FRP Composites 101 for Architects

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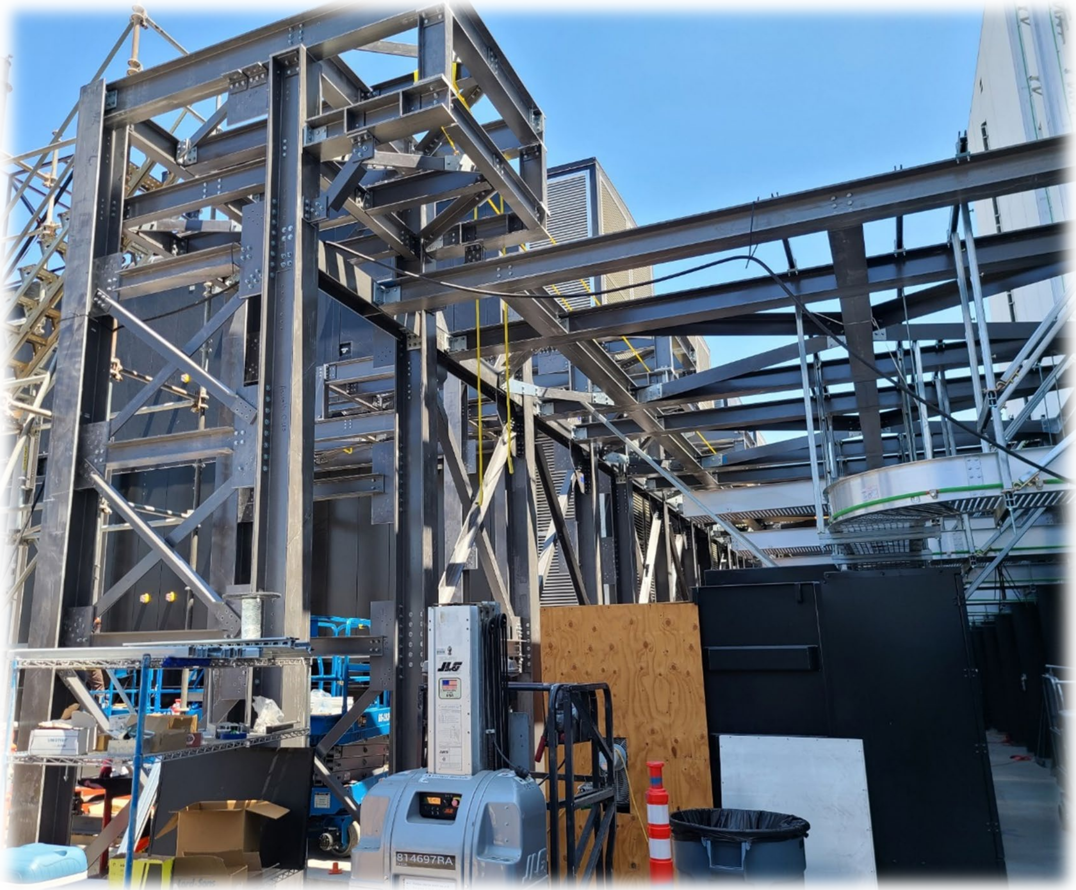
Composites
AN INFINITE WORLD OF POSSIBILITIES

Outline

1. Composite materials and manufacturing processes
2. Features and benefits of composite materials
3. Codes, standards, and specifications
4. Material performance and sustainability



Learning Objectives

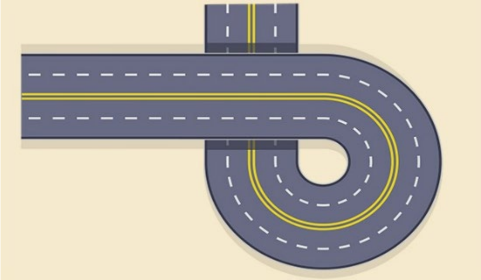
1. Fundamental understanding of composite materials and manufacturing processes
2. Features and benefits of composite materials focusing on key performance qualities related to safety, radio transparency, contribution LEED points, and fire resistance.
3. Why composite materials should be considered in architectural applications that cover cost versus performance, and sustainability benefits of designing with composites
4. Overview of regulations and specifications to be considered when using composites in architectural structures

Source: Compositeslab.com

Focus: Construction and Infrastructure

Aerospace

Architecture



Infrastructure

Marine

Automotive

Energy

Pipe & Tank

Transportation

Sports and Rec

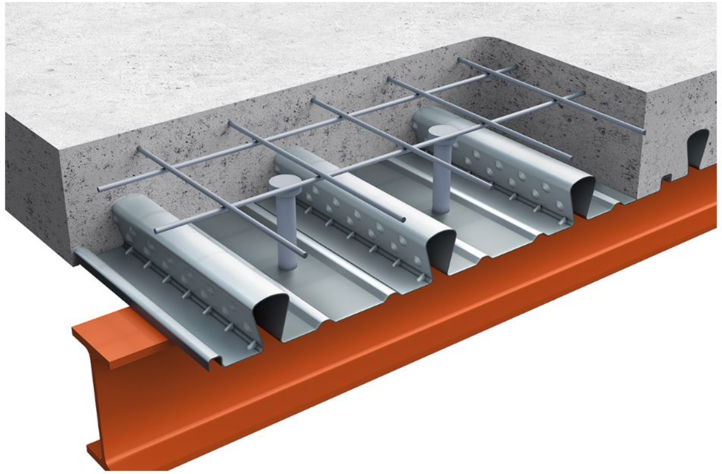
Source: Compositeslab.com

Composite materials and manufacturing processes

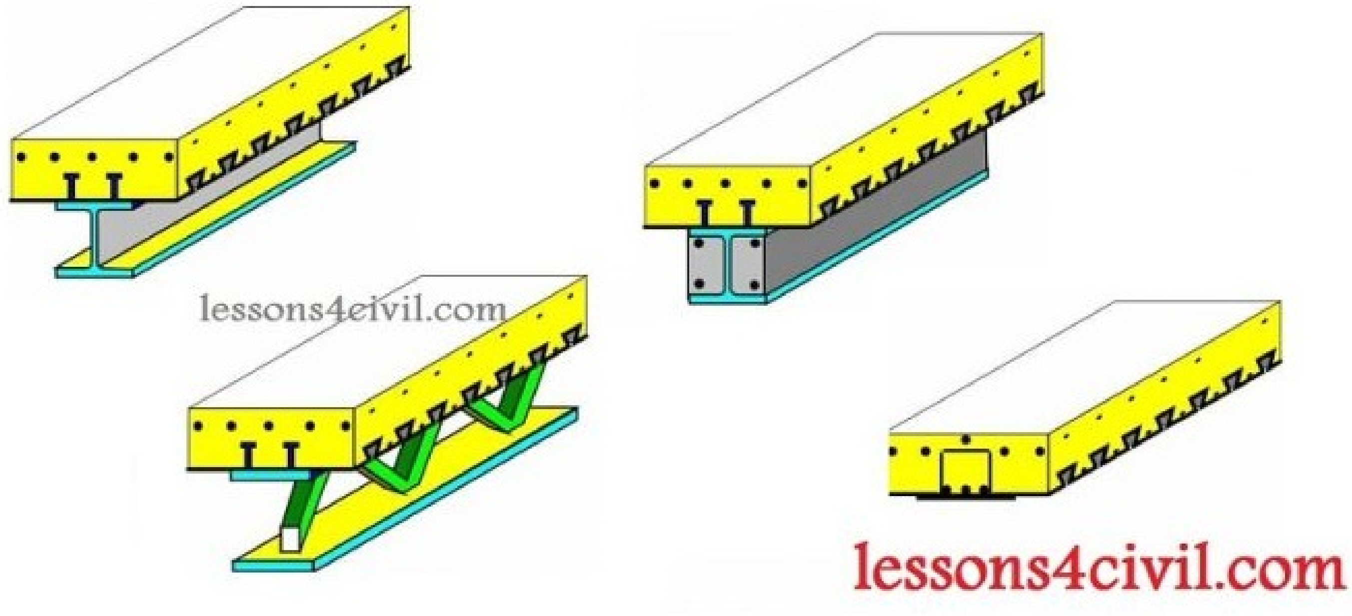
What material are we even talking about?

Composite materials

- The word “composites” represents the mixture of two or more materials
  - To many structural engineers, steel beams or joists + welded studs into concrete = “composite”



https://structville.com/2020/07/design-of-profiled-metal-deck-composite-slabs.html



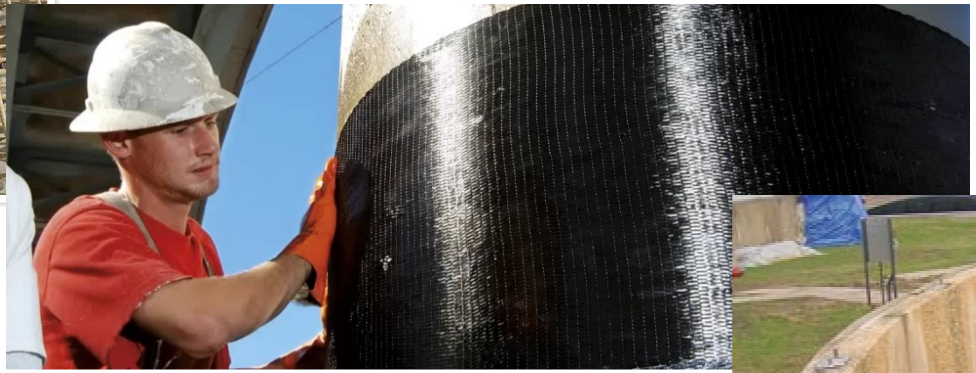
Composite materials

- In this presentation, we are referring to **fiber reinforced polymer (FRP) composites**
  - Have been used in commercial applications in a variety of markets for over a century
  - In buildings, bridges, and other structures, FRP composites have most prominently been used as…

Reinforcing in concrete

https://www.tuf-bar.com/products/tuf-bar/

Retrofit wrap of concrete elements



Sika - https://www.youtube.com/watch?v=fZJ_n-3UtTs

Handrail and grating at wastewater treatment plants and for other small utility or pedestrian accessways

https://www.strongwell.com/news/why-use-fiberglass-for-wastewater-treatment-grating/

Composite materials

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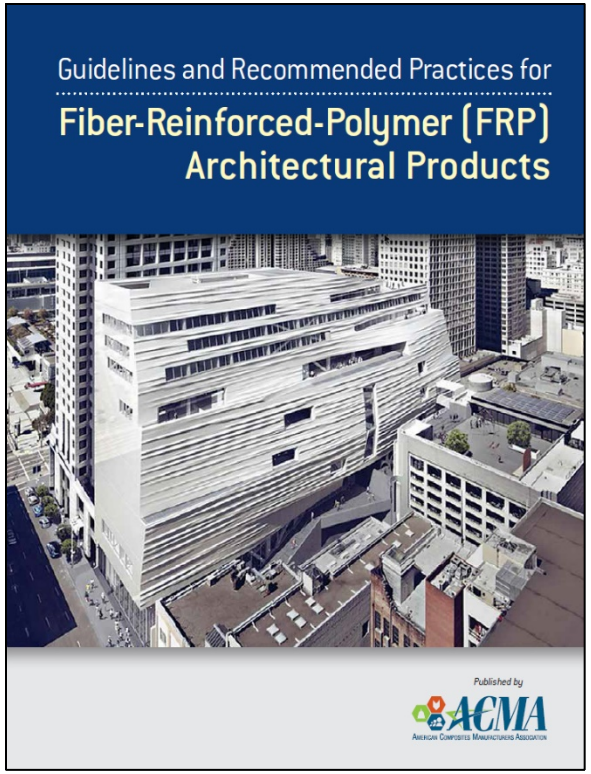
Architectural facades and other features

http://www.bfgarchitecture.com/bfg-projects-gallery



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Constituent Materials – Overview

Polymer Resin + Reinforcement + Core + Performance Additives + Coating = FRP

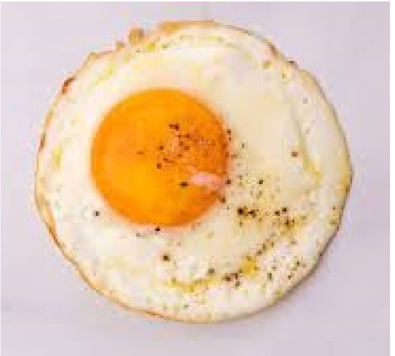
Constituent Materials – Resin

Thermoplastics

- Polyethylene
- Nylon
- Polyamide
- PEI
- PEEK

Thermosets

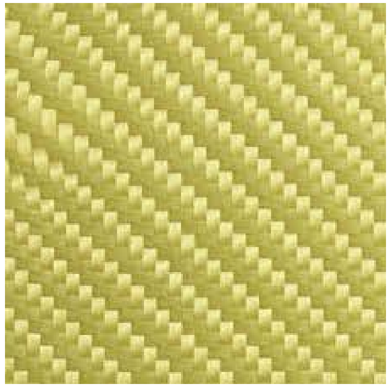
- Polyester
- Vinyl Ester
- Epoxy
- Urethanes
- Phenolics



Constituent Materials – Fiber Reinforcements

Types

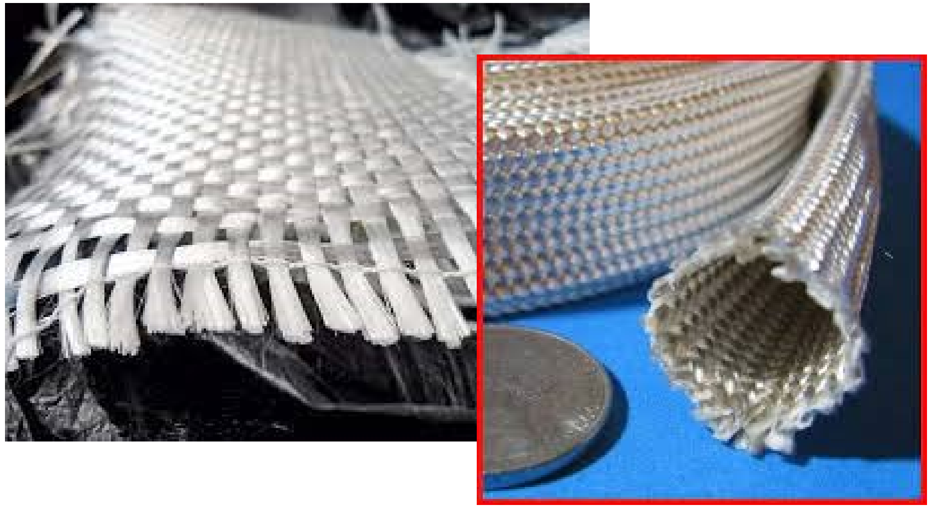
- Glass
  - E-glass
  - E-CR glass
  - S-glass
  - H-glass
  - AR glass
- Carbon
  - Varying moduli
- Aramid
- Basalt
- Thermoplastics



