The Role of Compatibility in Geotechnical Interface Behavior

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Reprise of H. Bolton Seed Medal Lecture

55th Annual KU Geotechnical Engineering Conference
November, 2023

Georgia Tech

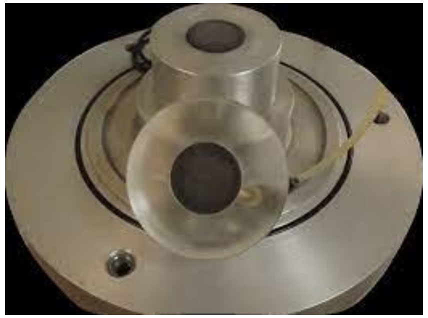
CBBG
Center for Bio-mediated & Bio-inspired Geotechnics

Tensar
A Division of CMC

NSF

Interfaces are Ubiquitous in Geotechnical Engineering

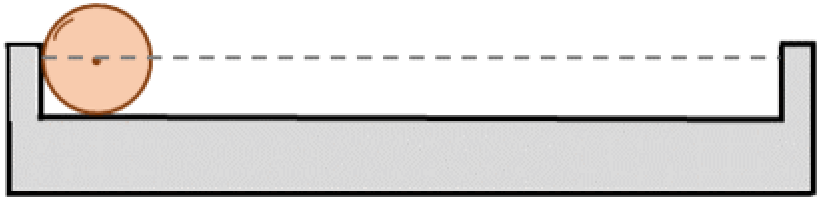
Lab Tests



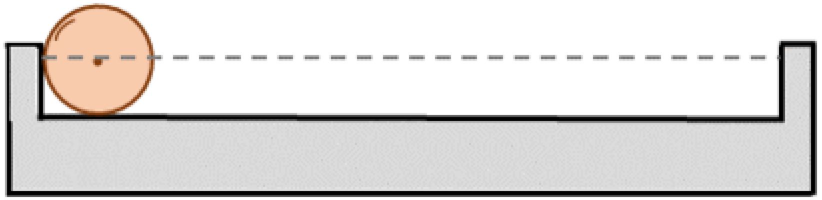
Field Tests

Geo-structures

Idealized Single Particle Geotechnical Interfaces

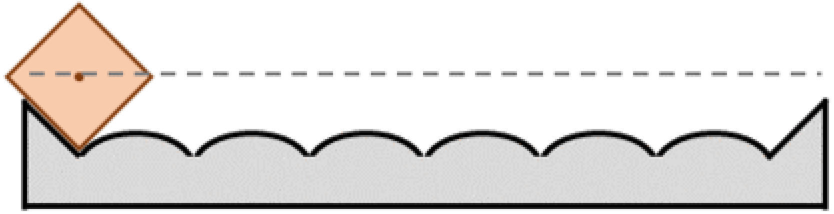


Pure Rolling

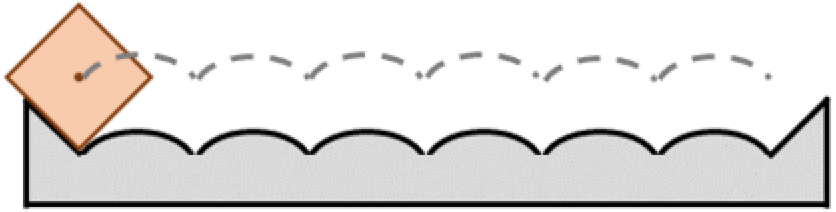


Pure Sliding

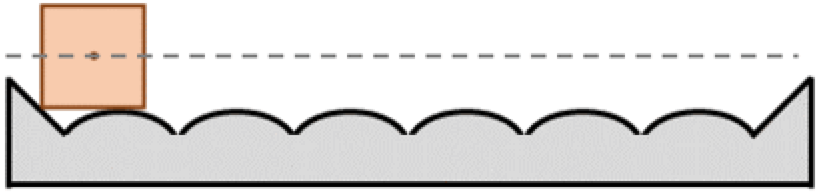
Actual Geotechnical Interfaces



Pure Rolling

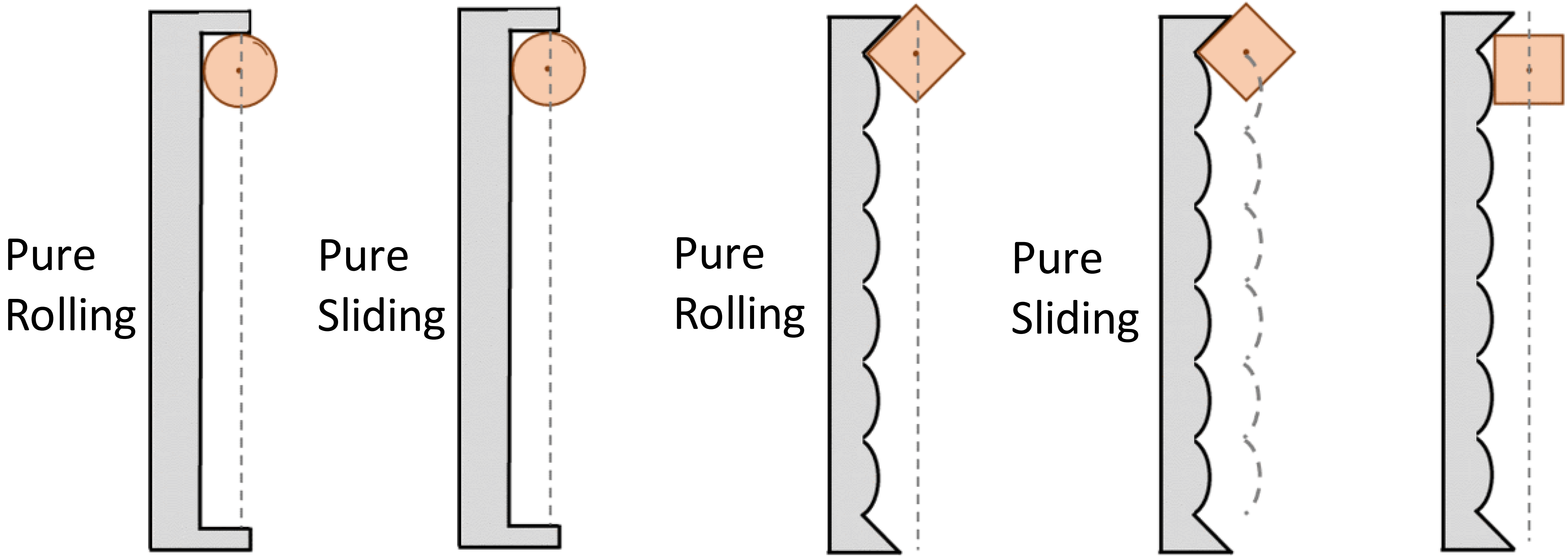


Pure Sliding



Interfaces Have Different Compatibilities!

Idealized Single Particle Pile Interfaces

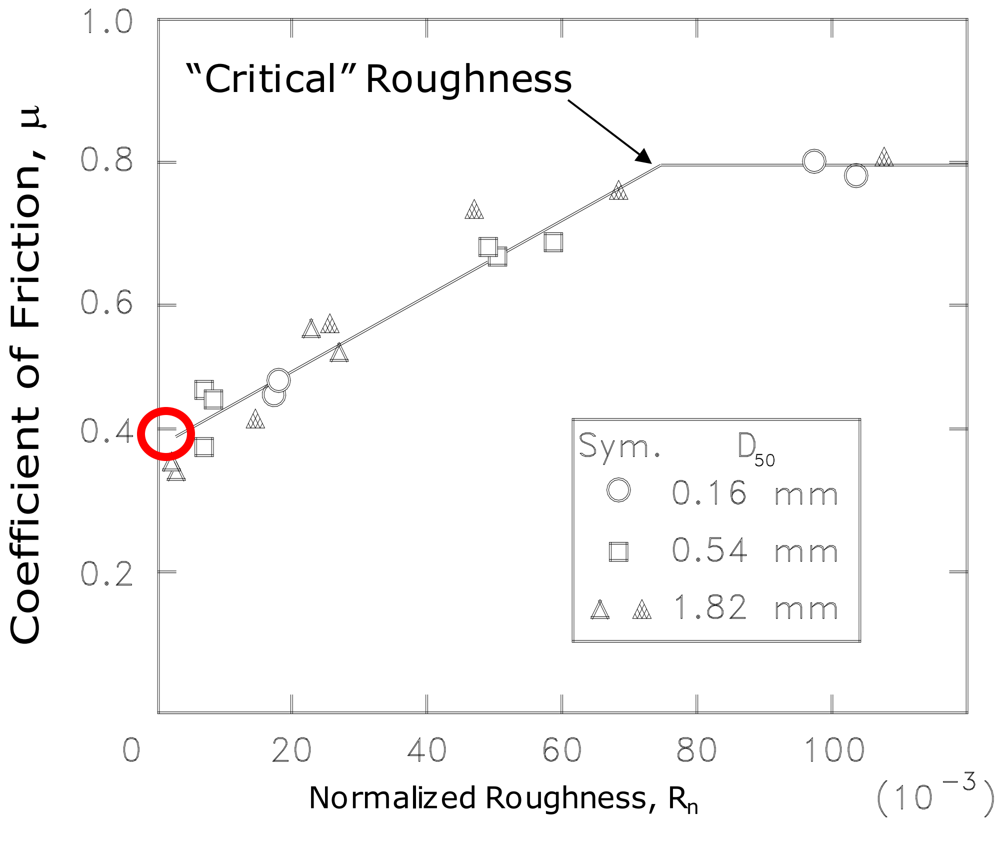


Pile Interfaces Have Different Compatibilities!

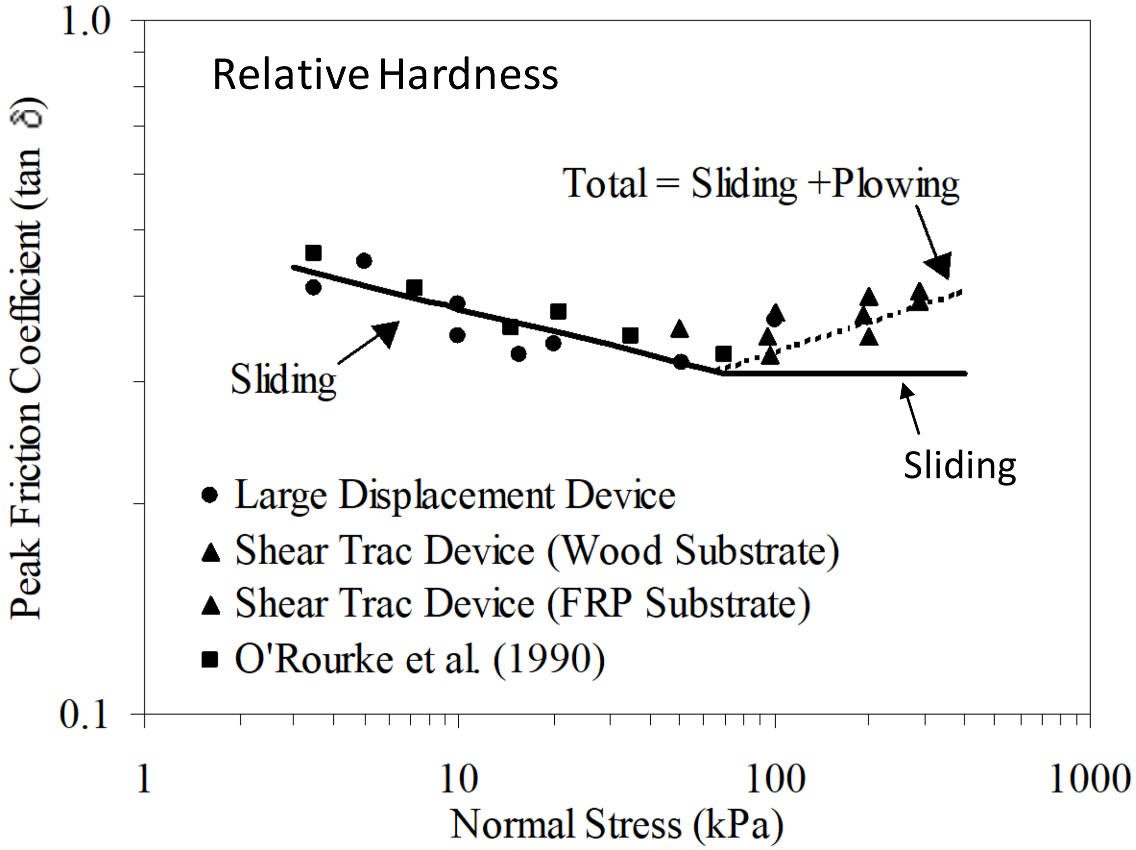
Failed or Underutilized Pile Interfaces

Real Interfaces Are Much More Complex

Important Bi-linear Plots in Interface Behavior…



After Uesugi & Kishida, 1986



After Dove & Frost, 1999

Lecture Outline

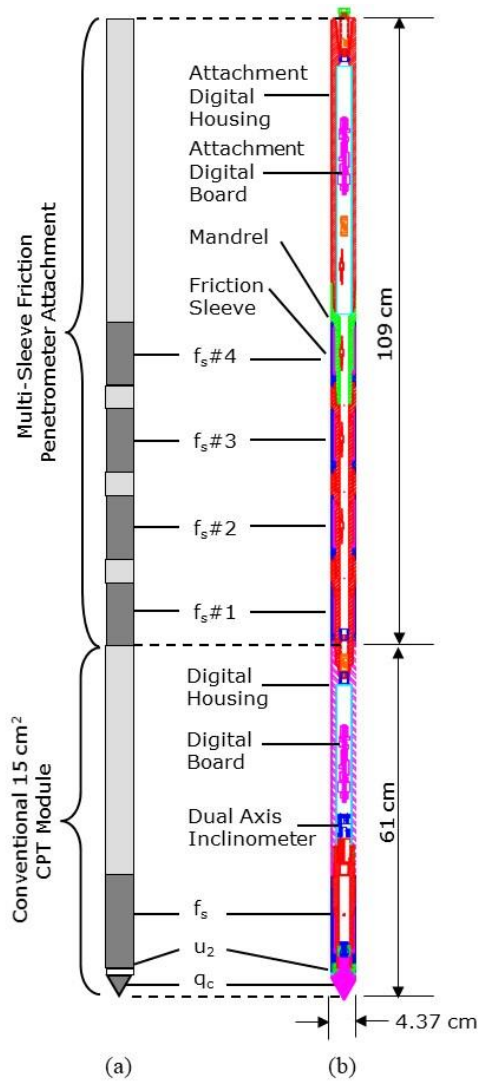
- Factors Enhancing and/or Limiting Compatibility
- Selected Insights from Various Past Studies
- Exploring Micro-scale interactions with DEM
- New Framework and Inspiration for Interface Designs
- Summary Comments

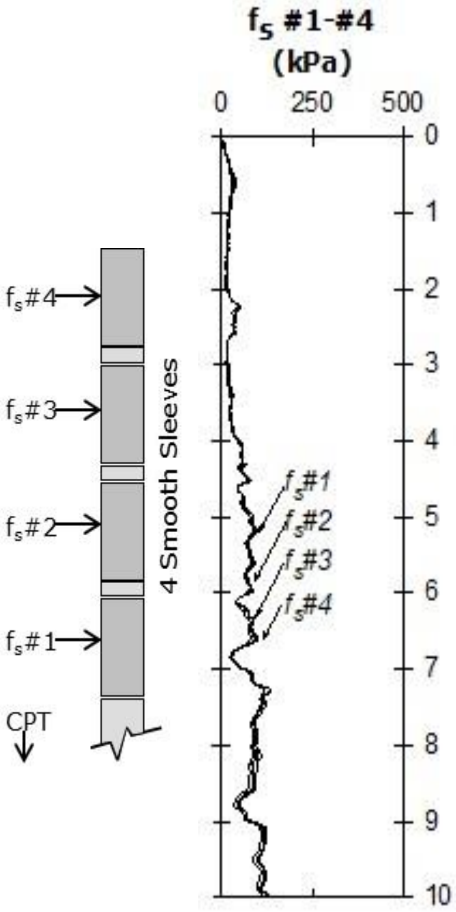
Factors Enhancing and/or Limiting Compatibility

