NHERI@ UC Davis Centrifuge Modeling: Designing Experiments across Scales

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With contributions from:

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University of California, Davis

Today's Plan

- *Center for Geotechnical Modeling*
  - *People, facilities, and capabilities*
  - *Workflow of operations*
  - *User's activities, accomplishments, and contributions*

- *Designing Tests to Identify Mechanisms*
  - *Void redistribution in liquefiable soils*
  - *Liquefaction-induced downdrag on piles*

- *Summary*

Leadership Team & Staff…

Ross W. Boulanger
CGM Director

Bruce L. Kutter
CGM Past-Director

Daniel W. Wilson
CGM Assoc. Director

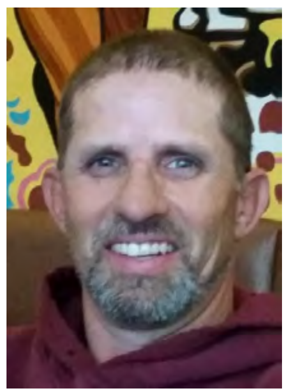
Jason T. DeJong
Faculty Advisor

K. Ziotopoulou
Faculty Advisor

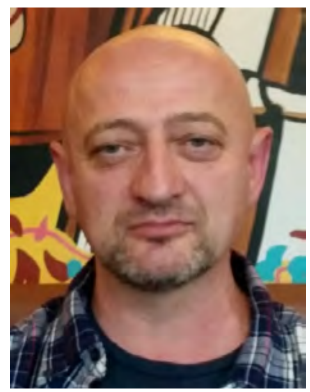
Alejandro Martinez
Faculty Advisor

Colleen Bronner
Faculty Advisor

Tom Kohnke
Development Engineer



Chad Justice
Development Technician



Anatoliy Ganchenko
Electronics Technician

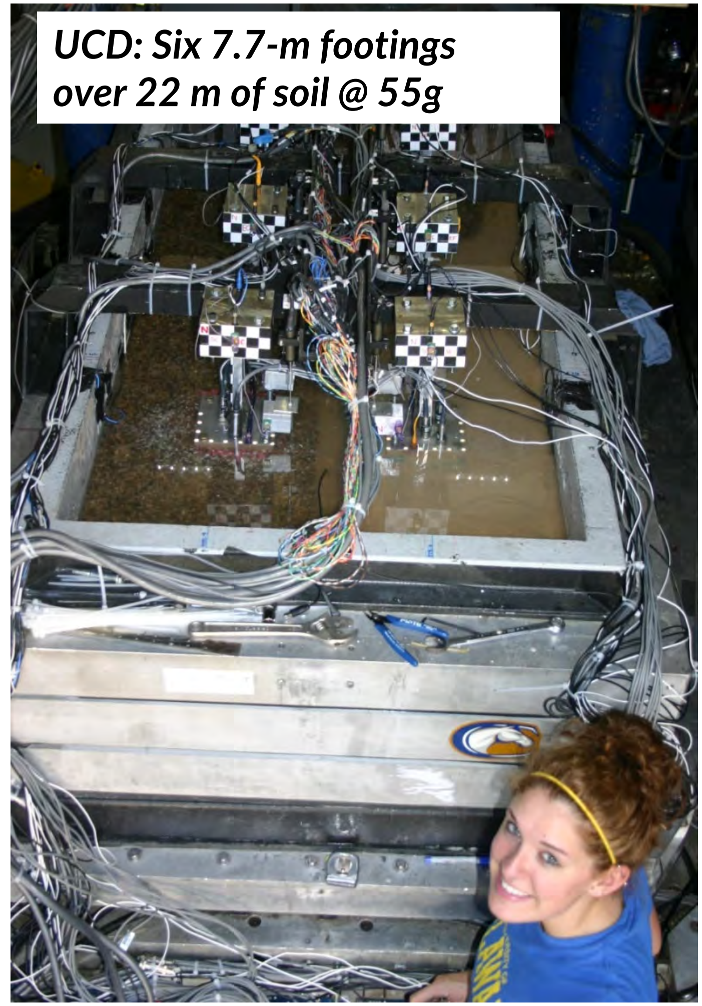
Mary Carrillo
Analyst

...Community of Users

… Infrastructure

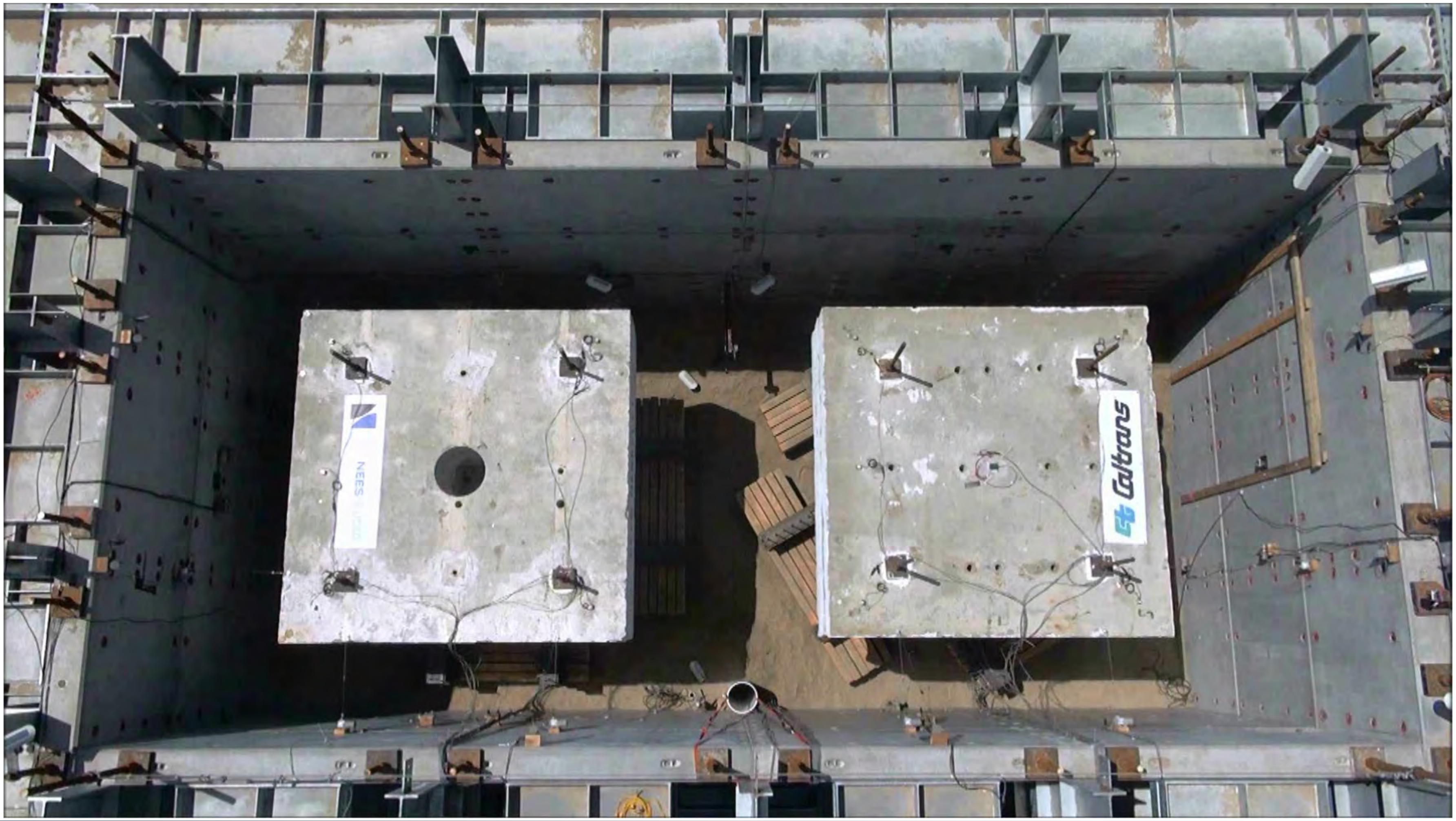
- *Largest centrifuge with a shaking table in the world*
- *Synergy of 1-m and 9-m radius centrifuges with common technologies*
- *Breadth of supporting technologies & capabilities*
- *Continuously advancing capabilities through acquiring new funds, partnering with researchers to add capability, and leveraging operations funds as allowable to increase productivity and capability across research teams*

9-m centrifuge: Scaled Modeling

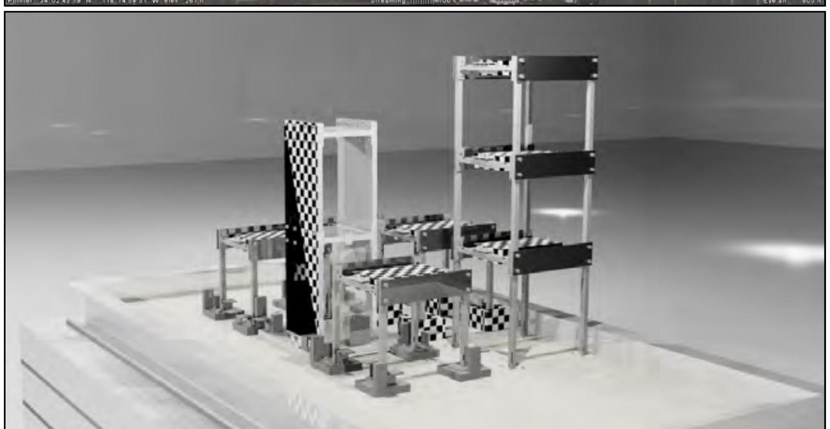


9-m centrifuge: Scaled Modeling

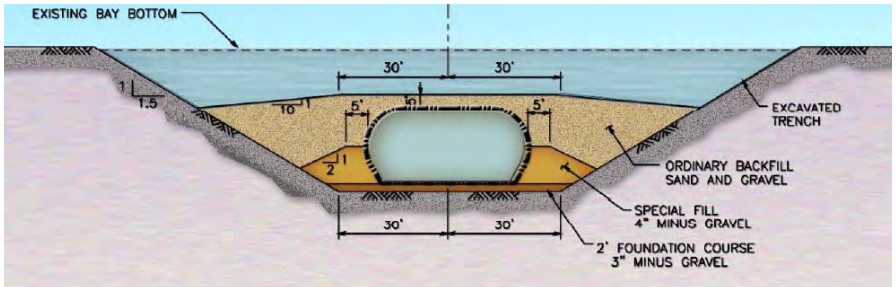
1-g Shake Table

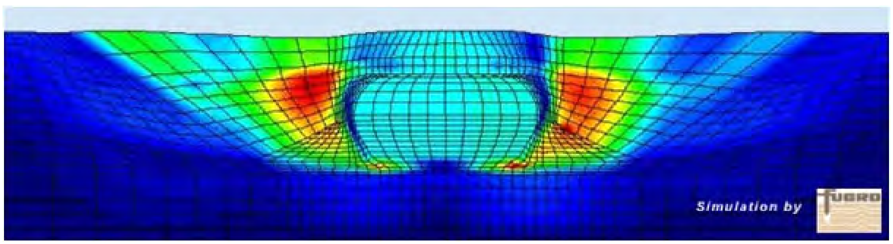


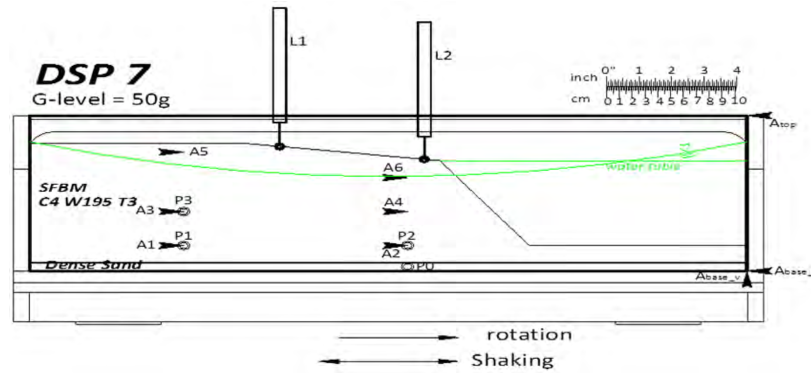
9-m centrifuge: Scaled Modeling

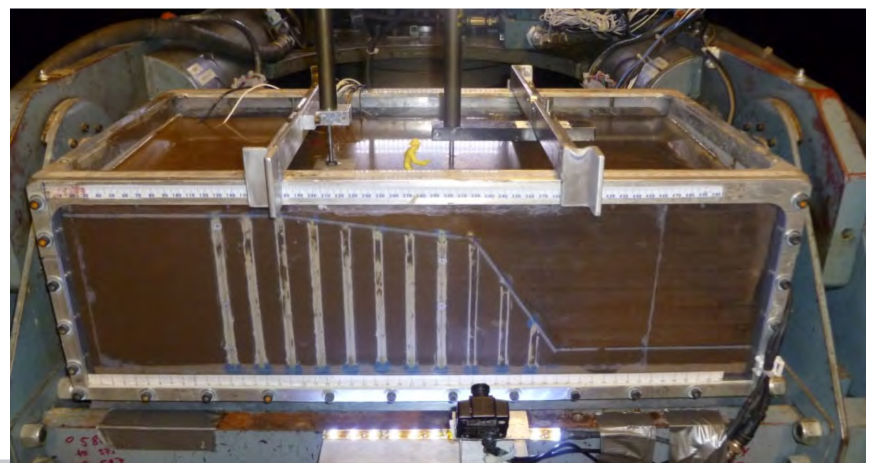

Slide courtesy Ben Mason

9-m and 1-m centrifuges: Choice based on Science









9-m and 1-m centrifuges: Capabilities

- *The 9-m radius centrifuge*
  - *Largest radius of any centrifuge equipped with a shaking table worldwide, and one of only two worldwide that can test physical models with at least 1500 kg of soil*
  - *Large model size provides unique ability to:*
    - *Construct models with **holistic system levels of complexity**, including variations in soil **stratigraphy** and **structural configurations** that are not possible in smaller models*
    - *Use **dense instrumentation** arrays and inverse analysis techniques to measure complex local mechanisms that cannot be measured by other means*
    - *Perform **in-flight soil characterization** tests at a higher degree of resolution and across a broader range of soil types where scale effects are important*
- *The 1-m radius centrifuge*
  - *Provides for a high throughput of relatively simple (component) tests that enables efficient **exploration of new ideas** and **rapid parametric studies**, which collectively builds knowledge*
  - *Increases the quality and complexity of subsequent 9-m centrifuge tests*

9-m and 1-m centrifuges: Range of Possibilities

*Combined, the 9-m and 1-m radius centrifuges provide the **unique and versatile modeling** capabilities required for scientific and engineering advances in our discipline's ability to predict and improve the performance of soil and soil-structure systems affected by earthquake, wave, wind, and storm surge loadings:*

- *Building of basic science knowledge & understanding of mechanisms*
- *Validation of computational models from the component to holistic system level, across a broad range of challenging soil types & infrastructure systems*
- *Scale models representing nonlinear, stress-dependent responses of soil masses that are many times larger than is possible on 1-g shaking tables*
- *Integration of research, education, and outreach activities in the training of a broad and inclusive STEM workforce*

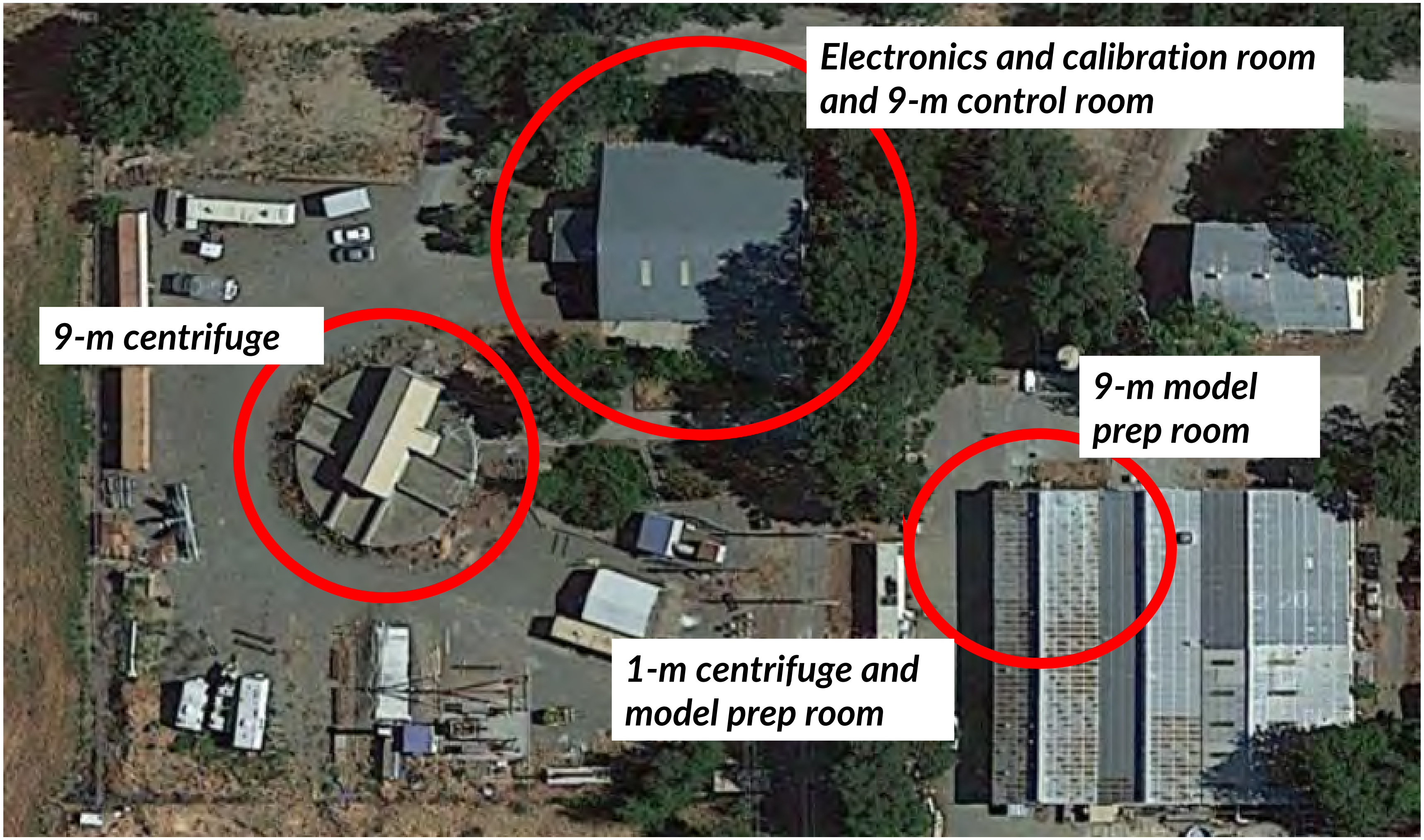
The Workflow

Standard Experiment Protocol

- *Pretest planning*
  - *Iterate to match research objectives with experimental capabilities and available resources. Confirm the feasibility of new developments. Researcher presents Experiment Plan to CGM staff and other onsite users.*
- *Sensors and instrumentation*
  - *Check out, calibrate, and verify sensors from CGM inv[illegible] to half). Install and test custom bridges and sensors. Time varies from two days for simple experiments to a m[illegible] or complex structures.*
- *Work in the model prep room*
  - *Place soil, sensors, and structures. Comple[illegible] tasks before moving model onto the arm. Delays can allow a second team to leapfrog the first team. Model [illegible] can range from two to eight weeks.*
- *Final work on the centrifuge arm*
  - *Model saturated, instrument r[illegible] and adjusted, and sensors connected to the DAQ. Typically requires three to ten days for the 9-m centrifuge*
- *Spinning and testing the mo[illegible]*
  - *Typically includes s[illegible]zation, simulated seismic events, and/or structural loading using servo-hydraulic actuators. Multiple spins can [illegible] days to a few weeks*
- *Dissection*
  - *Users dissect the model in a process that typically takes one to two weeks and return sensors to CGM staff for cleaning, testing, and returning to inventory*
- *Data Archiving*
  - *Archiving of experimental data, recommend using standard data report format. Typically two months to produce.*

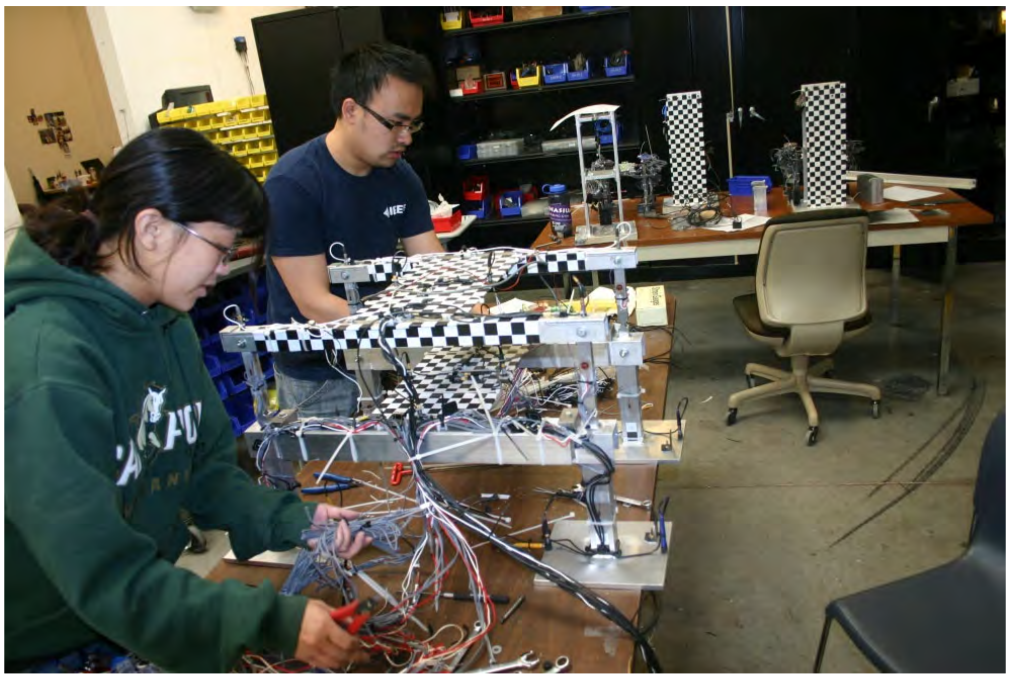
VISUAL BETTER…

CGM Facilities Tour: Parallel Workflow through Five Primary Working Areas



E&C Room: Constructing, Assembling and Calibrating Components

- *Emphasis on training by overlapping apprenticeships within a ladder mentoring framework*
- *Stations and tools for up to four teams: instrumentation, assembly, calibration, pore fluids*



