Topic: Waterfront Structures
Tuesday June 22nd
12:10 pm - 12:40 pm
.5 PDH

FRP Sheet Piling Design and Installation

Dustin Troutman
Director of Marketing and Product Development
Creative Composites Group

Composites
AN INFINITE WORLD OF POSSIBILITIES

Pultruded Sheet Piling

Agenda Info

- Typical Applications
- Installation Techniques
- Standard Details
- Process and Materials
- Design Values and Validation

Hurricane Sandy 2012 Repair and Protect

2.5 miles of Completed Cantilever Storm Wall

LONG BEACH, NEW YORK BOARDWALK

LONG BEACH, NEW YORK BOARDWALK

Bulkhead Example:

Tied-back wall with FRP wale

Storm outfall pipe penetration

35’ long sheets

Polyester Resin

CITY OF OCEAN CITY, NJ

EGG HARBOR / MARGATE, NJ

Hurricane Sandy Repair & Storm Protection

LAURENCE HARBOR, NJ

COLBOURNE CREEK BOAT RAMP - MD DNR - MARION STATION, MD

After Hurricane Matthew

HARBOUR ISLAND, SC

MARGATE, NJ

SARASOTA, FL

3,280 ft (1000+ meters) Causeway

AZERBAIJAN PROJECT

BEAUFORT, SC

Elevated Bridge Approach

SOUTHAMPTON, NY

Installation Options Include

- Water Jetting
- Vibro Hammer e.g. ICE Model 6E
- Vibratory Compactor

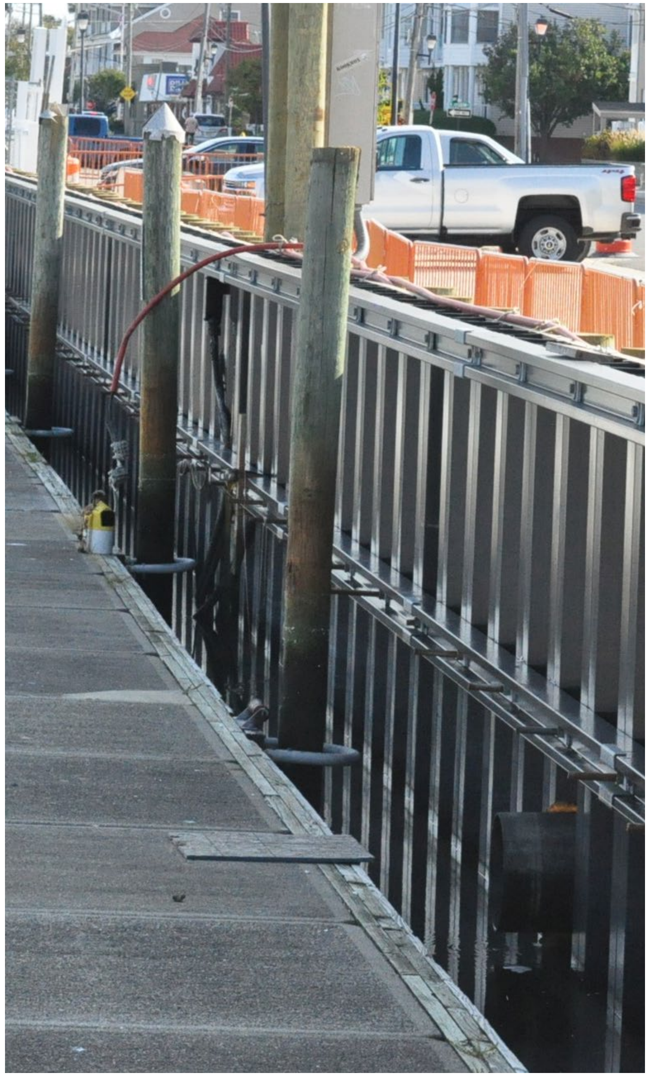
Can be driven in soils with a Blow Count of 20 or less without a mandrel.

FRP Sheet Piling Typical Designs

Tied Back from Concrete Cap

Curved Wall with Concrete CAP

Cut-Off Walls



Tied Back FRP Wales into Timber Piles

FRP Sheet Piling Typical Designs

NAVY Style Construction

Tie Rods with Anchors

Cantilever Walls

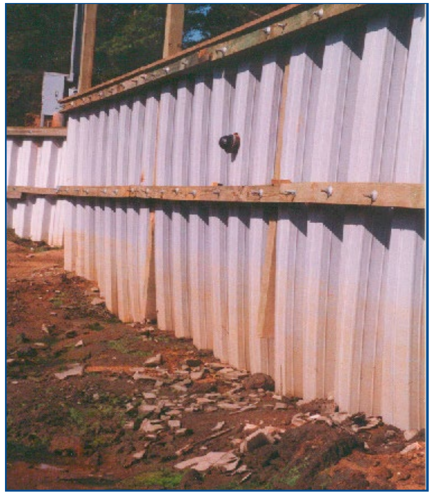
Why Specify FRP Sheet Piles?

