North American Pultrusion Conference

ASCE/SEI 74: LRFD for Pultruded FRP Structures – A review of changes from the Pre-Standard, improvements, and needs for future editions

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ACMA American Composites Manufacturers Association | EPTA

Presentation prep

- I am not on the ASCE 74 committee
- I was asked by ACMA to present on ASCE 74 objectively from an AEC professional's perspective
- I'm not here to technically inform so much as to build confidence in codes and standards bases, and identify major future needs

1907 – **Baekland** synthetized the first composite plastic: **Bakelite**

1930s – **FRP** began to be used for **commercial** applications

1935 – Founding of **Owens-Corning** and “**Fiberglas**” patenting

1937 – The first **FRP boat** and first **FRP airplane** were fabricated

1944 – **Watson** patented the first **pultrusion-type** process

1950s – First production of **Carbon** fibers and **aramid** fibers

1970s – Production of larger **load-bearing pultruded FRP profiles** began

1973 – **Hart-Smith** published an extensive report on **pultruded FRP connections limit states** for aeronautical applications

1980s – First **structural** applications of **pultruded FRP profiles** in **EMI** test laboratory **buildings**

1980s – A new **pultruded FRP system** for **cooling towers** was developed

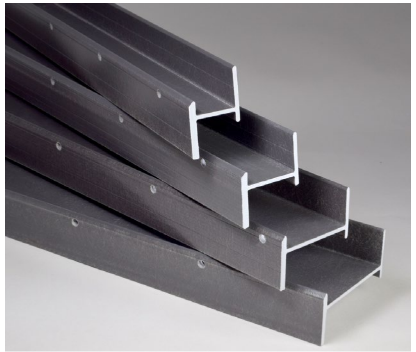
1990s – Extensive **research** on **pultruded FRP** performance for **structural** applications was conducted

1992 – **Rosner** published extensive research on **pultruded FRP connection limit states** for structural applications

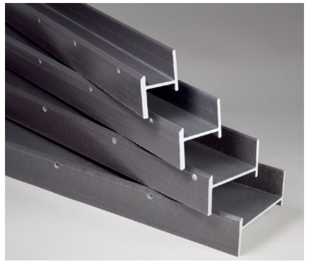
2010 – The ASCE **pre-standard** for **LRFD design** of **pultruded FRP** was published

2016 – The **pre-Eurocode** for **design** of **pultruded FRP** was published

2023 ? – **ASCE standard for LRFD design of pultruded FRP (ASCE 74)** to be published?

