civil Engineers (ICE) and the Outstanding Reviewer Award from Elsevier for his work for Computers and Geotechnics (2015 and 2017). Dr. Salgado's interests lie in geomechanics, computational mechanics, constitutive modeling and offshore engineering.

Prof. Monica Prezzi
Co-Director of the Center for Offshore, Foundation and Energy Engineering
Ph.D. in Civil Engineering, University of California, Berkeley, 1995
M.S., University of California, Berkeley, 1995
M.Eng., UFRGS, 1990
Civil Engineer, UGRGS, 1986

Dr. Monica Prezzi is a Professor of Civil Engineering at Purdue University. She received the Deep Foundations Institute (DFI) Young Professor Paper Award for her work on auger cast-in-place and drilled displacement piles in 2005. In 2011, Dr. Prezzi received from the Institution of Civil Engineers (ICE) the Telford Premium for their paper on theoretical analysis of PVDs. In 2015, Dr. Prezzi was recognized with the ICE Geotechnical Research Medal for the best geotechnical engineering paper published in Géotechnique in 2014 on the use of Digital Image Correlation (DIC) in the experimental study of complex boundary-value problems. Dr. Prezzi is currently doing research on image analysis applications to geomechanics, analysis and design of piles, particle morphology and crushing, and utilization of recyclable materials in civil engineering.

Current research topics

Directed by Professors Rodrigo Salgado and Monica Prezzi, the Center for Offshore, Foundation and Energy Engineering (COFFEE) at Purdue University has been actively contributing in research areas of computational geomechanics, advanced image techniques, offshore engineering, foundation engineering (both on and off-shore) and innovative energy engineering applications.

1 Advanced Computational Geomechanics

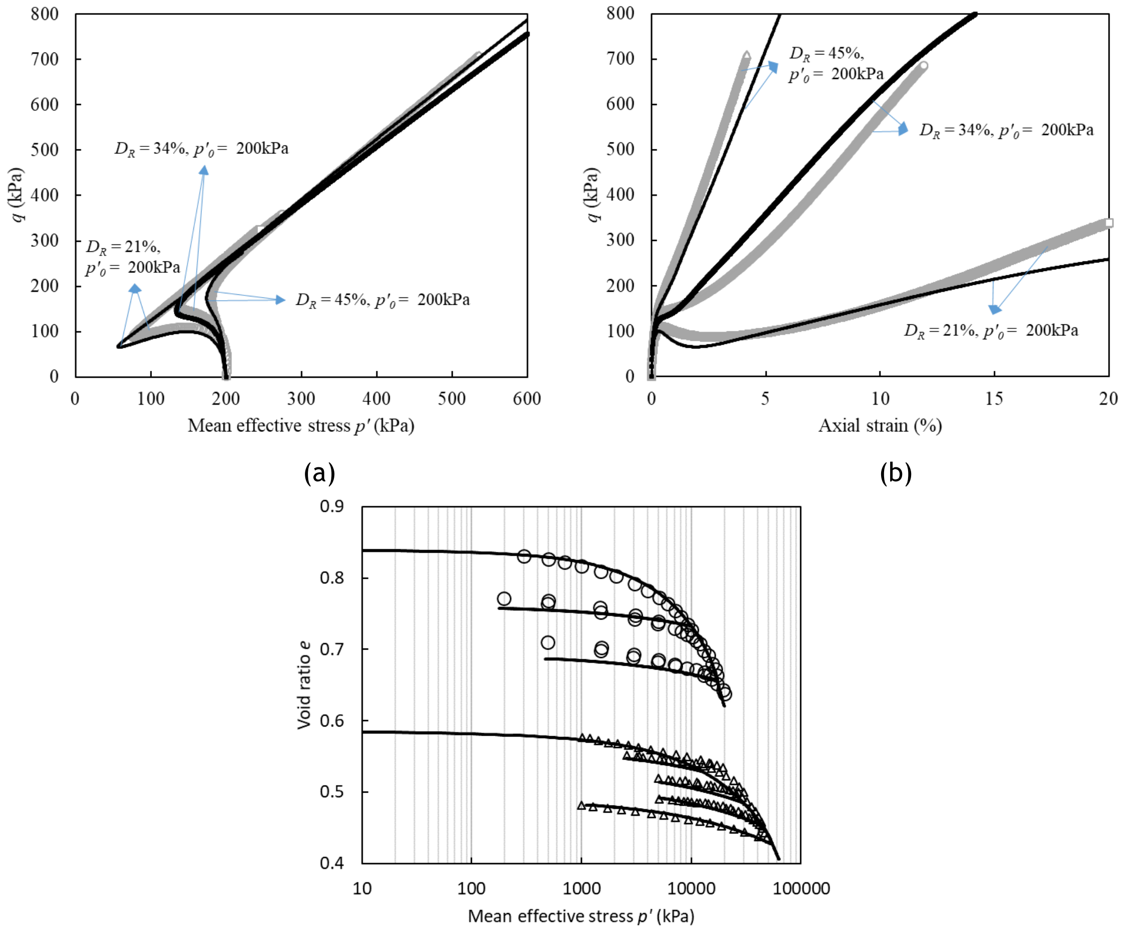
1.1 Development of realistic constitutive models for sand and clay

Student currently working on this topic: Jeehee Lim

Researchers at COFFEE have been continuously developing and perfecting realistic and rigorous constitutive models for sand and clay following the framework of critical-state soil mechanics. Based on two-surface plasticity, the first generation of the sand model [1] captures the peak strength and dilatancy response of sand as a function of relative density, confining pressure and initial fabric. The first generation of the clay model [2] also uses two-surface plasticity to capture the mechanical response of clay under different loading paths. In addition, the clay model uses a cap bounding surface to capture the mechanical response of clay in consolidation. The second generation of the sand model [3] was developed to capture the evolution of fabric under shearing and its effect on the mechanical response of sand. To be applied in large-deformation boundary-value problems (BVPs), the third generation of the sand model has recently been developed based on the laws of thermodynamics [4,5], the principle of material frame indifference [6,7], the self-consistency criterion [8-10], and the yielding stationary principle [10,11]. It also uses a cap bounding surface to capture sand response under consolidation. Figure 1 shows the performance of the third generation of the sand model under shearing and compression. Currently, COFFEE researchers are developing a new generation of soil models that capture the response of soil to cyclic loading.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University



(c)

Figure 1 Performance of the third generation of the sand model developed at COFFEE: (a) and (b) comparison between experimental data [12] (grey symbols) and model predictions (black lines) for undrained triaxial compression tests of dry-deposited Toyoura sand; (c) comparison between experimental data [13–15] (hollow symbols) and model predictions (solid lines) for isotropic compression tests on initially loose and dense samples (with D_R = 37% and 100%)

Related references: [1–3,16,17]

1.2 Large deformation simulations using the Material Point Method (MPM)

Student currently working on this topic: Vibhav Bisht

At COFFEE, an in-house Material Point Method (MPM) [18] code has been developed to simulate large deformation geotechnical boundary-value problems. The MPM code was constructed with a focus on (1) efficiency and (2) robustness. Efficiency is achieved in various ways, including use of a structured irregular background grid [19] that minimizes the time required for the element search operation. Additionally, computationally heavy methods can be run in parallel to minimize run time. Robustness is achieved through use of rigorous computational schemes. An explicit time integration scheme is used to minimize convergence issues commonly encountered in implicit integration with non-linear materials. Stress integration of the constitutive model is performed using the robust adaptive sub-stepping scheme proposed by Sloan [20].

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

Currently, the MPM code is being used to simulate cone penetration in Toyoura sand. An advanced two-surface constitutive model is used to ensure that the obtained soil response is realistic. Figure 2 shows the contours of the vertical displacement in sand around the cone penetrometer advanced to different depths.

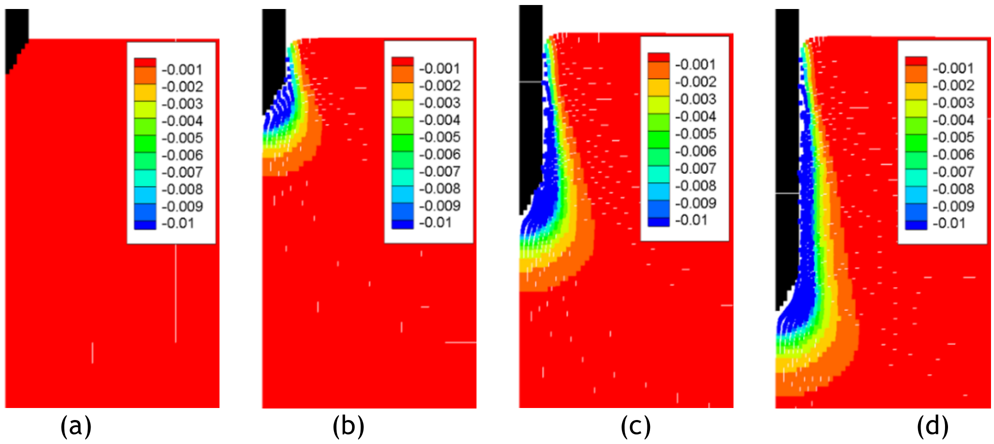


Figure 2 Vertical displacement contours in sand around the cone penetrometer simulated using the material point method, at a penetration depth of: (a) 0.5 d_{cone}; (b) 1.5 d_{cone}; (c) 3.5 d_{cone}; and (d) 5.5 d_{cone}

Related references: [19,21,22]

1.3 Rigorous Finite-Element (FE) analyses of geotechnical BVPs

Postdoc and student currently working on this topic: Fei Han and Qian Hu

Using realistic two-surface constitutive models, COFFEE researchers have been performing rigorous Finite-Element (FE) simulations of footings, walls, single piles and pile groups installed in sand/clay subjected to axial, lateral and combined loading [23–28]. The mesh used in the FE analyses are carefully prepared so that the FE analysis captures the formation of shear bands realistically in soil. These high-quality FE analyses have laid the theoretical foundation of the Purdue pile design methods and continue to shed light on the relationship between the global response of the soil-structure system and the behavior of soil elements.

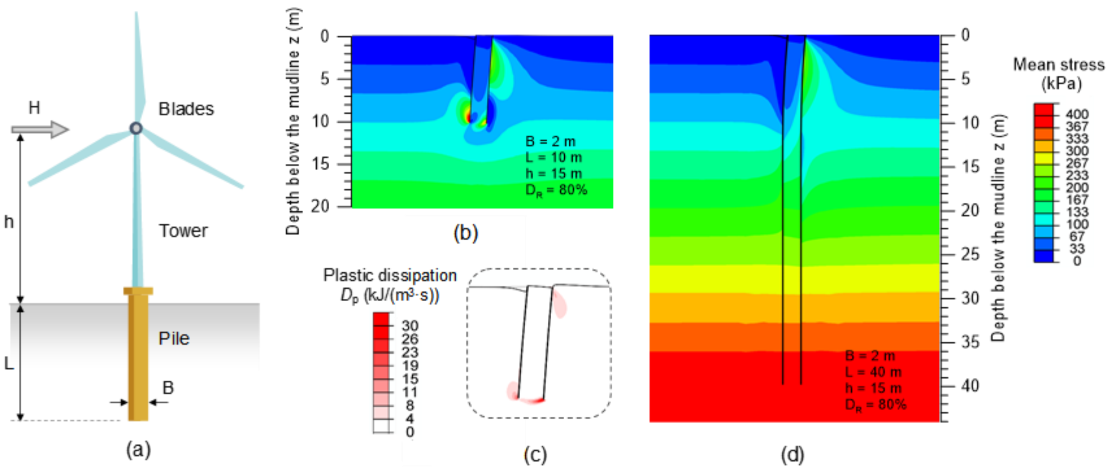


Figure 3 Finite-element analysis of laterally loaded monopiles: (a) a typical laterally loaded monopile supporting a wind turbine; (b) contour plots of the mean stress in sand for a 2-m-diameter monopile with L = 10 m (L/B = 5); (c) plastic dissipation in the sand for a 2-m-diameter monopile with L = 10 m (L/B = 5); (d) mean stress in sand for a 2-m-diameter monopile with L = 40 m (L/B = 20). Both piles are embedded in dense sand (D_R = 80%) and loaded at h = 15 m to a pile rotation of 1° at the mudline.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

As an example, a series of rigorous FE analyses of laterally-loaded monopiles were performed covering a wide range of pile dimensions, load eccentricities, sand relative densities, and layering of the soil profile [23]. The analyses revealed the different responses and deflection modes of short, stiff piles and long, slender piles subjected to lateral loads, as shown in Figure 3. Based on the analysis results, design equations were proposed for calculation of the lateral capacity of monopiles in sand that produce estimates that are in very close agreement with the FE results.