Steel rusts

Concrete spalls

Wood Rots

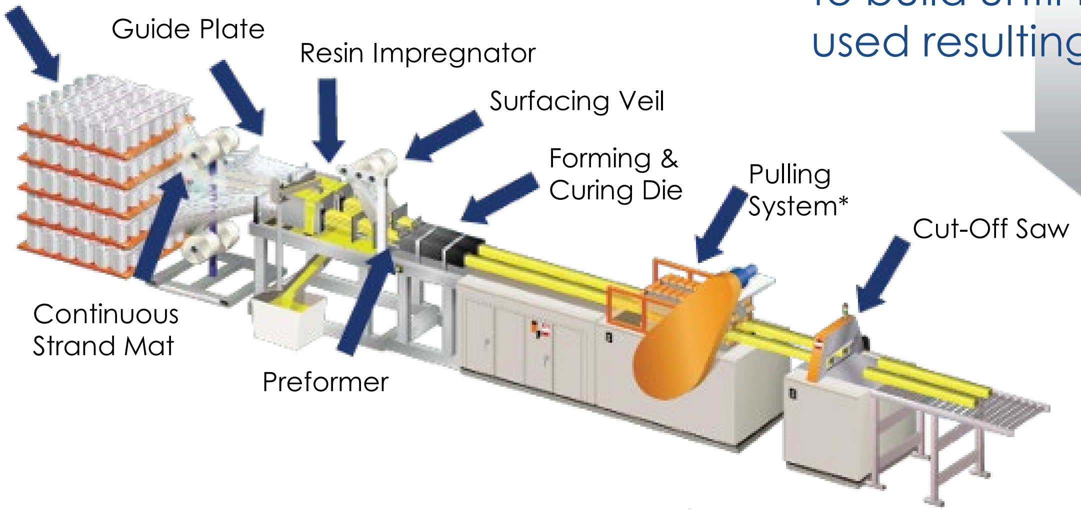
PVC deflects and requires additional walers



FRP Sheet Piles Are Manufactured By The Pultrusion Process

1. **Thermoset** resin and glass fiber reinforcements are combined and formed into the shape of the die on a continuous process.

2. The resin is initiated by the thermal decomposition process. The initiator is heated until a chemical bond dissociation produces two radicals. The chain continues to build until the monomer is used resulting in a cured resin.



Caterpillar Pullers (shown) or Reciprocating Pullers

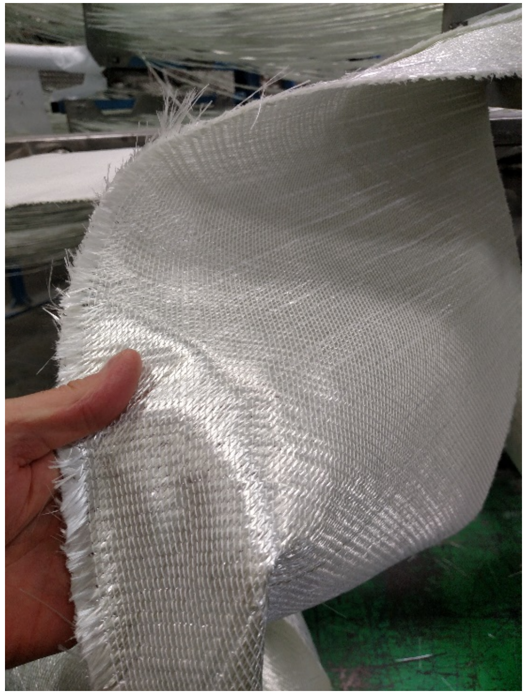
4. Pultruded profiles are cut to length during the continuous manufacturing process.

3. The profiles are pulled through a die.

Fiber Architecture

FRP Sheetpiles are made of E-glass Reinforcements.

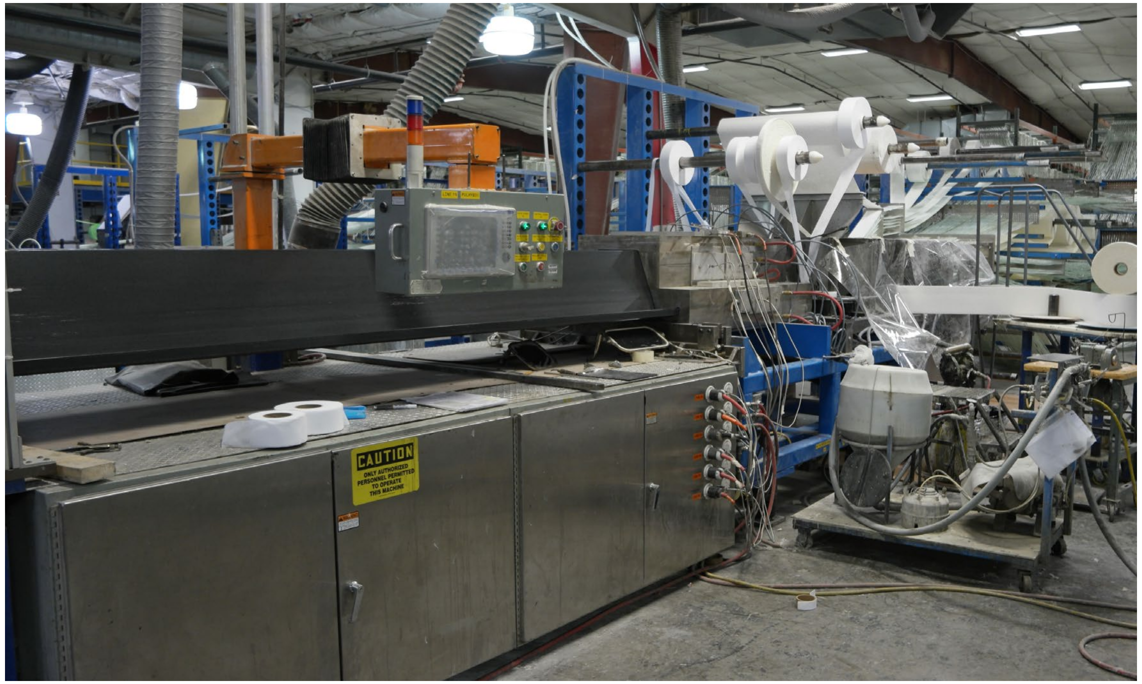
Unidirectional roving make up the bulk of the longitudinal properties



Engineered fabrics are stitched unidirectional that form a mat.