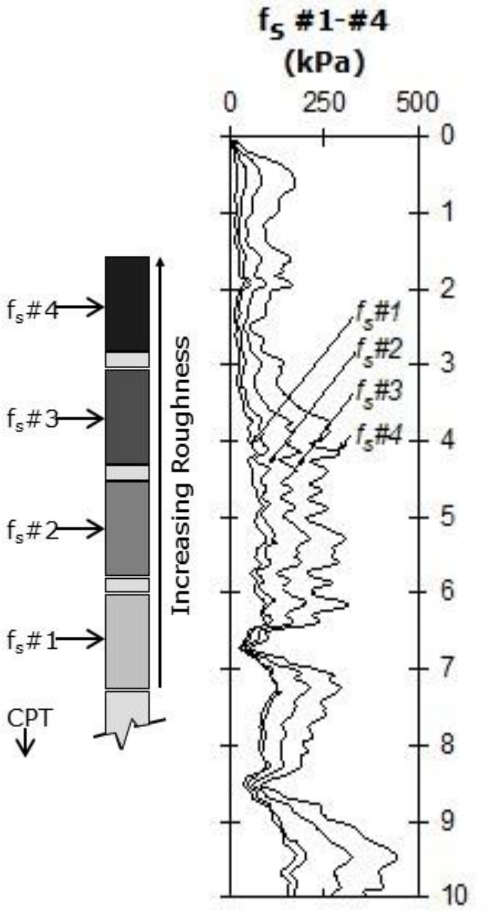
- Relative roughness
- Relative hardness
- Asperity shape
- Asperity spacing
- Ridge versus valley features
- Wear
- Lubrication (air/water/fluid)
- Clogging
- Arching
- Mineralogy
- Opening size
- Particle size
- Particle shape
- Particle gradation
- Number of contacts
- Stress level (state – contr./dil.)
- Material stiffness
- Fabric
- Surface directionality
- Temperature sensitivity
- Others…

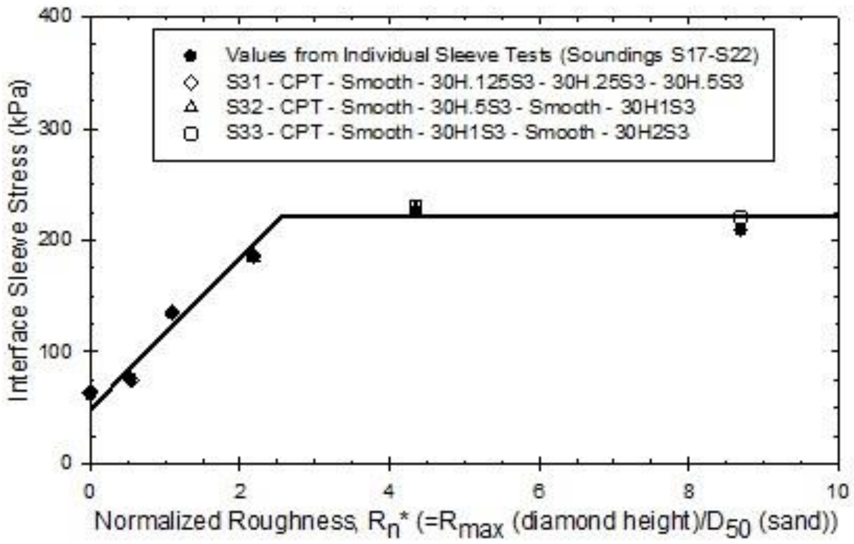
Selected Insights from Various Past Studies..

Some Insights from Multi-Sleeve CPT Studies



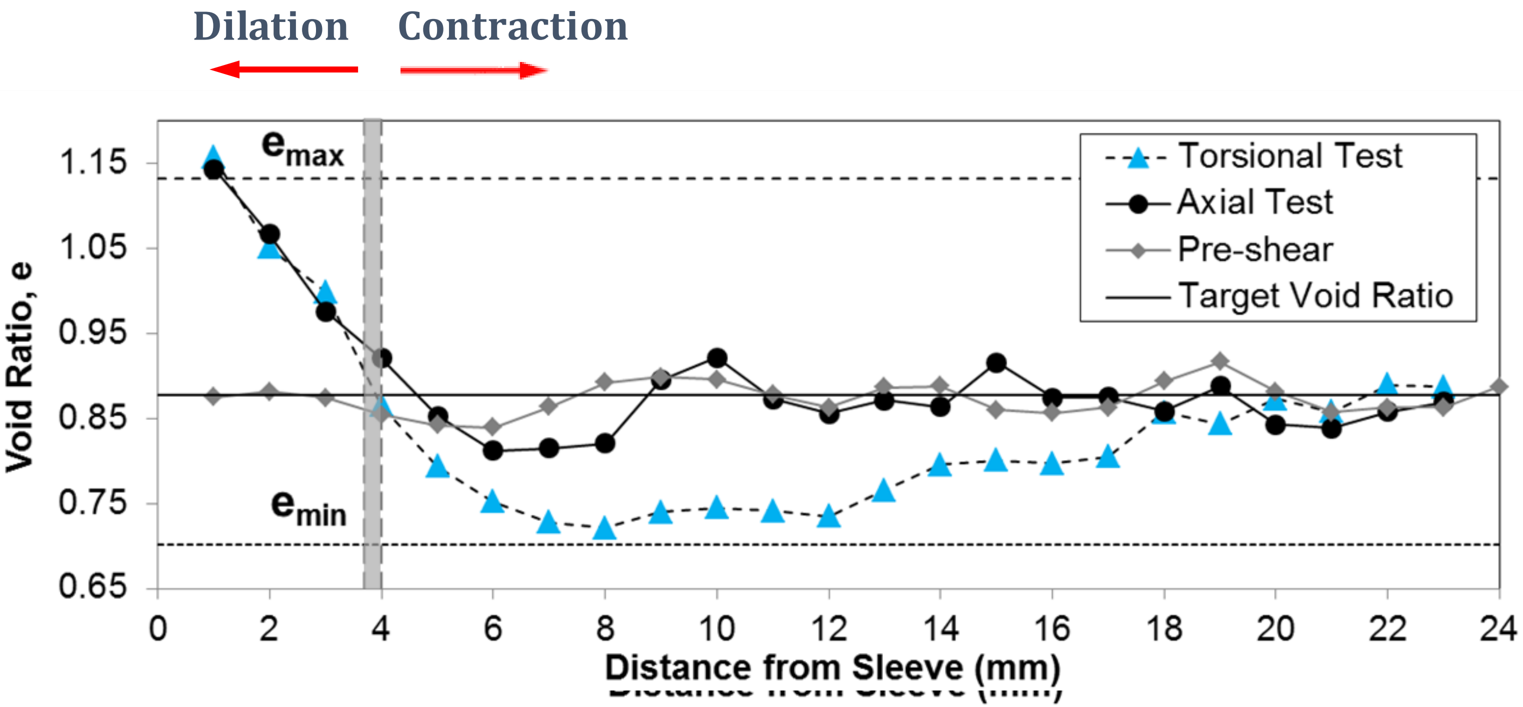


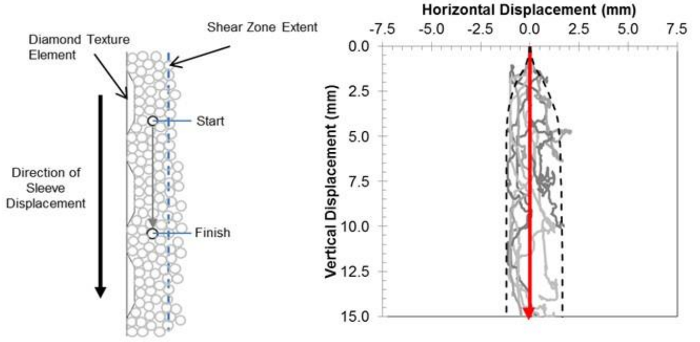


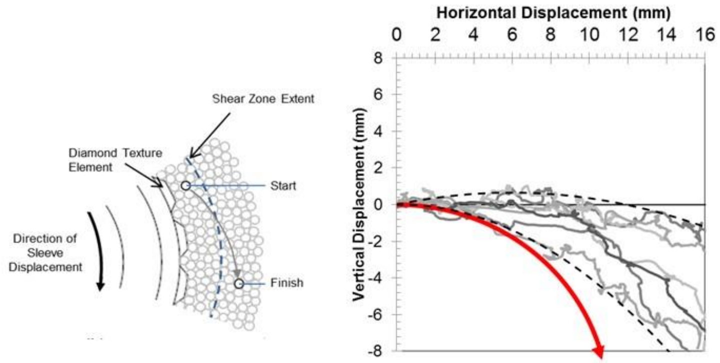


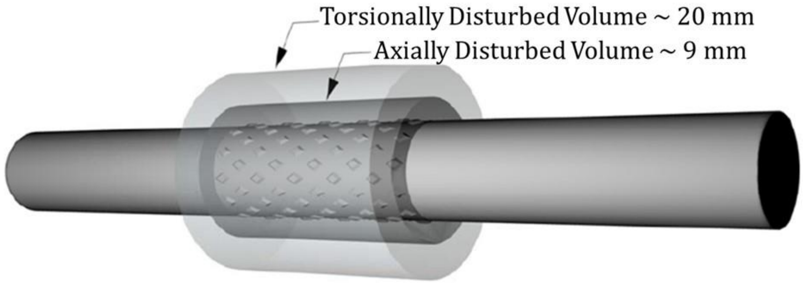
Varying compatibilities yield different interface responses.

Some Insights from Interface Movement Studies

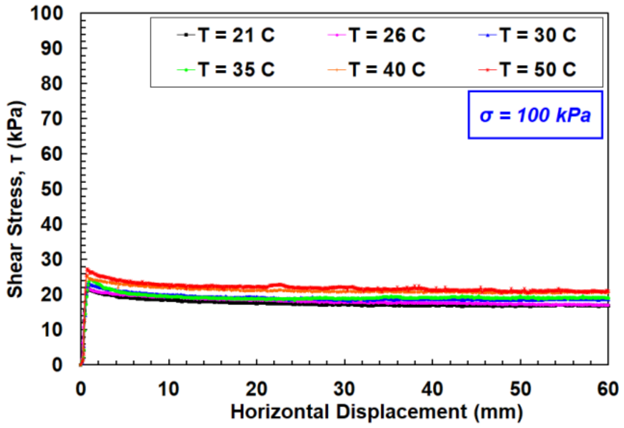




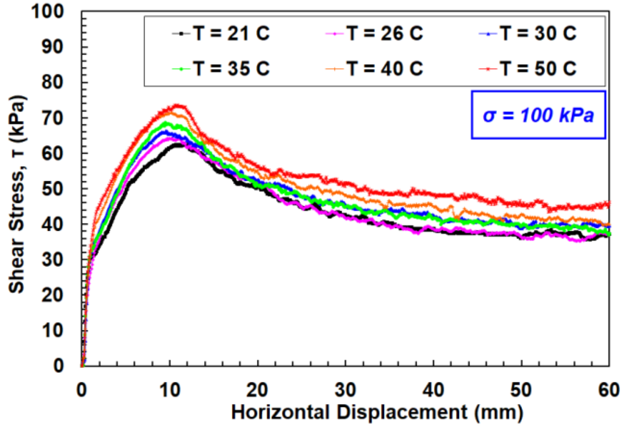




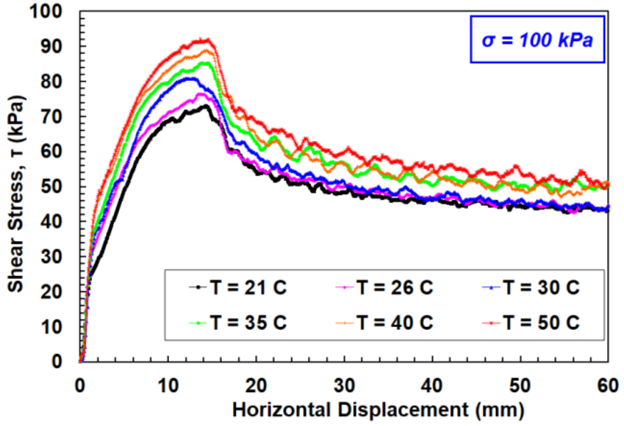
Some Insights from Elevated Temperature Studies