Constituent Materials – Fiber Reinforcements

Roving

Mat and Veil



Woven, Stitched, Braided, 3D Fabric

Unidirectional

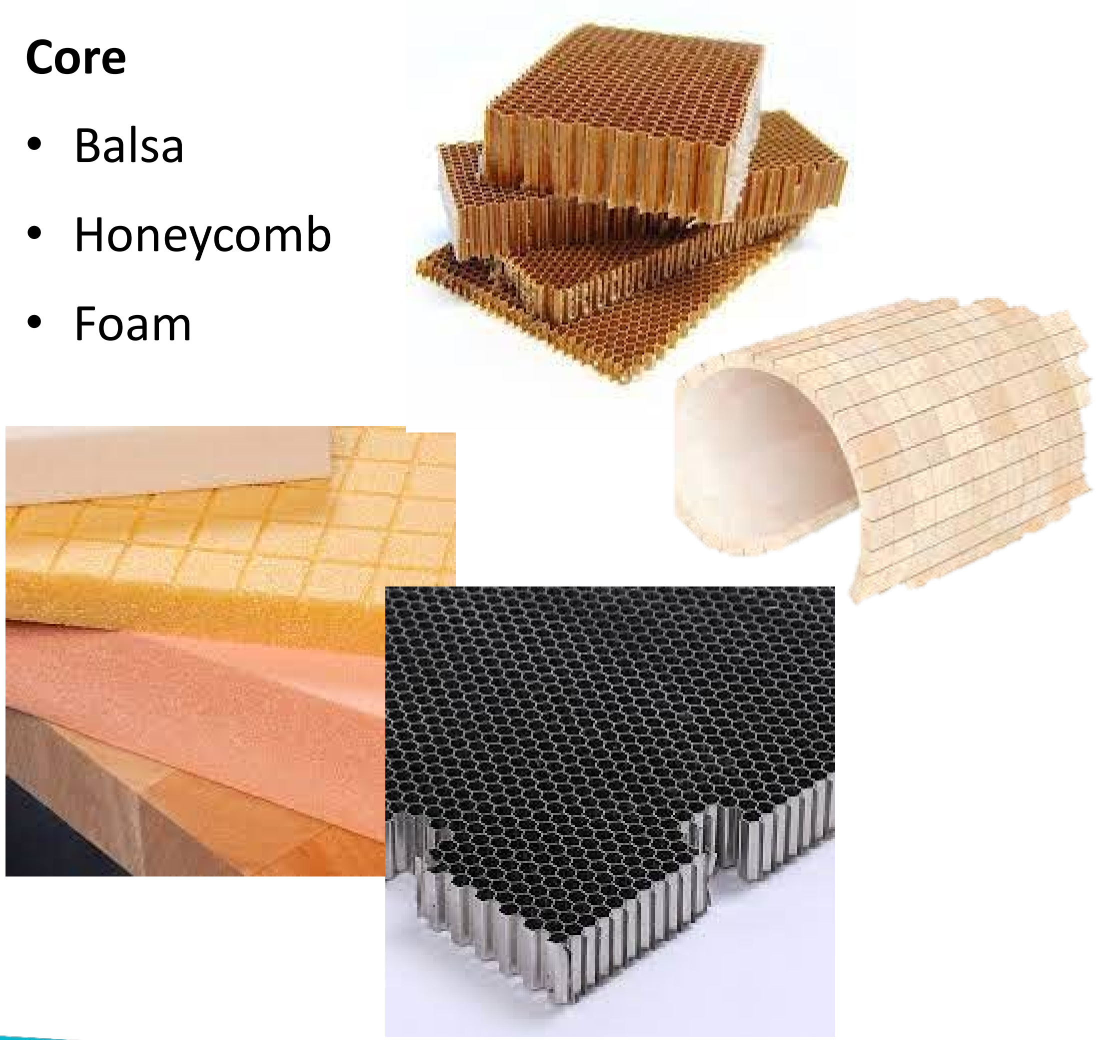
Prepreg

Milled or Chopped

Constituent Materials – Core, Fillers, and Additives

Core

- Balsa
- Honeycomb
- Foam



Fillers and Additives

- Process control – shrinkage, viscosity, durability
- Fire resistance / behavior
- Improved part economy
- Improved mechanical strength

Constituent Materials – Surface Treatments

Gel Coats and Paints

- Barrier layer, typically for environmental conditions
- Aesthetic cosmetic surface finish
- Sheen or gloss

Other Coatings

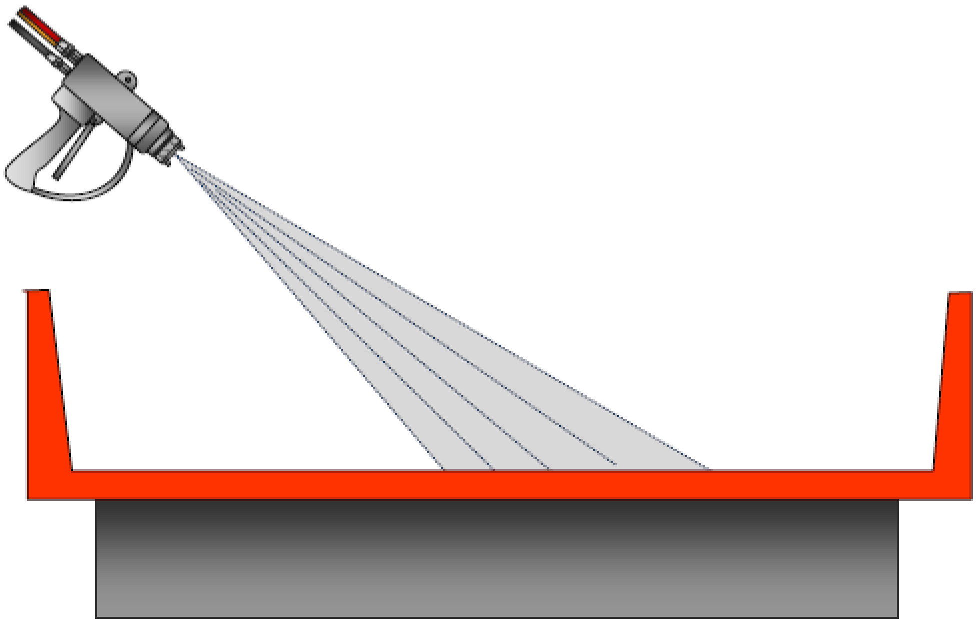
- Flame / smoke control via intumescent
- Abrasion control via high hardness flake or filler additives (glass, silica carbide, sand)

