Determining Bearing Resistance of Cantilever Sheet Piles
BDV31-977-90

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Outline

- Background
- Objectives
- Research Tasks
- Task 2b: Numerical Modeling
- Task 3b: Centrifuge Testing

Background

- The current FDOT practice requires discrete deep foundation (piles or drilled shafts) for bearing purposes which may or may not be combined with permanent sheet piles for lateral retaining purposes.

- Some designers has previously considered using sheet piles to support both vertical bridge loads and lateral earth loads. However, the concept has not survived final design due to the inability to confirm the capacity of these elements in the field and accept them as bearing piles.

- For end bents of small bridges, there is a potential for realizing savings if we can verify the axial resistance of the sheet piling and eliminate the need for separate deep foundation.

- This would also relieve the complications that arise in construction when driving piles and sheet piles in close proximity.

Background (cont'ed): Uncertainties and Issues

- Evaluation of side friction and end bearing resistance by conventional pile design approaches
- Assessment of soil-sheet pile interaction under combined axial and lateral loading
- Evaluation of buckling potential and plastic hinge formation under axial loading
- Determination of the bearing capacity of axially loaded sheet piles through standardized practical field testing protocols

Objectives

I. Quantify the bearing capacity of permanent steel sheet pile walls
II. Evaluate both the friction and bearing components
III. Develop practical recommendations for designers to estimate the bearing capacity of steel sheet pile walls
IV. Develop practical methods to determine and verify the bearing capacity in the field

Research Tasks

Task 1 - Literature Review and Information Collection

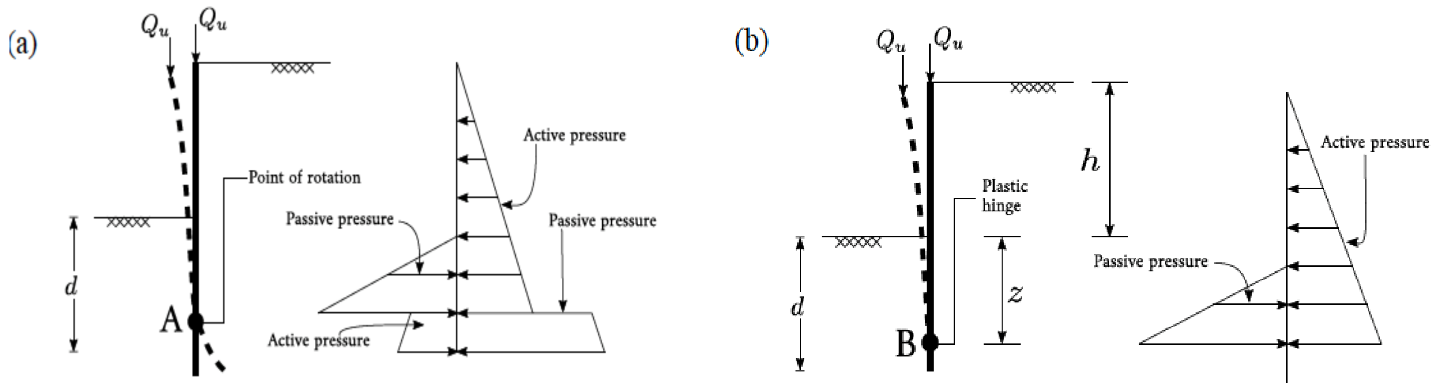
Task 2 - Numerical Modeling

Task 3 - Centrifuge Testing

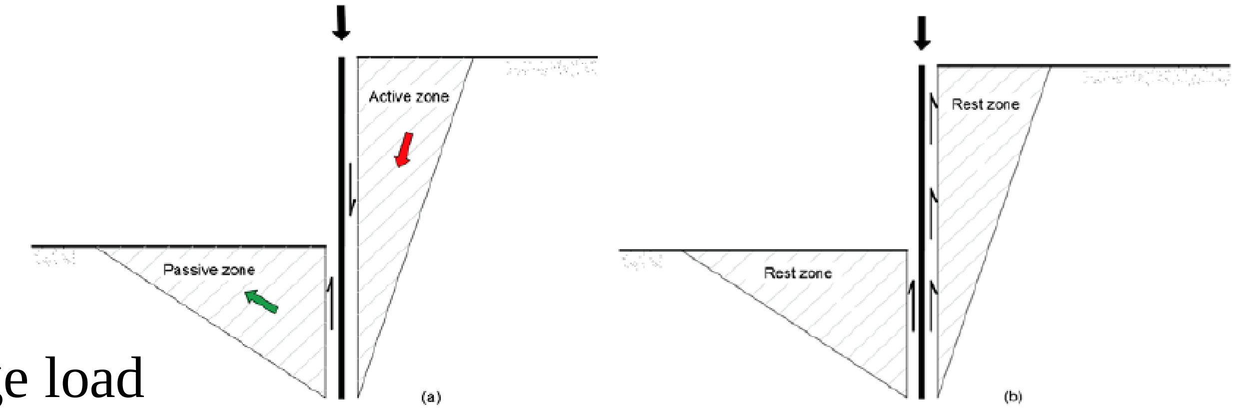
Task 4 - Field testing protocol

Task 2b - Simulation Scenarios

1. Effect of penetration depth and unsupported length



2. Effect of sheet pile wall stiffness
3. Effect of sand relative density and layering
4. Effect of the sheet pile head fixity



5. Effect of surcharge load

Task 2b - Nonlinear FE Program

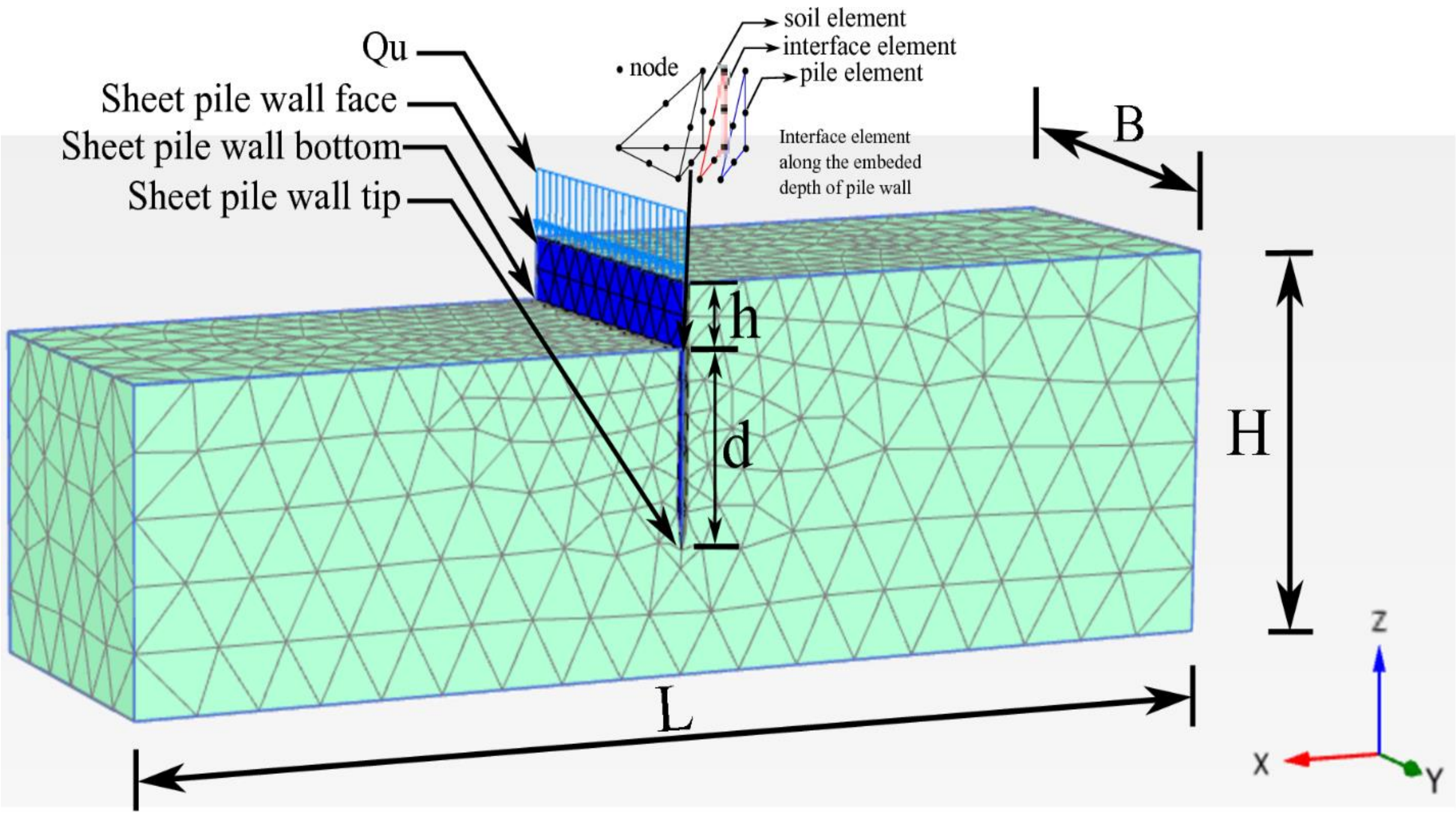


Figure 1. Finite element model for the sheet pile wall

Five scenarios of the numerical analysis through PLAXIS 3D.

Task 2b - Numerical Modeling

- Sands: Elastic-plastic Mohr-Coulomb model by continuum elements
- Sheet pile wall: an elastic model by a structural element
- The interface: Elastic-plastic Mohr-Coulomb model

Table 1. Material properties used in the finite element simulations

Parameter	Sheet pile	Very dense sand	Dense sand	Loose sand	Interface elements
Material model	Elastic	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Young's modulus	438594.12 ksf	2360.1 ksf	2006.1 ksf	1705.2 ksf	/
Cohesion	-	0	0	0	/
Poisson ratio	0.25	0.3	0.3	0.3	/
Friction angle	-	35	32	27	/

Task 2 - Numerical Modeling

- Effect of penetration depth and unsupported length

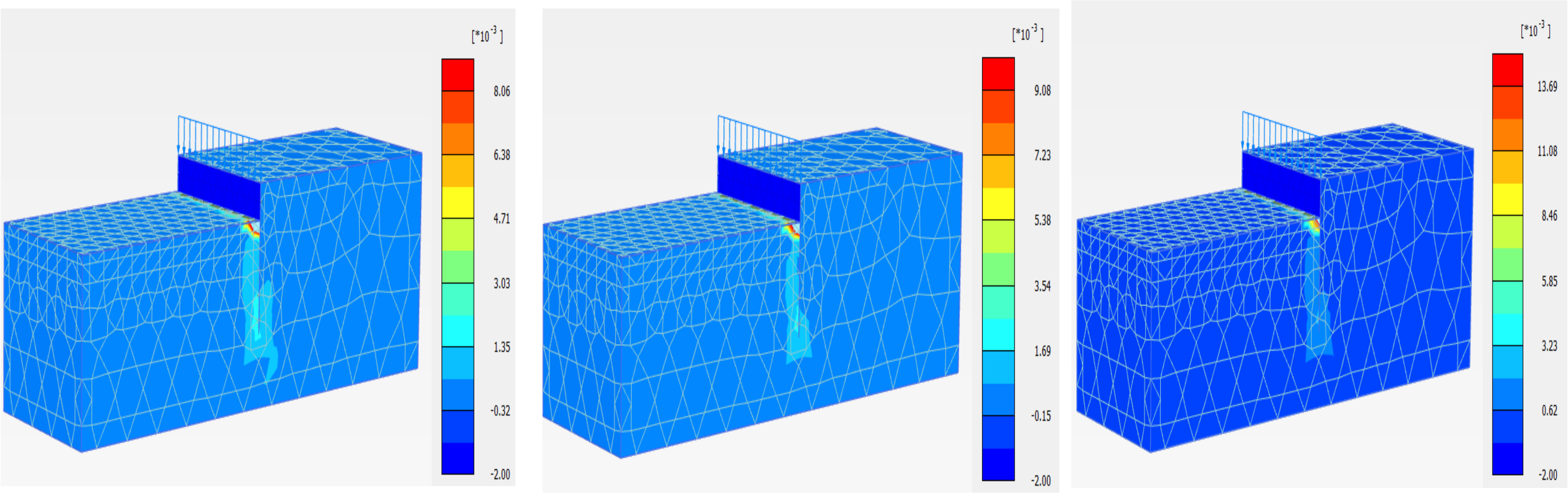


Figure 2. Contour of plastic shear strain for three different sand of d/h = 3 at vertical displacement 0.118in; (left) Very dense sand; (middle) Dense sand; (right) Loose sand.