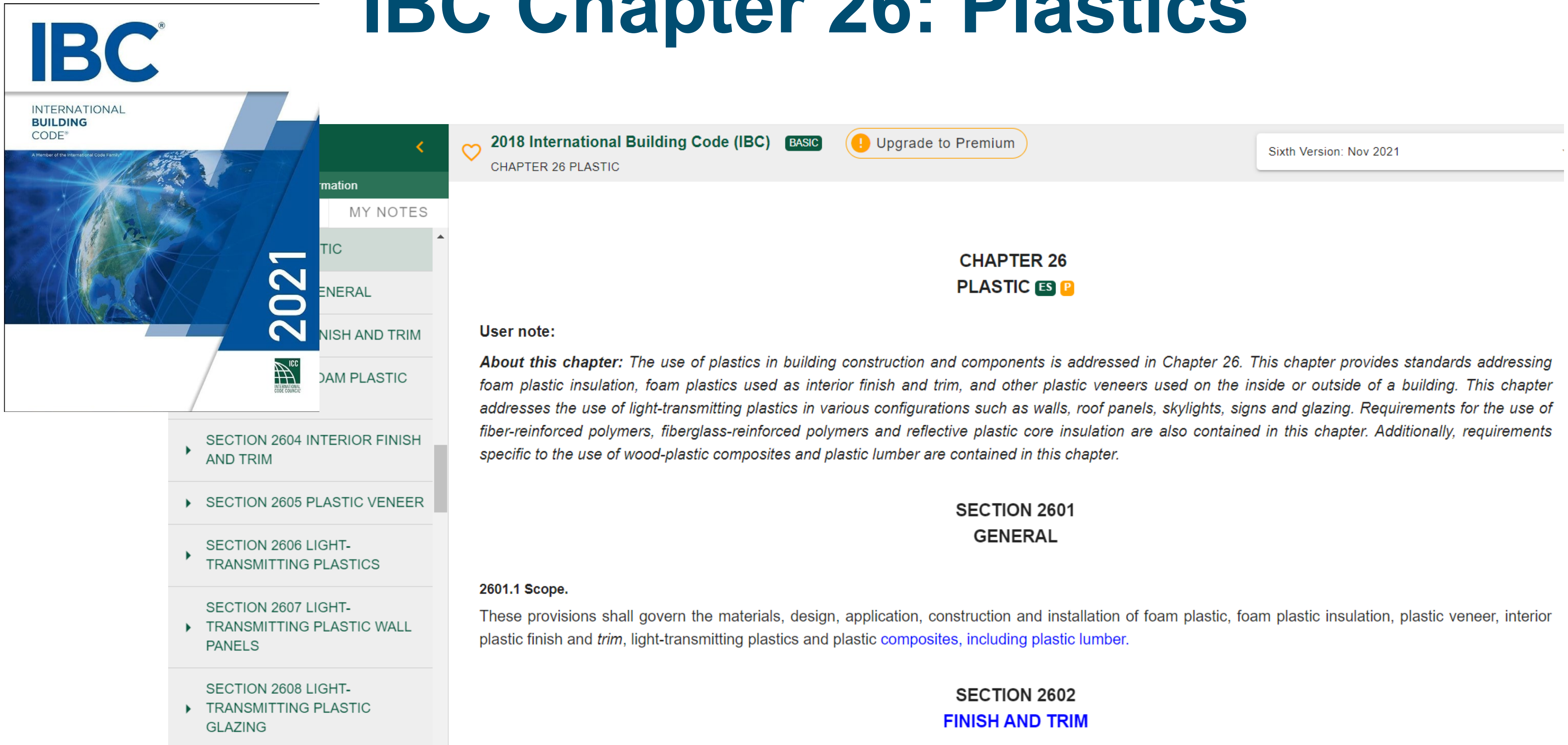


Pedestrian Bridges	Cooling Towers	Interventions on the Existing	Utility and Access Platforms	Buildings
130 ft pedestrian and cycle bridge in Kolding, Denmark (1997). Inspected **15 years after** installation with **no damage** reported.	Cooling tower in Hamm Uentrop, Germany (2005). More than **100 tons** of pultruded FRP used.	**1,300 ft** long walkway in the de-Arrikrutz cave in Oñati, Spain (2007).	Helipad in pultruded FRP in France. Design for **rapid construction** and **fire protection.**	**50 ft** tall **5-story** building in Basilea, Germany (1999). Footprint: **1,300 sq ft.**
135 ft pedestrian in Moscow, Russia (2004). Longest span: **50 ft.** Installed in **49 minutes.**	Cooling tower in Salavat, Russia (2007). More than **100 tons** of pultruded FRP used.	Renovation of a sewage plant in Copenaghen, Danmark (2008). **13,000 sq ft** of pultruded FRP covering.	Multilevel platform in Santa Clara, California, US (2021). One of the **largest** pultruded FRP structures **in area of high seismicity.**	Novantis Campus entrance building in Switzerland (2006). Footprint: **4,300 sq ft.**
130 ft pedestrian and cycle bridge in Svendborg, Denmark (2009). Installed in **2 hours.**	Cooling tower in Hellisheidi, Iceland (2008). More than **100 tons** of pultruded FRP used.	Roof replacement of the S. Maria Paganica **church** after the L'Aquila **earthquake** in L'Aquila, Italy (2010).	Boardwalk in St. Mary's Lake at Notre Dame, Indiana, US (2022). Design for **100-year** service life.	Cathedral of Creteil in France (2014). Footprint: **3,800 sq ft.** and **5,800 ft** of pultruded FRP tubes used.



Relevant codes, standards, and guidelines

IBC Chapter 26: Plastics



2018 International Building Code (IBC) BASIC | Upgrade to Premium | Sixth Version: Nov 2021

CHAPTER 26 PLASTIC

rmation | MY NOTES

TIC
ENERAL
NISH AND TRIM
OAM PLASTIC
SECTION 2604 INTERIOR FINISH AND TRIM
SECTION 2605 PLASTIC VENEER
SECTION 2606 LIGHT-TRANSMITTING PLASTICS
SECTION 2607 LIGHT-TRANSMITTING PLASTIC WALL PANELS
SECTION 2608 LIGHT-TRANSMITTING PLASTIC GLAZING

CHAPTER 26
PLASTIC ES P

User note:

About this chapter: *The use of plastics in building construction and components is addressed in Chapter 26. This chapter provides standards addressing foam plastic insulation, foam plastics used as interior finish and trim, and other plastic veneers used on the inside or outside of a building. This chapter addresses the use of light-transmitting plastics in various configurations such as walls, roof panels, skylights, signs and glazing. Requirements for the use of fiber-reinforced polymers, fiberglass-reinforced polymers and reflective plastic core insulation are also contained in this chapter. Additionally, requirements specific to the use of wood-plastic composites and plastic lumber are contained in this chapter.*

SECTION 2601
GENERAL

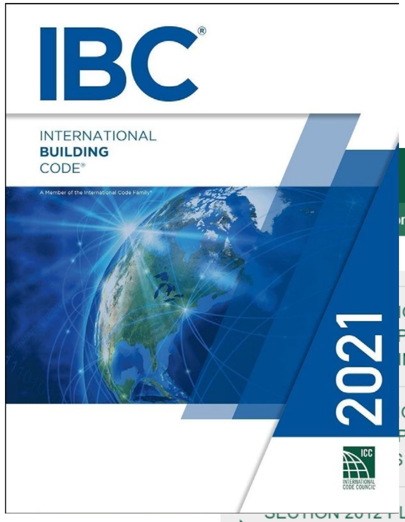
2601.1 Scope.

These provisions shall govern the materials, design, application, construction and installation of foam plastic, foam plastic insulation, plastic veneer, interior plastic finish and *trim*, light-transmitting plastics and plastic composites, including plastic lumber.