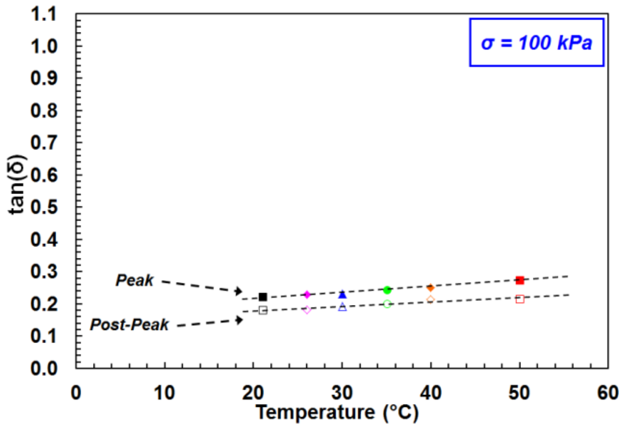
Smooth HDPE – NPNW Geotextile

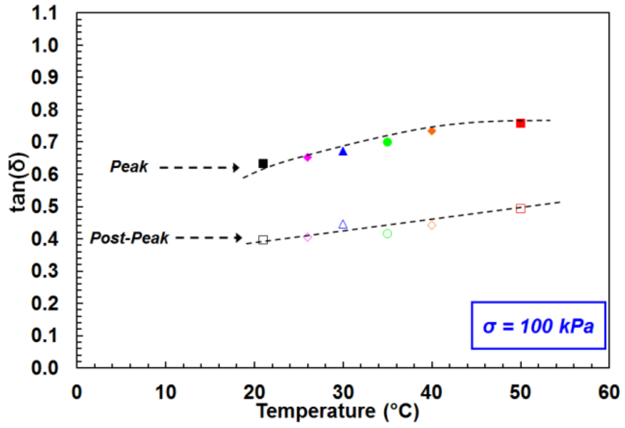


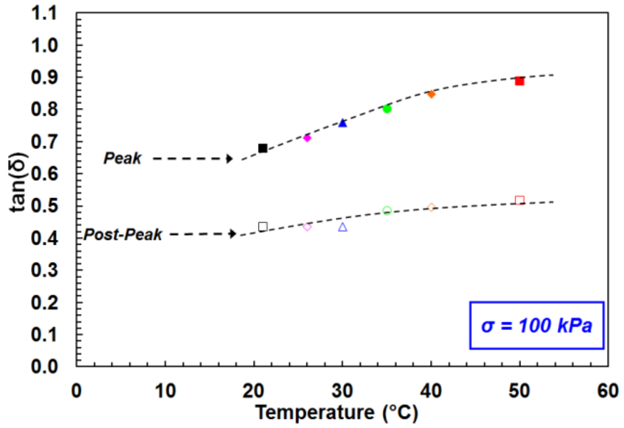
Co-extruded HDPE – NPNW Geotextile



Structured HDPE – NPNW Geotextile

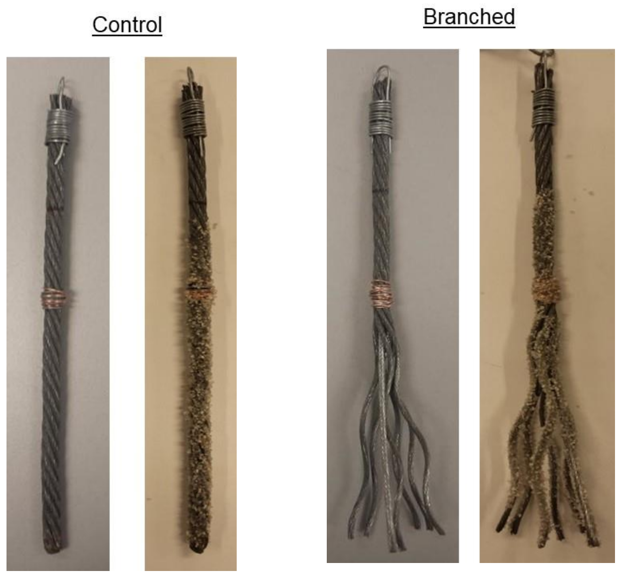


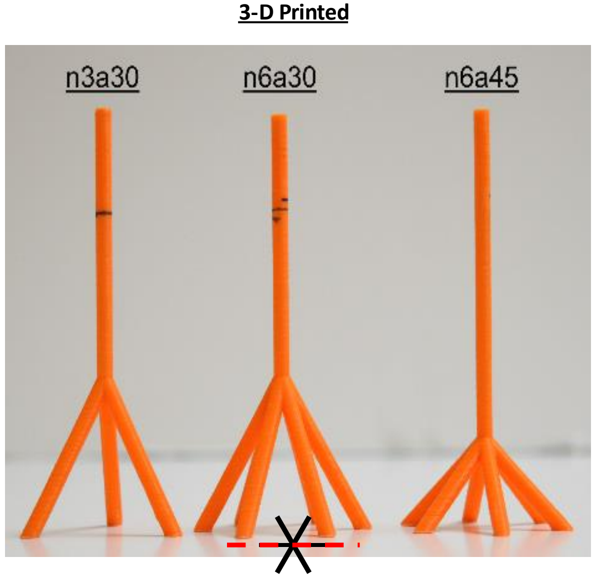


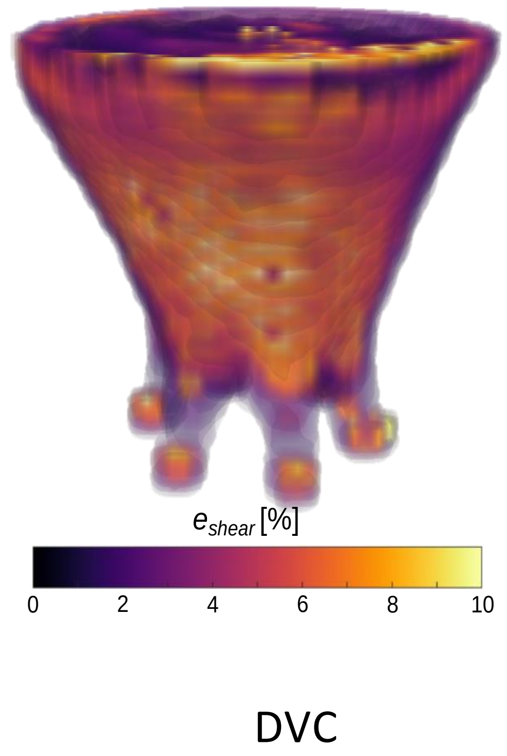


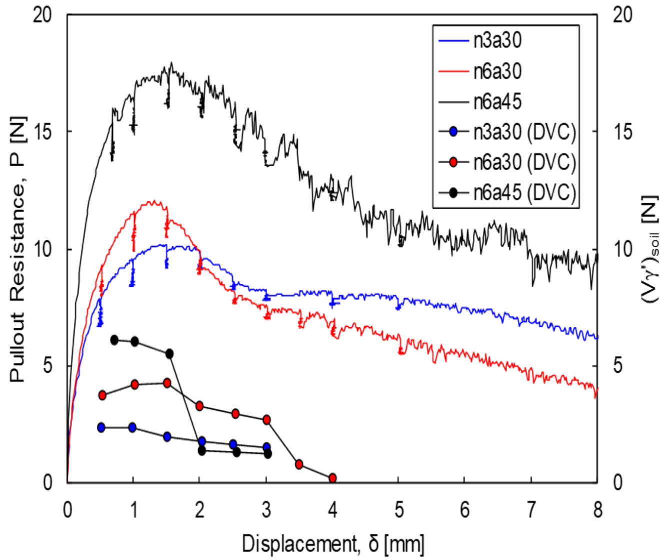
Elevated Temperatures Influence Interface Compatibility.

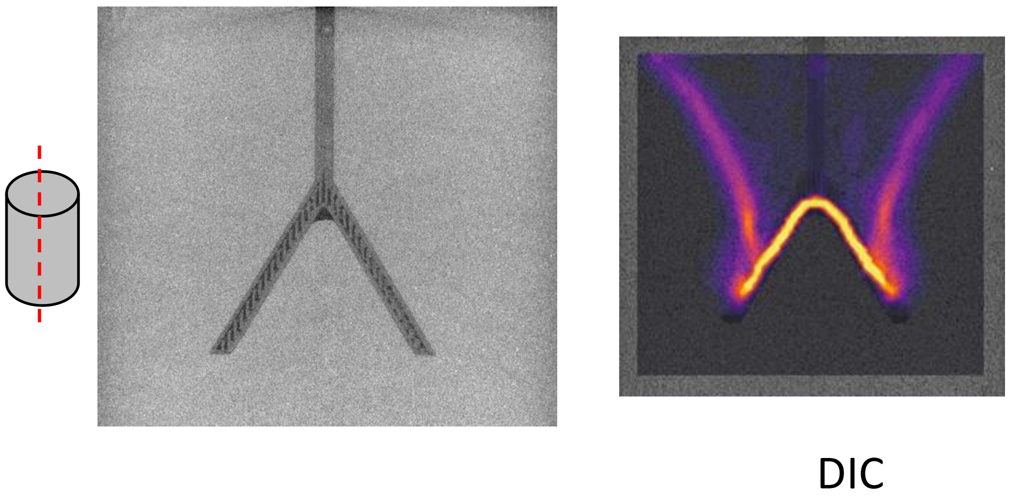
Some Insights from Anchor Pullout Studies



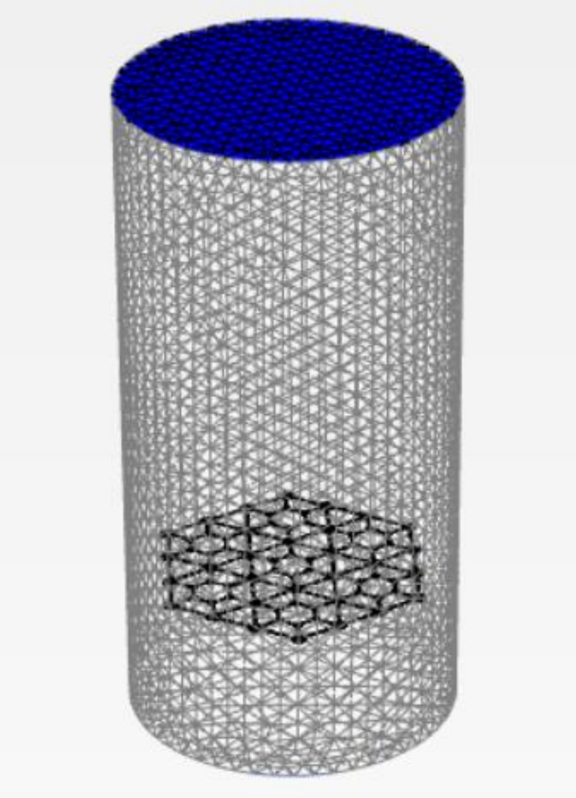




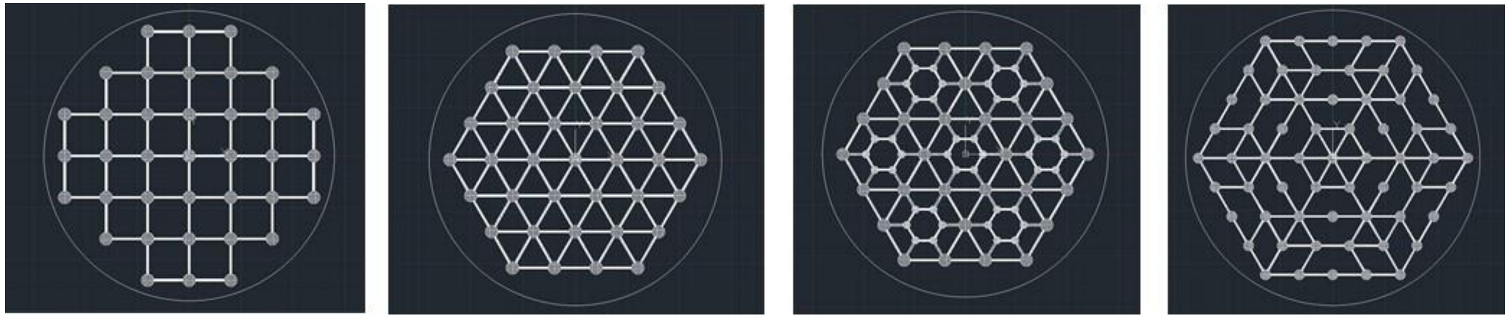




Some Insights from Aggregate-Geogrid Interaction Studies

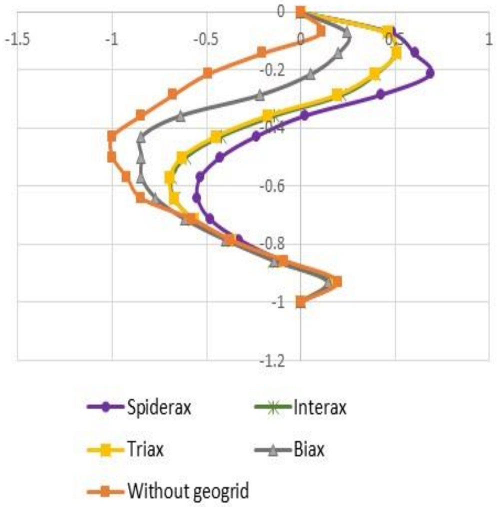


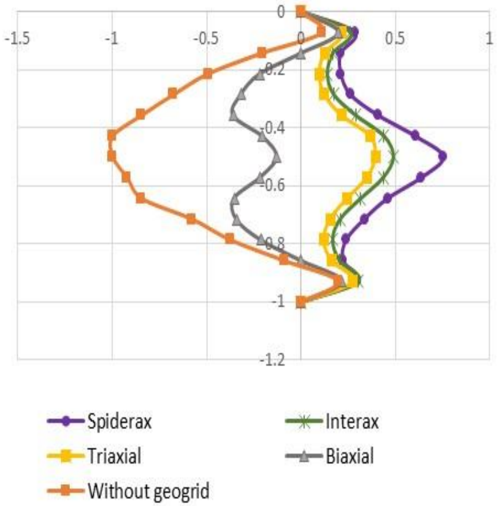
14 cm-diameter, 28 cm-length soil mass(H/D=2)

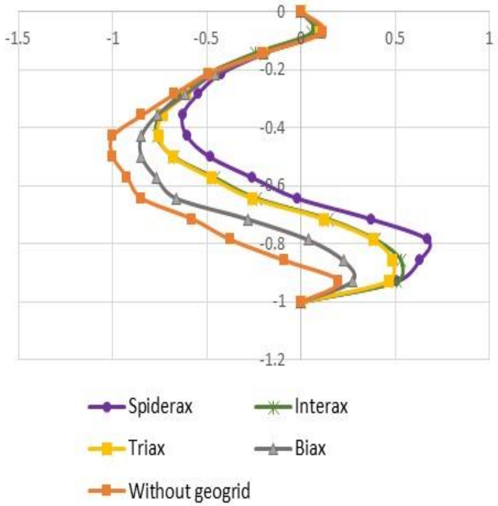


Biaxial   Triaxial   Interax   Spiderax I

Axial stress of 200 kPa applied and lateral deformation profiles (parallel to x-axis) for the boundary (minx/left part) were drawn for cases with/without geogrids.