Manufacturing Processes

- Right constituents
- Right production rate
- Right tooling
- Right economy

https://www.youtube.com/watch?v=SeqDm9l3yEM

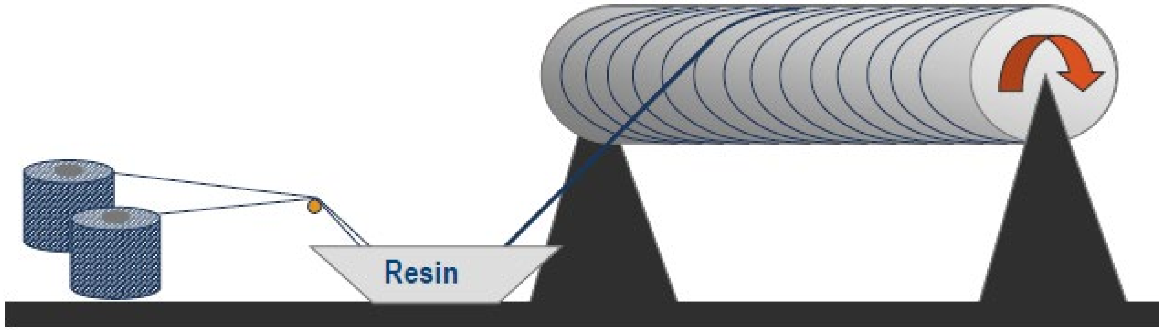
Manufacturing Processes



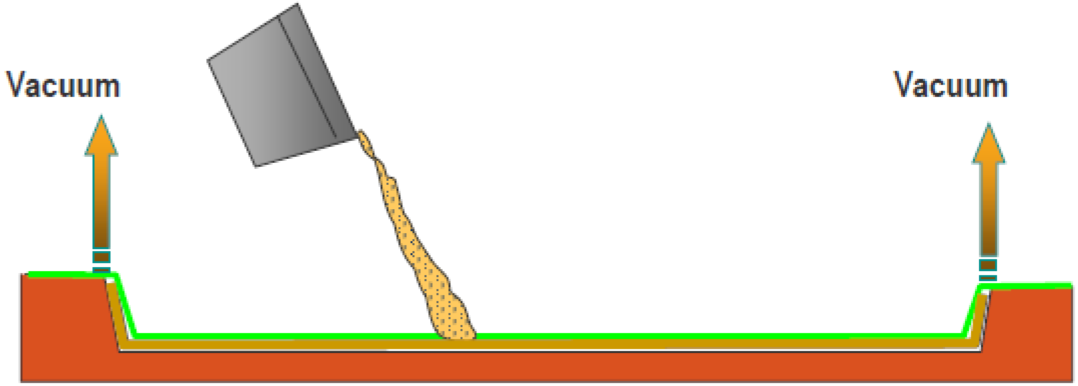
Spray Up

Hand Lay Up

Manufacturing Processes

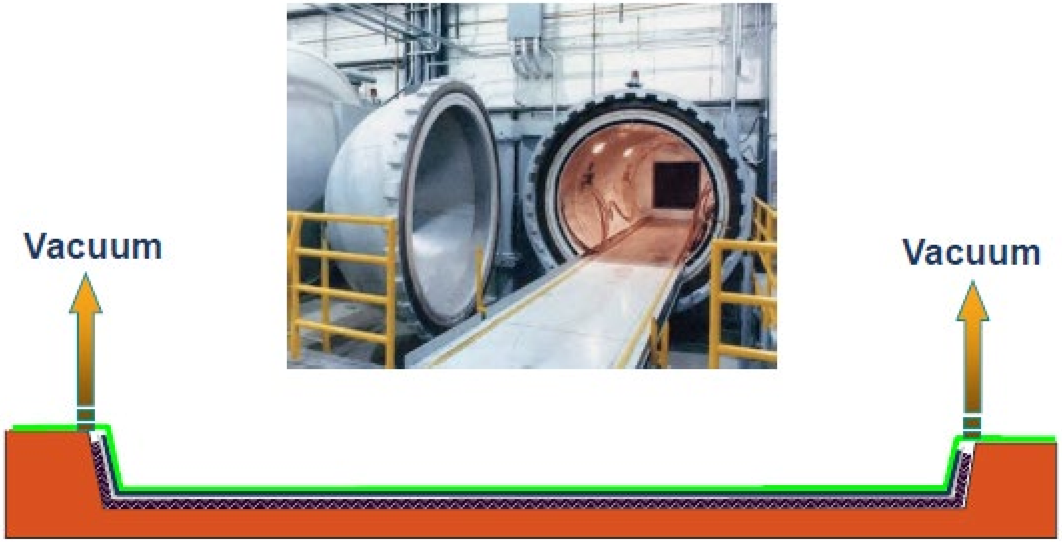


Filament Winding

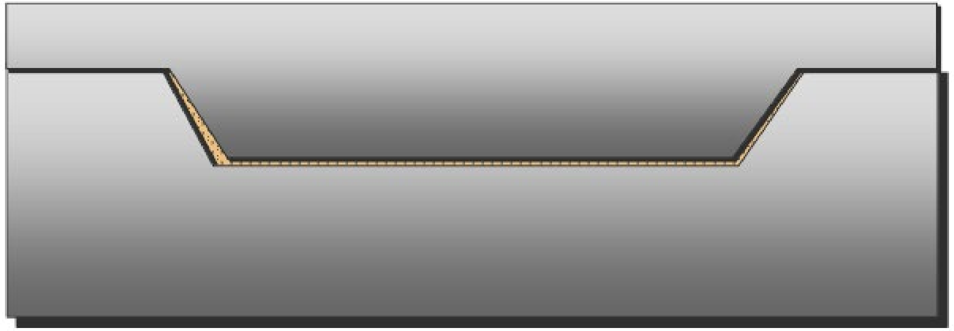


Wet Lay-Up Vacuum Bagging

Manufacturing Processes

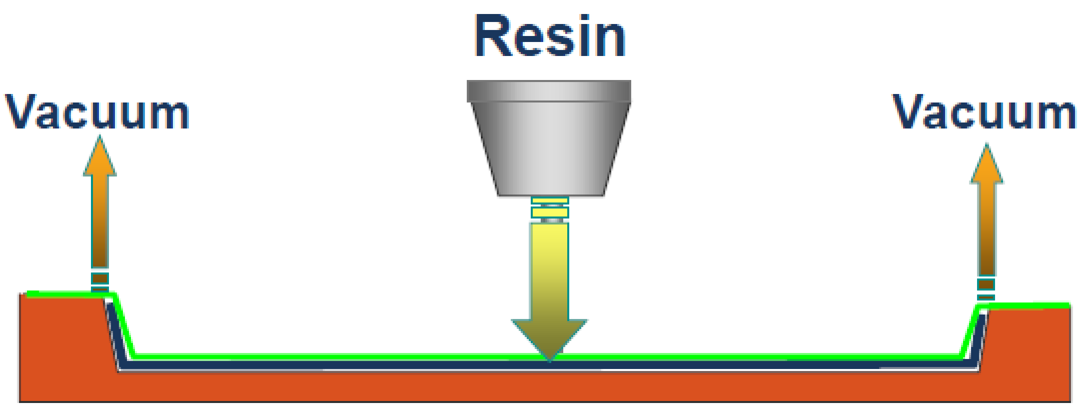


Prepreg Vacuum Bagging

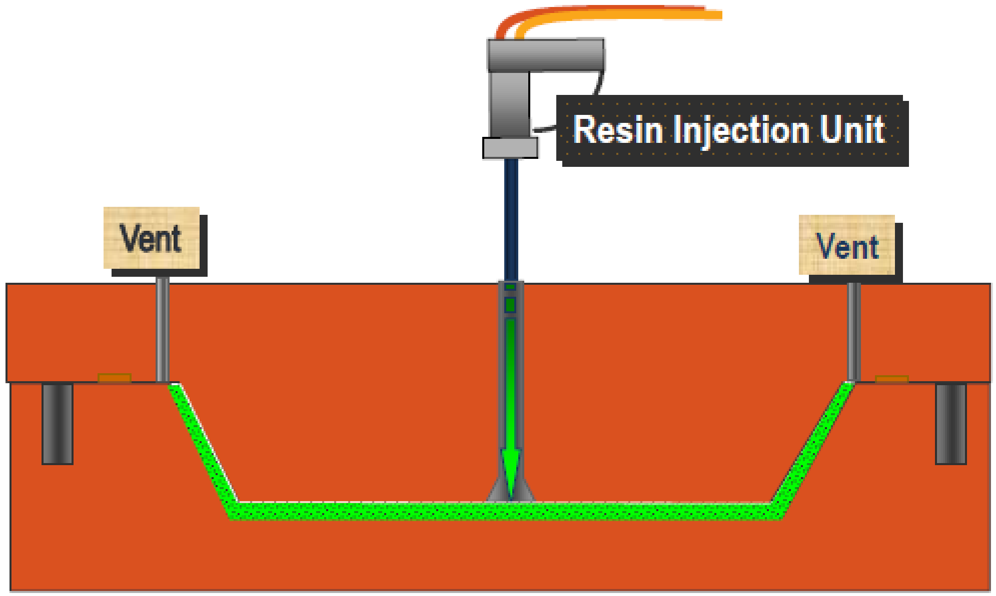


Closed Molding Processing

Manufacturing Processes

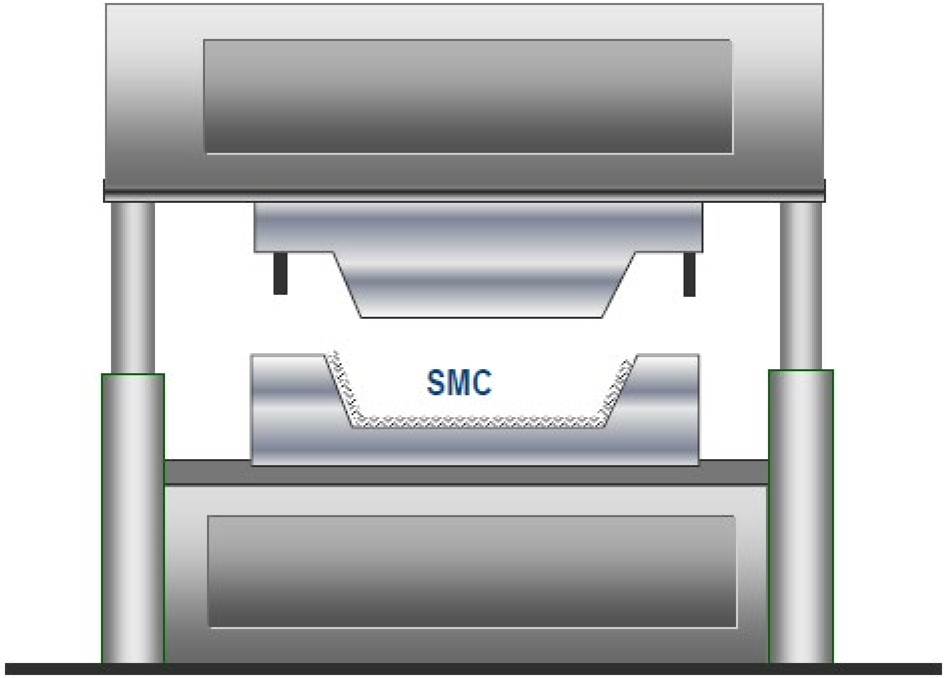


Vacuum Infusion Processing



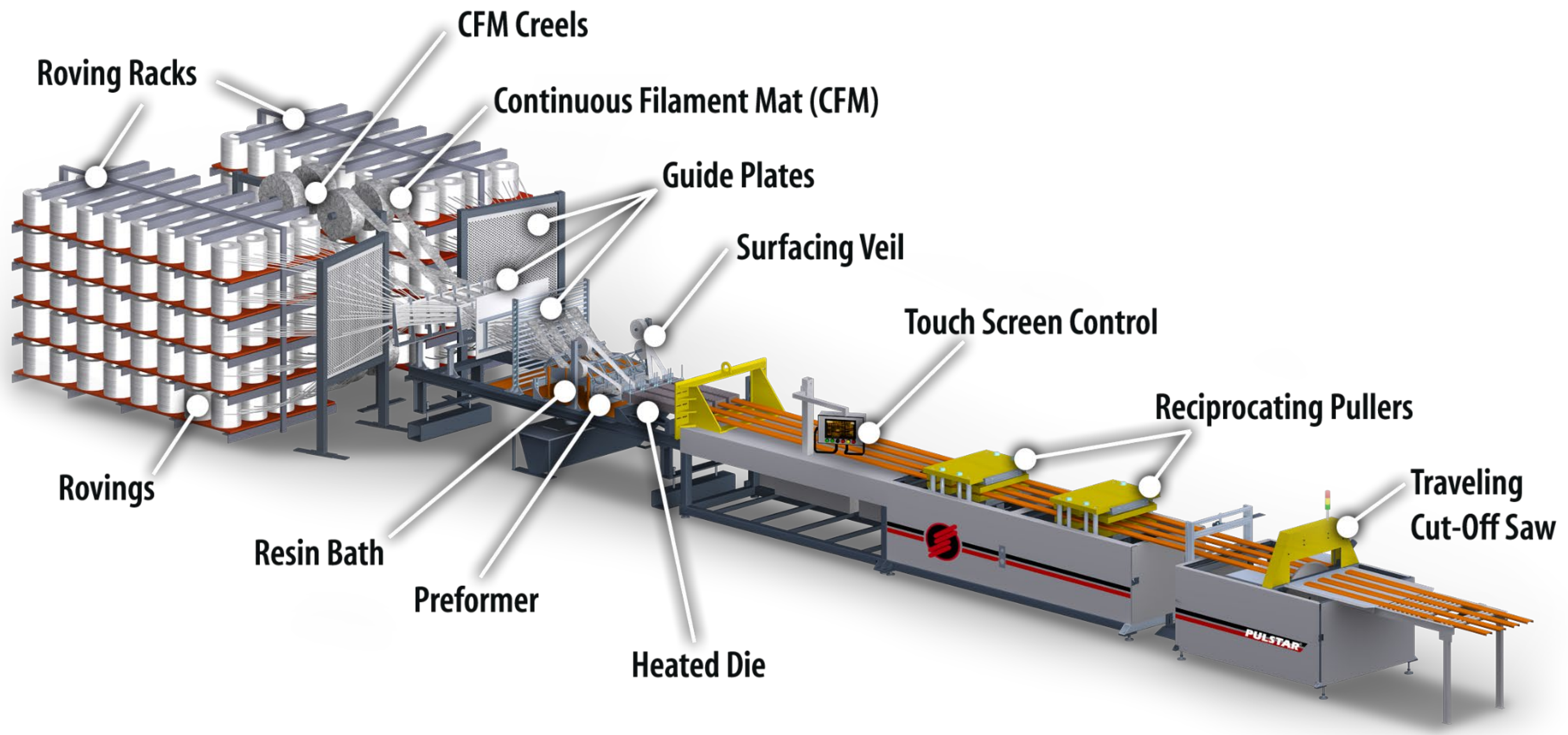
Resin Transfer Molding

Manufacturing Processes



Compression Molding

Manufacturing Processes



Pultrusion Processing

Features and benefits of composite materials

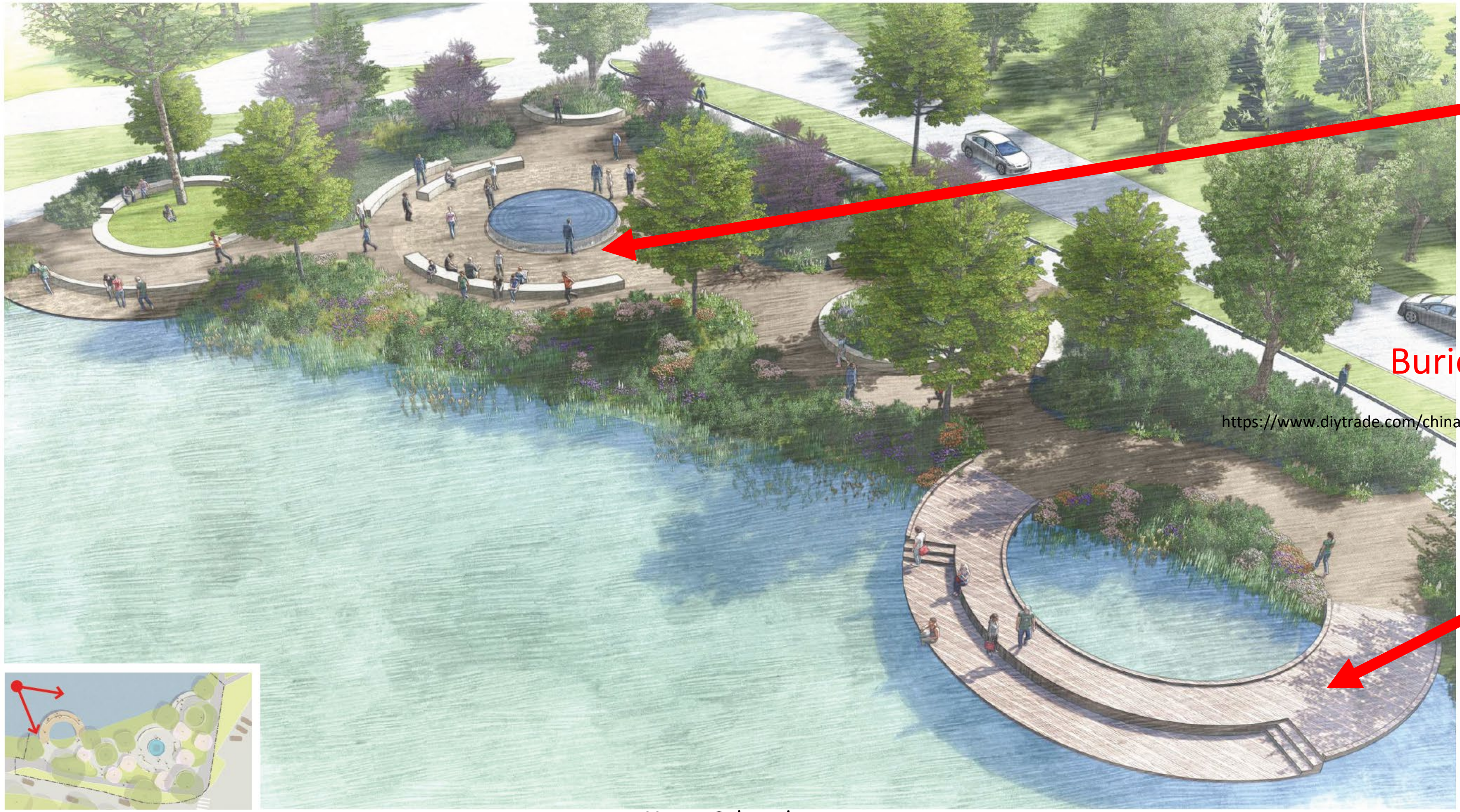
Why would I specify FRP and to what precedents can I point?

Benefits of FRP in Construction

- 1/5 – 1/3 the weight of steel
  - Install ease and savings on supporting foundations, etc.
- Increasingly competitive lead times
  - Accelerated production/fabrication/delivery versus steel
- ~30% installation savings over steel (pultruded)
  - Installed by carpenters instead of ironworkers
  - Reduced need for overhead lift equipment
- Fully corrosion resistant (i.e., versus salt-water, chlorine, etc.)
- Non-conductive (i.e., virtually no RF interference)

Industrial Facilities

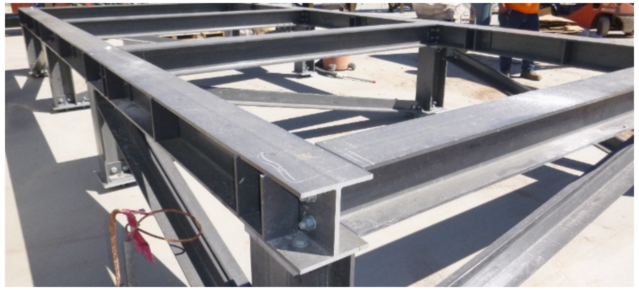
FRP Reinforcing in Concrete & Pultruded FRP



Hoerr Schaudt

Buried pile-supported mat foundation

Representative image from:
https://www.diytrade.com/china/pd/11145821/FRP_GRP_Rebars_Used_in_Constructuion_Foundation.html



Pultruded FRP framing and grating

Representative image

FRP Strengthening of Concrete

717 S Wells, Chicago, IL

Constructed 1923

Concrete column reinforcement wrap

Representative image from: https://www.structuremag.org/?p=8643

Slab reinforcement strips

Representative image from: https://fcsconcreterepairs.com.au/category/carbon-fibre-reinforced-polymer/

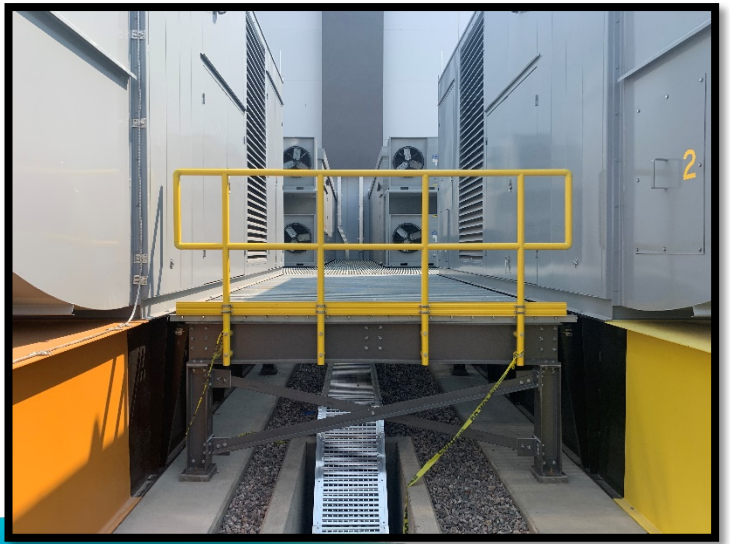
Industrial Facilities

Industrial Facilities: Case study

- ✓ Engineer-led development
- ✓ FRP sub for Stainless steel
  - ✓ 15-20% cost savings
- ✓ High production process temperature conditions
- ✓ Design overload condition
- ✓ Moderate seismic demands
- ✓ Accelerated install: 1 day