Related references: [23–33]

2 Advanced Image Techniques in Geotechnical Engineering

2.1 Digital Image Correlation (DIC) analysis of penetration experiments

Students currently working on this topic: Eshan Ganju, Ayda Catalina-Galvis Castro, Firas Hashem, Rameez Raja, and Juliana Pereira

The penetration problem contains virtually all the challenges that geomechanicians may face, i.e., large displacements, large rotations, large strains, strain localization, crushing, and a moving soil-metal boundary. To better understand the penetration processes in sands, COFFEE researchers carry out penetration experiments in a unique half-cylindrical calibration chamber with observation windows that allow the collection of images of the sand and penetrometer during penetration. Figure 4 shows the DIC calibration chamber. As the penetration experiment progresses, a sequence of images of the sand and advancing penetrometer (see Figure 5a and Figure 6a for examples) is captured and then analyzed using the Digital Image Correlation (DIC) algorithm to obtain displacement and strain fields in the sand domain [34–36].

Ongoing research at the center focuses on the visualization of displacement fields, strain fields and shear band patterns around deep and shallow foundations. Recent research findings have shown that the displacement and strains are highly localized near the surface of deep foundations or cone penetrometers (see Figure 5c), whereas localizations are observed for shallow foundation (flat footings) not only near the surface of the shallow foundation, but also away from it (Figure 6c). Other ongoing work on DIC analysis at the Center includes the effect of particle morphology and particle strength on the penetration resistance in sands and the effect of cyclic loading on the capacity of deep foundations. The data generated from the DIC analysis will serve as a useful benchmark for validation of numerical simulations of the penetration process in both deep and shallow environments.

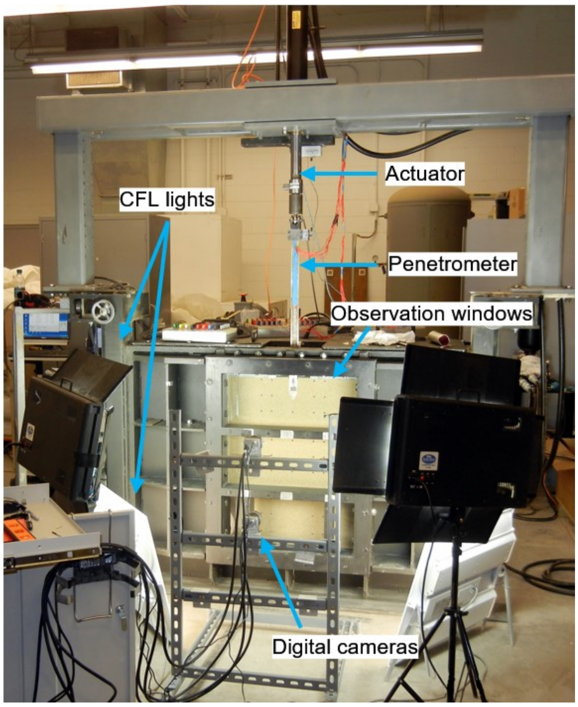
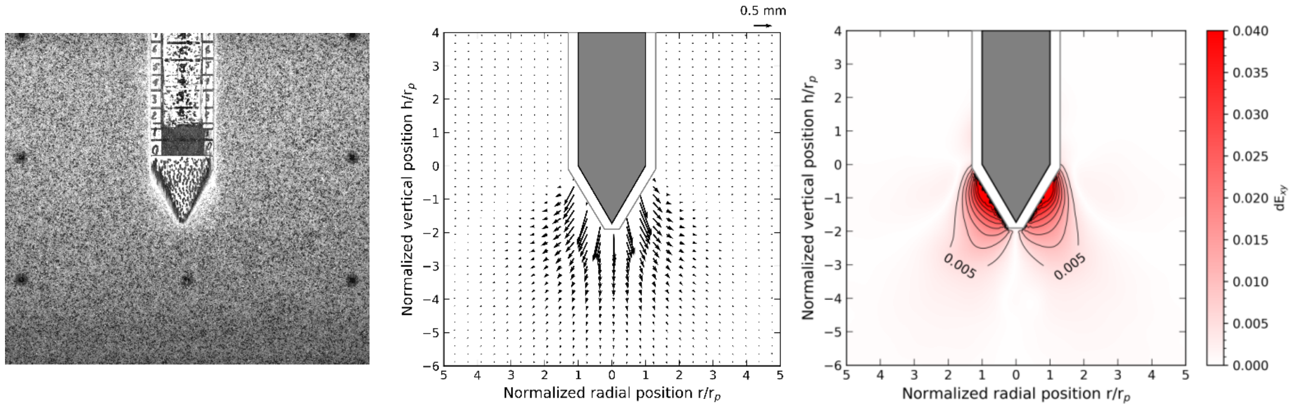


Figure 4 Experimental setup: the half-cylindrical calibration chamber with three observation windows, and digital cameras positioned in front of it for image acquisition [37]

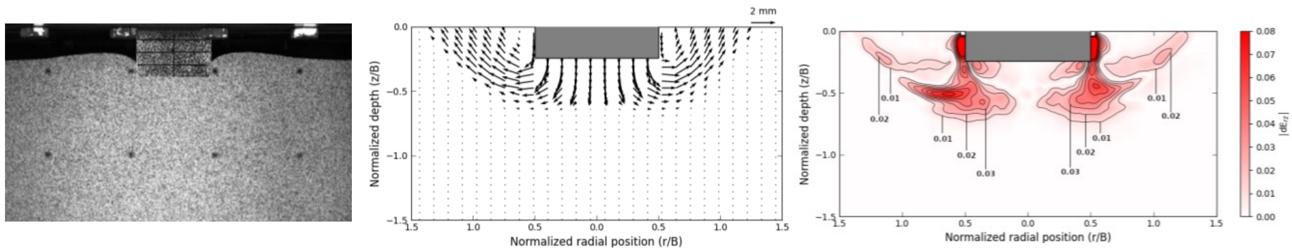
Research highlights (Con't)

Geotechnical Engineering Research at Purdue University



(a) (b) (c)

Figure 5 DIC calibration chamber experiment on deep penetration: (a) high-resolution image taken during penetration; (b) displacement vectors; (c) heatmap and contours in-plane shear strain in the sand domain ([37,38])



(a) (b) (c)

Figure 6 DIC calibration chamber experiment on shallow penetration: (a) high-resolution image taken during penetration; (b) displacement vectors; (c) heatmap and contours in-plane shear strain in the sand

Related references: [34,37–47]

2.2 Analysis of CT-scan images of undisturbed samples to quantify crushing

Students currently working on this topic: Eshan Ganju and Mustafa Kilic

Particle crushing plays an important role in the development of penetration resistance. To quantify the crushing around a penetrometer, COFFEE researchers use X-ray CT scans of undisturbed samples extracted around the cone penetrometer at the end of the penetration experiments. Agar, a biopolymer, is used to extract undisturbed soil samples that are then scanned in a high-resolution X-ray CT scanner. This provides "3D images" of the sand around the cone penetrometer. Subregions can then be extracted from within the 3D images of the sand samples and analyzed using a watershed segmentation algorithm to obtain the sizes of the sand particles. In this manner, researcher at COFFEE are able to quantify the particle-size distribution and particle crushing around the cone penetrometer [37]. Figure 7 shows the broad outline of the procedure followed to quantify crushing. Ongoing research at the center is focused on developing the analysis method to quantify the particle morphology, inter-particle contact, and fabric.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

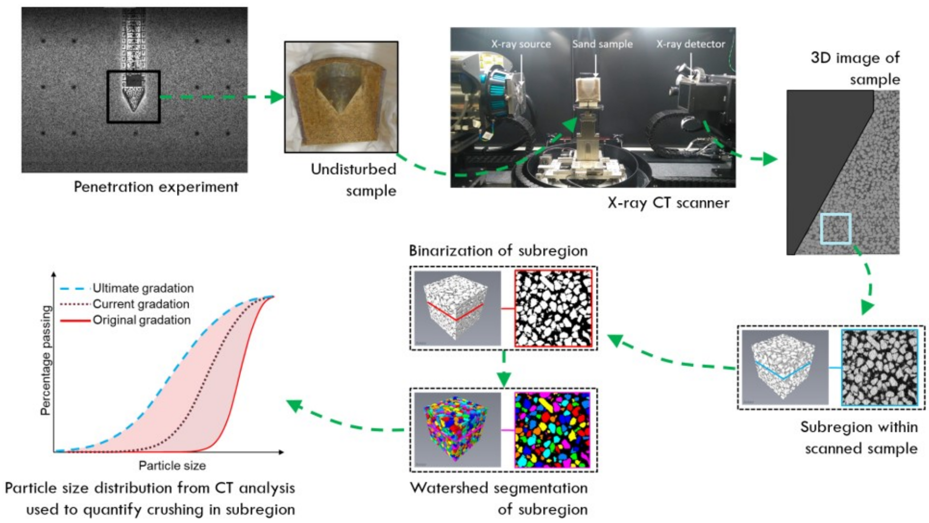


Figure 7 Summary of the procedure followed to quantify the crushing of particles around a penetrometer in a deep penetration environment

Related references: [37,38]

2.3 Analysis of 3D images during 1D compression to quantify fabric evolution

Students currently working on this topic: Eshan Ganju and Mustafa Kilic

Fabric plays a major role in the mechanical behavior of sands. To better understand how the fabric of sands evolves during loading, researchers at COFFEE perform 1D compression experiments in a special loading frame positioned inside an X-ray CT scanner. The scanner allows ones to capture 3D images of the sand *in situ* as it is being loaded. X-ray CT scans at multiple load levels are performed and then analyzed to obtain the particle-size distribution and fabric of the sample. The fabric of the sand is quantified by identifying the inter-particle contact normals between particles following the procedure outlined in [48]. Ongoing research at COFFEE aims to study the effect of the sand particle morphology and relative density on fabric evolution during loading. The objective of this research is to make meaningful measurements of fabric that can be used in the development of realistic constitutive models of sand. Figure 8 shows the outline:.

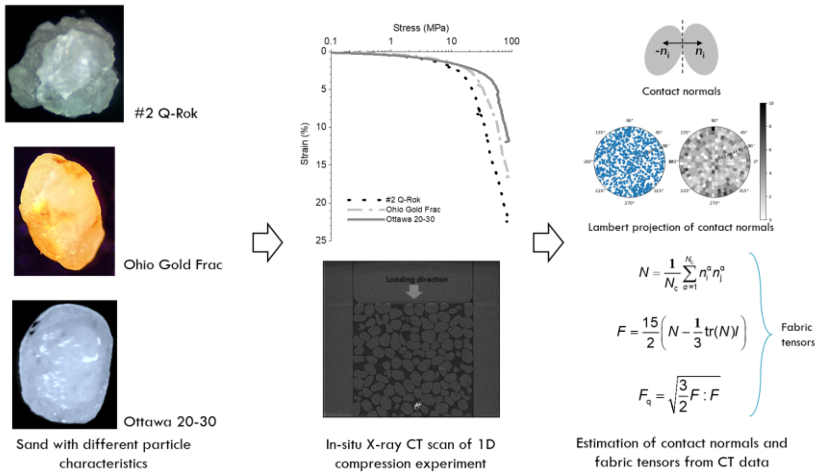


Figure 8 The scheme to quantify fabric evolution in sand during 1D compression accounting for difference in particle characteristics

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

3 Large-Scale Field Testing with Instrumentation

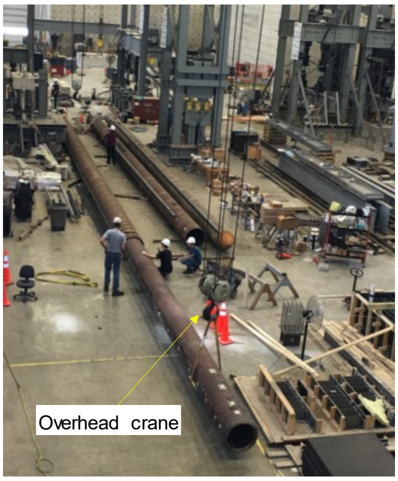
3.1 Static and dynamic testing on open-ended and closed-ended pipe piles

Postdoc and student currently working on this topic: Fei Han and Eshan Ganju

Closed-ended and open-ended pipe piles are often used as the foundation of buildings and bridges to transfer the superstructure load to the soil. COFFEE researchers have successfully performed a series of dynamic and static load tests [49–56] on heavily-instrumented piles with the following objectives:

(1) study the load-settlement response of closed-ended and open-ended pipe piles;
(2) relate the observed pile responses to soil data obtained through *in situ* and laboratory testing;
(3) understand how plugging develops during driving of open-ended pipe pile and how plugging affects the pile's axial capacity;
(4) validate and improve pile design methods.