SECTION 2602
FINISH AND TRIM

- References NFPA, UL, and ASTM standards for flame spread, smoke, etc.
- References ANSI 100 for wind pressures on cladding

IBC Section 2613: FRP



2021 International Building Code (IBC) BASIC | Upgrade to Premium
CHAPTER 26 PLASTIC
Second Version: Sep 2021

SECTION 2612 PLASTIC COMPOSITES
SECTION 2613 FIBER-REINFORCED POLYMER
SECTION 2614 REFLECTIVE PLASTIC CORE INSULATION
CHAPTER 27 ELECTRICAL
CHAPTER 28 MECHANICAL SYSTEMS
CHAPTER 29 PLUMBING SYSTEMS

SECTION 2613
FIBER-REINFORCED POLYMER

2613.1 General.
The provisions of this section shall govern the requirements and uses of *fiber-reinforced polymer* in and on buildings and structures.

2613.2 Labeling and identification.
Packages and containers of *fiber-reinforced polymer* and their components delivered to the job site shall bear the *label* of an *approved agency* showing the manufacturer's name, product listing, product identification and information sufficient to determine that the end use will comply with the code requirements.

2613.3 Interior finishes.
Fiber-reinforced polymer used as *interior finishes, decorative materials or trim* shall comply with Chapter 8.

2613.3.1 Foam plastic cores.
Fiber-reinforced polymer used as *interior finish* and that contains foam plastic cores shall comply with Chapter 8 and this chapter.

2613.4 Light-transmitting materials.
Fiber-reinforced polymer used as light-transmitting materials shall comply with Sections 2606 through 2611 as required for the specific application.

2613.5 Exterior use.
Fiber-reinforced polymer shall be permitted to be installed on the *exterior walls* of buildings of any type of construction where such polymers meet the requirements of Section 2603.5. *Fireblocking* shall be installed in accordance with Section 718.

- Again, mostly references flame spread and cladding performance

Since we're on the topic of fire…

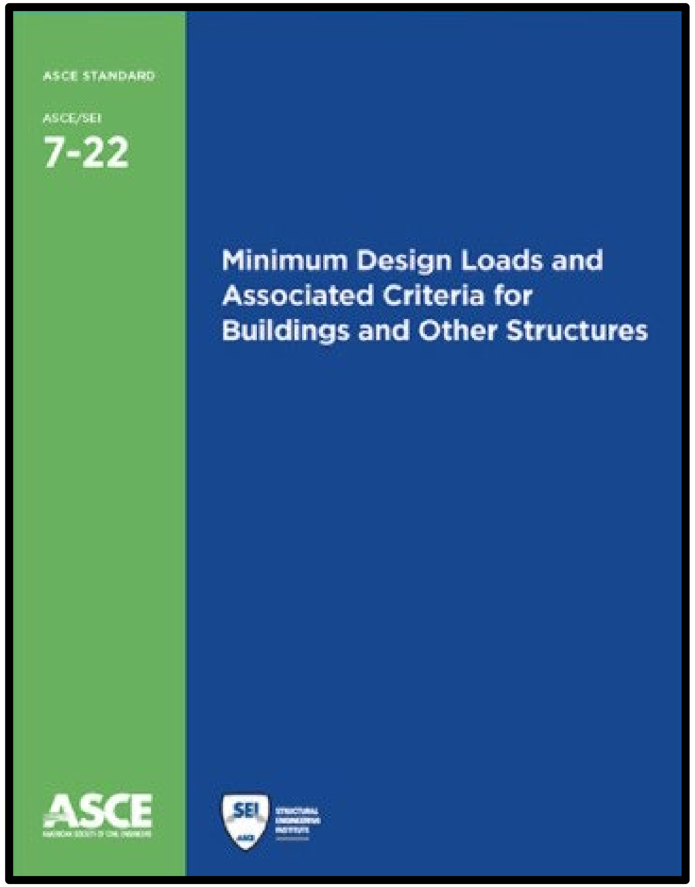
- Question from Oregon-based AHJ just last week:
- *With the building being of Type II-B construction, please provide documentation verifying the FRP structural materials/elements meet the requirements for non-combustibility per OSSC 703.5* **["non-combustible" and have a flame spread index of 50 max]**. *Please note looking for testing of the FRP under ASTM E136 to meet the non-combustible criteria*

Fire Retardant Polyester and Fire Retardant Vinylester Structural Profiles:

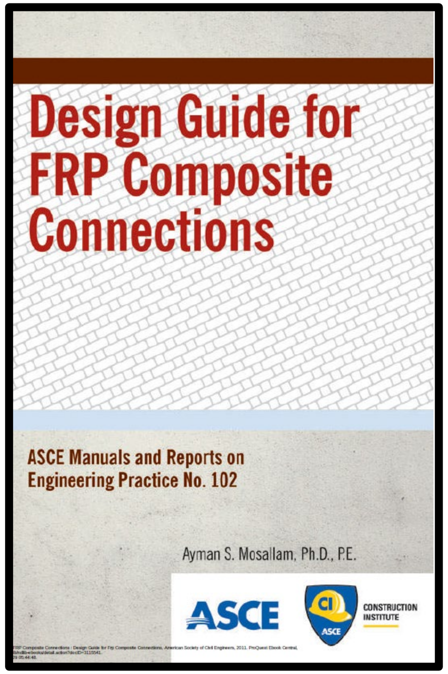
FLAMMABILITY PROPERTIES	ASTM	Units	Value
Tunnel Test	E-84	Flame Spread	25 max.
Flammability	D-635	— —	Nonburning
UL	94	VO	
NBS Smoke Chamber	E-662	Smoke Density 600-700	