Task 2 - Numerical Modeling

- Effect of penetration depth and unsupported length

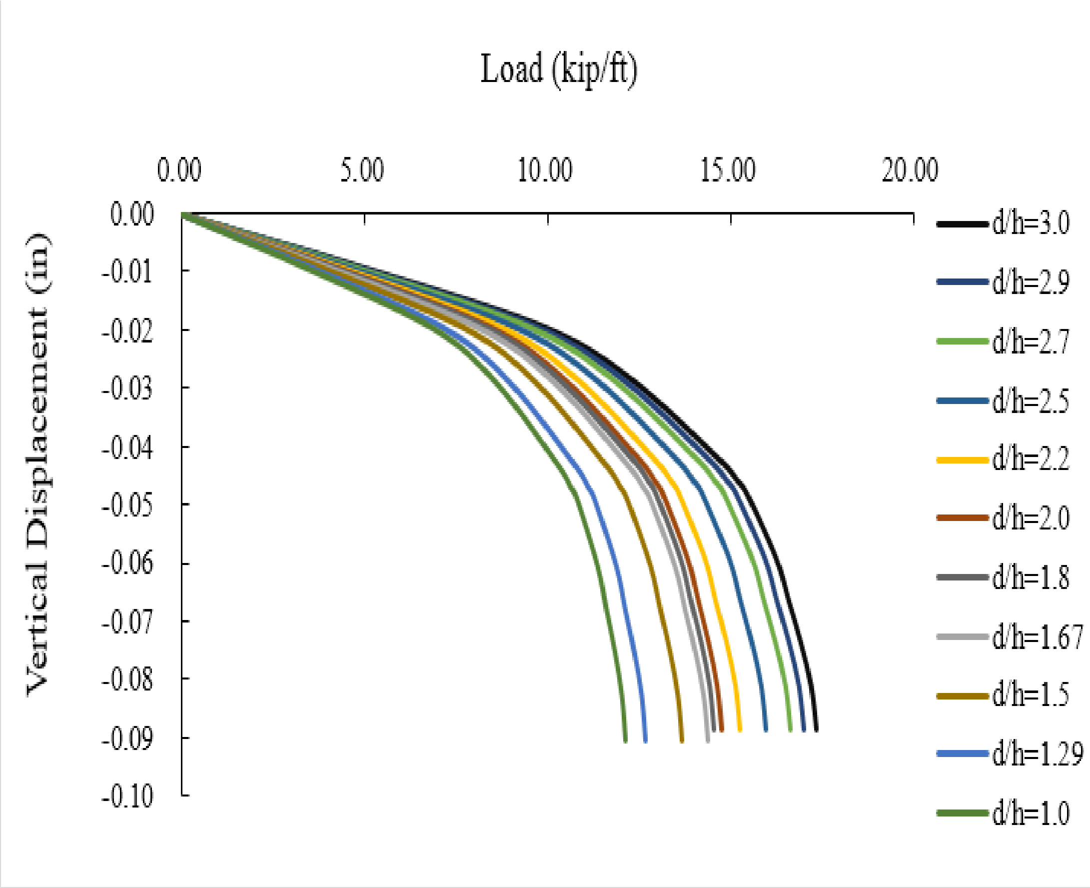


Figure 3. Load versus vertical displacement curve of very dense sand for different ratio of d/h

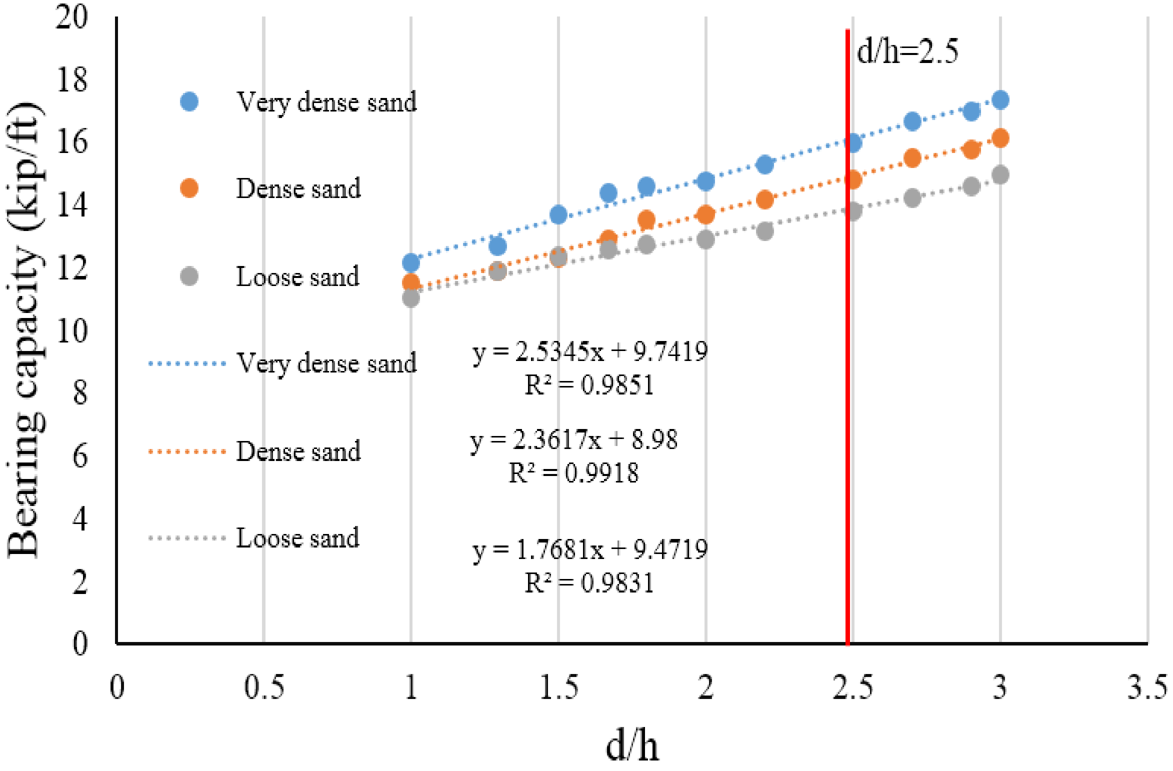


Figure 4. Relationship between the bearing capacity and ratio of d/h

- Effect of sheet pile wall stiffness

(upper) E= $2.1 \times 10^6\ tsf$; (lower) E=$1.0 \times 10^6\ tsf$.

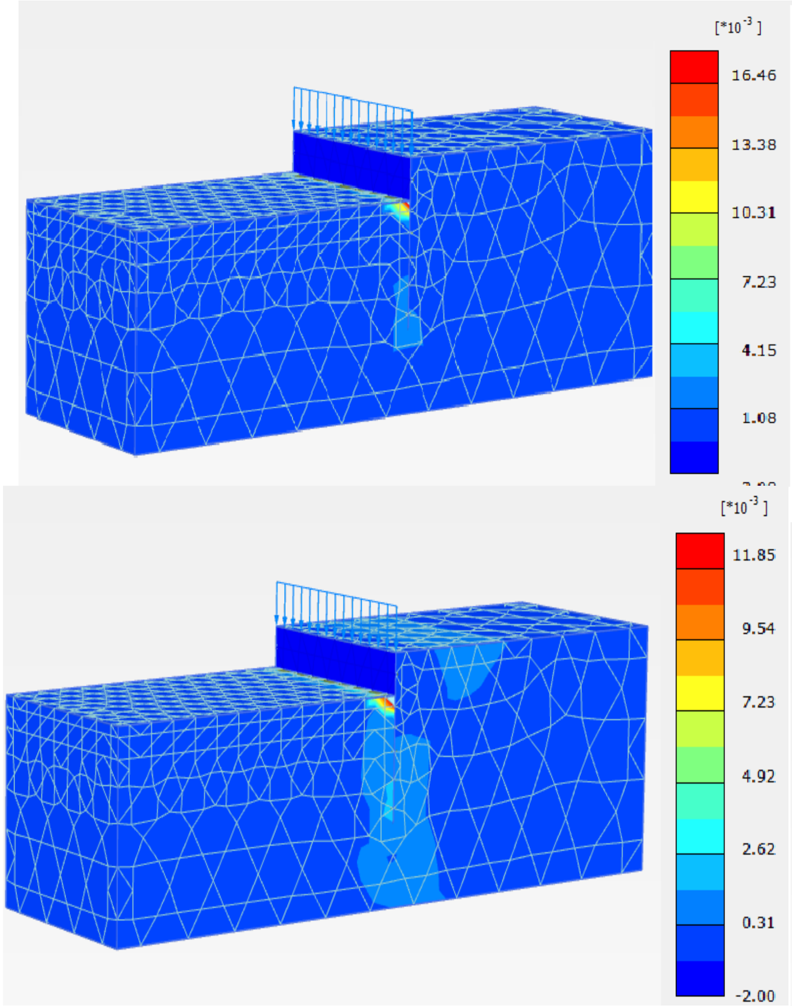


Figure 5. Contour of plastic shear strains for very dense sand

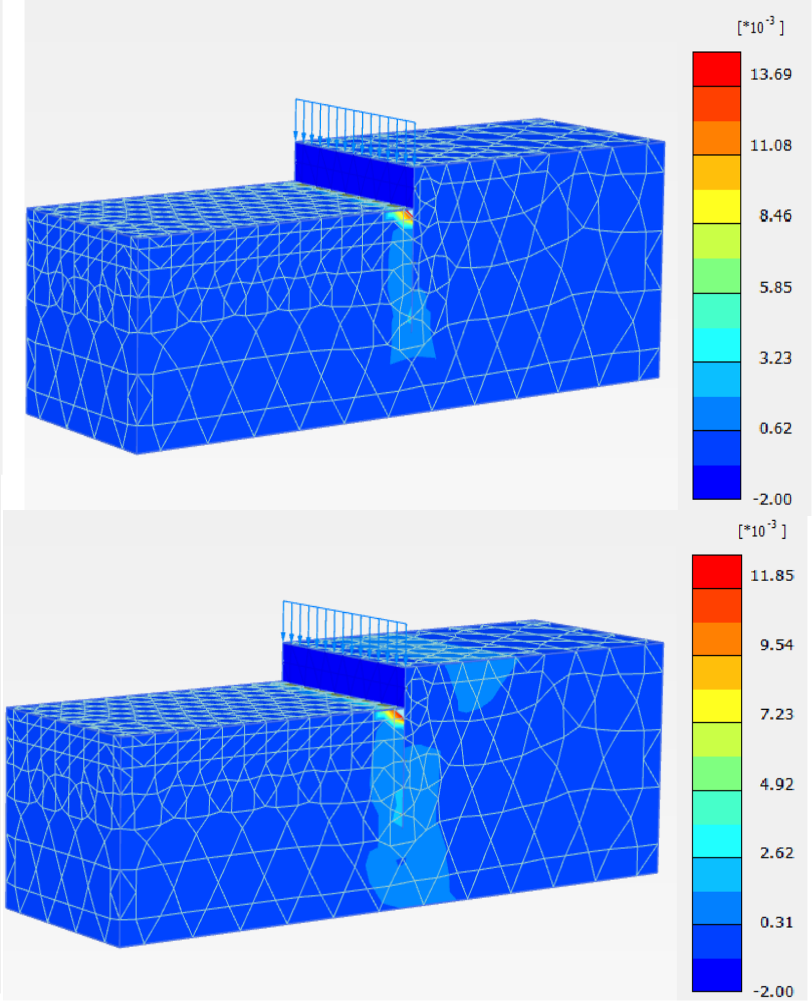


Figure 6. Contour of plastic shear strains for dense sand

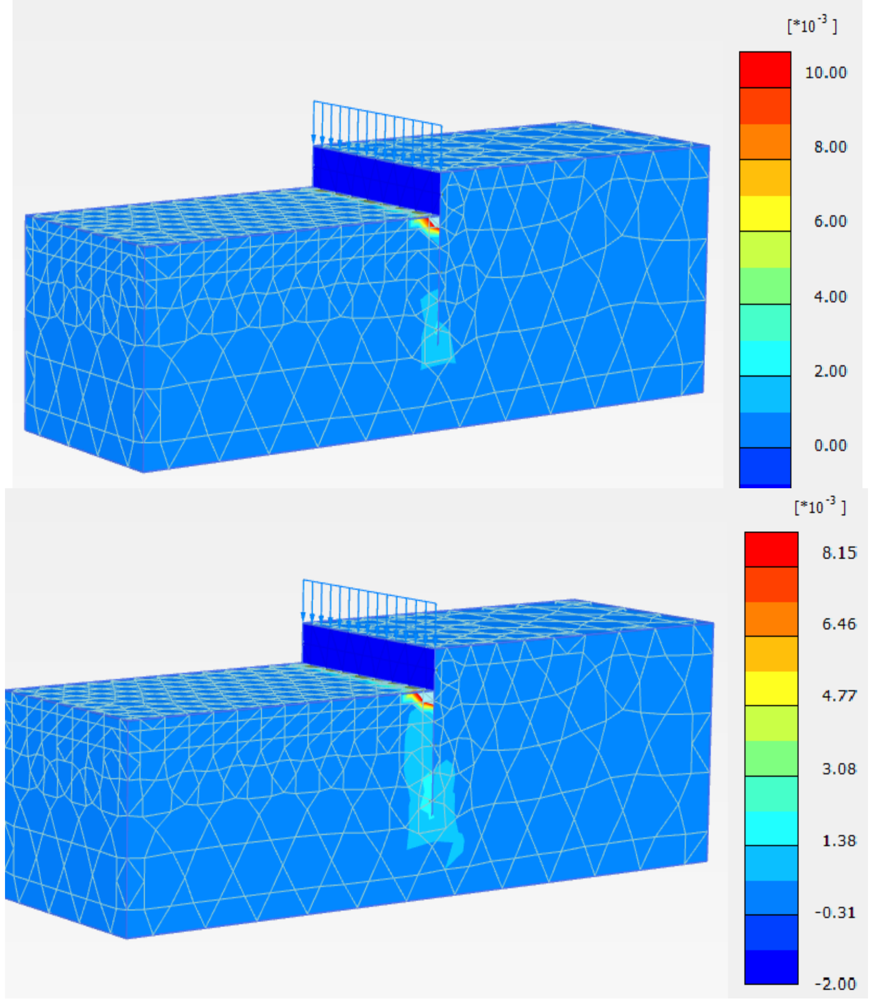


Figure 7. Contour of plastic shear strains for loose sand

- Effect of sheet pile wall stiffness

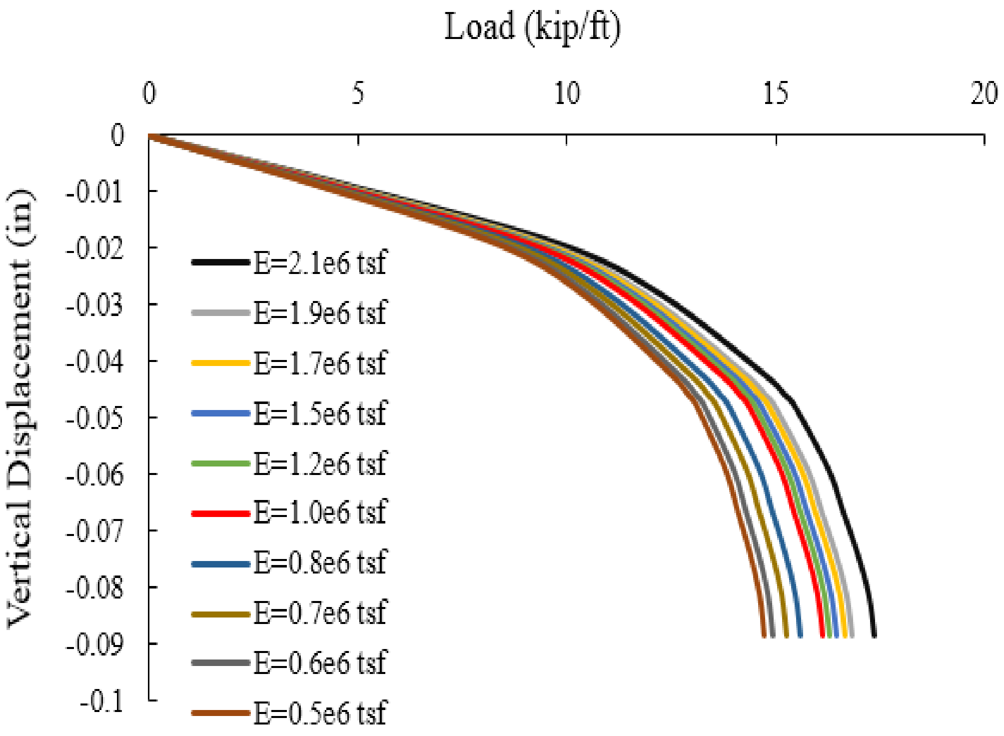


Figure 8. Load versus displacement curve for different Young’s modulus of sheet piles for very dense sand.

