Best Practice: Structural Engineering for Composite Substructure Materials – Composite Metal Hybrid (CMH) vs. Generic FRP for Cladding Support of Exterior Walls

Accurate FEA Simulation and Structural Analysis and Durability

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Introduction

The state of the art for exterior cladding attachment has improved over the last several years. High-performance CMH, a composite metal hybrid material, and, more recently, generic fiber-reinforced polymer (FRP) Z sections are available as thermally efficient continuous insulation system components. The purpose of this study is to review the structural performance of these products relative to (1) best practice procedures for structural analysis and (2) standard wall loading conditions.

In the drive for thermally efficient continuous insulation systems, it is critical to maintain or improve the engineering, structural, and durability characteristics of the thermally efficient product. As is shown in the data contained in this paper, that is not always the case.

Material Selection – Generic FRP vs. Steel vs. CMH

The Difference

FRP composites have been used as a structural material since World War II. However, compared to steel, there is much more to be learned about FRP for specific applications as the state of knowledge continues to grow at a fast rate. Structural steel design practices are routinely done using well-established uniform codes across the United States and the world. Meanwhile, FRP composite design is dependent on manufacturer recommendations, which vary tremendously as different approaches and design methods are adopted by different manufacturers. The status of FRP design practices is not favorable for advancing the successful use of FRP due to variations in the design practice methods used.

Another significant difference between steel and FRP is the fact that steel materials are homogeneous and isotropic, meaning that the properties are the same independent of the direction considered. However, FRP materials are, in general, orthotropic, meaning that their engineering properties are different in each of the three space directions (x, y, z). The properties depend on the direction considered and primarily on the number of glass fibers oriented in the direction under consideration, which makes the analysis of FRP more involved.

Adding to the complexity of FRP is the fact that it can be customized using different resins, fibers, fillers, color pigments, and the proportions thereof. Each combination of these constituents will compose a different material with unique properties, which makes FRP highly customizable with respect to its engineering properties.

Among the advantages of FRP over steel are the following:

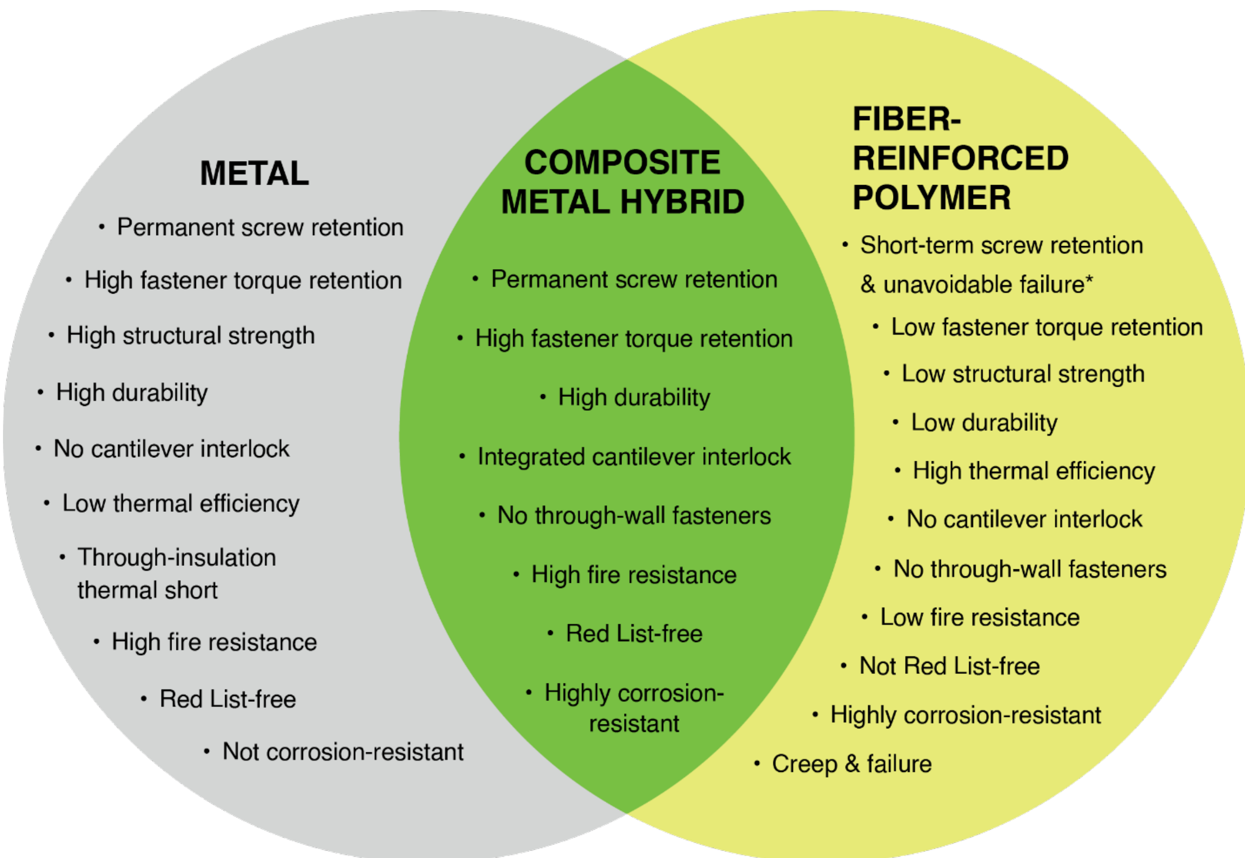
- Better thermal properties
- Lower weight, leading to lower transportation costs
- Customizable manufacturing process through pultrusion
- FRP is not susceptible to corrosion compared to steel
- FRP is easy to work with for cutting or drilling

Among the main advantages of steel structural components are:

- Its larger modulus of elasticity compared to FRP
- Easier and faster connection using fasteners with durable, large loads
- Better durability, torque retention, and pull-out loads when using screws compared to fastening to FRP

To take advantage of both steel and FRP materials, CMH uses a continuous metal insert located in the FRP flange of the cross-linked thermoset Z-profile. This steel insert allows the fastening of cladding systems using steel screws. Such a hybrid system is referred to as a composite metal hybrid, with its maximized properties highlighted in the green-filled intersection of the two circles in Image 1.

Image 1: Benefits of Composite Metal Hybrid: Best of Both Worlds



**Mosallam, Ayman S. "Design Guide for FRP Composite Connections," ASCE Manuals and Reports on Engineering Practice No. 102. 2011.*

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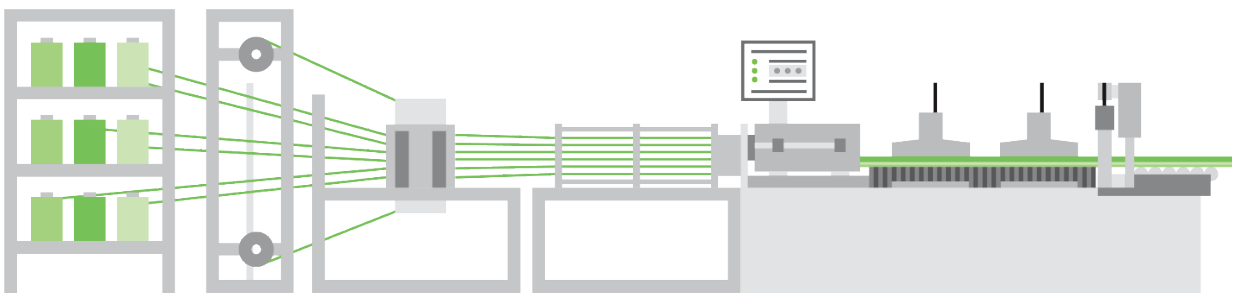
[1] Krause, G. Matt; Gauchel, James; and Aouadi, Fadhel. "Use of high-performance Composite Metal Hybrid for NFPA 285 fire-rated continuous insulation systems." July 25, 2016.

How Steel and FRP are Made and Why Third-Party Validation is Important

Humans have been using iron for thousands of years, and the modern production of steel is systematic and efficient. This results in a high level of quality for steel material that is measurable and predictable.

In contrast to steel manufacturing, FRP production through pultrusion dates to the last seven decades. A typical pultrusion manufacturing process is depicted in Image 2.

Image 2: Schematic of the Pultrusion Process



Each manufacturing process of FRP through pultrusion is proprietary to individual manufacturers and evolves continuously with the adoption of newer technologies. Due to the non-standardized manufacturing process of FRP through pultrusion, quality assurance, and quality control (QA/QC) of the end product is paramount to the suitability of the end product for its design purpose, expected engineering properties, and to limit the variations in engineering properties of the material.

Maintaining a rigorous QA/QC program to validate the quality of the FRP product during the manufacturing process is crucial to a successful FRP product that meets engineering design intentions. Such a QA/QC program needs the following minimum components:

- Well-documented QA/QC processes in a quality control manual that is kept up to date and has logs of all procedures and testing done on a regular basis to establish product quality.
- Third-party evaluation, review, and approval of the product's published engineering data.
- Third-party inspection certification of the QA/QC program that is ISO 17020 compliant.

Physical Properties of FRP

FRP is versatile and can be engineered to have custom properties. Both the engineer and the manufacturer, upon agreement, need to decide on the required material properties.

In general, the physical and mechanical properties of the pultruded FRP components depend on the type of thermoset resin and the glass fibers used, as well as the mix proportion of the fibers, filler, and other constituents. The minimum fiber content is 30% by volume.

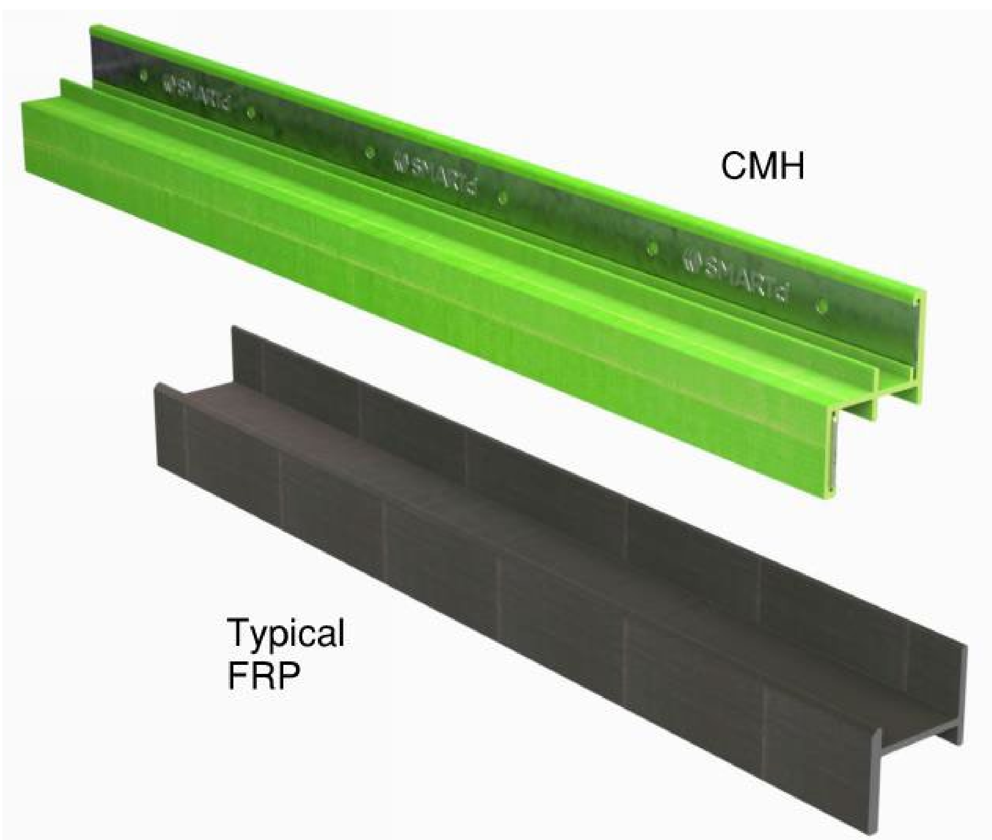
Two main directions are recognized in FRP components:

- Longitudinal or lengthwise is usually along the main length of the component. In this direction, fibers are usually continuous along the full length of the component.
- Transversal or crosswise usually refers to any direction that is perpendicular to the main lengthwise or longitudinal direction of the component.

When using Z-girts to carry cladding loads on exterior walls, tensile strength is the primary controlling factor. See Table 1 below.

Table 1: Typical Minimum Mechanical Properties

Mechanical Property	CMH	ASTM Test Method	Generic FRP
Longitudinal Tensile Strength	50,000 psi*	D638	30,000 psi
Transverse Tensile Strength	40,000 psi	D638	10,000 psi
Longitudinal Tensile Modulus	29,000,000 psi*	D638	2,500,000 psi
Transverse Tensile Modulus	3,300,000 psi	D638	800,000 psi
**Longitudinal properties represent 16 ga. (50 KSI) steel insert*			



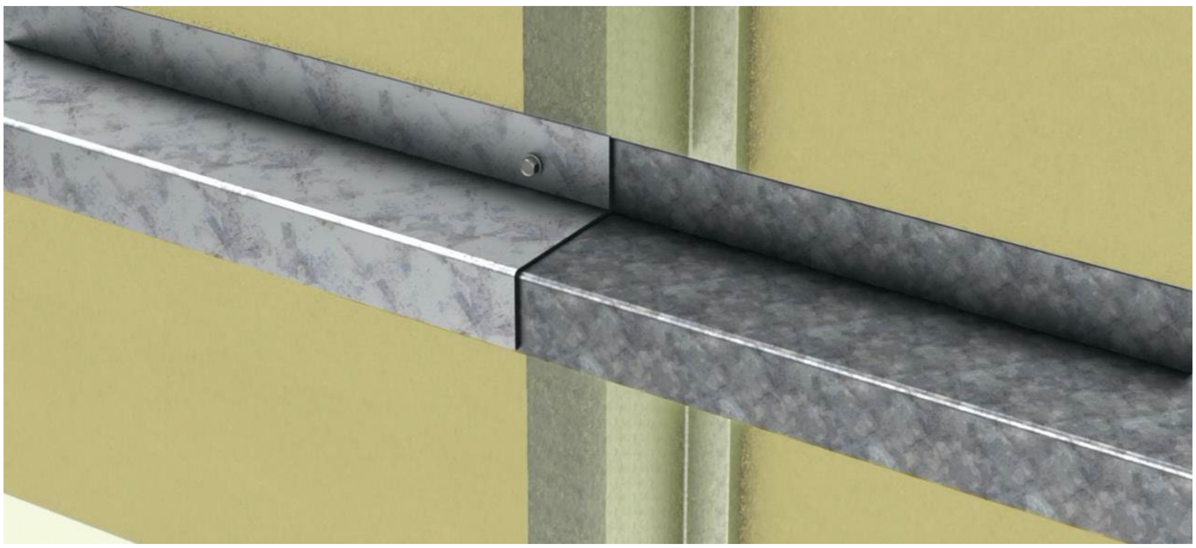
Joinery Methods for Steel, CMH, and FRP Z-Girts

The girt lateral joinery detail is required for structural calculations for horizontal installation over vertical studs, which is the most common wall configuration. These are the typical joinery solutions for each system:

Steel Girts:

- **Lap Joint:** Traditionally, steel Z-girts are made of relatively thin metal (i.e., 0.062") with a large stiffness (modulus of elasticity), so they can easily lap and be stitched together, as shown in Image 3.

