Bio-mediated and Bio-inspired Geotechnics REU Project Descriptions
Summer 2020 REU Project Descriptions

For your application, please list all projects you are interested in working on by the number (e.g., UCD-4, ASU-5, NMSU-1) in your order of preference. For the same question, you should briefly identify who you are interested in your top projects.

Projects are listed by for each Center for Bio-mediated and Bio-inspired Geotechnics partner university.
University of California, Davis (Davis, CA)
New Mexico State University (Las Cruces, NM)
Georgia Tech (Atlanta, GA)
Arizona State University (Tempe, AZ)

University of California, DAVIS (Davis, CA) Projects

Project UCD-1: Universal Biomechanical Processes for Subsurface Exploration and Underground Construction

Description: The natural variability of geologic deposits poses a significant challenge to engineers because current characterization technologies only provide information at discrete points within the subsurface, requiring engineers to interpolate the data available to estimate the subsurface profile. The need for interpolation introduces significant uncertainty in the assessment of geologic hazards, often resulting in either inefficient or unsafe infrastructure. The objective of this project is to improve current subsurface exploration technologies by developing a bioinspired robotic probe with the unique capability of burrowing in any direction to reach locations within the subsurface that drive the risk of failure. This work will obtain bioinspiration from limbless burrowing organisms, assess the mechanical efficiency of their burrowing strategies, and implement the most efficient strategies in a robotic prototype design plan.
Suggested Background/Interests: Civil infrastructure, geology, soil mechanics, ecology, robotics
Principal Investigator: Dr. Alejandro Martinez

Project UCD-2: Snakeskin-inspired Anisotropic Surfaces Prescription of Frictional Interactions at Soil-Structure Interfaces

Description: Nature has developed efficient solutions to optimize soil-organism interfaces. A notable example is the skin along the underbody of snakes. The skin mobilizes higher frictional resistances when soil is sheared against the scales to generate reaction for locomotion (i.e. cranial direction). On the other hand, snakeskin mobilizes lower frictional resistance when soil is sheared along the scales to minimize friction during forward movement (i.e. caudal direction). Snakeskin-inspired surfaces are a promising technology to optimize load transfer between construction materials and soil for various geotechnical applications such as deep foundations, geosynthetics, soil anchors and soil reinforcement. This passive technology has potential to improve the mechanical capacity, efficiency and safety of geotechnical structures. Snakeskin-inspired surfaces can enable multi-functionality in applications such as a pile foundations. The bio-inspired surfaces also mobilize larger friction than traditional engineered surfaces, potentially reducing the amount of material required to reach the given capacity.
Suggested Background/Interests: geotechnical engineering, infrastructure, soils
Principal Investigator: Dr. Alejandro Martinez

Project UCD-3: Life Cycle Sustainability Assessment of Emerging Biogeotechnical Engineering Solutions

Description: This REU project will help to quantify and improve the sustainability of geotechnical engineering solutions—specifically, of a new bio-mediated and/or bio-inspired technology. The project is aligned with the CBBG's strategic vision to develop biogeotechnical processes and solutions that support the "development and rehabilitation of resilient and sustainable civil infrastructure systems" (https://cbbg.engineering.asu.edu). In this project, a life cycle sustainability assessment (LCSA) will be performed to evaluate the environmental, economic, and social impacts associated with an emerging biogeotechnical engineering solution being developed within CBBG.
Suggested Background/Interests: Sustainable design; civil infrastructure
Principal Investigator: Drs. Alissa Kendall & Jason DeJong

Project UCD-5: Microbial-Induced Calcite Precipitation (MICP) – Innovative Ground Improvement Technology

Description: Biocementation uses natural microbes and chemical processes to cement sand together, resulting in substantial increases in stiffness and strength – MICP transforms sand into sandstone. This project will consist of working with the research team to prepare the MICP technology for deployment at a field project site. It will including working in the laboratory with a variety of equipment, ranging from microscopes, to soil strength tests, to larger column tests, and may also include field work.
Suggested Background/Interests: geotechnical engineering, sustainability
Principal Investigator: Dr. Jason DeJong