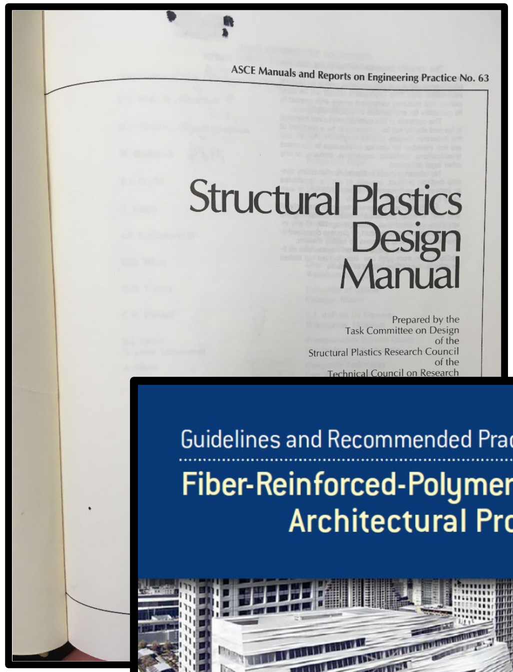
PROPERTY	TEST	VALUE
FLAMMABILITY (Only Series 525 and 625)		
Flammability Classification (1/8")	UL 94	VO
Tunnel Test	ASTM E84	25 Max
NBS Smoke Chamber	ASTM E662	650-700 (Typical)
Flammability	ASTM D635	Self Extinguishing
UL Thermal Index	Generic	266°F
British Fire Test	BS 476-7	Class 1

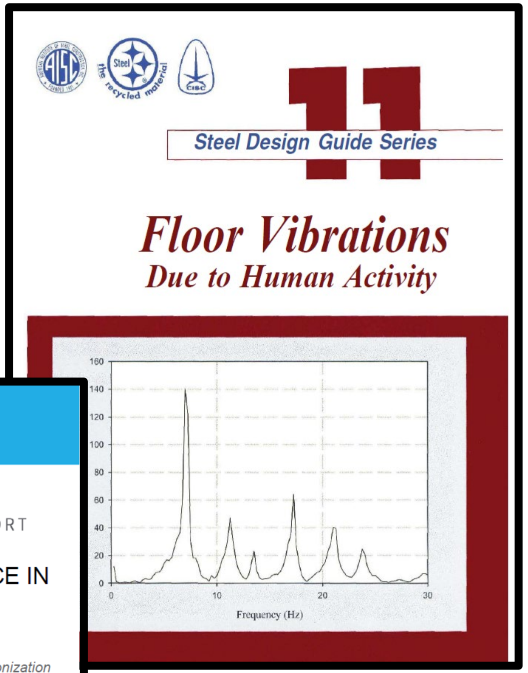
Current standards for loads, capacities, and details

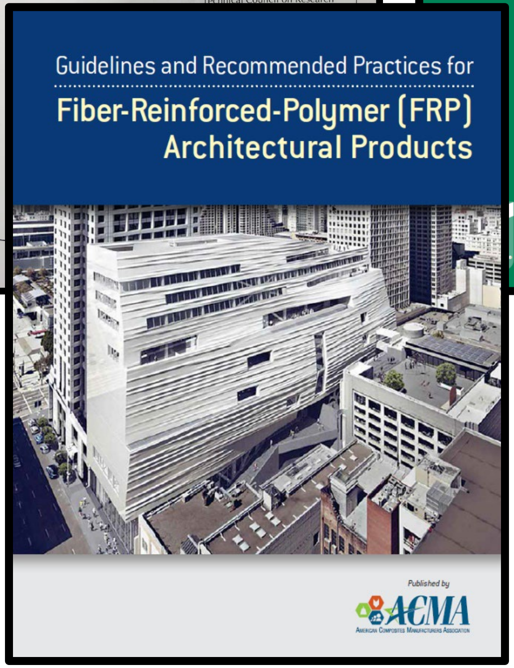


Other referenced capacities standards & guides









Specifications

SECTION 06 82 00 (06610)

ARCHITECTURAL FIBERGLASS REINFORCED POLYESTER

PART 1 - GENERAL

1.01 RELATED DOCUMENTS

A. Drawings, Conditions of the Contract and Division 1 Specifications sections, apply to work of this section.

1.02 SUMMARY

A. Section Includes: Fiberglass reinforced resin fabrications.

1.03 RELATED SECTIONS

A. Section 05 12 13 (05120): Architecturally-Exposed Structural Steel Framing: Support framing for fiberglass fabrications.
B. Section 06 10 53 (06100): Miscellaneous Rough Carpentry: Framing of Openings and Blocking.
C. Section 07 92 13 (07900): Elastomeric Joint Sealants.

1.04 REFERENCE STANDARDS

A. ASTM D638: Test Method for Tensile Properties of Plastic.
B. ASTM D695: Test Method for Compressive Strength of Rigid Plastics.
C. ASTM D790: Test Methods for Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.
D. ASTM E84: Test Method for Surface Burning Characteristics of Building Materials.