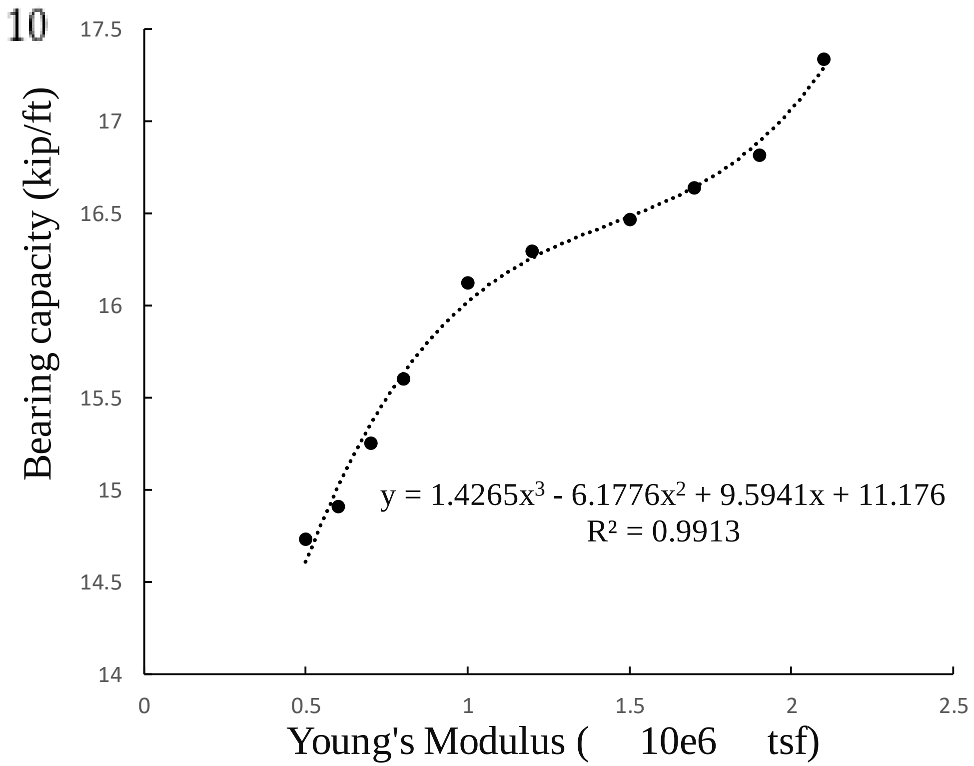


Figure 9. Relationship between the bearing capacity and stiffness of steel

- Effect of surcharge load (design vehicular live load specified in 3.6.1.2 of ASSHTO, 2014)

(upper) Surcharge loading 2,080 psf; (lower) Surcharge loading 4,170 psf

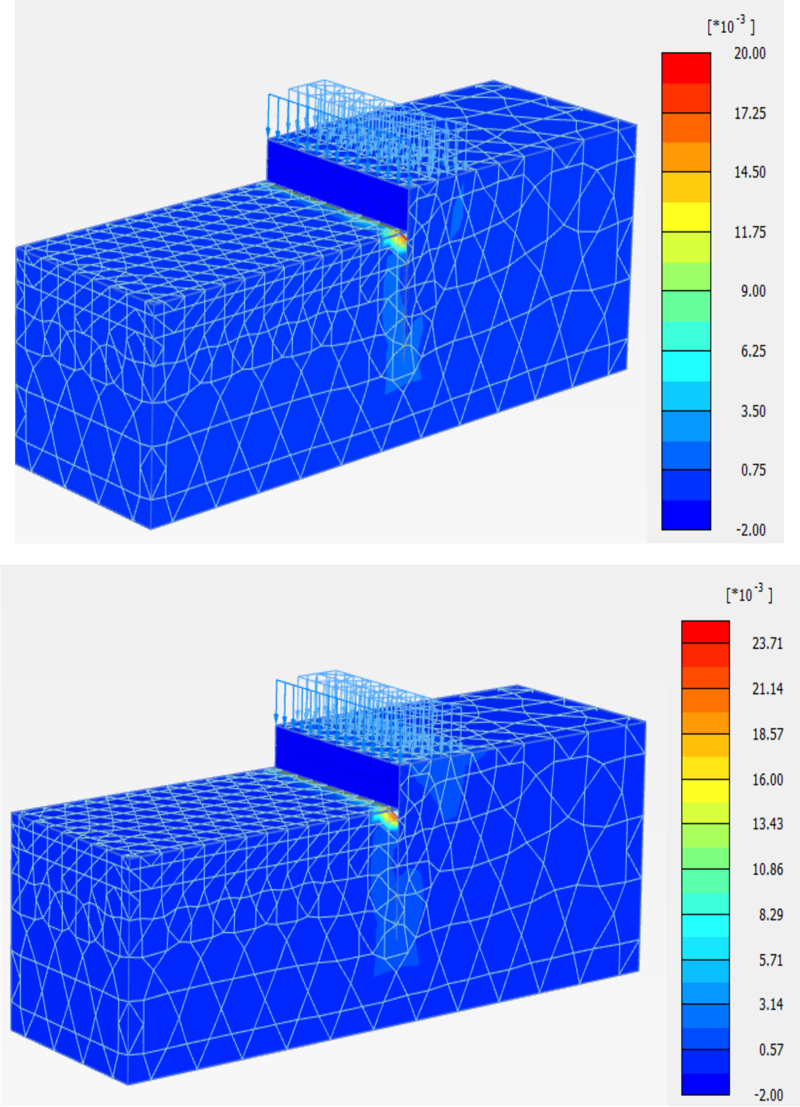


Figure 10. Contours of plastic shear strain in very dense sand

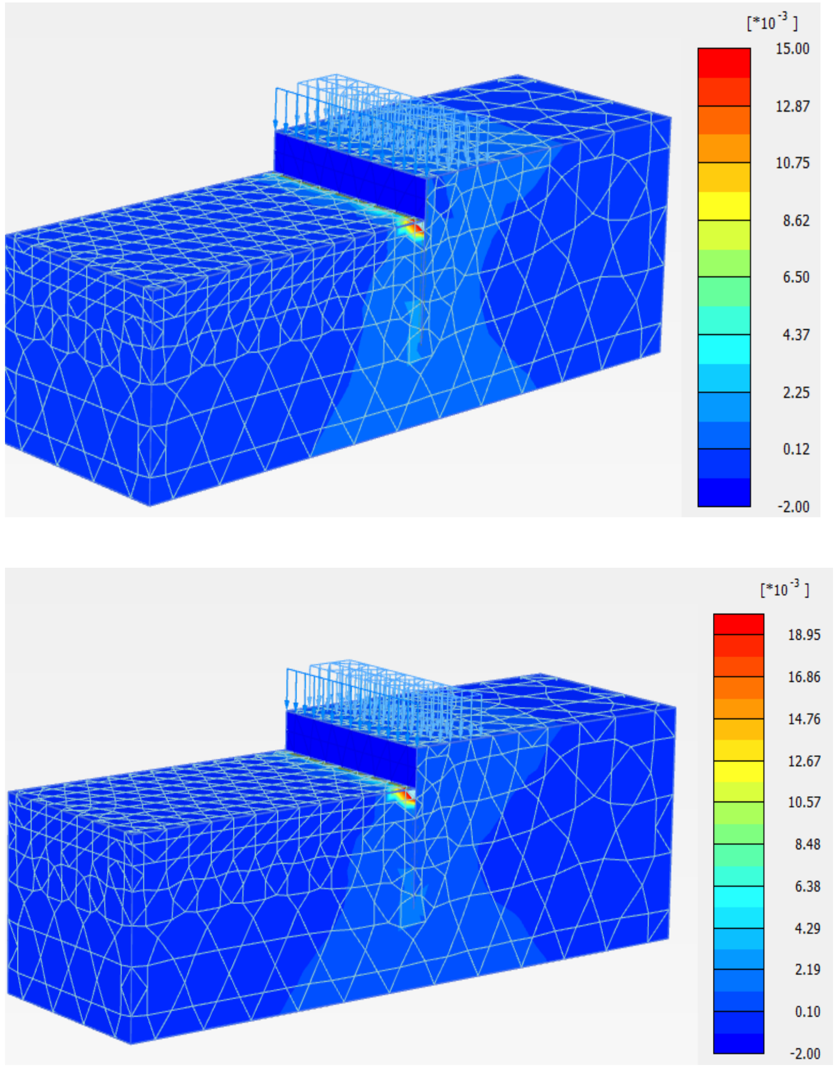


Figure 11. Contours of plastic shear strain in dense sand

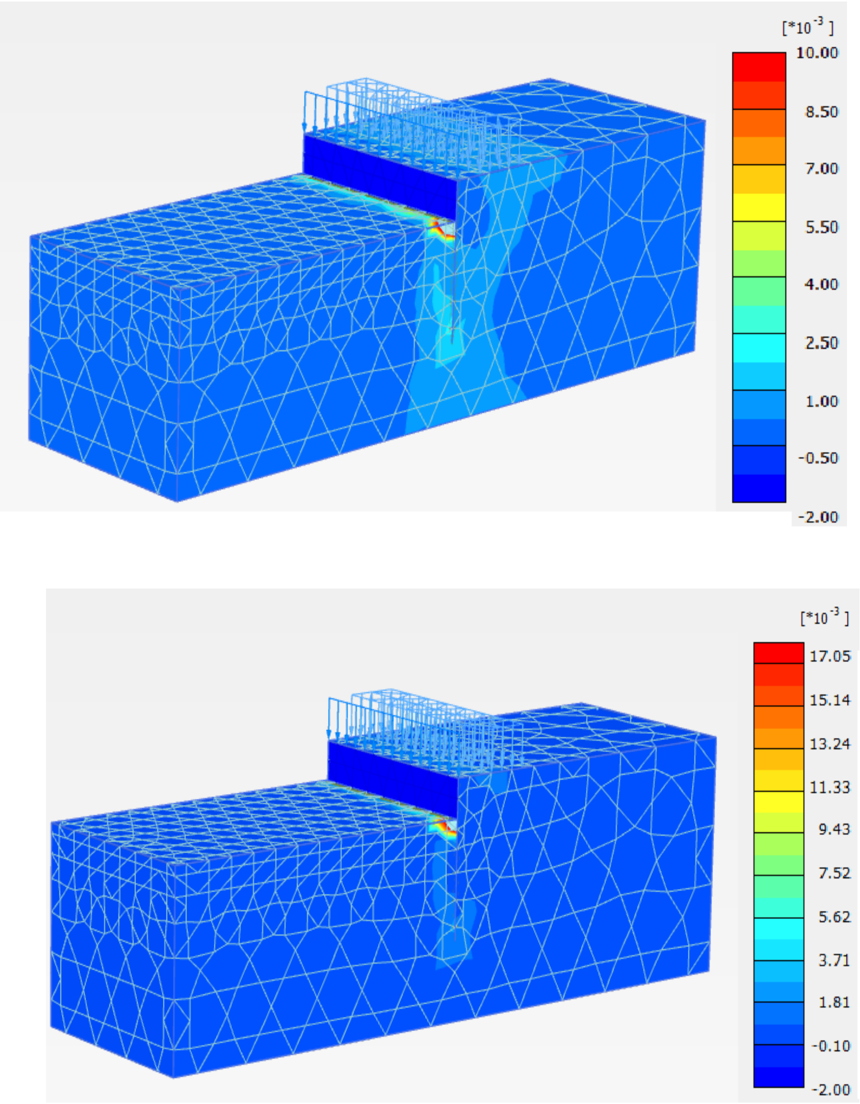


Figure 12. Contours of plastic shear strain in loose sand

Task 2 Numerical Modeling

- Effect of surcharge load

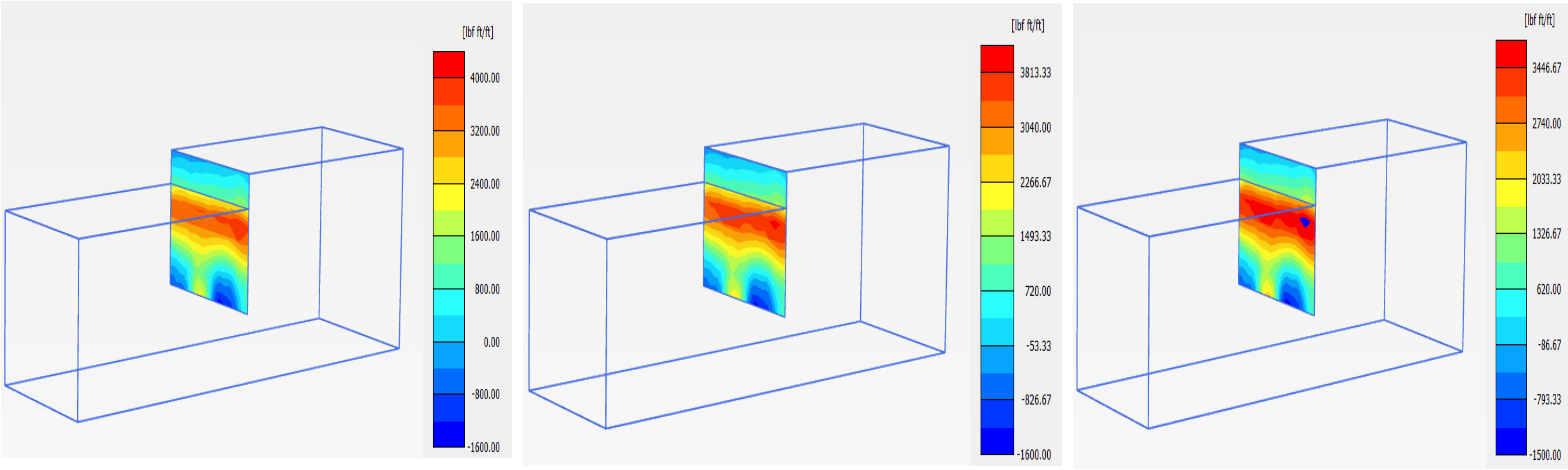


Figure 13. Contours of bending moment (M_{11}) for sheet pile wall under surcharge loading 4,170 psf: (left) Very dense sand; (middle) Dense sand; (right) Loose sand