The roving are stitched at predetermined angles

Thermoplastic polyester veils are applied to the outer surface for added UV protection



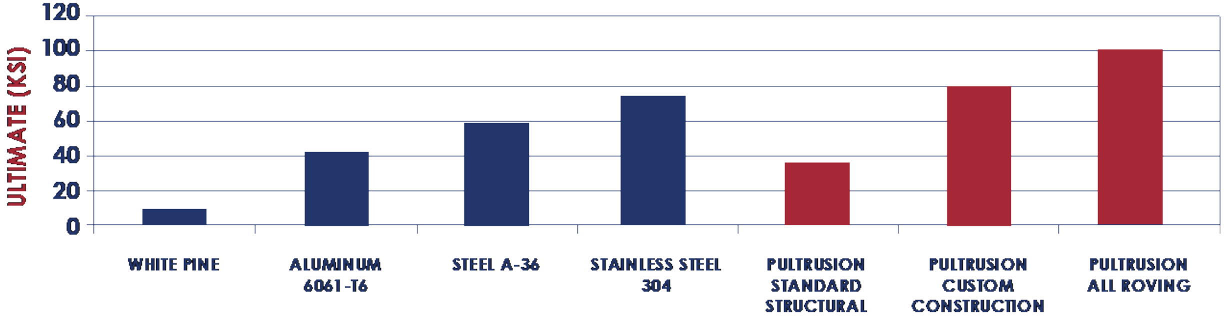
Glass reinforcements are guided into the die

The fiberglass is saturated with resin, in the die, and heat cured in a continuous process

Sheet piles are cut to length and prepared for shipment

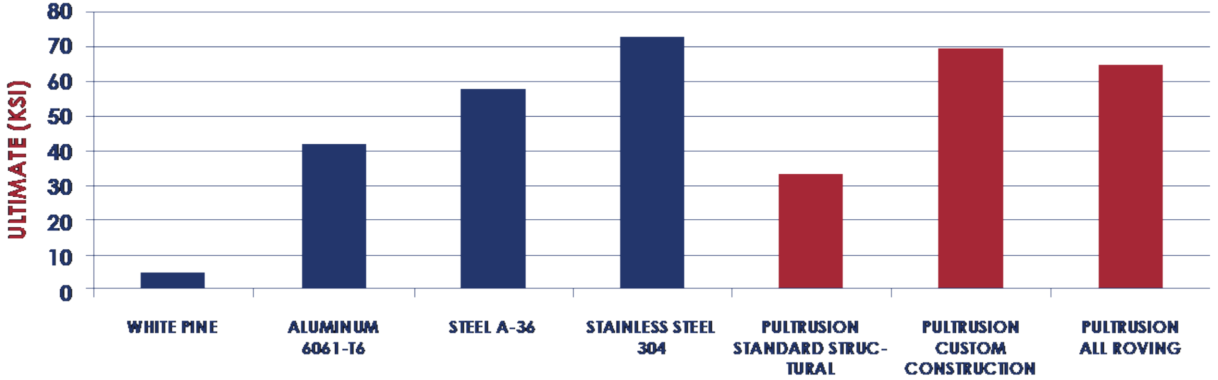
Material Properties, How Do Pultruded Composites Stack Up?

TENSILE STRENGTH



- Superior Tensile Strength/Stronger than A-36 Steel
- Linear Stress/Strain Curve with Little to No Yield