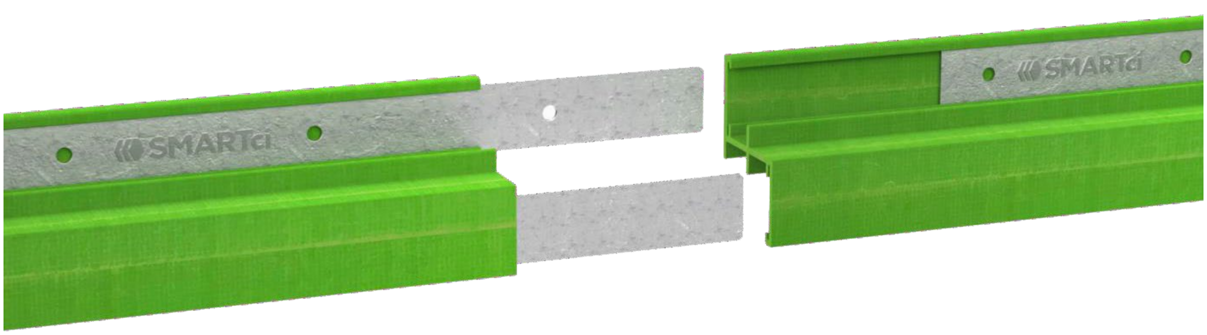
Image 3: Steel Lap Joint



CMH Girts:

- **Interlocking Joint:** The composite metal hybrid girt has an integral interlocking system that enables one end of a girt to connect to the adjacent girt, as shown in Image 4.

Image 4: The Integral Interlocking System of the Composite Metal Hybrid Z-Girt



FRP Girts:

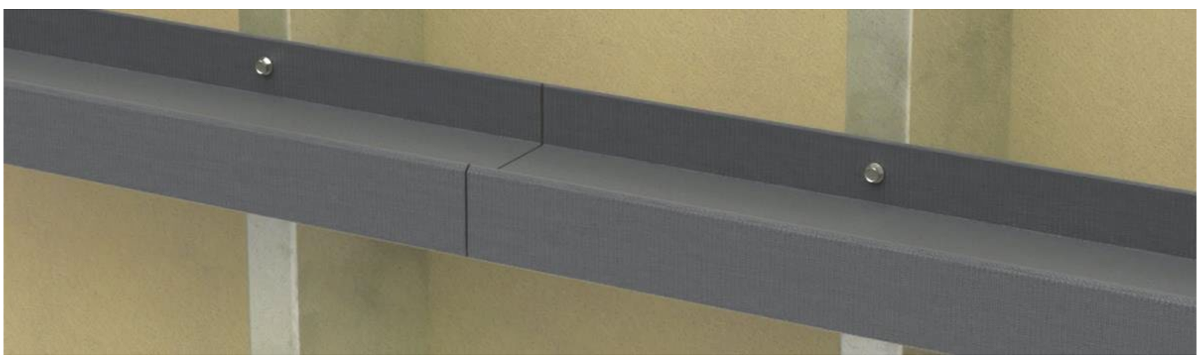
At the time of this writing, there is no detail published showing an FRP interconnection detail or splice. Therefore, there are two possible methods for a horizontal girt joint detail over studs:

- **Butt Joint**: This method would have each girt end on half of a 1.5" wide stud. This method is unacceptable for best practice considerations due to a minimum required margin space of 2.5 fastener diameters at the end of girt, per ASCE requirements for FRP[2] (0.25" fastener diameter x 2.5 required margin space + 0.25" fastener + 0.1875" metal edge margin x 2 sides = minimum flange width of 2.125"). If this detail is to be used, a double stud would be required for every FRP girt length, as shown in Image 5.

Image 5: FRP Butt Joint

- **Cantilever**: This method involves installing girts horizontally with a cantilever over the studs on both ends as shown in Image 6. For structural calculations, use the maximum possible cantilever for the worst typical case. This is the only practical solution currently available.

Image 6: FRP Cantilever



[2] "Pre-Standard for Load and Resistance Factor Design (LRFD) for Pultruded Fiber Reinforced Polymer (FRP) Structure," American Society of Civil Engineers. November 2010.

Cladding/Substrate Attachment Methods

There are varying degrees of effectiveness when it comes to the cladding attachment for continuous insulation systems. These are the typical attachment techniques for each system:

Steel Girts: Traditional steel Z-girts have, for years, utilized self-drilling fasteners for strong, effective cladding attachment. The same is true for attaching to the substrate.

CMH Girts: CMH receives fasteners into its integral continuous metal insert. Therefore, it uses time-proven self-drilling fasteners for strong, effective cladding attachment. Values for pullout, shear, etc., are the same as with its steel counterpart. The attachment through the FRP into the continuous steel also strengthens the profile. The same is true for attaching to the substrate.

Generic FRP Girts: The FRP industry data does not recommend screws as a best practice for structural attachment. Potential liabilities include the following:

- Singularity points for stress are created, which weakens the section
- Discontinuity in the fibers weakens the section
- The discontinuity in the matrix is prone to crack propagation and fracture
- Torque resistance of the screw into FRP deteriorates with time
- Ability for load retention in case of fire is reduced
- Reduced fastener pullout values and retention performance

The best practice for cladding attachment in FRP remains a bolted connection as far as structural integrity.[3]

There is less liability in attaching a fastener through the composite and into a solid substrate, as torque and pullout are not an issue. However, calculations must be made for material pull-through if the flange material is thin, if the fastener head bearing surface is small, or if the product is unevenly installed.

Safety Factors

For this comparison, the safety factors are defined as the ratio of the maximum material strength in a specific direction to its corresponding maximum stress in the same direction.

FRP manufacturers often use large stress safety factors to account for the material property variability and other factors that can affect the material performance besides the service loading, such as:[4]

- High service temperature for commodity resins, as cavity temperatures > 190°F are possible
- Creep effects
- Material aging effects

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[3] Flynn, Susan Keen, and O'Leary, Melissa. "University R&D Advances Novel Ideas to Ground-Breaking Applications," American Composites Manufacturers Association. "Composites Manufacturing," July/August 2017, Pages 14-16
"Guidelines and Recommended Practices for Fiber-Reinforced-Polymer (FRP) Architectural Products." ACMA: American Composites Manufacturers Associations. 2016.
Duthinh, Dat. "Connection of Fiber Reinforced Polymer (FRP) Structural Members: A Review of the State of the Art," National Institute of Standards and Technology 6532, August 2000.
"Prospect for New Guidance in The Design Of FRP," European Commission, 2016

- Repeated exposure to cyclic loading and environmental effects
- Effects of the introduction of small notches and holes
- Allowance for minor damage and missing and/or stripped fasteners during installation

For the structural analysis included in this paper, a reference safety factor of 4 is used. However, according to the ASCE's Design Guide for FRP Composite Connections, that recommended factor of safety often does not include "the effects of the environment and are mainly for normal environmental and loading conditions." Therefore, A2P typically recommends a safety factor of at least 6 depending on product and application. See Appendix for further safety factor calculations.*

Structural Analysis of Z-Shaped Sub-Framing Girts

Z-shaped girts are frequently used as sub-framing members to support wall cladding and insulation for practical reasons, including:

- Girts are easy to access and connect through the flanges without creating thermal bridging.
- The insulation discontinuity through the sub-framing member is limited to the web thickness of the Z-shape. Hence, it is easier to create continuous insulation in the walls.

However, the structural analysis of the Z-shaped girts can be challenging to do by hand calculations or using closed-formula types of solutions. The analysis difficulty arises from the double asymmetry of the cross-section of the Z-shape and the eccentricity of the applied loads, as the applied load path goes through the flanges of the Z-shapes and specifically at the fastener locations. The asymmetry of the section and the eccentricity of the loads create additional torsional and warping stresses and deformations in the section due to the applied loads.

Inexperienced stress analysts may fail to include these critical additional effects in calculations. Furthermore, typically the only practical way to get meaningful and correct stress analysis results is through careful Finite Element Analysis (FEA) modeling of the sub-frame structure using accurate 3D geometry modeling, accurate loading, and end condition modeling. Such modeling needs to depict exact 3D features of the Z-shape section and exact location of the point-loading at the fastener location. Without proper 3D FEA and computer analysis tools, even experienced engineers and stress analysts may find the Z-shape stress analysis problem too challenging.

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[4] "Structural Plastic Design Manual," American Society of Civil Engineers. ASCE Manuals Reports on Engineering Practice No 63, ASCE 1984.
"Pre-Standard for Load and Resistance Factor Design (LRFD) for Pultruded

**Mosallam, Ayman S. "Design Guide for FRP Composite Connections," ASCE Manuals and Reports on Engineering Practice No. 102. 2011.*

Best Practices

The following are best practices for structural stress analysis of Z-shaped sub-framing for cladding support and exterior wall applications:

- Load approximation using uniform loading will underestimate both stresses and deflections of the girts. Using accurate modeling of loads as point loads at the fastener locations is the best practice to provide accurate stress and deflection results that correlate with experimental results. To account for the eccentricity of the loads, these loads need to be applied at the exact locations of the fasteners on the flange of the girt.
- For lateral loading, such as wind and seismic, the direction of the loading, whether toward or away from the wall (positive or negative), makes a large difference in the results due to the asymmetry of the section. Therefore, both directions need to be considered as best practice for the stress analysis of the Z-shaped girts.
- Any calculations by hand that do not use accurate mechanics formulas specific to the Z-sections and do not explicitly consider the eccentricity of the loading will give erroneous results and underestimate the resulting stresses and deformations. For best practices, a 3D FEA modeling and analysis computer software capable of using the exact geometry of the sub-framing girt and accurately modeling the loading needs to be used.
- The end condition of individual girts needs to be correctly modeled. As presented in a previous section, although it is not best practice, it is common to cantilever girts between substrate supports, such as framing studs, when joining individual girts. This type of end condition often controls the design of the girt and must be correctly accounted for in the structural analysis.
- Both deflection and stress analysis must be considered. If a girt has a safety factor of 4 in stress in all directions but fails in deflection – or vice-versa – it is considered an overall failure and cannot safely be used in design.

See the Appendix for information on how to run FEA modeling accurately, including settings, orthotropic analysis, point loading, and more.

Description of Materials Tested

	CMH	**GENERIC FRP**
	Approximate Dimensions	Approximate Dimensions
Exterior Flange Height	1.5"	2"
Exterior Flange Thickness	0.2" *	0.25"
Web Thickness	0.105"	0.15"
Interior Flange Height	1.75"	2"
Interior Flange Thickness	0.2" *	0.15"
Modeled Girt/Insulation Depths	2", 2.5", 3", 3.5", 4" **	2", 2.5", 3", 3.5", 4" **
**Dimension includes 16 ga. (50 KSI) steel insert* ***Dimensions on generic FRP girt are .4" deeper to accept standard insulation sizes*		

Description of Testing Parameters

Parameters for orientation, spacing, and loading utilized in the Finite Element Analysis (FEA) represent typical wall assembly scenarios.

FEA Stress Analysis Comparison of CMH and Generic FRP

Two types of FEA stress analyses will be analyzed herein: supported on both ends and cantilevered. The FEA results and discussion utilizing CMH and FRP will be shown with girt/insulation depths of 2", 2.5", 3", 3.5", and 4" with fixed parameters of the simulations as shown in Table 2.

Table 2: FEA Parameters

	Case 1: Studs 16" OC with cantilever	**Case 2: Studs 16" OC, no cantilever**	**Case 3: Studs 24" OC, no cantilever**	**Case 4: Studs 24" OC, with cantilever***
Simulation parameter description	Fixed-parameter value(s)	Fixed-parameter value(s)	Fixed-parameter value(s)	Fixed-parameter value(s)
Span of girt substrate support	16"	16"	24"	24"
Vertical spacing of girts	24"	24"	24"	16"
Orientation of girts	Horizontal	Horizontal	Horizontal	Horizontal
Spacing of cladding fastener (point loads spacing)	16"	16"	16"	16"
End conditions of each 8-footer girt	Cantilever	Both ends supported	Both ends supported	Cantilever
Maximum cantilevered distance of the girt	15"	N/A	N/A	23"
Location of the cantilever load	1 inch from end		N/A	1 inch from end
Cladding dead load	5 PSF	5 PSF	5 PSF	5 PSF
(*) Stress and deflection for the 23" cantilever for the FRP exceeded the FEA parameters of the generic FRP material for 2.5" through 4" for the positive wind pressures, so the rest of the data was extrapolated for positive wind pressure.				

Table 3: Material Properties of CMH and Generic FRP

Material Property	**CMH**	**Generic FRP**
Longitudinal Max Stress	50 KSI *	30 KSI
Transversal Max Stress	40 KSI	10 KSI
Longitudinal Modulus of Elasticity	29,000 KSI *	2,500 KSI
Transversal Modulus of Elasticity	3,300 KSI	800 KSI
**Longitudinal properties include 16 ga. (50 KSI) steel insert*		

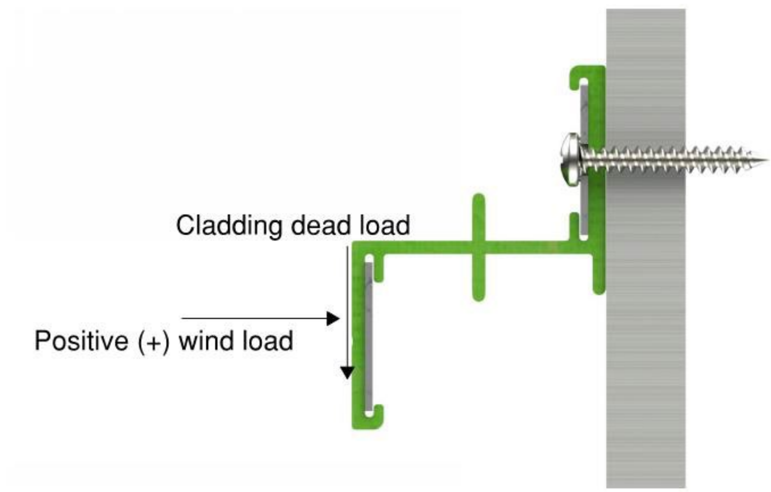
Loading Conditions

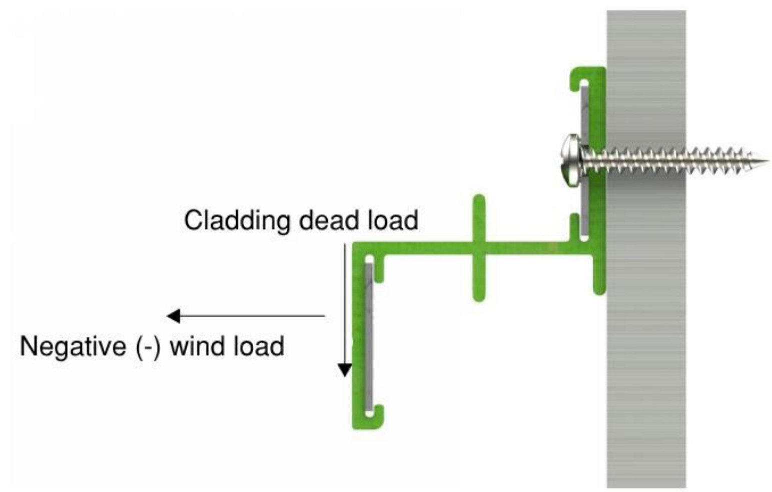
The wind loads selected are typical components and cladding values for mid-sized buildings. The cladding dead load of 5 PSF encompasses the majority of cladding selections, including metal panels, ACM, fiber cement, and phenolic panels, among others.