- Effect of the sheet pile head fixity

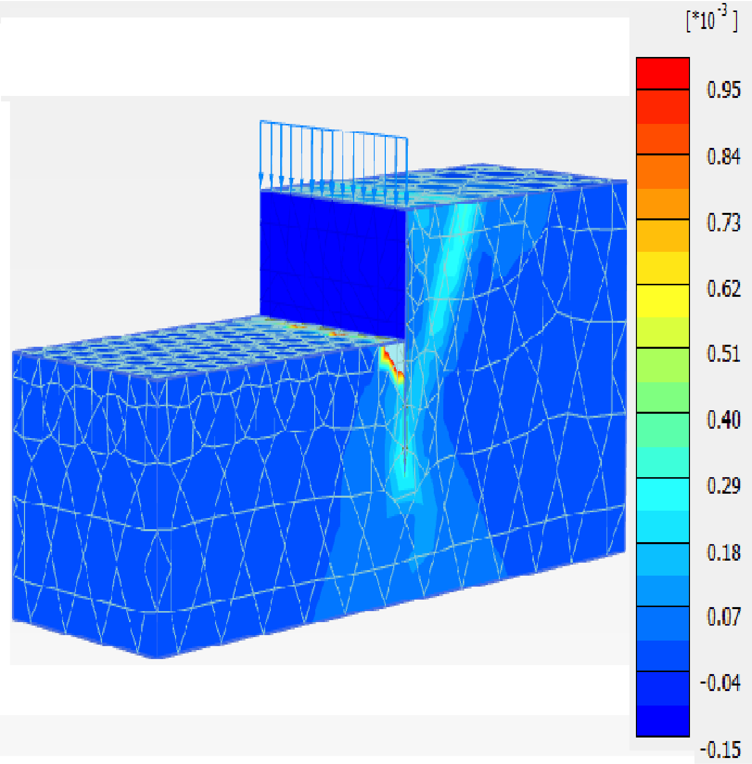


Figure 17. Contour of plastic shear strain for free head condition at d/h = 1

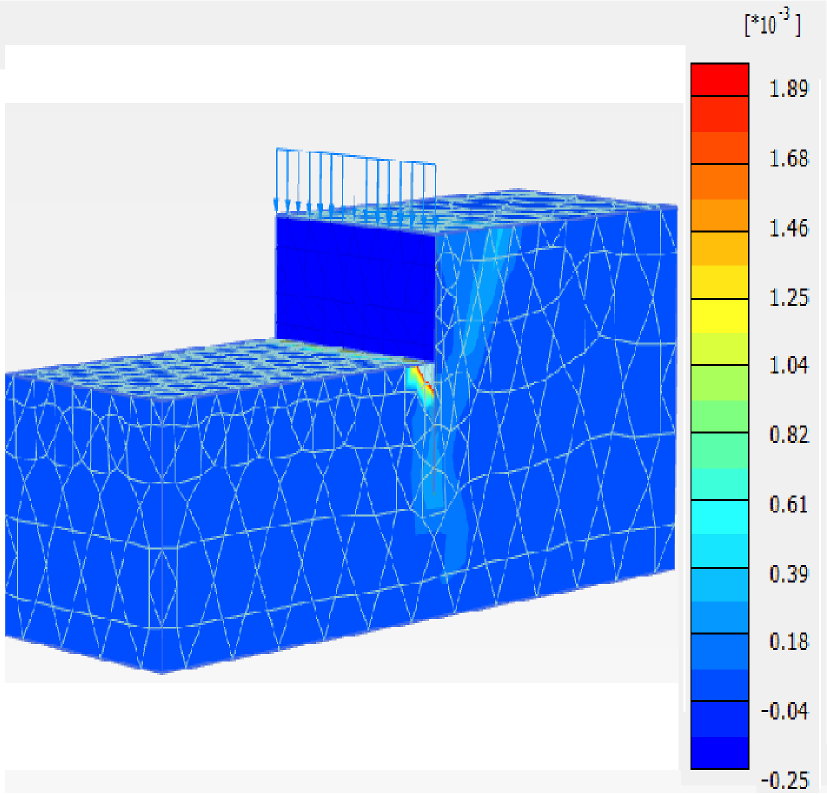


Figure 18. Contour of plastic shear strain for fixed head condition at d/h = 1

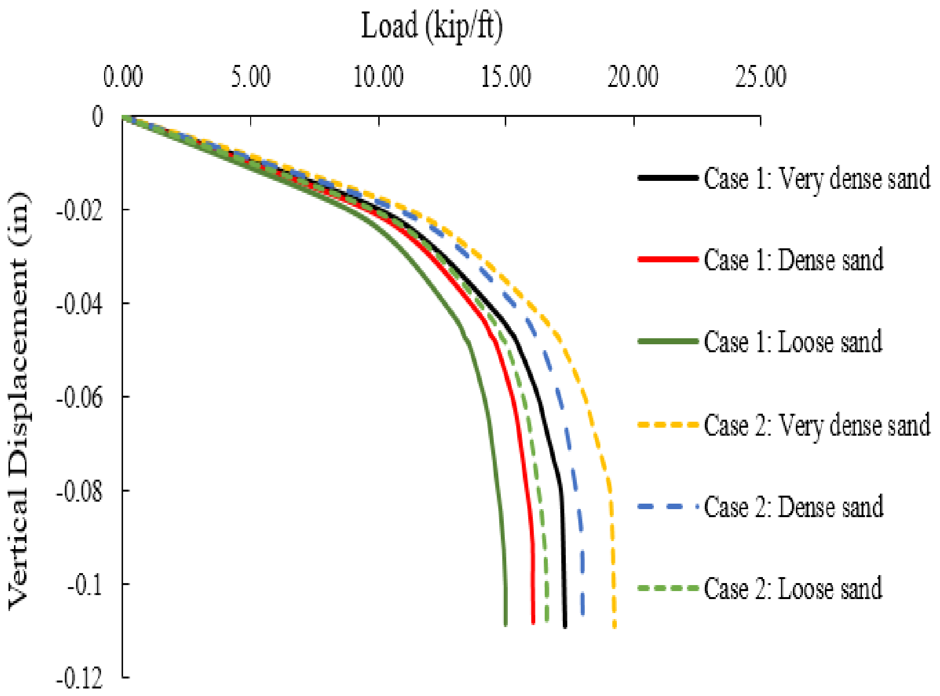
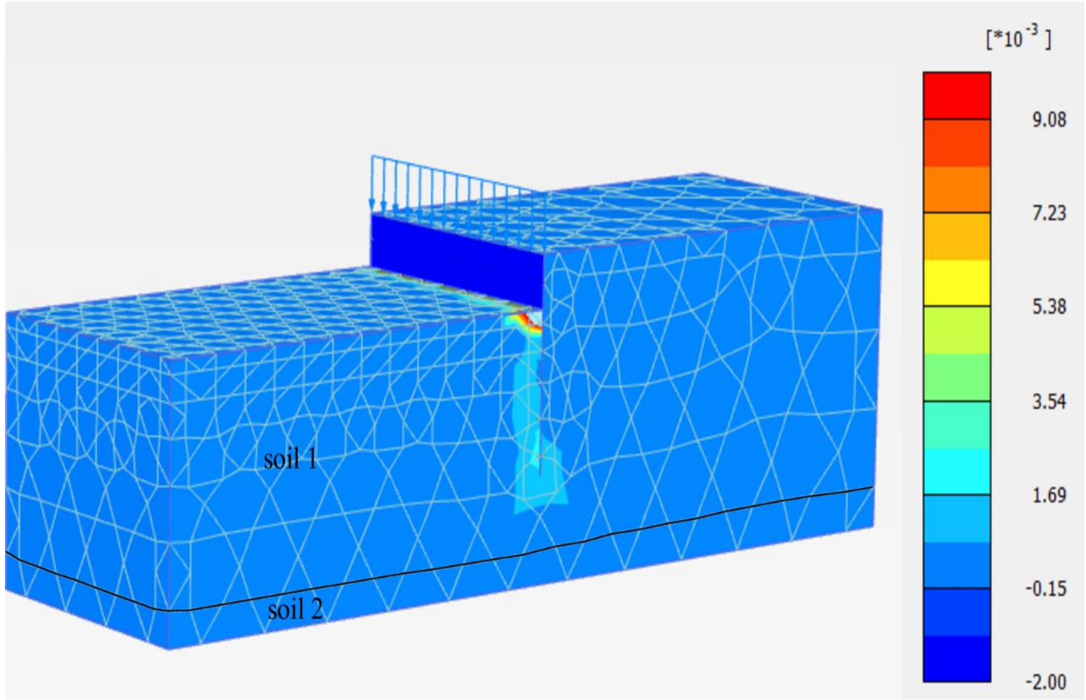


Figure 19. Load versus vertical displacement curve of different density sand at ratio of d/h=1: Case 1 for the free head condition and Case 2 for the fixed head condition

Task 2 - Numerical Modeling

- Effect of sand relative density and layering



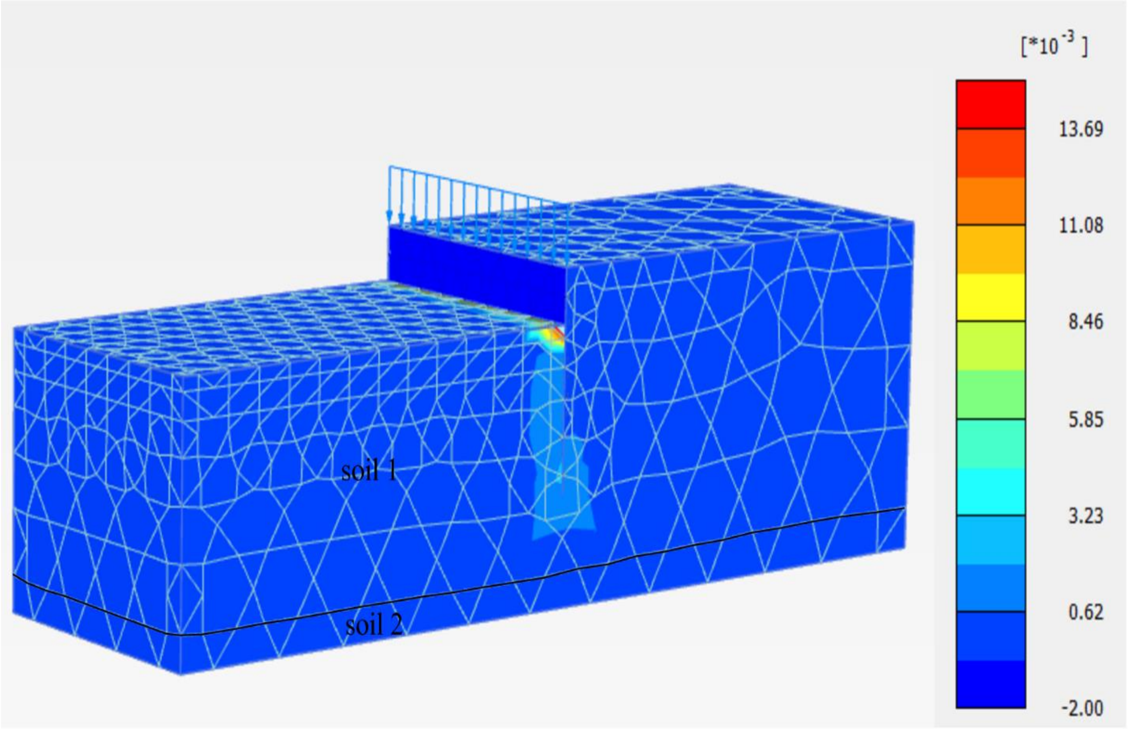


Figure 20. Contour of plastic shear strains for top dense sand d/h = 3 at vertical displacement 0.104 in

Figure 21. Contour of plastic shear strains for top loose sand d/h = 3 at vertical displacement 0.104 in

Task 2 - Numerical Modeling

- Effect of sand relative density and layering

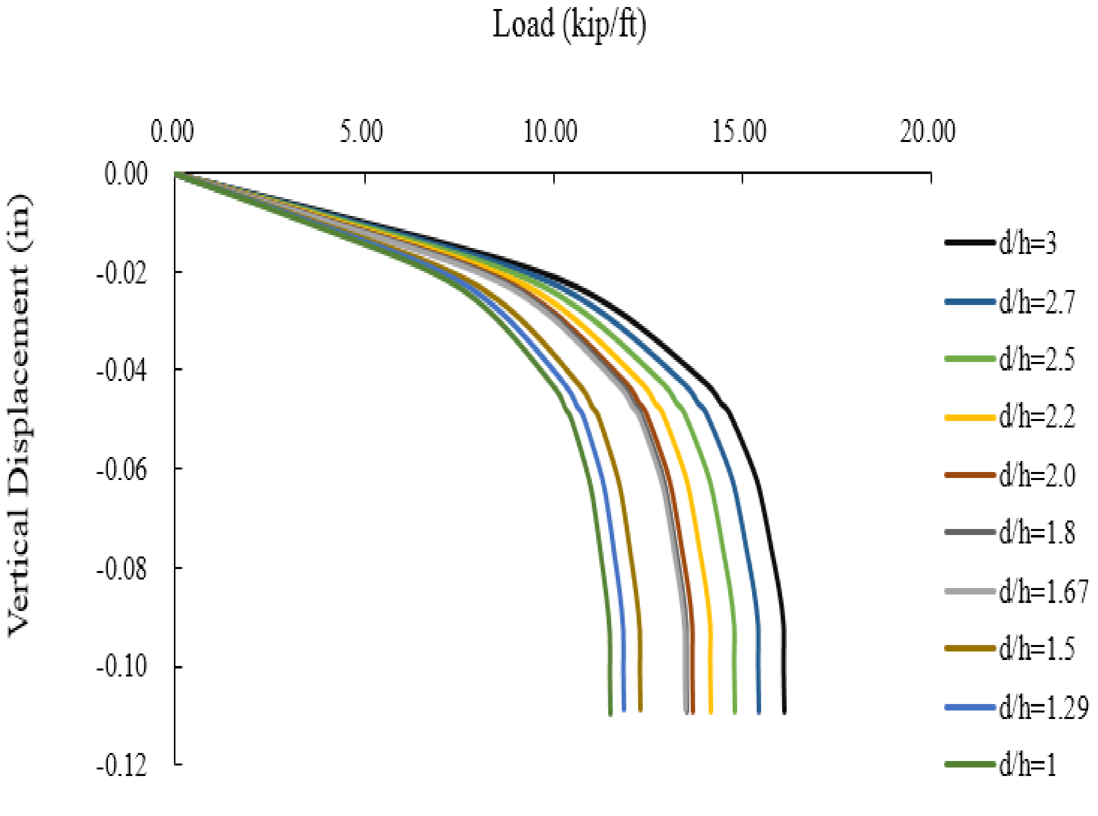


Figure 22. Load versus vertical displacement curve of top dense sand layer for different ratio of d/h