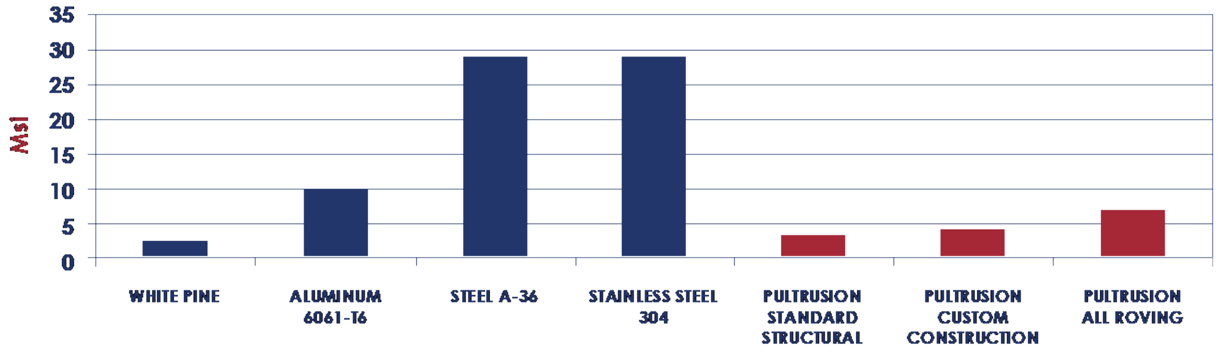
COMPRESSION STRENGTH



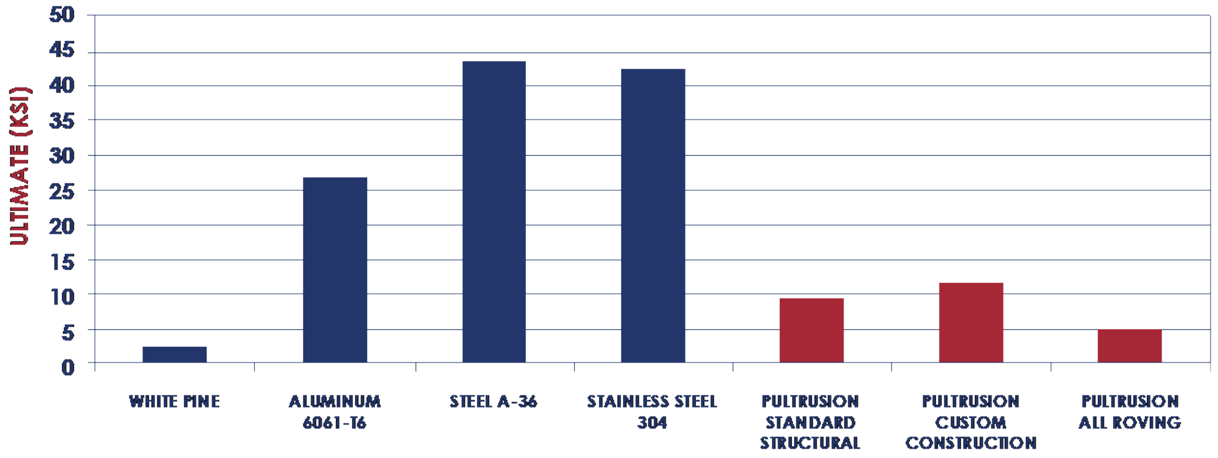
- Superior Compression Strength/Stronger 6061-T6 Aluminum
- Compression Strength and Compression Buckling Normally Govern the Design when Strength Governs

Material Properties, How Do Pultruded Composites Stack Up?

MODULUS OF ELASTICITY



SHEAR STRENGTH



- Lower Shear Strength than Steel and Aluminum
- Lower Shear Modulus than Steel and Aluminum; Serviceability Calculations Should Include Shear Deflection Computations, Especially for Short Spans

Moment Capacity Validation Of FRP Sheet Piles

Two Design approaches were utilized to predict the moment capacity of the 1580 Sheet Pile Section.

Mechanics of Materials and FEA

(a) *Compression flange local buckling*

$$f_{cr} = \frac{4\pi^2 t_f^2}{b_f^2}\left(\frac{\sqrt{(E_{L,f}E_{T,f})(1+4.1\xi)}}{6} + \left(2+0.62\xi^2\right)\left(\frac{E_{T,f}\nu_{LT}}{12} + \frac{G_{LT}}{6}\right)\right) \qquad (5.2.3.4\text{-}1)$$

with

$$\xi = \frac{1}{1+\dfrac{4E_{T,f}t_f^3}{5k_r b_f}} \qquad (5.2.3.4\text{-}2)$$

$$k_r = \frac{E_{T,w}t_w^3}{3h}\left(1-\left[\left(\frac{2t_f^2h^2E_{L,f}}{11.1b_f^2t_w^2E_{L,f}}\right)\left(\frac{\sqrt{E_{L,f}E_{T,f}} + E_{T,f}\nu_{LT} + 2G_{LT}}{1.25\sqrt{E_{L,w}E_{T,w}} + E_{T,w}\nu_{LT} + 2G_{LT}}\right)\right]\right) \qquad (5.2.3.4\text{-}3)$$

(b) *Web local buckling*

$$f_{cr} = \frac{11.1\pi^2 t_w^2}{6h^2}\left(1.25\sqrt{E_{L,w}E_{T,w}} + E_{T,w}\nu_{LT} + 2G_{LT}\right) \qquad (5.2.3.4\text{-}4)$$


Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures (Final)

Submitted to: American Composites Manufacturers Association (ACMA)

November 9, 2010

ASCE

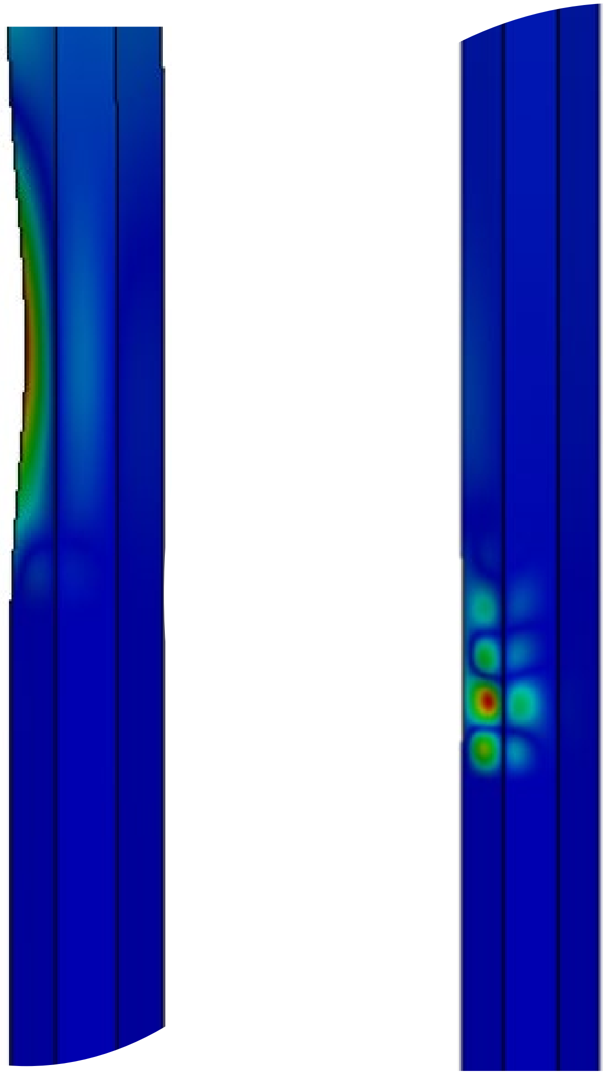
LRFD PRE-STANDARD local buckling equations were used to predict the critical buckling stress in each profile.