As an example, in conjunction with the construction of the Sagamore Parkway Bridge in West Lafayette, Indiana, USA, a 26-inch-diameter, 100-ft-long, open-ended pipe pile was driven and load tested at the construction site to provide guidance for the foundation design [55]. The test pile was instrumented using a double-wall system, which consists of two concentric steel pipes connected on the top end. The two pipes were first instrumented separately and then assembled by sliding the inner pipe into the outer pipe (as shown in Figure 9a). The assembly of the double-wall pile was challenging, as it required tremendous care to ensure concentricity of the two pipes without damaging any of the strain gauges or their cables, given that the clearance between the two pipes was minimal. The double-wall instrumentation allowed independent measurements of the mobilization of the outer shaft, inner shaft (plug) and annulus resistances as a function of the pile-head settlement during the static load test (see Figure 9c). With more than 100 sensors installed on both pipes, a detailed profile of the locked-in residual load during driving, and the axial load and unit shaft resistance distribution during static loading were obtained. The complete dataset, consisting of full soil profile characterization, continuous measurement of plug formation, and detailed pile resistance measurements, advances the understanding of the effect of plugging on pile resistance mobilization, provides benchmark data for numerical analysis, and serves as the basis for the development and validation of pile design methods.



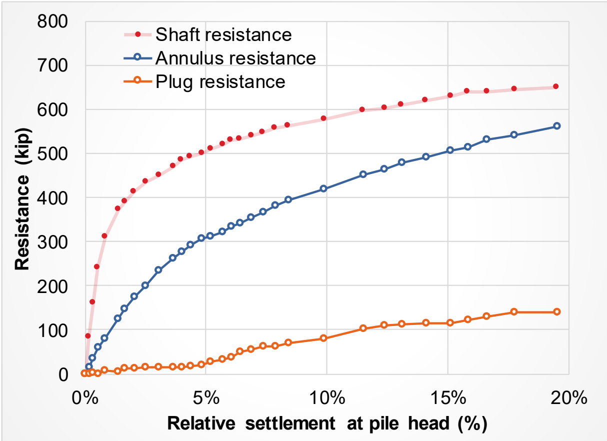
(a)

(b)

Figure 9. Static and dynamic load tests on large-diameter open-ended pipe pile: (a) assembly of the double-wall system; (b) on-site operations at the end of pile installation;

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University



(c)

Figure 9(c) development of the three resistance components (shaft, annulus, and plug resistances) of the open-ended test pile obtained from the static load test

Related references: [49-62]

3.2 Long-term monitoring of bridge and foundation under dead and live loads

Postdoc and student currently working on this topic: Fei Han and Mehdi Marashi

The Sagamore Parkway Bridge consists of twin parallel bridges over the Wabash River in Indiana, USA. The old steel-truss eastbound bridge was demolished in November 2016 and replaced with a new seven-span concrete bridge. During bridge construction, one of the bridge piers and its foundation elements were selected for instrumentation for monitoring the long-term response of the bridge to dead and live loads [63]. As shown in Figure 10, sensors were installed in the bridge pier and on all of the fifteen piles supporting it. The main goals of the project were:

(1) to compare the estimated loads (dead and live loads) in bridge design with the measured loads;
(2) to study the transfer of the superstructure loads to the foundation and the load distribution among the individual piles in the group.

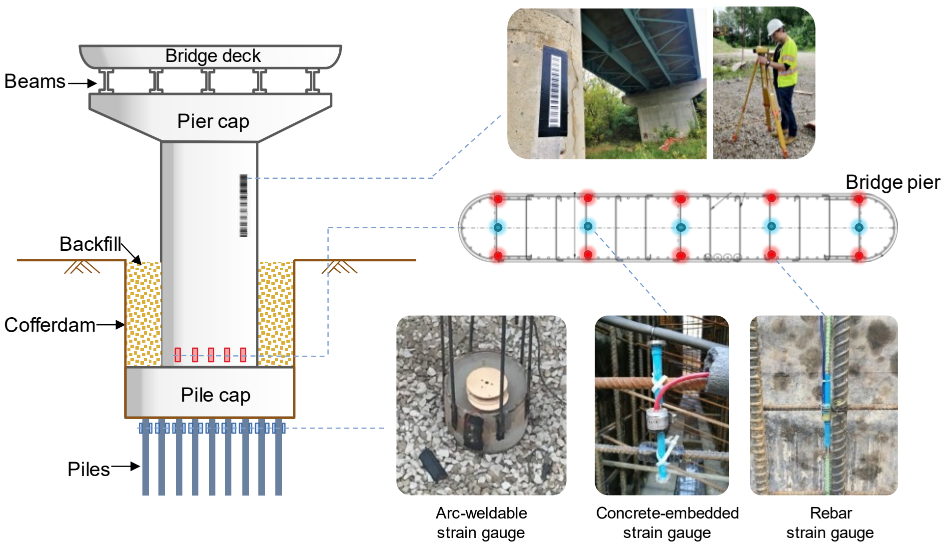


Figure 10 The instrumentation scheme for measurement of bridge pier settlement and load transfer from the superstructure to the foundation elements

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

The pier settlement and the dead load transferred from the bridge pier to its foundation elements were monitored during the bridge construction stages. In addition, a live load test was performed [64] by parking twelve loaded triaxle trucks at specified locations on the bridge deck near the target pier in a sequence that simulates a group of trucks approaching the bridge pier, parking for a period of time at specified locations, driving over the pier and leaving the bridge (see Figure 11). The dataset generated in this research provides valuable insights on bridge foundation design regarding:

(1) the contribution of the pile cap to the overall foundation capacity (the soil below the pile cap carried about 20%-25% of the total load);
(2) load-settlement response of individual piles in the group vs. that of an isolated, single pile;
(3) dead and live loads estimated in bridge design vs. the actual loads carried by bridge components.

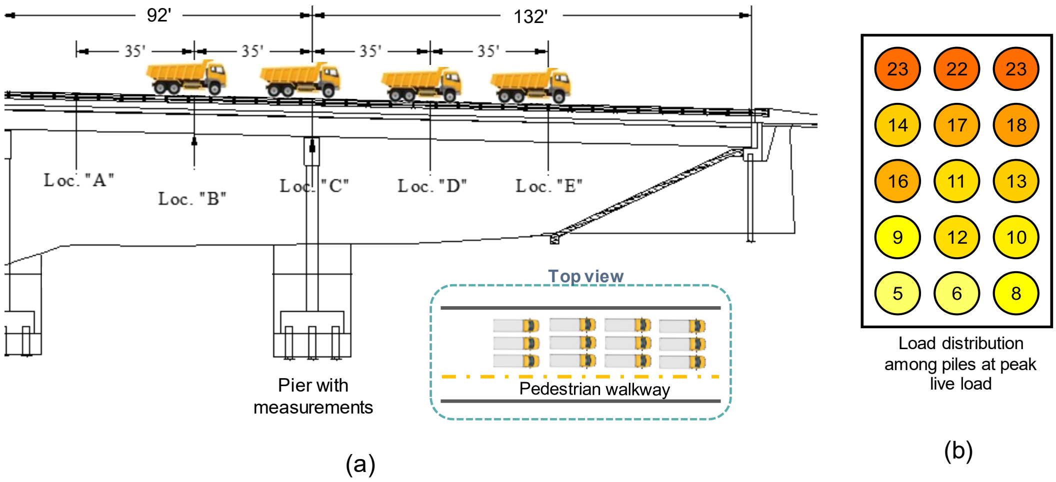


Figure 11 Live load test performed on the Sagamore Parkway Bridge: (a) location of the loaded trucks on the bridge deck to apply the live load; (b) the distribution of live load (resulting from the truck loads) among individual piles in the group at peak live load (uneven loads were measured in piles due to the eccentricity of the live load caused by the asymmetric driveway lane design)

Related references: [63,64]

3.3 Monitoring of instrumented MSE wall during construction and under service

Students currently working on this topic: Venkata Abhishek Sakleshpur and Rameez Raja

Researchers at COFFEE are actively working on instrumentation and monitoring of MSE walls during construction and under service. Figure 12 shows an example of the instrumentation scheme that involves the installation of inclinometers, rebar strain gauges, arc-welded and spot-welded vibrating-wire strain gauges, vertical and lateral earth pressure cells, settlement cells, and crackmeters. The objectives of the instrumentation are to obtain the:

(1) lateral displacement profile of the wall facing;
(2) settlement profile of the reinforced fill;
(3) loads carried by the pile cap and piles;
(4) reinforcement tension profile;
(5) vertical and lateral stress distribution within the reinforced fill;
(6) load transferred to the leveling pad;
(7) magnitude of expansion and/or contraction of the vertical and horizontal joints between adjacent precast concrete panels.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

Collected instrumentation data will assist researchers diagnose potential problems arising during MSE wall installation, assess current MSE wall design methods, and carry out long-term monitoring of the MSE wall performance under service.

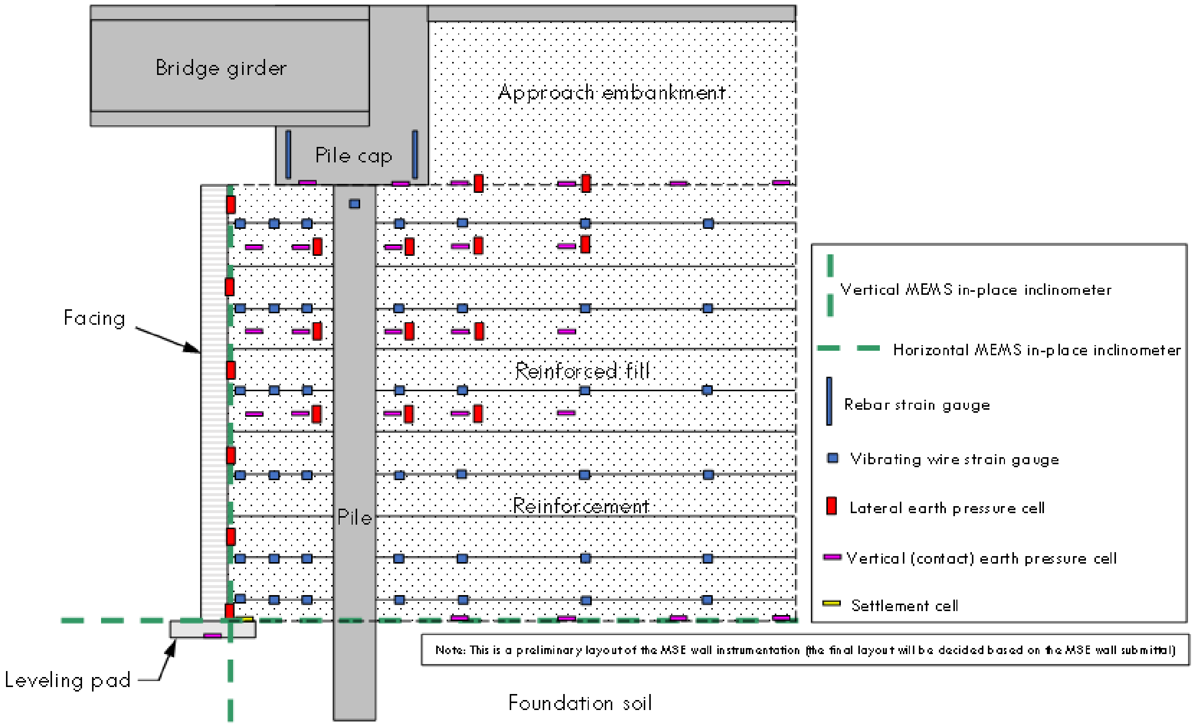
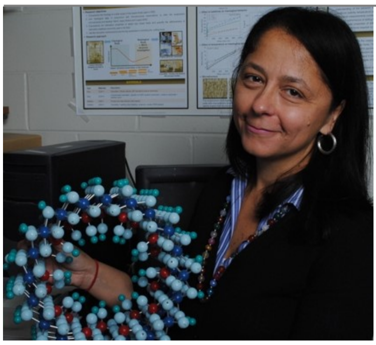


Figure 12 Instrumentation scheme for the MSE wall

Prof. Marika Santagata's Research Program



Prof. Marika Santagata

Ph.D. in Civil and Environmental Engineering, Massachusetts Institute of Technology, 1998

M.S. in Civil and Environmental Engineering, Massachusetts Institute of Technology, 1994

Laurea in Civil Engineering, University of Ancona, Italy, 1990

Dr. Santagata is an Associate Professor of Civil Engineering at Purdue University. Her research interests are founded on fundamental studies of the behavior of a broad range of soils and of their interaction with other materials, employing experimental investigations that probe the materials of interest at different scales. Dr. Santagata is past Chair of the Committee on Soil Properties and Modeling of the Geo-Institute of ASCE and serves on ASCE's Walter L. Huber Research Prizes committee. She served as Associate Editor for ASCE's Journal of Geotechnical and Geoenvironmental Engineering between 2005 and 2013. Dr. Santagata is a recipient of the US National Science Foundation Faculty Early CAREER Development Award (2007).

