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SECTION 1

INTRODUCTION

The contents of this Design Manual are intended to give the structural engineer the tools with which he or she needs to safely and correctly design a fiberglass structure using pultruded fiberglass shapes.

When designing fiberglass structures, the attached Structural Design Basis (Section 3), should be followed as a minimum unless specifically required to follow a different set of design parameters. It should be noted that the following recommended design formulas and procedures are a compilation of input from different fiberglass pultrusion companies. Delta Composites believes it has utilized the best, and most conservative of the available options. In addition to this design manual, Delta Composites has developed a 3-dimensional, structural analysis program which analyzes and designs specifically for fiberglass structural shapes, calculates deflections, stress, calculates unity ratios, and resizes members based upon the design parameters set forth in this manual.

The structural design engineer should be familiar with the concept of stress and deflection and the impact that one has on the other-----and the engineer should know that they are not interchangeable in fiberglass. It can typically be said that the sizing of fiberglass structural shapes is governed by deflection much more so than by stress, and that the converse is sometimes not true---that stress governs more than deflection. It should always be the practice of the engineer to check both stress and deflection when designing fiberglass structures.

If you have any questions or comments, please feel free to contact us toll free at (866) 361-2100, or e mail us at engineering@deltacomposites.com.

SECTION 2

THE BASICS OF FIBERGLASS PULTRUSION

The contents of this Section are primarily a compilation of data from Creative Pultrusions, Inc. Delta Composites has endeavored in this section to introduce to the users of this manual the basics of manufacturing fiberglass structural shapes.

Pultruded fiberglass structural shapes are manufactured by, and are available from several pultrusion companies, but there are three major suppliers that dominate the industry. The three most commonly used manufacturers of fiberglass pultruded structural shapes and their respective trade names are as follows:

Creative Pultrusions, Inc., Alum Bank, PA	Pultex®
Strongwell, Inc., Bristol, VA	Extren®
Bedford Reinforced Plastics, Inc., Bedford, PA	Bedford Shapes

It has been our experience that, among the three major suppliers, the quality of their products is very good. There are some differences in tensile strengths, flexural strengths, shear strengths, and modulii of elasticity, but as long as the engineer keeps this in mind when performing the structural analysis, there should not be a negative side to inter-changing suppliers. However, Creative Pultrusions' Pultex® SuperStructurals have significantly higher material properties---a modulus of elasticity that is 43% higher than the rest of the field, and tensile and flexural strengths that are approximately 40% higher. The engineer can create some serious problems for his or herself if the design is based upon Creative's SuperStructurals and a someone else buys from an alternative source. The engineer must be aware of this possible scenario and make every effort to prevent it from occurring. The use of SuperStructurals can be very cost effective as compared to designing with the standard structural shapes supplied by others.

Delta Composites, unless otherwise required to do so by customer requirement, uses solely the Creative Pultrusions' Pultex® line of structural shapes, however, we have no problems with using one of the other two, if requested to do so. This design specification incorporates, and is built around the Creative Pultrusions Pultex® product line as well as their resin and shape designations, however, the design equations are applicable to the shapes of other manufacturers as long as the proper physicals particular to that manufacturer are used.

A pultruded fiberglass structural shape is comprised of reinforcing fibers and resin. In simple terms, the fiber reinforcement provides the structural stiffness, and the resin provides the resistance to the environment, be it ultra-violet resistance, chemical resistance, impact resistance, fire resistance, etc. Resins typically contain fillers to assist in achieving an intended performance characteristic.

Reinforcing fibers consist of continuous strand mat and continuous strand roving. Coupling the reinforcing fibers with the resin and a surfacing veil, the pultrusion product is complete. Typical structural shapes contain from 45% - 75% fiber reinforcement by weight.

A variety of continuous and woven reinforcement types are commonly used in fiberglass pultrusions. The four major types are E-Glass, S-Glass, aramid, and carbon. The most commonly used reinforcement is E-Glass. Other reinforcements are more costly, and therefore are used more sparingly in construction. The following Table 2-1 provides the physical properties of the four reinforcing fibers.

Table 2-1 Typical Properties of Fibers Used in Pultruded Structural Profiles

Property	E-Glass	S-Glass	Aramid	Carbon
Density lbs/in^3	.094	.090	.053	.064
Tensile Strength (psi)	500,000	665,000	400,000	275,000 – 450,000
Tensile Modulus (10^6 psi)	10.5	9.0	9.0	33 – 55
Elongation to break (%)	4.8	2.3	2.3	0.6 – 1.2

The following is a brief description of the reinforcing fibers:

> **Continuous Strand Mat**: Long glass fibers intertwined and bound with a small amount of resin, called a binder. Continuous strand mat provides the most economical method of obtaining a high degree of transverse, or bi-directional strength characteristics. These mats are layered with roving, and this process forms the basic composition found in most pultruded products. The ratio of mat to roving determines the relationship of transverse to longitudinal strength characteristics.
>
> **Continuous Strand Roving**: Each strand contains from 800-4,000 fiber filaments. Many strands are used in each pultursion profile. This roving provides the high longitudinal strength of the pultruded product. The amount and location of these “rovings” can, and does alter the performance of the product. Roving also provides the tensile strength needed to pull the other reinforcements through the manufacturing die.

Since pultrusion is a low-pressure process, fiberglass reinforcements normally appear close to the surface of the product. This can affect appearance, corrosion resistance or handling of the products. Surface veils can be added to the laminate construction, and when used, displaces the reinforcement from the surface of the profile, creating a resin-rich surface. The two most commonly used veils are E-Glass and polyester.

Resin formulations typically consist of polyesters, vinyl esters, and epoxies, and are either fire retardant or non-fire retardant.

Polyesters and vinyl esters are the two primary resins used in the pultrusion process. Epoxy resins are typically used with carbon fiber reinforcements in applications where higher strength and stiffness characteristics are required. Epoxies can also be used with E-glass for improved physical properties.

The following Table 2-2 provides typical physical properties of resins used in pultruded structural shapes.

Table 2-2 Typical Properties of Resins Used in Structural Pultrusions

Property	**Polyester**	**Vinylester**	**Epoxy**	**Test Method**
Tensile Strength (psi)	11,200	11,800	11,000	ASTM D638
% Elongation	4.5	5	6.3	ASTM D638
Flexural Strength (psi)	17,800	20,000	16,700	ASTM D790
Flexural Modulus (10^6 psi)	.43	0.54	0.47	ASTM D790
Heat Distortion Temperature (°F)	160	220	330	ASTM D648
Short Beam Shear (psi)	4,500	5,500	8,000	ASTM D2344

Various fillers are also used in the pultrusion process. Aluminum silicate (kaolin clay) is used for improved chemical resistance, opacity, good surface finish and improved insulation properties. Calcium carbonate offers improved surfaces, whiteness, opacity and general lowering of costs. Alumina trihydrate and antimony trioxide are used for fire retardancy. Alumina trihydrate can also be used to improve insulation properties.

