

Phase III: Implementation of Shallow Foundations on Florida Limestone in FB-MultiPier

FDOT BED31-977-17

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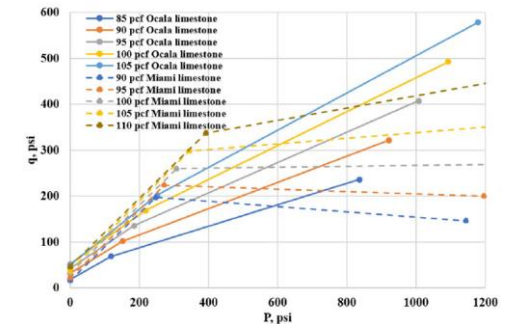
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Project Background and Objectives

- FDOT has funded a multiphase research effort on the use of shallow foundations for bridge substructure on limestone.
 - In Phase I (BDV31-977-51) – Developed bearing capacity equations for any footing width, shape, embedment depth and rock-over-sand scenario
 - In Phase II (BDV31-977-124) – Performed three full scale load tests to validate the bearing capacity equations
 - Developed moduli by formation for load-settlement predictions
- In Phase III (current phase)
- Implement bearing capacity and load-settlement prediction methods into FB-MultiPier;
- Investigate and implement
 - Lateral resistance of embedded footings
 - Effects of inclined and eccentric loadings on bearing capacity and load-settlement
- Document the feature sets developed in FB-MultiPier in the user manual



- **Task 1 – Implement Strength Envelopes (completed)**
- **Task 2 – Implement Load-settlement Analysis (completed)**
- Task 3 – Implement Lateral Resistance (current)
- Task 4 – Investigate Effects of Inclined and Eccentric Loadings (current)
- Task 5 – Develop Software Manual Documentation
- Task 6 – Draft Final and Closeout Teleconference
- Task 7 – Final Report

Task 1 – Implement Strength Envelopes – Summary

• FB-MultiPier Integration

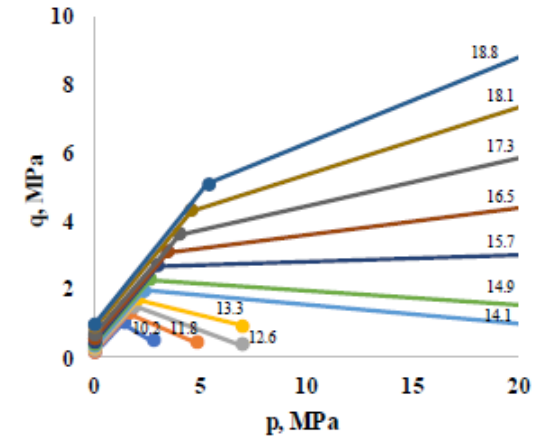
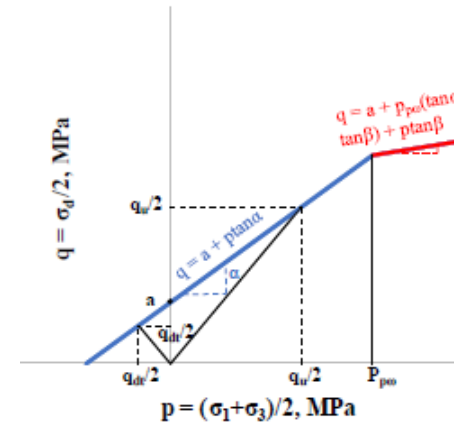
- Implemented Florida bearing capacity equations and Carter & Kulhawy analyses for pier design
- Bi-linear strength parameters based on bulk dry unit weight/porosity and formation
- Rock-over-sand case requires modulus ratio and intact modulus functions

• UI and Engine Updates

- FB-MultiPier UI updated for shallow foundation design in Florida limestone
- Analytical engines enhanced for accuracy

• Bearing Stress Comparisons

- Extensive comparisons between FB-MultiPier and Florida bearing equations
- Errors <2.5% in both English and SI units, considered acceptable



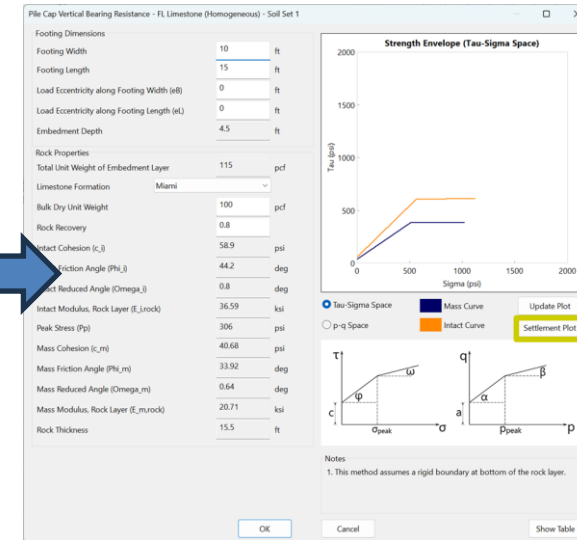
$$Q_u = \min(Q_{u1}, Q_{u2}) * \xi / N_R$$

$$\xi = \text{Shape factor;}$$

$$N_R = \text{Rock over sand reduction factor;}$$

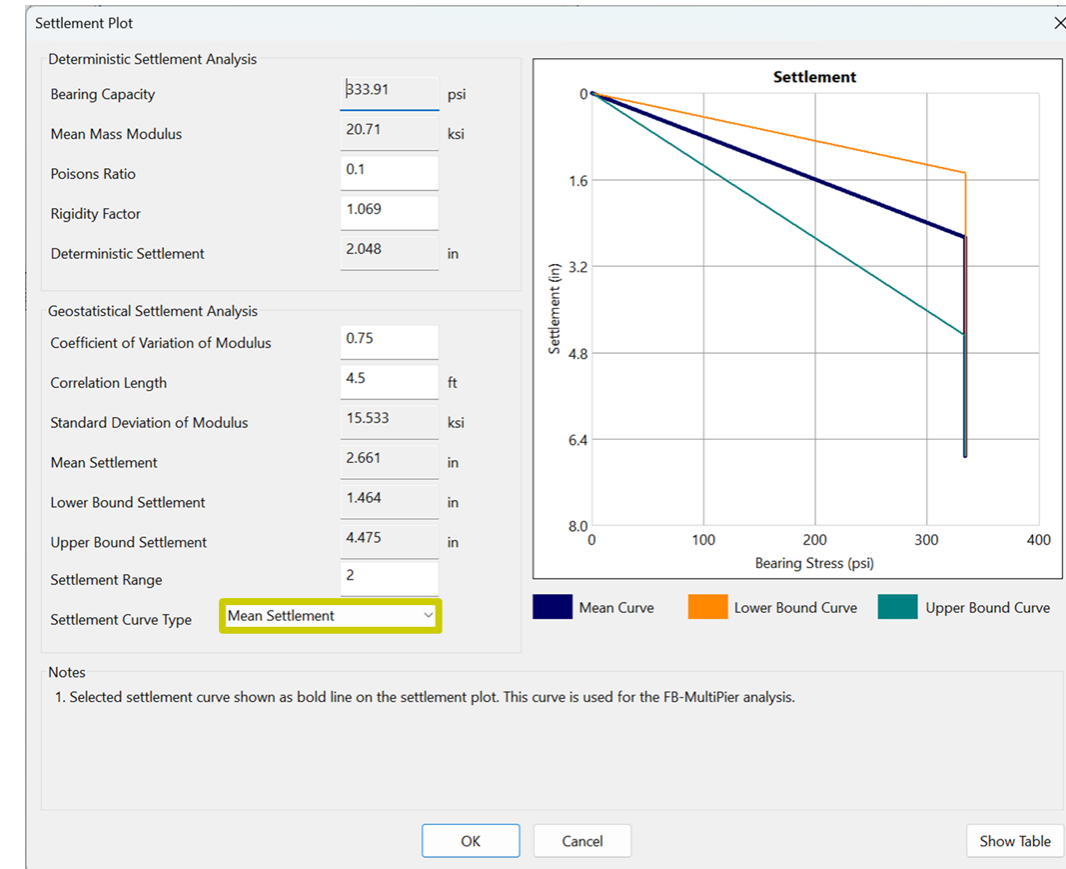
$$Q_{u1} = n * c * N_c + q * N_q$$

$$Q_{u2} = n * [c * N'_c + p_p * N_\gamma] + q * N_q$$



Task 2 – Implement Load-settlement Analysis – Summary

- **Florida Limestone Characteristics**
 - High bulk porosity
 - Bi-linear strength envelopes, ductile stress-strain response, and low Young's Modulus compared to sand
 - Service limit state (settlement) may control shallow foundation design
- **Probabilistic Settlement Approach**
 - High CV of Young's Modulus
 - Use probabilistic settlement approach (Fenton & Griffith)
 - Large zone of influence (2B) affects differential and mean settlement
- **Stress-Strain Response & Bearing Failure**
 - Bilinear stress-strain response: linear until failure/crushing
 - Excessive rock crushing due to limestone's high porosity
- **Rock-over-Sand Layer Analysis**
 - FEM used to analyze footing on rock-over-sand
 - Harmonic Mean Modulus replicates FEM results for modulus and zone of influence
- **Field Load Test Validation**
 - Validated with field load tests in Phase II
 - Numerical simulations in Phase III
- **FB-MultiPier Implementation (Task 2)**
 - Settlement predictions for homogeneous and rock-over-sand cases implemented into FB-MultiPier
 - Settlement influenced by rock mass modulus CV, modulus ratio, and stress-dependent harmonic mean modulus for rock-over-sand cases



Task 2 – Implement Load-settlement Analysis – Summary

• Florida Limestone Characteristics

- High bulk porosity → bi-linear, ductile stress-strain response
- Young's Modulus only slightly higher than sand
- Settlement often governs foundation design

• Probabilistic Settlement Approach

- High variability (CV) in Young's Modulus
- Use Fenton & Griffith probabilistic method
- Large influence zone (2B) affects mean and differential settlement

• Stress-Strain Response & Bearing Failure

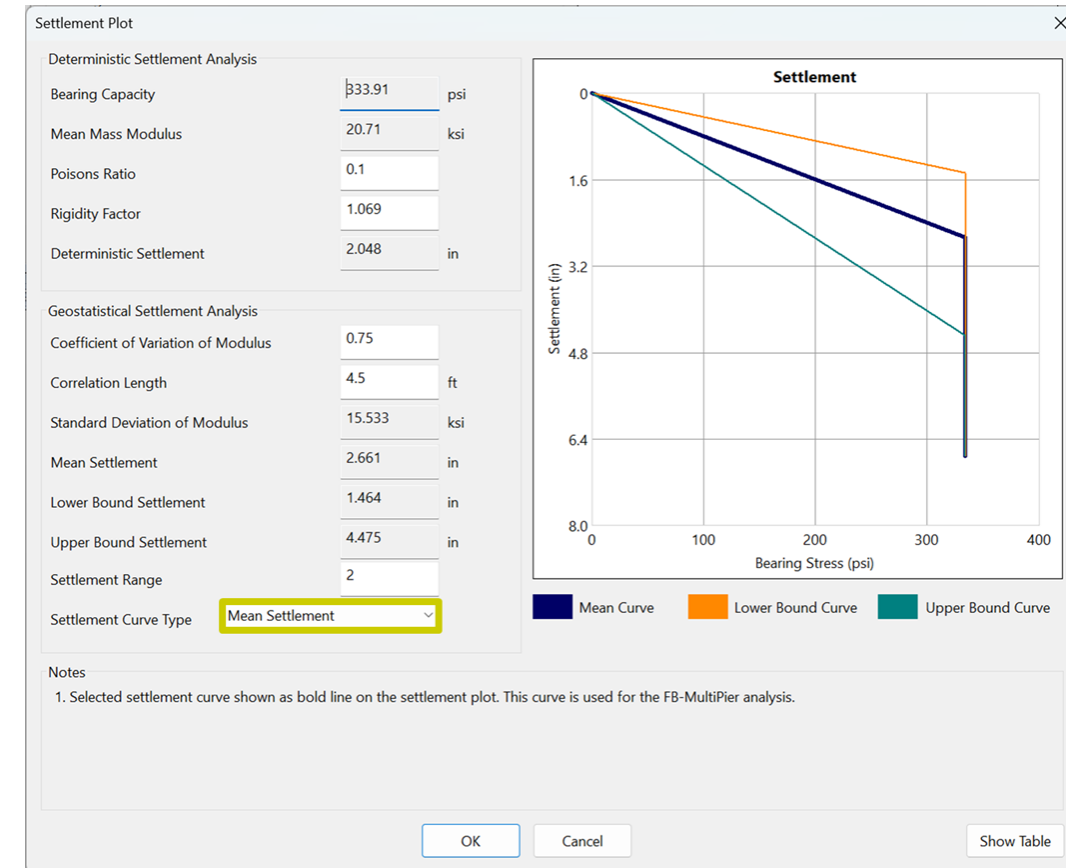
- Bilinear: linear up to failure/crushing
- Excessive rock crushing due to high porosity

• Rock-over-Sand Foundations

- FEM analysis for layer effects
- Harmonic Mean Modulus replicates FEM results

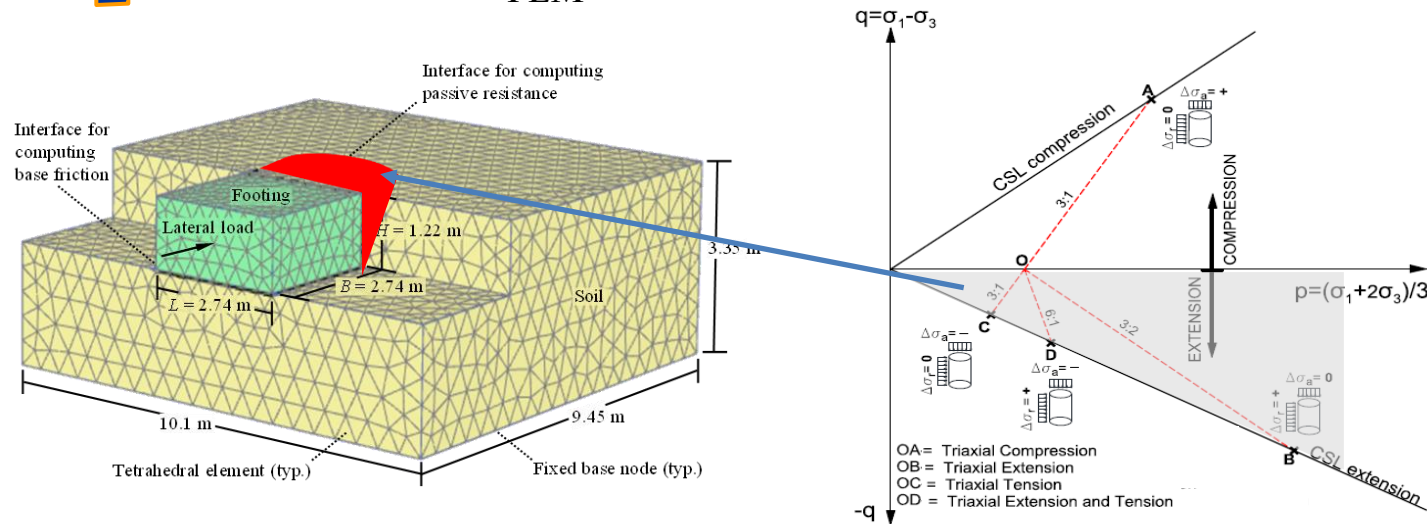
• Validation & Implementation

- Field load tests (Phase II) and numerical simulations (Phase III)
- Settlement predictions integrated into FB-MultiPier
- Influencing factors: rock mass modulus CV, modulus ratio, stress-dependent harmonic mean

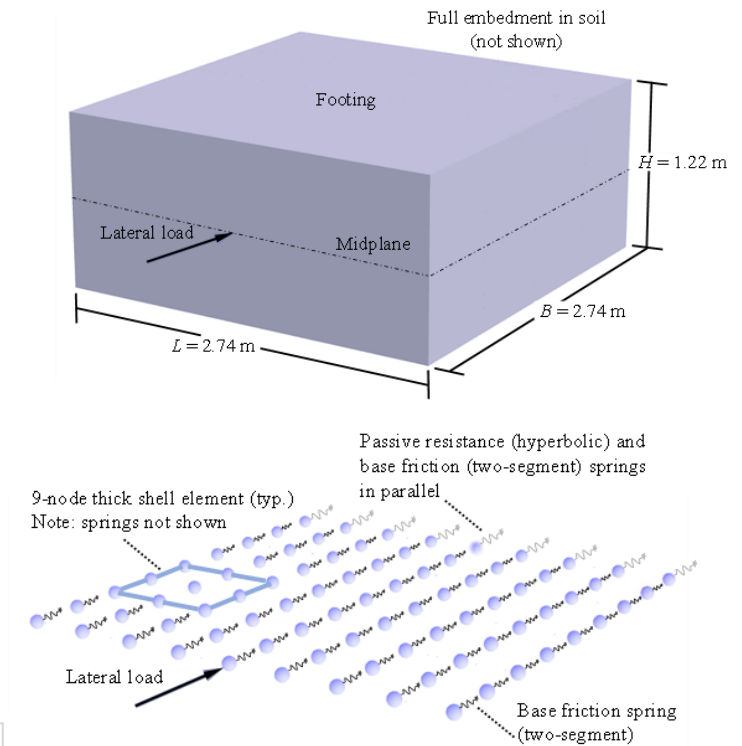


Task 3 – Implement Lateral Resistance

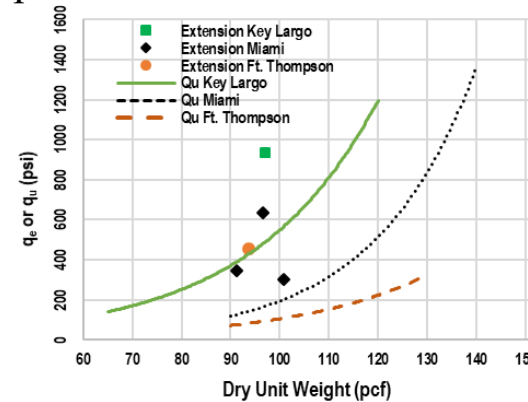
FEM



FB-Multiplier



- Stress path in extension space may be critical-SMO performing triaxial tests
- Extension strength influenced by porosity and sedimentary formation process
- Phase I research tested a few rock cores in extension space
- Extension strength, q_e , at vertical stress $= 0 \geq q_u$
- Extension strength at vertical stress representative of overburden stress need to be tested