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

Current Research Topics

1. Mitigation of soil liquefaction using nanomaterials

In collaboration with:
Professors Antonio Bobet and Joe Sinfield, Lyles School of Civil Engineering, Purdue University
Professor Cliff Johnston, Department of Agronomy, Purdue University

Graduate researchers: Alain El Howayek, Felipe Ochoa-Cornejo

Work performed at Purdue [65–69] has pioneered the use of laponite, a synthetic nanoclay with structure comparable to that of natural hectorite, to treat soils susceptible to liquefaction. This novel approach to liquefaction mitigation, which builds on previous work with bentonite, involves the modification of the pore fluid between the grains ("pore fluid engineering") through the introduction, with no alteration of the soil skeleton, of a laponite suspension, which, over time, develops solid like response and thixotropic properties, creating a secondary nanostructure (Figure **13**(b)) in the pore space. Careful engineering of the colloidal interactions is required to delay the formation of this nanostructure, and facilitate "delivery" of the clay particles in suspension form inside the pore space. Figure **13** illustrates the different scales involved in the problem.

Laboratory cyclic and resonant column tests on sand-laponite specimens demonstrate that the addition of small amounts of laponite impacts all stages of cyclic loading, increasing the cyclic resistance and delaying generation of excess pore pressure and degradation of shear modulus.

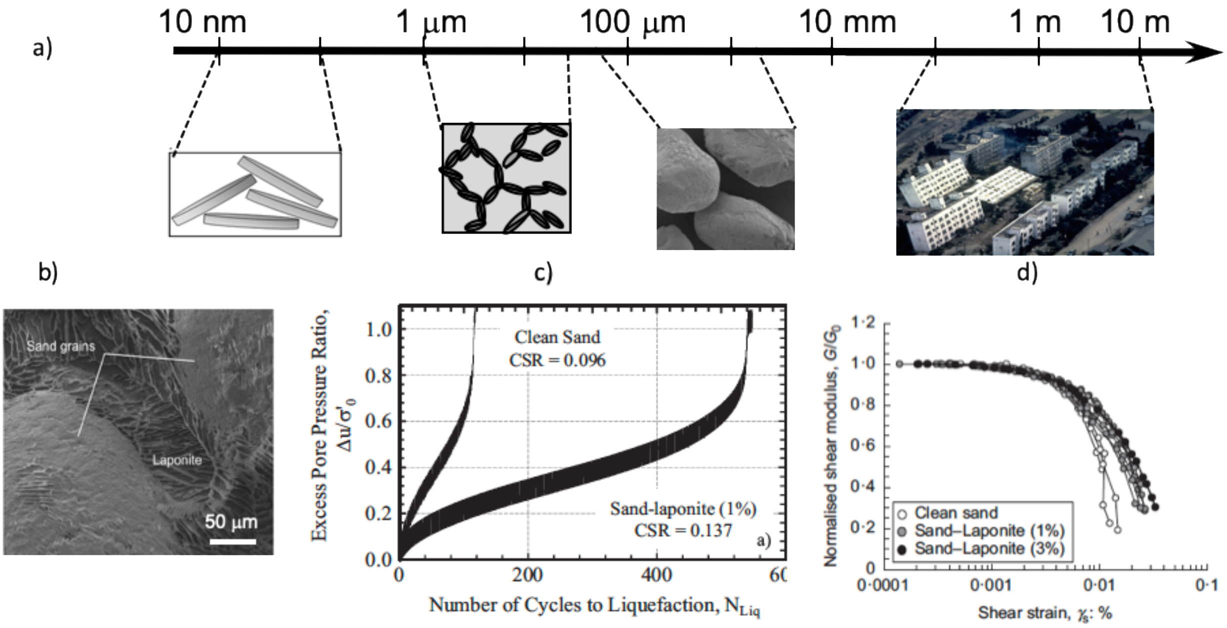


Figure 13 a) Multi-scale approach to liquefaction mitigation [65]; b) cryo-SEM image of structure of sand specimen permeated with laponite suspension [65]; c) improvement in liquefaction resistance [67] and delayed stiffness degradation [69] in sand-laponite specimens. Note: c)-d) are for sand-laponite dry-mixed specimens

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

4 Rheology and microstructure of ultra-soft geomaterials

Current graduate researchers: Amy Getchell, Mohammadhasan Sasar

Clay-water suspensions are geomaterials, whose structure is dominated by the presence of water, and that are characterized by mechanical properties falling much below those characteristic of traditional soft clays examined in the geotechnical literature (e.g. shear stiffness G in the Pa to kPa range – see Figure 14). Within the geotechnical field, the study of these ultra-soft geomaterials is relevant to the behavior of dredged sediments, coastal and underwater deposits, mining tailings, drilling and trenchless technology fluids, grouts, slurries used for cutoff walls and ground support.

Current research at Purdue is employing advanced rheometrical techniques, in particular small and large amplitude oscillatory strain tests, to characterize the flow and deformation behavior of these geomaterials. This work has highlighted some key features of their mechanical response, including the presence of a region characterized by "solid-like" behavior that extends to very large strains, the marked sensitivity of the response to stress history, and the effects of thixotropy and aging.

These methods also find application in the development of methodologies for modifying the behavior of clay-water systems, as changes in the particle-to-particle interactions and the overall microstructure of these materials due to interaction with the additives are fingerprinted in the rheological response.

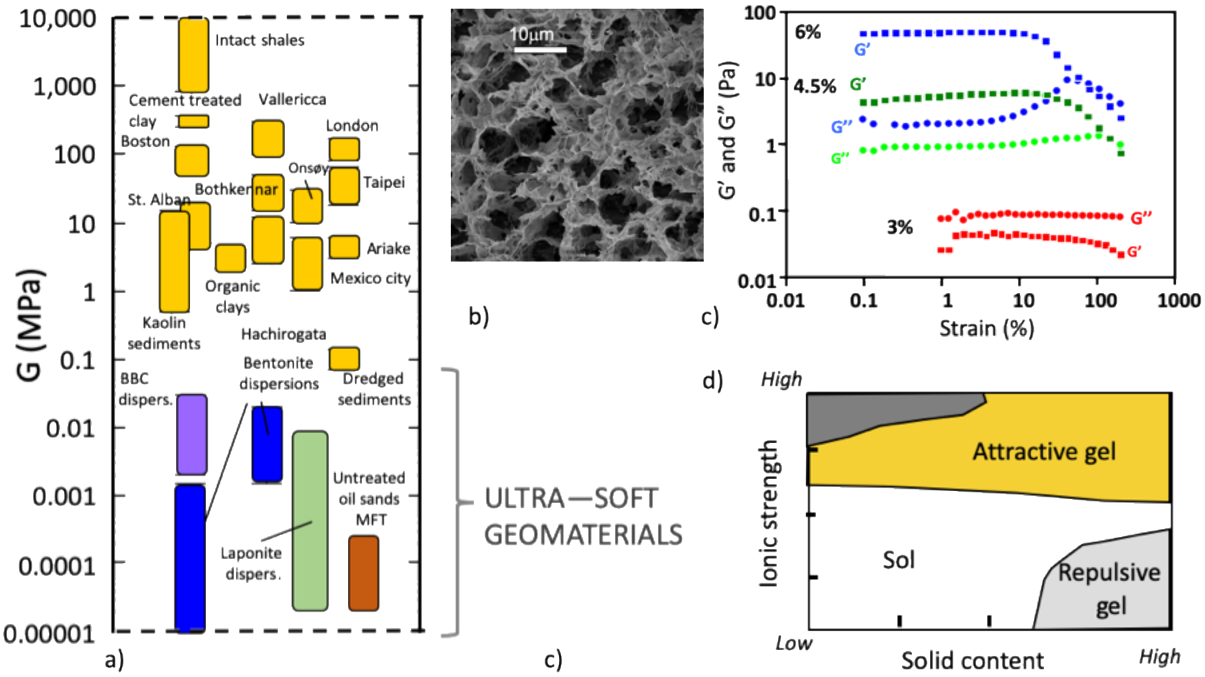


Figure 14 a) Shear stiffness of clay-based geomaterials (adapted from [70]); b) cryo-SEM image of concentrated bentonite gel [65]; c) deformation behavior of bentonite-based drilling fluid [71]; d) schematic of phase diagram of bentonite suspensions in water [72]

5 Polymer flocculation of clay tailings

In collaboration with: Professor Cliff Johnston, Department of Agronomy, Purdue University

Current graduate researcher: Mohammadhasan Sasar

Polymeric flocculants currently represent the most effective approach to accelerating consolidation of the nearly one billion m^3 of mature fine tailings (MFTs) generated by the extraction of bitumen from oil sands.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

Despite the wide application of this methodology, the mechanisms that control the effectiveness of the treatment are not completely understood, and many questions remain regarding the long term engineering properties of the geomaterial created as a result of the treatment. This is due to the complex and variable nature of MFTs, that are composed of micron and nano-sized clay minerals, some residual bitumen, and process chemicals, and the many other factors that come into play, including chemistry of the process water, type and amount of polymer added, and mixing energy applied.

Research underway at Purdue is aimed at developing an improved understanding of the interplay that exists between the chemistry of polymer treated mature fine tailings and their short term and long term structure and engineering properties. This understanding is critical for the prediction of the geotechnical behavior of polymer-treated MFTs, and their interaction with the environment.

