April 3, 2024

Via E-Mail: Howard.Ashley@EPA.Gov

Ms. Ashley Howard
Remedial Project Manager, Superfund Emergency Management Division
United States Environmental Protection Agency, Region 6
1201 Elm Street, Suite 500
Dallas, Texas 75270

RE: San Jacinto Waste Pits Superfund Site, Channelview, Texas (Site)
Barge Impact Protection Memo- Supplement to Plan in Response (Plan) to the United States Environmental Protection Agency (EPA) January 5, 2024 Notification of Serious Deficiency (Notice) Pursuant to Paragraph 59 of Administrative Settlement Agreement and Order on Consent for Remedial Design (AOC), CERCLA Docket No. 06-02-18

Dear Ms. Howard:

International Paper Company (IPC) and McGinnes Industrial Maintenance Corporation (MIMC), collectively referred to as the Respondents, hereby submit the enclosed Barge Impact Protection Memorandum as a supplement to Respondents' Plan submitted on January 25, 2024 in response to the above referenced Notice received from EPA on January 5, 2024. GHD prepared the memorandum on behalf of the Respondents as part of our continuing work on a number of design items as outlined in the Plan.

As noted in Respondents' Plan and as expressed in both the meeting held on February 9, 2024, between Respondents and EPA, as well as in the February 19, 2024 email to John Meyer, Respondents are committed to addressing EPA's concerns and continuing work on remedial design items as outlined in the Plan.

Regards,

International Paper Company

By: Brent Sasser
Brent Sasser
Sr. Environmental/Remediation Manager

McGinnes Industrial Maintenance Corporation

By: Judy Armour
Judy Armour
Senior District Manager
Environmental Legacy Management Group

cc: Anne Foster, EPA
Lauren Poulos, EPA
Robert Appelt, EPA
Katie Delbeq, P.G., TCEQ

Technical Memorandum

April 3, 2024

To	Lee Lavergne	**Contact No.**	(925) 849-1019
Copy to	Charles Munce, P.E.	**E-Mail**	Satish.Chilka@GHD.com
From	Satish Chilka, P.E. (CA, TX)	**Project No.**	11215702-MEM-10
Project Name	San Jacinto River Waste Pits SF - Northern Impoundment		
Subject	Barge Impact Protection		

1. Introduction

GHD Services Inc. (GHD) has prepared this memorandum to document the continued efforts to evaluate barge impact protection of the engineered barrier or cofferdam using a best management practice (BMP) that will encircle the Northern Impoundment of the San Jacinto River Waste Pits Superfund Site (Site), as presented in the Pre-Final 90% Remedial Design (RD) submitted to the United States Environmental Protection Agency (EPA) in June 2022. The BMP will be required to divert water around the Northern Impoundment and allow excavation of waste material. The Revised 90% RD to be submitted to EPA, as contemplated by the Respondents' Plan in Response to United States Environmental Protection Agency Comments to Pre-Final 90% Remedial Design (90% RD) - Northern Impoundment dated January 25, 2024, would include detailed designs and specifications for the additional barge impact protection measures described in this memorandum.

Given the heavy barge traffic in the San Jacinto River, the BMP will likely be exposed to potential barge impact. An impact could be the result of a barge coming off its mooring and drifting toward the BMP during a storm or it could be the result of a towed barge veering off course or a barge losing control/power. Although the 90% RD barge impact analysis concluded that the current BMP wall design could withstand a specified barge impact without sustaining global failure, this memorandum was developed to document the design and analysis of a protective barrier wall to serve as an additional layer of protection for the BMP from potential barge impacts.

The segment of the river around the BMP that is actively used by barges is shown on Figure 1.1. The barges traveling in the navigational waterway, either empty or loaded, would be likely to make contact with the BMP at an angle. Any barges moored directly north of the BMP would be likely to make head-on contact with the BMP, if they were to come off their mooring.

The Texas Department of Transportation (TxDOT)'s design criteria for the dolphin and fender system protecting the Interstate-10 (I-10) Bridge piers includes impact from a 30,000-barrel (bbl) barge, which represents one of the larger barges operating in the vicinity of the bridge. A typical 30,000 bbl barge is 300-feet (ft) long, 54-ft wide, and 12-ft tall. In a laden condition, loaded to full capacity, such a barge would displace the equivalent of 30,000 bbl or approximately 168,500 cubic feet (ft^3) of water. Thus, the barge is assumed to weigh approximately 5,250 U.S.-tons or 10,500 kilopounds (kips) in laden condition. In ballasted condition, the barge carries only fuel and ballast water, and weighs approximately 910 U.S.-tons or 1,820 kips.

The head-on impact from the 54 ft wide, 30,000 bbl barge, in laden condition, was considered for the evaluation of the BMP that was included in the 90% RD. The American Association of State Highway Transportation Officials (AASHTO)[1] method to determine impact force absorbed by bridge piers was used for evaluating the BMP for direct impact. This method is conservative since the BMP will have a much larger profile area than the typical bridge piers to absorb impact and distribute the energy. The kinetic energy from impact can be determined from the river flow velocity or the navigation speed. The energy of impact will be lower for any impact angle other than a head-on collision.

Figure 1.1 Navigational Waterway - Northern Impoundment

2. Direct Impact on BMP

The standard design guidelines require structures, such as bridge piers within the navigational waterway, to be designed for barge impacts. The equations available to calculate energy and force from barge impact were developed for design of bridge piers, which have a smaller profile than the BMP wall and absorb a large portion of the impact energy assuming minimal damage to the barge itself. The equations therefore are likely conservative for use in evaluating impacts on the BMP.

The 95th percentile velocities for the river flow from the hydrodynamic analysis[2] report are summarized in the below Table 2.1. Based upon this data, the barge impact for the BMP was evaluated for flow velocity of 2.20 feet per second (ft/s). A contact width of 50-ft was assumed to account for variations in the barge bow shapes.

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[1] AASHTO LRFD Bridge Design Specifications, Section 3.14.

[2] Hydrodynamic Modelling Report, San Jacinto River Waste Pits - Northern Impoundment by GHD, June 27, 2022.

Table 2.1 95th Percentile Velocity - Hydrodynamic Model

95th Percentile Velocity (ft/s)	Existing Conditions (No BMP)			With BMP in Place		
	2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
Maximum	2.21	1.45	0.73	2.16	2.20	1.04
Average	0.51	0.50	0.35	0.46	0.50	0.36

Thereby a 54-ft wide, 30,000 bbl barge moving at 2.20 ft/s would result in impact energy of 829 kilopounds per foot (kip/ft) on contact with the BMP. The energy will be absorbed by the BMP and the barge itself will absorb some energy. However, energy absorbed by the barge has been ignored in order to more conservatively evaluate the impact on the BMP.

The barge impact analyses showed that the sheet piles would be overstressed if an impact from a laden 30,000 bbl barge at 2.20 ft/s velocity were to occur; however, the strain calculations do not indicate a global failure. The impact loads are reduced significantly at lower velocity of impact. The barges and tugboats typically slow down as the width of the navigational waterway narrows closer to the I-10 Bridge.

The stresses in the sheet piles can be reduced by installing additional measures, such as a barrier wall (as described in Section 3).

3. Additional Measures - Barrier Wall

As an additional measure to provide increased protection from potential barge impacts, a barrier wall would be installed at approximately 20 to 25 ft from the exterior wall of the BMP. The barrier wall would be installed to the north and east side of areas exposed to potential barge impacts. The west side of the Northern Impoundment is not exposed to any barge traffic; therefore, a barrier wall in this area is not necessary. The general alignment, typical section and elevation of the barrier wall are shown on Figure 3.1 through Figure 3.3.

The barrier wall will be comprised of 18-inch diameter fiberglass reinforced polymer (FRP) composite piles spaced at 8-ft on center. Four rows of 12-inch by 12-inch reinforced high-density polyethylene (HDPE) walers will be installed horizontally on the exterior side of the FRP piles, evenly spaced between Elevation +2 and +12 ft above mean water level (Figure 3.2 and Figure 3.3).

Similar to the BMP, the height of the FRP piles above riverbed and the variation in subsurface strata will affect the performance of the barrier wall. Hence, design parameters corresponding to various BMP cross-sections, such as Section C2, Section C3, Section C4, and Section C5 were considered to evaluate the energy absorption capacity of the barrier wall. Section C4 governs over Section C4A, due to relatively greater depth to riverbed.

The piles used in the analysis are a proprietary product manufactured by Creative Pultrusion’s and marketed as Superpile. The walers are manufactured by Tangent Materials. However, other FRP pile or HDPE walers with equivalent properties can be used in construction. The allowable design values (i.e., moment capacity of the FRP piles and walers), as shown in the below Table 3.1, are determined through full-scale testing by the manufacturer. The barrier wall is designed as a sacrificial element (i.e., acceptable to undergo damage) to absorb maximum amount of impact energy. Hence, no reduction factors are applied to the moment capacity.

Table 3.1 Moment Capacity of FRP Piles and Wales

Component	Moment Capacity (kip/ft)	
	ASTM D6109 Mean Test Results	ASTM D7290 Design Property
FRP Pile, 18-in x 0.75-in TU 465	803	699
Wale, 12-in x 12-in 8F12	283	N/A

Figure 3.1 Alignment - FRP Barrier Wall

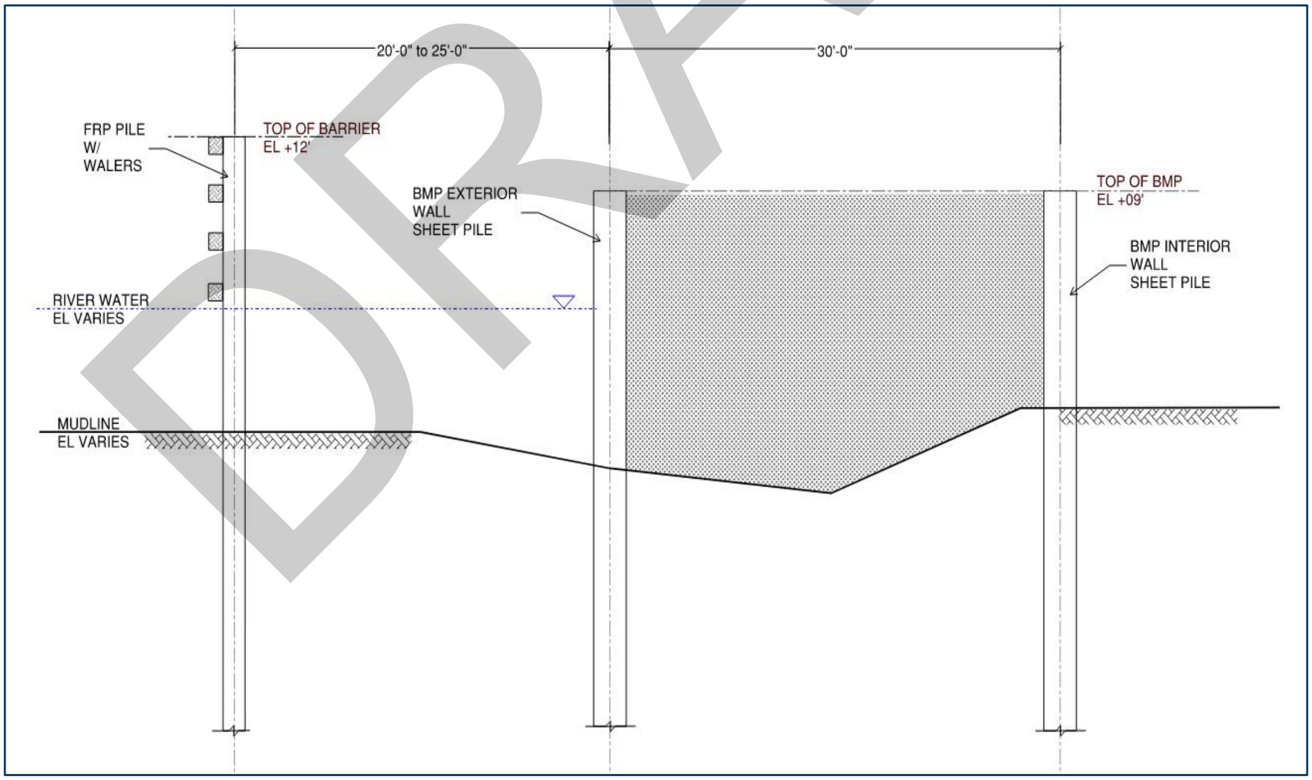


Figure 3.2 Typical Section - FRP Barrier Wall

This Technical Memorandum is provided as an interim output under our agreement with International Paper Company and McGinnes Industrial Maintenance Corporation. It is provided to foster discussion in relation to technical matters associated with the project and should not be relied upon as a final deliverable.

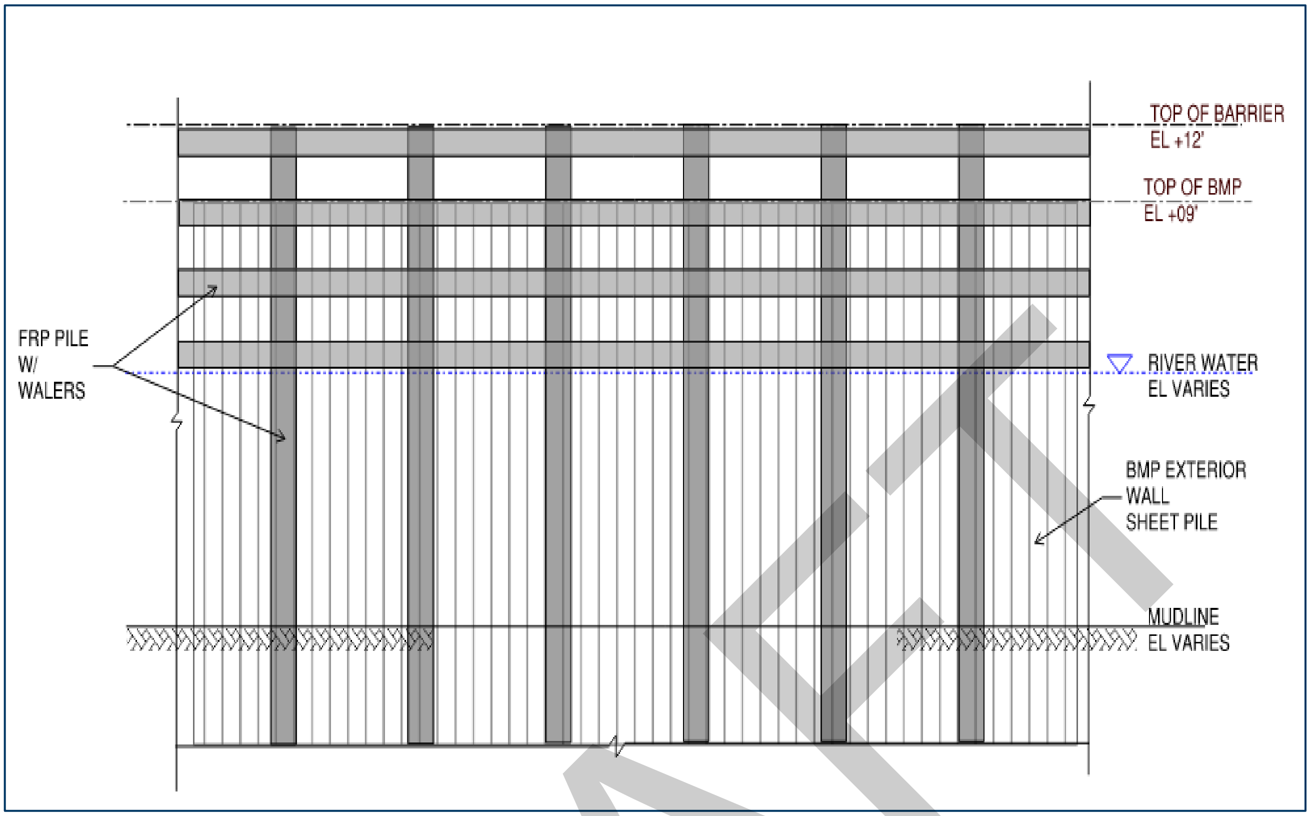


Figure 3.3 Typical Elevation - FRP Barrier Wall

As noted in Section 2, a 54-ft wide, a 30,000 bbl barge moving at 2.20 ft/s would result in impact energy of 829 kip/ft on contact with the barrier wall. The barge will contact the walers and in turn, multiple FRP piles are engaged, and the barrier wall system will deflect to absorb the impact energy. The largest moment demands on the pile sections are seen when the barge impact is at or near the top of the barrier wall. At lower elevations of impact, the moment demands are lower and do not govern the design. The results from the analysis are shown in the below Table 3.2. Detailed calculations and additional information for the barrier wall are provided in the enclosed Attachment 1.

Table 3.2 Energy Absorption Capacity of FRP Barrier Wall

FRP Location	BMP Design Parameters	Pile Deflection (inches)	Energy Absorbed (kip/ft)	FRP Pile Length (ft)
Section 1	Section C2	117	886	61
Section 2	Section C3	97	843	53
Section 2	Section C4	110	872	56
Section 3	Section C4	108	849	56
Section 4	Section C4	106	837	56
Section 4	Section C5	126	886	60

Regards,

GHD

Satish Chilka

Satish Chilka, P.E. (CA, TX)

Encl.: Attachment 1 - San Jacinto Fender System Design Calculations

This Technical Memorandum is provided as an interim output under our agreement with International Paper Company and McGinnes Industrial Maintenance Corporation. It is provided to foster discussion in relation to technical matters associated with the project and should not be relied upon as a final deliverable.

Attachment 1

San Jacinto Fender System Design Calculations

San Jacinto Fender System Design

Location – Texas

Prepared For:

GHD

Prepared By:

AXCESS

Span the Gap

Andrew Loff, PE
aloff@axcessinfrastructure.com
Mark Watt, PE
mwatt@axcessinfrastructure.com
937-907-0069

Rev-A
March 25, 2024

March 25, 2024

Satish Chilka
GHD

Re: San Jacinto Fender System Design

Enclosed herewith are calculations for the San Jacinto fender system in Texas. This design was based on the design criteria detailed in "Structural Update: San Jacinto River Waste Pits Superfund Site" dated from October 21, 2022.

Design Energy – 829 kip-ft (AASHTO LRFD Bridge Design Specification, Ninth Edition, 2020)

Deflection Limitation – None Specified

Fender System Length – 1,879 ft

Water Elevations –
- MLW +2' (Provided by GHD)
- MHW +9' (Provided by GHD)

Top of Fender System Wale – EL +12' (Provided by GHD)

Bottom of Fender System Wale – EL +4'

Design Mudline Elevation – Varies based on soil profiles provided by GHD (2022-09-09 Soil Properties – FRP Dolphins)

Soil Profile – FB Multipier Soil Inputs provided by GHD. Report on FB Multipier inputs shown in appendix E.

Principal Structural Materials of Construction –
- 18" x ¾" SuperPILE from Creative Composites Group
- 12x12-8F12 (12" x 12" w/8ea 1. 5" FRP rebar in HDPE wale) from Tangent

The design assumptions detailed in this letter have been utilized in the design of the San Jacinto fender system.

Contents

1 Executive Summary

Andrew K Loff, PE evaluated the composite fender system for the San Jacinto fender system using the 18” diameter with 3/4” wall thickness SuperPILEs manufactured by the Creative Composites Group in conjunction with the 12x12 8F12 SeaTimber Wales manufactured by Tangent.

The intent of this design is to provide a system that meets the energy absorption requirements specified and conforms to the geometric footprint laid out for this project.

These calculations show that the proposed system of 18” diameter SuperPILEs in combination with 12x12-8F12 plastic lumber wales achieves the design requirement of 829 ft-kip of energy absorption required while deflecting less than 10.5 ft (126 in). Table 1 below shows a summary of the results.

Table 1: Load Case and Results Summary

Load Case	Max Pile Deflection (in)	Absorbed Energy (ft-kip)
Section 1 - C2 Soil Load Case	117.1	886
Section 2 - C3 Soil Load Case	97	842.6
Section 2 - C4 Soil Load Case	109.5	871.9
Section 3 - C4 Soil Load Case	107.9	849.2
Section 4 - C4 Soil Load Case	106.3	836.8
Section 4 - C5 Soil Load Case	125.7	885.9

A non-linear analysis utilizing FB-Multipier (BSI) software was used to calculate the energy capacity, maximum moments in the piles and wales, as well as the system deflection. The load cases that were evaluated were based on barge dimensions and angle of impact provided by GHD.

Minimum tip analysis was also run, which details the minimum tip for this application.

2 Fender Layout Sketch

Fender system length is assumed to be 1,879 ft. System will be broken into 4 sections as shown in Figure 1. Wale sections are to be delivered in 64’ or 72’ sections and to be spliced together between pile spacings. Each transition between sections will be spliced with FRP plates with a pile installed at either end of the splice plate. Figure 2 shows a sketch of the typical elevation view of the fender system at a pile location.

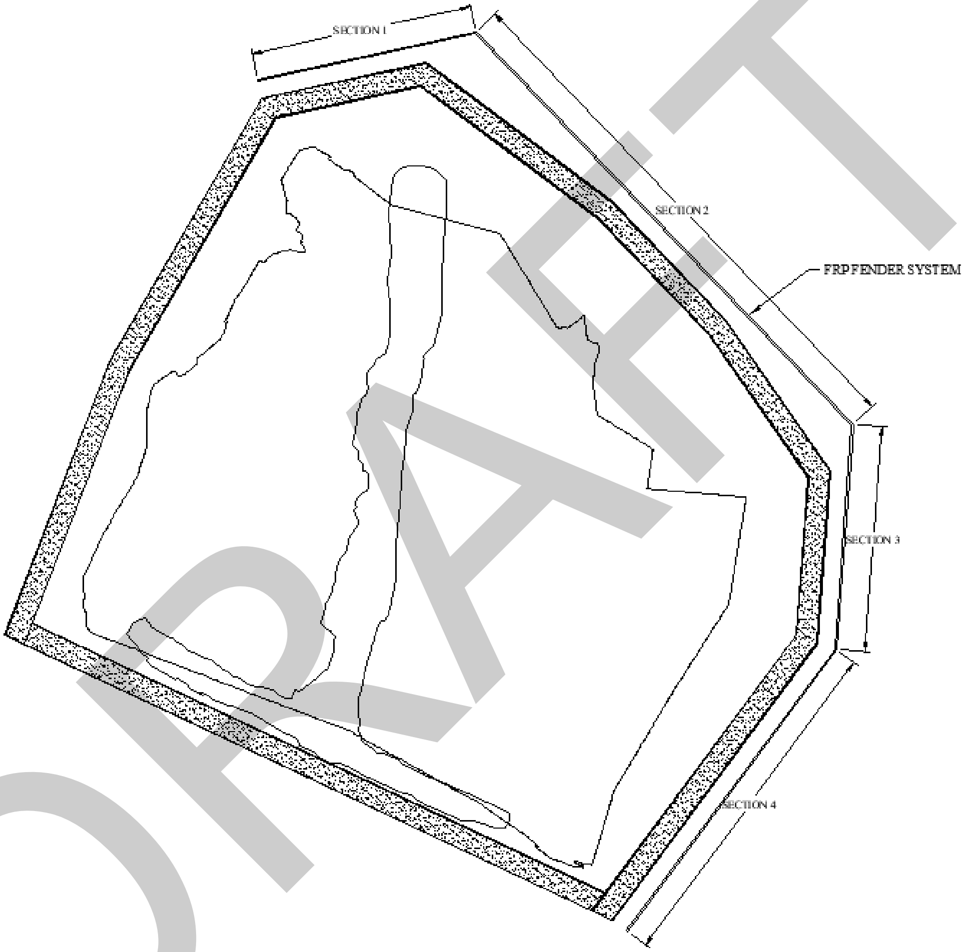


Figure 1: Fender Elevation

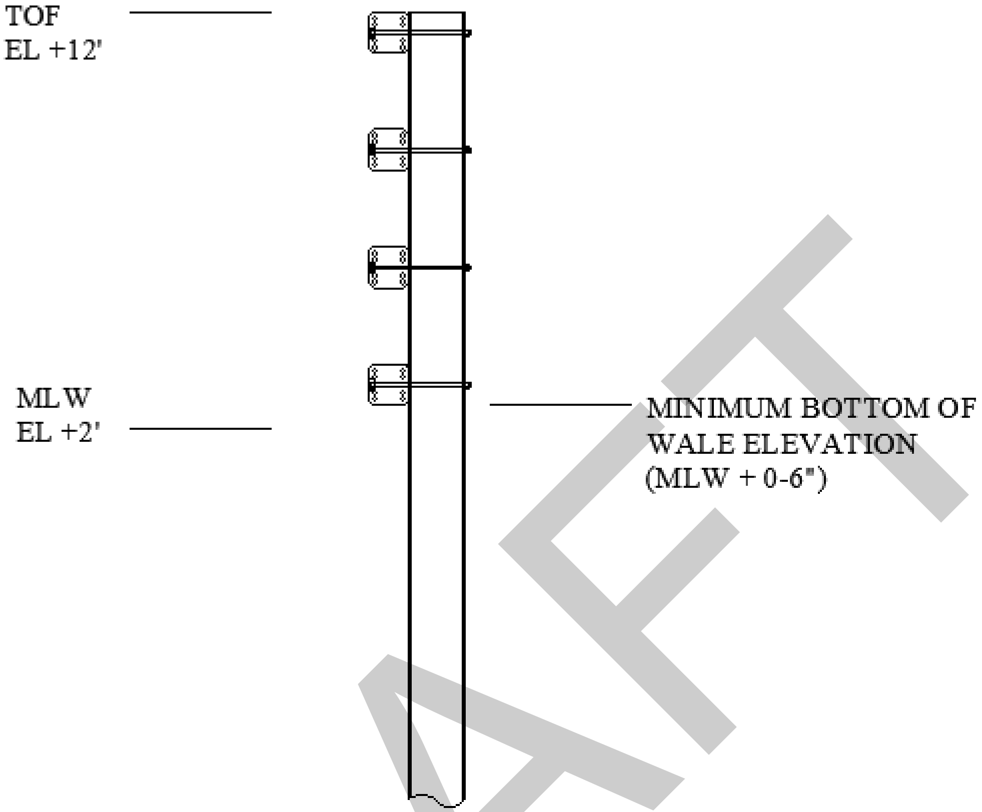


Figure 2: Fender Elevation

3 Analysis

a. Fender System Layout (Figure 3 - Figure 6)

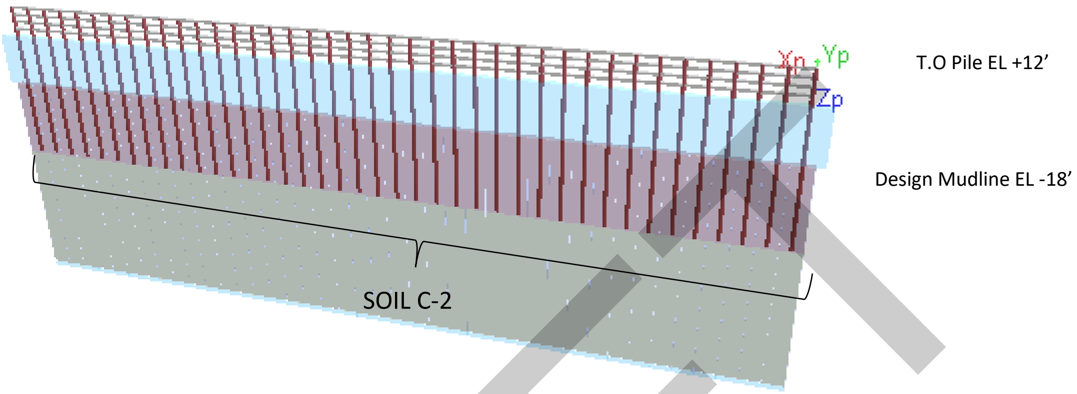


Figure 3: Section 1 Fender System - Soil Profile C2

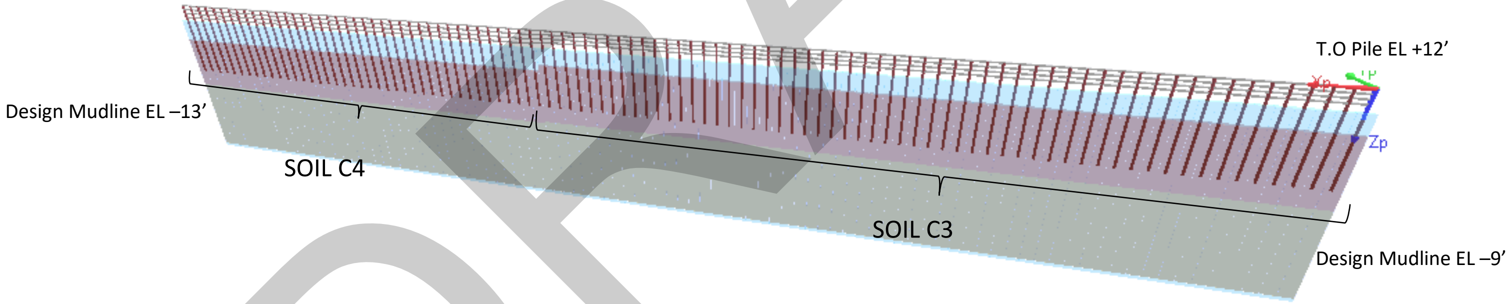


Figure 4: Section 2 Fender Layout –Soil Profile C3 & C4

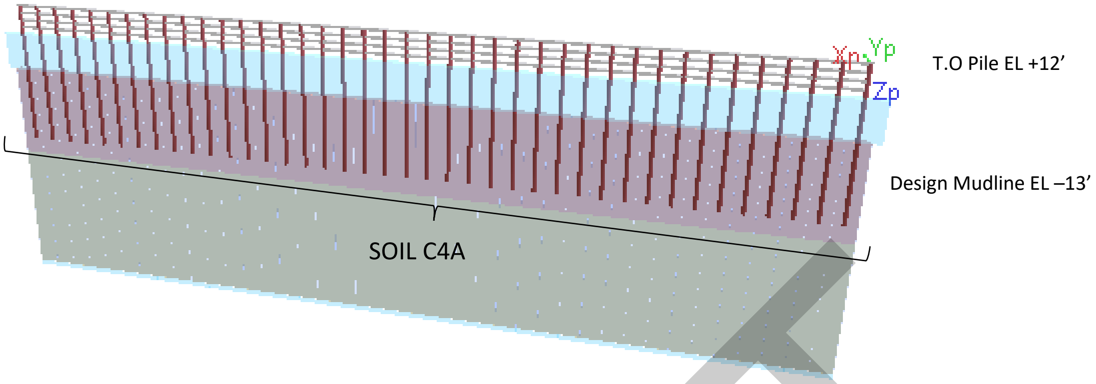


Figure 5: Section 3 Fender Layout –Soil Profile C4

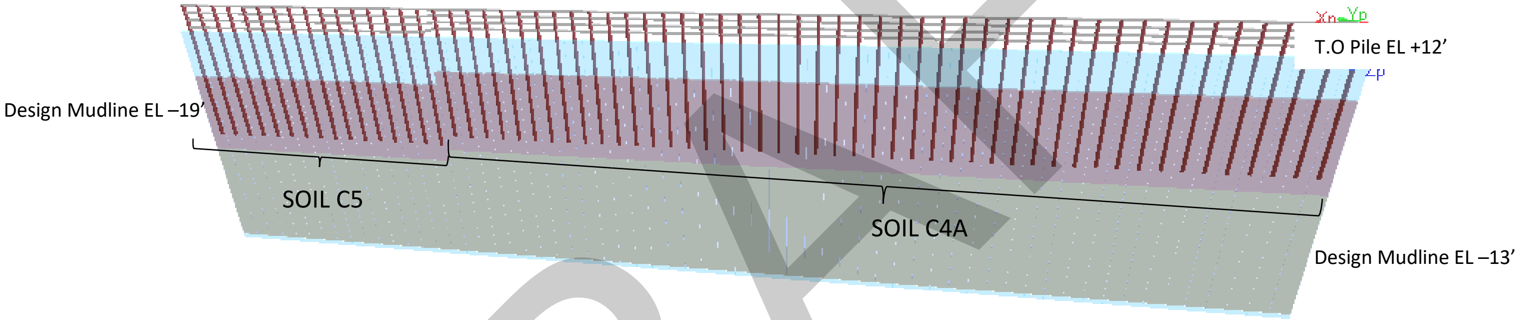


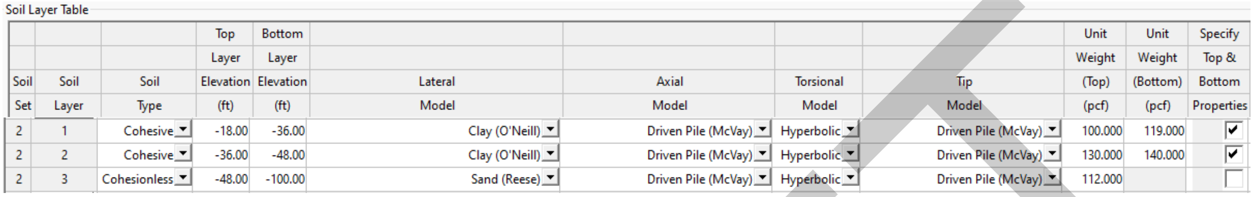
Figure 6: Section 4 Fender Layout –Soil Profile C4 & C5

- Pile and Wale spacings in FB-Multipier model are per the drawing layout.
- Piles are 18” diameter x ¾” wall SuperPiles from the Creative Composites Group.
- Wales are four rows of 12x12 8F12 SeaTimber Wales from Tangent.

3.1 Soil Properties

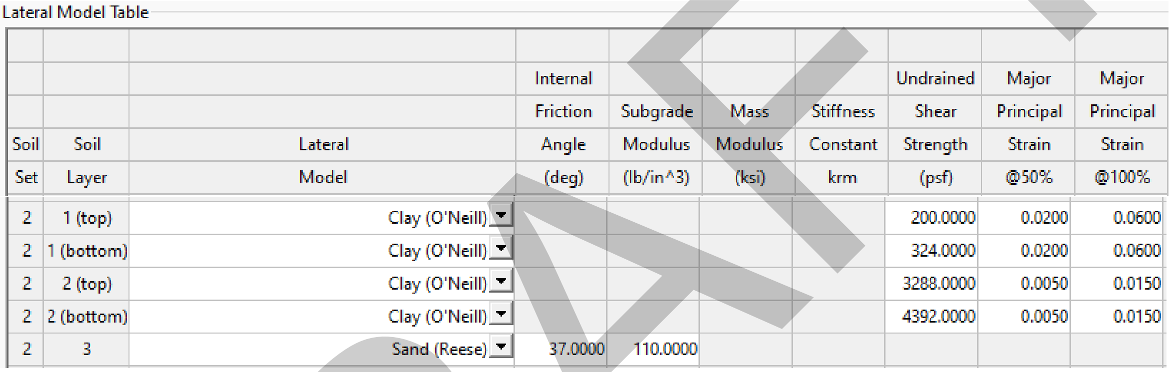
Figure 7 - Figure 30 below summarize the parameters for the soil layers added to the FB-Multipier model for the Fender System. The soil profiles were created from the soil parameters given by GHD and shown in Appendix F. Based on the soil profile provided, there are four separate profiles for the fender system.

3.1.1 C2 Soil Properties



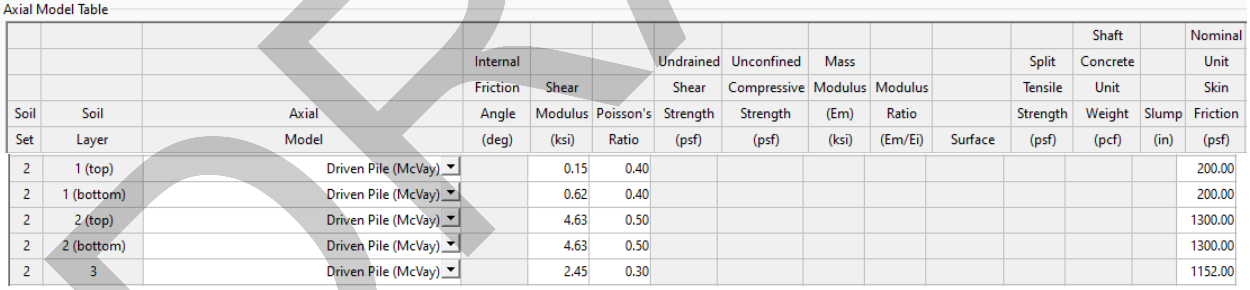
Soil Set	Soil Layer	Soil Type	Top Layer Elevation (ft)	Bottom Layer Elevation (ft)	Lateral Model	Axial Model	Torsional Model	Tip Model	Unit Weight (Top) (pcf)	Unit Weight (Bottom) (pcf)	Specify Top & Bottom Properties
2	1	Cohesive	-18.00	-36.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	100.000	119.000	☑
2	2	Cohesive	-36.00	-48.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	130.000	140.000	☑
2	3	Cohesionless	-48.00	-100.00	Sand (Reese)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	112.000		☐

Figure 7: Global Soil Elevations – C2



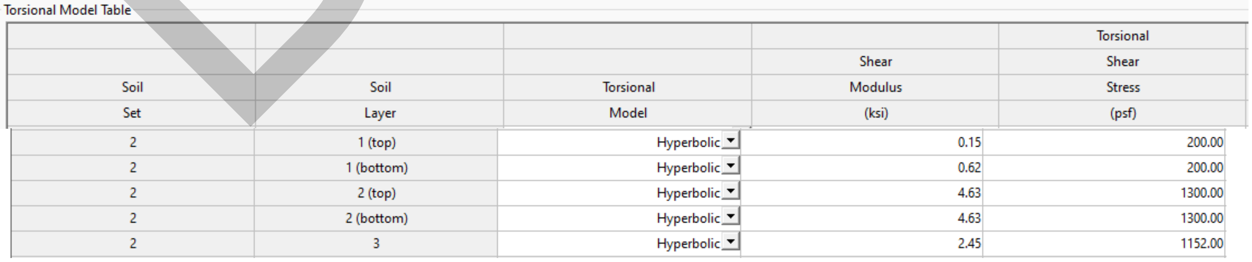
Soil Set	Soil Layer	Lateral Model	Internal Friction Angle (deg)	Subgrade Modulus (lb/in^3)	Mass Modulus (ksi)	Stiffness Constant krm	Undrained Shear Strength (psf)	Major Principal Strain @50%	Major Principal Strain @100%
2	1 (top)	Clay (O'Neill)					200.0000	0.0200	0.0600
2	1 (bottom)	Clay (O'Neill)					324.0000	0.0200	0.0600
2	2 (top)	Clay (O'Neill)					3288.0000	0.0050	0.0150
2	2 (bottom)	Clay (O'Neill)					4392.0000	0.0050	0.0150
2	3	Sand (Reese)	37.0000	110.0000					

Figure 8: Lateral Soil Properties – C2



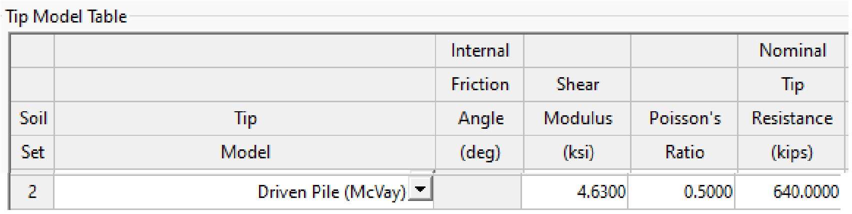
Soil Set	Soil Layer	Axial Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Undrained Shear Strength (psf)	Unconfined Compressive Strength (psf)	Mass Modulus (Em) (ksi)	Modulus Ratio (Em/Ei)	Surface	Split Tensile Strength (psf)	Shaft Concrete Unit Weight (pcf)	Slump (in)	Nominal Unit Skin Friction (psf)
2	1 (top)	Driven Pile (McVay)		0.15	0.40									200.00
2	1 (bottom)	Driven Pile (McVay)		0.62	0.40									200.00
2	2 (top)	Driven Pile (McVay)		4.63	0.50									1300.00
2	2 (bottom)	Driven Pile (McVay)		4.63	0.50									1300.00
2	3	Driven Pile (McVay)		2.45	0.30									1152.00

Figure 9: Axial Soil Properties – C2



Soil Set	Soil Layer	Torsional Model	Shear Modulus (ksi)	Torsional Shear Stress (psf)
2	1 (top)	Hyperbolic	0.15	200.00
2	1 (bottom)	Hyperbolic	0.62	200.00
2	2 (top)	Hyperbolic	4.63	1300.00
2	2 (bottom)	Hyperbolic	4.63	1300.00
2	3	Hyperbolic	2.45	1152.00

Figure 10: Torsional Soil Properties – C2



Tip Model Table

Soil Set	Tip Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Nominal Tip Resistance (kips)
2	Driven Pile (McVay)		4.6300	0.5000	640.0000

Figure 11: Tip Soil Properties – C2

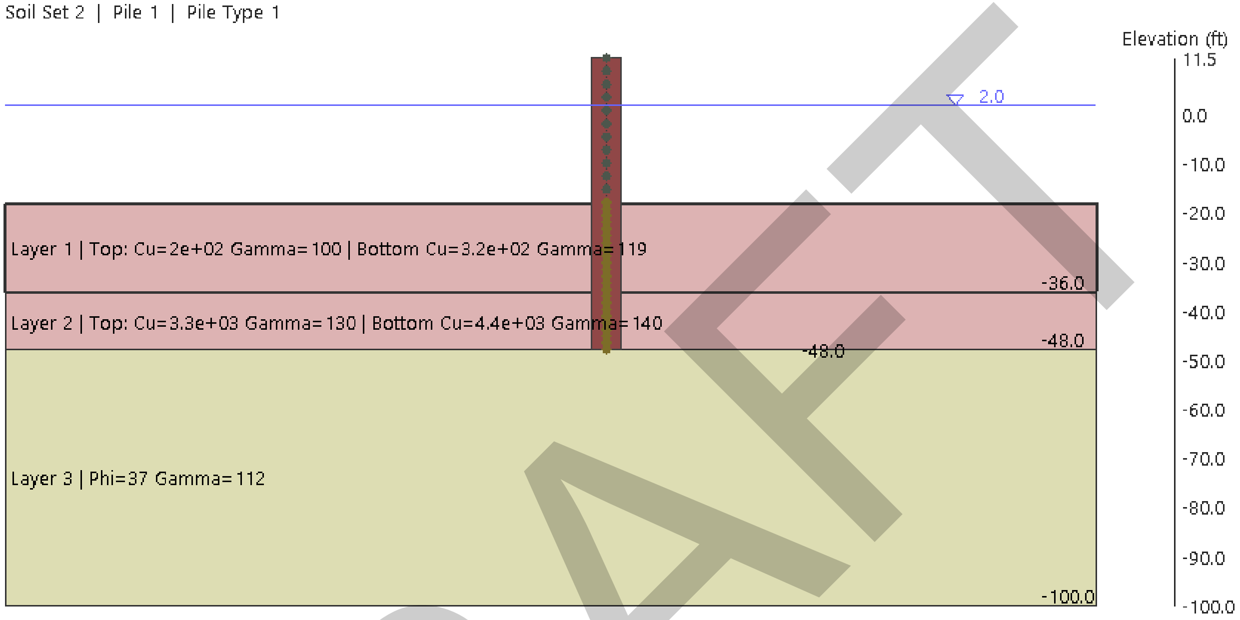
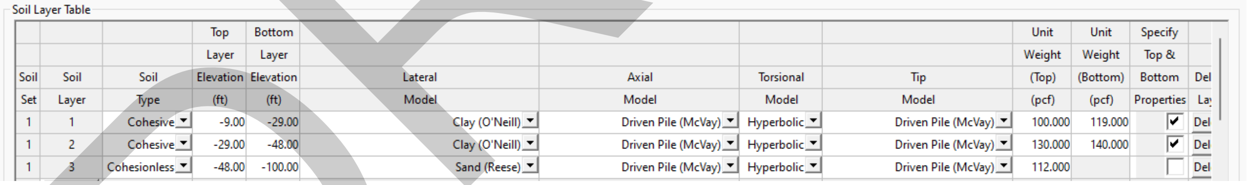


Figure 12: 18" SuperPILE Soil Cross Section – C2 SOIL

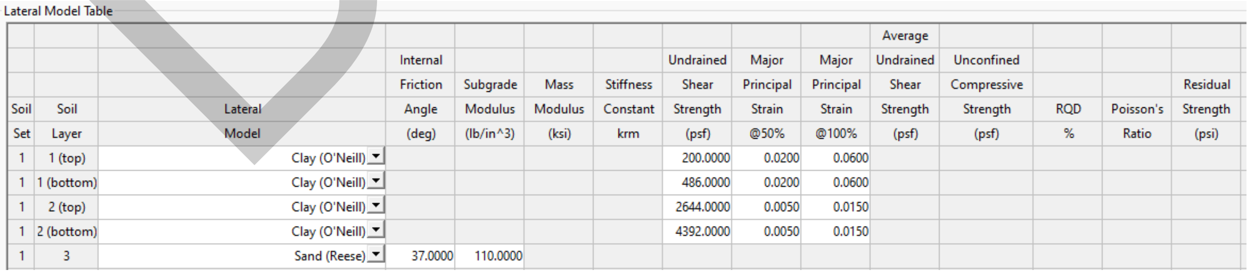
3.1.2 C3 Soil Properties



Soil Layer Table

Soil Set	Soil Layer	Soil Type	Top Layer Elevation (ft)	Bottom Layer Elevation (ft)	Lateral Model	Axial Model	Torsional Model	Tip Model	Unit Weight (Top) (pcf)	Unit Weight (Bottom) (pcf)	Specify Top & Bottom Properties	Del La
1	1	Cohesive	-9.00	-29.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	100.000	119.000	☑	Del
1	2	Cohesive	-29.00	-48.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	130.000	140.000	☑	Del
1	3	Cohesionless	-48.00	-100.00	Sand (Reese)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	112.000		☐	Del