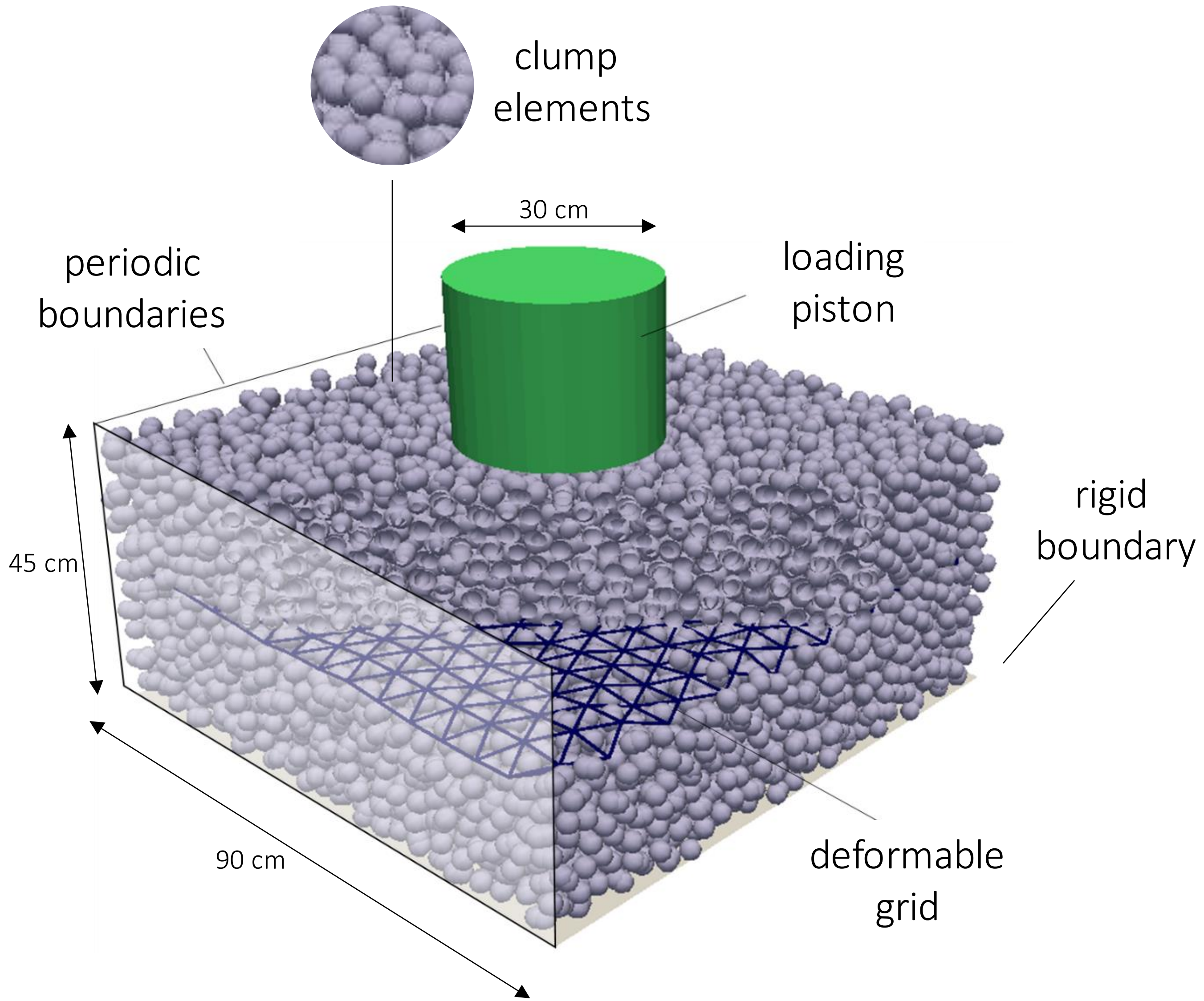


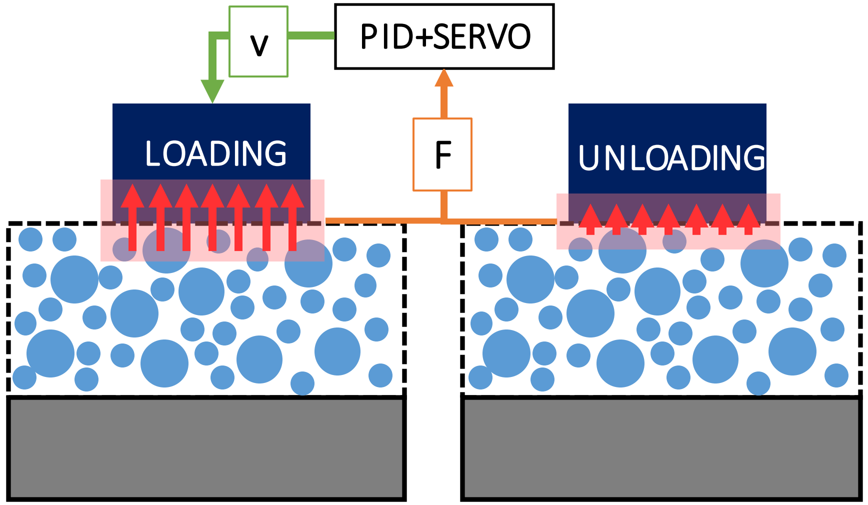




Exploring micro-scale aggregate-geogrid interactions with DEM

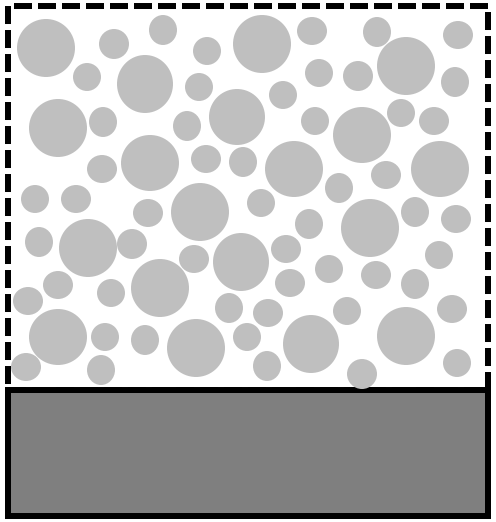
Modeling approach using 3D DEM



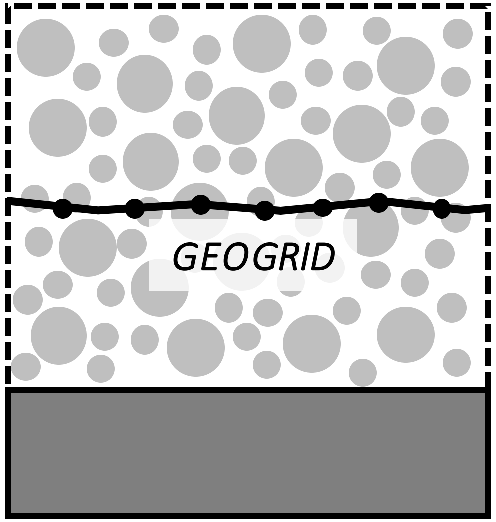


Modeling approach using 3D DEM

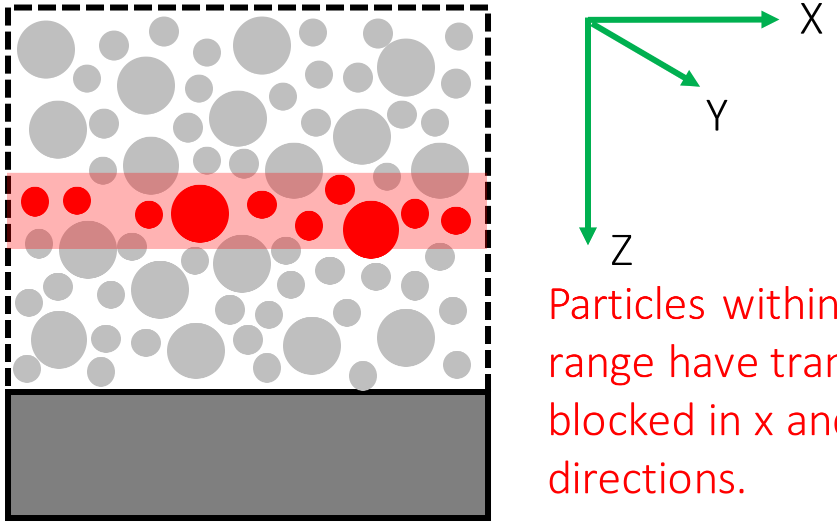
- Grids can only partially restrict lateral displacement of aggregates
- In order to quantify maximum enhancement achievable using grid stabilization - laterally lock a layer



UNREINFORCED
upper bound → max(δ)



REINFORCED
max(δ) < δ < min(δ)



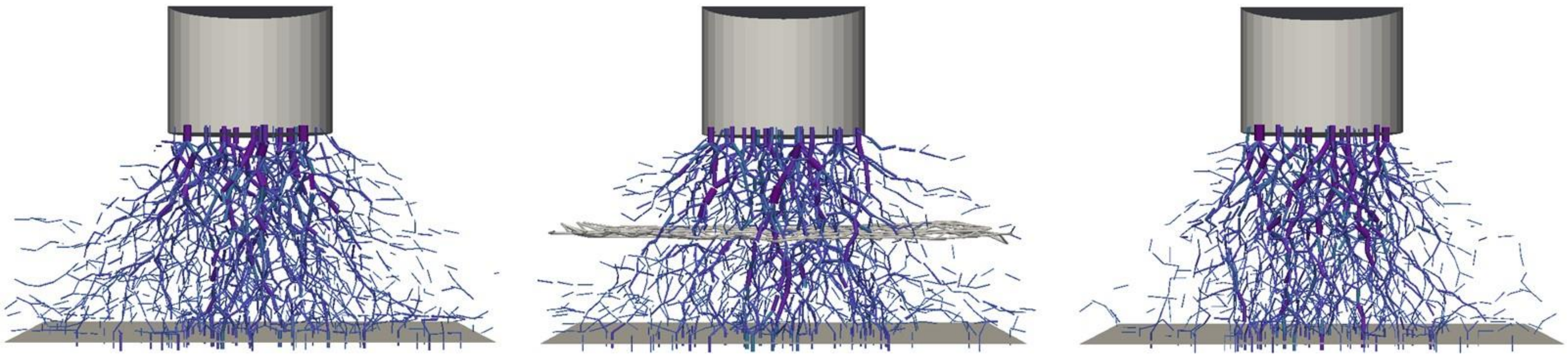
FULL LATERAL CONFINEMENT
lower bound → min(δ)

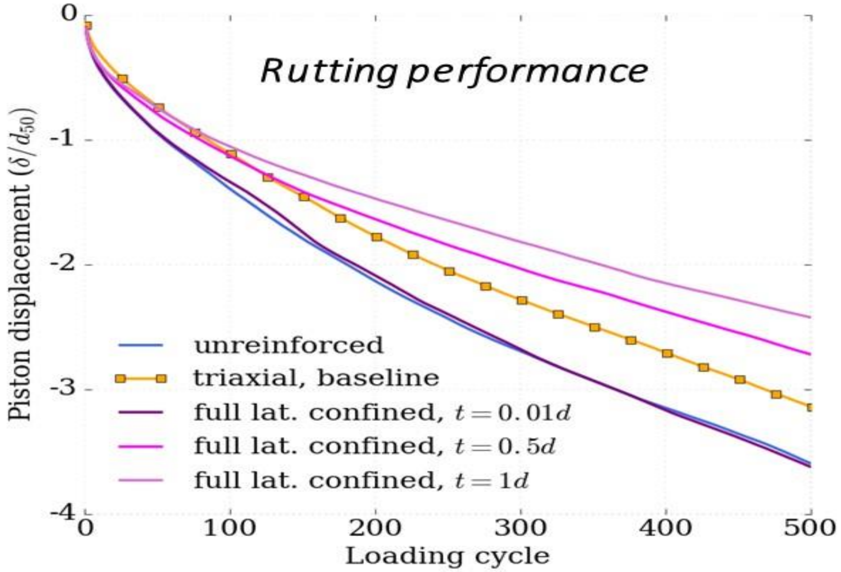
Particles within specified range have translation blocked in x and y directions.

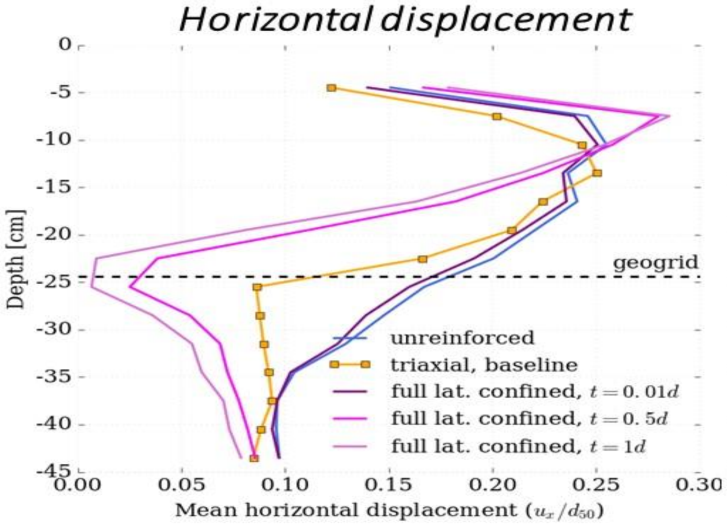
Free rotations in all directions and translation in z direction

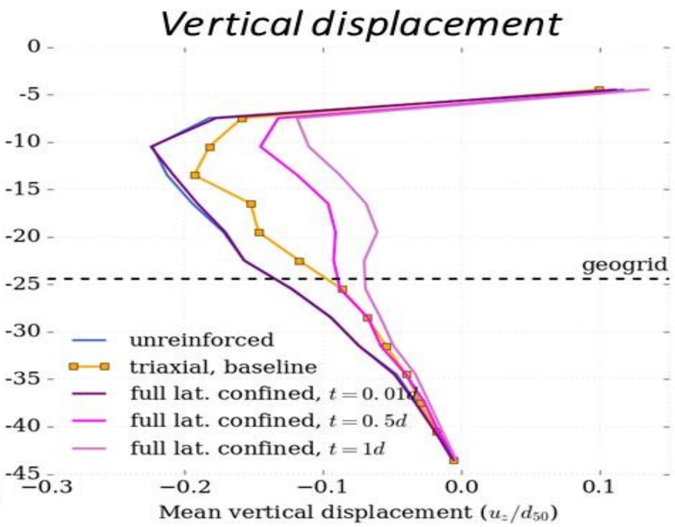
Force networks at 100 cvcles

UNREINFORCED *TX190L REINFORCED* *PERFECTLY REINFORCED*

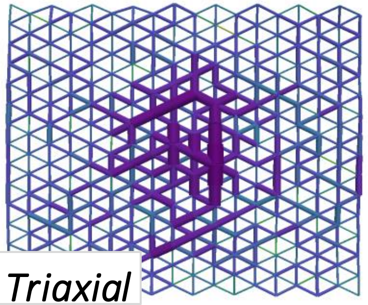




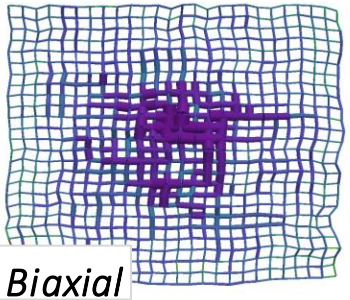




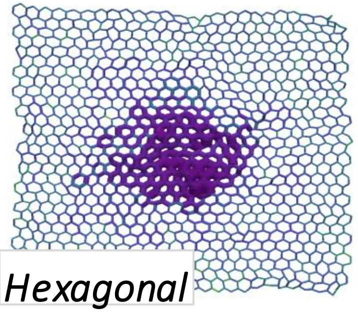
Force network distribution: *geometry*



Triaxial

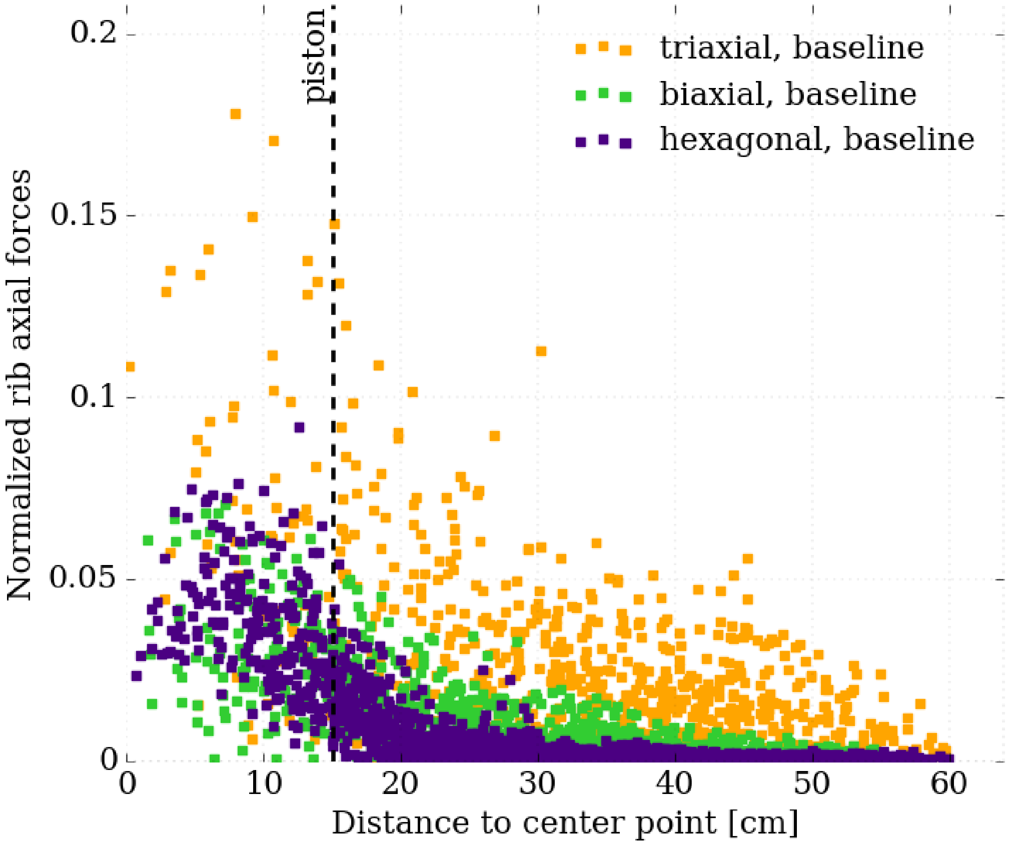


Biaxial

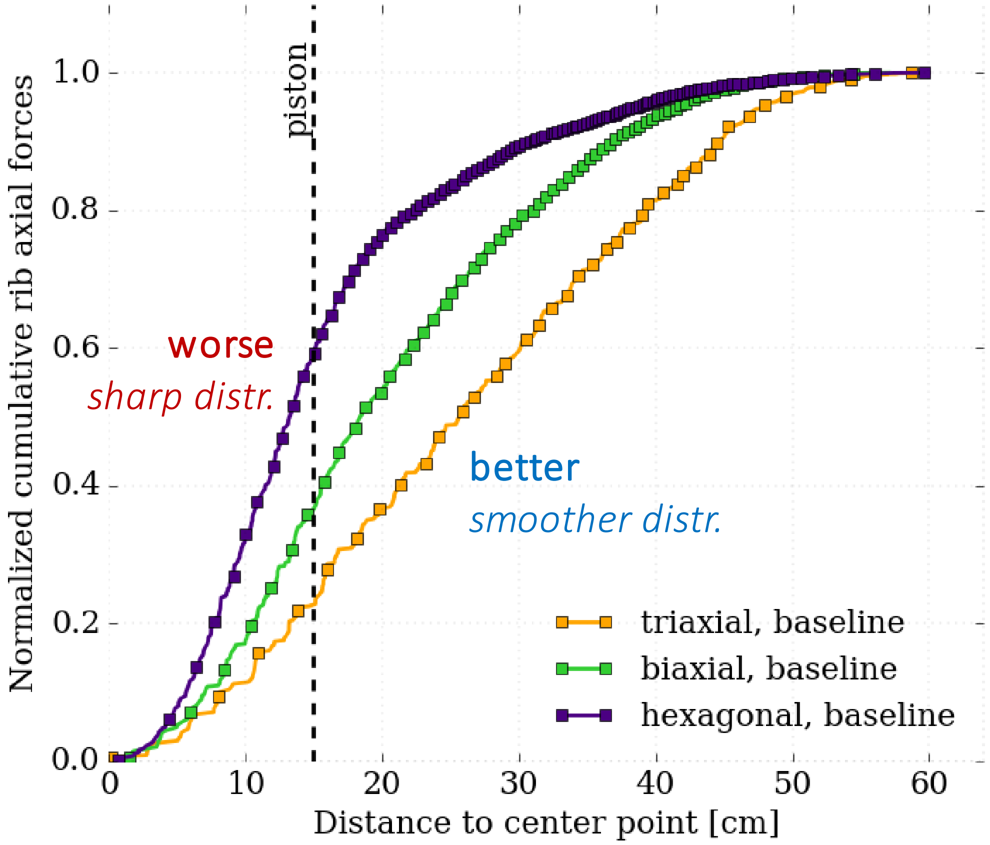


Hexagonal

Norm. rib axial forces



Norm. cumulative axial forces



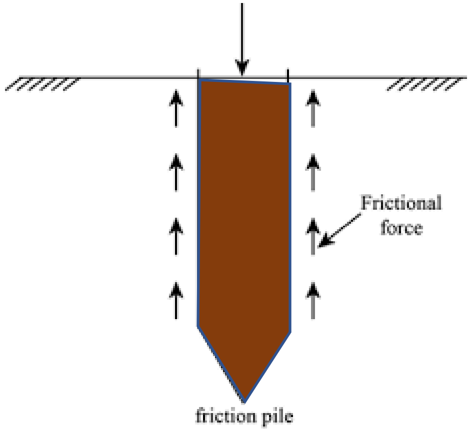
New Framework and Sources of Inspiration for Geotechnical Interface Designs..

