

Pultrusion Conference 2021

Building Pultrusion Product Opportunities in Structural Engineering

Emily Guglielmo, SE, PE, F.SEI

Martin/Martin, Inc.

Building Pultrusion Product Opportunities in Structural Engineering

- Successes with Composites
- Success with Pultrusion
- Challenges for Pultrusion in Structural Engineering
- Opportunities for Pultrusion in Structural Engineering

Building Pultrusion Product Opportunities in Structural Engineering

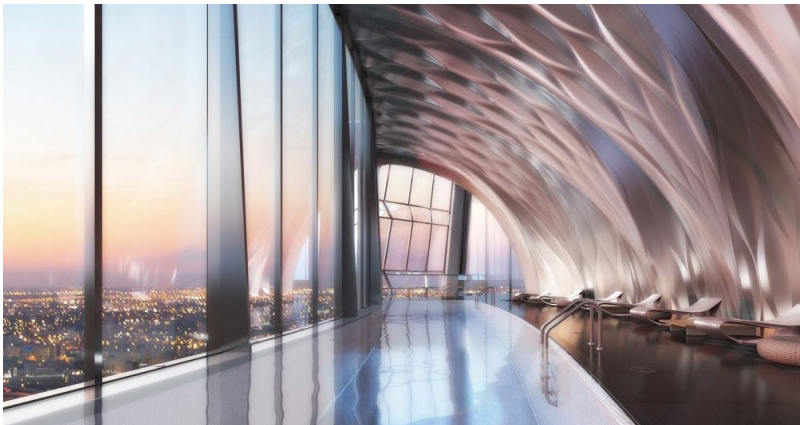
- Successes with Composites
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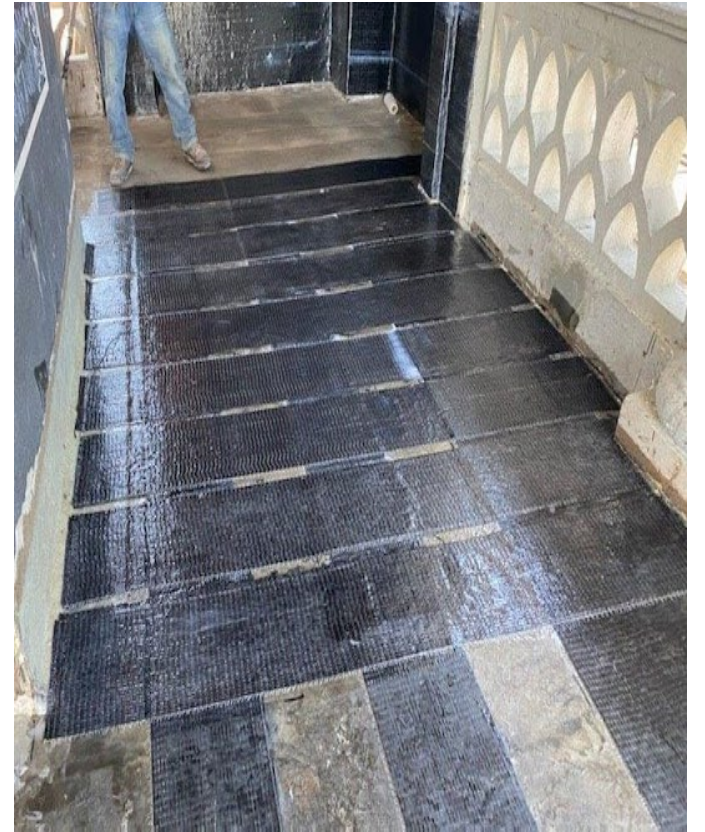
Successes with Composites: Sculpture



Successes with Composites: Canopies



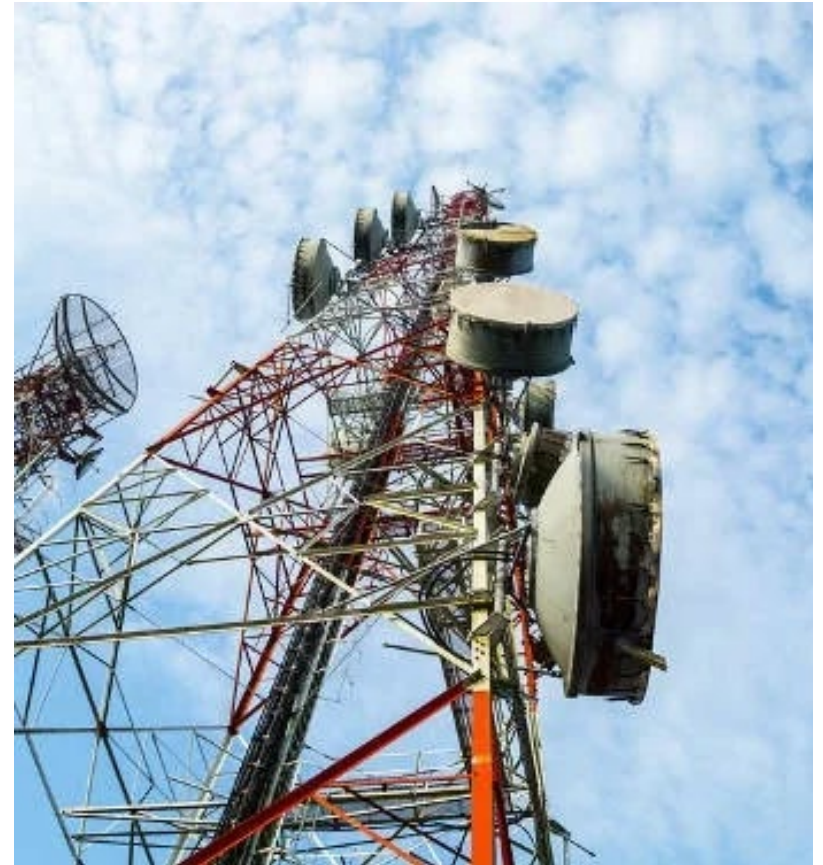
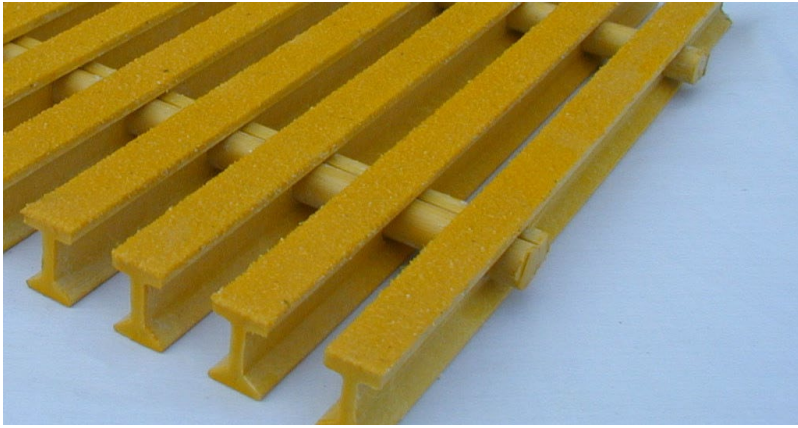
Successes with Composites: Building Facades