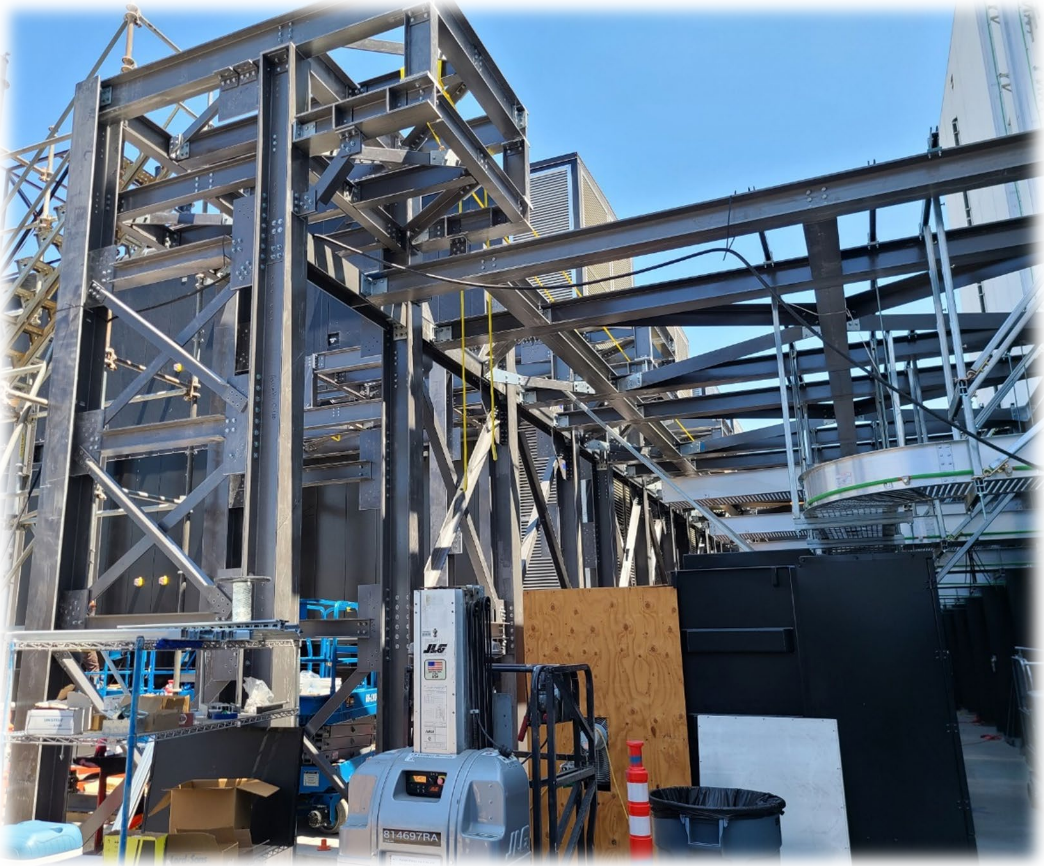
Mission Critical: Data centers

Mission Critical: Data centers



Mission Critical: Data centers

Mission Critical: Data centers
Santa Clara, CA



<u>**Key Stats**</u>

- ✓ Two stories
- ✓ 20+ ft tall
- ✓ 7,000 square feet
- ✓ High seismic region
- ✓ All FRP (beams, columns, braces and majority of connection clips)
- ✓ Extensive BIM coordination w/ clearances of 1/8 inch
- ✓ Largest freestanding FRP structure to our knowledge in a region of high seismicity (in terms of bulk weight)

Mission Critical: Data centers
Ashburn, VA

- ✓ Onsite 8 weeks from NTP
- ✓ 1/3 mile long encompassing 150,000 ft^2 equipment yard
- ✓ 40,000 sq ft exposed wall area
  - ✓ 2,500 sq ft daily install rate
- ✓ 24 ft average exposed height

Mission Critical: Data centers Phoenix, AZ

- ✓ ½ mile long encompassing much of the 55-acre site
- ✓ Sound attenuation for nearby residential properties
  - ✓ Noise absorption coefficient (NRC) 1.05
  - ✓ Sound transmission class (STC) 35
- ✓ 26 ft exposed height

Structures exposed to water

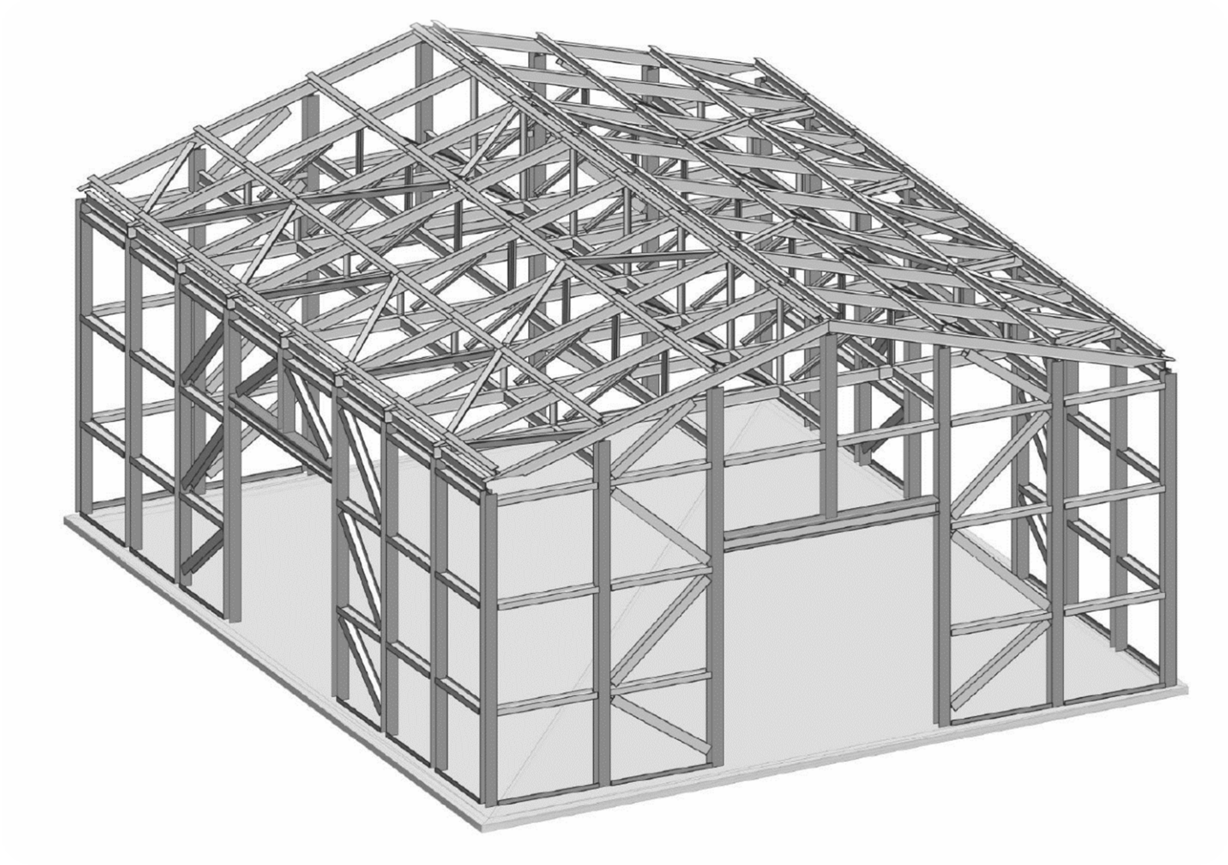
DoD

Hoerr Schaudt

FRP Buildings

- ✓ Corrosive environment
- ✓ Design complete: 2-1/2 weeks from NTP
- ✓ 14 ft average exposed height
- ✓ Shop-built vertical bents for ease of install

FRP Buildings

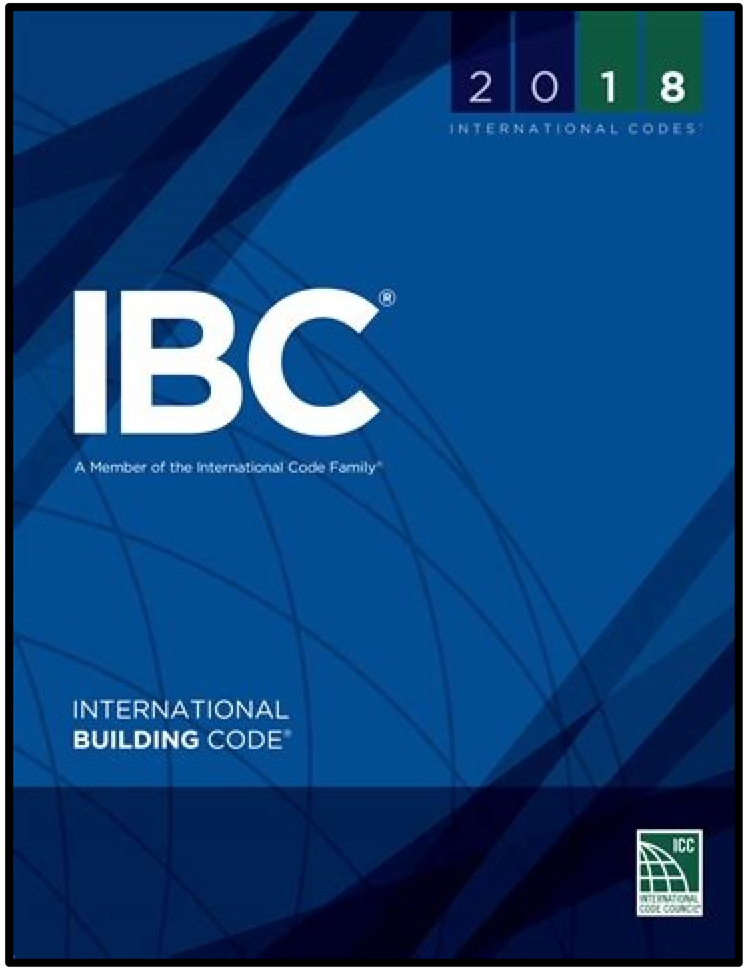


- ✓ Non-conductive building
- ✓ Fully corrosion resistant
- ✓ 100% FRP including beams, columns, braces & fasteners
- ✓ 30 ft tall w/ 22 ft clear height
- ✓ 50 ft clear span FRP trusses
- ✓ Vertical brace towers w/ direct W8 to W10 brace to column connections

Codes, standards, and specifications

By what industry basis can I confidently specify FRP on my project?

FRP in IBC Chapter 26: Plastic

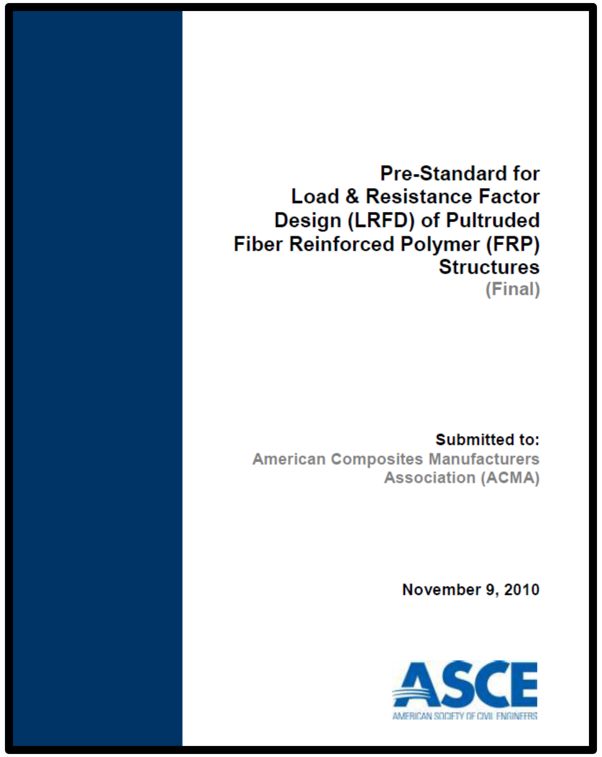


- The International Code Council began recognizing FRP Composites broadly in 2009 issuance of the International Building Code
- FRP components require third-party labeling
- Specific tests required for multi-story use, radiant heat, flame spread, and smoke development

FRP has been successfully deployed on transit vehicles, within aircraft interiors, in occupied underground spaces, and throughout building shells and interior finishes.

Flame, smoke, and toxicity requirements can readily be achieved through appropriate specification and design.