Resin formulations in a pultruded fiberglass structural shape can be altered to achieve special characteristics as dictated by the environment in which the shape is intended for use. The most commonly used resins and trade names manufactured by Creative Pultrusions Inc. are:

> **Pultex® Series 1500**, a non-fire retardant polyester resin, possesses good chemical resistance combined with high mechanical and electrical properties. This standard product is commonly used in moderately corrosive environments where fire resistance is not a concern.
>
> **Pultex® Series 1525**, a fire retardant polyester resin, possess a flame spread rating of 25 or less as determined by the ASTM E-84 Tunnel Test, while maintaining the same characteristics as the 1500 Series. This product is commonly used in fire retardant structures commonly used offshore, such as wellhead access platforms, cable trays, etc., and it is commonly used onshore where fire resistance and moderate corrosion resistance are key elements in the design.
>
> **Pultex® Series 1625** is a fire retardant vinyl ester resin which possesses excellent corrosion resistance, as well as better performance characteristics at elevated temperatures. This product should be used in highly corrosive environments and is a high performance standard structural. This material possesses an ASTM E-84 Tunnel Test flame spread rating of 25 or less.
>
> **Pultex® Series 3535** is a modified polyester resin which possesses a low smoke generation characteristic, as well as a low flame spread rating, and is commonly used in the mass transit industry and in all applications where low smoke and low toxicity is of key importance.

When selecting the appropriate resin system to be incorporated into the pultruded product, the structural engineer should first refer to the Corrosion Guide in Section 8 of this document. Vinyl esters typically cost in the range of 10-15% more than polyester resins.

The structural engineer should also know that, because fiberglass is a plastic, it will undergo some decay and change of appearance due to prolonged exposure to outdoor weathering. In order to minimize this effect on fiberglass pultruded shapes, various options are available. Use of UV stabilizers and surfacing veils can be used, and coatings can also be applied to the structural shape. It should be noted that all Pultex® shapes contain UV stabilizers in the resin, and all shapes contain a surfacing veil as a standard.

UV stabilizers will retard the effect of weathering, but eventually the profile will degrade. A condition called "fiber blooming" will occur on the surface of the profile, and this is coupled with a slight reduction in physical properties.

Surfacing veils further enhance the profiles resistance to weathering. A synthetic veil, when applied to the surface of the fiberglass pultrusion during the manufacturing process, enhances weatherability and corrosion resistance by adding resin thickness to the surface of the product, i.e., it provides for a resin rich surface.

The optimum method of maintaining surface appearance during outdoor exposure is to apply a coating to the surface. Two-component, UV stabilized urethanes work very well with this application. A 1.5 mil dry film thickness coating will provide protection for many years with minimal change in appearance. This step, however, is non-standard for the Pultex® product line, and should be done by the fiberglass fabrication contractor in a controlled environment. Delta Composites typically does not paint its structures, however, we have painted handrails since they are typically the most visible component of a structure.

SECTION 3

STRUCTURAL DESIGN BASIS

The beams and girders of the a fiberglass structure should, as a minimum, be designed for the following basic load cases:

Basic Load Cases

BLC1. **Dead Load** of structure.
BLC2. **Design Live Load** as stipulated by the customer or by code.
BLC3. **Design Storm Wind** speed @ El. (+) 33'-0" (10 meters) as stipulated by the customer or by code. The wind speed is a function of the elevation of the pertinent structure as related to the El. (+) 33’-0”, and adjustments for the elevation should be made using the Wind Speed Evaluation per API RP 2A, 20th Edition, or by the appropriate governing code.
BLC4. **Design Operating Wind** speed @ El. (+) 33'-0" (10 meters) as stipulated by the customer or by code, again with the same adjustments for elevation as discussed above.
BLC5. If applicable, the forces resulting from the horizontal and vertical accelerations caused by a 100-yr storm or hurricane on a floating vessel or as provided by the customer or by code (i.e., the movement resulting from a vessel on the high seas).
BLC6. If applicable, the forces resulting from the horizontal & vertical accelerations caused by an operating storm on a floating vessel or as provided by the customer or by code (i.e., the movement resulting from a vessel on the high seas).
BLC7. If applicable, the horizontal & vertical accelerations resulting from seismic activity as defined by code for the design location.

Combined Load Cases

As a minimum, the combined load cases should be as follows:

A. For filler beams or deck beams (not for girders, columns, truss rows, nor for wind bracing):

Operating Case:

(if applicable)
(BLC1 x 1.0) + (BLC2 x 1.0) + (BLC4 x 1.0) + (BLC6 x 1.0)

B. For columns, girders, truss rows, and wind bracing:

Operating Case (non-seismic):

(if applicable)
(BLC1 x 1.0) + (BLC2 x 1.0*) + (BLC4 x 1.0) + (BLC6 x 1.0)

Storm Case (non-seismic):

(if applicable)
(BLC1 x 1.0) + (BLC2 x 1.0*) + (BLC3 x 1.0) + (BLC5 x 1.0)

Operating Case (seismic):

(BLC1 x 1.0) + (BLC2 x 1.0*) + (BLC4 x 1.0) + (BLC7 x 1.0)

* see live load reduction below for additional information

The above design load combinations for the storm case assumes that the 100-yr storm will not occur at the same time as seismic activity. If the design premise set forth by the customer or code requires that they can occur simultaneously, then the engineer will be required to add (BLC7 x 1.0) to the load combinations.

Further, when applying wind loadings, the engineer must consider all of the critical wind directions and apply them to the structural model. As a minimum, the engineer should evaluate the winds in the X direction, the Y and an array of diagonal wind approach directions to create the worst load conditions on the particular member under evaluation.

Uniform Live Load vs. Actual Operating Equipment Loads

The uniform live load used above should be compared against the true and actual operating equipment loads to be applied to the structure (if this information is available). The engineer is to use whichever loading creates the worst loading on the structural elements under evaluation, either the true and actual operating equipment loads, or the uniform live loads. When using the actual operating equipment loads, **no live load reduction** (see below) is permitted.

Live Load Reduction

Girders, trusses and columns beams are to be designed for the full dead load and 100% of the uniform live load unless the girder, truss row, or column supports an area greater than or equal to 200 square feet. If the supported area exceeds 200 square feet, a twenty (20%) percent Live Load Reduction (LLR) factor can be applied to the uniform live loading. This LLR is not applicable to dead loads, nor is it applicable to the actual equipment loads ---only the uniform live loads. **If the actual operating equipment loads are greater than the reduced live load (i.e., uniform live load x LLR), the engineer must not use uniform live loads in the analysis, but use only the actual operating equipment loads.**

> Deck/Floor Live Loads: For any member supporting 200 square feet or more, be it a column, a girder, or a truss row, the design uniform live load applied to that member may be reduced by 20%, (i.e., multiplied by 0.80) if it meets the criteria set forth above.
>
> Roof Live Loads: Use of a LLR for roof live loads is not permitted in any case.