The wind loads in the study are +40 PSF and -70 PSF ultimate wind pressures, with positive pushing inward toward the inside of the building and negative pulling outward away from the building. The controlling load combinations per ASCE 7-10 and International Building Code 2015 are D + 0.6 * W for stress and D + 0.42 * W for deflection.

Wind and dead loads are applied as a point load at the attachment point. The steel in the CMH is not included in the results as it maintains a safety factor of 4 in all cases.

Image 7: Directions of Wind and Dead Loads





FEA Modeling

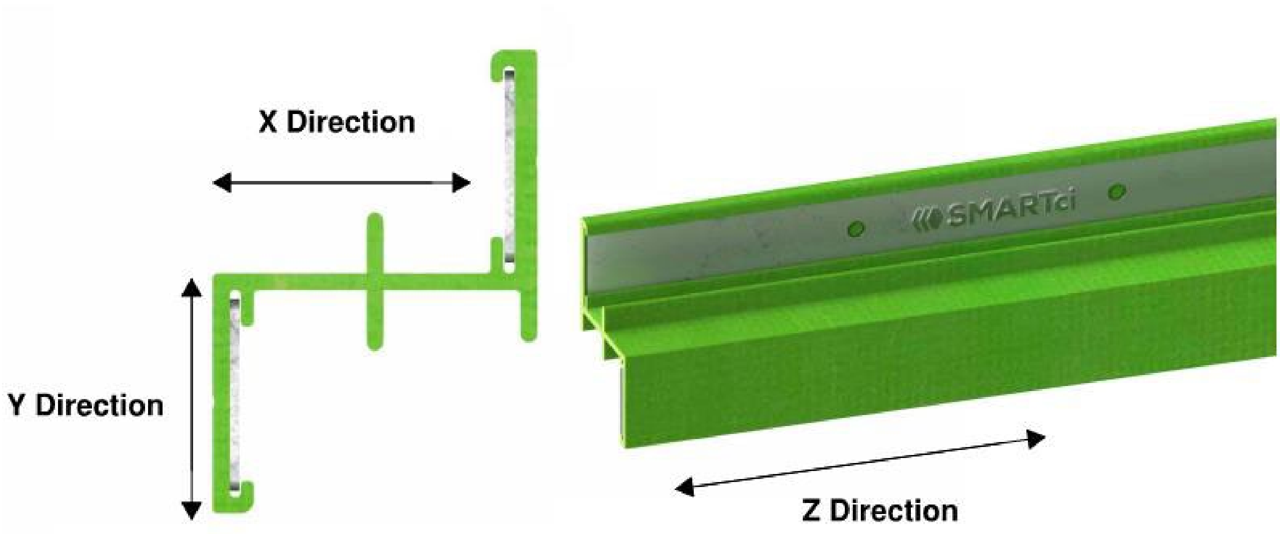
Results and Discussion, Case I

Based on the parameters from Table 3, the FEA stress analysis results are shown in the following pages for each of the types of Z-girts (CMH and generic FRP) and for the different sizes and wind pressures.

As evidenced by the data, the FEA simulation results show the generic FRP section will not work for the input loading of cladding weights and wind pressures, as its stress safety factors are generally less than what is acceptable for a safe design, typically 4 or larger.

FEA stress analysis of the CMH shows an acceptable stress safety factor that is, in general, larger than 6 and always more than 4.

Image 8: Schematic of the Directional Stresses



Schematic of GreenGirt CMH™ Z-Girt

A comparison between CMH and FRP for directional stress is shown in Fig. 1 – 6. The stress level corresponding to a safety factor of 4 is shown by a horizontal line. In Fig. 1 – 6, whenever a stress level breaks through the safety factor line, that indicates the material performance for stress does not meet the design criteria for an acceptable safety factor, and such material shall not be used. For comparison of the two materials' performance, the FRP figures are shown on the right side of the page, while the CMH figures are shown on the left. None of the CMH cases cross the safety factor line; however, most of the FRP cases cross the safety factor horizontal line.

Fig. 1 and 4 show the maximum x-direction stresses, and it indicates that the FRP girt stresses are larger than the maximum stresses developed for CMH girts in all but three of the 10 loading cases. The FRP stresses are about 50% larger than those of the CMH. The three cases in which the FRP stresses are lower than CMH correspond to the negative wind pressure for the 3", 3.5", and 4" girts. The negative pressure loading cases do not control the design as the stress produced by these cases is lower than those produced by positive pressure, as seen in Image 7. The reason for this is negative pressure counteracts any eccentricity effect of dead loading, while a positive pressure will magnify the eccentricity effects of the dead loads. That is why a 40 PSF positive pressure produces higher stresses than a 70 PSF negative pressure for the same cladding dead weight and the same girt geometry.

The same conclusion regarding the x stresses is applicable to the y-direction stresses and the z-direction stresses (Fig. 2, 5, 3, 6).

In the data presented herein, the z-direction is the main longitudinal direction along the girt. Fig. 3 and 6 show the FRP girt stresses are much larger than the CMH girts, except for the three cases previously mentioned. For the same reason as above, these three cases do not control the stress design as their values are smaller than those of the positive wind pressure cases.

The only directional stress that is larger in all cases for CMH than the generic FRP sections is the Y-directional stress, which is crosswise (transversal direction) on the flange. However, the CMH strength in the transversal direction is 40 KSI, while that of the FRP section is 10 KSI. This makes the safety factors for the CMH case larger than 6 for all cases, while the safety factors for the FRP cases fail to meet the minimum 4 benchmark in seven out of 10 cases, as evidenced by the stress levels of the FRP sections crossing the horizontal safety factor line in Fig. 5.

The deflection ratios in most cases for the generic FRP girts will not meet common practice deflection criteria for exterior wall applications, as set by the building codes. For metal flexible cladding type with a required span-to-deflection ratio of 90 or better (45 for a cantilever, as 2L/x is used for a cantilevered member), the generic FRP girts fail to meet the criteria of serviceability, so it will also not meet the deflection criteria for brittle types of cladding which require larger span to deflection ratio performance.[5, 6]

A deflection comparison between CMH and FRP in all the cases studied is shown in Fig. 7 – 9. The deflection of the generic FRP cases is large and fails to meet reasonable exterior wall applications in six out of ten cases. However, the four cases with acceptable deflection levels are related to the 70 PSF negative pressure, and these same girts have larger deflection for the 40 PSF positive wind load. All generic FRP girts fail the design criteria with respect to deflection and cannot be accepted as supports for cladding and insulation in building exterior wall applications. The same argument can be made with respect to the span-to-deflection ratios shown in Fig. 9, as all five girts fail the design criteria by having a span-to-deflection ratio less than 90 (or 45 for a cantilever).

In all cases, the CMH deflection is low and acceptable. The CMH girt deflection ratio makes it suitable for supporting most cladding types.

Deflection criteria are typically called out in the specification for each cladding, as shown in Table 4.[6.] Deflection includes both wind load and dead load per criteria called out in the International Building Code load combinations.

Table 4: Typical Deflection Criteria by Cladding Type

Cladding Type	Typical Deflection Criteria
Corrugated metal panels	L/90* or L/120
Fiber cement siding	L/120
ACM/MCM and concealed fastener metal panels	L/180 or L/240
Fiber cement panels	L/240
Stucco, terra cotta, and thin brick	L/360
Masonry (brick, stone, etc.)	L/600
** While Table 1604.3 of the International Building Code gives a minimum of L/120 for deflection limits, footnote A provides L/90 for secondary wall members supporting formed metal siding.*	

5 "Minimum Design Loads for Buildings and Other Structures (ASCE Standard 7-10)," American Society of Civil Engineers. 2010, Reston, VA.

6 "International Building Code," International Code Council, 2015. Falls Church, VA.

Stresses for Case I (16" span, 24" spacing, 15" cantilever) with CMH and Generic FRP

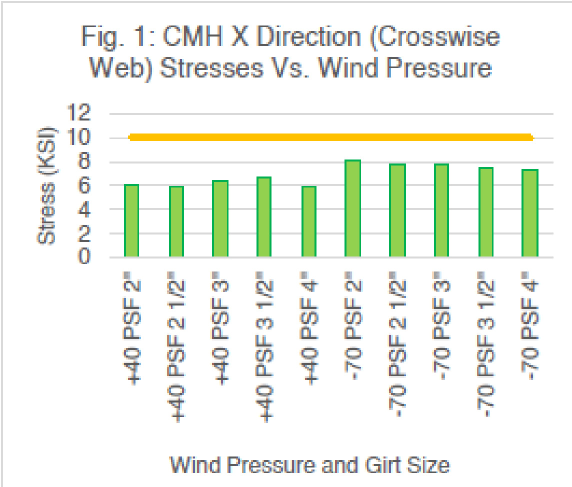


Fig. 1: CMH X Direction (Crosswise Web) Stresses Vs. Wind Pressure

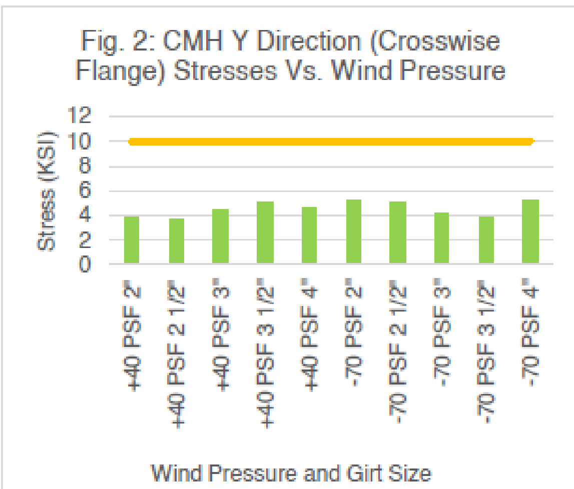


Fig. 2: CMH Y Direction (Crosswise Flange) Stresses Vs. Wind Pressure

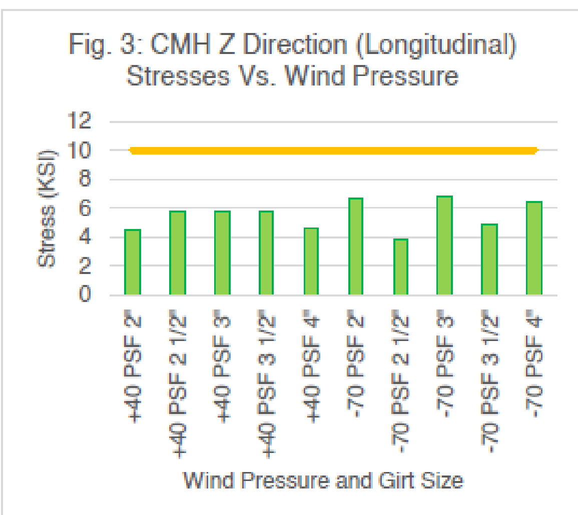


Fig. 3: CMH Z Direction (Longitudinal) Stresses Vs. Wind Pressure

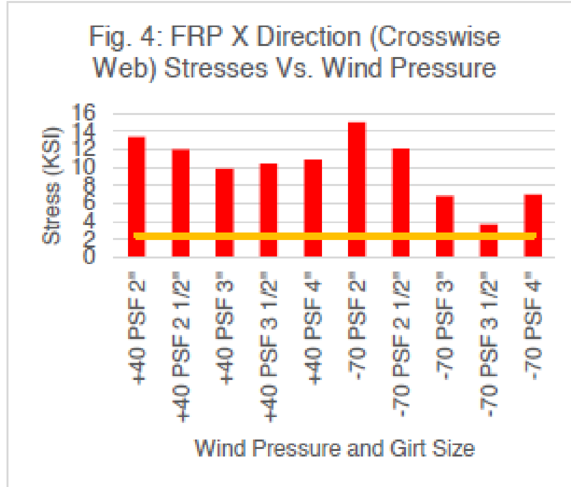


Fig. 4: FRP X Direction (Crosswise Web) Stresses Vs. Wind Pressure

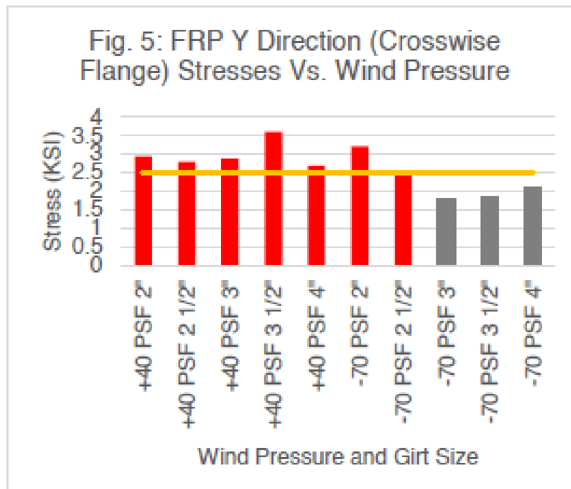


Fig. 5: FRP Y Direction (Crosswise Flange) Stresses Vs. Wind Pressure

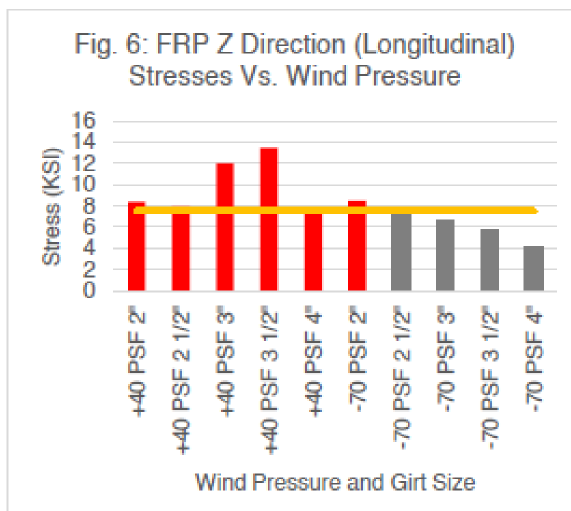
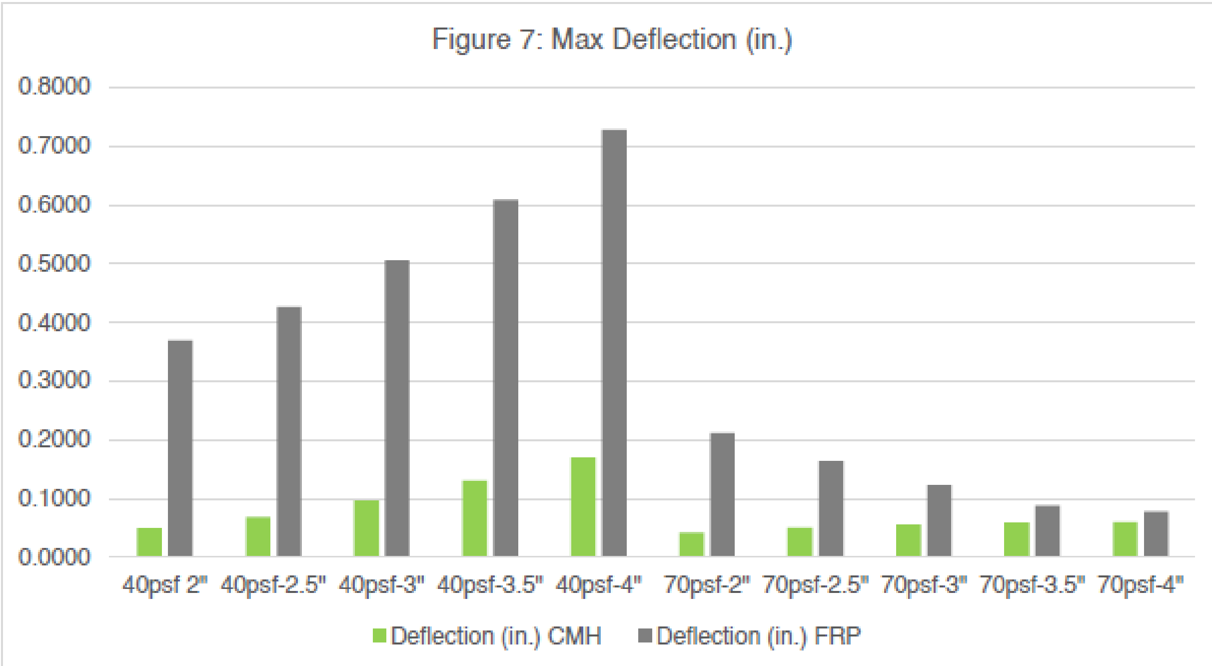