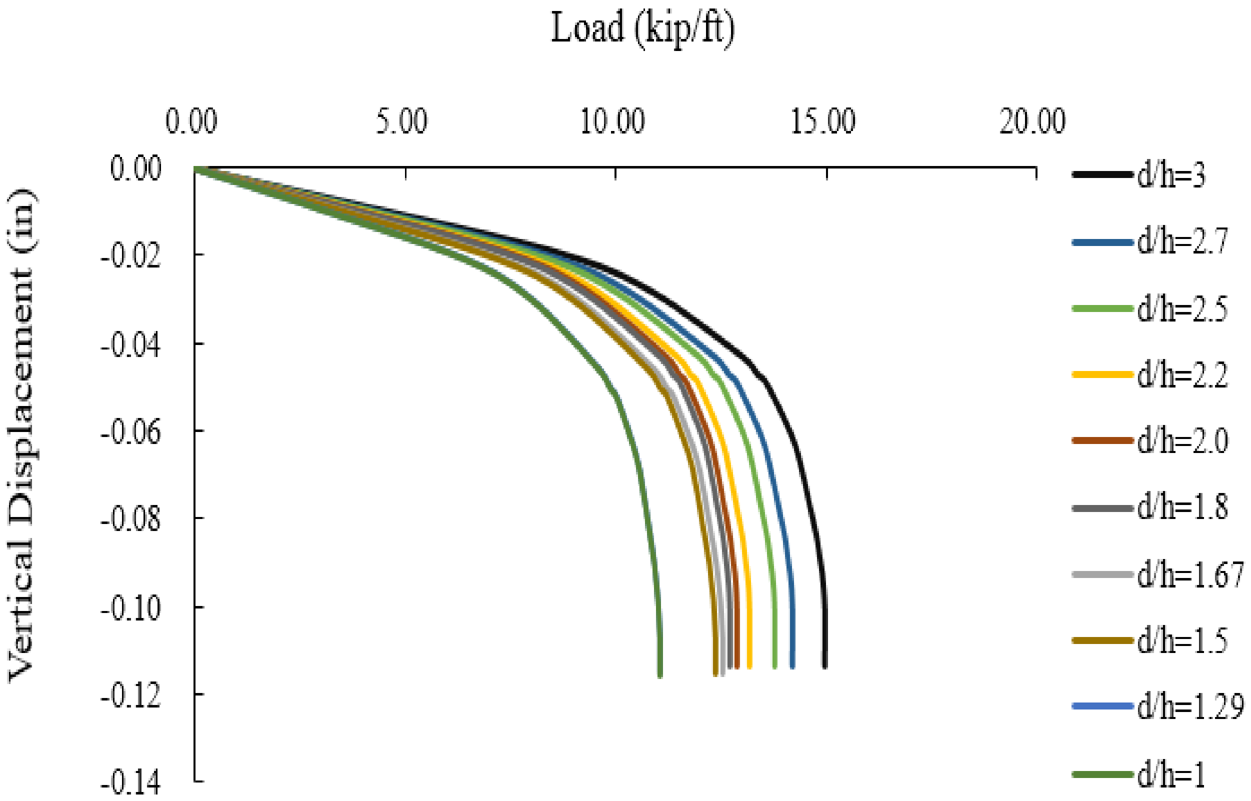


Figure 23. Load versus vertical displacement curve of top loose sand layer for different ratio of d/h

Task 2 - Numerical Modeling

- Effect of sand relative density and layering

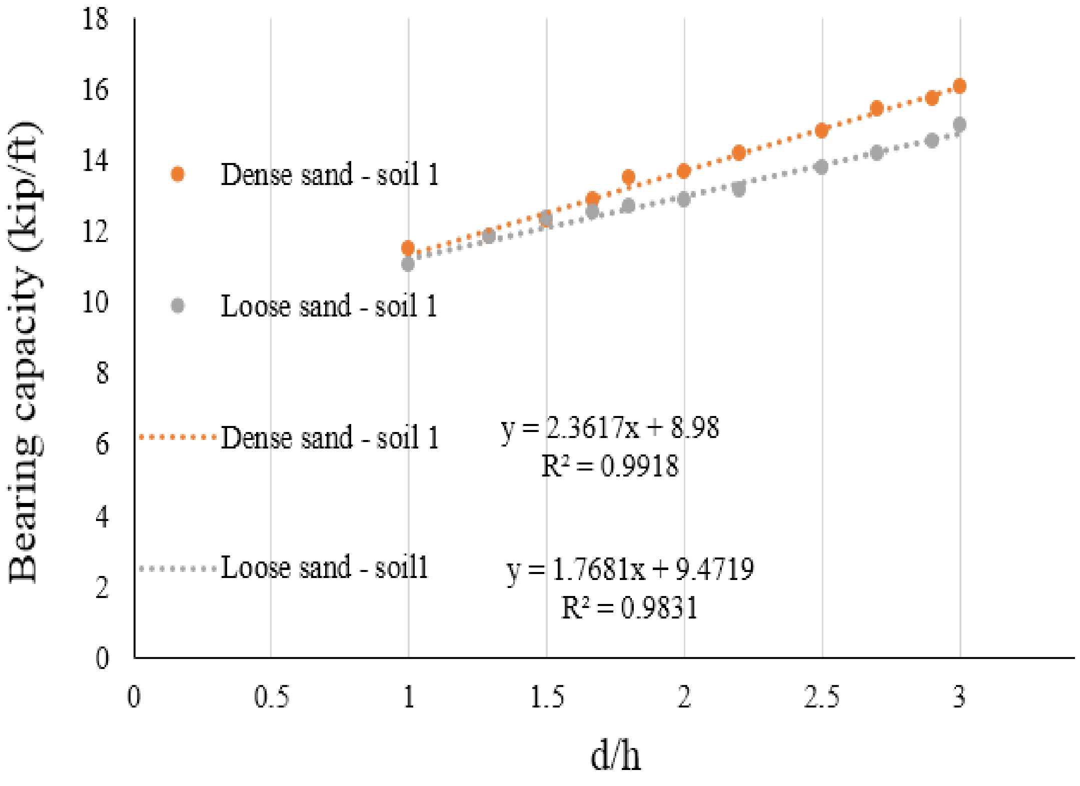


Figure 24. Relationship between the bearing capacity and ratio of d/h for two layers

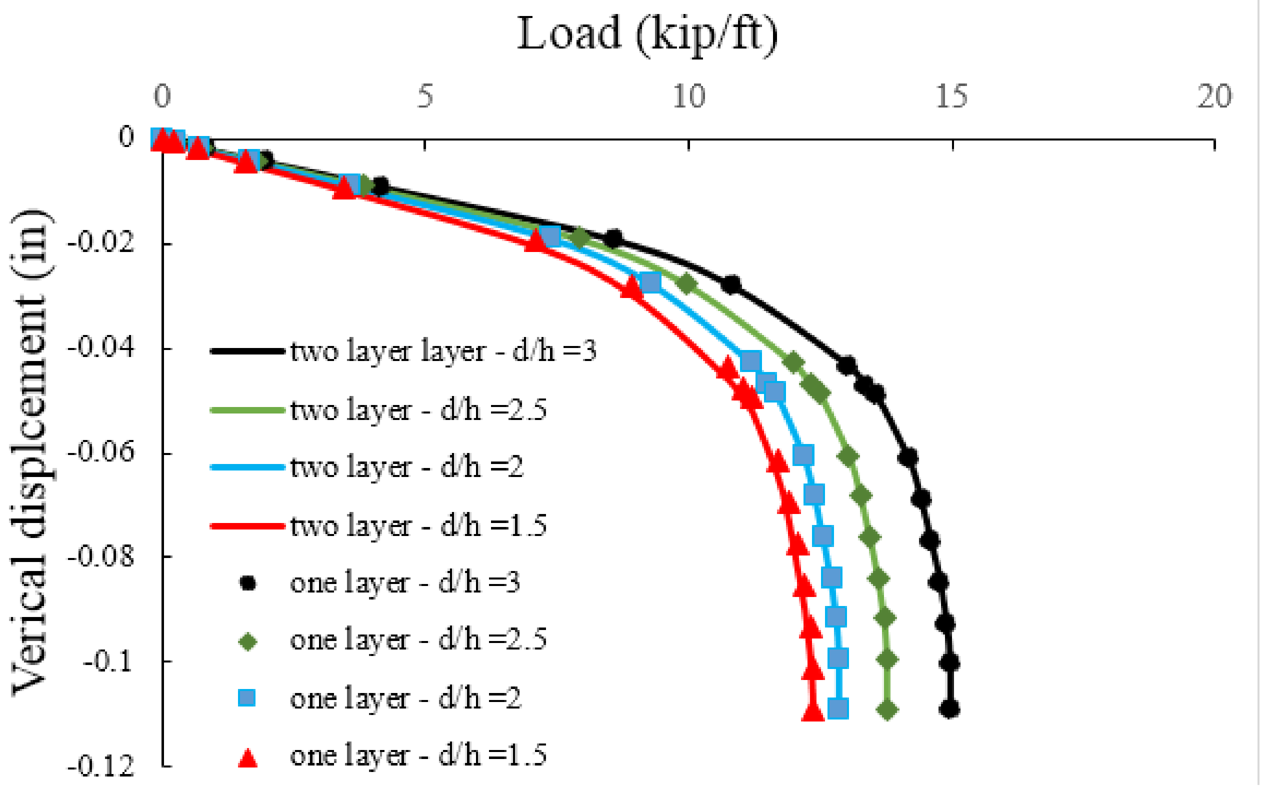


Figure 25. Comparison of load versus vertical displacement curve of loose sand as top layer for one-layer and two-layer systems.

Task 3 – Centrifuge Testing

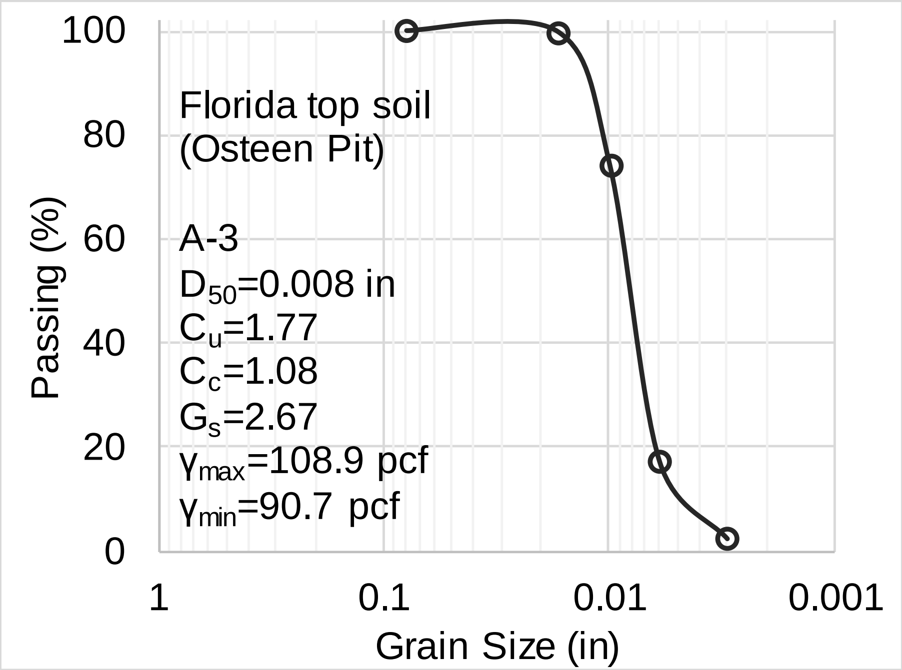
- Understand the behavior of axially loaded sheet pile walls through investigating the effects of

  - - *sand relative density and soil layering,*
  - - *sheet pile wall penetration depth,*
  - - *sheet pile wall head boundary conditions,*
  - - *rate effects during load testing, and*
  - - *sheet pile wall stiffness*

- Validate numerical models

Task 3 – Centrifuge Testing

- Soil properties



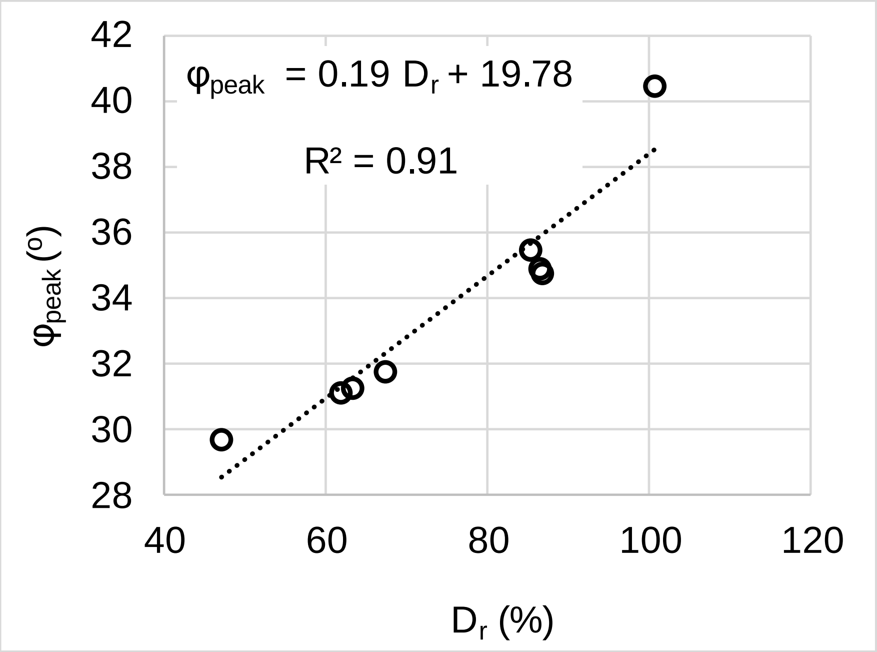
Target relative densities of FL sand (by pluviation) = 60% and 90%