Task 3 – Implement Lateral Resistance

Log-Spiral Based Passive Earth Pressure Coefficients

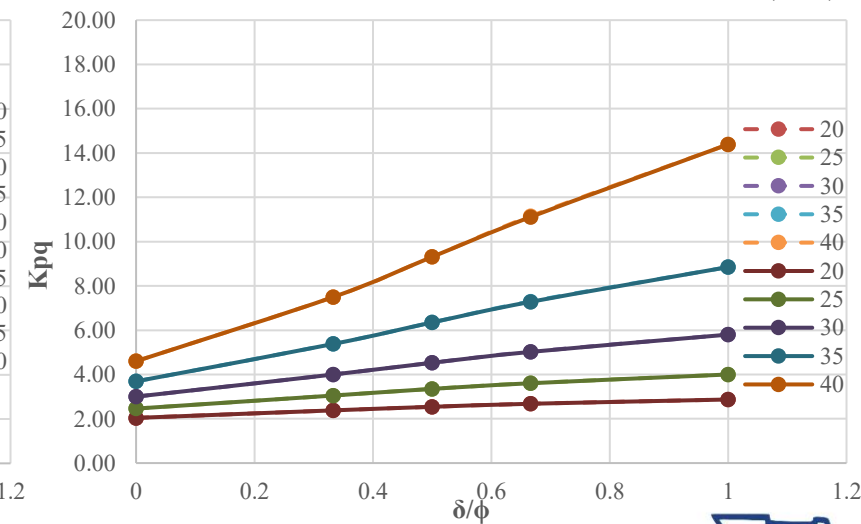
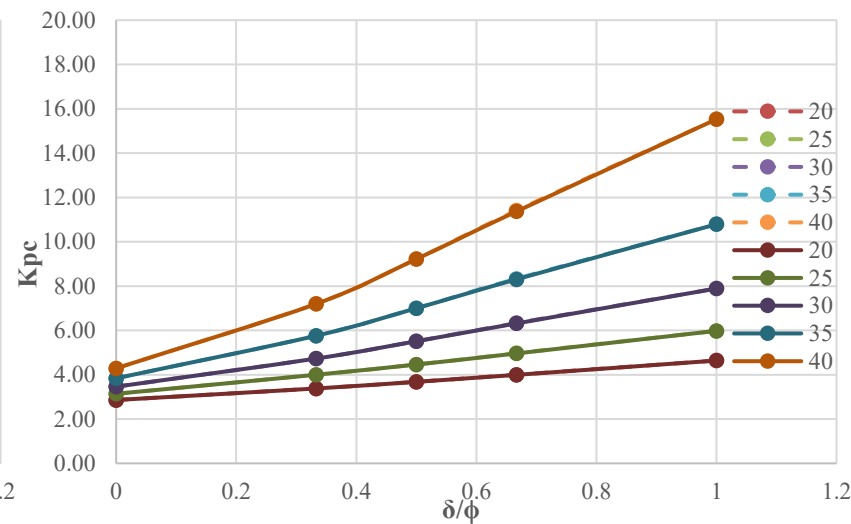
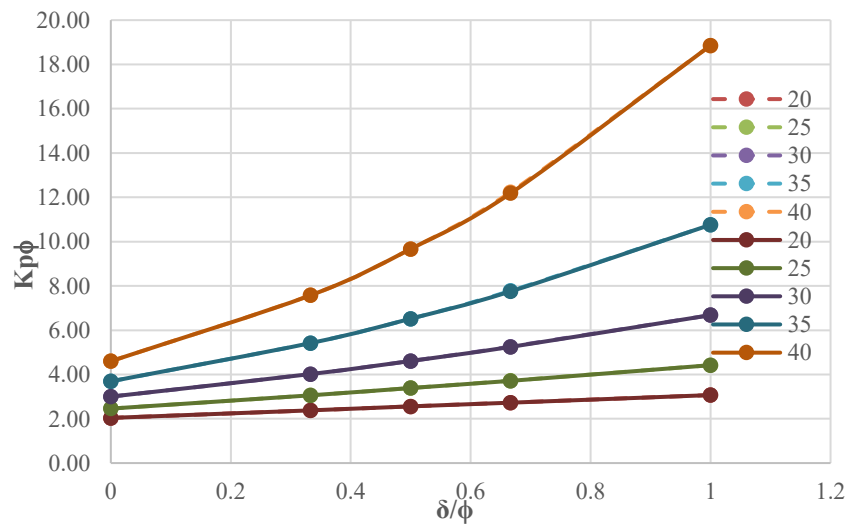
- Soil (c, ϕ) failure surface is observed to be generally log-spiral
- Coulomb's theory over-estimates K_p with increasing interface friction
- Lui et al (2018) used a modified log-spiral method and verified with FEM
- K_p functions for friction, cohesion, and surcharge contributions developed for implementation in FB-MultiPier.

Table 1

Results comparison ($\phi = 40^\circ$).

δ/ϕ	$K_p = 2P_p/(\gamma H^2) = 2P_{p,h}/(\gamma H^2 \cos \delta)$	Coulomb theory	Soubra and Macuh (2002)	Patki et al. (2015b)	Shiau et al. (2008), LB (UB)	Logarithmic spiral method Duncan and Mokwa (2001)	This study
0	4.6	4.6	4.6	4.6 (4.61)	4.6	4.6	
1/3	8.15	7.62	7.62	6.87 (7.79)	8.17	7.58	
1/2	11.77	9.81	9.82	8.79 (10.03)	10.5	9.67	
2/3	18.72	12.6	12.6	11.3 (12.87)	13.08	12.24	
1	92.72	20.01	20.01	18.64 (20.1)	17.5	18.86	

Note: LB and UB are the lower and upper bounds, respectively. from Lui et al. (2018)



Task 3 – Implement Lateral Resistance

Passive Force, P , and Base Friction, F_b , Displacement, y , Model

Passive Resistance

$$P = \frac{y}{\left[\frac{1}{K_{max}} + R_f \frac{y}{P_{ult}} \right]} \quad R_f = 1 - \frac{P_{ult}}{K_{max} \cdot \Delta_{max}} \quad K_{max} \text{ is the initial stiffness}$$

$$P_{ult} = R_{3D} \cdot E_p \cdot B \quad E_p = \frac{1}{2} \gamma H^2 K_{p\phi} + c H K_{pc} + q H K_{pq}$$

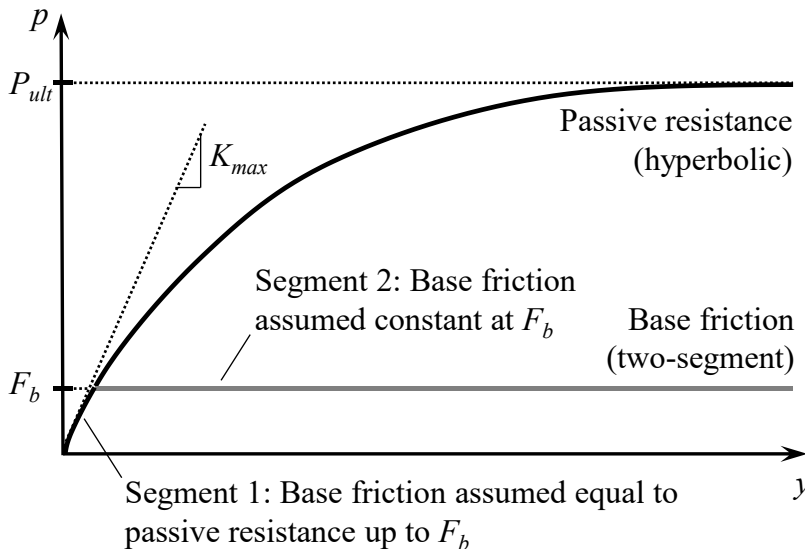
$$R_{3D} = 1 + (K_{p\phi} - K_a)^{\frac{2}{3}} \left[1.1 S^4 + \frac{1.6x}{1 + 5 \frac{B}{H}} + \frac{0.4(K_{p\phi} - K_a) S^3 x^2}{1 + 0.05 \frac{B}{H}} \right] \quad S = 1 - \frac{H}{D_t + H}$$

where R_{3D} is a 3-D modifying factor, B is the footing width, $K_a = \tan(45 - \frac{\phi}{2})^2$, $K_{p\phi}$, K_{pc} , and K_{pq} represent the passive earth pressure coefficients associated with friction angle, cohesion, and surcharge, respectively, γ is the unit weight of soil, H denotes the footing thickness, c is the cohesion, q is the surcharge loading, $x=1$ for a single footing, D_t is the distance from the ground surface to the top of the footing.

Base Friction

$$F_b = \alpha \cdot c \cdot L \cdot B + W \cdot \tan \delta$$

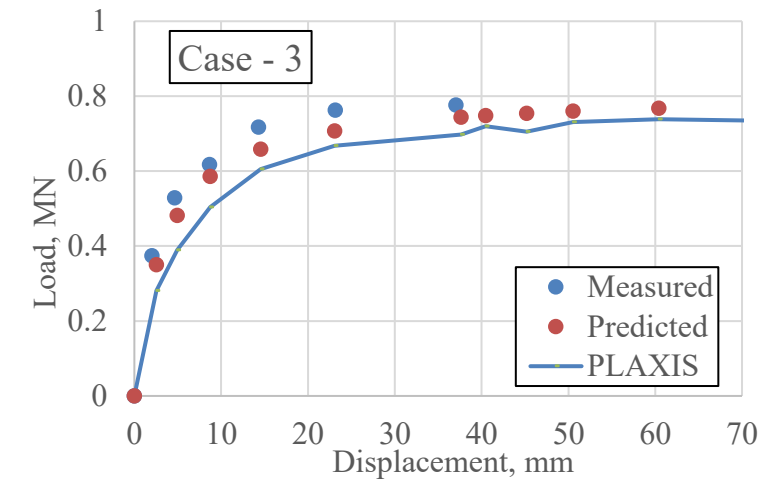
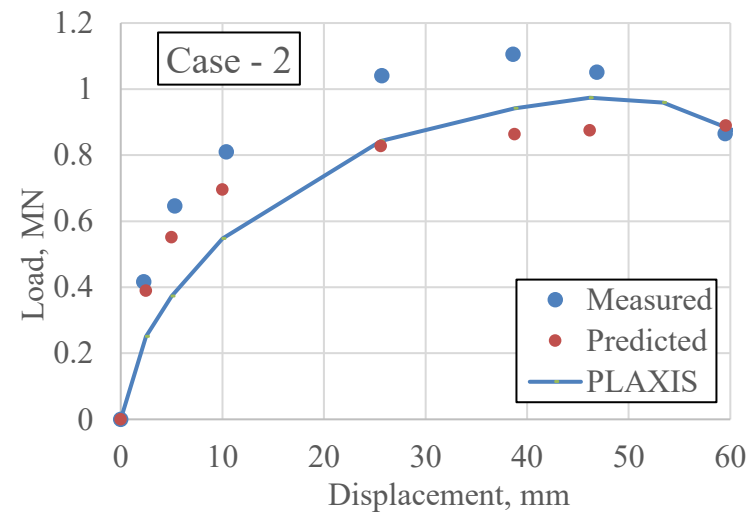
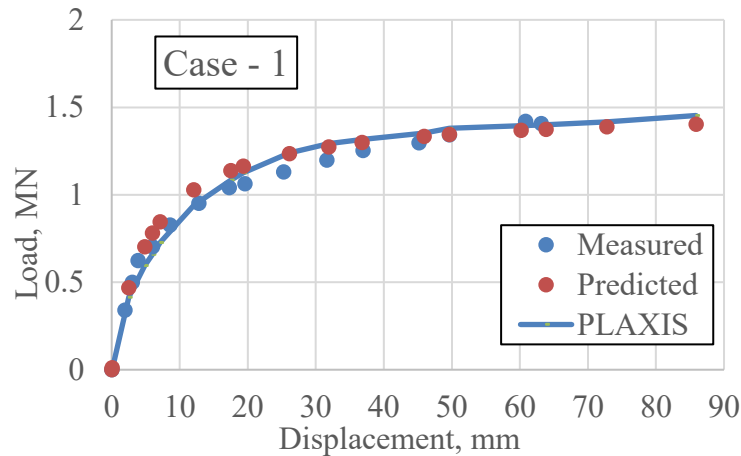
where α is the adhesion factor, c is cohesion, L is the footing length, W is the dead load on footing, δ is the interface friction.



Task 3 – Implement Lateral Resistance

Passive Force-Displacement in Sand: Full-Scale Tests

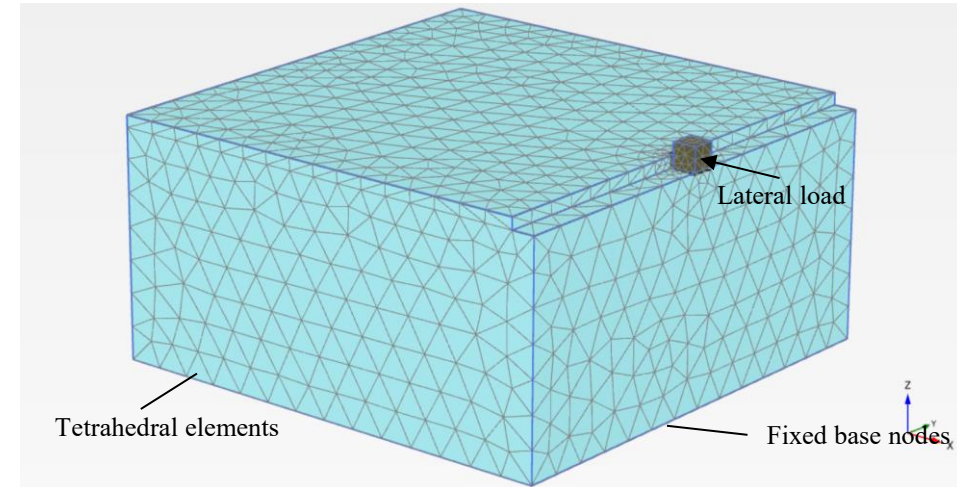
Case	Source	Soil Type	Foundation Member Geometry			Soil Properties				Test Results	
			L (m)	B (m)	H (m)	c (kPa)	ϕ (°)	γ (kN/m ³)	δ (°)	P _{ult} , kN	$\Delta_{\max}/H$
1	(Rollins and Cole, 2006)	Silty Sand	5.18	3.05	1.12	27.3	27	19	21	1428	0.05
2	(Rollins and Cole, 2006)	Clean Sand	5.18	3.05	1.12	0	39	18.4	30	1090	0.05
3	(Rollins and Cole, 2006)	Fine Gravel	5.18	3.05	1.12	3.8	34	20.8	26	774	0.04



Task 3 – Implement Lateral Resistance

Sand: Plaxis passive force model ($L=B=H= 5\text{ m}$, $D_f = 2.5\text{ m}$)

SOIL	Soil Model	γ_{sat} (kN/m ³)	γ_{unsat} (kN/m ³)	E'_{ref} (kN/m ²)	ν (nu)	c'_{ref} (kN/m ²)	ϕ' (phi)	ψ' (psi)
Footing	Linear-elastic	21	-	200×10^6	0.2	-	-	-
Sand	Mohr-coulomb	19	19 Footing	95.76×10^3	0.27	10	39	14
Interface	Mohr-coulomb	19	19	95.76×10^3	0.27	6.6667	26.13	3



Passive Model

$$p = \frac{y}{\left[\frac{1}{K_{\max}} + R_f \frac{y}{P_{\text{ult}}} \right]}$$

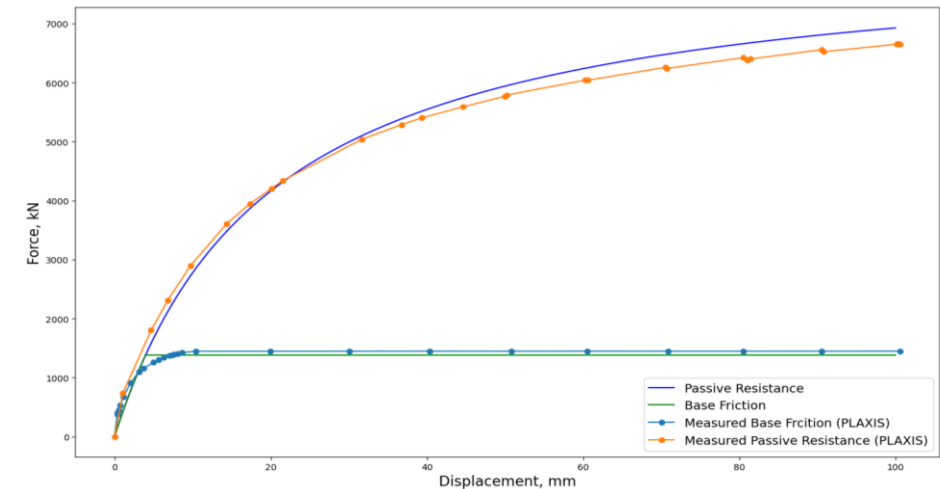
$$R_f = 1 - \frac{P_{\text{ult}}}{K_{\max} \cdot \Delta_{\max}}$$

$K_{\max}$ is the initial stiffness

Base Friction Model

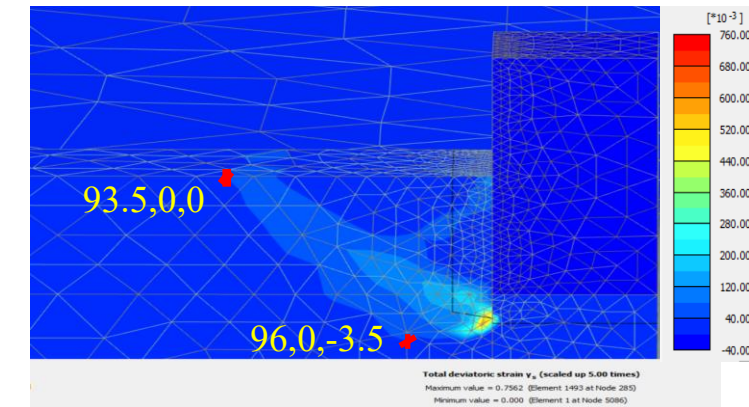
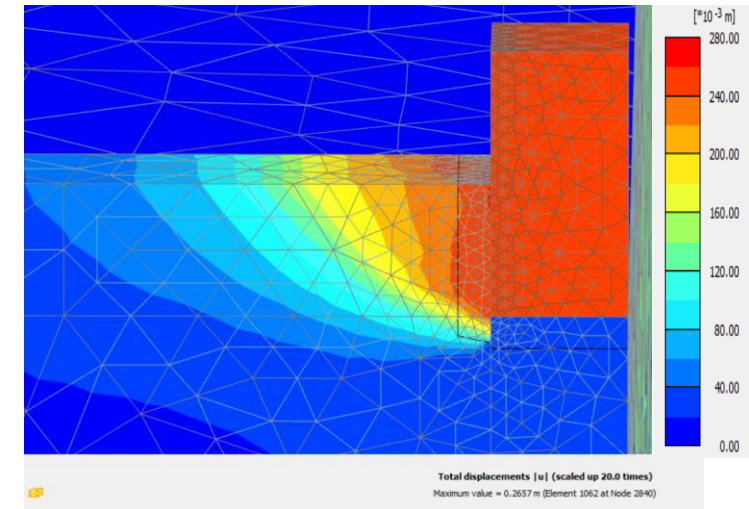
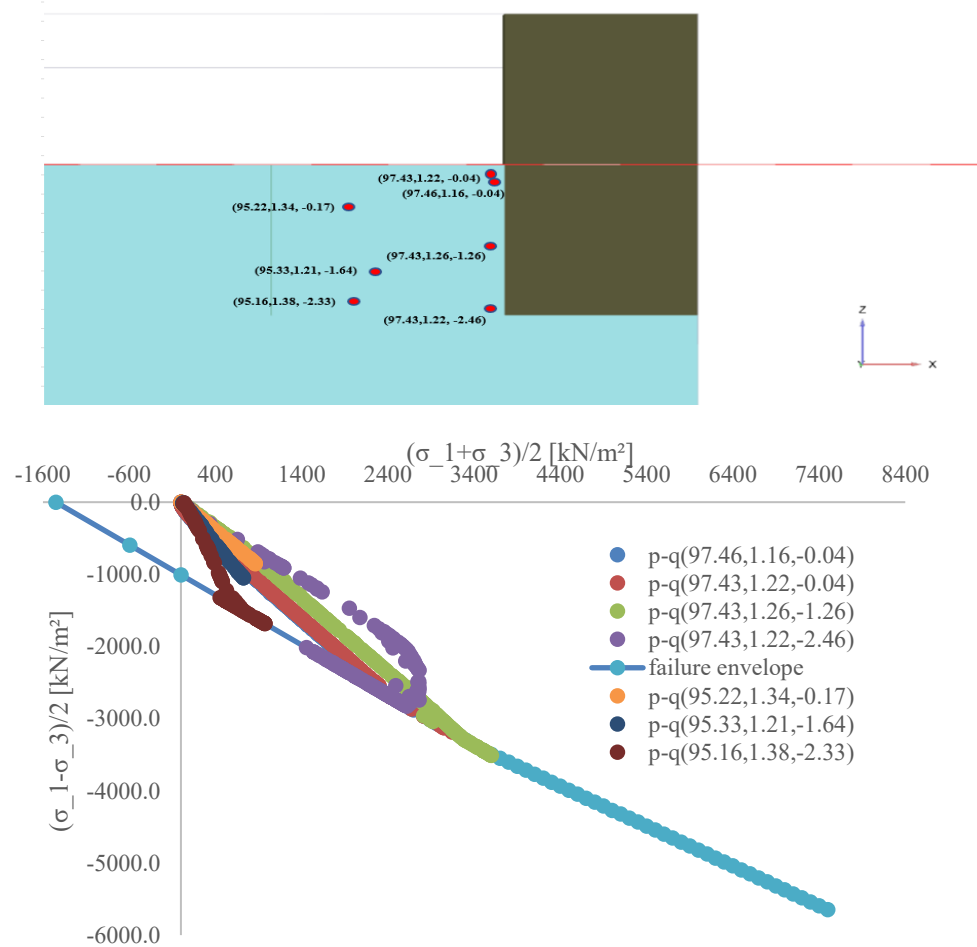
$$F = K_{\max} y \quad y \leq y_{\text{intersection with Pult}}$$

$$F = F_{\text{ult}} \quad y > y_{\text{intersection with Pult}}$$

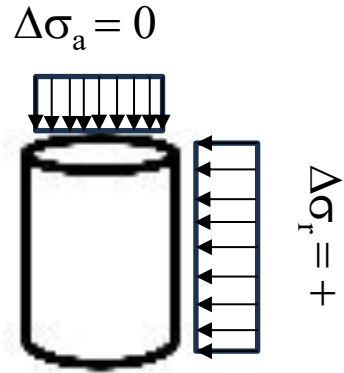


Task 3 – Implement Lateral Resistance

FL Limestone: Plaxis stress paths in passive state ($L=B=H= 2.5\text{ m}$, $D_f = 2.5\text{ m}$)



Triaxial Extension Tests on Florida Limestone



- Tests with a range of isotropic stresses encountered in the field (15 psi, 50 psi, and 300 psi).
- Preliminary assessment of passive strength (extension space).
- Limited samples from Ocala, Miami, and Ft Thompson formations.
- Complimentary triaxial compression tests performed at isotropic stress of 50 psi.