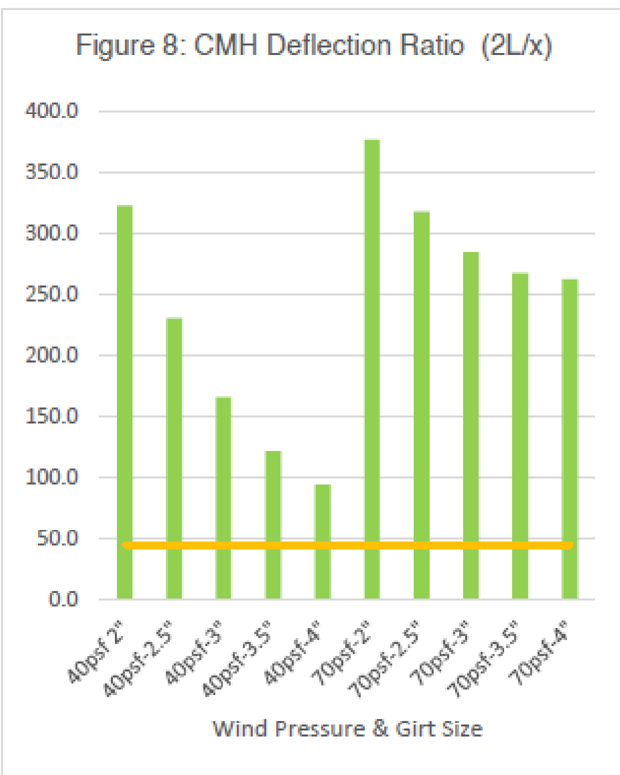
Fig. 6: FRP Z Direction (Longitudinal) Stresses Vs. Wind Pressure

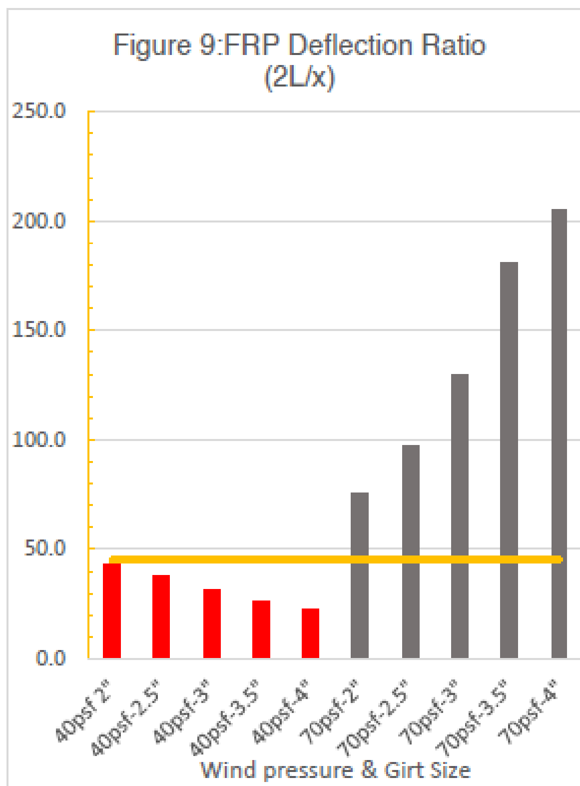
Line denotes allowable stress with safety factor of 4

Green bars are CMH　Gray bars are generic FRP　Red bars indicate a failure

Deflection for Case I (16" span, 24" spacing, 15" cantilever) with CMH and Generic FRP







Line denotes deflection ration of L/90 (2L/90 for cantilever). Deflection includes wind and dead load.

Green bars are CMH   Gray bars are generic FRP   Red bars indicate a failure

The larger the deflection criteria, the less deflection (below the line is a failure)

Results and Discussion, Case II

This case covers the girt span condition 16" with the girt ends supported (no cantilever). Although this case is the least demanding case for performance compared to all other cases in this study – due to the lower span and no cantilever condition – the results, as shown in Fig. 10-15, show that the FRP girts have a stress safety factor less than the minimum of four in the x-crosswise direction, while the CMH girts meet the minimum safety factor of four in all directions and girt sizes.

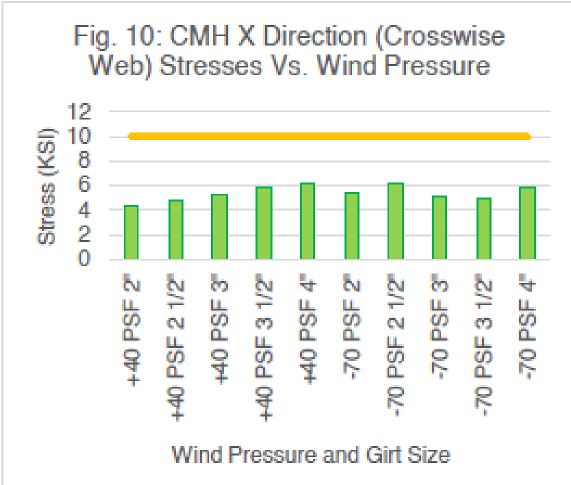
Also, the deflection ratios for the CMH girts are above the minimum of 90 for all girt sizes and in most cases, greater than 260.

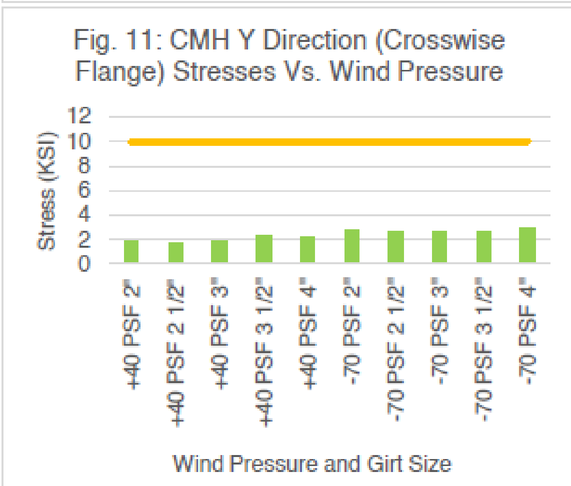
However, the deflection ratios of the FRP girts are less than the minimum of 90 for the girt sizes of 3", 3.5", and 4".

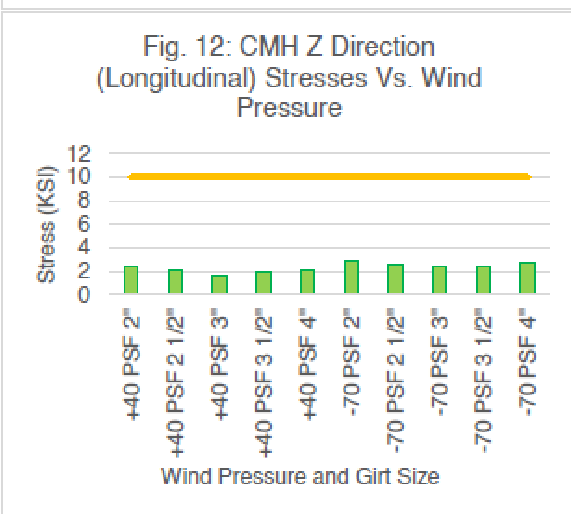
In summary, even though this case has the lowest span and a no-cantilever end condition, the FRP girts failed to meet the minimum requirements for stress safety factor and deflection ratio.

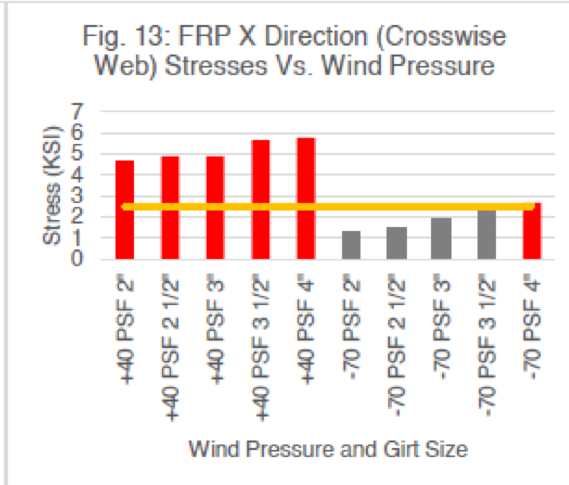
See the Appendix for further data.

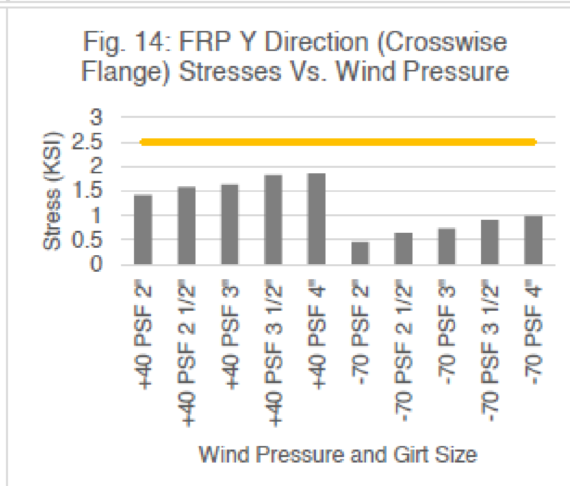
Stresses for Case II (16" span, 24" spacing, no cantilever) with CMH and Generic FRP

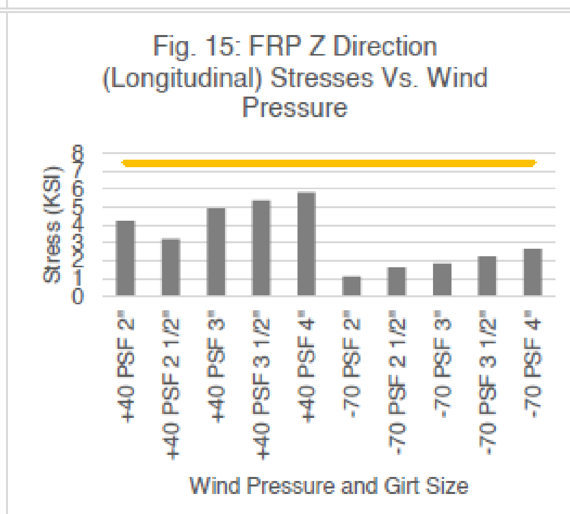










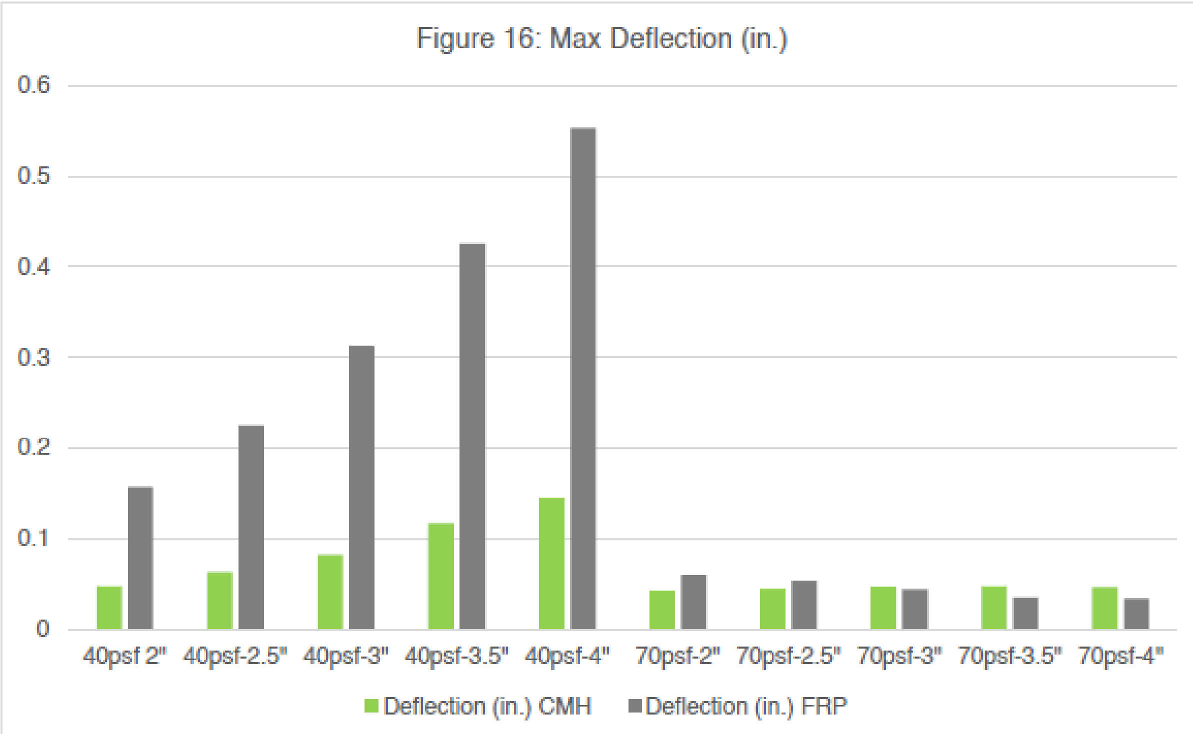


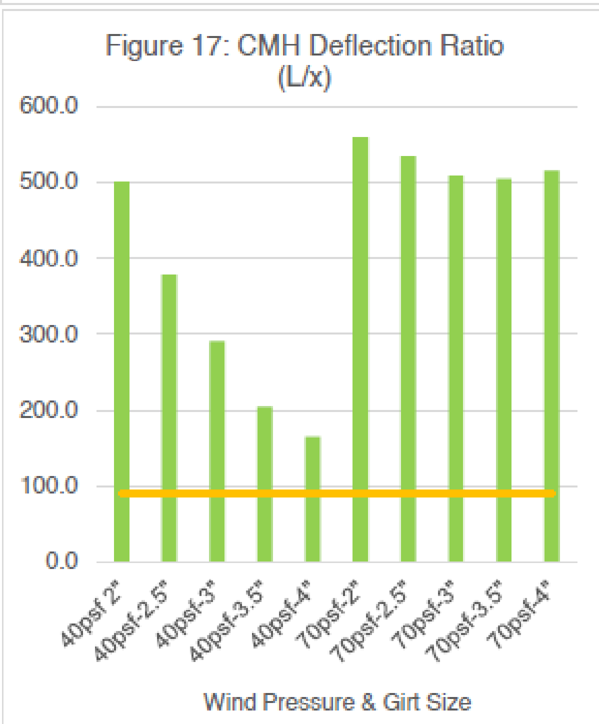
Line denotes allowable stress with safety factor of 4