Finite Element Analysis

An FEA model was created using SolidWorks Simulation.

The simulation, based on the minimum mechanical properties, predicted a buckling stress of 12,044 psi or a ground line moment of 13,128 ft-lbs/ft of wall.

The mechanics of materials calculations predicted a moment capacity of 14,472 ft-lbs/ft of wall.



Full Section Testing To Failure

SUMMARY:

Mechanics of materials – 14,472 ft-lbs/ft of wall

FEA – 13,128 ft-lbs/ft of wall

Full Section – 16,569 ft-lbs/ft of wall

The Failure moment was 16,569 lb-ft/ft of wall which correlated to a compression stress of 15,201 psi. Note: the ultimate compression strength of the FRP material is about 50 Ksi. CAUTION!

Which Design Values Are Important?

Typical Spec.– which values are relevant?
Which value governs the capacity of the pultruded sheet pile section?

Steel Sheets are normally specified based on the factored yield strength and section modulus which equate to the moment capacity.

Steel has a modulus of elasticity of about 8x that of FRP, and most steel shapes have been designed to be compact sections. Hence, bucking is usually not a concern.

FRP sheet piles cannot be analyzed the same way. FRP materials do not have a traditional yield strength! In most cases the local compression buckling strength dictates the moment capacity.

SHEET PHYSICAL PROPERTIES

Minimum average physical properties (unless otherwise noted) of the finished sheet pile material shall be:

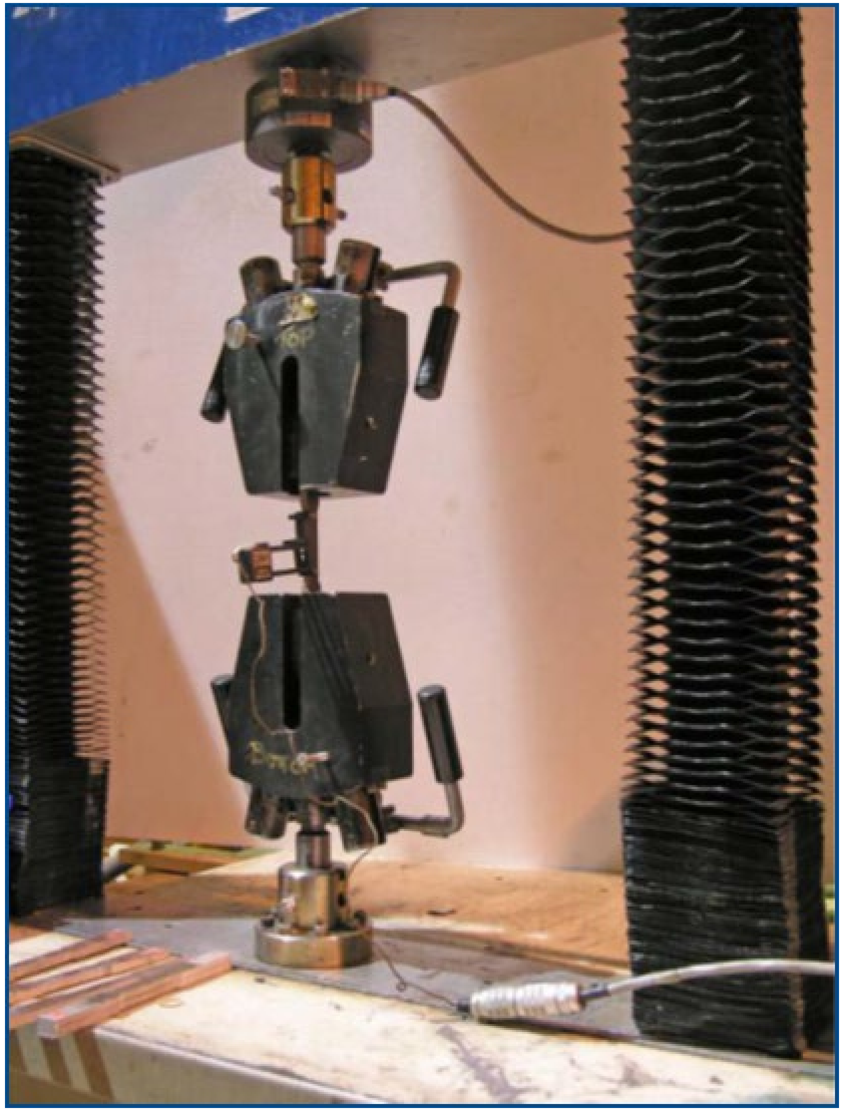
• Ultimate Flexural Stress (AL)	100,000 psi	ASTM D790-03
• Ultimate Flexural Modulus (AL)	4,200,000 psi	ASTM D790-03
• Ultimate Flexural Stress (AWS)	27,000 psi	ASTM D790-03
• Ultimate Flexural Modulus (AWS)	1,700,000 psi	ASTM D790-03
• Ultimate Tensile Stress (AL)	95,000 psi	ASTM D638-03
• Ultimate Tensile Modulus (AL)	4,600,000 psi	ASTM D638-03
• Ultimate Tensile Stress (AWS)	10,000 psi	ASTM D638-03
• Ultimate Tensile Modulus (AWS)	2,000,000 psi	ASTM D638-03
• Ultimate Shear Stress (AL)	5,000 psi	ASTM D3846-02
• Ultimate Shear Stress (AWS)	6,200 psi	ASTM D3846-02
• Ultimate Compression Stress (AL)	56,000 psi	ASTM D695-02a
• Ultimate Compression Modulus (AL)	806,000 psi	ASTM D695-02a
• Ultimate Compression Stress (AWS)	22,000 psi	ASTM D695-02a
• Ultimate Compression Modulus (AWS)	641,000 psi	ASTM D695-02a
• Izod Impact (AL)	59 ft-lb/in	ASTM D256-05
• Izod Impact (AWS)	20 ft-lb/in	ASTM D256-05
• Charpy Impact at 70°F (AL)	63 ft-lbs/in	ASTM D6110-08
• Charpy Impact at -30°F (AL)	61 ft-lbs/in	ASTM D6110-08
• Dynamic Modulus	862,240 psi (32°F)[A] 753,760 psi (100°F)[A]	ASTM D4065