9-m Model Preparation Room: Preparing Models

- *Three work stations: sand pluviation, clay consolidation, model dissection*

9-m Model Preparation Room: Preparing Models

- *Large models require teams and staff support to construct and instrument*

9-m Centrifuge: On the Arm

- *More team work in mounting & saturating models, & placing structures, actuators & sensors*

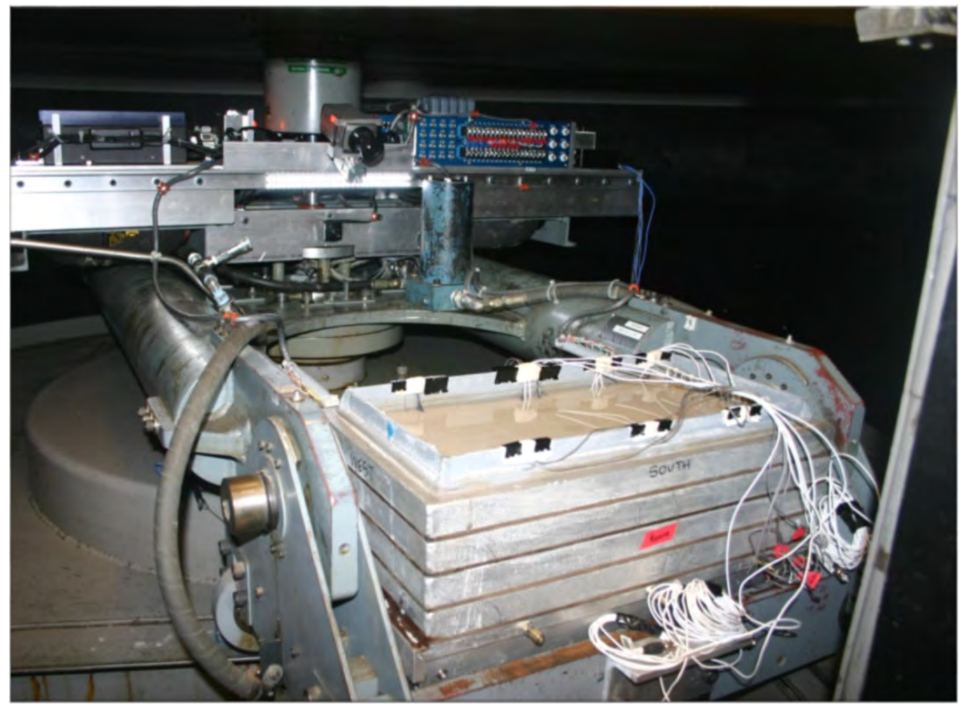
Kate (UC Davis) apprenticing under Mohammad (Virginia Tech) in 2013

Maggie (OSU) apprenticing under Kate (UC Davis) in 2017

9-m Centrifuge: Executing the experiment protocol from the control room

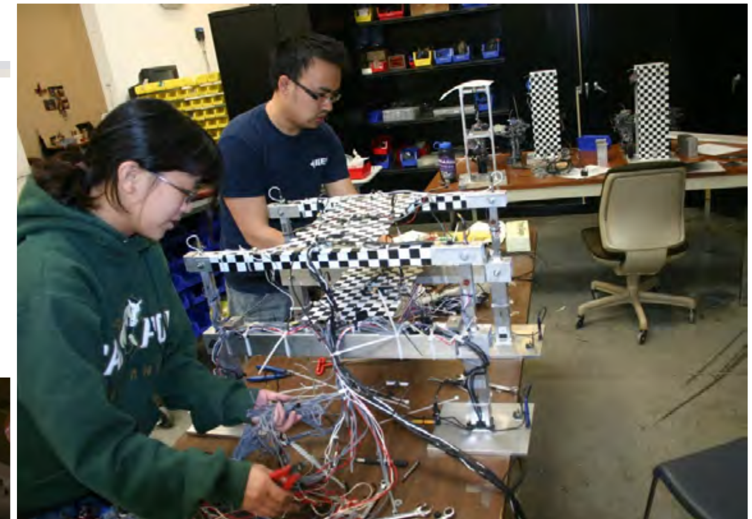
1-m Centrifuge and 1-m Model Preparation Room

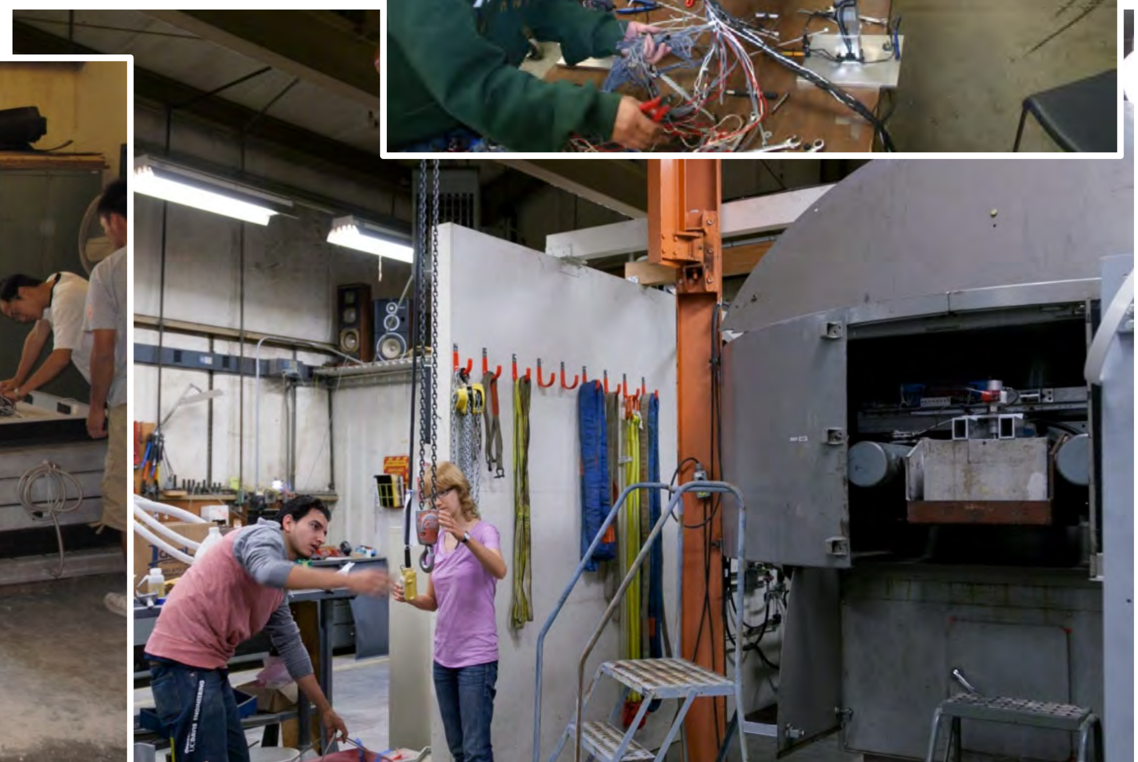
- *Same sensors, DAQ, and controls as on 9-m centrifuge*
- *Two teams can work in parallel – one preparing a model and one testing a model*



Parallel Workflow is Critical to Open Access…..

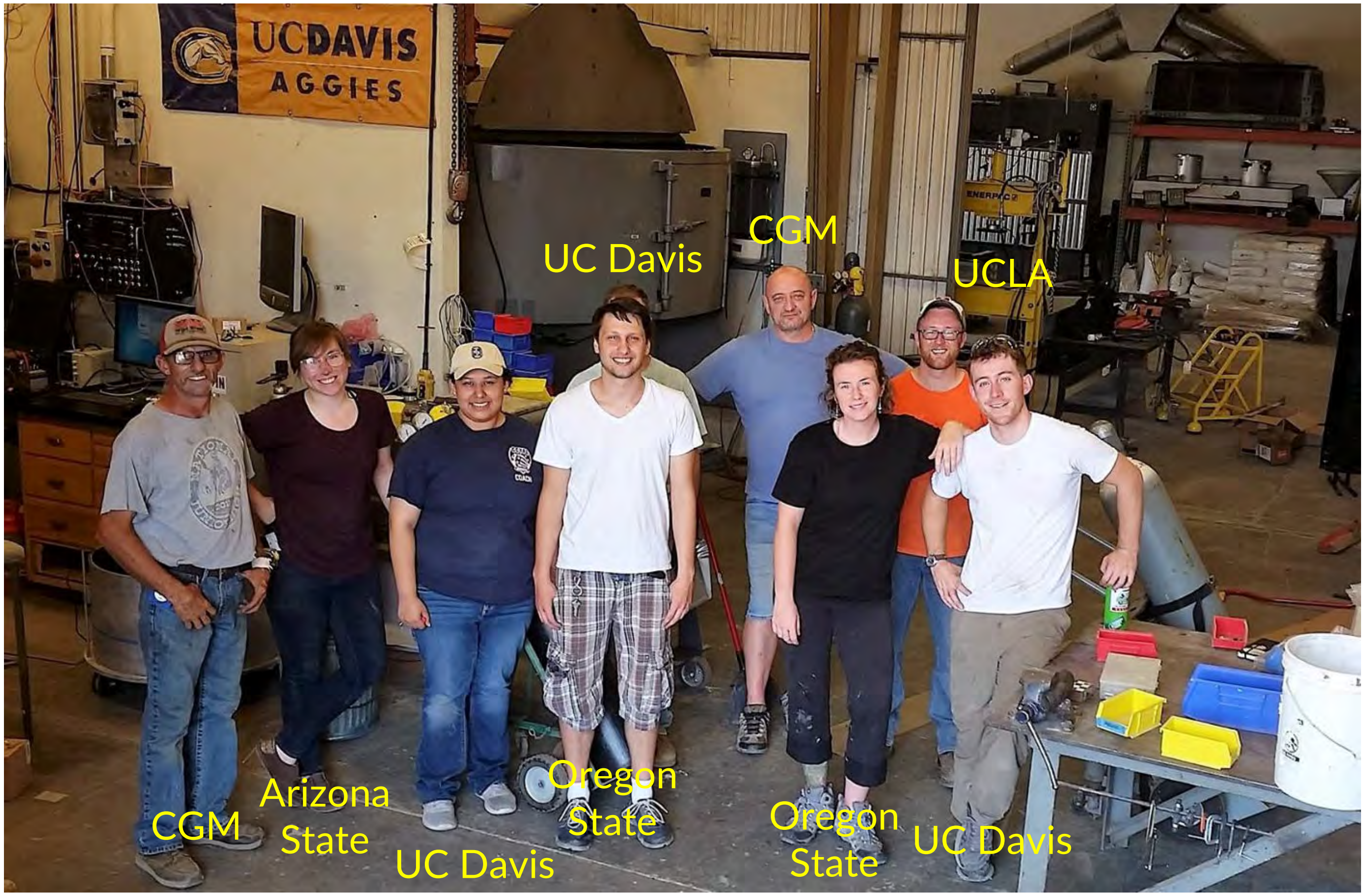
- *Ten workstations across site*
- *Five containers, hundreds of sensors*
- *Have had up to 6 teams on site under NHERI*
- *Adding resources adds capacity*





Parallel Workflow….Apprenticeships, Ladder mentoring, and staff support

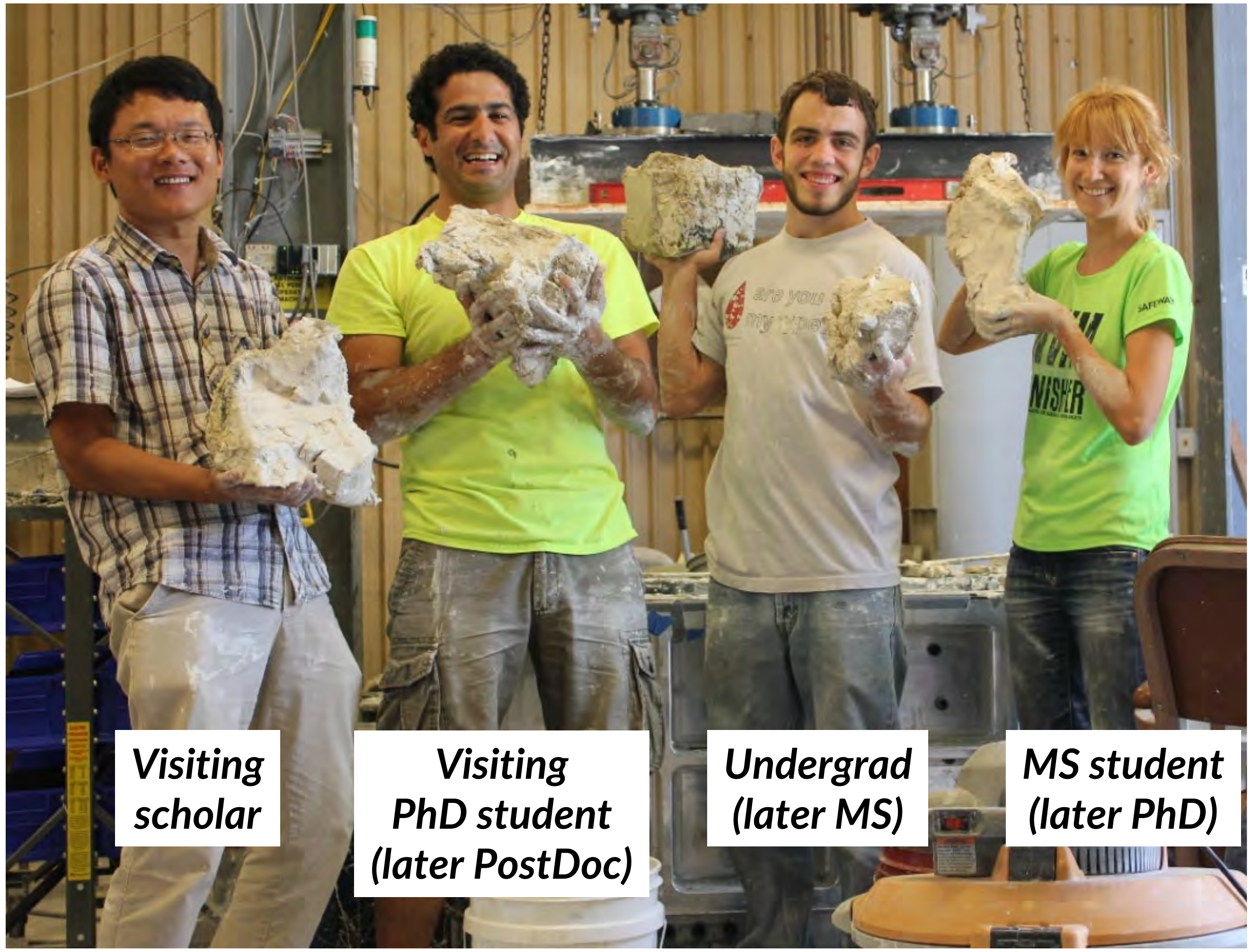
- *Parallel workflow facilitates, & recharge rates encourage, **apprenticeship training** across teams*
- *Parallel workflow provides **scheduling flexibility** & reduces potential **conflicts***
- *Ladder Mentoring Model has established a **sustainable culture** of inclusion, helpfulness, & collaboration among users*



Winter 2017 – five teams on site (three external, two internal)

Ladder Mentoring in Practice

- *Mentoring by near-peers, typically one or two steps "up" the ladder*
- *Often short term, task oriented (focused), meets individual needs*
  - *Mentee benefits by hands-on learning*
  - *Mentor benefits from direct help, professional growth*
- *Natural progression, participants mentor up and down, often simultaneously*



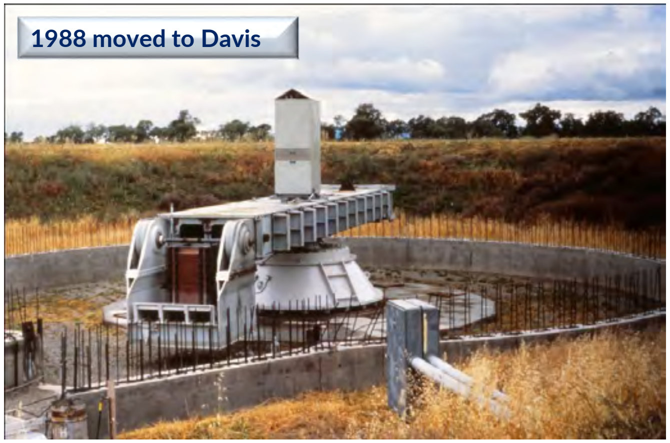
Users' activities, accomplishments, & contributions

Internal and External User Base Active during the NSF NHERI Award

- *Boulanger and DeJong (UC Davis) - CPT-Based Characterization of Intermediate Soils (**1300518**)*
- ***Kavazanjian (ASU)** and DeJong (UC Davis) - Engineering Research Center for Bio-mediated and Bio-inspired Geotechnics (CBBG) (**1449501**)*
- ***Mason and Yeh (Oregon State)** - Centrifuge Modeling of Coastal Soil-Structure Instability (**1538211**)*
- ***Brandenberg and Stewart (UCLA)** - Soil-Foundation-Structure Interaction Effects on Cyclic Failure Potential of Silts and Clays (**1563638**)*
- *Kutter (UC Davis) - Collaborative Research: Validation of Constitutive and Numerical Modeling Techniques for Soil Liquefaction Analysis (**1635307**)*
- *Boulanger and DeJong (UC Davis) - Liquefaction Evaluations of Finely Interlayered Sands, Silts and Clays (**1635398**)*
- ***Olson (UIUC) and Dewoolkar (Vermont)** - Collaborative Research: Novel Measurement of Shear Strength Evolution in Liquefied Soil and Calibration of a Fluid Dynamics-based Constitutive Model for Flow Liquefaction (**1728172 & 1728199**)*
- *Ziotopoulou (UC Davis) and **Hashash (UIUC)** – Collaborative Research: Soil-Structure-Water Interaction Effects in Buried Reservoirs - Centrifuge and Numerical Modeling (**1763129 & 1762749**)*
- *Martinez and Wilson (UC Davis) – Geotechnical Centrifuge Tests to Assess Stability of Fly Ash Impoundments (EPRI)*
- *Ziotopoulou and Kutter (UC Davis) – Centrifuge testing of downdrag on piles (Caltrans)*

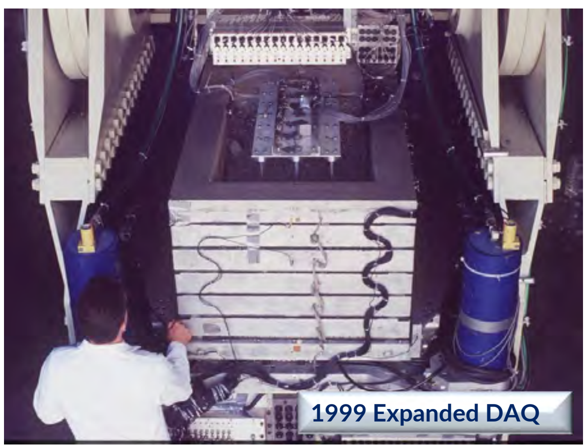
Developing Capacity to Support Advancing Research Topics

- *Continuous updates to meet demands of users' science*


1988 moved to Davis


1990 rotunda increases g


1995 added shaker

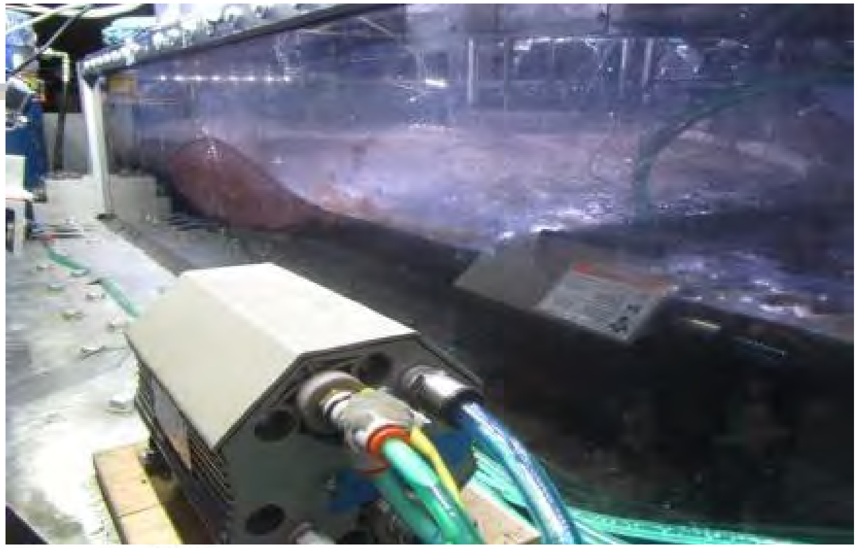

1999 Expanded DAQ

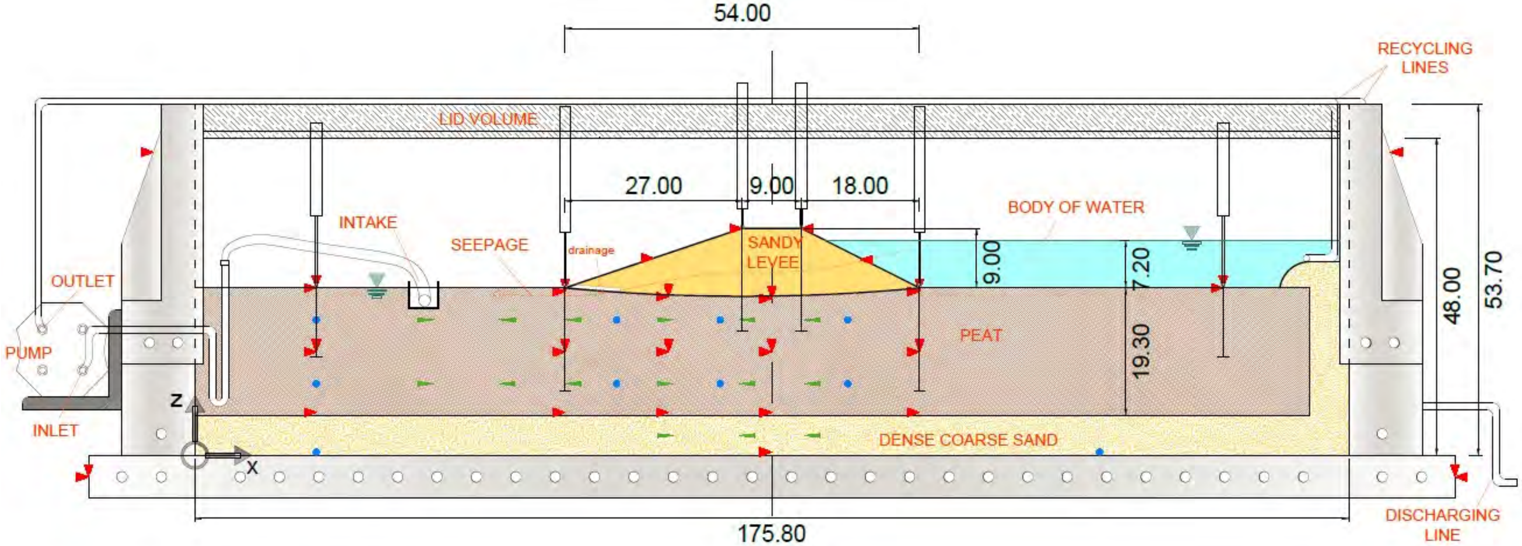

2010 after NEES updates


2013 gantry & DAQ

New Capabilities Developed by Researchers

- *The CGM supports its users in developing, commissioning, and using new experimental techniques that are in the forefront in the field of physical modeling.*