Successes with Composites:
Repair and Retrofit

Building Pultrusion Product Opportunities in Structural Engineering

- Successes with Composites
- **Success with Pultrusion**
- Challenges for Pultrusion in Structural Engineering
- Opportunities for Pultrusion in Structural Engineering

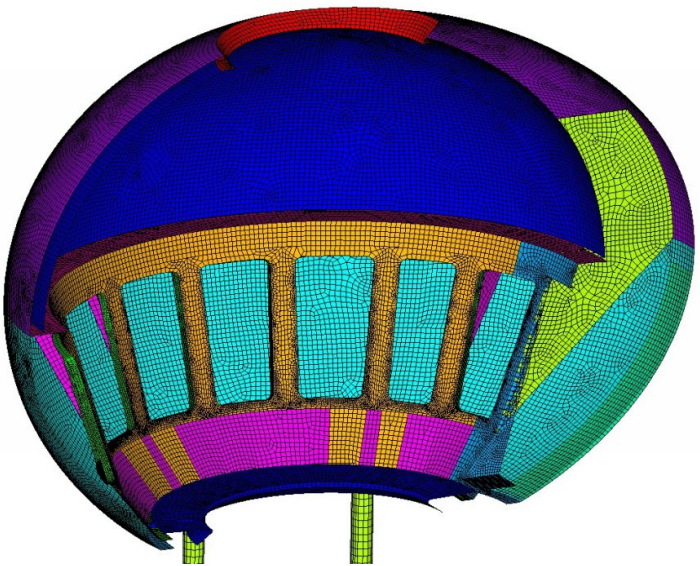
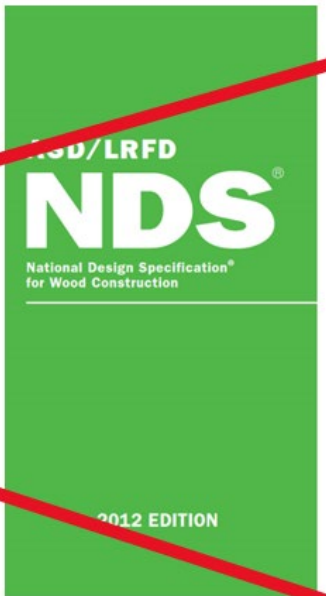
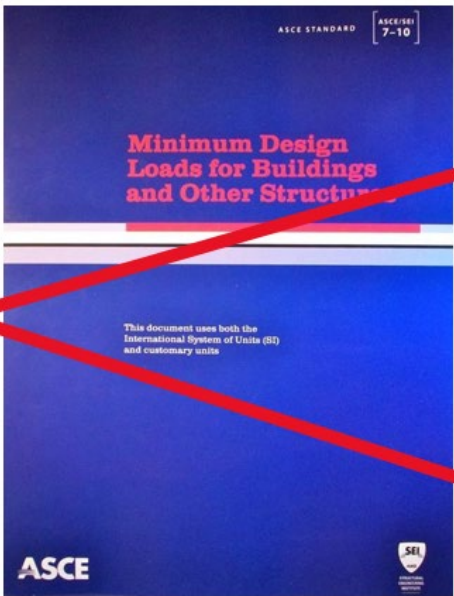
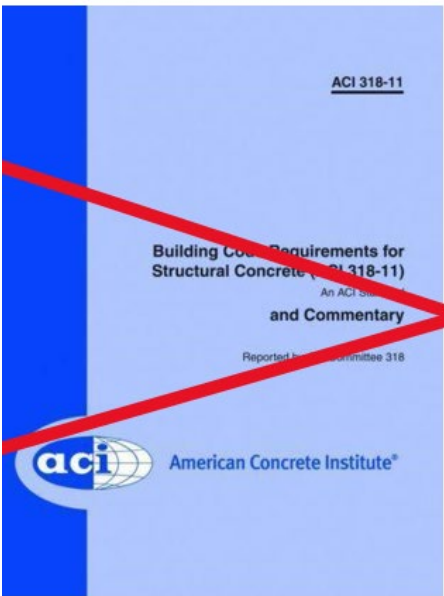