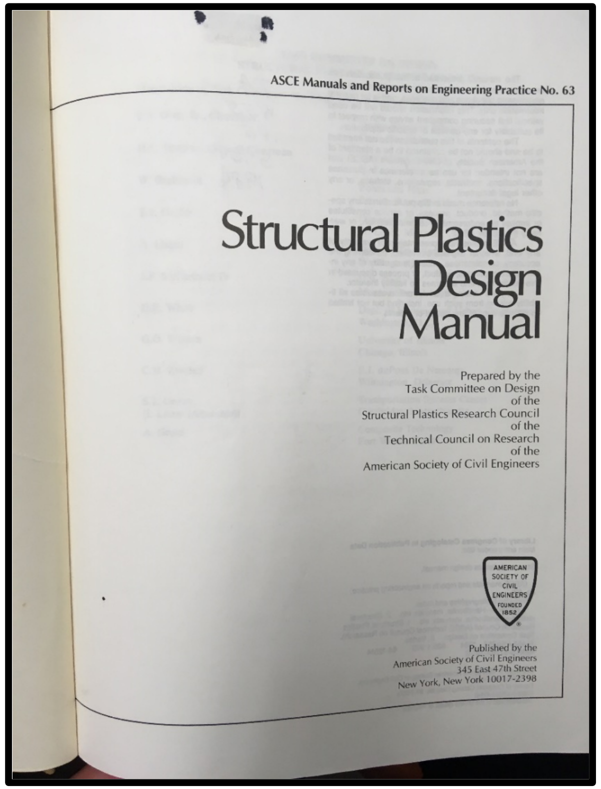
ASCE Standards and Guides exist…


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
AMERICAN SOCIETY OF CIVIL ENGINEERS


ASCE Manuals and Reports on Engineering Practice No. 63

Structural Plastics
Design
Manual

Prepared by the
Task Committee on Design
of the
Structural Plastics Research Council
of the
Technical Council on Research
of the
American Society of Civil Engineers

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

Published by the
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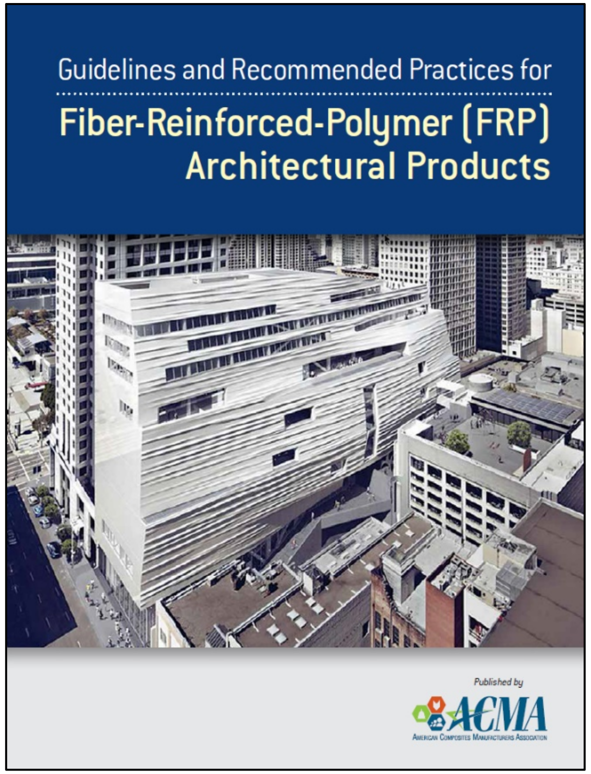
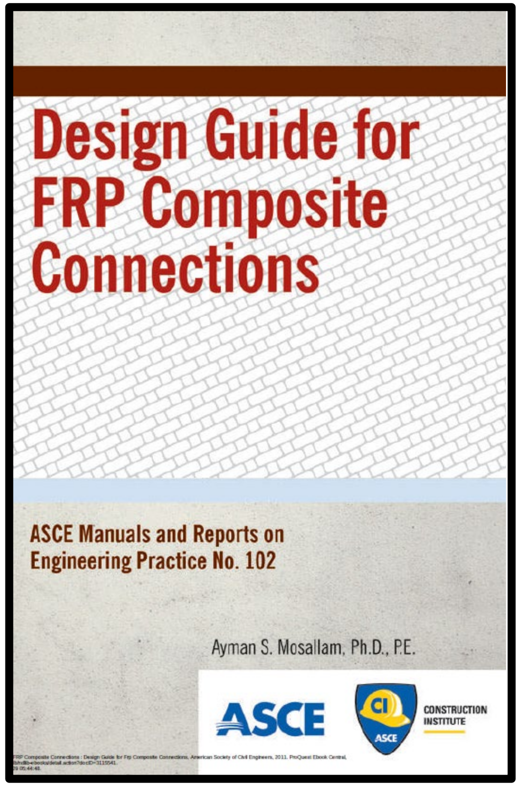
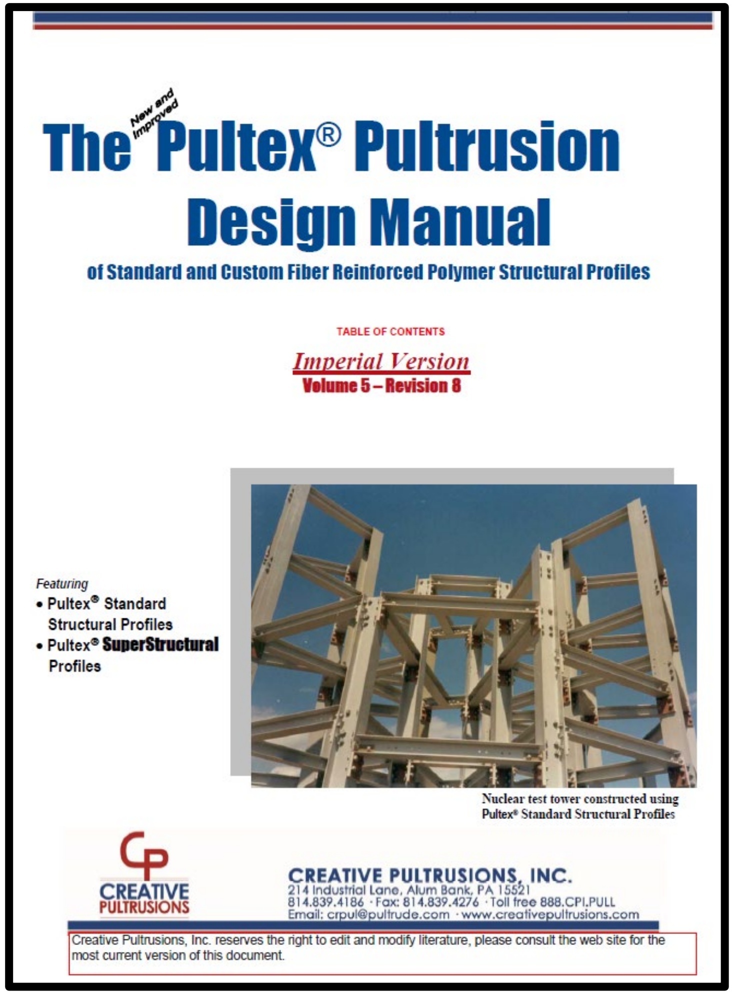
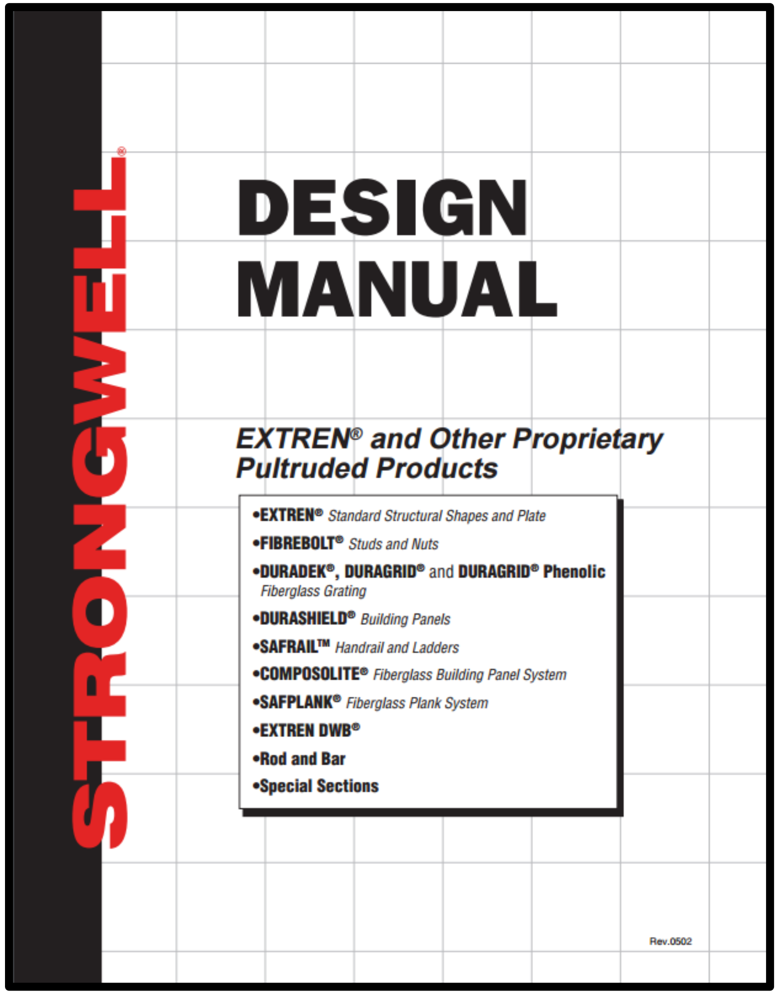
New York, New York 10017-2398





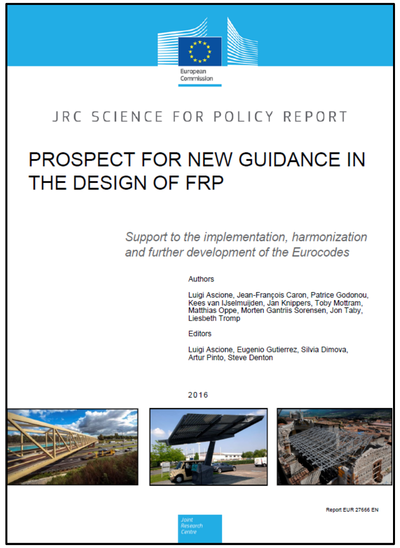
And industry design manuals…

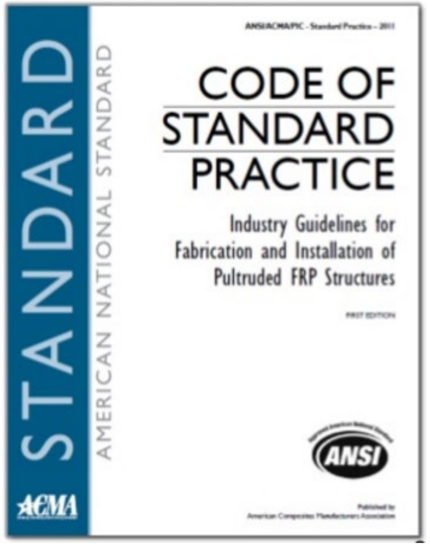


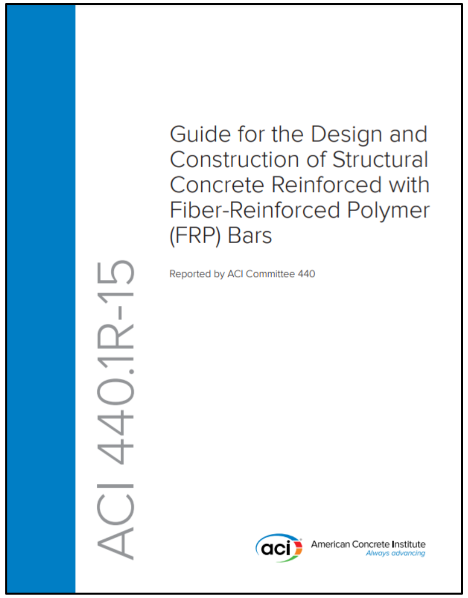


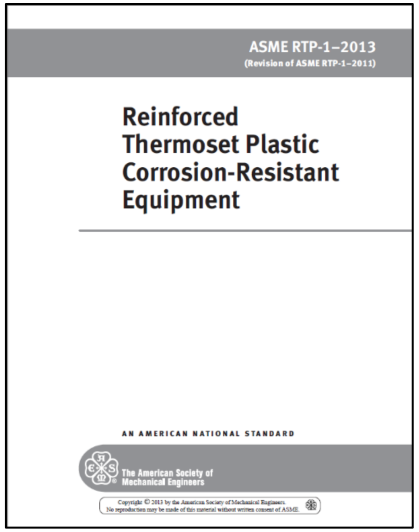
https://www.strongwell.com/tools/design-manual/

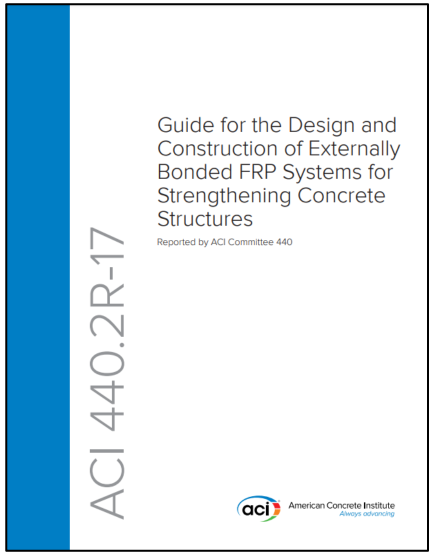
As well as ANSI, ACI, ASTM, and Eurocode standards and guidelines…











There is a relevant Masterspec section…

SECTION 068200 – FIBERGLASS REINFORCED PRODUCTS

PART 1 - GENERAL

1.1 RELATED DOCUMENTS

A. Drawings and general provisions of the Contract, including General and Supplementary Conditions and Division 01 Specification Sections, apply to this Section.

1.2 SUMMARY

A. Section includes fiber reinforced polymer products and fabrications.

1.3 SCOPE OF WORK

A. Furnish all labor, materials, equipment and incidentals governed by this section necessary to install the fiber reinforced polymer (FRP) products as specified herein.

1.4 ACTION SUBMITTALS

A. Shop Drawings: Show fabrication of all FRP components.
1. Include details of cuts, connections, splices, holes, and other pertinent data.
2. Indicate type, size, and length of bolts, distinguishing between shop and field bolts.
3. Detail shop drawings showing:
   a. All key dimensions
   b. Sectional assembly
   c. Location and identification marks
   d. Size and type of supporting frames required

1.5 INFORMATIONAL SUBMITTALS

A. Qualification Data: For Fabricator, Manufacturer and Installer.

B. Samples of each type of product.

C. Manufacturer of structural shapes shall submit material property characteristic test results for both flange and web of relevant cross-section profiles via ASTM D7290 for the following properties:
1. Lengthwise tensile modulus
2. Lengthwise tensile strength

Forthcoming Masterspec sections…

- 06 70 XX Pultruded Structural Composite Fabrications
- 06 74 XX FRP Composite Grating
- 06 81 XX FRP Composite Guardrail

See also…

- ANSI/ACMA Code of Standard Practice for Fabrication and Installation of Pultruded FRP Structures

And we have developed plan notes for spec and inspections…

7.0 FIBER REINFORCED POLYMER (FRP) STRUCTURAL FRAMING

1. All FRP shall be supplied in accordance with the project specifications Section 'Fiber Reinforced Polymer (FRP) Products and Fabrications."
2. Pultruded FRP designed by ASCE/ACMA 'Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforce Polymer (FRP Structures', 2010.
3. All structural framing, including wide flange, angle, and channel cross sections as well as flat plate, shall be comprised of pultruded FRP structural framing as defined in this section, U.N.O.
4. FRP shall be detailed, fabricated, and erected by an approved and certified fabricator in accordance with ANSI/ACMA Code of Standard Practice 'Industry Guidelines for Fabrication and Installation of Pultruded FRP Structures', Latest Edition.
5. All pultruded FRP materials shall be Extren Series 525 by Strongwell Inc. of Bristol, Virginia, USA, or alternate equal approved by Advantic.
6. Holes in FRP shall be 1/16" larger diameter than nominal size of bolt used, except as noted.
7. Any adhesive bonds shall be performed in the shop and not in the field whenever possible. Design of adhesive bonds and quality control requirements for fabrication shall be approved by Advantic prior to fabrication, and will require sufficient empirical testing to demonstrate with statistical significance bond line capacity in a comparable fabrication and use scenario.
8. Manufacturer shall have a minimum of five years' experience in the manufacture of composite products, with proven ability and who is regularly engaged in the manufacture, fabrication, and installation of FRP composite systems.
9. Substitution of any component or modification of system shall be made only when approved by Advantic.
10. Contractor shall warrant FRP composites product to be free from defects due to materials and workmanship for one year.
11. All structural assemblies shall be comprised of FRP composites fabricated by contact molded or pultruded processes to produce uniform, smooth surfaces. All surfaces shall be smooth, resin rich, free of voids and porosity, without dry spots, crazes, or unreinforced areas. All cut or machined edges shall be resin sealed.
12. Structural profiles shall provide continuous synthetic polyester surface veil to prevent glass print through, provide additional UV, abrasion, and corrosion protection, and ultimate Class A finish.
13. Resin shall be a corrosion-resistant unsaturated polyester.
14. Fillers and additives shall be as required to achieve color or thixotropic, UV, or fire-retardant performance only.
15. Fiber Type: E or E-CR glass fiber.
16. Glass Content (Fiber Volume Fraction): Minimum 60%.
17. FRP composites and system assemblies shall achieve the following:
    a. Flame spread rating of less than 25 per ASTM E-84.
    b. Flammability characteristics of UL 94 V0.
    c. Self-extinguishing requirements of ASTM D-635.
18. Comply with FRP composites manufacturer's recommendations and instructions for protecting installed products during construction activities.
19. Supply and fabrication of FRP structural framing shall be by:
    a. Advantic LLC; Dayton, Ohio (937) 490-4712, info@advanticllc.com
20. All bolts for FRP structural framing shall be ASTM A307 (for 3/8" Ø bolts) or A325 (for all other bolt diameters), U.N.O. All Bolts shall be accompanied by washers in accordance with ASTM A436.