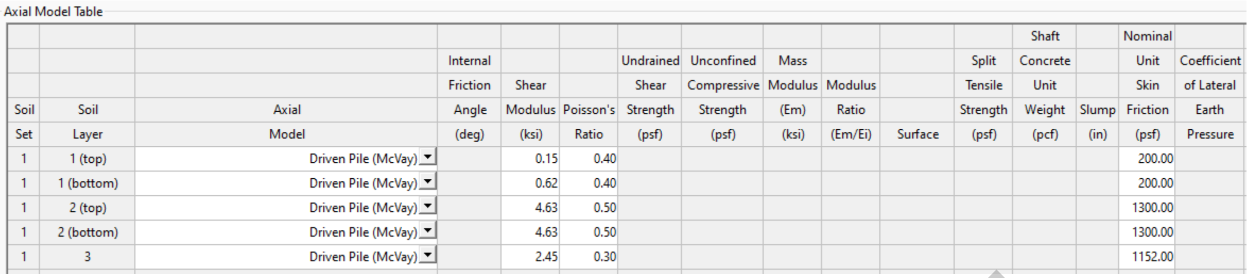
Figure 13: Global Soil Elevations – C3



Lateral Model Table

Soil Set	Soil Layer	Lateral Model	Internal Friction Angle (deg)	Subgrade Modulus (lb/in^3)	Mass Modulus (ksi)	Stiffness Constant krm	Undrained Shear Strength (psf)	Major Principal Strain @50%	Major Principal Strain @100%	Average Undrained Shear Strength (psf)	Unconfined Compressive Strength (psf)	RQD %	Poisson's Ratio	Residual Strength (psi)
1	1 (top)	Clay (O'Neill)					200.0000	0.0200	0.0600					
1	1 (bottom)	Clay (O'Neill)					486.0000	0.0200	0.0600					
1	2 (top)	Clay (O'Neill)					2644.0000	0.0050	0.0150					
1	2 (bottom)	Clay (O'Neill)					4392.0000	0.0050	0.0150					
1	3	Sand (Reese)	37.0000	110.0000										

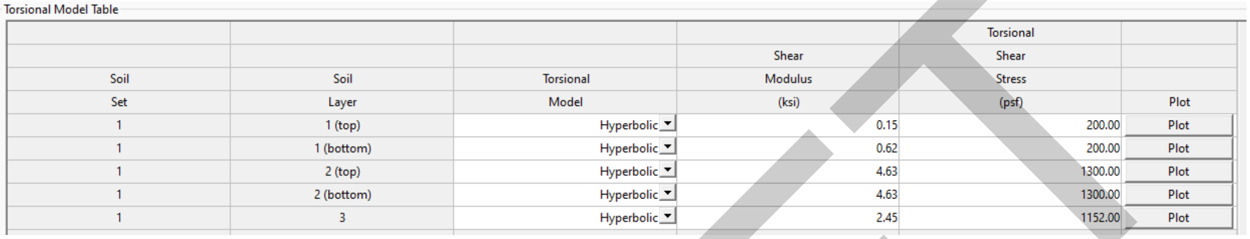
Figure 14: Lateral Soil Properties – C3



Axial Model Table

Soil Set	Soil Layer	Axial Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Undrained Shear Strength (psf)	Unconfined Compressive Strength (psf)	Mass Modulus (Em) (ksi)	Modulus Ratio (Em/Ei)	Surface	Split Tensile Strength (psf)	Shaft Concrete Unit Weight (pcf)	Slump (in)	Nominal Unit Skin Friction (psf)	Coefficient of Lateral Earth Pressure
1	1 (top)	Driven Pile (McVay) ▼		0.15	0.40									200.00	
1	1 (bottom)	Driven Pile (McVay) ▼		0.62	0.40									200.00	
1	2 (top)	Driven Pile (McVay) ▼		4.63	0.50									1300.00	
1	2 (bottom)	Driven Pile (McVay) ▼		4.63	0.50									1300.00	
1	3	Driven Pile (McVay) ▼		2.45	0.30									1152.00	

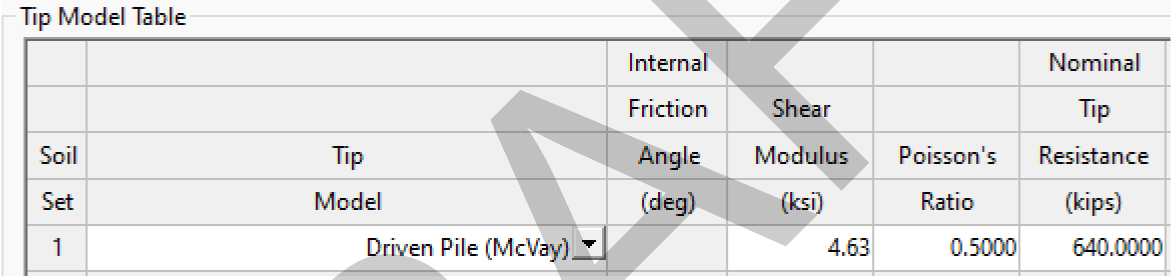
Figure 15: Axial Soil Properties – C3



Torsional Model Table

Soil Set	Soil Layer	Torsional Model	Shear Modulus (ksi)	Torsional Shear Stress (psf)	Plot
1	1 (top)	Hyperbolic ▼	0.15	200.00	Plot
1	1 (bottom)	Hyperbolic ▼	0.62	200.00	Plot
1	2 (top)	Hyperbolic ▼	4.63	1300.00	Plot
1	2 (bottom)	Hyperbolic ▼	4.63	1300.00	Plot
1	3	Hyperbolic ▼	2.45	1152.00	Plot

Figure 16: Torsional Soil Properties – C3



Tip Model Table

Soil Set	Tip Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Nominal Tip Resistance (kips)
1	Driven Pile (McVay) ▼		4.63	0.5000	640.0000

Figure 17: Pile Tip Properties – C3

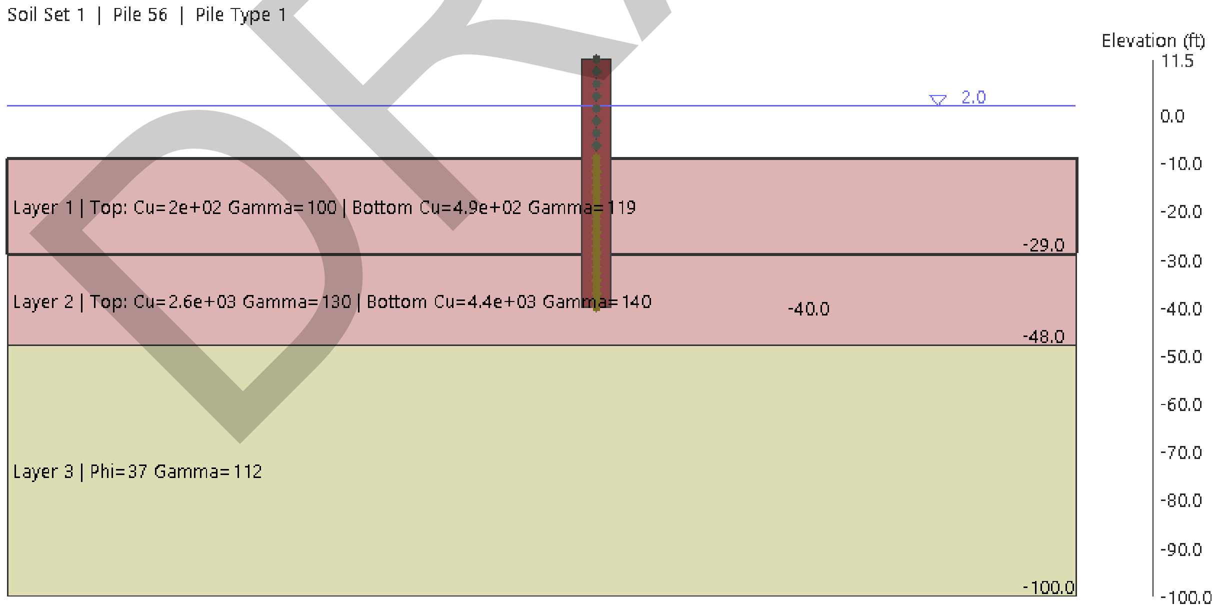
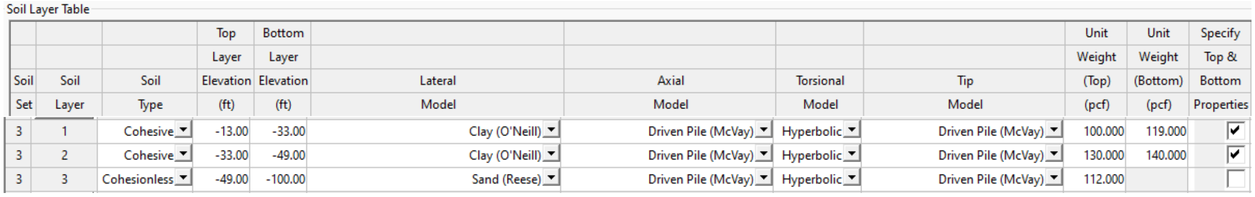


Figure 18: 18" SuperPILE Soil Cross Section – C3 Soil

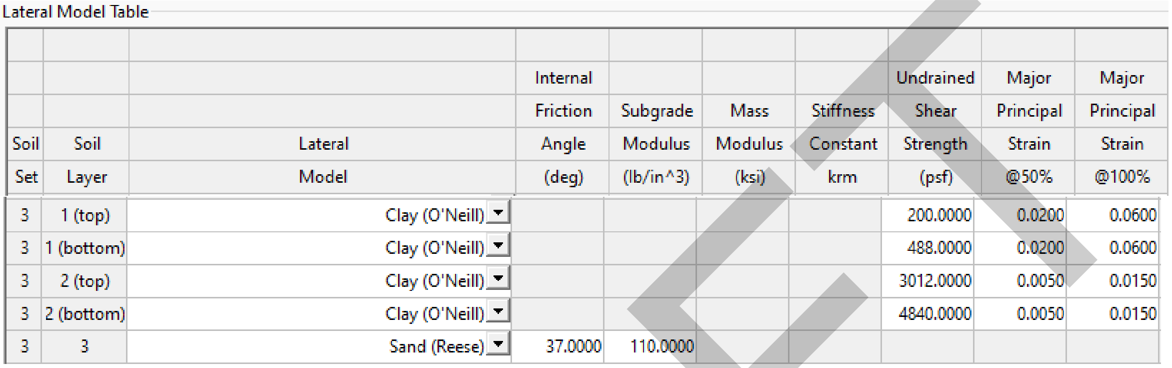
3.1.3 C4 Soil Properties



Soil Layer Table

Soil Set	Soil Layer	Soil Type	Top Layer Elevation (ft)	Bottom Layer Elevation (ft)	Lateral Model	Axial Model	Torsional Model	Tip Model	Unit Weight (Top) (pcf)	Unit Weight (Bottom) (pcf)	Specify Top & Bottom Properties
3	1	Cohesive	-13.00	-33.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	100.000	119.000	☑
3	2	Cohesive	-33.00	-49.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	130.000	140.000	☑
3	3	Cohesionless	-49.00	-100.00	Sand (Reese)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	112.000		☐

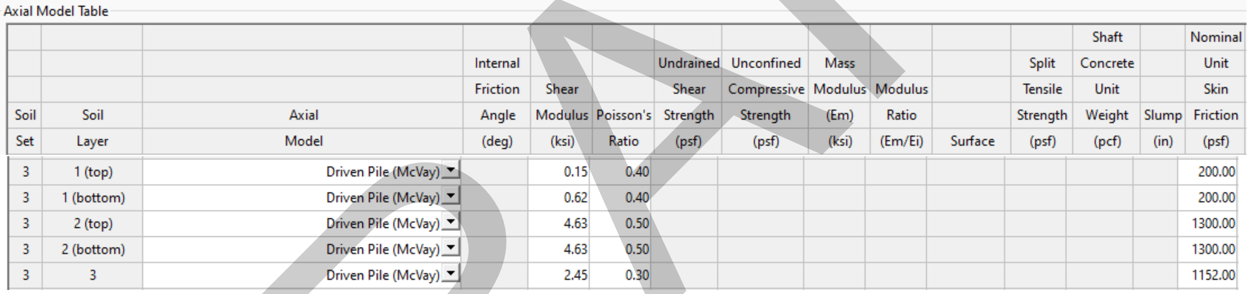
Figure 19: Global Soil Elevations – C4



Lateral Model Table

Soil Set	Soil Layer	Lateral Model	Internal Friction Angle (deg)	Subgrade Modulus (lb/in^3)	Mass Modulus (ksi)	Stiffness Constant krm	Undrained Shear Strength (psf)	Major Principal Strain @50%	Major Principal Strain @100%
3	1 (top)	Clay (O'Neill)					200.0000	0.0200	0.0600
3	1 (bottom)	Clay (O'Neill)					488.0000	0.0200	0.0600
3	2 (top)	Clay (O'Neill)					3012.0000	0.0050	0.0150
3	2 (bottom)	Clay (O'Neill)					4840.0000	0.0050	0.0150
3	3	Sand (Reese)	37.0000	110.0000					

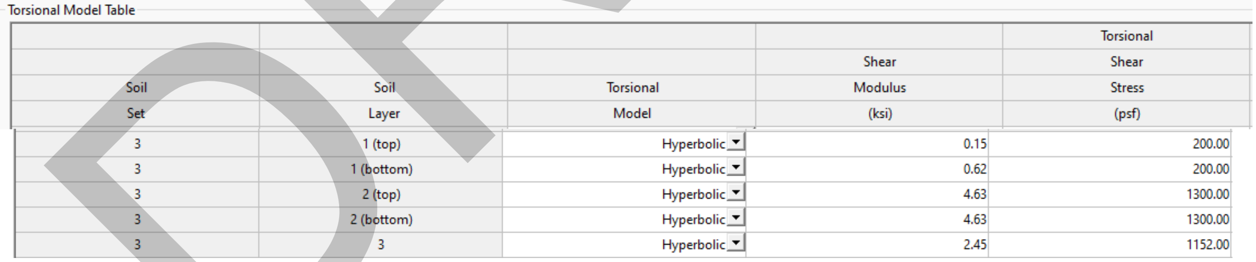
Figure 20: Lateral Soil Properties – C4



Axial Model Table

Soil Set	Soil Layer	Axial Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Undrained Shear Strength (psf)	Unconfined Compressive Strength (psf)	Mass Modulus (Em) (ksi)	Modulus Ratio (Em/Ei)	Surface	Split Tensile Strength (psf)	Shaft Concrete Unit Weight (pcf)	Slump (in)	Nominal Unit Skin Friction (psf)
3	1 (top)	Driven Pile (McVay)		0.15	0.40									200.00
3	1 (bottom)	Driven Pile (McVay)		0.62	0.40									200.00
3	2 (top)	Driven Pile (McVay)		4.63	0.50									1300.00
3	2 (bottom)	Driven Pile (McVay)		4.63	0.50									1300.00
3	3	Driven Pile (McVay)		2.45	0.30									1152.00

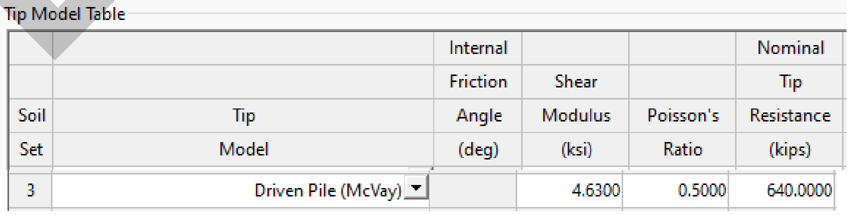
Figure 21: Axial Soil Properties – C4



Torsional Model Table

Soil Set	Soil Layer	Torsional Model	Shear Modulus (ksi)	Torsional Shear Stress (psf)
3	1 (top)	Hyperbolic	0.15	200.00
3	1 (bottom)	Hyperbolic	0.62	200.00
3	2 (top)	Hyperbolic	4.63	1300.00
3	2 (bottom)	Hyperbolic	4.63	1300.00
3	3	Hyperbolic	2.45	1152.00

Figure 22: Torsional Soil Properties – C4



Tip Model Table

Soil Set	Tip Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Nominal Tip Resistance (kips)
3	Driven Pile (McVay)		4.6300	0.5000	640.0000

Figure 23: Tip Soil Properties – C4

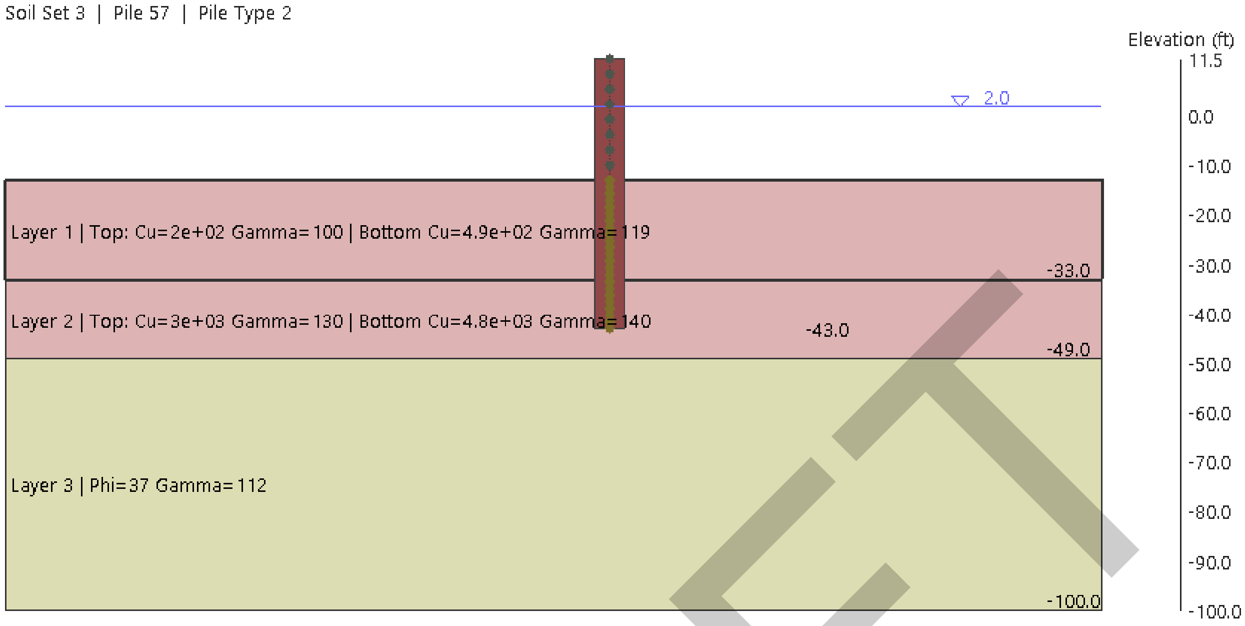
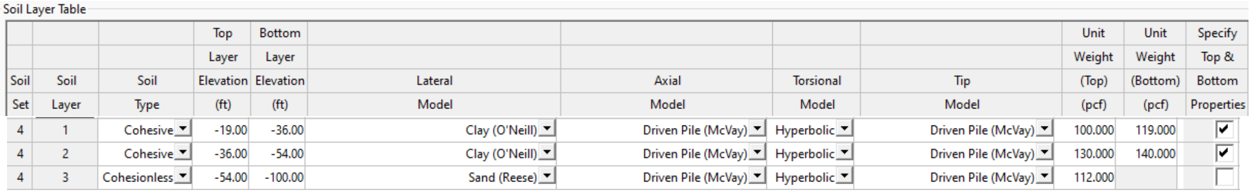


Figure 24: 18" SuperPILE Soil Cross Section – C4 Soil

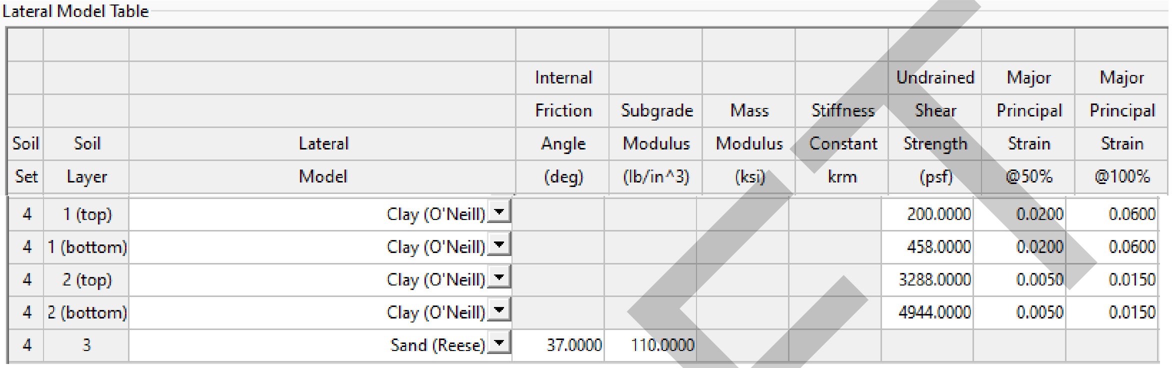
3.1.4 C5 Soil Properties



Soil Layer Table

Soil Set	Soil Layer	Soil Type	Top Layer Elevation (ft)	Bottom Layer Elevation (ft)	Lateral Model	Axial Model	Torsional Model	Tip Model	Unit Weight (Top) (pcf)	Unit Weight (Bottom) (pcf)	Specify Top & Bottom Properties
4	1	Cohesive	-19.00	-36.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	100.000	119.000	☑
4	2	Cohesive	-36.00	-54.00	Clay (O'Neill)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	130.000	140.000	☑
4	3	Cohesionless	-54.00	-100.00	Sand (Reese)	Driven Pile (McVay)	Hyperbolic	Driven Pile (McVay)	112.000		☐

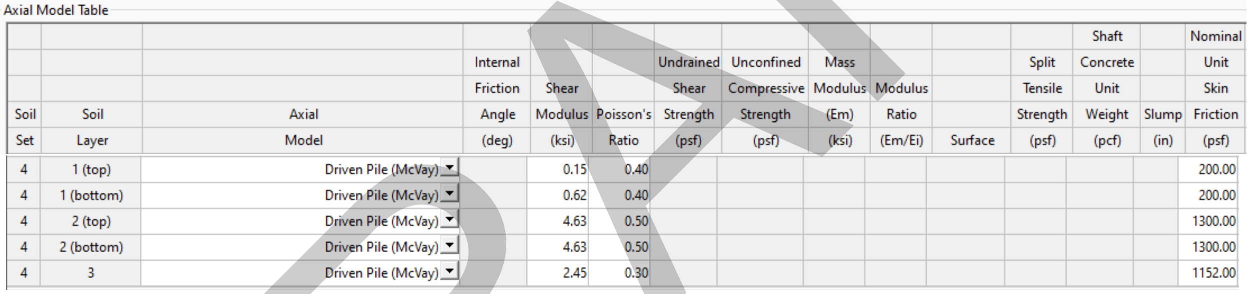
Figure 25: Global Soil Elevations – C5



Lateral Model Table

Soil Set	Soil Layer	Lateral Model	Internal Friction Angle (deg)	Subgrade Modulus (lb/in^3)	Mass Modulus (ksi)	Stiffness Constant krm	Undrained Shear Strength (psf)	Major Principal Strain @50%	Major Principal Strain @100%
4	1 (top)	Clay (O'Neill)					200.0000	0.0200	0.0600
4	1 (bottom)	Clay (O'Neill)					458.0000	0.0200	0.0600
4	2 (top)	Clay (O'Neill)					3288.0000	0.0050	0.0150
4	2 (bottom)	Clay (O'Neill)					4944.0000	0.0050	0.0150
4	3	Sand (Reese)	37.0000	110.0000					

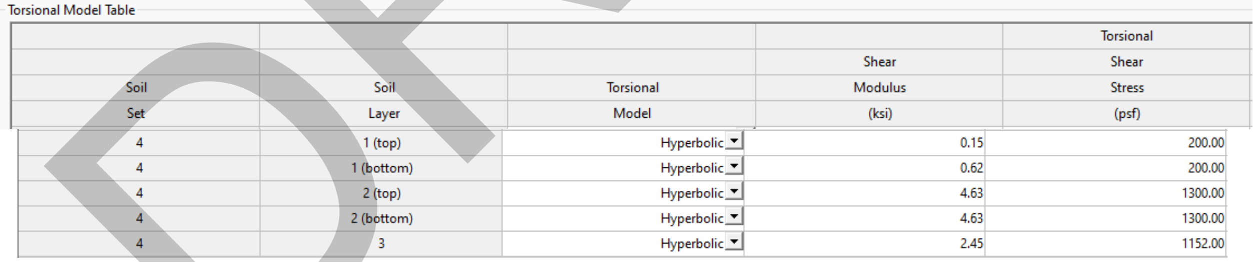
Figure 26: Lateral Soil Properties – C5



Axial Model Table

Soil Set	Soil Layer	Axial Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Undrained Shear Strength (psf)	Unconfined Compressive Strength (psf)	Mass Modulus (Em) (ksi)	Modulus Ratio (Em/Ei)	Surface	Split Tensile Strength (psf)	Shaft Concrete Unit Weight (pcf)	Slump (in)	Nominal Unit Skin Friction (psf)
4	1 (top)	Driven Pile (McVay)		0.15	0.40									200.00
4	1 (bottom)	Driven Pile (McVay)		0.62	0.40									200.00
4	2 (top)	Driven Pile (McVay)		4.63	0.50									1300.00
4	2 (bottom)	Driven Pile (McVay)		4.63	0.50									1300.00
4	3	Driven Pile (McVay)		2.45	0.30									1152.00

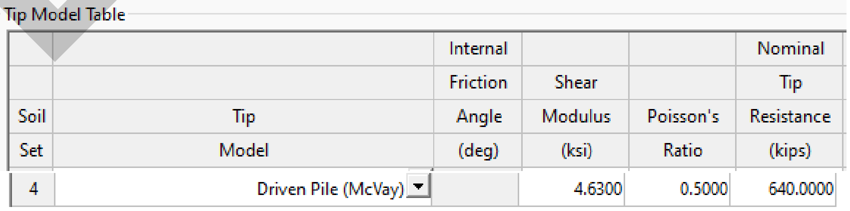
Figure 27: Axial Soil Properties – C5



Torsional Model Table

Soil Set	Soil Layer	Torsional Model	Shear Modulus (ksi)	Torsional Shear Stress (psf)
4	1 (top)	Hyperbolic	0.15	200.00
4	1 (bottom)	Hyperbolic	0.62	200.00
4	2 (top)	Hyperbolic	4.63	1300.00
4	2 (bottom)	Hyperbolic	4.63	1300.00
4	3	Hyperbolic	2.45	1152.00

Figure 28: Torsional Soil Properties – C5



Tip Model Table

Soil Set	Tip Model	Internal Friction Angle (deg)	Shear Modulus (ksi)	Poisson's Ratio	Nominal Tip Resistance (kips)
4	Driven Pile (McVay)		4.6300	0.5000	640.0000

Figure 29: Tip Soil Properties – C5

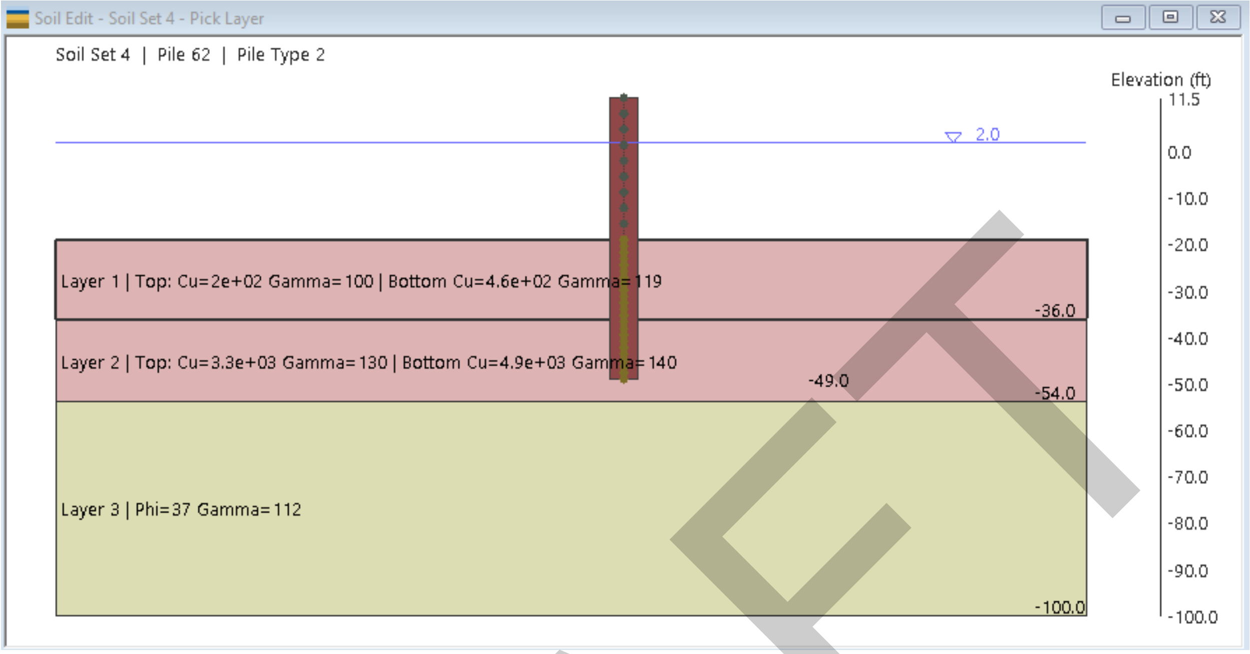
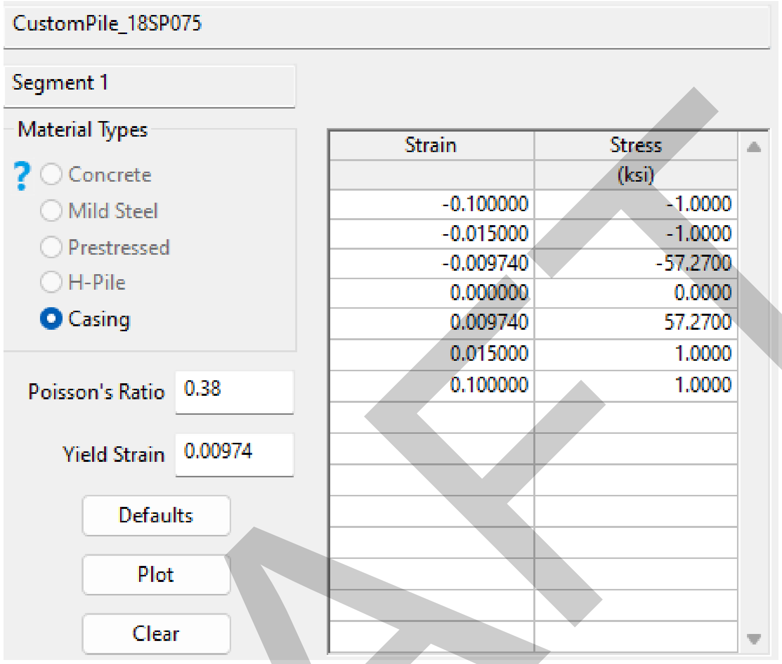


Figure 30: 18” SuperPILE Soil Cross Section – C5 Soil

3.2 FB-Multipier Pile/Wale Input Stress/Strain Curves

See Figure 31 and Figure 32 for the stress and strain inputs used to generate the Pile and Wale stress/strain curves, respectively. Pile Modulus reduced 5% per reviewer request on piles only.



CustomPile_18SP075

Segment 1

Material Types

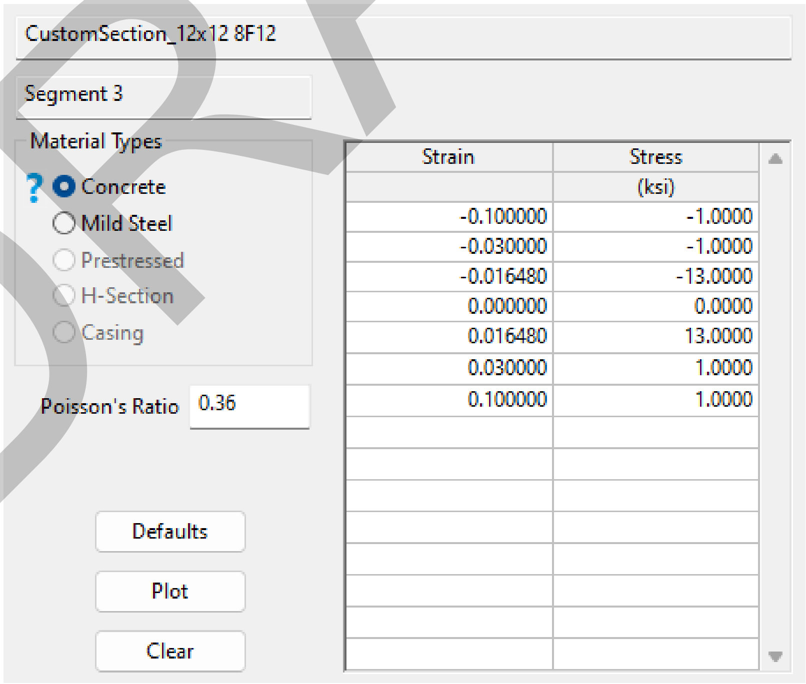
○ Concrete
○ Mild Steel
○ Prestressed
○ H-Pile
● Casing

Poisson's Ratio: 0.38

Yield Strain: 0.00974

Strain	Stress (ksi)
-0.100000	-1.0000
-0.015000	-1.0000
-0.009740	-57.2700
0.000000	0.0000
0.009740	57.2700
0.015000	1.0000
0.100000	1.0000

Figure 31: 18" OD x 0.75" WT SUPERPILE Properties



CustomSection_12x12 8F12

Segment 3

Material Types

● Concrete
○ Mild Steel
○ Prestressed
○ H-Section
○ Casing

Poisson's Ratio: 0.36

Strain	Stress (ksi)
-0.100000	-1.0000
-0.030000	-1.0000
-0.016480	-13.0000
0.000000	0.0000
0.016480	13.0000
0.030000	1.0000
0.100000	1.0000

Figure 32: 12x12 8F12 Wale Properties

3.3 Pile and Wale Properties

The allowable design values for the piles and wales used in the fender system design were determined through full scale testing and the application of appropriate reduction factors. The processes used to determine the design values for each component type are provided below and the resulting moment capacities are shown in Table 2.

Since this fender system is a temporary protection system and is designed to be damaged to absorb the maximum amount of energy, there are no knockdowns applied to the moment capacity used in the design.

Piles:

- Test full-scale piles to ASTM D6109 with a minimum of 10 specimens.
- Conduct ASTM D7290 compliant statistical reductions to find allowable capacity.

Wales:

- Test full-scale wales to ASTM D6109 with a minimum of 5 specimens.

Table 2: Allowable Moment Capacity for SuperPILE Piles and SeaTimber Wales

Component Type	ASTM D6109 Mean Test Results (kip-ft)	ASTM D7290 Design Property (kip-ft)
Pile - 18”x 0.75” TU465	803	699
Wale - 12x12 8F12	283	N/A

3.4 Energy Analysis and Calculation

The fender system was analyzed in FB Multipier using a non-linear analysis to determine the energy absorption, maximum moments, and deflections for each load case. Each section of the fender system was analyzed separately to determine the sufficiency to absorb the required 829 kip-ft.

3.4.1 Load Case 1 – Section 1 Fender System - C2 Soil

The illustration of the nodes that are loaded are shown in Figure 33. Different iterations were performed modifying the applied load. Energy calculations (see Table 3) were performed until the vessel impact energy equal to or above 829 ft-kip was achieved.

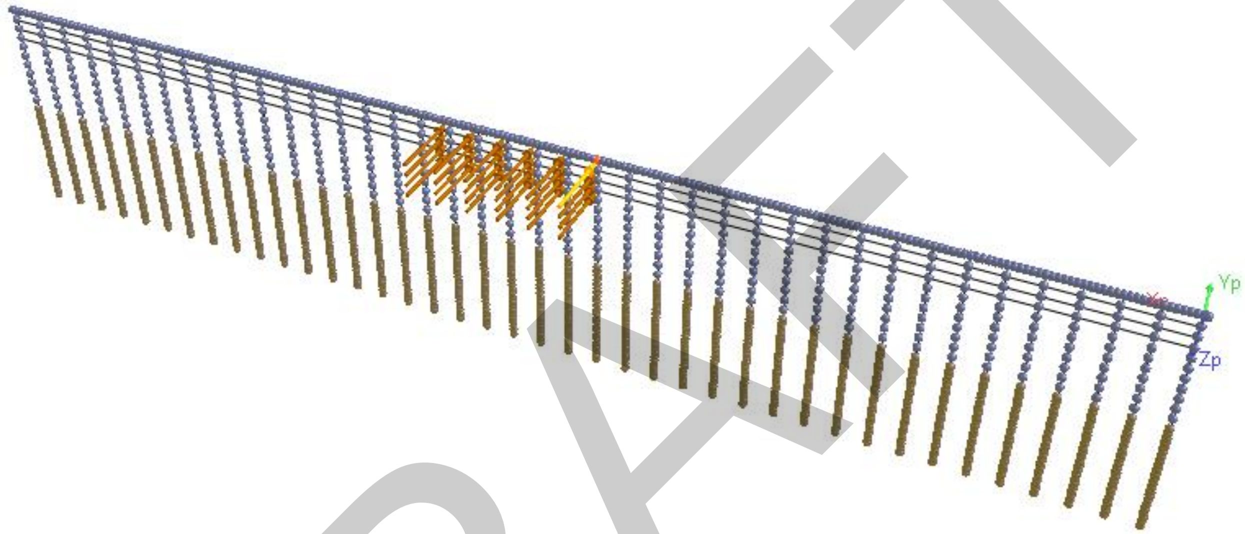


Figure 33: Layout – Load Case 1 (Section 1 – Soil C2)

Table 3: Energy Calculations - Load Case 1 (Section 1 – Soil C2)

Node	Load (kips)	Deflection (in)	Energy (ft-kips)
18	8.7	101.04	36.63
807	8.7	93.08	33.74
808	8.7	85.11	30.85
809	8.7	77.15	27.97
19	8.7	117.8	42.70
840	8.7	108.7	39.40
841	8.7	99.7	36.14
842	8.7	90.63	32.85
20	8.7	126.7	45.93
873	8.7	117.06	42.43
874	8.7	107.4	38.93
875	8.7	97.71	35.42
21	8.7	126.7	45.93
906	8.7	117.06	42.43
907	8.7	107.4	38.93
908	8.7	97.71	35.42
22	8.7	117.8	42.70
939	8.7	108.7	39.40
940	8.7	99.7	36.14
941	8.7	90.63	32.85
23	8.7	101.04	36.63
972	8.7	93.08	33.74
973	8.7	85.11	30.85
974	8.7	77.15	27.97
Total Energy (ft-kip)			**886.01**

EAC = 886 ft-kip > Emin = 829 ft-kip (Acceptable)

Pile Moment Capacity Check - Load Case 1 (Section 1 – Soil C2)

Maximum pile moment (18” x ¾” SuperPILE) = 653ft-kip (See Figure 34 below)

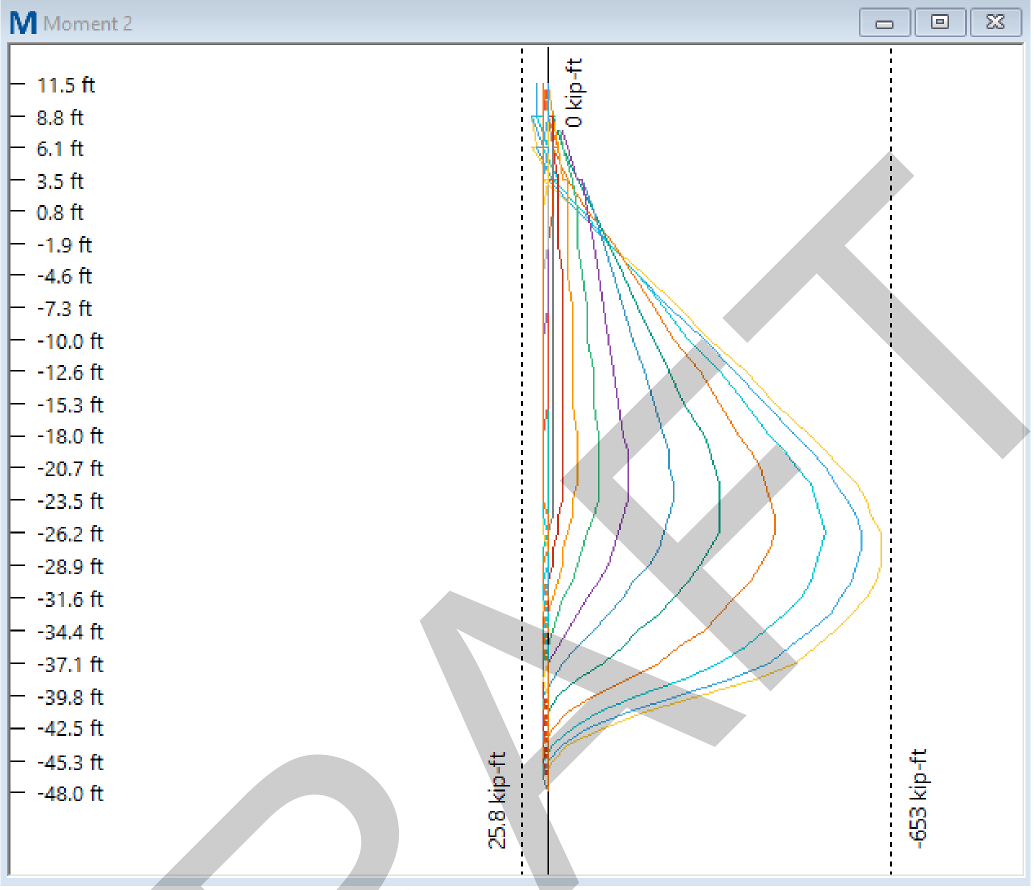


Figure 34: Max Pile Moment - Load Case 1 (Section 1-Soil C2)

Allowable Pile Design Capacity after statistical reductions = 699 ft-kip
Actual of 653 ft-kip <= Allowable of 699 ft-kip (Acceptable)

Pile Shear Capacity Check - Load Case 1 (Section 1- Soil C2)

Maximum pile moment (18" x ¾" SuperPILE) = 79.8 kips (See Figure 34 below)

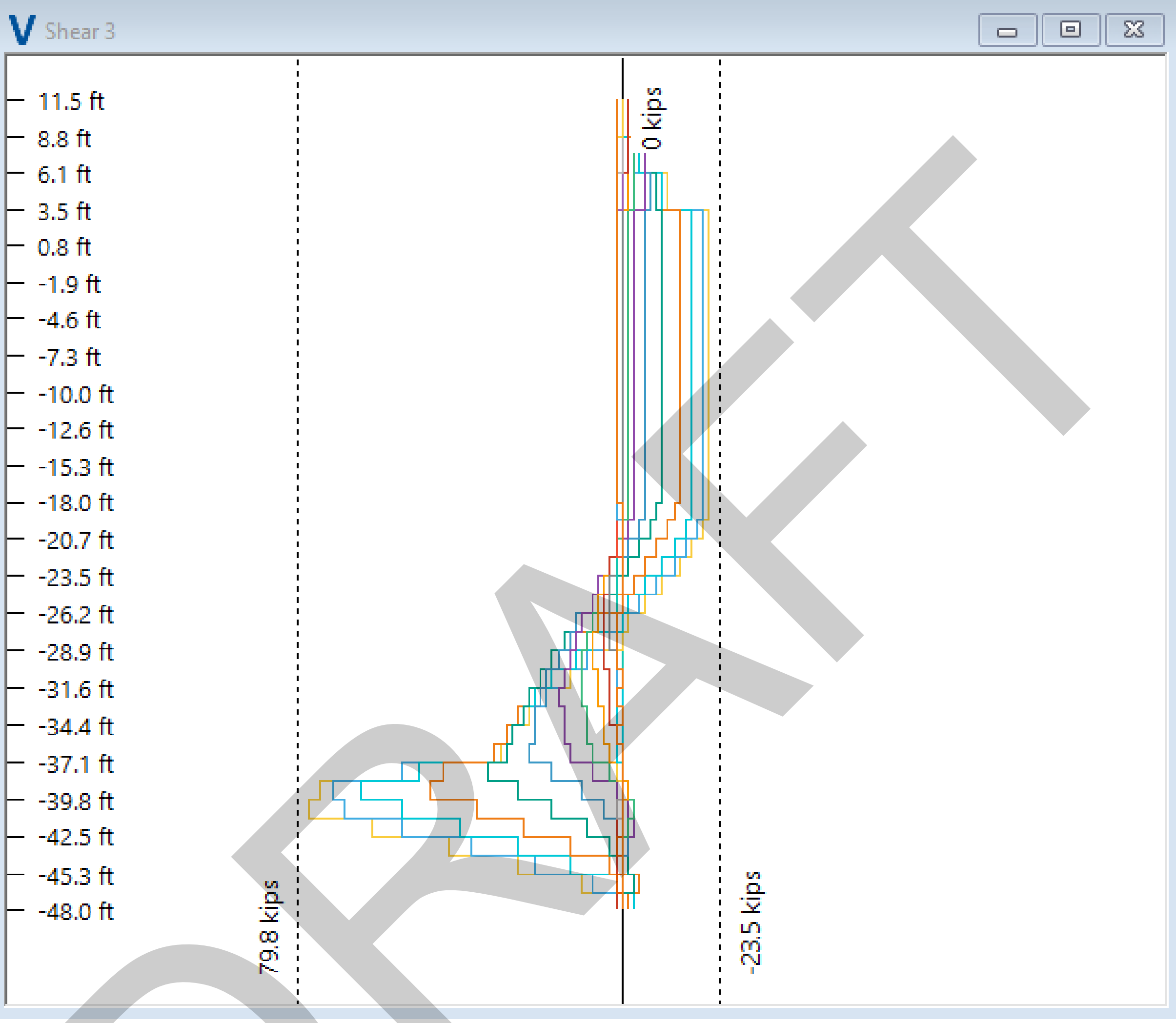


Figure 35: Max Pile Shear - Load Case 1 (Section 1 -Soil C2)

Allowable Pile Shear Design Capacity after statistical reductions = 303.5 kip
Actual of 79.8 kips <= Allowable of 303.5 kips (Acceptable)

Wale Moment Capacity Check - Load Case 1 (Section 1- Soil C2)

Maximum wale moment (12x12 8F12) = 146 ft-kip (See Figure 36 below)

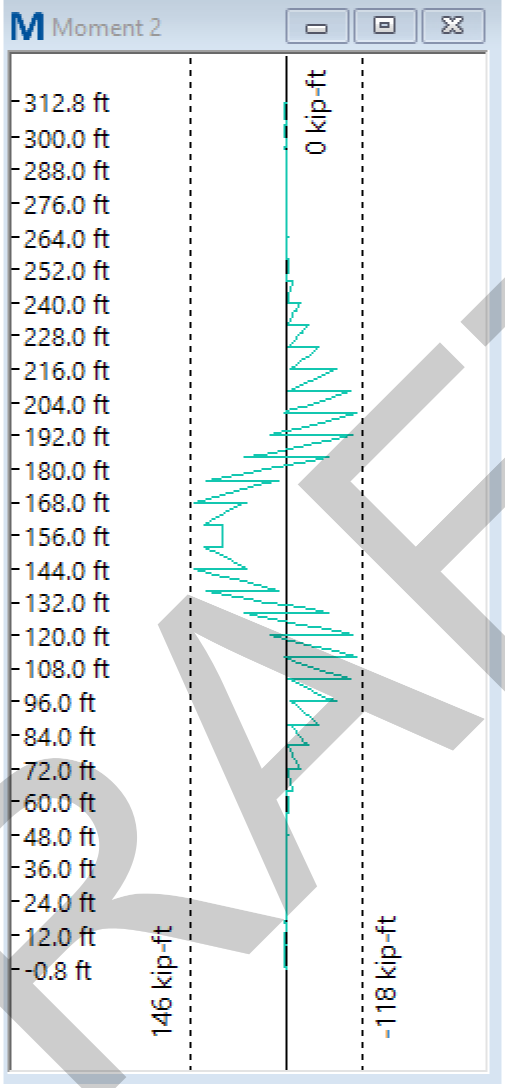


Figure 36: Max Wale Moment - Load Case 1 (Section 1-Soil C2)

Allowable Wale Design Capacity after environment reductions = 226 ft-kip
Actual of 146 ft-kip <= Allowable of 283 ft-kip (Acceptable)

Pile Displacement Check - Load Case 1 (Section 1 – Soil C2)

See Figure 37 below.