Successes with Composite Pultrusion: Non-Building

Photo Credits: Defiffiberglass, Southern Cooling Towers, Bedford & Pearson Pilings, E.T. Techtonics, Creative Pultrusions Inc., Structural Fiberglass Inc., Strongwell

Building Pultrusion Product Opportunities in Structural Engineering

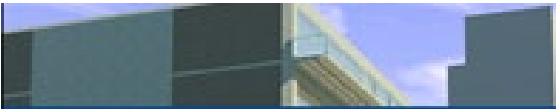
- Successes with Composites
- Success with Pultrusion
- **Challenges for Pultrusion in Structural Engineering**
- Opportunities for Pultrusion in Structural Engineering



Challenges for Pultrusion in Structural Engineering

Table 4-12 (continued)
Available Strength in
Axial Compression, kips
L8-L7 Eccentrically Loaded Single Angles

Step	LE x 4c				LF x 4c			
	$\frac{2}{3}F_{11}^a$	$\frac{1}{2}F_{11}^a$	$\frac{2}{3}F_{11}^a$	$\frac{1}{2}F_{11}^a$	$\frac{2}{3}F_{11}^a$	$\frac{1}{2}F_{11}^a$	$\frac{2}{3}F_{11}^a$	$\frac{1}{2}F_{11}^a$
Bv/ft	21.8	19.8	17.2	28.2	22.1			
Design	P_n/A_1	$\phi_c P_n$	P_n/A_1	$\phi_c P_n$	P_n/A_1	$\phi_c P_n$	P_n/A_1	$\phi_c P_n$
	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
0	60.0	96.2	57.5	86.4	54.7	82.2	55.2	86.0
1	59.3	88.2	56.8	85.4	54.1	81.3	54.4	81.4
2	57.4	88.4	54.9	82.8	52.1	78.5	52.2	78.6
3	54.4	82.0	51.9	78.3	49.2	74.3	50.8	76.2
4	50.5	76.4	49.1	72.8	45.5	68.9	46.9	70.8
5	46.2	70.1	43.3	66.6	41.4	62.8	43.4	67.5
6	41.7	63.6	39.5	60.2	37.2	56.4	38.6	62.1
7	37.4	57.0	35.3	53.9	33.1	50.9	34.1	58.2
8	33.2	50.8	31.3	47.9	29.3	44.9	30.7	51.7
9	29.4	45.0	27.4	43.4	25.8	39.9	27.4	45.8



The Reinforced Concrete Design Handbook
A Companion to ACI 318M-14



CodeMaster

STRUCTURAL WOOD DESIGN ASD/LRFD 2012 IBC ASCE 7-10 2012 NDS

STRUCTURAL DESIGN OF WOOD MEMBERS

This CodeMaster provides ten steps to guide the engineer in structurally designing typical wood framing members (columns, beams, joists, rafters, etc.) in accordance with the 2012 International Building Code (IBC), ASCE 7-10 Minimum Design Loads for Buildings and Other Structures (ASCE 7), and the 2012 National Design Specification[®] for Wood Construction (NDS). The NDS includes a valuable commentary and an NDS Supplement which provides section properties and reference design values. Allowable Stress Design (ASD) is emphasized; however, Load and Resistance Factor Design (LRFD) is also included. The CodeMaster addresses the design of rectangular sawn lumber and structural glued laminated timbers (GLT). Wood structural panels, wood joists, structural composite lumber (LVL, PSL, LSL, OSB, etc.) and decking are not addressed.

Wood has a wide array of different material properties in separate orthogonal directions that are influenced by many factors. Recognizing wood's unique properties and proper application of adjustment factors is at the heart of timber design. Calculated stresses are denoted by lower case letters (such as f_x for calculated bending stress) and reference design values by upper case letters (such as F_b). The NDS denotes the adjusted design values with a "prime" marking (F_b' , F_c' , F_t' , F_s' , E' , E_{min}' , etc.) and it is these adjusted values that are the basis for design.

STEP 1 DETERMINE LOADS AND LOAD COMBINATIONS

Wood structural members such as beams and columns are subject to many types of loads, including gravity loads (e.g., dead, live, snow, and rain) and lateral loads (e.g., wind, earthquake, and soil). Gravity loads are determined by computing the structure's self-weight in addition to live and snow loads determined in accordance with IBC Sections 1607, 1607.1608, and ASCE 7 Chapter 7. Wind loads are determined in accordance with IBC Section 1609 and ASCE 7 Chapters 26 through 31. Earthquake loads are determined in accordance with IBC Section 1613 and ASCE 7 Chapters 11 through 22, including Chapter 14. See the 2012 IBC Seismic Design CodeMaster for more information. Once the loads have been determined, the load path through the structure is analyzed to determine its effects such as bending moments, shear forces, compression forces, and tension forces on individual framing members. The load effects are then combined in accordance with the load combinations of IBC Section 1605.

SECRETS OF THE CODEMASTER: The self-weight of wood framing may be assumed to be "35 lb/ft" for most structural lumber at typical equilibrium moisture contents. NDS Supplement Table 1B provides unit weights for common member sizes. However, published dead loads assumed for certain applications (e.g., residential) often already include self-weight of sawn lumber framing members.

SECRETS OF THE CODEMASTER: Designers have a choice of using ASD or LRFD load combinations. While ASD is more conventional, designs using LRFD loads are easily adaptable with simple conversion factors and with most adjustments remaining unchanged.

STEP 2 DETERMINE AXIAL, SHEAR, AND BENDING FORCES

Using unit loads from STEP 1 in conjunction with tracing the load path, member bending, shear, compression, and tension forces are determined. Computing member tributary area is critical to load path analysis and is also necessary in determining any applicable live load reductions. Tributary area live load reductions are determined in accordance with IBC Section 1607.10 (floor live) and Section 1607.12.2 (roof live). Where applied beam loads occur near the member's support, the design shear force may be reduced per NDS Section 3.4.3.1.