Framework for Designing Interfaces....

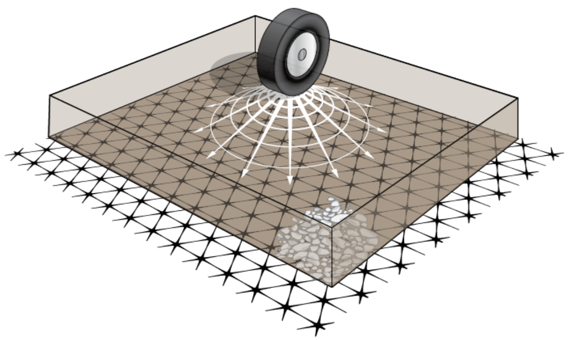
- Pre-formed interfaces
- In-situ formed interfaces
- Adaptable interfaces
- Thermal interfaces

- All embody different degrees of compatibility....

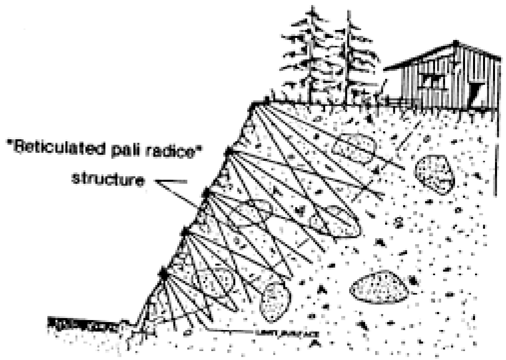
Geotechnical Interface Bio-inspiration Sources



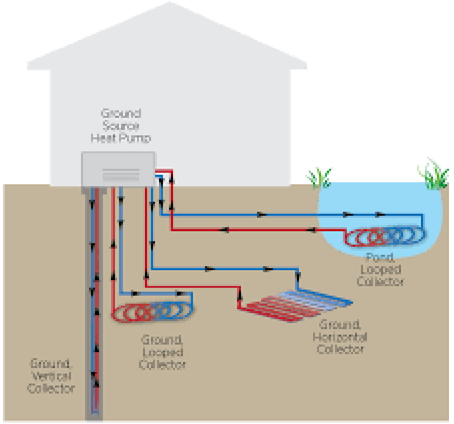
Friction Piles



Geogrid Reinforcement



Ground Anchors



Thermal Exchange

Snakeskin

Spider Webs

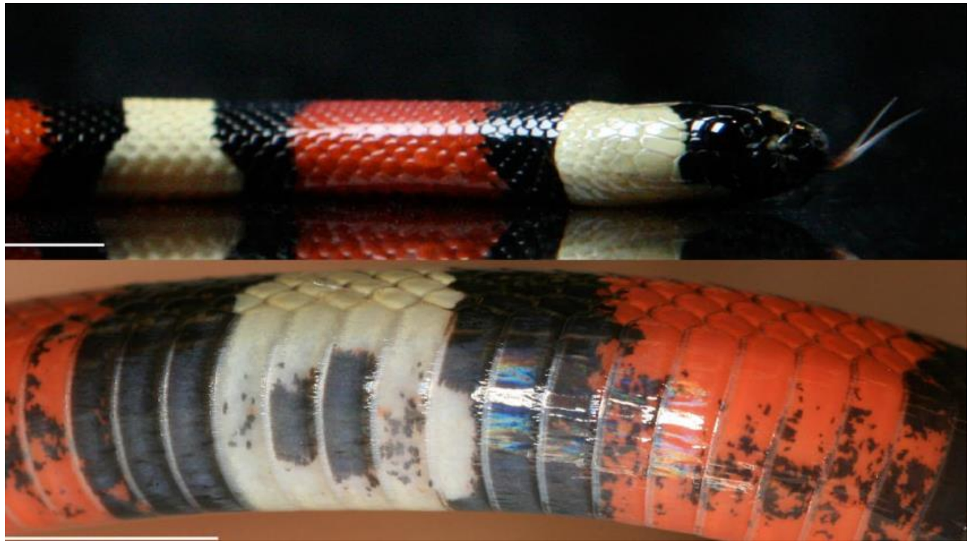
Tree Roots

Bamboo Stems

Pre-formed Interfaces….

Snakeskin-inspired Surfaces

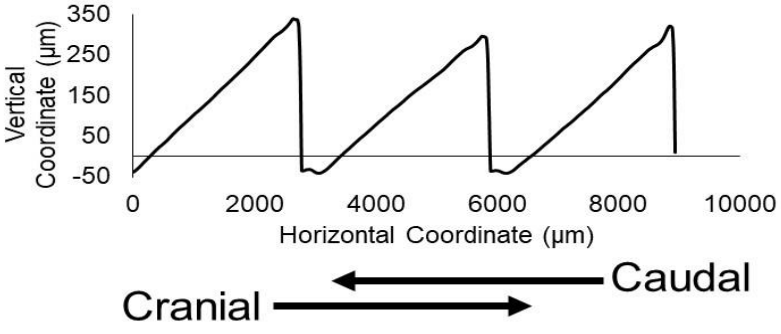
- Motivation: mobilization of direction-dependent friction for application in piles, soil nails, and geosynthetics

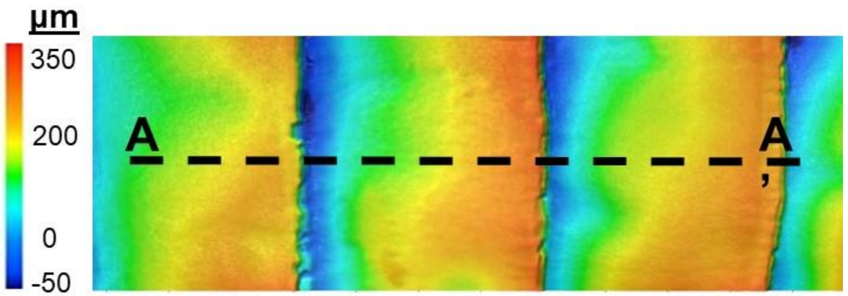


Marvi et al., 2013

Caudal shearing (with scales, towards the tail) mobilizes low frictional resistance along scales

Cranial shearing (against scales, towards the head) mobilizes high frictional resistance

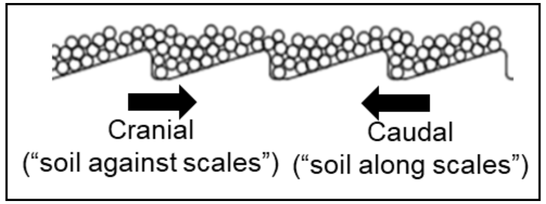




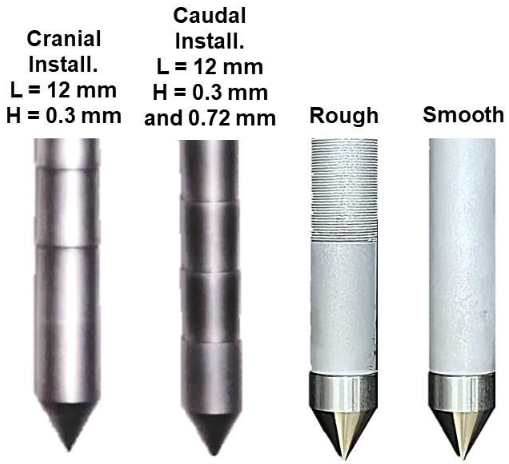
Compatibility different depending on direction of relative movement.

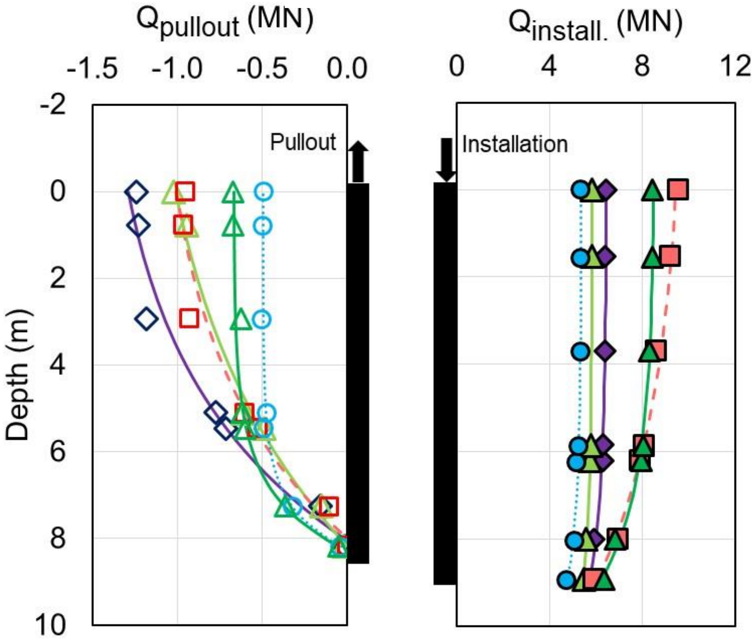
(after A. Martinez, UC Davis)

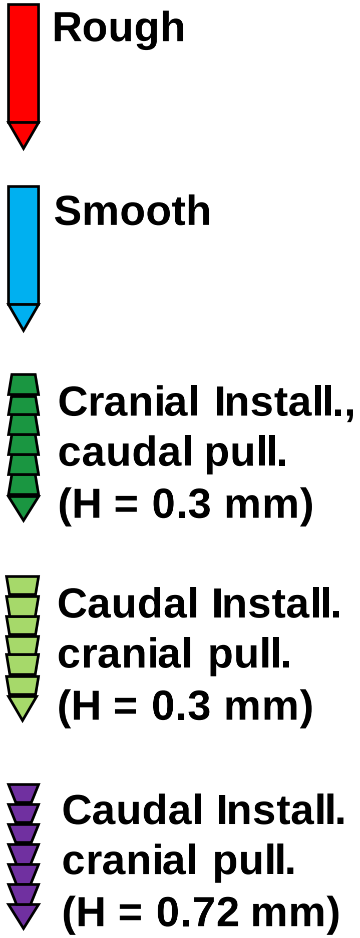
Snakeskin-inspired Piles - Centrifuge Testing



- Installation load distribution:
  - Greatest shaft resistance for rough pile, smallest for smooth pile
  - Similar shaft resistance for cranially-installed and rough piles
  - Smaller loads for caudally-installed piles
- Pullout load distribution:
  - Smaller shaft resistance for cranially-installed pile
  - Greatest shaft resistance for caudally-installed pile with tall asperities



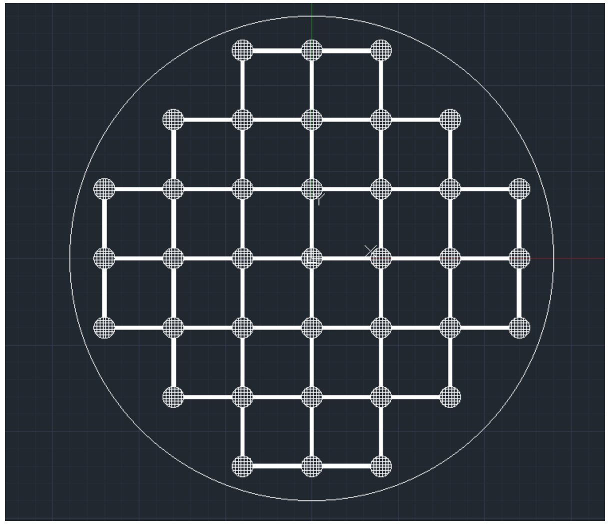


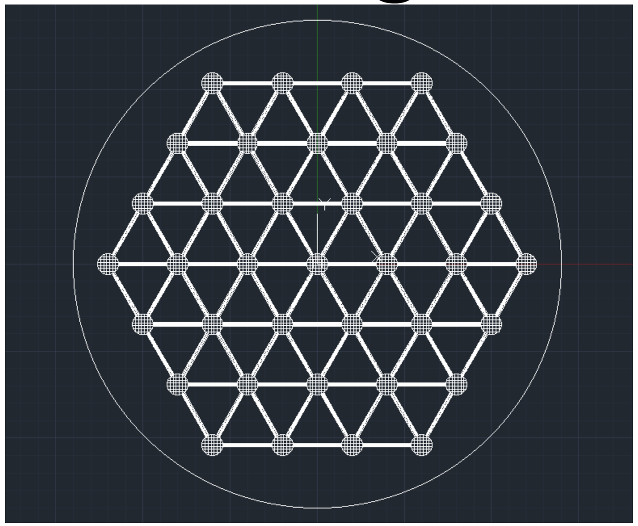


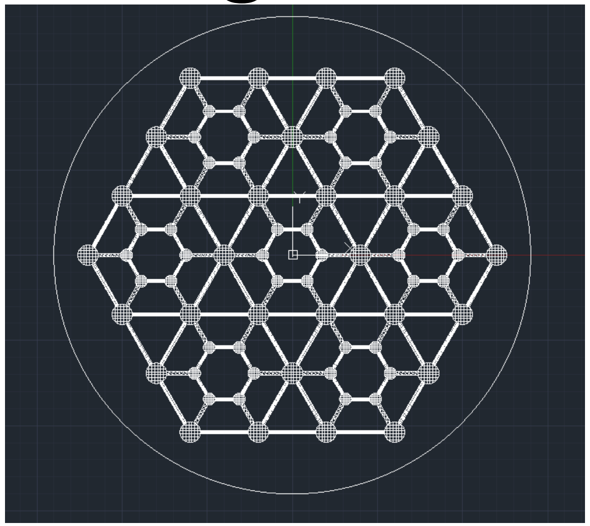
O'Hara and Martinez (2022)

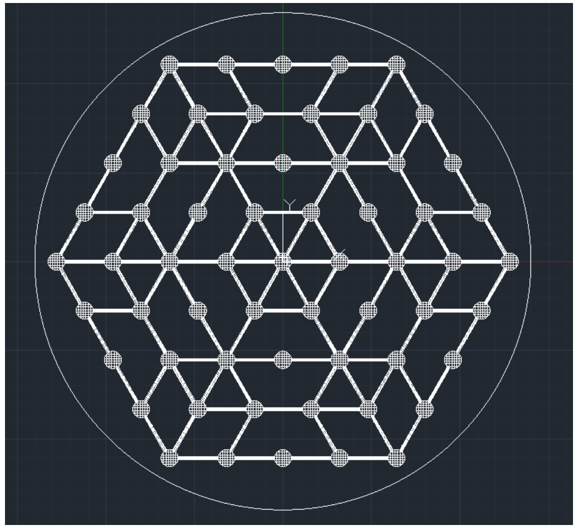
In-Situ Formed Interfaces….