Characteristic Design Strengths Should Be Published Per ASTM D7290

ASTM D7290 - 06(2017)

Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications

Active Standard ASTM D7290 | Developed by Subcommittee: D30.10



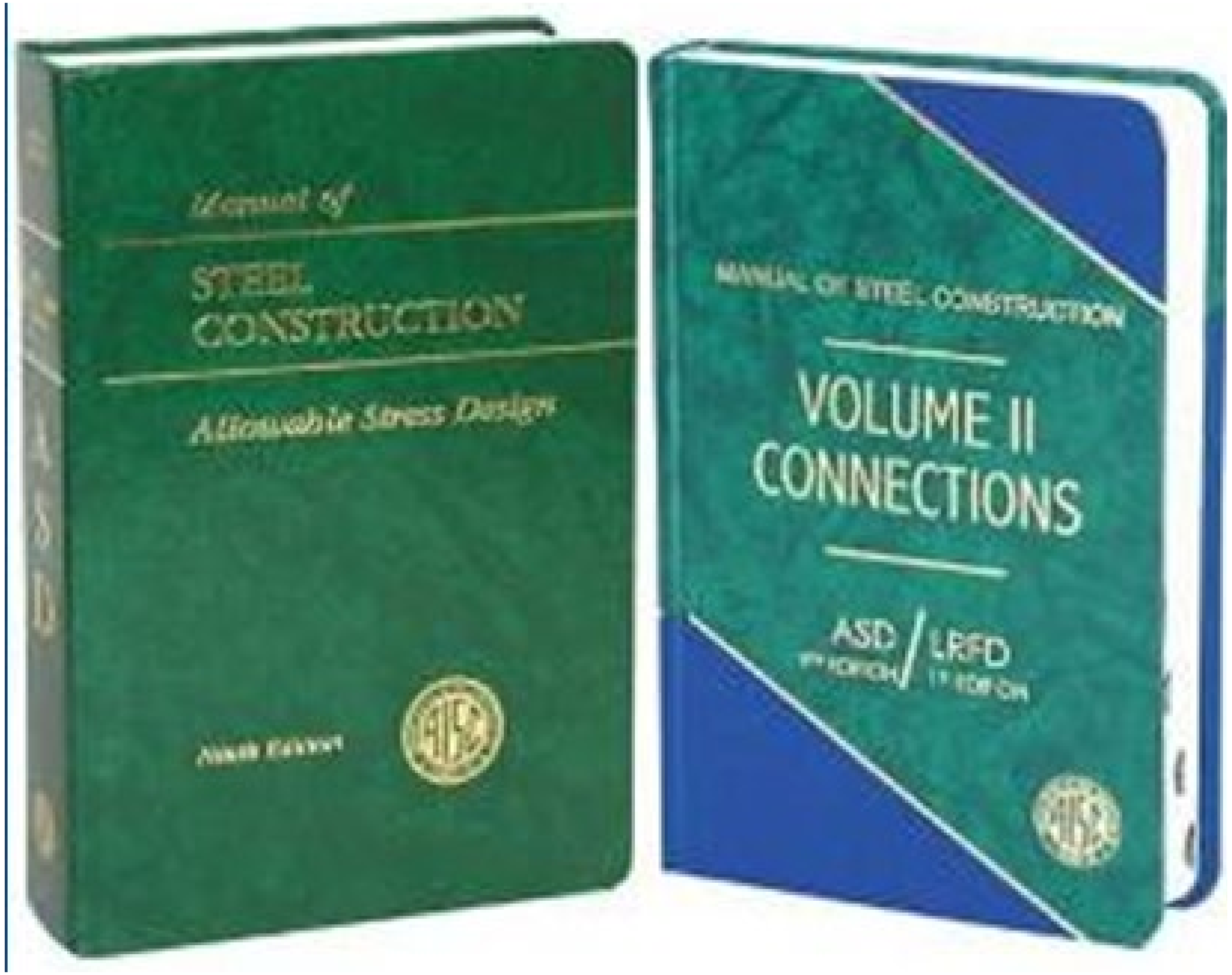
Why ASTM D7290?

It is an internationally recognized standard for evaluating material property characteristic values for polymeric composites for civil engineering structural applications.

The characteristic value is a statistically-based material property representing the 80% lower confidence bound on the 5th-percentile value of a specified population.