INSPECTIONS, QUALITY ASSURANCE, VERIFICATIONS, AND TEST REQUIREMENTS

INSPECTIONS: Foundations, footings, under slab systems and framing are subject to inspection by the Building Official in accordance with IBC 2018. Contractor shall coordinate all required inspections with the Building Official.

SPECIAL INSPECTIONS, VERIFICATIONS, and TESTS: Special inspections, Verifications and Testing shall be done in accordance with IBC Chapter 17 and the STATEMENT OF SPECIAL INSPECTIONS herein per IBC Sections 1704 and 1705, including 1705.11 and 1705.12 for seismic resistance for projects in Seismic Design Categories C, D, E, and F as applicable.

SPECIAL INSPECTION AGENCY and SPECIAL INSPECTORS: Owner shall retain and 'approved agency" per IBC 1703 to provide Special Inspections for the project. Special Inspectors shall be qualified persons per IBC 1704.2.1.

STATEMENT OF SPECIAL INSPECTIONS. Special Inspections and Testing per IBC Sections 1704 and 1705 are required for the following:

FABRICATION SHOP INSPECTION: Where off-site Fabrication of gravity LOAD BEARING MEMBERS & ASSEMBLIES is performed, Special Inspector shall verify that the fabricator complies with IBC 1704.2.5 which includes the following:

- **Prior to the start of fabrication**, Special Inspector(s), representing the Owner, shall visit the Fabricator's shop(s) where the work is to be performed, and verifies that the Fabricator maintains detailed Fabrication and Quality Control procedures that provide a basis for inspection, control of workmanship, material control, and fabricator's ability to conform to approved Construction Documents and referenced Standards.
- **Fabricator shall have available** for Inspector's review, detailed procedures for material control that demonstrates the fabricator's ability to maintain suitable records and procedures such that, at any time during the fabrication process, the material specification, grade, and applicable test reports for primary load-carrying members, are capable of being determined.

FIBER REINFORCED POLYMER (FRP) per ASCE/ACMA 'Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures', 2010.

A qualified Special Inspector of an 'approved agency" providing Quality Assurance (QA) Special Inspections for the project shall review and confirm the Fabricator and Erector's Quality Control (QC) procedures for completeness and adequacy relative to ASCE/ACMA 'Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures', 2010 Section 1.7.3, and 2012 IBC code requirements for the fabricator's scope of work.

Material performance and sustainability

How should I expect the material to perform?

Table 1.3-2(a) Minimum Required Characteristic Mechanical Properties for FRP Composite Shapes

Mechanical Property	Minimum Requirement	ASTM Test Method	Minimum Number of Tests
Longitudinal Tensile Strength	30,000 psi	D638	10
Transverse Tensile Strength	7,000 psi	D638	10
Longitudinal Tensile Modulus	3×10^6 psi	D638	10
Transverse Tensile Modulus	0.8×10^6 psi	D638	10
Longitudinal Compressive Strength	30,000 psi	D6641	10
Longitudinal Compressive Modulus	3×10^6 psi	D6641	10
Transverse Compressive Modulus	1×10^6 psi	D6641	10
In-Plane Shear Strength	8,000 psi	D5379	10
In-Plane Shear Modulus	0.4×10^6 psi	D5379	10
Interlaminar shear strength	3,500 psi	D2344	10
Longitudinal pin-bearing strength	21,000 psi	D953[a]	10
Transverse pin-bearing strength	18,000 psi	D953[a]	10
Pull-through strength per fastener		D7332/Proc. B	10
t = 3/8 in	650 lb		
t = ½ in	900 lb		
t = ¾ in	1,250 lb		

Note: 1 psi = 6.895 kPa; 1 lb = 4.448 N
[a]Tests shall be conducted with bolt sizes and plate thicknesses stipulated in this *Standard*. The limitation of 4% on deformation shall not apply.

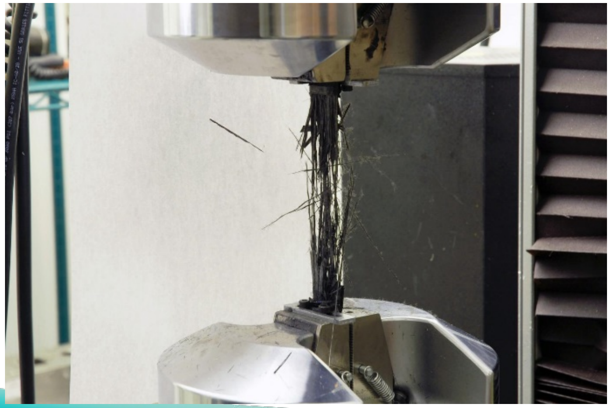
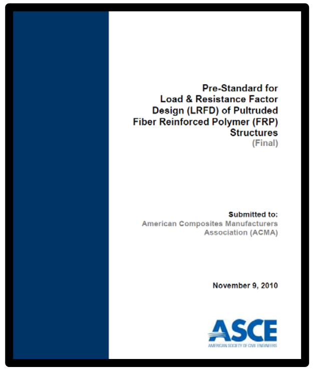
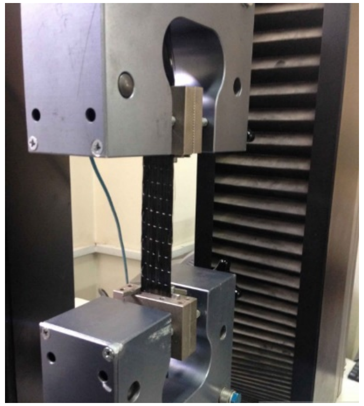


Table 1.3-2(b) Minimum Required Characteristic Mechanical Properties for FRP Composite Plates

Mechanical Property	Minimum Requirement	ASTM Test Method	Minimum Number of Tests
Longitudinal Tensile Strength	20,000 psi	D638	10
Transverse Tensile Strength	7,000 psi	D638	10
Longitudinal Tensile Modulus	1.8×10^6 psi	D638	10
Transverse Tensile Modulus	0.7×10^6 psi	D638	10
Longitudinal Compressive Strength	24,000 psi	D6641	10
Transverse Compressive Strength	15,500 psi	D6641	10
Longitudinal Compressive Modulus	1.8×10^6 psi	D6641	10
Transverse Compressive Modulus	1.0×10^6 psi	D6641	10
Longitudinal Flexural Strength	30,000 psi	D790	10
Transverse Flexural Strength	13,000 psi	D790	10
Longitudinal Flexural Modulus	1.6×10^6 psi	D790	10
Transverse Flexural Modulus	0.9×10^6 psi	D790	10
In-Plane Shear Strength	6,000 psi	D5379	10
In-Plane Shear Modulus	0.4×10^6 psi	D5379	10
Interlaminar shear strength	3,500 psi	D2344	10
Longitudinal pin-bearing strength	21,000 psi	D953[a]	10
Transverse pin-bearing strength	13,000 psi	D953[a]	10
Pull-through strength per fastener		D7332/Proc. B	10
t = 3/8 in	650 lb		
t = ½ in	900 lb		
t = ¾ in	1,250 lb		

Note: 1 psi = 6.895 kPa
[a]Tests shall be conducted with bolt sizes and plate thicknesses stipulated in this *Standard*. The limitation of 4% on deformation shall not apply.





https://afzir.com/en/frp-tests/

https://afzir.com/en/frp-tests/

Table 1.3-2(a) Minimum Required Characteristic Mechanical Properties for FRP Composite Shapes

Mechanical Property	Minimum Requirement	ASTM Test Method	Minimum Number of Tests
Longitudinal Tensile Strength	30,000 psi	D638	10
Transverse Tensile Strength	7,000 psi	D638	10
Longitudinal Tensile Modulus	3 x 10^6 psi	D638	10
Transverse Tensile Modulus	0.8 x 10^6 psi	D638	10
Longitudinal Compressive Strength	30,000 psi	D6641	10
Longitudinal Compressive Modulus	3 x 10^6 psi	D6641	10
Transverse Compressive Modulus	1 x 10^6 psi	D6641	10
In-Plane Shear Strength	8,000 psi	D5379	10
In-Plane Shear Modulus	0.4 x 10^6 psi	D5379	10
Interlaminar shear strength	3,500 psi	D2344	10
Longitudinal pin-bearing strength	21,000 psi	D953[a]	10
Transverse pin-bearing strength	18,000 psi	D953[a]	10
Pull-through strength per fastener		D7332/Proc. B	10
t = 3/8 in	650 lb		
t = ½ in	900 lb		
t = ¾ in	1,250 lb		

Note: 1 psi = 6.895 kPa; 1 lb = 4.448 N
[a]Tests shall be conducted with bolt sizes and plate thicknesses stipulated in this *Standard*. The limitation of 4% on deformation shall not apply.

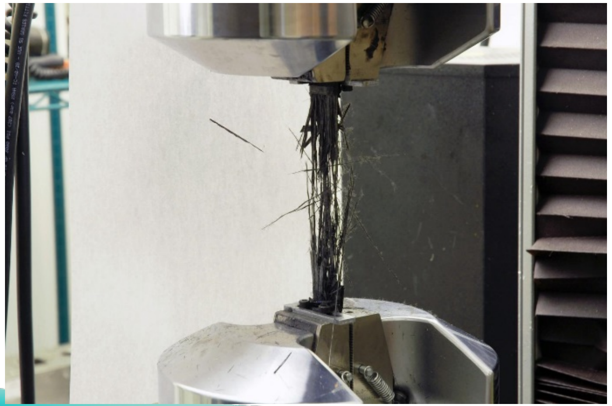


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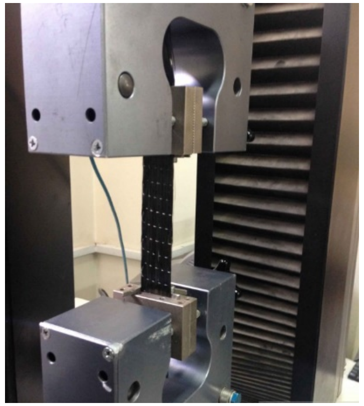
Table 1.3-2(b) Minimum Required Characteristic Mechanical Properties for FRP Composite Plates

Mechanical Property	Minimum Requirement	ASTM Test Method	Minimum Number of Tests
Longitudinal Tensile Strength	20,000 psi	D638	10
Transverse Tensile Strength	7,000 psi	D638	10
Longitudinal Tensile Modulus	1.8 x 10^6 psi	D638	10
Transverse Tensile Modulus	0.7 x 10^6 psi	D638	10
Longitudinal Compressive Strength	24,000 psi	D6641	10
Transverse Compressive Strength	15,500 psi	D6641	10
Longitudinal Compressive Modulus	1.8 x 10^6 psi	D6641	10
Transverse Compressive Modulus	1.0 x 10^6 psi	D6641	10
Longitudinal Flexural Strength	30,000 psi	D790	10
Transverse Flexural Strength	13,000 psi	D790	10
Longitudinal Flexural Modulus	1.6 x 10^6 psi	D790	10
Transverse Flexural Modulus	0.9 x 10^6 psi	D790	10
In-Plane Shear Strength	6,000 psi	D5379	10
In-Plane Shear Modulus	0.4x 10^6 psi	D5379	10
Interlaminar shear strength	3,500 psi	D2344	10
Longitudinal pin-bearing strength	21,000 psi	D953[a]	10
Transverse pin-bearing strength	13,000 psi	D953[a]	10
Pull-through strength per fastener		D7332/Proc. B	10
t = 3/8 in	650 lb		
t = ½ in	900 lb		
t = ¾ in	1,250 lb		

Note: 1 psi = 6.895 kPa
[a]Tests shall be conducted with bolt sizes and plate thicknesses stipulated in this *Standard*. The limitation of 4% on deformation shall not apply.



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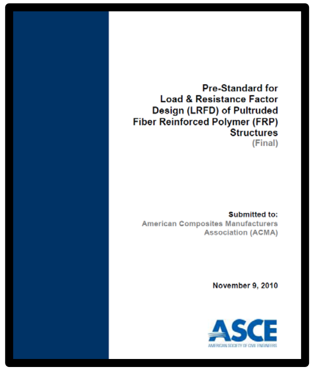

Table 1.3-2(a) Minimum Required Characteristic Mechanical Properties for FRP Composite Shapes

Mechanical Property	Minimum Requirement	ASTM Test Method	Minimum Number of Tests
Longitudinal Tensile Strength	30,000 psi	D638	10
Transverse Tensile Strength	7,000 psi	D638	10
Longitudinal Tensile Modulus	3 x 10^6 psi	D638	10
Transverse Tensile Modulus	0.8 x 10^6 psi	D638	10
Longitudinal Compressive Strength	30,000 psi	D6641	10
Longitudinal Compressive Modulus	3 x 10^6 psi	D6641	10
Transverse Compressive Modulus	1 x 10^6 psi	D6641	10
In-Plane Shear Strength	8,000 psi	D5379	10
In-Plane Shear Modulus	0.4 x 10^6 psi	D5379	10
Interlaminar shear strength	3,500 psi	D2344	10
Longitudinal pin-bearing strength	21,000 psi	D953[a]	10
Transverse pin-bearing strength	18,000 psi	D953[a]	10
Pull-through strength per fastener		D7332/Proc. B	10
t = 3/8 in	650 lb		
t = ½ in	900 lb		
t = ¾ in	1,250 lb		

Note: 1 psi = 6.895 kPa; 1 lb = 4.448 N
[a]Tests shall be conducted with bolt sizes and plate thicknesses stipulated in this *Standard*. The limitation of 4% on deformation shall not apply.

