New Standard for Load & Resistance Factor Design (LRFD) for Pultruded Fiber Reinforced Polymer (FRP) Structures

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- Section 3 - Requirements for Design of Members
- Section 4 - Requirements on Connections
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General

ASCE/SEI 74 - LRFD DESIGN OF PULTRUDED FRP STRUCTURES

(In final stage of approval, coming soon)

Why A Design Standard is Needed

- **The Standard**
  - follows the **consensus process of ASCE** which is open to all members of Fiber Composites and Polymers Standards (FCAPS) committee of ASCE and to the public.
  - follows the **consensus process,** which is documented, reviewed and approved by the American National Standard Institute (ANSI).
  - provides a set of **mandatory requirements** for the design of pultruded FRP structure.
  - provides a **basis for standard of care for design** of such structures in legal jurisdictions.
  - **drastically reduces the risks** associated with the design of pultruded FRP structures for a structural designer who has followed the standard before the structure can be constructed.

What the Standard is Intended to Achieve

- **Promotes the use of pultruded FRP structures** and expected to have a significant impact on the demand for pultrusion products.
- Uses **load and resistance factor design approach** and thus provides strength, reliability, and durability comparable to other materials of construction.
- **Allows for future innovation** in the development of new products and new applications for such products.
- **Allows flexibility in design** of structure for different service life.

Design Applications Goal of Standard

- **New buildings** and other structures constructed of pultruded glass fiber reinforced polymer (FRP) composite structural shapes and profiles
- **Connections**
- **Prefabricated** building components
- **Industrial Structures** that are exposed to adverse environments

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Design Challenges Pultruded FRP Composites

- **Anisotropic/Orthotropic** and more difficult to design, but allow innovation
- **Creep and creep rupture** which must be accounted for in design
- **Long-term exposure to certain environments** which must be accounted for in design as end-use properties may differ from initial properties

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The Standard Table of Contents

- The Standard consists of **nine chapters** of **Mandatory** provisions along with nine chapters of **Commentary**.
- **Chapters:**
  1. General Provisions
  2. Design Requirements
  3. Design of Tension Members
  4. Design of Compression Members
  5. Design of Members for Flexure and Shear
  6. Design of Members Subject to Combined Forces and Torsion
  7. Design of Plates and Built-up Members
  8. Design of Bolted Connections
  9. Seismic Design Requirements
  10. Glossary
  11. Symbols

Section 1

Requirements on Materials

Material Qualifications

- The material and the design must meet certain criteria
  - ✓Fiber system
  - ✓Resins (polyester, vinyl ester, epoxy)
  - ✓Other Constituents (fillers, promoters, accelerators, inhibitors, UV agents, pigments)
  - ✓Minimum physical (e.g., Tg) and mechanical properties of laminate
  - ✓Fire, smoke and toxicity requirements
  - ✓Durability and environmental effects.
  - ✓Time effects

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Example of Fiber System Requirements

- ***Fiber Form**:* All forms including rovings; woven, braided, or stitched fabrics; continuous strand mats, and chopped strand mat.
- ***Fiber Orientations***: Each element of a pultruded FRP member shall have reinforcing fibers oriented in a minimum of two directions separated by a minimum of 30 degrees.
- ***Fiber Volume Fraction***: The minimum total fiber volume fraction of each pultruded FRP element shall not be less than 30%.
- ***Percentage of Fiber Orientation***: The total fiber volume reinforcement in the longitudinal direction shall be at least 30% for shapes and 25% for plates.
- ***Fiber Fraction Through Multiple Element Edge***: When multiple elements share a common edge, 50% of the non-roving reinforcement of the element shall extend through the junction of the connecting the elements.
- ***Minimum Tensile Strength of Fiber**:* The characteristic value shall be not less than 290 ksi when tested according to ASTM D2343.