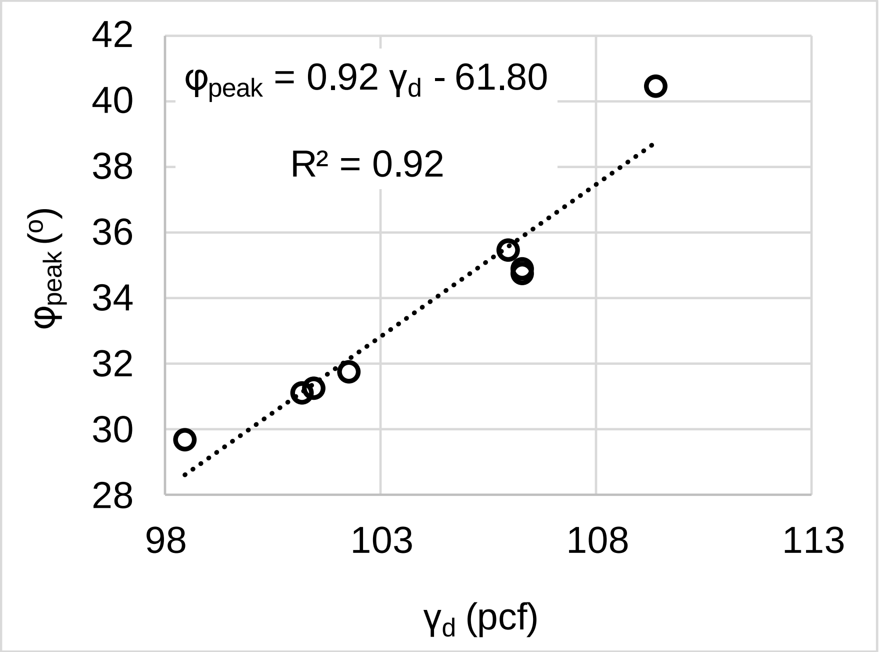
UF centrifuge:

Radius = 1.5 m; Test Acceleration = 50 g

Task 3 – Centrifuge Testing

- Direct shear tests on sand

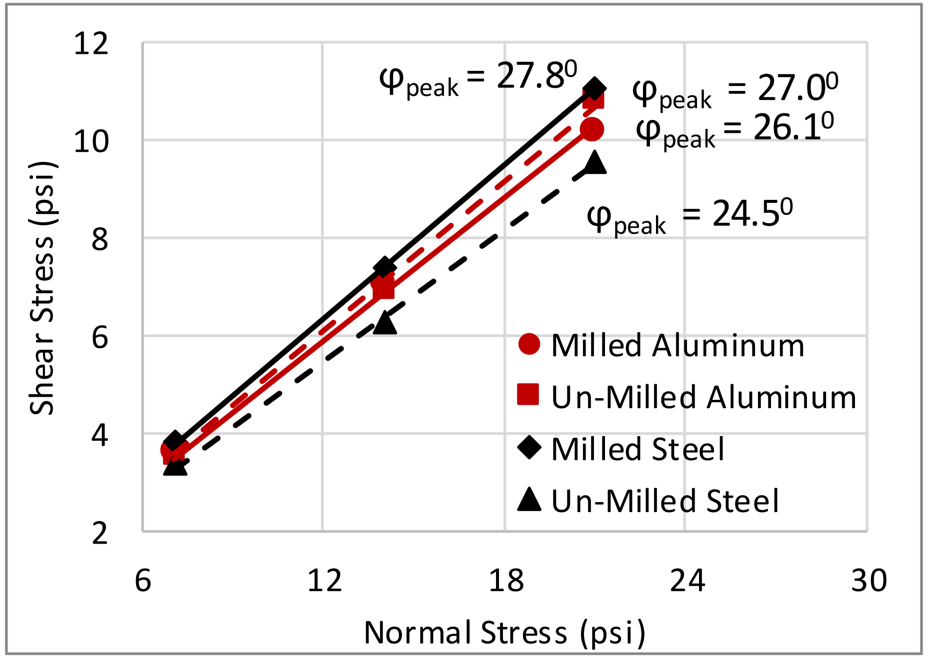




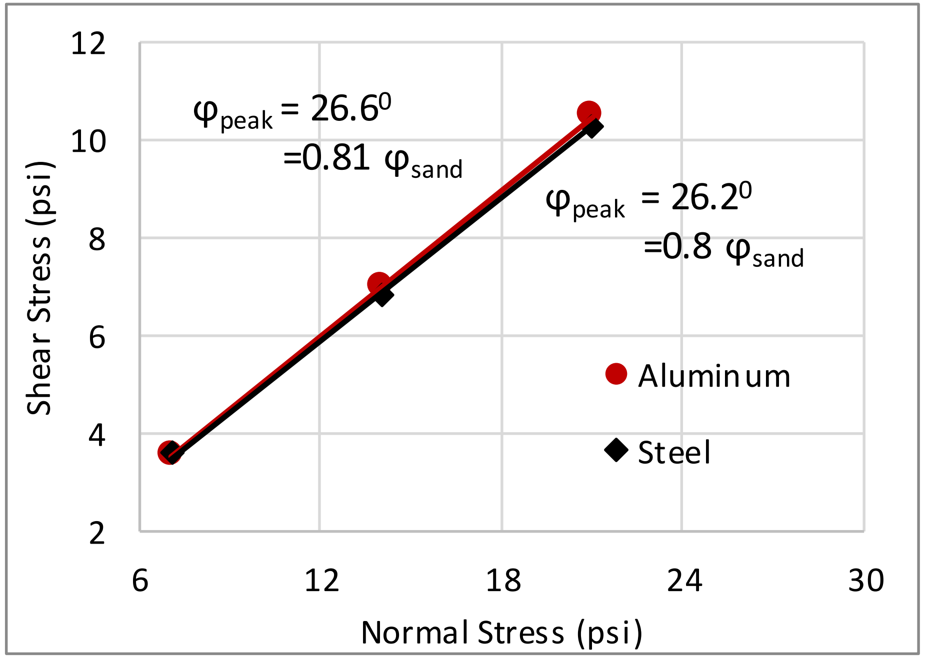
Task 3 – Centrifuge Testing

- Shear-box tests on sand-structure interface

D_r (%) = 67; w (%) = 12



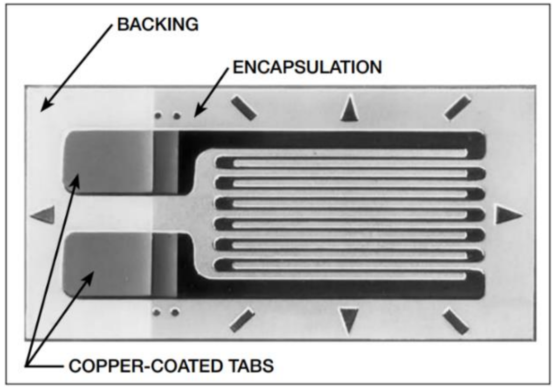
Tests on "milled" and "un-milled" plates



Average values

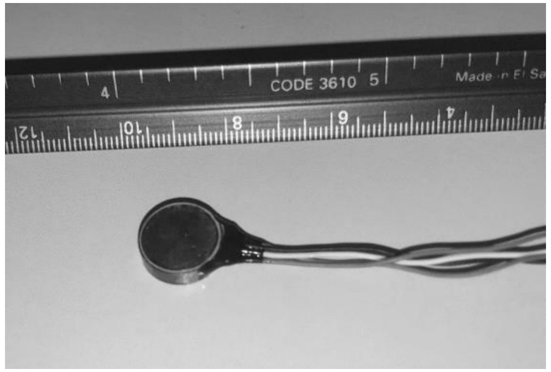
Task 3 – Centrifuge Testing

- Instrumentation



Strain Gage

Linear Potentiometer

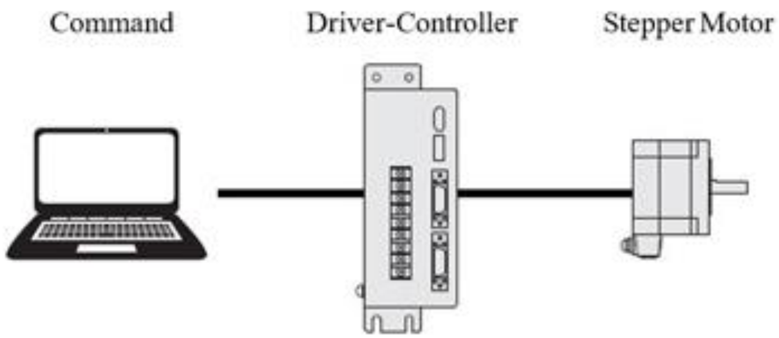


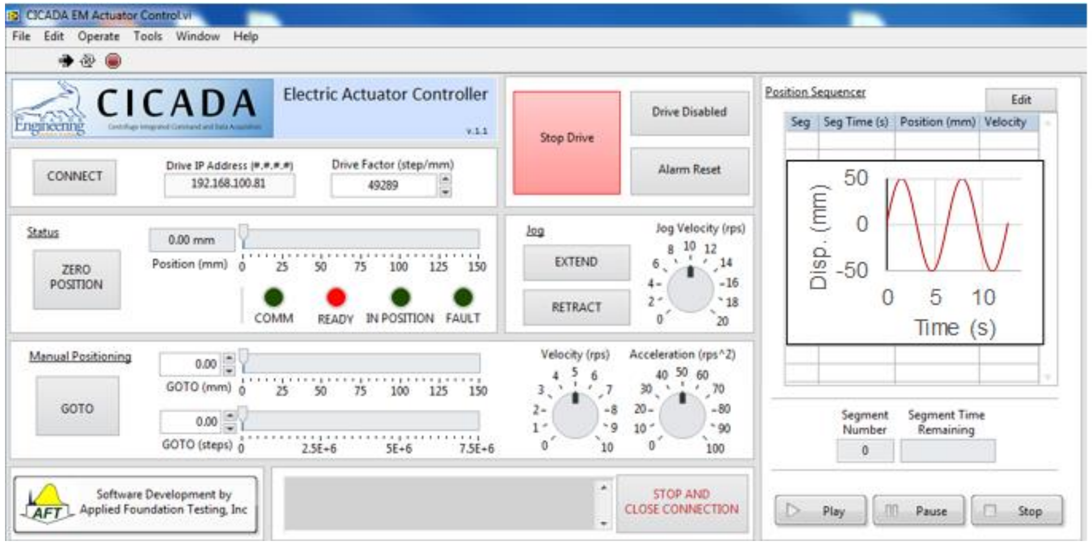
Pressure Sensor

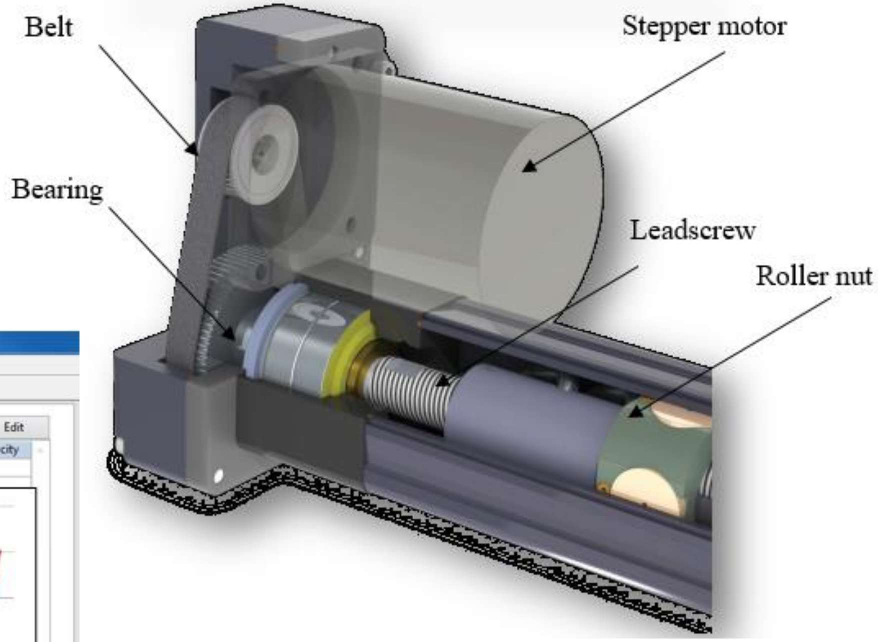
Custom-Designed
Load Cell

Task 3 – Centrifuge Testing

- Custom-designed electric linear actuator



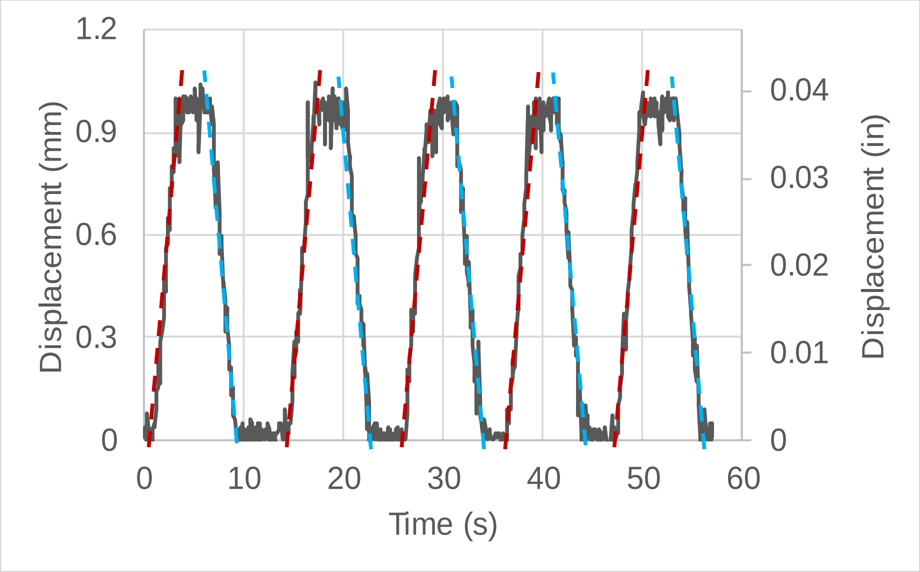


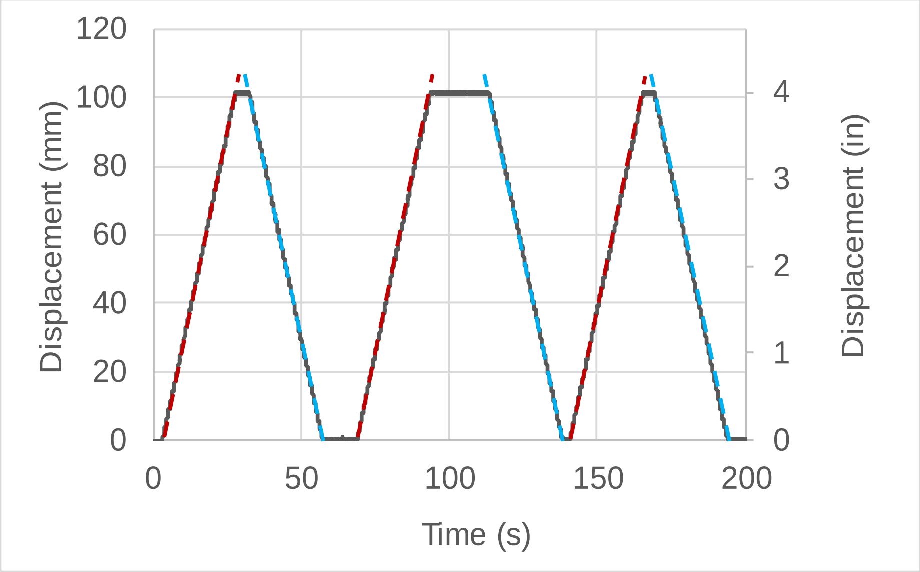


Produced Force ≈ 4000 lb;
Actuator Stroke = 6 in

Task 3 – Centrifuge Testing

- Actuator feedback





Actuator feedback during centrifuge tests performed at 50-g: results are presented in model-scale with target amplitude of 1.00 and 100 mm

