# Effect of Proximity of Sheet Pile Walls on the Apparent Capacity of Driven Displacement Piles (BDV31 TWO 977-26)


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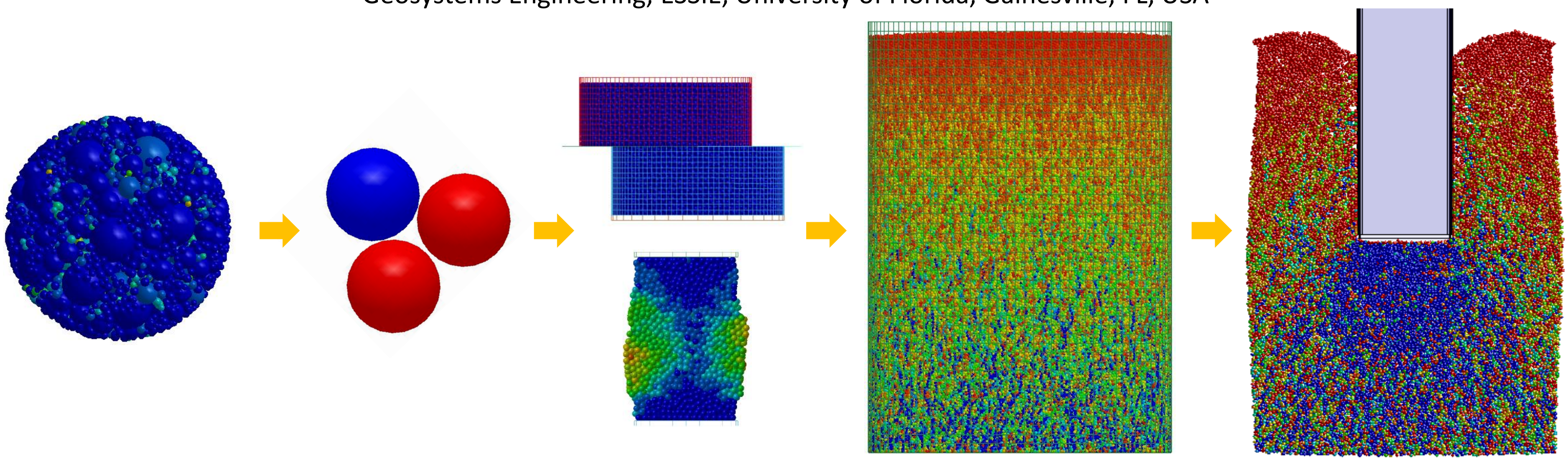

2016 Geotechnical Research in Progress (GRIP) Meeting
Gainesville, Florida
July 15, 2016

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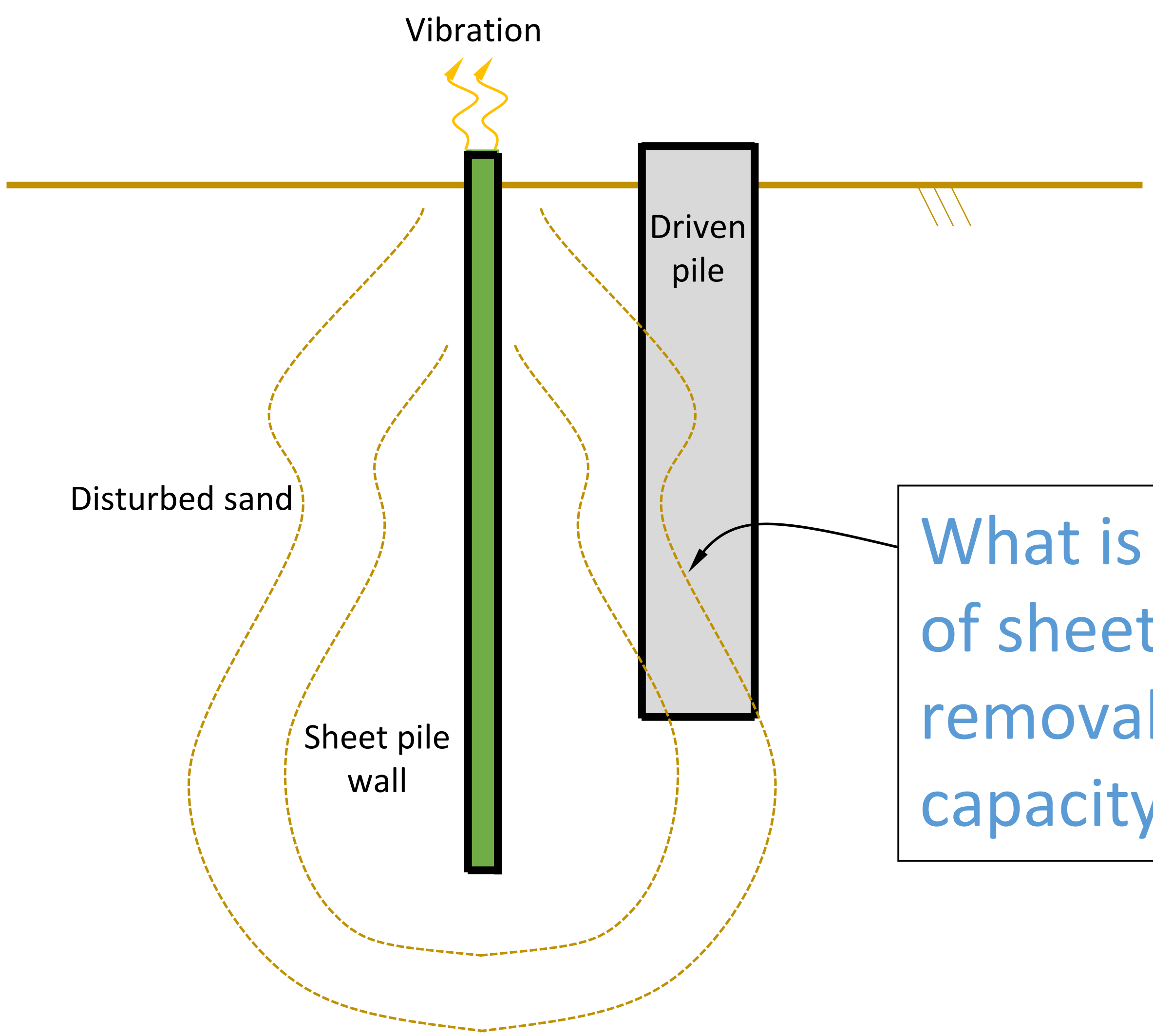
# Agenda

- Introduction
- Task 3 Activities
- Progress on Remaining Task 3 items
- Progress and Planning on Task 4

# Introduction

- Effect of Sheet Pile Walls in the Vicinity of Driven Piles




What is the effect of sheet pile wall removal on pile capacity?

# Introduction: Project Approach

- Identify design-relevant parameters for calculating pile capacities in the vicinity of SPWs
- Develop design charts and/or tabularized matrices for use in calculation of pile-capacity changes
- Methodology:
  - Combined Discrete (soil) and Finite (pile and sheet pile wall) Element Analysis
  - Spectrum of model validation (laboratory and centrifuge testing)

# Introduction: Project Approach

- **Phase I (12 months; July 2014 - June 2015)**
- Task 1. Literature Review, Scenario Identification, and Field-Data Acquisition
- Task 2. Numerical Modeling Schemes and Granular Soil Units

- **Phase II (18 months; July 2015 - December 2016)**
- Task 3. Numerical Modeling of Driven foundation in Granular Soils
- Task 4. Physical Laboratory/Centrifuge Experimentation
- Task 5. Reporting of Findings and Design-Oriented Recommendations
- Task 6. Final Report

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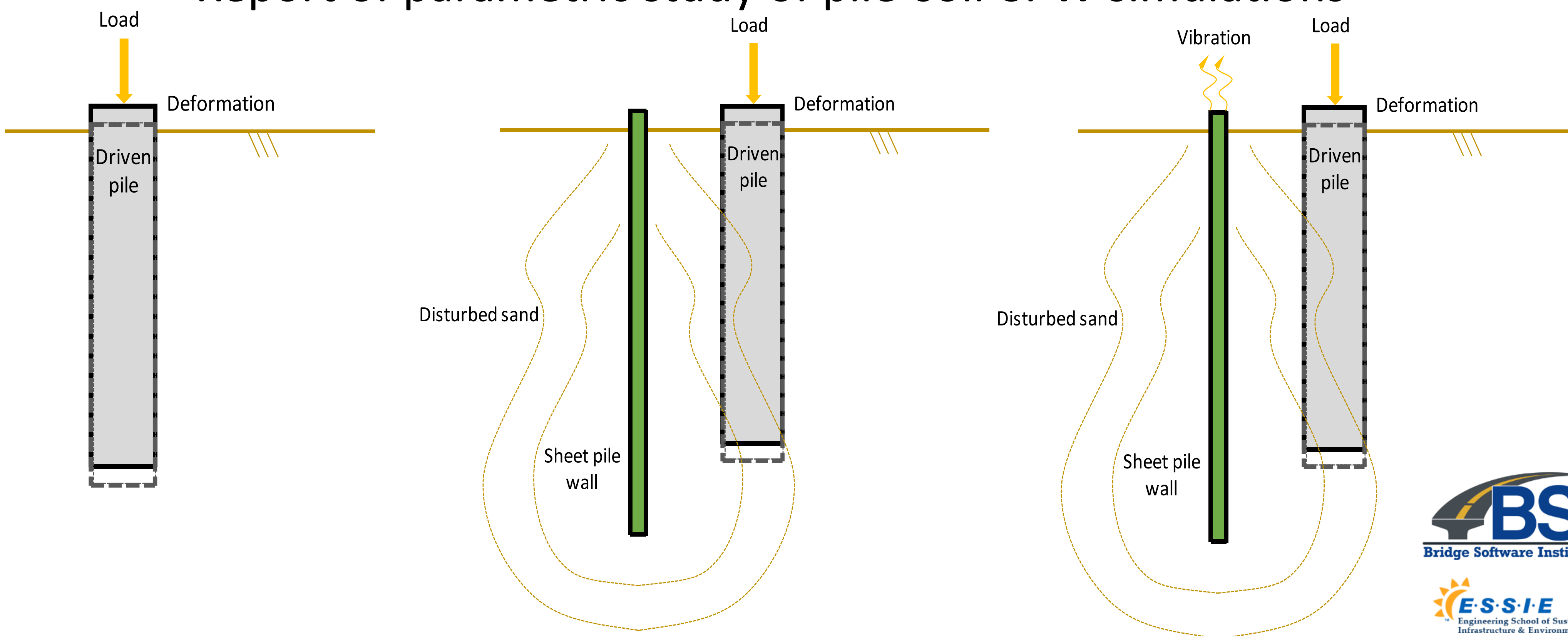
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- **Deliverables**
  - Development of a driven pile model
  - Development of a pile and pre-driven SPW model (no removal)
  - Development of a pile and pre-driven SPW model (w/ removal)
  - Report of parametric study of pile-soil-SPW simulations

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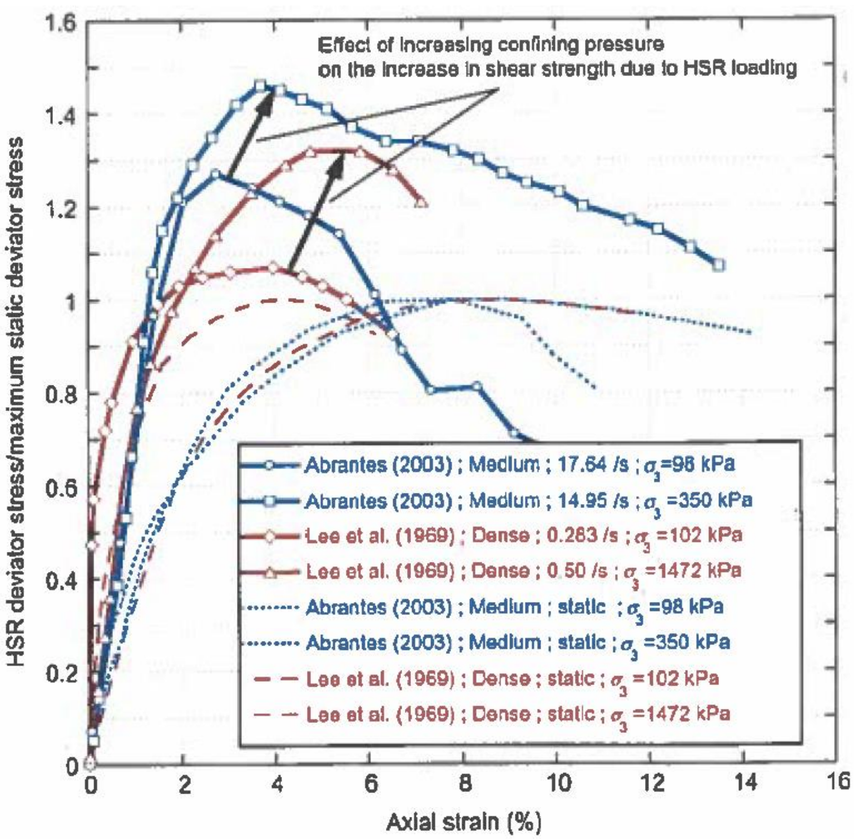
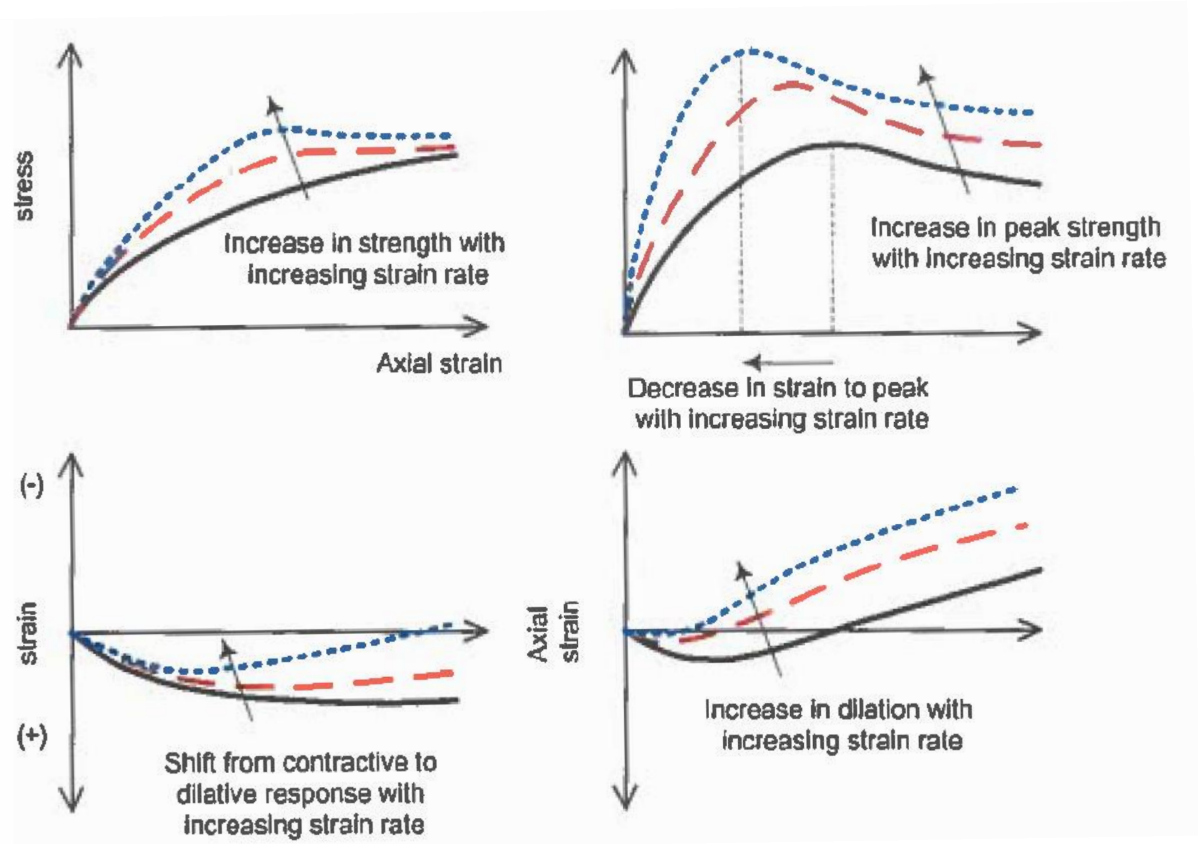
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- High Strain Rate (HSR) Effects on stress-strain response and volumetric strains (from Iskander et al., 2015)