Section 2

Requirements on Design

Loads, Load Factors and Load Combinations

Loads, load factors, and load combinations are the same for all materials of construction. Therefore, like other materials of construction we rely on the requirements of ASCE Standard 7, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures.*

- The structure should be designed for the following one of many load combinations in ASCE 7.

$$1.2D + 1.6L + 0.5(Lr \text{ or } S \text{ or } R)$$

where D= Dead Load, L = Live Load, Lr = Roof Live Load, S = Snow Load, and R = Rain Load

Basic Strength Requirement

Design is based on the following:

$$R_u \leqq \lambda\phi R_n = \lambda\phi(CR_o)$$

R_u = required strength when subjected to factored load combinations

λ = time effect factor, accounts for the material creep rupture of under sustained loads

φ = resistance factor that accounts for the variability and the bias of resistance

R_n = nominal strength in the end-use condition,

C = material adjustment factor that accounts for durability material exposed to exposure environment for service life of the structure

R_o = reference strength of new material as tested in the laboratory based upon the characteristic value at 80% lower confidence interval per ASTM D7290

Material Adjustment Factor

- **Design must account for the long–term environmental effects** during the service life of the structure.
- Adjustment factor for strength or modulus is **the retained value at the end of service life** relative to in the reference condition.
- **Long term exposure tests** for 1,000 to 10,000 hrs followed by strength and modulus tests are conducted on the materials.
- The results are **extrapolated to the service life** of the structure.

Material Adjustment Factors for End-Use Condition

- C_M = exposure to sustained moisture,
- C_T = exposure to sustained temperature higher than 90°F (38°C) but less than Tg – 40°F.
- C_{CH} = exposure to chemical environmental (high alkalinity, acidity), from the results of ASTM C581 tests for 1,000 hours, or as stipulated by Registered Design Professional.

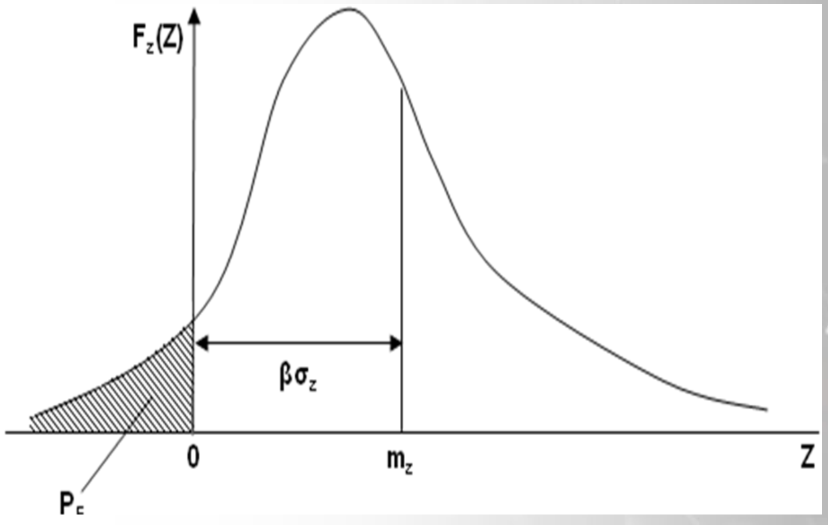
Reference Property		Moisture C_M	Temperature (°F) C_T for $(90 < T \leq 140)$
Vinyl Ester	Strength	0.75	1.7 – 0.008T
	Modulus	0.90	1.5 – 0.006T
Polyester	Strength	0.75	1.9 – 0.010T
	Modulus	0.90	1.7 – 0.008T

Time Effect Factors, λ

Load Combination	λ
1.4D (permanent load)	0.4
1.2D + 1.6L + 0.5(L_r or S or R)	0.8 when L from occupancy 0.6 when L is from storage 1.0 when L is from LL impact
1.2D + 1.6(L_r or S or R) + 1.0 L or 0.5W	0.75
All other load combinations involving full design wind and seismic loads	1.0