Visualization of Geogrid Opening Sizes







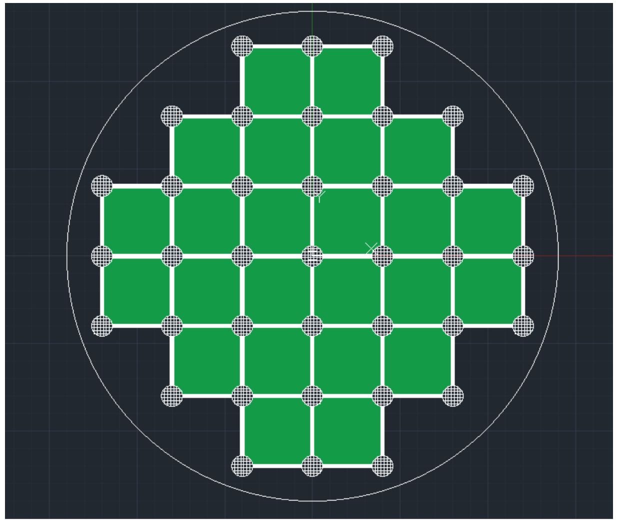


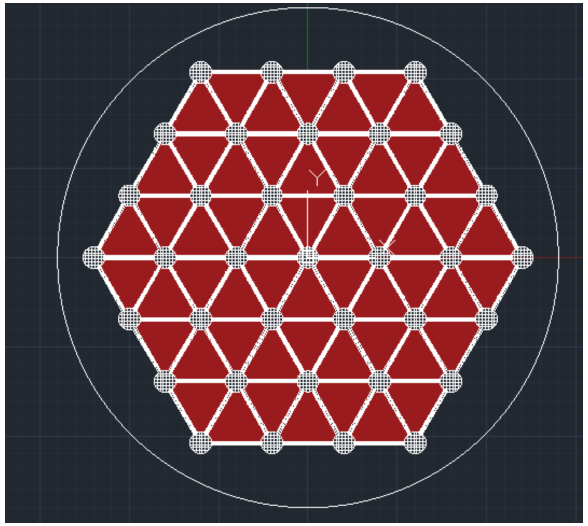
Biaxial

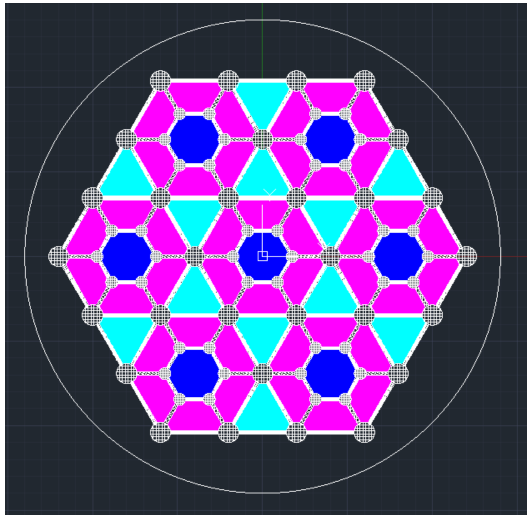
Triaxial

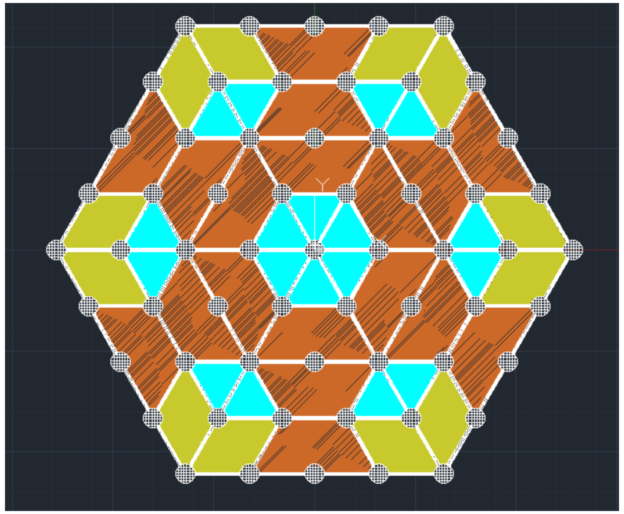
Interax

Spiderax I

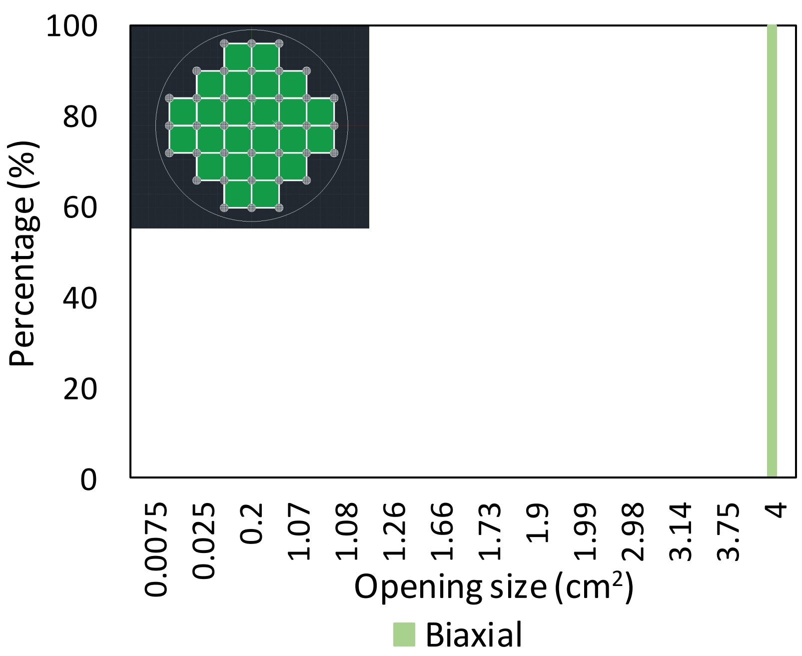


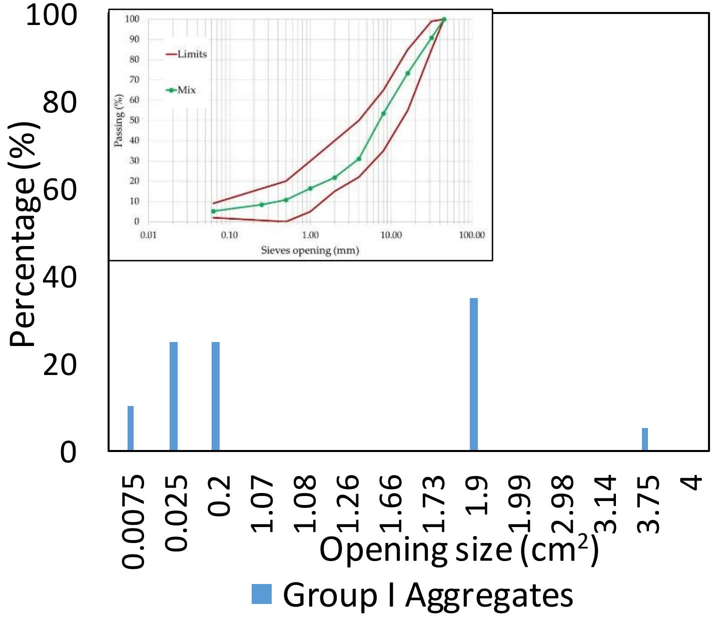


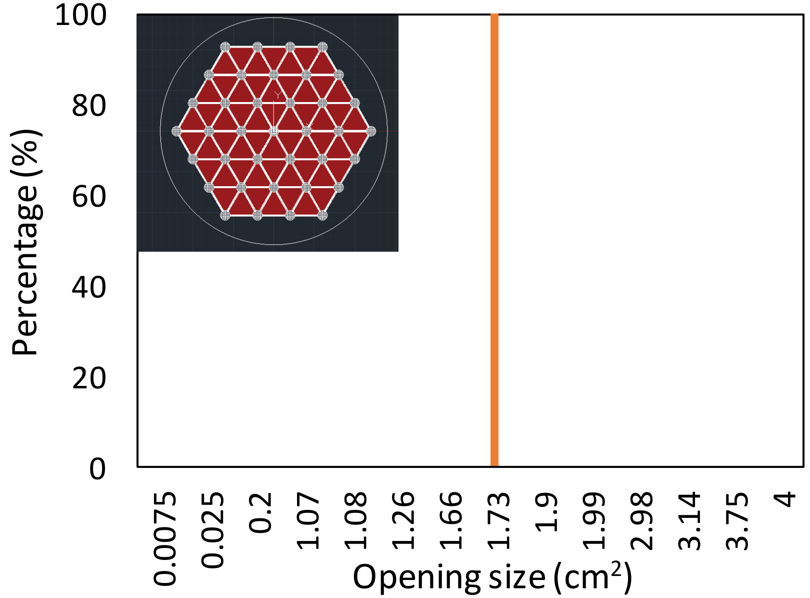


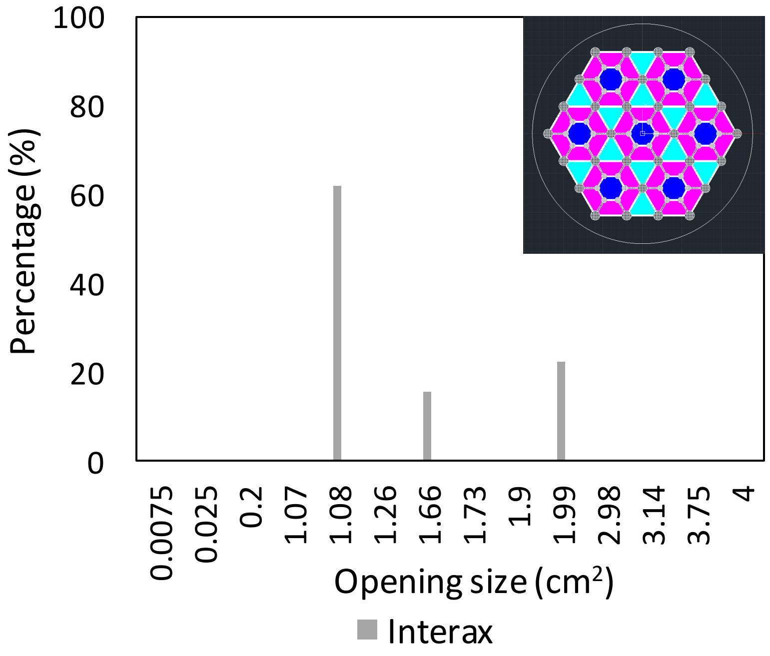


Geogrid Opening and Aggregate Histograms

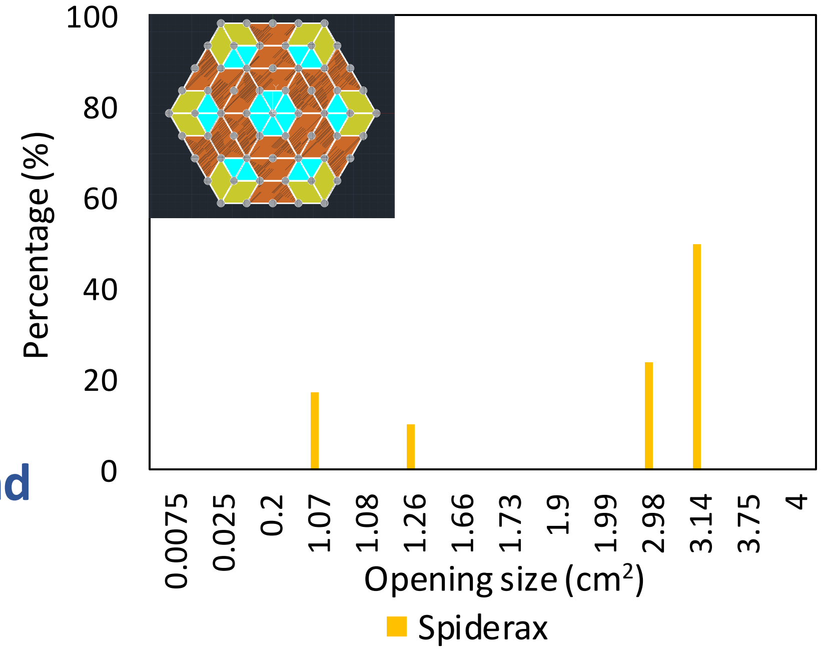




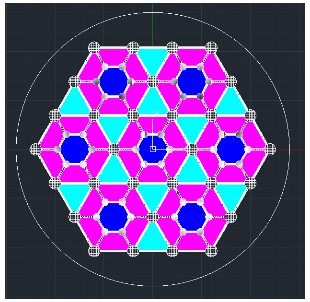


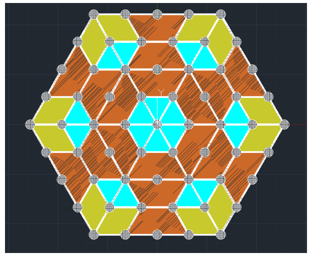


Which combination of geogrid and aggregate is most compatible?

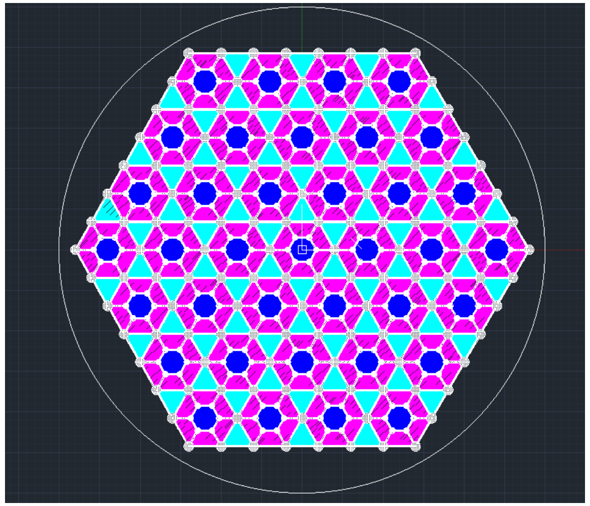


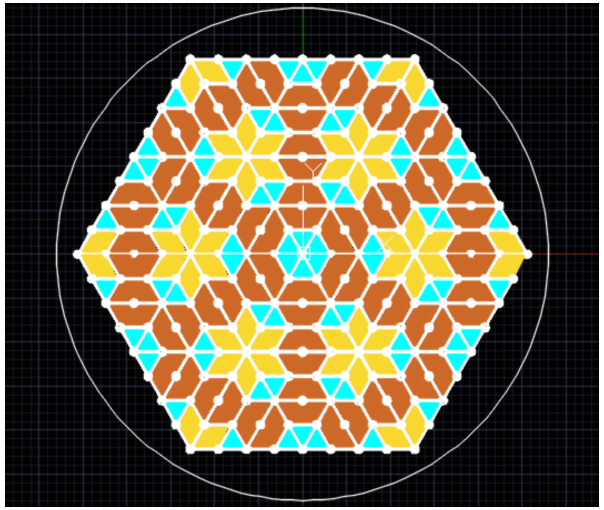
Large-scale comparison of InterAx and SpiderAx

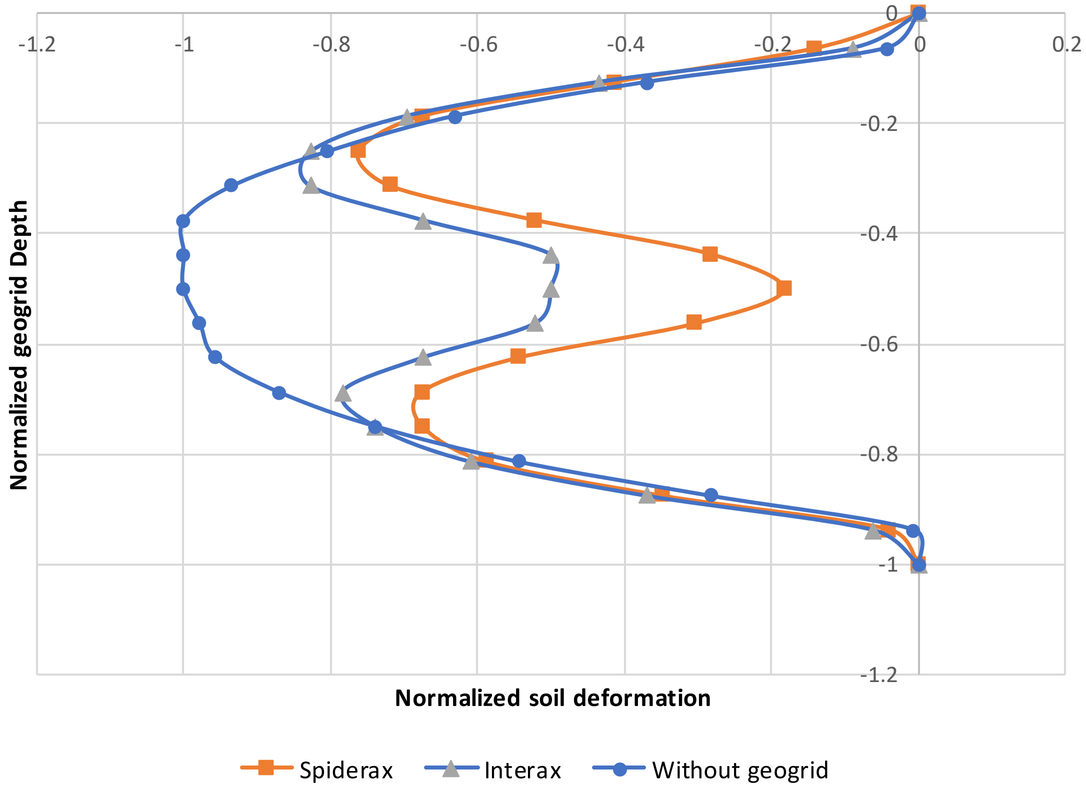




Does emergence of secondary structure alter compatibility and improve performance?