Table 1.3-2(b) Minimum Required Characteristic Mechanical Properties for FRP Composite Plates

Mechanical Property	Minimum Requirement	ASTM Test Method	Minimum Number of Tests
Longitudinal Tensile Strength	20,000 psi	D638	10
Transverse Tensile Strength	7,000 psi	D638	10
Longitudinal Tensile Modulus	1.8 x 10^6 psi	D638	10
Transverse Tensile Modulus	0.7 x 10^6 psi	D638	10
Longitudinal Compressive Strength	24,000 psi	D6641	10
Transverse Compressive Strength	15,500 psi	D6641	10
Longitudinal Compressive Modulus	1.8 x 10^6 psi	D6641	10
Transverse Compressive Modulus	1.0 x 10^6 psi	D6641	10
Longitudinal Flexural Strength	30,000 psi	D790	10
Transverse Flexural Strength	13,000 psi	D790	10
Longitudinal Flexural Modulus	1.6 x 10^6 psi	D790	10
Transverse Flexural Modulus	0.9 x 10^6 psi	D790	10
In-Plane Shear Strength	6,000 psi	D5379	10
In-Plane Shear Modulus	0.4x 10^6 psi	D5379	10
Interlaminar shear strength	3,500 psi	D2344	10
Longitudinal pin-bearing strength	21,000 psi	D953[a]	10
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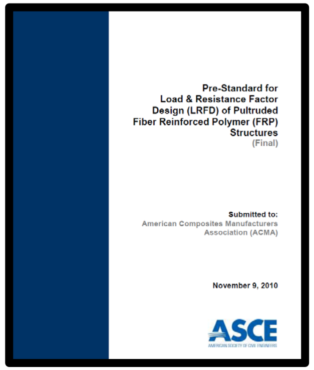
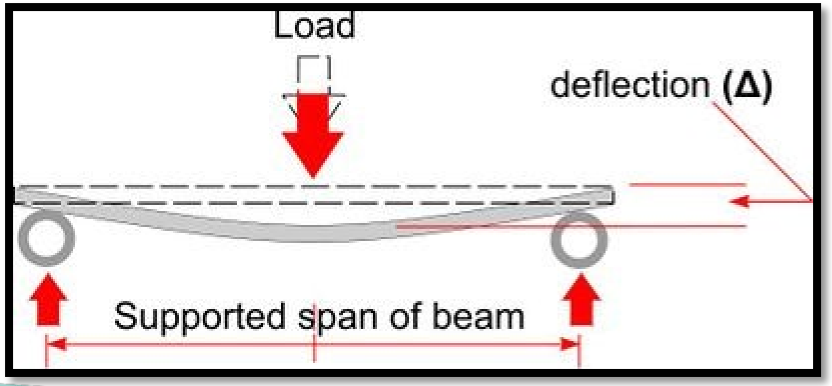
Pull-through strength per fastener		D7332/Proc. B	10
t = 3/8 in	650 lb		
t = ½ in	900 lb		
t = ¾ in	1,250 lb		

Note: 1 psi = 6.895 kPa
[a]Tests shall be conducted with bolt sizes and plate thicknesses stipulated in this *Standard*. The limitation of 4% on deformation shall not apply.

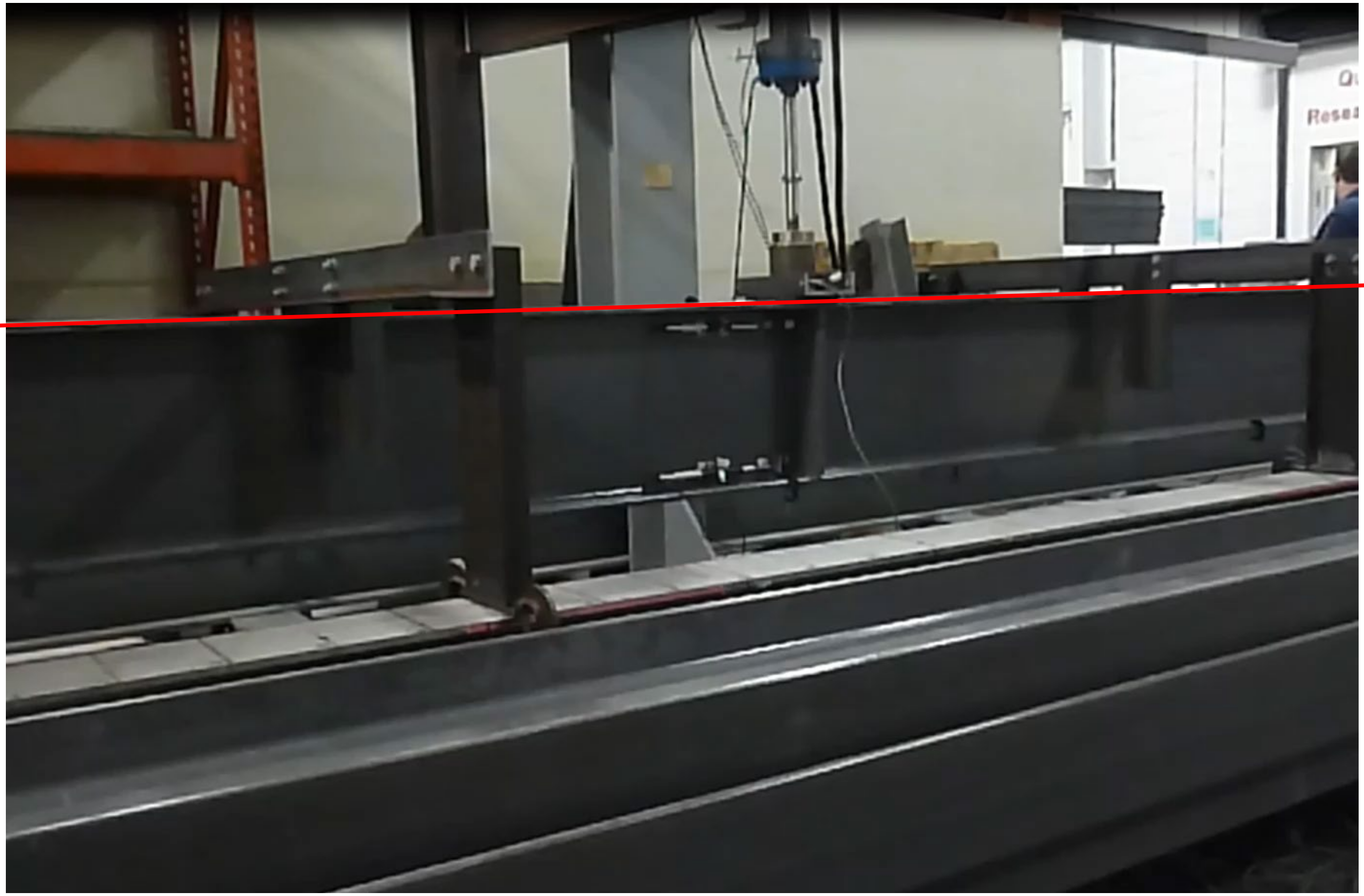




http://wiki.dtonline.org/index.php/Beam_Deflection

FRP is flexible relative to steel

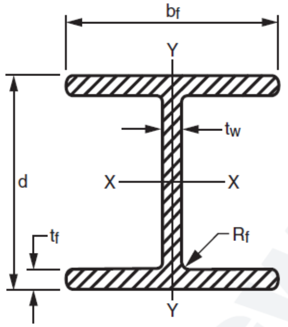
Initial Top of
Beam Elevation



Section property and capacity tables

Section 6
Elements of Sections

STRONGWELL



EXTREN® W-SHAPES

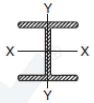
PHYSICAL PROPERTIES							SECTION PROPERTIES						DESIGN PROPERTIES		
SIZE				A	NOM. Wt/ft	R_f	AXIS X—X			AXIS Y—Y			b_f/t_f	A_w	J
d	b_f	t_w	t_f				I	S	r	I	S	r			
in	in	in	in	in^2	lbs	in	in^4	in^3	in	in^4	in^3	in		in^2	in^4
2	2	1/8	1/8	0.72	0.60	1/16	0.50	0.50	0.83	0.17	0.17	0.48	16.00	0.22	0.004
3	3	1/4	1/4	2.13	1.79	1/8	3.17	2.11	1.22	1.13	0.75	0.73	12.00	0.63	0.044
4	4	1/4	1/4	2.89	2.43	1/8	7.94	3.97	1.66	2.67	1.34	0.97	16.00	0.88	0.060
6	6	1/4	1/4	4.39	3.69	1/8	28.28	9.43	2.54	9.00	3.00	1.44	24.00	1.38	0.091
6	6	3/8	3/8	6.48	5.44	3/16	40.17	13.40	2.50	13.52	4.50	1.45	16.00	1.97	0.303
8	8	3/8	3/8	8.73	7.33	3/16	99.18	24.80	3.38	32.03	8.01	1.92	21.33	2.72	0.409
8	8	1/2	1/2	11.51	9.67	1/4	127.06	31.76	3.33	42.74	10.69	1.93	16.00	3.50	0.958
10	10	3/8	3/8	10.98	9.22	1/4	198.82	39.70	4.26	62.54	12.50	2.39	26.67	3.47	0.514
10	10	1/2	1/2	14.55	12.22	1/4	256.20	51.20	4.22	83.42	16.65	2.40	20.00	4.50	1.208
12	12	1/2	1/2	17.51	14.71	1/4	452.70	75.50	5.07	144.10	24.00	2.88	24.00	5.50	1.458

Section 8
Flexural Members (Beams)

STRONGWELL

BEAMS

W-SHAPES — EXTREN® 500 & 525
E = 2.6 x 10^6 psi
Allowable Uniform Loads in Pounds Per Foot

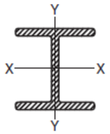


SPAN IN FEET		LATERALLY UNSUPPORTED		LATERALLY SUPPORTED--GOVERNED BY:					
				Stress	Deflection				
		F_b' (psi)	W	*F_b or F_v	l/100	l/150	l/180	l/240	l/360
3 x 3 x 1/4									
w = 1.69 lb/ft	3	8,419	630	630	—	—	553	414	276
b_f/t_f = 12.0	4	5,211	458	473	—	337	281	211	141
F_b = 12,000 psi	5	3,689	208	378	286	191	159	119	80
A_w = 0.63 sq. in.	6	2,834	111	315	176	117	98	73	49
I_x = 3.17 $in.^4$	7	2,296	66	270	115	77	64	48	32
S_x = 2.11 $in.^3$	8	1,929	42	236	79	53	44	33	22
I_y = 1.13 $in.^4$	9	1,665	29	*208	56	38	31	23	16
J = 0.044 $in.^4$	10	1,465	21	*169	42	28	23	17	12
4 x 4 x 1/4									
w = 2.22 lb/ft	3	8,125	880	880	—	—	—	793	529
b_f/t_f = 16.0	4	7,462	660	660	—	—	582	436	291
F_b = 8,125 psi	5	5,007	528	528	—	416	347	260	173
A_w = 0.88 sq. in.	6	3,664	269	440	397	265	220	165	110
I_x = 7.94 $in.^4$	7	2,846	154	377	266	177	148	111	74
S_x = 3.97 $in.^3$	8	2,307	95	330	185	124	103	77	52
I_y = 2.67 $in.^4$	9	1,932	63	*265	134	89	75	56	37
J = 0.060 $in.^4$	10	1,657	44	*215	100	67	56	42	28
	11	1,450	32	*178	76	51	42	32	21
	12	1,288	24	*149	60	40	33	25	17

STRONGWELL

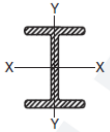
Section 9
Compression Members (Columns)

LONG COLUMN-ALLOWABLE COMPRESSION STRESSES



EXTREN®
W/ I SHAPES

E = 2.5 x 10^6 psi



NOTE: These calculations assume the long column buckling mode for an axially applied load. The transition from the short column mode (limited by b_f/t_f) to the long column mode (limited by Kl/r) will vary with the member size.

Kl/r	F_a (psi)	Kl/r	F_a (psi)	Kl/r	F_a (psi)
45	6318	84	2186	123	1143
46	6086	85	2142	124	1128
47	5867	86	2101	125	1112
48	5661	87	2060	126	1097
49	5466	88	2020	127	1083
50	5282	89	1982	128	1068
51	5108	90	1944	129	1054
52	4940	91	1908	130	1041
53	4784	92	1873	131	1027
54	4634	93	1839	132	1014
55	4492	94	1806	133	1001
56	4356	95	1774	134	988
57	4227	96	1742	135	976
58	4104	97	1712	136	964
59	3986	98	1682	137	952
60	3874	99	1654	138	940
61	3767	100	1625	139	929
62	3664	101	1598	140	917
63	3566	102	1572	141	906
64	3471	103	1546	142	896
65	3381	104	1520	143	885
66	3294	105	1496	144	875
67	3211	106	1472	145	864
68	3131	107	1449	146	854
69	3054	108	1426	147	844
70	2981	109	1404	148	835
71	2910	110	1382	149	825
72	2842	111	1361	150	816
73	2776	112	1341	155	772
74	2712	113	1321	160	731

What it's like designing FRP connections

Connections (and bracing)… govern design

8. DESIGN OF BOLTED CONNECTIONS

This chapter provides provisions for design of bolted connections of pultruded FRP structural shapes and plates. It is organized as follows:

8.1 Scope

The design provisions of this chapter apply to *bearing-type* bolted connections for pultruded FRP shapes and plates and other FRP and/or metallic components, referred to hereafter as members, and comply with the requirements specified in Section 8.2 general Provisions. Connections of pultruded FRP members can be direct (member to member), or can incorporate connecting elements (e.g., gussets, splice plates, and angles) using steel or stainless steel bolts. Connecting elements are to be of steel, stainless steel or aluminium. FRP connection elements are allowed where connections are pre-qualified by testing in accordance with Section 2.3.2. The chapter provides guidelines for initial sizing of FRP connection elements. Design of steel connection components shall be accordance with ANSI/AISC specifications.