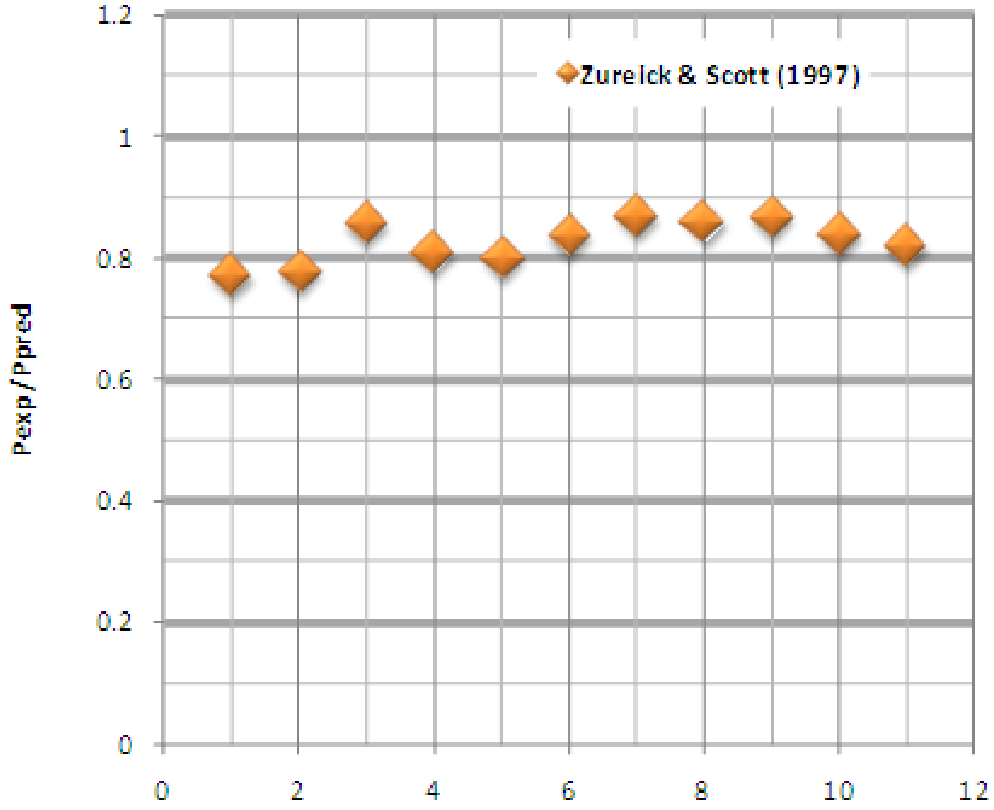
Material Resistance Factor, ϕ

- Material resistance factor accounts for **bias and variability** of resistance, and involves
  - Performing tests to failure
  - Comparing test results with the predictive formulas in the standard. Determine the bias.
  - Compute the standard deviation.
  - Resistance factor = 1- Bias/(Mean Strength) – β (Standard Deviation /mean Strength) where **β = reliability index**.
  - **Reliability of designs of PFRP by this Standard is the same as other materials of construction if β is the same.**



Determination of ϕ for Compression Members

- Compressive Strength of Pultruded Square Tubes



$$F_{crw} = \frac{\left(\frac{\pi^2}{6}\right)\left[\sqrt{E_{L,w}E_{T,w}} + \nu_{LT}E_{T,w} + 2G_{LT}\right]}{\beta_w^2}$$

Reliability Index Values

Limit state	Target reliability range
Global instability	3.0 – 3.5
Local instability	3.5 – 4.0
Material strength – tension, compression, shear	3.5 – 4.0
Connection failure modes; bearing, net tension	4.0 – 4.5

Section 3

Requirements for Design of Members

Design of Members

- The requirements for determining the capacity of pultruded FRP structural shapes are discussed in six chapters as follows
- Members
  - subjected to **tension** through the centroid of the transformed cross section.
  - subjected to **compression** through the centroid of the transformed cross section. (details are provided in the following slides)
  - subjected to **flexure and shear** resulting from loading transverse to their axes
  - subjected to **axial force and bending** and **axial force, bending, and torsion**.
  - Design of pultruded FRP **flat plates** subjected to flexure, through-the-thickness shear, and in-plane loading.

Design of Compression Members

Design of a PFRP member subjected axial compression is governed by

- **Rupture of Members in Compression**: Compression members are designed for rupture and allows for stress risers.
- **General Buckling of Member:** Accounting for initial imperfection, but axial force shall not exceed 30% of compressive strength over the gross section.
- **Local Buckling Strength of Flanges and Webs** of PFRP Sections**.**
- **Slenderness Ratio** of a compression member is bounded.