Hoek Cell Triaxial Test

Miami Formation



300 psi
Pre-Test Post-Test

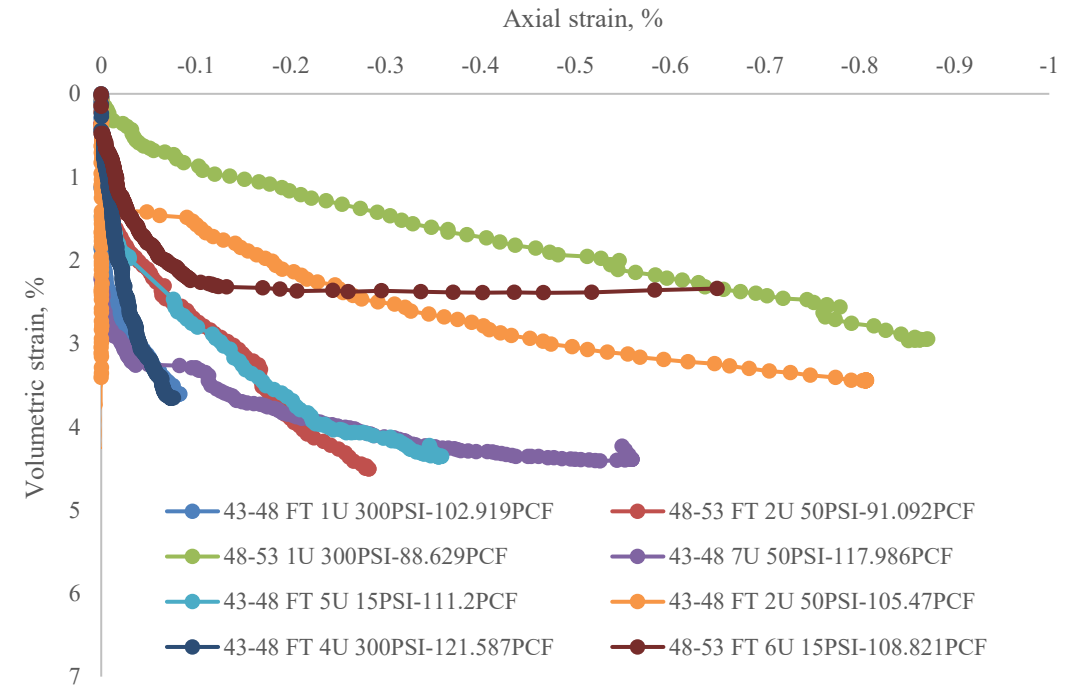
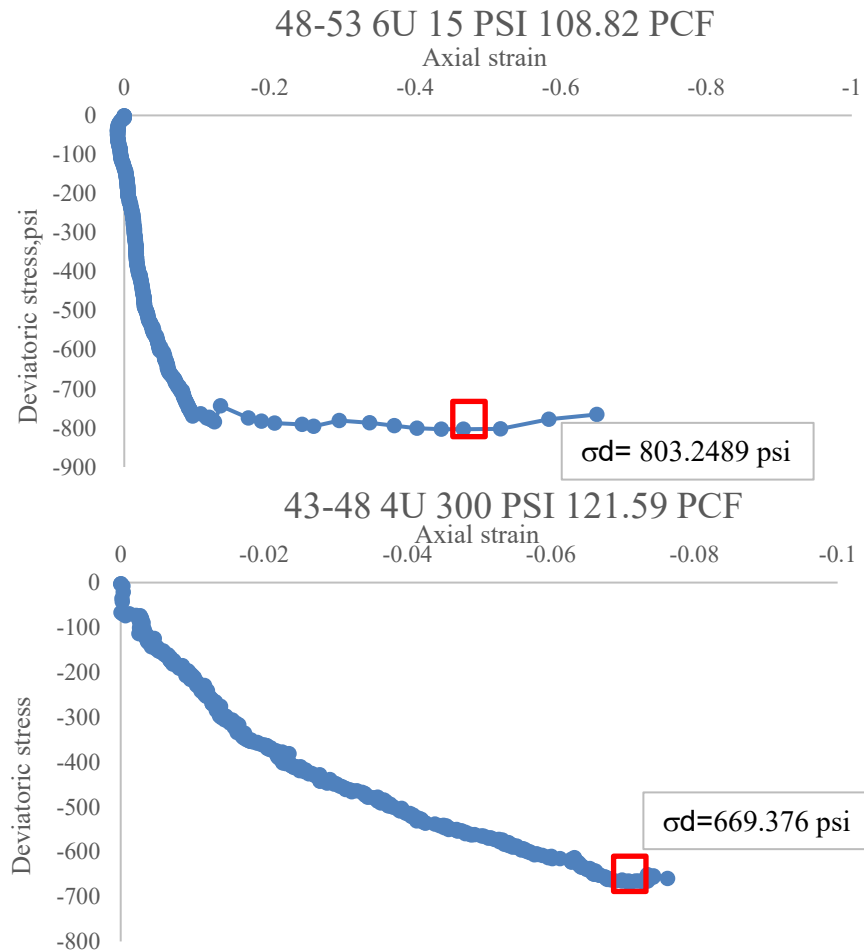
Miami Formation



15 psi
Pre-Test Post-Test

Task 3 – Implement Lateral Resistance

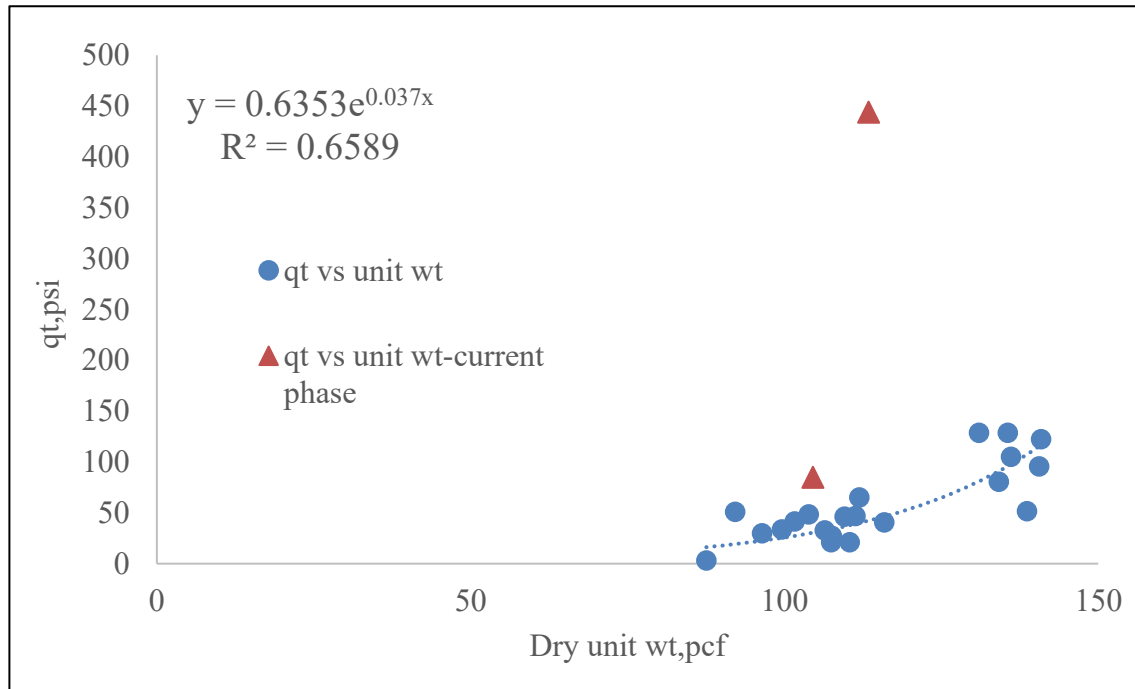
Triaxial Extension Tests: Deviatoric Stress-Strain and Volumetric Strain



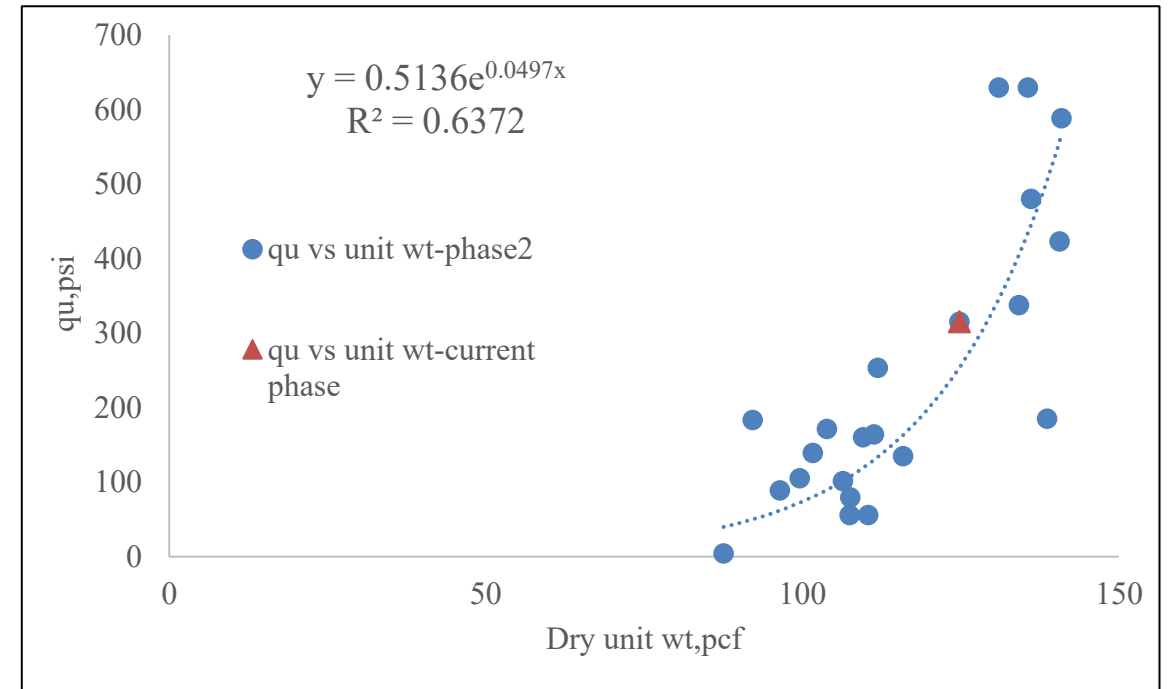
Task 3 – Implement Lateral Resistance

Ft. Thompson q_t and q_u : Current Phase and Phase 1

Split Tension Test data-current phase & phase 1

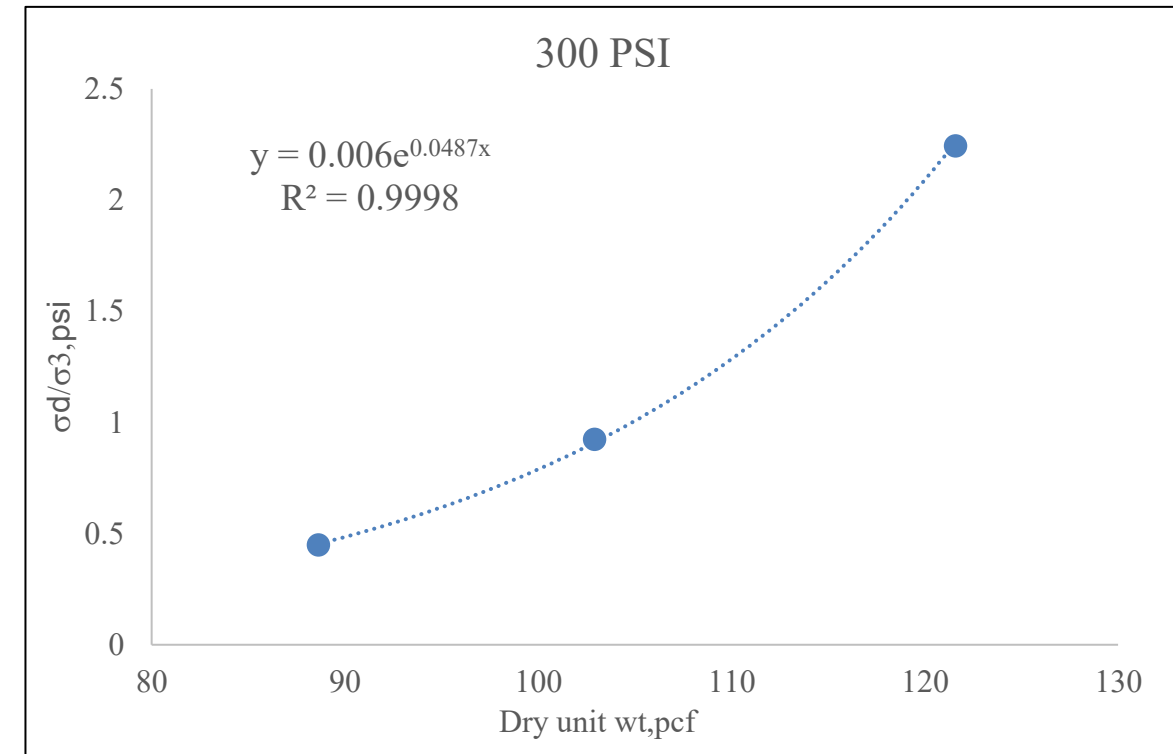
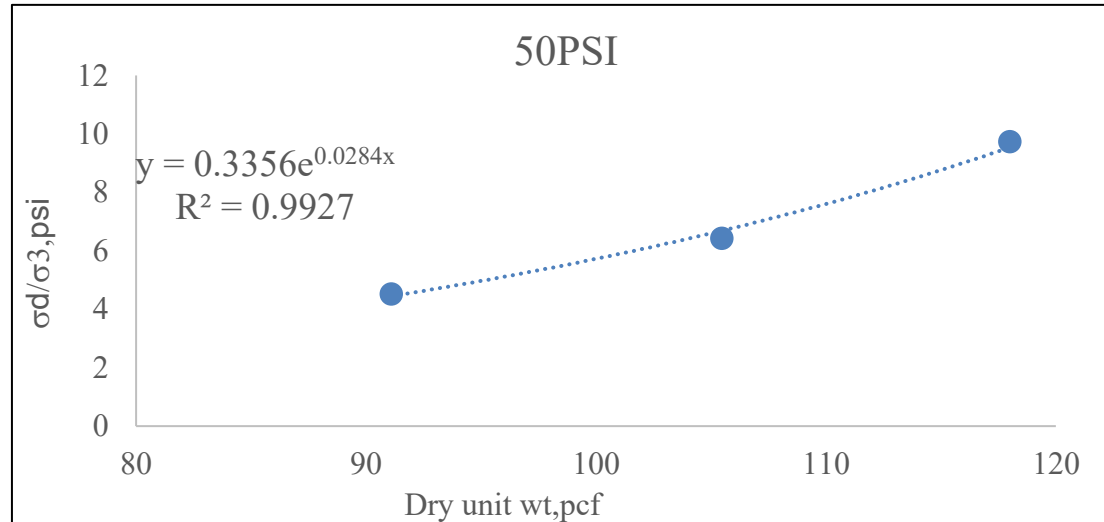
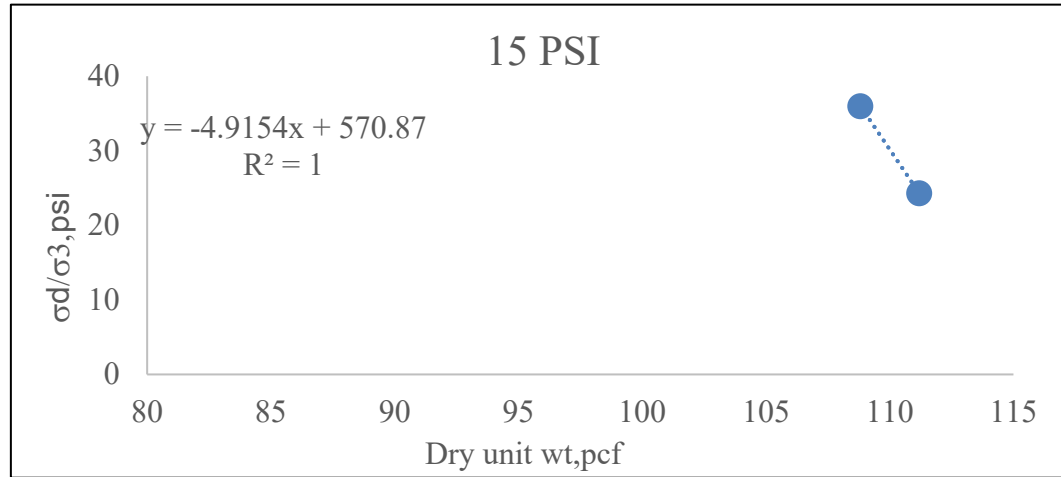