Snow Loading

The engineer is to consider snow loading, and all other environmental loadings in the structural analysis when applicable. The appropriate local design codes are to be adhered to.

Impact and/or Dynamic Loading

The engineer is to consider impact loading on a case by case basis. When facing a design situation involving an impact or a dynamic loading situation, it is recommended that the structural designer increase the safety factors used in design by a magnitude of 2.0 (See Section 6).

Concentrated Loads and Web Crippling

When designing beams which are subjected to concentrated loads, the structural engineer shall consider using web stiffeners to eliminate the effects of web crippling on the fiberglass pultruded shape. Stiffening can be achieved by bolting and/or epoxying angles, tees, or channels to the web of the beam being subjected to the concentrated loading. The analysis to determine the effectiveness is accomplished by treating the stiffening elements as a column, and designing in accordance with the criteria set forth in Section 11.

One-third Increase in Allowable Stresses

A 1/3rd increase in allowable stress is permitted for all combines load cases involving storm winds, storm motions or seismic activity. A 1/3rd increase in allowable stress is not permitted when evaluating combined loadings involving operating environmental conditions.

Effects of Temperature

When designing fiberglass structures that will be subjected to high heat exposure, the engineer is cautioned to consider the effect of temperature as it relates to the allowable stresses and to the modulus of elasticity. The result of higher temperatures on structural fiberglass is a reduction in modulus of elasticity and thus, a lowering of the allowable stresses. These reductions in allowable stress and in modulus of elasticity are discussed in Section 7 of this document. Vinyl ester resins are better in elevated temperatures than polyester resins.

Effects of Corrosion

Before the structural engineer begins any structural analysis, he or she should be knowledgeable as to the environment in which the structure is to be installed. The environment dictates the type of resin to be used, and the different resins possess different structural properties. In essence, the use of a polyester resin in designing a fiberglass structure will have lower allowable stresses and higher deflections than would the use of a vinyl ester resin in the same environment. Refer to Section 8 of this document for assistance in this matter.

Deflections

As a minimum, all live load deflections of all beams and girders should be limited such that the deflection over length ratio (Δ/L) does not exceed 1/150. For cantilevered beams and girders, the deflection ratio should be limited to 1/100 ratio, or 1/4", whichever is greater.

The engineer is to be aware that, due to fiberglass' relatively low shear modulus, the total deflection of a fiberglass beam is actually comprised of two components:

- flexural deflection
- shear deflection

When calculating deflections of steel beams, due to steel's relatively high shear modulus, the shear deflection component is typically neglected. This is not the case in designing with fiberglass shapes. Refer to Section 9, Table 9-2 for the methodology in calculating the two components of the deflection. On average, the shear deflection will add an additional 10-15% to the deflection. The engineer is to use all standard and conventional methods for calculating deflections.

SECTION 4

PHYSICAL PROPERTIES FOR DESIGNING WITH FIBERGLASS STRUCTURAL SHAPES

Pultruded Fiberglass Structural Shapes distributed by Delta Composites, unless otherwise required by specification, are the Pultex® Pultrusion line of products manufactured by Creative Pultrusions, Inc. The following physical properties and tables are excerpts from the Pultex® Pultrusion Design Manual as prepared by Creative Pultrusions with corporate headquarters located at 214 Industrial Lane, P.O. Box 6, Alum Bank, Pennsylvania 15521. If the structural engineer plans to use the materials supplied by another pultrusion supplier, it is strongly recommended that he or she evaluates and compares the physical properties of the alternative materials and uses the appropriate values.

Delta Composites and Creative Pultrusions, Inc. believe the information put forth in the following property sheets to be accurate and reliable as of the date of this publication. However, Delta Composites and Creative Pultrusions, Inc. assume no obligation or liability which may arise as a result of its use. While Delta Composites and Creative Pultrusions, Inc. have no knowledge that the information put forth infringes any valid patent, we assume no responsibility with respect thereto and each user must satisfy oneself that one's intended application process or product infringes no patent.

Material Properties of Pultex® Fiber Reinforced Polymer Structural Profiles

Rectangular Tubes, Channels, Angles, Square Tubes

Angle profile sizes are 3” x 3” x ¼” and less.

1500 Series- Thermoset Polyester- Olive Green
1525 Series- Thermoset Polyester Class 1 FR- Gray
1625 Series- Thermoset Vinyl Ester Class 1 FR- Beige

The following data was derived from ASTM coupon and full section testing. The results are average values based on random sampling and testing of production lots. Composite materials are not homogeneous, and therefore the location of the coupon extraction can cause variances in the coupon test results. Creative Pultrusions, Inc. publishes an average value of random samples from production lots.

Property (coupon values)	**ASTM Test**	**Units**	**1500/1525 Series**	**1625 Series**
Mechanical				
Tensile Strength (LW)	D638	psi	33,000	37,500
Tensile Strength (CW)	D638	psi	7,500	8,000
Tensile Modulus (LW)	D638	10^6 psi	2.5	3.0
Tensile Modulus (CW)	D638	10^6 psi	0.8	1.0
Compressive Strength (LW)	D695	psi	33,000	37,500
Compressive Strength (CW)	D695	psi	16,500	20,000
Compressive Modulus (LW)	D695	10^6 psi	3.0	3.0
Compressive Modulus (CW)	D695	10^6 psi	1.0	1.2
Flexural Strength (LW)	D790	psi	33,000	37,500
Flexural Strength (CW)	D790	psi	11,000	12,500
Flexural Modulus (LW)	D790	10^6 psi	1.6	2.0
Flexural Modulus (CW)	D790	10^6 psi	0.8	1.0
Modulus of Elasticity	Full Section [2]	10^6 psi	2.8 – 3.2	2.8 – 3.2
(Channels)	Full Section [2]	10^6 psi	2.8	2.8
(Square & Rectangular Tubes)	Full Section [2]	10^6 psi	3.2	3.2
Shear Modulus	Full Section [2]	10^6 psi	0.42	0.42
Interlaminar Shear Strength (LW)[3]	D2344	psi	4,500	4,500
Shear Strength by Punch (PF)	D732	psi	5,500	6,000
Notched Izod Impact (LW)	D256	ft – lbs/in	28	30
Notched Izod Impact (CW)	D256	ft – lbs/in	4	5
Bearing Stress (LW)	D953	psi	30,000	30,000
Bearing Stress (CW)	D953	psi	18,000	18,000
Poisson’s Ration (LW)	D3039	in/in	0.35	0.35
Poisson’s Ration (CW)	D3039	in/in	0.15	0.15
In-plane Shear (LW)	Modified D2344[4]	psi	7,000	7,000
In-plane Shear (CW)[5]	Modified D2344[4]	psi	4,500	4,5000
Clip Angle Shear Strength (LW)**	**D2344**	**psi**	**1,333**	**1,450**

LW = Lengthwise CW = Crosswise PF = Perpendicular to Laminate Face

**** Use the appropriate safety factor to these values for shear strength for clip angles when designing connections. The reduced shear strength is attributed to the eccentricity of the load causing bending stresses in the clip angles. Failure to adhere to this could result in a classical shear failure through the throat of the clip angle.**

(Continued next page)

Material Properties of Pultex® Fiber Reinforced Polymer Structural Profiles

Rectangular Tubes, Channels, Angles, Square Tubes

Angle profile sizes are 3” x 3” x ¼” and less.