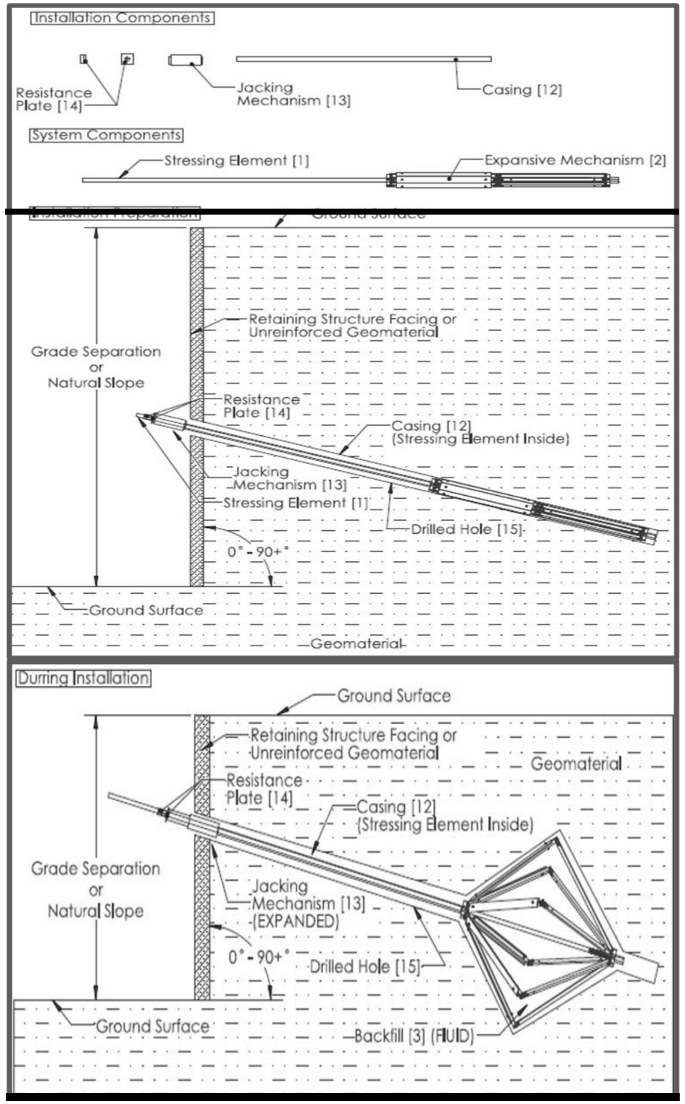


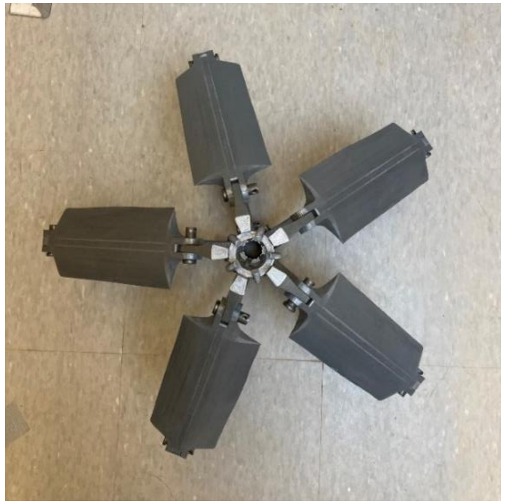




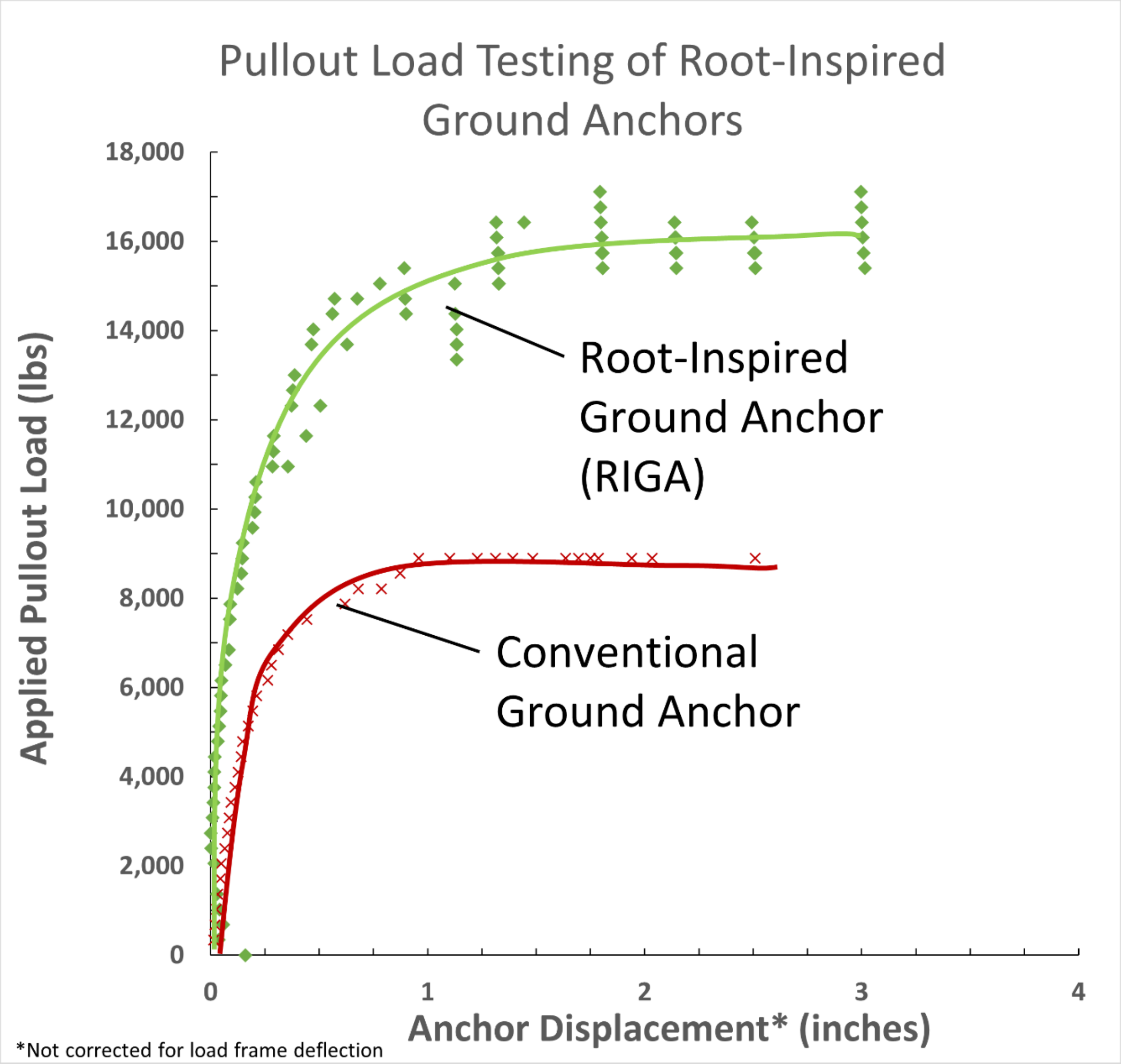
Adaptable Interfaces….

Adaptable Root Inspired Ground Anchor (RIGA)



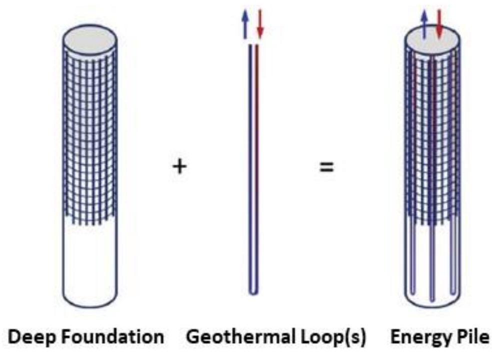


Field Expansion and Test Pull-out Test

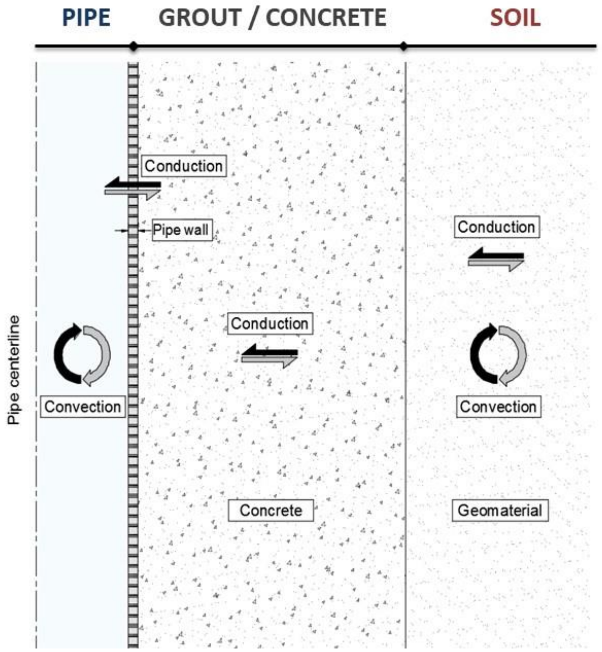


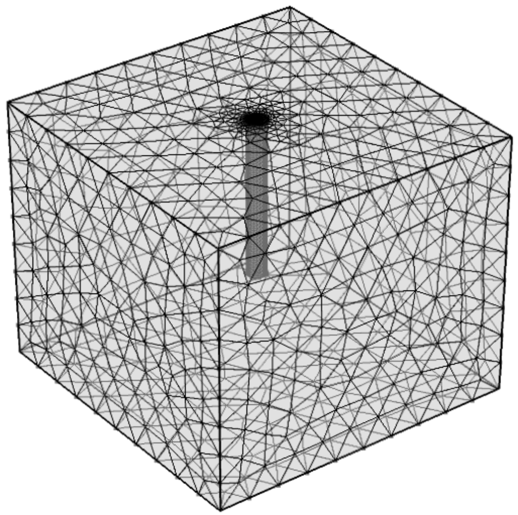
Bio-inspired ETZ Thermal Interfaces….

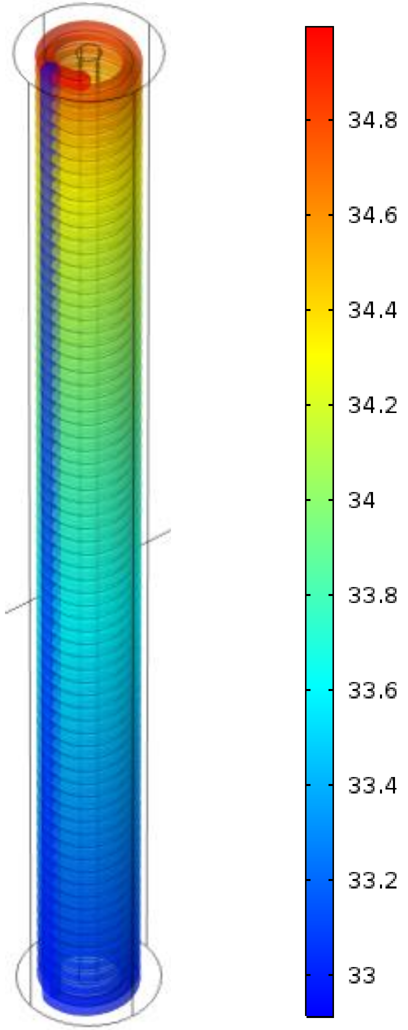
Thermo-Active Foundations (Thermal Interface Problem)



(after Olgun & McCartney, 2014)





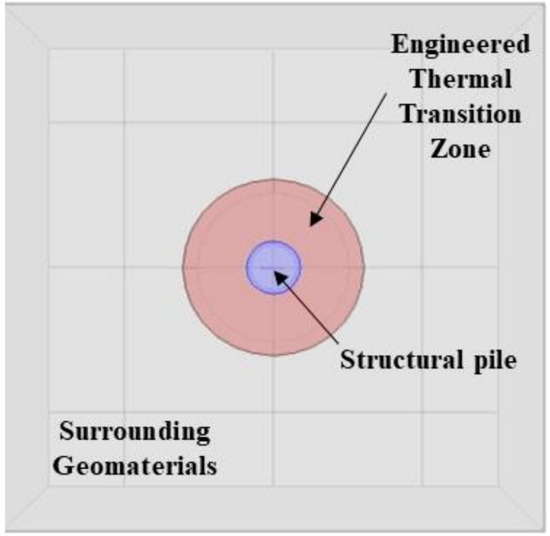


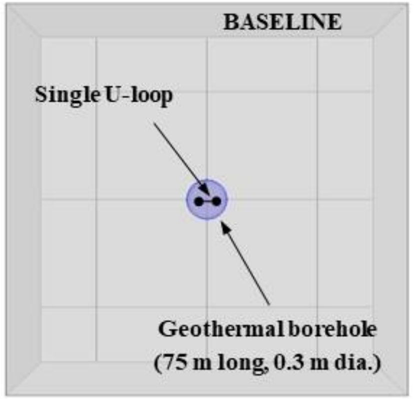
- Existing design methods focus primarily on the structural aspects
- Heat transfer component is constrained due to limited space for fluid circulation loops between pile edge and reinforcement cage
- Thermo-hydro-mechanical behavior has reached a state of mature understanding

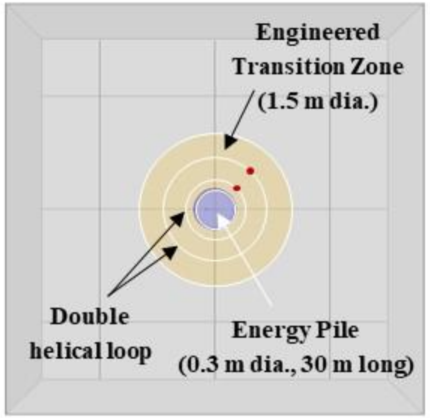
- Numerical modeling performed using COMSOL multi-physics
- Model validated using Thermal Response Test (TRT) results from Cecinato & Loveridge (2015) and Nguyen (2017)