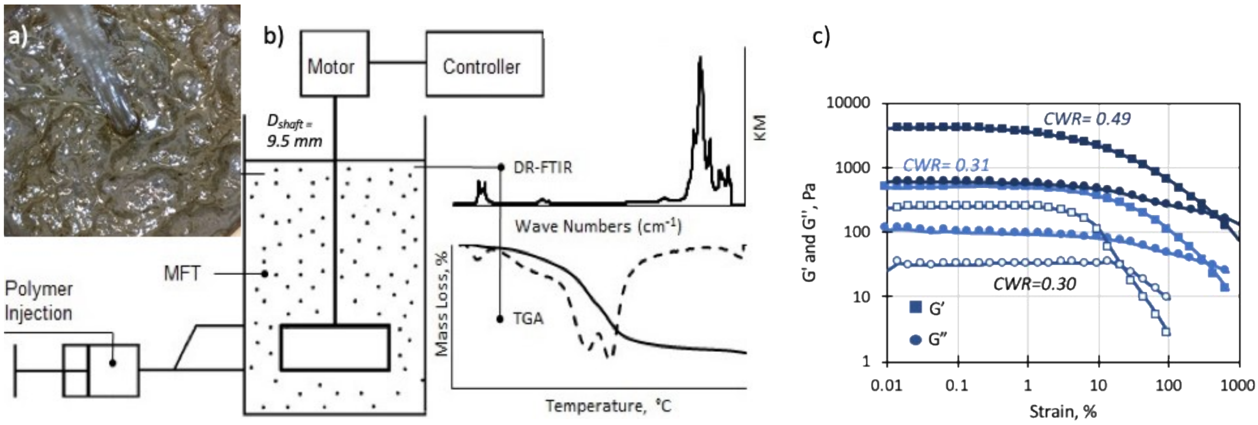


Figure 15 a) structure of flocculated MFT; b) schematic of experimental setup used to prepare optimally-dosed/optimally-mixed samples of polymer flocculated MFT for rheological tests and chemical analyses [73]; c) large amplitude oscillatory strain behavior of raw (hollow symbols) and flocculated (solid symbols) MFT with different clay-water ratio (CWR)

6 Tunable clay-water systems

Current graduate researcher: Amy Getchell

Clay-water systems possess a "large response function" in that the dependence of their structure on geochemical parameters provides the opportunity to achieve a target response at the macro-scale. Previous research at Purdue explored how dispersants can be used to control rheology of bentonite suspensions to allow their injection in a porous medium [74]. Current work with suspensions of laponite, a synthetic nano-clay, demonstrates that, again through the use of a dispersant, it is possible to carefully tailor the time dependent rheology of these suspensions, controlling the early age viscosity, the time period over which the dispersion exhibits Newtonian behavior, the time associated with the transition of the dispersions from sol to gel, and the mechanical properties of the gel ultimately formed. Laponite suspensions therefore represent excellent model fluids to study a wide range of complex solid-fluid interaction problems. A current research project is utilizing this approach to conduct a fundamental study of pore fluid effects on the undrained behavior of saturated granular materials.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

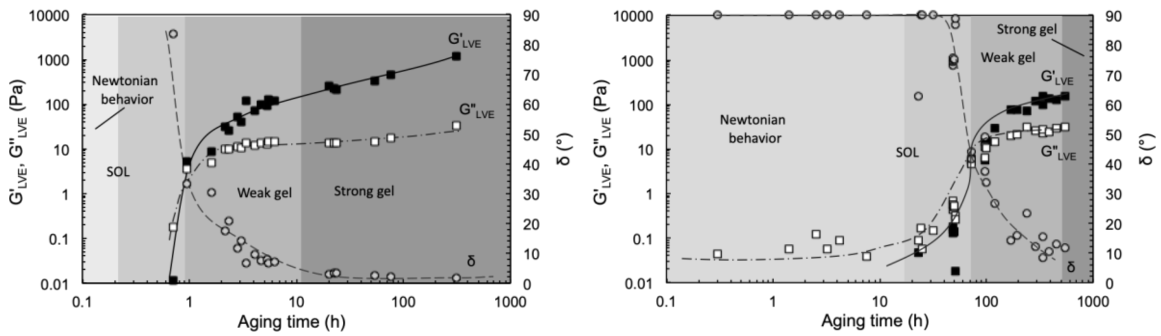


Figure 16 Time dependent rheology of 3% Laponite suspensions a) without; b) with addition of a dispersant

7 Nanoconfined water in halloysite

In collaboration with: Professor Cliff Johnston, Department of Agronomy, Purdue University

Central to a wide range of disciplines are the interactions of water with clay minerals. These interactions are complex and influenced by the nature of the clay mineral surface, type of exchangeable cations, pH and ionic composition of the aqueous phase, particle size and shape, and the overall pore size distribution. Through thermal, spectroscopic and structural methods, a study of the de-hydration of halloysite conducted at Purdue has shown the unique characteristics of the four populations of water molecules contained in this mineral: the 'free H_2O' external to the halloysite particles, the 'lumen H_2O' molecules located on the hydrophilic inner surface of the halloysite tubes, the 'interlayer water' molecules between the layers and the 'structural H_2O' that is lost from the sample through dehydroxylation. The observed effects of nanoconfinement on the properties of water have broad applications in material science and biology.

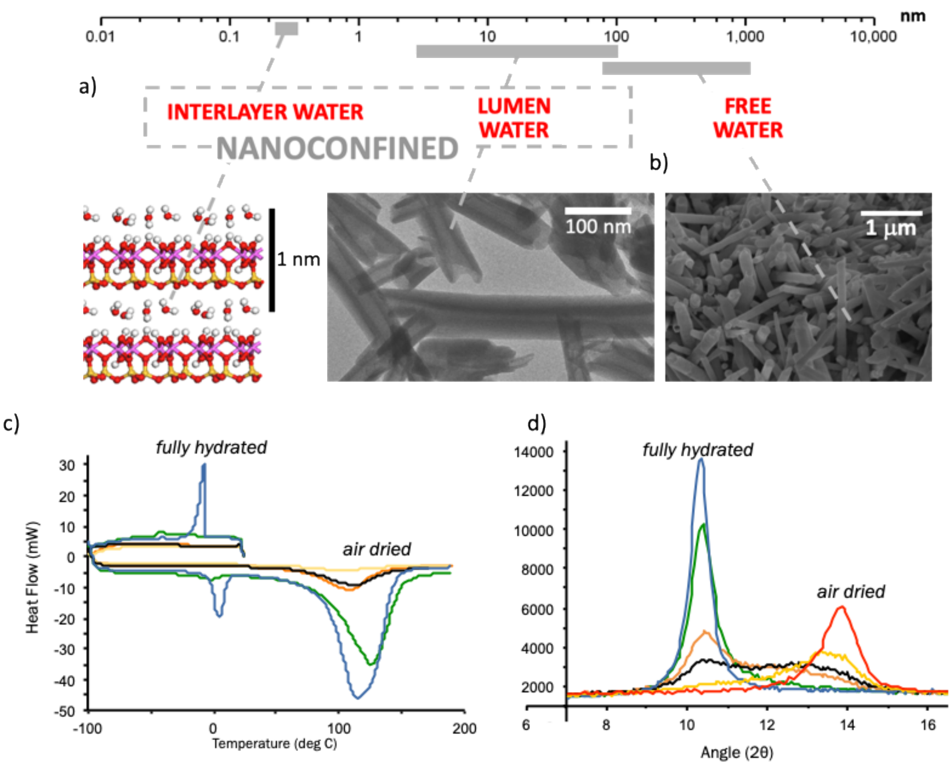


Figure 17 a) Multi-scale architecture and b) TEM and cryo-SEM images of halloysite; c) low temperature differential scanning calorimetry and d) X-ray diffraction of halloysite during de-hydration

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

8 Geotechnical properties of soft carbonatic deposits

In collaboration with: Professor Antonio Bobet, Lyles School of Civil Engineering, Purdue University
Graduate researcher: Alain El Howayek

Soft, carbonate-rich, fine-grained soils are commonly found in the glaciated regions of the northern United States and Canada. A recent study of a glaciolacustrine carbonatic fine-grained soil deposit (35-60% carbonates) formed ~22,000 BP in southwest Indiana, USA, involved field tests (seismic cone penetration tests, standard penetration tests, field vane shear tests), and laboratory experiments (including incremental and constant rate of strain consolidation tests, and K_0-consolidated undrained triaxial tests) conducted on high quality Shelby tube samples. Additionally, X-ray diffraction and thermogravimetric analyses were used to obtain the mineral composition; while scanning electron microscopy equipped with energy dispersive X-ray spectroscopy was employed to examine the microstructure of the soil, including the morphology of select minerals, the biological intrusions present, and the distribution of carbonates within the soil. The work has provided insights into the nature of the structure formed in presence of carbonates, the impact of carbonate cementation on the engineering properties, and the applicability of published correlations for interpretation of the geotechnical properties of carbonatic soils from field results.

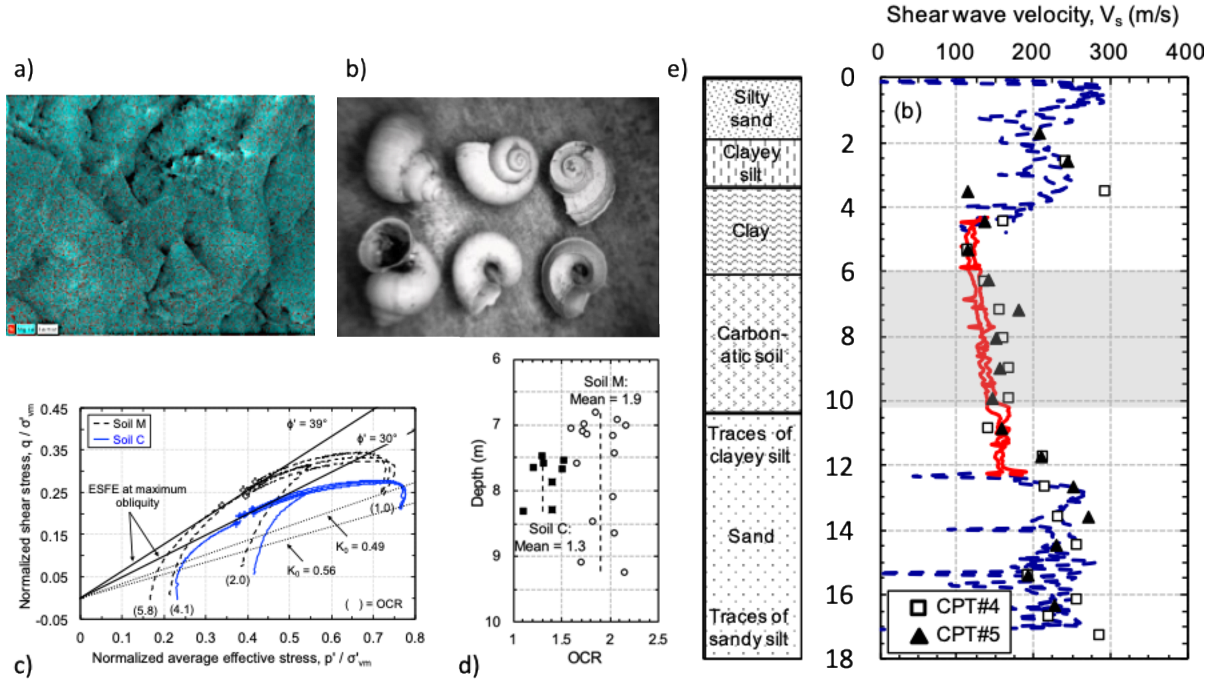


Figure 18 a) Map from EDX analyses showing the distribution of Ca and Mg (teal) and Si (red) in a carbonatic silt [75]; b) examples of gastropods collected from the carbonatic silt [76]; c) distinct triaxial response from SHANSEP tests on two carbonatic sublayers [77]; d) variation of OCR in sublayers [78]; e) comparison of shear wave velocity measured with seismic CPT to predictions (red and blue lines) from CPT data [77]

9 Hydro-mechanical properties of pavement unbound granular layers

In collaboration with:
Professor Emeritus Philippe Bourdeau, Lyles School of Civil Engineering, Purdue University
Dr. Peter Becker, Research Division, Indiana Department of Transportation

Current graduate researchers: Luis-Enrique Garzon-Sabogal, Amy Getchell
In pavement structures, unbound granular materials are routinely used for subbase/base layers to provide a stable construction platform, facilitate drainage, mitigate pumping of the subgrade fines, and protect the

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

pavement from the effects of frost. These layers are critical in achieving the desired pavement performance and extending the service life of the structure.

Work at Purdue is evaluating the performance and applicability of novel approaches for measuring the hydro-mechanical properties of coarse aggregates used in bases and subbases that will result in the development of performance-based specifications.