Section 4

Requirements on Connections

Design of Bolted Connections

Bolted Connection Limit States

(a) bolt tension and shear
(b) pull-out tension
(c) pin bearing
(d) net tension
(e) shear-out
(f) cleavage

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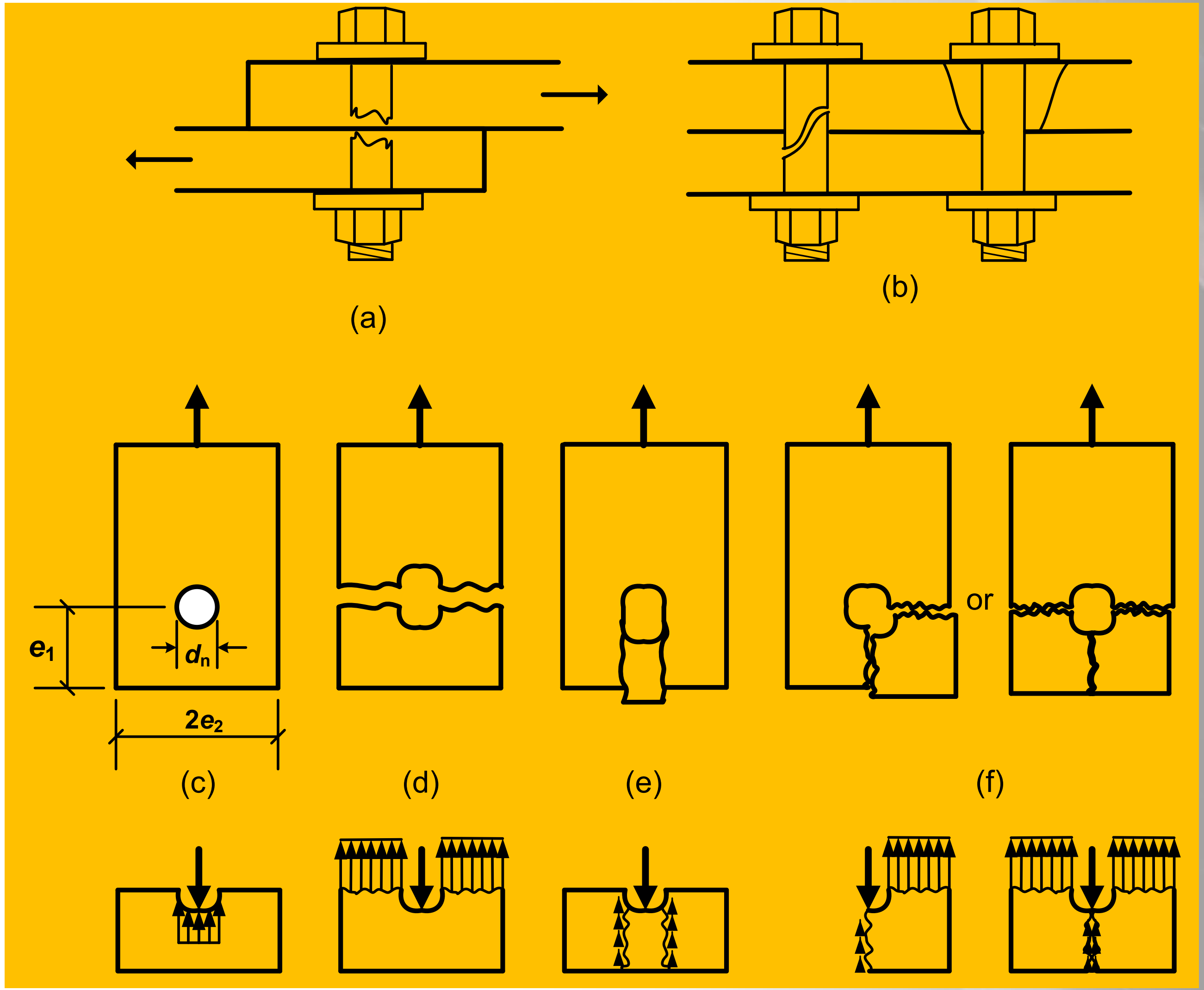
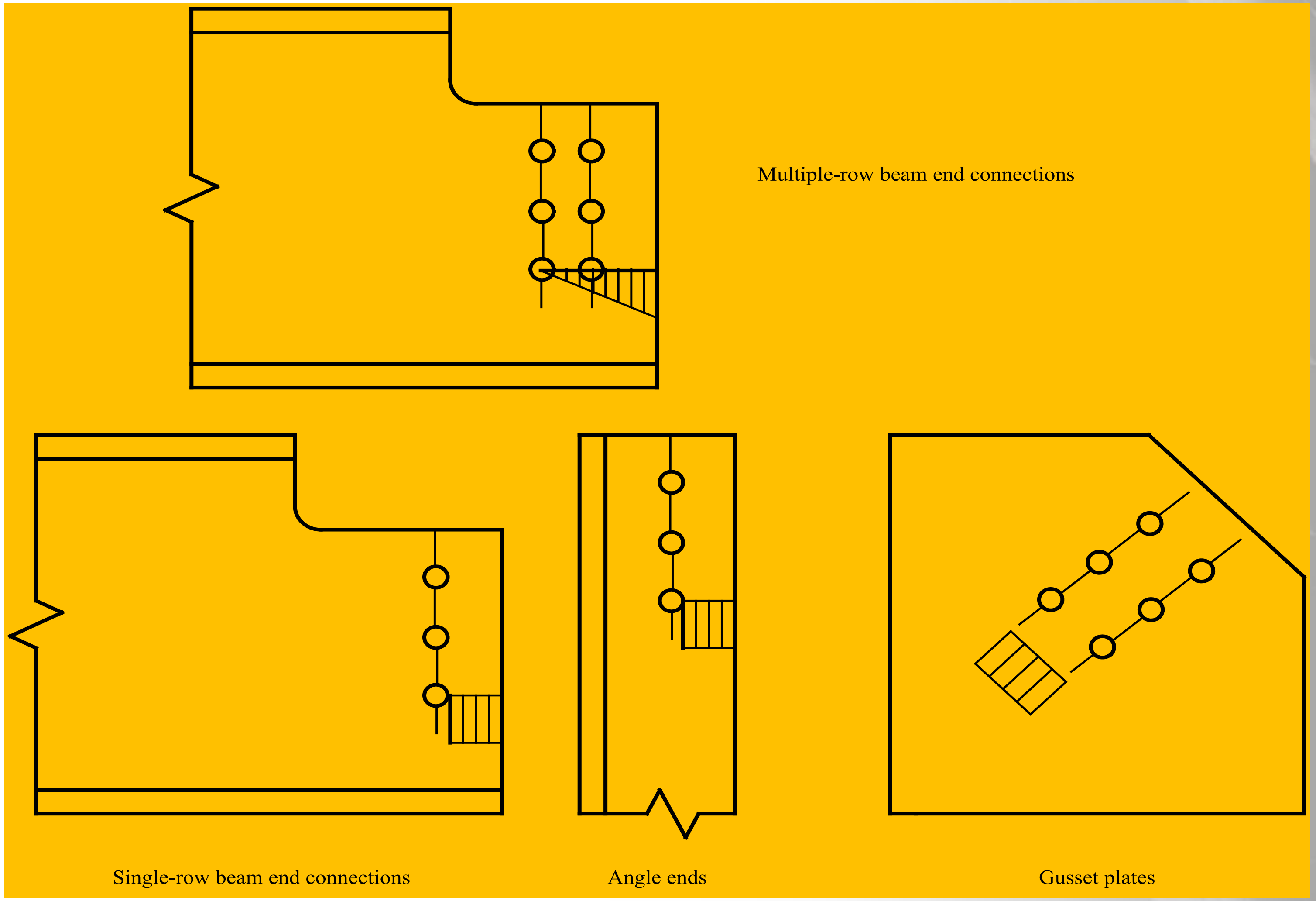