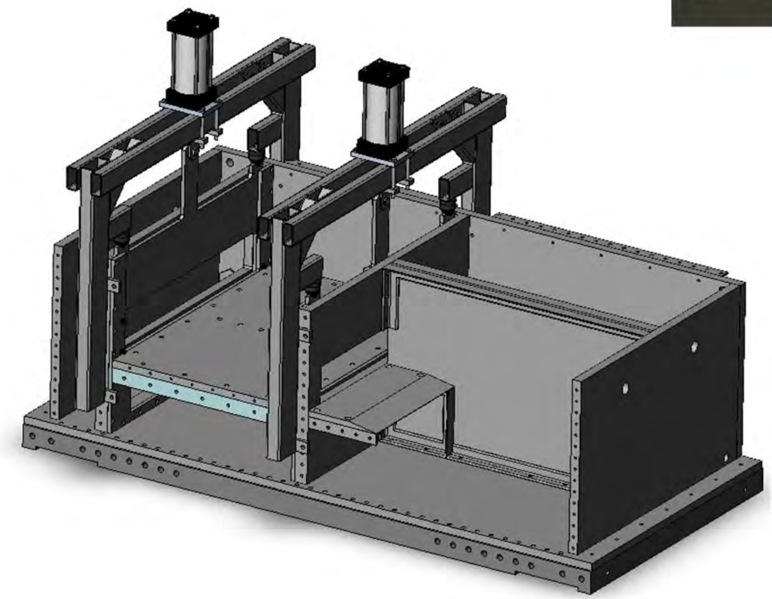


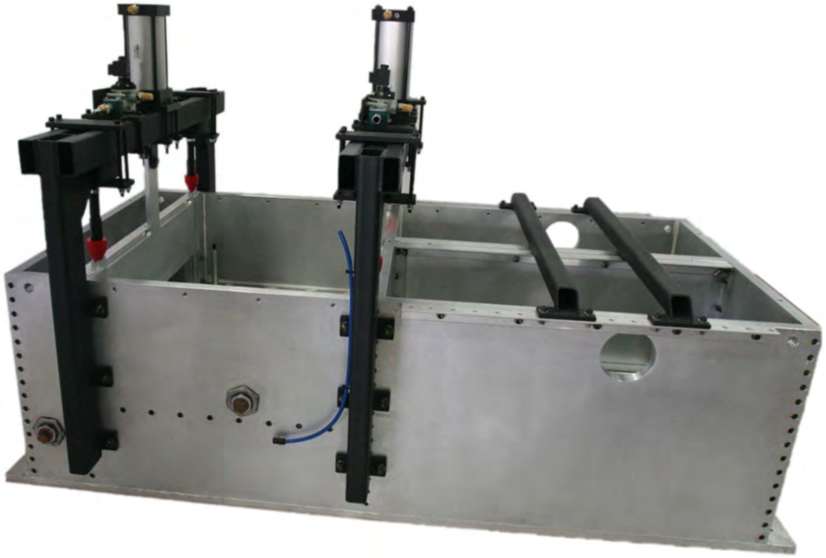


Maintaining a phreatic surface in a levee (UCLA 2013, 1208170)

New Capabilities Developed by Researchers

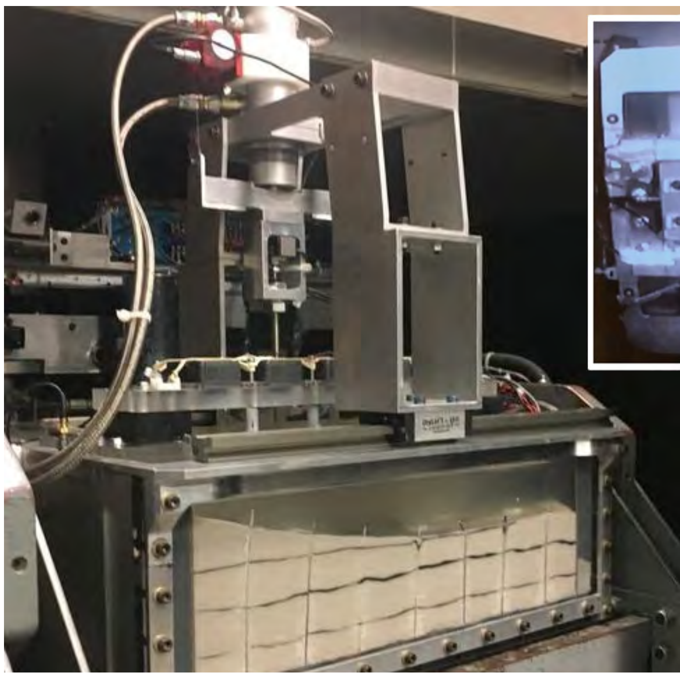
Tsunami-induced scour & a centrifuge gate configuration for generating tsunami wave inundation and drawdown cycles (Oregon State 2016,1538211)

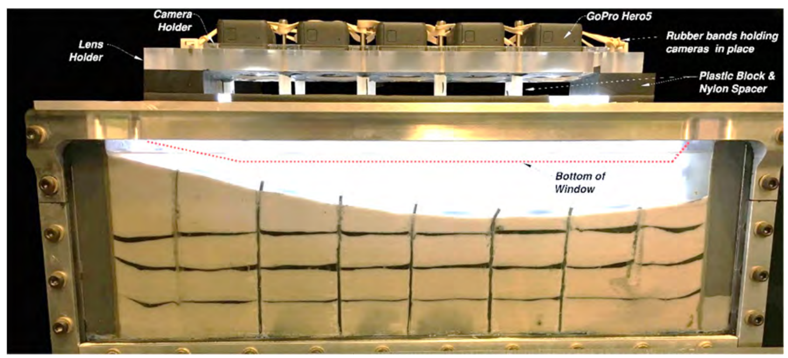


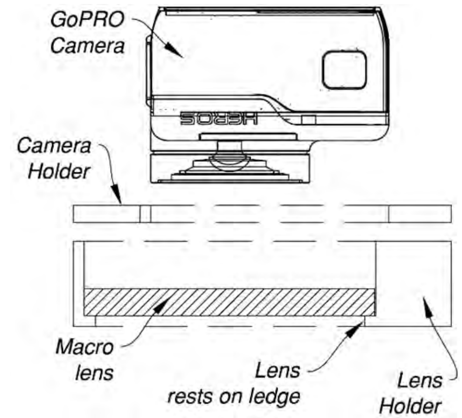


New Capabilities Developed by Researchers

- *Particle Image Velocimetry (PIV) displacement tracking & economical CPT cones for standardization across the international testing community (LEAP UC Davis, 1635307)*

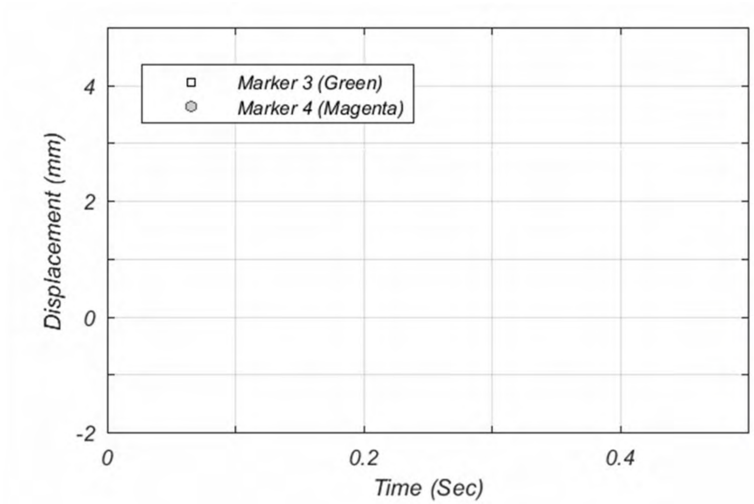


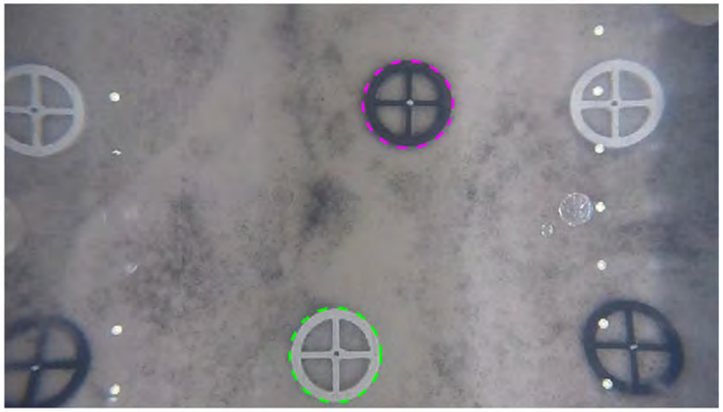




New Capabilities Developed by Researchers: Displacements of Liquefied Ground

- *The videos can be converted to images*
- *Using GEO-PIV displacement time histories can generated*





Videos of displacements were recorded during spinning and shaking. Magenta and green rings are initial positions of the markers

Summary I

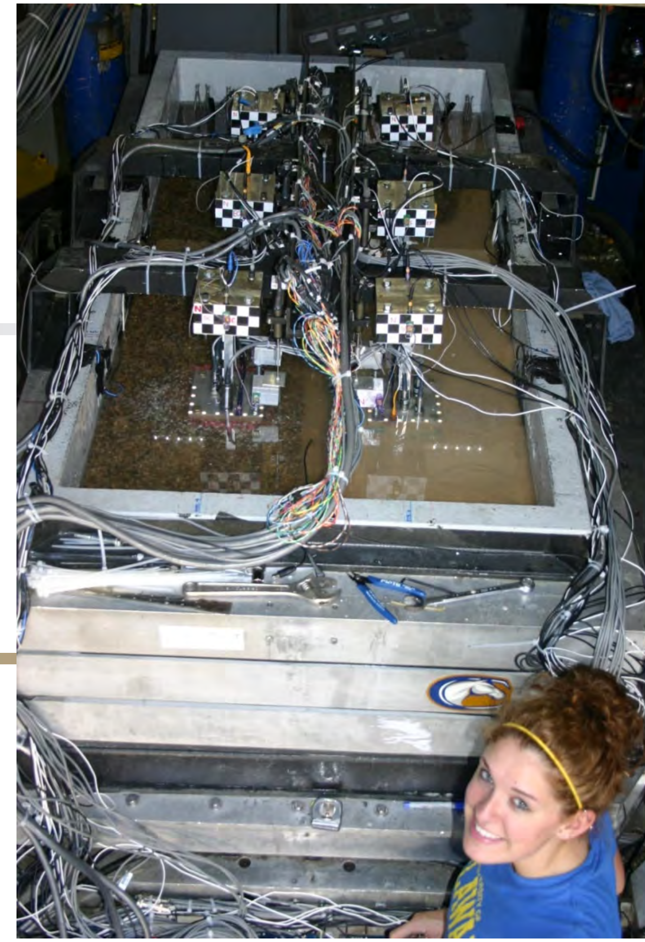
- *Largest centrifuge with a shaking table in the world*
- *Synergy of 1-m and 9-m radius centrifuges with common technologies*
- *Breadth of supporting technologies & capabilities*
- *Continuously advancing capabilities through acquiring new funds, partnering with researchers to add capability, and leveraging operations funds as allowable to increase productivity and capability across research teams*

- *Understanding the workflow of operations can help with test design, planning, and resource allocation*
- *Articulating the fundamental mechanism(s) to be studied should guide the overall process…*

Newer Projects that are also working on new capabilities

- *Novel Measurement of Shear Strength Evolution in Liquefied Soil and Calibration of a Fluid Dynamics-based Constitutive Model for Flow Liquefaction (1728172 & 1728199)*
  - *New PIs from both UVM (Dewoolkar) and UIUC (Olson)*
  - *Students from UVM and UIUC visited Davis in winter 2018 for mentoring*
  - *New characterization tool – coupons with embedded sensors*
  - *New loading equipment to be installed on 1m and 9m centrifuges*
  - *First tests scheduled for 1m centrifuge in the fall of 2018*
- *Soil-Structure-Water Interaction Effects in Buried Reservoirs - Centrifuge and Numerical Modeling (1763129 & 1762749)*
  - *Funded July 2018*
  - *New PI (Ziotopoulou) and repeat external PI from UIUC (Hashash)*
  - *First experiments on soil-water-structure interaction*
  - *Fluid modeling will benefit from tsunami project (1538211)*
  - *Visiting professor from Kyoto is planning 9m experiment for January of 2019 – accelerated schedule*

Designing Tests to Identify Mechanisms



Principles of Centrifuge Modeling

- *Nonlinear strength, stiffness, and dilatancy of soil depends on effective stress and stress history.*
- *Idea is to produce a realistic stress and realistic stress distribution in controlled experiments with well defined boundary conditions and well defined material properties.*

  - *Let* $\sigma^{*} = \sigma_m / \sigma_p = 1$ *(soil properties depend on σ′) (ref. Kutter 1995)*
  - $\sigma^{*} = 1$ *is important because strength, stiffness, dilatancy, void ratio of soil have nonlinear dependence effective stress.* ***Modeling similarity is enhanced by stress similarity.***

  - *Let* $L^{*} = L_m/L_p = 1/N$ *(definition of scale factor, N)*
  - *Let* $\rho^{*} = \rho_m/\rho_p = 1$ *(same materials)*
  - *And because* $[\sigma] = [\rho][g][L]$ *[x] = units of x*

$$\sigma^{*} = \rho^{*} g^{*} L^{*}$$

$$1 = (1)(g^{*})(L^{*}) \rightarrow g^{*} = 1/L^{*} = N$$

Principles of Centrifuge Modeling

- *Nonlinear strength, stiffness, and dilatancy of soil depends on effective stress and stress history.*
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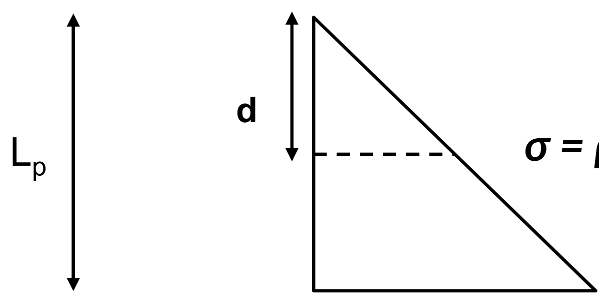
Prototype Stress Distribution



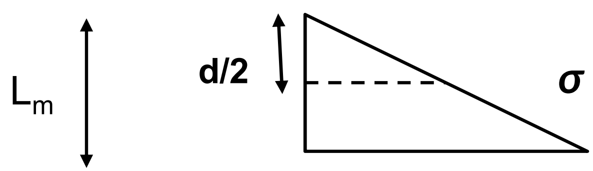
$\sigma = \rho\, g\, d$

$L^* = L_m/L_p = 0.5$

$g^* = g_m/g_p = 2$

$\rho^* = \rho_m/\ \rho_p = 1$

Stress Distribution in 1/2 Scale Model Under 2g



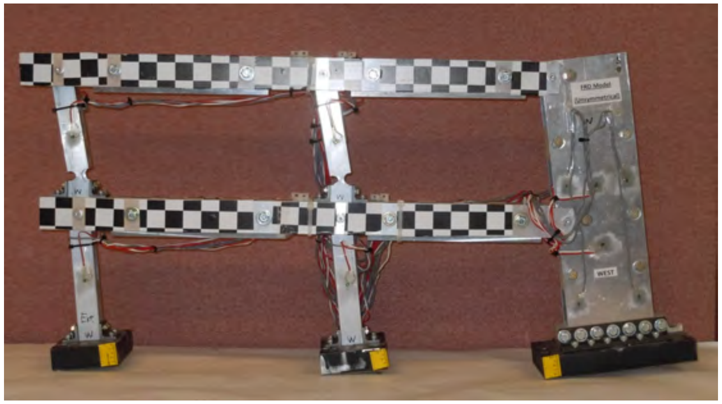
$\sigma = \rho\,(2g)\,(d/2) = \rho\, g\, d$

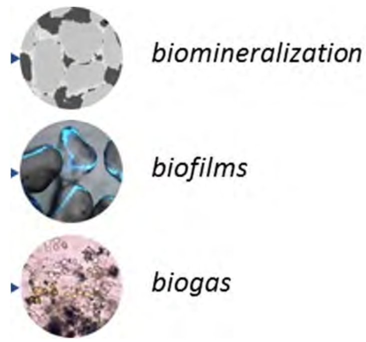
Garnier et al. (2007) – IJPMG3 1-23

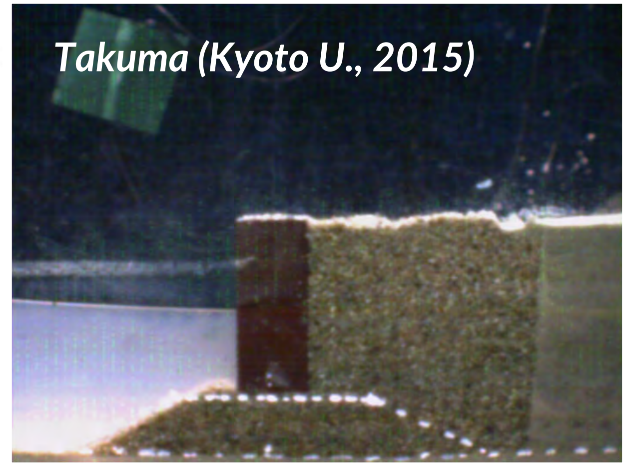
Main topics and main contributors to the catalogue

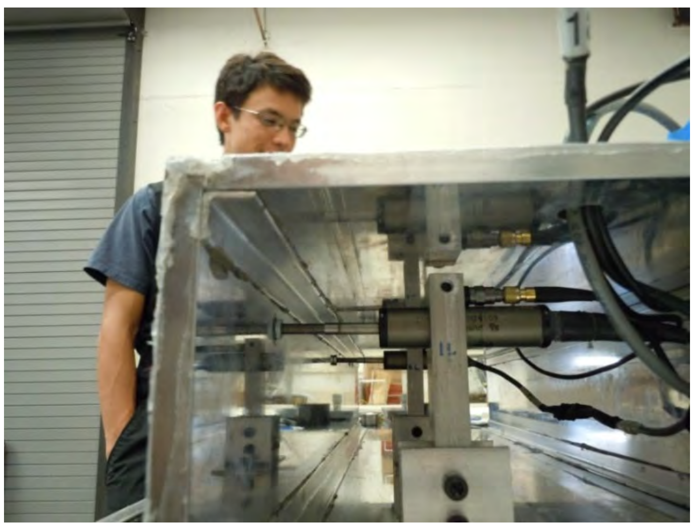
A-Fundamental laws of statics, time and rate scaling factors *(C. Gaudin, J. Garnier)*	**B-Grain size effects on soil-structure interaction** *(D. König, J. Garnier)*	**C-Grain size effects on interfaces and shear band patterns** *(B. Kutter, D. König,)*	**D-Size effects derived from continuous media mechanics** *(C. Gaudin, J. Garnier)*	**E-Density and stress distribution in centrifuge models** *(J. Garnier)*
F-In-flight in-situ tests *(M.F. Randolph, J. Garnier)*	**G-Fluid flow in saturated centrifuge samples** *(D. Goodings)*	**H-Unsaturated conditions** *(D. König, J. Garnier)*	**I-Dynamic conditions** *(B. Kutter, S.M. Springman)*	**J-Aqueous phase transport in saturated soils** *(P.J. Culligan)*
K-Non aqueous phase transport in soils and fractures *(P.J. Culligan)*	**L-Heat transfer** *(P.J. Culligan)* **Frost, Ice** *(R. Phillips)*	**M-Erosion, sedimentation** *(D. Goodings)*	**N-Current propagation, electro-osmosis** *(L. Thorel)*	**Other topics to come?**

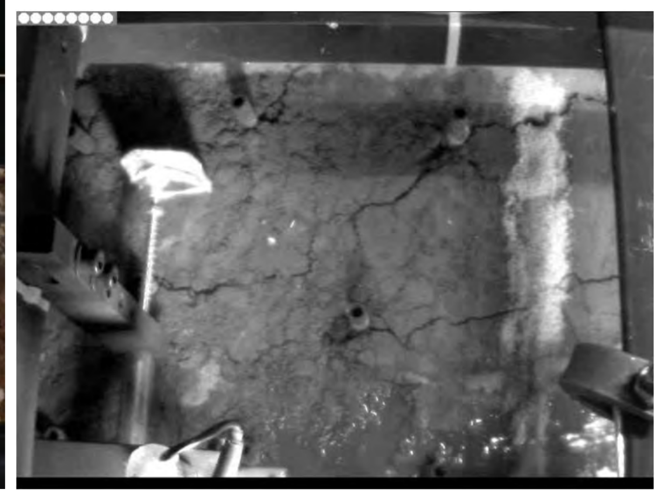
A Multitude of Complex Physics…











Centrifuge Modeling

- *Advantages*
  - *System response and performance evaluation*
  - *Controlled 'full-scale' environment*
  - *Isolation & systematic study of specific mechanisms w/ parametric study*
  - *Less physical work and cost than full scale*

- *Challenges*
  - *Scaling of particle level processes*
  - *Gradient of stress change with depth is large*
  - *Design and analysis effort comparable to field scale study (not bench scale test)*
  - *Development of miniature sensors & monitoring*

- *+Plus you get different pros and cons by working on 1m vs 9m radius centrifuge*

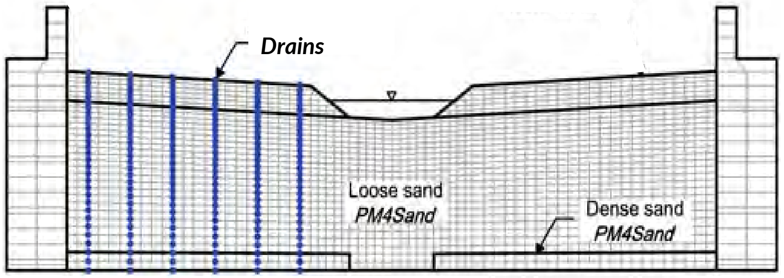
So…. Good Idea to:

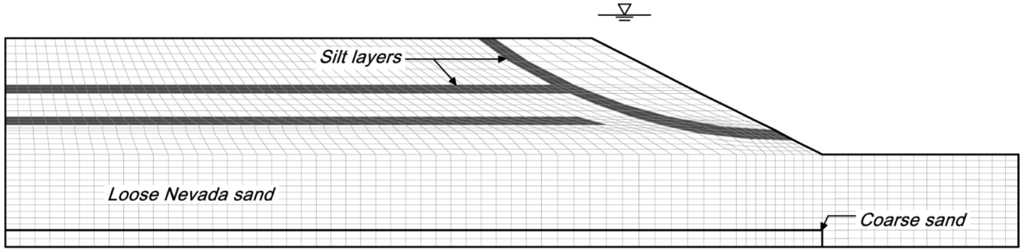
- *Articulate the fundamental mechanism(s) that you are studying or most concerned about.*
- *Articulate how you will be using the experimental data:*
  - *Validation of numerical simulations?*
  - *Validation of design methodologies?*
  - *Identification of mechanisms and behaviors using back-analyses or system identification methodologies?*
- *Design model configuration so that it has the desired sensitivity to the fundamental mechanism of interest or will provide an appropriate test of your analysis method.*
- *For every sensor, ask yourself what you expect to see, how you will use the data, and why you need it. Focus your sensors where they will be useful for you.*
- *How? Start by using somebody else's data!*
- ***Coming up: examples from personal experience…***

Today's Plan

- Center for Geotechnical Modeling
  - People, facilities, and capabilities
  - Workflow of operations
  - User's activities, accomplishments, and contributions
- Designing Tests to Identify Mechanisms
  - Void redistribution in liquefiable soils
  - Liquefaction-induced downdrag on piles
- Summary

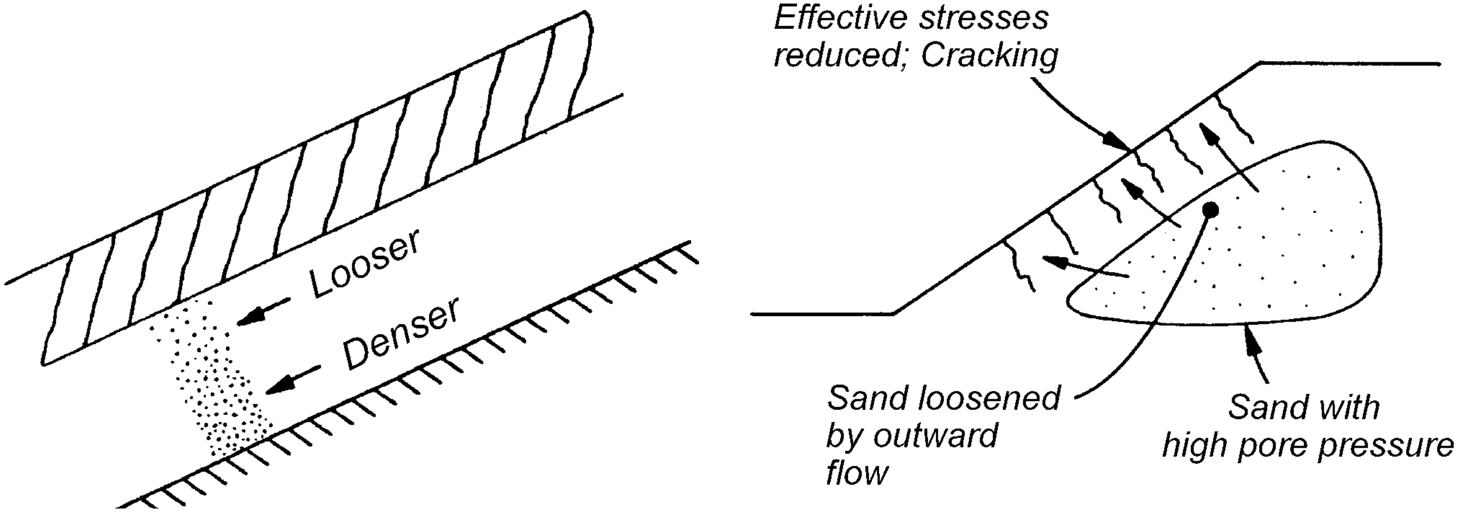
Void Redistribution in Liquefying Soils





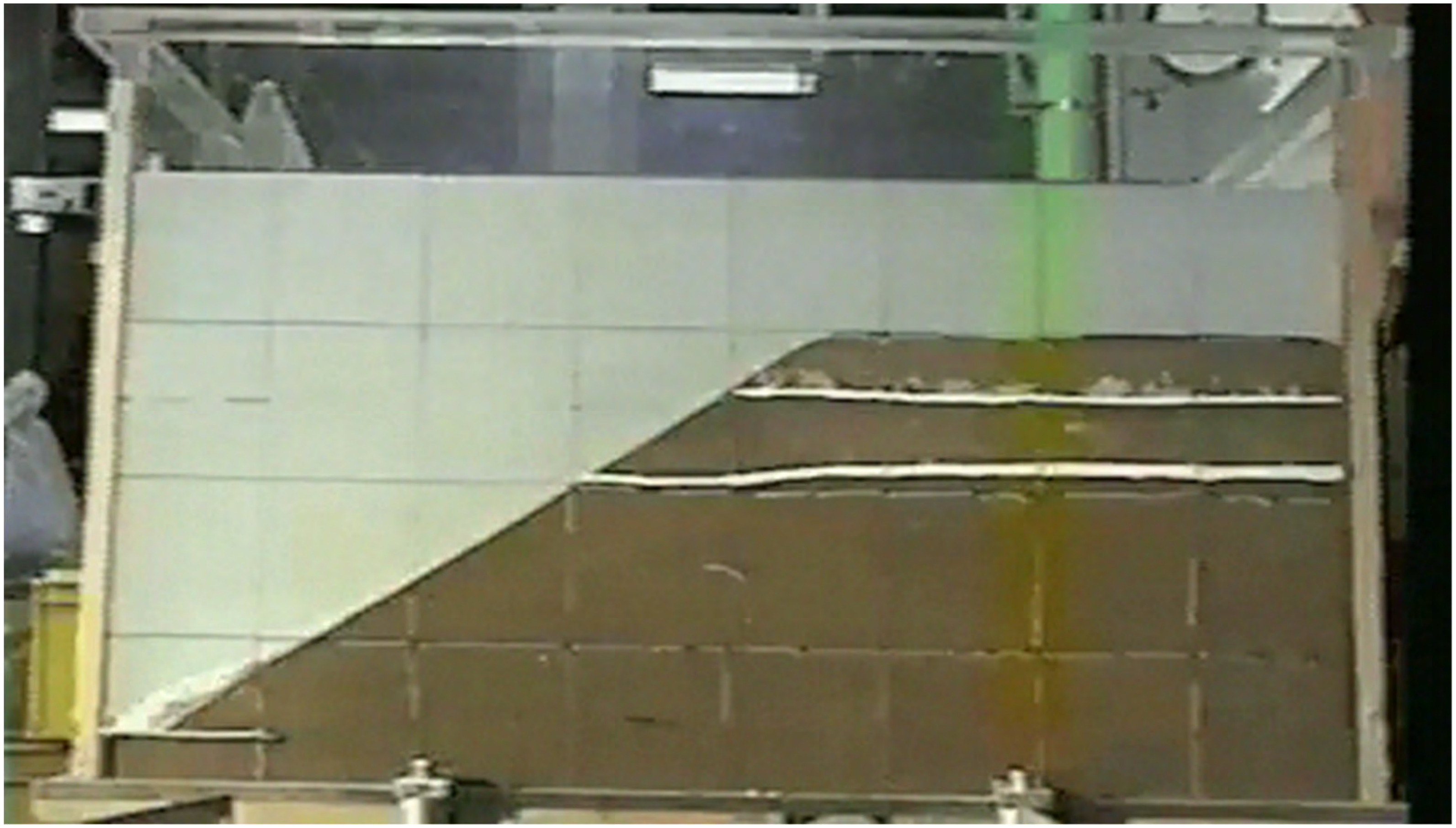
Void Redistribution

- *Void ratio can locally increase and lead to strength decrease*
- *This means that pre-earthquake D_R or $(N_1)_{60}$ are insufficient predictors of the in-situ residual strength S_r*
- *Has frequently led to delayed flow failures in the field.*

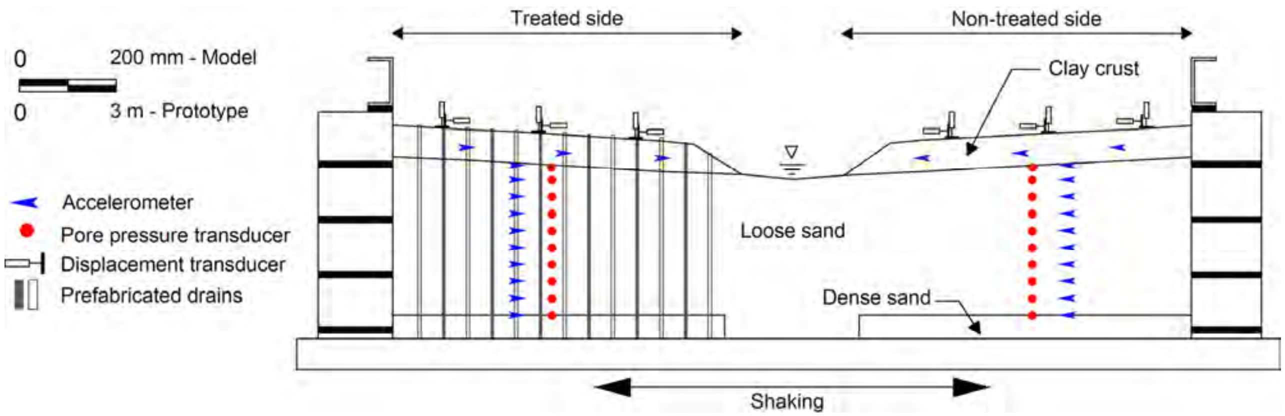


After Whitman (1985)

Shaking Table Test: Void Redistribution and Delayed Flow Failure

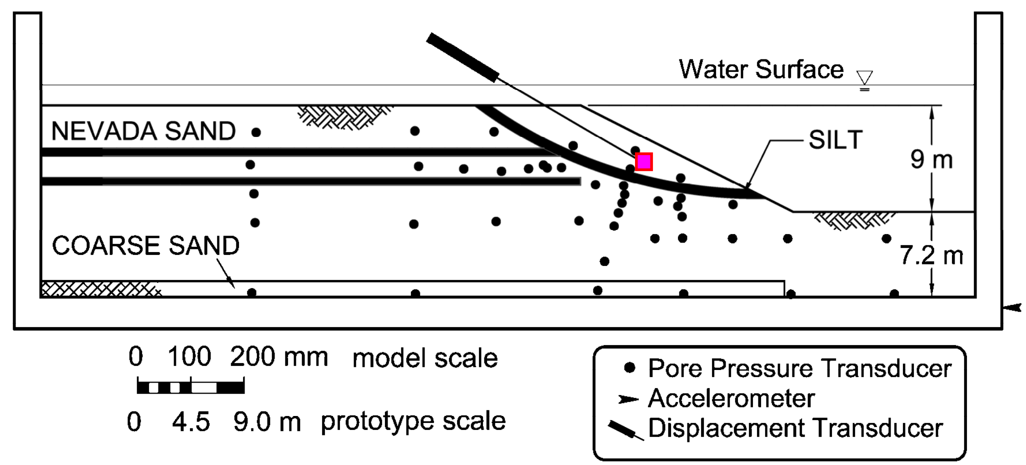


Purpose - Identifying mechanisms



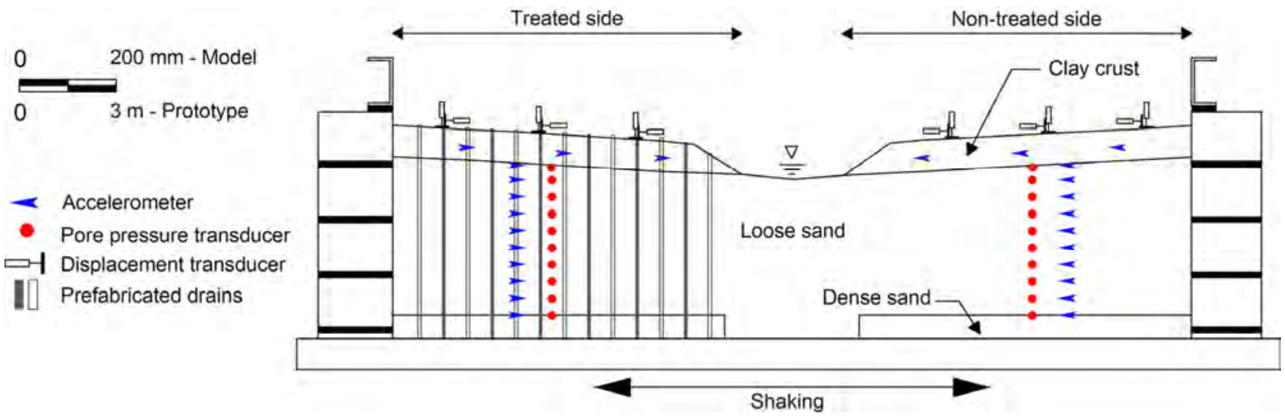
[NEES test by Kamai, Kano, Conlee, Marinucci, Boulanger, Rathje, Rix, and Howell 2008]

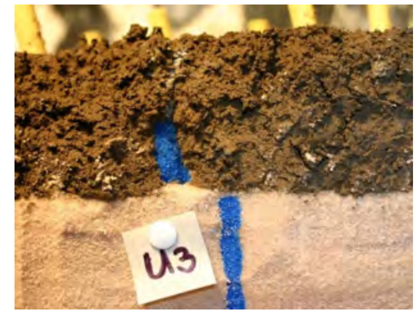
- *Effectiveness of prefabricated drains for liquefaction mitigation (Rathje, Howell, Kamai, Boulanger, and others) / 1m clay overlying 5m sand, D_R = 40%, 3° slope.*

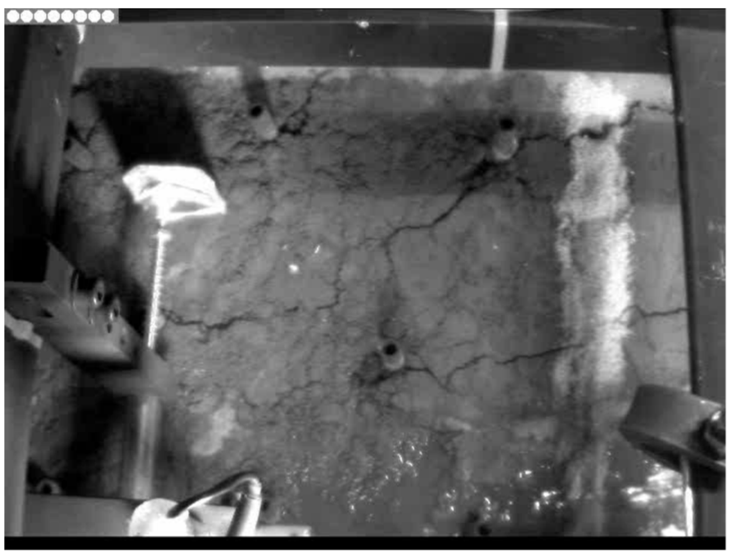


- *Dense arrays!*

Purpose – Identifying Mechanisms





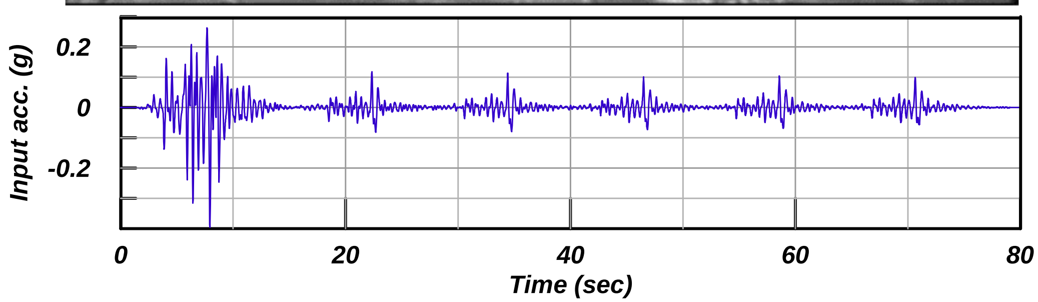


[NEES test by Kamai, Kano, Conlee, Marinucci, Boulanger, Rathje, Rix, and Howell 2008]

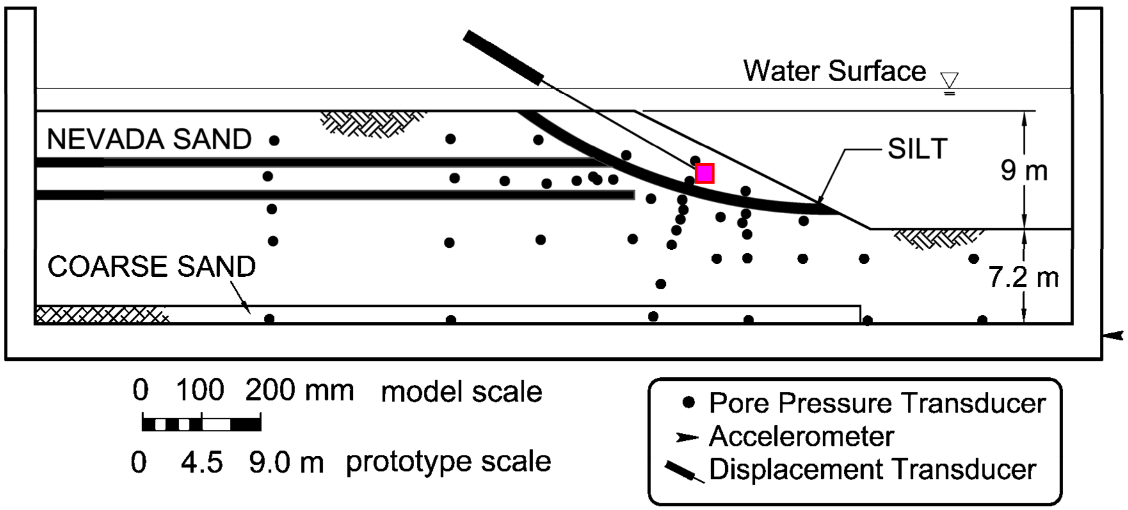
Centrifuge Test: Void Redistribution and Delayed Flow Failure

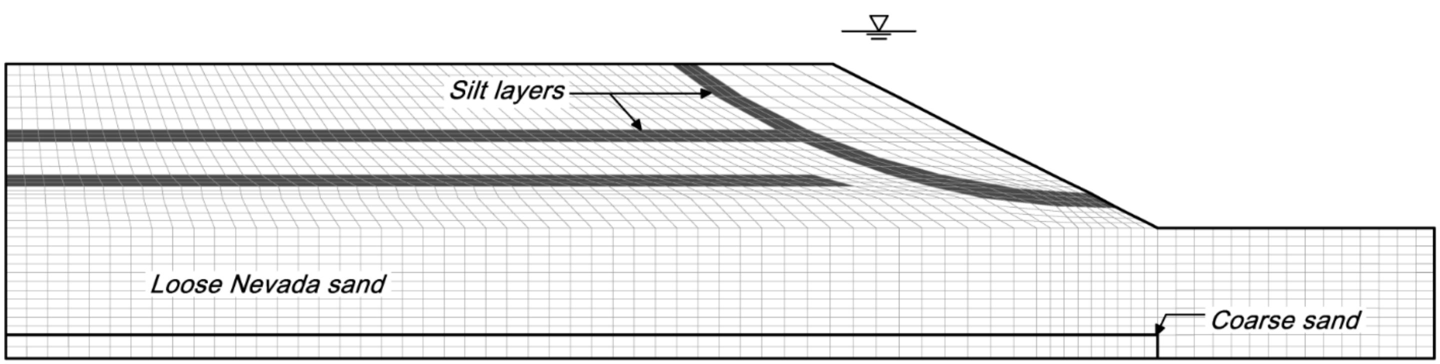
Malvick et al. (2008)