1.05 SUBMITTALS

A. Shop Drawings: Dimensions, adjacent construction, materials, thicknesses, fabrications details, required clearances, field jointing, tolerances, colors, finishes, methods of support, integration of components and anchorages.
B. Parts List: Complete list of parts with numbers.
C. Product Data: Manufacturer's product data and installation and maintenance instructions.
D. Manufacturer's Instructions: Manufacturer's instructions and recommendations for product delivery, storage and handling.
E. Product Samples: Minimum 3 inch x 3 inch sample. Match sample provided by Architect.

1.06 QUALITY ASSURANCE

Bolted connections and limit states

ASCE 74 Chapter 8: Design of Bolted Connections

ASCE STANDARD

ASCE/SEI

74-XX

Load and Resistance Factor Design (LRFD) for Pultruded Fiber Reinforced Polymer (FRP) Structures

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

SEI STRUCTURAL ENGINEERING INSTITUTE

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8.1 Scope

The design provisions of this chapter shall apply to *bearing-type* and *tension-type* bolted connections for pultruded FRP shapes and plates and other FRP and/or metallic components and comply with the requirements specified in Section 8.2. Connections of pultruded FRP members can be direct or can incorporate connecting elements (e.g., gussets, splice plates, and angles) using steel or stainless steel bolts. Connecting elements shall be steel, stainless steel, or aluminum, except as permitted by Section 8.1.3. Design of steel connection components shall be in accordance with AISC 360 and aluminium connection components shall be in accordance with the *Aluminium Design Manual*. Column-bases bearing on concrete shall be in accordance with ACI 318 and AISC *Steel Construction Manual*.

The types of connection covered shall take the form of lap shear configurations with the loading principally in plane with the connecting members. Also covered are simple frame connections in the forms of a single or a pair of clip angles.

We recommend clarifying the limitations expected in this provision. For example, can a FRP L-shape vertical brace element be designed using these provisions but not an L-shape clip angle with the exact same demands and bolt configuration?

Slip-critical connections are not permitted.

FRP connection elements are permitted where connections are designed in accordance with the requirements of Section 2.3.2. Connections in FRP structures using FRP nuts and bolts or solid reinforced rods or adhesive bonding are designed in accordance with the requirements of Section 2.3.2. Connection elements and fasteners shall be of compatible materials.

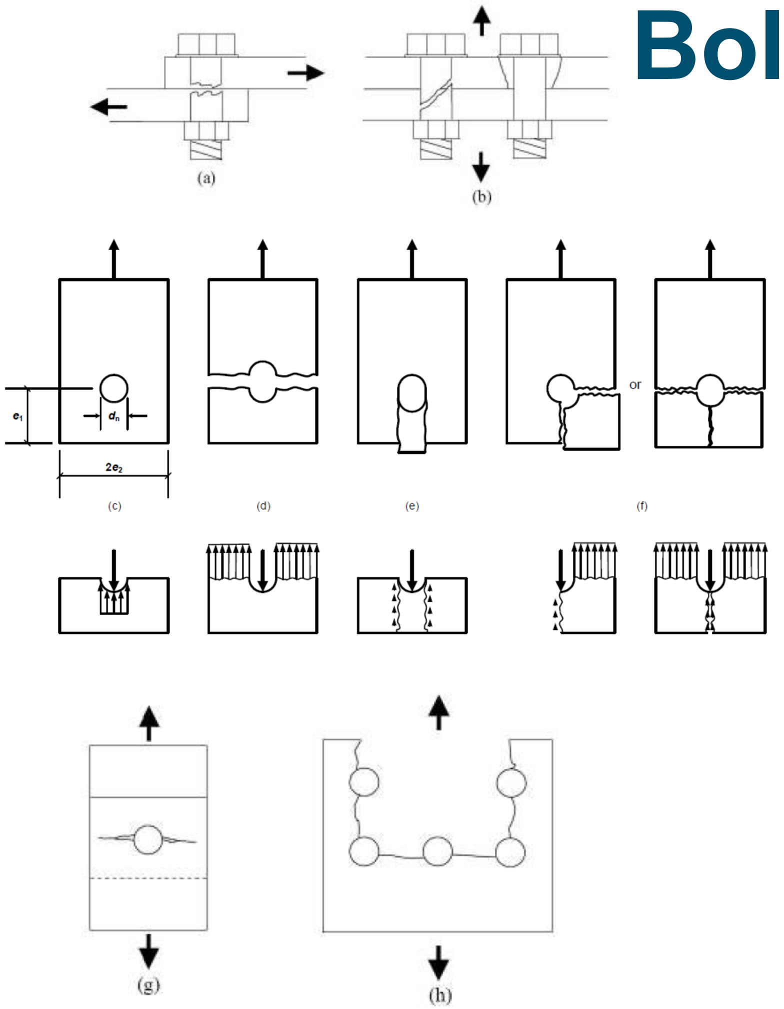
Bolts referenced in this chapter shall conform to the provisions in Sections 8.2.2 and 8.3.2.1.