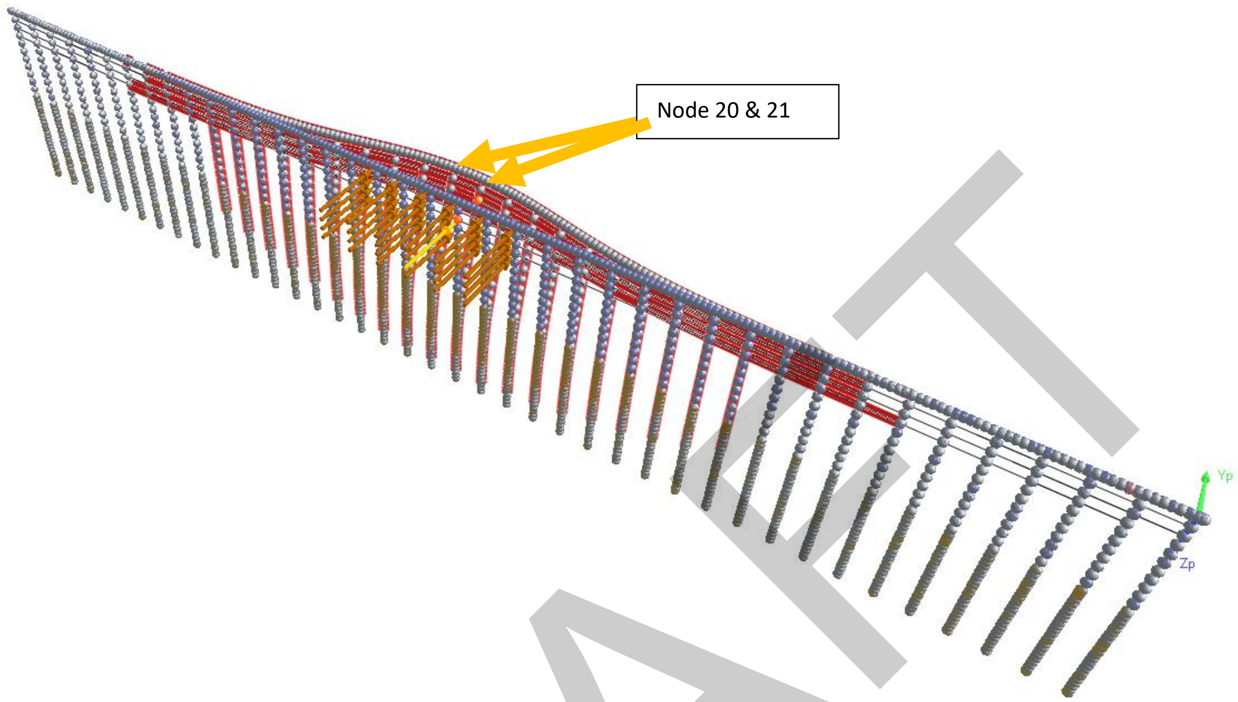


Figure 37: Displacement - Load Case 1 (Section 1-Soil C2)

Maximum Pile displacement of system at back face is on node 20 & 21 with a displacement of 126.7 in.

3.4.2 Load Case 2 – Section 2 Fender System – C3 Soil

The illustration of the nodes that are loaded are shown in Figure 33. Different iterations were performed modifying the applied load. Energy calculations (see Table 4) were performed until the vessel impact energy equal to or above 829 ft-kip was achieved.

Figure 38: Layout – Load Case 2 (Section 2 – Soil C3)

Table 4: Energy Calculations - Load Case 2 (Section 2 – Soil C3)

Node	Load (kips)	Deflection (in)	Energy (ft-kips)
26	11.3	72.84	34.30
1332	11.3	66.1	31.12
1333	11.3	59.4	27.97
1334	11.3	52.7	24.81
27	11.3	88.58	41.71
1362	11.3	80.7	38.00
1363	11.3	72.82	34.29
1364	11.3	64.93	30.57
28	11.3	96.97	45.66
1392	11.3	88.46	41.65
1393	11.3	79.92	37.63
1394	11.3	71.39	33.61
29	11.3	96.97	45.66
1422	11.3	88.46	41.65
1423	11.3	79.92	37.63
1424	11.3	71.39	33.61
30	11.3	88.58	41.71
1452	11.3	80.7	38.00
1453	11.3	72.82	34.29
1454	11.3	64.93	30.57
31	11.3	72.84	34.30
1482	11.3	66.1	31.12
1483	11.3	59.4	27.97
1484	11.3	52.7	24.81
Total Energy (ft-kip)			**842.61**

EAC = 842.61 ft-kip > Emin = 829 ft-kip (Acceptable)

Pile Moment Capacity Check - Load Case 2 (Section 2 – Soil C3)

Maximum pile moment (18” x ¾” SuperPILE) = 696 ft-kip (See Figure 39 below)

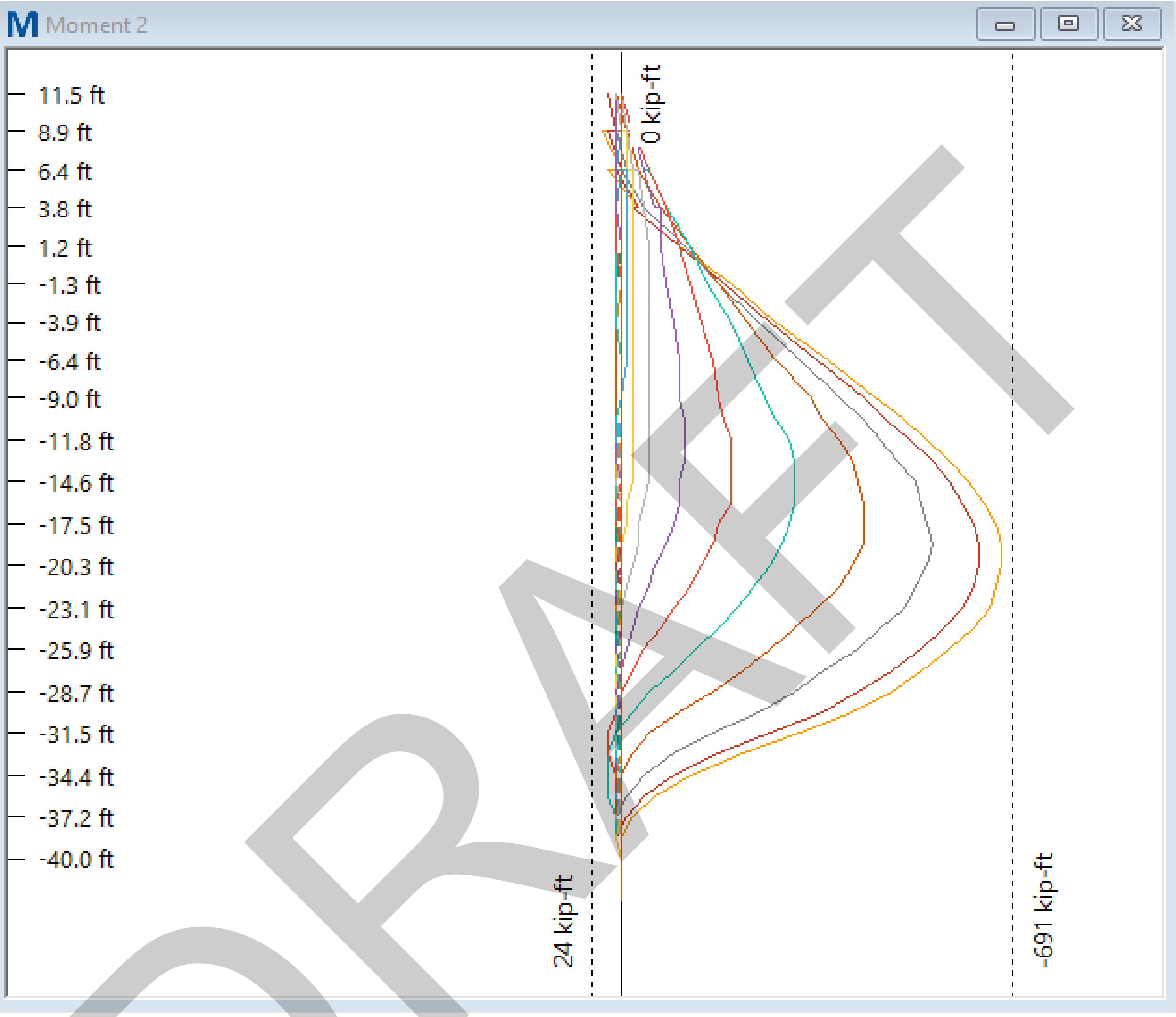


Figure 39: Max Pile Moment - Load Case 2 (Section 2 - Soil C3)

Allowable Pile Design Capacity after statistical reductions = 699 ft-kip
Actual of 691 ft-kip <= Allowable of 699 ft-kip (Acceptable)

Pile Shear Capacity Check - Load Case 2 (Section 2 – Soil C3)

Maximum pile moment (18” x ¾” SuperPILE) = 75.7 kips (See Figure 40 below)

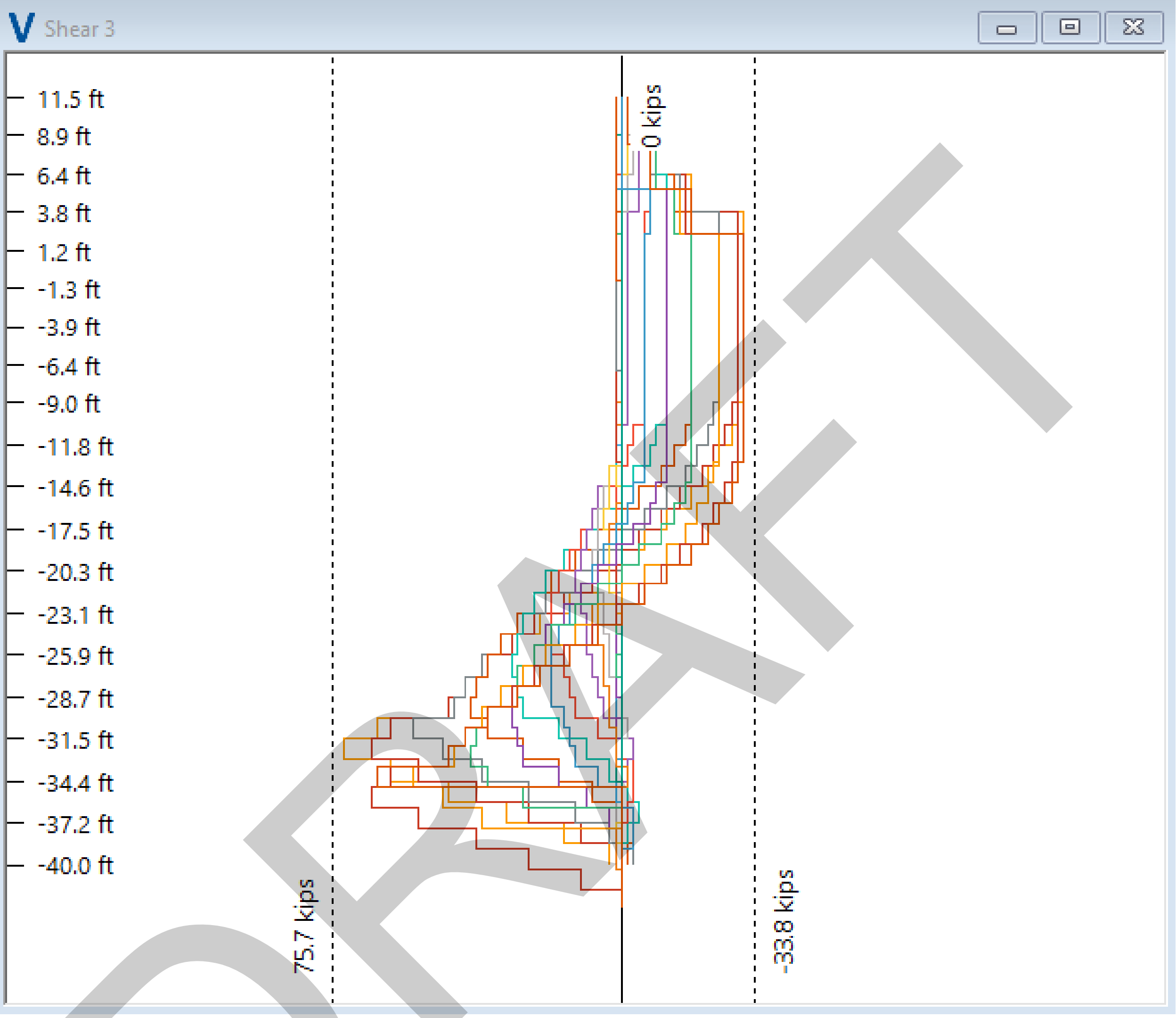


Figure 40: Max Pile Shear - Load Case 2 (Section 2 - Soil C3)

Allowable Pile Shear Design Capacity after statistical reductions = 303.5 kip
Actual of 75.7 kips <= Allowable of 303.5 kips (Acceptable)

Wale Moment Capacity Check - Load Case 2 (Section 2 – Soil C3)

Maximum wale moment (12x12 8F12) = 114 ft-kip (See Figure 41 below)

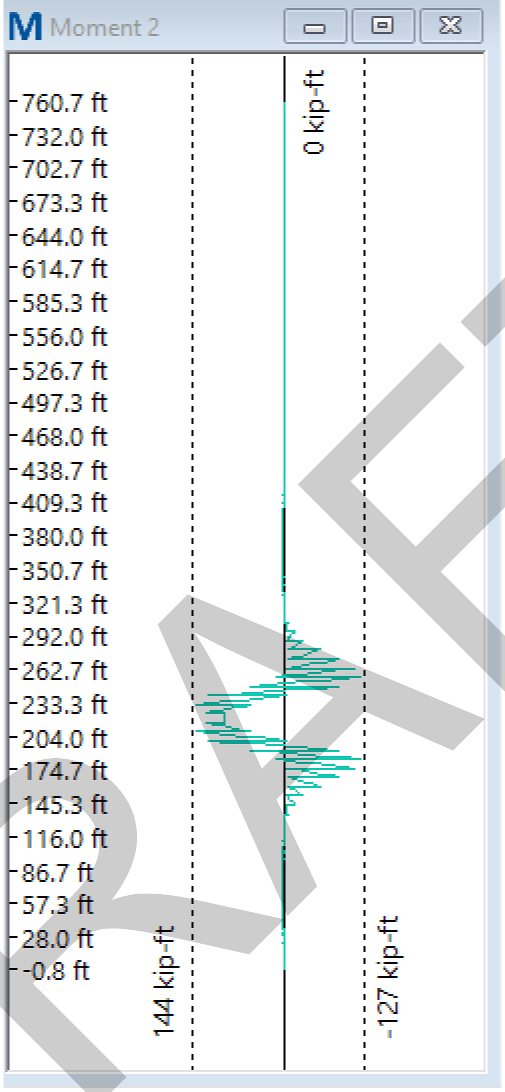


Figure 41: Max Wale Moment - Load Case 2 (Section 2-Soil C3)

Allowable Wale Design Capacity after environment reductions = 283 ft-kip
Actual of 144 ft-kip <= Allowable of 283 ft-kip (Acceptable)

Pile Displacement Check - Load Case 2 (Section 2 – Soil C3)

See Figure 42 below.

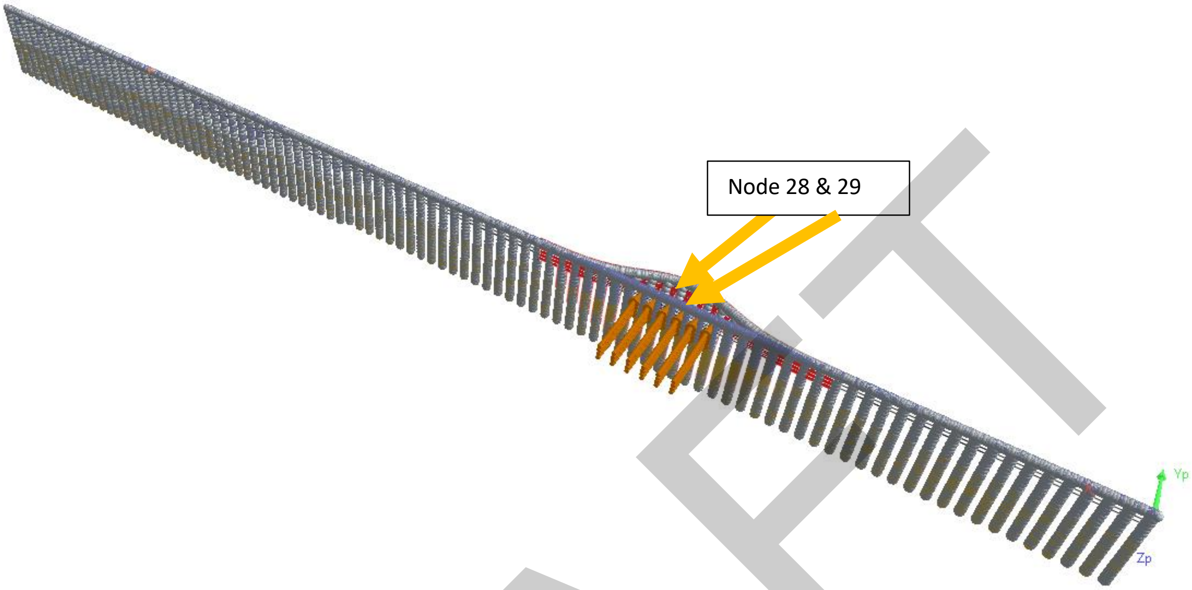


Figure 42: Displacement - Load Case 2 (Section 2 – Soil C3)

Maximum Pile displacement of system at back face is on node 28 & 29 with a displacement of 97 in.

3.4.3 Load Case 3 – Section 2 Fender System – C4 Soil

The illustration of the nodes that are loaded are shown in Figure 43. Different iterations were performed modifying the applied load. Energy calculations (see Table 5) were performed until the vessel impact energy equal to or above 829 ft-kip was achieved.

Figure 43: Layout – Load Case 3 (Section 2 – Soil C4)

Table 5: Energy Calculations - Load Case 3 (Section 2 – Soil C4)

Node	Load (kips)	Deflection (in)	Energy (ft-kips)
74	10.4	84.34	36.55
2772	10.4	75.89	32.89
2773	10.4	67.44	29.22
2774	10.4	59.01	25.57
75	10.4	100.76	43.66
2802	10.4	90.99	39.43
2803	10.4	81.21	35.19
2804	10.4	71.43	30.95
76	10.4	109.52	47.46
2832	10.4	99.02	42.91
2833	10.4	88.5	38.35
2834	10.4	77.97	33.79
77	10.4	109.52	47.46
2862	10.4	99.02	42.91
2863	10.4	88.5	38.35
2864	10.4	77.97	33.79
78	10.4	100.76	43.66
2892	10.4	90.99	39.43
2893	10.4	81.21	35.19
2894	10.4	71.43	30.95
79	10.4	84.34	36.55
2922	10.4	75.89	32.89
2923	10.4	67.44	29.22
2924	10.4	59.01	25.57
Total Energy (ft-kip)			**871.9**

EAC = 871.9 ft-kip > Emin = 829 ft-kip (Acceptable)

Pile Moment Capacity Check - Load Case 3 (Section 2 – Soil C4)

Maximum pile moment (18” x ¾” SuperPILE) = 689 ft-kip (See Figure 44: Max Pile Moment - Load Case 3 (Section 2 - Soil C4) below)

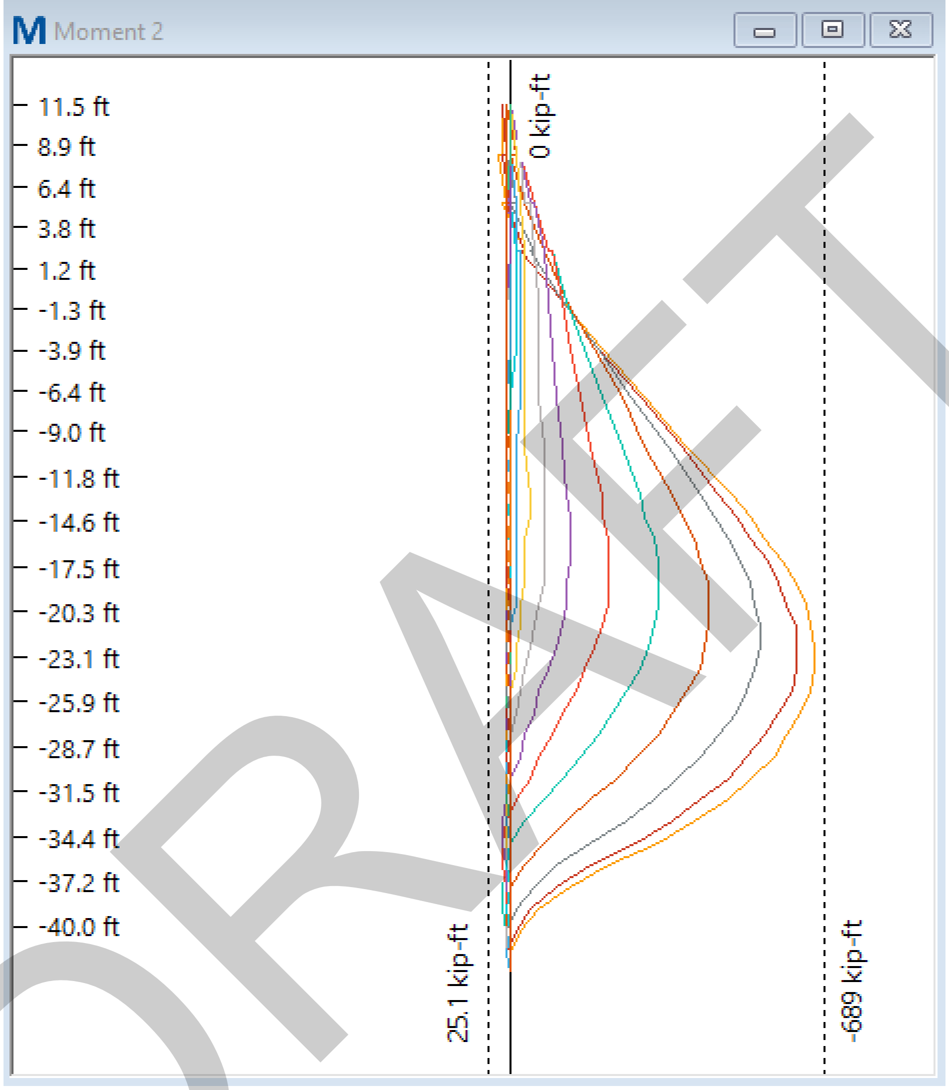


Figure 44: Max Pile Moment - Load Case 3 (Section 2 - Soil C4)

Allowable Pile Design Capacity after statistical reductions = 699 ft-kip
Actual of 689 ft-kip <= Allowable of 699 ft-kip (Acceptable)

Pile Shear Capacity Check - Load Case 3 (Section 2 – Soil C4)

Maximum pile moment (18" x ¾" SuperPILE) = 78.5 kips (See Figure 45 below)

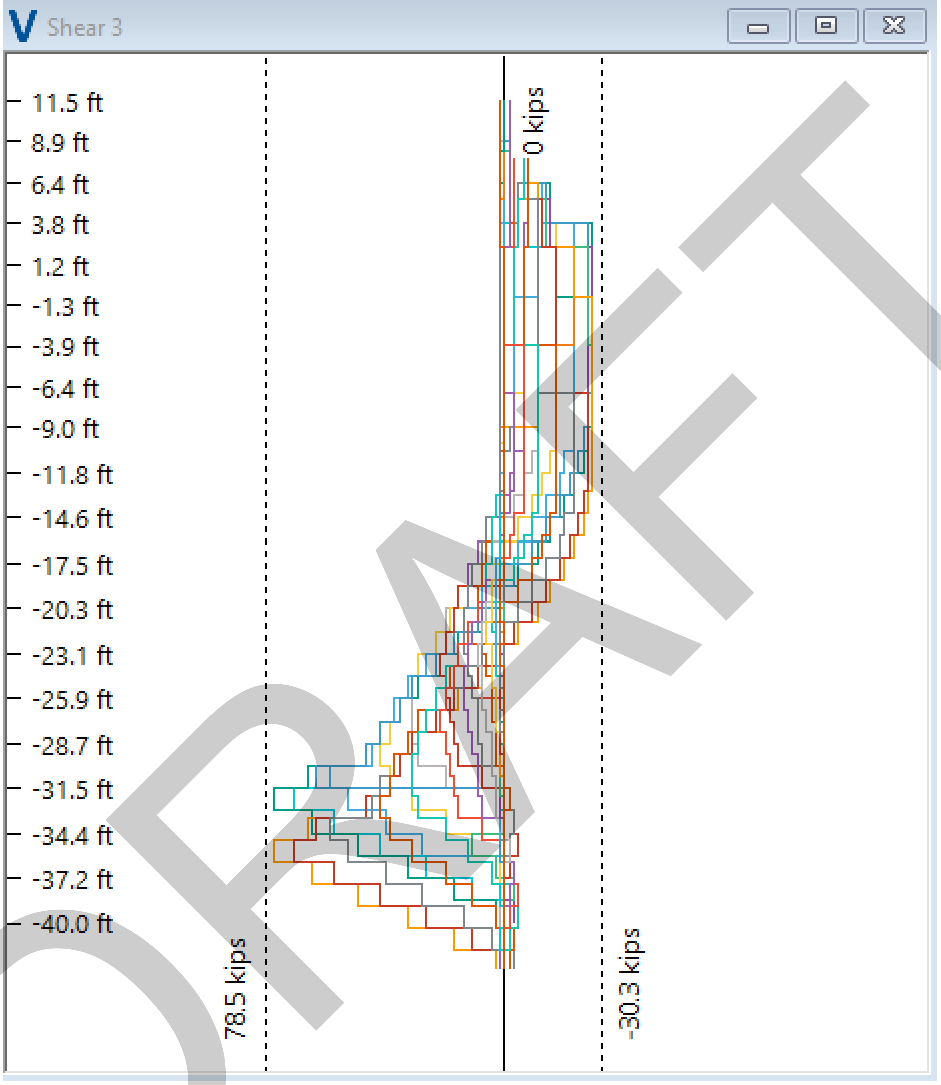


Figure 45: Max Pile Shear - Load Case 3 (Section 2 - Soil C4)

Allowable Pile Shear Design Capacity after statistical reductions = 303.5 kip
Actual of 78.5 kips <= Allowable of 303.5 kips (Acceptable)

Wale Moment Capacity Check - Load Case 3 (Section 2 – Soil C4)

Maximum wale moment (12x12 8F12) = 149 ft-kip (See Figure 46 below)

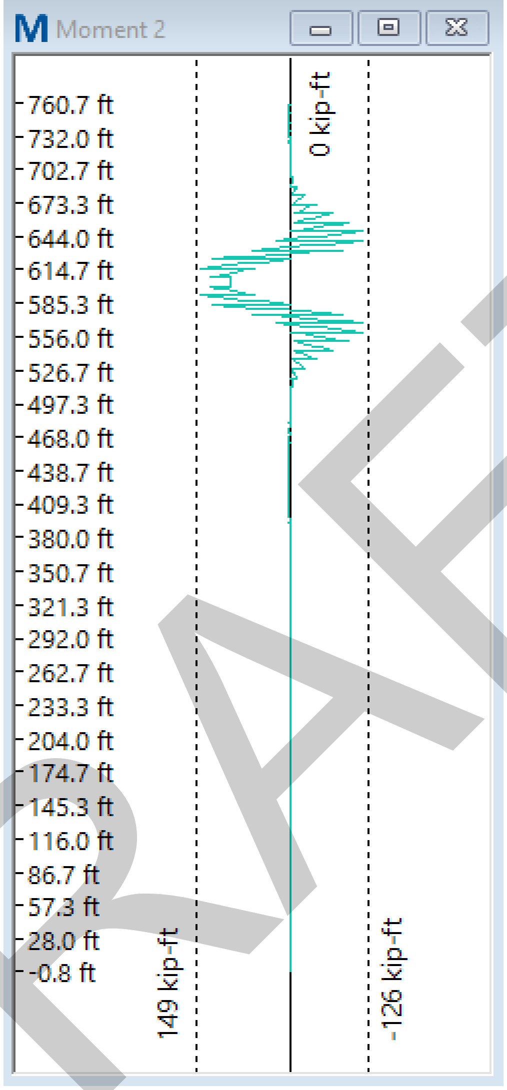


Figure 46: Max Wale Moment - Load Case 3 (Section 2 – Soil C4)

Allowable Wale Design Capacity after environment reductions = 283 ft-kip
Actual of 149 ft-kip <= Allowable of 283 ft-kip (Acceptable)

Pile Displacement Check - Load Case 3 (Section 2 – Soil C4)

See Figure 47 below.

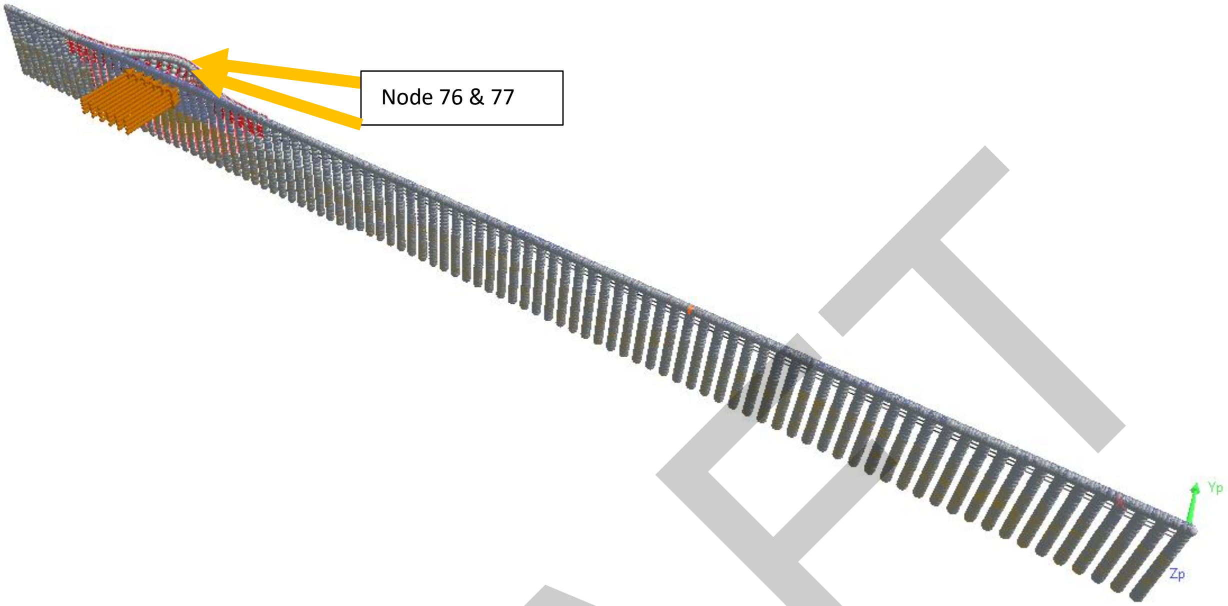


Figure 47: Displacement - Load Case 3 (Section 2 – Soil C4)

Maximum Pile displacement of system at back face is on node 76 & 77 with a displacement of 109.5 in.

3.4.4 Load Case 4 – Section 3 Fender System – C4 Soil

The illustration of the nodes that are loaded are shown in Figure 48. Different iterations were performed modifying the applied load. Energy calculations (see Table 6) were performed until the vessel impact energy equal to or above 829 ft-kip was achieved.

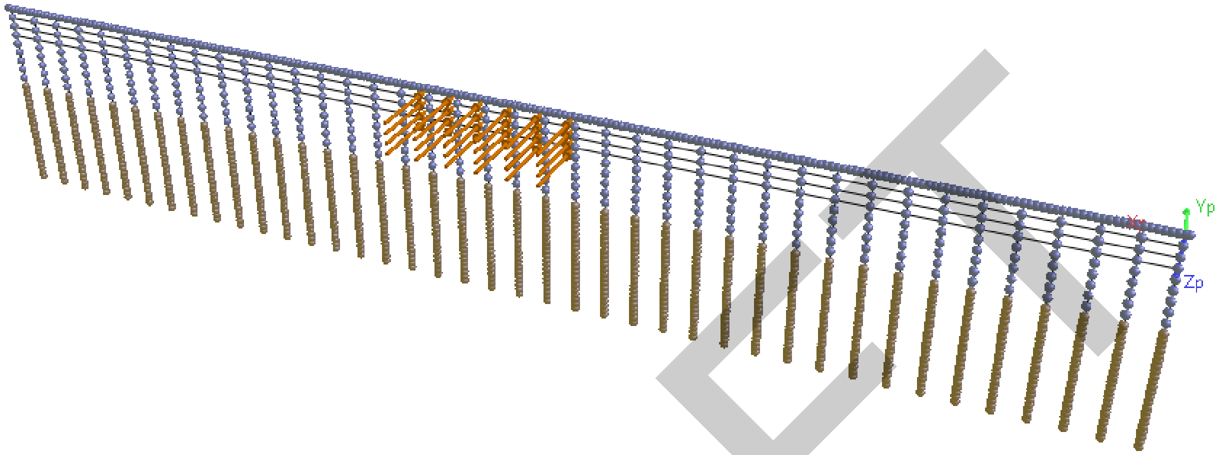


Figure 48: Layout – Load Case 4 (Section 3 – Soil C4)

Table 6: Energy Calculations - Load Case 4 (Section 3 – Soil C4)

Node	Load (kips)	Deflection (in)	Energy (ft-kips)
18	10.1	83.18	35.00
773	10.1	75.7	31.86
774	10.1	68.22	28.71
775	10.1	60.76	25.57
19	10.1	99.31	41.79
804	10.1	90.67	38.16
805	10.1	82.01	34.51
806	10.1	73.35	30.87
20	10.1	107.91	45.41
835	10.1	98.62	41.50
836	10.1	89.3	37.58
837	10.1	79.98	33.66
21	10.1	107.91	45.41
906	10.1	98.62	41.50
907	10.1	89.3	37.58
908	10.1	79.98	33.66
22	10.1	99.31	41.79
939	10.1	90.67	38.16
940	10.1	82.01	34.51
941	10.1	73.35	30.87
23	10.1	83.18	35.00
972	10.1	75.7	31.86
973	10.1	68.22	28.71
974	10.1	60.76	25.57
Total Energy (ft-kip)			**849.25**

EAC = 849.25 ft-kip > Emin = 829 ft-kip (Acceptable)

Pile Moment Capacity Check - Load Case 4 (Section 3 – Soil C4)

Maximum pile moment (18” x ¾” SuperPILE) = 681 ft-kip (See Figure 49 below)

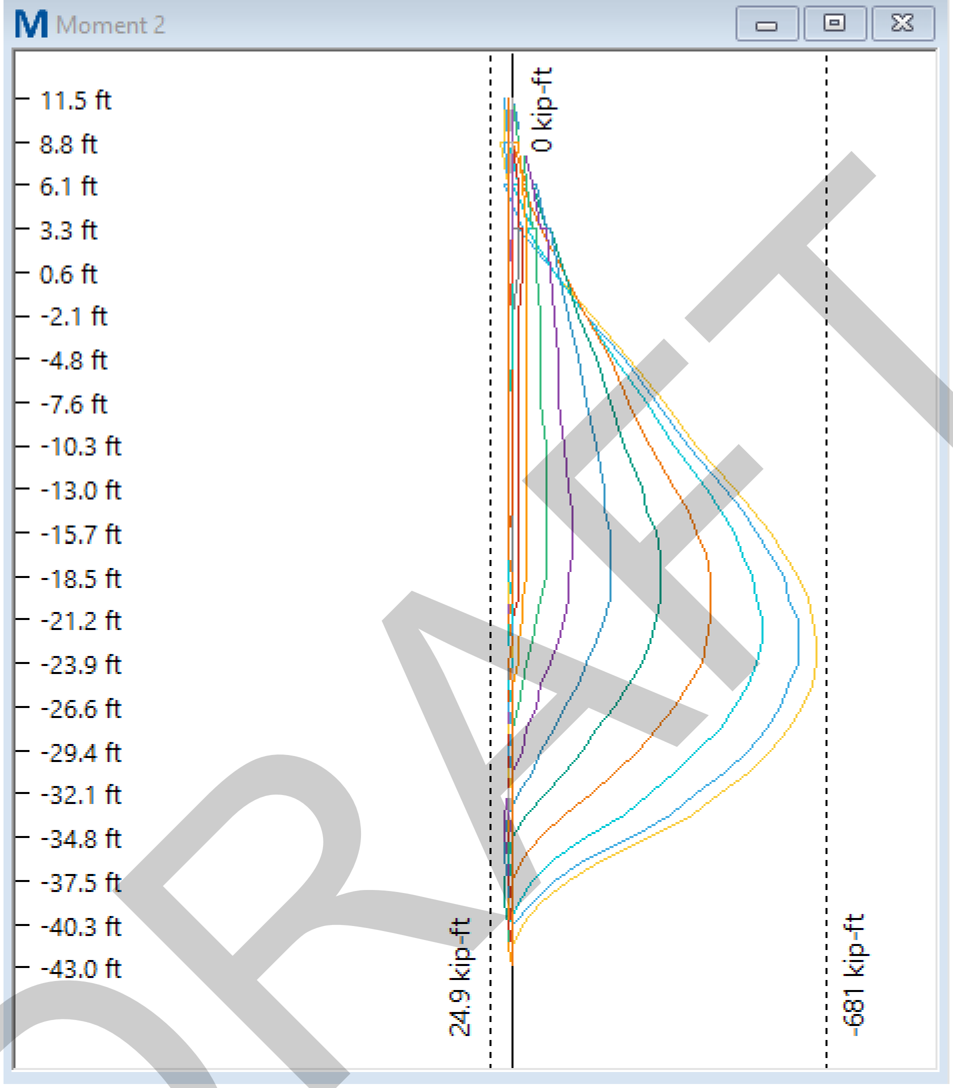


Figure 49: Max Pile Moment - Load Case 4 (Section 3 - Soil C4)

Allowable Pile Design Capacity after statistical reductions = 699 ft-kip
Actual of 681 ft-kip <= Allowable of 699 ft-kip (Acceptable)

Pile Shear Capacity Check - Load Case 4 (Section 3 – Soil C4)

Maximum pile moment (18" x ¾" SuperPILE) = 76.6 kips (See Figure 50 below)

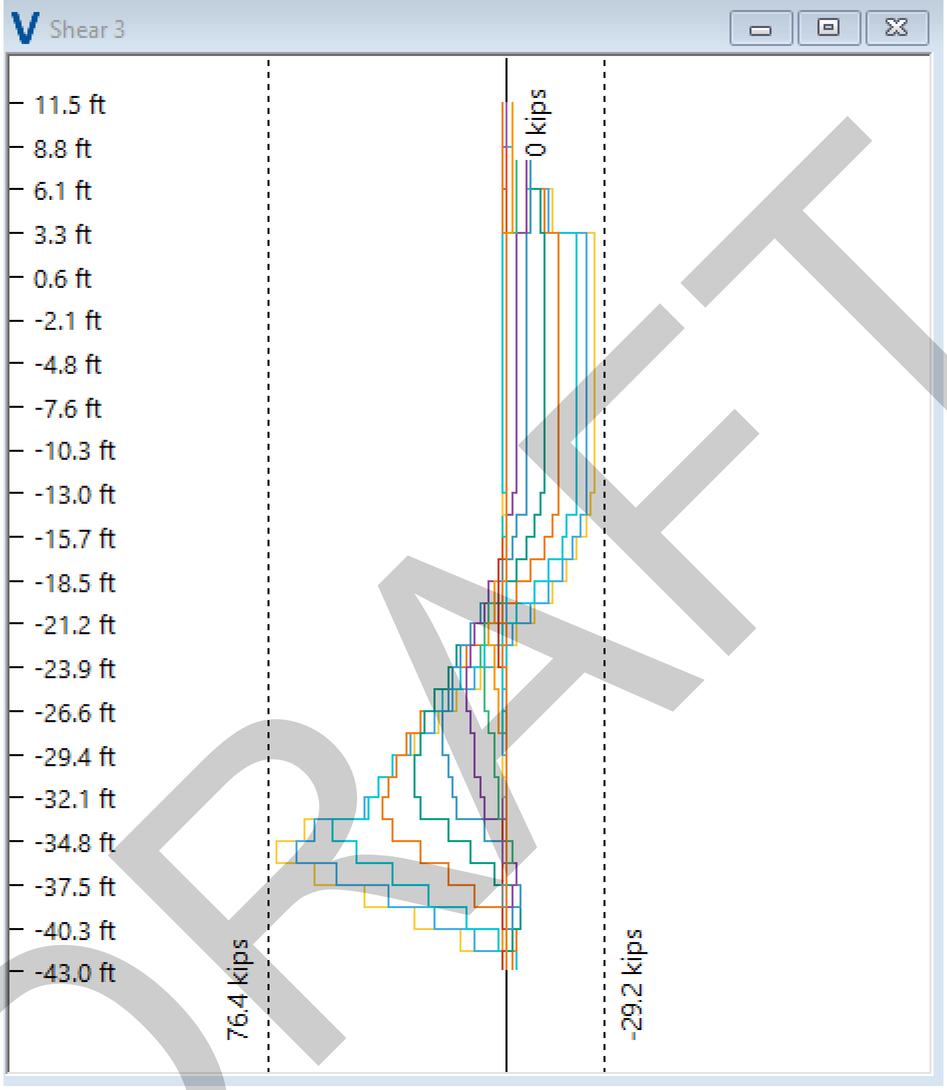


Figure 50: Max Pile Shear - Load Case 4 (Section 3 - Soil C4)

Allowable Pile Shear Design Capacity after statistical reductions = 303.5 kip
Actual of 76.4 kips <= Allowable of 303.5 kips (Acceptable)

Wale Moment Capacity Check - Load Case 4 (Section 3 – Soil C4)

Maximum wale moment (12x12 8F12) = 145 ft-kip (See Figure 51 below)

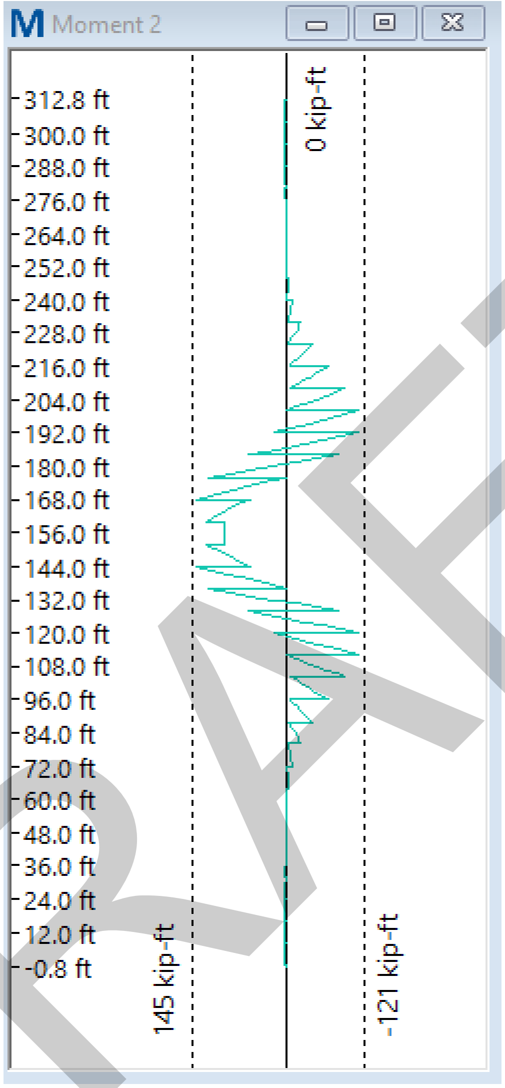


Figure 51: Max Wale Moment - Load Case 4 (Section 3 – Soil C4)

Allowable Wale Design Capacity after environment reductions = 283 ft-kip
Actual of 145 ft-kip <= Allowable of 283 ft-kip (Acceptable)

Pile Displacement Check - Load Case 4 (Section 3 – Soil C4)

See Figure 52 below.