Interpretation based on literature data

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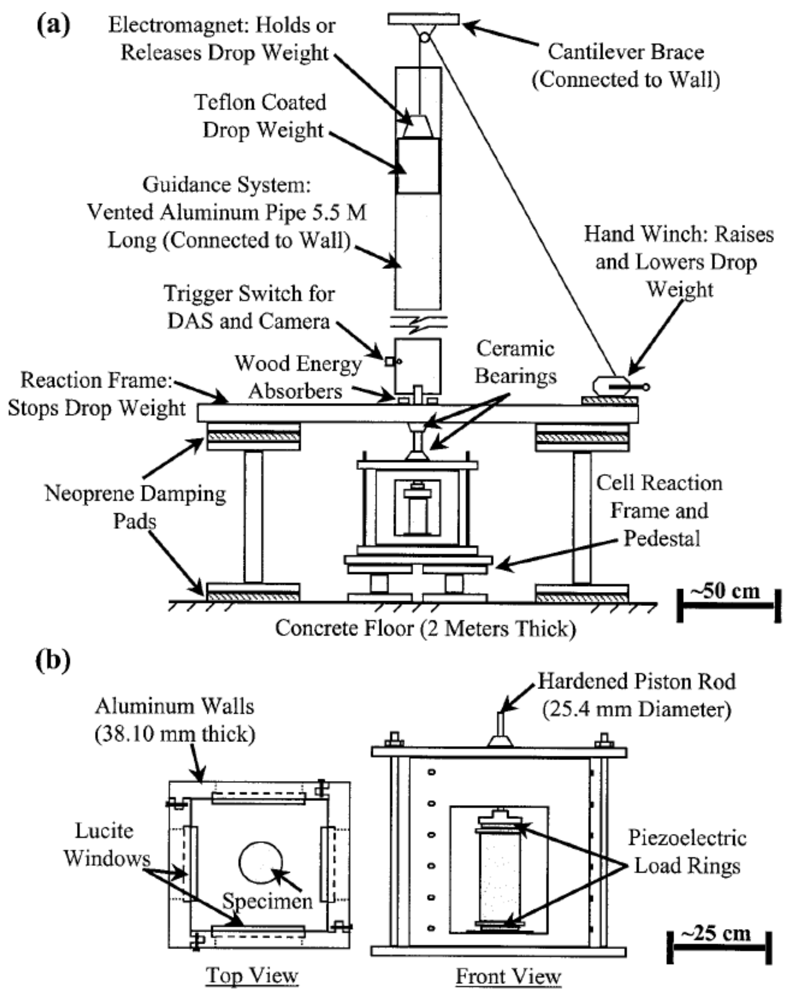
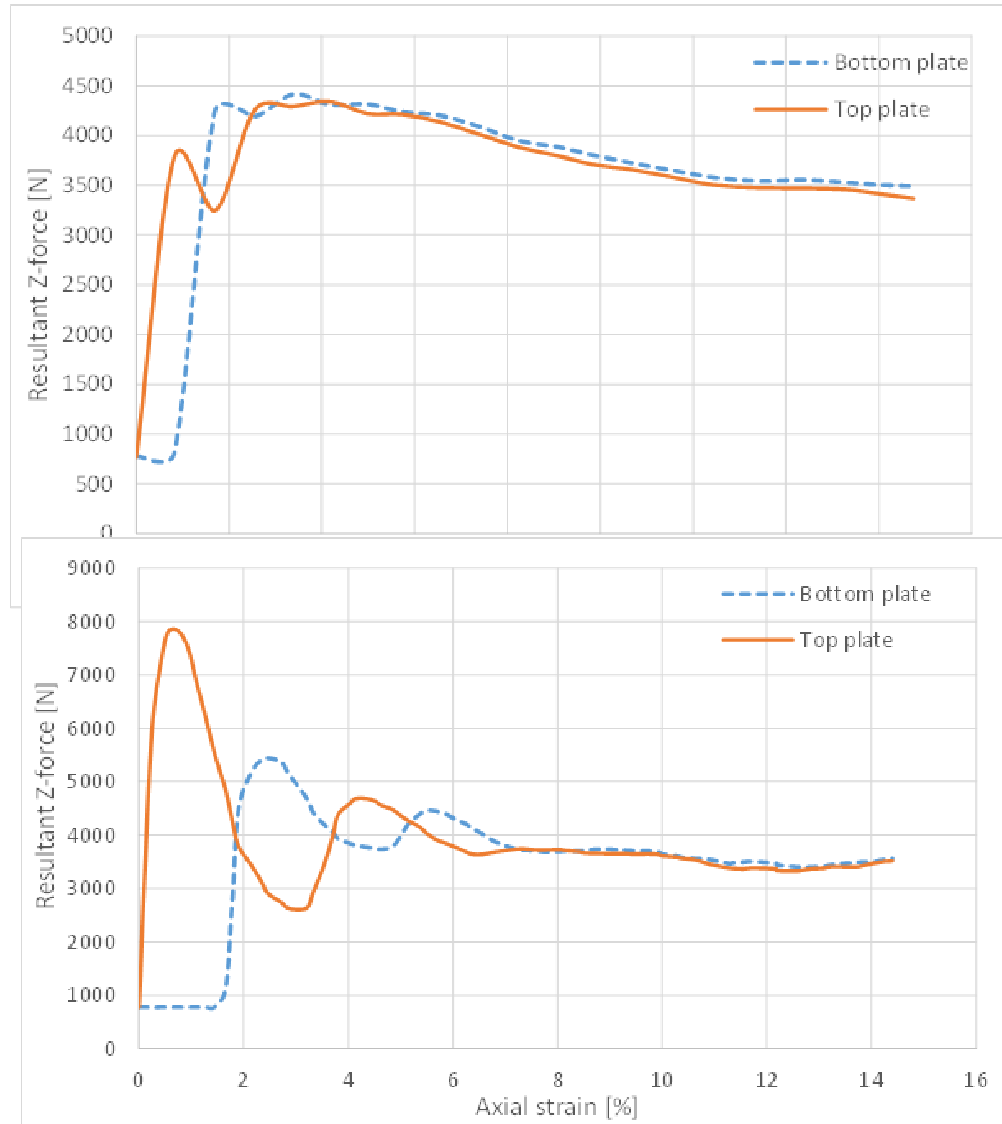
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- High Strain Rate (HSR) Loading Effects



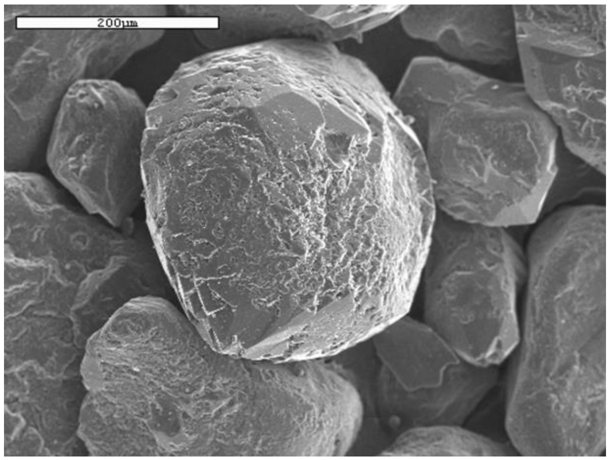

From Abrantes and Yamamoto (2002)

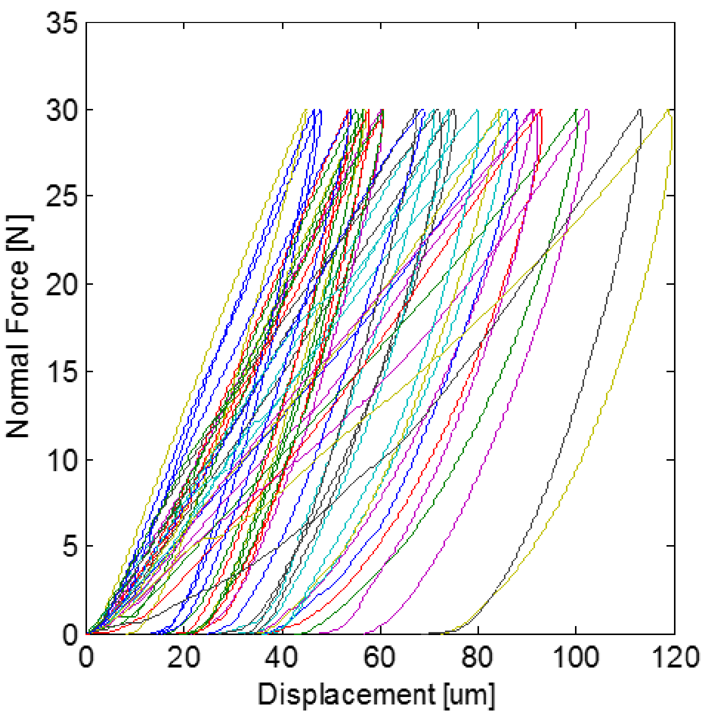


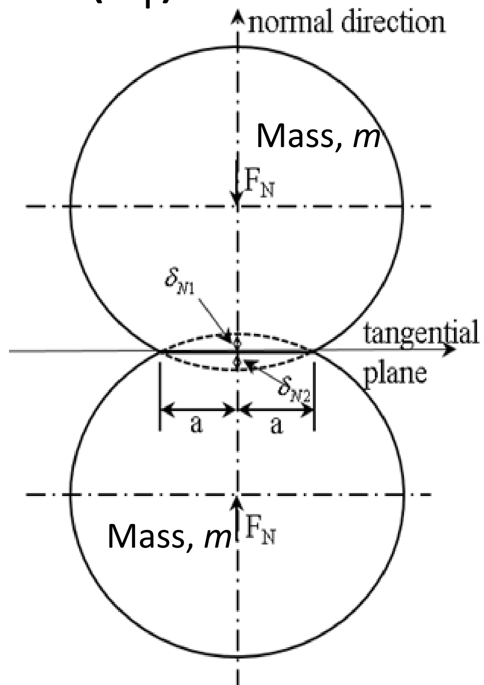

DEA prediction of Resultant loads

# Task 3. Numerical Modeling of Driven foundation in Granular Materials

Example: ratio of tangential ($k_T$) to normal ($k_N$) contact stiffness



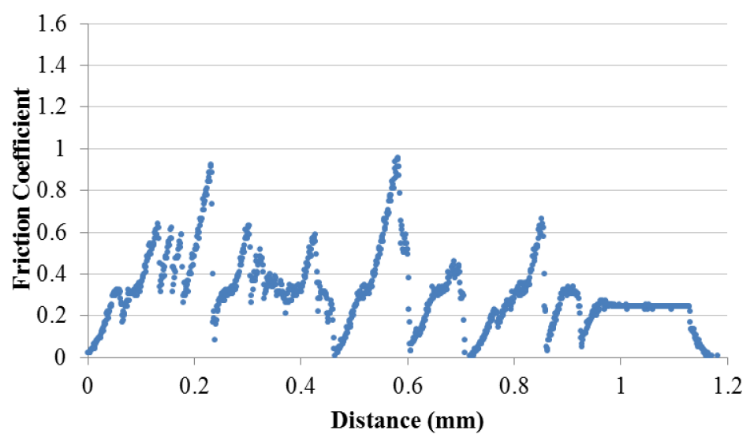



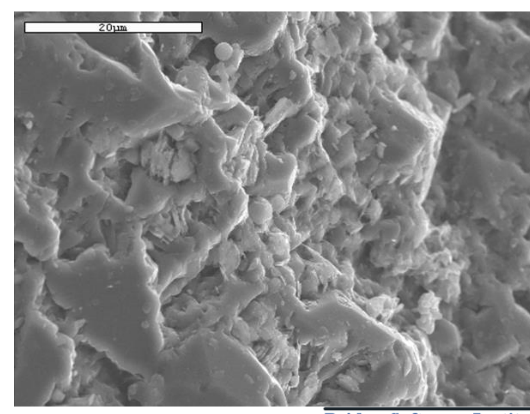

Two granules in contact

$$T_N = \frac{2\pi}{\sqrt{\dfrac{k_N}{(m/2)}}} \qquad T_T = \frac{2\pi}{\sqrt{\dfrac{\left(I_0 + mR^2\right)k_T}{(mI_0/2)}}}$$

Equate normal and tangential periods of vibration

$$\frac{k_T}{k_N} = \frac{I_0}{I_0 + mR^2} = \frac{2}{7}$$

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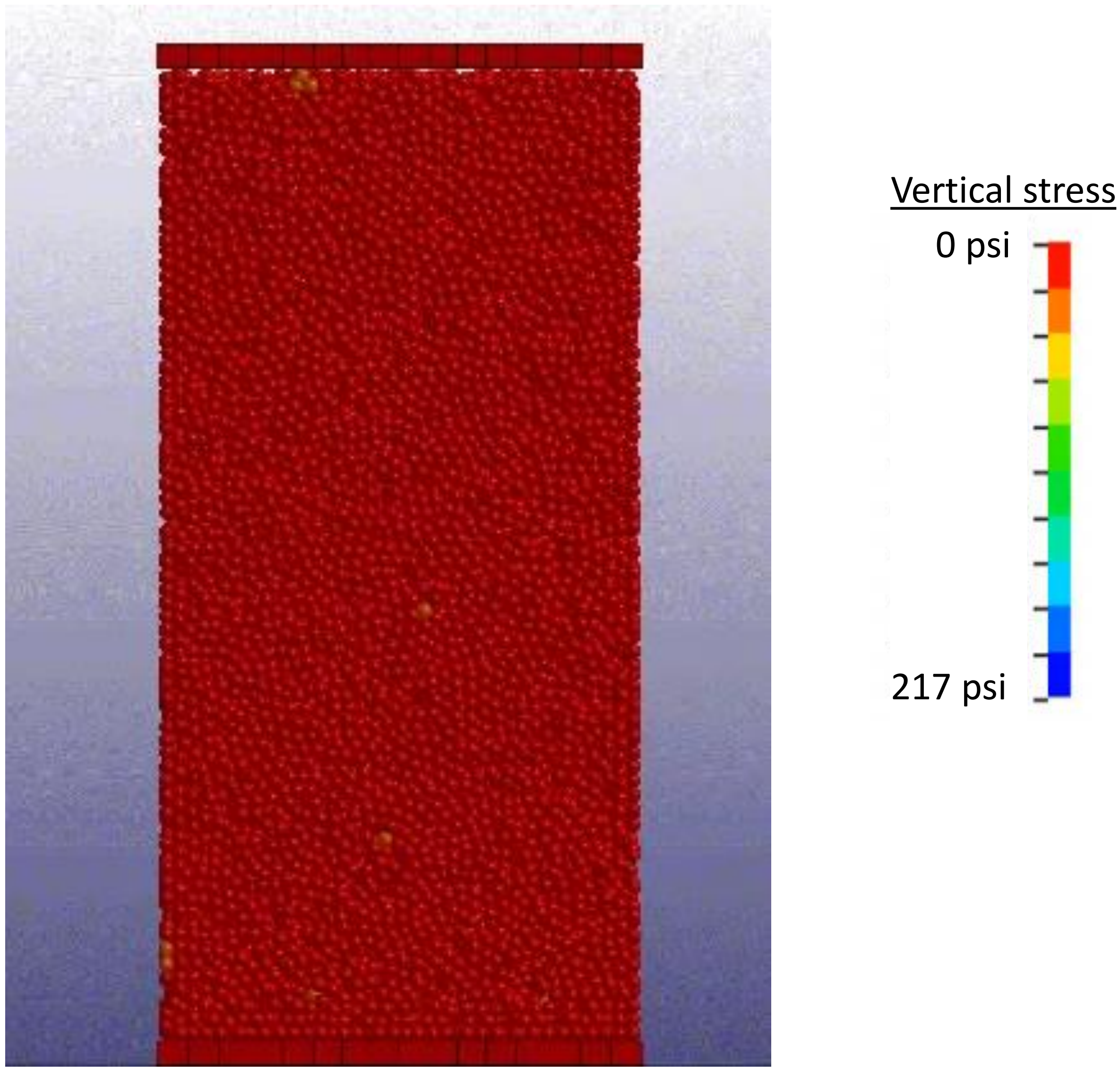
# Task 3. Numerical Modeling of Driven foundation in Granular Materials