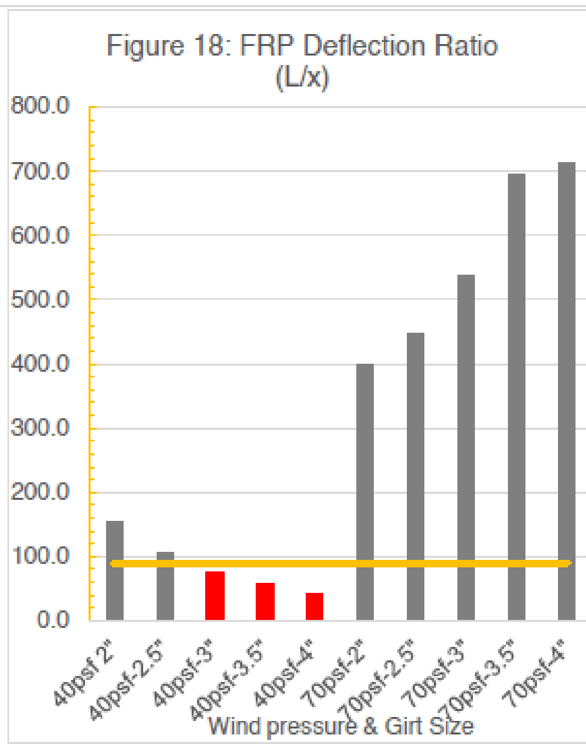
Green bars are CMH   Gray bars are generic FRP   Red bars indicate a failure

See Image 8 for explanation of X, Y, and Z directions

Deflection for Case II (16" span, 24" spacing, no cantilever) with CMH and Generic FRP







Line denotes deflection ration of L/90. Deflection includes wind and dead load.

Green bars are CMH   Gray bars are generic FRP   Red bars indicate a failure

The larger the deflection criteria, the less deflection (below the line is a failure)

Results and Discussion, Case III

In these FEA stress analysis models, the end of the girts are simply supported and do not cantilever.

The model parameters are shown in Table 3, and the same material properties are used as in Case I. However, in the Case III models, the unsupported span of the girts was increased to 24 inches (corresponding to a substrate/stud spacing of 24 inches).

As in Case I, the FEA simulation results were for five different girt sizes using generic FRP and CMH types. The girt depths are 2", 2.5", 3", 3.5", and 4".

Case III results are presented in Fig. 19 – 27.

Both Cases I and III results and discussions provide similar trends of behavior for the girts. Furthermore, the discussions and conclusions indicated in Case I are also true for Case III.

See the Appendix for further data.

Stresses for Case III (24" span, 24" spacing, no cantilever) with CMH and Generic FRP

Fig. 19: CMH X Direction (Crosswise Web) Stresses Vs. Wind Pressure

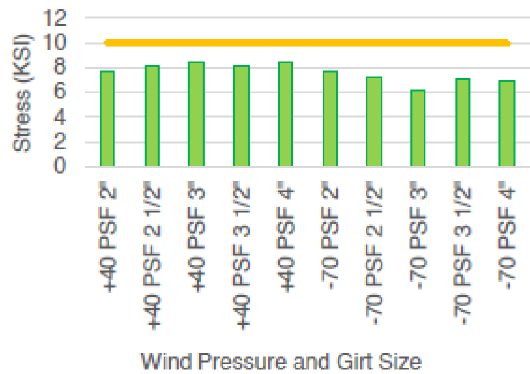


Fig. 22: FRP X Direction (Crosswise Web) Stresses Vs. Wind Pressure

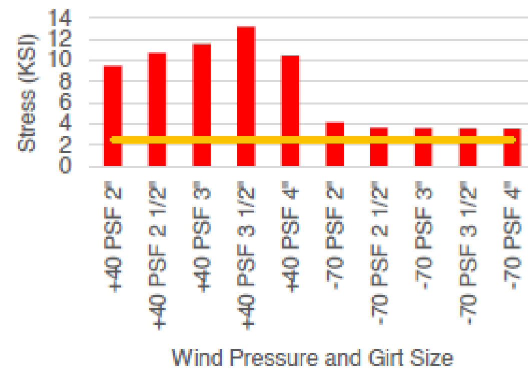


Fig. 20: CMH Y Direction (Crosswise Flange) Stresses Vs. Wind Pressure

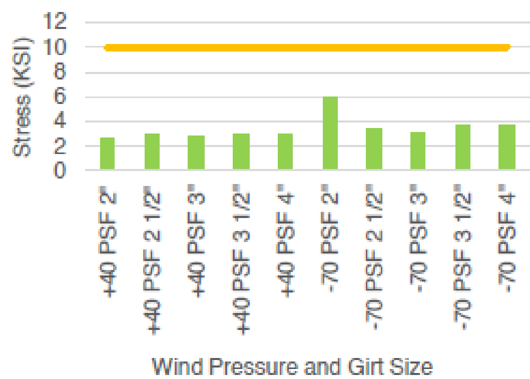


Fig. 23: FRP Y Direction (Crosswise Flange) Stresses Vs. Wind Pressure

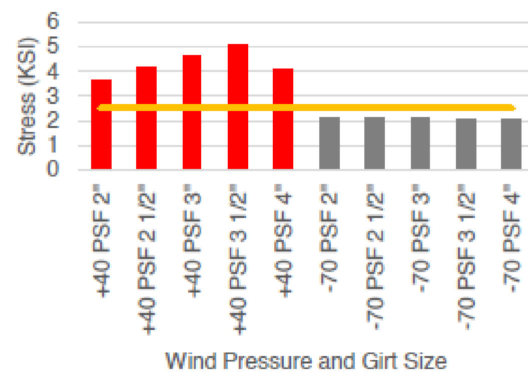


Fig. 21: CMH Z Direction (Longitudinal) Stresses Vs. Wind Pressure

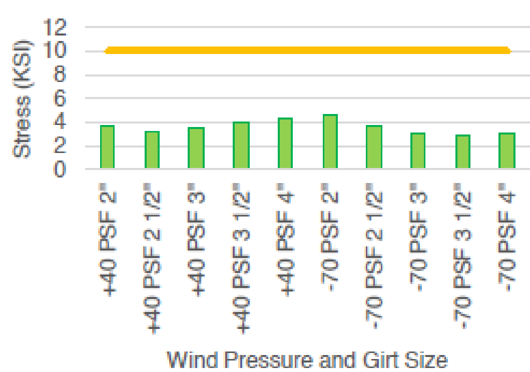
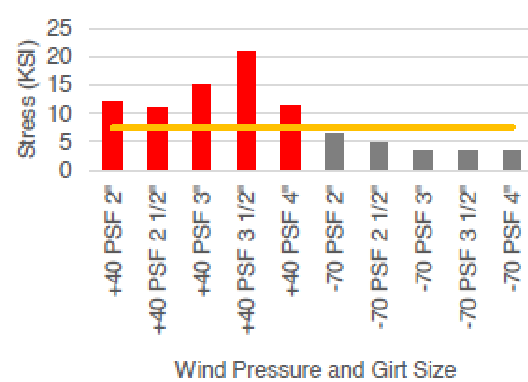


Fig. 24: FRP Z Direction (Longitudinal) Stresses Vs. Wind Pressure

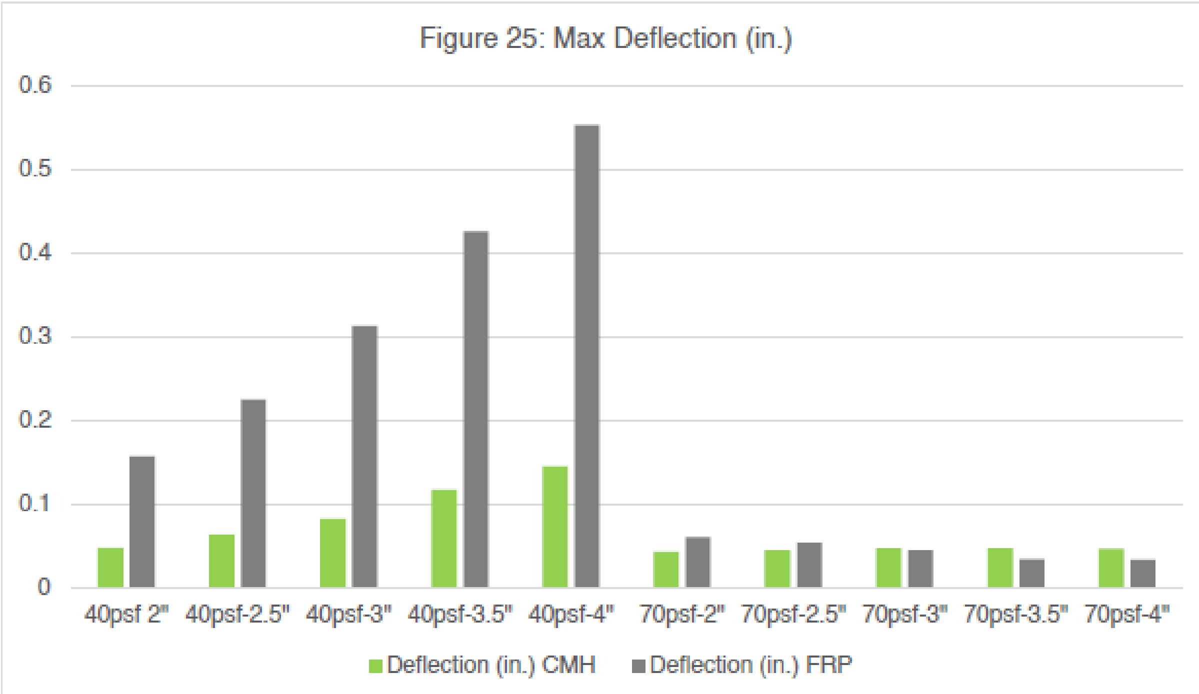


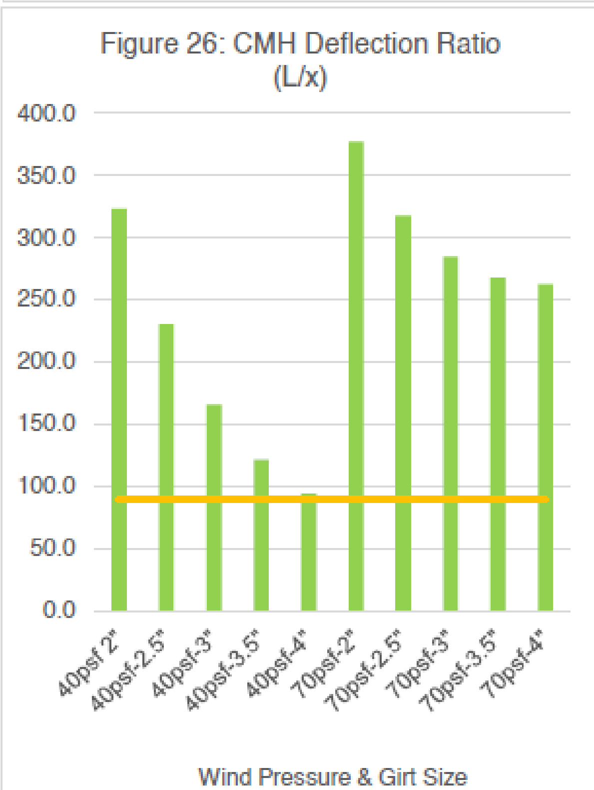
Line denotes allowable stress with safety factor of 4

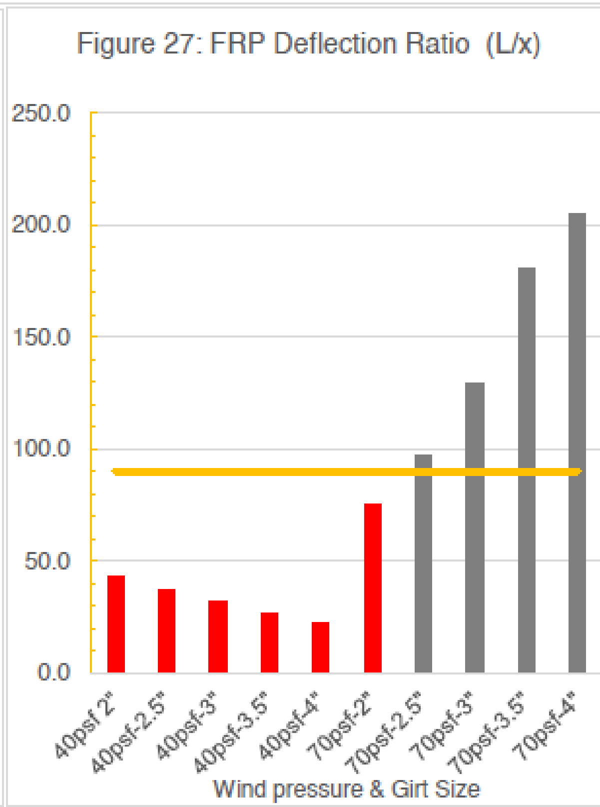
Green bars are CMH Gray bars are generic FRP Red bars indicate a failure

See Image 8 for explanation of X, Y, and Z directions

Deflection for Case III (24" span, 24" spacing, no cantilever) with CMH and Generic FRP







Line denotes deflection ration of L/90. Deflection includes wind and dead load.

Green bars are CMH   Gray bars are generic FRP   Red bars indicate a failure

The larger the deflection criteria, the less deflection (below the line is a failure)

Results and Discussion, Case IV

Of all the cases considered in this study, this case has the most severe loading conditions. There is a larger performance demand on the modeled girts due to the wider span of 24 inches and the cantilever distance of 23 inches.

All CMH girts met the minimum requirements of stress safety factors of four in all directions.