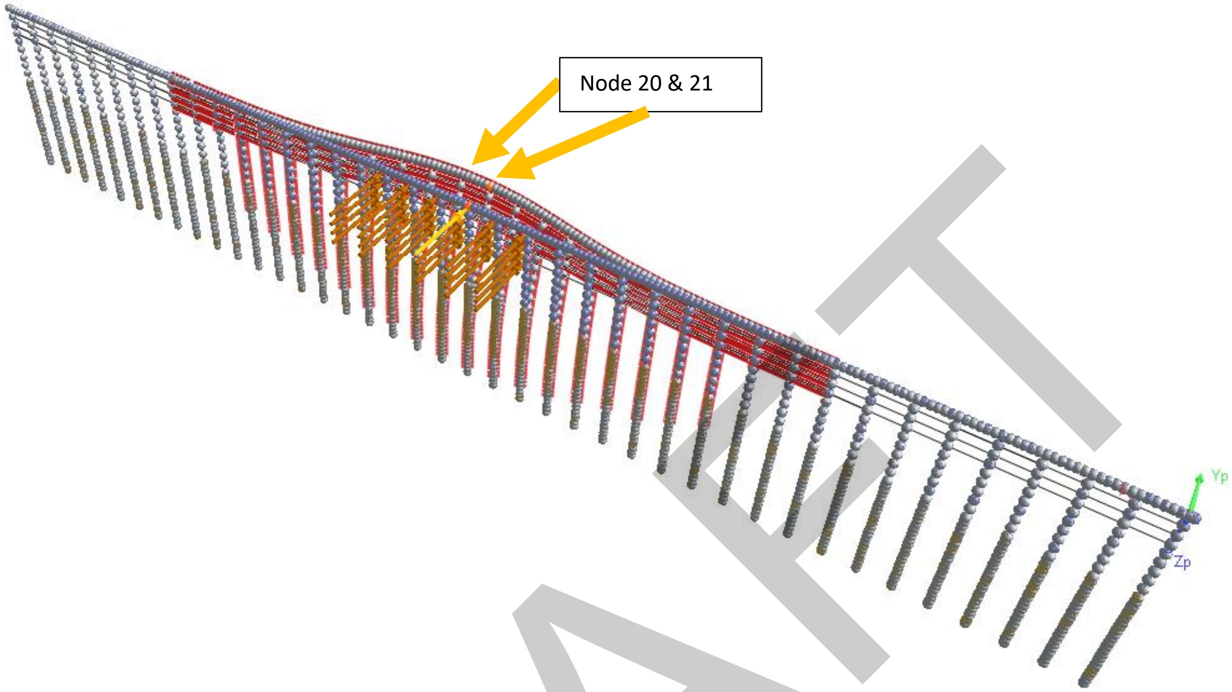


Figure 52: Displacement - Load Case 4 (Section 3 – Soil C4)

Maximum Pile displacement of system at back face is on node 20 & 21 with a displacement of 107.9 in

3.4.5 Load Case 5 – Section 4 Fender System – C4 Soil

The illustration of the nodes that are loaded are shown in Figure 53 Figure 33. Different iterations were performed modifying the applied load. Energy calculations (see Table 7) were performed until the vessel impact energy equal to or above 829 ft-kip was achieved.

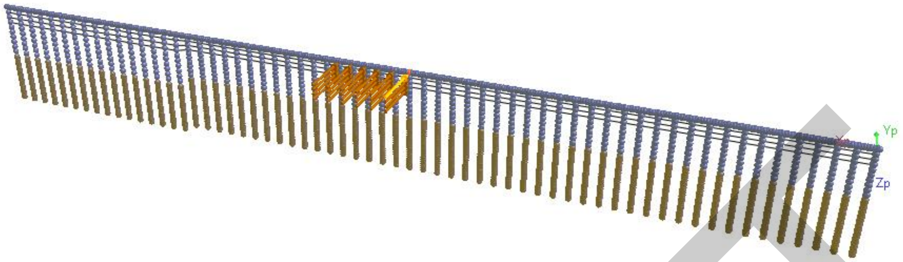


Figure 53: Layout – Load Case 5 (Section 4 – Soil C4)

Table 7: Energy Calculations - Load Case 5 (Section 4 – Soil C4)

Node	Load (kips)	Deflection (in)	Energy (ft-kips)
29	10.1	82.1	34.55
1246	10.1	74.7	31.44
1247	10.1	67.3	28.32
1248	10.1	59.9	25.21
30	10.1	97.89	41.20
1277	10.1	89.34	37.60
1278	10.1	80.78	33.99
1279	10.1	72.22	30.39
31	10.1	106.3	44.73
1308	10.1	97.11	40.87
1309	10.1	87.9	36.99
1310	10.1	78.7	33.12
32	10.1	106.3	44.73
1370	10.1	97.11	40.87
1371	10.1	87.9	36.99
1372	10.1	78.7	33.12
33	10.1	97.89	41.20
1402	10.1	89.34	37.60
1403	10.1	80.78	33.99
1404	10.1	72.22	30.39
34	10.1	82.1	34.55
1434	10.1	74.7	31.44
1435	10.1	67.3	28.32
1436	10.1	59.9	25.21
Total Energy (ft-kip)			**836.82**

EAC = 836.2 ft-kip > Emin = 829 ft-kip (Acceptable)

Pile Moment Capacity Check - Load Case 5 (Section 4 – Soil C4)

Maximum pile moment (18” x ¾” SuperPILE) = 674 ft-kip (See Figure 54 below)

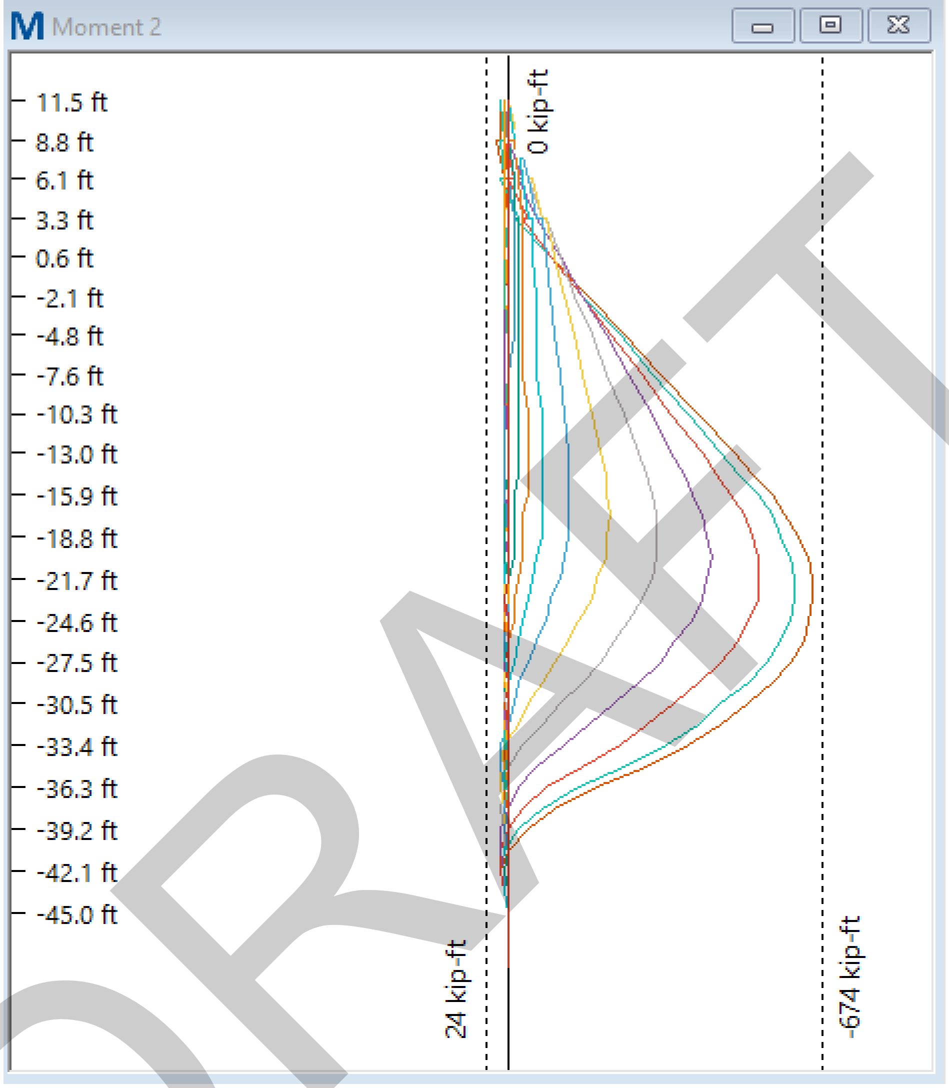


Figure 54: Max Pile Moment - Load Case 5 (Section 4 - Soil C4)

Allowable Pile Design Capacity after statistical reductions = 699 ft-kip
Actual of 674 ft-kip <= Allowable of 699 ft-kip (Acceptable)

Pile Shear Capacity Check - Load Case 5 (Section 4 – Soil C4)

Maximum pile moment (18” x ¾” SuperPILE) = 75.9 kips (See Figure 55 below)

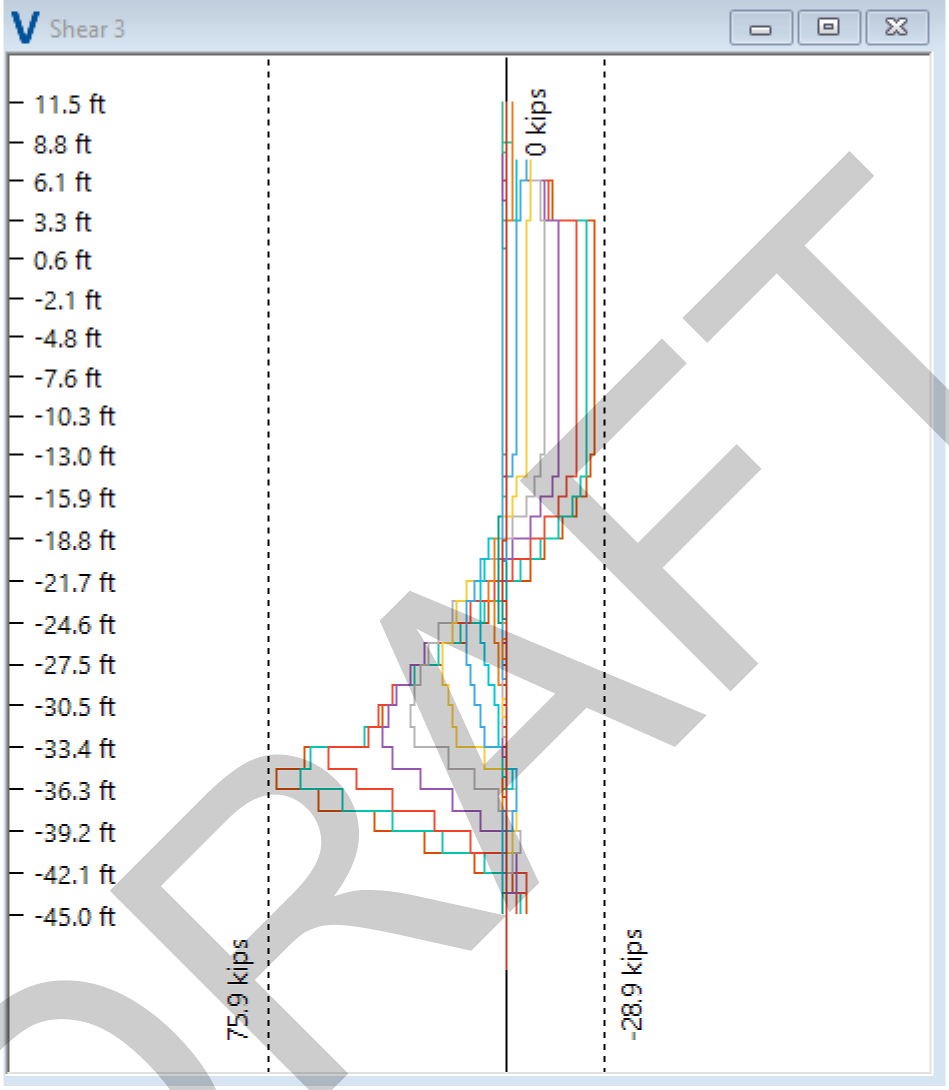


Figure 55: Max Pile Shear - Load Case 5 (Section 4 - Soil C4)

Allowable Pile Shear Design Capacity after statistical reductions = 303.5 kip
Actual of 75.9 kips <= Allowable of 303.5 kips (Acceptable)

<u>Wale Moment Capacity Check - Load Case 5 (Section 4 – Soil C4)</u>

Maximum wale moment (12x12 8F12) = 143 ft-kip (See Figure 56 below)

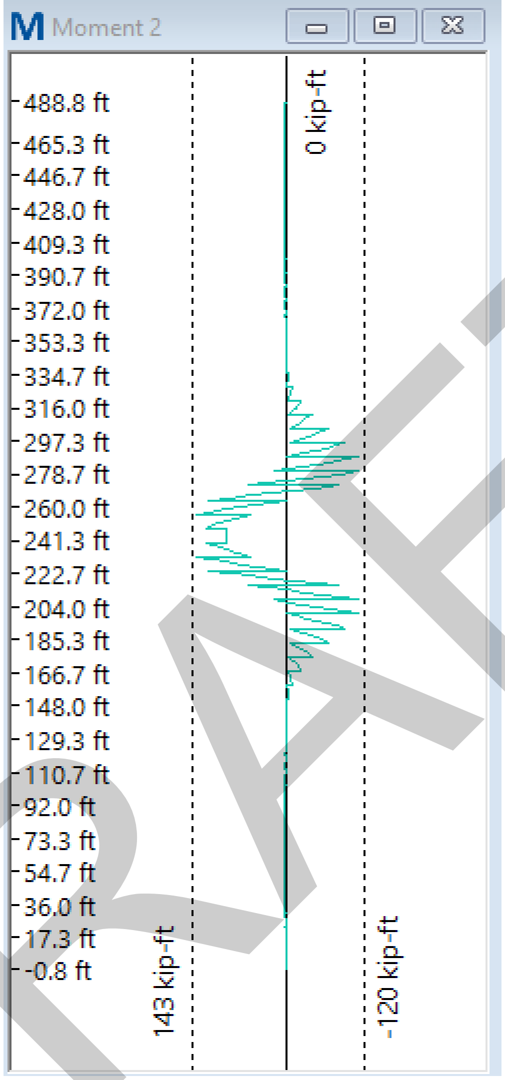


Figure 56: Max Wale Moment - Load Case 5 (Section 4 – Soil C4)

Allowable Wale Design Capacity after environment reductions = 283 ft-kip
Actual of 143 ft-kip <= Allowable of 283 ft-kip (Acceptable)

Pile Displacement Check - Load Case 5 (Section 4 – Soil C4)

See Figure 57 below.

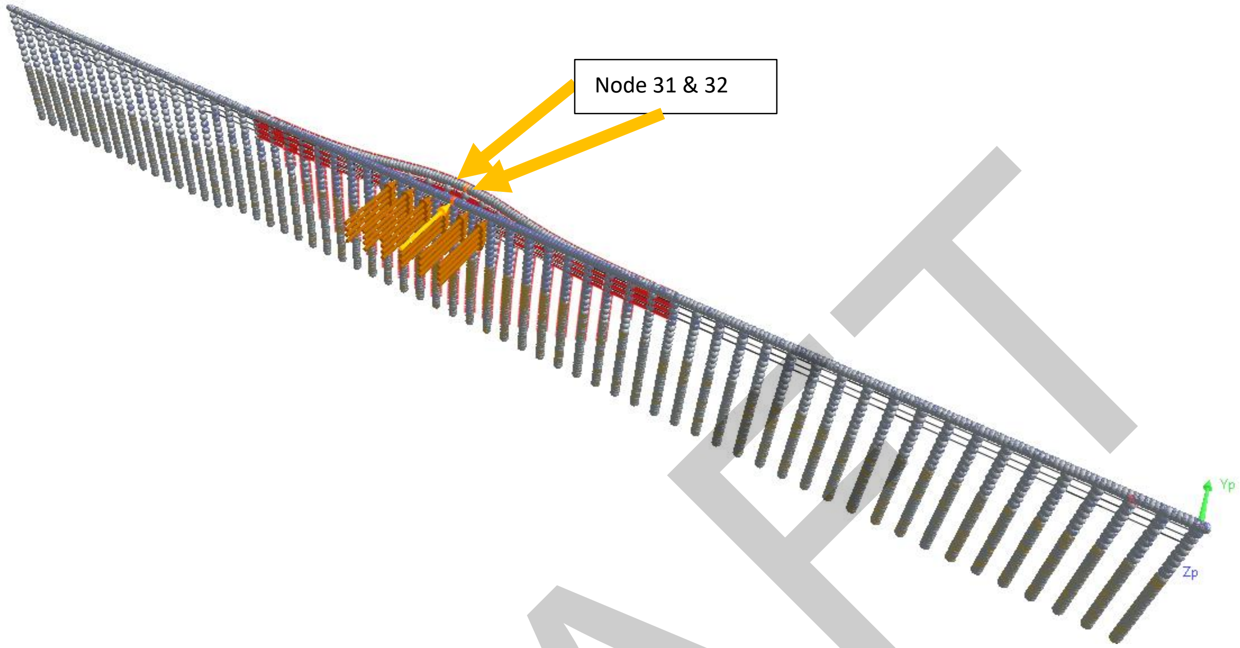


Figure 57: Displacement - Load Case 5 (Section 4 – Soil C4)

Maximum Pile displacement of system at back face is on node 31 & 32 with a displacement of 106.3 in

3.4.6 Load Case 6 – Section 4 Fender System – C5 Soil

The illustration of the nodes that are loaded are shown in Figure 58. Different iterations were performed modifying the applied load. Energy calculations (see Table 8) were performed until the vessel impact energy equal to or above 829 ft-kip was achieved.

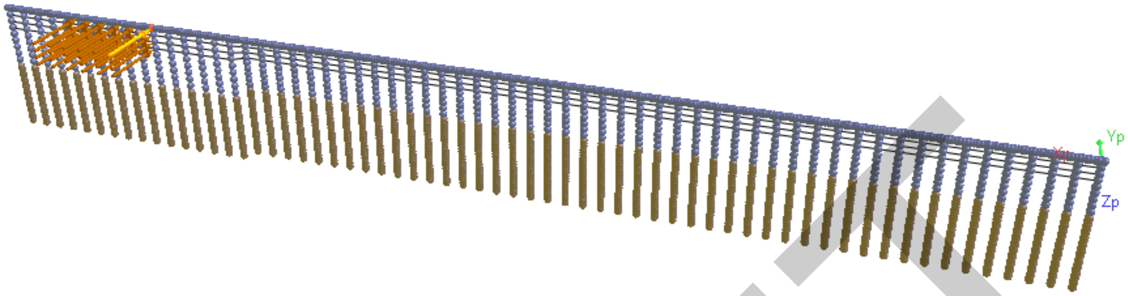


Figure 58: Layout – Load Case 6 (Section 4 – Soil C5)

Table 8: Energy Calculations - Load Case 6 (Section 4 – Soil C5)

Node	Load (kips)	Deflection (in)	Energy (ft-kips)
52	9.1	99.66	37.79
1959	9.1	89.79	34.05
1960	9.1	79.9	30.30
1961	9.1	70	26.54
53	9.1	116.5	44.17
1990	9.1	105.2	39.89
1991	9.1	94.01	35.65
1992	9.1	82.74	31.37
54	9.1	125.7	47.66
2021	9.1	113.64	43.09
2022	9.1	101.6	38.52
2023	9.1	89.5	33.94
55	9.1	125.7	47.66
2052	9.1	113.64	43.09
2053	9.1	101.6	38.52
2054	9.1	89.5	33.94
56	9.1	116.5	44.17
2083	9.1	105.2	39.89
2084	9.1	94.01	35.65
2085	9.1	82.74	31.37
57	9.1	99.66	37.79
2114	9.1	89.79	34.05
2115	9.1	79.9	30.30
2116	9.1	70	26.54
Total Energy (ft-kip)			**885.9**

EAC = 885.9 ft-kip > Emin = 829 ft-kip (Acceptable)

Pile Moment Capacity Check - Load Case 6 (Section 4 – Soil C5)

Maximum pile moment (18” x ¾” SuperPILE) = 682 ft-kip (See Figure 59 below)

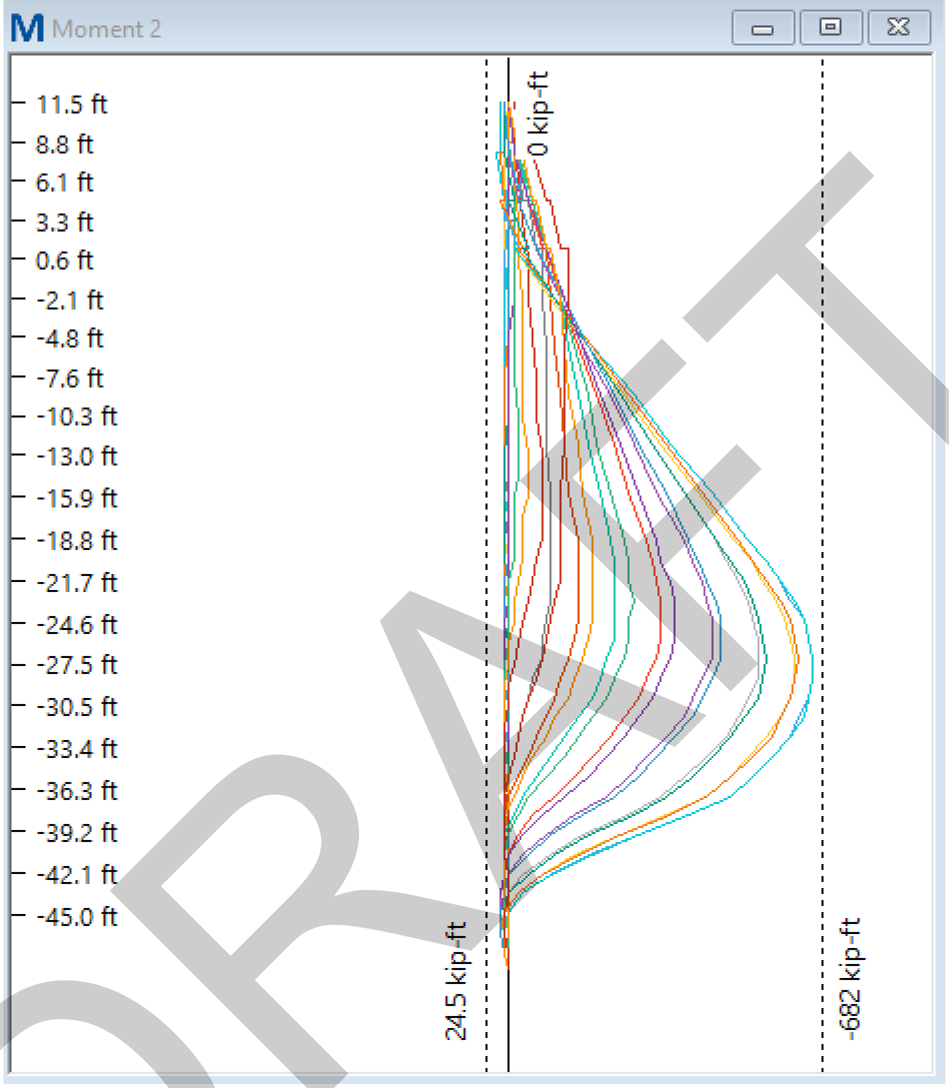


Figure 59: Max Pile Moment - Load Case 6 (Section 4 - Soil C5)

Allowable Pile Design Capacity after statistical reductions = 699 ft-kip
Actual of 682 ft-kip <= Allowable of 699 ft-kip (Acceptable)

Pile Shear Capacity Check - Load Case 6 (Section 4 – Soil C5)

Maximum pile moment (18” x ¾” SuperPILE) = 83.8 kips (See Figure 60 below)

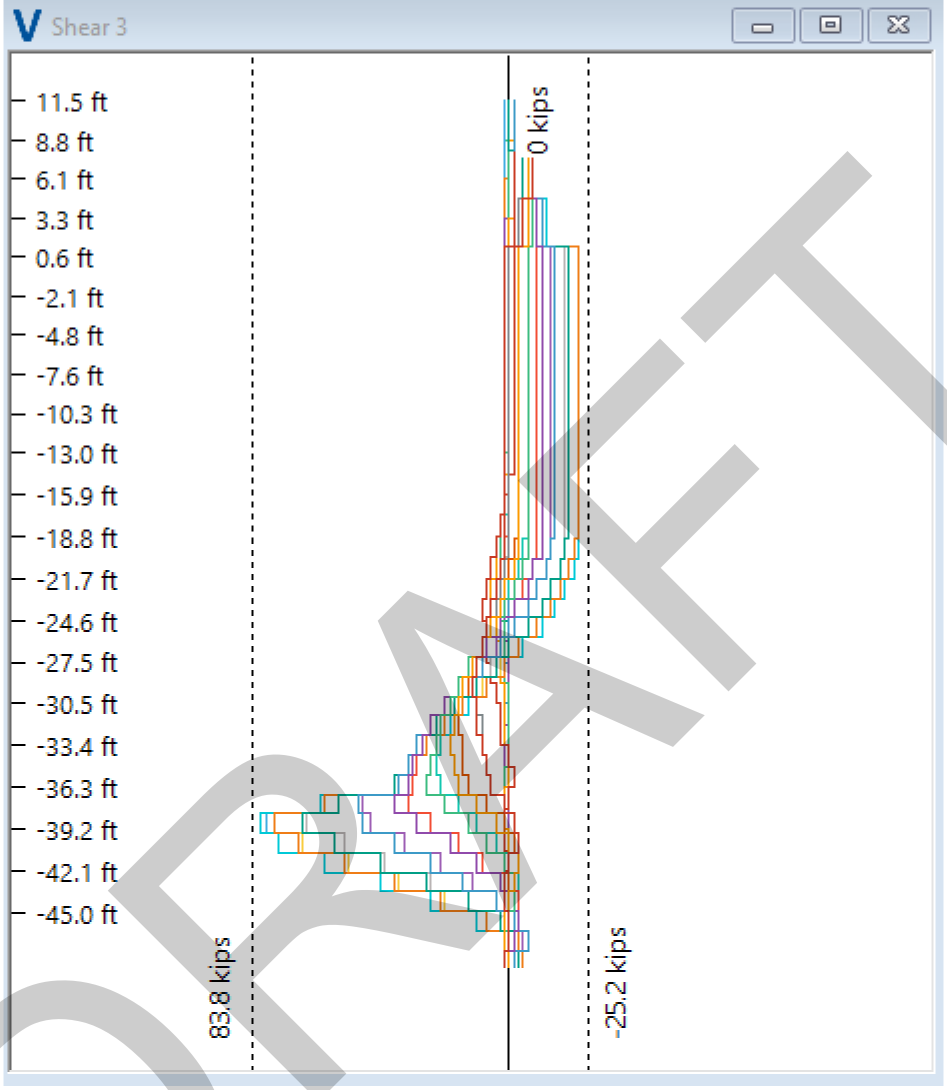


Figure 60: Max Pile Shear - Load Case 6 (Section 4 - Soil C5)

Allowable Pile Shear Design Capacity after statistical reductions = 303.5 kip
Actual of 83.8 kips <= Allowable of 303.5 kips (Acceptable)

Wale Moment Capacity Check - Load Case 6 (Section 4 – Soil C5)

Maximum wale moment (12x12 8F12) = 148 ft-kip (See Figure 61 below)

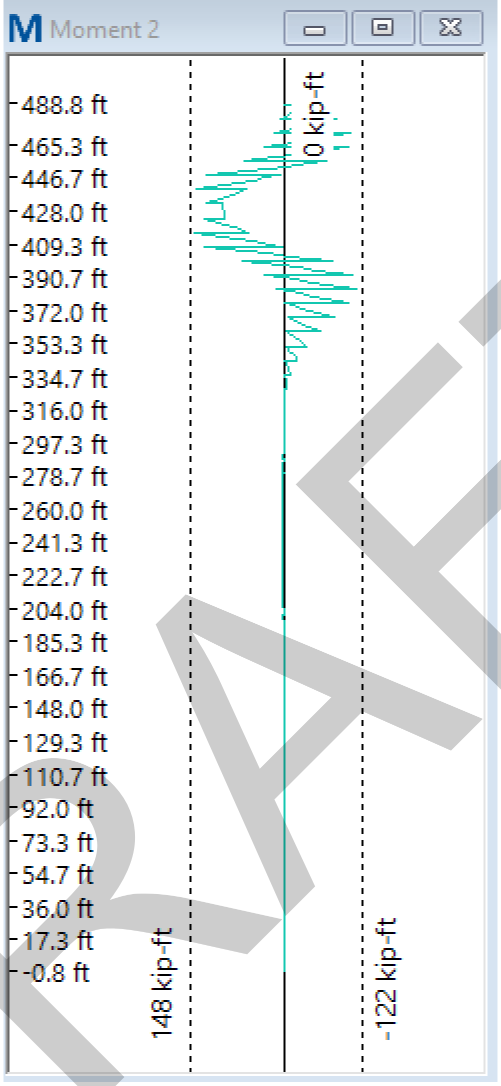


Figure 61: Max Wale Moment - Load Case 6 (Section 4 – Soil C5)

Allowable Wale Design Capacity after environment reductions = 283 ft-kip
Actual of 148 ft-kip <= Allowable of 283 ft-kip (Acceptable)

Pile Displacement Check - Load Case 6 (Section 4 – Soil C5)

See Figure 62 below.

Figure 62: Displacement - Load Case 6 (Section 4 – Soil C5)

Maximum Pile displacement of system at back face is on node 54 & 55 with a displacement of 125.7in

4 Minimum Tip Analysis

Pile tip analysis in FB-MultiPier is done with a single cantilever pile model. The pile is loaded with a transverse load that generates the failure moment in the pile. Then the unstable embedment depth (Eo) is determined by raising the pile tip elevation until pile deflections become unreasonable or the program does not converge on a solution. Once the unstable depth is identified the pile is lengthened 1’ at a time until a reaction moment occurs at the bottom of the pile allowing for an installation depth that will cause the pile to fail before the soil.

4.1 Tip Analysis by Boring Location

4.1.1 18” x 3/4” SUPERPILE – C2 Soil

At pile length 56 ft (embedment of E_0=26 ft), the software no longer finds a solution (soil fails). See Figure 63 This indicates the elevation at which the pile will tip over before it fails. Increasing the pile length to 60 ft created a reaction moment at the bottom of the pile.

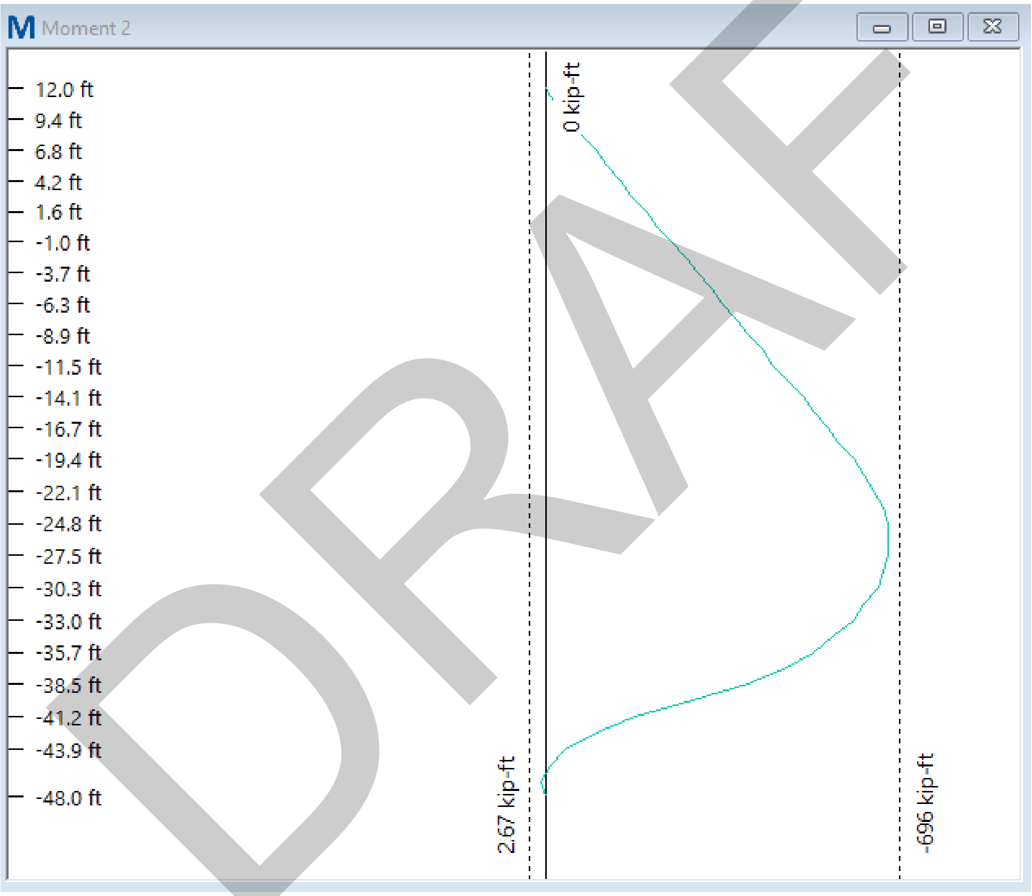
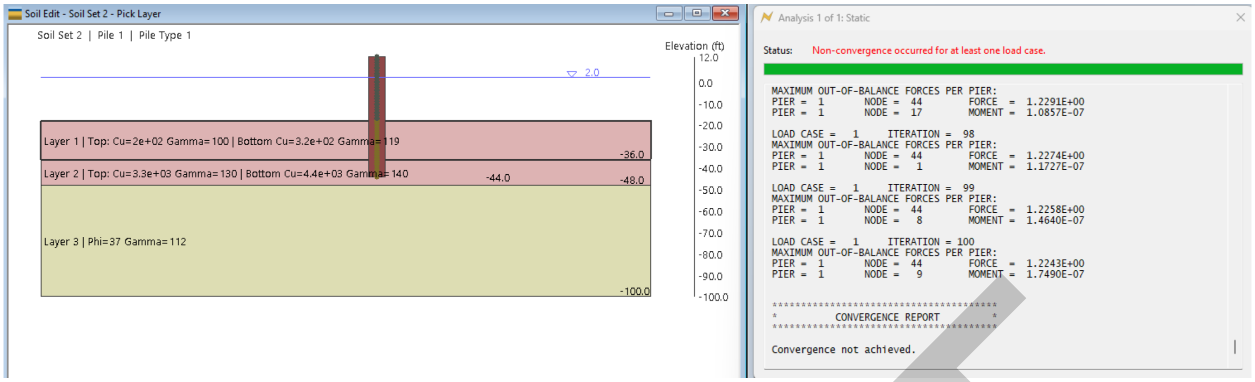


Figure 64 below shows the moment down the elevation of the pile to show the pile at its failure moment based on the controlling minimum tip.



Status: Non-convergence occurred for at least one load case.

```
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  44       FORCE  =  1.2291E+00
PIER =  1       NODE =  17       MOMENT =  1.0857E-07

LOAD CASE =   1     ITERATION =  98
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  44       FORCE  =  1.2274E+00
PIER =  1       NODE =   1       MOMENT =  1.1727E-07

LOAD CASE =   1     ITERATION =  99
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  44       FORCE  =  1.2258E+00
PIER =  1       NODE =   8       MOMENT =  1.4640E-07

LOAD CASE =   1     ITERATION = 100
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  44       FORCE  =  1.2243E+00
PIER =  1       NODE =   9       MOMENT =  1.7490E-07


**************************************
*          CONVERGENCE REPORT        *
**************************************

Convergence not achieved.
```

Figure 63: Non-Convergence Pile Depth (Soil C2)

Supplied pile length for piles in soil C2 to be 61 ft (1' for damage + 12' above the waterline + 48' below the waterline)

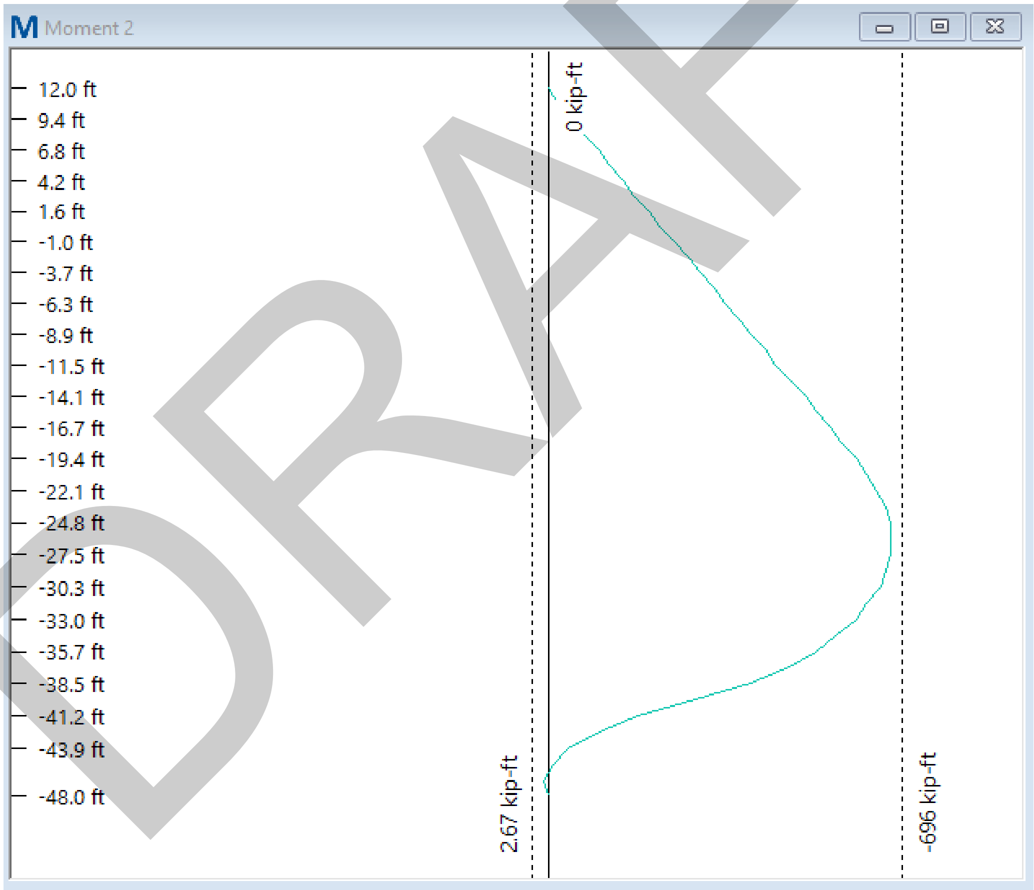


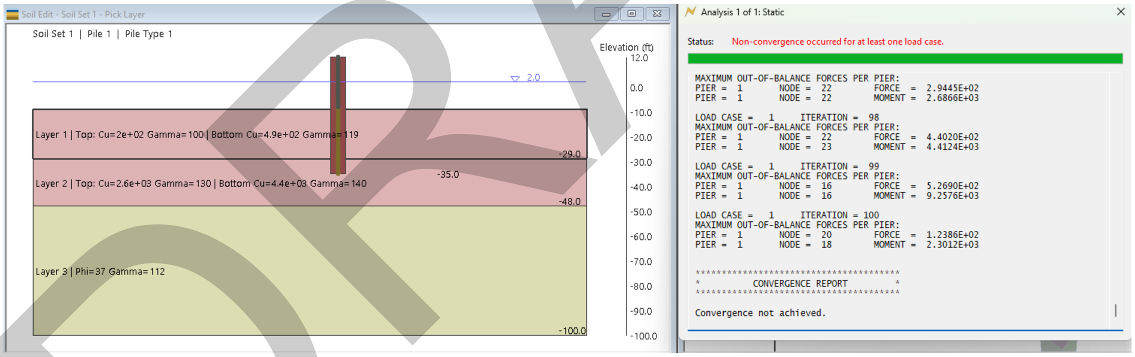
Figure 64: Moment Diagram Down the Elevation (Soil C2)

Bending moment from tip analysis of 696 ft-kip is close to the design ultimate capacity of the SUPERPILE (18" x 3/4") of 699 ft-kip.

4.1.2 18” x 3/4” SUPERPILE – C3 Soil

At pile length 47 ft (embedment of E_0=26 ft), the software no longer finds a solution (soil fails). See Figure 65This indicates the elevation at which the pile will tip over before it fails. Increasing the pile length to 52 ft created a reaction moment at the bottom of the pile.

Figure 66 below shows the moment down the elevation of the pile to show the pile at its failure moment based on the controlling minimum tip.



Status: Non-convergence occurred for at least one load case.

```
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  22        FORCE  =  2.9445E+02
PIER =  1       NODE =  22        MOMENT =  2.6866E+03

LOAD CASE =   1     ITERATION =  98
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  22        FORCE  =  4.4020E+02
PIER =  1       NODE =  23        MOMENT =  4.4124E+03

LOAD CASE =   1     ITERATION =  99
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  16        FORCE  =  5.2690E+02
PIER =  1       NODE =  16        MOMENT =  9.2576E+03

LOAD CASE =   1     ITERATION = 100
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  20        FORCE  =  1.2386E+02
PIER =  1       NODE =  18        MOMENT =  2.3012E+03


****************************************
*          CONVERGENCE REPORT          *
****************************************

Convergence not achieved.
```

Figure 65:Non-Convergence Pile Depth (Soil C3)

Supplied pile length for piles in soil C3 to be 53 ft (1’ for damage + 12’ above the waterline + 40’ below the waterline)

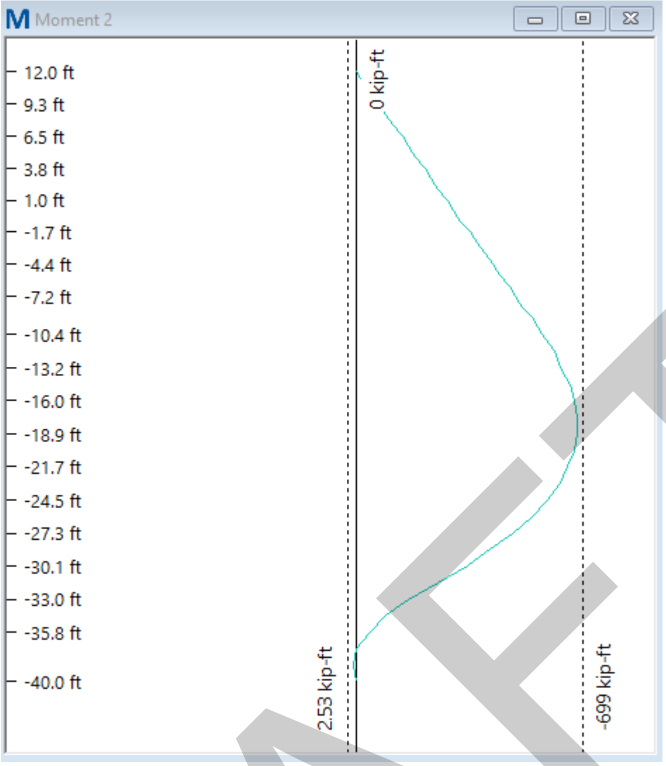


Figure 66: Moment Diagram Down the Elevation (Soil C3)

Bending moment from tip analysis of 699 ft-kip is the design ultimate capacity of the SUPERPILE (18" x 3/4")

4.1.3 18" x 3/4" SUPERPILE – C4 Soil

At pile length 50 ft (embedment of E_0=25 ft), the software no longer finds a solution (soil fails). See Figure 67 This indicates the elevation at which the pile will tip over before it fails. Increasing the pile length to 55 ft created a reaction moment at the bottom of the pile.