High strain-rate triaxial compression test (900%/sec; 14.2 psi confinement)

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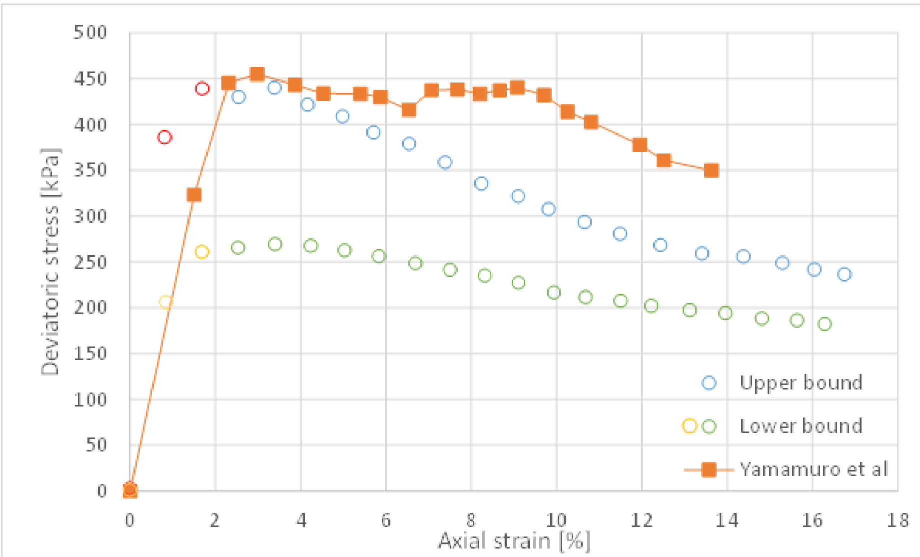
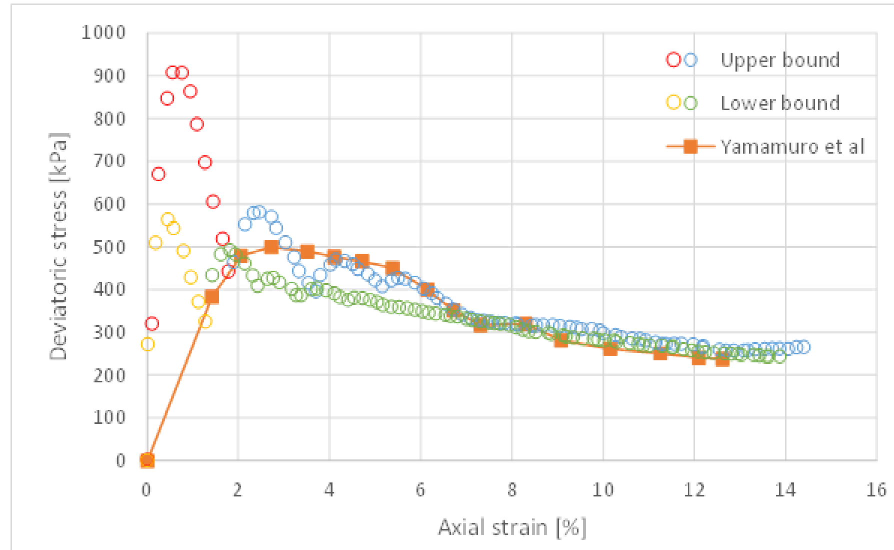
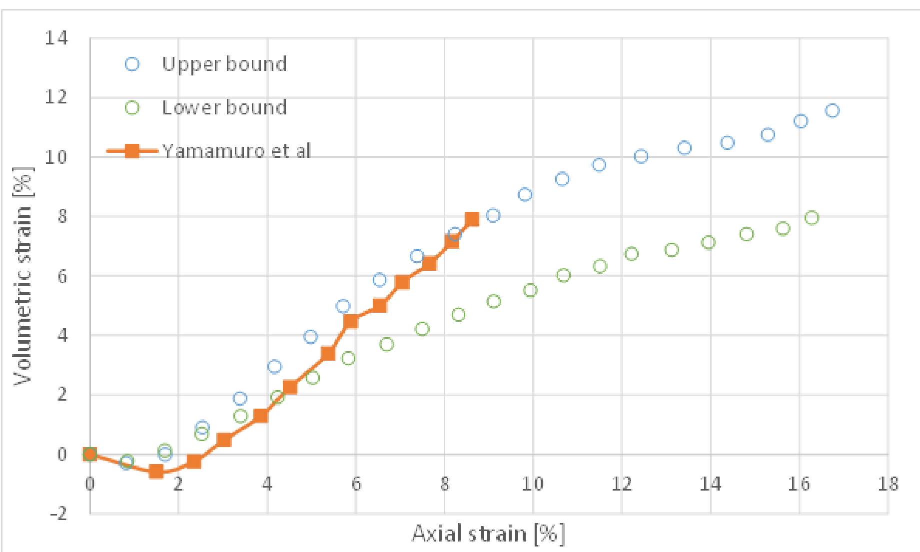
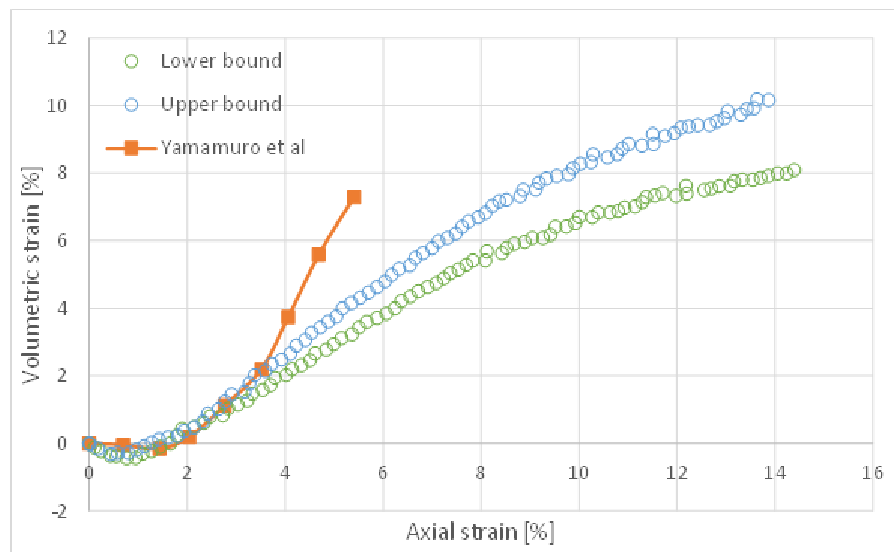
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Yamamuro et al. (2015) conducted HSR tests on crushed coral sand samples (Mean Dia. 0.32 mm, Dr = 58%, and Uniformity Coeff. =2.18) under confining stress of 14.2 psi, and subjected to applied impact loads equivalent to 900 – 1750 %/sec strain rates.

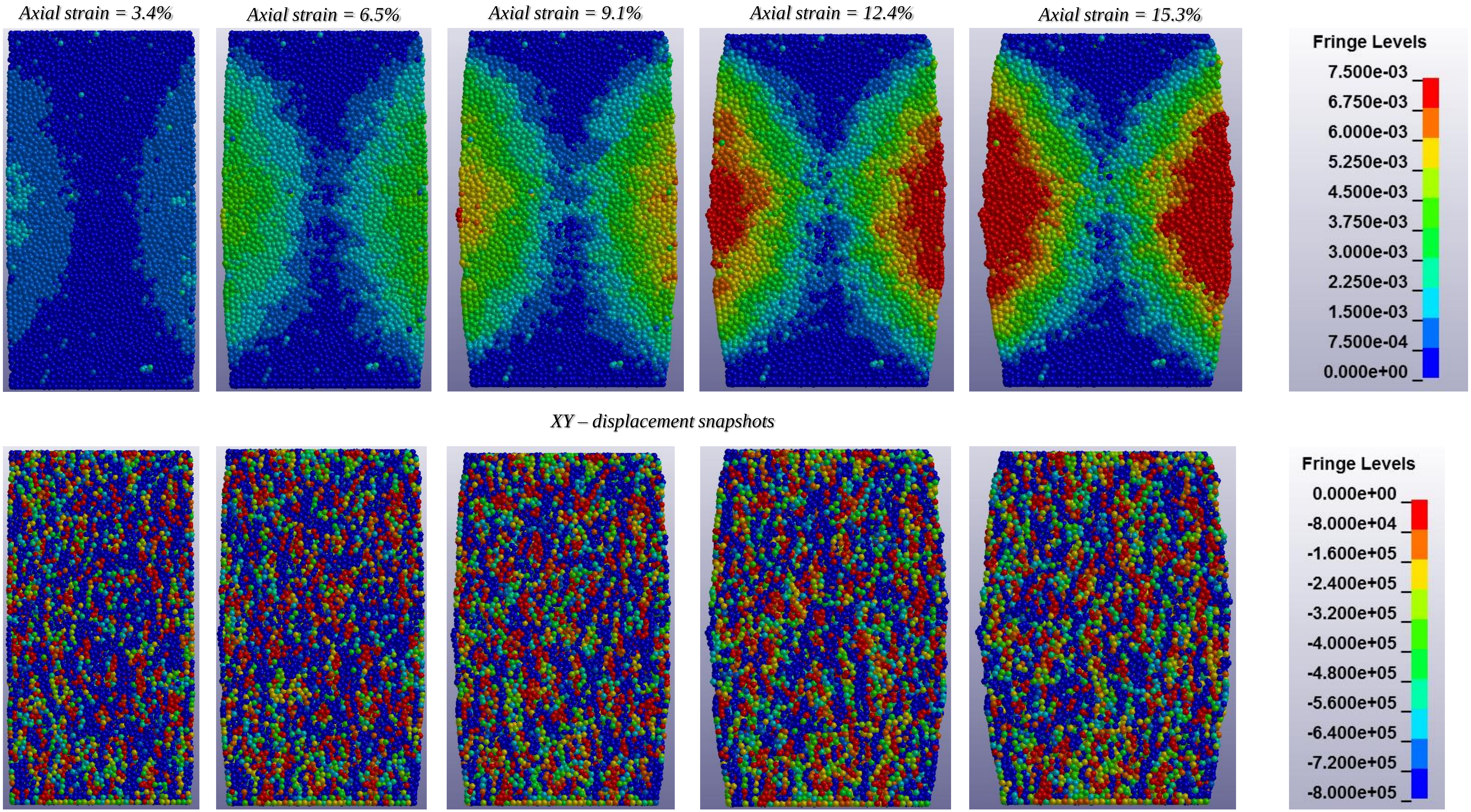


# Task 3. Numerical Modeling of Driven foundation in Granular Material: 900%/sec strain rate loading



Z-stresses snapshots

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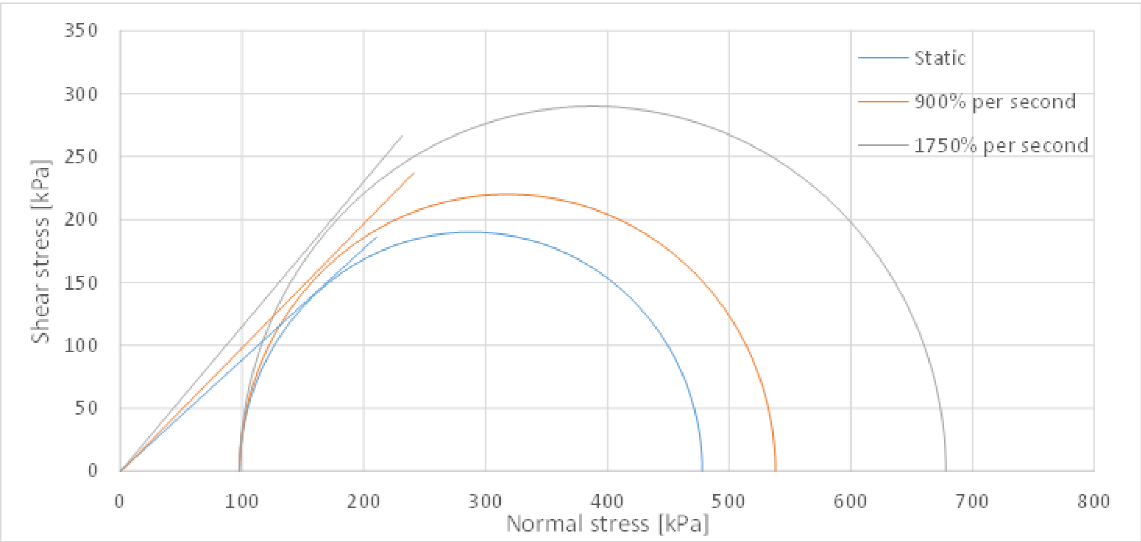
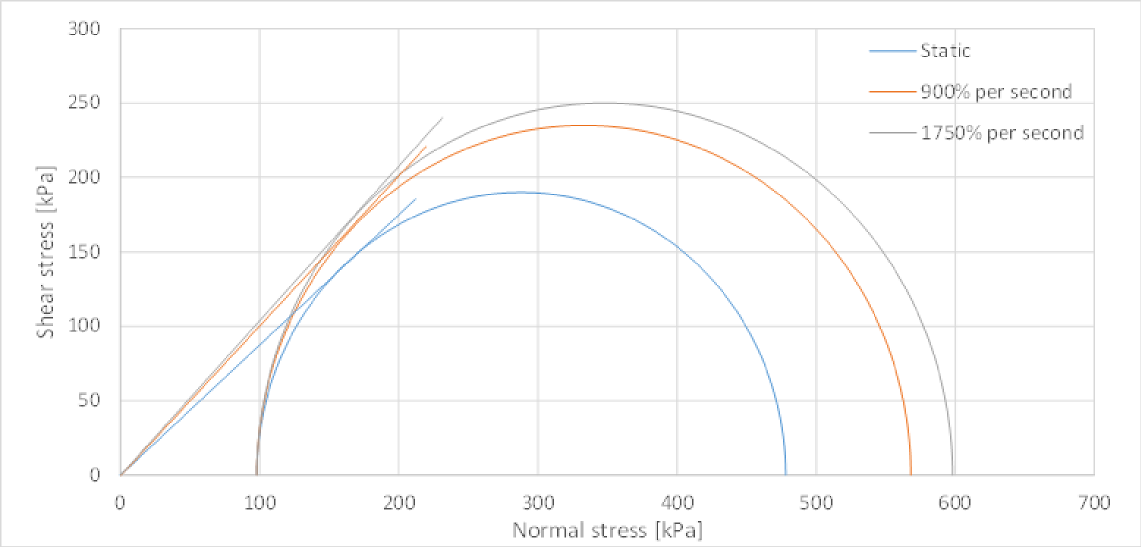
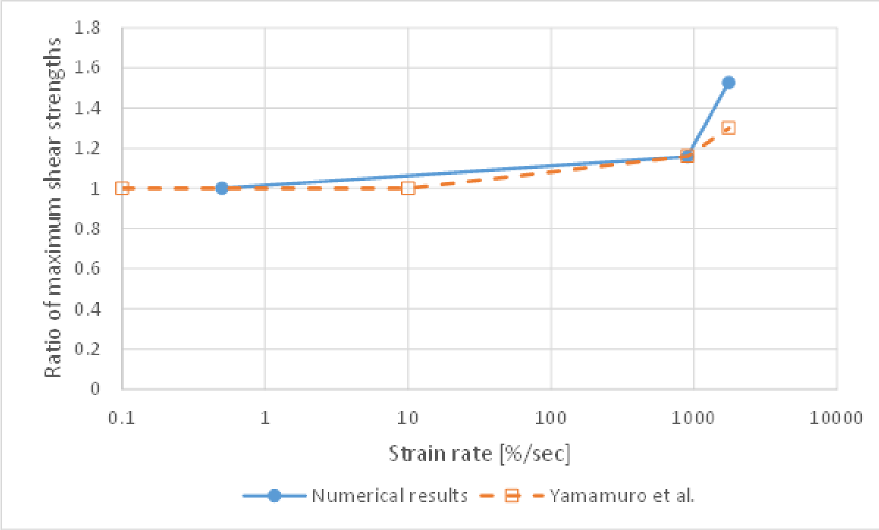
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Mohr-Coulomb Failure Envelopes per Strain Rate Effects (Top: DEM, Bottom: Experiments)