STEP 3 SELECT MATERIALS TO BE USED

Selection of sawn lumber member size and wood species group is largely driven by regional availability. For a given location, only a few species groups will generally be available. Most common are the following softwood species groups:

- Douglas fir-larch
- Southern pine
- Hem-fir
- Spruce-pine-fir

Most typically specified are dressed sizes which are $\frac{1}{8}$ -inch to 1-inch smaller than specified nominal sizes, the range of dressed sizes and their section properties are in NDS Supplement Table 1B. Dimensional size terminology defines thickness (breadth) as the narrow dimension and width (depth) as the largest dimension.

Figure 1. Roof or Floor Framing Plan

Figure 2. Tributary Areas of Valley and Hip Rafters

Figure 3. Typical Rafter Span Simplification

CodeMaster developed by:
Structures & Codes Institute
A subsidiary of S.C. Group Associates Inc.
www.scihq.com
888-915-1000/20-8

Am. Wood Council - www.awc.org
International Code Council - www.iccsafe.org
WoodWorks - www.woodworks.org

Design Guide for FRP Composite Connections

ASCE Manuals and Reports on
Engineering Practice No. 182

Ajman S. Muzaffar, Ph.D., P.E.

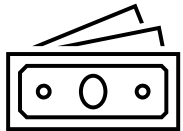
Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures (Final)

Submitted to:
American Composites Manufacturers
Association (ACMA)

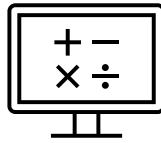
November 9, 2010

Challenges for Pultrusion in Structural Engineering Codes

Analysis
Software
Costs



Lack of
Expertise
in Analysis
Software



Lack of
Expertise in
Composites
Behavior: Non-
Linear, Non-
Isotropic




Lack of
Education in
Composites for
Practicing
Engineers, Plan
Check Engineers



Challenges for Pultrusion in Structural Engineering:
Analysis

Type 1	Fire Resistive	Least Combustible
Type 2	Non-Combustible	
Type 3	Ordinary	
Type 4	Heavy Timber	
Type 5	Wood Frame	Most Combustible



Challenges for Pultrusion in Structural Engineering: Fire

Building Pultrusion Product Opportunities in Structural Engineering

- Successes with Composites
- Success with Pultrusion
- Challenges for Pultrusion in Structural Engineering
- **Opportunities for Pultrusion in Structural Engineering**

Key Advantages

Structural Properties:

- Lightweight
- High-strength
- Dimensional stability
- Non-Isotropic
- Impact resistant
- Unlimited shapes, lengths

Long-Term:

- Long life cycle
- Low-maintenance
- Durability
- Corrosion resistance
- Chemical resistance
- Non-conductivity (thermally and electrically)
- Non-magnetic

Pultrusion

- Lighter weight
- Stronger
- No Rot, mildew, mold, warp when subject to moisture
- No Insect infestation
- No coatings required

Wood



Pultrusion v. Wood

Pultrusion

- Non-Conductive
- Corrosion Resistant
- Lighter weight
- No welding
- Lead time, availability

Steel



Pultrusion v. Steel

Pultrusion

- Non-Conductive (thermally, electrically)
- Corrosion Resistant
- Lighter weight (30% lighter)
- Impact Resistant