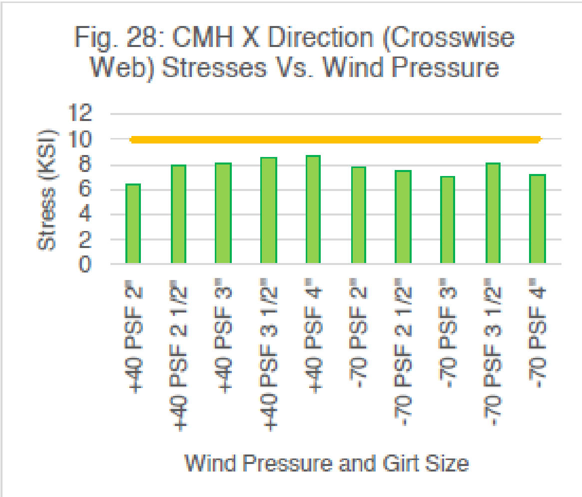
The FRP girts had, in most cases, stresses larger than the minimum allowed with a safety factor of four. Furthermore, for the FRP girts, all linear elastic analysis models (except for the 2” girts) were unstable and went into large excessive deformations. This is indicated by the maximum stress and deflection shown in the graphs for girt sizes of 2.5 inches to 4 inches with a +40 PSF wind pressure.

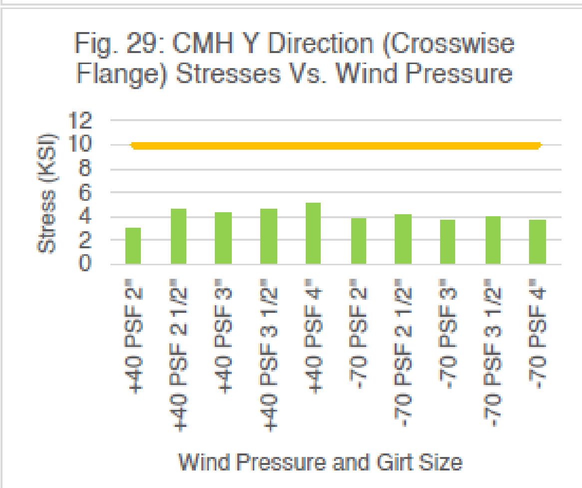
For deflection, all CMH girts have a span-to-deflection ratio greater than the minimum of 90. The FRP girts had deflection ratios less than the minimum of 90 when subjected to a +40 PSF wind pressure and 5 PSF dead load.

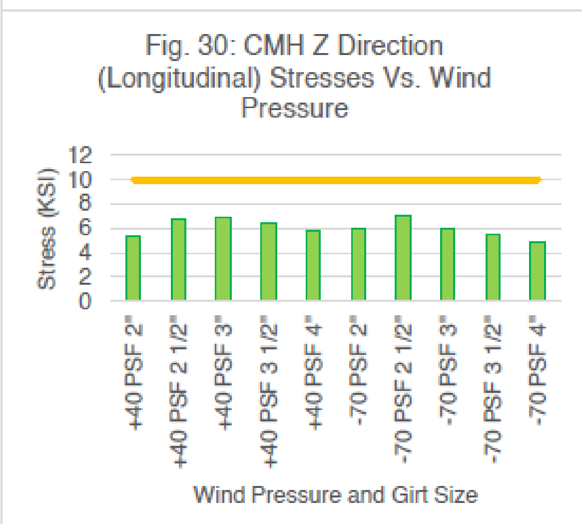
In this case, generic FRP girts failed to meet minimum design requirements for performance as supports for cladding and insulation in exterior wall application.

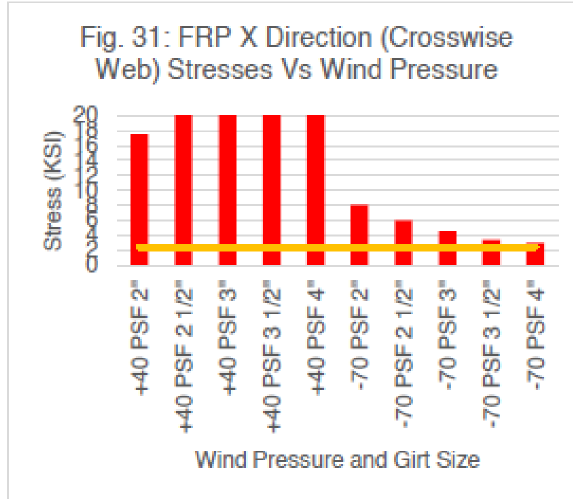
See the Appendix for further data.

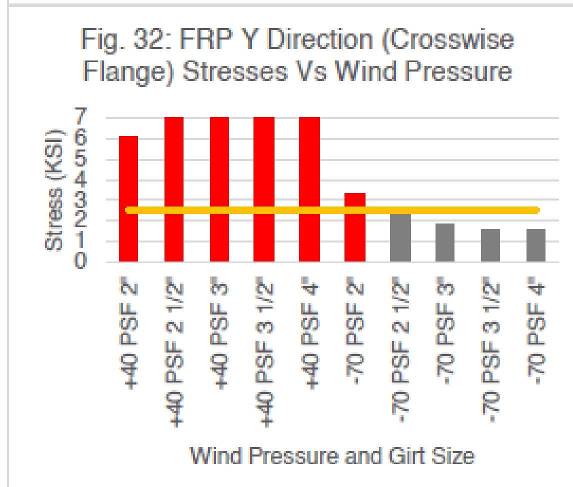
Stresses for Case IV (24" span, 16" spacing, 23" cantilever) with CMH and Generic FRP

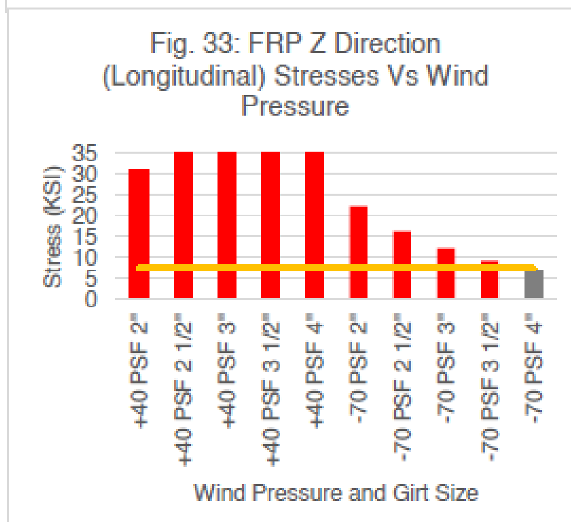










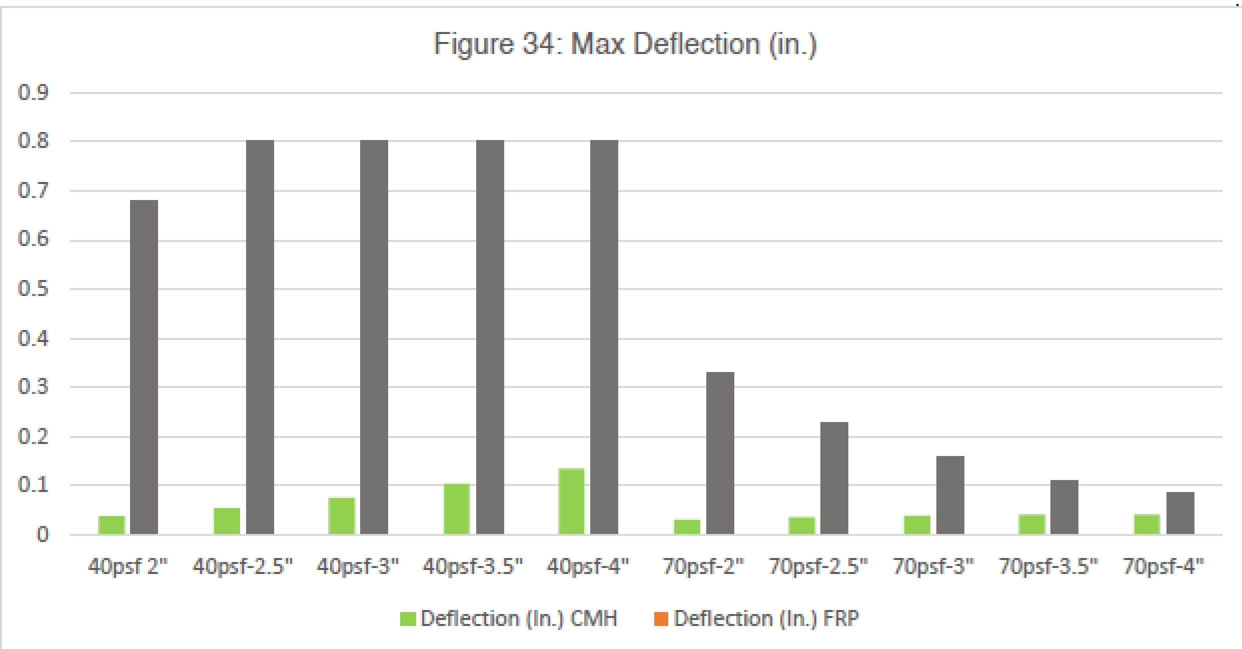


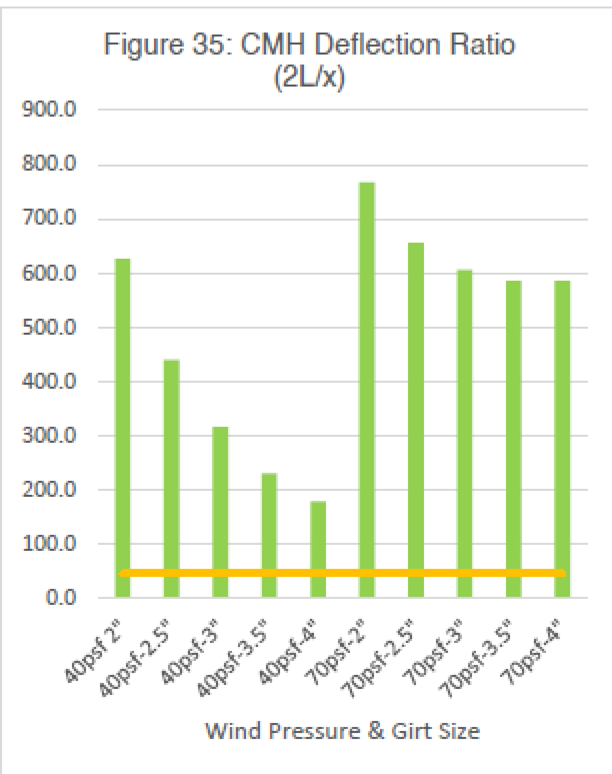
Line denotes allowable stress with safety factor of 4

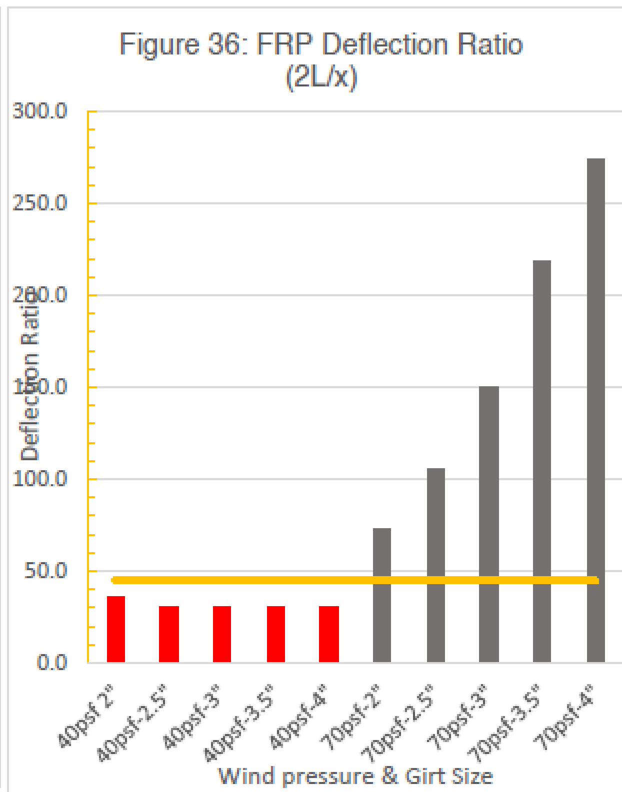
Green bars are CMH Gray bars are generic FRP Red bars indicate a failure

2 ½" through 4" with positive wind pressure resulted in excessive deformation, so it is shown as maximum

Deflection for Case IV (24" span, 16" spacing, 23" cantilever) with CMH and Generic FRP







Line denotes deflection ration of L/90 (2L/90 for cantilever). Deflection includes wind and dead load.

Green bars are CMH   Gray bars are generic FRP   Red bars indicate a failure

The larger the deflection criteria, the less deflection (below the line is a failure)
2 ½" through 4" with positive wind pressure resulted in excessive deformation, so it is shown as maximum

FEA Simulation Computer Images

The 3-D Solid Works 2020 package was used to model the different girts and run the FEA structural analysis simulations. Typical screenshots of the FEA analysis are shown in the figures below. The steel inserts are included in the CMH simulations but are hidden for clarity.