Centrifuge Test: Void Redistribution and Delayed Flow Failure



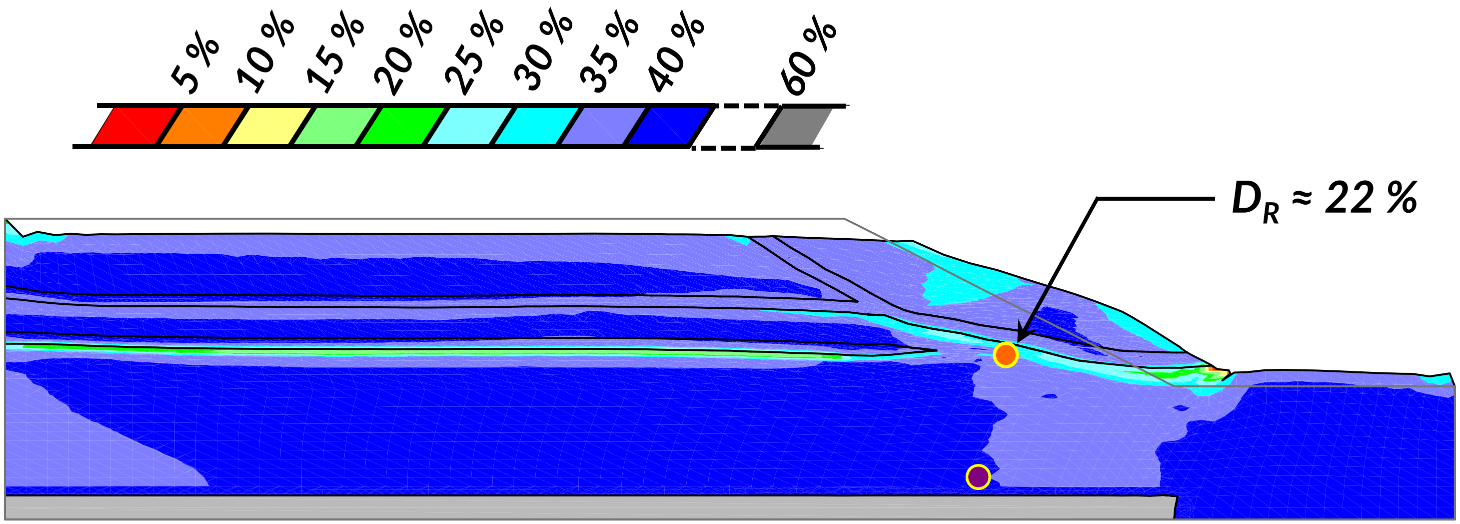
Problem Configuration





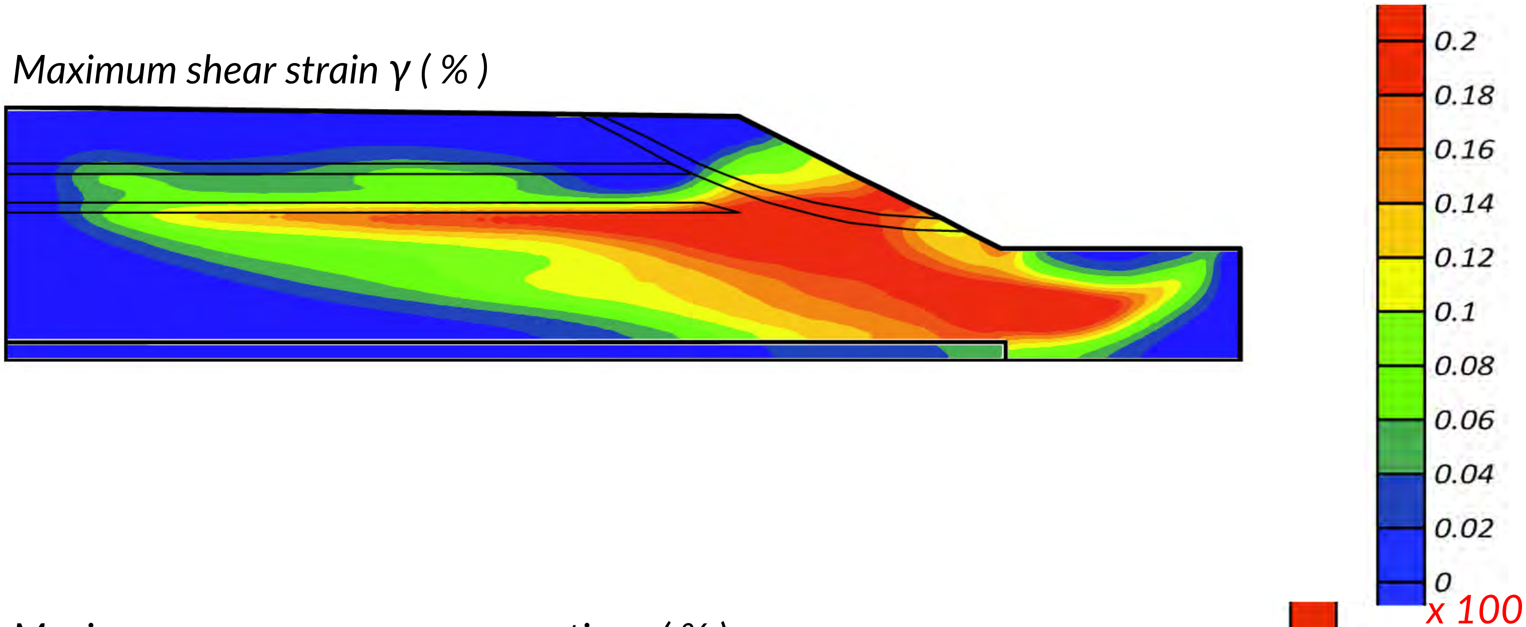
Contours of Relative Density – End of Reconsolidation

- *Initial relative density of loose Nevada Sand 35%*

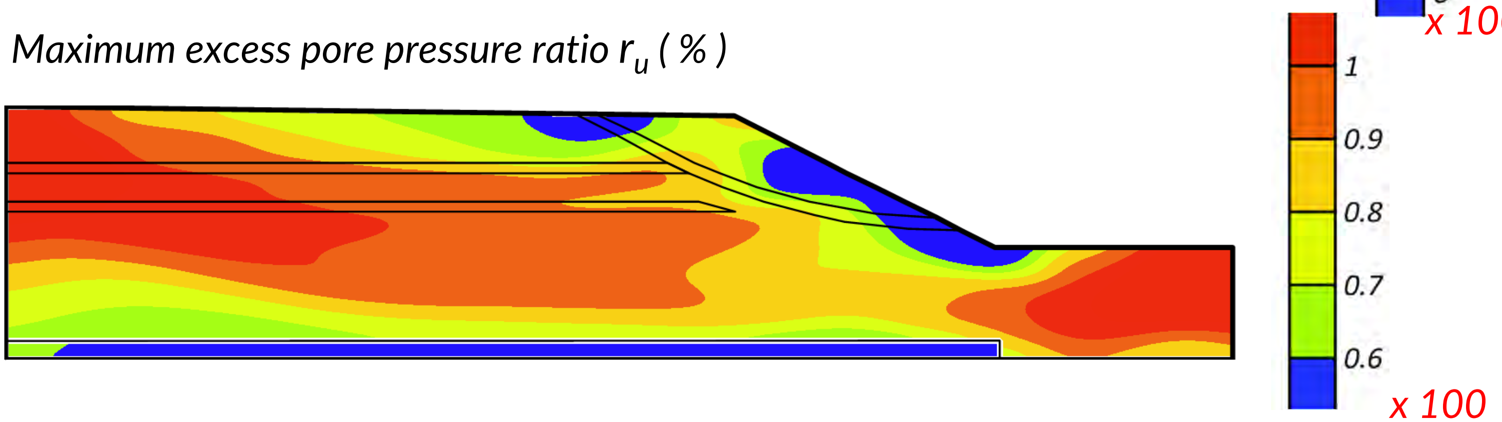


Dynamic Response: Contours

Maximum shear strain γ (%)

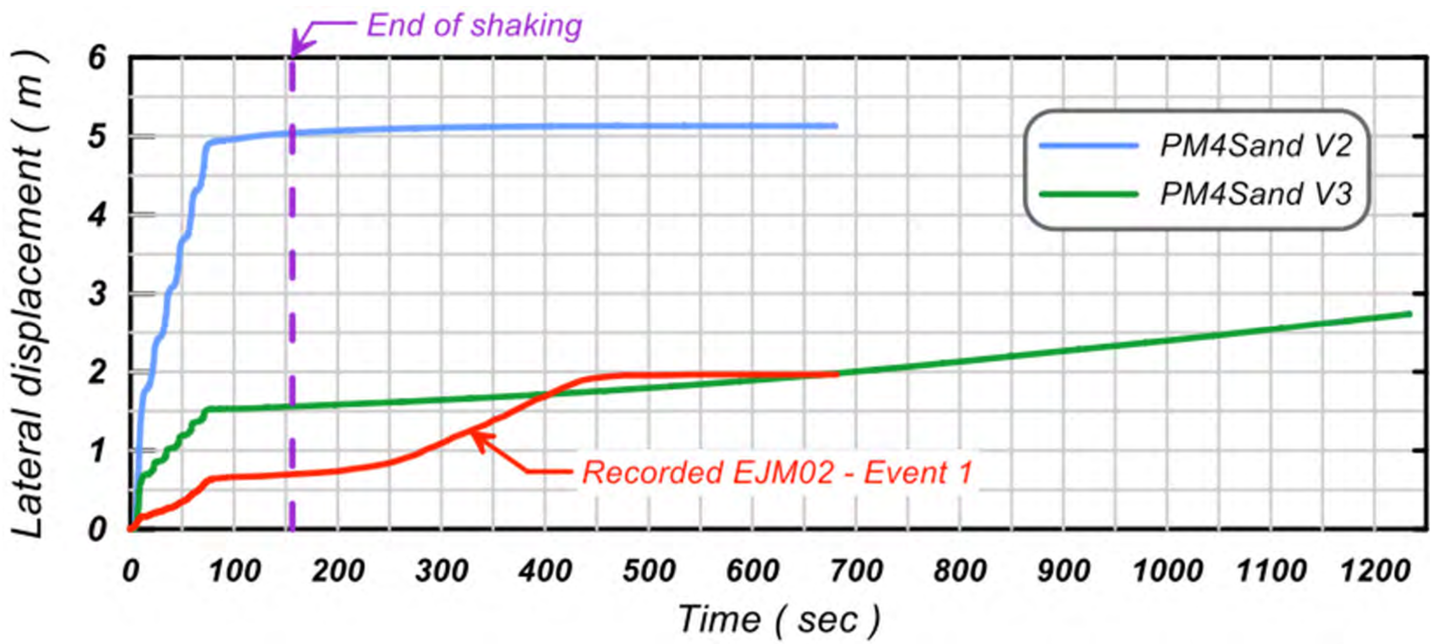


Maximum excess pore pressure ratio r_u (%)



Delayed Flow Failure: Lateral Displacements

Preliminary results



Summary II

- *Fundamental interaction mechanisms can be identified using dense instrumentation arrays and data processing techniques*
  - *Also provides an improved basis for validating numerical simulation and analysis methods*
  - *Lots of generic instrumentation does not necessarily help unless it is placed where you need it*

- *Using archived and curated data can assist in numerical advances*

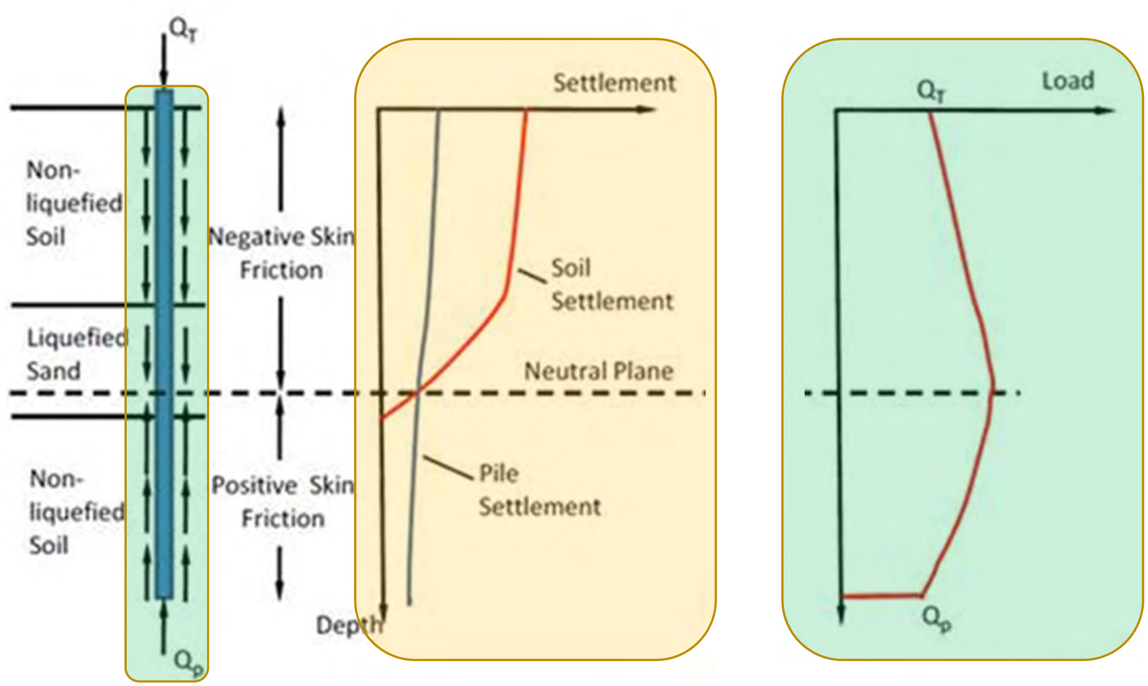
- *Extra needs?*
  - *More precise ways for locating sensors and tracking positions over time >> working on it*
  - *Instrumentation arrays and data processing techniques that can incorporate 2- and 3-dimensional effects and boundary conditions.*
  - *Integration with video imagery (PIV) >> working on it*
  - *Improved sensors for local measurements of volumetric strain, shear strain, or displacement.*

Example 2 – Liquefaction-induced Downdrag on Piles

Downdrag on Piles

- ***Downdrag :*** *settlement in the pile due to the* ***settlement of soil*** *(at the neutral plane)*
  - *sites underlain by compressible material*
  - *sites where a fill has been recently placed*
  - *ground water is lowered*
  - ***post liquefaction reconsolidation***

- *It can result in*
  - *settlement*
  - *drag load*

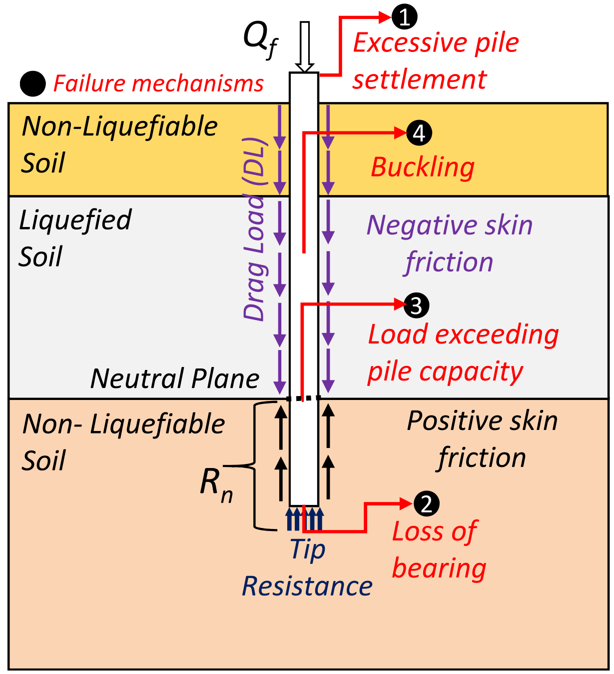


Axially Loaded Piles in Liquefiable Soils

- *Liquefaction and excess pore-pressure generation can lead to*
  - *loss of shear strength,*
  - *lateral spreading, and*
  - *settlement of soil*

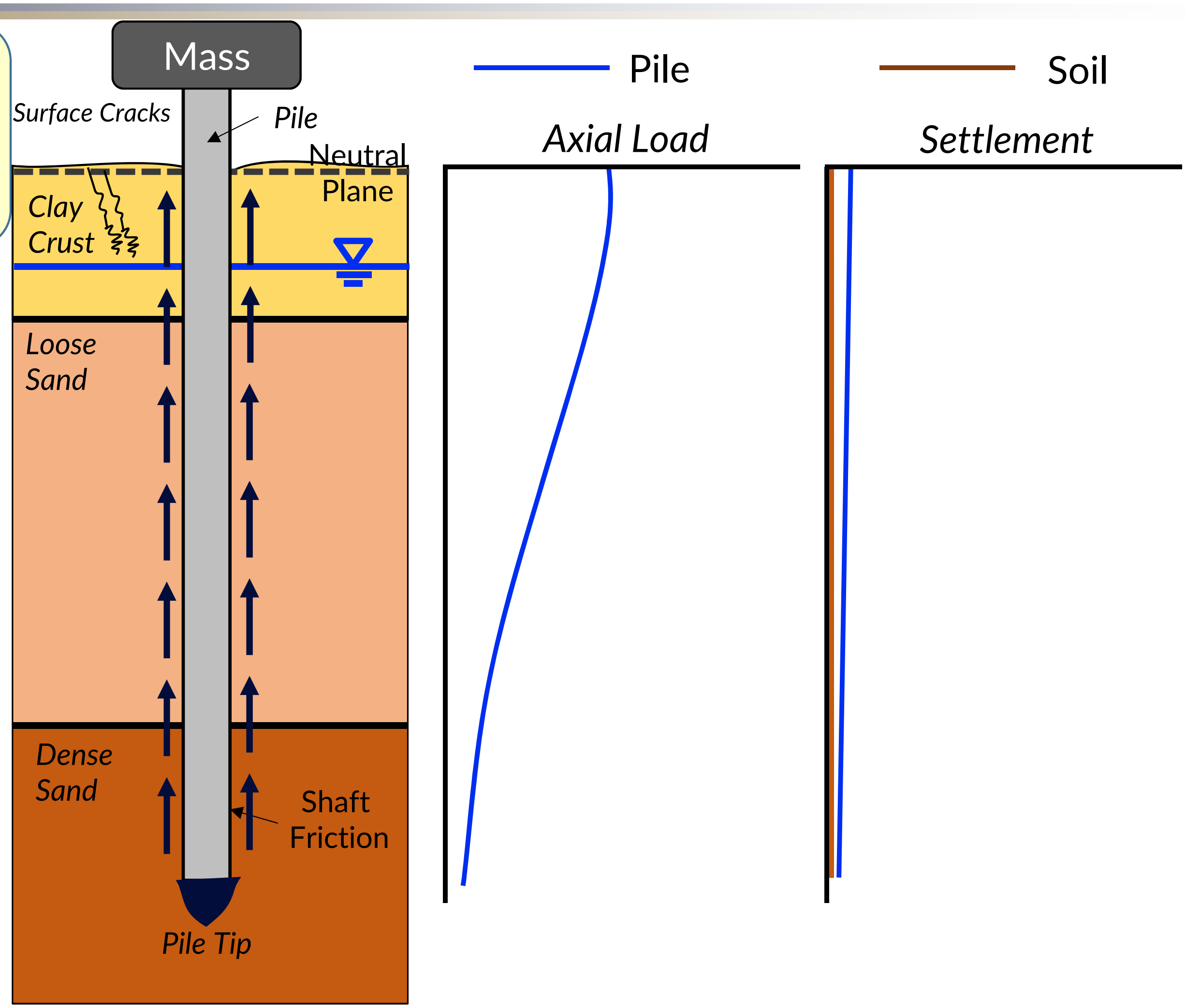
- *In axially loaded piles, it can result in*
  - *Downdrag (DD): settlement of pile*
  - *Drag Load (DL): extra internal load on pile*

Q) Which failure mechanism is more important ?



What happens during a liquefaction event on axially loaded piles?

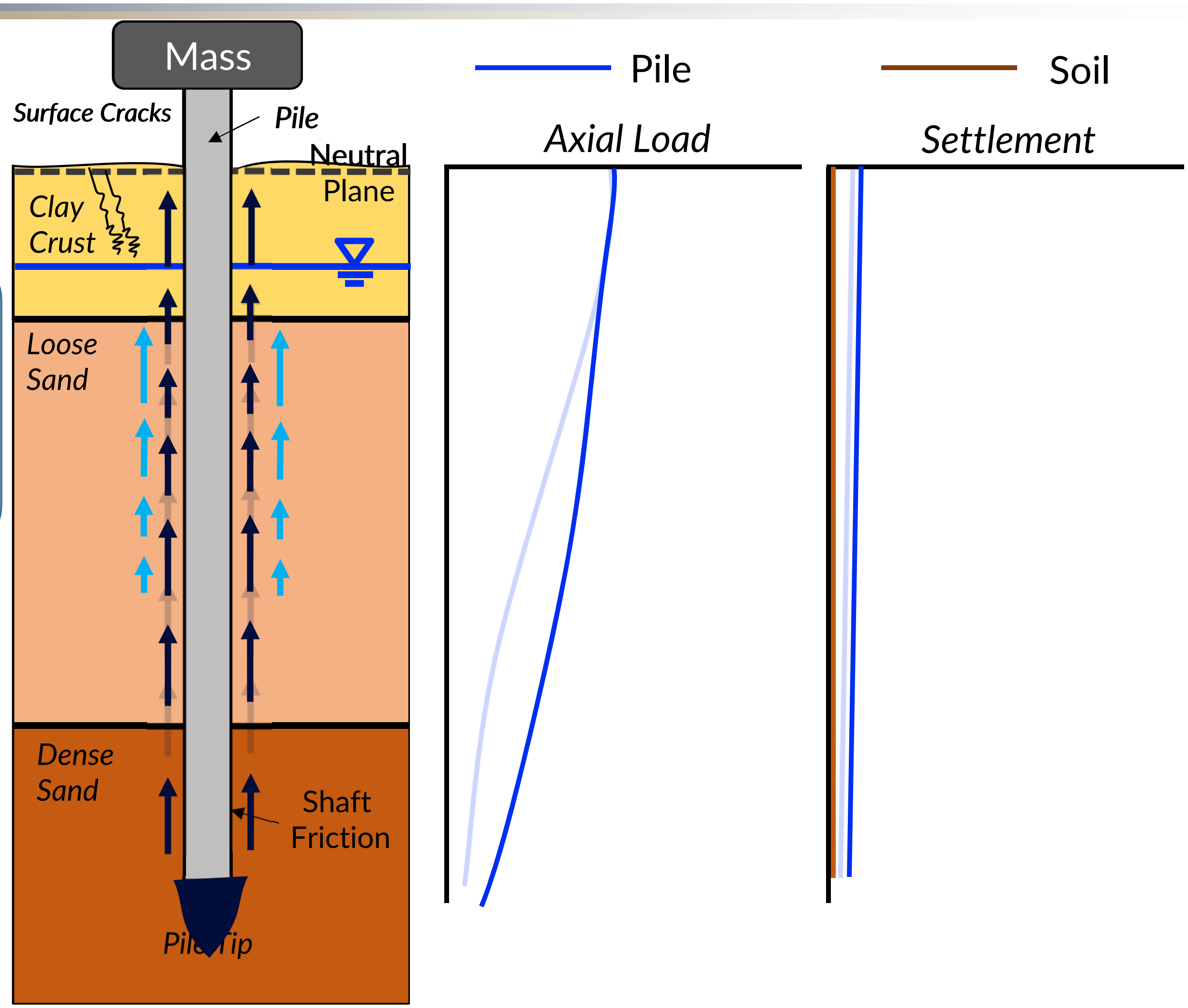
- ***Static Condition:*** *before onset of earthquake*
  - *resistance offered by full **skin friction** and **pile tip***



What happens during a liquefaction event on Axially loaded piles?