UC Test data-current phase & phase 1



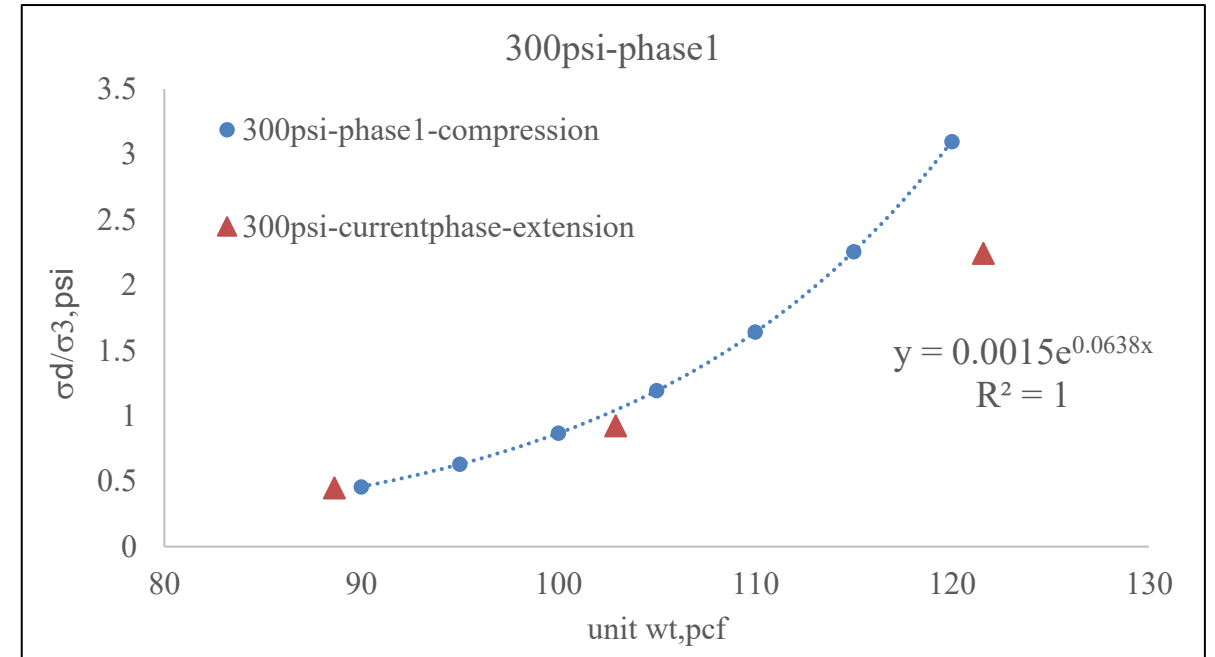
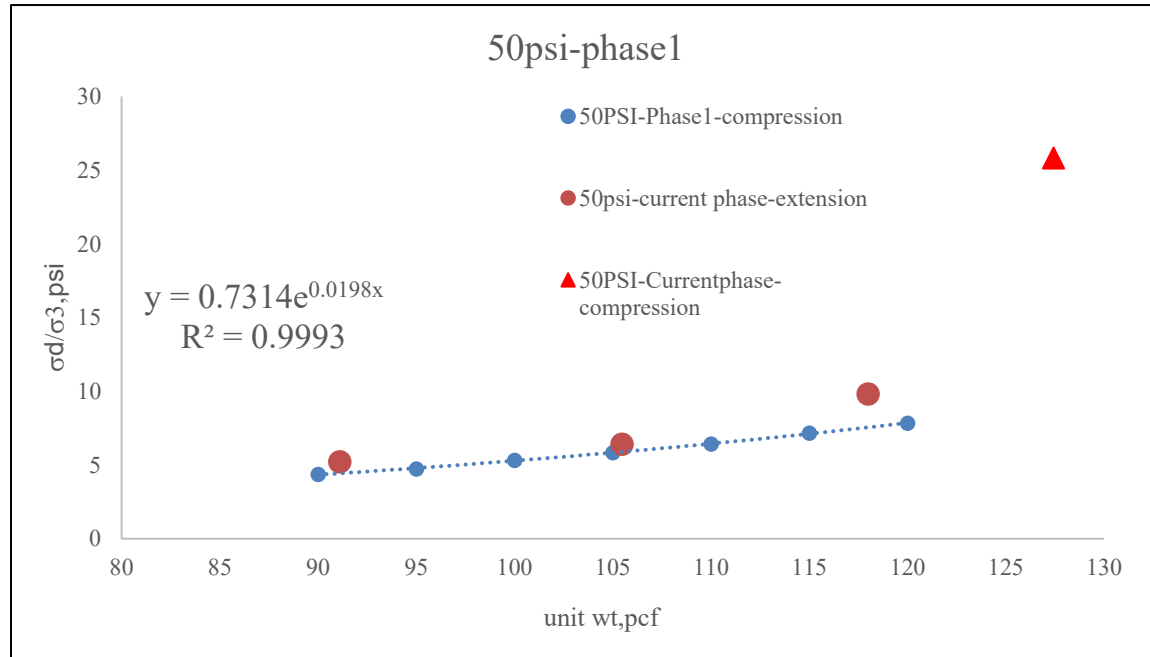
Task 3 – Implement Lateral Resistance

Ft. Thompson Deviatoric Stress – Dry Unit Weight for 15 psi, 50 psi, and 300 psi Confining Stresses



Task 3 – Implement Lateral Resistance

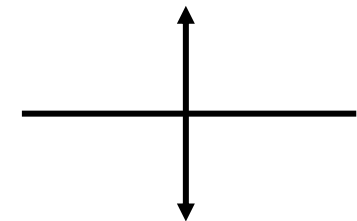
Compression Test data – current & phase-1



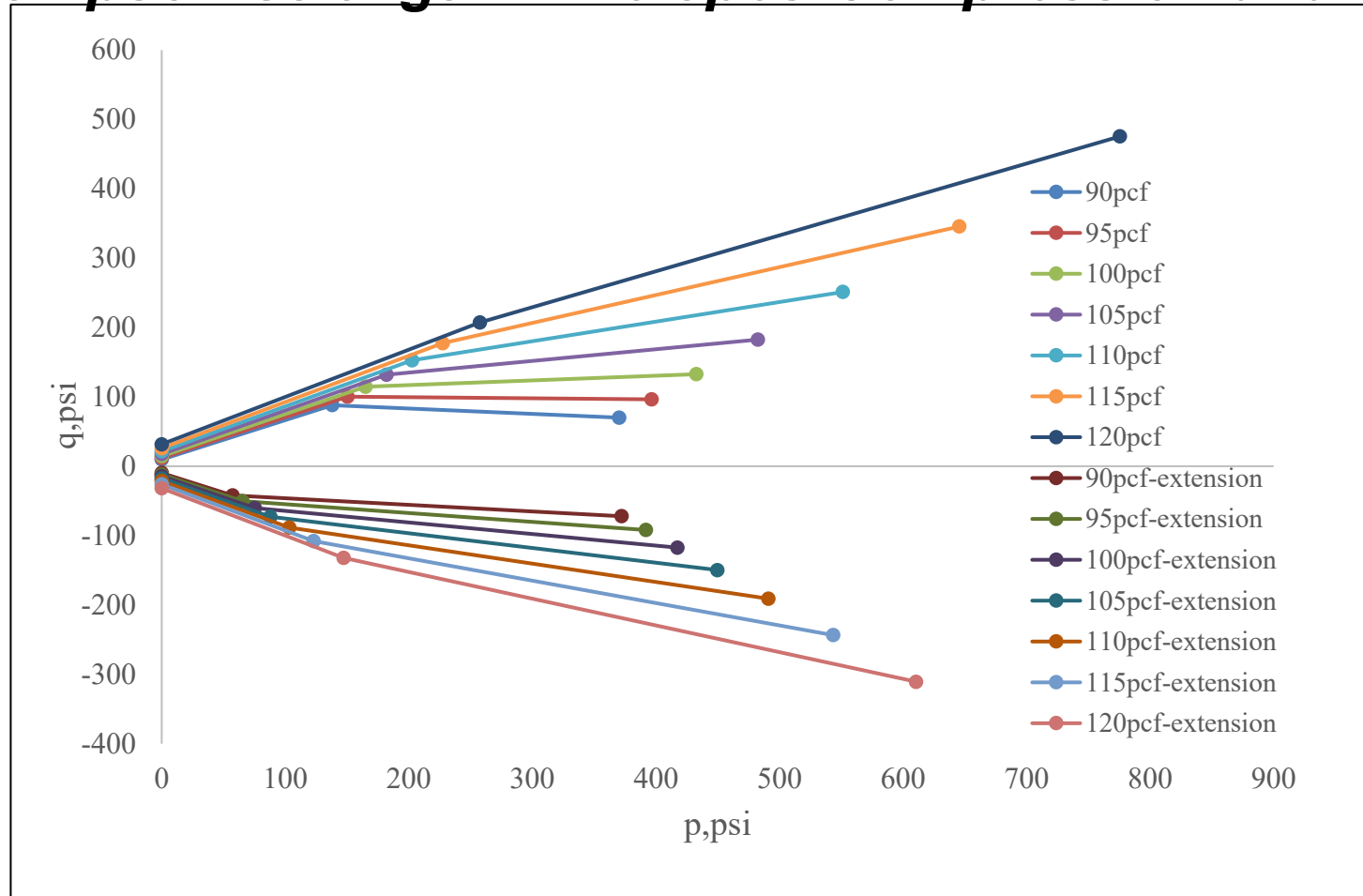
Task 3 – Implement Lateral Resistance

Ft. Thompson Strength Envelopes-Compression and Extension

Compression
(Bearing Stress)



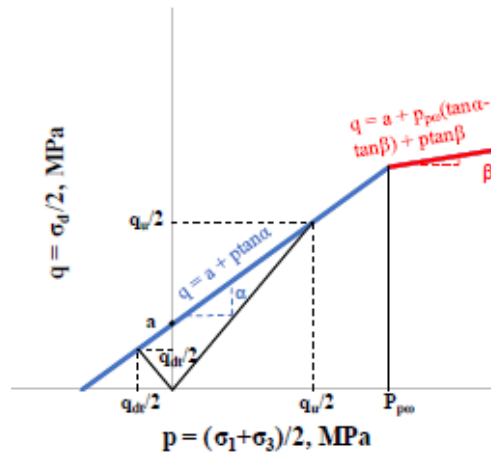
Extension
(Passive Stress)



Task 3 – Implement Lateral Resistance

Ft. Thompson Limestone Strength Envelope Modification Factors

Dry Unit Wt (pcf)	c-ext/c-comp	phi-ext/phi-comp	omega-ext/omega-comp	Pp-ext/Pp-comp	beta-ext/beta-comp	a-ext/a-comp
90	1	1	1.23	0.41	1.23	1
95	1	1	8.17	0.43	8.10	1
100	1	1	2.50	0.46	2.47	1
105	1	1	1.26	0.48	1.25	1
110	1	1	0.93	0.51	0.94	1
115	1	1	0.79	0.54	0.82	1
120	1	1	0.73	0.57	0.77	1
125	1	1	0.70	0.60	0.76	1

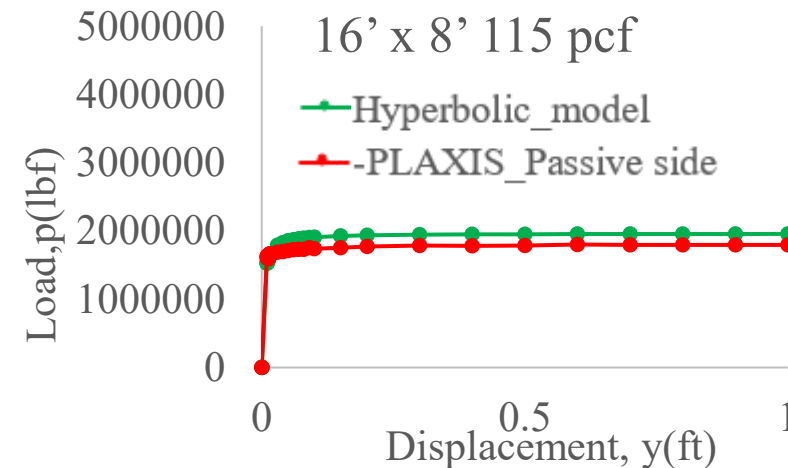
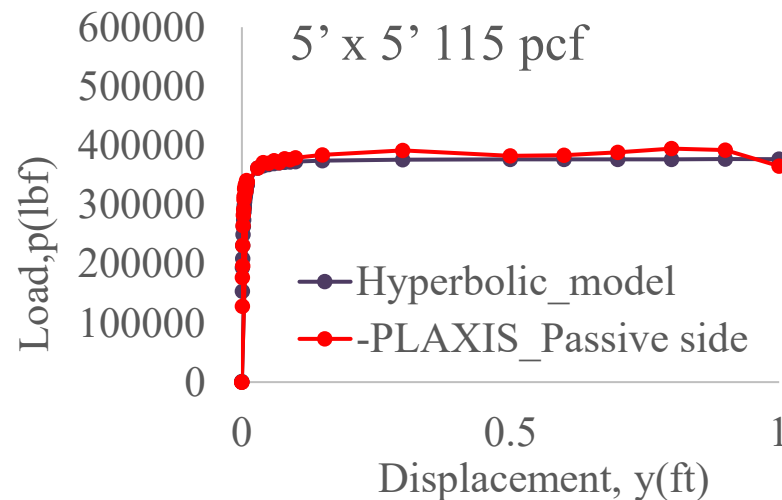
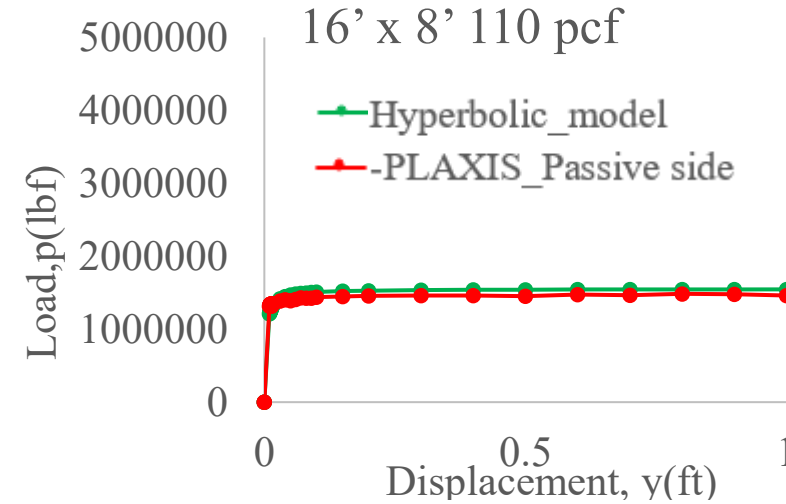
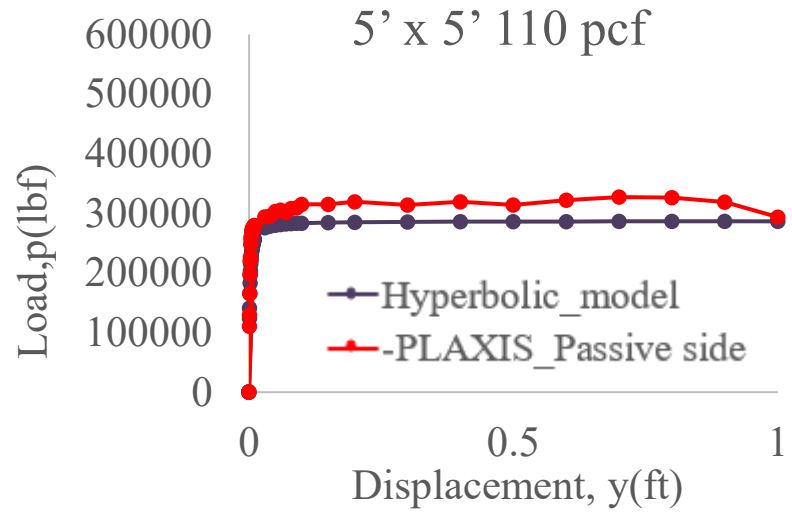


- $c_{ext} = F_c * c_{comp}$
- $\phi_{ext} = F_\phi * \phi_{comp}$
- $\omega_{ext} = F_\omega * \omega_{comp}$
- $P_{pext} = F_{Pp} * P_{pcomp}$
- $\beta_{ext} = F_\beta * \beta_{comp}$
- $a_{ext} = F_a * a_{comp}$

- Limited testing suggests reductions in strength envelope parameter Pp.
- Evaluating low dry unit weights for modification to Kp.
- Lime-cement improved clay showed reduced strengths under extension than compression (Ignat et al., 2019).
- Extension and compression $\phi \approx 3\%$ different for different rock types tested (Yu and Ng, 2022).

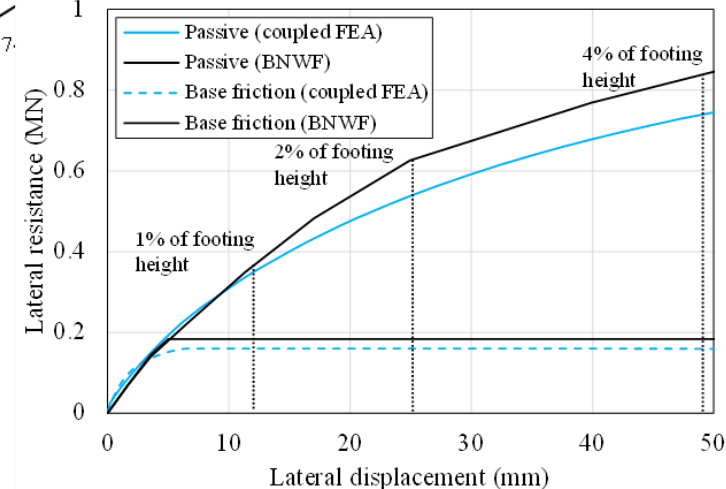
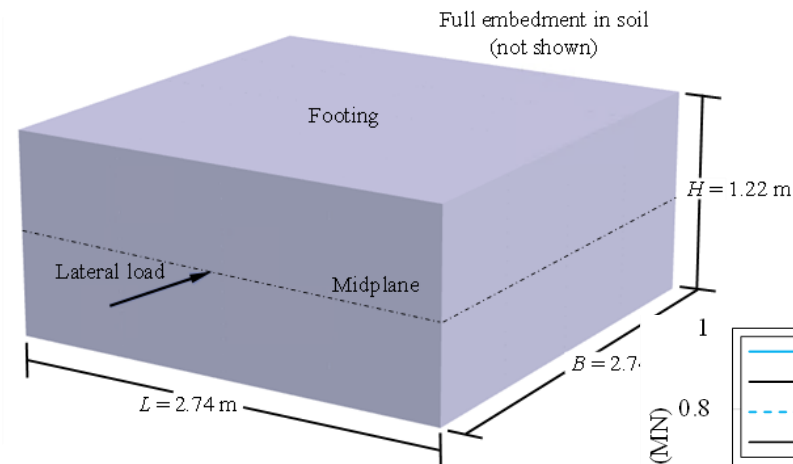
Task 3 – Implement Lateral Resistance

Plaxis Model Passive Load-Deformation in Ft. Thompson Limestone

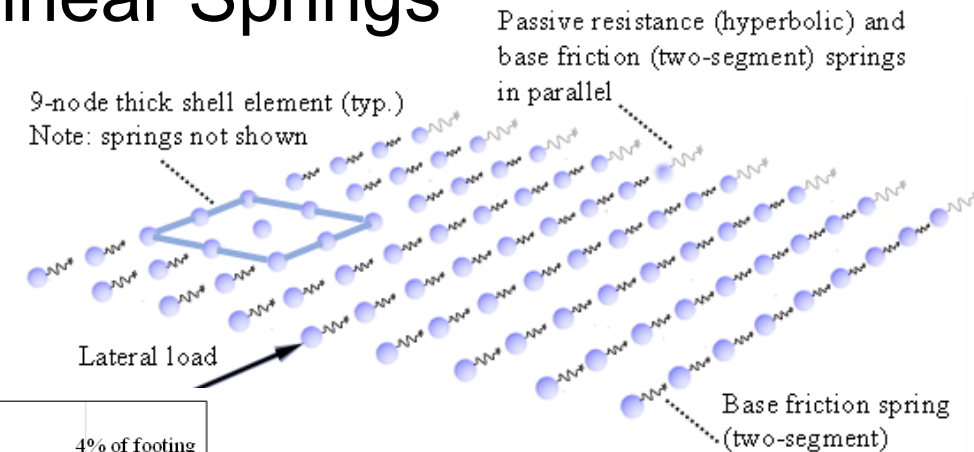


Implement Lateral Resistance in FB-MultiPier

- Shallow Foundation – 9-Node Shell Element
- Soil/Rock Resistance – Discrete Non-Linear Springs