New Mexico State University (Las Cruces, NM) Projects

Project NMSU-1: Microbially Enhanced Iron-Modified Zeolite Permeable Reactive Barrier

Description: Migration of trace metals and metalloids, such as arsenic and selenium, from contaminated sites, including mining sites, is a major environmental concern. The goal of this project is to develop a permeable reactive barrier that is enhanced by the presence of microbiological communities and iron-coated zeolites to enhance the remediation of sites contaminated with oxyanions, such as arsenic and selenium. This research has the potential to enhance the remediation of contaminated sites, as well as to prevent spreading of contamination to adjacent aquifers. Therefore, the proposed research has also the potential to safeguard drinking water sources.
Suggested Background/Interests: Environmental, groundwater, chemistry, microbiology
Principal Investigator: Dr. Lambis Papelis

Project NMSU-2: Bio-inspired Resilient Earthen Construction

Description: The goal of this project is to develop enhancements to traditional adobe construction, inspired by biological processes and materials, to increase its resilience against weather and natural hazards while preserving its inherent sustainable, economic, and accessible aspects. This research seeks inspiration and materials in nature to create sustainable, low-cost and easy-to-do methods of making adobe bricks and masonry that perform better than those made with the traditional adobe techniques when subject to moisture and/or lateral loading. A key aspect of this project is using solely natural materials. The research targets new construction as well as rehabilitation or retrofitting of existing mud-brick masonry (regionally called adobe). The summer work will focus on studying biological or natural

analogs to extract ideas and strategies to enhance the properties of the interface between soil bricks and mud mortar in adobe.
Suggested Background/Interests: Biology, bioinspired design, civil infrastructure, geotechnical, materials engineering
Principal Investigator: Dr. Paola Bandini

Project NMSU-3: GUSANO: Utilitarian Subterranean Annelid-Inspired Geo-Probe

Description: The goal of this project is to create a self-excavating geo-probe inspired on the evolutionary adaptations developed by the earthworm (Lumbricus Terrestris). The development of an earthworm inspired geo-probe that can be driven into the ground without the need for surface reaction, and that can move within the soil in any direction could revolutionize in-situ geotechnical testing. It could facilitate the three-dimensional delineation of liquefiable soil deposits to help mitigate these hazards, and delineation of spatial heterogeneities in general. The probe could also be used as a disposable (in-place) environmental monitoring device. Work this summer will concentrate on the instrumentation of the geo-probe with sensors to monitor mechanical, thermal, and hydraulic soil properties.
Suggested Background/Interests: Civil infrastructure, biology, animal physiology, geotechnical engineering, robotics
Principal Investigator: Dr. Douglas Cortes

Project NMSU-4: EICP for Erosion Control in Sloping Ground

Description: The project develops a method for erosion control against water runoff in sloping ground using Enzyme Induced Carbonate Precipitation (EICP) technique. The current focus is on new or existing sites along highways and bridge abutments (transportation infrastructure) that require permanent erosion protection (medium-term or long-term), particularly in areas of arid or semi-arid climate in which establishing vegetative cover is very challenging. Bench-scale laboratory tests for natural sands are performed to determine a treatment and construction method that can be used in the field for this application. The summer work will also include design and installation plot tests/field tests to assess effectiveness of the method and treatment technique for erosion control in natural soils.
Suggested Background/Interests: Civil infrastructure, geotechnical, chemistry/chemical engineering, geology
Principal Investigator: Dr. Paola Bandini