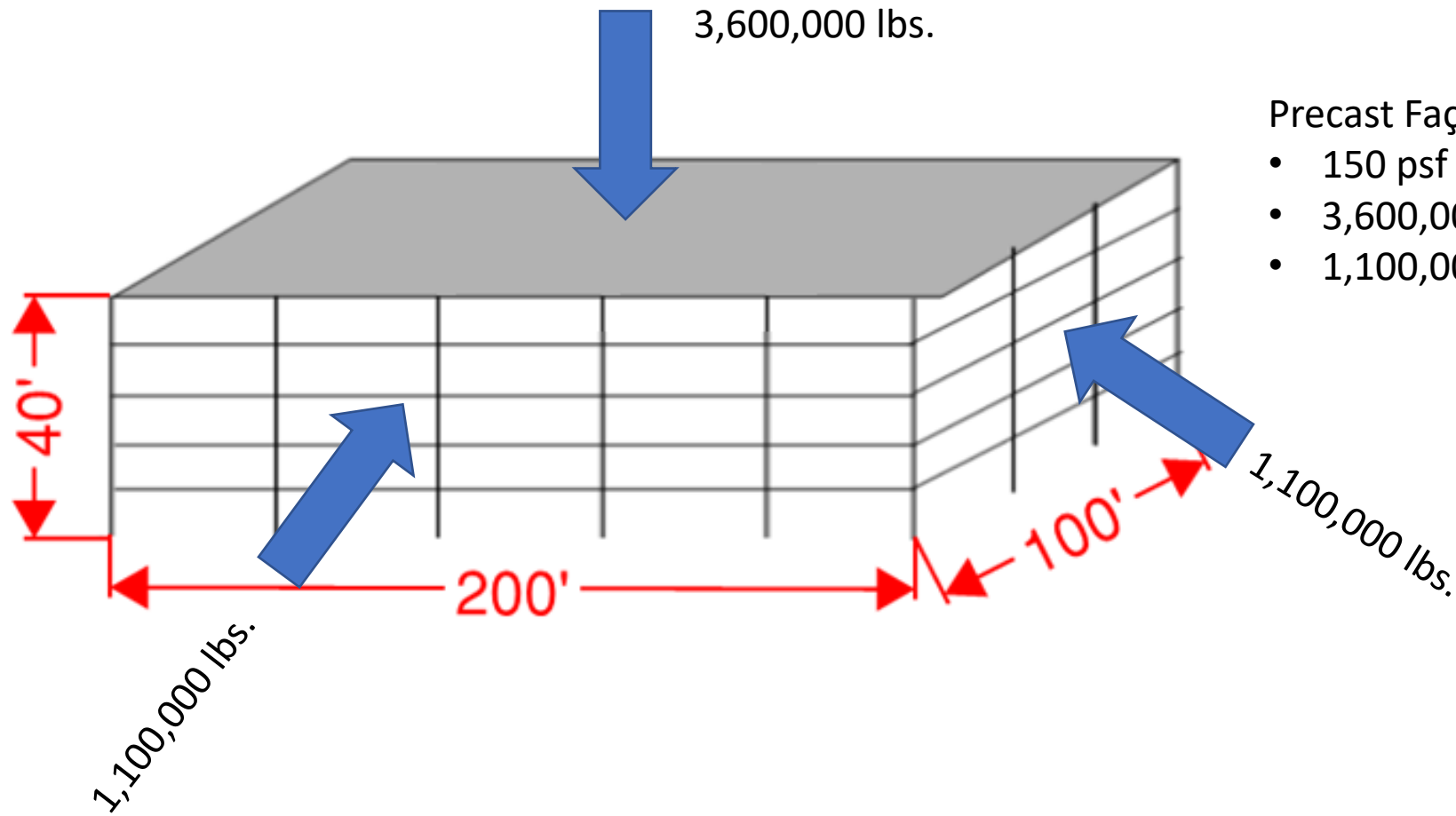
Aluminum



Pultrusion v. Aluminum



Building Weight



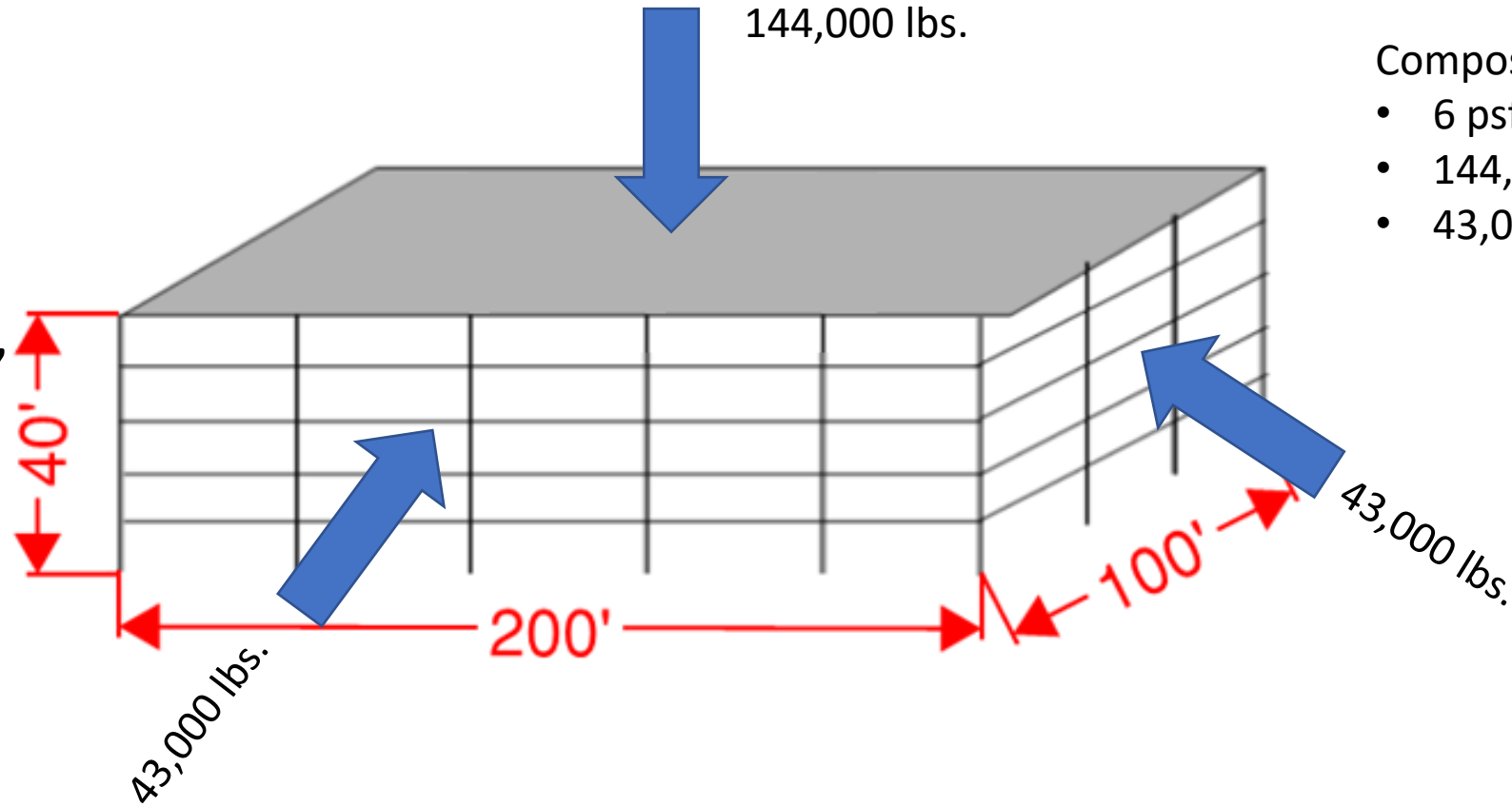
- Precast Façade:
- 150 psf (12" thick)
 - 3,600,000 lbs. gravity load
 - 1,100,000 lbs. seismic load