This chapter does not apply to bolted connections (Figure 8.2-1) with more than three bolts positioned in a line (a column) that is parallel to the direction of a connection force component and/or with more than three or more bolts in a single line (a row) with the same connection force component acting perpendicular to this line of bolting. The detailing of a connection with more

Types of FRP connections

- Ductility of steel connections moot because plasticity of steel connections unlikely to occur prior to FRP fracture
- Therefore, steel only used in skewed connections and when required for high demand scenarios
- Three FRP connection scenarios are prominent in our projects:
  - WT-shape connections for braces (lower loads)
  - Gusset plate connections for braces (higher loads)
  - Double angle connections for beams

Bolted FRP connections: Limit states



Pre-Standard for pultruded FRP design – Figure C8.3

Guidance in ASCE 74

- Tension and shear strength of the bolts
- Tension (through-the-thickness) strength
- Pin-bearing strength
- Net tension strength at first bolt row
- Shear-out strength
- Block shear strength

No guidance in ASCE 74

- Prying of the connection

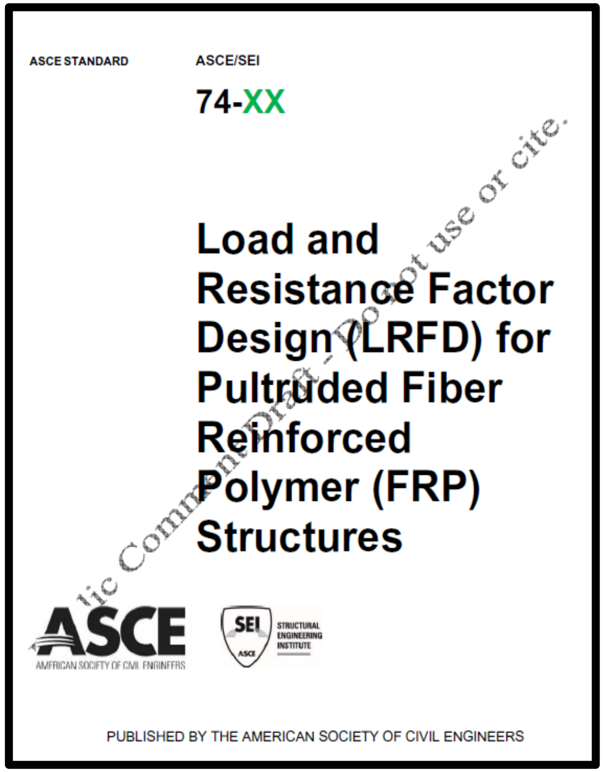
Major differences between the Pre-Standard and ASCE 74

Seismic Design Coefficients New to ASCE 74

Seismic design coefficient per material and structural system	Generic FRP	Multi-tier braced FRP frame	Steel ordinary concentrically braced frames	Steel special concentrically braced frames
Response modification coefficient, R	1.00	1.50	3.25	6.00
Deflection amplification factor, C_d	1.00	1.50	3.25	5.00
Overstrength factor, Ω_0	1.50	1.50	2.00	2.00

Base shear decrease →

Component demand increase →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Pre-Standard for
Load & Resistance Factor
Design (LRFD) of Pultruded
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Structures
(Final)

Submitted to:
American Composites Manufacturers
Association (ACMA)

November 9, 2010

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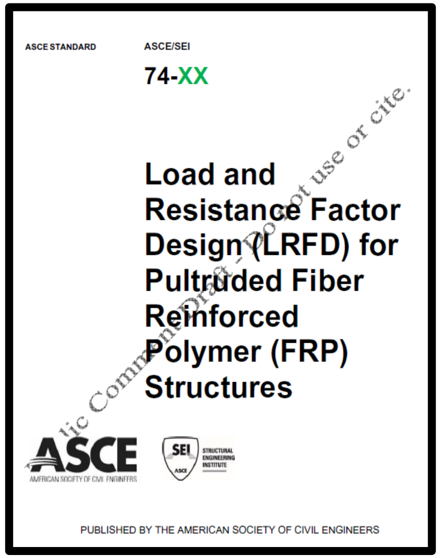
- Testing laboratory approved by the Engineer of Record
- Minimum material properties specified for all cases
- Vinyl ester considered more resistant against moisture

- Testing laboratory accredited per ISO/IEC 17025
- Material properties (e.g., pin-bearing strength) to be tested potentially for any new application
- Moisture factors decrease for both vinyl ester and polyester, and no difference between the two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$$f_{cr} = \frac{4t_f^2}{b_f^2}\left(\frac{7}{12}\sqrt{\frac{E_{L,f}E_{T,f}}{1+4.1\xi}} + G_{LT}\right)$$

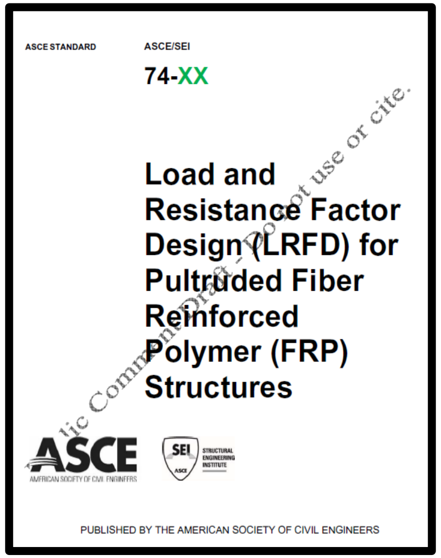
with

$$\xi = \frac{E_{T,f}t_f^3}{b_f k_r 6}$$

$$k_r = \frac{E_{T,w}t_w^3}{6h}\left(1-\left[\left(\frac{48t_f^3h^2E_{L,w}}{11.1\pi^2t_w^3b_f^3E_{L,f}}\right)\left(\frac{G_{LT}}{1.25\sqrt{E_{L,w}E_{T,w}}+E_{T,w}\nu_{LT}+2G_{LT}}\right)\right]\right)$$