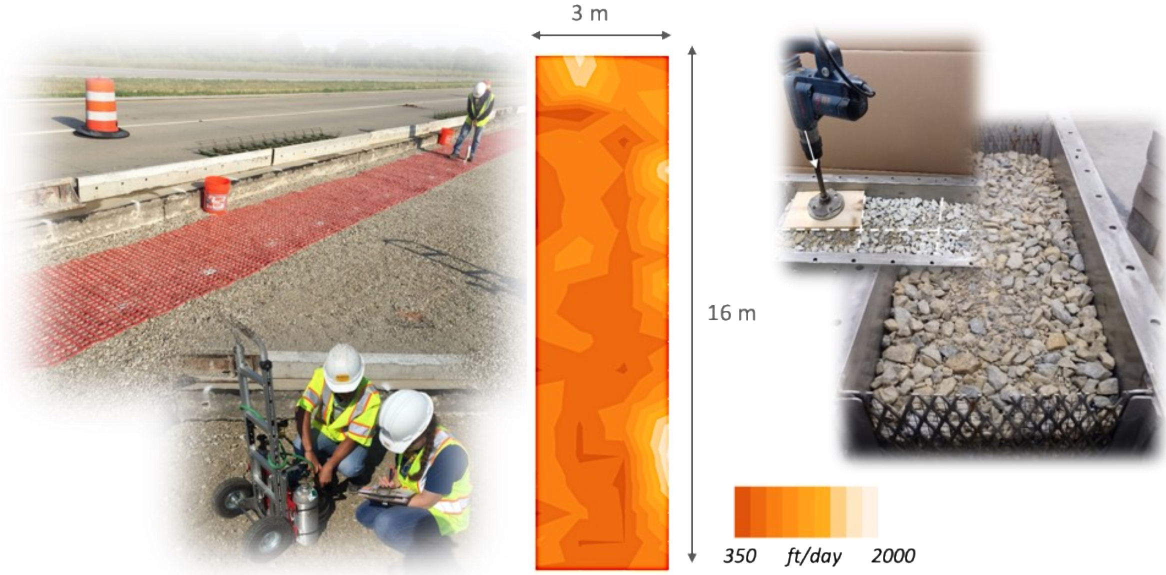


Figure 19 a) Mapping of hydraulic conductivity of compacted aggregate in the field using the air permeameter [79]; b) large permeameter used for laboratory measurements

Prof. Joe Sinfield's Research Program

Prof. Joe Sinfield
Professor of Civil Engineering and

Director of the College of Engineering Innovation and Leadership Studies Program

Ph.D. in Civil and Environmental Engineering, Massachusetts Institute of Technology, 1997

M.S. in Civil and Environmental Engineering, Massachusetts Institute of Technology, 1994

B.S. in Civil Engineering, Bucknell University, 1992

Dr. Sinfield is a Professor of Civil Engineering at Purdue University, founding Director of Purdue University's College of Engineering Innovation and Leadership Studies Program, and proposal co-PI and Innovation Science Lead for the USAID LASER PULSE program (Long-term Assistance and SErvices for Research, Partners for University-Led Solutions Engine). His work focuses on sensing, systems, and innovation science. In the civil engineering arena, he develops and adapts sensors that make use of electromagnetic radiation to achieve a deeper understanding of physical and chemical phenomena that underlie critical geoenvironmental and geotechnical problems.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

Current Research Topics

1. Improved background and clutter reduction for pipe detection under pavement using Ground Penetrating Radar (GPR)
Graduate researcher: Hao Bai

Pavement drainage systems are one of the key drivers of pavement function and longevity, and effective drain maintenance can significantly extend a pavement's service life. Maintenance of these drains, however, is often hampered by the challenge of locating the drains which are often undocumented on as-built drawings, and may have outlets that are completely obscured due to silt build-up and overgrowth of vegetative cover. Thus, locating existing drainage pipes is considered a critical part of pavement field maintenance operations. Work in the Purdue Civil Engineering Sensing Laboratory has advanced the potential to employ Ground Penetrating Radar (GPR) for rapid and effective detection of these often obscured underground targets. Specifically, a dual-frequency GPR system has been developed that takes advantage of the inherent downward frequency shift of a signal transmitted through earth materials to enhance collection efficiency and collected signal energy. As shown in the Figure 20, the use of a frequency shifted receiver improves signal amplitude and overall signal to noise [80]. In addition, work probabilistic algorithms have been developed to improve background noise and clutter reduction in GPR signatures to enhance target signals in what amounts to a constructed environment that tends to have more consistent subsurface properties than one might encounter in a general setting [81].

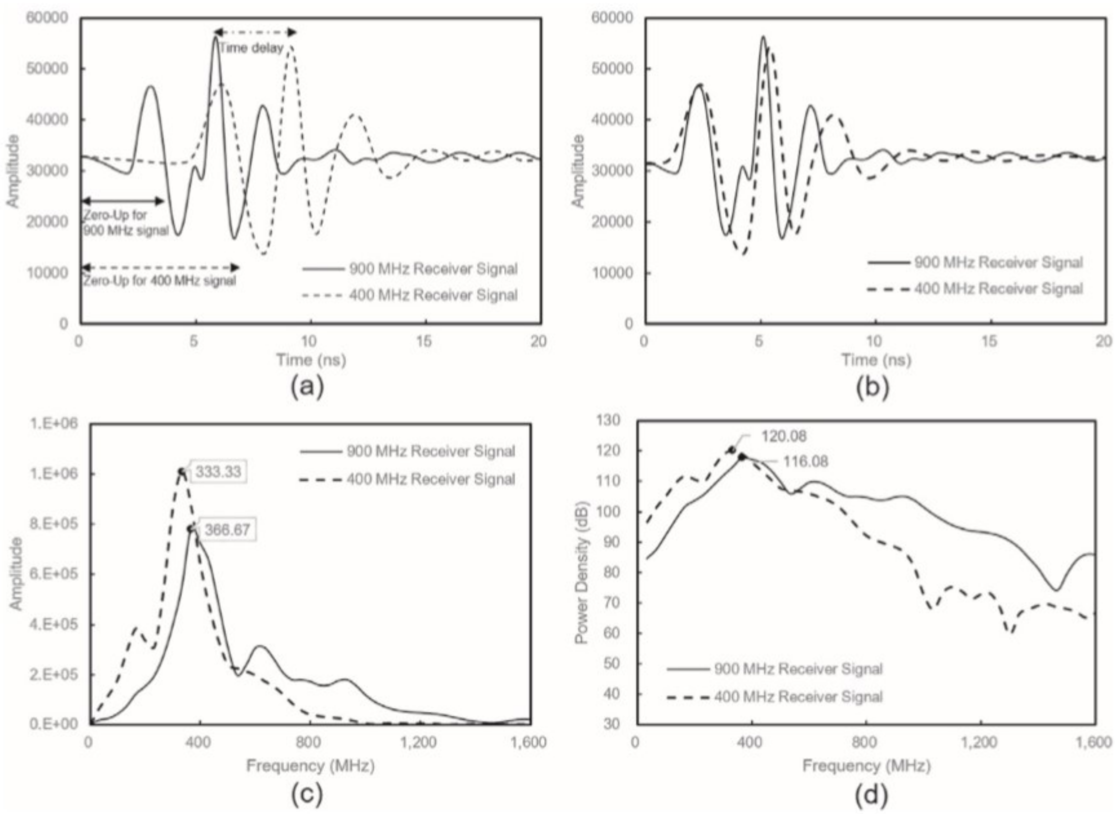


Figure 20 GPR signals received by 900 MHz receiver and 400 MHz receiver at target locations under the laboratory test pavement: (a) Time domain signals; (b) Zero-up adjusted time domain signals; (c) Frequency domain signals; (d) Power spectra of signals (excitation at 900 MHz) [80]

Key references: [80,81]

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

2. Holistic synergy analysis for building subsystem performance
Graduate researcher: Domenique Lumpkin

This work focuses on the development of a structured process to systematically study the complex interactions between building subsystems and their occupants to specifically define their effects on human and building performance outcomes. Employing systems theory, work is being carried out to define the dynamic interactions between the human and technical parts and processes of building systems to provide a holistic lens on human-building interaction. Findings to date highlight that independent building subsystem outputs have functional, social, and emotional effects on humans that are not intentionally captured in the traditional building design metrics, offering opportunities for innovation in the design process and in realized building solutions [82].

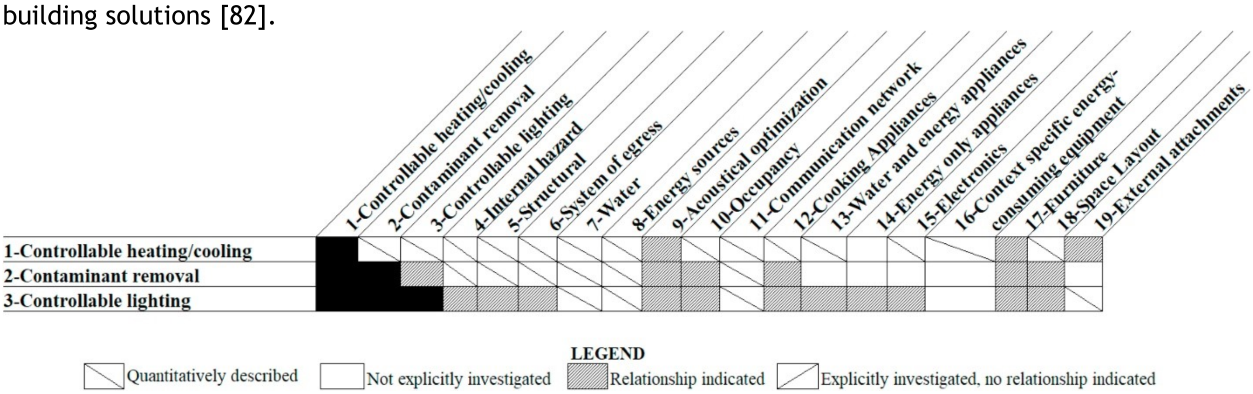


Figure 21 Illustrative subset of linkages between building technical systems and indication of documented/quantifiable relationship to occupant performance measures [82].

Key reference: [82]

3. Pursuit of Low-Cost Field-Deployable Quantitative Raman Spectroscopy
Graduate researchers: Oliver Colic, Daniel Fagerman, Chike Monwuba, Yu-Chung Lin

Long-term efforts in the Purdue Civil Engineering Sensing Laboratory have focused on realizing the potential offered by Raman spectroscopy for the in-situ study of a broad array of environmentally relevant compounds. While the analytical specificity, sensitivity, and versatility of the technique is significant, its use has been hampered by challenges in optimizing the sensor-sample interface, managing turbidity for quantitative analysis, limiting fluorescence interference, preventing biofouling (particularly for long-term monitoring), and achieving low cost. Research at Purdue over the last several years has systematically addressed each of these factors so that Raman spectroscopy is arguably ready to be revisited as a robust and flexible field measurement technique that may now warrant targeted development effort so that it may become a more routinely employed field analysis method [83–85]. One such advance is illustrated in the figure below, which highlights the ability of a patented time resolved photon counting method to significant increase signal-to-noise and thus improve detection sensitivity of Raman observations at field-relevant concentrations. The developments achieved to date are believed to be applicable to material analyses in an array of complex, turbid, and/or fluorescence-prone settings encountered across a broad set of fields [86].

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

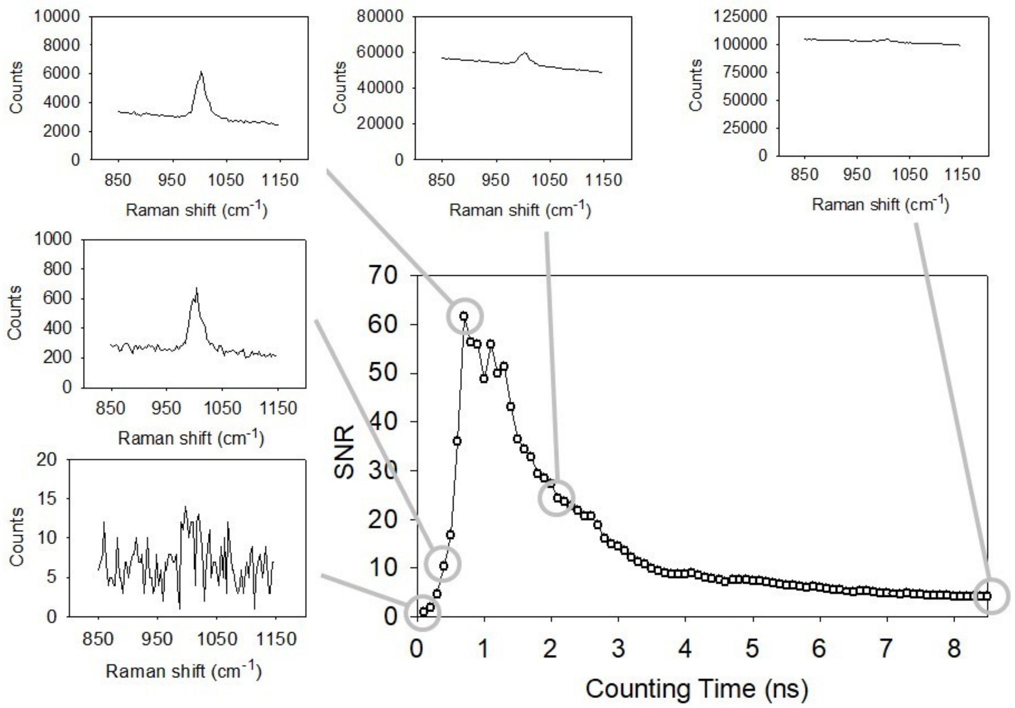


Figure **22** Variation in neat benzene Raman peak SNR in the presence of 100 mM rhodamine 6G as a function of counting time **[85]**

4. Grand Challenge Problem Solving

Graduate and post-doctoral researchers: Anan Sheth, Romika Kotian, Akash Patil, Dr. Daniel Bampoh

At Purdue, our Laboratory for Innovation Science is linking schools of thought from strategy, data science, innovation and design to understand the fundamental principles that underlie the innovative mindsets, behaviors and methods of innovative individuals and organizations, and employing these insights to frame and systematically address some of the most complex problems faced by society through in-depth collaboration with researchers and development practitioners engaged in the USAID LASER PULSE initiative. Work to date has engaged stakeholders in Uganda, Colombia, Vietnam, and Ethiopia with problem loci encompassing food security, material and child health, potable water availability, rural development, youth, and national resilience, among other complex socio technical topics. One of the many techniques employed in this work includes natural language processing. Advances at Purdue have led to means to link problem and solution spaces through automated content analysis of large language corpuses, using language relationships as shown in the figure below.