(continued)

Property (coupon values)	**ASTM Test**	**Units**	**1500/1525 Series**	**1625 Series**
Physical				
Barcol Hardness [1]	D2583		45	45
Water Absorption	D570	% Max	0.6	0.6
Density	D792	lbs/in^3	0.060-0.070	0.060-0.070
Specific Gravity	D792		1.66-1.93	1.66-1.93
Coefficient of Thermal Expansion (LW)	D696	10^{-6}in/in/°F	4.4	4.4
Thermal Conductivity (PF)	C177	BTU-in/ft^2/hr/°F	4	4
Electrical				
Arc Resistance (LW)	D495	seconds	120	120
Dielectric Strength (LW	D149	KV/in	40	40
Dielectric Strength (PF)	D149	Volts/mil	200	200
Dielectric Constant (PF)	D150	@60Hz	5.2	5.2

1 Pultex® uses a synthetic surface veil that reduces the Barcol hardness, but does not reflect lack of cure.

2 Full section testing based on a 3-point bend with simply supported end conditions.

3 Tested on a 3:1 span to depth ration.

4 Follow ASTM D2344 but rotate coupon 90-degrees (cut section of coupon length faces up.

5 In-plane Shear (CW) values for square and rectangular tubes = 2,500 psi, angles = 3,000 psi.

Fire and Smoke Property	**Test**	**Value 1525**	**Value 1625**
Tunnel Test	ASTM E84	25 Max	25 Max
Flammability Classification	UL94	(VO)	(VO)
Flammability Extinguishing	ASTM 635	Self Extinguishing	Self Extinguishing
NBS Smoke Chamber	ASTM E662	650	650
Flame Resistance (Ignition/Burn)	FTMS 406-2023	55/30 (seconds)	55/30 (seconds)

Material Properties of Pultex® Fiber Reinforced Polymer Flat Sheets

1500 Series- Thermoset Polyester- Olive Green
1525 Series- Thermoset Polyester Class 1 FR- Gray
1625 Series- Thermoset Vinyl Ester Class 1 FR- Beige

The following data was derived from ASTM coupon and full section testing. The results are average values based on random sampling and testing of production lots. Composite materials are not homogeneous, and therefore the location of the coupon extraction can cause variances in the coupon test results. Creative Pultrusions, Inc. publishes an average value of random samples from production lots.

Property (coupon values)	**ASTM Test**	**Units**	**1500/1525 Series**	**1625 Series**
Mechanical				
Flexural Stress, Flatwise (LW)	D790	psi	35,000	35,000
Flexural Stress, Flatwise (CW)	D790	psi	15,000	15,000
Flexural Modulus, Flatwise (LW)	D790	10^6 psi	2.0	2.0
Flexural Modulus, Flatwise (CW)	D790	10^6 psi	1.1	1.1
Tensile Stress (LW)	D638	psi	20,000	20,000
Tensile Stress (CW)	D638	psi	10,000	10,000
Tensile Modulus (LW)	D638	10^6 psi	1.8	1.8
Tensile Modulus (CW)	D638	10^6 psi	1.0	1.0
Compressive Stress, Edgewise (LW)	D695	psi	24,000	24,000
Compressive Strength, Edgewise (CW)	D695	psi	16,000	16,000
Compressive Modulus, Edgewise (LW)	D695	10^6 psi	1.8	1.8
Compressive Modulus, Edgewise (CW)	D695	10^6 psi	1.0	1.0
Notched Izod Impact (LW)	D256	ft – lbs/in	20	20
Notched Izod Impact (CW)	D256	ft – lbs/in	5	5
Bearing Stress (LW)	D953	psi	32,000	32,000
Bearing Stress (CW)	D953	psi	32,000	32,000
Poisson’s Ration (LW)	D3039		0.32	0.32
Poisson’s Ration (CW)	D3039		0.25	0.25
Physical				
Barcol Hardness [1]	D2583		40	40
Water Absorption	D570	% Max	0.6	0.6
Density	D792	lbs/in^3	0.060-0.070	0.060-0.070
Specific Gravity	D792		1.66-1.93	1.66-1.93
Coefficient of Thermal Expansion (LW)	D696	10^{-6}in/in/°F	8.0	8.0
Electrical				
Arc Resistance (LW)	D495	seconds	120	120
Dielectric Strength (LW	D149	KV/in	40	40
Dielectric Strength (PF)	D149	Volts/mil	200	200
Dielectric Constant (PF)	D150	@60Hz	5.2	5.2

LW = Lengthwise CW = Crosswise PF = Perpendicular to Laminate Face

[1] Pultex® uses a synthetic surface veil that reduces the Barcol hardness, but does not reflect lack of cure.

Fire and Smoke Property	**Test**	**Value 1525**	**Value 1625**
Tunnel Test	ASTM E84	25 Max	25 Max
Flammability Classification	UL94	(VO)	(VO)
Flammability Extinguishing	ASTM 635	Self Extinguishing	Self Extinguishing
NBS Smoke Chamber	ASTM E662	650	650
Flame Resistance (Ignition/Burn)	FTMS 406-2023	55/30 (seconds)	55/30 (seconds)

Material Properties of Pultex® Fiber Reinforced Polymer Rods & Bars

1500 Series- Thermoset Polyester- Olive Green
1525 Series- Thermoset Polyester Class 1 FR- Gray
1625 Series- Thermoset Vinyl Ester Class 1 FR- Beige

The following data was derived from ASTM coupon and full section testing. The results are average values based on random sampling and testing of production lots. Composite materials are not homogeneous, and therefore the location of the coupon extraction can cause variances in the coupon test results. Creative Pultrusions, Inc. publishes an average value of random samples from production lots.