Georgia Tech (Atlanta, GA) PROJECTS

Project GT-1: Geotechnics of bio-locomotion systems

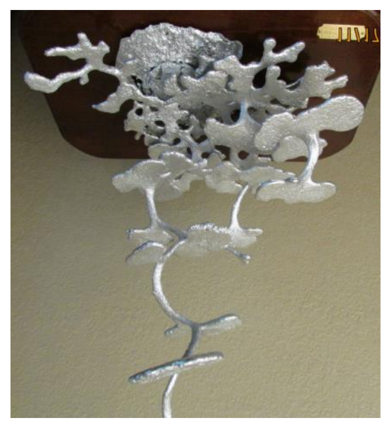
Description: Traditional methods for exploration of the subsurface for site characterization and monitoring purposes have involved insertion of devices from the surface. Historically, this has involved advancing near vertical penetrations that traverse what are often predominantly near horizontal strata. We seek to explore how subsurface bio-locomotion systems that can move in any orientation in the subsurface can provide new insights that can be ultimately leveraged to enhance the sustainability and resiliency of subsurface space development for infrastructure construction and hazard mitigation purposes.

Research Approach: The research team will use a combination of microscale experimental methods in conjunction with Discrete Element Modeling simulation systems to develop new insight into the geotechnics of bio-locomotion systems (e.g. worms). The experimental methods will seek to characterize and understand what factors contribute to the geometry of the subsurface network of tunnels excavated by worms while the particulate modeling simulations will study issues such as the role of force chains in the overall stability of real subsurface structures.

Preferred Background/Interests: Civil infrastructure, microscopy, computer modeling

Principal Investigator: Dr. David Frost

Project GT-2: Geotechnics of self-excavating systems



Description: Traditional methods for accessing underground spaces has involved the construction of tunnels that involve boring or pushing tube like structures into the ground. Recent studies have shown that ants are able to construct tunnels using less than 0.1% of the energy per unit volume of soil removed that the most efficient human tunnel boring machine.

Research Approach: The research team will use a combination of microscale experimental methods in conjunction with Discrete Element Modeling simulation systems to develop new insight into the activities of self-excavating systems (e.g. ants). The experimental methods will seek to characterize and understand what factors contribute to the geometry of the subsurface network of tunnels and chambers excavated by ants while the particulate modeling simulations will study issues such as the role of force chains in the overall stability of real subsurface structures. One of the REU positions will lead laboratory experiments while the other will lead field experiments although the students will have the opportunity to work on both aspects of the work.

Preferred Background/Interests: Civil infrastructure, microscopy, computer modeling

Principal Investigator: Dr. David Frost

Project GT-3: Root system inspired anchors

Description: The overarching goal of the proposed research is to provide insight into the performance of multi-function root systems which can lead to the development of novel construction configurations and techniques for the enhancement of common infrastructure anchorage systems, such as deep pile foundations and retaining structure reinforcement systems. This project aims to elucidate the anchorage and failure mechanisms of roots of varying architecture subjected to typical plant loading situations, including pullout extension (herbivores), compression (self-weight), and lateral (wind) forces. Analogous synthetic root structures, instead of living roots, will be designed and utilized based on simplified optimal root architectures revealed in previous experimental studies.

Research Approach: Observation of the failure mechanisms of 3-D printed root analogues during pull-out tests will allow for a conceptual model to be formulated to predict the system capacity under different loading scenarios for various root analogues structures. The role of the root shape and surface characteristics will be evaluated. This may serve as a starting point for bridging biology and physics, enabling new design heuristics of synthetic tree-like structures inspired by root branching morphogenesis. Experimental studies will be complemented by Discrete Element Model simulations of root-particulate systems.

Suggested Background/Interests: Civil infrastructure, biology, computer modeling

Principal Investigator: Dr. David Frost

Project GT-4: Colloidal Facilitation of Microbial Induced Calcite Precipitation (MICP)

Description: Precipitation of calcite from solution is driven in large part by nucleation mechanics, which is primarily heterogeneous nucleation at sites on the surface of soils or adhered bacteria surface; therefore, an increase in nucleation sites may effectively increase the rate of calcite deposition, the uniformity of calcite formation throughout the coarse medium, as well as the total amount of calcite deposition, even though it does not increase the urease activity. Injection of relatively small colloids, that can be transported as suspended particles along with the urea solution can be beneficial to both the uniformity of calcite formation, and to the amount of precipitated calcite. When colloids suspended in the aqueous phase, or filtered and attached to the solid phase, act to serve as nucleation sites, the advantage of utilizing colloids in MICP process will be roughly controllable (or predictable) nucleation sites distributed throughout the coarse soils. Work this year focused on performing column and batch tests to control the distribution of colloids and bacteria, as well as dissolution of iron oxides.