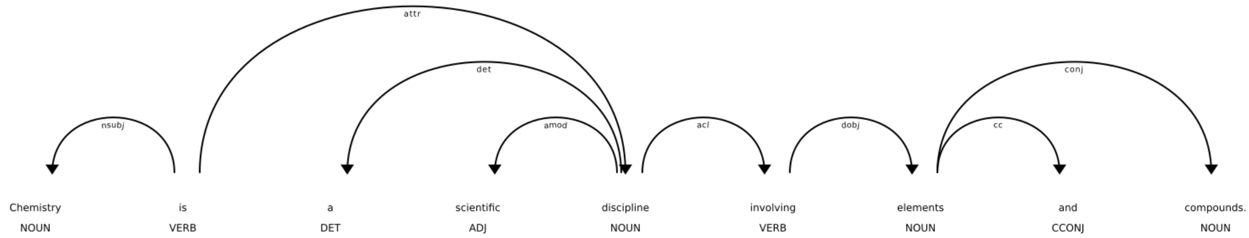


Figure 23 A dependency parse of language in the domain of chemistry – a potential solution source for an array of complex challenges [87]

Key reference: [87]

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

Centers and programs with which faculty members are associated:

Directed by Professors Rodrigo Salgado and Monica Prezzi, Purdue University's Center for Offshore, Foundation and Energy Engineering (COFFEE) is engaged in the creation and dissemination of knowledge and development of resources for the practicing community in the areas of offshore engineering, foundation engineering (both on and offshore) and innovative energy engineering applications.

https://engineering.purdue.edu/COFFEE/index.html

Professor Antonio Bobet is one of the PIs of the NASA-funded RETH Institute where researchers are developing technologies needed to establish Resilient Extra-Terrestrial Habitats.

https://www.purdue.edu/reth/

Professor Antonio Bobet is one of the PIs of the NSF-funded NHERI Network Coordination Office. The NCO serves as a focal point and leader of a multi-hazards research community focused on mitigating the impact of future earthquakes and windstorms, and related hazards such as tsunamis and storm surge on our nation's physical civil infrastructure

https://www.designsafe-ci.org/about/designsafe/

Professor Joe Sinfield is proposal co-PI and Innovation Science Lead for LASER (Long-term Assistance and Services for Research) PULSE (Partners for University-Led Solutions Engine), which fosters a global network of researchers and implementers that is collaborating with the U.S. Agency for International Development (USAID) to more deeply understand grand challenges, identify critical gaps in current approaches to address these problems, and fund research that can help close identified gaps, all while building local capacity to carry out this work in USAID interest countries.

https://stemedhub.org/groups/laserpulse/aboutus

All Purdue geotechnical faculty are active in research related to transportation infrastructure through the Joint Transportation Research Program (JTRP), a long-lasting partnership between Purdue University and Indiana Department of Transportation (INDOT).

https://engineering.purdue.edu/JTRP

References

[1] Loukidis D, Salgado R. Modeling sand response using two-surface plasticity. Comput Geotech 2009;36:166–86. https://doi.org/10.1016/j.compgeo.2008.02.009.

[2] Chakraborty T, Salgado R, Loukidis D. A two-surface plasticity model for clay. Comput Geotech 2013;49:170–90. https://doi.org/10.1016/j.compgeo.2012.10.011.

[3] Woo SI, Salgado R. Bounding surface modeling of sand with consideration of fabric and its evolution during monotonic shearing. Int J Solids Struct 2015;63:277–88. https://doi.org/10.1016/j.ijsolstr.2015.03.005.

[4] Coleman BD. Thermodynamics of Materials with Memory. Arch Ration Mech Anal 1964;17:1–46.

[5] Coleman BD, Noll W. The Thermodynamics of Elastic Materials with Heat Conduction and Viscosity. Arch Ration Mech Anal 1963;13:167–78. https://doi.org/10.1007/BF01262690.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

[6] Noll W. A Mathematical Theory of the Mechanical Behavior of Continuous Media. Arch Ration Mech Anal 1958;2:197–226. https://doi.org/10.1007/BF00277929.

[7] Truesdell C, Noll W. The Non-linear Field Theories of Mechanics. Third Edit. Springer Berlin Heidelberg; 2004.

[8] Bruhns OT, Xiao H, Meyers A. Self-consistent Eulerian Rate Type Elasto-plasticity Models based upon the Logarithmic Stress Rate. Int J Plast 1999;15:479–520. https://doi.org/10.1016/S0749-6419(99)00003-0.

[9] Bruhns OT, Meyers A, Xiao H. On Non-corotational Rates of Oldroyd's Type and Relevant Issues in Rate Constitutive Formulations. Proc R Soc London A Math Phys Eng Sci 2004;460:909–28. https://doi.org/10.1098/rspa.2003.1184.

[10] Xiao H, Bruhns OT, Meyers A. The choice of objective rates in finite elastoplasticity: general results on the uniqueness of the logarithmic rate. Proc R Soc A Math Phys Eng Sci 2000;456:1865–82. https://doi.org/10.1098/rspa.2000.0591.

[11] Prager W. An Elementary Discussion of Definition of Stress Rate. Q Appl Math 1961;18:403–7.

[12] Yoshimine M. Yoshimine M. Archives – soil mechanics laboratory. Tokyo Metro- politan University. <http://geot.civil.metro-u.ac.jp/archives/ index.html> [7 April 2005]. 2013.

[13] Miura N, Murata H, Yasufuku N. Stress-Strain Characteristics of Sand in a Particle-Crushing Region. Soils Found 1984;24:77-89.

[14] Miura N. A Consideration on the Stress-Strain Relation of a Sand Under High Pressures. Proc Japan Soc Civ Eng 1979;1979:127–30. https://doi.org/10.2208/jscej1969.1979.282_127.

[15] Nakata Y, Kato Y, Hyodo M, Hyde AFL, Murata H. One-Dimensional Compression Behaviour of Uniformly Graded Sand Related To Single Particle Crushing Strength. Soils Found 2001;41:39–51.

[16] Woo SI, Salgado R. Determination of an image point on a surface based on a π plane-based algorithm. Comput Mech 2013. https://doi.org/10.1007/s00466-013-0947-3.

[17] Woo SI, Salgado R, Prezzi M. Dilatancy-triggering surface for advanced constitutive modelling of sand. Géotechnique Lett 2019;9:136–41. https://doi.org/10.1680/jgele.17.00085.

[18] Sulsky D, Chen Z, Schreyer HL. A particle method for history-dependent materials. Comput Methods Appl Mech Eng 1994;118:179–96. https://doi.org/10.1016/0045-7825(94)90112-0.

[19] Woo SI, Salgado R. Simulation of penetration of a foundation element in Tresca soil using the generalized interpolation material point method (GIMP). Comput Geotech 2018;94:106-17. https://doi.org/10.1016/j.compgeo.2017.08.007.

[20] Sloan SW. Substepping schemes for the numerical integration of elastoplastic stress-strain relations. Int J Numer Methods Eng 1987;24:893-911. https://doi.org/10.1002/nme.1620240505.

[21] Bisht V, Salgado R. Local transmitting boundaries for the generalized interpolation material point method. Int J Numer Methods Eng 2018;114:1228–44. https://doi.org/10.1002/nme.5780.

[22] Bisht V, Salgado R, Prezzi M. Simulating penetration problems in incompressible materials using the material point method. Comput Geotech 2020;(in print).

[23] Hu Q, Han F, Salgado R, Prezzi M, Zhao M. Design of laterally loaded monopiles in sand. Géotechnique 2020;in review.

[24] Han F, Salgado R, Prezzi M, Lim J. Shaft and base resistance of non-displacement piles in sand. Comput Geotech 2017;83:184–97. https://doi.org/10.1016/j.compgeo.2016.11.006.

[25] Salgado R, Han F, Prezzi M. Axial resistance of non-displacement piles and pile groups in sand. Riv Ital Di Geotec 2017;51:35–46. https://doi.org/10.19199/2017.4.0557-1405.35.

[26] Han F, Salgado R, Prezzi M. Numerical and experimental study of axially loaded non-displacement piles in sand. Int. Conf. Deep Found. Gr. Improv., Hawthorne, NJ: Deep Foundations Institute: 2018, p. 221-9.

[27] Han F, Salgado R, Prezzi M, Lim J. Axial Resistance of Nondisplacement Pile Groups in Sand. J Geotech Geoenvironmental Eng 2019;145:04019027. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002050.

[28] Loukidis D, Salgado R. Analysis of the shaft resistance of non-displacement piles in sand. Géotechnique 2008;58:283-96. https://doi.org/10.1680/geot.2008.58.4.283.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

[29] Basu P, Loukidis D, Prezzi M, Salgado R. Analysis of shaft resistance of jacked piles in sands. Int J Numer Anal Methods Geomech 2011;35:1605–35.
[30] Han F, Lim J, Salgado R, Prezzi M, Zaheer M. Load and resistance factor design of bridge foundations accounting for pile group-soil Interaction. West Lafayette, IN: 2015. https://doi.org/10.5703/1288284316009.
[31] Basu P, Loukidis D, Prezzi M, Salgado R. The mechanics of friction fatigue in jacked piles installed in sand. From Soil Behav. Fundam. to Innov. Geotech. Eng., Reston, VA: American Society of Civil Engineers; 2014, p. 546–57. https://doi.org/10.1061/9780784413265.044.
[32] Loukidis D, Salgado R. Bearing capacity of strip and circular footings in sand using finite elements. Comput Geotech 2009;36:871–9.
[33] Loukidis D, Salgado R. Active pressure on gravity walls supporting purely frictional soils. Can Geotech J 2012;49:78–97. https://doi.org/10.1139/t11-087.
[34] Arshad MI, Tehrani FS, Prezzi M, Salgado R. Experimental study of cone penetration in silica sand using digital image correlation. Géotechnique 2014;64:551–69. https://doi.org/10.1680/geot.13.P.179.
[35] Raffael M, Willert C, Wereley ST, Kompenhans J. Particle Image Velocimetry (the Third Edition). 2007. https://doi.org/10.1007/978-3-540-72308-0.
[36] Sutton MA, Orteu J, Schreier HW. Image correlation for shape, motion and deformation measurements. 1st ed. New York, NY: 2009. https://doi.org/10.1007/978-0-387-78747-3.
[37] Ganju E, Han F, Prezzi M, Salgado R, Pereira JS. Quantification of displacement and particle crushing around a penetrometer tip. Geosci Front 2020;11:389–99. https://doi.org/10.1016/j.gsf.2019.05.007.
[38] Ganju E, Han F, Castro A, Prezzi M, Salgado R. Experimental Study of Crushing in Cone Penetration Test in Silica Sand. Geo-Congress 2020, Reston, VA: American Society of Civil Engineers; 2020, p. 132–41. https://doi.org/10.1061/9780784482803.015.
[39] Tehrani FS, Arshad MI, Prezzi M, Salgado R. Physical modeling of cone penetration in layered sand. J Geotech Geoenvironmental Eng 2018;144:04017101. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001809.
[40] Tovar-Valencia RD, Galvis-Castro AC, Prezzi M, Salgado R. Short-Term Setup of Jacked Piles in a Calibration Chamber. J Geotech Geoenvironmental Eng 2018;144:04018092. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001984.
[41] Galvis-Castro AC, Ganju E, Tovar-Valencia RD, Prezzi M, Salgado R. Effect Of installation method on the ratio of tensile to compressive unit shaft resistance of piles in dense sand. 44th Annu Conf Deep Found 2019:609–18.
[42] Tovar-Valencia RD, Galvis-Castro A, Salgado R, Prezzi M. Effect of surface roughness on the shaft resistance of displacement model piles in sand. J Geotech Geoenvironmental Eng 2018;144. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001828.
[43] Tehrani FS, Han F, Salgado R, Prezzi M, Tovar RD, Castro AG. Effect of surface roughness on the shaft resistance of non-displacement piles embedded in sand. Géotechnique 2016;66:386–400. https://doi.org/10.1680/jgeot.15.P.007.
[44] Doreau-Malioche J, Galvis-Castro A, Tovar-Valencia R, Viggiani G, Combe G, Prezzi M, et al. Characterising processes at sand-pile interface using digital image analysis and X-ray CT. Géotechnique Lett 2019:1–9. https://doi.org/10.1680/jgele.18.00232.
[45] Galvis-Castro AC, Tovar-Valencia RD, Salgado R, Prezzi M. Compressive and tensile shaft resistance of nondisplacement piles in sand. J Geotech Geoenvironmental Eng 2019;145:04019041. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002071.
[46] Tehrani FS, Han F, Salgado R, Prezzi M. Laboratory study of the effect of pile surface roughness on the response of soil and non-displacement piles. Geotech. Front. 2017, vol. 50, Reston, VA: American Society of Civil Engineers; 2017, p. 256–64. https://doi.org/10.1061/9780784480465.027.
[47] Galvis-Castro AC, Tovar-Valencia RD, Salgado R, Prezzi M. Effect of loading direction on the shaft resistance of jacked piles in dense sand. Geotechnique 2019;69:16–28. https://doi.org/10.1680/jgeot.17.P.046.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