FEA and the BNWF force-displacement comparison

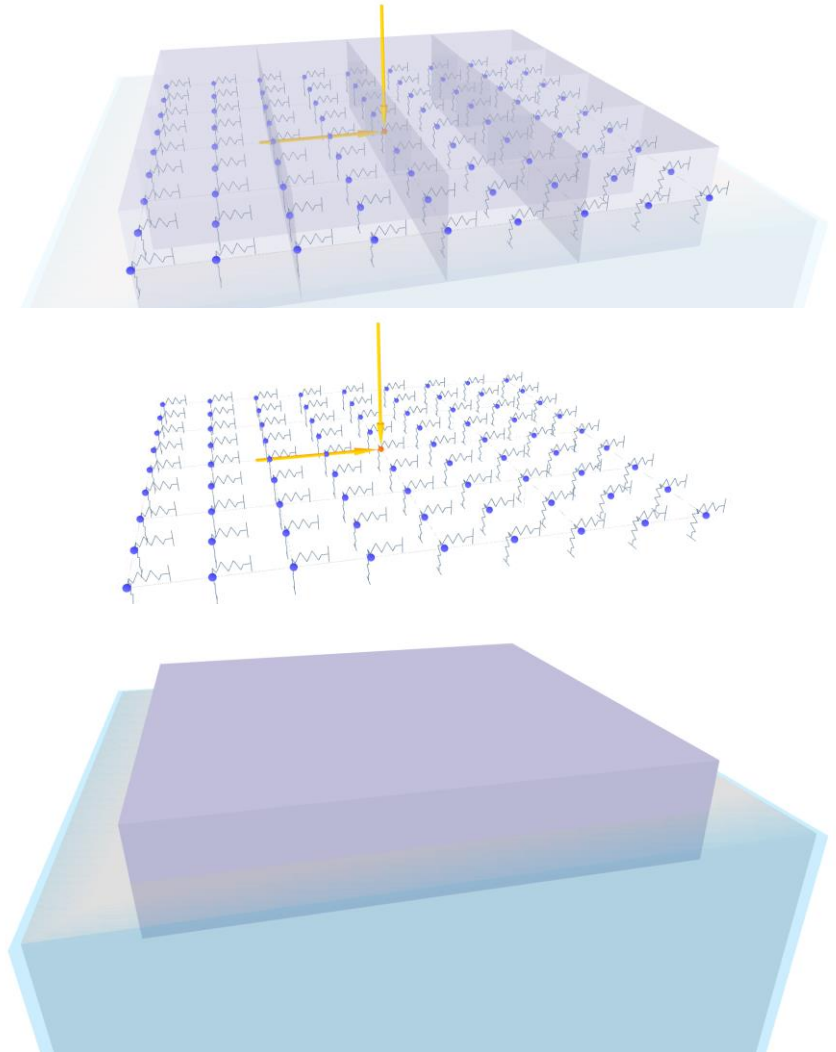
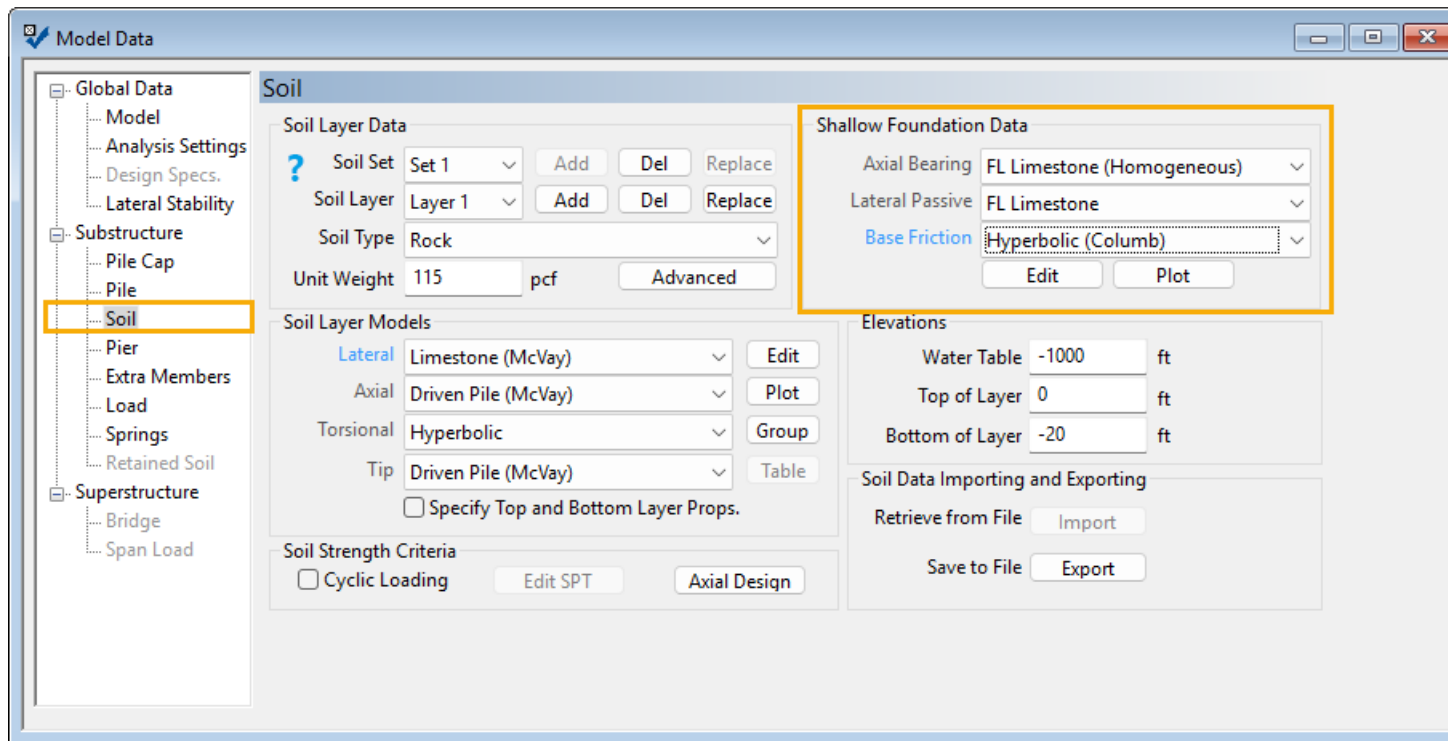


FB-MultiPier Edit Side

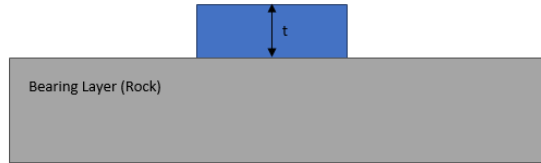
The screenshot displays the FB-MultiPier Edit Side software interface, which is divided into four main panels:

- Model Data Panel:** Contains settings for the model. The left sidebar shows a tree view with categories like Global Data, Model, Analysis Settings, Design Specs., Lateral Stability, Substructure, Pile Cap, Pile, Soil (highlighted), Pier, Extra Members, Load, Springs, Retained Soil, Superstructure, Bridge, and Span Load. The main area is divided into sections:
 - Soil Layer Data:** Includes fields for Soil Set (Set 1), Soil Layer (Layer 1), Soil Type (Rock), and Unit Weight (115 pcf). Buttons for Add, Del, and Replace are provided.
 - Shallow Foundation Data:** Includes Axial Bearing (FL Limestone (Homogeneous)), Lateral Passive (Hyperbolic), and Base Friction (None). Buttons for Edit and Plot are available.
 - Soil Layer Models:** Includes Lateral (Limestone (McVay)), Axial (Driven Pile (McVay)), Torsional (Hyperbolic), and Tip (Driven Pile (McVay)). Buttons for Edit, Plot, Group, and Table are provided.
 - Elevations:** Includes Water Table (-1000 ft), Top of Layer (0 ft), and Bottom of Layer (-20 ft).
 - Soil Data Importing and Exporting:** Includes buttons for Retrieve from File, Import, Save to File, and Export.
 - Soil Strength Criteria:** Includes checkboxes for Cyclic Loading and buttons for Edit SPT and Axial Design.
- Pile Plan View Panel:** Shows a grid of points representing the pile layout. A coordinate system with Xp (red) and Yp (green) axes is shown at the bottom left.
- Soil Edit Panel:** Shows a cross-section of the soil profile. The title is "Soil Set 1 | Pile 1 | Pile Type 1". The profile shows a pile extending from an elevation of -1.8 ft to -3.8 ft. The soil layer is labeled "Layer 1 | Top: qu=1.00000e-07 Gamma=115 | Bot.: qu=1.00000e-07 Gamma=115". The elevation scale ranges from 0.0 to -20.0 ft. A coordinate system with Xp (red), Yp (green), and Zp (blue) axes is shown at the bottom left.
- 3D View Panel:** Shows a 3D perspective view of the pile and soil. A coordinate system with Xp (red), Yp (green), and Zp (blue) axes is shown at the bottom left.

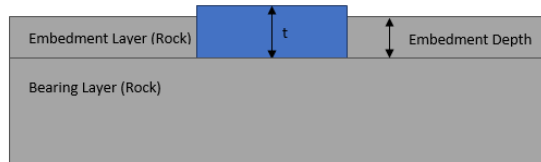
- Lateral Passive Resistance Springs
- Base Friction Resistance Springs



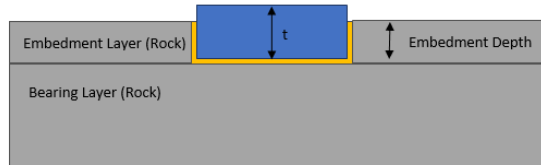
FB-MultiPier Soil Layer Profiles of Interest



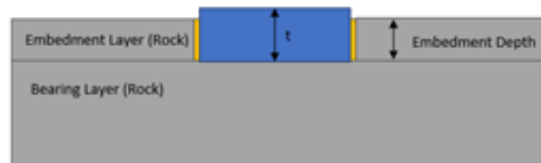
Case 1a. No Embedment, Bearing on Florida Limestone



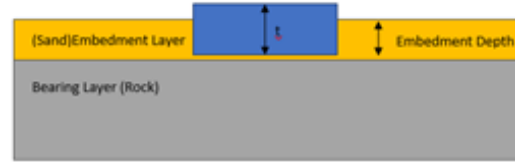
Case 1b. Embedment in Florida Limestone, Bearing on Florida Limestone.



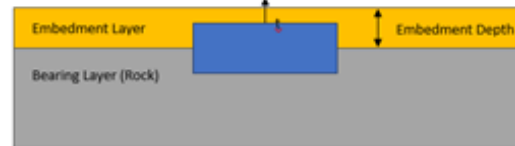
Case 1c. Embedment in Florida Limestone with aggregate backfill around foundation perimeter and base while Bearing on Florida Limestone.



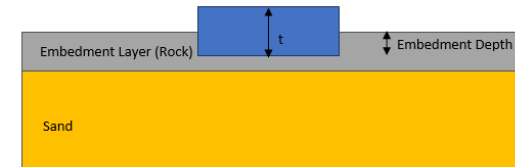
Case 1d. Embedment in Florida Limestone with aggregate backfill around foundation perimeter and Bearing on Florida Limestone.



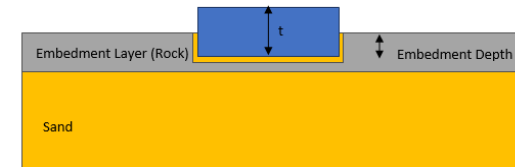
1e. Embedment in Sand underlain by Florida Limestone.



1f. Embedment in Sand, Bearing on Florida Limestone.



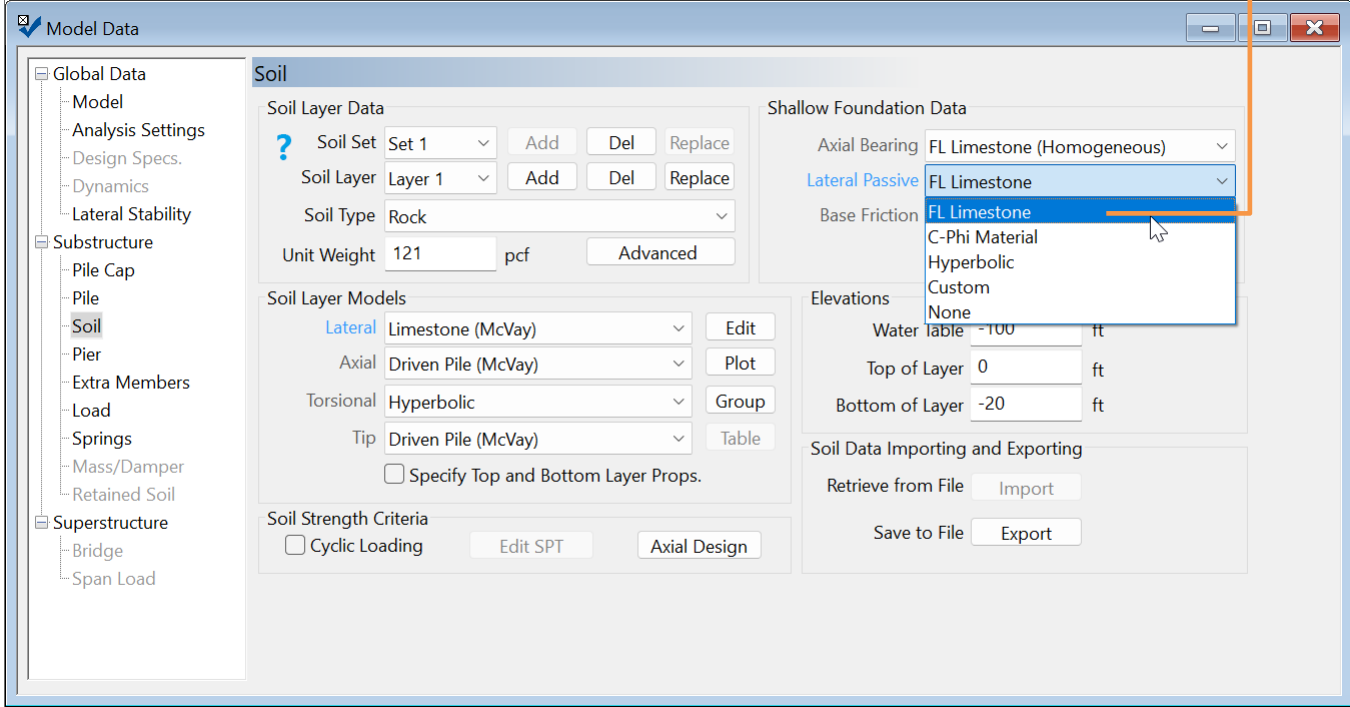
Case 2a. Partial Embedment in Florida Limestone underlain by Sand.

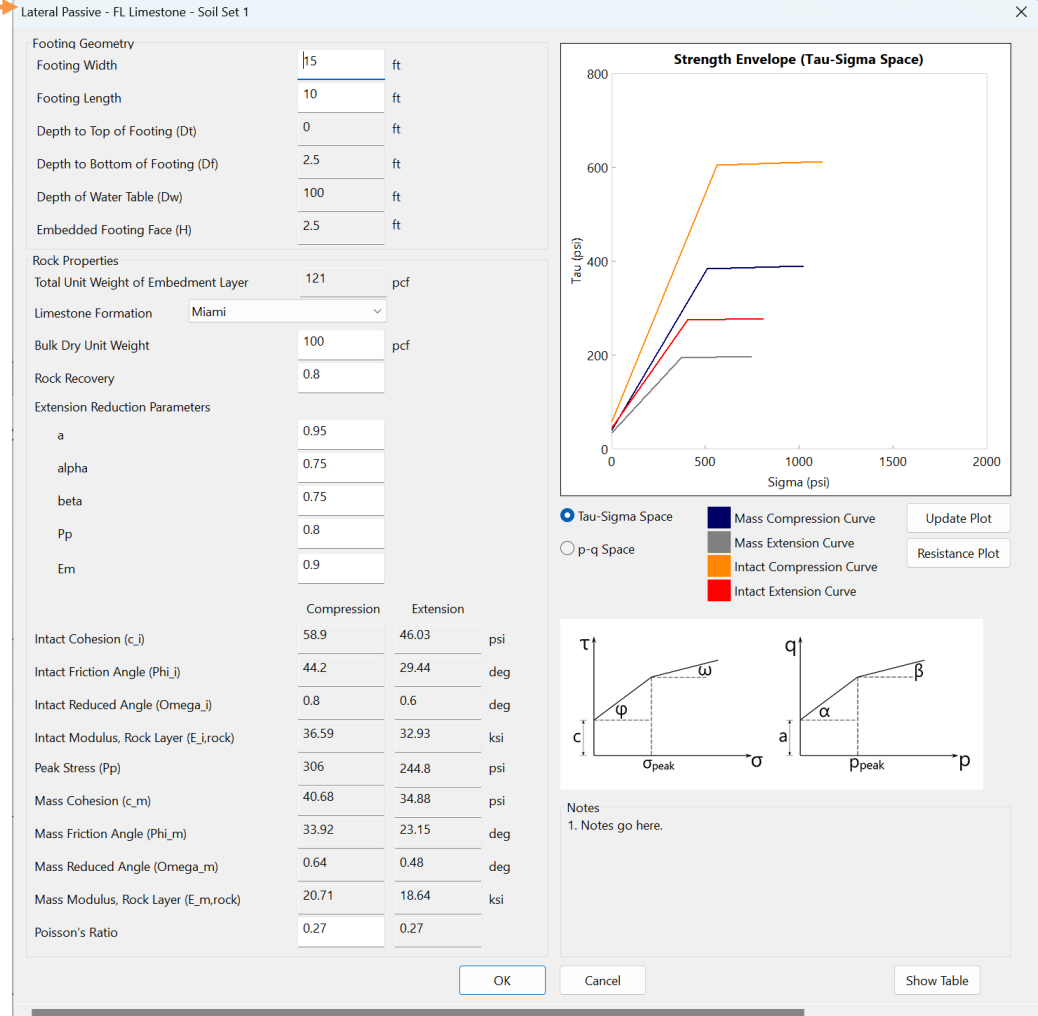


Case 2b. Partial Embedment in Florida Limestone underlain by Sand with sand or aggregate backfill around foundation perimeter and base while Bearing on Florida Limestone.