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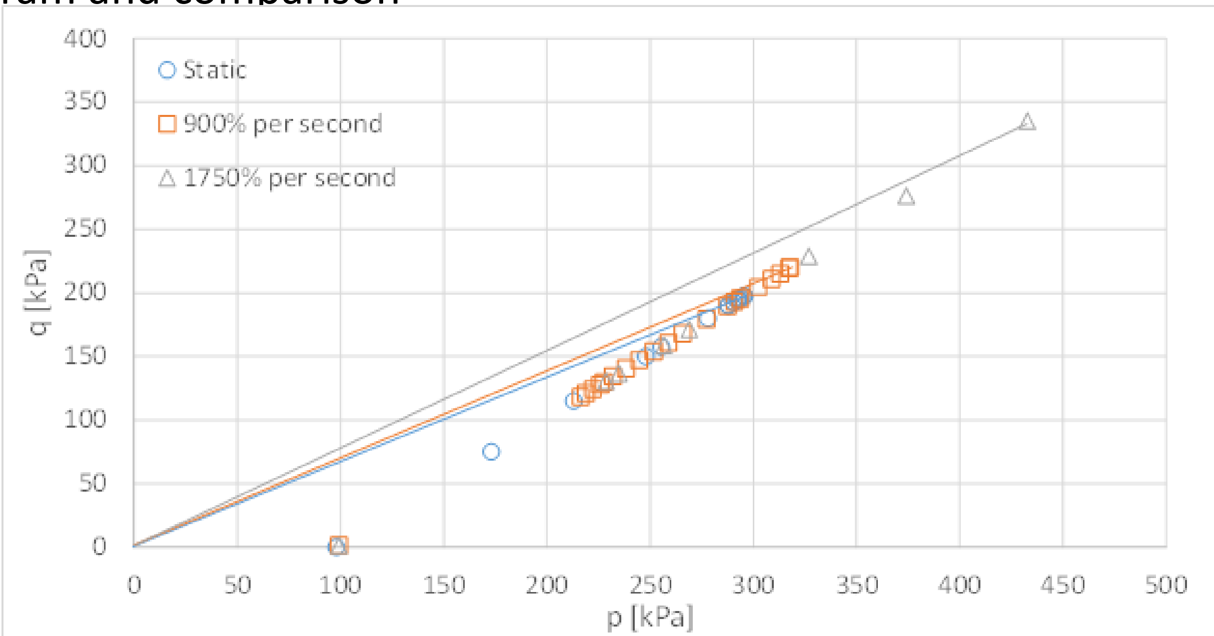
- p-q diagram and comparison

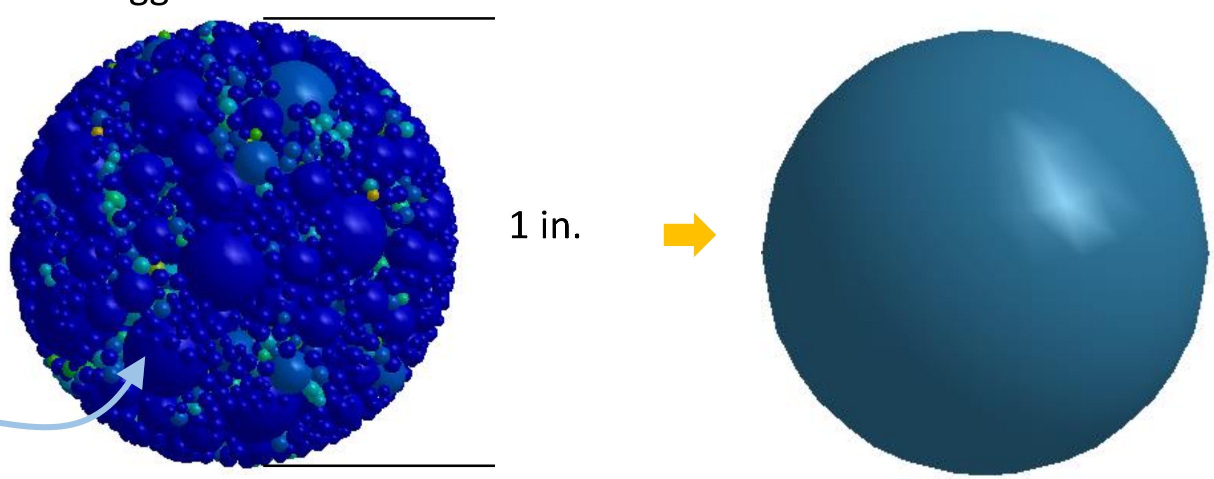



| Strain Rate | Friction angle | | | |
|---|---|---|---|---|
| | Numerical Results | | Yamamuro et al. | |
| | Peak | Constant Volume | Peak | Constant Volume |
| Static | 41.3 | 31.5 (cont.) | 41.3 | 41.3 |
| 900% per second | 43.8 | 33.17 | 44.9 | 41.05 |
| 1750% per second | 48.4 | 35.1 | 45.9 | 33.4 |

| Strain rates | Slope of $K_f$ – lines (ψ) | |
|---|---|---|
| | Numerical results | Yamamuro et al |
| Static | 33.75 | 33.75 |
| 900% per second | 34.7 | 34.9 |
| 1750% per second | 37.72 | 35.7 |

# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Discrete Spherical Element (DSE) Upscaling Efforts:
  - Modeling DSE to match grain scale is not feasible for megascopic assemblies.
    - Requires ~1E+09 elements
    - Current limits are ~1E+07 elements
  - Use Walton's theory (1987) to estimate mesoscopic properties of upscaled DSE

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# Task 3. Numerical Modeling of Driven foundation in Granular Materials

Below is one of two upscaling approaches that are newly developed:

- Effective moduli for hydrostatic compression
  - Perfectly smooth/Infinitely Rough spheres

$$\lambda^* = \mu^* = \frac{1}{10}\left(\frac{3\phi^2 n^2 p}{\pi^4 B^2}\right)^{1/3}$$

$$\lambda^* = \frac{C}{10(2B+C)}\left(\frac{3\phi^2 n^2 p}{\pi^4 B^2}\right)^{1/3}$$

$$\mu^* = \frac{(5B+C)}{10(2B+C)}\left(\frac{3\phi^2 n^2 p}{\pi^4 B^2}\right)^{1/3}$$

*where*, $\lambda^*$ and $\mu^*$ are effective Lame′ constants,
$\phi$ is the volume fraction,
$n$ is the average coordination number,
$p$ is the hydrostatic pressure,
$B$ and $C$ is a constant based on material properties of particle spheres.

- Effective material properties:

$$k^* = \lambda^* + \frac{2}{3}\mu^* \qquad \nu^* = \frac{\lambda^*}{2(\lambda^* + \mu^*)}$$

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# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Discrete Spherical Element (DSE) Upscaling Efforts:

  - Upscaled properties used for DSE in pile driving model
    - Upscaled weight matches agglomerate weight
    - Loose to Medium Dense States
    - Inter-granular sliding and rolling friction
    - Low restitution: Coulombic damping is dominant

| Property | Value | Unit |
|---|---|---|
| **Radius** | 0.5 | in |
| **Density (by weight)** | 98 | $lb/ft^3$ |
| **Bulk modulus** | 22.5 | ksi |
| **Inter-granular friction coefficient** | 1.0 | - - |
| **Coefficient of restitution** | 0.001 | - - |

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# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Development of a driven pile model:
  - FDOT standard pile shape
    - 24 in. square/60 ft long: a limit of model size
  - Assembly of monospheres
    - 1 in. diameter
    - Upscaled properties
  - Cylindrical assembly
    - 6.5 ft diameter
    - 50 ft deep
    - ~3.3 million spheres
  - Unit weight of assembly under gravity
    - ~105 pcf
  - Avg. Internal Friction Angle ~30º

Driven pile model

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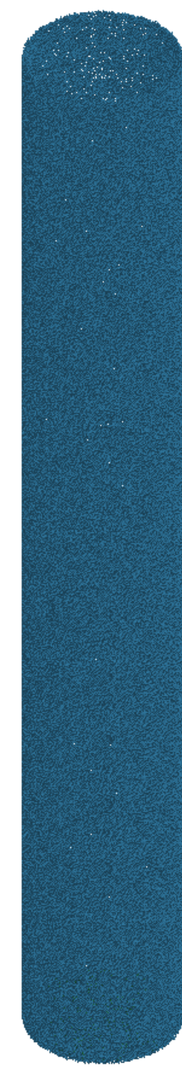
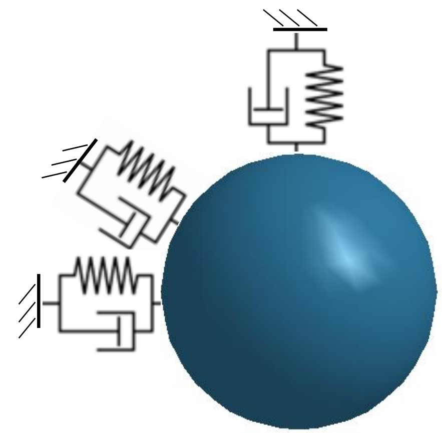
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Development of a driven pile model:
  - Network of boundary spheres
    - Sides
    - Bottom
  - Confining Pressure
    - Based on profile of volume-averaged stress
  - Spring-damper
    - Each translation DOF
    - Stiffness small fraction of DSE bulk modulus
    - Spring is critically damped



Network of boundary spheres



Spring-damper configuration

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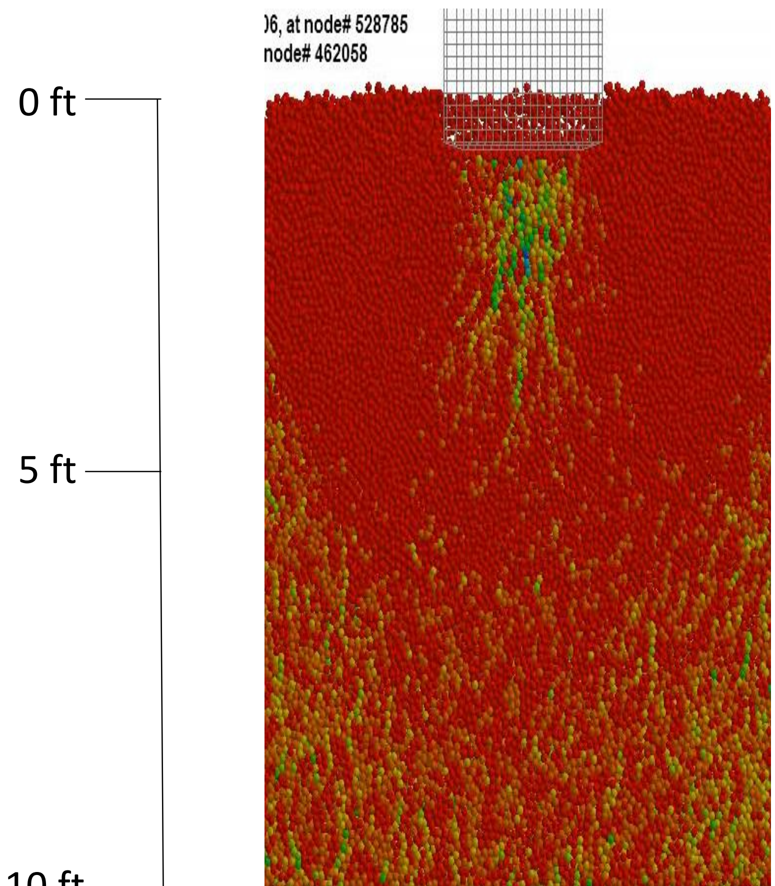
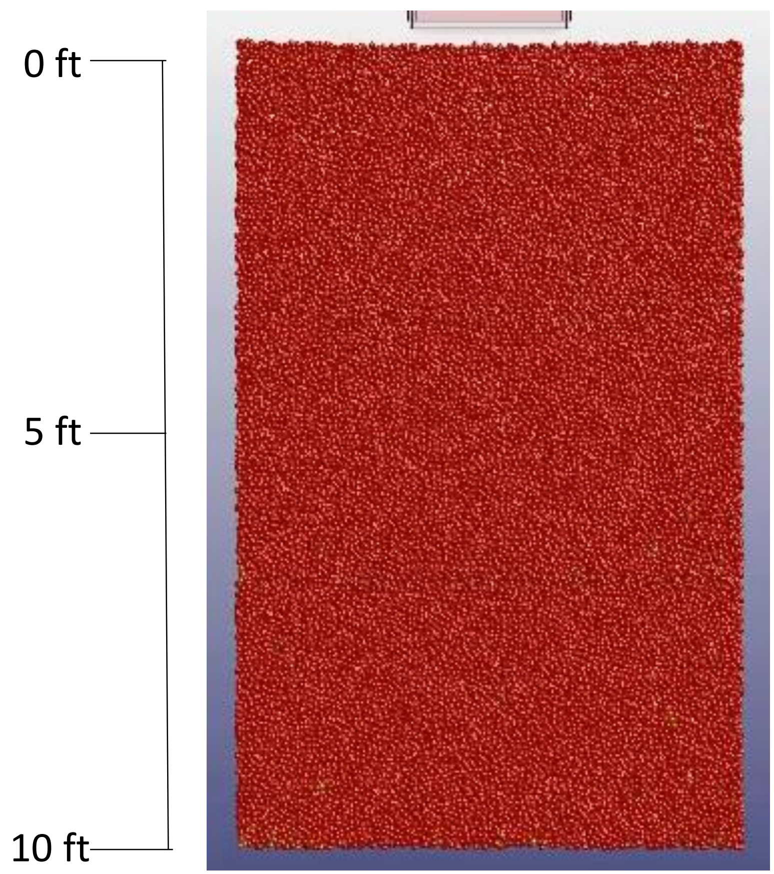
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

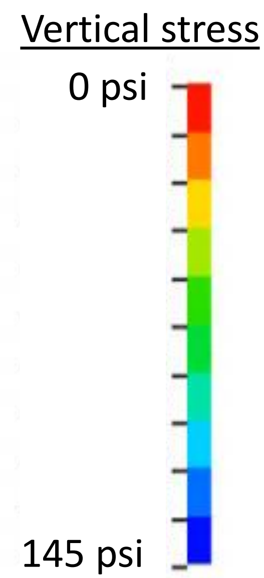
- Effect of boundary condition modeling:




Fixed boundary (5 blows)