Design of Bolted Connections (Cont.)

Block shear loading situations with assumed direct stress distributions

- Multiple row beam end connection
- Single row beam end connection
- Gusset plate
- Angle ends



Section 5

Requirements for Seismic Design

Seismic Design

- **Scope:** The standard committee felt that seismic design provisions were needed for completeness and to allow structural engineers to make use of the high strength-to-weight ratio of this product.
- **Seismic loads:** Earthquake load effect, E, are determined per *ASCE 7.*
- Designs by this standard meets the **General Structural Integrity** provisions of ASCE 7.
- Seismic Design Parameters of PFRP structures provided **must be incorporated in standards and building codes**.
- To resist lateral seismic loads, PFRP structures **are required to be designed with braces**.

Conclusions

This presentation highlights the major accomplishments of this new ASCE standard.

- After **three years of effort spent in drafting** the Pre-standard by a team of experts, getting it reviewed by a committee of renowned researchers, and trial design by practicing engineers,
- After **many drafts and rewrites** of the chapters by the ASCE FCAPS Committee, and
- After **43 ballots** by the ASCE FCAPS Committee over a span of 10 years.
- **But it is only a significant first step**, and a **lot more research and testing is needed** by the industry, academia, and structural engineers until this product's impact on structures and infrastructures is fully realized.

Thank you, Questions?

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