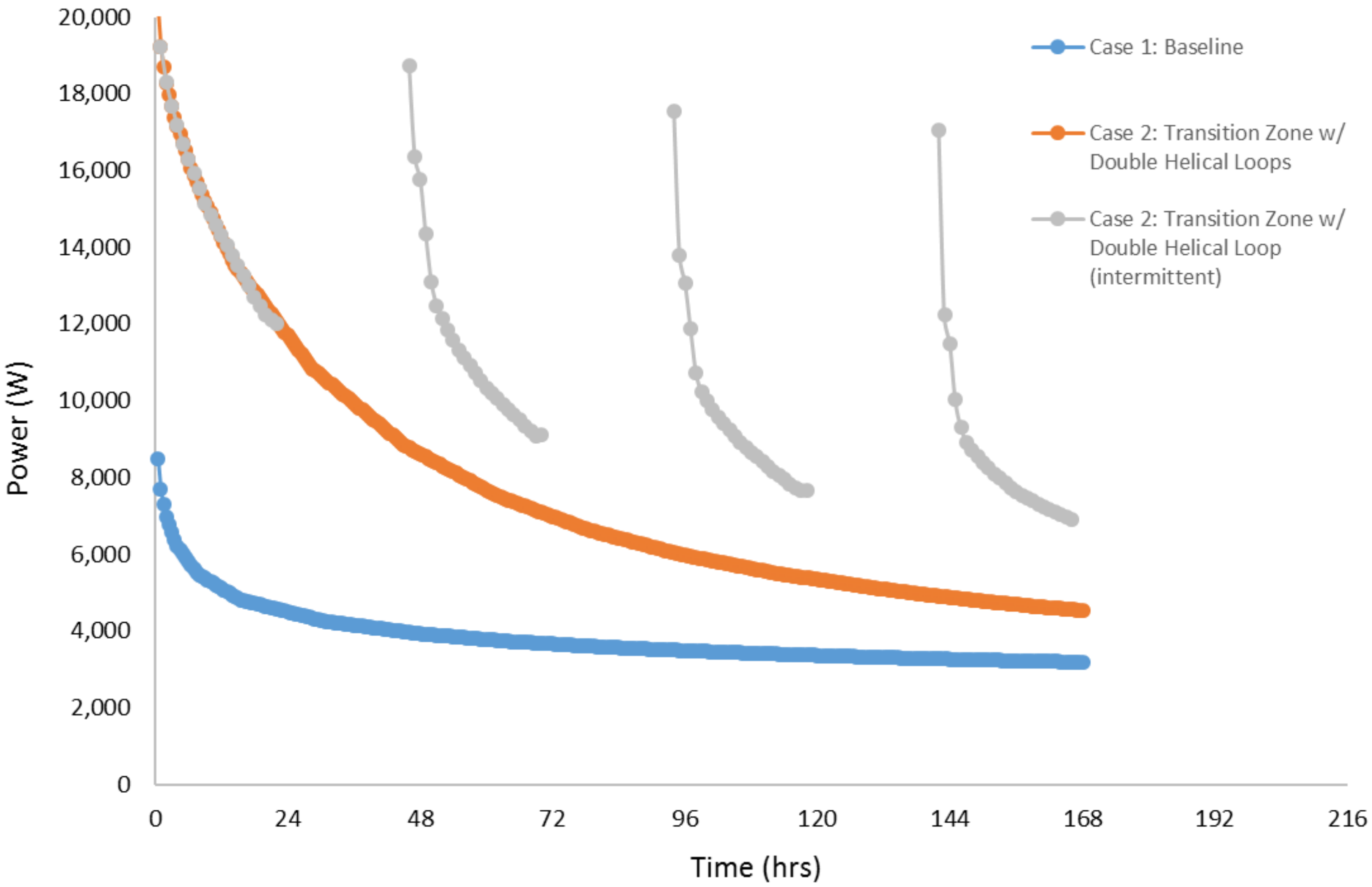
Engineered Thermal Transition Zone - ETTZ

Focus needs to be shifted to other areas, including **optimizing heat transfer characteristics**

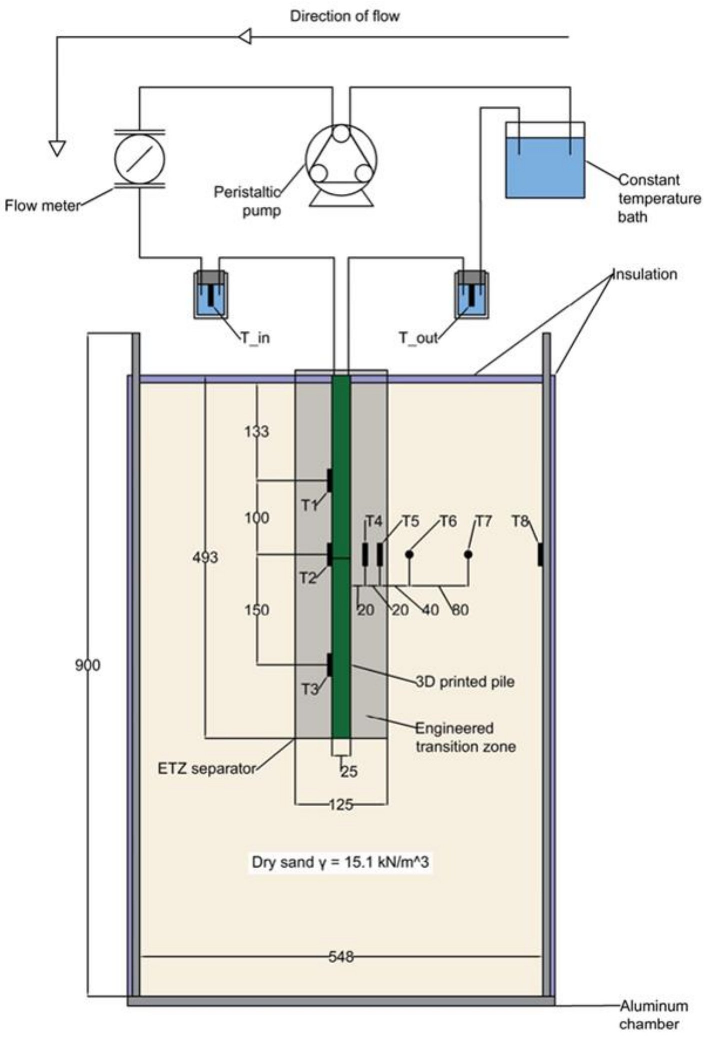


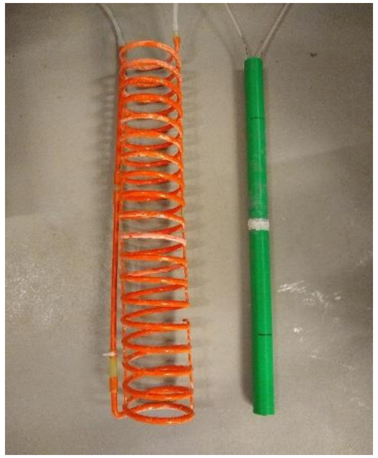


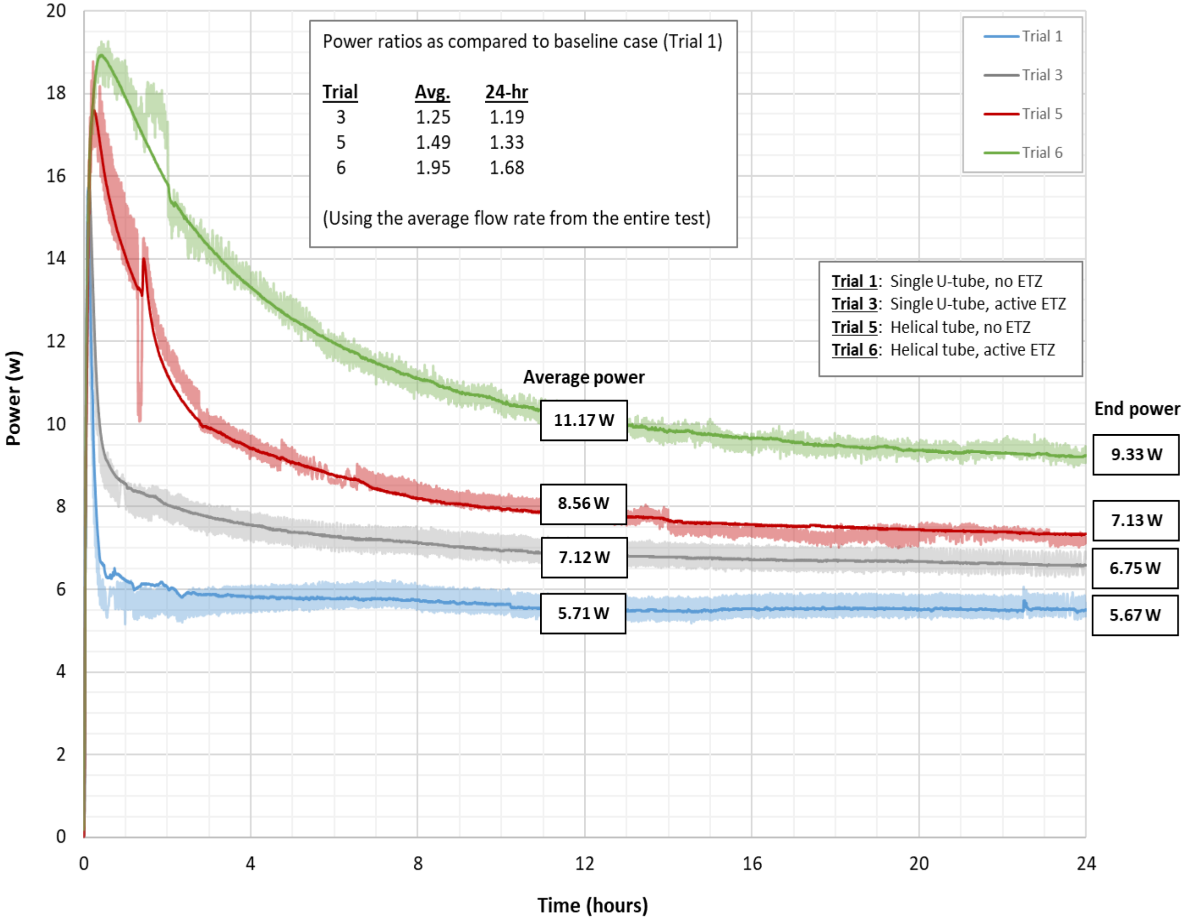




Lab-scale Testing of ETTZ Concept

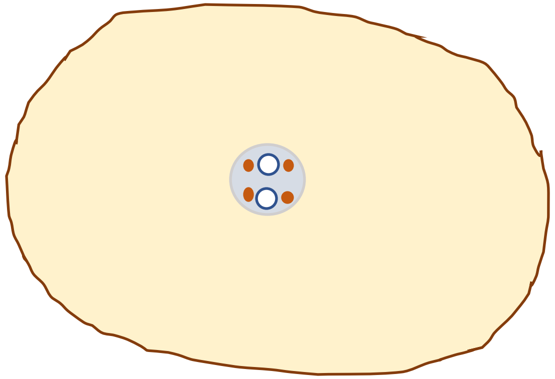




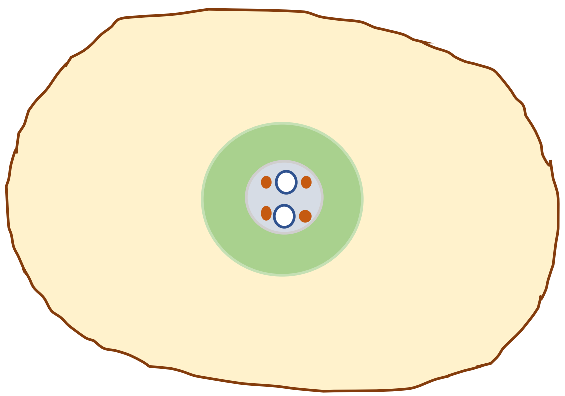


Both numerical model and laboratory chamber test results indicate that it is possible to significantly increase the thermal performance of shallow thermo-active foundations using an engineered transition zone (ETZ)

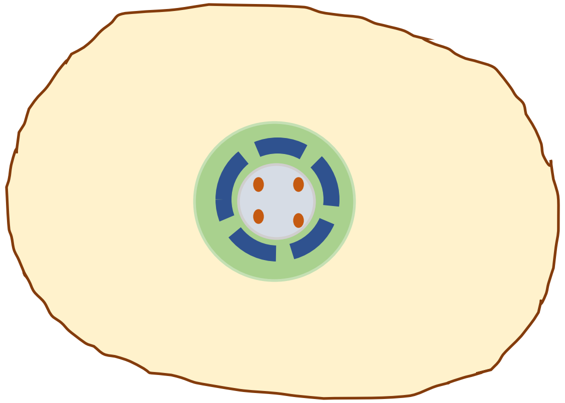
Multi-function BID-ETTZ Piles



Conventional Energy Pile

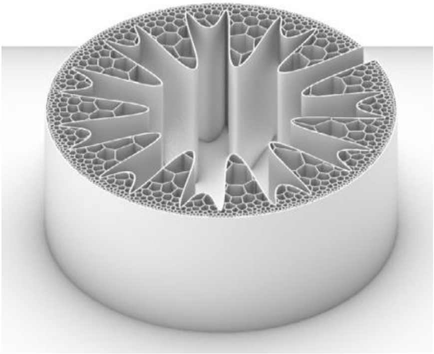


Original ETTZ Concept

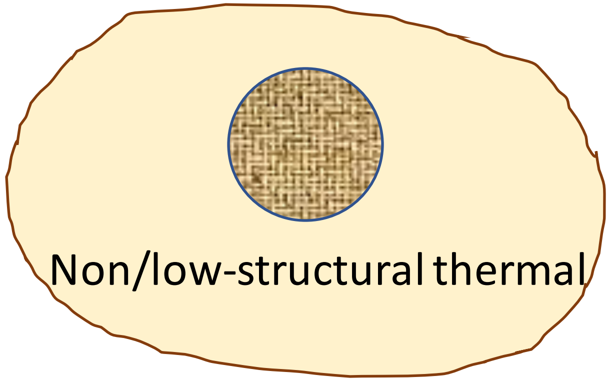


Spiral Loop ETTZ Concept

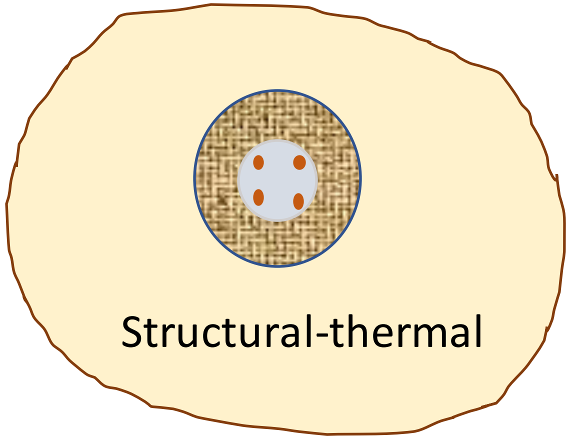
- Decoupling of structural and thermal component
- Structural and thermal functions can both be optimized



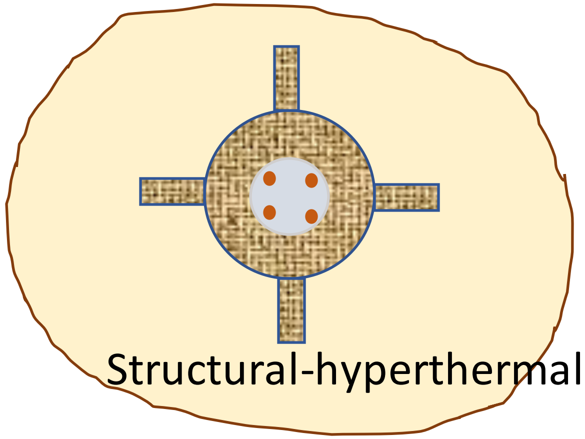
Bio-inspired ETTZ



BID ETTZ “Concept 1”



BID ETTZ “Concept 2”



BID ETTZ “Concept 3”

Summary Comments

- The properties and performance of both materials at an interface are important – individually and collectively.
- Opportunities for interface design innovation are abundant.
- We need to be willing to question "existing approaches" and seek new inspiration that can lead to transformational, not just incremental, changes.
- Fully questioning how compatibility can improve interface performance is critical.
- We have the necessary tools (experimental, numerical, visualization.

Seed Medal Lecture Recap

- H. Bolton Seed studied pile-soil interfaces early in his career (1957 paper with Lymon Reese)....

- The Alaska earthquake came along in 1964 and “distracted” Professor Seed for the next 40 years as he created the field of geotechnical earthquake engineering....

- Professor Seed wrote in his 1979 Rankine Lecture “it is extremely important that we take every opportunity that Nature provides to continually refine our procedures.”....

- Hopefully, I have filled in some of the gaps linking Professor Seed’s early work on interfaces while respecting his vision for the role of Nature in what we do....with interfaces!!

Thank You.

Contributions of and discussions with numerous teachers, students and colleagues I have had the pleasure to work with, in the past and present, have been very rewarding.

I would especially like to thank rwk, jhac, deb, kb, wjb, jlc, gal, rdh, meh, plb, jdb, mj, gwc, glr, pwm, seb, jcs, cfa, jm, hh, sd, jef, ag, sn, jed, jh, lbw, swl, jtd, zbs, glh, tme, xy, ks, dhk, ceb, yl, arf, tk, am, mmr, js, fa, tx, fzl, sdm, ssh, nr, rbv, jl, pv, jh, co, ed, ec, tez, mi, ap, gr, ns, ms, bd, ri, cl, ml, nf, mhw, jc, Jody, Alex and Anna…..df/2023

Thank you to ASCE G-I for selecting me for the honor of receiving the Seed Medal and delivering the original lecture. Thanks to KU for the opportunity to present again.

Georgia Tech

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