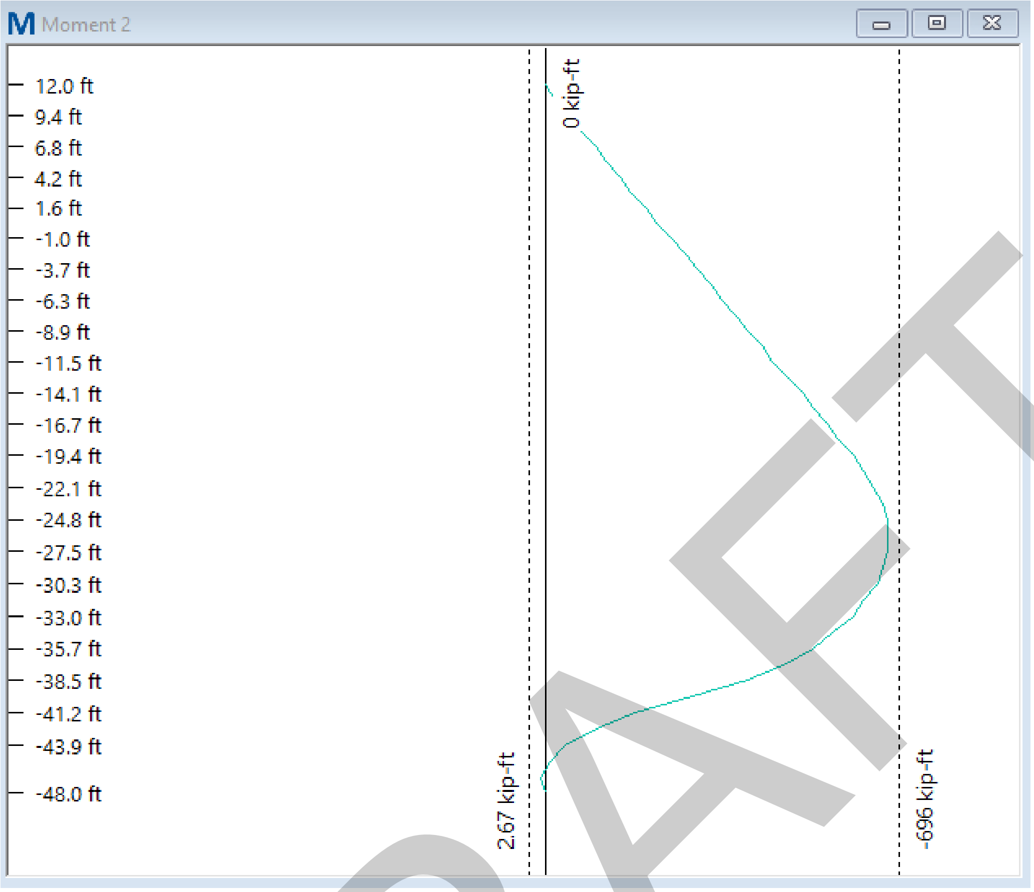
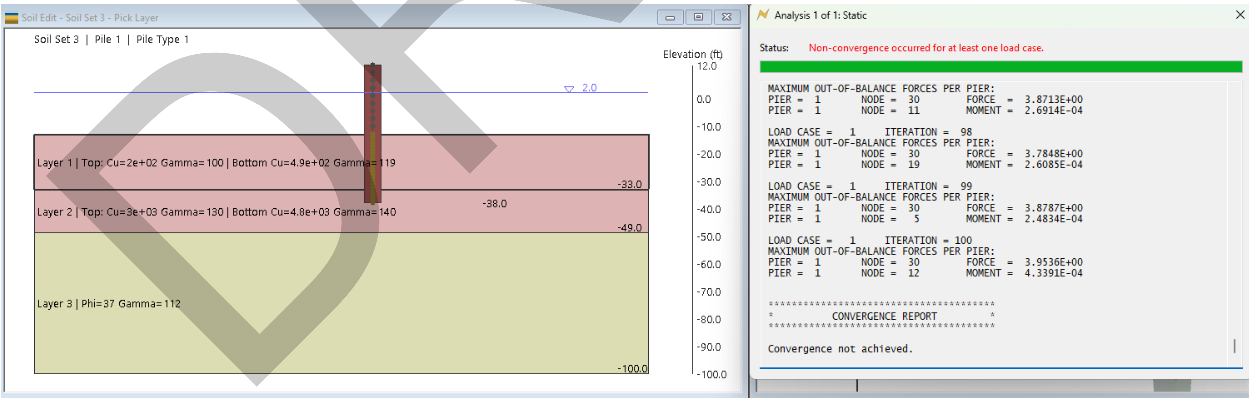


Figure 64 below shows the moment down the elevation of the pile to show the pile at its failure moment based on the controlling minimum tip.



Status: Non-convergence occurred for at least one load case.

```
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30        FORCE  =  3.8713E+00
PIER =  1       NODE =  11        MOMENT =  2.6914E-04

LOAD CASE =   1     ITERATION =  98
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30        FORCE  =  3.7848E+00
PIER =  1       NODE =  19        MOMENT =  2.6085E-04

LOAD CASE =   1     ITERATION =  99
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30        FORCE  =  3.8787E+00
PIER =  1       NODE =   5        MOMENT =  2.4834E-04

LOAD CASE =   1     ITERATION = 100
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30        FORCE  =  3.9536E+00
PIER =  1       NODE =  12        MOMENT =  4.3391E-04


***************************************
*          CONVERGENCE REPORT         *
***************************************

Convergence not achieved.
```

Figure 67:Non-Convergence Pile Depth (Soil C4)

Supplied pile length for piles in soil C4 to be 56 ft (1’ for damage + 12’ above the waterline + 43’ below the waterline)

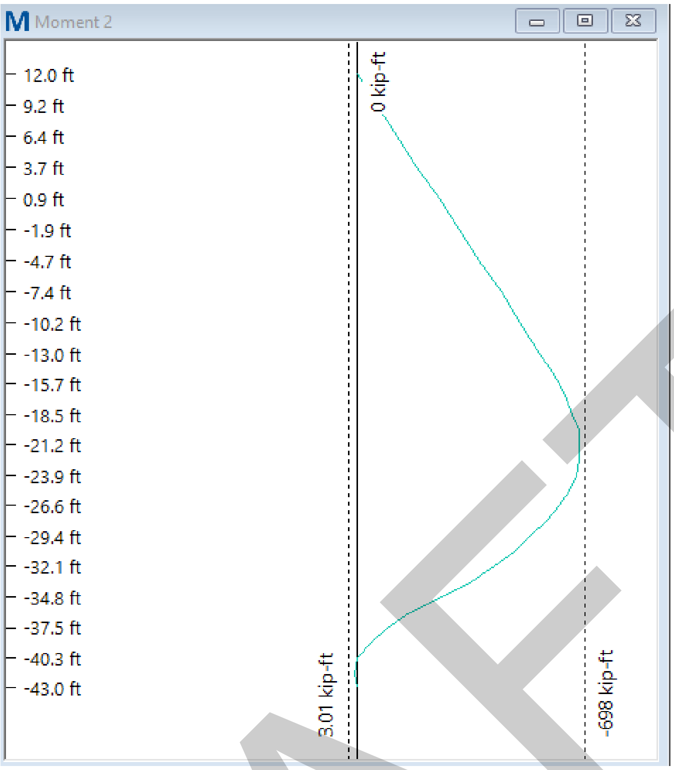


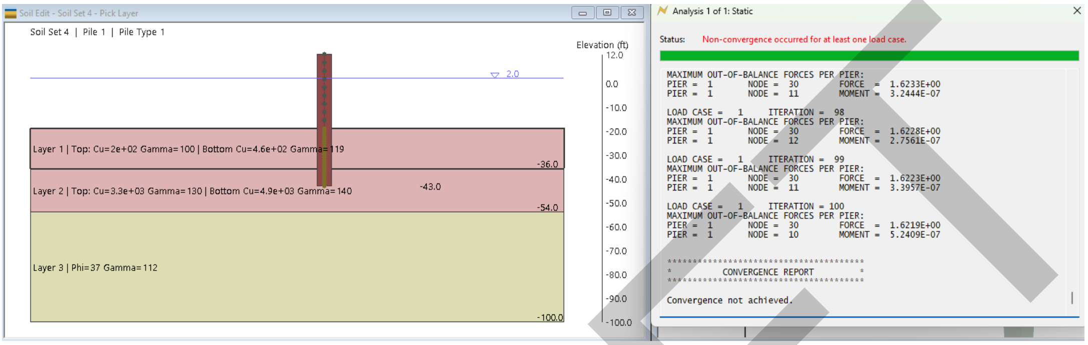
Figure 68: Moment Diagram Down the Elevation (Soil C4)

Bending moment from tip analysis of 698 ft-kip is close to the design ultimate capacity of the SUPERPILE (18" x 3/4") of 699 ft-kip.

4.1.4 18” x 3/4” SUPERPILE – C5 Soil

At pile length 55 ft (embedment of E_0=24 ft), the software no longer finds a solution (soil fails). See Figure 69 This indicates the elevation at which the pile will tip over before it fails. Increasing the pile length to 59 ft created a reaction moment at the bottom of the pile.

Figure 70 below shows the moment down the elevation of the pile to show the pile at its failure moment based on the controlling minimum tip.



Status: Non-convergence occurred for at least one load case.

```
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30       FORCE  =  1.6233E+00
PIER =  1       NODE =  11       MOMENT =  3.2444E-07

LOAD CASE =   1     ITERATION =  98
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30       FORCE  =  1.6228E+00
PIER =  1       NODE =  12       MOMENT =  2.7561E-07

LOAD CASE =   1     ITERATION =  99
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30       FORCE  =  1.6223E+00
PIER =  1       NODE =  11       MOMENT =  3.3957E-07

LOAD CASE =   1     ITERATION = 100
MAXIMUM OUT-OF-BALANCE FORCES PER PIER:
PIER =  1       NODE =  30       FORCE  =  1.6219E+00
PIER =  1       NODE =  10       MOMENT =  5.2409E-07


**************************************
*          CONVERGENCE REPORT        *
**************************************

Convergence not achieved.
```

Figure 69:Non-Convergence Pile Depth (Soil C5)

Supplied pile length for piles in soil C4 to be 60 ft (1’ for damage + 12’ above the waterline + 47’ below the waterline)

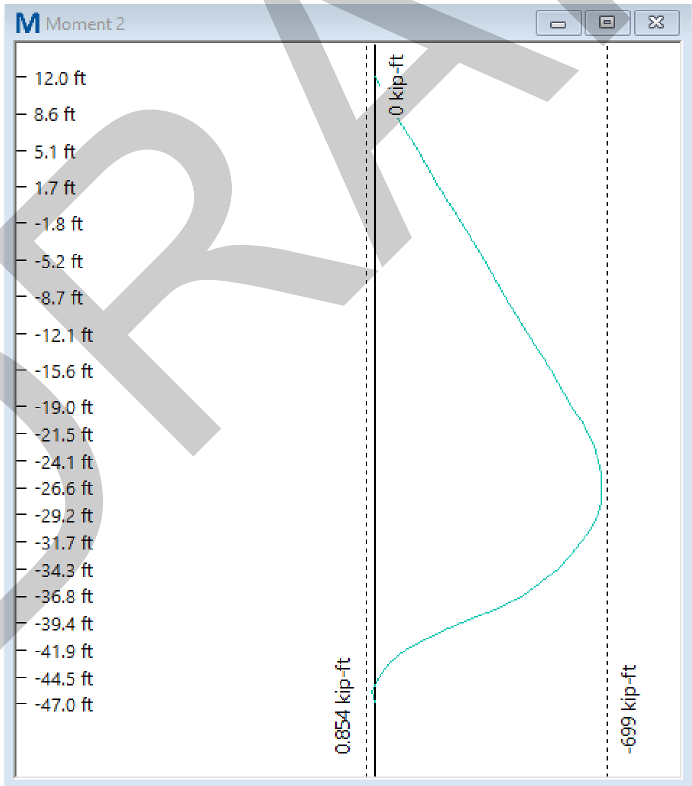
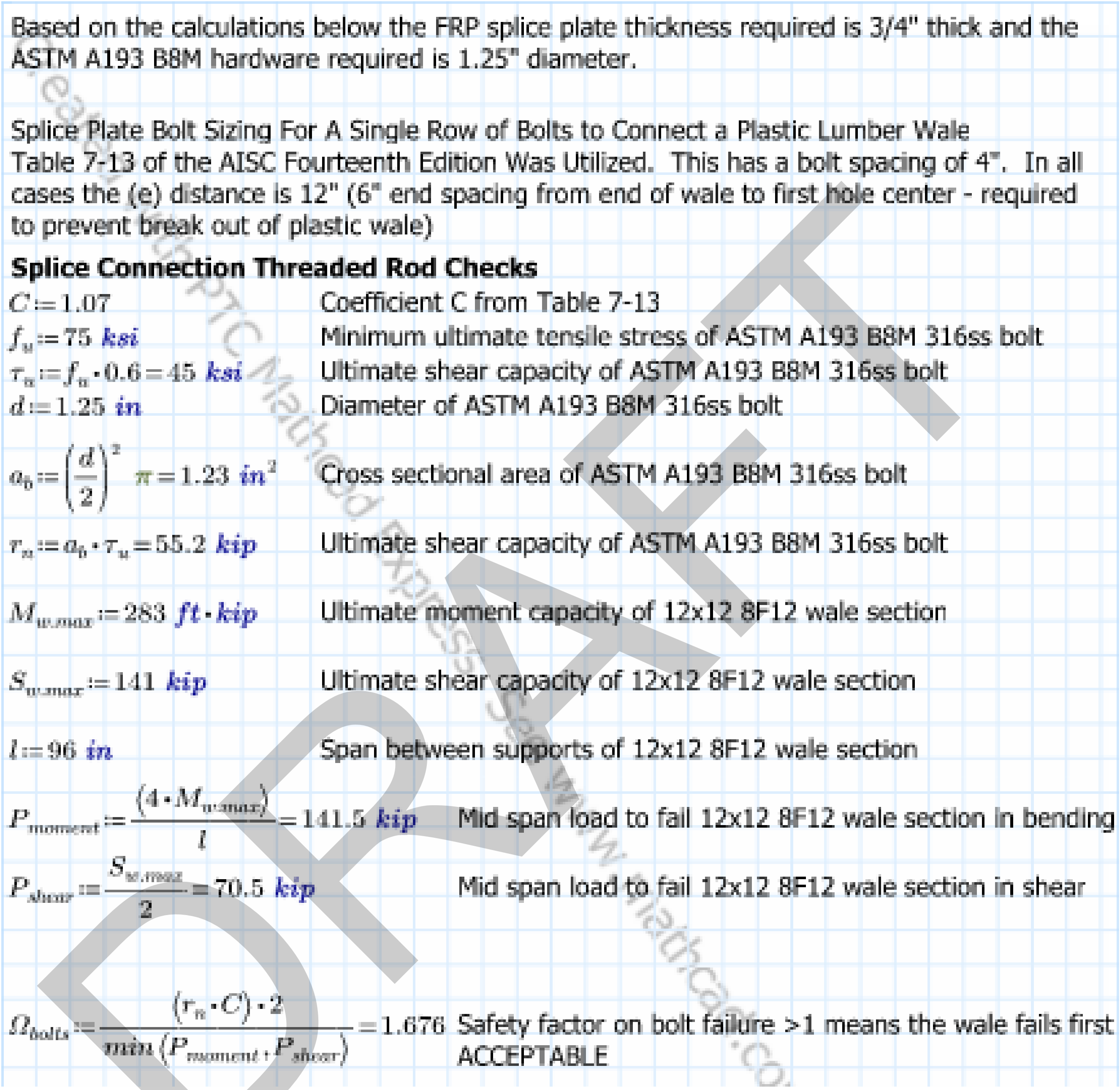


Figure 70:Moment Diagram Down the Elevation (Soil C5)

Bending moment from tip analysis of 699 ft-kip is the design ultimate capacity of the SUPERPILE (18” x 3/4”)

5 FRP Splice Plate Calculations



Based on the calculations below the FRP splice plate thickness required is 3/4" thick and the ASTM A193 B8M hardware required is 1.25" diameter.

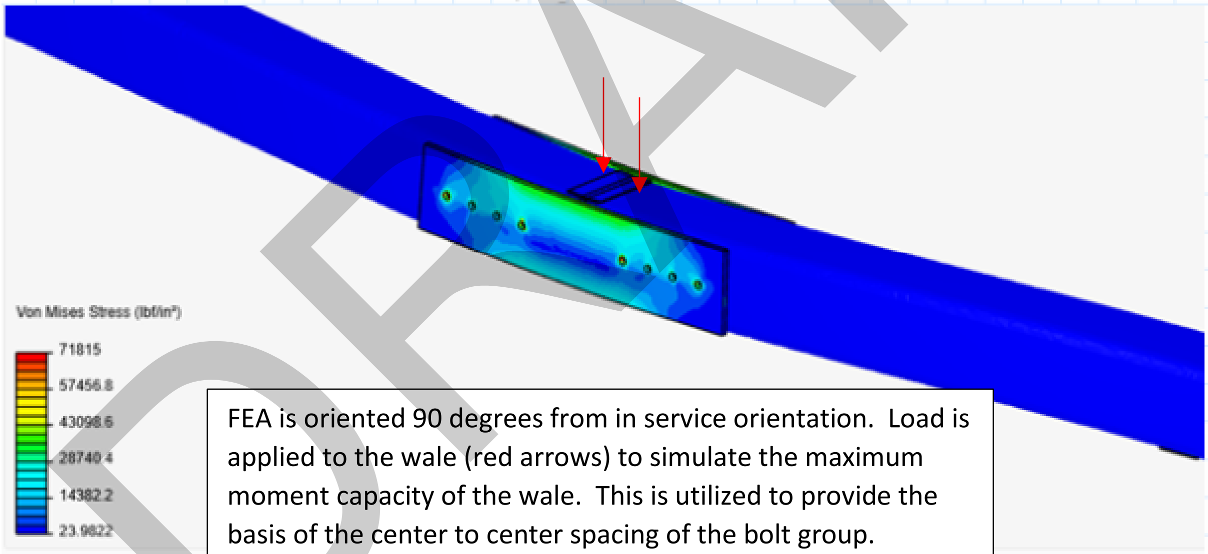
Splice Plate Bolt Sizing For A Single Row of Bolts to Connect a Plastic Lumber Wale Table 7-13 of the AISC Fourteenth Edition Was Utilized. This has a bolt spacing of 4". In all cases the (e) distance is 12" (6" end spacing from end of wale to first hole center - required to prevent break out of plastic wale)

Splice Connection Threaded Rod Checks

$C := 1.07$	Coefficient C from Table 7-13
$f_u := 75\ ksi$	Minimum ultimate tensile stress of ASTM A193 B8M 316ss bolt
$\tau_u := f_u \cdot 0.6 = 45\ ksi$	Ultimate shear capacity of ASTM A193 B8M 316ss bolt
$d := 1.25\ in$	Diameter of ASTM A193 B8M 316ss bolt
$a_b := \left(\frac{d}{2}\right)^2 \pi = 1.23\ in^2$	Cross sectional area of ASTM A193 B8M 316ss bolt
$r_n := a_b \cdot \tau_u = 55.2\ kip$	Ultimate shear capacity of ASTM A193 B8M 316ss bolt
$M_{w.max} := 283\ ft \cdot kip$	Ultimate moment capacity of 12x12 8F12 wale section
$S_{w.max} := 141\ kip$	Ultimate shear capacity of 12x12 8F12 wale section
$l := 96\ in$	Span between supports of 12x12 8F12 wale section
$P_{moment} := \frac{(4 \cdot M_{w.max})}{l} = 141.5\ kip$	Mid span load to fail 12x12 8F12 wale section in bending
$P_{shear} := \frac{S_{w.max}}{2} = 70.5\ kip$	Mid span load to fail 12x12 8F12 wale section in shear
$\Omega_{bolts} := \frac{(r_n \cdot C) \cdot 2}{\min(P_{moment}, P_{shear})} = 1.676$	Safety factor on bolt failure >1 means the wale fails first ACCEPTABLE

Splice Connection FRP Plate Checks

$h := 10.75\ in$	Height of FRP splice plate
$t := 0.75\ in$	Thickness of FRP splice plate
$f_u := 65.7\ ksi$	Ultimate in plane flexural strength of FRP splice plate
$\tau_{frp} := 22.1\ ksi$	Ultimate in plane shear strength of FRP splice plate
$M_{p.ult} := \left(\frac{1}{6} \cdot t \cdot h^2\right) \cdot f_u = 79.1\ ft \cdot kip$	Ultimate moment capacity of each FRP splice plate
$S_{p.ult} := h \cdot t \cdot \tau_{frp} = 178.2\ kip$	Ultimate shear capacity of each FRP splice plate
$s := 22\ in$	Center to center spacing of FRP splice plate bolt groups. Based on FEA analysis this is a good approximation of the span for simple analysis.
$M_{p.ser} := \frac{(P_{moment} \cdot s)}{4} \cdot \frac{1}{2} = 32.4\ ft \cdot kip$	Actual moment loading per FRP splice plate
$\Omega_{frp} := min\left(\frac{M_{p.ult}}{M_{p.ser}}, \frac{S_{p.ult}}{P_{shear}}\right) = 2.439$	Safety factor on FRP splice plate failure >1 means the wale fails first ACCEPTABLE



FEA is oriented 90 degrees from in service orientation. Load is applied to the wale (red arrows) to simulate the maximum moment capacity of the wale. This is utilized to provide the basis of the center to center spacing of the bolt group.

The ultimate pin bearing capacity of the FRP splice plate exceeds the shear capacity of the 316ss threaded rod.

$P_{bearing} := 60.45\ ksi$
$U_{pin.bearing} := P_{bearing} \cdot d \cdot t = 56.7\ kip$

Greater than the ultimate shear capacity of threaded rod. ACCEPTABLE.

6 Material Maintenance

The 18” OD FRP Pipe Piles and 12”x12” Fiberglass Reinforced Plastic Lumber (FRPL) Wales are expected to offer a 50+ year maintenance-free service life. Both products are very durable and designed for long term exposure in the aggressive, marine environment. The FRP Pipe Piles have been in service for 20+ years while the FRPL Wales have been in service for 30+ years on hundreds of fendering projects throughout the USA and internationally. Neither the FRP Pipe Piles, nor the FRPL Wales require any periodic maintenance to preserve the structural integrity of the members.

The recommended repair procedure provided in appendix D for the wales states the following: “SeaPile & SeaTimber are incredibly durable. There is no need to patch or repair abrasions, cuts or grooves for any other reason than aesthetics.”

For additional information about CPI composite piling products, or to learn how to lower your costs while increasing performance, contact a technical representative at 888-CPI-PULL (274-7855), or visit our website at www.creativepultrusions.com.

214 Industrial Lane, Alum Bank, PA 15521
Phone 814.839.4186 • Fax 814.839.4276 • Toll Free 888.CPI.PULL
www.creativepultrusions.com

CREATIVE PULTRUSIONS

PLEASE SCAN WITH PHONE

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DLR: August 11, 2015

CREATIVE PULTRUSIONS

PRODUCT BROCHURE

SUPERPILE®

FIBERGLASS REINFORCED POLYMER (FRP) PIPE PILES

PROVIDING LEADERSHIP IN FRP PIPE PILE TECHNOLOGY

FASTEST DRIVEN & LONGEST LASTING

CPI PIPE PILES

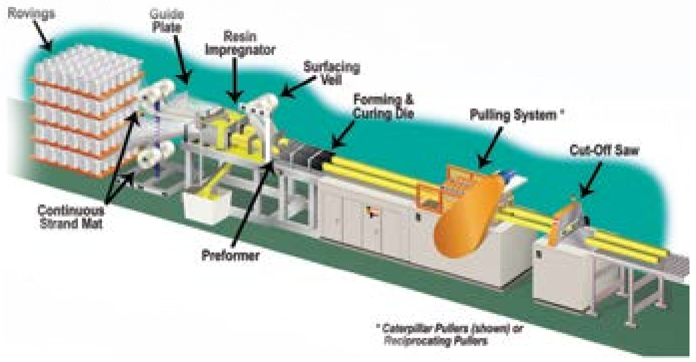
The SUPERPILE® product line was developed based on what owners, end users, engineers and contractors value in a pipe pile.

Creative Pultrusions, Inc. (CPI) is the world leader in pultrusion manufacturing. Our commitment to continuous process and product improvement has transformed CPI into a world-renowned pultruder specializing in custom profiles while utilizing high-performance resins and our proprietary high-pressure injection pultrusion technology.

As the world's most innovative leader in the FRP pultrusion industry, over the last two decades, we've developed structural systems that out perform and outlast structures built with traditional materials of construction. CPI has continued to build upon their reputation by introducing a pipe pile product line known as SUPERPILE®. Developed to provide superior performance in harsh marine environments, SUPERPILE® has been developed to drive faster and last longer than traditional piles.

WHAT IS PULTRUSION?

Pultrusion is a continuous manufacturing process utilized to make composite profiles with constant cross-sections whereby reinforcements, in the form of roving and mats, are saturated with resin and guided into a heated die. The resin undergoes a curing process known as polymerization. The once resin saturated reinforcements exit the die in a solid state and in the form of the cross section of the die. The pultrusion process requires little labor and is ideal for mass production of constant cross section profiles.



WHAT DO OWNERS VALUE IN SUPERPILE®?

- **Longevity** - Significant Reductions of Future Capital Expenditures
- **Maintenance** - Significant Reduction of Future Maintenance Expenditures
- **Aesthetics** - No Rust Marks, Spalling, Rotting or Section Loss
- **Green** - Low Embodied Energy
- **Environmentally Friendly** - Will Not Leach Dangerous Pesticides, Antifungal or Preservatives into the Environment

WHAT DO END USERS VALUE IN SUPERPILE®?

- **Functionality** - Performs as Designed and Intended
- **Aesthetics** - Professional Look
- **Performance** - Protects Your Boat and Structures

WHAT DO ENGINEERS VALUE IN SUPERPILE®?

- **Engineered Product** - Unlike Wood, FRP is an Engineered Product with a Low Coefficient of Variation (COV)
- **High Strength** - Pound for Pound Stronger than Steel, Concrete and Wood
- **Low Modulus of Elasticity** - Dissipates Vessel Impact Energy
- **Versatile** - Can Be Used as a Foundation Bearing, Dock or Fender Pile
- **Reliable** - Design Values Are Based on a 95% Confidence Value
- **Design** - Can Be Designed Based on Load and Resistance Factor Design (LRFD) or Allowable Stress Design (ASD)
- **Factory Made** - Manufactured in an Environmentally Controlled Complex to Stringent Quality Assurance (QA) Standards

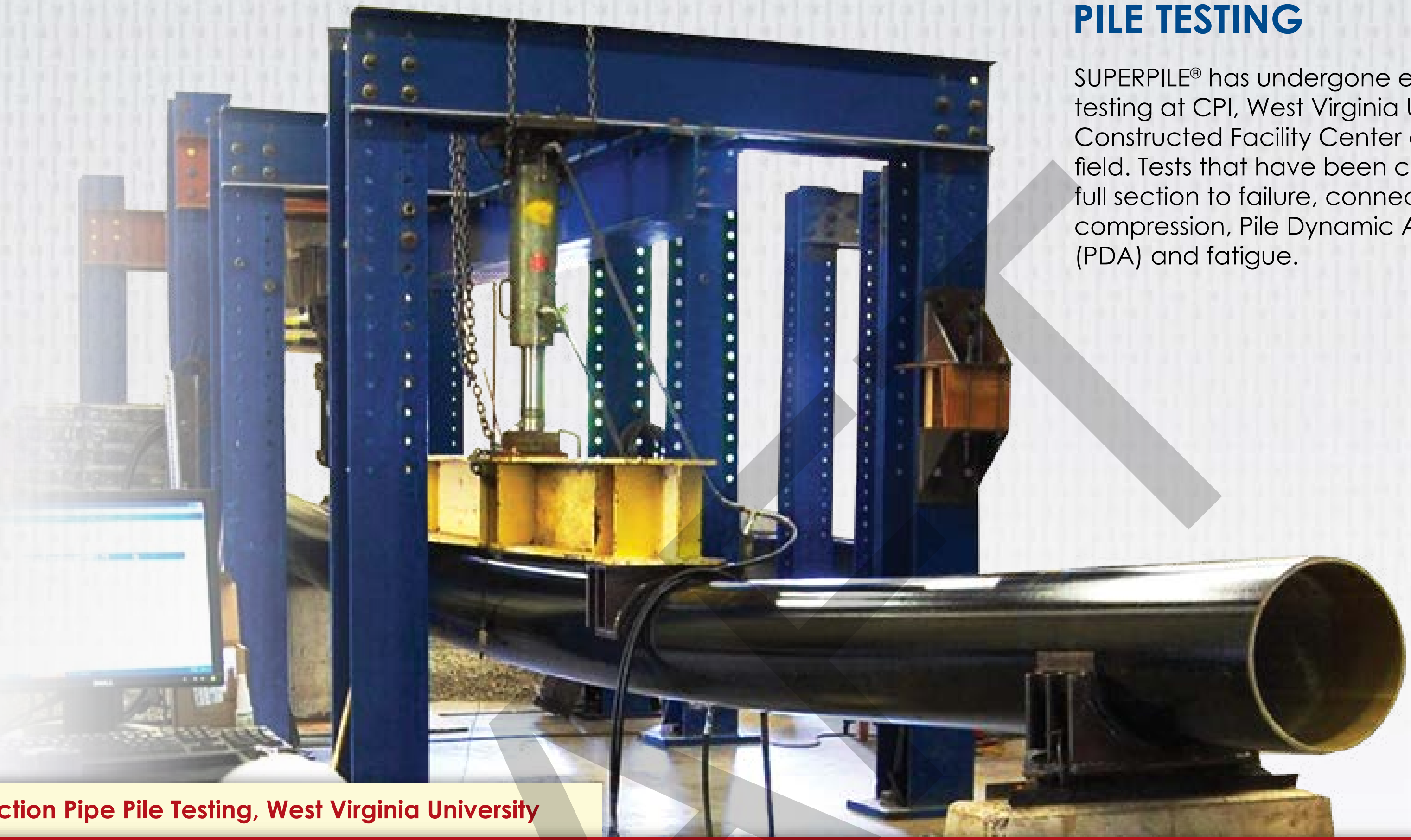
WHAT DO CONTRACTORS VALUE IN SUPERPILE®?

- Significant Shipping Savings
- Drills and Cuts 2x Faster Than Thermoplastic Polymer Piles
- Driven with Standard Pile Driving Equipment
- Lightweight - 1/10th the Weight of a Concrete Pile and 1/4th the Weight of Steel
- Field Drillable
- Ease of Fabrication with Traditional Construction Tools

PDA Analysis, Virginia

PILE CONSTRUCTION

SUPERPILE® Composite Pipe Pile is manufactured with electrical grade fiberglass and high impact, high strength polyurethane resin. The combination of the advanced resin and high strength glass produces a superior strength, highly corrosion resistant pipe pile.



Full Section Pipe Pile Testing, West Virginia University

PILE TESTING

SUPERPILE® has undergone extensive testing at CPI, West Virginia University's Constructed Facility Center and in the field. Tests that have been conducted: full section to failure, connection, compression, Pile Dynamic Analysis (PDA) and fatigue.

PDA Testing, Virginia

> "I have researched, tested and installed composite systems related to civil infrastructure over my entire career. **I was astonished at the high strength and modulus values achieved with the polyurethane pipe piles manufactured by Creative Pultrusions, Inc.** I expect that the US infrastructure will benefit greatly from this tubular pile technology."
>
> ~ Hota GangaRao, PhD, P.E., F. ASCE
> West Virginia University

1. ADVANCED UV PROTECTION

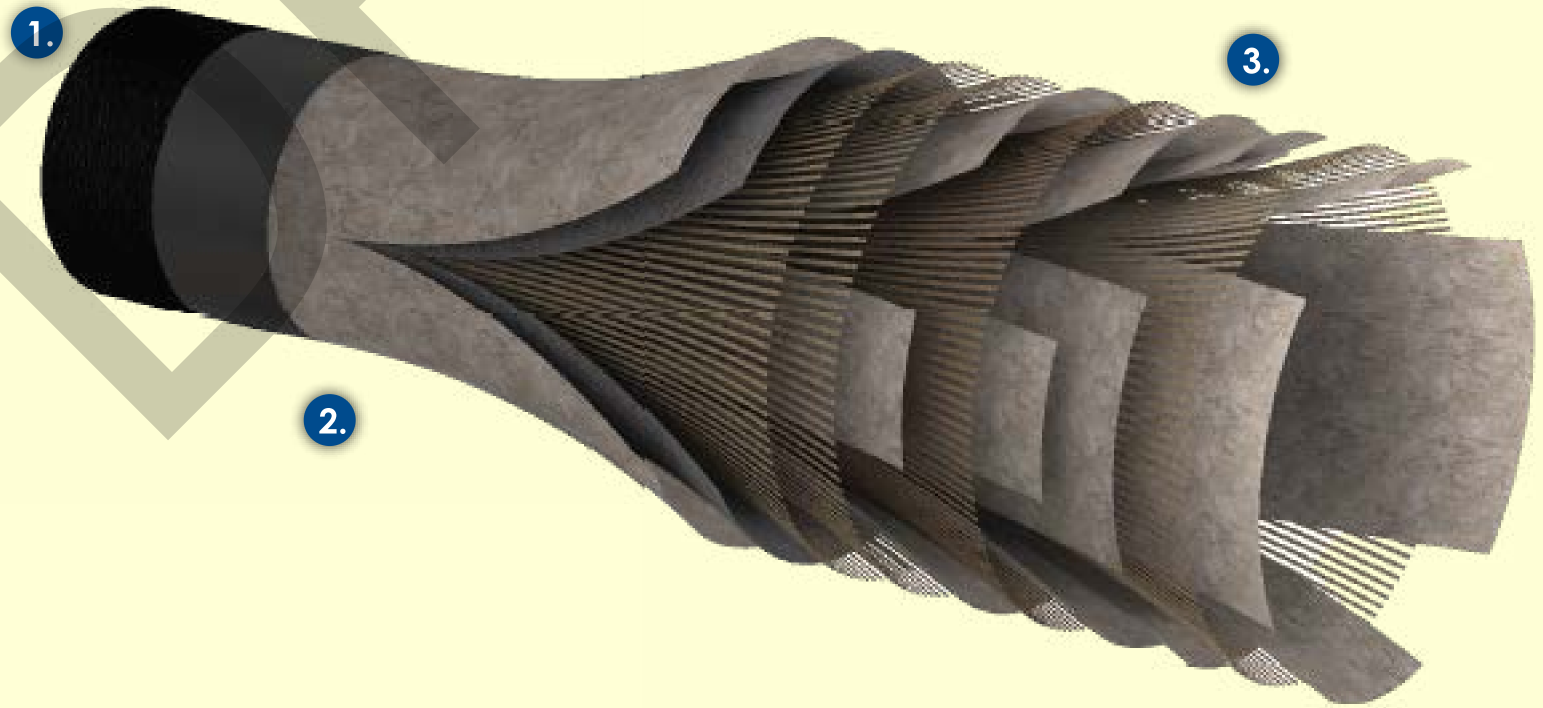
CPI's composite pipe piles are shipped standard with two layers of Ultra Violet (UV) protection. First, CPI adds light stabilizers to each pile. The light stabilizers are mixed into the thermoset resin, prior to production, and function as long term thermal and light stability promoters. Second, the composite pipe piles are encompassed with a 10 mil polyester surfacing veil. The 10 mil veil creates a resin rich surface and protects the glass reinforcements from fiber blooming. Additional UV and or abrasion barriers are available.

2. RESIN/MATRIX

The pipe piles are pultruded with high performance Vinyl Ester (VE) and Polyurethane resins. The octagonal pipe piles are manufactured with VE resin for its superior toughness and fatigue strength, VE resins are ideal for long term performance in harsh marine environments. The round pipe piles are manufactured standard with SUPURTUF™ Polyurethane resin. Polyurethane resins provide all of the performance of VE resins in addition to optimal strength, toughness and impact resistance. When it comes to high strength, toughness and impact properties, nothing outperforms SUPURTUF™ Polyurethane.

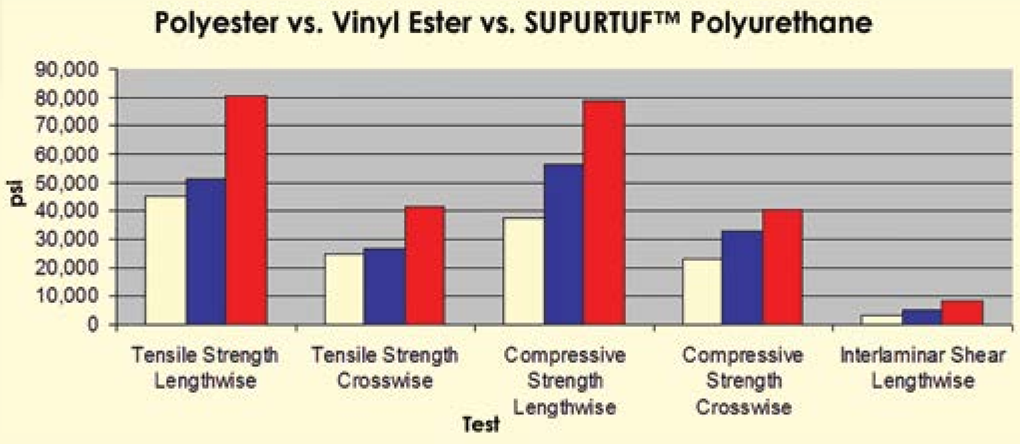
3. FIBERGLASS REINFORCEMENTS

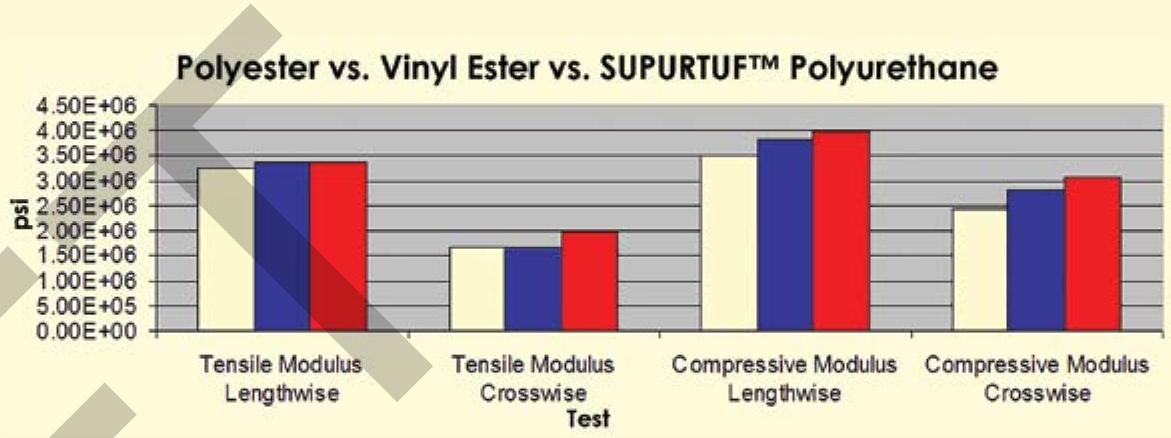
All composite pipe piles are manufactured with electrical grade E-glass reinforcements in the form of unidirectional roving, Continuous Filament Mat (CFM) and stitched fabric mats. The combination of fiber reinforcements have been engineered for optimal bending and crush strength, as well as superior stiffness. All E-glass reinforcements meet a minimum tensile strength of 290 ksi per ASTM D2343.



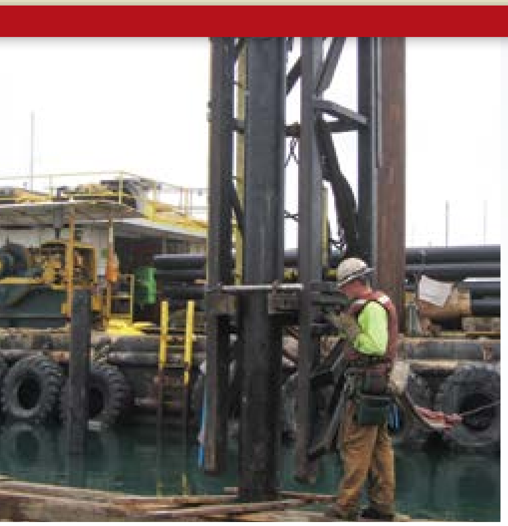
WHY SHOULD YOU BUY & SPECIFY CPI PIPE PILES?

☐ Polyester
🟦 Vinyl Ester
🟥 Polyurethane





The graphs demonstrate a comparison of polyester, VE and Polyurethane resins. The fiber architecture is the same, only the resin type has been modified. The chart clearly demonstrates the strength advantage of VE and SUPURTUF™ Polyurethane resins over that of polyester composites.

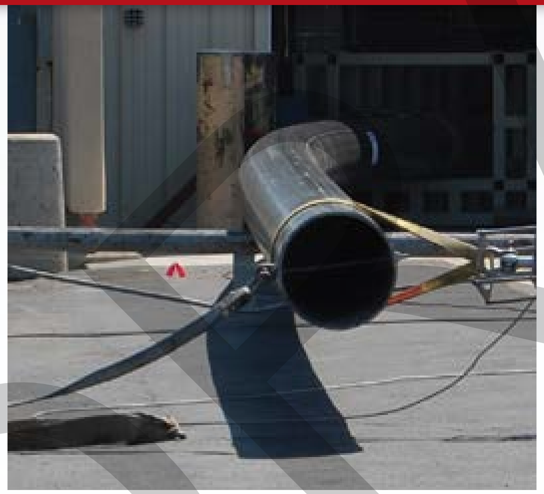


FASTEST DRIVEN

Contractors all agree that the hollow SUPERPILE® drives twice as fast as solid wood, concrete and thermoplastic piles.

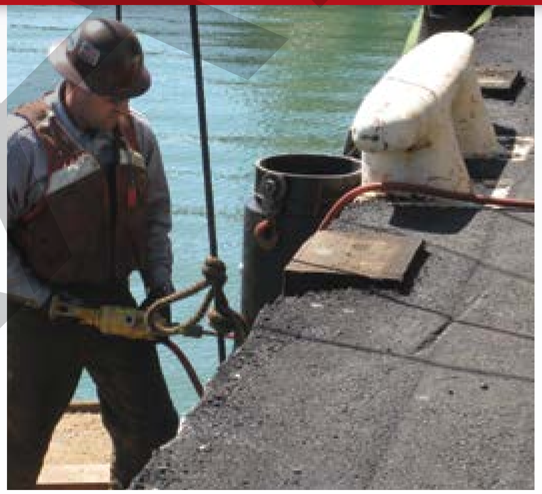
LONGEST LASTING

Long term durability projections predict a 75+ year service life.



ENERGY ABSORPTION

High strength, low modulus equates to very high energy absorption capacities when compared to wood, steel and concrete.



EASE OF FABRICATION

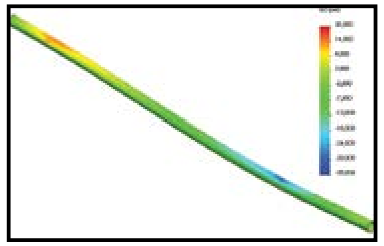
Can be field drilled and cut in seconds.

NO LEACHING OF PRESERVATIVES, FUNGICIDES OR INSECTICIDES

Environmentally friendly, the SUPERPILE® is inert, unlike wood that leaches dangerous chemicals into the environment.

ENGINEERED SOLUTION

Designed specifically for the piling market and manufactured in a production environment.



- **UNAFFECTED BY MARINE BORERS**
  Will not succumb to aquatic mollusks or crustaceans.
- **WILL NOT ROT**
  Inert to fungi or microbial attack.
- **LIGHTWEIGHT**
  Significantly lighter than steel, concrete and wood piles.
- **SAFETY**
  Very low electrical conductivity, ideal for working around power lines.
- **GREEN**
  Low embodied energy.
- **NON-POLLUTING**
  Accepted by NJDEP as non-polluting material for water and land use.

WHAT ARE OWNERS AND CONTRACTORS SAYING ABOUT SUPERPILE®?

San Francisco West Harbor Renovation Project
December 2011 (Phase 1), San Francisco, California

"Creative Pultrusions manufactured 190 SUPERPILES that were supplied by Lee Composites to Dutra Construction. The SUPERPILES replaced deteriorating creosote treated wood guide piles for the San Francisco Marina West Harbor Renovation Project. These piles are used as a fender by boats navigating in and out of their slips. The SUPERPILES are both aesthetically pleasing and have superior functionality to the treated wood piles. In addition, they are more environmentally friendly than their wood counterparts. They were installed very easily with a drop hammer and met all of our expectations. We expect these piles to stand the test of time by offering many years of maintenance free service. We expect to see a lot more of the SUPERPILES on future projects."

~Mike Edde
Dutra Construction

"Creative Pultrusions manufactured and supplied fifty-two FRP SUPERPILES to me through Lee Composites. The piles were supplied to specification and arrived on time. The piles were of high quality and drove twice as fast as a solid pile. The 80' piles were lightweight and easy to handle. Given that the piles will not rot, rust or corrode, I anticipate driving many more SUPERPILES in the future. In fact, I see no reason not to use them!"

~Rich Walters
R.A. Walters & Sons

"When our Margate Bridge wooden fender system succumbed to the years of wear and tear in a hostile environment, we knew it was time to invest in a new fender system. We chose to specify the latest in fender technology and go with Creative Pultrusion's SUPERPILE. The piles were manufactured to spec. and delivered on time. The robust piles will protect our bridge foundations for many years without leaching any chemicals into our waterways. The piles made sense from a business and environmental standpoint, making the decision to procure the piles easy."

~David Goddard
Ole Hansen and Sons, Inc.

"Upon award of the bid, Crofton knew that choosing the right supplier for the FRP piles was critical in order to get value engineering proposal approval by the project start date. Creative was the best choice since they have done extensive testing, are listed on multiple state's Qualified Products Lists and have the engineering support to assist in securing this approval.

Creative addressed all material related questions and concerns brought about by the Engineer of Record and VADOT engineering. In fact, they provided piles so that a PDA could be performed on the 16" dia. FRP SUPERPILE. The PDA eliminated all concerns and questions that Crofton and the Engineering firm had with regards to installation and connection details.

Not only did Creative supply a quality product at a fair price, they stood behind us through the entire project. The engineering team at CPI made my life easier and saved Crofton money in the process."

~Brad Gribble
Crofton Industries

Margate Bridge Installation,
Margate New Jersey

Fender Rehabilitation
Route 3 Over Piankatank River, Virginia

MECHANICAL & PHYSICAL PROPERTIES

PIPE PILES

The mechanical and physical data detailed herein is provided for the structural engineer. The mechanical data is published in terms of average and characteristic values. The characteristic values were derived per the requirements as set forth in ASTM D7290 Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications. The characteristic value is defined as a statistically-based material property representing the 80% lower confidence bound on the 5th-percentile value of a specified population. The characteristic value accounts for statistical uncertainty due to a finite sample size. The characteristic value is the reference strength.

In terms of Load and Resistance Factor Design (LRFD) design, the reference strength shall be adjusted for end use conditions by applying the applicable adjustment factors to establish the nominal resistance strength. The design strength shall include the nominal resistance, adjusted for end-use conditions, a resistance factor and time effect factor. The reference strength and stiffness shall be multiplied by .85 and .95 respectively to establish the nominal strength and stiffness for installations in sea and fresh water. A time effect factor of 0.4 shall be applied for full design permanent loads that will act during the service life of the structure. Resistant factors shall be established as set forth in the LRFD of Pultruded Fiber Reinforced Polymer (FRP) Structures Pre-Standard. Serviceability shall be checked based on the adjusted average full section modulus of elasticity as established per ASTM D6109.