Characteristic Values Can Be Used For ASD or LRFD Design Approaches

- Typical industry ASD safety factors include:
  - 2.0 to 2.5 in flexure
  - 2.0 to 3.0 in shear
  - 2.5 to 3.0 for connections



Writing a Spec.

ASTM D7290 derived design strengths should be specified.

Can be used for ASD or LRFD design basis.

Series 1580 (SS860) 18″ (457.2mm) W x 8″ (203.2mm) H Mechanical Properties	Test Method	ASTM D7290-06 Characteristic Values				Units
		Polyester Resin		Vinyl Ester Resin		
		Imperial	Metric	Imperial	Metric	
Tensile Modulus (LW)	ASTM D638	3.47	22.96	3.41	23.51	Msi / GPa
Tensile Modulus (CW)	ASTM D638	1.22	8.41	1.45	10	Msi / GPa
Compression Modulus (LW)	ASTM D6641	3.6	24.82	3.27	22.55	Msi / GPa
Compression Modulus (CW)	ASTM D6641	0.88	6.07	1.23	8.48	Msi / GPa
Tensile Strength (LW)	ASTM D638	66.68	459.76	73.42	506.21	ksi / MPa
Tensile Strength (CW)	ASTM D638	6.31	43.53	8.81	60.74	ksi / MPa
Compression Strength (LW)	ASTM D6641	48.69	335.68	54.92	378.66	ksi / MPa
Compression Strength (CW)	ASTM D6641	13.87	95.66	15.05	103.77	ksi / MPa
Inplane Shear Strength	ASTM D5379	4.51	31.1	5.72	39.44	ksi / MPa
Inplane Shear Modulus	ASTM D5379	0.5	3.45	0.5	3.45	Msi / GPa
Short Beam Shear Strength	ASTM D2344	3.79	26.1	4.18	28.82	ksi / MPa

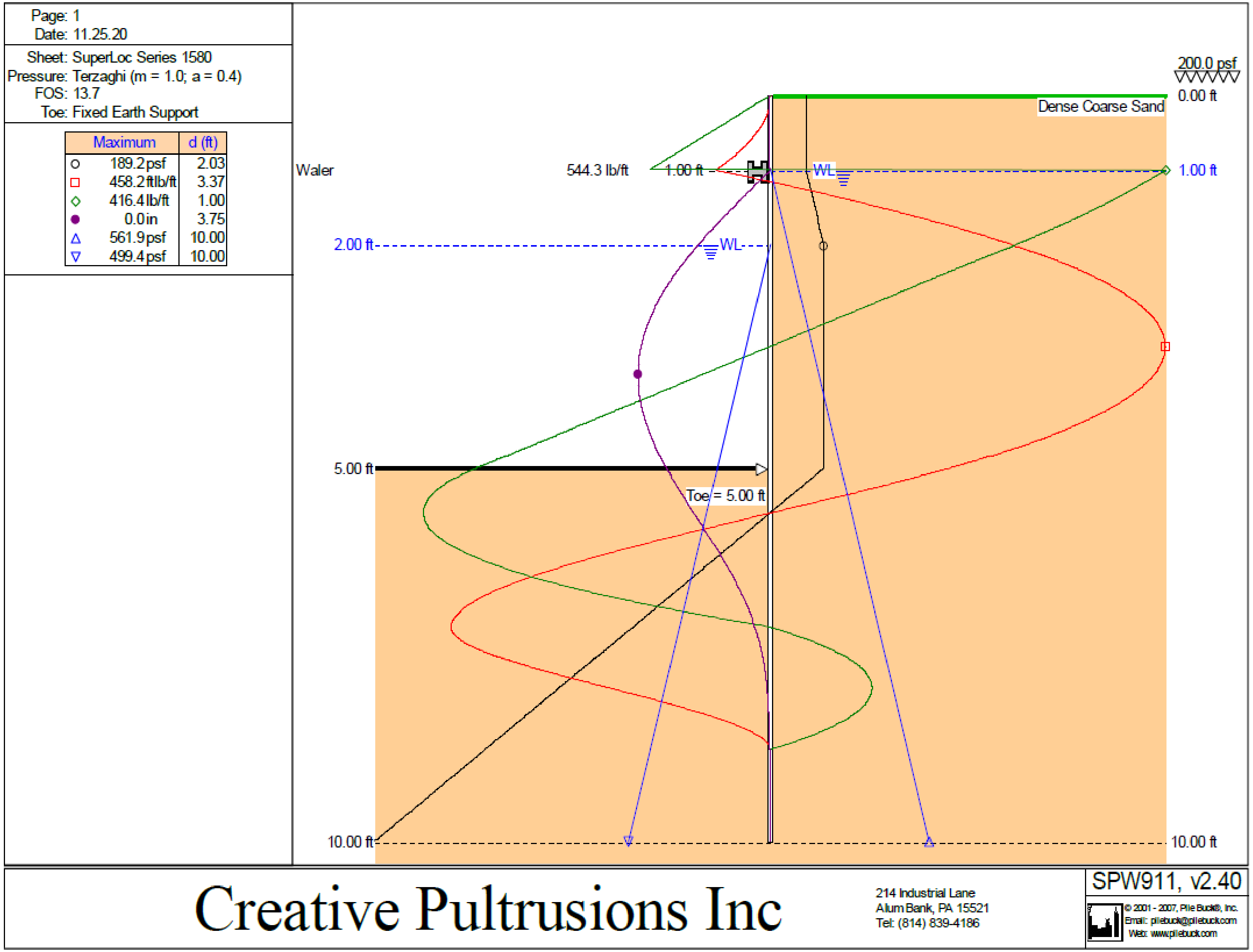
Series 1580 (SS860) 18″ (457.2mm) W x 8″ (203.2mm) H Mechanical Properties		
Moment Capacity	**Imperial**	**Metric**
Moment Capacity Polyester(1)	14,904 lb-ft/ft. of wall	66.3 kN-m/meter of wall
Moment Capacity Vinyl Ester(1)	16,795 lb-ft/ft. of wall	74.7 kN-m/meter of wall
Shear Strength	**Imperial**	**Metric**
Shear Strength Polyester(1)	26,321 lbs per ft. of wall	384.1 kN/meter of wall
Shear Strength Vinyl Ester(1)	31,203 lbs per ft. of wall	455.4 kN/meter of wall
Full Section Modulus of Elasticity	**Imperial**	**Metric**
Average Full Section Modulus of Elasticity(2)	4.41 Msi (Polyester) 4.56 Msi (Vinyl Ester)	30.41 GPa (Polyester) 31.44 GPa (Vinyl Ester)
Web Buckling Capacity from Wale Force (based on 8″ wale section)	2,376 lbs/ft of wall	34.7 kN/m of wall