Connections in FRP structures using FRP nuts and bolts, or solid unidirectional reinforced FRP rods are permitted if tested as indicated in Section 2.3.2 – Prequalified FRP Building Products.

Reference to bolts in this chapter shall apply only to steel bolts and Sections 8.2.2 and 8.3.2.1.

The types of connection covered shall be lap shear configuration with the loading principally in-plane of the connecting members.

This chapter does not apply to bolted connections (Figure 8.1) with more than three bolts in a line that is parallel to the direction of the connection force or/and with three or more bolts in a single line with the connection force acting perpendicular to this line of bolting. Connection detailing with more than three bolts per row and/or with more than three rows must be shown by testing (in accordance with Section 2.3.2) or analysis to be justified. Double row joints may be justified over only a single row for stability to resist compressive loads. Design of bearing-type connections in this chapter do not require the bolting to be combined with adhesive bonding.

The nominal strengths appropriate to the material of an element in the bolted connection shall be used with the strength formulae in this Chapter.

Where bolts are required to carry tensile forces between the members joined, the connection components shall be designed to resist the additional out-of-the-plane force due to prying action, where this occurs.

All requirements established in this chapter are subjected to the limitation established in Section 1.1.1.

8.1.1 Axially Loaded Connection Types

8.1.1.1 Angles and Channels

In the case of unsymmetrical or unsymmetrically connected members, such as angles and channels, the eccentricity of bolts in end connection and the effects of the spacing and edge distances of bolts shall be taken into account when determining the nominal strength.

67

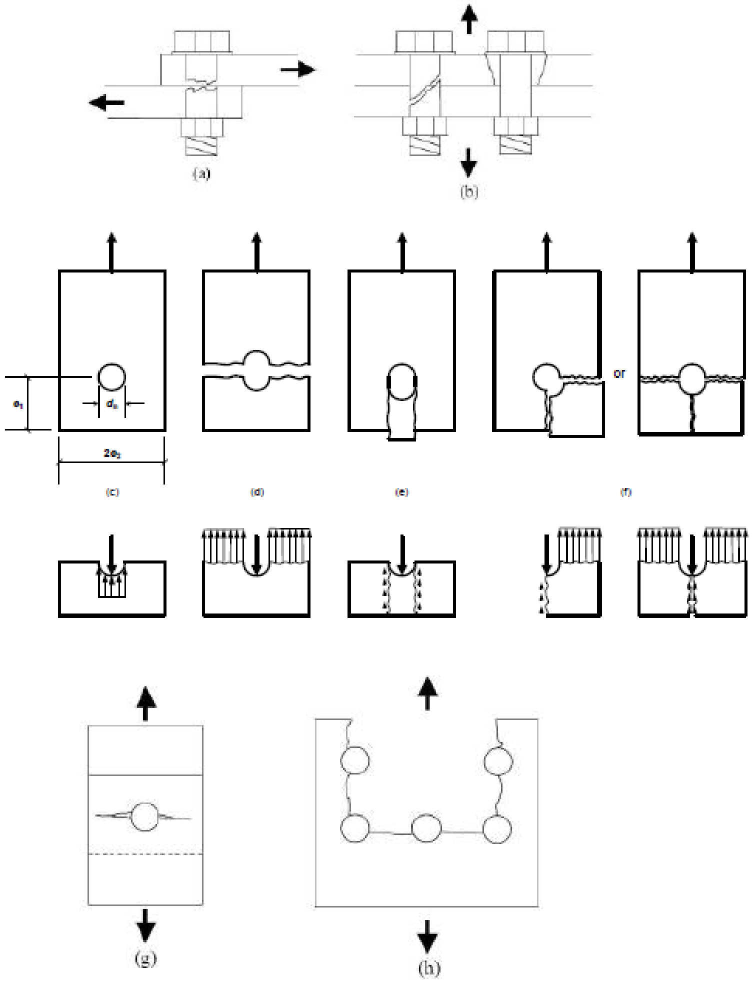
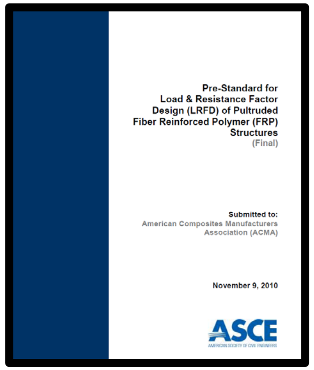


Figure C8.3. Bolted connection distinct modes of failure and simplified stress distributions (a) bolt failure, (b) through-the-thickness tension, (c) bearing, (d) net tension, (e) shear-out, (f) cleavage, (g) net tension 'splitting', when unloaded edges are not nearby, and (h) block shear.

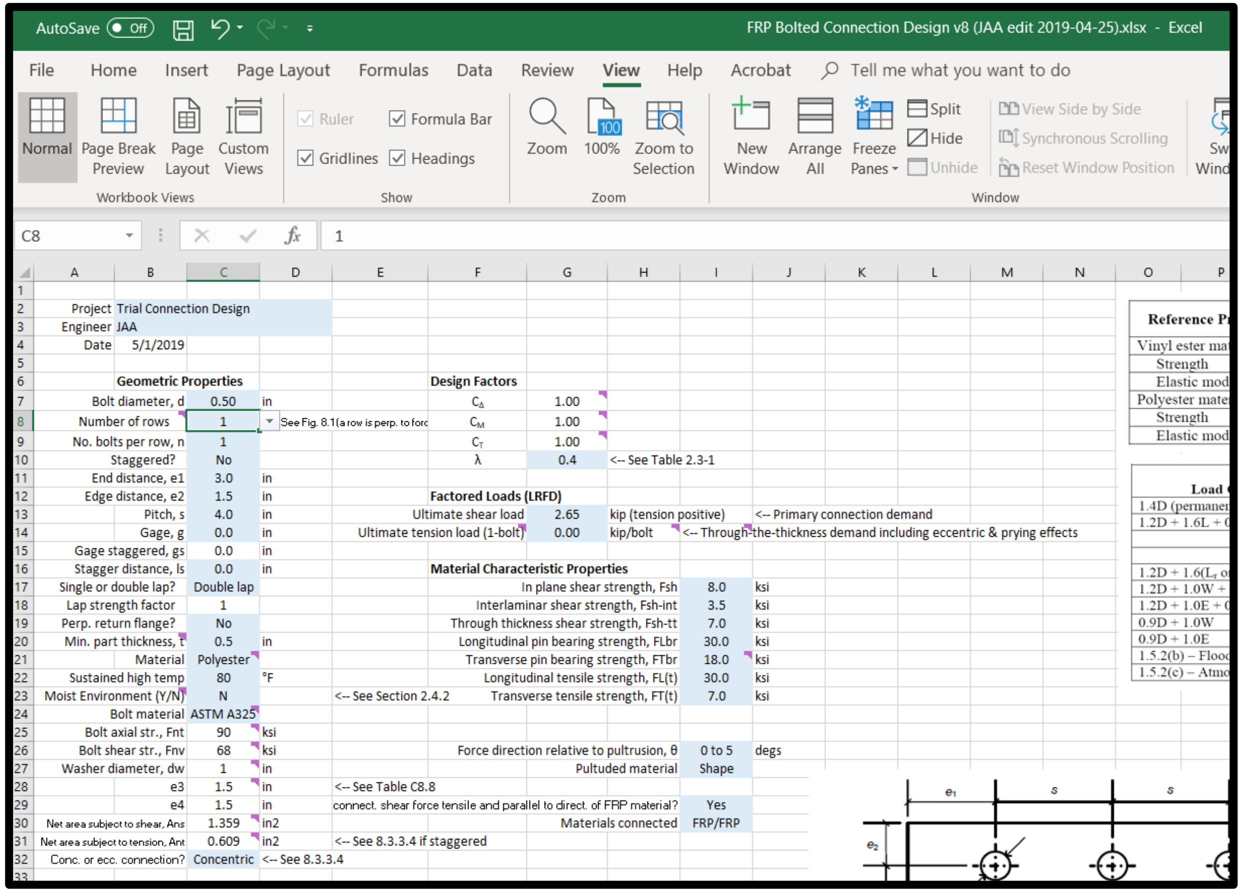

Pre-Standard for
Load & Resistance Factor
Design (LRFD) of Pultruded
Fiber Reinforced Polymer (FRP)
Structures
(Final)

Submitted to:
American Composites Manufacturers
Association (ACMA)

November 9, 2010

ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS

Connections (and bracing)… govern design



Adhesives… the FRP counterpart to welding

Section 19
Fabrication

STRONGWELL

CONNECTIONS

PROCEDURE FOR MAKING STRUCTURAL EPOXY JOINTS

Materials Used

Strongwell epoxy adhesive base
Strongwell epoxy adhesive hardener
Small wax coated paper cup for mixing
Clean wooden or FRP stick for mixing
80 grit sandpaper
Clamps for holding epoxy joints during cure
Clean cloth

Surface Preparation

1) Sand mating surfaces with 80 grit sandpaper until the surface gloss has been removed. The surfacing veil must be ground off to expose the glass reinforcement. Sand blasting equipment can also be used.
2) Remove all dust with a clean cloth; air blasting equipment may also be used. Avoid recontamination of the surface from handling.

Mixing of Epoxy

Mix equal volume portions of the base and hardener in a small wax coated paper cup with a clean stick until a uniform gray color is attained and all marbled appearance is gone.

NOTE: Other adhesive systems compatible with fiberglass can be utilized and the manufacturer's mixing instructions for these systems should be followed.

Application and Cure

1) Apply the mixed epoxy uniformly to all surfaces to be joined. A thin application is often more beneficial than a thick application.
2) Avoid introducing moisture into the joint.
3) Join the surfaces to be bonded. The pot life at 77°F for a 3 oz. mixture of equal volumes of base and hardener is 2.5 hours.
4) Secure the joint with clamps (or rivets or bolts) and allow 24 hours for a full cure. The assembly can often be handled with reasonable care in less than 8 hours. The structure should not be required to support its design load until at least 48 hours (at 70°F) after bonding. Lower temperatures require a longer cure.
5) After securing the joint, wipe away excess epoxy.

https://exelcomposites.com/guide-to-composites/fabrication-methods/

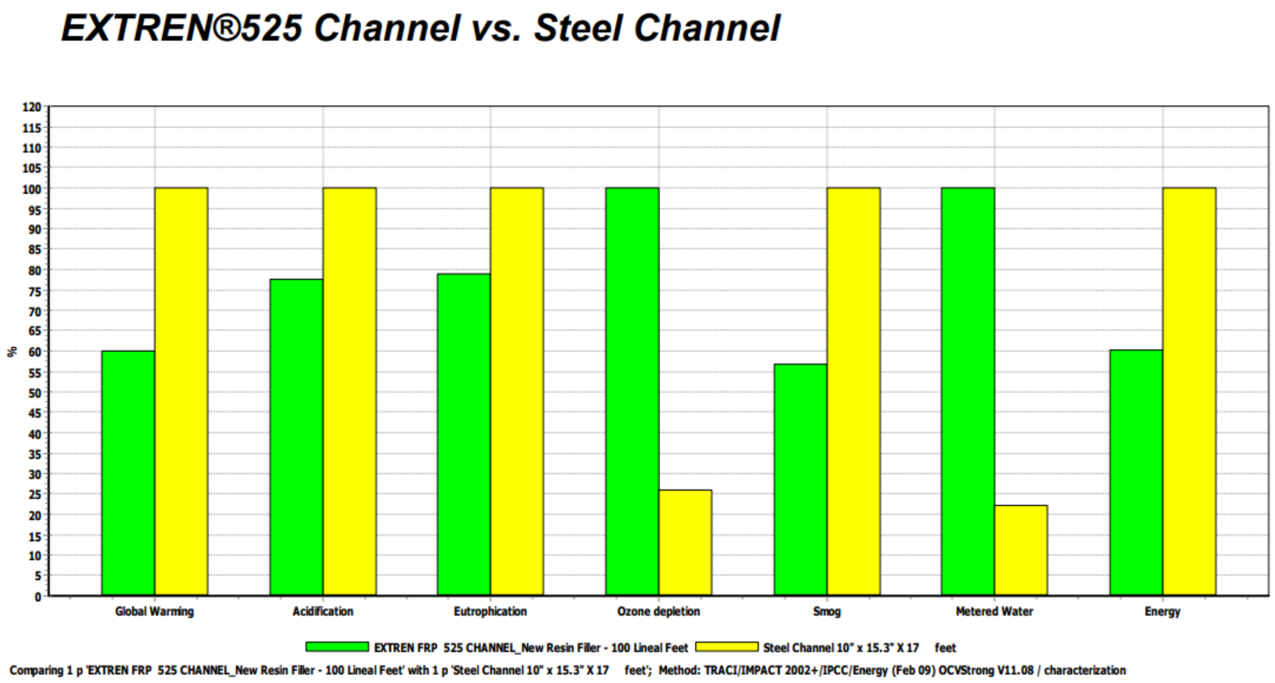
Sustainability benefits of FRP

"The construction industry consumes more resources taken from the earth (up to 50%) than any other industry. The construction, operation, and subsequent demolition of all built facilities accounts for 40-45% of the global energy use."

Compared to conventional materials, FRP enables…

- Lighter system designs
- Longer service life
- Lower transportation costs
- Production from readily available raw constituent materials like silica
- Material embodied energy in GFRP is similar to other construction materials
- Recyclability at end of life

Source: Composites UK (2016) "Environmental Impact and Embodied Energy"



Third Party Cradle-to-Gate Life Cycle Analysis
Steel vs. Pultruded Channel

Source: "A Life Cycle Assessment Approach in Examining Composite Raw Materials, Steel and Aluminum Materials Used in the Manufacturing of Structural Components" (2009)

Conclusions

1. Benefits of using FRP extend beyond historically acknowledged benefits of corrosion-resistance
    1. FRP is progressively becoming the faster and less expensive material solution for a wider range of projects
    2. Can be used in “hybrid” frames with steel and other materials as needed for faster install times

2. Industry standards support the specification of FRP with a high level of reliability

3. Life-cycle performance of FRP makes it a sustainable product spec in many scenarios

4. Design team needs to emphasize importance of detailing (i.e., interfaces and connections) for structural FRP at early stages of project

Contact us!

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