Property (coupon values)	**ASTM Test**	**Units**	**Test Results**
Mechanical			
Tensile Strength (LW)	D638	psi	100,000
Tensile Modulus (LW)	D638	10^6 psi	6.0
Compressive Strength (LW)	D695	psi	60,000
Flexural Strength (LW)	D790	psi	100,000
Flexural Modulus (LW)	D790	10^6 psi	6.0
Notched Izod Impact (LW)	D256	ft – lbs/in	40
Physical			
Barcol Hardness	D2583		50
Water Absorption	D570	% Max	.25
Density	D792	lbs/in^3	0.073-0.076
Coefficient of Thermal Expansion (LW)	D696	10^{-6}in/in/°F	3.0

LW = Lengthwise

Material Properties of Superstud!™/Nuts! Square Nuts
Fiber Reinforced Polymer Fastener System

The following data was derived from ASTM coupon and full section testing. The results are average values based on random sampling and testing of production lots. Composite materials are not homogeneous, and therefore the location of the coupon extraction can cause variances in the coupon test results. Creative Pultrusions, Inc. publishes an average value of random samples from production lots.

Property (coupon values)	**ASTM Test**	**Units**	**Diameter/Threads per Inch**				
			3/8” 16 UNC	**1/2” 13 UNC**	**5/8” 11 UNC**	**3/4” 10 UNC**	**1” 8 UNC**
Ultimate Thread Shear Capacity Using Standard CP Square Nut [1,2,6]		lbs	1,000	2,000	3,100	4,500	6,200
Max. Ultimate Design Tensile Load using CP Nut [1,2,5,6]		lbs	800	1,600	2,480	3,600	4,960
Flexural Strength [2,3]	D790	psi	60,000	60,000	60,000	60,000	60,000
Flexural Modulus [2,3]	D790	10^6psi	2.0	2.0	2.0	2.5	2.75
Compressive Strength (LW) [2,3]	D695	psi	55,000	55,000	55,000	55,000	60,000
Ultimate Transverse Shear [2,3]	B565	load lb	4,200	7,400	11,600	17,200	27,400
Transverse Shear Yield [2,3]		load lb	2,100	3,300	4,500	7,500	12,500
Dielectric Strength [2,3]	D149	KV/in	40	40	40	40	40
Water Absorption [2]	D570	%	1	1	1	1	1
Coefficient of Thermal Expansion (LW)	D696	10^{-6}in/in/°F	3.0	3.0	3.0	3.0	3.0
Torque Strength Using CP Square Nut Lubricated w/ SAE 10W30 Motor Oil [2,4,5,6]	Ult.	ft-lb	8	15	33	50	115
	Recommended	ft-lb	4	8	16	24	50
Flammability			SE*	SE*	SE*	SE*	SE*
Stud Weight [3]		lb/ft	.076	.129	.209	.315	.592
Thickness Square Nut		in	.437	.562	.688	.813	1.062
Width Square Nut		in	.688	.875	1.062	1.250	1.625

LW = Lengthwise * SE = Self Extinguishing

[1] Applies to single nut only; multiple nuts do not yield corresponding results.
[2] Ultimate strength values are averages obtained in design testing.
[3] Values are based on unthreaded rod.
[4] Torque results are dependant on several variable factors including the lubricant used, the length of the studs between nuts, alignment, washer surfaces, etc. Therefore, if such results of torque are important, it is vital that torque limits be determined experimentally for the exact installation conditions.
[5] Appropriate safety factors must be applied.
[6] Properties apply to Superstud!™ used with CP nut.

Material Properties of Pultex® Fiber Reinforced Polymer SuperStructural Profiles

Wide Flange Sections and I Sections

1500 Series- Thermoset Polyester- Olive Green
1525 Series- Thermoset Polyester Class 1 FR- Gray
1625 Series- Thermoset Vinyl Ester Class 1 FR- Beige

The following data was derived from ASTM coupon and full section testing. The results are average values based on random sampling and testing of production lots. Composite materials are not homogeneous, and therefore the location of the coupon extraction can cause variances in the coupon test results. Creative Pultrusions, Inc. publishes an average value of random samples from production lots.

Property (coupon values)	**ASTM Test**	**Units**	**1500/1525 Series**	**1625 Series**
Full Section				
Modulus of Elasticity	Full Section[2]	10^6 psi	3.9-4.0	3.9-4.0
(1/2” thick profiles)	Full Section[2]	10^6 psi	3.9	3.9
(1/4” & 3/8” thick profiles)	Full Section[2]	10^6 psi	4.0	4.0
Shear Modulus (Modulus of Rigidity)	Full Section[2]	10^6 psi	0.50	0.50
Flexural Stress	Full Section[2]	psi	33,000	33,000
Flange Section Mechanical				
Tensile Strength (LW)	D638	psi	40,000	46,000
Tensile Modulus (LW)	D638	10^6 psi	4.16	4.16
Compressive Strength (LW)	D695	psi	45,770	52,500
Compressive Strength (CW)	D695	psi	17,800	20,400
Compressive Modulus (LW)	D695	10^6 psi	3.85	3.85
Compressive Modulus (CW)	D695	10^6 psi	1.9	1.9
Flexural Strength (LW)	D790	psi	42,800	49,200
Flexural Modulus (LW)	D790	10^6 psi	2.0	2.0
Interlaminar Shear (LW)[5]	D2344	psi	4,000	4,500
Shear Strength by Punch (PF)	D732	psi	5,500	6,000
Notched Izod Impact (LW)	D256	ft – lbs/in	28	32
Notched Izod Impact (CW)	D256	ft – lbs/in	21	24
Bearing Stress (LW)	D953	psi	33,000	38,000
Bearing Stress (CW)	D953	psi	23,000	26,500
Poisson’s Ration (LW)	D3039	in/in	0.35	0.35
Poisson’s Ration (CW)	D3039	in/in	0.12	0.12
Web Section Mechanical				
Tensile Strength (LW)	D638	psi	30,300	35,000
Tensile Strength (CW)	D638	psi	10,500	12,000
Tensile Modulus (LW)	D638	10^6 psi	3.1	3.1
Tensile Modulus (CW)	D638	10^6 psi	1.4	1.4
Compressive Strength (LW)	D695	psi	37,500	43,125
Compressive Strength (CW)	D695	psi	14,200	16,330
Compressive Modulus (LW)	D695	10^6 psi	2.8	2.8
Compressive Modulus (CW)	D695	10^6 psi	1.9	1.9
Flexural Strength (LW)	D790	psi	43,320	49,800

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Material Properties of Pultex® Fiber Reinforced Polymer SuperStructural Profiles

Wide Flange Sections and I Sections (continued)