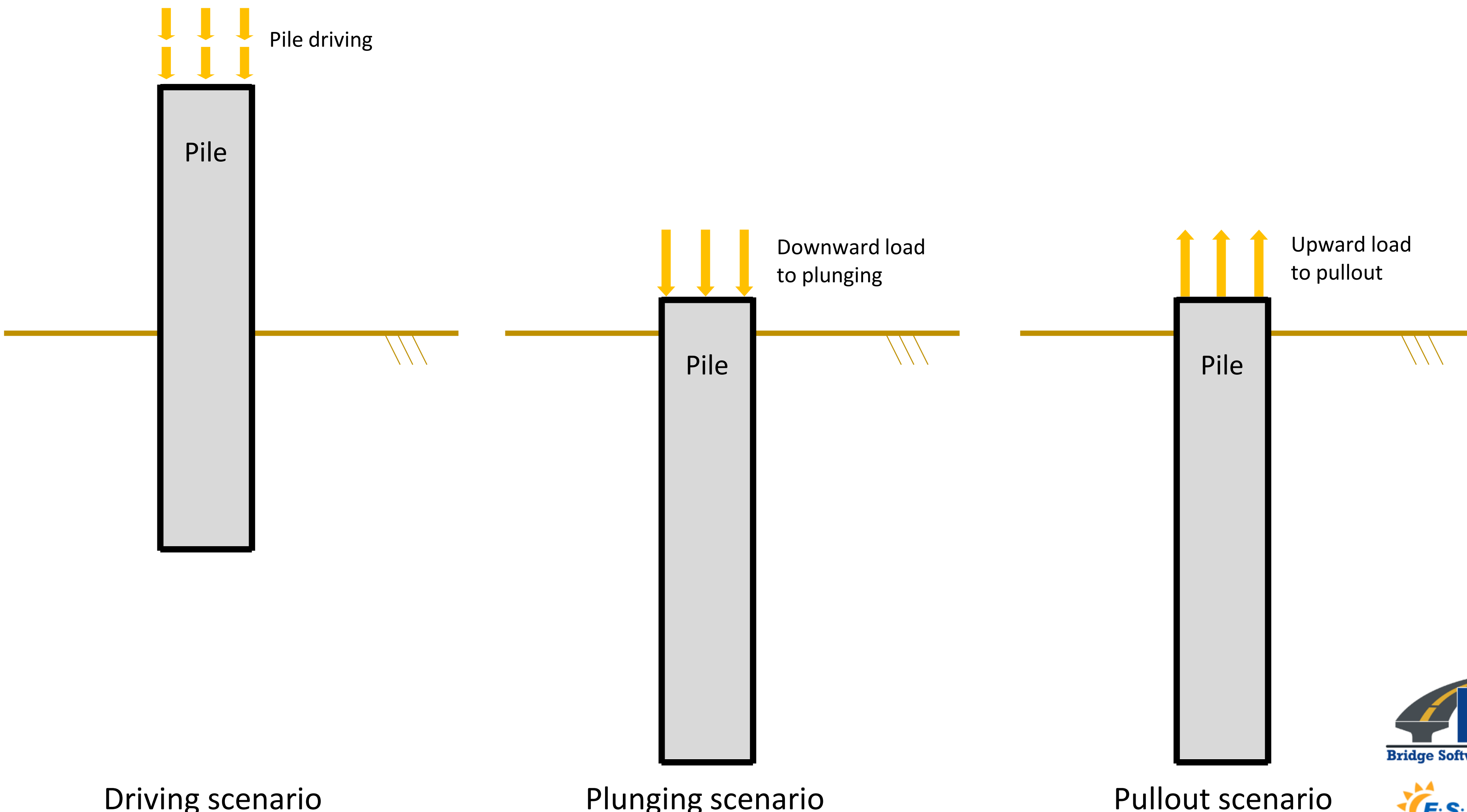



Local non-reflecting boundary (2 blows)



# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Development of a driven pile model:
  - Three scenarios considered

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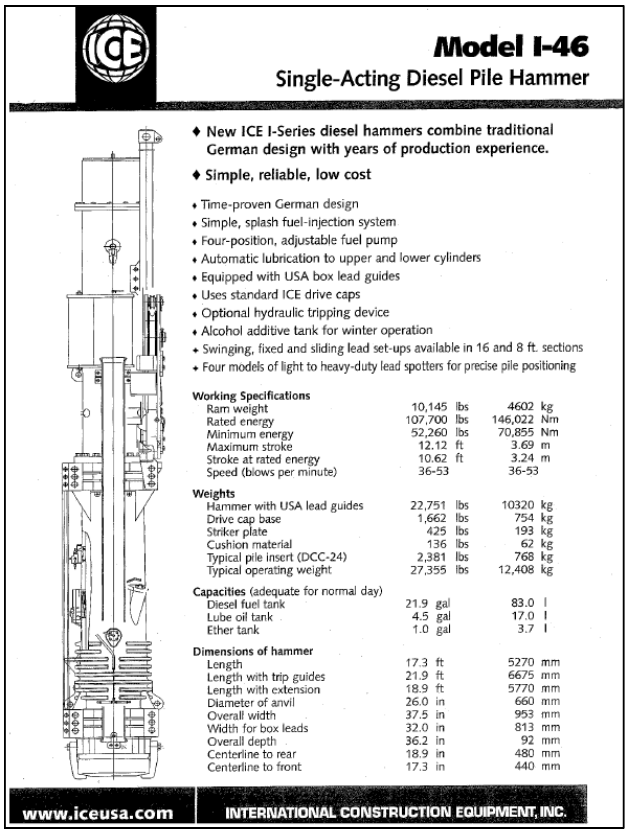
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Pile driving scenario:
  - Triangular pulse load estimated from ICE Model I-46
  - 44 blows per minute



## Model I-46
Single-Acting Diesel Pile Hammer

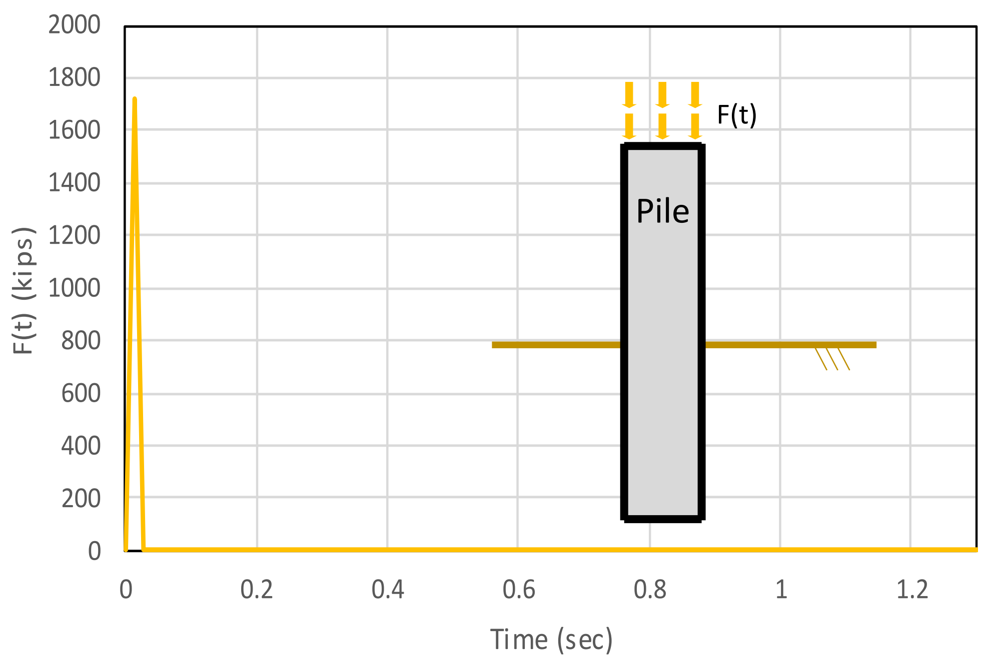
- New ICE I-Series diesel hammers combine traditional German design with years of production experience.
- Simple, reliable, low cost

- Time-proven German design
- Simple, splash fuel-injection system
- Four-position, adjustable fuel pump
- Automatic lubrication to upper and lower cylinders
- Equipped with USA box lead guides
- Uses standard ICE drive caps
- Optional hydraulic tripping device
- Alcohol additive tank for winter operation
- Swinging, fixed and sliding lead set-ups available in 16 and 8 ft. sections
- Four models of light to heavy-duty lead spotters for precise pile positioning

| | | | | |
|---|---|---|---|---|
| **Working Specifications** | | | | |
| Ram weight | 10,145 | lbs | 4602 | kg |
| Rated energy | 107,700 | lbs | 146,022 | Nm |
| Minimum energy | 52,260 | lbs | 70,855 | Nm |
| Maximum stroke | 12.12 | ft | 3.69 | m |
| Stroke at rated energy | 10.62 | ft | 3.24 | m |
| Speed (blows per minute) | 36-53 | | 36-53 | |
| **Weights** | | | | |
| Hammer with USA lead guides | 22,751 | lbs | 10320 | kg |
| Drive cap base | 1,662 | lbs | 754 | kg |
| Striker plate | 425 | lbs | 193 | kg |
| Cushion material | 136 | lbs | 62 | kg |
| Typical pile insert (DCC-24) | 2,381 | lbs | 768 | kg |
| Typical operating weight | 27,355 | lbs | 12,408 | kg |
| **Capacities** (adequate for normal day) | | | | |
| Diesel fuel tank | 21.9 | gal | 83.0 | l |
| Lube oil tank | 4.5 | gal | 17.0 | l |
| Ether tank | 1.0 | gal | 3.7 | l |
| **Dimensions of hammer** | | | | |
| Length | 17.3 | ft | 5270 | mm |
| Length with trip guides | 21.9 | ft | 6675 | mm |
| Length with extension | 18.9 | ft | 5770 | mm |
| Diameter of anvil | 26.0 | in | 660 | mm |
| Overall width | 37.5 | in | 953 | mm |
| Width for box leads | 32.0 | in | 813 | mm |
| Overall depth | 36.2 | in | 92 | mm |
| Centerline to rear | 18.9 | in | 480 | mm |
| Centerline to front | 17.3 | in | 440 | mm |

www.iceusa.com INTERNATIONAL CONSTRUCTION EQUIPMENT, INC.

Pile hammer data sheet




Example load pulse (44 bpm)

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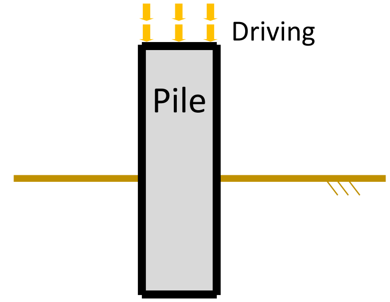
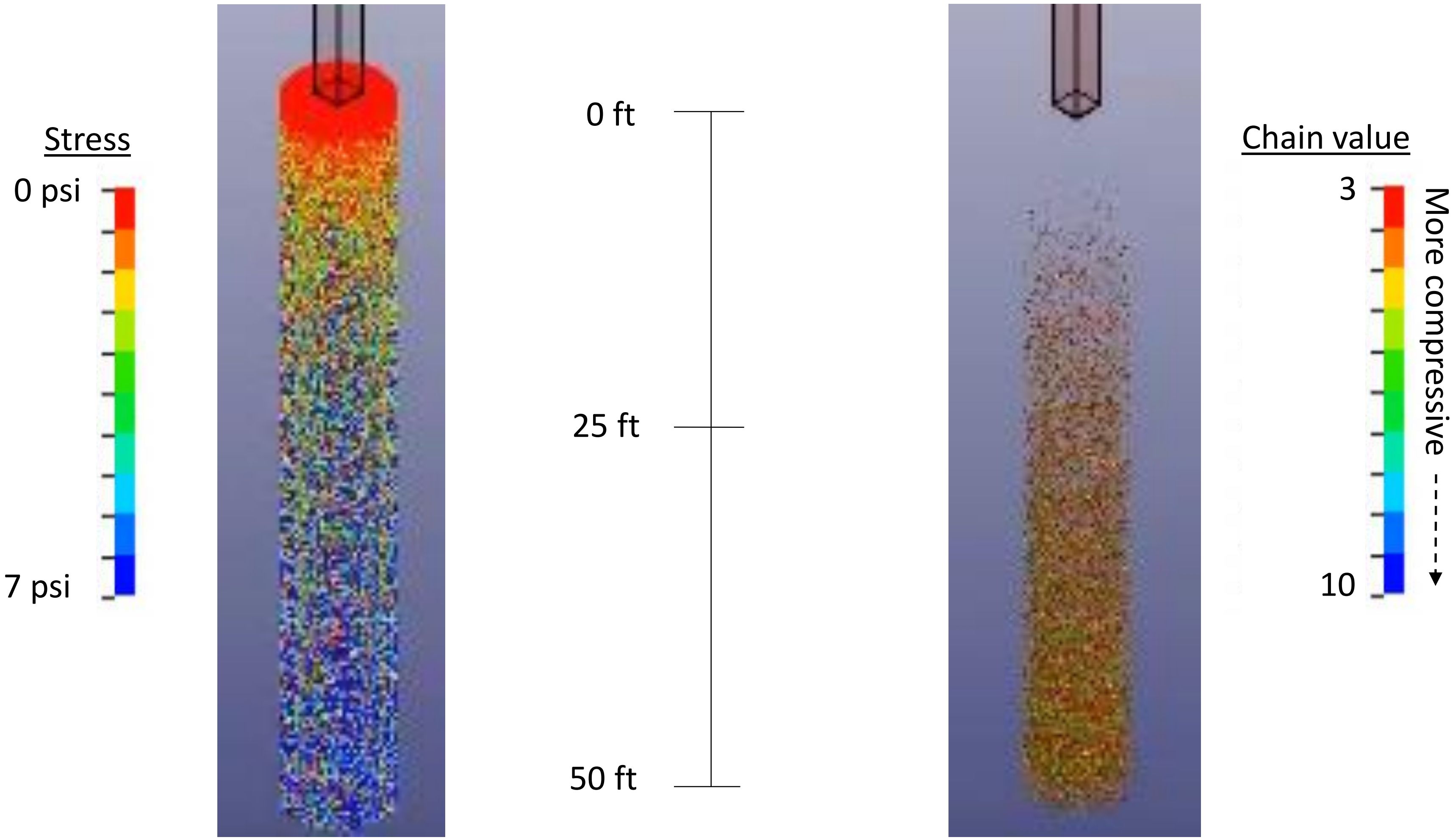



- Initial loose-to-medium dense density states due to gravitational effects




Iso-view with vertical stresses

Iso-view with force chain

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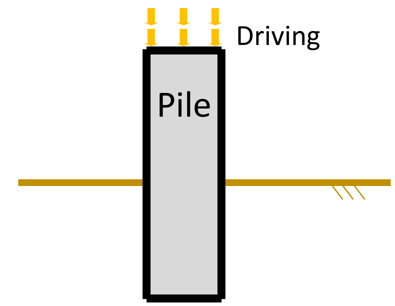
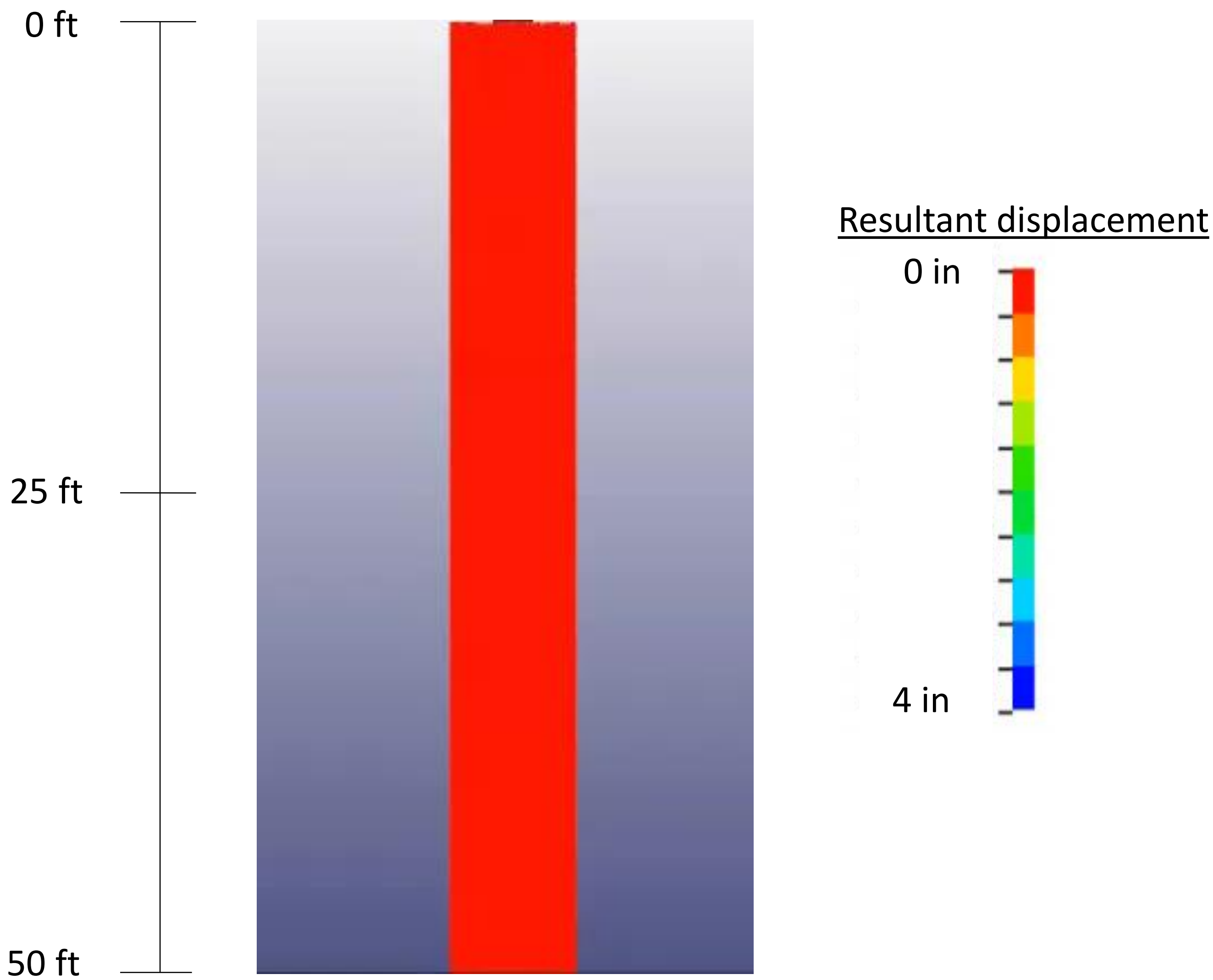
# Task 3. Numerical Modeling of Driven foundation in Granular Materials