Case	Bearing Model	Passive Model	Friction Model
1a	FL Limestone (Homogeneous)	None	Hyperbolic (Columb)
1b	FL Limestone (Homogeneous)	FL Limestone	Hyperbolic (Columb)
1c	FL Limestone (Homogeneous)	None	Hyperbolic (Columb)
1d	FL Limestone (Homogeneous)	None	Hyperbolic (Columb)
1e	FL Limestone (Homogeneous)	C-Phi Material	Hyperbolic (Columb)
1f	FL Limestone (Homogeneous)	C-Phi Material	Hyperbolic (Columb)
2a	FL Limestone (Rock over Sand)	FL Limestone	Hyperbolic (Columb)
2b	FL Limestone (Rock over Sand)	None	Hyperbolic (Columb)

Lateral Passive - FL Limestone





Lateral Passive - FL Limestone

Lateral Passive - FL Limestone - Soil Set 1

Footing Geometry

Footing Width: 15 ft

Footing Length: 10 ft

Depth to Top of Footing (Dt): 0 ft

Depth to Bottom of Footing (Df): 2.5 ft

Depth of Water Table (Dw): 100 ft

Embedded Footing Face (H): 2.5 ft

Rock Properties

Total Unit Weight of Embedment Layer: 121 pcf

Limestone Formation: **Miami**

Bulk Dry Unit Weight: **Miami** pcf

Rock Recovery: **Shallow Ft. Thompson**

Extension Reduction Parameter:

a: **Custom Intact (Compression)**

alpha: **Custom Mass (Compression)**

beta: **Custom Intact (Extension)**

Pp: 0.8

Em: 0.9

Intact Cohesion (c_i): 58.9 psi

Intact Friction Angle (Phi_i): 44.2 deg

Intact Reduced Angle (Omega_i): 0.8

Intact Modulus, Rock Layer (E_{i,rock}): 36.59 ksi

Peak Stress (Pp): 306 psi

Mass Cohesion (c_m): 40.68 psi

Mass Friction Angle (Phi_m): 33.92 deg

Mass Reduced Angle (Omega_m): 0.64

Mass Modulus, Rock Layer (E_{m,rock}): 20.71 ksi

Poisson's Ratio: 0.27

Strength Envelope (p-q Space)

q (psi) vs p (psi)

Legend:
☐ Tau-Sigma Space
☒ p-q Space

Mass Compression Curve (Blue)
 Mass Extension Curve (Grey)
 Intact Compression Curve (Orange)
 Intact Extension Curve (Red)

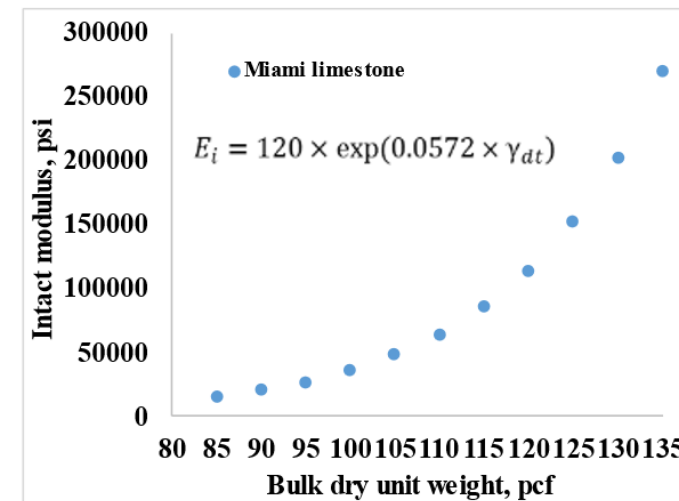
Update Plot
 Resistance Plot

Notes

1. Notes go here.

OK Cancel Show Table

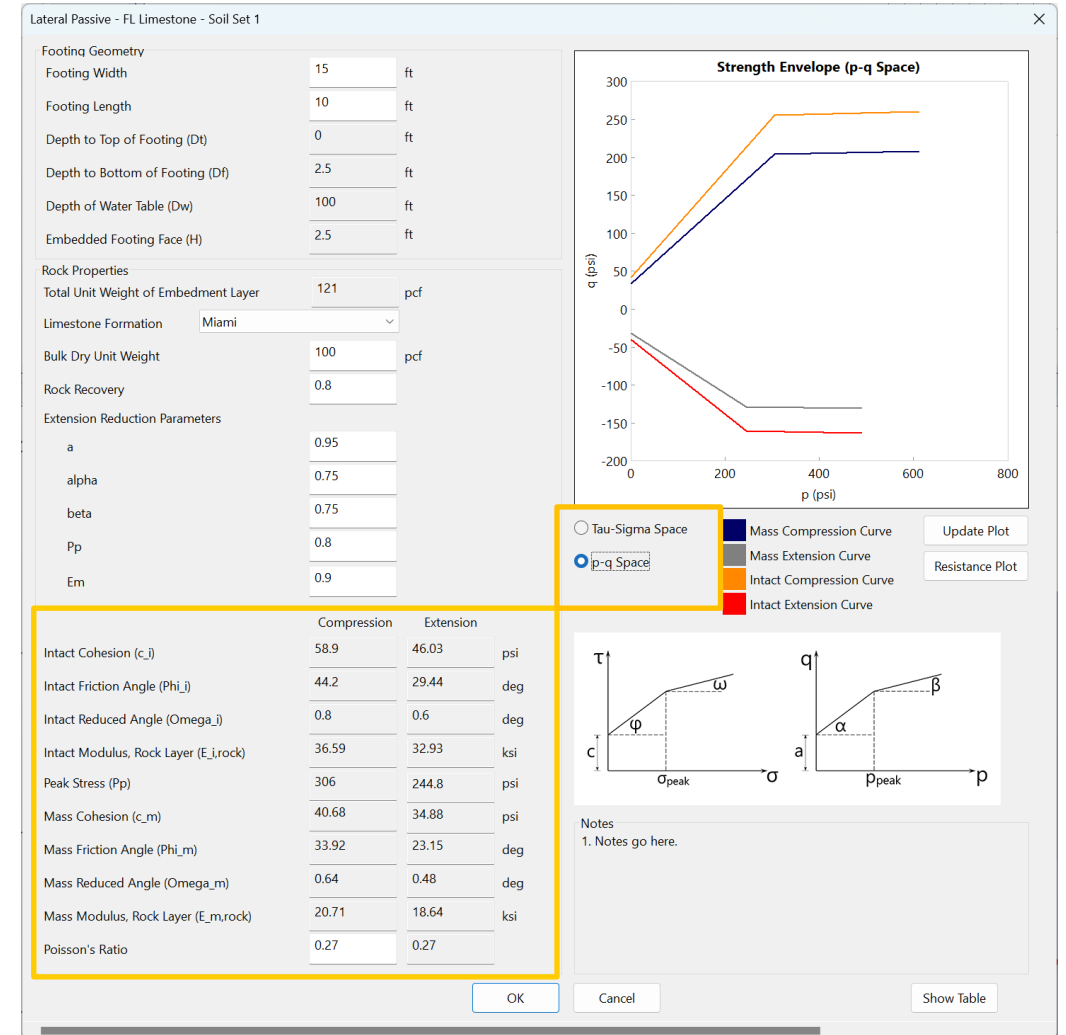
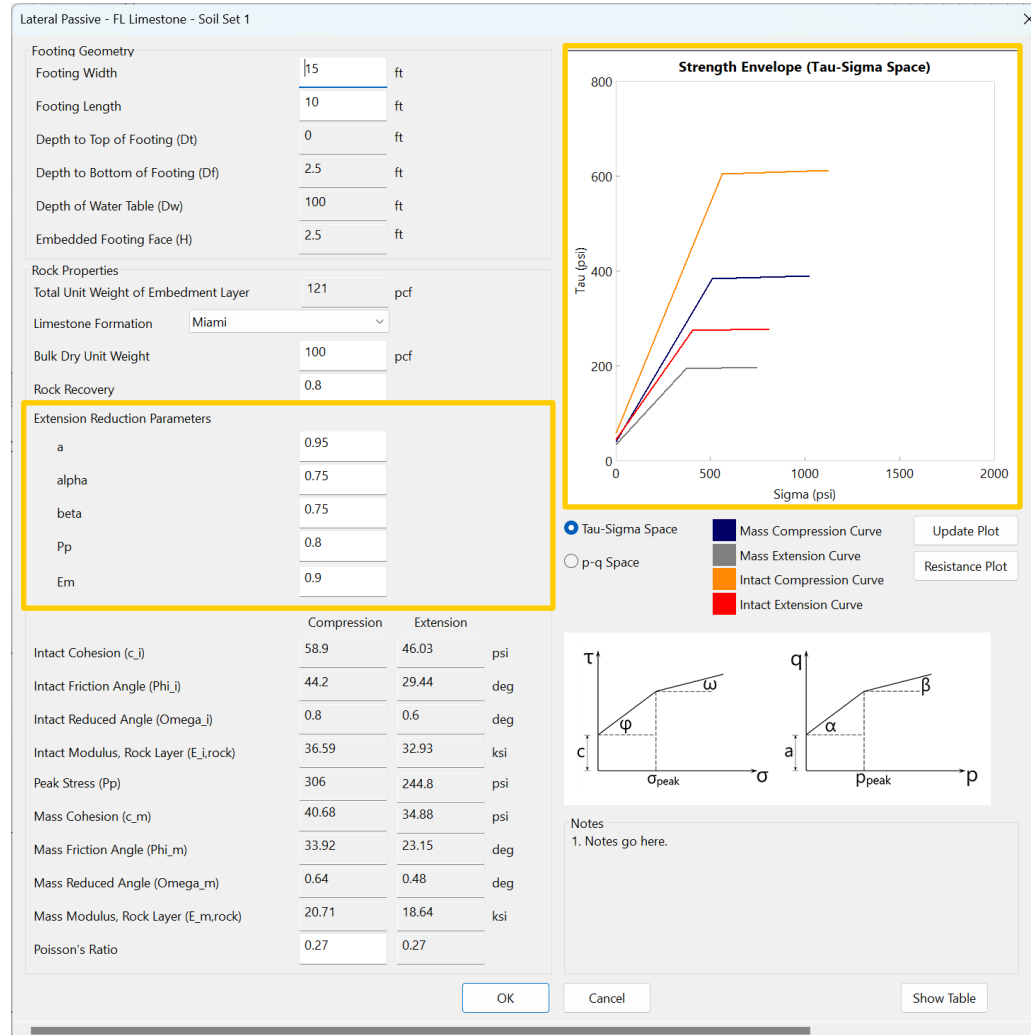
Formation	γ_{dt} , pcf	c_i , psi	ϕ_i , °	$\sigma_{peak\ i}$, psi	ω_i , °	a_i , psi	α_i , °	P_p , psi	β_i , °
Miami Limestone	90	42.0	42.2	444	-3.0	31.1	33.9	247	-3
	95	49.9	43.2	498	-1.4	36.4	34.4	274	-1.4
	100	58.9	44.2	562	0.8	42.2	34.9	306	0.8
	105	70.9	45.3	640	3.7	49.9	35.4	345	3.7
	110	84.1	46.4	730	7.3	58	35.9	390	7.2
	115	99.9	47.3	840	11.6	67.8	36.3	445	11.4
	120	118.8	48.2	969	16.6	79.2	36.7	510	15.9
	125	141.8	49.1	1126	22.2	92.8	37.1	588	20.7
	130	169.0	50.1	1314	28.5	108.4	37.5	682	25.5
	135	202.5	51.1	1541	35.4	127.1	37.9	795	30.1



● 3000 Unconfined Compression test

● 225 Triaxial Test

Lateral Passive - FL Limestone



Lateral Passive - FL Limestone

Lateral Passive - FL Limestone - Soil Set 1

Footings Geometry

Footings Width	15	ft
Footings Length	10	ft
Depth to Top of Footing (Dt)	0	ft
Depth to Bottom of Footing (Df)	2.5	ft
Depth of Water Table (Dw)	100	ft
Embedded Footing Face (H)	2.5	ft

Rock Properties

Total Unit Weight of Embankment Layer	121	pcf
Limestone Formation	Miami	
Bulk Dry Unit Weight	100	pcf
Rock Recovery	0.8	

Extension Reduction Parameters

a	0.95
alpha	0.75
beta	0.75
Pp	0.8
Em	0.9

Compression

Intact Cohesion (c _i)	58.9	psi
Intact Friction Angle (Phi _i)	44.2	deg
Intact Reduced Angle (Omega _i)	0.8	deg
Intact Modulus, Rock Layer (E _{i,rock})	36.59	ksi
Peak Stress (Pp)	306	psi
Mass Cohesion (c _m)	40.68	psi
Mass Friction Angle (Phi _m)	33.92	deg
Mass Reduced Angle (Omega _m)	0.64	deg
Mass Modulus, Rock Layer (E _{m,rock})	20.71	ksi
Poisson's Ratio	0.27	

Extension

Intact Cohesion (c _i)	46.03	psi
Intact Friction Angle (Phi _i)	29.44	deg
Intact Reduced Angle (Omega _i)	0.6	deg
Intact Modulus, Rock Layer (E _{i,rock})	32.93	ksi
Peak Stress (Pp)	244.8	psi
Mass Cohesion (c _m)	34.88	psi
Mass Friction Angle (Phi _m)	23.15	deg
Mass Reduced Angle (Omega _m)	0.48	deg
Mass Modulus, Rock Layer (E _{m,rock})	18.64	ksi
Poisson's Ratio	0.27	

Strength Envelope (p-q Space)

☐ Tau-Sigma Space ☒ p-q Space

☐ Mass Compression Curve ☐ Mass Extension Curve ☐ Intact Compression Curve ☐ Intact Extension Curve

Resistance Plot

Notes
1. Notes go here.

OK Cancel Show Table

Resistance Plot - FL Limestone - Soil Set 1

Footings Geometry

Footings Width	15	ft
Footings Length	10	ft
Depth to Top of Footing (Dt)	0	ft
Depth to Bottom of Footing (Df)	2.5	ft
Depth of Water Table (Dw)	100	ft
Embedded Footing Face (H)	2.5	ft

Passive Resistance

Lateral Earth Pressure: Ultimate

Total Unit Weight	121	pcf
Mass Cohesion (c _m)	5022.72	psf
Mass Friction Angle (Phi _m)	23.15	deg
Mass Modulus, Rock Layer (E _{m,rock})	18640	psi
Poissons Ratio	0.27	
Soil/Wall Friction Angle, small delta	26	deg
Max Lateral Deflection, delta	3	in
Additional Uniform Surcharge	0	psf

Passive Resistance (auto-generated, not editable)

Property	Width	Length	Units
Initial Elastic Stiffness (Kmax)	8011.6446	6133.4731	kips/in
Failure Ratio (Rf)	0.9570	0.9606	%
Ult. Lateral Earth Pressure (Pult)	1032.8977	724.5240	kips
Net Lateral Earth Pressure (Pnet)	781.8060	557.1295	kips
Friction Passive Earth Pressure Coeff (Kpphi)	4.1164	4.1164	
Cohesion Passive Earth Pressure Coeff (Kpc)	5.6622	5.6622	
Surcharge Passive Earth Pressure Coeff (Kpq)	3.6450	3.6450	
Rankine Active Earth Pressure Coeff (Ka)	0.4356	0.4356	
Ovesen's 3D Factor (R)	1.1230	1.1816	

Lateral Earth Pressure Force

☒ Load ☐ Pressure ☐ Length Curve ☐ Width Curve

Notes
1. Note 1 goes here.

OK Cancel Show Table

Base Friction – Hyperbolic (Columb)

Model Data

- Global Data
 - Model
 - Analysis Settings
 - Design Specs.
 - Dynamics
 - Lateral Stability
- Substructure
 - Pile Cap
 - Pile
 - Soil**
 - Pier
 - Extra Members
 - Load
 - Springs
 - Mass/Damper
 - Retained Soil
- Superstructure
 - Bridge
 - Span Load

Soil

Soil Layer Data

? Soil Set Set 1 Add Del Replace

Soil Layer Layer 1 Add Del Replace

Soil Type Rock

Unit Weight 121 pcf Advanced

Soil Layer Models

Lateral Limestone (McVay) Edit

Axial Driven Pile (McVay) Plot

Torsional Hyperbolic Group

Tip Driven Pile (McVay) Table

☐ Specify Top and Bottom Layer Props.

Soil Strength Criteria

☐ Cyclic Loading Edit SPT Axial Design

Shallow Foundation Data

Axial Bearing FL Limestone (Homogeneous)

Lateral Passive FL Limestone

Base Friction Hyperbolic (Columb)

FL Limestone

Hyperbolic (Columb)