Property (coupon values)		ASTM Test	Units	1500/1525 Series	1625 Series
Flexural Strength (CW)		D790	psi	17,360	19,900
Flexural Modulus (LW)		D790	10^6 psi	1.9	1.9
Flexural Modulus (CW)		D790	10^6 psi	1.75	1.75
Interlaminar Shear (LW)[5]		D2344	psi	3,400	3,900
Shear Strength by Punch (PF)		D732	psi	5,500	6,000
Notched Izod Impact (LW)		D256	ft – lbs/in	38	43
Notched Izod Impact (CW)		D256	ft – lbs/in	19	22
Bearing Stress (LW)		D953	psi	33,980	39,000
Bearing Stress (CW)		D953	psi	30,000[3]	34,500
Poisson's Ration (LW)		D3039	in/in	0.35	0.35
Poisson's Ration (CW)		D3039	in/in	0.12	0.12
In-plane Shear (LW)	modified	D2344[4]	psi	7,000	7,000
In-plane Shear (CW)	modified	D2344[4]	psi	4,500	4,500
Physical					
Barcol Hardness [1]		D2583		33	39
Water Absorption		D570	% Max	0.6	0.6
Density		D792	lbs/in^3	0.060-0.070	0.060-0.070
Specific Gravity		D792		1.66-1.93	1.66-1.93
Coefficient of Thermal Expansion (LW)		D696	10^{-6}in/in/°F	4.4	4.4
Thermal Conductivity (PF)		C177	BTU-in/ft^2/hr/°F	4	4
Electrical					
Arc Resistance (LW)		D495	seconds	120	120
Dielectric Strength (LW		D149	KV/in	40	40
Dielectric Strength (PF)		D149	Volts/mil	200	200
Dielectric Constant (PF)		D150	@60Hz	5.2	5.2

LW = Lengthwise CW = Crosswise PF = Perpendicular to Laminate Face

[1] Pultex® uses a synthetic surface veil that reduces the Barcol hardness, but does not reflect lack of cure.
[2] Full section testing based on a 3-point bend with simply supported end conditions.
[3] Crosswise bearing stress of Web sections of ¼" profiles = 20,500 psi
[4] Follow ASTM D2344, but rotate coupon 90 deg. (cut section of coupon length faces up)
[5] Tested on a 3:1 span to depth ratio.

Property	ASTM Test	1525 Series	1625 Series
Flammability Classification	UL94	(VO)	(VO)
Tunnel Test	ASTM E84	25 Max	25 Max
Flammability Extinguishing	ASTM D635	Self Extinguishing	Self Extinguishing
NBS Smoke Chamber	ASTM E662	650	650
Flame Resistance (Ignition/Burn)	FTMS 406-2023	55/30 (seconds)	55/30 (seconds)

Material Properties of Pultex® Fiber Reinforced Polymer SuperStructural Profiles

Angles

Angle profile sizes are 4" x4" x ¼" and larger.

1500 Series- Thermoset Polyester- Olive Green
1525 Series- Thermoset Polyester Class 1 FR- Gray
1625 Series- Thermoset Vinyl Ester Class 1 FR- Beige

The following data was derived from ASTM coupon and full section testing. The results are average values based on random sampling and testing of production lots. Composite materials are not homogeneous, and therefore the location of the coupon extraction can cause variances in the coupon test results. Creative Pultrusions, Inc. publishes an average value of random samples from production lots.

Property (coupon values)	**ASTM Test**	**Units**	**1500/1525 Series**	**1625 Series**
Mechanical				
Tensile Strength (LW)	D638	psi	31,000	35,600
Tensile Strength (CW)	D638	psi	16,500	18,900
Tensile Modulus (LW)	D638	10^6 psi	3.5	3.5
Tensile Modulus (CW)	D638	10^6 psi	1.0	1.0
Compressive Strength (LW)	D695	psi	38,800	44,500
Compressive Strength (CW)	D695	psi	25,500	29,000
Compressive Modulus (LW)	D695	10^6 psi	3.0	3.0
Compressive Modulus (CW)	D695	10^6 psi	2.2	2.2
Flexural Strength (LW)	D790	psi	43,500	50,000
Flexural Strength (CW)	D790	psi	24,000	27,500
Flexural Modulus (LW)	D790	10^6 psi	1.9	1.9
Flexural Modulus (CW)	D790	10^6 psi	1.6	1.6
Modulus of Elasticity	Full Section [2]	10^6 psi	2.8	2.8
Shear Modulus	Full Section [2]	10^6 psi	0.5	0.5
Interlaminar Shear (LW)	D2344	psi	3,400	3,900
Shear Strength by Punch (PF)	D732	psi	5,500	6,000
Notched Izod Impact (LW)	D256	ft – lbs/in	34	39
Notched Izod Impact (CW)	D256	ft – lbs/in	33	38
Bearing Stress (LW)	D953	psi	33,000	38,000
Bearing Stress (CW)	D953	psi	33,000	38,000
Poisson's Ration (LW)	D3039	in/in	0.35	0.35
Poisson's Ration (CW)	D3039	in/in	0.12	0.12
In-plane Shear (LW)	Modified D2344	psi	7,000	7,000
In-plane Shear (CW)	Modified D2344	psi	4,500	4,500
Clip Angle Shear Strength (LW)**	**D2344**	**psi**	**3,400**	**3,900**

**** Use the appropriate safety factor to these values for shear strength for clip angles when designing connections. The reduced shear strength is attributed to the eccentricity of the load causing bending stresses in the clip angles. Failure to adhere to this could result in a classical shear failure through the throat of the clip angle.**

(Continued next page)

Material Properties of Pultex® Fiber Reinforced Polymer SuperStructural Profiles

Angles

Angle profile sizes are 4” x4” x ¼” and larger.

(continued)

Property (coupon values)	**ASTM Test**	**Units**	**1500/1525 Series**	**1625 Series**
Physical				
Barcol Hardness [1]	D2583		45	45
Water Absorption	D570	% Max	0.6	0.6
Density	D792	lbs/in^3	0.060-0.070	0.060-0.070
Specific Gravity	D792		1.66-1.93	1.66-1.93
Coefficient of Thermal Expansion (LW)	D696	10^{-6}in/in/°F	4.4	4.4
Thermal Conductivity (PF)	C177	BTU-in/ft^2/hr/°F	4	4
Electrical				
Arc Resistance (LW)	D495	seconds	120	120
Dielectric Strength (LW	D149	KV/in	40	40
Dielectric Strength (PF)	D149	Volts/mil	200	200
Dielectric Constant (PF)	D150	@60Hz	5.2	5.2

LW = Lengthwise CW = Crosswise PF = Perpendicular to Laminate Face

[1] Pultex® uses a synthetic surface veil that reduces the Barcol hardness, but does not reflect lack of cure.
[2] Full section testing based on a 3-point bend with simply supported end conditions.
[3] Follow ASTM D2344, but rotate coupon 90 deg. (cut section of coupon length faces up)