Building Weight: Precast Façade

95% lighter

Foundations,
Gravity

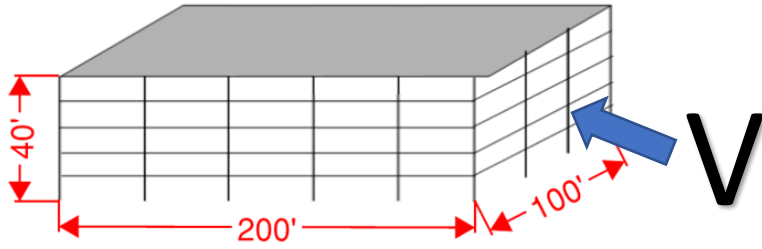
Support Frame,
Braced Frames



Composites Façade:

- 6 psf
- 144,000 lbs. gravity load
- 43,000 lbs. seismic load

Building Weight: Composite Façade



$$V = C_s W$$

← W: Building Weight

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I_e}\right)}$$

← S_{DS} : Proximity to fault, seismicity, soil conditions

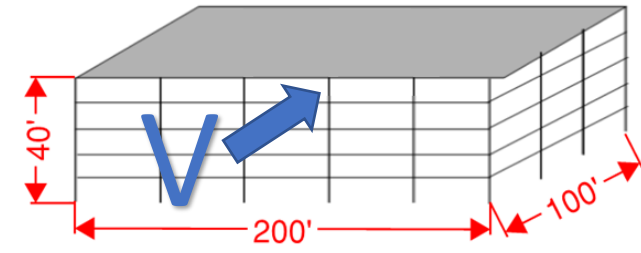
← I_e : Importance Factor

Building Weight: Seismic

System	Response Modification Coefficient
Concrete Shear Wall	6.0
Steel Braced Frame	8.0
Steel Moment Frame	8.0
Masonry Shear Wall	5.5
Wood Shear Wall	6.5

$$V = \frac{S_{DS}}{R} W$$

← Building Weight
 ← Response Modification Coefficient



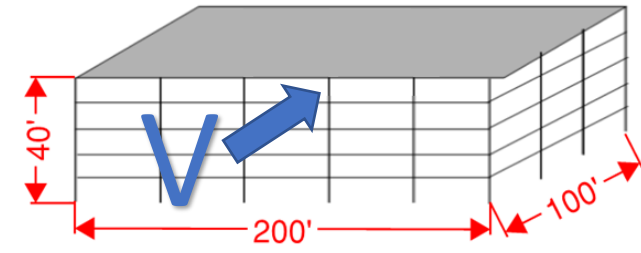
Bigger R = Lower Seismic Force

Building Weight: Seismic

System	Response Modification Coefficient
Concrete Shear Wall	6.0
Steel Braced Frame	8.0
Steel Moment Frame	8.0
Masonry Shear Wall	5.5
Wood Shear Wall	6.5
Generic FRP	1.0
Multi-Tier Braced Frame	1.5
Enhanced Connection Strength Braced Frame	2.0

$$V = \frac{S_{DS}}{R} W$$

← Building Weight
 ← Response Modification Coefficient



Bigger R = Lower Seismic Force

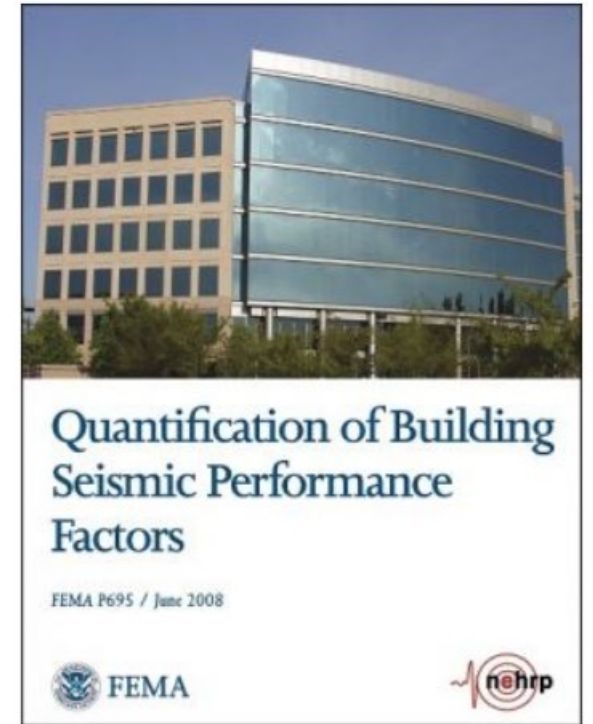
Building Weight: Seismic

System	Response Modification Coefficient
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Enhanced Connection Strength Braced Frame	2.0

$$V = \frac{S_{DS}}{R} W$$

← Building Weight
← Response Modification Coefficient

Reduction of Weight Offset by Reduction in R-Value



Building Weight: Seismic



Back-Up Structure



Exterior Elevated Elements (EEE)

Balconies: Durability



BSR/ASHRAE/IES Addendum av
to ANSI/ASHRAE/IES Standard 90.1-2016

Public Review Draft

Proposed Addendum av to Standard 90.1-2016, Energy Standard for Buildings Except Low-Rise Residential Buildings

First Public Review (August 2018)
(Draft Shows Proposed Changes to Current Standard)

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at www.ashrae.org/standards-research-technology/public-review-drafts and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