- Displaced granular mass




Elevation view with displacements

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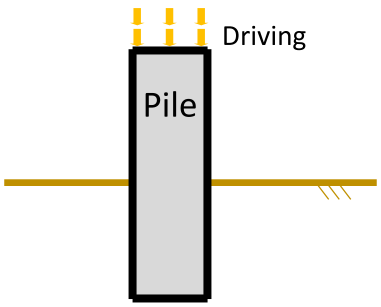
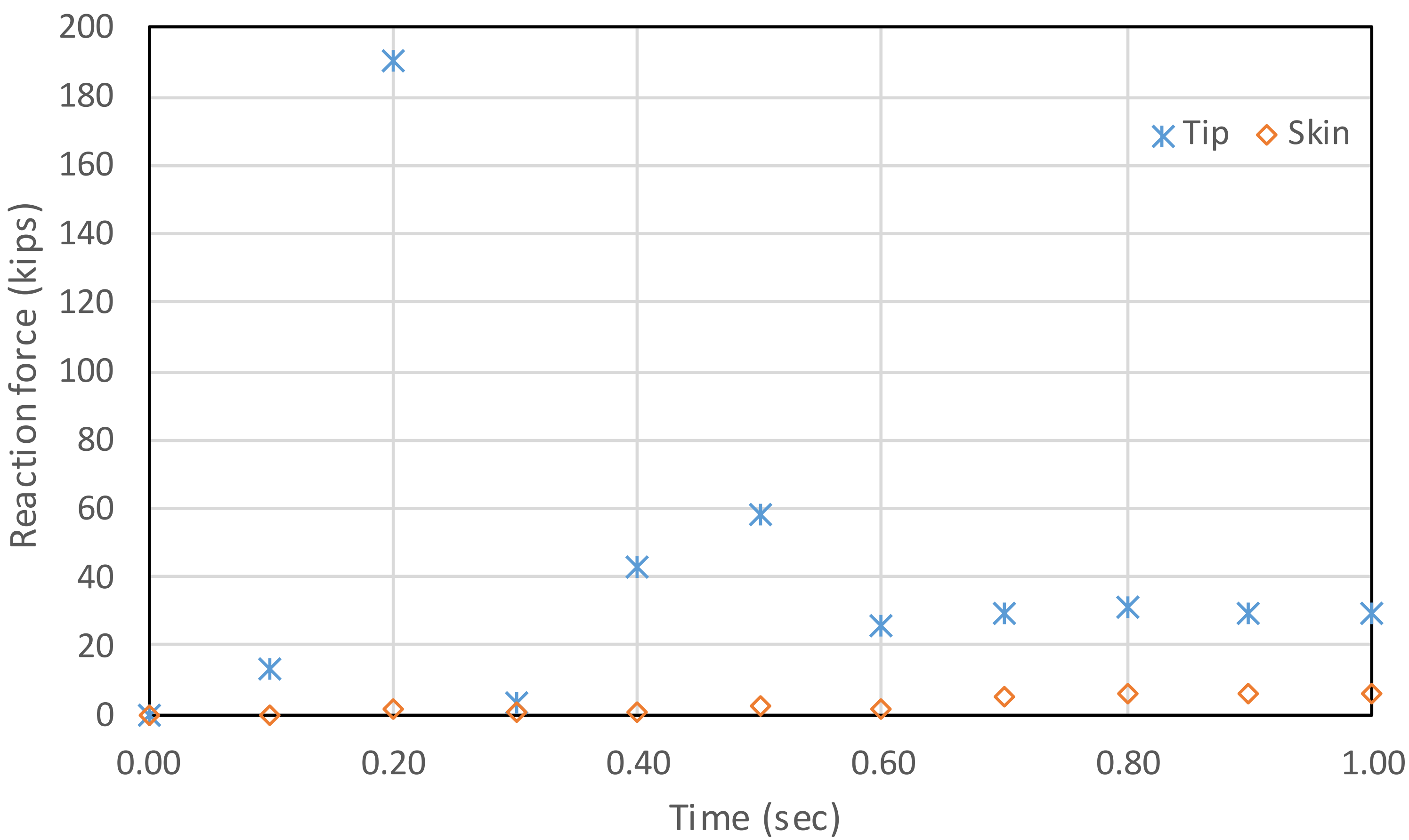



- Pile driving scenario:
  - Loads attributed to tip and skin are cataloged




Reaction forces along pile skin and tip during first pile blow

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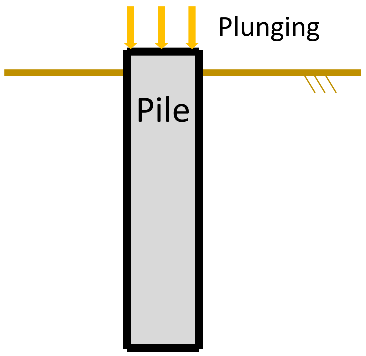
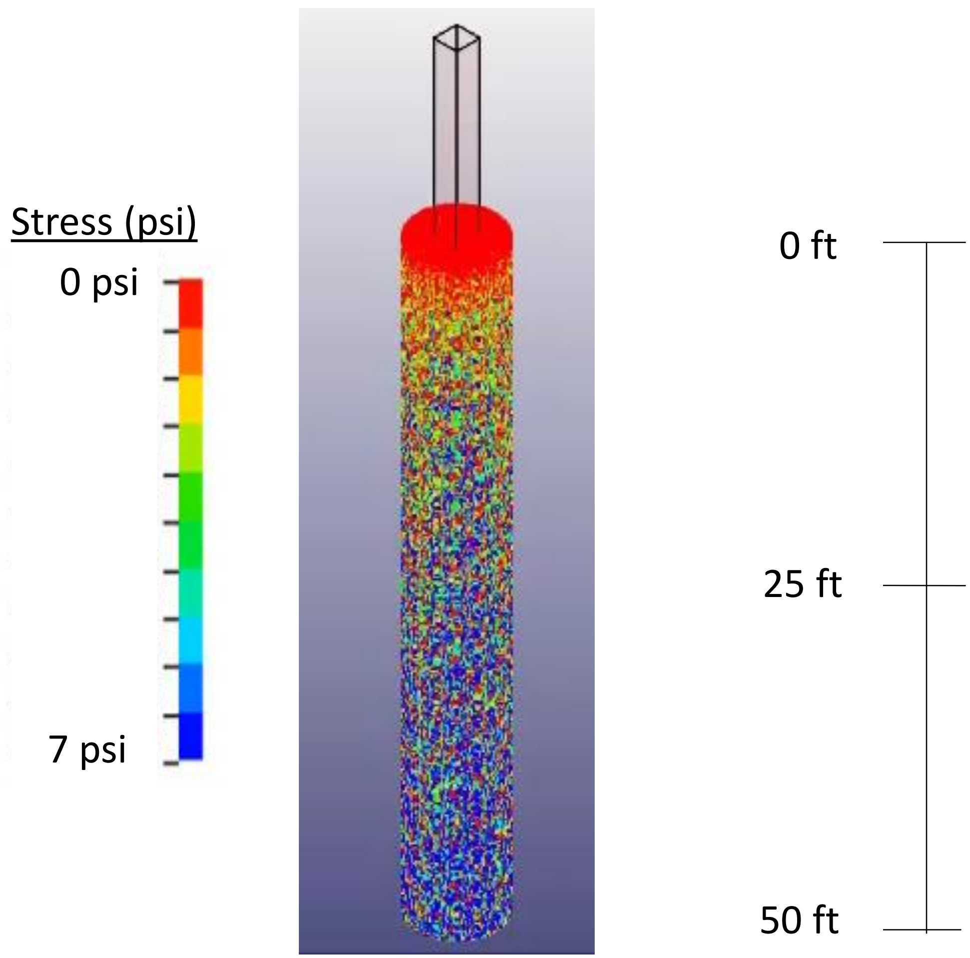
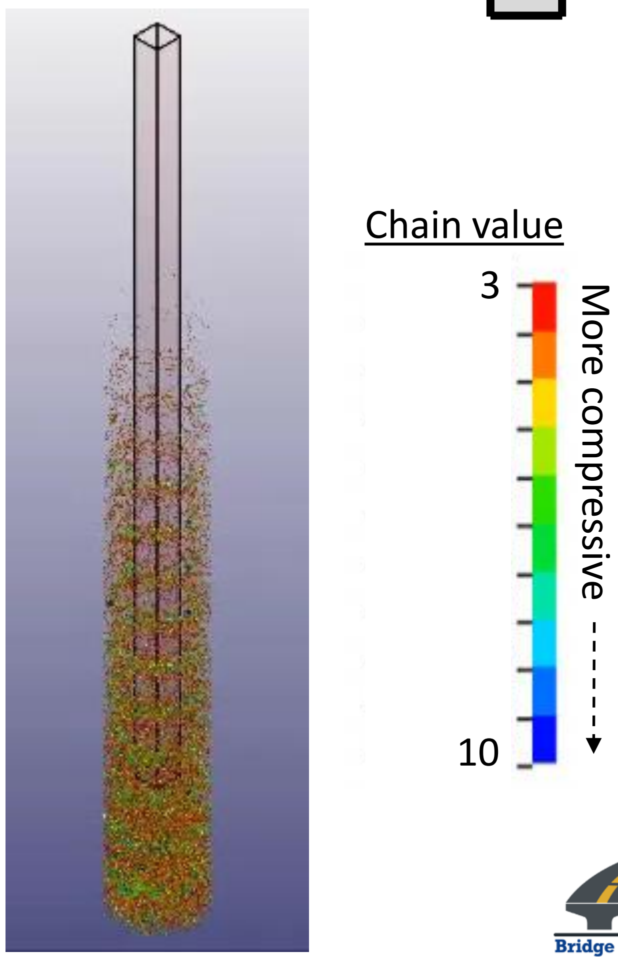



- Top-down load test scenario:
  - Load increased linearly until plunging occurs




Isometric view with vertical stresses




Isometric view with force chain

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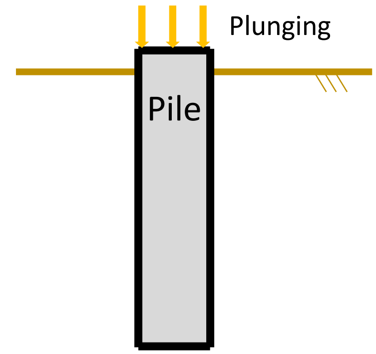
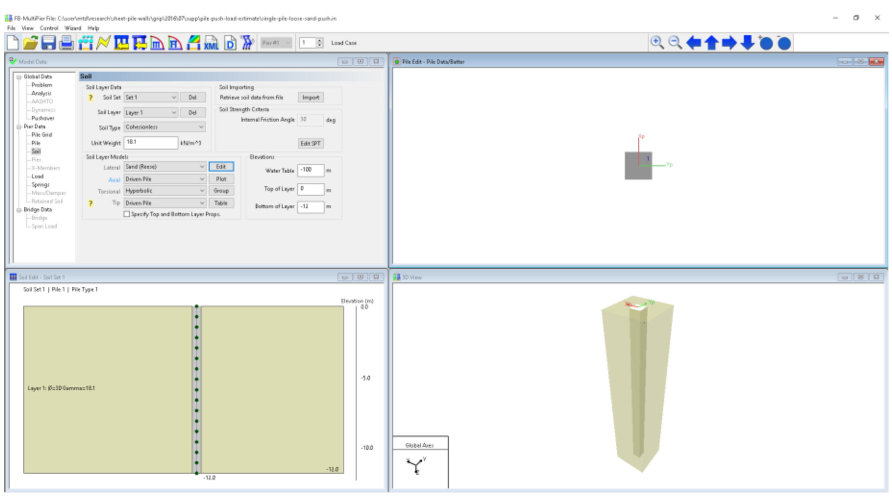



- Top-down load test simulation:
  - Comparison to single pile model in FB-MultiPier
    - Driven pile in Reese sand
    - 40 ft embedment
    - Avg. unit weight input as 105 pcf
    - Avg. internal friction angle input as 30°
    - Avg. ultimate skin friction input as 280 psf (FB-Deep analysis)
    - Ultimate bearing failure load input as 100 kips (FB-Deep analysis)



FB-MultiPier single pile model

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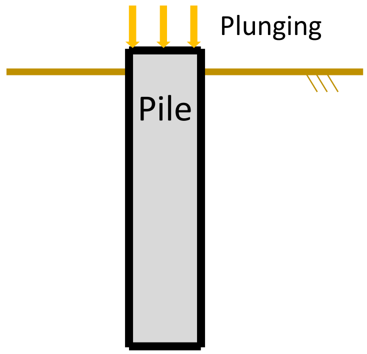
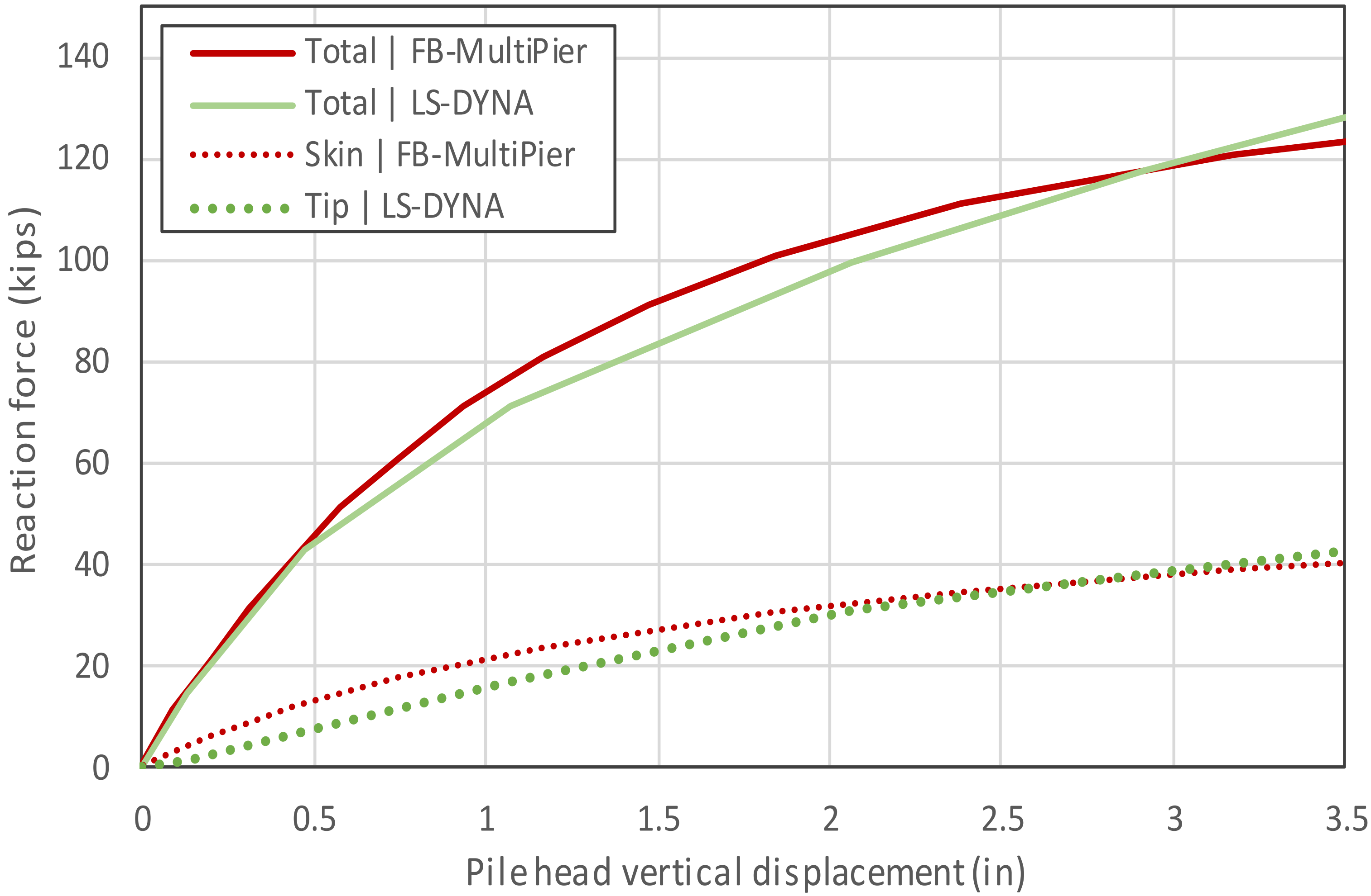
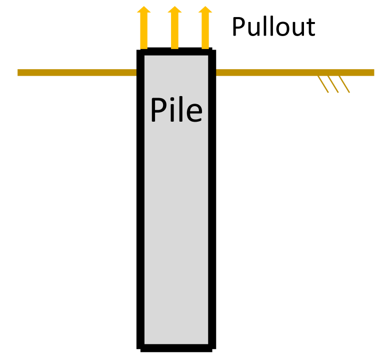
# Task 3. Numerical Modeling of Driven foundation in Granular Materials