In terms of Allowable Stress Design (ASD), the pultrusion industry uses a 3.0 safety factor for compression members, 2.5 for flexural members, 3.0 for connections and 3.0 for shear. The characteristic reference strength shall be used for strength and the average E-modulus shall be used for serviceability calculations.

SUPERPILE® Mechanical Properties	**Round FRP Pipe Pile TU455 Polyurethane 12"x3/8" Metric (305mm x 9.52mm)**		**Round FRP Pipe Pile TU450 Polyurethane 12"x1/2" Metric (305mm x 12.7mm)**		**Round FRP Pipe Pile TU460 Polyurethane 16"x1/2" Metric (406mm x 12.7mm)**	
Average Flexural Strength per ASTM D6109 psi (Mpa)	52,000	(359)	69,658	(480)	57,270	(395)
Characteristic Flexural Strength per ASTM D6109 psi (Mpa)[2]	*****	*****	56,111	(387)	49,840	(344)
Average Compression Strength per ASTM D6109 psi (Mpa)	52,000	(359)	69,658	(480)	57,270	(395)
Characteristic Compression Strength per ASTM D6109 psi (Mpa)[2]	*****	*****	56,111	(387)	49,840	(344)
Average In-Plane Shear Strength psi (Mpa)	15,605	(108)	16,039	(111)	17,170	(118)
Characteristic In-Plane Shear Strength psi (Mpa)	13,212	(91)	13,713	(95)	14,936	(103)
Average Shear Capacity lbs (Kg)	106,894	(48,486)	145,153	(65,840)	208,616	(94,626)
Characteristic Shear Capacity lbs (Kg)	90,502	(41,051)	124,103	(56,292)	181,472	(82,314)
Average Torque Strength lb-ft (kN▪m)	103,519	(140)	138,829	(188)	269,987	(366)
Characteristic Torque Strength lb-ft (kN▪m)	87,644	(119)	118,696	(161)	234,859	(318)
Average Axial Compression Strength psi (Mpa)	52,000	(359)	69,658	(480)	57,270	(395)
Characteristic Axial Compression Strength psi (Mpa)[2]	*****	*****	56,111	(387)	49,840	(344)
Average Axial Compression Capacity (Short Column) lb (kg)	712,400	(323,139)	1,260,810	(571,894)	1,391,661	(631,247)
Characteristic Axial Compression Capacity (Short Column) lb (kg)[2]	*****	*****	1,015,609	(460,673)	1,211,112	(549,351)
Average Modulus of Elasticity per ASTM D6109 psi (Gpa)	5.26E+06	(36.3)	5.91E+06	(40.7)	5.99E+06	(41.3)
Bending Stiffness (EI) per ASTM D6109 lbs▪in^2 (kg▪mm^2)	1.22E+09	(3.57E+11)	1.77E+09	(5.17E+11)	4.38E+09	(1.28E+12)
Average Moment Capacity per ASTM D6109 kip-ft (kN▪m)	167	(227)	289	(392)	437	(592)

MECHANICAL & PHYSICAL PROPERTIES

PIPE PILES

SUPERPILE® Mechanical Properties	**Round FRP Pipe Pile TU455 Polyurethane 12"x3/8" Metric (305mm x 9.52mm)**		**Round FRP Pipe Pile TU450 Polyurethane 12"x1/2" Metric (305mm x 12.7mm)**		**Round FRP Pipe Pile TU460 Polyurethane 16"x1/2" Metric (406mm x1 2.7mm)**	
Characteristic Moment Capacity per ASTM D6109 kip-ft (kN▪m)[2]	*****	*****	233	(316)	380	(515)
Average Energy Absorption kip-in (kN▪m)	341	(39)	643	(73)	829	(94)
Characteristic Energy Absorption kip-in (kN▪m)[2]	*****	*****	405	(46)	603	(68)
Average Pin Bearing Strength Crosswise psi (Mpa)	19,823	(137)	21,676	(149)	23,666	(163)
Characteristic Pin Bearing Strength Crosswise psi (Mpa)	12,447	(86)	12,546	(87)	20,771	(143)
Average Pin Bearing Strength Lengthwise psi (Mpa)	30,793	(212)	30,149	(208)	27,788	(192)
Characteristic Pin Bearing Strength Lengthwise psi (Mpa)	18,053	(125)	25,132	(173)	19,217	(133)
Average Pile Crush Strength lb (kg) (based on a 9" wide load path)[1]	10,600	(4,808)	17,970	(8,151)	16,600	(7,530)
Characteristic Pile Crush Strength lb (kg) (based on a 9" wide load path)[1]	8,060	(3,656)	13,782	(6,251)	11,667	(5,292)
Average Crush Strength, with FRP Insert, lb (kg) (based on a 9" wide load path)[1,2]	*****	*****	73,780	(33,466)	44,213	(20,055)
Characteristic Crush Strength, with FRP Insert, lb (kg) (based on a 9" wide load path)[1,2]	*****	*****	51,370	(23,301)	*****	*****
Average Washer Pull Through Strength lb (kg) using a 6"x1/2" square/radius washer	26,084	(11,832)	30,686	(13,919)	27,582	(12,511)
Characteristic Washer Pull Through Strength lb (kg) using a 6"x1/2" square/radius washer	22,107	(10,028)	26,815	(12,163)	25,103	(11,387)
Average Washer Pull Through Strength lb (kg) using a 6"x3/8" square/radius washer	18,893	(8,570)	25,205	(11,433)	18,878	(8,563)
Characteristic Washer Pull Through Strength lb (kg) using a 6"x3/8" square/radius washer	13,977	(6,340)	22,420	(10,170)	13,521	(6,133)
Allowable torque permitted on a bolted connection with a 6" radius washer lb-ft (N▪m)	50	(68)	50	(68)	50	(68)

SUPERPILE® Physical Properties	**Round FRP Pipe Pile TU455 Polyurethane 12"x3/8" Metric (305mm x 9.52mm)**		**Round FRP Pipe Pile TU450 Polyurethane 12"x1/2" Metric (305mm x 12.7mm)**		**Round FRP Pipe Pile TU460 Polyurethane 16"x1/2" Metric (406mm x 12.7mm)**	
Diameter in (cm)	12	(30.48)	12	(30.48)	16	(40.64)
Wall thickness in (mm)	0.375	(9.5)	0.5	(12.7)	0.5	(12.7)
Moment of Inertia in^4 (cm^4)	232	(9,657)	299	(12,445)	732	(30,468)
Section Modulus in^3 (cm^3)	38.6	(633)	49.8	(816)	91.5	(1,499)
Radius of Gyration in (mm)	4.11	(104)	4.07	(103)	5.48	(139)
Weight lb/ft (Kg/m)	12.6	(18.8)	16.9	(25.1)	22.6	(33.6)
Coefficient of Thermal Expansion (CTE) Lengthwise in/in/°F (mm/mm/°C)	5.00E-06	(9.00E-06)	5.00E-06	(9.00E-06)	5.00E-06	(9.00E-06)
Water Absorption ASTM D570	0.15% (24hrs)	0.15% (24hrs)	0.15% (24hrs)	0.15% (24hrs)	0.15% (24hrs)	0.15% (24hrs)
Fiber Volume Fraction %	≥50%	≥50%	≥50%	≥50%	≥50%	≥50%
Cross Sectional Area in^2 (cm^2)	13.7	(88)	18.1	(116.8)	24.3	(156.8)
Surface Area ft^2/ft (m^2/m)	3.14	(0.96)	3.14	(0.96)	4.19	(1.28)

[1] The crush strength value is based on full section testing. The strength value was recorded at the first audible sound and change in the load deflection curve. The ultimate capacity is approximately 60% higher and is defined as the highest recorded load documented during the crush strength test.

[2] Characteristic data is unavailable due to the number of tests required. A minimum of 10 tests are required to generate the ASTM D7290 characteristic values.

MECHANICAL & PHYSICAL PROPERTIES

OCTAGONAL PILES

The mechanical and physical data detailed herein is provided for the structural engineer. The mechanical data is published in terms of average value and either characteristic or 5% Lower Exclusion Limit (LEL) values. The characteristic values were derived per the requirements as set forth in ASTM D7290 Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications. The characteristic value is defined as a statistically-based material property representing the 80% lower confidence bound on the 5th-percentile value of a specified population. In instances where sufficient data was not available to calculate the characteristic value, a 5% LEL was calculated. The 5% LEL, like the characteristic value, is the 5th-percentile value, however it is somewhat less conservative in that it does not account for the 80% lower confidence bound. The values are listed to account for statistical uncertainty due to a finite sample size. These statistically reduced values should be used as the reference strength.

In terms of Load and Resistance Factor Design (LRFD) design, the reference strength shall be adjusted for end use conditions by applying the applicable adjustment factors to establish the nominal resistance strength. The design strength shall include the nominal resistance, adjusted for end-use conditions, a resistance factor and time effect factor. The reference strength and stiffness shall be multiplied by .85 and .95 respectively to establish the nominal strength and stiffness for installations in sea and fresh water. A time effect factor of 0.4 shall be applied for full design permanent loads that will act during the service life of the structure. Resistant factors shall be established as set forth in the LRFD of Pultruded Fiber Reinforced Polymer (FRP) Structures Pre-Standard. Serviceability shall be checked based on the adjusted average full section modulus of elasticity as established per ASTM D1036.

In terms of Allowable Stress Design (ASD), the pultrusion industry uses a 3.0 safety factor for compression members, 2.5 for flexural members, 3.0 for connections, and 3.0 for shear. The reference strength shall be used for strength and the average modulus shall be used for serviceability calculations.

Octagonal Pile Mechanical Properties	**Octagonal Pile 8"x.25" Series II CP076 (203mm x 6.35mm)**		**Octagonal Pile 10"x.25"Series II CP074 (254mm x 6.35mm)**		**Octagonal Pile 10"x.275" Series III CP210 (254mm x 6.98mm)**	
Average Flexural Strength per ASTM D1036 psi (Mpa)	49,173	(339)	43,832	(302)	43,893	(303)
5% LEL Flexural Strength per ASTM D1036 psi (Mpa)[1]	46,999	(324)	41,374	(285)	42,076	(290)
Average Compression Strength per ASTM D1036 psi (Mpa)	49,173	(339)	43,832	(302)	43,893	(303)
5% LEL Compression Strength per ASTM D1036 psi Mpa)[1]	46,999	(324)	41,374	(285)	42,076	(290)
Average In-Plane Shear Strength psi (Mpa)	12,554	(87)	12,706	(88)	12,866	(89)
Characteristic In-Plane Shear Strength psi (Mpa)	10,940	(75)	10,101	(70)	11,616	(80)
Average Shear Capacity lbs (Kg)	48,458	(21,980)	68,359	(31,007)	86,649	(39,304)
Characteristic Shear Capacity lbs (Kg)	42,230	(19,155)	54,344	(24,650)	78,237	(35,488)
Average Torque Strength lb-ft (kN•m)	24,675	(33)	41,166	(56)	45,621	(62)
Characteristic Torque Strength lb-ft (kN•m)	21,504	(29)	32,726	(44)	41,191	(56)
Average Axial Compression Strength psi (Mpa)	49,173	(339)	43,832	(302)	43,893	(303)
5% LEL Axial Compression Strength psi (Mpa)[1]	46,999	(324)	41,374	(285)	42,076	(290)
Average Axial Compression Capacity (Short Column) lb (kg)	379,617	(172,191)	471,634	(213,930)	591,245	(268,184)
5% LEL Axial Compression Capacity (Short Column) lb (kg)[1]	362,832	(164,578)	445,184	(201,932)	566,764	(257,080)
Average Modulus of Elasticity per ASTM D1036 psi (Gpa)	4.30E+06	(29.6)	4.00E+06	(27.6)	3.70E+06	(25.5)
Bending Stiffness (EI) per ASTM 1036 lbs•in^2 (kg•mm^2)	2.62E+08	(7.67E+10)	5.58E+08	(1.63E+11)	6.35E+08	(1.86E+11)
Average Moment Capacity per ASTM D1036 kip-ft (kN•m)	62	(85)	100	(136)	123	(167)
5% LEL Moment Capacity per ASTM D1036 kip-ft (kN•m)[1]	60	(81)	94	(128)	118	(160)
Average Pin Bearing Strength Crosswise psi (Mpa)	15,357	(106)	11,562	(80)	11,280	(78)
Characteristic Pin Bearing Strength Crosswise psi (Mpa)	8,131	(56)	5,839	(40)	5,453	(38)

MECHANICAL & PHYSICAL PROPERTIES

OCTAGONAL PILES

Octagonal Pile Mechanical Properties	**Octagonal Pile 8"x.25" Series II CP076 (203mm x 6.35mm)**		**Octagonal Pile 10"x.25"Series II CP074 (254mm x 6.35mm)**		**Octagonal Pile 10"x.275" Series III CP210 (254mm x 6.98mm)**	
Average Pin Bearing Strength Lengthwise psi (Mpa)	27,263	(188)	28,223	(195)	27,132	(187)
Characteristic Pin Bearing Strength Lengthwise psi (Mpa)	16,679	(115)	21,029	(145)	12,867	(89)
Average Washer Pull Through Strength lb kg) using a 4"x3/8" square washer	13,697	(6,213)	14,698	(6,667)	14,571	(6,609)
Characteristic Washer Pull Through Strength lb (kg) using a 4"x3/8" square washer	10,705	(4,856)	11,916	(5,405)	11,798	(5,351)
Allowable torque permitted on a bolted connection with a 4"x3/8" square washer lb-ft (N•m)	50	(68)	50	(68)	50	(68)

Octagonal Pile Physical Properties	**Octagonal Pile 8"x.25" Series II CP076 (203mm x 6.35mm)**		**Octagonal Pile 10"x.25"Series II CP074 (254mm x 6.35mm)**		**Octagonal Pile 10"x.275" Series III CP210 (254mm x 6.98mm)**	
Diameter in (cm)	8	(20.32)	10.2	(25.91)	10.2	(25.91)
Wall thickness in (mm)	0.25	(6.4)	0.25	(6.4)	0.275	(7.0)
Moment of Inertia in^4 (cm^4)	60.87	(2,534)	139.69	(5,814)	171.57	(7,141)
Section Modulus in^3 (cm^3)	15.22	(249)	27.39	(449)	33.64	(551)
Radius of Gyration in (mm)	2.81	(71)	3.60	(91)	11.05	(281)
Weight lb/ft (Kg/m)	6.33	(9)	8.82	(13.1)	11.05	(16.4)
Coefficient of Thermal Expansion (CTE) Lengthwise in/in/°F (mm/mm/°C)	5.00E-06	(9.00E-06)	5.00E-06	(9.00E-06)	5.00E-06	(9.00E-06)
Water Absorption ASTM D570	0.60% (24hrs)	0.60% (24hrs)	0.60% (24hrs)	0.60% (24hrs)	0.60% (24hrs)	0.60% (24hrs)
Fiber Volume Fraction %	≥50%	≥50%	≥50%	≥50%	≥50%	≥50%
Cross Sectional Area in^2 (cm^2)	7.72	(50)	10.76	(69.4)	13.47	(86.9)
Surface Area ft^2/ft (m^2/m)	2.20	(0.67)	2.80	(0.85)	2.80	(0.85)

Octagonal Pile Fire Properties	**Octagonal Pile 8"x.25" Series II CP076 (203mm x 6.35mm)**	**Octagonal Pile 10"x.25"Series II CP074 (254mm x 6.35mm)**	**Octagonal Pile 10"x.275" Series III CP210 (254mm x 6.98mm)**
Flame Rating (UL 94)	V0 Self Extinguishing	V0 Self Extinguishing	V0 Self Extinguishing
Flame Spread ASTM E-84	Class A 25 or less	Class A 25 or less	Class A 25 or less

Octagonal Pile Electrical Properties	**Octagonal Pile 8"x.25" Series II CP076 (203mm x 6.35mm)**	**Octagonal Pile 10"x.25"Series II CP074 (254mm x 6.35mm)**	**Octagonal Pile 10"x.275" Series III CP210 254mm x 6.98mm)**
ASTM F711 (100 kVAC per foot - 5 minutes dry)	Passed	Passed	Passed
IEEE978 (75 kVAC per foot - 1 minute wet)	Passed	Passed	Passed

Notes:

[1] 5% Lower Exclusion Limit (LEL) was used as a statistical knockdown in instances where the sufficient number of data points was not available to calculate the characteristic value.

[2] All connection testing was conducted utilizing 3/4" hardware.

The Mechanical and Physical Property Charts for the Octagonal piles have been developed based on extensive third party and in house testing.

THERMOPLASTIC PIPE PILE AND SLEEVE COMPARISON

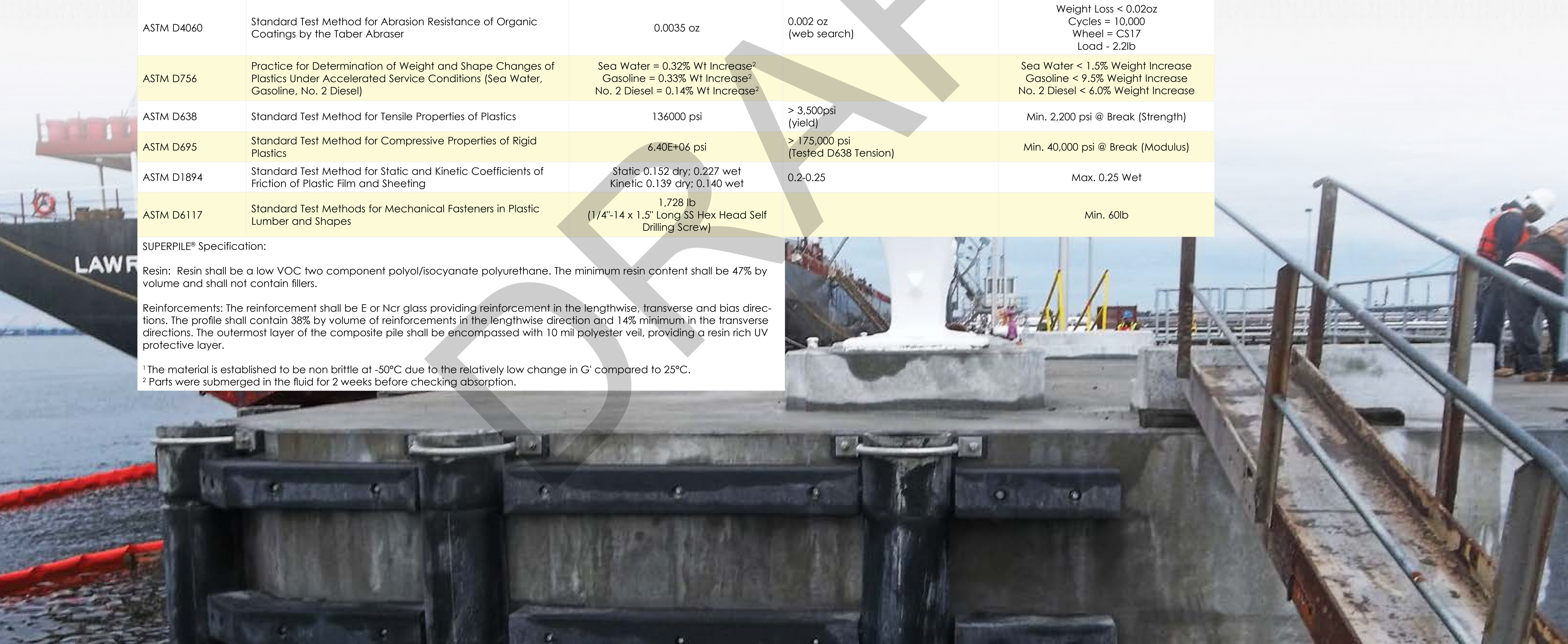
Specification Test Requirement	Standard Title	SUPERPILE®	CPI Supplied HDPE Sleeve(when applicable)	Required Properties for FRP Composite Lumber (SCL)
ASTM D792	Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement	Density = 122.3 pcf Void Content < 1%	59.9 pcf (tested D1505)	55-63 pcf
ASTM D570	Standard Test Method for Water Absorption of Plastics	0.15% (24hrs)	.01-.1% (From www.matweb.com HDPE Extruded)	2hrs <1.0% weight increase 24hrs <3.0% weight increase
ASTM D746	Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact	Test using ASTM D7028 (DMA) Tan Delta Peak = 132°C G' (-50°C) = 6.5 GPa G' (25°C) = 5.29 GPa[1]	< -75-deg C	Brittleness Temp < -40-deg C
ASTM D256	Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics	90 ft-lb/in	1.47-11.0 ft-lb/in (From www.matweb.com HDPE Pipe Grade)	> 0.55ft-lb/in
ASTM D2240	Standard Test Method for Rubber Property—Durometer Hardness	85 Shore D	62 Shore D	44-75 (Shore D)
ASTM D4329	Standard Practice for Fluorescent UV Exposure of Plastics	No measurable hardness change after 1344hrs UV exposure		500 hours < 10% change in Hardness
ASTM D4060	Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser	0.0035 oz	0.002 oz (web search)	Weight Loss < 0.02oz Cycles = 10,000 Wheel = CS17 Load - 2.2lb
ASTM D756	Practice for Determination of Weight and Shape Changes of Plastics Under Accelerated Service Conditions (Sea Water, Gasoline, No. 2 Diesel)	Sea Water = 0.32% Wt Increase[2] Gasoline = 0.33% Wt Increase[2] No. 2 Diesel = 0.14% Wt Increase[2]		Sea Water < 1.5% Weight Increase Gasoline < 9.5% Weight Increase No. 2 Diesel < 6.0% Weight Increase
ASTM D638	Standard Test Method for Tensile Properties of Plastics	136000 psi	> 3,500psi (yield)	Min. 2,200 psi @ Break (Strength)
ASTM D695	Standard Test Method for Compressive Properties of Rigid Plastics	6.40E+06 psi	> 175,000 psi (Tested D638 Tension)	Min. 40,000 psi @ Break (Modulus)
ASTM D1894	Standard Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting	Static 0.152 dry; 0.227 wet Kinetic 0.139 dry; 0.140 wet	0.2-0.25	Max. 0.25 Wet
ASTM D6117	Standard Test Methods for Mechanical Fasteners in Plastic Lumber and Shapes	1,728 lb (1/4"-14 x 1.5" Long SS Hex Head Self Drilling Screw)		Min. 60lb

SUPERPILE® Specification:

Resin: Resin shall be a low VOC two component polyol/isocyanate polyurethane. The minimum resin content shall be 47% by volume and shall not contain fillers.

Reinforcements: The reinforcement shall be E or Ncr glass providing reinforcement in the lengthwise, transverse and bias directions. The profile shall contain 38% by volume of reinforcements in the lengthwise direction and 14% minimum in the transverse directions. The outermost layer of the composite pile shall be encompassed with 10 mil polyester veil, providing a resin rich UV protective layer.

[1] The material is established to be non brittle at -50°C due to the relatively low change in G' compared to 25°C.
[2] Parts were submerged in the fluid for 2 weeks before checking absorption.



SUPERPILE® MECHANICAL LOAD CHARTS

SUPERPILE® is ideal for bridge and dock fendering. The high strength attributes combined with the mid range Modulus of Elasticity (MOE) permits SUPERPILE® to absorb a high amount of energy. The SUPERPILE® Energy Absorption Capacity Chart details the energy absorption capacity in terms of the average and characteristic values. The values were derived from full section testing to failure based on ASTM D6109. The energy calculation is derived by calculating the area under the load deflection curve.

SUPERPILE® ENERGY ABSORPTION CHART

Round FRP Pipe Pile TU455 Polyurethane12"x3/8" Metric (305mmx9.52mm)	Round FRP Pipe Pile TU450 Polyurethane12"x1/2" Metric (305mmx12.7mm)	Round FRP Pipe Pile TU460 Polyurethane16"x1/2" Metric (406mmx12.7mm)
Average Energy Absorption kip-in (kN•m) ASTM D6109		
341 (39)	643 (73)	829 (94)
Characteristic Energy Absorption kip-in (kN•m) ASTM D6109		
***** *****	405 (46)	603 (68)

Notes:
****** Data not available or minimum test quantity not available.

SUPERPILE® BOLTED CONNECTION CAPACITY CHARTS

The following charts depict the round and octagonal piles bolted characteristic connection capacity. Specifically, the piles were tested by positioning a 3/4" dia. rod through the octagonal piles and 1" dia. rod through the round pipe piles. The rods were loaded as depicted in the photos until an ultimate load was achieved. The ultimate load is defined as the maximum recorded load. The failure mode is pin bearing of the FRP material. The tests were conducted in both the lengthwise and transverse directions. The ultimate pin bearing stress was calculated based on the pin diameter, wall thickness and the fact that the rod penetrated two walls. The values used to make the chart were derived from the pin bearing strength obtained during testing. The charts values are based on the diameter of the bolt or bolts used in the connection, the number of bolts and the pile series. The average and characteristic values are included and represent the capacity of a bolt loaded entirely on one side of the pile as depicted in the photograph. The thermoplastic wale, although connected with a bolt that protrudes through both walls of the pipe pile, is supported by the pin bearing strength of one wall, in the lengthwise direction of the FRP pile.

Characteristic Strengths of Bolted Connections for Forces Applied Parallel to the Pile

Round Polyurethane Piles	Single 5/8" Bolt	Two 5/8" Bolts	Single 3/4" Bolt	Two 3/4" Bolts	Single 1" Bolt	Two 1" Bolts
TU455 12" x 3/8" (305mmx9.52mm)	4,231	8,462	5,077	10,155	6,770	13,540
TU450 12" x 1/2" (305mmx12.7mm)	7,854	15,708	9,425	18,849	12,566	25,132
TU460 16" x 1/2"(406mmx12.7mm)	6,005	12,011	7,206	14,413	9,609	19,217
Octagonal Vinyl Ester Piles	**Single 5/8" Bolt**	**Two 5/8" Bolts**	**Single 3/4" Bolt**	**Two 3/4" Bolts**	**Single 1" Bolt**	**Two 1" Bolts**
CP076 8" x .25" (203mmx6.35mm)	2,606	5,212	3,127	6,255	4,170	8,340
CP074 10" x. 25" (254mmx6.35mm)	3,286	6,572	3,943	7,886	5,257	10,515
CP210 10" x. 275" (254mmx6.98mm)	2,212	4,423	2,654	5,308	3,539	7,077

Notes:
Table published based on characteristic values per ASTM D7290; proper safety factors are required.

Bolted Connection Test - Parallel

Bolted Connection Test - Perpendicular

Characteristic Strengths of Bolted Connections for Forces Applied Perpendicular to the Pile

Round Polyurethane Piles	Single 5/8" Bolt	Two 5/8" Bolts	Single 3/4" Bolt	Two 3/4" Bolts	Single 1" Bolt	Two 1" Bolts
TU455 12" x 3/8" (305mmx9.52mm)	2,917	5,835	3,501	7,001	4,668	9,335
TU450 12" x 1/2" (305mmx12.7mm)	3,921	7,841	4,705	9,410	6,273	12,546
TU460 16" x 1/2"(406mmx12.7mm)	6,491	12,982	7,789	15,578	10,386	20,771
Octagonal Vinyl Ester Piles	**Single 5/8" Bolt**	**Two 5/8" Bolts**	**Single 3/4" Bolt**	**Two 3/4" Bolts**	**Single 1" Bolt**	**Two 1" Bolts**
CP076 8" x .25" (203mmx6.35mm)	1,271	2,541	1,525	3,049	2,033	4,066
CP074 10" x .25" (254mmx6.35mm)	912	1,825	1,095	2,190	1,460	2,919
CP210 10" x .275" (254mmx6.98mm)	937	1,875	1,125	2,249	1,500	2,999

Notes:
Table published based on characteristic values per ASTM D7290; proper safety factors are required.

SUPERPILE® MECHANICAL LOAD CHARTS

SUPERPILE® CRUSH STRENGTH CHARTS

SUPERPILE® sections were tested to evaluate the full section crush strength. Both the 12" and the 16" piles were tested. The 1/2" thick piles were tested with and without an FRP insert. The insert was developed to increase the crush strength in strategic locations within the pile that will have high stress concentrations. The test setup, as depicted in the photograph, involves a section of SUPERPILE® with an induced load applied through a 10" x 10" thermoplastic wale section.

The crush strength was determined based on the recorded load that caused an initial change in the load deflection curve and is the value listed in the charts. The ultimate load, defined as the ultimate load recorded during the test, is approximately 60% higher than the loads depicted in the charts.

SUPERPILE® Crush Strength with a 10" x 10" (24.5mm x 24.5mm) Thermoplastic Wale

Round FRP Pipe Pile TU455 Polyurethane12"x3/8" Metric (305mm x 9.52mm)	Round FRP Pipe Pile TU450 Polyurethane12"x1/2" Metric (305mm x 12.7mm)	Round FRP Pipe Pile TU460 Polyurethane16"x1/2" Metric (406mm x 12.7mm)
Average Crush Strength lb (kg)		
10,600 (4,808)	17,970 (8,151)	16,600 (7,530)
Characteristic Crush Strength lb (kg)		
8,060 (3,656)	13,782 (6,251)	11,667 (5,292)

SUPERPILE® Crush Strength Test Set Up

SUPERPILE® with Insert, Crush Strength Test Set Up

SUPERPILE®, with FRP Insert, Crush Strength with a 10"x 10" (25.4mm x 25.4mm) Thermoplastic Wale

Round FRP Pipe Pile TU455 Polyurethane12"x3/8" Metric (305mmx9.52mm)	Round FRP Pipe Pile TU450 Polyurethane12"x1/2" Metric (305mmx12.7mm)	Round FRP Pipe Pile TU460 Polyurethane16"x1/2" Metric (406mmx12.7mm)
Average Crush Strength lb (kg)		
***** *****	73,780 (33,466)	44,213 (20,055)
Characteristic Crush Strength lb (kg)		
***** *****	51,370 (23,301)	***** *****

Notes:
****** Data not available or minimum test quantity not available.

SUPERPILE® MECHANICAL LOAD CHARTS

WASHER PULL THROUGH CHARTS

The round and octagonal pipe piles were tested to determine the washer pull through capacity. The test set up, as depicted in the photo, involves a series of tests in which 6" steel washers, bent to the required radius were loaded to simulate a connection in which the load causes the washer to pull though the pile. The failure load is the load recorded at the first drop in strength on the load/deflection curve. In most cases, the washer deformed prior to the failure load. Note that curved washers are required for use with the round pile and straight washers are required for use with the octagonal piles.

SUPERPILE® Washer Pull Through Strength with a 6"x1/2" (152mm x12.7mm) Steel Washer

Round FRP Pipe Pile TU455 Polyurethane12"x3/8" Metric (305mm x 9.52mm)	Round FRP Pipe Pile TU450 Polyurethane12"x1/2" Metric (305mm x 12.7mm)	Round FRP Pipe Pile TU460 Polyurethane16"x1/2" Metric (406mm x 12.7mm)
Average Pull Through Strength lb (kg)		
26,084 (11,832)	30,686 (13,919)	27,582 (12,511)
Characteristic Pull Through Strength lb (kg)		
22,107 (10,028)	26,815 (12,163)	25,103 (11,387)

SUPERPILE® Washer Push Pull Through Test Set Up

SUPERPILE® Washer Pull Through Strength with a 6"x3/8" (152mm x9.5)mm Steel Washer

Round FRP Pipe Pile TU455 Polyurethane12"x3/8" Metric (305mm x 9.52mm)	Round FRP Pipe Pile TU450 Polyurethane12"x1/2" Metric (305mm x 12.7mm)	Round FRP Pipe Pile TU460 Polyurethane16"x1/2" Metric (406mm x 12.7mm)
Average Pull Through Strength lb (kg)		
18,893 (8,570)	25,205 (11,433)	18,878 (8,563)
Characteristic Pull Through Strength lb (kg)		
13,977 (6,340)	22,420 (10,170)	13,521 (6,133)

SUPERPILE® Washer Pull Through Strength with a 4"x3/8" (102mm x 9.5mm) Steel Washer

Octagonal FRP Pile 8"x.25" Series II CP076 Metric (203mm x 6.35mm)	Octagonal FRP Pile 10"x.25" Series II CP074 Metric (254mm x 6.35mm)	Octagonal FRP Pile 10"x.275" Series III CP210 Metric (254mm x 6.98mm)
Average Pull Through Strength lb (kg)		
13,697 (6,213)	14,698 (6,667)	14,571 (6,609)
Characteristic Pull Through Strength lb (kg)		
10,705 (4,856)	11,916 (5,405)	11,798 (5,351)

TYPICAL DOCK TO FENDER PILE CONNECTION

The pile/dock connection cartoon illustrates an attachment scheme that alleviates stress risers. Specifically, hollow composite pipe piles, although extremely strong and robust, have a lower modulus of elasticity than steel. The ability of the FRP material to distribute high load concentrations is not the same as a steel pipe. Therefore, the correct connection details are important in dock fender design. High stress concentration pipe pile connections should include a steel washer or wood block that wraps 1/4 to 1/2 the way around the pile. Tangential loads should be avoided. The chart depicts the loads that can be induced into the pile with a connection that is typical of the test set up and detail cartoon.

SUPERPILE® Typical Dock to Pile Connection

TYPICAL DOCK TO FENDER PILE CONNECTION

SUPERPILE® Typical Dock to Pile Connection Capacity Test Set Up

SUPERPILE® Dock Connection Capacity for Fender Applications

Round FRP Pipe Pile TU455 Polyurethane12"x3/8" Metric (305mm x 9.52mm)	Round FRP Pipe Pile TU450 Polyurethane12"x1/2" Metric (305mm x 12.7mm)	Round FRP Pipe Pile TU460 Polyurethane16"x1/2" Metric (406mm x 12.7mm)
Average Connection Capacity lb (kg)		
26,084 (11,832)	30,686 (13,919)	27,582 (12,511)
Characteristic Connection Capacity		
22,107 (10,028)	26,815 (12,163)	25,103 (11,387)

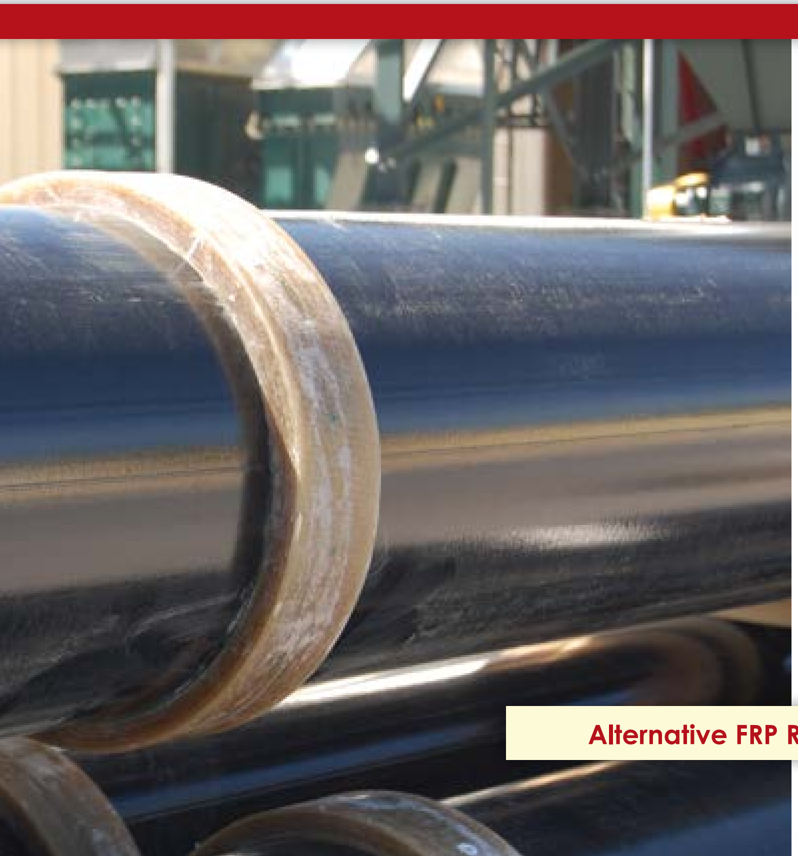
The chart depicting the dock connection capacity is based on crush strength testing conducted with a 9" long by 6" wide by 1/2" thick steel washer.

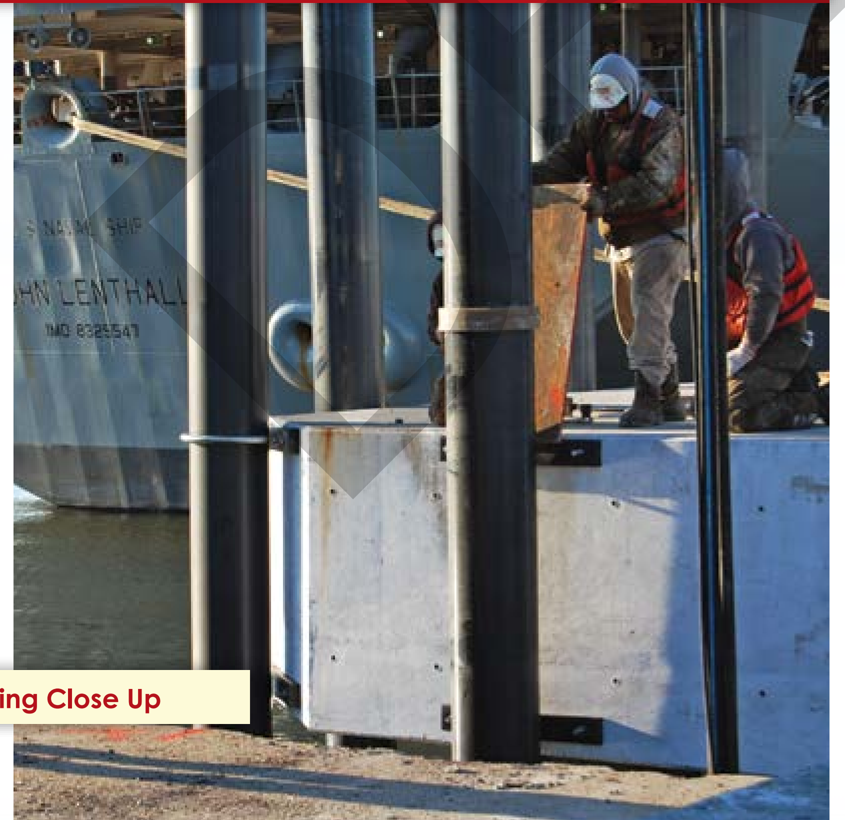
SLEEVE OPTIONS
THICK AND THIN

The FRP Polyurethane SUPERPILE® exhibits very good abrasion resistance qualities. However, for applications in which continuous rubbing or severe scour can take place, CPI recommends that the pile and/or watercraft be protected with the use of a High Density Polyethylene (HDPE) sleeve. CPI offers several HDPE sleeve profiles.

A thin wall casing sleeve with a thickness of 0.175" (4.4mm), and a thick wall pipe sleeve with a minimum wall thickness of .824" (21mm), are offered for the 12" diameter pipe pile. The resin compound used for the manufacture of polyethylene casing shall be high-density polyethylene with a minimum cell classification of PE334430C, when classified in accordance with ASTM D3350. The thick wall sleeve is classified as a 14" DR 17IPS HDPE Pipe. The 16" diameter pile requires an 18" DR26 IPS Pipe with a minimum wall thickness of .692" (17.6mm).

Thin Wall Sleeve





Alternative FRP Ring Close Up

SLEEVE OPTIONS
THICK AND THIN

The thin casing sleeve can be attached to the pipe at the factory and driven as a pile/sleeve assembly. The thick sleeves can be shipped assembled with the pipe pile; however, driving conditions may require that the sleeve be removed from the pile prior to driving and then secured after the pile has been driven. The heavy sleeves are secured with four 3/4" (19mm) bolts and washers placed near the top of the pile.

Thick Wall Sleeve

An alternative option that has had great success involves CPI attaching an FRP ring to the pile prior to being driven. The FRP ring keeps the sleeve held into position onto the pile while allowing the thick sleeve to spin on the pile when a vessel comes into contact with the pile. This detail allows the vessel to freely rub along side of the pile with less friction and for the HDPE sleeve to grow and contract independently of the FRP pile as the coefficient of thermal expansion of the HDPE sleeve is significantly higher than that of the FRP pile.

PILE CAP OPTIONS

Polyethylene Pile Cap

The round SUPERPILE® can be capped with non structural or structural caps. The cosmetic caps are cone or flat shaped and are strictly cosmetic and intended to keep birds and such from entering the piles. CPI recommends that structural caps be used in areas where people can climb on the piles as the possibility exists that a small child could collapse the thermoplastic cap and fall into the piles. The non structural Polyethylene Pile Cap options are white or black. The sleeve is 2" tall and the cone height is 3-1/2" - 4".

The Polyethylene Pile Cap is UV resistant and has an estimated life of 15 years for black tops and 9 years for white tops. The polyethylene caps should be attached with large head stainless steel self drilling screws that are normally included if caps are purchased through CPI.

FRP Structural Cap

The **FRP Structural Cap** is a structural cap that will last indefinitely. It is milled from solid FRP plate, painted black and is attached with stainless steel self drilling screws. The cap will support significant loads and can be used to mount lights and other navigational or marine accessories. The FRP cap matches the pile outside diameter and fits flush with the top of the pile with a protruding insert that fits the interior of the pile. The thickness of the flush top plate is 1/2". The protrusion portion of the FRP pile cap ranges from 3/4" to 1".

The octagonal piles are capped with a low density, UV stabilized polyethylene cap. The UV stabilized polyethylene octagonal caps should be fastened with self drilling stainless steel screws.

UV Stabilized Polyethylene Top Cap

COLOR OPTIONS

The standard color of the FRP pile is black. Custom colors are available upon request. CPI recommends that a UV protection layer be incorporated onto the pile surface if the pile is exposed to UV light and the application is architectural or cosmetic.

The UV protection is available in the form of a paint or polyurethane coating or in the form of a high density polyethylene sleeve.

Polyurethane coatings have an advantage as they provide UV and abrasion protection while exhibiting a textured architectural appearance. Polyurethane and paint coatings are offered in various colors. Consult the factory and talk to a representative to determine the best UV protection option for your installation.

BEARING AND DOCK PILES

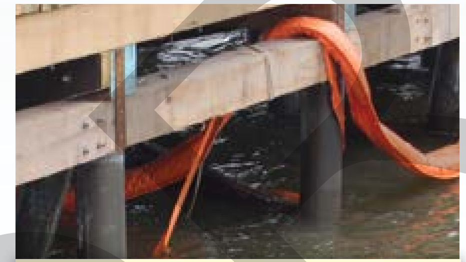
SUPERPILE® is used extensively for bearing pile applications. The SUPERPILE® can be utilized hollow or concrete filled depending on the strength and stiffness requirements for your application.

Engineers and owners are discovering the benefits of using FRP piles in the splash zone. This exercise will significantly increase the service life of your structure.

As an example, after Hurricane Sandy, the Federal Highway Administration (FHWA) replaced the visitor and service docks on Liberty Island, NY with new docks made of FRP and wood. The FHWA engineers specified polymer piles to be used for the bearing piles in order to increase the service life of the structure. The piles were driven to refusal and filled with concrete. The dock structure was erected and the wood plank decking attached.

Visitor Center Reopens

Liberty Island Installation Site



FRP Bearing Piles

Another example of engineers and owners taking advantage of FRP materials involves the construction of an all composite fire boat dock in Jacksonville, Florida. The dock was designed for a category three hurricane direct hit, as the structure is critical for the fire department rescue team.

SUPERPILE® supports the boat lift. The substructure is made of FRP pultruded channels and beams that support the pultruded grating walkway that extends from the firehouse to the boat lifts.

BEARING AND DOCK PILES

FRP Pultruded Grating Walkway Leading to Dock

Pultex® Standard Structural Channels Support FRP Grating

COLUMN LOAD CHARTS

The compression capacity of the pultruded piles can be determined based on both short and long column behavior. The ultimate column load shall be determined by the lesser value of the two equations. Euler buckling governs the capacity of the long column poles.

$$F_{cr} = \sigma_c - 1/7 \frac{KL}{r}$$

Where:
F_{cr} = Critical compression stress
= Axial compression strength
K = Effective length factor
L = Laterally unbraced length of member
r = Radius of gyration about the axis of buckling

$$F_{cr} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

Where:
F_{cr} = Critical compression stress
E = Modulus of elasticity
K = Effective length factor
L = Laterally unbraced length of member
r = Radius of gyration about the axis of buckling

The column load charts have been set up based on the short and long column equations presented. Reference Pultex® Pultrusion Design Manual. The column height is considered to be the length of the pile, out of the ground, to the applied compression load. The effective length factor "K" is equal to 1 based on pinned-pinned end conditions.

A pultruded column will fail in either short or long column mode. The long column capacity follows Euler buckling and is influenced by the modulus of elasticity and the radius of gyration and the length of the column.

The loads depicted in the column charts are un-factored ultimate load capacities. A safety factor of three is recommended.