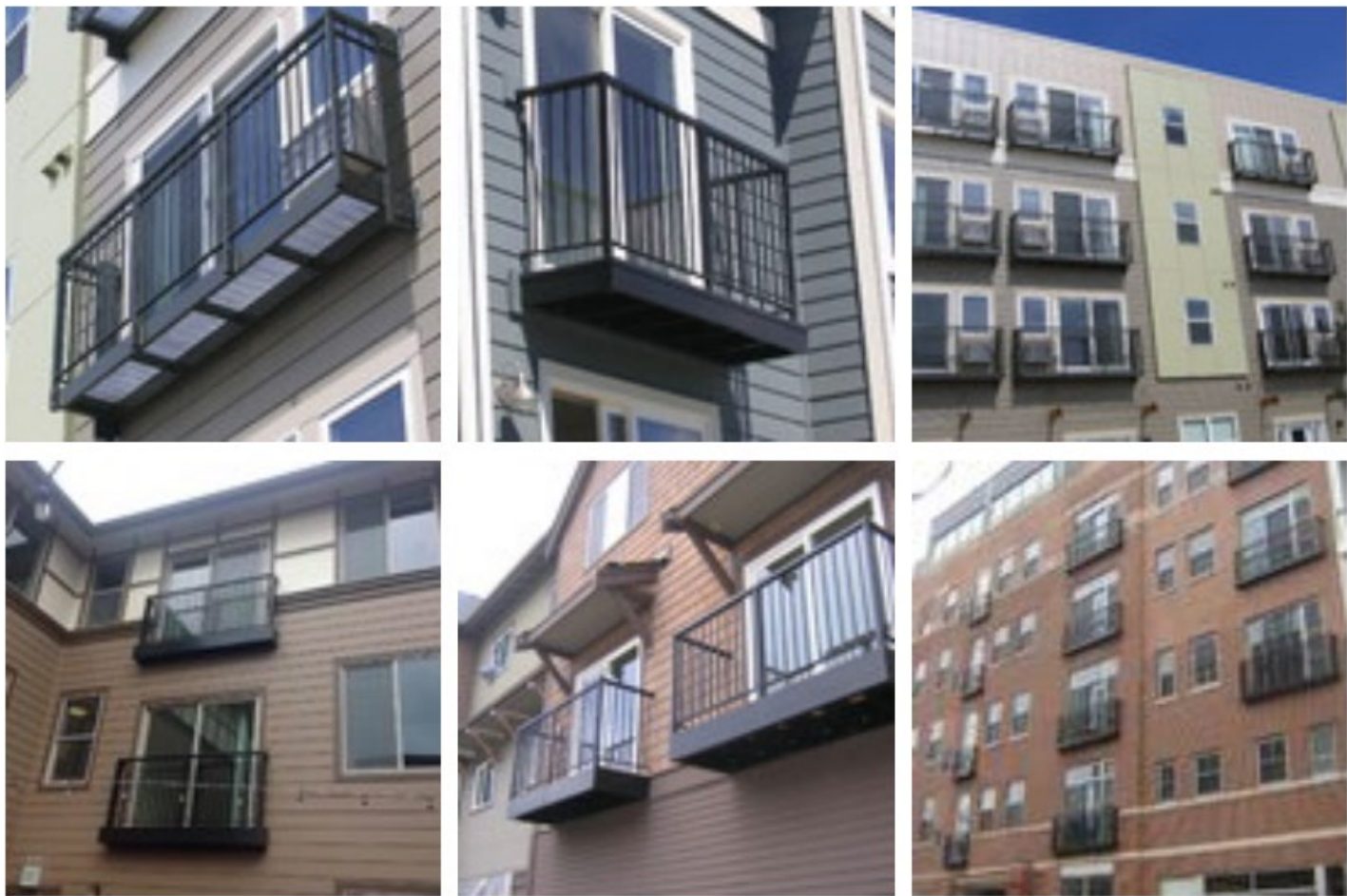
This standard is under continuous maintenance. To propose a change to the current standard, use the change submittal form available on the ASHRAE website, www.ashrae.org.

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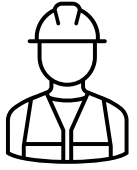
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ASHRAE, 1791 Tullie Circle, NE, Atlanta GA 30329-2305