Figure 37: Typical FEA results output CMH model

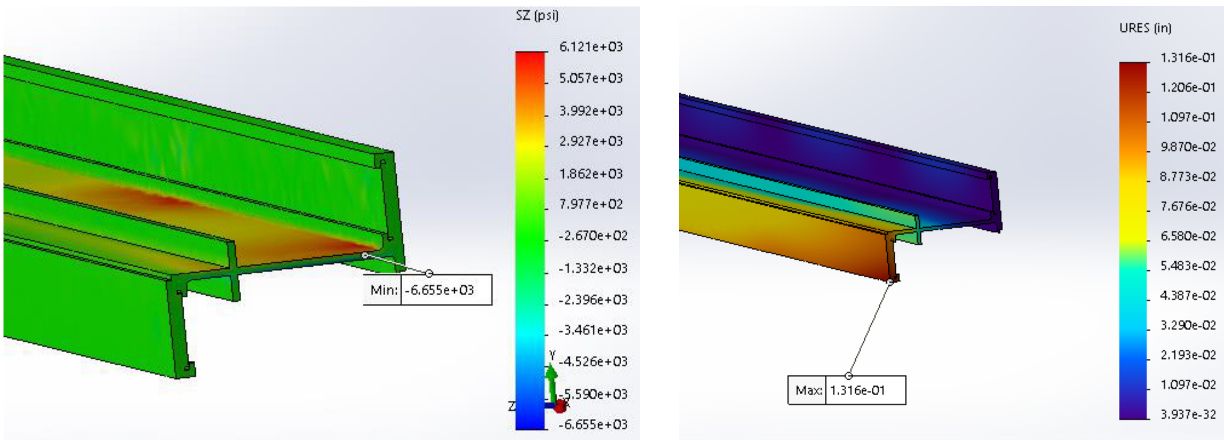


Figure 38: Typical cantilever condition at CMH ends

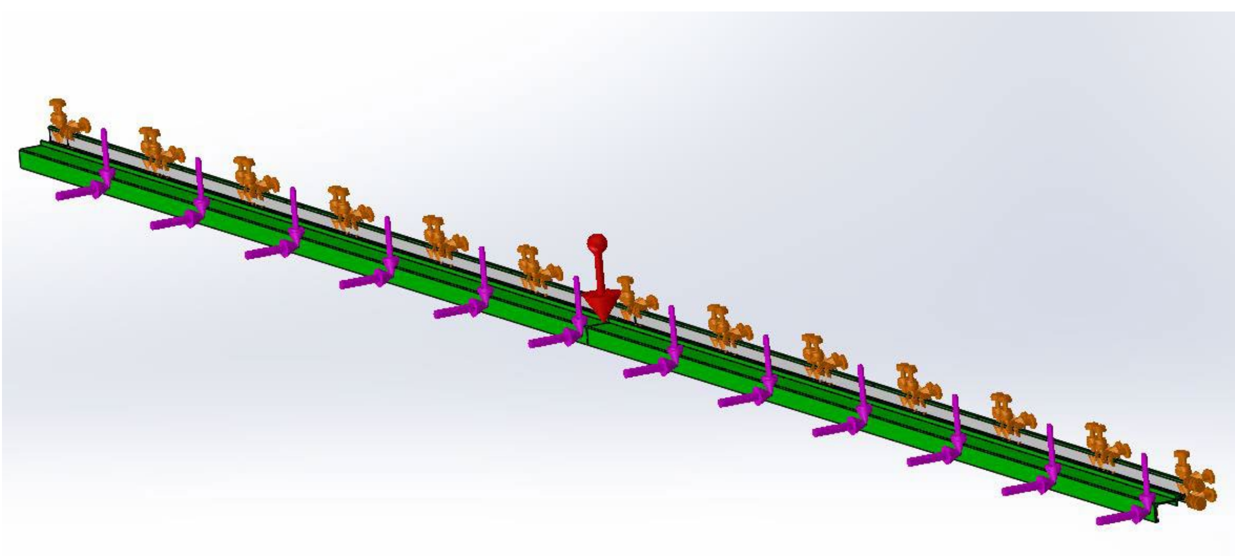


Figure 39: Typical FEA results output FRP model

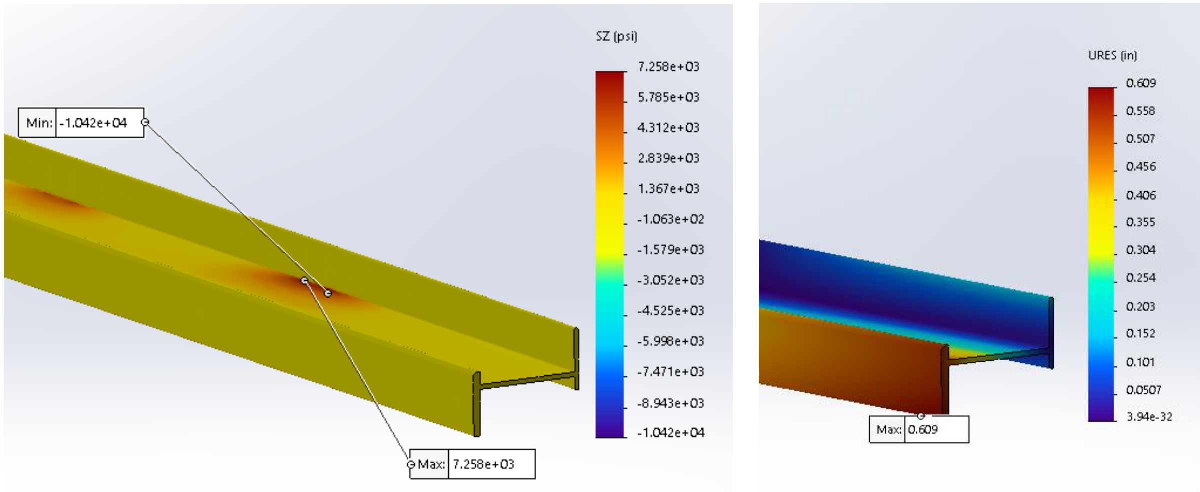
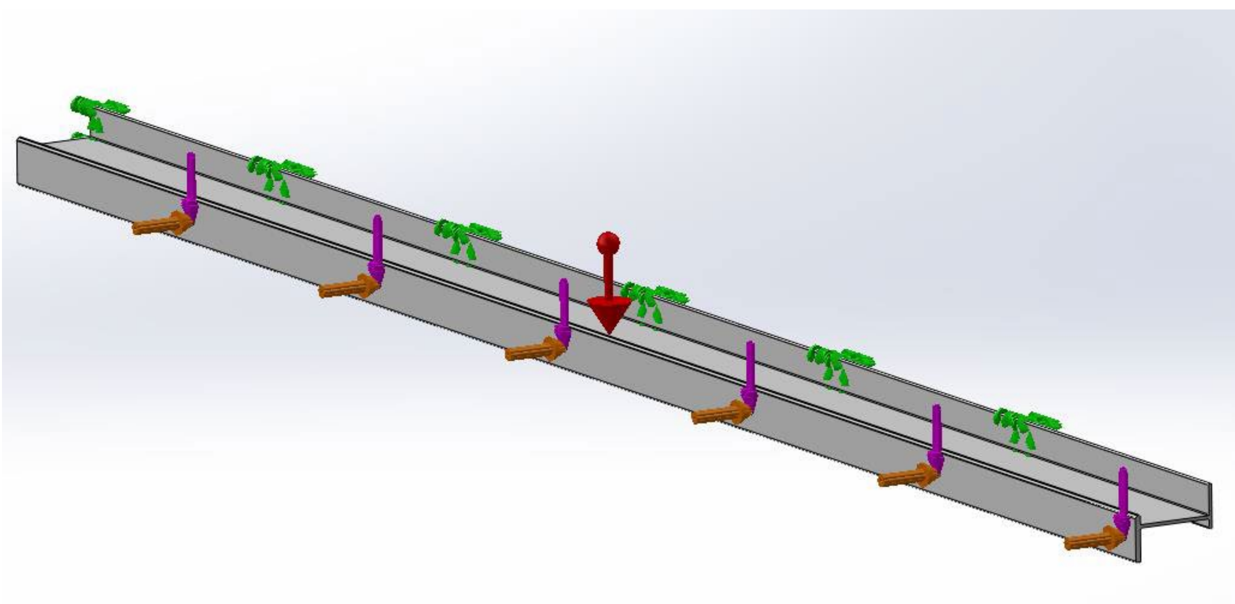


Figure 40: Typical FRP model with cantilever



Summary

In this study, a summary of engineering best practices was presented for composite metal hybrid Z-girts (GreenGirt CMH) and generic FRP sub-framing Z-girts with respect to the following areas:

- Best practices for structural stress analysis of Z-shaped girts as sub-frame members
- Best practice for detail for girt end conditions at the ends of individual girt pieces
- Best practices for attaching and connecting cladding to sub-framing composite girts
- Best practices for using safety factors in the design of composite sub-framing girts

Also, in this study, four standard wall configuration case studies illustrate the use of these best practices as well as the failure to use such best practices and the consequences in terms of the design being structurally unsafe and not meeting reasonable design criteria.

In all the FEA cases, the generic FRP Z-girts did not meet appropriate stress safety factors and/or deflection criteria.

In all the FEA cases, the composite metal hybrid Z-girts (GreenGirt CMH™) passed the structural loading conditions with appropriate stress, safety factors, and acceptable deflection.

Marketplace research has indicated generic FRP profiles with material properties called out in this study are commonplace. As illustrated in this study, such profiles do not provide an equivalent structural design when compared to CMH. The inability to take adequate safety factors, design criteria, and/or directional material properties under consideration may result in an unsafe design.

Appendix

A. Joinery Methods

Sub-framing girts are usually manufactured in finite lengths (8 to 10 feet), which are often less than most wall lengths. Therefore, the end condition for the continuation of the girts along the wall needs to be carefully detailed. Among the critical engineering metrics that need to be considered for these end conditions are:

- Structural stress and deformation analysis
- Attachment detail to substrate
- Allowance for thermal expansion along the length of the girt

Typically, the only method of joining end conditions of generic FRP girts is to leave the girt ends cantilevered over the supports. Unless the stress and structural analysis is performed for such special end conditions (which often is not for generic FRP), such a condition is to be avoided.

Another method of joining the girts is by lapping the girt ends. Though this may be common practice with light gauge steel, it is not feasible with FRP girts due to the relatively larger material thicknesses of FRP girts. It also creates out-of-plane offsets in the wall's vertical plane if the girts can be lapped at all.

The third method of joining girt ends is butt joints on a substrate support such as a framing stud. Due to the required offsets for spacing of fasteners to the edge of the girt (minimum of 2.5x fastener diameter), a wider stud is required, as illustrated in Table 6, for a 16-gauge stud substrate.

Table 5: Required Offsets for Spacing of Fasteners to Edge of Girt

	Description	Required distance (inches)
FRP Girt 1	Edge of steel 3x thickness	0.1875
	Edge distance of girt 2.5x fastener diameter (0.25)	0.625
	Fastener	0.25
	Space for thermal expansion	0.08
FRP Girt 2	Edge of steel 3x thickness	0.1875
	Edge distance of girt 2.5x fastener diameter (0.25)	0.625
	Fastener	0.25
Minimum required steel face		2.205
Width of steel face (typical)		1.5
Deficiency		-0.705

From Table 5, the required distance to butt join the ends of two consecutive girts on one stud exceeds the width of a typical single stud. This conclusion applies to steel stud substrates as well as wood stud substrates. Therefore, a wider stud or doubling the stud is required. Such a change is not often welcomed by owners or project managers due to the added costs involved. Therefore, butt-joining composite FRP girts on a single (or double stud substrate) is not best practice.

Another method of joining girt ends is via properly engineered splices. However, for generic FRP girts, such a splice detail is not available from any manufacturer in the market, is not utilized, and no manufacturer information or recommendations are available.

For best practices of properly engineering a splice detail, the following points need to be addressed:

- Properly designed splices need to allow for thermal expansion and transfer/resist all necessary loading.
- Splices should not be bulky as it can get in the way of rigid insulation.
- Splices should not be a single metal piece, as it will thermally conduct and create thermal
- bridging.
- Splice connection should be through bolted.

The last method is the utilized method of joining CMH girt ends. The method interlocks the ends of the girts using the steel inserts in the flanges, creating a solid, continuous connection. Such a connection allows for thermal expansion, transfers all necessary loads across the girt, does not interfere with the insulation or wall plane, and does not require any additional components.

The CMH interlocking method of joining girt ends is the best practice.

B. Cladding/Substrate Attachment Methods

Fiber Reinforced Polymer (FRP) Cladding Attachment

The conventional method to connect to FRP shapes is to use positive through connectors such as bolting and riveting with large enough washers to distribute stresses. Although this attachment method is effective in transferring loads, it can be expensive, labor intensive, and not practical for cladding attachment as it requires access to both sides of the wall to install a fastener.

From a practical perspective, the preferred method of connecting cladding to generic FRP girts is using screws in a manner like the use of self-drilling screws with light gauge steel. However, the main shortcoming of using screws as an attachment method of cladding to FRP sub-framing members is that the load-carrying capacity is generally low and will not provide a reasonable safety factor against failure. A discussion of adequate safety factors and the rationale behind such requirements is presented in the following section. Furthermore, the load-carrying capacity of a screw in generic FRP can seriously degrade over time as the fastener loses its torque and pullout capacity due to the relaxation of FRP material.

Generally, introducing any fastener in the FRP materials in connections weakens the material compared to the main FRP part without fasteners. Therefore, using screws to attach cladding to FRP girts is typically done for low levels of loading and is not considered a good practice due to the degradation of load-carrying capacity with time, especially when exposed to severe environmental conditions such as thermal cycling loads and freeze/thaw conditions.

An improvement on using simple screws for attaching cladding to generic FRP is using screws along with an adhesive. Such attachment methods usually provide better load transfer capacity and load retention levels compared to using screws' low-level loadings, though such practice is not typically used in building wall structures.

CMH Cladding Attachment

The best practice method is to attach cladding to CMH. Because CMH has a light gage insert as an integral part of the hybrid girt, self-drilling screws similar to what is used in light gage steel are driven, using common tools, through the FRP part of the girt and into the continuous steel insert, providing a positive base metal attachment capable of transferring high-level loads. Due to the combined effect of the FRP and the steel insert, the load capacity of such attachment is larger than the sum of the added component capacities (i.e., adding the load capacity of the FRP to the steel insert).

Most importantly, the CMH cladding connection retains its torque and pullout capacity over time and does not seriously degrade, even when exposed to harsh environmental conditions. Such performance is better, or at least similar to, the behavior of self-drilling screws in light gage steel.

Fiber Reinforced Polymer (FRP) Substrate Attachment

As far as connecting FRP girts to the substrate structure, generic FRP girts require the use of sufficiently large washers to distribute the loads on the surface of the FRP flange and avoid possible fastener pull-through in the FRP material. Although the load transfer capacity may be sufficient, the FRP girt can be damaged from over-torque and is susceptible to stress singularities.

CMH Substrate Attachment

Attaching the CMH girt to the substrate structure involves driving the screw fastener through the steel insert into the substrate with the FRP part of the girt sandwiched in between. This avoids the possibility of any pull-through from the FRP material, as the insert will resist such action.

Thus, connecting the CMH to the substrate has a superior load transfer capacity, eliminates stress singularities, and protects the composite from premature failures such as fastener pull-through.

C. Fastener Use with FRP Products

FRP joint connections are a delicate matter and must be done with great attention to detail.

The main reason for such complexity is that traditional connection methods used with classic materials such as metals do not work the same way or as well when joining to FRP structural shapes.

In general, the section of the FRP shape at the joint will be weaker than the main, undisturbed section away from the joint. For example, drilling a hole in composites reduces the load-carrying capacity. As some of the fibers become discontinuous, stress concentrations are created around the hole, which act as failure initiation and singularity points, and therefore the joint is weaker than the main part.

The following are weakening mechanisms that are introduced by driving a fastener into the FRP:[1]

- Singularity points for stress are created which weakens the section.
- Discontinuity in the fibers weakens the section.
- The discontinuity in the matrix is prone to crack propagation and fracture.
- Torque resistance of the screw into FRP deteriorates with time.
- Ability for load retention in case of fire is reduced.

A review of recommendations from FRP manufacturers with respect to connecting to their FRP structural shapes as indicated in their installation and design guidelines indicates the following conclusions:

Bolting

- FRP bolts, stainless-steel bolts, or galvanized bolts are recommended to connect FRP panels to FRP structural shapes.
- Bolt and Nut (Steel, Galvanized, Silicon, Bronze, Nylon, Polyester, etc.) methods are used to fasten FRP profiles together. It is best to use washers to distribute the loads.
- Threaded fiberglass rods with molded fiberglass nuts are used to fasten FRP profiles together. This is good for highly corrosive applications, and this method has good shear values.
- Using a bolt and threaded hole is a possible assembly technique for FRP to metal or FRP to FRP.
- Epoxies or other adhesives significantly improve joint strength.
- FRP bolts, nuts, and washers may be specified to suit aggressive environments or for electric isolation.

Riveting

- Tubular rivets can be used in conjunction with a washer or metal backup plate to connect FRP to FRP. They are stronger than pop rivets because of the solid shank, which requires accessibility from both profile sides.
- Solid rivets may be used to join FRP profiles together and should be used with backup plates or washers, but this method must have accessibility to both sides of the profile.