Moment capacity derived via the LRFD Manual of Pultruded Fiber Reinforced Polymer Structures

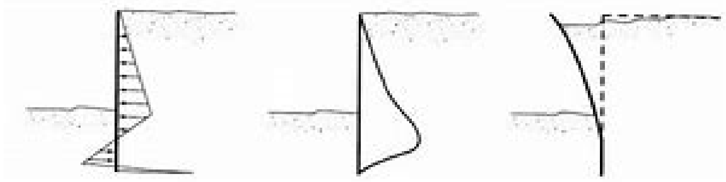
Note that the average modulus of elasticity values should be used for serviceability calculations

Engineering

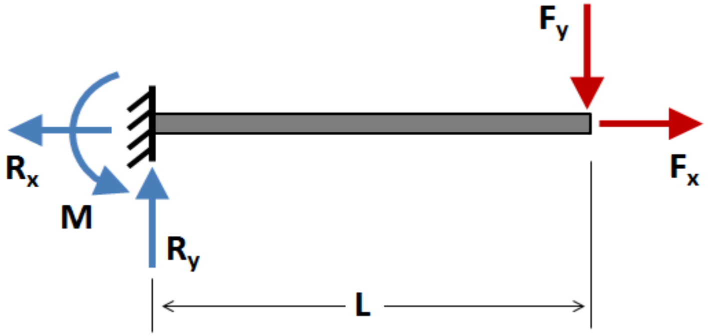
- Modeling software is readily available e.g. SPW911
- Geotechnical conditions, wall height, sheet pile section, water levels, slope angles and surcharges are considered in the design
- The wall is modeled, and the output is evaluated against the sheet pile capacity in terms of moment capacity, shear capacity, wale force on the sheet and serviceability.
- Recommended safety factors: 2.5 in flexure and 3 in shear



Important Design Considerations



Deflection – The modulus of elasticity shall be the lessor of the average coupon derived (LW) tensile, or compression E-modulus. Deflection, in a lot of cases, dictates the design.



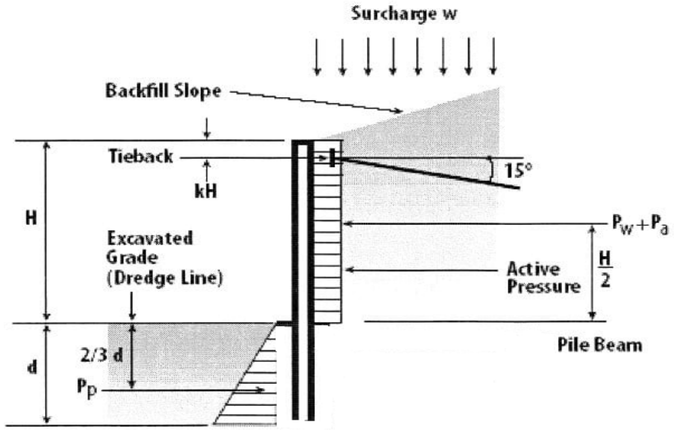
Moment Capacity –Based on the local compression buckling capacity of the sheet, not the yield strength! Caution!

Force on Wall Induced by Wale – Reference characteristic crush strength values published by the manufacture.

Drive Ability of the Sheets Based on the Soil Profile Including Blow Counts – Soils with blow counts of 20 or less can penetrated with FRP sheets.

Point Loads – Use oversized hardware to dissipate load

Severe Abrasion Installations (e.g. Heavy ice flow) – Not a fit



Concluding Points

- Safety factors of 2.5 are recommended for members in bending and 3.0 for shear
- FRP sheet piles are corrosion resistant, offer superior longevity and typically drive better than PVC sheet piling
- Engineers should specify material design properties based on ASTM D7290
- FRP sheet piles can typically be installed in soils with blow counts of 20 or less with vibro hammers
- Stiffer soils will more than likely require excavation or driving mandrel to ensure proper installation depth
- Pay particular attention to the deflection and point loads when designing FRP sheet pile walls.
- Always specify the manufactures recommended hardware to avoid stress risers
- Caps and connecters are common and offered by most manufacturers
- Consult with the manufacturer for proper design values, construction details and installation techniques – Not all pultruded sheet piles are the same!

Thank You!

Questions?

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