Preferred Background/Interests: Microbiology

Principal Investigator: Dr. Susan Burns

Project GT-5: Geotechnics of termite mounds

Description: Termite mounds are resilient structures that rely on bio-cementation of granular soils to create above ground structures that can house millions of termites. The potential to emulate the construction techniques used by termites to build these structures offers significant potential in a range of geotechnical problems ranging from settlement to liquefaction. We seek to explore how bio-cementation utilized by these self-excavating systems can provide new insights and thus concepts that can be ultimately leveraged to enhance the sustainability and resiliency of subsurface space development for infrastructure construction and hazard mitigation purposes.

Research Approach: The research team will use a combination of microscale experimental methods in conjunction with Discrete Element Modeling simulation systems to develop new insight into the geotechnics of termite mound construction. The experimental methods will seek to characterize and understand what factors contribute to the geometry of the above ground network of tunnels and chambers created by termites while the particulate modeling simulations will study issues such as the role of force chains in the overall stability of these structures.

Preferred Background/Interests: Civil infrastructure, biology, microscopy, computer modeling

Principal Investigator: Dr. David Frost

Project GT-6: Angel Wing shells (cyrtopleura costata) inspired hard rock drilling

Description: Drilling is widely applied for many purposes relevant to resources, environment, infrastructures, science, and health, including for example geological studies and search for resources, mining and tunneling, petroleum and gas drilling and exploration, ocean and seafloor drilling, planetary drilling and sampling, and dental drills, to name a few. Enormous capabilities of drilling that emerged in the last 100 years have helped to build our cities, including the freeways, tunnels, sewage and water systems, and many other underground utilities. Efficient drilling requires longer-lasting drills, improved penetration rates, much higher levels of autonomy, reduced cost, and increased safety. Several CBBG projects have investigated the borrow mechanisms of earthworms, roots, snakes, and razor clams that mainly bore granular media, i.e., soils. This research project investigates the mechanisms of Angel Wing shells (cyrtopleura costata) boring shales and rocks and aims to provide innovative solutions to efficient drilling in hard rocks. The Angel Wing shell is thin and brittle, yet can burrow into hard rocks through unique body shape and surface denticle patterns to effectively break the rock and remove the cuttings. This research will combine tomography characterization, surface properties testing, and numerical shear-mode cutting simulation to unravel the underlying mechanics and develop bio-inspired technologies for drilling greater depths, harder media, and extreme environments.

Suggested background/interests:

Principle investigator: Dr. Sheng Dai

Arizona State University (Tempe, AZ) Projects

Project ASU-1: The Effectiveness of Enzyme Induced Carbonate Precipitation for Mitigating Wind Erosion of Soil

Description: Wind-blown soil, or fugitive dust, presents a significant threat to human health and the environment in the southwestern United States and many other areas around the world. Enzyme induced carbonate precipitation (EICP) is a biogeotechnical process that offers the promise of increased wind erosion resistance of soil at a lower cost and with lower environmental impact than alternative technologies. Laboratory testing will be conducted using a “vortex generator” (a device that generates “dust devils” of varying intensity) to quantify the relationship between wind erosion resistance and the level of EICP treatment for typical soils that are susceptible to wind erosion.
Suggested Background/Interests: geotechnical engineering, wind erosion, fugitive dust control, soil improvement
Principal Investigator: Dr. Ed Kavazanjian

Project ASU-2: Enzyme Induced Carbonate Precipitation for Soil Improvement

Description: Enzyme induced carbonate precipitation (EICP) is a biogeotechnical process that provides an alternative to conventional Portland cement for soil improvement. In EICP, calcium carbonate is precipitated from a chemical solution to cement soil particles together, increasing the strength and stiffness of the soil. The effectiveness of EICP varies from soil to soil, and the reasons behind this variability is unknown. Specimens of soil from different sources will be treated using EICP and subject to laboratory strength testing as part of the effort to identify the source(s) of and quantify the variability in EICP effectiveness.
Suggested Background/Interests: Geotechnical engineering, soil cementation chemistry/geochemistry, and ground improvement
Principal Investigator: Dr. Ed Kavazanjian