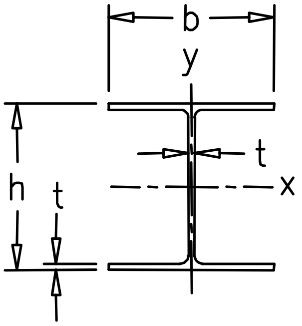
Property	**ASTM Test**	**1525 Series**	**1625 Series**
Flammability Classification	UL94	(VO)	(VO)
Tunnel Test	ASTM E84	25 Max	25 Max
Flammability Extinguishing	ASTM D635	Self Extinguishing	Self Extinguishing
NBS Smoke Chamber	ASTM E662	650	650
Flame Resistance (Ignition/Burn)	FTMS 406-2023	55/30 (seconds)	55/30 (seconds)

SECTION 5

CROSS SECTIONAL AND ENGINEERING PROPERTIES OF FIBERGLASS STRUCTURAL SHAPES

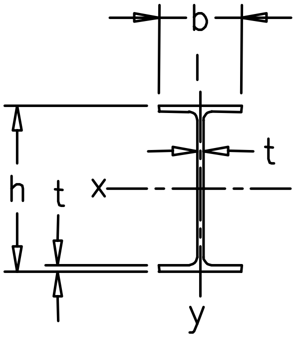
Wide Flange Sections

Depth (h)	**Width (b)**	**Thickness (t)**	**Area**	**Weight**	**X-X Axis**			**Y-Y Axis**			**Design**	
					I	**S**	**r**	**I**	**S**	**r**	**J**	**C_w**
in	**in**	**in**	**in^2**	**lb/ft**	**in^4**	**in^3**	**in**	**in^4**	**in^3**	**in**	**in^4**	**in^6**
3.00	3.00	0.25	2.17	1.63	3.23	2.15	1.22	1.11	0.74	0.71	0.047	2.49
4.00	4.00	0.25	2.92	2.19	8.05	4.03	1.66	2.63	1.32	0.95	0.063	10.52
6.00	6.00	0.25	4.42	3.31	28.58	9.53	2.54	8.91	4.46	1.42	0.094	80.21
6.00	6.00	0.375	6.57	4.92	40.76	13.59	2.49	13.32	4.44	1.42	0.316	119.84
8.00	8.00	0.375	8.82	6.61	100.35	25.09	3.37	31.65	7.91	1.90	0.422	506.46
8.00	8.00	0.50	11.67	8.75	128.81	32.20	3.32	42.09	10.52	1.90	1.000	673.41
10.00	10.00	0.375	11.07	8.30	200.45	40.09	4.26	61.94	12.39	2.37	0.527	1548.59
10.00	10.00	0.50	14.67	11.00	259.36	51.87	4.20	82.38	16.48	2.37	1.250	2059.52
12.00	12.00	0.50	17.67	13.25	457.26	76.21	5.09	142.59	23.77	2.84	1.500	5133.35



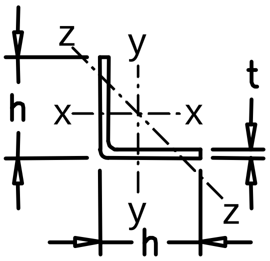
I Sections

Depth (h)	Width (b)	Thickness (t)	Area	Weight	X-X Axis			Y-Y Axis			Design	
					I	S	r	I	S	r	J	C_w
in	in	in	in^2	lb/ft	in^4	in^3	in	in^4	in^3	in	in^4	in^6
3.00	1.50	0.25	1.42	1.06	1.80	1.20	1.18	0.14	0.19	0.31	0.031	0.31
4.00	2.00	0.25	1.92	1.44	4.53	2.27	1.54	0.33	0.33	0.41	0.042	1.32
6.00	3.00	0.25	2.92	2.19	16.17	5.39	2.35	1.11	0.74	0.62	0.063	9.99
6.00	3.00	0.375	4.32	3.24	22.93	7.64	2.31	1.67	1.11	0.62	0.211	15.00
8.00	4.00	0.375	5.82	4.36	56.71	14.18	3.12	3.95	1.97	0.82	0.281	63.12
8.00	4.00	0.50	7.67	5.75	72.48	18.12	3.07	5.27	2.63	0.82	0.667	84.26
10.00	5.00	0.375	7.32	5.49	113.55	22.71	3.94	7.71	3.08	1.03	0.352	192.80
10.00	5.00	0.50	9.67	7.25	146.45	29.29	3.89	10.27	4.11	1.03	0.833	256.84
12.00	6.00	0.50	11.67	8.75	258.76	43.13	4.71	17.76	5.92	1.23	1.000	639.33



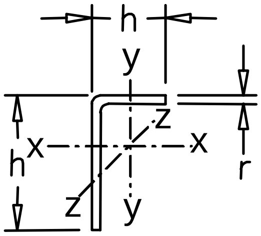
Equal Leg Angles

Depth (h)	Width (b)	Thickness (t)	Area	Weight	X-X Axis or Y-Y Axis			
in	in	in	in^2	lbs/ft	I in^4	S in^3	$r_{x,y}$ in	r_z in
1.00	1.00	0.125	0.22	0.170	0.02	0.03	0.30	0.182
1.00	1.00	0.250	0.42	0.320	0.03	0.05	0.29	0.183
1.125	1.125	0.125	0.25	0.190	0.03	0.04	0.34	0.207
1.50	1.50	0.125	0.35	0.260	0.08	0.07	0.47	0.284
1.50	1.50	0.1875	0.51	0.390	0.11	0.10	0.45	0.282
1.50	1.50	0.250	0.67	0.500	0.13	0.13	0.45	0.281
2.00	2.00	0.125	0.47	0.350	0.19	0.13	0.63	0.386
2.00	2.00	0.1875	0.70	0.530	0.27	0.19	0.62	0.383
2.00	2.00	0.250	0.92	0.690	0.34	0.24	0.61	0.381
3.00	3.00	0.125	0.72	0.540	0.65	0.30	0.95	0.590
3.00	3.00	0.1875	1.08	0.810	0.95	0.44	0.94	0.587
3.00	3.00	0.250	1.42	1.070	1.22	0.57	0.93	0.584
3.00	3.00	0.375	2.09	1.570	1.72	0.82	0.91	0.578
4.00	4.00	0.250	1.92	1.440	3.00	1.03	1.25	0.787
4.00	4.00	0.375	2.84	2.130	4.29	1.50	1.23	0.780
4.00	4.00	0.500	3.72	2.790	5.45	1.93	1.21	0.774
6.00	6.00	0.250	2.92	2.190	10.49	2.38	1.89	1.194
6.00	6.00	0.375	4.34	3.250	15.23	3.49	1.87	1.185
6.00	6.00	0.500	5.72	4.290	19.65	4.55	1.85	1.177