- ***Static Condition:*** *before onset of earthquake*
  - *resistance offered by full* ***skin friction*** *and* ***pile tip***

- ***Seismic Loading:*** *onset of liquefaction*
  - *pore-pressure starts to build up*
  - *skin friction reduces in the liquefiable layer*



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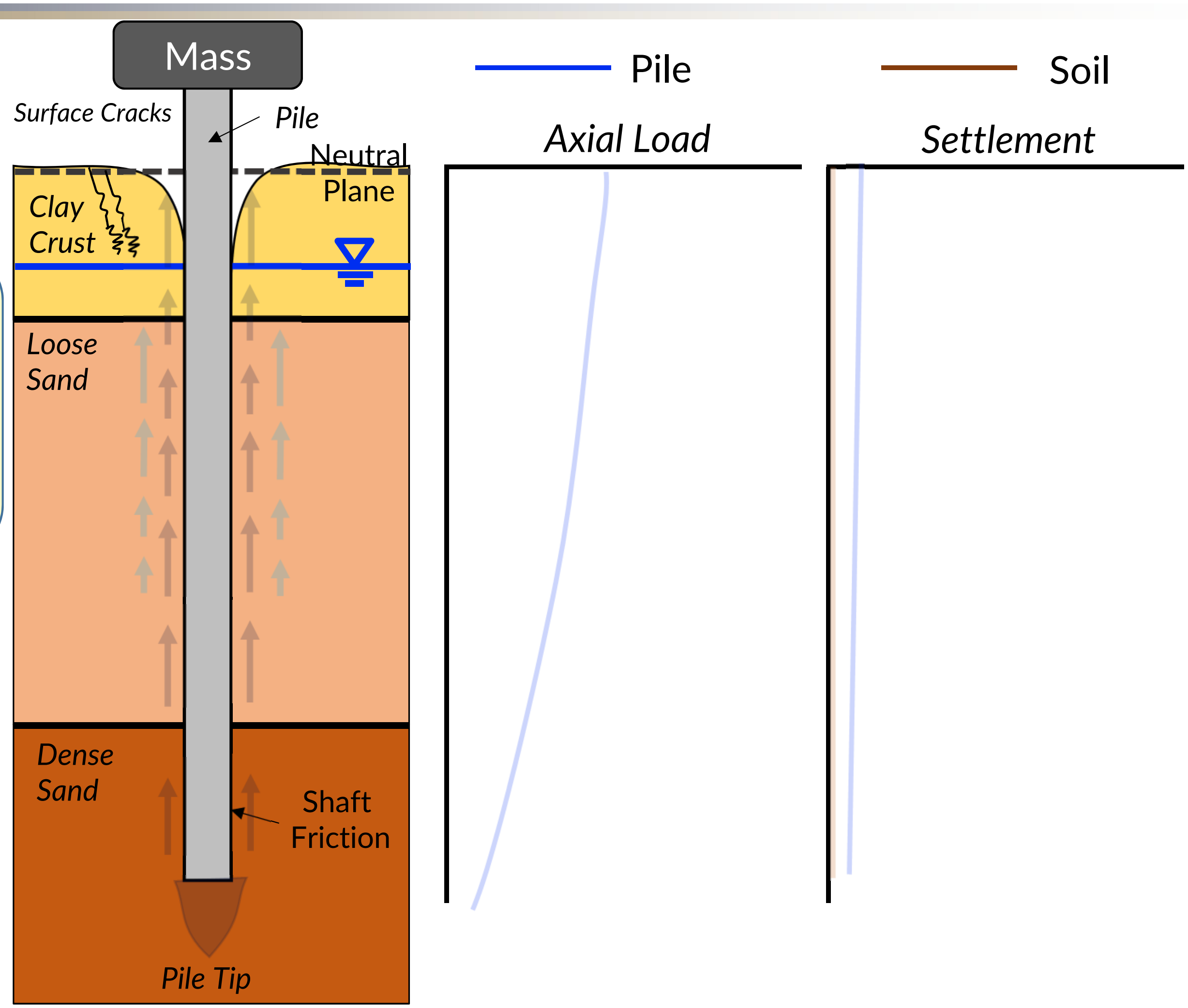

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- ***Static Condition:*** *before onset of earthquake*
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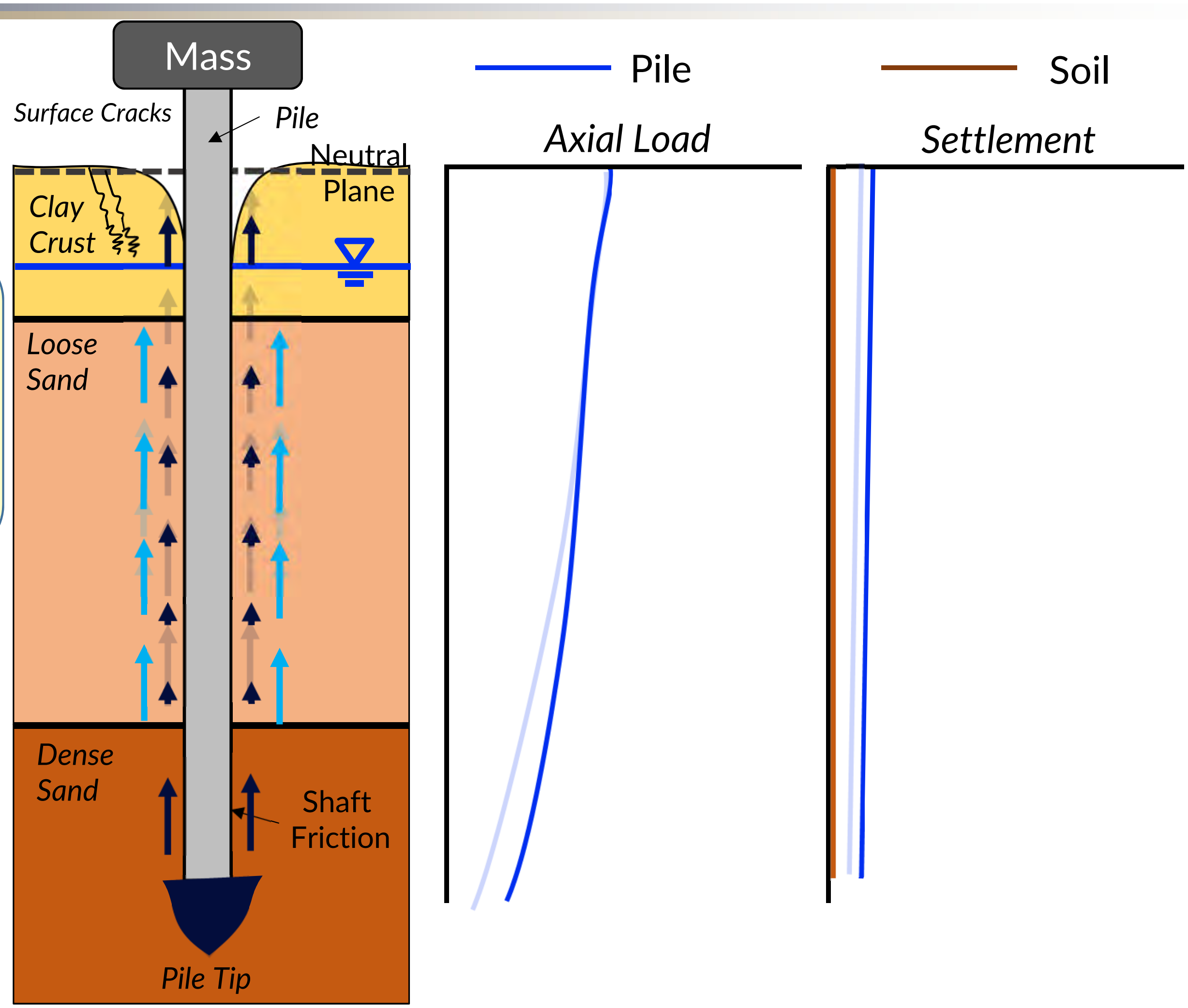
- ***Seismic Loading:*** *full liquefaction*
  - *excess pore-pressure (r_u = 1) in the liquefiable layer*
  - *skin friction reduces a lot in the liquefiable layer*



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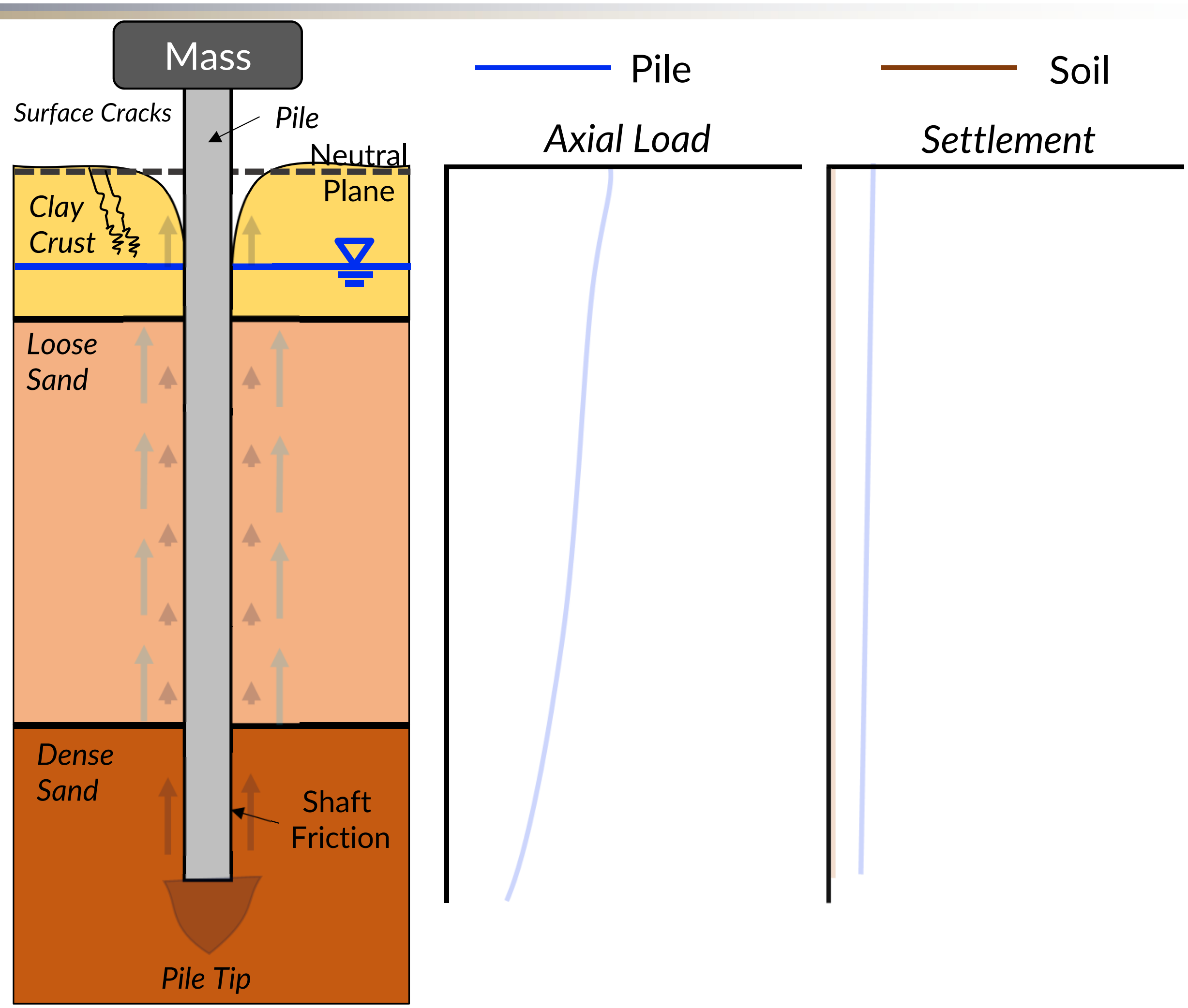

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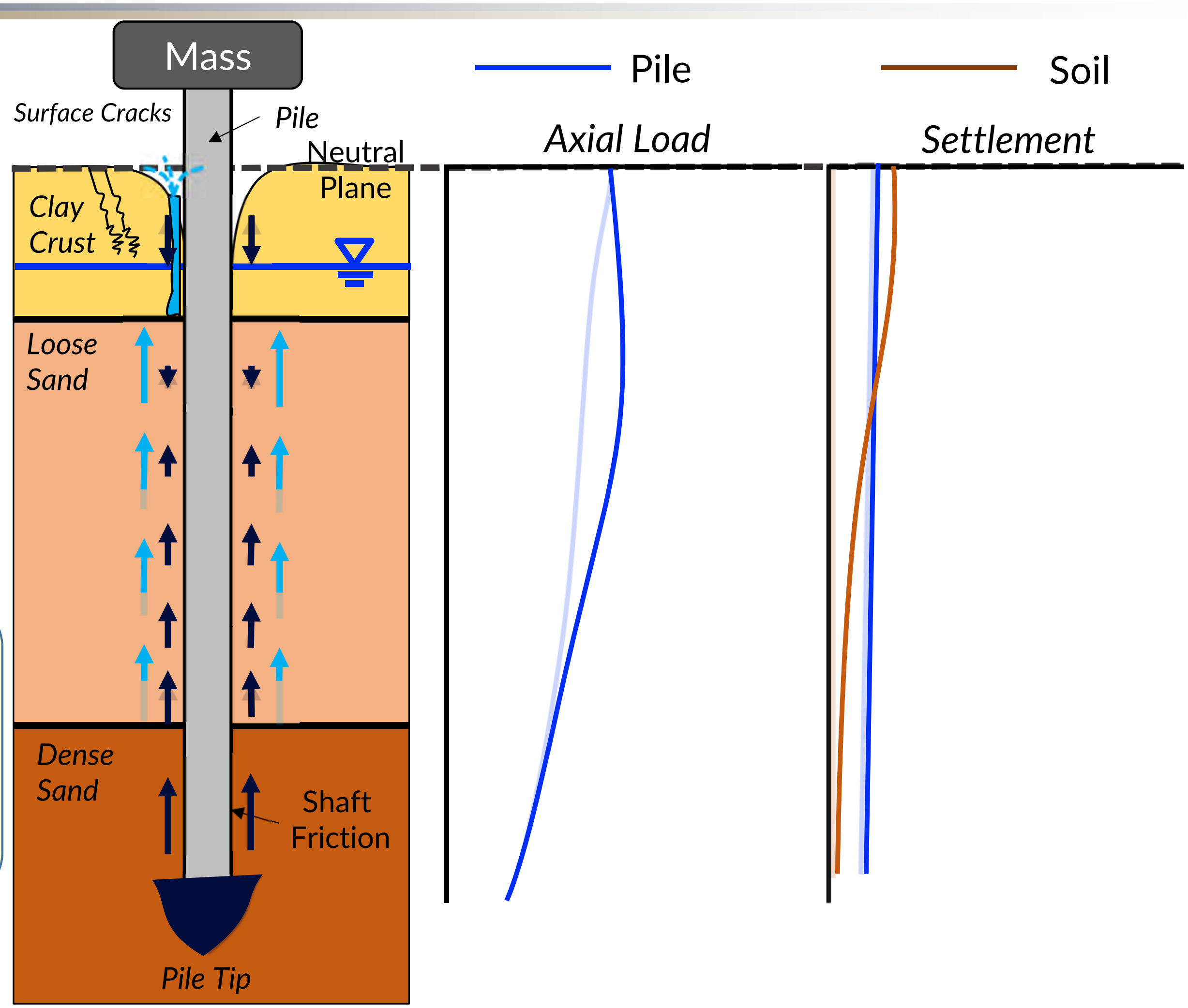
  - skin friction reduces a lot in the liquefiable layer
- **Reconsolidation:** onset
  - excess pore-pressure starts to dissipate
  - skin friction in liquefied layer starts to develop
  - onset of settlement in soil



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  - *excess pore-pressure starts to dissipate*
  - *skin friction in liquefied layer starts to develop*
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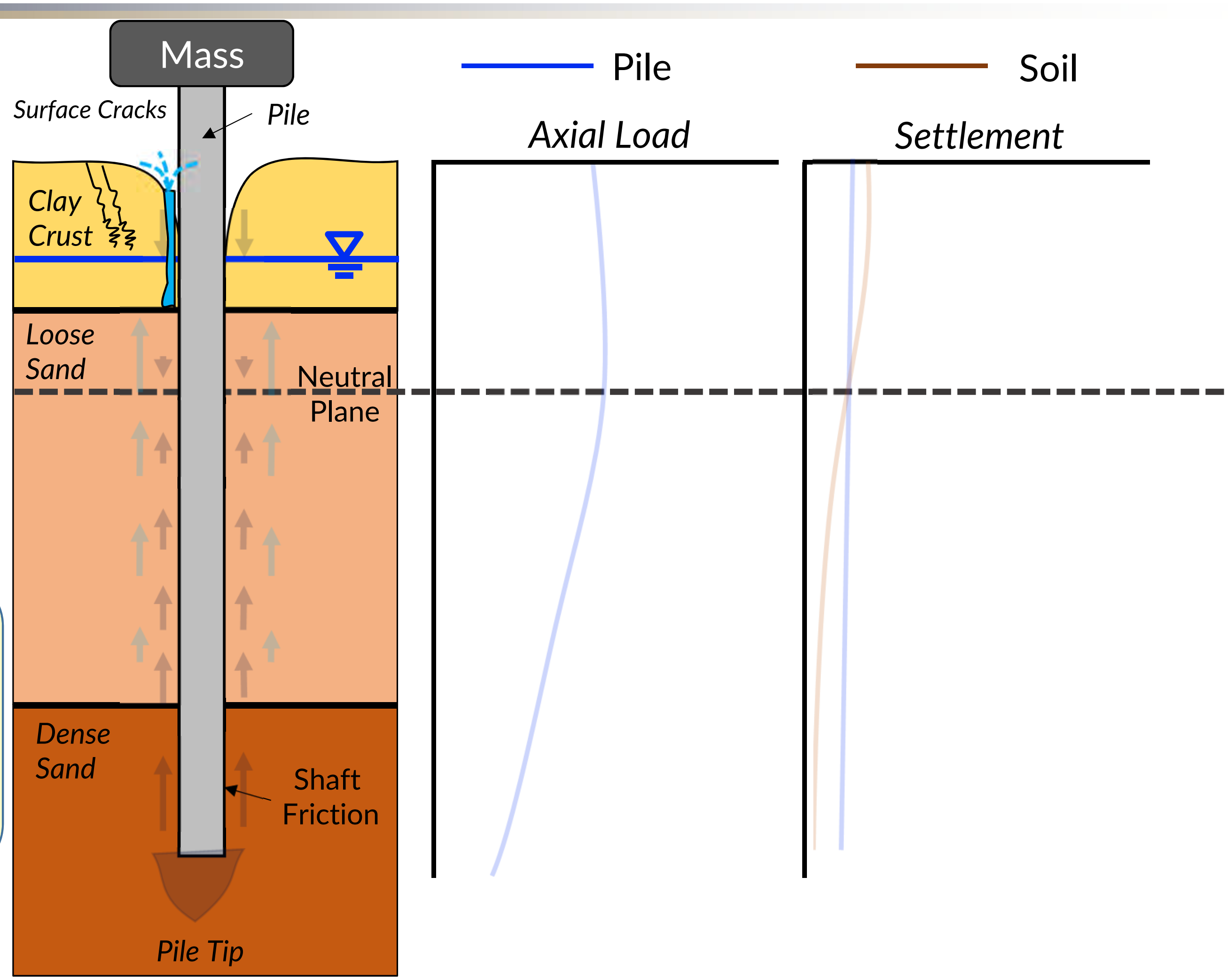

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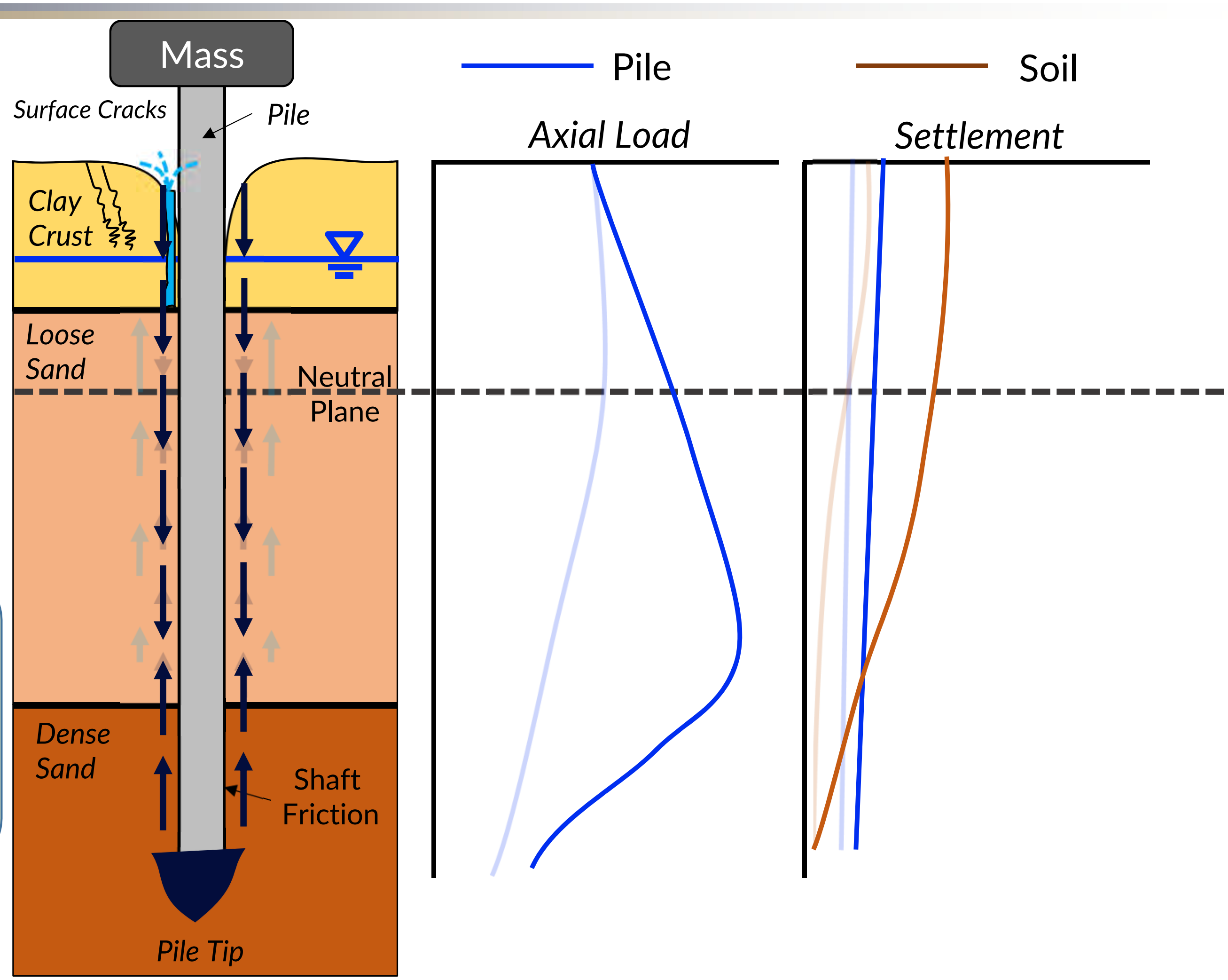
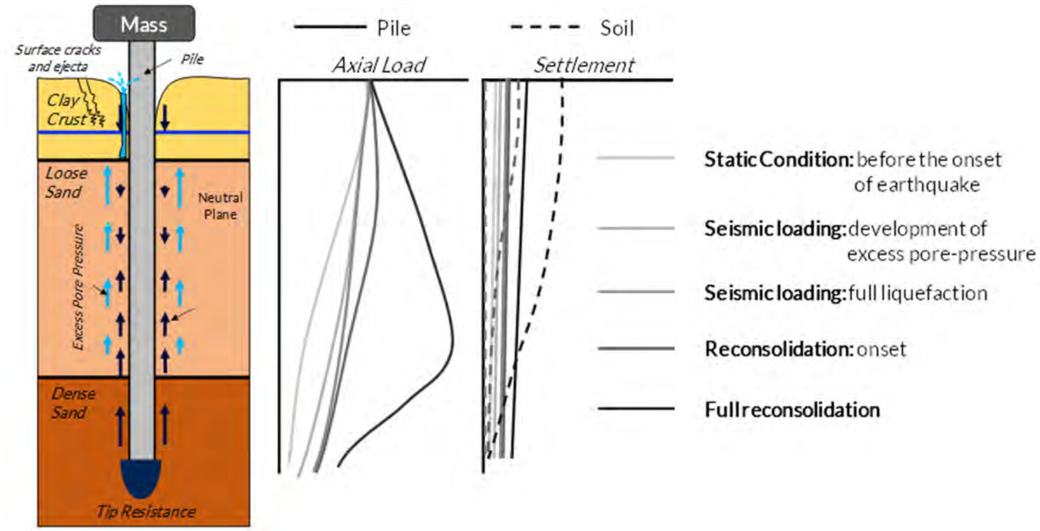
- ***Static Condition:*** *before onset of earthquake*
  - *resistance offered by full* ***skin friction*** *and* ***pile tip***
- ***Seismic Loading:*** *full liquefaction*
  - *excess pore-pressure (r_u = 1) in the liquefiable layer*
  - *skin friction reduces a lot in the liquefiable layer*
- ***Reconsolidation:*** *full*
  - *all excess pore-pressure dissipated*
  - *skin friction in liquefied layer developed*
  - *settlement in soil*



Factors Affecting Downdrag in Liquefied Soils

- *Soil profile and pile tip conditions*
- *Liquefied soil thickness and depth*
- *Excess pore–pressure generation/dissipation*
- *Shaft and tip resistance*
- *Interface gaps and ejecta*



Q) How do these mechanisms and their sequencing play role in the development of downdrag during post liquefaction reconsolidation?