Task 3 – Centrifuge Testing

- Helmet

Field

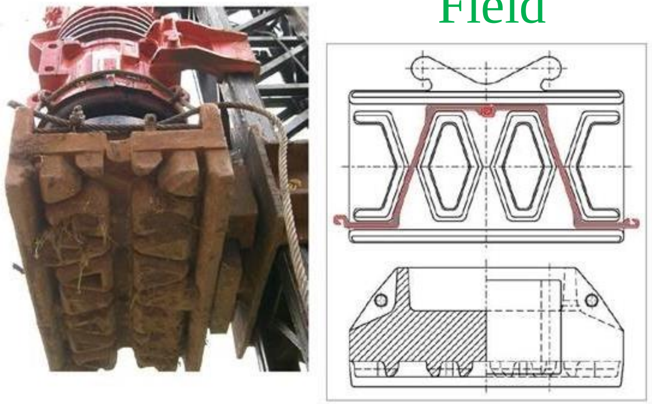
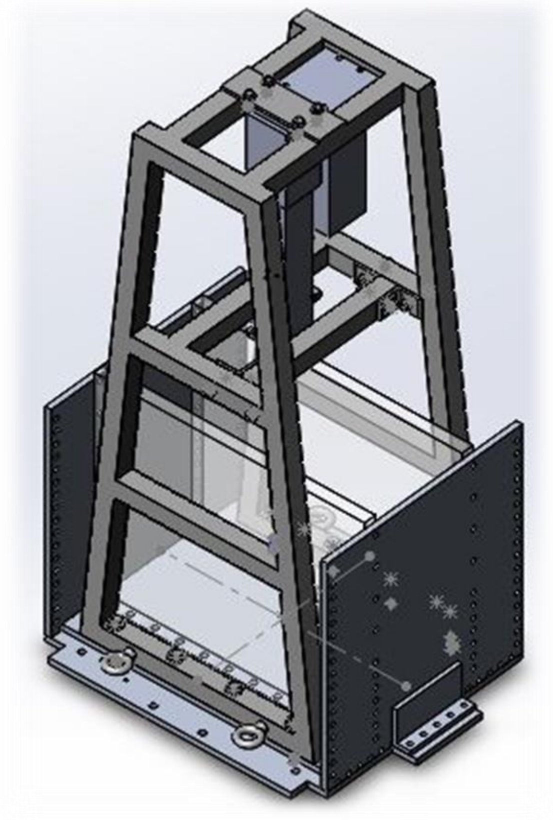


Photo Courtesy of GRL Engineers, Inc.

Centrifuge

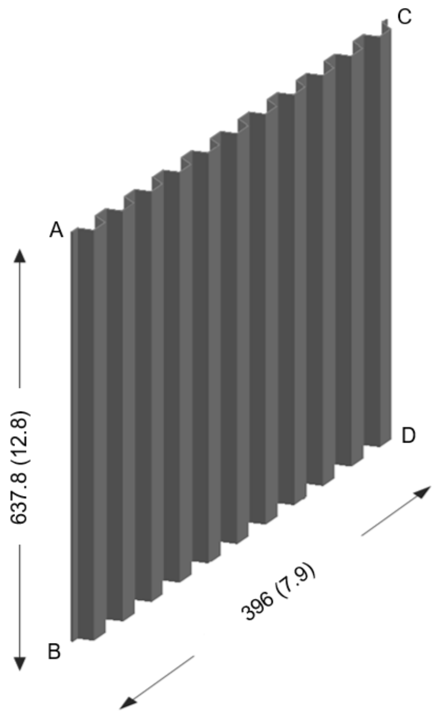
- Frame

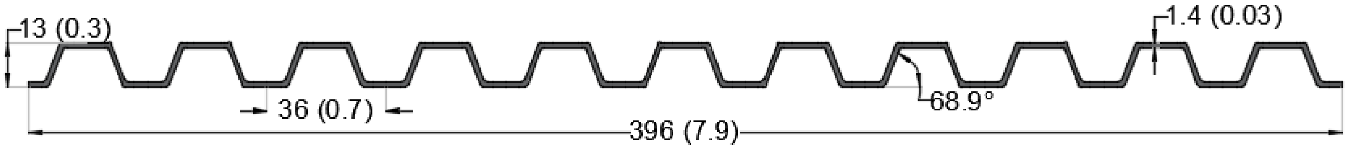


Task 3 – Centrifuge Testing

- Sheet pile wall machining

- Computer Numerical Control (CNC) machines are used to cut aluminum sheets in the desired dimensions and geometry.

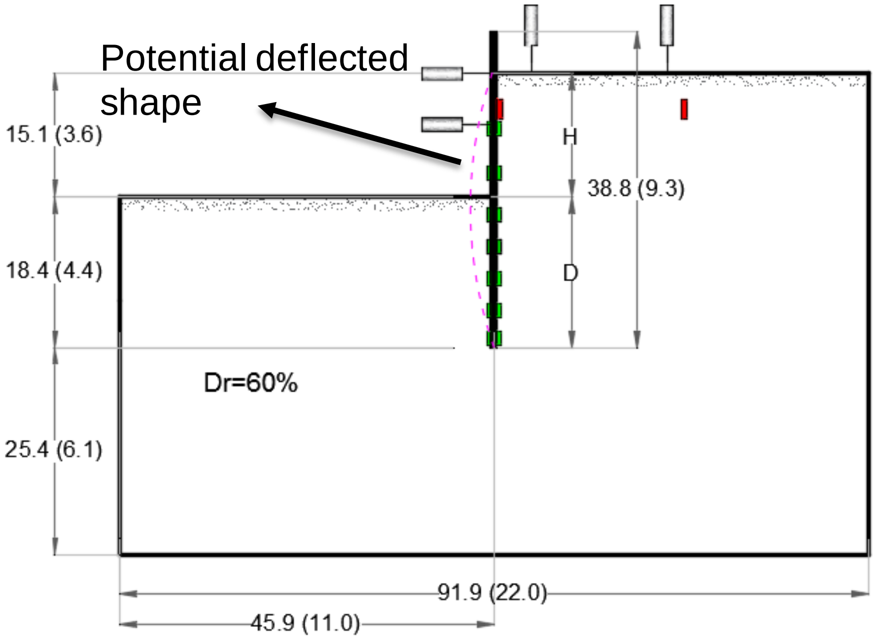


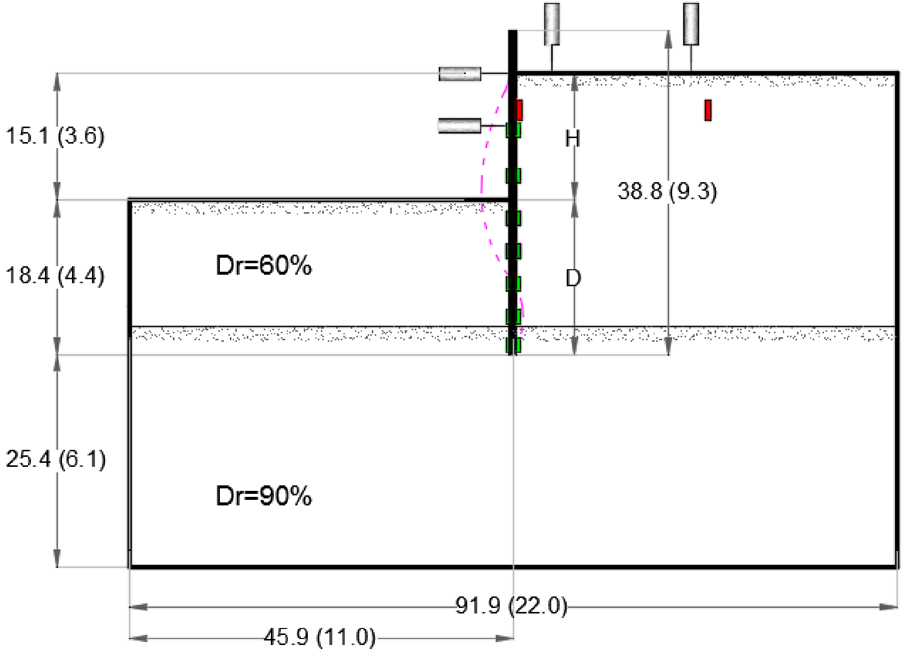


Dimensions in inches at prototype-scale (and in model-scale)

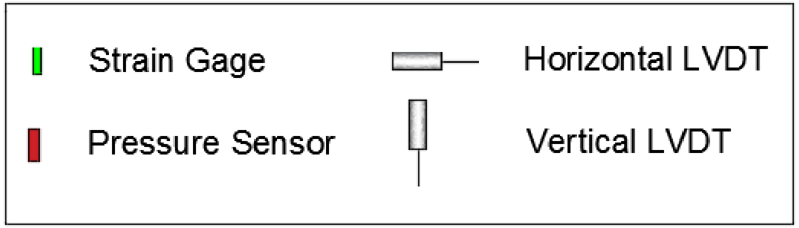
Task 3 – Centrifuge Testing

I) Axial load transferring mechanism



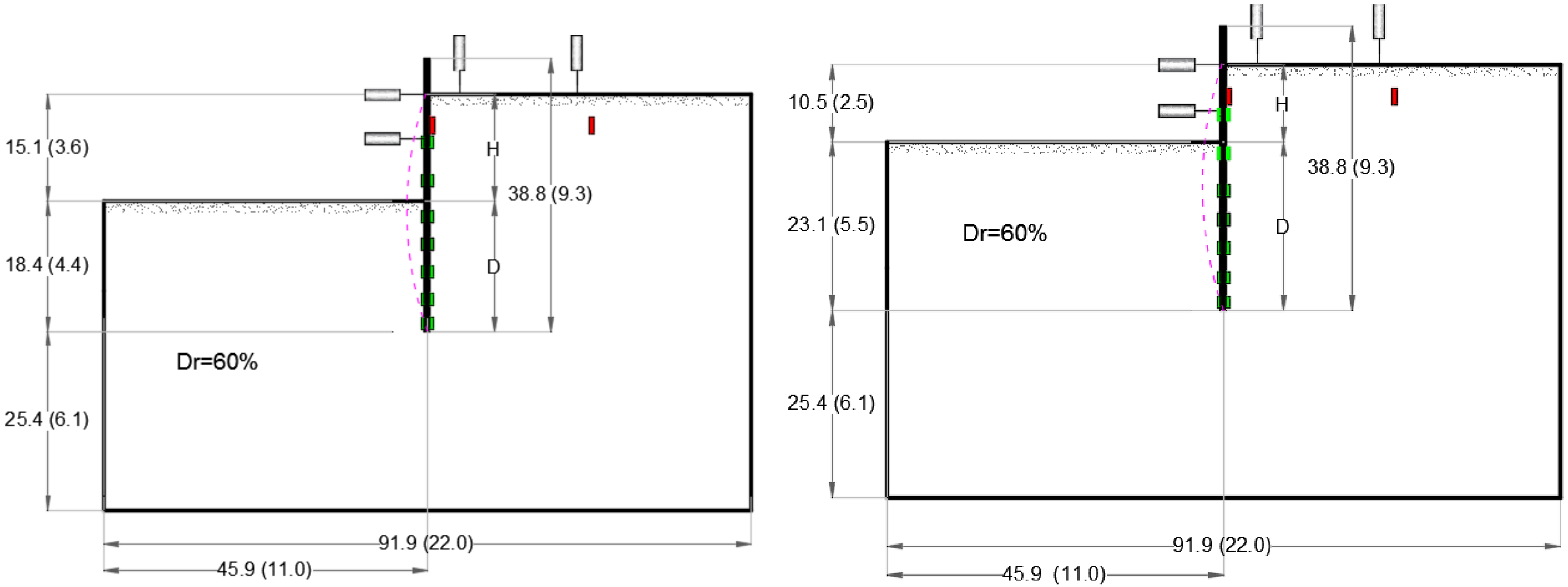


Dimensions in feet at prototype-scale (and inches in model-scale)