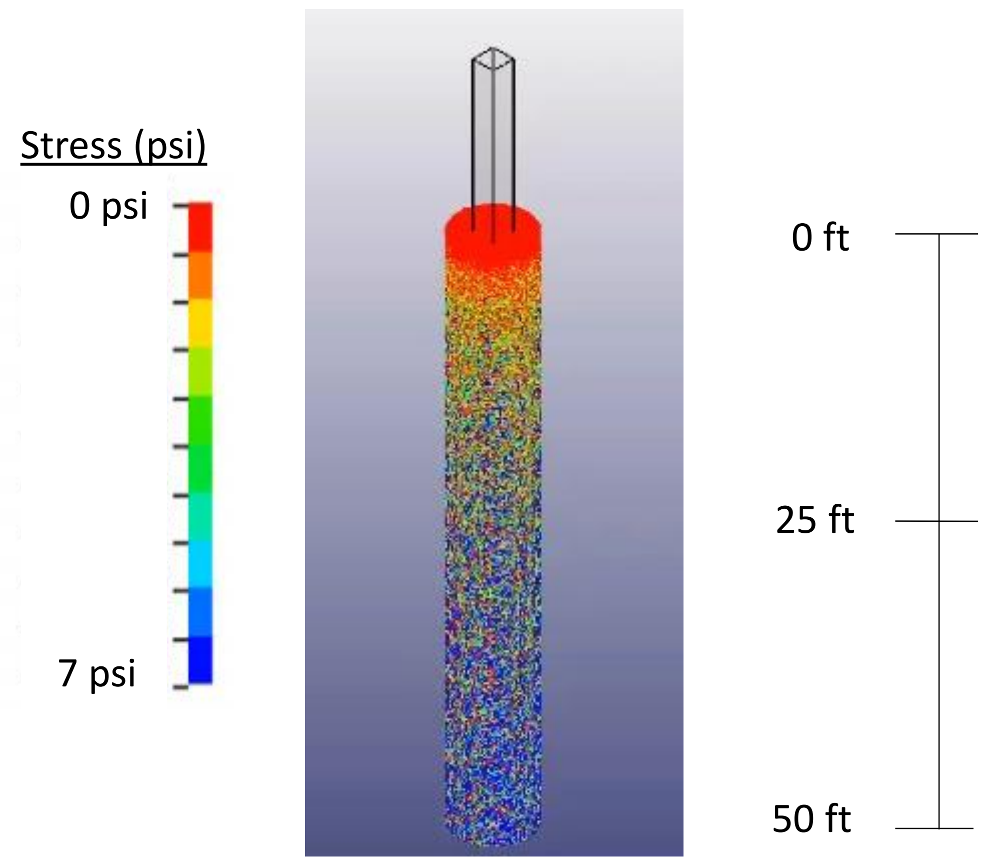

- Pile plunging scenario:



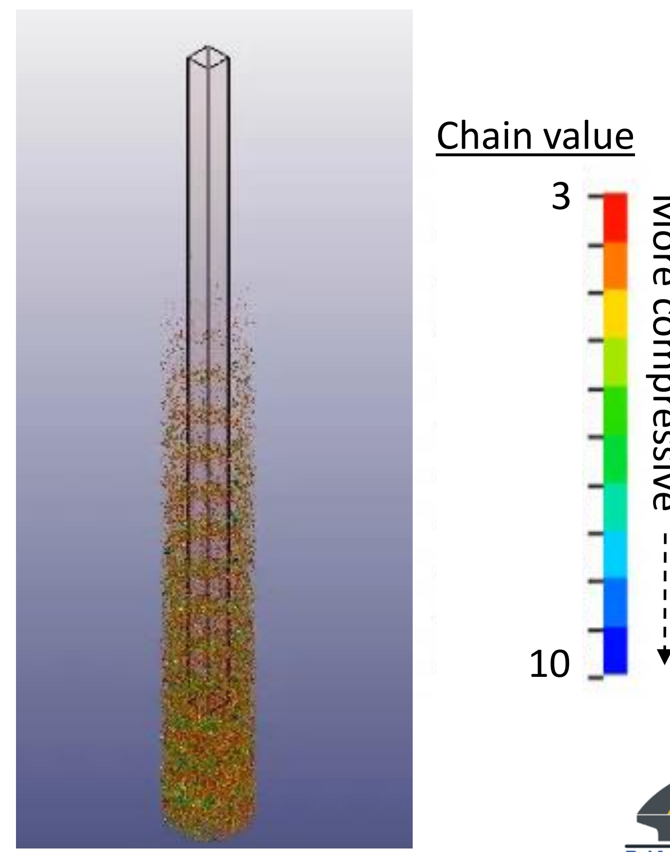
# Task 3. Numerical Modeling of Driven foundation in Granular Materials




- Pile pullout scenario:
  - Load increased linearly until pullout occurs



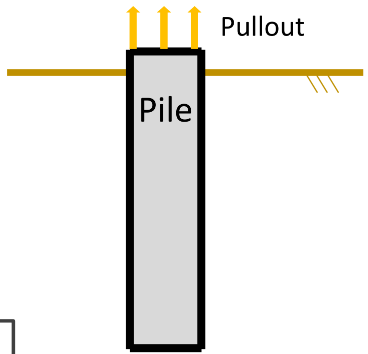

Isometric view with vertical stresses

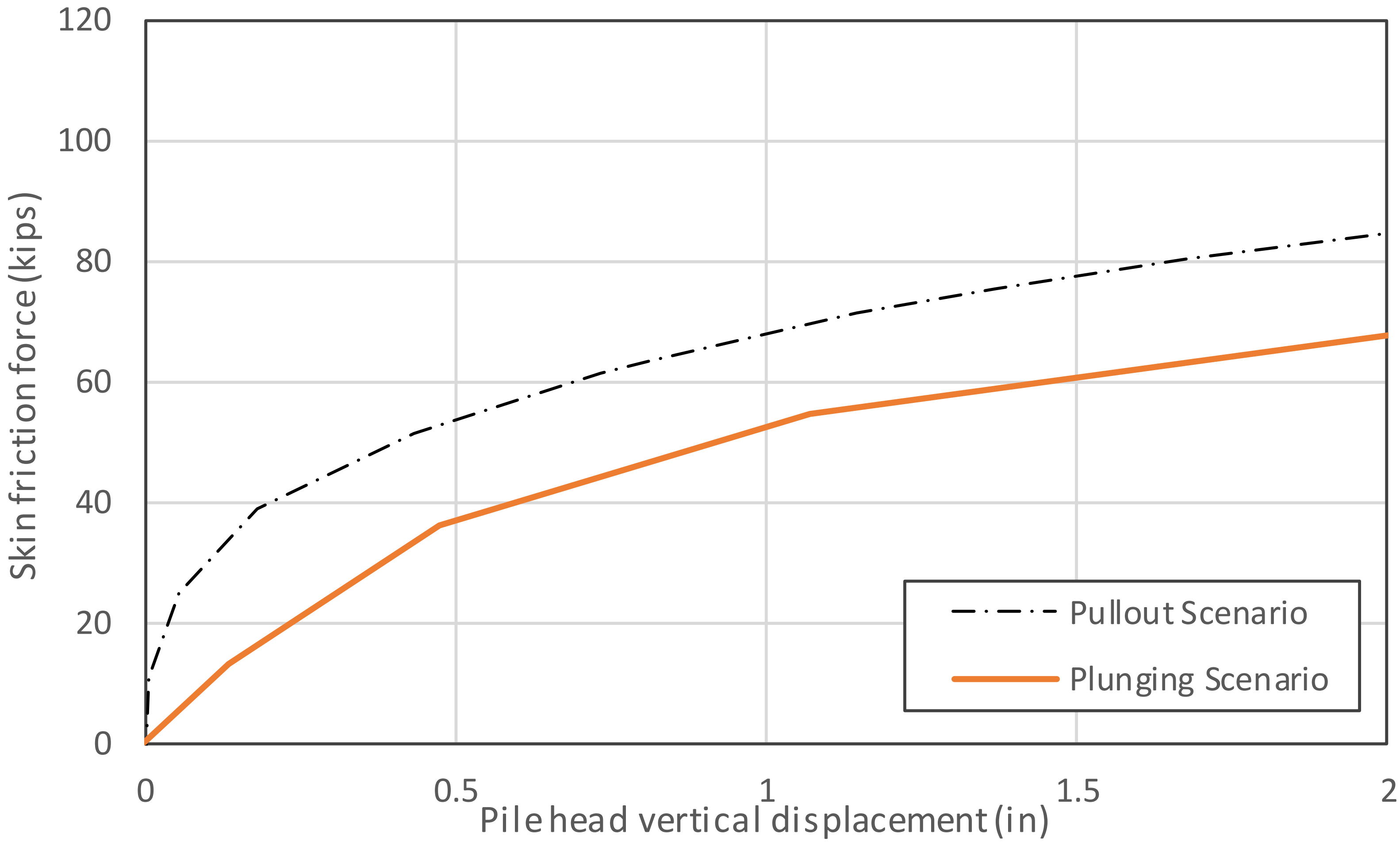



Isometric view with force chain

# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Pile pullout scenario:



# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Parametric study of pile driving simulations:
  - 3D simulations of megascopic assemblies can require millions of elements
    - Approx. four days of run time in HiPerGator 2.0 Supercomputer to simulate one second
  - 2D axisymmetric simulations can be used to streamline parametric study
    - 1 to 2 orders of magnitude reduction in simulation time
    - Can  be calibrated (bulk modulus; sliding friction)
    - Can be benchmarked against 3D models

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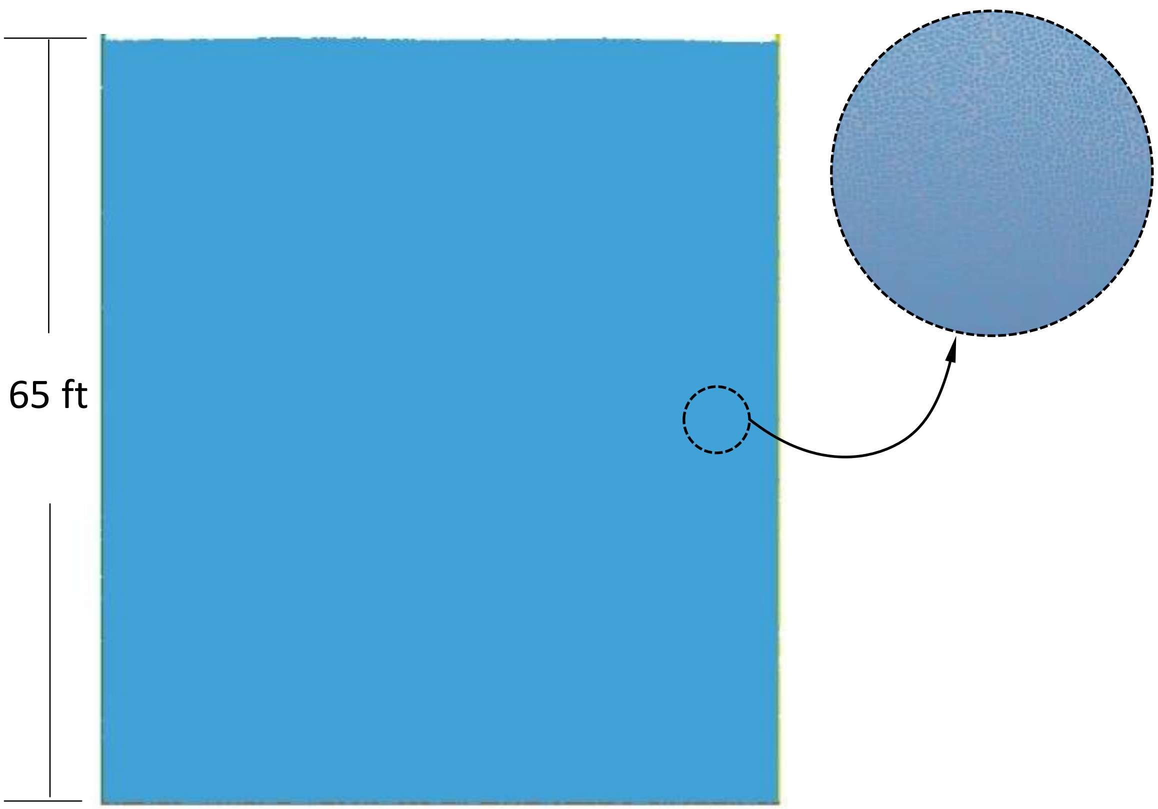
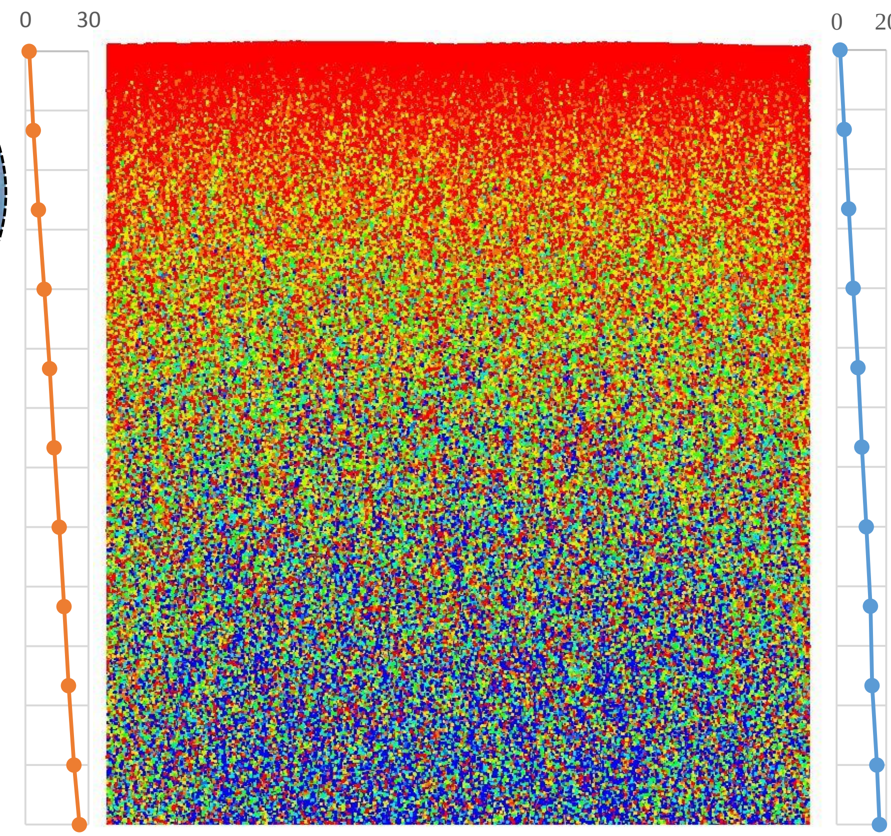
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- A tool for parametric study of pile driving simulations in 2-D axisymmetry or plane-strain boundary conditions
  - A case of loose packing under gravity: a homogeneous granular mass with internal friction angle ~20 deg.