Q) How much is the drag load ?

Q) How much would be the tip settlement ?

Designing the Experiment

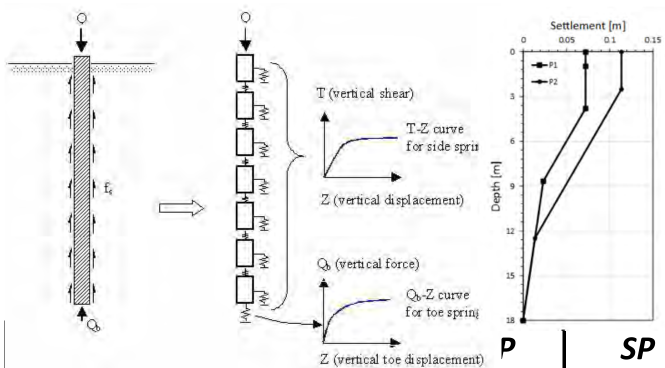
- *Depth of liquefiable layer*
  - *theoretically, no limit*
  - *generally, <25-30m*
- *Typical soil profile*
  - *2-3 m weathered clay crust*
  - *12-15m poorly graded loose sand (interbedded with silt or clay)*
  - *15-30m medium/dense soil or high OCR clay*
  - *>30m rock conglomerate, weathered rock or intact rock*
- *Typical pipe pile properties in bridge design*
  - *diameter*
    - *average ~0.70 m (L/D~25-30)*
    - *short >1.4 m (L/D~10-15)*
    - *slender ~0.35 m (L/D>50)*
  - *length: ~20-25 m*
  - *thickness: 10-20 mm*
- *Static loads on piles*
  - *200-500 kN for medium piles*
  - *higher for longer piles*
- *Floating/rigid tip condition*

Q) What soil profile?

Q) What type of pile?

Q) How much load at pile head?

TZPILE2004 (ENSOFT Inc) Analysis



...a' [...n³]	C [kPa]	Factor α	K	δ_r [°]	Nq
	20	0.4			
			0.8	30	20
			0.8	30	40

		P	SP
Length [m]	18	18	18
Outer Dia [m]	1.45	0.73	0.36
Thickness [mm]	63	34	34
E [GPa]	68	68	68
Density [kg/m³]	2700	2700	2700
L/D	12	25	50
Inner Dia [m]	1.324	0.662	0.292
Area [m²]	0.27	0.07	0.03

Liquefiable layer thickness

- 4m , 8m and 12m

Settlement Profile

Reconsolidation Strain	
Liquefiable Layer	Dense Layer
1%	0%
1%	0.25%
2%	0%
2%	0.1%
No Downdrag → 0%	0%

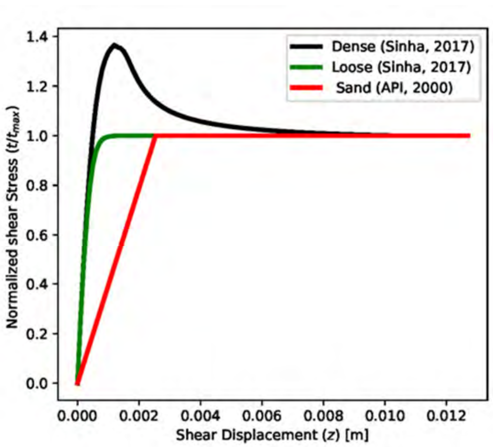
Two end bearing conditions

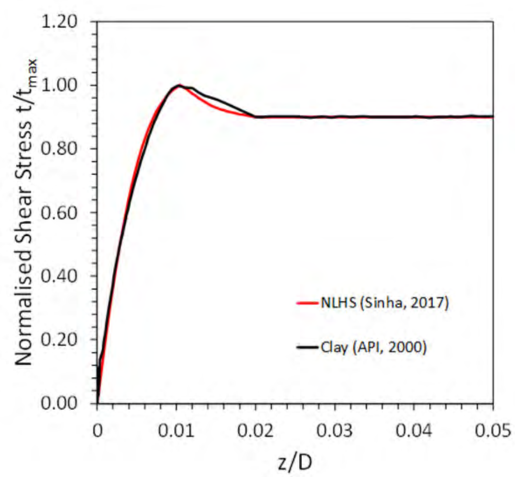
- **Case R:** Pile resting on rock or rigid stratum
- **Case F:** A floating pile resting in dense soil

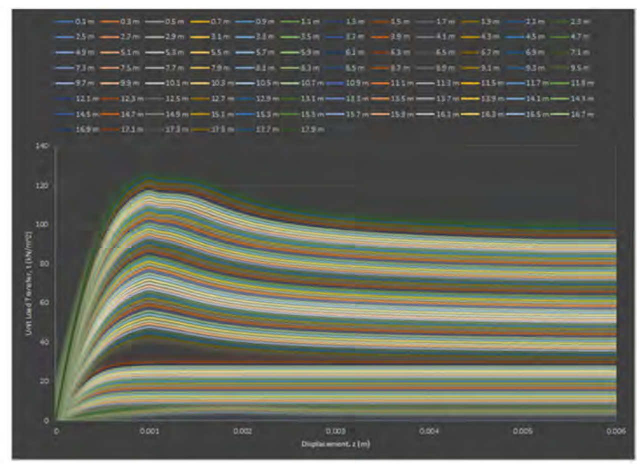
T-z curve

- ***For clays***
  - *(API, 2000) : residual strength factor of 0.8*

- ***For sands***
  - *(API, 2000): considers a perfectly elastic-plastic curve*
  - *Sands also show peak and residual strength (Uesugi and Kishida, 1986)*
  - *Non-linear hardening softening model (Sinha, 2017).*
    - *interface friction angle (δ_r=30^o) i.e. a normalized shear strength of 0.57*

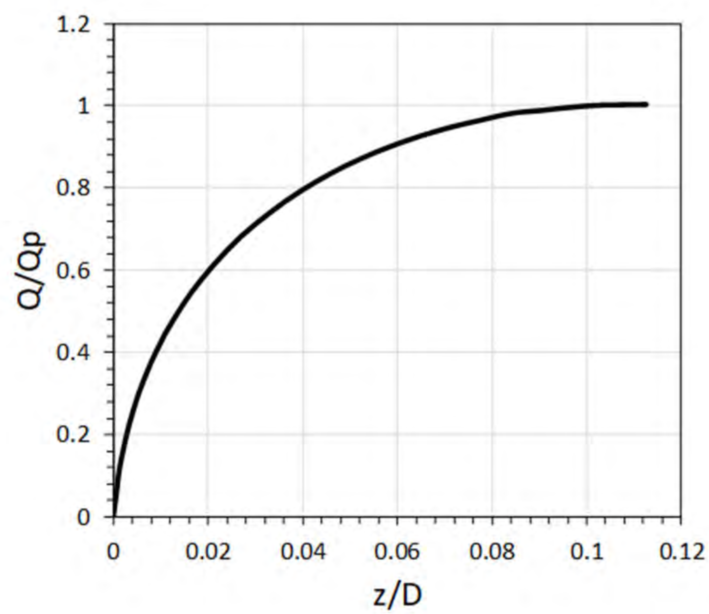






Q-z curve

- *(API, 2000)*
  - ***Rigid tip condition*** *(like the base of the centrifuge model container)*
    - *Nq = 50000*
    - *The neutral plane remains at the tip of the pile*
  - ***Floating tip condition*** *(dense sand)*
    - *Nq = 40*

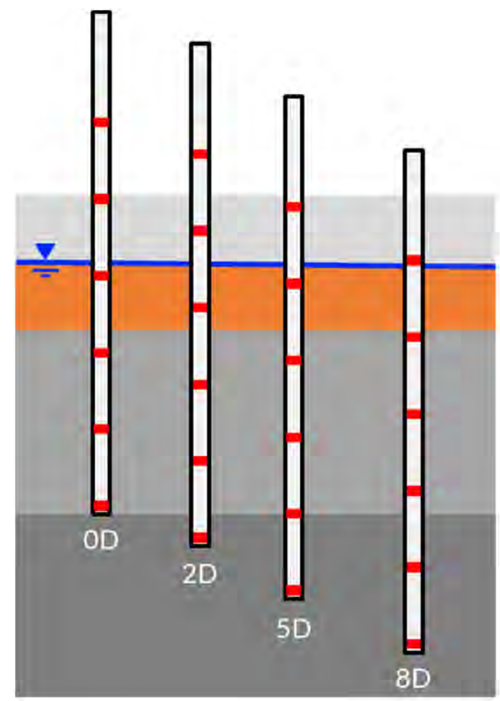


Pile Design and Properties

- ***Prototype dimensions*** *material: Steel*
  - *outer diameter : 0.635 m (~25 in)*
  - *thickness: 11mm*

- ***Model pile dimensions*** *(@ 40g level)*
  - *material : Aluminum*
  - *outer diameter (D) : 0.625 in (~15.8 mm)*
  - *thickness : 0.035 in (~0.9mm)*
  - *inner diameter: 0.555 in (~14.1 mm)*
  - *length: 70 cm*

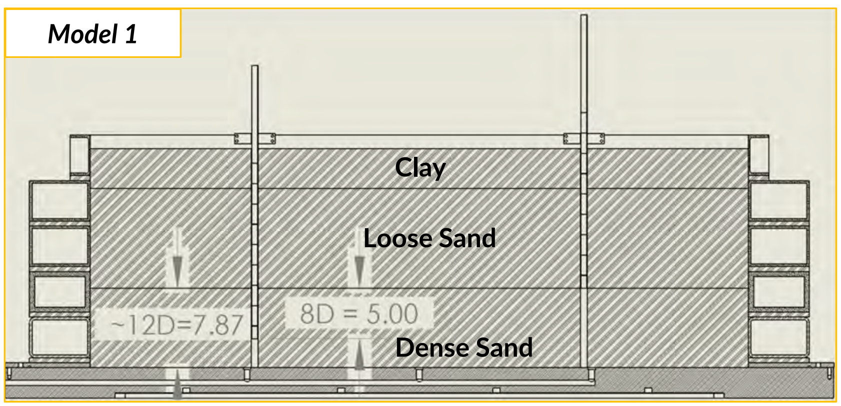
- ***Centrifuge model***
  - *soil profile depth: ~55 cm*
  - *embedment's in dense soil @ depth of 0.35 m (14 m prototype scale)*
    - *0 D: tip resting on boundary of liquefiable and dense sand*
    - *2-8D: tip resting in dense sand*

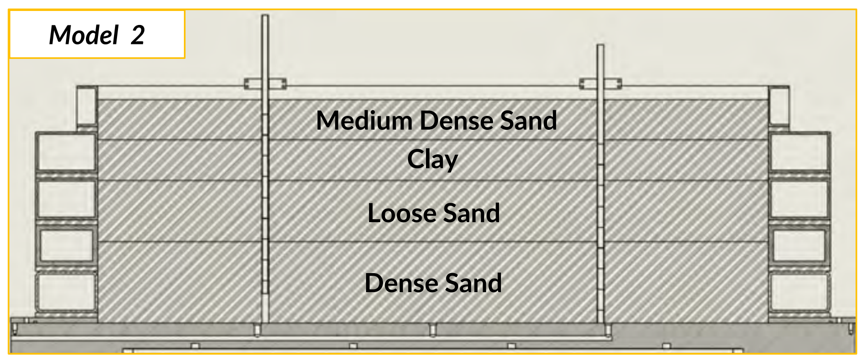


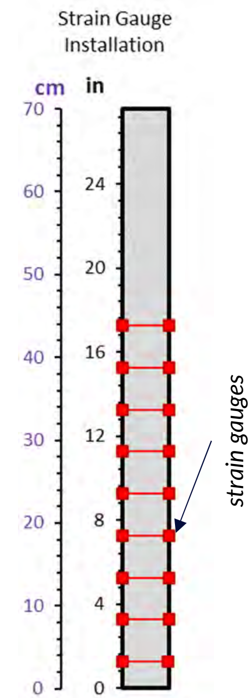
Model Pile Strain Gauge Installation

- ***Pile dimensions***
  - *material : Aluminum*
  - *length : 27.56 in (~70 cm)*
  - *outer diameter (D) : 0.625 in (~15.8 mm)*
  - *thickness : 0.035 in (~0.9mm)*
  - *inner diameter: 0.555 in (~14.1 mm)*

- ***Strain gauge installation***
  - *spacing : 2 in (~5 cm)*
  - *start from bottom : 2 D ~1.25 in*
  - *total gauges: 9*



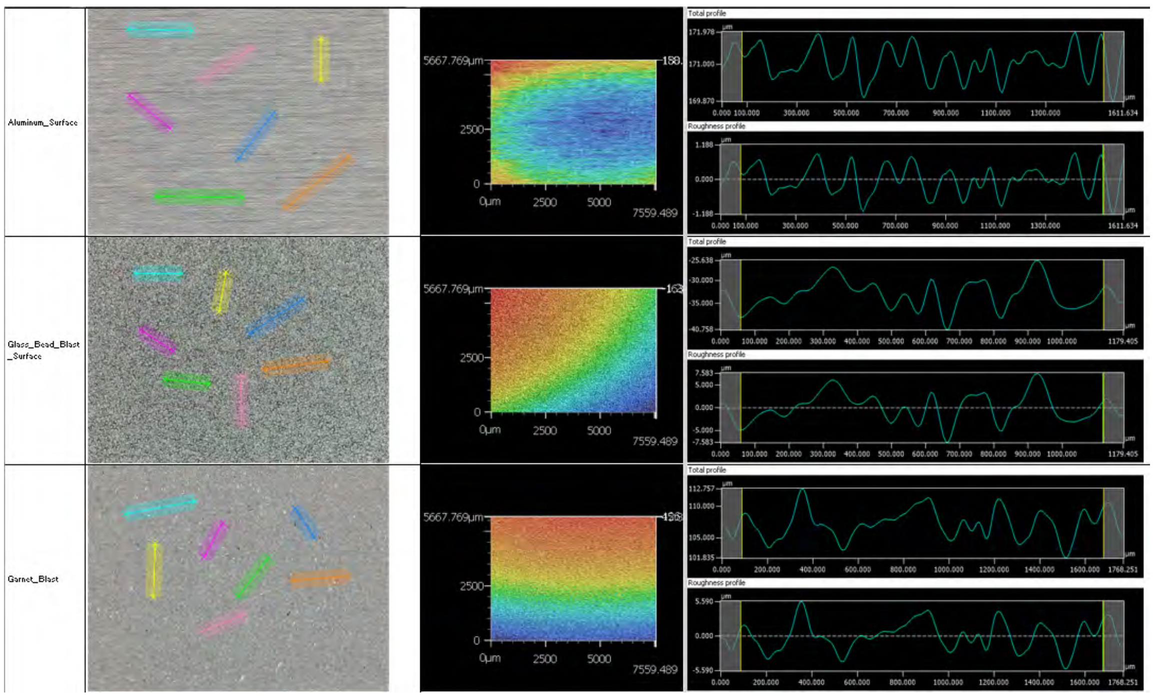




Location of strain gauges for tip embedment of 0D, 8D and at base of the model

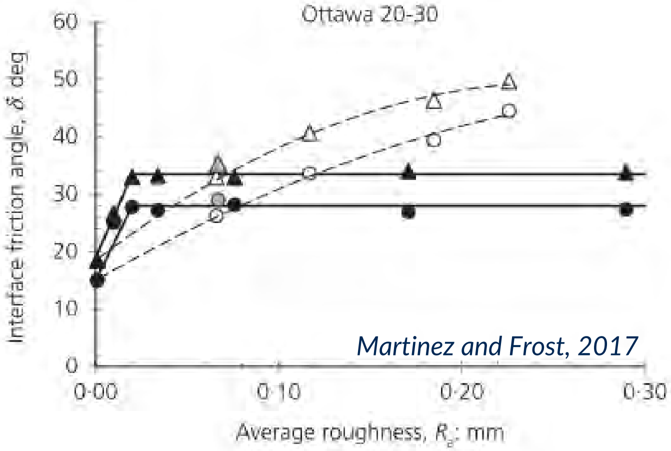
Designing Interface on Pile

- ***Sand blasting at UC Davis***
  - *glass beads*
    - *different sizes available (45-600 μm)*
  - *garnet*
    - *sizes available (Grade 30/60 mesh ≈ 250-500 μm*

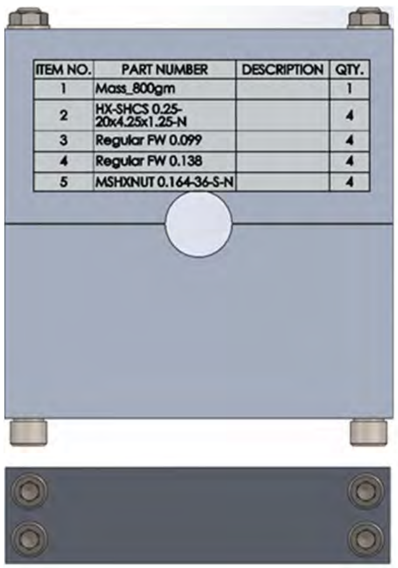


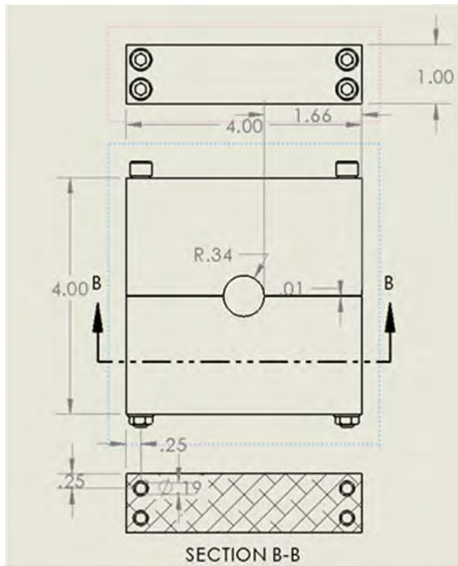
Glass Bead

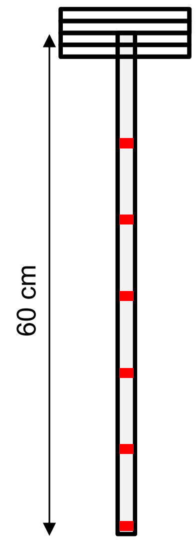
Garnet

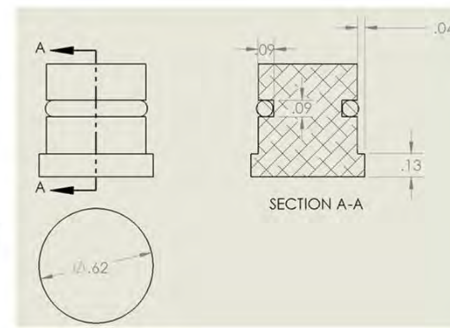


Design of pile head and base



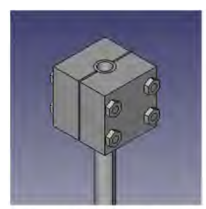






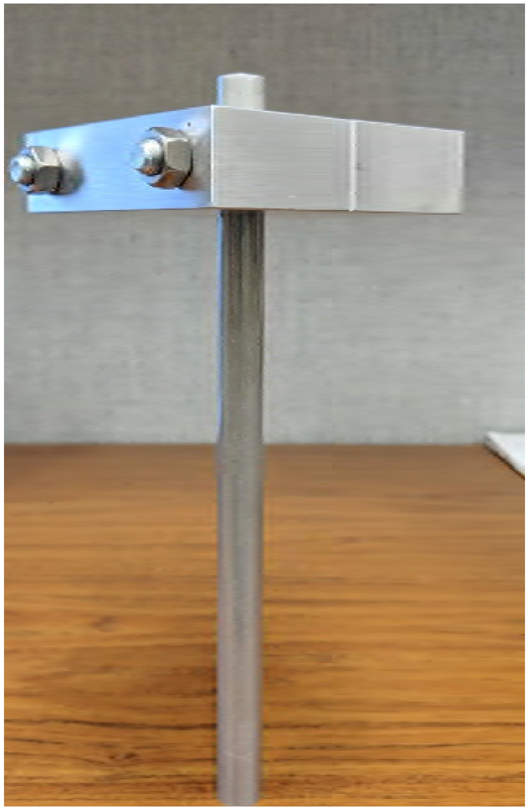
Pile Tip Cap [O-Seal]

Pile Head Load [800 gm]



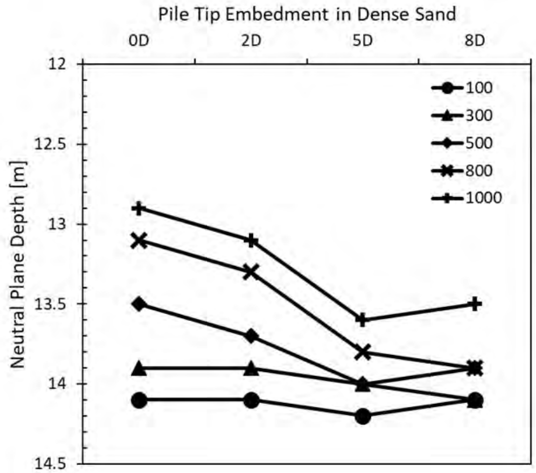
Clamping mechanism used in past centrifuge models (Zheng and Kutter, 2015)