[48] Wiebicke M, Andò E, Šmilauer V, Herle I, Viggiani G. A benchmark strategy for the experimental measurement of contact fabric. Granul Matter 2019;21:54. https://doi.org/10.1007/s10035-019-0902-x.
[49] Lee J, Salgado R, Paik K. Estimation of load capacity of pipe piles in sand based on cone penetration test results. J Geotech Geoenvironmental Eng 2003;129:391–403. https://doi.org/10.1061/(ASCE)1090-0241(2003)129:6(391).
[50] Paik K, Salgado R, Lee J, Kim B. Behavior of open- and closed-ended piles driven into sands. J Geotech Geoenvironmental Eng 2003;129:296–306. https://doi.org/10.1061/(ASCE)1090-0241(2003)129:4(296).
[51] Bica AVD, Prezzi M, Seo H, Salgado R, Kim D, Seo H, et al. Instrumentation and axial load testing of displacement piles. Proc Inst Civ Eng - Geotech Eng 2014;167:238–52. https://doi.org/10.1680/geng.12.00080.
[52] Kim D, Bica AV, Salgado R, Prezzi M, Lee W. Load testing of a closed-ended pipe pile driven in multilayered soil. J Geotech Geoenvironmental Eng 2009;135:463–73. https://doi.org/10.1061/(ASCE)1090-0241(2009)135:4(463).
[53] Han F, Prezzi M, Salgado R, Zaheer M. Axial resistance of closed-ended steel-pipe piles driven in multilayered soil. J Geotech Geoenvironmental Eng 2017;143:04016102. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001589.
[54] Han F, Ganju E, Salgado R, Prezzi M. Comparison of the load response of closed-ended and open-ended pipe piles driven in gravelly sand. Acta Geotech 2019;14:1785–803. https://doi.org/10.1007/s11440-019-00863-1.
[55] Han F, Ganju E, Prezzi M, Salgado R, Zaheer M. Axial resistance of open-ended pipe pile driven in gravelly sand. Géotechnique 2020;70:138–52. https://doi.org/10.1680/jgeot.18.P.117.
[56] Ganju E, Han F, Prezzi M, Salgado R. Static Capacity of Closed-Ended Pipe Pile Driven in Gravelly Sand. J Geotech Geoenvironmental Eng 2020;146:04020008. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002215.
[57] Han F, Prezzi M, Salgado R. Static and dynamic pile load tests on closed-ended driven pipe pile. Int. Found. Congr. Equip. Expo. (IFCEE 2018), Reston, VA: American Society of Civil Engineers; 2018, p. 496–506. https://doi.org/10.1061/9780784481578.047.
[58] Han F, Ganju E, Salgado R, Prezzi M. Effects of interface roughness, particle geometry, and gradation on the sand-steel interface friction angle. J Geotech Geoenvironmental Eng 2018;144:04018096. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001990.
[59] Han F, Ganju E, Prezzi M, Salgado R. Closure to "Effects of interface roughness, particle geometry, and gradation on the sand-steel interface friction angle" by Fei Han, Eshan Ganju, Rodrigo Salgado, and Monica Prezzi. J Geotech Geoenvironmental Eng 2019;145:07019017. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002172.
[60] Han F, Ganju E, Salgado R, Prezzi M, Zaheer M. Experimental Study of the Load Response of Large Diameter Closed-Ended and Open-Ended Pipe Piles Installed in Alluvial Soil. West Lafayette, IN: 2019. https://doi.org/10.5703/1288284316880.
[61] Seo H, Yildirim IZ, Prezzi M. Assessment of the axial load response of an H pile driven in multilayered soil. J Geotech Geoenvironmental Eng 2009;135:1789-804. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000156.
[62] Han F, Ganju E, Salgado R, Prezzi M. Static Load Test on Open-Ended Pipe Pile Using Double-Wall Instrumentation. Geo-Congress 2020, Reston, VA: American Society of Civil Engineers; 2020, p. 73-81. https://doi.org/10.1061/9780784482780.008.
[63] Han F, Prezzi M, Salgado R, Marashi M, Wells T, Zaheer M. Verification of bridge foundation design assumptions and calculations. West Lafayette, IN: 2020.
[64] Han F, Marashi M, Prezzi M, Salgado R, Wells T, Zaheer M. Live load test on the Sagamore Parkway Bridge over the Wabash River. Transp Res Rec 2020;in review.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

[65] Santagata M, Bobet A, El Howayek A, Ochoa-Cornejo F, Sinfield J V., Johnston CT. Building a nanostructure in the pore fluid of granular soils. Geomech. from Micro to Macro - Proc. TC105 ISSMGE Int. Symp. Geomech. from Micro to Macro, IS-Cambridge 2014, vol. 2, CRC Press; 2015, p. 1377–82. https://doi.org/10.1201/b17395-249.

[66] Ochoa-Cornejo F, Bobet A, Santagata M, Sinfield J, Johnston C. Liquefaction 50 Years After Anchorage 1964; How Nanoparticles Could Prevent It. 10th U.S. Natl. Conf. Earthq. Eng. – Front. Earthq. Eng., 2014.

[67] Ochoa-Cornejo F, Bobet A, Johnston CT, Santagata M, Sinfield J V. Cyclic behavior and pore pressure generation in sands with laponite, a super-plastic nanoparticle. Soil Dyn Earthq Eng 2016;88:265–79. https://doi.org/10.1016/j.soildyn.2016.06.008.

[68] Ochoa-Cornejo F, Bobet A, El Howayek A, Johnston CT, Santagata M, Sinfield J V. Discussion on: "Laboratory investigation of liquefaction mitigation in silty sand using nanoparticles" [Eng.Geol.204:23-32]. Eng Geol 2017;216:161–4. https://doi.org/10.1016/j.enggeo.2016.11.015.

[69] Ochoa-Cornejo F, Bobet A, Johnston C, Santagata M, Sinfield J V. Dynamic properties of a sand-nanoclay composite. Géotechnique 2020;70:210–25. https://doi.org/10.1680/jgeot.18.P.017.

[70] Santagata MC. Invited Key-note Paper: Effects of stress history on the stiffness of a soft clay. 4th Int. Symp. Deform. Charact. Geomaterials, Netherlands: 2008.

[71] Huang PT. Rheology and lubrication properties of clay-based fluids for trenchless technologies applications. Purdue University, West Lafayette, IN, 2013.

[72] Reddy KR, Bohnhoff GL, Palomino AM, Santagata MC. Fundamental Research on Geochemical Processes for the Development of Resilient and Sustainable Geosystems. Geotech. Fundam. Face New World Challenges, 2019, p. 169–92. https://doi.org/10.1007/978-3-030-06249-1_6.

[73] Johnston, Cliff T.;Bobet, Antonio; Sasar, Mohammadhasan; Kaminsky, Heather A.;Santagata, Marika; Duan L. Polymer MFT Interactions: From surface chemistry to rheology. Int. Oil Sands Tailings Conf., Lake Louise, Canada: 2016, p. 203-13.

[74] Santagata M, Clarke JP, Bobet A, Drnevich VP, El Mohtar CS, Huang PT, et al. Rheology of concentrated bentonite dispersions treated with sodium pyrophosphate for application in mitigating earthquake-induced liquefaction. Appl Clay Sci 2014;99:24–34. https://doi.org/10.1016/j.clay.2014.05.017.

[75] El Howayek A, Bobet A, Santagata M. Microstructure and cementation of two carbonatic fine-grained soils. Can Geotech J 2019;56:320–34. https://doi.org/10.1139/cgj-2018-0059.

[76] El Howayek A, Bobet A, Santagata M. Geologic origin effects on mineralogy, index properties and fabric of a fine-grained carbonatic deposit. Eng Geol 2017;216:108–21. https://doi.org/10.1016/j.enggeo.2016.11.017.

[77] El Howayek A, Santagata M, Bobet A, Zia-Siddiki N. Engineering Properties of Marls. West Lafayette, IN: 2015. https://doi.org/10.5703/1288284315533.

[78] Santagata M, Bobet A, El Howayek A. Characterization of a carbonatic deposit across scales. Proc. IS Atlanta 2018 Symp. Geomech. from Micro to Macro Res. Pract., Atlanta: 2018, p. (in press).

[79] White DJ, Vennapusa PKR, Suleiman MT, Jahren CT. An in-situ device for rapid determination of permeability for granular bases. Geotech Test J 2007;30:282–91. https://doi.org/10.1520/gtj100648.

[80] Bai H, Sinfield J V. Effects of GPR antenna configuration on subpavement drain detection based on the frequency-shift phenomenon. J Appl Geophys 2017;146:198–207. https://doi.org/10.1016/j.jappgeo.2017.09.019.

[81] Bai H, Sinfield J V. Improved background and clutter reduction for pipe detection under pavement using Ground Penetrating Radar (GPR). J Appl Geophys 2020;172. https://doi.org/10.1016/j.jappgeo.2019.103918.

[82] Lumpkin DR, Horton WT, Sinfield J V. Holistic synergy analysis for building subsystem performance and innovation opportunities. Build Environ 2020;178:106908. https://doi.org/10.1016/j.buildenv.2020.106908.

Research highlights (Con't)

Geotechnical Engineering Research at Purdue University

[83] Sinfield J V., Monwuba C. Inferential monitoring of chlorinated solvents through Raman spectroscopic observation of the vibrational modes of water. Talanta 2016;148:7–16. https://doi.org/10.1016/j.talanta.2015.10.055.

[84] Sinfield J V., Monwuba CK. Assessment and correction of turbidity effects on Raman observations of chemicals in aqueous solutions. Appl Spectrosc 2014;68:1381–92. https://doi.org/10.1366/13-07292.

[85] Sinfield J V., Colic O, Fagerman D, Monwuba C. A Low Cost Time-Resolved Raman Spectroscopic Sensing System Enabling Fluorescence Rejection. Appl Spectrosc 2010;64:201–10. https://doi.org/10.1366/000370210790619636.

[86] Sinfield J V. Advances in Raman Spectroscopy for the Geoenvironment. In: Sivakumar Babu GL, Reddy KR, De A, Datta M, editors. Geoenvironmental Pract. Sustain. Linkages Dir., 2017, p. 117–28. https://doi.org/10.1007/978-981-10-4077-1_12.

[87] Sheth A, Sinfield JV. Systematic Problem-specification in Innovation Science using Language. Int J Innov Sci 2020.