- Conservative but sometimes complex member strength equations
- Connection limit state equations generally more complex although more “accurate”
- ϕ-factors calibrated for the limited amount of available test data and for the brittle behavior of pultruded FRP

- Member strength equations generally more simple and more conservative
- Net tension strength equation significantly simplified in a conservative manner
- ϕ -factors are generally equal to or lower than the Pre-Standard (with limited exceptions)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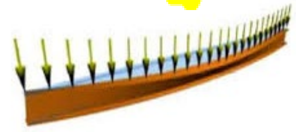
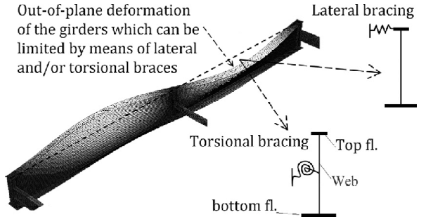
$$F_{crf} = \frac{G_{LT}}{\left(\frac{b_f}{2t_f}\right)^2}$$





Recommended industry needs for future versions of ASCE 74

- Tests for prying effects on FRP connections
- Tests for inelastic behavior of pultruded FRP framing
- FEMA P-695 analyses to establish (less conservative?) seismic design coefficients (i.e., R, C_d, and Ω_0)

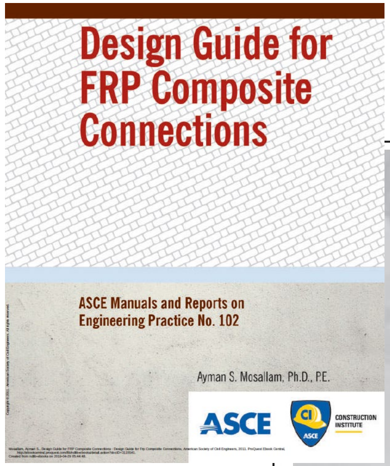
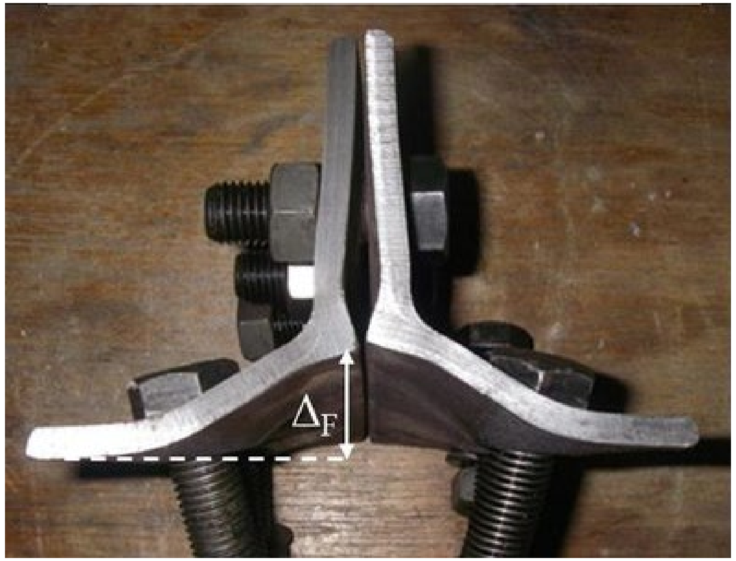


Figure 7-76. Seismic evaluation of 3-D PFRP frame structure with PFRP gratings.
Source: Mosallam (2000).