BEARING AND DOCK PILES

COLUMN LOAD CHARTS

SUPERPILE® Round Pile Load Chart

Column Capacity Based on a K=1.0 (Rotation and Translation Fixed)		Ultimate Column Capacity, lb (kg)					
Pole Length, Above Ground, ft	Pole Length, Above Ground, m	Round Pole TU455 12"x3/8"		Round Pole TU450 12"x1/2"		Round Pole TU460 16"x1/2"	
40	12.19	52,145	(23,652)	75,906	(34,430)	187,246	(84,934)
42	12.80	47,297	(21,453)	68,849	(31,229)	169,838	(77,037)
44	13.41	43,095	(19,547)	62,732	(28,455)	154,749	(70,193)
46	14.02	39,429	(17,885)	57,396	(26,034)	141,585	(64,222)
48	14.63	36,212	(16,425)	52,712	(23,910)	130,032	(58,982)
50	15.24	33,373	(15,138)	48,580	(22,035)	119,838	(54,357)
52	15.85	30,855	(13,995)	44,915	(20,373)	110,797	(50,257)
54	16.46	28,612	(12,978)	41,649	(18,892)	102,742	(46,603)
56	17.07	26,604	(12,068)	38,727	(17,566)	95,534	(43,333)
58	17.68	24,801	(11,250)	36,103	(16,376)	89,059	(40,396)
60	18.29	23,175	(10,512)	33,736	(15,302)	83,221	(37,748)
62	18.90	21,704	(9,845)	31,594	(14,331)	77,938	(35,352)
64	19.51	20,369	(9,239)	29,651	(13,449)	73,143	(33,177)
66	20.12	19,153	(8,688)	27,881	(12,647)	68,777	(31,197)
68	20.73	18,043	(8,184)	26,265	(11,914)	64,791	(29,389)
70	21.33	17,027	(7,723)	24,786	(11,243)	61,142	(27,733)
72	21.94	***	***	23,428	(10,627)	57,792	(26,214)
74	22.55	***	***	22,178	(10,060)	54,710	(24,816)
76	23.16	***	***	21,026	(9,537)	51,869	(23,527)
78	23.77	***	***	19,962	(9,055)	49,243	(22,336)
80	24.38	***	***	18,976	(8,608)	46,812	(21,233)

Octagonal Pile Load Chart

Column Capacity Based on a K=1.0 (Rotation and Translation Fixed)		Ultimate Column Capacity, lb (kg)					
Pole Length, Above Ground, ft	Pole Length, Above Ground, m	8 in. Series II CP076		10 in. Series II CP074		10 in. Series III CP210	
22	6.71	37,119	(16,837)	78,990	(35,829)	89,950	(40,800)
24	7.31	31,190	(14,148)	66,373	(30,106)	75,583	(34,284)
26	7.92	26,576	(12,055)	56,555	(25,653)	64,402	(29,212)
28	8.53	22,915	(10,394)	48,764	(22,119)	55,530	(25,188)
30	9.14	19,962	(9,054)	42,479	(19,268)	48,373	(21,942)
32	9.75	17,544	(7,958)	37,335	(16,935)	42,515	(19,285)
34	10.36	15,541	(7,049)	33,072	(15,001)	37,661	(17,083)
36	10.97	13,862	(6,288)	29,499	(13,381)	33,592	(15,237)
38	11.58	12,441	(5,643)	26,476	(12,009)	30,149	(13,676)
40	12.19	11,228	(5,093)	23,894	(10,838)	27,210	(12,342)
42	12.80	10,184	(4,620)	21,673	(9,831)	24,680	(11,195)
44	13.41	9,280	(4,209)	19,747	(8,957)	22,487	(10,200)
46	14.02	8,490	(3,851)	18,068	(8,195)	20,575	(9,332)
48	14.63	7,797	(3,537)	16,593	(7,527)	18,896	(8,571)
50	15.24	7,186	(3,260)	15,292	(6,937)	17,414	(7,899)

BEARING AND DOCK PILES

CONCRETE FILLED PILES

SUPERPILE® can be filled with concrete. Most contractors have chosen to drive the pile hollow and then pump the pile full of concrete. Concrete increases the transverse crush strength, bending strength and lengthwise compression strength. Full section testing performed on the 16"diameter pile with 3,800 psi concrete resulted in a 40% increase in bending stiffness and a 50% increase in strength. Note that the pile was not tested to failure. It was tested to a load of 150 kips due to limitations of the test equipment.

The concrete filled 16" SUPERPILE® was tested to determine the crush strength. The pipe pile was loaded by applying a crush load through a 10"square thermoplastic wale section. The load was applied until the predetermined limit of 180 kips was obtained. The pile showed no signs of distress.

Crush Test on Concrete Filled Pile

Full Section Testing of Concrete Filled Pile

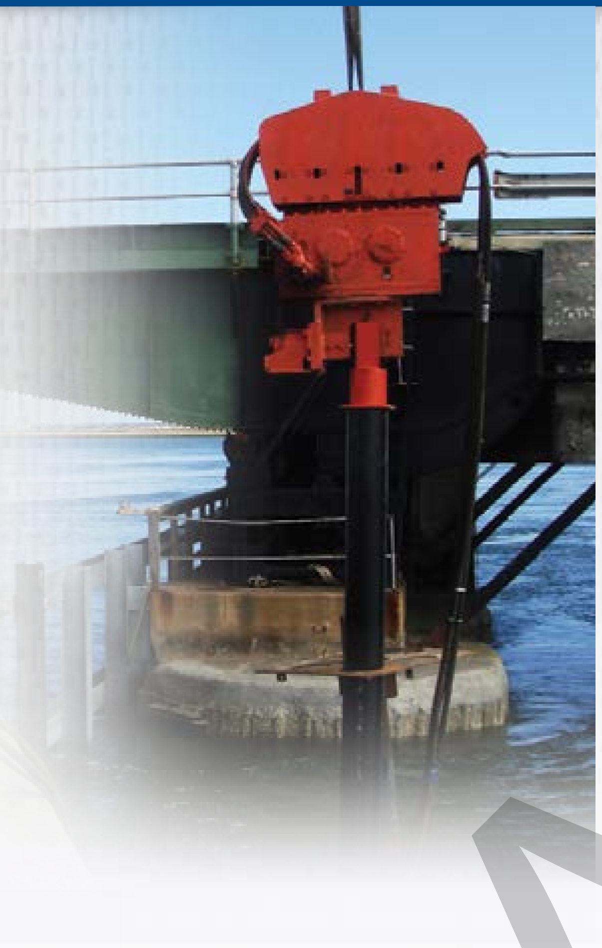
Piles with Driving Tips Ready to Ship

DRIVING TIPS

Driving tips are available for the 12" and 16" pipe piles. The cast steel driving tips are conical and are attached to the pile at the production plant. They offer bearing resistance and permit the piles to be concrete filled in situ.

INSTALLATION METHODS

VIBRATORY HAMMER

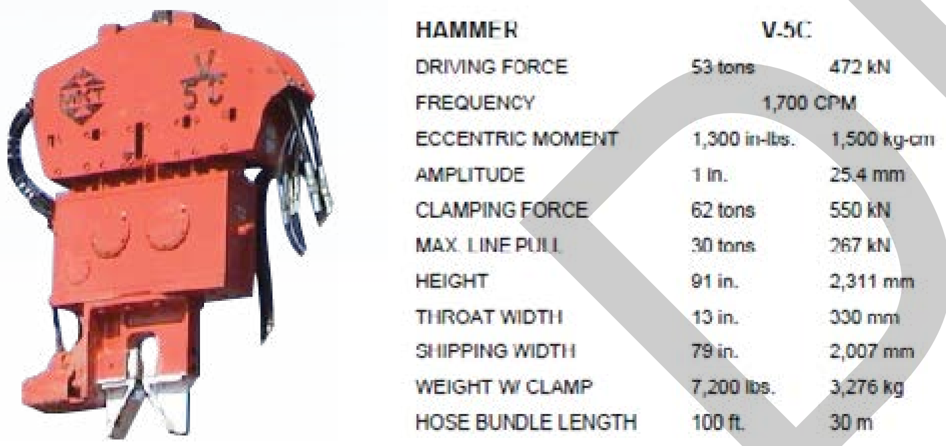


SUPERPILE® can be efficiently driven with a vibratory hammer. When utilizing a vibratory hammer, an adaptor shall be fabricated to connect the pile to the vibratory hammer. The adaptor shall include an interior steel pipe that fits into the SUPERPILE® to guide the pile. The interior tube should be between 0.5" and 2" of the interior diameter of the FRP pile. The interior pipe shall be welded onto a flat steel plate. The steel plate will apply the compression force into the top of the pile. The steel plate shall be connected to a beam that can be clamped by the vibratory hammer.

The contractor is cautioned that, on some occasions, the pile may require an FRP insert for added compression or pin bearing strength. Therefore, the interior diameter of the pile will change. The contractor should base the vibratory adaptor fabrication on the approved pile drawings.

In the event that a pile needs to be pulled, a vibratory hammer can be utilized to pull the piles. Through bolt the pile and the drive head with three 1" diameter bolts spaced a minimum of 5" apart. Vibrate the pile and pull tension until the pile begins to move. Once the friction has broken, pull the pile without the vibratory hammer engaged. The vibratory hammer oscillation will cause the bolt holes to elongate if engaged for an extended period of time.

Example of Vibratory Hammer Steel Fabrication



HAMMER	V-5C	
DRIVING FORCE	53 tons	472 kN
FREQUENCY	1,700 CPM	
ECCENTRIC MOMENT	1,300 in-lbs.	1,500 kg-cm
AMPLITUDE	1 in.	25.4 mm
CLAMPING FORCE	62 tons	550 kN
MAX. LINE PULL	30 tons	267 kN
HEIGHT	91 in.	2,311 mm
THROAT WIDTH	13 in.	330 mm
SHIPPING WIDTH	79 in.	2,007 mm
WEIGHT W/ CLAMP	7,200 lbs.	3,276 kg
HOSE BUNDLE LENGTH	100 ft.	30 m

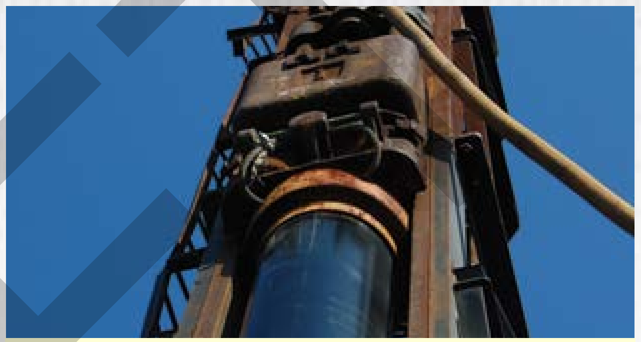
Typical Vibratory Drive Hammer Specifications (Courtesy of RPI Construction Equipment)

IMPORTANT NOTICE: In reference to the proper use of this equipment, please be advised that job site conditions may vary due to a change in the geology of a particular area. It is always a good practice to consult with a geotechnical engineer prior to starting a project. Also, a good rule of thumb is to know your soil conditions before selecting pile driving equipment. This can be accomplished by reviewing test soil borings before every project. The above equipment is being used in a granular soil condition which is recommended when using vibratory driver / extractors.
~ RPI Construction Equipment

INSTALLATION METHODS

AIR AND DIESEL IMPACT DRIVING HAMMERS

Diesel and air impact hammers have been successfully utilized to drive install the 12" and 16" diameter SUPERPILE®. A pipe insert driving head or steel pipe cap is required for driving the hollow FRP piles. It is important that the piles are impacted so that the driving force is dissipated over the cross section of the top of the pile. A plywood or composite material pile cushion can also be utilized to reduce driving stresses induced into the pile.



Vulcan 01 Impact Hammer Driving
16" Diameter SUPERPILE®

Example of Pipe Insert Driving Head
for Driving Hollow Piles

PDA ANALYSIS

Dynamic Pile Testing (PDA) has been successfully performed on SUPERPILE® in the Coastal Plain soils of Virginia. CPI contracted to Crofton Construction Services, Inc. and to Atlantic Coast Engineering for installation of SUPERPILE® by impact driving and to perform PDA analysis in order to have a Pile Dynamic Analysis (PDA) performed on SUPERPILE®.

Crofton Construction Services, Inc. installed two SUPERPILE® in Norfolk, Virginia. The first test pile was installed with a Vulcan 01 Impact Hammer and the second with an APE D30-32 Impact Hammer. Both piles were driven with a closed-end steel toe plate bolted to the bottom of the pile in order to increase the driving resistance of the soils. The pile driven with the Vulcan 01 Air Hammer was driven to refusal (120 blows/ft.) at a depth of 35 feet and then extracted for visual inspection. The pile driven with the APE D30-32 Impact Hammer was driven to a depth of 50 feet, allowed to set overnight, and was re-driven on the following date with dynamic test gauges attached to the pileday and dynamically monitored by Atlantic Coast Engineering.

Testing was performed to aid contractors in the selection of the appropriate impact hammers for installation of the SUPERPILE®. And, to establish, for Geotechnical Engineers, the feasible soil resistances in which the piles may be driven without damage and to identify the allowable driving stress.

The rated capacity of each hammer is utilized in the PDA as follows:

Hammer	Rated Driving Energy	Typical Energy Expected to be Delivered to Pile
Vulcan 01	15 kip-ft	6--9 kip-ft
APE D30-32	74 kip-ft	20-40 kip-ft

PDA ANALYSIS

The test pile driven with the Vulcan 01 Impact Hammer, to refusal, demonstrated a driving resistance of 160 kips, a driving energy of 8 kip-ft., and a compressive driving stress of 8 ksi. The pile was extracted, inspected and revealed no signs of damage.

The test pile driven with the larger APE D30-32 Impact Hammer was driven through the same soils at a blowcount of 9 blows/ft. ending at a blowcount of 12 blows/ft., which was evaluated to represent a resistance of 200 kips with a compressive stress of 11 ksi. No evidence of damage was observed.

After a one day set up period, the pile was re-driven with the APE D30-32 Impact Hammer at a substantially greater resistance. At 235 blows/ft., a driving resistance of 340-370 kips, an average energy transfer of 30 ksi and a recorded compressive driving stress of 13-15 ksi, the pile head split and the pile failed. Prior to the pile head splitting, a CAPWAP® analysis indicated an ultimate axial compressive capacity of 350 kips.

PDA Analysis - Crofton Yard

The PDA testing indicates that impact hammers with a rated energy of 15 to 35 kip-ft are appropriate for the installation of SUPERPILE®.

Hammers with rated energies in the range of 35 to 50 kip-ft should be used with some level of caution, and may require a pile cushion to reduce driving stresses.

Based on observations made during the test pile program, it is recommended that Dynamic Consultants utilize a model PAX PDA unit (with a longer pretrigger buffer than the PAK unit) due to the longer pre-compression time.

For impact and vibratory installed SUPERPILE®, CPI recommends the use of a Wave-Equation Analysis and Driveability Study to assess the soil-pile interaction and estimate pile driving stresses during installation considering the proposed hammer assembly and site soil profile.

CUTTING AND DRILLING INSTRUCTIONS

CUTTING PILES

Concrete Saw

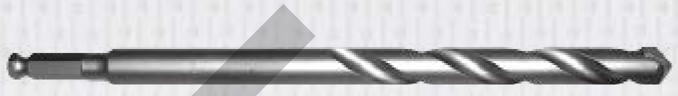
SUPERPILE® can be field cut with a concrete, skill or reciprocating saw. An abrasive blade should always be used. Concrete saws work the best and can be utilized with a standard concrete cutting blade. During drill and sawing operations, dust will be emitted. The dust is considered a nuisance dust, which can irritate your eyes and skin. Therefore, safety glasses, gloves and long sleeve shirts are recommended during the cutting and drilling process.

As documented by OSHA, FRP dust millings have potential to cause eye, skin, and upper respiratory tract irritation.

- Cause - mechanical-irritant properties of the glass fibers.
- FRP particulate is non-hazardous.
- FRP particulate is greater than 6 microns; therefore, it cannot reach the alveoli.
- The International Agency for Research on Cancer (IARC) classified FRP particulate as non-cancer causing in June of 1987.

DRILLING PILES

SUPERPILE® can be drilled with carbide tipped drill bits. CPI recommends B & A Manufacturing Company (http://www.bamanufacturing.com) FGH series drill bits for applications that require multiple holes in a short period of time. Many contractors and utilities have had success when utilizing the FGH series drill bits. The bits will save time and drill thousands of holes before needing to be replaced.



FCH Series Fiberglass Pile Driving Bit

PROPER HANDLING UPON DELIVERY

Lift-It® Sling Double Wrapped Around SUPERPILE®

Proper care should be taken during handling. The piles were packaged and loaded on the flatbed with a tow motor. Contact CPI for the weights of the piles and individual packages.

Proper care should be taken when removing the tie-down straps. Although the piles are cradled in wood chalks, never assume that the wood chalks will keep the piles from shifting.

The pultruded piles are smooth and can be very slippery if they become wet. Never use steel chokers or chains to unload the piles. A nylon strap, preferably with a neoprene skin is recommended. This will reduce the chance of the pile sliding during the picking process. CPI prefers to use light pole handling slings, made by Lift-It® (http://www.lift-it.com). The slings must be double wrapped and the manufacturer's recommendations must be followed.

VISUAL INSPECTION UPON DELIVERY

Upon delivery of the piles, the piles shall be inspected for damage that could affect the long term performance of the piles. Normal wear and tear including abrasions and scuff marks are common and shall not cause concern.

The piles are manufactured to the most current version of ASTM D4385. ASTM D4385 is a pultrusion industry recognized visual specification and can be used for inspection of the piles during delivery or at the plant.

SHIPPING AND RECEIVING

SUPERPILE® is shipped to the job site via flatbed dedicated truck. The continuous manufacturing process permits Creative Pultrusions, Inc. (CPI) to manufacture piles to long lengths eliminating the need for splices.

Prior to shipping, the contractor shall communicate with CPI regarding the packaging and shipping method. Considerations shall include but may not be limited to:

- Length of piles
- Quantity of piles on the truck
- Weight of the pile packages
- Unloading method

Dedicated Truck Hauling 80' Piles to Margate, New Jersey

SUPERPILE® SPECIFICATION

This specification is intended to define pultruded FRP pipe piles for procurement purposes.

1.0 SCOPE

1.1 This specification applies to the material requirements, the manufacture and performance of fiber reinforced polymer piles.

1.2 The mechanical properties shall be published per ASTM D7290.

2.0 MATERIAL DESIGN

2.1 The pultruded pipe pile shall be manufactured by the pultrusion process using a polymer binder containing a minimum 52% "E-CR" or "E" fiberglass by volume. Glass volume shall be 47% in the lengthwise direction and 14% in the crosswise direction.

2.2 E-glass reinforcements shall meet a minimum tensile strength of 290 ksi per ASTM D2343.

2.3 The octagonal pipe piles shall be pultruded with a high performance Vinyl Ester (VE) resin that is based on a bisphenol-A epoxy matrix. The VE resin shall be utilized for its superior toughness and fatigue attributes. The VE resin provides fire retardant properties that permit the pole to "self extinguish" in the event of a brush fire. Poles shall be classified as "self extinguishing" per UL94 with a V0 rating. The flame spread shall be class I per ASTM E-84 with a Flame Spread Index (FSI) of 25 or less.

2.4 The round pipe piles shall be manufactured with a low Volatile Organic Compound (VOC) two component polyol/isocyanate polyurethane matrix with a minimum resin content of 47%.

2.5 The piles shall contain Ultra Violet (UV) protection as a long term thermal and light stability promoter. Second, the fiberglass piles shall be encompassed with a 10 mil polyester surfacing veil. The 10 mil veil shall create a resin rich surface and protect the glass reinforcements from fiber blooming.

3.0 STRENGTH & STIFFNESS PROPERTIES

3.1 The octagonal pipe pile strength and stiffness values shall be derived per ASTM D1036.

3.2 The round pipe pile characteristic strength and stiffness values shall be derived per ASTM D6109.

4.0 FINISH

4.1 The surface of the pile shall contain a UV resistant, resin rich, smooth and aesthetically pleasing finish uniform along the entire pile length. The piles shall be manufactured and visually inspected in accordance with ASTM D4385.

SUPERPILE® SPECIFICATION

5.0 MANUFACTURING TOLERANCES

5.1 Pile Length (± 2") or 50 mm

5.1.1 Squareness of end cut (1/4") or 6.35 mm.
5.1.2 Pile profile dimensions per ASTM D 3917.
5.1.3 Straightness: 0.030"/ft. (2.5mm/m) with weight minimizing.
5.1.4 Weight: +/- 10%.

6.0 SHIPPING

6.1 Crated piles shall be individually protected in cardboard or equivalent protective material in areas in which dunnage makes contact with piles.

6.2 Piles shall be crated in bundles for ease of handling and transfer without damage to the piles by lift equipment.

7.0 QUALITY ASSURANCE

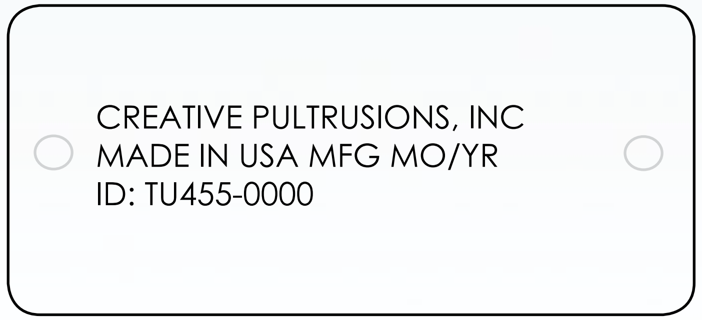
7.1 Quality Assurance shall be performed as described in the organizations quality plan, as approved by the Engineer of Record.

IDENTIFICATION TAGS

Identification Tags, when required by the customer, are supplied by CPI.

Standard tags are made of 304 dull stainless, 1" x 3.5" x .015" in size with two .250" holes for riveting to the pile.

The tag is embossed with information, including the manufacturing month and year, the pile part number and a serial number, specific to the application. The information is documented for future reference.



West Virginia University
Constructed Facilities Center
Morgantown, WV 26506-6103
(304) 293-7608

TEST REPORT

BENDING AND JOINT RESPONSE OF PILES

16 INCH DIAMETER 1/2 INCH THICK POLYURETHANE

16 INCH DIAMETER 1/2 INCH THICK VINYL ESTER

12 INCH DIAMETER 1/2 INCH THICK POLYURETHANE

PREPARED BY:

HOTA GANGARAO, Ph.D., PE

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8/11/2011

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1 INTRODUCTION

Creative Pultrusions Inc. has requested WVU-CFC to test piles of circular sections. Two different sets of materials (Polyurethane and Vinyl Ester) were tested, and the test methods used and test data are conveyed in this report. The tests done were four point bending under static load to failure, four point bending fatigue, crush strength test, and two different connection tests. The three types of test specimens consisted of 16 inch diameter ½ in thick vinyl ester samples, 16 inch ½ in thick polyurethane samples, and 12 inch diameter ½ in thick polyurethane samples.

2 TEST METHODOLOGY

1. Four-Point Bending Tests

Five piles of each material set were supplied by Creative Pultrusions, Inc to the West Virginia University Constructed Facilities Center on June 2010 for a variety of tests including four-point bending tests. The tests were conducted during July and early August as per ASTM D6109 and Creative Pultrusion's test protocol. The 12 inch piles were setup with a clear span of 240-inches out of a total length of 288-inches, with the load span equal to 1/3rd of the clear span or 80-inches. The samples were supported and loaded by using 8-inch long steel saddles that covered slightly less than half of the circumference as shown in Figure 1. The 16 inch piles were set up similarly with the clear span being 320 inches and the load span equal to 1/3rd of the clear span or 106.67 inches. The saddles were loaded at the midpoint through round steel stock to simulate simply supported conditions, and with neoprene padding between the saddle and pile. All piles tested were instrumented with a Celesco SP3 string pot to measure deflections up to 50 inches and an Omega LC8400-200-200 kip load cell. Vishay strain gages were installed in the longitudinal direction, with additional gages on certain samples for internal investigations. All samples were loaded to failure with a hydraulic actuator controlled by an electric pump, and a few tests were recorded using audio-visual system. Figure 2 shows the four-point bending of a 16-inch sample, which is identical to the 12-inch testing except for span length.

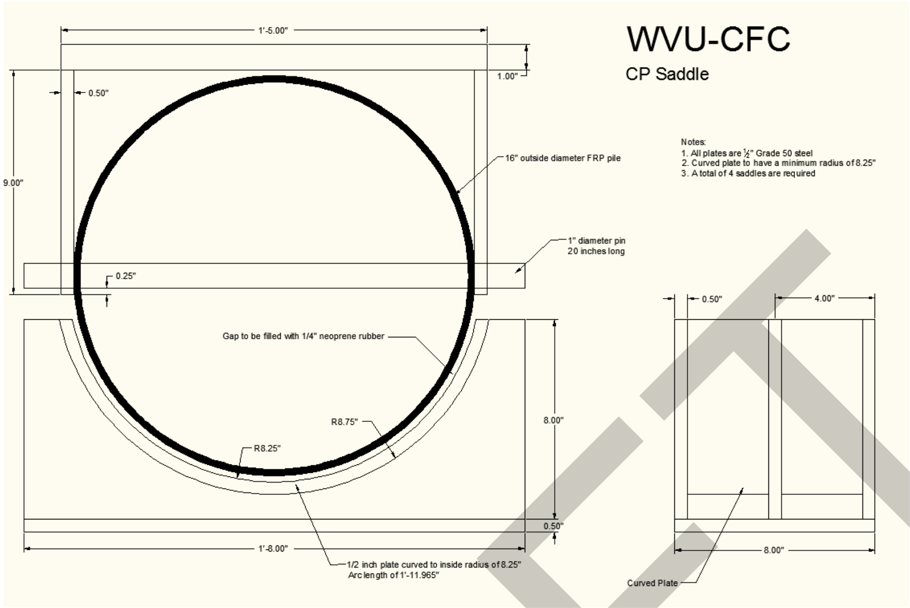

Figure 1: Saddle for testing

Figure 2: Four-Point Bending: 16-inch sample

2. Crush Strength Test

Crush testing was conducted on 6 feet sections of the piles supplied by Creative Pultrusions, Inc to the West Virginia University Constructed Facilities Center following their testing under four-point bending. The four-point bending tests led to the failure in the middle (mostly) of the 32-feet long piles, with the ends showing no signs of distress after testing to failure. Therefore the tested piles were cut near the ends to harvest undamaged ends so that they can be used for crush testing. The samples were set in the same saddles used in the four-point bend test with the rollers under the saddles removed. For the 16-inch piles, the saddles were set at 6-feet apart and the damaged end from four-point testing was left to hang off the end, supported by a gantry crane to keep the specimen level. For the 12-inch piles, 4-foot sections of the piles were cut from the undamaged ends and set in the saddles, with the saddles supporting roughly 4 inches at each end of the pile as shown in Figure 3. For each test, the area between the saddles under the pile was fully supported longitudinally on solid steel plates with neoprene pad between the steel support plate and the FRP composite. Load was applied by a hydraulic actuator controlled by an electric pump. Load was transferred through a steel plate to an Omega LC-8400-200-200 kip load cell and then through another plate into a 10-inch by 10-inch solid polymer wale section that was supplied by Creative Pultrusions, Inc. The wale section was connected to the steel plates by threaded rods for stability during testing. Deflection readings were taken from the wale section by a Celesco SP3 string pot. All test samples were loaded until the area around the application of the load (i.e. top of the pile) failed to the point at which the section was no longer circular and the wale section was nearly touching the sides of the pile. Testing was stopped before the sides were loaded as this caused damage to wale section (cutting into surface of wale section) and additional loading would simply crush flat the already failed structural system.

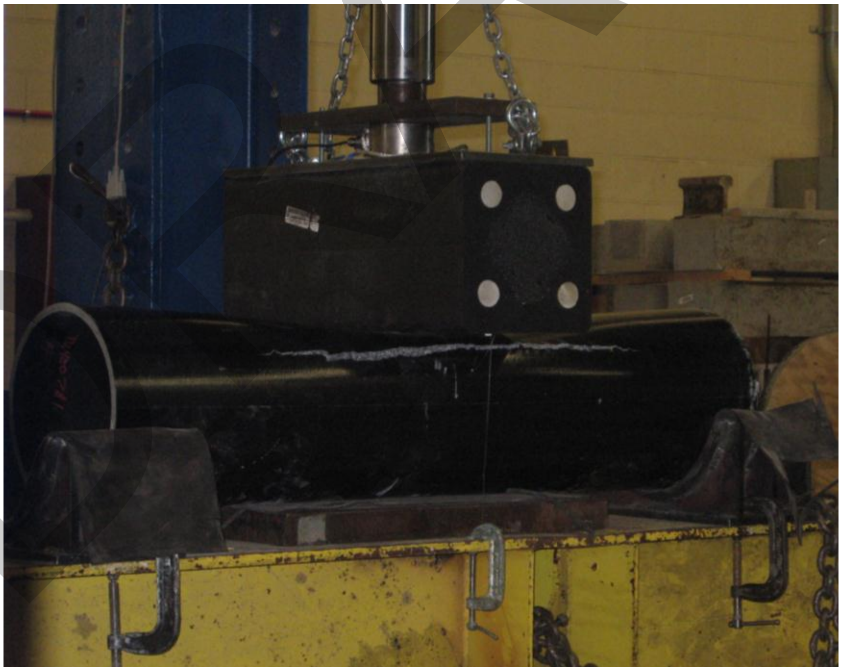

Figure 3: Crush Test: 12-inch pile

3. Connection Test A – Transverse Pin Test

A 1” diameter steel pin was inserted through the middle of the 16” and 12” diameter tubes (See Figure 1 and Figure 4). Each tube length was roughly 24”. The load was applied through the 1” diameter pin as shown in Figure 4. The load versus deflection of the pin was recorded at each point that it touched the pipe as shown in Figure 4. Two LVDTs were used directly under the pin on the outside of the load frame (See Figure 4). This positioning yielded accurate deflections and conveys how much the pin hole enlarged during loading to failure. Each specimen with the exception of the first few (Samples 1-3) was loaded until the frame was about to be in contact with the top of the pipe; this was done in order to obtain a good load-deflection curve with many points beyond the maximum load resistance offered by the tube.

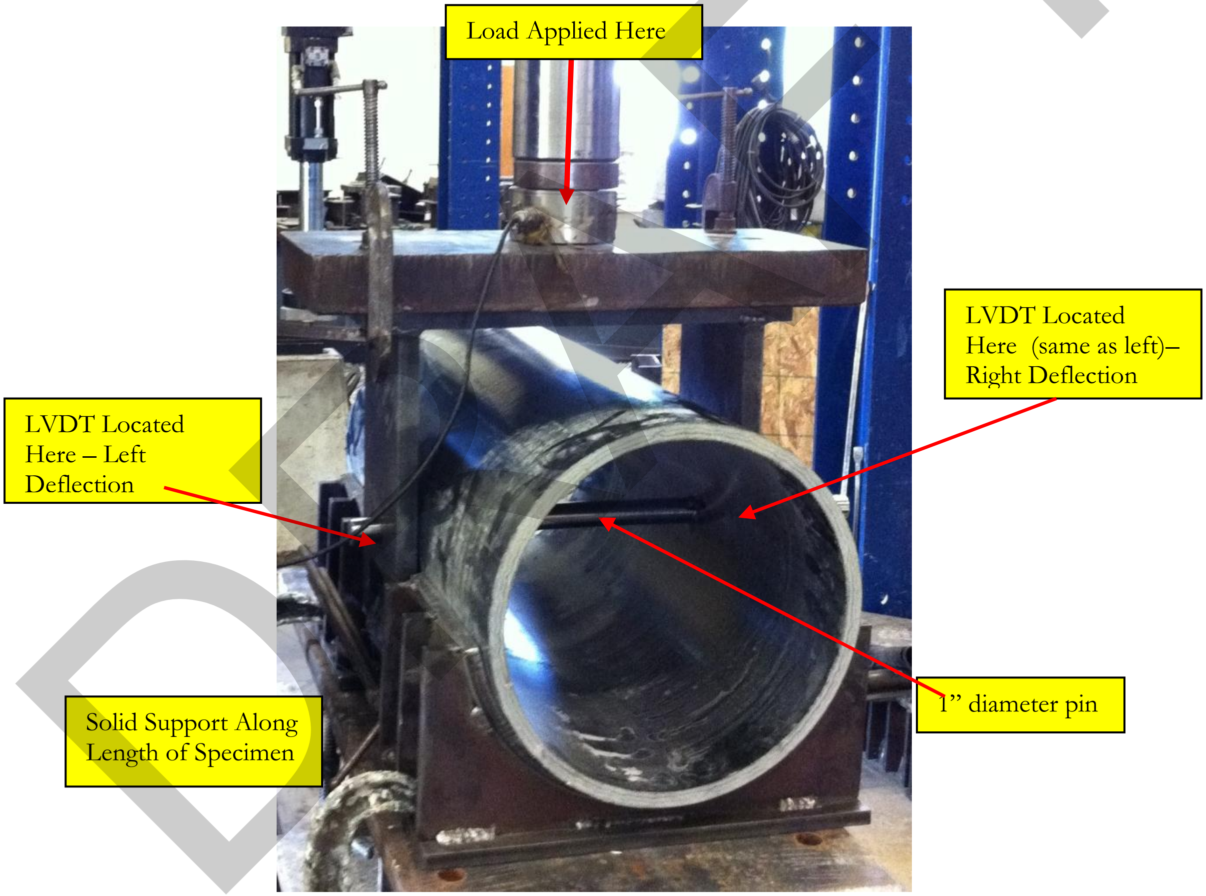

Figure 4: Connection Test A Setup

4. Connection Test B – Washer Test

This testing includes two different sized washers. The load – deflection data reveals the response of the composite piles under a point load over the washer. A bolt hole of 1 inch diameter was drilled straight through sections of the samples (same as Connection Test A). In this test however, a bolt and a washer that were provided by Creative Pultrusions were placed through the hole (See Figure 5). Two different sizes of washers were tested on test samples with three repetitions, except two repetitions in the 16 inch polyurethane pipe with a 6 inch washer. A 4" x 4" washer and a 6" x 6" were used, and these washers were curved to the fit the piles better (See Figure 5). The span lengths used for the 12" and 16" diameter samples were 5' and 6' respectively. In all test specimens, 6 inches of overhang was provided beyond the support.

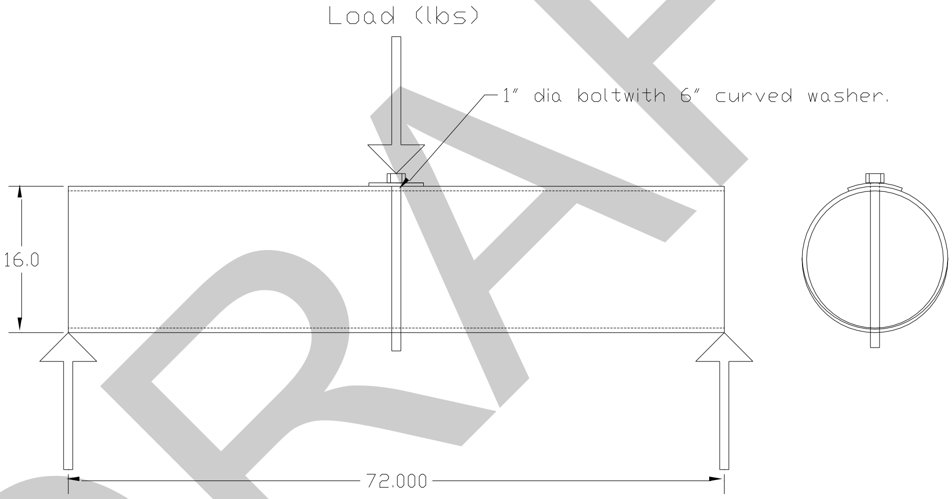

Figure 5: Connection Test B Setup

5. Four-Point Bending Fatigue

One sample of each material was tested in bending fatigue. Using the same test setup for four-point bending as described above, each sample underwent 200 cycles of approximately 40% of its respective average maximum load. It should be noted that a cycle consisted of roughly a 2 kip minimum load and a maximum load of 40% of the failure load. The values actually achieved by the fatigue loading system were slightly different and are recorded as shown in Table 8. At a rate of loading of .075 Hz (cycle/sec), each test endured 44 minutes to attain 200 cycles. This was chosen because of the MTS fatigue actuator's ability to run smoothly at this rate of loading. The machine used was an MTS Teststar Controller with a maximum compression load of 330 kips. It contains an internal load cell which was calibrated in February 2011 by MTS.

3 EXPERIMENTAL RESULTS

1. Four Point Bending – 12-inch Samples

The results from the 4-point bending tests are given in Table 1. Cracking sounds were clearly heard on all samples starting around 70 kips and continued regularly until failure though no cracks were visible from a safe viewing distance. Failure in all samples was sudden and abrupt, though preceded by much crackling. After failure, longitudinal cracks were found on the pile primarily centering about midspan along with crushing and tearing of the section in the middle third zone of a test specimen. *Sample numbers refer only to the order in which they were tested, and they are not sequenced between different test setups.*

Table 1: 12 inch Four-Point Bending Results

Sample	Max Load (kip)	Max Deflection (in)	Max Moment (kip-in)	Max Stress (ksi)	Max Longitudinal Strain (με)	Elastic Modulus (Msi)	Energy (load*defl) (kip-in)
1	93.55	13.42	3742	75.04	13206	6.65	705.06
2	100.35	13.78	4014	80.50	13325	6.62	780.86
3	80.36	11.03	3215	64.46	9657	7.06	489.02
4	87.76	11.39	3510	70.40	11584	6.24	566.15
5	92.61	12.35	3704	74.29	15829	6.47	631.48
Average	**90.93**	**12.39**	**3637.04**	**72.94**	**12720.14**	**6.61**	**634.51**

The load-deflection responses for all samples are shown in Figure 6.

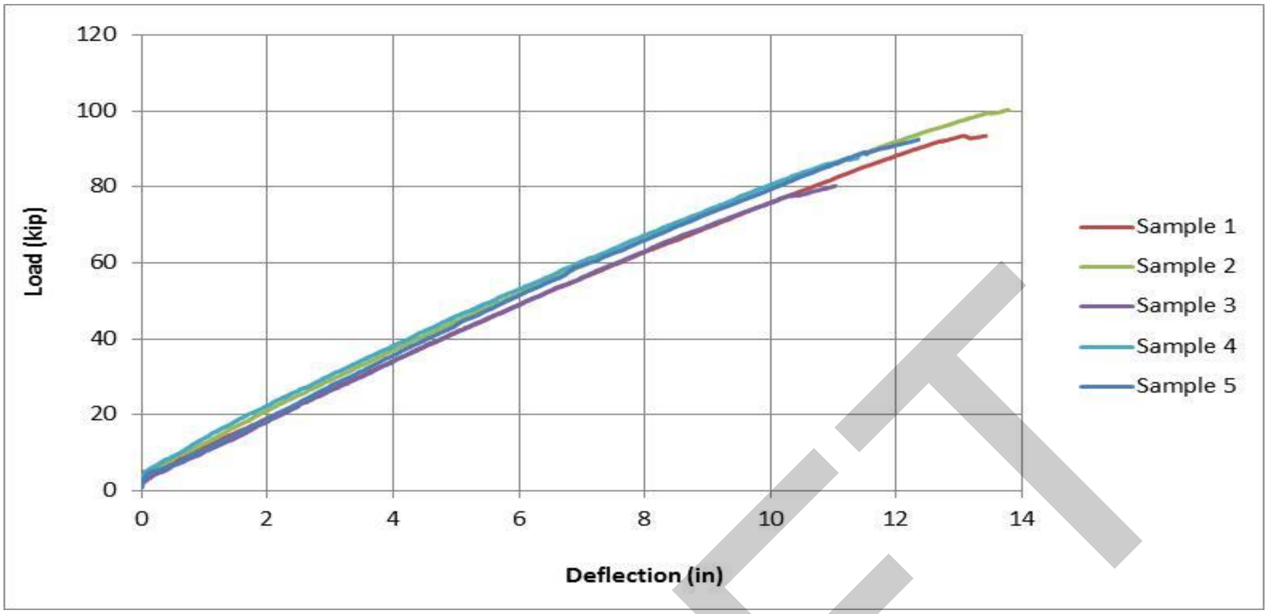

Figure 6: 12 inch Four-Point Bend Load-Deflection Response

2. Four Point Bending – 16 inch Polyurethane Samples

The results from the 4-point bending tests of the 16 inch Polyurethane samples are given in Table 2. Cracking sounds were clearly heard on all at around 75 kips though no cracks were visible from a safe viewing distance. Failure in all samples was sudden and abrupt with the load dropping to zero in roughly 0.2 seconds. After failure, longitudinal cracks were found on the pile centered about midspan along with crushing and tearing of the section at midspan. All samples failed in the middle third zone of the test span. *Sample numbers refer only to the order in which they were tested, and they are not sequenced between different test setups.*

Table 2: 16 inch Polyurethane Four-Point Bending Results

Sample	Max Load (kip)	Max Deflection (in)	Max Moment (kip-in)	Max Stress (ksi)	Max Longitudinal Strain (με)	Elastic Modulus (Msi)	Energy (load*defl) (kip-in)
1	101.18	16.39	5393	58.9	11137	5.79	944.45
2	100.29	16.88	5346	58.4	12122	5.51	938.47
3	101.58	-	5414	59.2	11794	5.42	-
4	104.42	-	5566	60.8	10109	6.16	-
5	95.69	-	5100	55.7	11265	5.87	-
Average	**100.63**	**16.64**	**5364**	**58.62**	**11285**	**5.75**	**941.46**

The load-deflection response for all samples is shown in Figure 7.

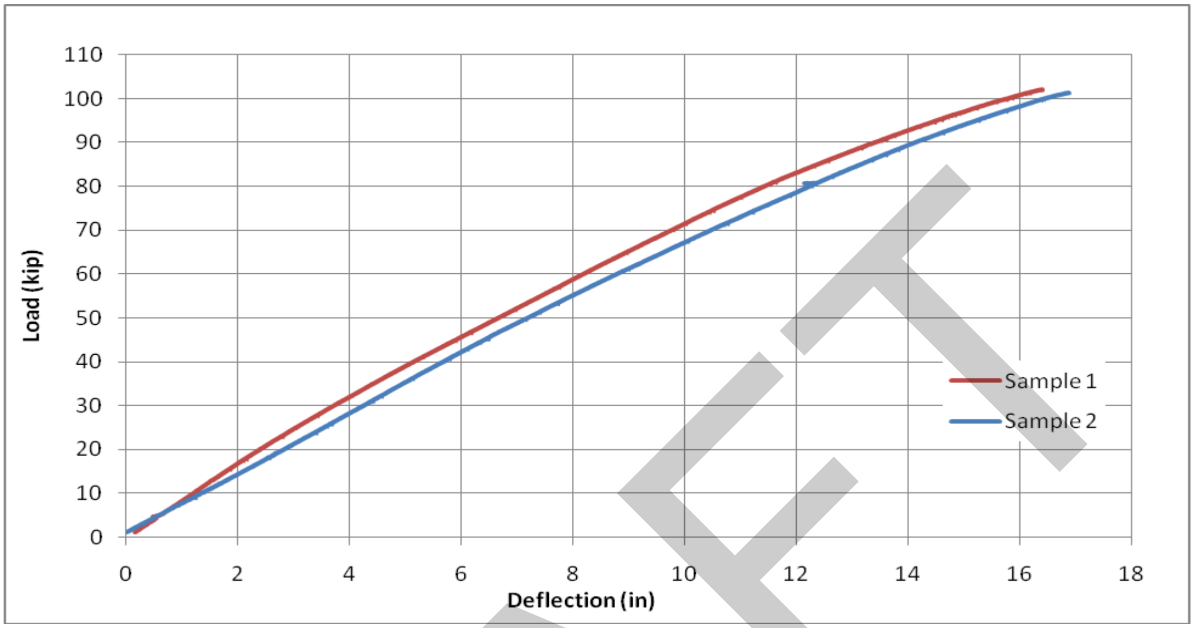

Figure 7: 16 inch Polyurethane Four-Point Bend Load-Deflection Response

3. Four Point Bending – 16 inch Vinyl Ester Samples

The results from the 4-point bending tests are given in Table 3. Cracking sounds were not clearly heard on any samples until the applied load was within roughly 5 kips of failure load. No cracks were visible from a safe viewing distance until failure. Failure of all samples was sudden and abrupt with the load dropping to zero in roughly 0.2 seconds. After failure, longitudinal cracks were found on the test specimen centered about midspan along with crushing and tearing of the section at midspan. All samples failed at the center with the exception of Sample 5 which failed under one of the loading saddles. Although neoprene padding was used between the saddles, there is probably some digging of the saddle with the pile near failure loads. It should be noted that the failure results from Sample 5 (Table 3) are very close to the average. *Sample numbers refer only to the order in which they were tested, and they are not sequenced between different test setups.*

Table 3: 16 inch Vinyl Ester Four-Point Bending Results

Sample	Max Load (kip)	Max Deflection (in)	Max Moment (kip-in)	Max Stress (ksi)	Max Longitudinal Strain (με)	Elastic Modulus (Msi)	Energy (load*defl) (kip-in)
1	87.41	13.85	4720.31	51.59	9891	5.66	687.45
2	64.53	9.77	3484.60	38.09	7136	5.54	340.97
3	86.70	12.98	4681.57	51.17	9311	5.43	624.76
4	90.31	13.27	4876.61	53.30	9461	5.45	667.60
5	86.35	10.67	4662.86	50.96	8763	5.80	540.74
Average	**83.06**	**12.11**	**4485**	**49.02**	**8913**	**5.57**	**572.30**

The load-deflection response for all samples is shown in Figure 8.