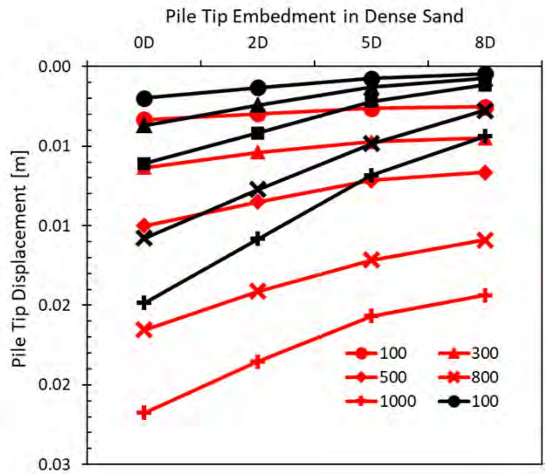
Model Pile Strain Gauge Installation



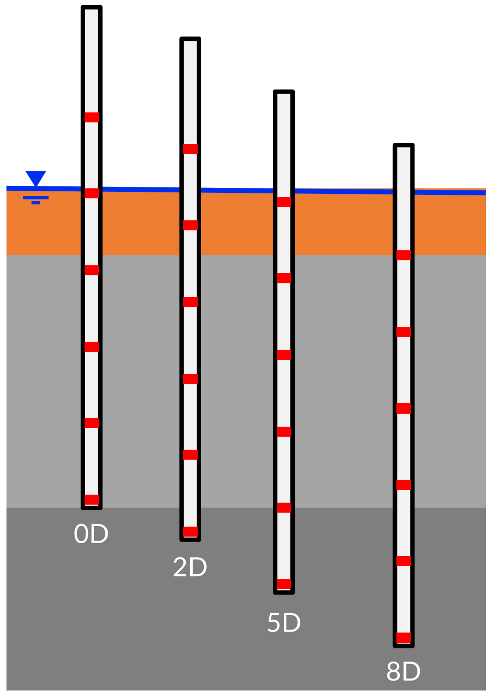
versus

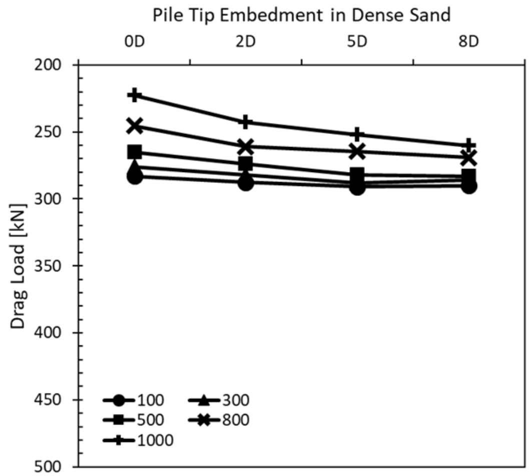
Response of Pile : Design Profile 1





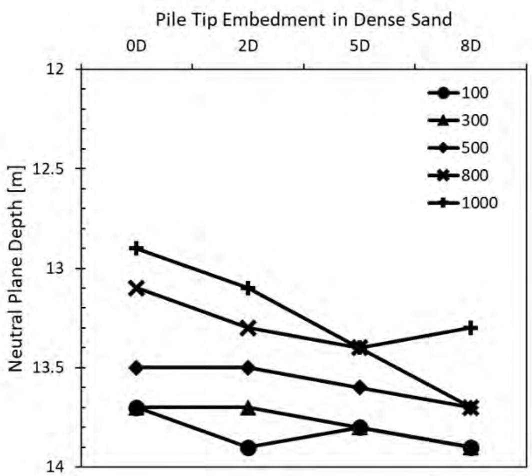
	Soil Profile 1
Crust	4
Loose Sand	10.00
Dense Sand	8.00

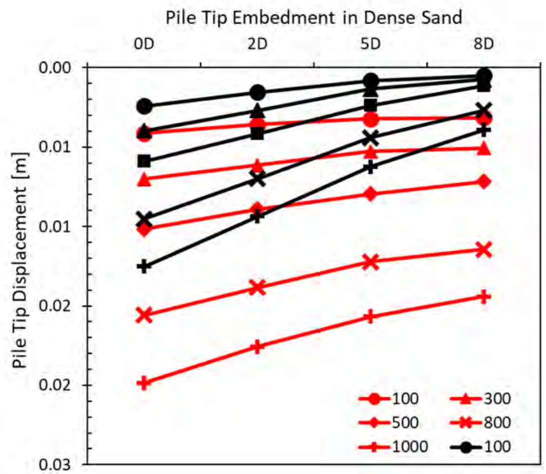


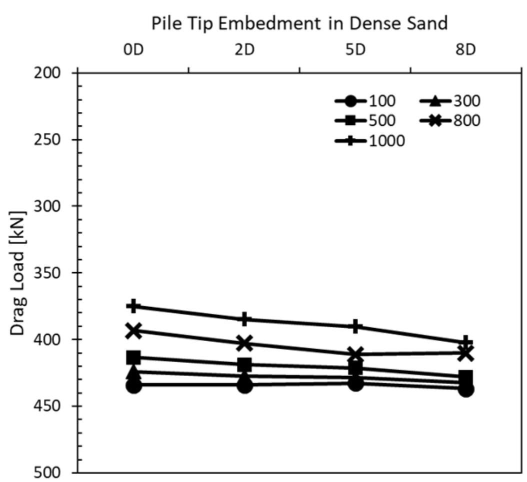


1% reconsolidation strain in loose sand

Response of Pile : Design Profile 2

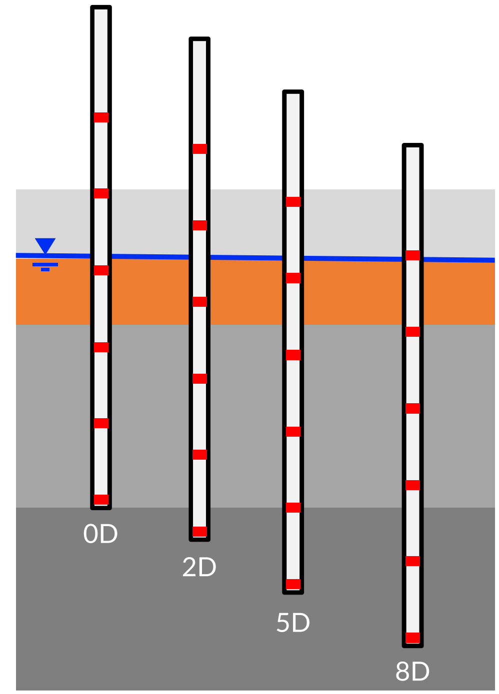




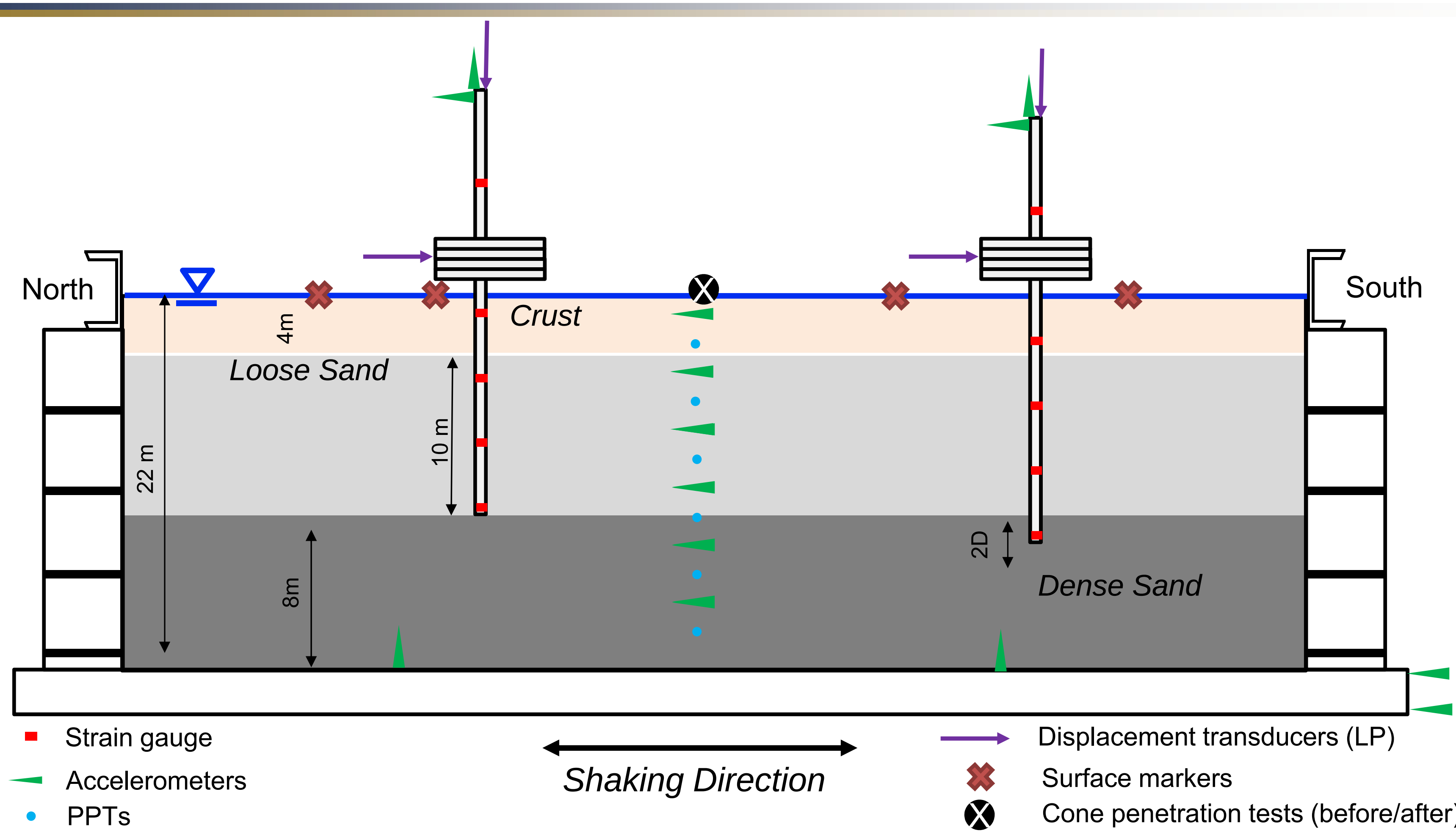


1% reconsolidation strain in loose sand

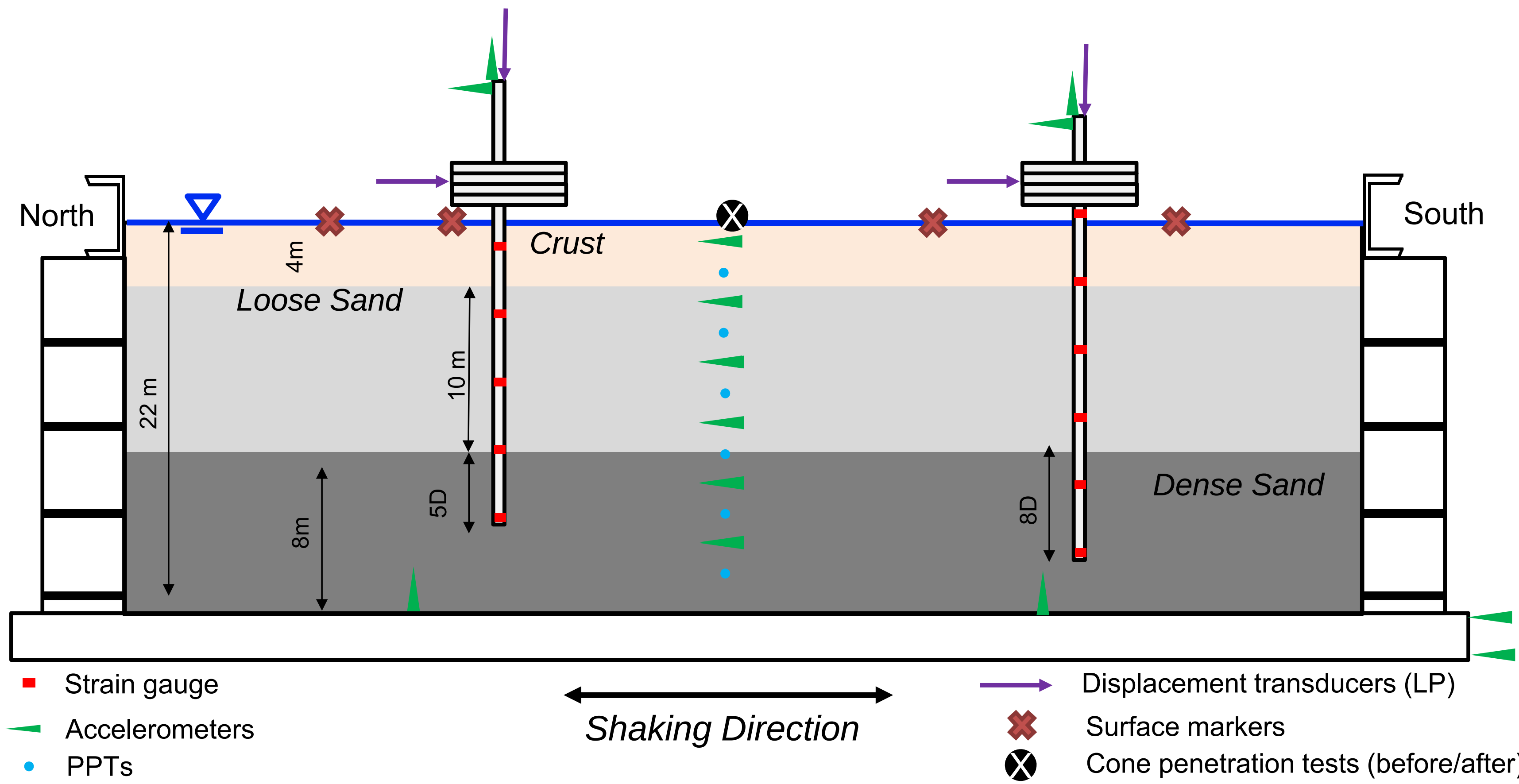
	Soil Profile 2
Coarse Medium Dense Sand	4
Crust	4
Loose Sand	6.00
Dense Sand	8.00



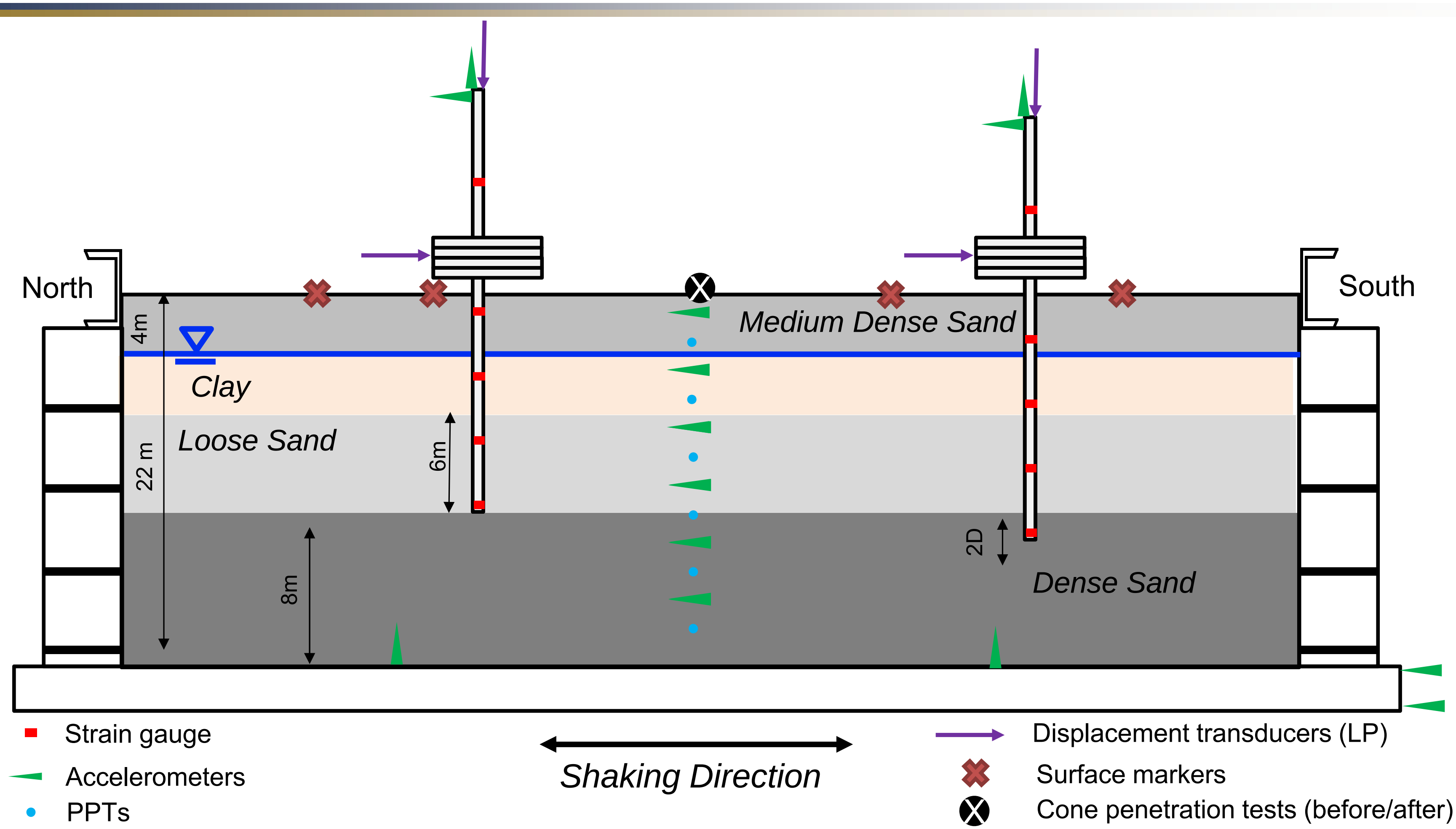
Preliminary Container 1 Spin 1



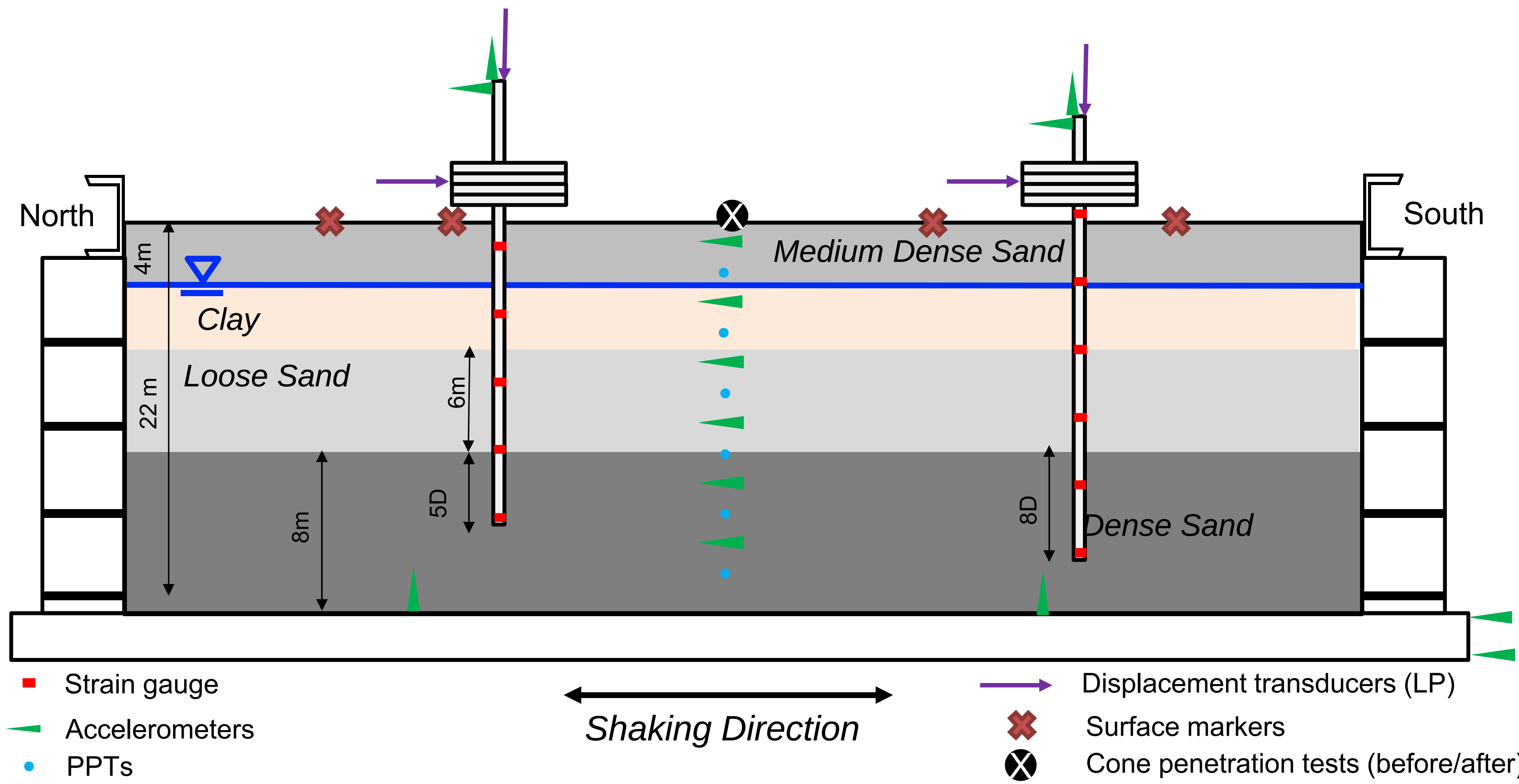
Preliminary Container 1 Spin 2



Preliminary Container 2 Spin 1



Preliminary Container 2 Spin 2



Summary

Summary III

- *Know what your objective is: the most important parameter, mechanism, or measurement and design the test accordingly.*
- *Do not think about what is available and what you can do with that.*
- *When proposing, remember the difference between conceptual designs and final designs. Include some contingency funds and time.*
- *Run preliminary analyses and make sure that your test will be able to replicate the features you are after.*
- *Be prepared for surprises!*

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Questions are welcome.

Thank you for your interest.