Prying Effects on FRP

Tensile force



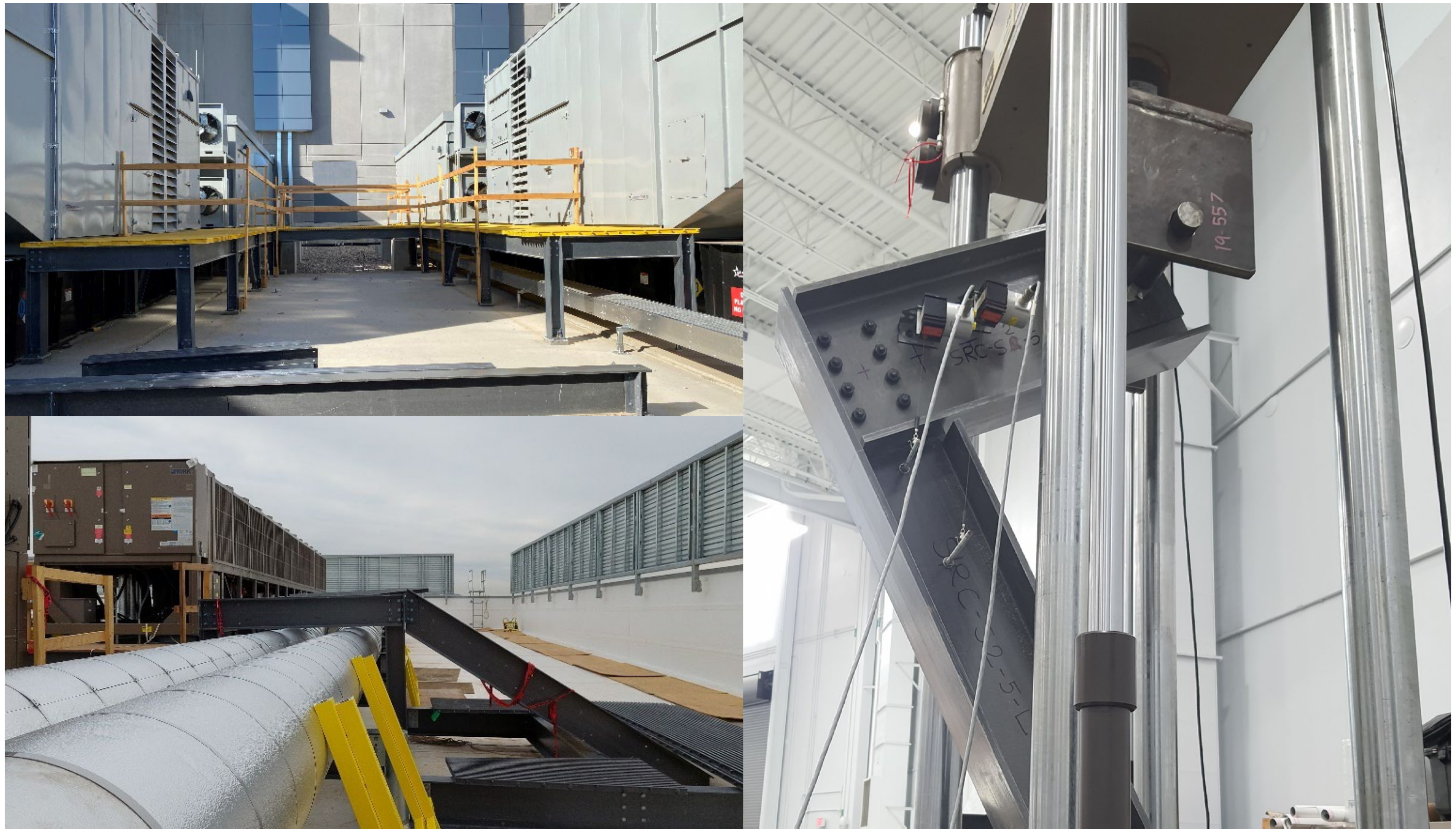
The image is of steel clips. The mechanism for FRP would be similar but with less deformation prior to fracture.

Most beams are also part of the lateral load resisting system; therefore, large axial loads and connection prying often governs

No prying action guidance in ASCE 74

Concern is bending rupture of a leg of the FRP connection.

Moment-Resisting Connections



Need for moment resisting connections to avoid interferences (i.e., clashes).

Need for formalized design and testing guidance; ultimately equations for stiffness and strength based on pre-qualified connections

Continuous Material Strength Function

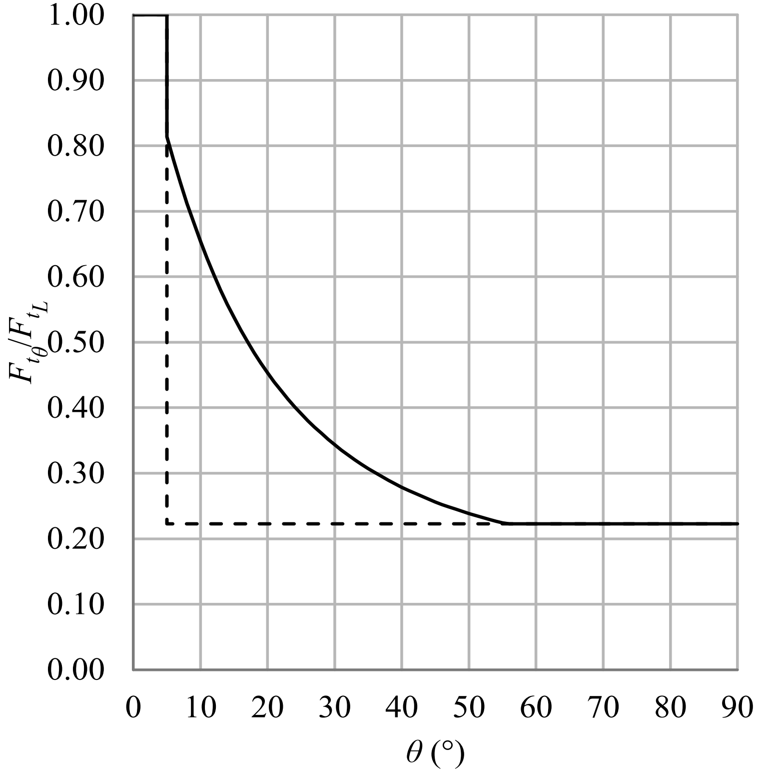


Table 1.3-2(a) Minimum Required Characteristic Mechanical Properties for FRP Composite Shapes

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.


THANK YOU!
Questions?
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