Elevation view of 2D assembly




Geostatic stress

Left : Vertical stress

Right : Horizontal stress

Unit : psi

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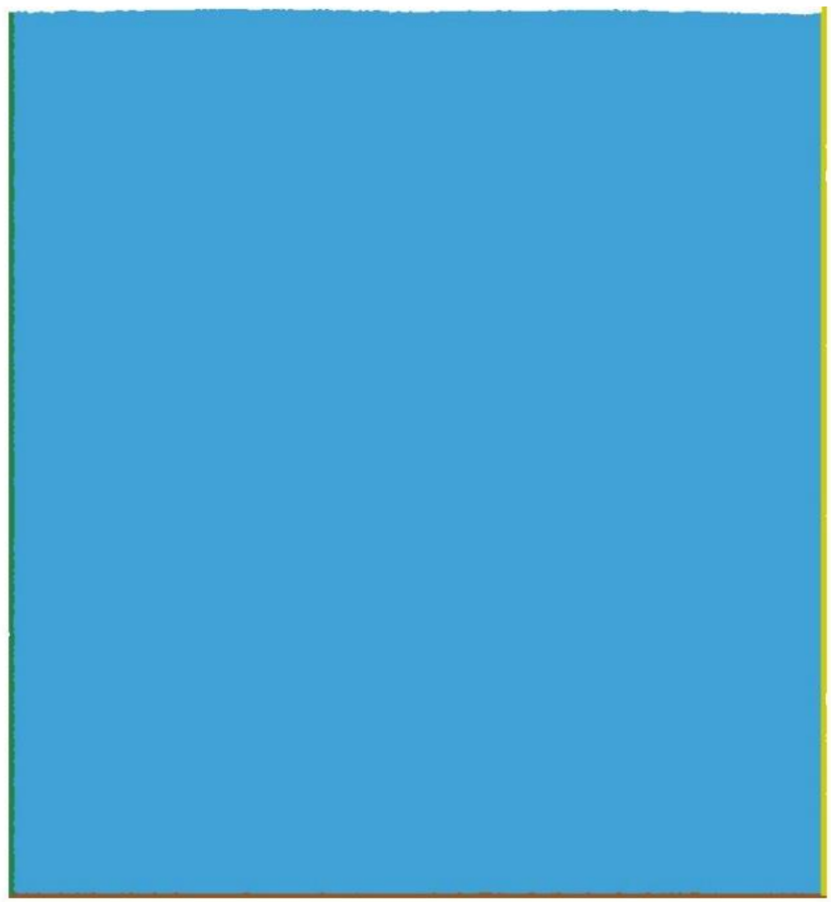
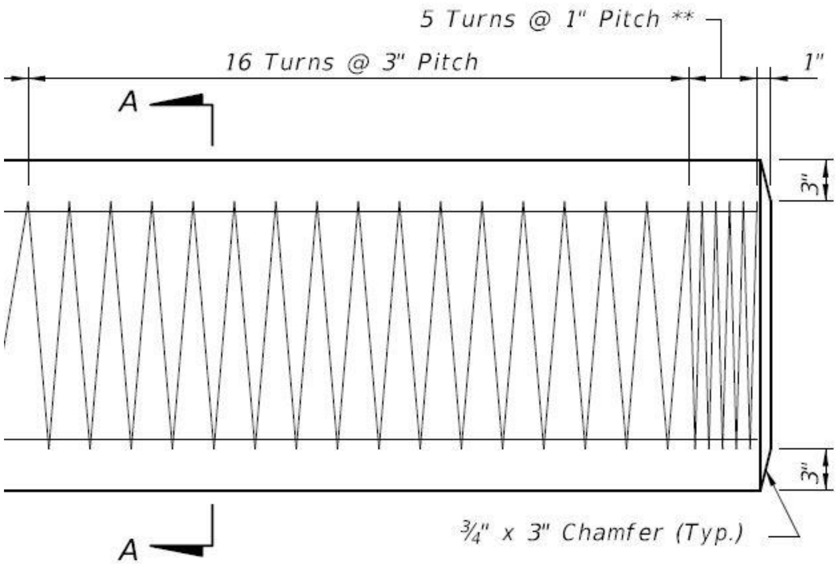
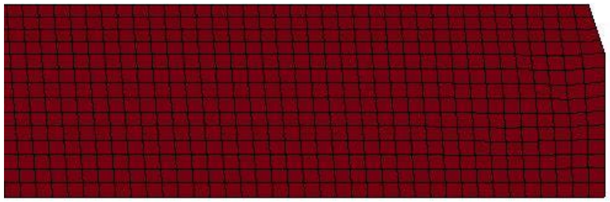
- Parametric study of pile driving simulations:
    - Boundary condition modeling



# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Parametric study of pile driving simulations:
  - Pile modeling



Standard prestressed pile (24 in. square)

Symmetry model (solid elements)

Unit width ouf-of-plane

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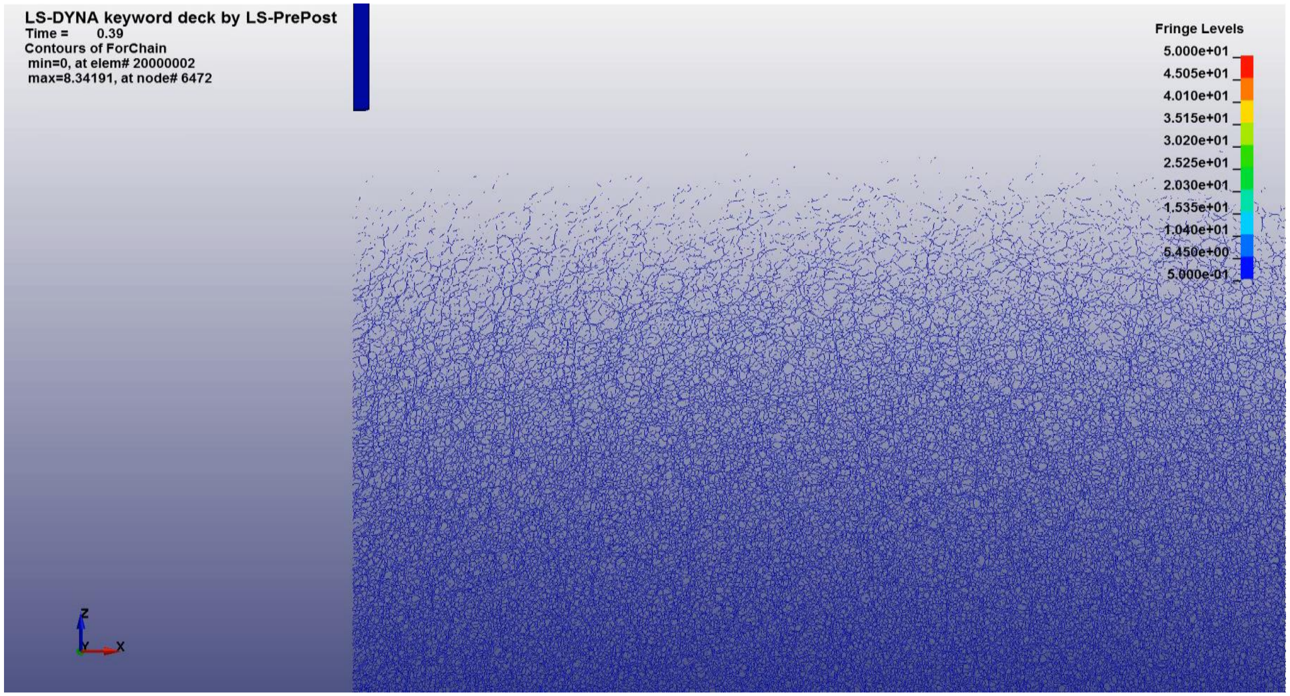
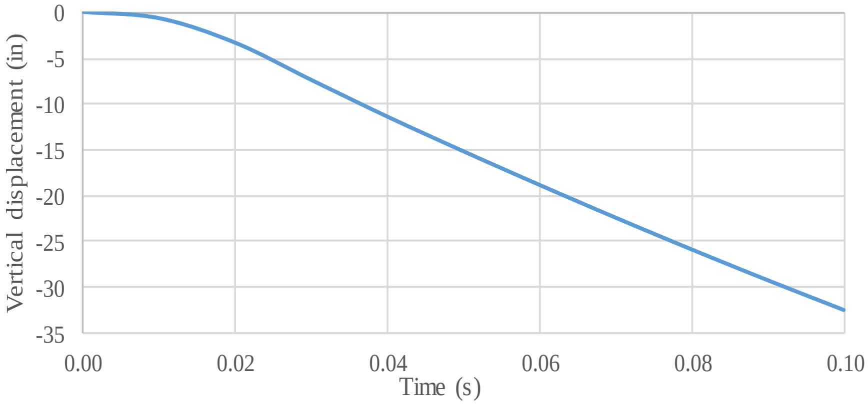
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- Parametric study of pile driving simulations:

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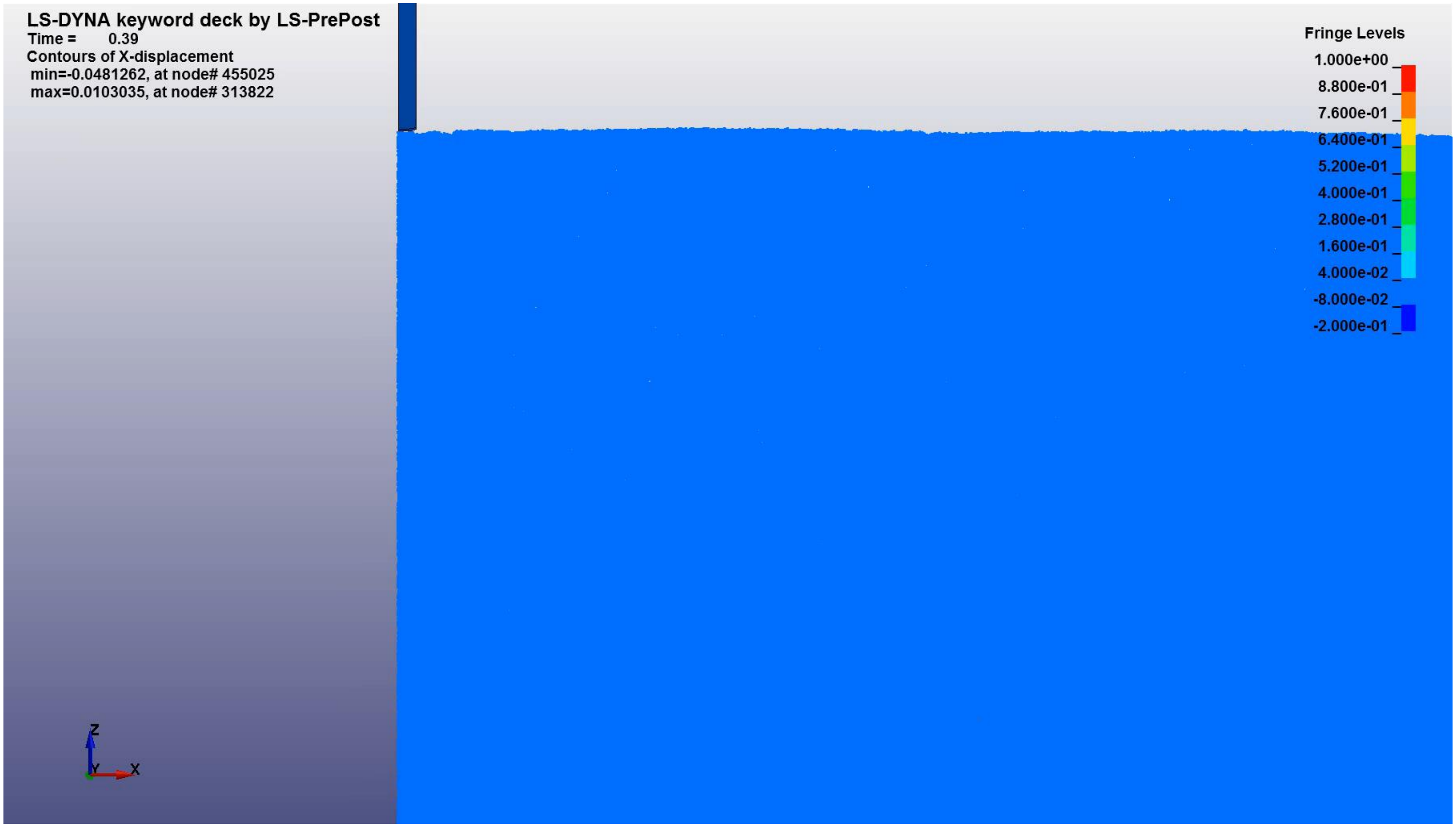
# Task 3. Numerical Modeling of Driven foundation in Granular Materials

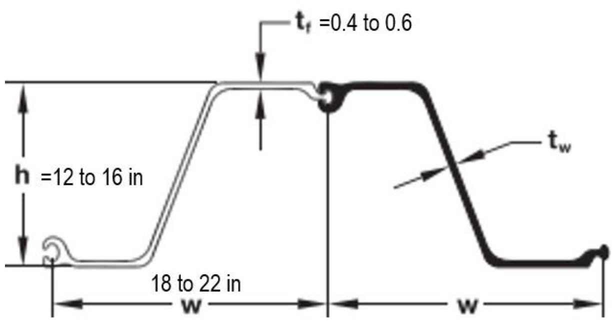
- Parametric study of pile driving simulations:
  - Horizontal displacement



# Task 3. Numerical Modeling of Driven foundation in Granular Materials

- **Remaining items**

  - Development of a sheet pile wall (SPW) FE model




  - Perform and report parametric study of pile-soil-SPW simulations

  - Establish three benchmark simulations for Task 4
    - Pile
    - Pile and pre-driven SPW model (no removal)
    - Pile and pre-driven SPW model (w/ removal)

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# Introduction: Project Approach

- **Phase I (12 months; July 2014 - June 2015)**
- Task 1. Literature Review, Scenario Identification, and Field-Data Acquisition
- Task 2. Numerical Modeling Schemes and Granular Soil Units

- **Phase II (18 months; July 2015 - December 2016)**
- Task 3. Numerical Modeling of Driven foundation in Granular Soils
- Task 4. Physical Laboratory/Centrifuge Experimentation
- Task 5. Reporting of Findings and Design-Oriented Recommendations
- Task 6. Final Report

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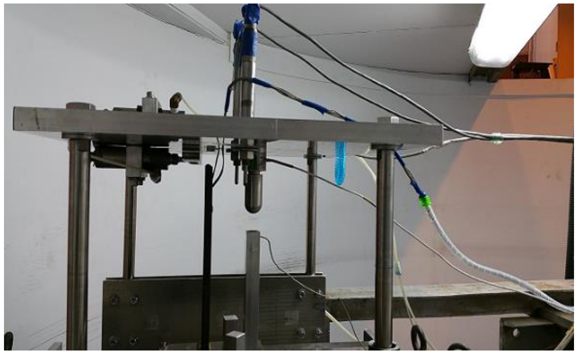
# Task 4. Physical Laboratory/Centrifuge Experimentation

- Progress on Task 4:
  - Calibration of LVDT and Pressure Transducers
  - Repair/Procurement of instrumentation: stress gages and new load cells



Centrifuge - UF Reed Laboratory

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# Plan for Tasks 4 and 5

- July/2016-September/2016: Standardize the laboratory test program: Protocols, Instrumentation, and Test Measurements
- October/2016-March/2017: Validate the centrifuge testing procedure, and conduct three benchmark simulations from Task 3
- April/2017-July/2017: Numerical parametric simulation per model calibration between physical centrifuge test measurements and simulation results

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# Thanks!

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