Project ASU-3: “Breaking new ground” by Bio-inspired self-burrowing robots

Description: This project is to study the burrowing mechanisms of living organisms and to design, prototype, and evaluate bio-inspired self-burrowing robots. Many burrowing organisms inhabit a range of substrata. They live, sense, locomote and communicate underground and thus are perfect biological role models of active self-burrowing robots. Common features of underground locomotion by natural organisms include self-motility and high efficiency, which are achieved by controlling the kinematics and shape of different body parts. By coordinating the movement of different parts of the body, anchorage and thrust can be achieved (often alternatively) to enable motility, so external reaction systems are not needed; at the same time, the changing body shape manipulates the surrounding soil to improve the effectiveness and efficiency of locomotion. In this project, the REU student will work with the PI and the student mentors to create and evaluate prototypes of bio-inspired self-burrowing robots with tools including 3D printing technologies, autonomous controls and soil chamber testing.

Suggested background/interests: robotics, electronics, soil mechanics, rapid prototyping, control
Principle investigator: Dr. Julian Tao

Project ASU-4: Bio-inspired underground communication

Description: This project is an extension to the self-burrowing robot project. The goal of this research is to explore innovative underground sensing and communication technologies inspired by subterranean mammals. It is known that many subterranean mammals generate and respond to seismic vibrations and rely on vibrations for underground communication. In this research, we will explore the feasibility of encoding and decoding seismic waves for underground data transmission. By integrating sensing and communication capabilities to the self-burrowing robots, it is envisioned to build an underground wireless sensing network (WSN). The specific tasks include: 1) integrating sensing and communication units to the existing soft burrowing robot; 2) evaluating the data-carrying capabilities of seismic signals in different soils based on an array of modulation strategies; 3) improving effectiveness and efficiency of the signal modulation methods.

Suggested background/interests: robotics, signal processing, wireless network, non-destructive testing
Principle investigator: Dr. Julian Tao

Project ASU-5: Microbial Metabolic Exploration (MME)

Description: Heavy metals are chemical elements that are toxic or poisonous at low concentrations (e.g., mercury, cadmium, arsenic, chromium and lead). Although these are natural components of earth's crust, increased concentration of these toxic elements in soil and groundwater is due to anthropogenic activities. Heavy metals can never be degraded or destroyed. However, microbes can be oxidize or reduce them and this will change their toxicity and mobility in the subsurface. Every heavy metal poses different levels of toxicity in different oxidation states. Microorganisms can potentially tolerate high concentrations of these heavy metals and thus oxidize/reduce them to less toxic/non-toxic forms. This project seeks to explore, discover and develop novel microbial cultures that can be used for detoxification and immobilization of heavy metals in soils. Chromium is a key candidate for this project. Chromiun is primarily used in alloys, pigments for paints, leather tanning and wood preservation. The oxidized form of chromium, Cr (VI) is a known carcinogen and highly soluble in water, thus very mobile in the subsurface, while the reduced stable form of chromium, Cr (III) is at least 1000 times less toxic and is insoluble in water (immobile in subsurface). Cr (VI) reduction to Cr (III) can be done by certain microorganisms. However, only few microorganisms are known to tolerate high concentrations of Cr (VI). The main goal of this project is to find and develop microbial cultures capable of tolerating high concentration of Cr (VI) and reduce it to Cr (III). For this purpose, chromium enrichment cultures will be developed and the microbes of interest will be isolated and characterized. These microbes can be used for in situ bioremediation of Cr (VI) compounds in the subsurface.

Suggested Background/Interests: environmental engineering, chemistry, microbiology
Principle Investigator: Dr. Rosa Krajmalnik-Brown