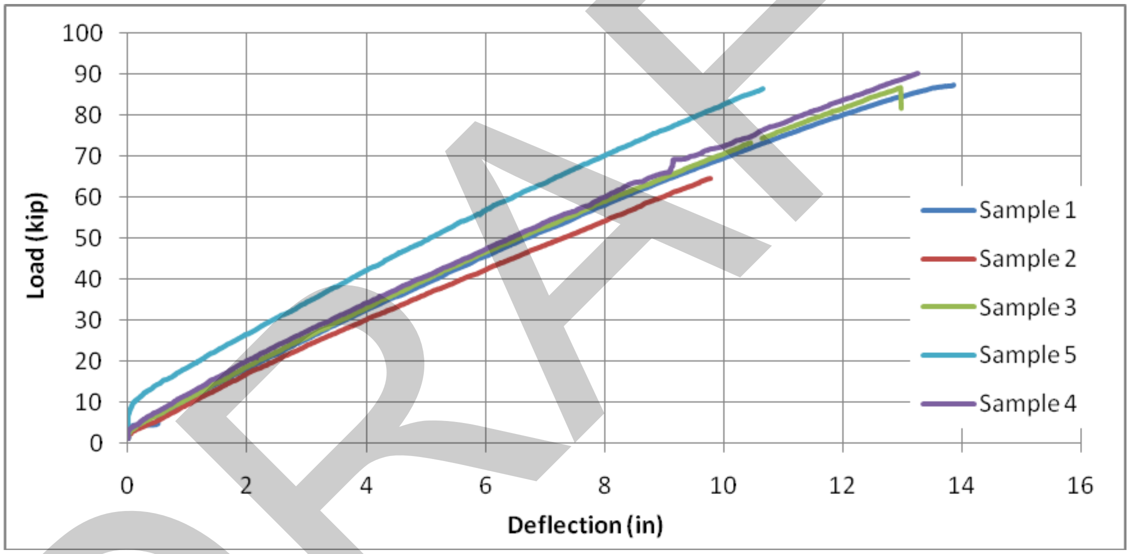

Figure 8: 16 inch Vinyl Ester Four-Point Bend Load-Deflection Response

4. Crush Test – 12-inch Polyurethane Samples

The results from the crush testing are given in Table 4 and Figure 9. Little deflection occurred with the increase in loading until the specimen started crackling, then deflection started to increase quickly. After 2-inches of deflection, the top of the pile had flattened out and longitudinal cracks were visible on both sides, which shows the pile failure but with full failure load on the pile (Figure 10). Upon releasing the load, the pile returned to a circular shape. It should be noted that the ends of the piles remained near circular in cross section, and no reinforcement effects were visible from the saddles. *Sample numbers refer only to the order in which they were tested, and they are not sequenced between different test setups.*

Table 4: 12-inch Pile Crush Test Results

Sample	Maximum Load (kips)	Deflection at Maximum Load (inches)
1	28.05	1.52
2	26.77	1.42
3	25.98	1.3
4	27.91	0.62
5	29.02	1.08
Average	**27.54**	**1.19**

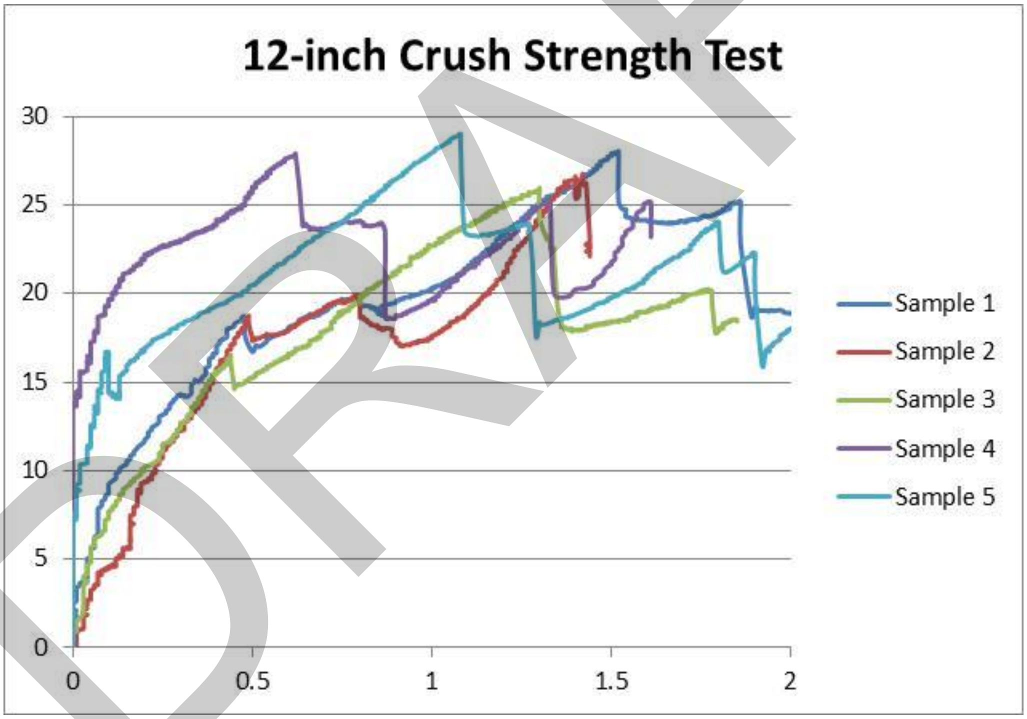

Figure 9: 12-inch Pile Crush Test Results

Figure 10: 12-inch Crush Test Pile Failure

5. Crush Test – 16-inch Polyurethane samples

The results from the crush testing are given in Table 5 and Figure 11. As with the 12-inch piles, typically there was little deflection induced under vertical loading until the specimen started crackling, then deflection started to grow quickly. After 2-inches of deflection, the top of the pile had flattened out and longitudinal cracks were visible on both sides as shown in Figure 12, which shows a pile at failure but with the full failure load still applied. Upon releasing the load, the pile returned to a circular shape as shown in Figure 13. It should be noted that the ends of the piles remained circular, and no boundary constraint effects were visible from the steel saddles. The string pot used to measure deflection did not work properly for Sample 4, so no deflection readings are available. However, Figure 14 shows the load versus time, which indicates that after the loading to a maximum of 24.59 kips, the total load dropped dramatically which is consistent with the load responses of the other samples. To further investigate if the failure load was peaked when the top flattened out, Sample 2 was loaded beyond this point. As shown in

Figure 15, after the sample passed the reported maximum load of 28.29 kips at 2.28 inches, the load reached a plateau until approximately 3 inches of deflection before picking up additional load of ~23 kips. This approximately corresponds to the location of the longitudinal cracks as seen in Figure 12 and Figure 13. At this point, the load was being primarily supported by the vertical faces of the pile which resulted in the pile cutting into the wale section slightly at these locations. Any further loading would simply crush the sample flat and would not accurately demonstrate its strength. *Sample numbers refer only to the order in which they were tested, and they are not sequenced between different test setups.*

Table 5: 16-inch Polyurethane Crush Strength Results

Sample	Maximum Load (kips)	Deflection at Maximum Load (inches)
1	28.40	1.54
2	29.29	2.28
3	24.86	2.22
4	24.59	N/A
5	30.50	2.037
Average	**27.53**	**2.02**

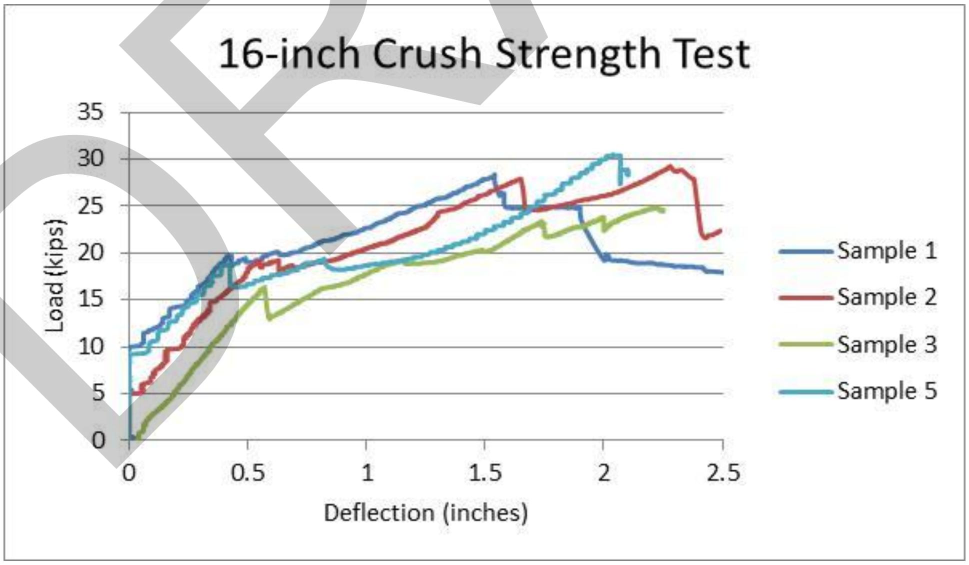

Figure 11: 16-inch Polyurethane Crush Strength Results

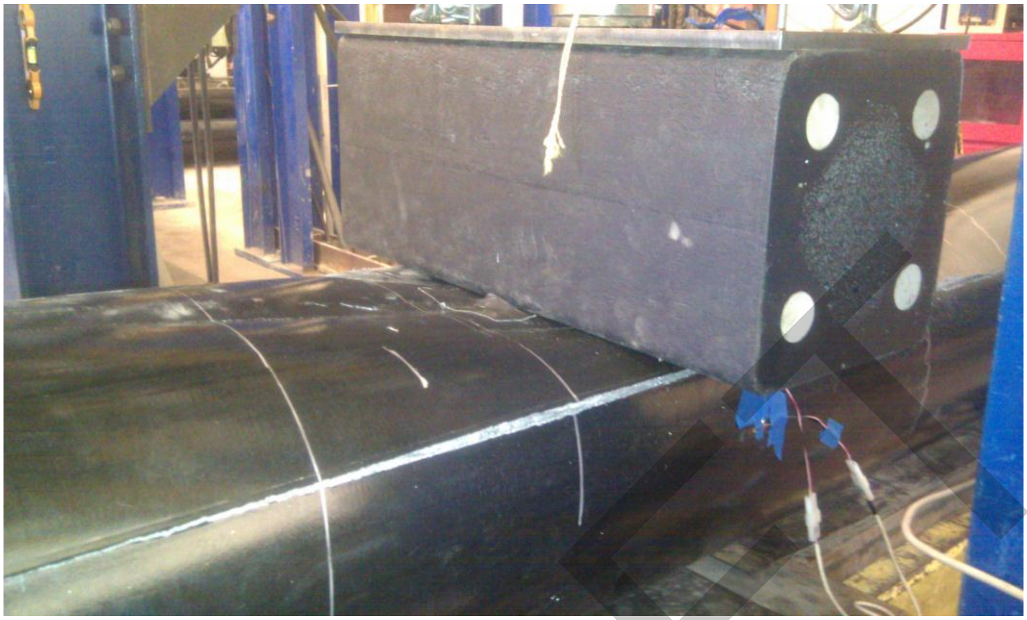

Figure 12: 16-inch Pile Failure Under Load

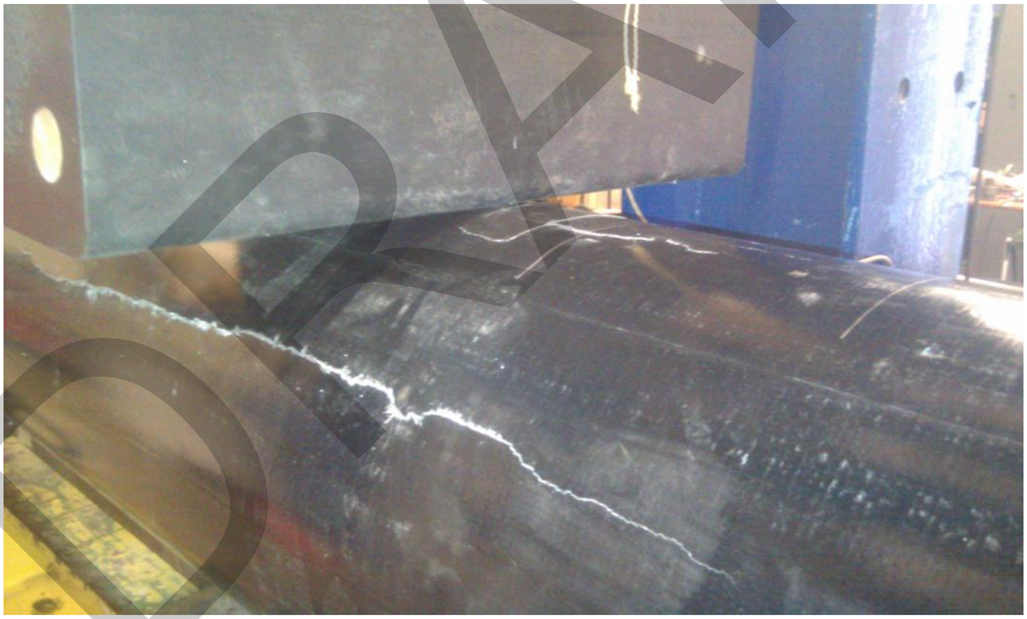

Figure 13: 16-inch Pile at Failure with Load Released

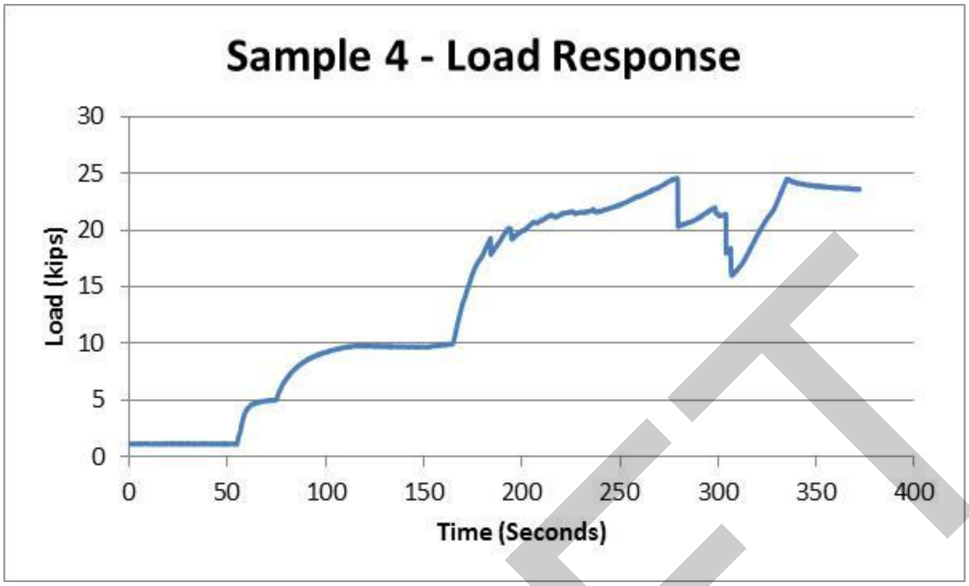

Figure 14: Sample 4 Load Response

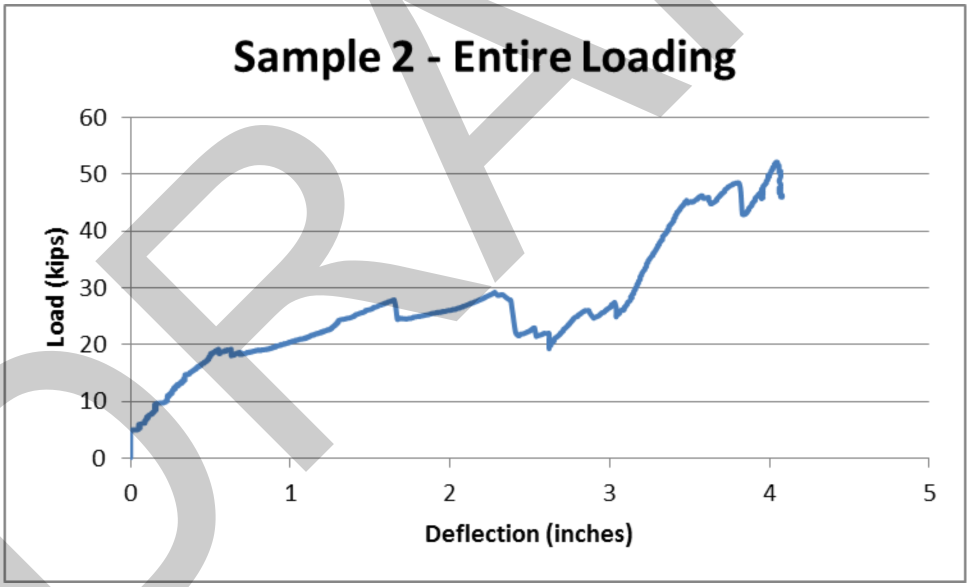

Figure 15: Sample 2 - Entire Loading

6. Crush Test – 16-inch Vinyl Ester Samples

The results from the 16-inch vinyl ester samples are very similar to those of the polyurethane. As noted above when the loading block reaches the sides of the cylinder it can take more load, but this was not allowed to happen during these samples. Table 6 provides maximum loads and deflections for all 4 test samples and it's noted that the vinyl ester samples failed at lower loads than polyurethane samples and deflected less. Of more value though is Figure 16 which shows the load versus deflection results. Each steep drop in loading indicates a cracking/failing of the material, perhaps on a layer by layer basis.

Table 6: 16-inch Vinyl Ester Crush Strength Results

Sample	Maximum Load (kips)	Deflection at Maximum Load (inches)
1	15.34	1.25
2	21.03	2.33
3	22.04	1.53
4	16.58	1.78
Average	**18.75**	**1.72**

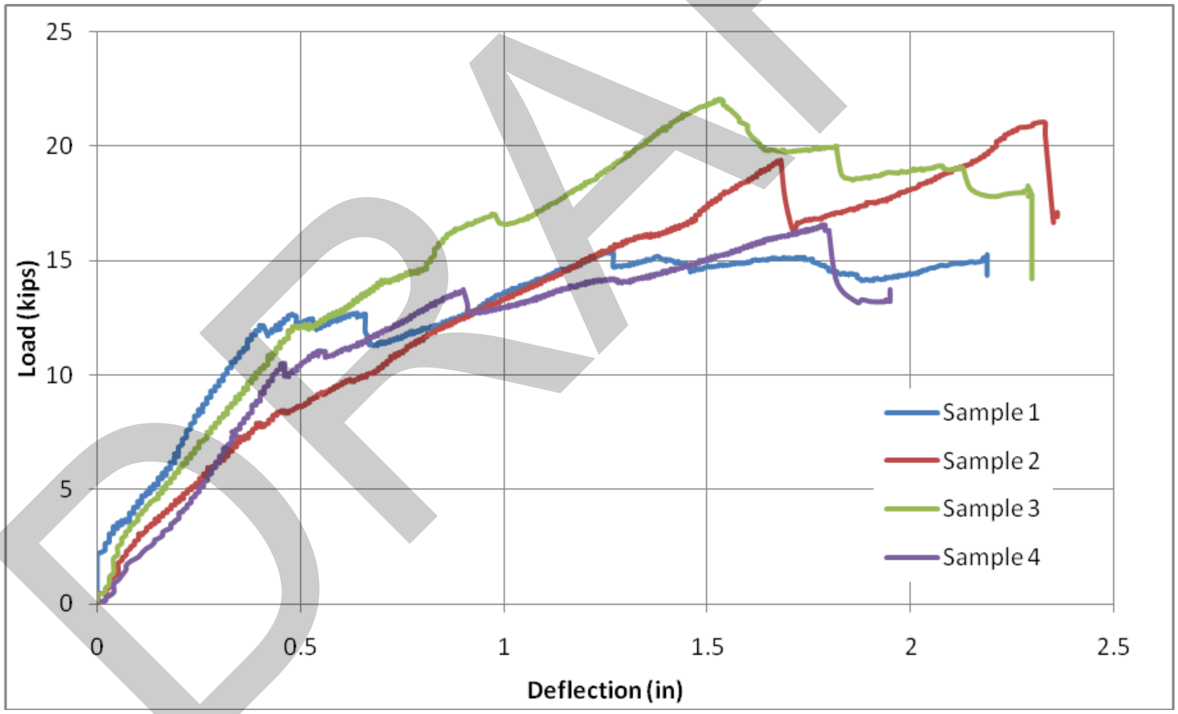

Figure 16: 16-inch Vinyl Ester Crush Strength Results

7. Connection Testing A – Transverse Pin Test

For each size and material tested, similar types of load and deflection results were found. Although the maximum loads differ for each material, the behavior was always the same. Eventually the load would not go any higher because the pin deflection was steadily increasing. As opposed to a catastrophic failure characterized by global cracking and delamination as seen in the bending and crush tests, this type of loading seemed to just push its way through the material locally (See Figure 17), i.e., large ductility was noted after initial cracking.

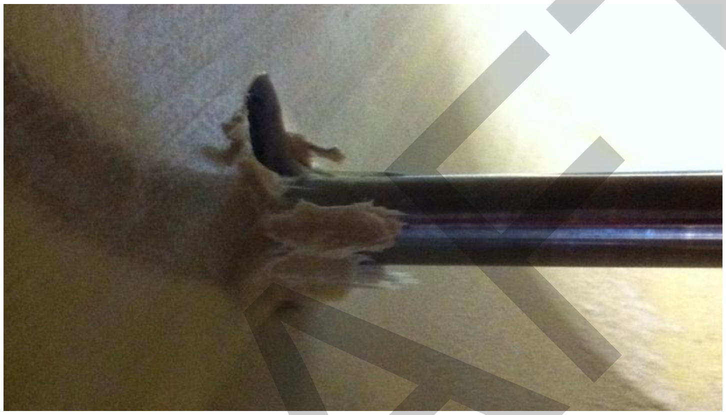

Figure 17: Typical Failure of Connection Test A

The load versus deflection curves for each material set are shown in Figures 18 - 20. Sample 1 is not shown because the LVDTs were not working properly and the load was terminated before failure. Also, as mentioned earlier (in methodology section), Samples 1-3 were not loaded as far as others because of setup uncertainties. Right deflection in Sample 4 also had an error at about .58 inches, but every sample tested after the initial ones was without error.

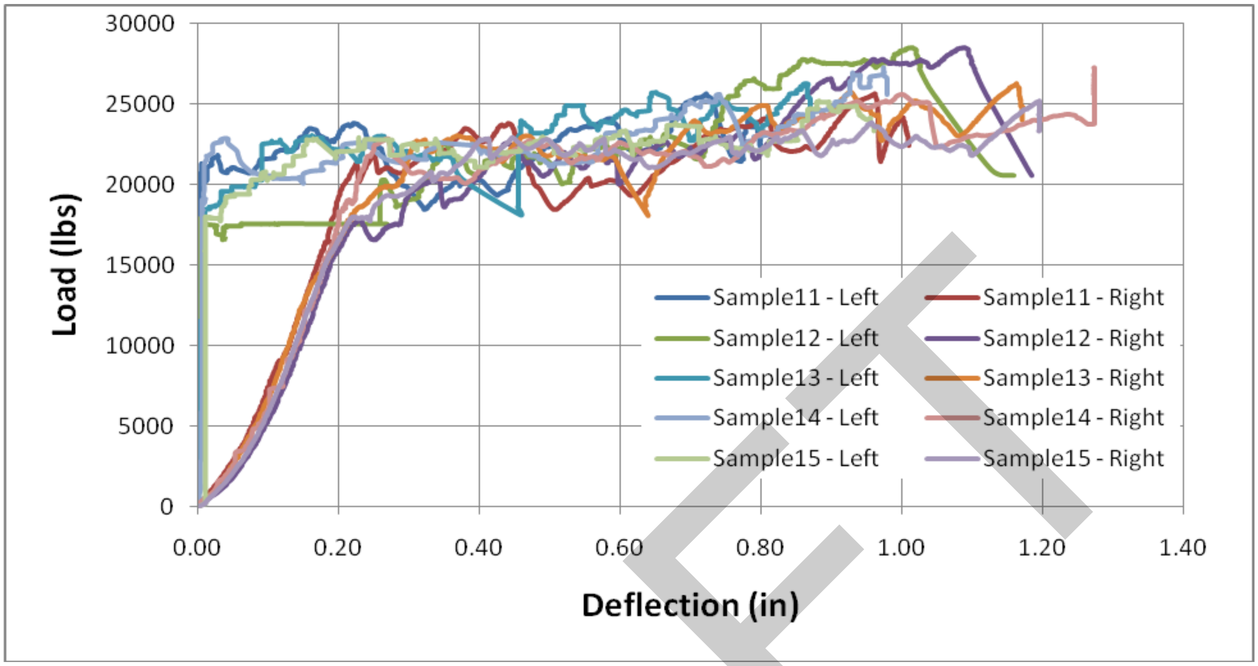

Figure 18:12 inch Connection Test A Results

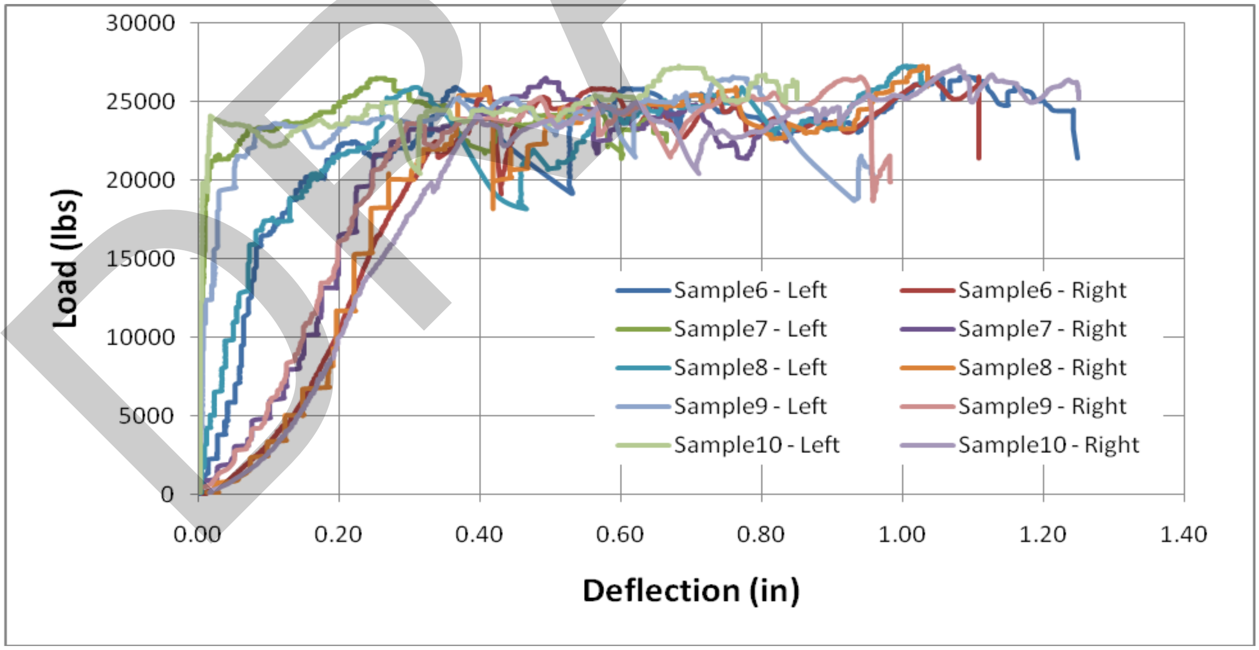

Figure 19: 16 inch Polyurethane Connection Test A Results

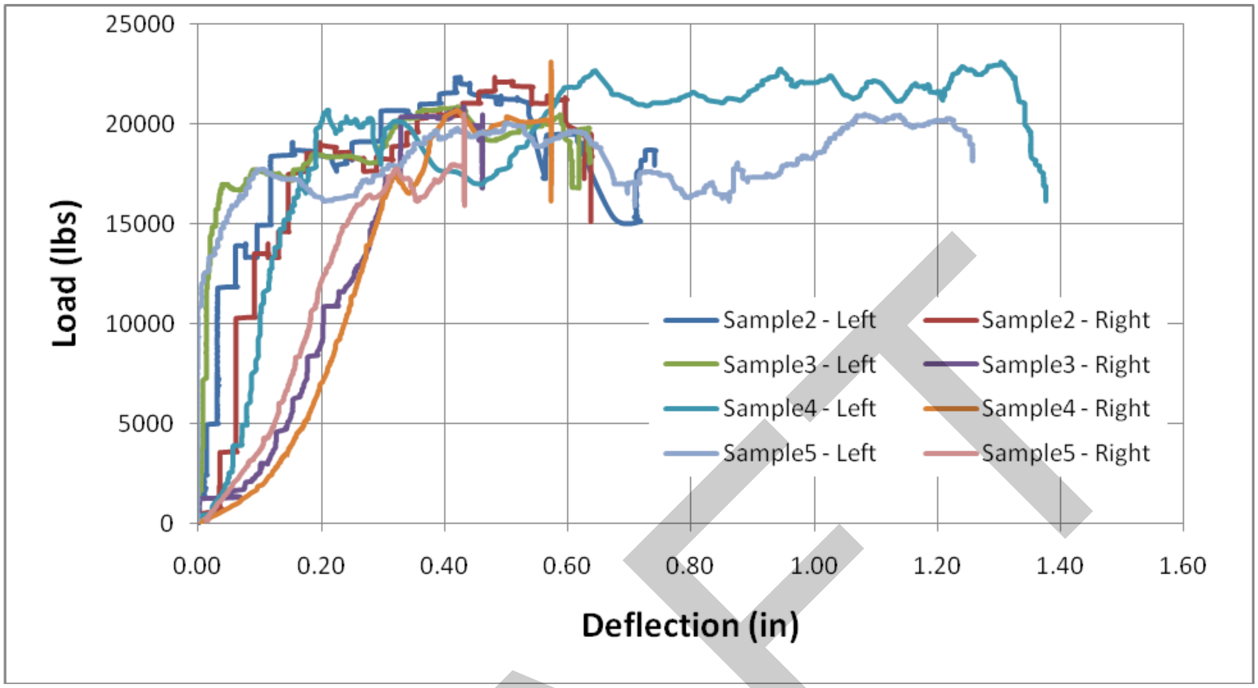

Figure 20: 16 inch Vinyl Ester Connection Test A Results

The load versus deflection curves reveal that a maximum load of approximately 18-20 kips was reached in the 16” vinyl ester samples, while the 16” polyurethane samples reached maximum loads of ~23-25 kips, and the 12” polyurethane samples reached a maximum load of ~22.5 kips.

8. Connection Testing B – Washer Test

The failure behavior of the washer testing was found to be local depression around the area of the washer and the washer itself deformed greatly until the load application tools were flat against the test samples (Figure 21). Loading was taken up to about the same point on each sample after initial behavior was witnessed. As seen in Figure 21 the 6 in washer eventually dug into the FRP material and created cracks that propagated along a significant longitudinal distance from the washer (Figure 21). The 6 in washers generally caused less local damage to the sample at equal loads when compared to the 4 in washer. The washer testing results had similar cracking and failure modes on all materials and even all washers; however, the 4 inch washer would create a more local depression and usually caused more local damage (Figure 22). Deflections were obtained using a tape measure at the bottom, measuring the distance from the sample and the nut and are reported in Table 7. The values Table 7 show how much deflection the local depression of the washer caused. These results however vary based on how much load was actually applied which is different with each case so they should be viewed with caution.

Figure 21: 16-in Sample with 6-in Washer at about 21 kips

Figure 22: 12-in Sample with 4-in Washer

Table 7: Connection Test B Results

Pile Type	Washer Size (in)	Sample (ID #)	Max Load (lbs)	Deflection at Max Load (in)	Average Load (lbs)
16 inch Diameter, 1/2 inch Wall, 72 inch span Polyurethane	4	1	16,402		17,210
		2 (PU6)	17,540	1.563	
		3 (PU6)	17,688	1.750	
	6	1	23,230		22,228
		2 (PU4)	21,226	1.938	
16 inch Diameter, 1/2 inch Wall, 72 inch span Vinylester	4	1	13,161		14,291
		2 (VE2)	15,115	2.188	
		3 (VE4)	14,596	1.500	
	6	1 (VE1)	17,738	1.563	17,837
		2 (VE6)	18,851	1.625	
		3 (VE2)	16,921	1.813	
12 inch Diameter, 1/2 inch Wall, 60 inch span	4	1 (S6)	21,275	1.250	19,569
		2	17,985	1.500	
		3	19,445	1.250	
	6	1 (S1)	24,219	1.563	27,642
		2	24,120	1.750	
		3	34,585	1.563	

9. Four Point Bending Fatigue

Each fatigue sample underwent the respective range of loading shown in Table 8. As mentioned earlier the frequency of loading was.075 Hz (cycles/sec).

Table 8: Fatigue Loading Ranges

Material	Average Low Load (kips)	Average Max Load (kips)
12"	4.8	36.41
16" PU	6.94	38.64
16" VE	5.39	36.44

When each of the fatigued samples was tested to failure, both the 16 inch samples failed under the applied load, i.e., under a steel saddle. The 12 inch sample failed in the middle third zone. Deflections were only obtained for one of the samples, because that sampled failed violently and damaged the string pot. The results from these samples are show in Table 9. Also, Table 9 provides the percent change in the results between the average static test data and the fatigue test data.

Table 9: Four Point Bending Fatigue - Failure Results

Samples under Fatigue	Max Load (kip)	Max Deflection (in)	Max Moment (k-in)	Max Stress (ksi)	Max Longitudinal Strain (με)	Elastic Modulus (Msi)	Energy (load*defl) (kip-in)
12 inch PU Sample 6	95.85	-	3834	76.89	12941	5.82	-
Percent Difference from Average	5.14	-	5.14	5.14	1.71	-13.56	-
16 inch PU Sample 6	103.72	-	5549	60.65	10372	5.76	-
Percent Difference from Average	2.97	-	3.34	3.34	-8.80	0.16	-
16 inch VE Sample 6	79.00	7.89	4227	46.20	7545	6.05	347.65
Percent Difference from Average	-5.14	-53.46	-6.12	-6.12	-18.13	7.81	-64.62

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SUSTAINABLE LUMBER

SeaTimber® Flexural Properties

Tangent SeaTimber (profile-ST-rebar)	Actual Height (in)	Actual Width (in)	Rebar Quantity (ea)	Rebar Size (in)	Flexural Strength (psi)	Flexural Modulus (psi)	Stiffness EI (lb-in^2)	Moment Capacity (kip-ft)	Weight Range (lb/ft)
8x12-ST-0F00	7 1/2	11 5/8	0	N/A	2,620	154,000	5.73E+07	22	31-38
8x12-ST-4F08	7 1/2	11 5/8	4	1	3,720	219,000	8.16E+07	31	32-39
8x12-ST-4F10	7 1/2	11 5/8	4	1 1/4	4,360	290,000	1.08E+08	36	33-40
8x12-ST-4F11	7 1/2	11 5/8	4	1 3/8	4,670	311,000	1.16E+08	39	33-41
8x12-ST-4F12	7 1/2	11 5/8	4	1 1/2	5,140	343,000	1.28E+07	43	34-41
8x12-ST-4F13	7 1/2	11 5/8	4	1 5/8	5,450	379,000	1.41E+07	45	34-42
8x12-ST-4F14	7 1/2	11 5/8	4	1 3/4	5,800	414,000	1.54E+07	48	35-42
12x8-ST-0F00	11 5/8	7 1/2	0	N/A	2,740	161,000	1.40E+08	35	31-38
12x8-ST-4F08	11 5/8	7 1/2	4	1	3,660	242,000	2.10E+08	46	32-39
12x8-ST-4F10	11 5/8	7 1/2	4	1 1/4	4,360	349,000	3.03E+08	55	33-40
12x8-ST-4F11	11 5/8	7 1/2	4	1 3/8	4,860	389,000	3.38E+08	61	33-41
12x8-ST-4F12	11 5/8	7 1/2	4	1 1/2	5,190	433,000	3.77E+08	65	34-41
12x8-ST-4F13	11 5/8	7 1/2	4	1 5/8	5,680	486,000	4.23E+08	72	34-42
12x8-ST-4F14	11 5/8	7 1/2	4	1 3/4	5,850	532,000	4.53E+08	74	35-42
10x10-ST-0F00	9 7/8	9 7/8	0	N/A	2,700	159,000	1.38E+08	34	33-40
10x10-ST-4F08	9 7/8	9 7/8	4	1	4,610	278,000	2.05E+08	45	34-41
10x10-ST-4F10	9 7/8	9 7/8	4	1 1/4	6,140	351,000	2.59E+08	76	34-42
10x10-ST-4F11	9 7/8	9 7/8	4	1 3/8	6,960	398,000	2.94E+08	86	35-42
10x10-ST-4F12	9 7/8	9 7/8	4	1 1/2	8,280	460,000	3.39E+08	103	35-43
10x10-ST-4F13	9 7/8	9 7/8	4	1 5/8	8,810	503,000	3.71E+08	109	36-44
10x10-ST-4F14	9 7/8	9 7/8	4	1 3/4	9,790	560,000	4.13E+08	121	37-45
12x12-ST-0F00	11 7/8	11 7/8	0	N/A	2,600	155,000	1.14E+08	57	42-51
12x12-ST-4F08	11 7/8	11 7/8	4	1	5,474	290,200	4.68E+08	125	43-52
12x12-ST-4F10	11 7/8	11 7/8	4	1 1/4	6,327	340,900	5.50E+08	144	44-52
12x12-ST-4F11	11 7/8	11 7/8	4	1 3/8	8,413	386,200	6.23E+08	191	45-53
12x12-ST-4F12	11 7/8	11 7/8	4	1 1/2	9,266	448,200	7.23E+08	211	46-53
12x12-ST-4F13	11 7/8	11 7/8	4	1 5/8	10,000*	516,000	8.32E+08	228*	46-54
12x12-ST-8F08	11 7/8	11 7/8	8	1	8,878	483,800	7.80E+08	202	47-55
12x12-ST-8F10	11 7/8	11 7/8	8	1 1/4	10,364	556,000	8.64E+08	226	48-56
12x12-ST-8F11	11 7/8	11 7/8	8	1 3/8	12,440	715,500	1.11E+09	271	48-56
12x12-ST-8F12	11 7/8	11 7/8	8	1 1/2	13,000	788,600	1.22E+09	283	50-59
12x12-ST-8F13	11 7/8	11 7/8	8	1 5/8	14,800	882,000	1.37E+09	325	52-60

Flexural values are ultimate. Resistance factors (LRFD) or safety factors (ASD) must be applied to these values.
Flexural Modulus is a Secant Modulus at 1% strain per ASTM D790. Some values for intermediate configurations have been interpolated.
* Values are projected based on flexural tests of similar sections

SeaPile® and SeaTi
Field Installation Guide

When installing the SeaPile® and SeaTimber®, the user must take the proper precautions used in installing all other types of piling; when cutting, finishing or attaching the SeaPile® and SeaTimber®, the user should also take all normal precautions, including, but not limited to, the use of hard hats, safety glasses, hearing protection and safety shoes. Operators should be aware of the weight of the SeaPile® and SeaTimber® prior to lifting. There are no toxic characteristics associated with the SeaPile® and SeaTimber®. Accordingly, shavings or cut ends may be disposed of wherever plastic is accepted.

LIKE ANY PLASTIC PRODUCT, SEAPILE® AND SEATIMBER® WILL BURN. THEREFORE, AVOID THE USE OF CUTTING TORCHES OR ANY OTHER OPEN FLAME DEVICES AROUND THE SEAPILE® COMPOSITE MARINE PILING.

DRIVING

The SeaPile® Composite Marine Piling exhibits many of the same driving characteristics of a timber pile. Since it is easy to drive, a lightweight hammer with a rated energy of between 8,000 and 15,000 ft-lbs may be used. Care should be taken in selecting the appropriate hammer for the length of pile to be driven. Once the hammer has been selected, a flat driving head should be used to ensure full surface contact with the squared flat top of the entire cross-sectional area of the pile. SeaPile® are designed to absorb energy, which is key to their performance as a fender piles, however, as a result, they are less efficient to drive than steel, concrete, or timber piles and will take more blows per foot.

A vibratory pile driver may be used to drive the SeaPile® Composite Marine Piling when conditions would permit vibratory driving of traditional timber piling. When planning to use a vibratory pile driver, consider fabricating a steel helmet to minimize damage to the top of the pile, alternatively piles can be supplied in a longer length and trimmed after being installed.

DRIVING POINTS OR SHOES

Steel driving shoes are not typically required, however they can be purchased and factory installed if difficult driving conditions are anticipated.

JETTING

SeaPile® can be jetted in a manner similar to any traditional timber pile. The post-driving procedures also remain the same.

CUTTING

SeaPile® & SeaTimber® are tough and harder to cut than timber. The fiberglass rebars are particularly difficult to cut through without the correct tools. We recommend the following:

Chainsaw:

- Stihl MS 661 Series, or similar

Chain Bar:

- 0.404 pitch with a 4040-7 sprocket
- 25” to 34” bar length for SeaPile® up to 13” Ø & SeaTimber® up to 12”x12”
- 34” bar length for 16” SeaPile®

Chain:

- RAPCO’s Impact Resistant Chisel Carbide Tip Chainsaw Chain
- 0.404” pitch w/ 0.63” gauge
- RAPCO Part# B3LM-T-RF
- RAPCO Vancouver, WA: **sales@rapcoindustries.com** (800-959-6130)

- Slow, consistent cutting keeping chain temperature low will greatly extend the chain life; excessive heat will stretch the chain beyond adjustment before chisel tips need sharpening
- Do not use bar/chain oil; oil will mix with the hot plastic and emulsify seizing the bar sprocket and chain within the bar
- Between cuts chainsaw should be blown with compressed air to remove shavings

Life Expectancy of Carbide Tipped Chains	
10” SeaPile®	8 to 10 cuts
13” SeaPile®	8 to 10 cuts
16” SeaPile®	6 to 10 cuts
8x12, 10x10, 10x12, 12x12 SeaTimber®	8 to 10 cuts

DRILLING / COUNTER BORING

Drill:

The following drill specification is recommended for all drilling and countersinking:

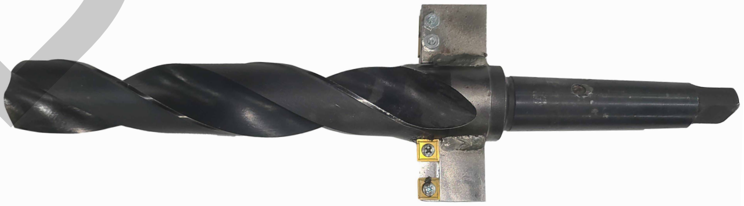
- Electric: 3/4” chuck or 3 Morse Taper, 250-350 rpm
- Pneumatic: 3/4” chuck, 1.5 to 2 HP, 200-350 rpm
- Minimum Torque: 1,800 in-lb

Drilling and Counter Boring SeaTimber® with No Rebar:

- Standard high-speed steel twist drills are suitable for drilling holes up to 1-1/2” diameter
- For larger holes, a 1” or 1-1/8” Ø pilot hole is recommended, followed by a counter-bore type bit to enlarge the hole to the finished diameter; counter-bore bits can be purchased, fabricated at local machine shop or purchased from Tangent; consult a Tangent rep for custom bits; allow for leadtime

Drilling and Counter Boring SeaTimber® with Rebar:

- Drill a 1” or 1-1/8” Ø pilot hole with a standard high-speed steel twist drill or carbide tipped twist bit if drilling through rebar
- Follow with a carbide insert, counter-bore type bit; consult Tangent rep for custom bits; allow for leadtime
- *CAUTION: Apply light pressure to reduce the risk of the bit snagging on the bar and violently spinning the drill*



Thermal Expansion and Contraction:

- Holes and counter-bored holes are oversized or slotted to allow for the Coefficient of Thermal Expansion/Contraction of SeaTimber® which is larger than traditional materials
- SeaTimber® with fiberglass rebar reinforcing = 0.00002 in/in/°F
- SeaTimber® with fiberglass filament rebar reinforcing, but no rebar = 0.000033 in/in/°F

RECOMMENDED REPAIR PROCEDURE

SeaPile® & SeaTimber® are incredibly durable. There is no need to patch or repair abrasions, cuts or grooves for any other reason than aesthetics.

If repairs are required, it's recommended that a commercially available plastic welder is used with the appropriately colored welding rod to build up the area to be patched. The repaired surface can then be sanded flush.

If a plastic welder is not available, a less refined repair method is detailed below:

Required Tools:

- Propane torch
- Shavings of plastic matrix, left over from drilling or cutting
- Putty knife
- Sandpaper (80-100 grit) and wooden block
- Orbital or palm type sander

For Small Patches:

- Pre-heat the hole until the surrounding plastic is soft & tacky, not runny
- Quickly press shavings into the hole and heat until liquified
- Repeat in layers, until the filled void is flush, or standing slightly proud of the surface
- Allow each layer to cool before applying the next
- Sand the patch area, blending in until flush with the outer surface

For Larger Patches:

- Cut a plug from a cut off to a slightly smaller shape than the void
- Pre-heat the hole until the surrounding plastic is soft & tacky, not runny
- Quickly press shavings into the hole and heat until liquified
- Pre-heat the plug and press into the depression
- Press shavings into the gap around the plug and heat until liquified
- Repeat in layers, until the gap is flush, or standing slightly proud of the surface
- Allow each layer to cool before applying the next
- Sand the patch area, blending in until flush with the outer surface

TANGENT®
SUSTAINABLE LUMBER

SeaPile® and SeaTi

Field Installation Guide

LIFTING & HANDLING

The following considerations are recommended to resist damage when lifting SeaPile® and SeaTimber®:

- Verify the weights and lengths of the material before each lift
- Short length may be handled with care by forklift
- Use a lifting beam to handle longer lengths with pick points at 1/5 of the overall length
- Use a nylon sling or choker to lift without damaging the surface
- All lifting plans and procedures are the responsibility of the customer

STORAGE

The following considerations are recommended to resist damage when storing:

- Use minimum 4 x 4” dunnage for support
- SeaPile®: support at 6’ to 10’ increments
- SeaTimber®: support at 4’ increments
- Stack SeaPile® and SeaTimber® no more than 5’ in height
- Chock, band, or tie to secure the stack appropriately
- If stored for an extended period, check the stack periodically for stability
- Store on level surface and bring to project site 24 hours before installation for material to acclimate to ambient temperatures

APPENDIX E
SOIL PROPERTIES

Section	TOW El (ft)	Mudline El (ft)	Layer 1: Alluvial Sediment					Layer 1: Beaumont Clay					Layer 3: Beaumont Sands	
			D (ft)	c' (psf)	ϕ' (deg)	Su - top (psf)	Su - bottom (psf)	D (ft)	c' (psf)	ϕ' (deg)	Su - top	Su - bottom	D (ft)	ϕ' (deg)
C1	9.0	-10.0	23	42	26	60	336	42	150	28	3012	5956	74	37
C2	9.0	-14.0	27	42	26	200	324	45	150	28	3288	4392	57	37
C3	9.0	-5.0	18	42	26	200	486	38	150	28	2644	4392	57	37
C4	9.0	-9.0	22	42	26	200	488	42	150	28	3012	484	58	37
C5	9.0	-14.5	28	42	26	200	458	45	150	28	3288	4944	63	37

TOW: Top of Wall

D (ft): Distance to top of layer from TOW

Su adjusted to ignore top 4-ft of alluvial sediments