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[1] Flynn, Susan Keen, and O'Leary, Melissa. "University R&D Advances Novel Ideas to Ground-Breaking Applications", American Composites Manufacturers Association. Composites Manufacturing, July/August 2017, Pages 14-16

"Guidelines and Recommended Practices for Fiber-Reinforced-Polymer (FRP) Architectural Products," ACMA: American Composites Manufacturers Associations. 2016.

Duthinh, Dat. "Connection of Fiber Reinforced Polymer (FRP) Structural Members: A review of the state of the art," National Institute of Standards and Technology 6532, August 2000.

"Prospect for New Guidance in The Design Of FRP", European Commission, 2016

Using Screws (for Low Loading Demand)

Self-drilling screws can be used in applications involving mechanical connections when high-strength fasteners are not required.

Self-drilling screws may also be used in combination with adhesives.

- Lag screws can be used to attach FRP profiles to wood. A washer should be used to distribute the load. Lag screws are not recommended for fastening FRP to metal and are also not recommended for attaching FRP to FRP.
- Self-drilling screws work well in conjunction with adhesives. Screws may be used without adhesive but will not provide a high-strength connection (FRP to FRP).

Summary

Installing self-drilling screws into FRP as a joining method introduces numerous damage mechanisms, which make the load-carrying capacity deteriorate over time, create an unsafe design, and make the load-carrying capacity of the fastener unpredictable over time, deviating from the initial design intentions.

D. Safety Factors

In the allowable stress design method (ASD), safety factors compensate for uncertainties in quantifying design metrics (or variables) involved with FRP composite materials. Such variables are:

- Material properties such as strength and stiffness
- Uncertainties in loads and the modeling of the structure
- Service environment

In this context, the safety factor is defined as the ratio of the ultimate stress to the allowable stress. In this section, the different sources of uncertainty contributing to the safety factor for FRP component design will be summarized and quantified.

The nominal ultimate strength of the FRP material considered herein shall be based on a rigorous statistical approach of experimental data with a high confidence in the nominal value. The base value shall be denoted by R_0, and all the safety factor components discussed below are to be applied to this base value.

The different constituents of a sound safety factor that can be used with the ASD method include:

- **Material properties:**
  This factor accounts for the deviation of the actual strength of the FRP material from the actual nominal strength R_0 and for the manner and consequence of the failure mode. Similar to other construction materials, a reduction factor of 0.8 is used, which corresponds to a safety factor multiplier of 1/0.8 = 1.25.

- **Loads and modeling of the structure uncertainties:**
  Traditionally, dead loads are more predictable than live loads or transient loads such as wind loads. A load factor of 1.2 is commonly used with dead loads, and a factor of 1.4 is used with live loads. For cladding wall applications, since live loads are not applicable, a factor of 1.2 is appropriate.

- **Service environment:**
  - **Service temperature:** The cavity of exterior walls of buildings where the FRP girts are typically located can reach a temperature as high as 190°F. Such high temperature warrants the use of a safety factor multiplier of 2 for a polyester-based FRP.[2]
  - **Moisture Effect:** An assumption is made that the wall cavity remains dry, and therefore, the multiplier adopted is 1.
  - **Aging and UV effects:** The FRP strength usually is affected by UV exposure. However, most well-designed FRP materials have UV inhibitor additives, which nullify such effects. Based on laboratory testing, a reduction factor of 10% in the strength may be expected in the long term, even though most sub-frame applications of girts are hidden in the cavity of the wall and not directly exposed to sunlight. A reduction factor in strength due to UV exposure of 0.9 is used, which can also be stated as a safety factor multiplier of 1.111.

- **Notches and holes in the girt:**
  Any notches or holes in addition to the normal cladding or substrate fastener attachments are to be explicitly designed for and checked separately as a design item and are not included in the general safety factor values. The weakening of the material caused by the normal fastener attachment of cladding or to the substrate must be considered. For this purpose, a ¼” diameter fastener is assumed in a 1.5” to 2” wide section element of the FRP girt. The reduction factor in strength is proportional to the ratio of the hole-reduced section to the full section. For this, a stress factor multiplier of 1.2 is used.

- **Creep effects:**
  Creep is a deformation condition of the material characterized by increasing deformation or strain under a constant sustained level of dead load stress. Glass fibers are relatively insensitive to creep; however, the polymer matrix creeps slightly. As a general rule, creep for FRP is not of significant concern if the sustained dead load stresses are limited below 20% of the maximum material stress.[3]

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[2] “Pre-Standard for Load and Resistance Factor Design (LRFD) for Pultruded Fiber Reinforced Polymer (FRP) Structure,” American Society of Civil Engineers. November 9, 2010.
Aldrich, Robb A., Arena, Lois, and Zoeller, William. “Practical Residential Wall Systems: R-30 and Beyond”, Steven Winter Associates Inc.
Winandy, Jerrold E. and Beaumont, Rhett. “Roof Temperatures in Simulated Attics.” United States Department of Agriculture Forest Service
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[3] “Structural Plastic Design Manual,” American Society of Civil Engineers. ASCE Manuals Reports on Engineering Practice No 63, ASCE 1984.

For computing the minimum safety factor, the creep effects are considered insignificant. If creep effects are a concern, then design checks are to be made separately.

- **Installation quality uncertainties:**
  Uncertainties related to the quality and workmanship of the installation are not usually included in the design safety factors. Situations such as missing fasteners, damaged girts, and poor site handling of the girts can be remedied by proper procedures and inspections. If such situations do happen, then it is considered as negligence and faulty workmanship or installation.

To summarize, a reasonable total safety factor can be estimated by multiplying the above factors, as summarized in Table 6. A minimum safety factor of 4 should be used for design.

Table 6: Safety Factor Multipliers and Cumulative Safety Factor

Uncertainty	Safety Factor Multiplier
Material properties	1.25
Loads and modeling of the structure	1.2
Service temperature	2
Moisture effect	1
Aging and UV effects	1.111
Notches and holes in the girt	1.2
Creep effect	1
Installation quality effects	1
Cumulative Safety Factor	***SF = 1.25*1.2*2*1*1.111*1.2*1*1*1 = 4***

Depending on the specific project, the upper range of the safety factor can be as high as 6 or 8.

E. FEA Analysis Settings

- **How to Accurately Run Composite Sub-Framing for Façade Cladding:**

  FEA analysis with 3D software packages, if performed correctly, is among the most accurate methods for analyzing FRP structural components used for cladding support. It is, at the least, highly recommended.

  While both steel and composite can be used structurally within the building envelope, they must be analyzed differently when it comes to finite element analysis. Orthotropic analysis, point loading, stress concentrations, cantilevers, and other added complexities must be considered when performing structural analysis on composites. The following general guidelines are necessary to accurately structurally model components or systems of components.

- **Orthotropic Analysis:**

  Unlike steel, composite properties like modulus of elasticity and tensile strength can vastly differ lengthwise and crosswise, which can lead to issues if not all directional properties are known or considered. An acceptable safety factor in the lengthwise direction must be duplicated in the crosswise direction as well. Finite element analysis should include the material properties in the x, y, and z directions for strength, modulus of elasticity, and any other properties that require consideration. Special care must be taken to ensure proper reference geometry is used so the correct material properties correspond to the correct direction.

  Maximum stresses must be taken in every direction, with consideration taken to the allowable stresses in that direction. An acceptable safety factor of at least four for overall stress means nothing if the safety factor is two in the crosswise direction.

- **Point Loading**

  Cladding options like stucco may result in uniform loading, but most claddings being used with composite sub-structures must utilize point loading to get the most accurate structural results. Point loads should be placed at a worst-case location, most likely midway between the attachments of the composite substructure to the substrate. This will result in worst-case stress concentrations, providing a more realistic model for what is occurring on the actual wall.

  Also, some wall panel attachments are only around the outside perimeter of the panel shape and depending upon the size and shape of the specific panel, create unusually concentrated loads in some portions of the sub-framing. This must be noted beforehand, and worst-case conditions should be modeled. The modeler and professional engineer must be aware of this type of loading dynamic. This overlooked situation is most likely a trailing liability on a number of standard construction projects.

  For example, an ACM panel may have a dead load of 3 PSF, but that panel will only attach along the perimeter. If the panel is 4' x 12', that is a 48 square foot panel that weighs 144 pounds. If the girt spacing is at 24” O.C., there will likely be 18 ACM clips to attach to the girts, with each carrying a +64 LB and -112 LB point load for wind to go with an 8 LB point load for weight. This is likely to result in an increase in stress and deflection over what would occur if uniform loading were utilized.

- **Non-Bonded Contacts:**

  One of the important facets of finite element analysis is accurately reflecting what is happening in the model. Items like bonding in component contacts can result in a more rigid model than can realistically be expected. Whenever possible, use fasteners and make contact sets as realistic as possible to avoid making the model stronger than it would be on the wall.

- **Mesh:**

  Performing FEA at a default mesh setting versus refining the mesh for a model can result in wildly different maximum stresses. It is recommended to use a curvature mesh, which results in the largest number of nodes and elements before reaching a point of diminishing returns.

  When using fasteners in models, stress discontinuities can occur around fastener holes. Best judgment and practices should be used in discerning what is and is not of concern.

- **Cantilevers:**

  In instances where butt joints cannot be used where composite substructures come together, the maximum cantilever between spans should be used to provide a worst-case scenario for stress. If the span is 16", a cantilever of 15" should be used, or if the span is 24", a cantilever of 23" should be used. This will provide a realistic design for what will occur when the composite substructure is being utilized on the wall.

- **Fastener Placement:**

  In general, fastener spacing and edge distance in FRP composites are as follows:

  - For center to center spacing of fasteners, at least 5 times the fastener diameter
  - From edge of profile (along the profile), fasteners should not be placed closer than 2.5 times the fastener diameter
  - From end of the profile, fasteners should not be placed closer than 3 times the fastener diameter

Final Checks

1. Any FEA or calculations should be checked by the professional engineer doing the cladding assembly calculations. A Professional Engineer with knowledge of composites should sign off on the settings and results provided by the FEA. In summary, the FEA process for developing and using the FEA analysis need to include, as a minimum, the following items: The FEA model must be validated with respect to mesh size, loading model, and boundary support model. Such validation may be carried out by comparing simulation to actual representative experimental results. Also, such validation may be performed by comparing simulation results to known closed-formula types of solutions.
2. Provide FEA to model and evaluate areas of the longest composite girt cantilever span possible between intermediate framing members/attachment.
   a. FEA shall include maximum dead load and wind load conditions.
   b. FEA shall include point loads representative of fastener locations.
   c. Maximum directional stresses in model shall have a safety factor of 4 or greater.
   d. Stresses shall be indicated and analyzed in three directions.
   e. FEA shall accurately replicate the wall system and physical loading dynamics.
   f. Report shall be furnished with the submittal.
   g. FEA shall be approved by a licensed PE familiar with composites.

3. Butt joints (non-interlocking joints) of adjacent girts shall be installed on a minimum surface width of 3” or double stud condition to accommodate proper fastener margins to composite.

F. Structural Analysis – Durability and Testing

FRP structural components need to be tested for the durability of the structural strength and stiffness to assess the environmental exposure effects during their service life.

Depending on the use of a building, the service life of a building varies from 5 years for temporary structures to 100 years for monumental structures. Fifty years is the usual design service life for a normal-use building such as a commercial or institutional building.

The maximum recommended service temperature of pultruded FRP components is 40°F below the glass transition temperature, T_g, of the composite system. The glass transition temperature of the composite system is the temperature above which the matrix changes from glassy to rubbery state and the mechanical properties degrade.

Among the environmental effects that FRP components may be sensitive to and need to be tested for are the following:

- Moisture (weather exposure)
- Temperature (weather exposure)
- Sun ultraviolet light exposure (if conditions of use allow for such exposure)
- Chemical attack (if conditions of use allow for such exposure)
- Salt exposure

Among the ASTM standards that are used to test for the above environmental effects are the following:

- For accelerated weathering effects (moisture, temperature, ultraviolet, etc.):
  - ASTM G152 “Standard Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials”
  - ASTM G155 “Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials”
- For Freeze-Thaw evaluation, a testing procedure like ASTM C666 “Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing,” may be adopted.
- Salt spray resistance
  - ASTM B117 “Standard Practice for Operating Salt Spray (Fog) Apparatus”
- Water resistance
  - ASTM D2247 “Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity”

Further discussions of durability and failure modes will occur in a future paper.

G. Results and Discussion

The following section presents a performance comparison between generic FRP components and hybrid metal composite components as used for insulation and cladding supports in exterior walls of building envelopes. Both materials are glass-fiber-based FRPs.

The performances of the two materials are evaluated using FEA stress analysis with respect to maximum stresses, safety factors, and maximum deformations, as the material is subject to loadings representative of field conditions.

The FEA stress analysis shows the superior performance of the CMH compared to the generic FRP, even though the generic FRP girt has a thicker section of FRP than the CMH girt. The generic FRP flange is 1.85 times thicker than the CMH flange, while the generic FRP web is 1.5 times thicker than the CMH web. Both sections support the same insulation thicknesses and, therefore, have similar depths.

Notes/Disclaimers

The content of this study is for general information purposes only and does not constitute legal, engineering, accounting, regulatory, or tax advice.

The material presented herein was prepared with great care and in accordance with industry recognized engineering principles and practices.

This information should not be used for any specific project without consulting with qualified engineering professionals in the area where the project is located, as design criteria are specific to each project. Furthermore, laws and regulations are specific to each location.

The reference to generic FRP girts is a general term and does refer to or imply any specific product brand name or manufactured or specific marketed product. Any resemblance in naming, description, dimensions, or configuration is merely a coincidence.

GreenGirt CMH™ is a registered Trademark for Advanced Architectural Products (A2P).

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Due to the general nature of the information contained in this white paper, such content cannot be used or referenced in any legal document such as construction documents, specifications, drawings, contracts, and codes.

Properties used for simulations were based upon data publicly available from manufacturers or using industry standard data to bridge the gap where information was missing.

This study is intended, but not promised or guaranteed to be, current, complete, or up to date. A2P may update the study as more data becomes available.

All FEA was done with SOLIDWORKS Simulation Software.

Wind loads utilized are ultimate per ASCE 7-10.

While Table 1604.3 of the International Building Code gives a minimum of L/120 for deflection limits, footnote A provides L/90 for secondary wall members supporting formed metal siding.

The content of this study excludes thermal spacers and only refers to zee shapes.

This study does not guarantee the performance of any specific products, including but not limited to GreenGirt CMH.

Engineering data in this study is meant to be used as an aid and does not constitute stamped engineering calculations.

Engineering data for GreenGirt CMH is based on installation per A2P installation guides.

Engineering data does not include the performance of the substrate or cladding. Substrate is assumed to be strong enough to carry the GreenGirt CMH or Generic FRP.

The purpose of this study is to provide basic information to product users for use in evaluating, processing, and troubleshooting the use of certain composite products. The information provided is general or summary in nature and is offered to assist the user. The information is not intended to replace the user's careful consideration of the unique circumstances and conditions involved in the use and processing of composite products. The user is responsible for determining whether this information is suitable and appropriate for the user's particular use and intended application.

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Patents: See GreenGirt.com/patents/

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Title of paper changed to reflect current product nomenclature