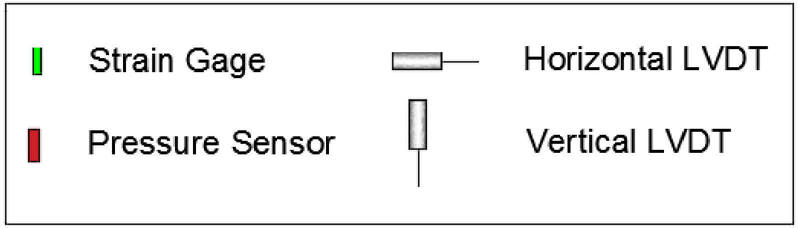


Task 3 – Centrifuge Testing

II) Penetration depth and unsupported length



Dimensions in feet at prototype-scale (and inches in model-scale)

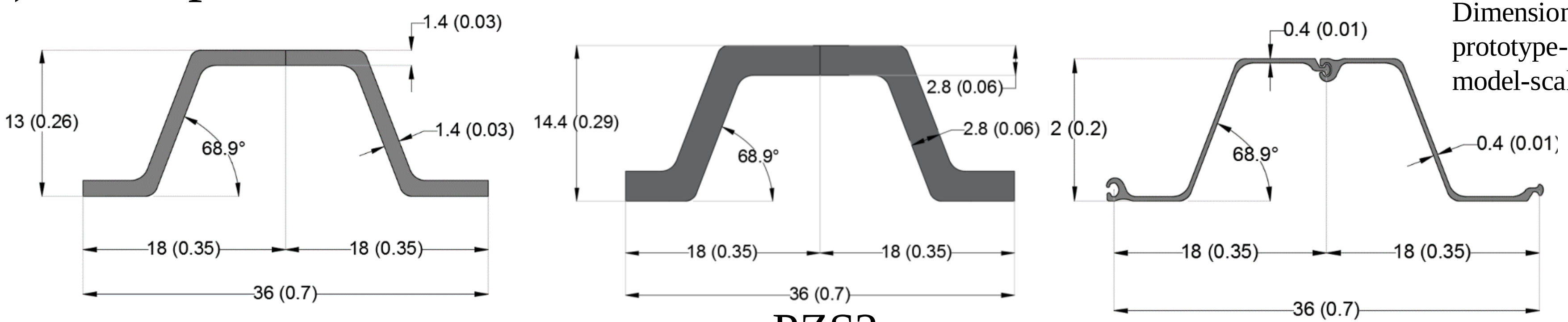


III) Head boundary conditions; and IV) Static versus quasi-static load testing

Task 3 – Centrifuge Testing

V) Sheet pile stiffness

Dimensions in inches at prototype-scale (and in model-scale)



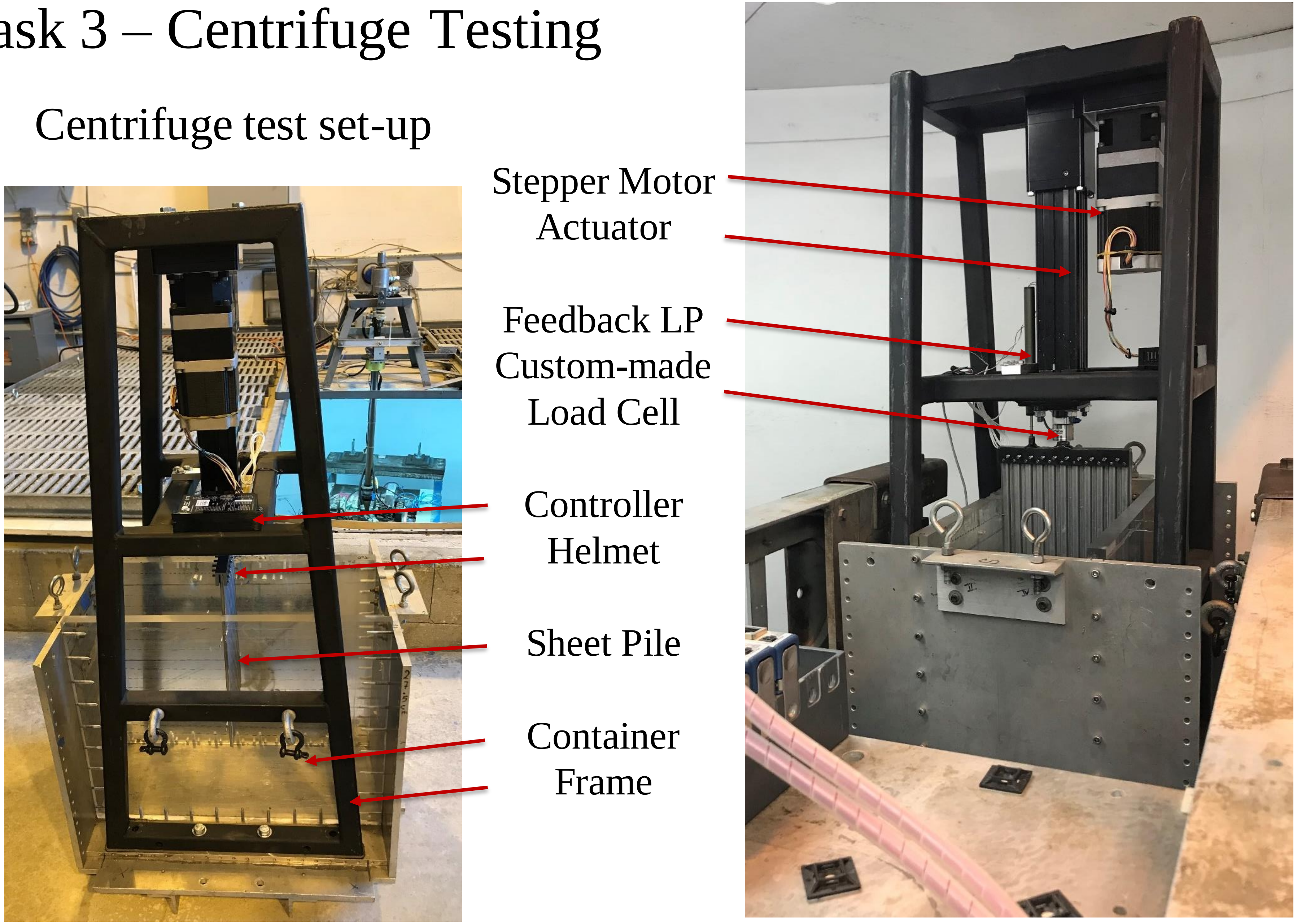
PZS1 PZS2 PZ27

Sheet pile section dimensions and properties

	Model-scale (1 g)		Prototype-scale (50 g)		PZ section
Section	PZS1	PZS2	PZS1	PZS2	PZ27
Width (in)	0.7	0.7	36	36	36
Height (in)	0.26	0.29	13	14.4	12
Flange thickness (in)	0.03	0.06	1.4	2.8	0.4
Web thickness (in)	0.03	0.06	1.4	2.8	0.4
Cross Sectional Area, A (in^2/ft)	0.03	0.06	72	144.4	24.2
Perimeter, P (in/ft)	0.22	0.23	10.77	11.32	11.83
Moment of inertia, I (in^4/ft)	0.001	0.002	7,369.8	1,5217.4	2,649.8
Material	aluminum	aluminum	aluminum	aluminum	steel
Young's modulus, E (psi)	10^7	10^7	10^7	10^7	2.9×10^7
Bending stiffness, EI ($kips.in^2/ft$)	12	24.7	7.5×10^7	1.5×10^8	7.7×10^7
Axial stiffness, EA (kips/ft)	292.3	586.8	731,164	1,466,341	702,678

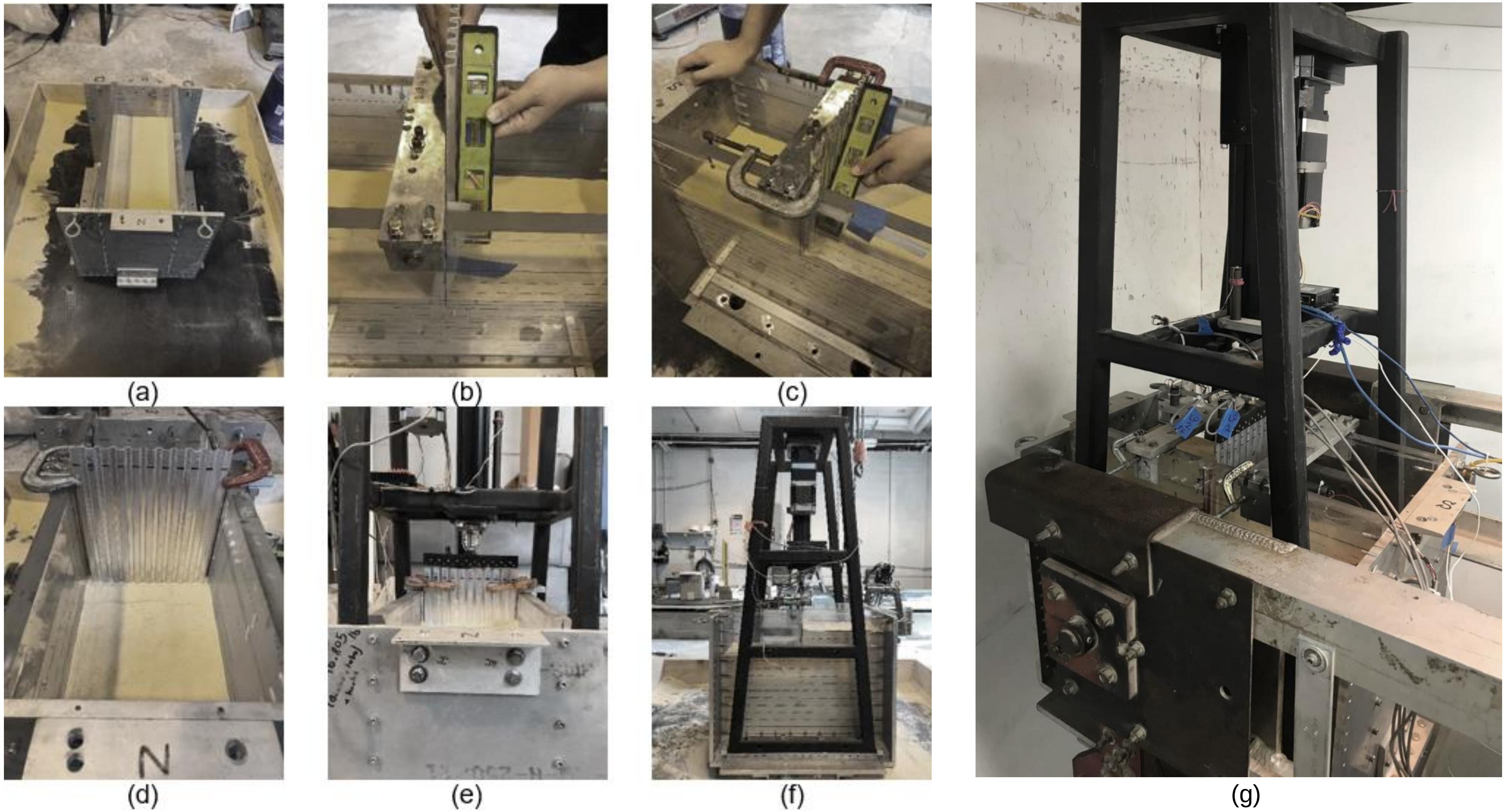
Task 3 – Centrifuge Testing

- Centrifuge test set-up



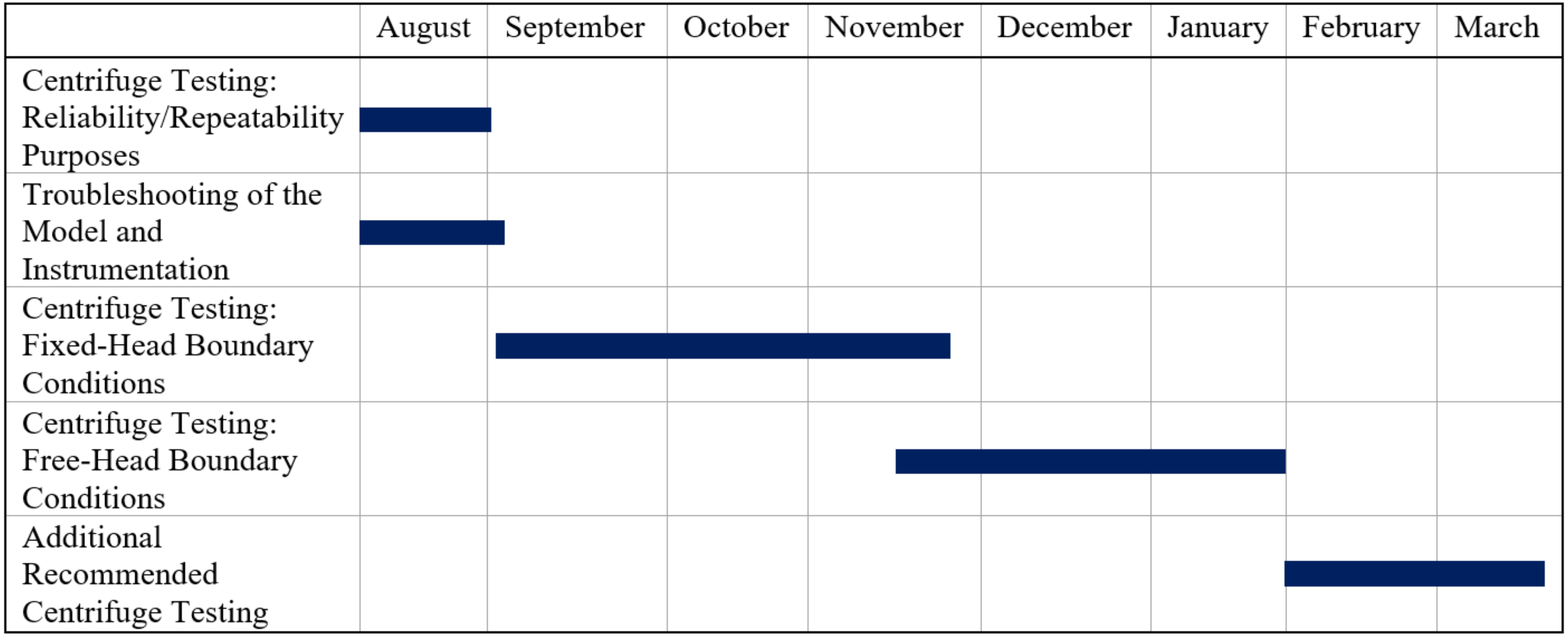
Task 3 – Centrifuge Testing

- Centrifuge model construction steps



Task 3 – Centrifuge Testing

- Ongoing centrifuge testing timetable



Thanks!

Questions?