Balconies: Thermal Break



Balconies: Modular/ Prefabricated

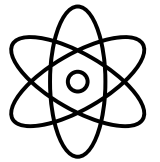


Durable



Lightweight

Enhanced Energy



Performance

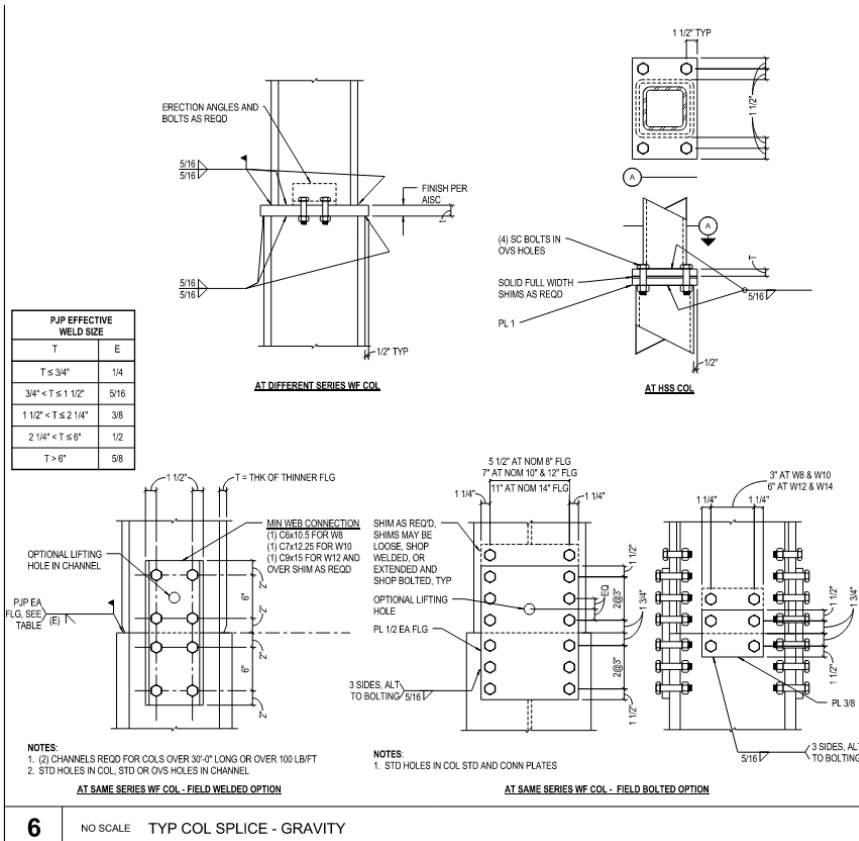
Prefabricated



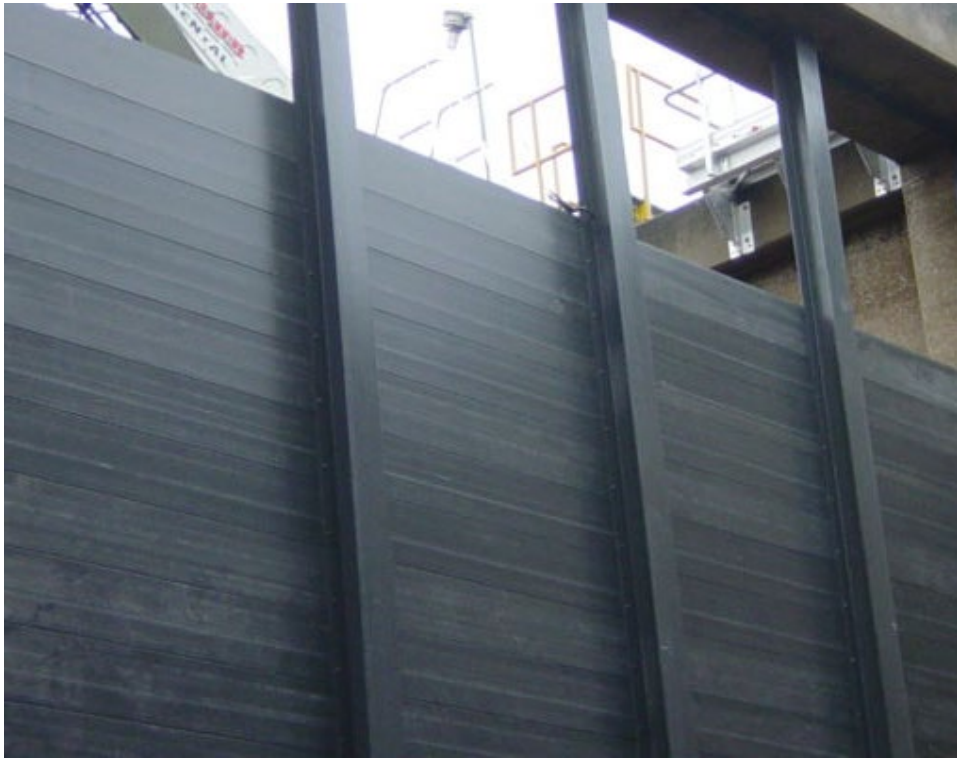
Balconies: Composite



Long Spans: Precast v. Tilt-Up



Long Spans: Steel Splices

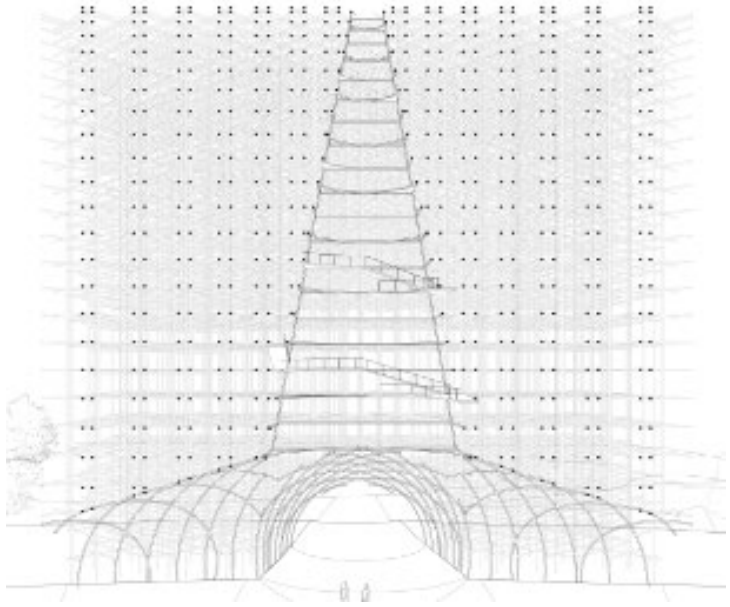


<https://www.libertypultrusions.com/pultrusion-products/>



<https://www.caddetails.com/>

Long Spans: Composite Pultrusion



Why is it all steel pipes? Can we use alternative materials?



**Is the node this simple and brutal?
It looks nothing more than
scaffoldings.**



Special Structures: Composite Pultrusion

- Lighter Structure = Fuel savings at every stage of transport.
- No galvanizing = Low CO2 emissions.
- Less heat than metal manufacturing



- End of Useful Life = Recycle

Sustainability: Composite Pultrusion

Building Pultrusion Product Opportunities in Structural Engineering

Questions?

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Martin/Martin, Inc.