Custom

None

Elevations

Water

Top of Layer 0 ft

Bottom of Layer -20 ft

Soil Data Importing and Exporting

Retrieve from File Import

Save to File Export

Base Friction - Hyperbolic (Columb) - Soil Set 1

P Ultimate 724 kips

Initial Stiffness (K_max) 6000 kips/in

Failure Ratio Between P Ultimate (R_f) 0.96

Adhesion Factor 0

Cohesion 0 psf

Footing Length 15 ft

Footing Width 10 ft

Normal Force 112.5 kips

Interface Friction 15 deg

Total Nominal Force Per Footing Node

Frictional Force

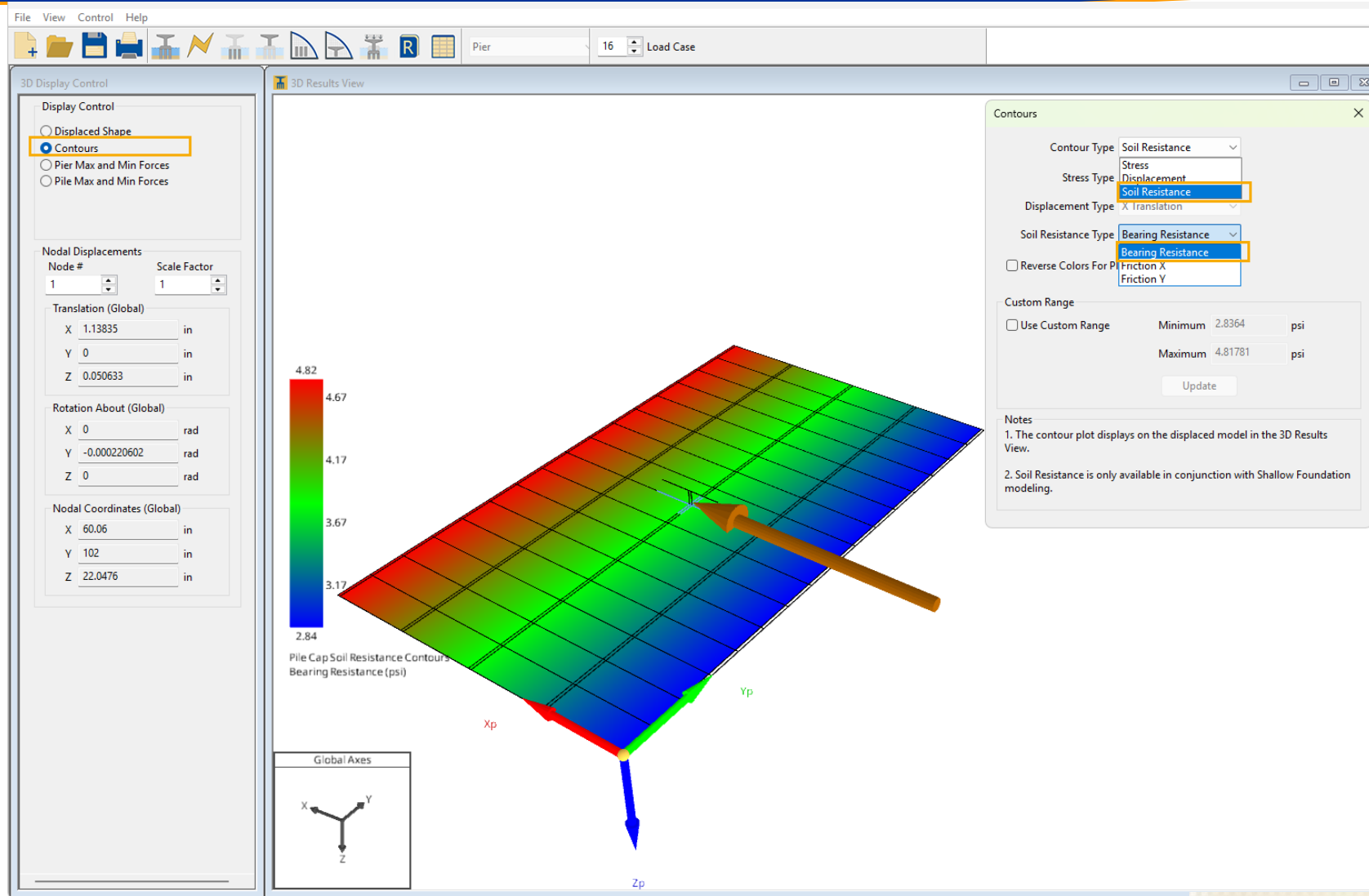
Update Plot

Notes

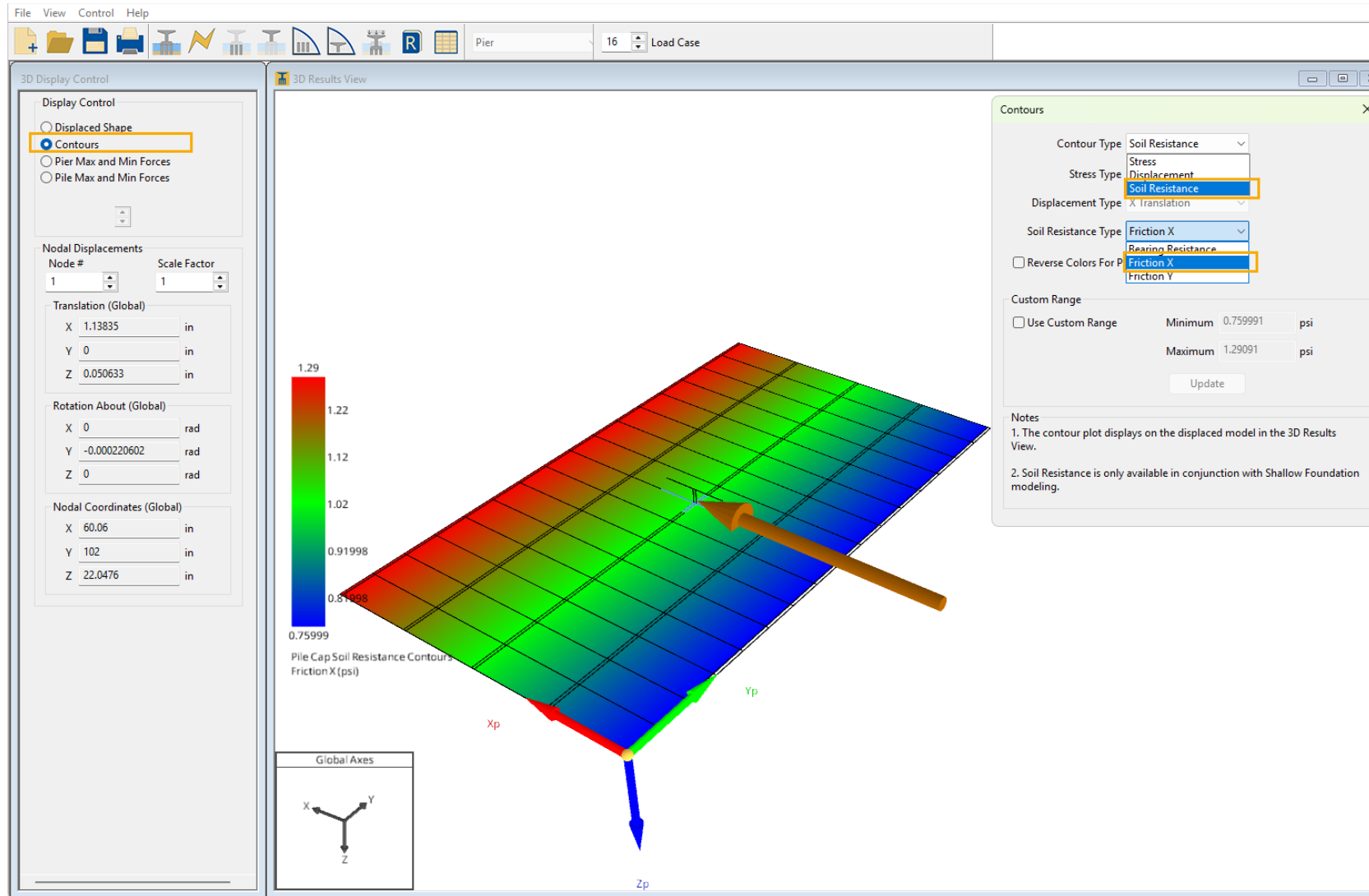
1. Friction Force in the plot is a function of the normal force input by the user. This plot is only to demonstrate the shape of the curve for a specific normal loading. During the analysis, the normal load is calculated by self-weight and applied external loads per individual nodes.

OK Cancel Show Table

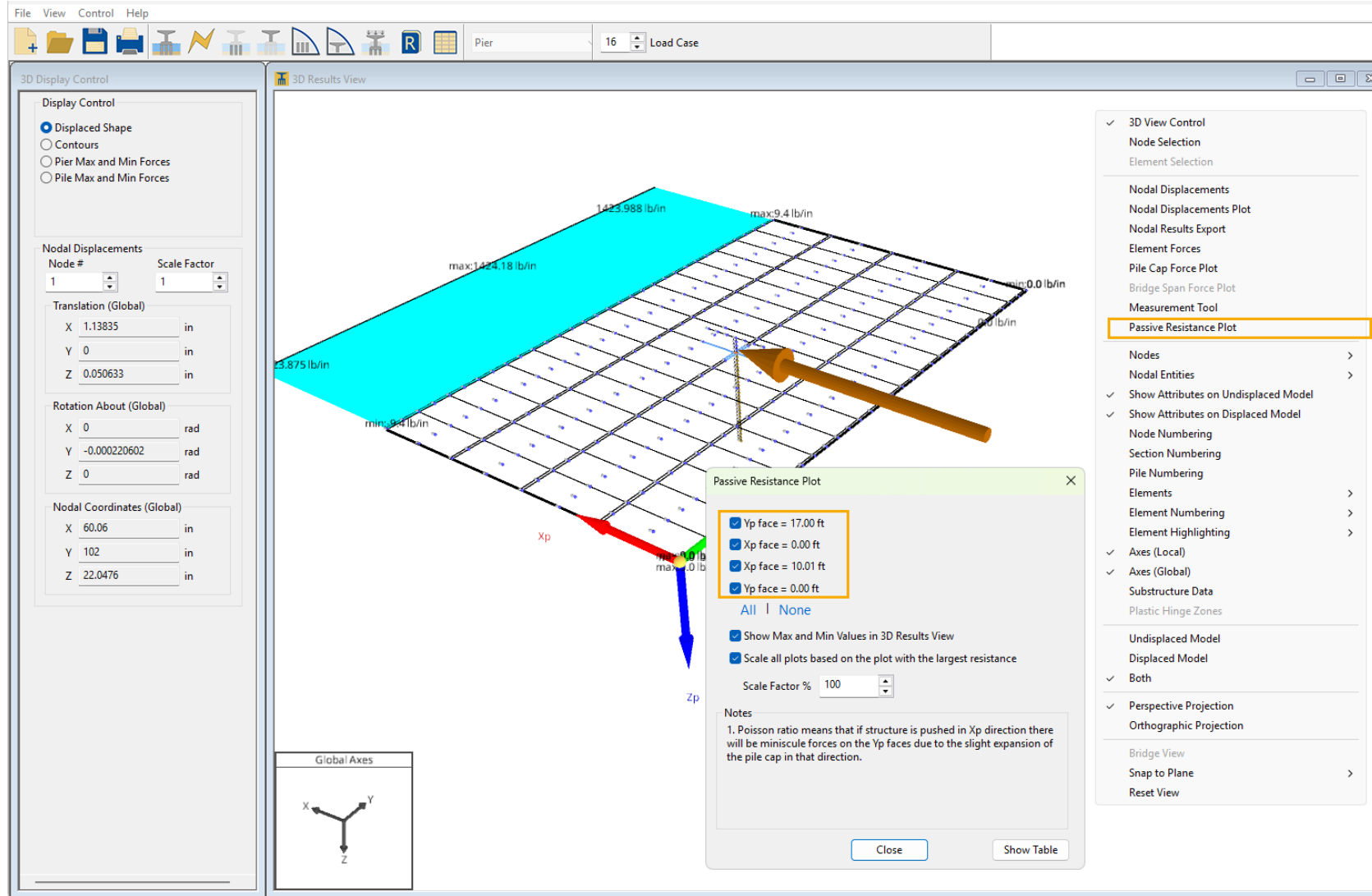
FB-MultiPier - 3D Results – Bearing Resistance Contour



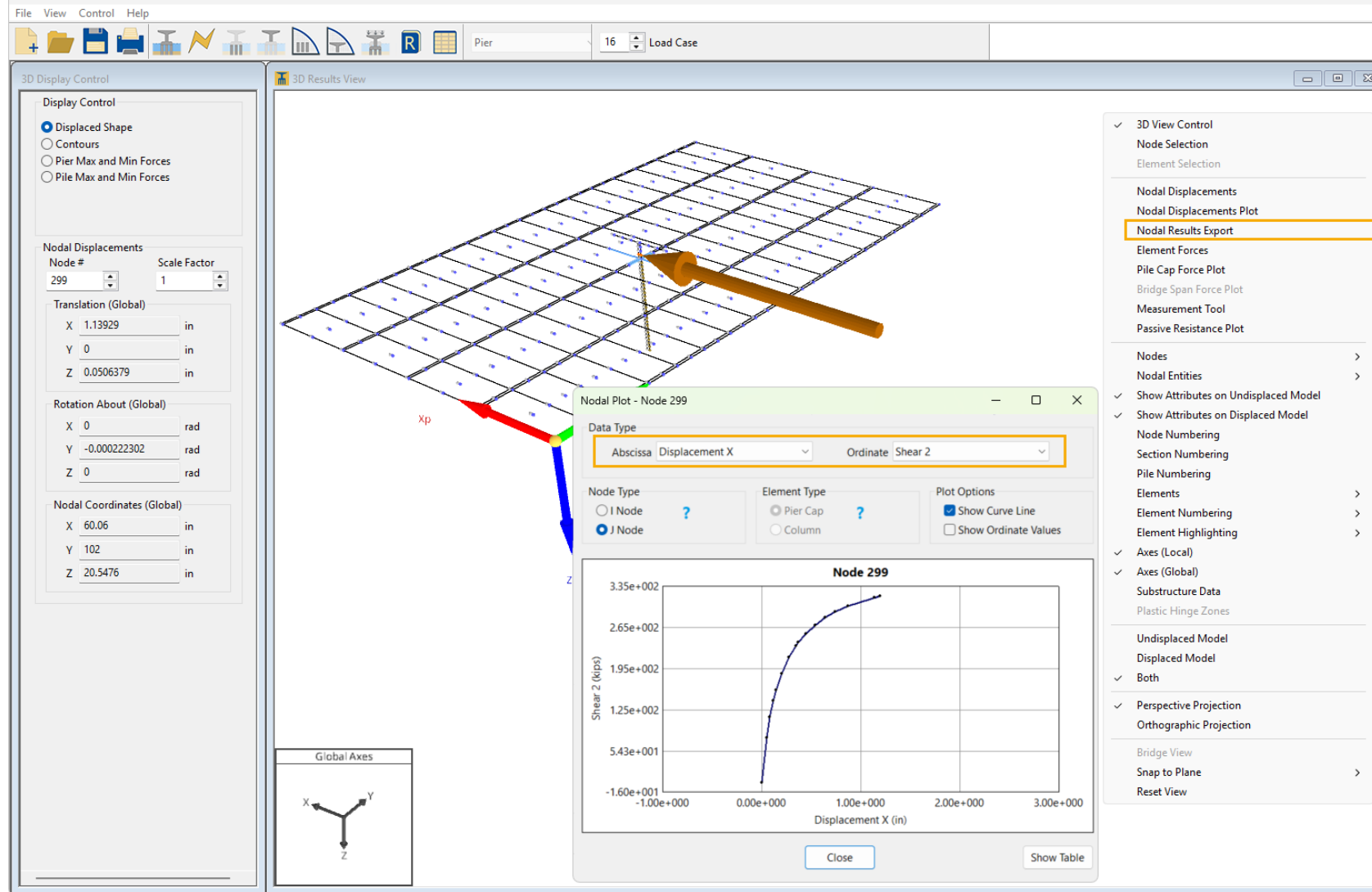
FB-MultiPier - 3D Results – Base Friction Contour

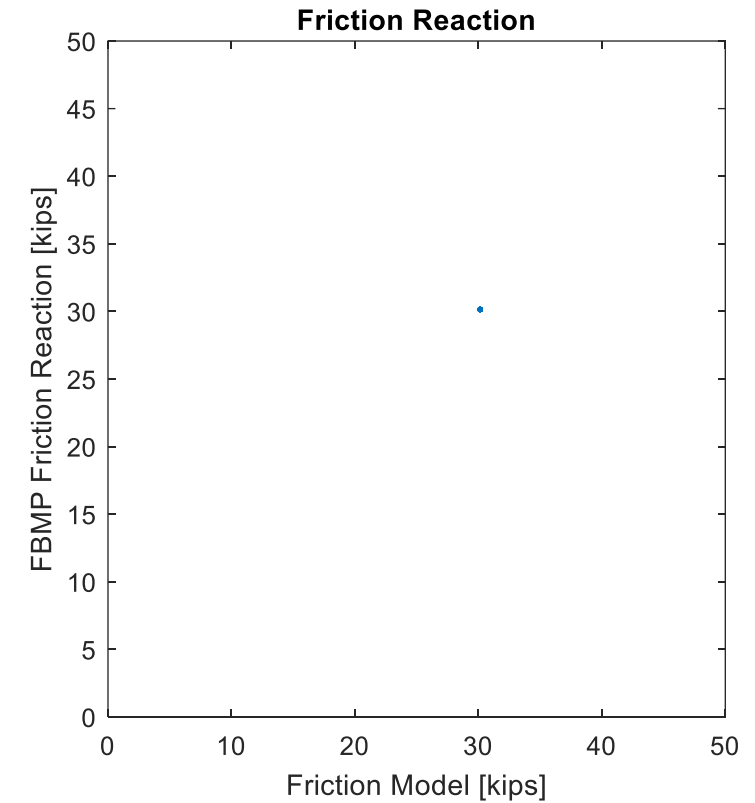
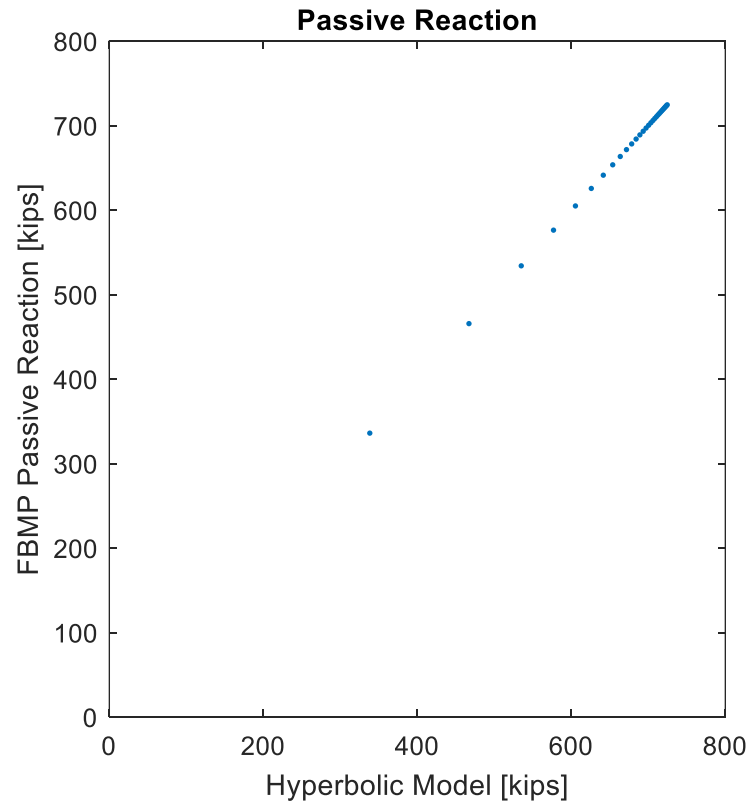
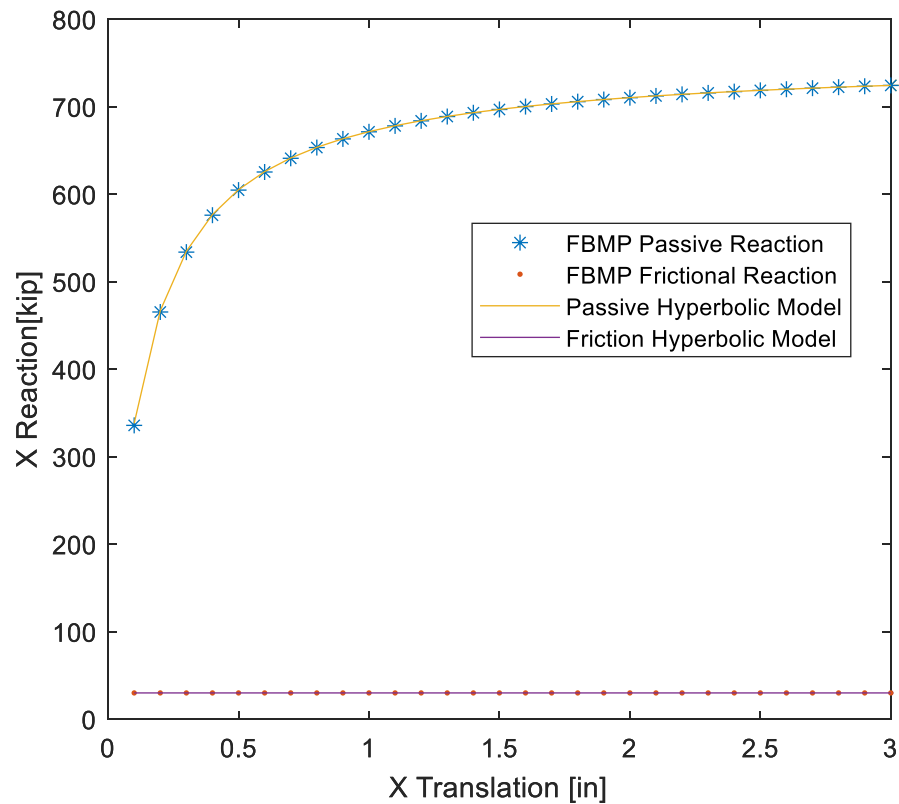


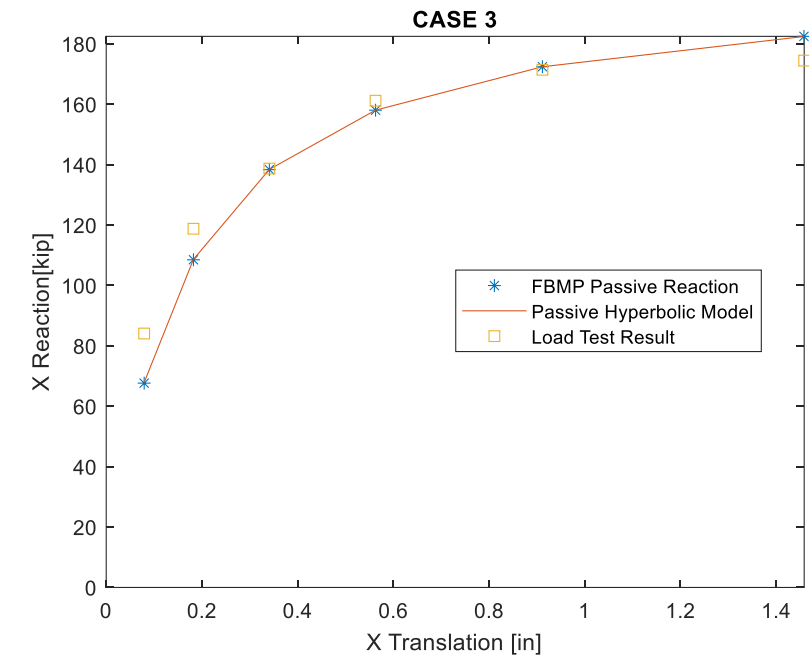
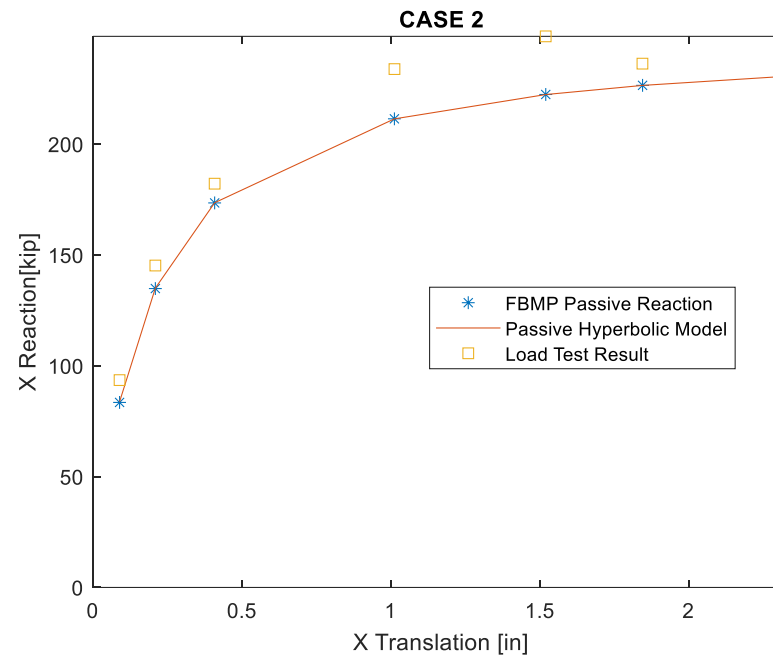
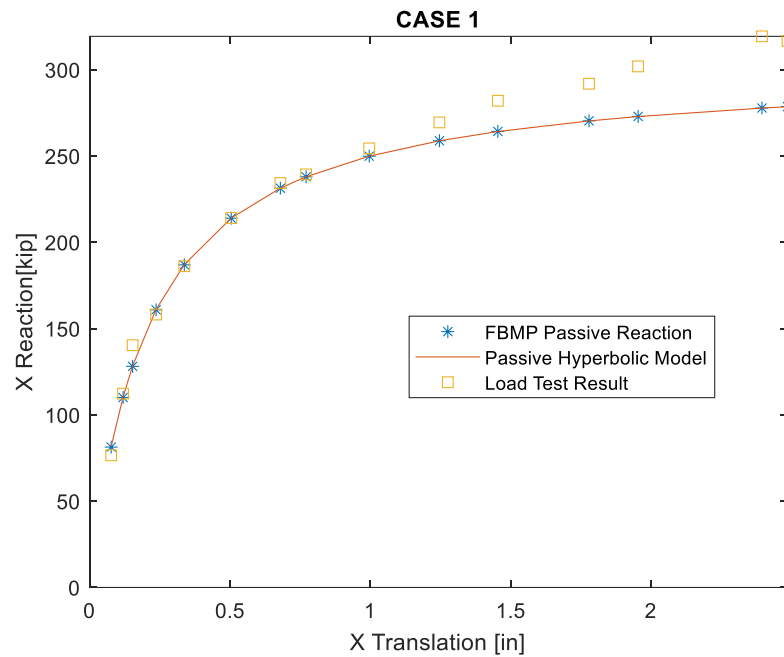
FB-MultiPier - 3D Results – Lateral Passive Contour



FB-MultiPier - 3D Results – Nodal Plot



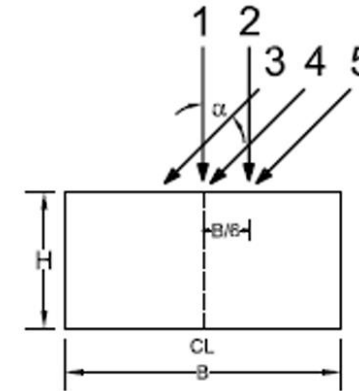




(Rollins and Cole, 2006)

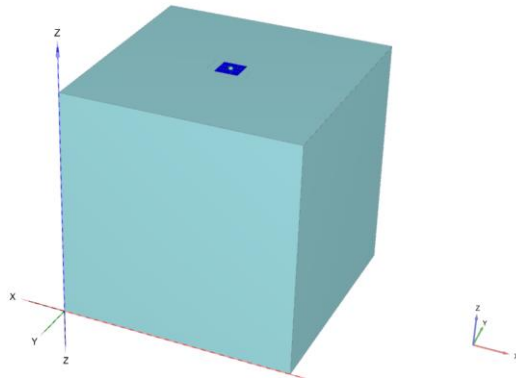
Task 4 – Investigate Effects of Inclined and Eccentric Loading

- Investigate load inclination and eccentricity effects on FL Limestone BC with Plaxis models.
- Based on FEM results, identify methods (modified Vesic, Meyerhof, etc.) for conservative modification to vertical bearing spring pressure values.
- Anticipated issues: lack of current research.



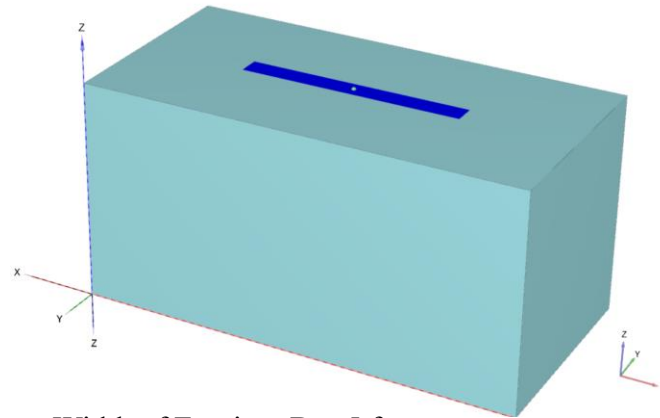
Load Case 1 - concentric, Load Case 2 - eccentric, Load Case 3 - eccentric-inclined (inclination-7 degrees), horizontal component positive (+), to the direction of the eccentricity, Load Case 4 - inclined (inclination-7 degrees) and Load Case 5 - eccentric-inclined (inclination-7 degrees), horizontal component negative (-), to the direction of the eccentricity as presented by Meyerhof (1953).

Square footing ($L/B=1$):



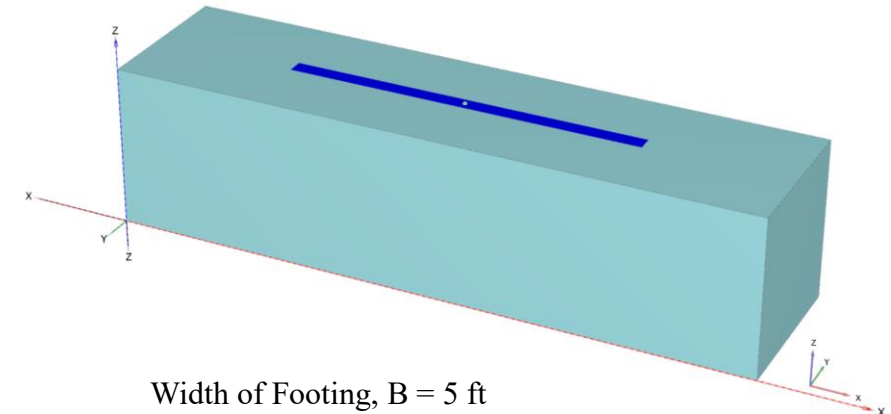
Length and Width of Footing, $L=B=5$ ft
Soil body = 50'x50'x50'

Rectangular footing ($L/B=10$):



Width of Footing, $B=5$ ft
Length of Footing, $L=50$ ft
Soil body = 100'x50'x50'

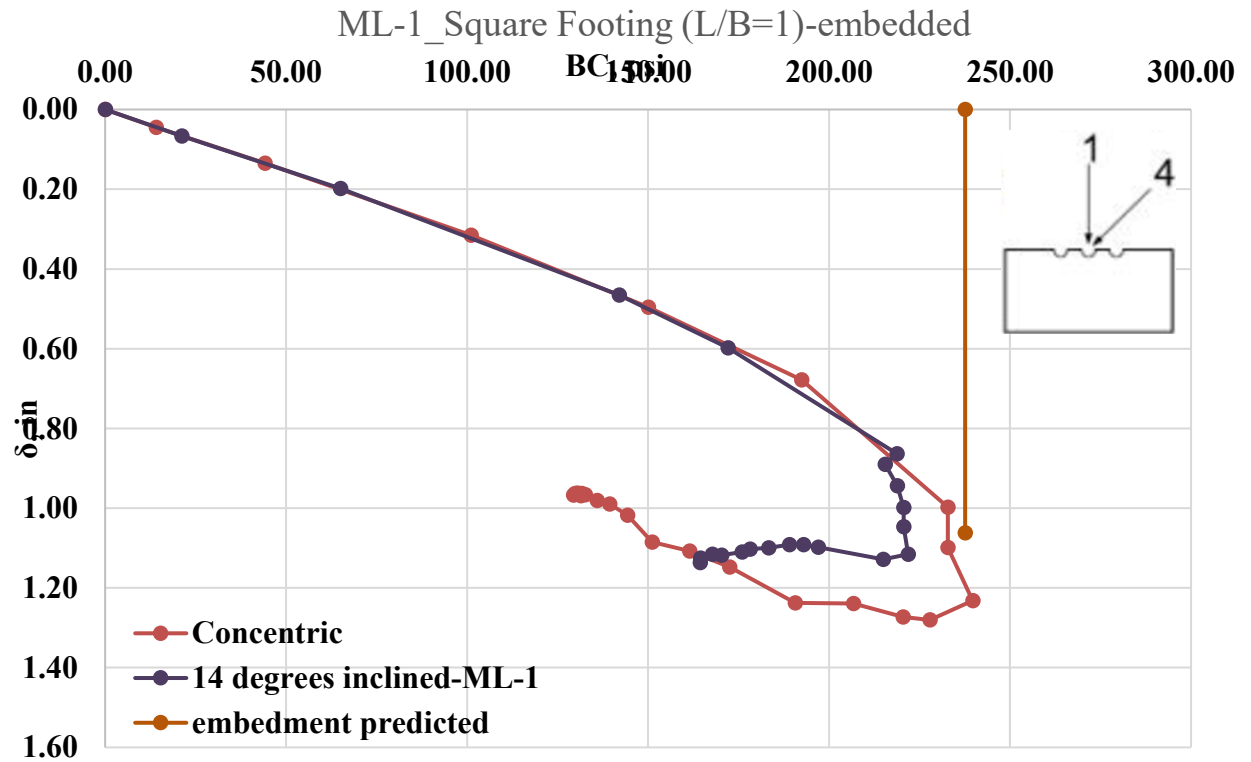
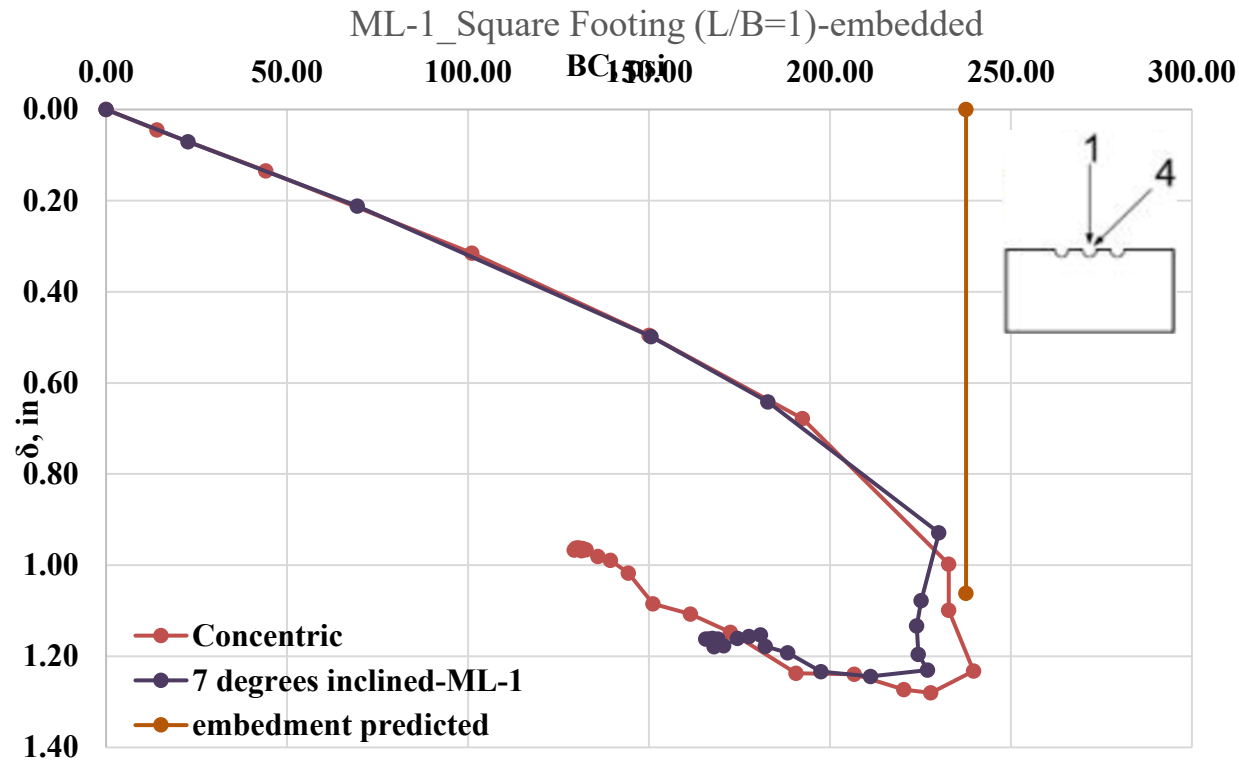
Strip footing ($L/B>20$):



Width of Footing, $B=5$ ft
Length of Footing, $L=110$ ft
Soil body = 200'x50'x50'

Task 4 – Investigate Effects of Inclined and Eccentric Loading

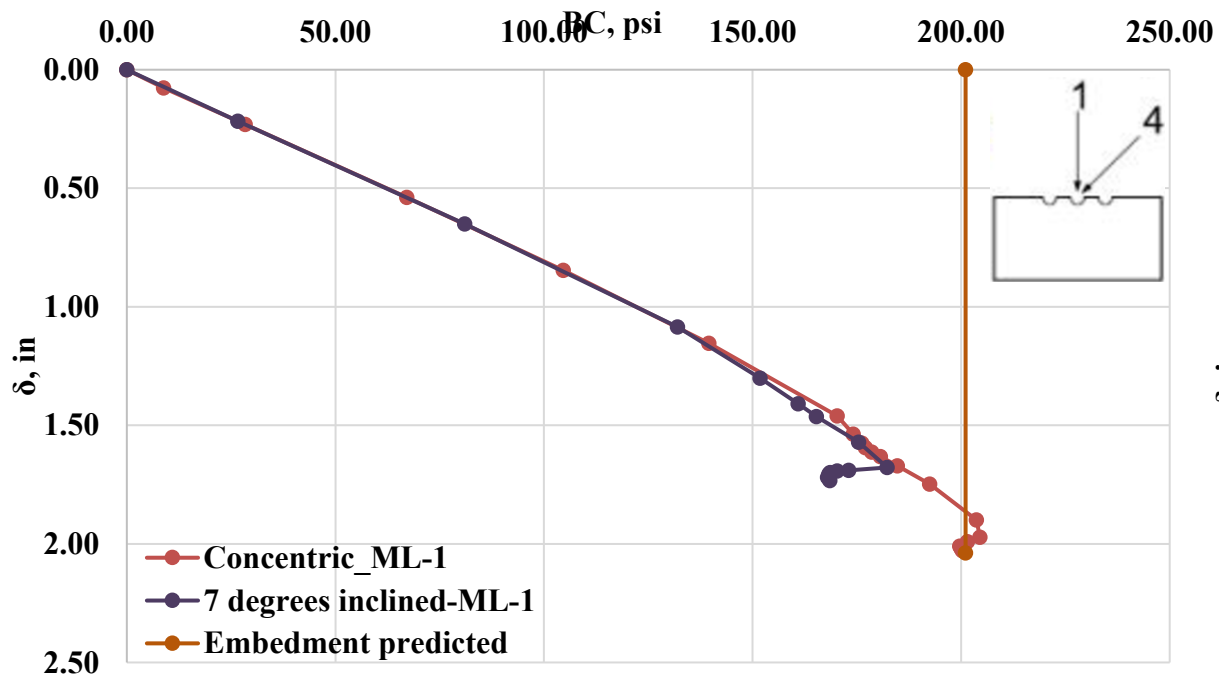
Miami Limestone: $L/B = 1$ and Fully Embedded with Inclined Loading



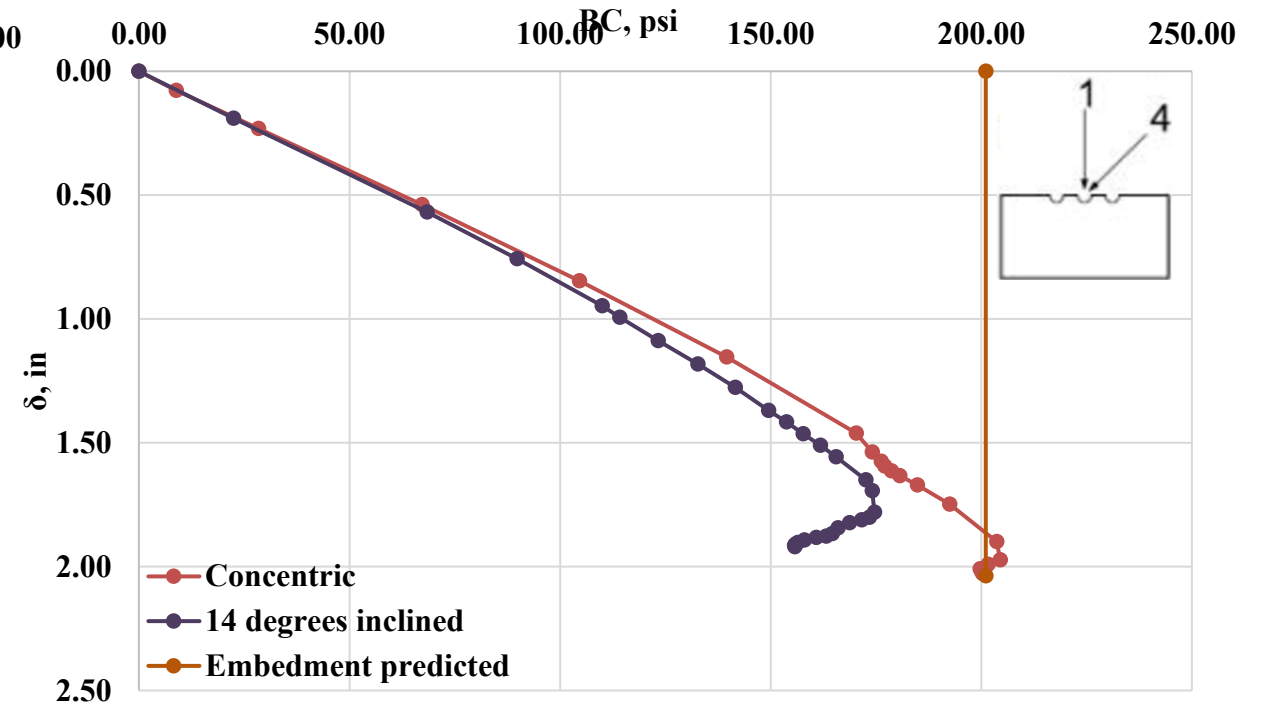
Task 4 – Investigate Effects of Inclined and Eccentric Loading

Miami Limestone: $L/B = 10$ and Fully Embedded with Inclined Loading

ML-1_Rectangular Footing (L/B=10)-embedded



ML-1_Rectangular Footing (L/B=10)-embedded



Thank You!

Questions & Answers