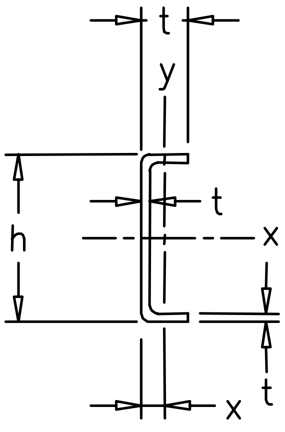
Unequal Leg Angles

Depth (h)	Width (b)	Thickness (t)	Area	Weight	X-X Axis			Y-Y Axis		
					I	S	R	I	S	R
in	in	in	in^2	lbs/ft	in^4	in^3	in	in^4	in^3	in
1.25	0.75	0.125	0.22	0.17	0.03	0.04	0.39	0.01	0.02	0.21
1.50	1.00	0.125	0.29	0.23	0.07	0.07	0.48	0.02	0.03	0.29
2.00	1.00	0.125	0.35	0.26	0.14	0.11	0.64	0.03	0.03	0.27
2.00	1.00	0.1875	0.51	0.39	0.21	0.16	0.63	0.04	0.05	0.26
2.00	1.00	0.25	0.67	0.5	0.26	0.21	0.62	0.04	0.060	0.25
2.00	1.25	0.250	0.73	0.55	0.29	0.22	0.62	0.09	0.090	0.34
2.00	1.50	0.125	0.41	0.31	0.17	0.12	0.64	0.08	0.07	0.45
2.00	1.50	0.25	0.80	0.60	0.31	0.23	0.62	0.15	0.14	0.43
2.25	1.50	0.1875	0.65	0.49	0.33	0.22	0.71	0.12	0.11	0.43
2.63	1.63	0.125	0.50	0.38	0.37	0.21	0.85	0.11	0.09	0.47
3.00	1.00	0.125	0.47	0.35	0.44	0.24	0.96	0.03	0.03	0.24
3.00	1.50	0.125	0.54	0.40	0.51	0.26	0.98	0.09	0.08	0.41
3.00	1.50	0.1875	0.80	0.60	0.74	0.39	0.97	0.13	0.11	0.40
3.00	1.50	0.250	1.05	0.79	0.96	0.50	0.96	0.16	0.14	0.40
3.00	2.00	0.1875	0.89	0.67	0.83	0.41	0.96	0.30	0.20	0.58
3.00	2.00	0.250	1.17	0.91	1.06	0.53	0.95	0.38	0.26	0.57
3.00	2.00	0.375	1.71	1.28	1.49	0.76	0.93	0.53	0.36	0.55
4.00	2.00	0.250	1.42	1.07	2.36	0.92	1.29	0.41	0.26	0.54
4.00	2.00	0.375	2.09	1.57	3.36	1.33	1.27	0.57	0.37	0.52
4.00	3.00	0.250	1.67	1.25	2.73	0.99	1.28	1.33	0.59	0.89
4.00	3.00	0.375	2.46	1.85	3.89	1.43	1.26	1.88	0.85	0.87
5.00	3.50	0.50	3.97	2.98	9.81	2.93	1.57	3.96	1.53	1.00
6.00	4.00	0.250	2.42	1.82	9.18	2.24	1.95	0.38	1.09	1.18
6.00	4.00	0.375	3.59	2.69	13.31	3.28	1.93	4.83	1.58	1.16
6.00	4.00	0.500	4.72	3.54	17.15	4.27	1.91	6.16	2.04	1.14
11.00	3.50	0.125	1.79	1.39	23.19	3.43	3.60	1.38	0.46	0.88



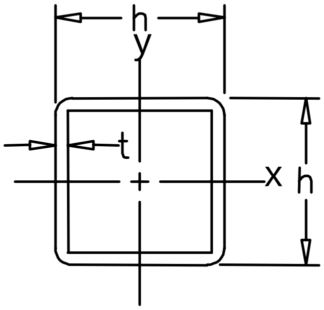
Channels

Depth (h)	Width (b)	Thickness (t)	Area	Weight	X-X Axis			Y-Y Axis		
in	in	in	in^2	lbs/ft	I in^4	S in^3	r in	I in^4	S in^3	r in
1.50	1.00	0.1875	0.55	0.41	0.17	0.22	0.55	0.05	0.08	0.30
1.23	1.50	0.100	0.39	0.29	0.10	0.16	0.51	0.09	0.10	0.48
2.00	0.56	0.125	0.34	0.260	0.16	0.16	0.69	0.01	0.02	0.15
2.31	1.00	0.160	0.60	0.45	0.43	0.38	0.85	0.05	0.07	0.29
2.50	0.75	0.0937	0.34	0.26	0.27	0.22	0.90	0.02	0.030	0.21
2.63	1.00	0.016	0.65	0.48	0.59	0.45	0.96	0.05	0.070	0.29
2.75	1.00	0.125	0.56	0.42	0.59	0.43	1.02	0.05	0.06	0.29
3.00	0.875	0.250	1.00	0.75	1.02	0.68	1.01	0.05	0.08	0.22
3.00	1.00	0.1875	0.83	0.62	0.95	0.63	1.07	0.06	0.09	0.27
3.00	1.50	0.250	1.310	0.98	1.61	1.07	1.11	0.25	0.25	0.44
4.00	1.06	0.125	0.71	0.53	1.46	0.73	1.43	0.06	0.07	0.29
4.00	1.13	0.250	1.37	1.03	2.62	1.31	1.38	0.12	0.14	0.29
4.00	1.75	0.1875	1.34	1.00	3.13	1.56	1.53	0.36	0.28	0.52
5.00	1.38	0.250	1.75	1.31	5.42	2.17	1.76	0.24	0.23	0.37
6.00	1.63	0.250	2.12	1.59	9.62	3.21	2.13	0.40	0.32	0.44
6.00	1.69	0.375	3.10	2.33	13.43	4.48	2.08	0.62	0.50	0.45
7.00	2.00	0.250	2.57	1.92	16.42	4.69	2.53	0.79	0.50	0.56
8.00	2.19	0.250	2.91	2.18	24.30	6.08	2.89	1.07	0.63	0.61
8.00	2.19	0.375	4.23	3.17	33.75	8.44	2.83	1.47	0.89	0.59
10.00	2.25	0.100	1.41	1.06	18.48	3.70	3.61	0.54	0.29	0.62
10.00	2.75	0.125	1.88	1.41	25.88	5.18	3.71	1.18	0.53	0.79
10.00	2.75	0.500	7.01	5.26	86.88	17.38	3.52	3.83	1.86	0.74
11.50	2.75	0.500	7.78	5.84	124.58	21.67	4.00	4.05	1.93	0.72
24.00	3.00	0.250	7.33	5.50	475.40	39.62	8.05	3.37	1.30	0.68
24.00	4.00	0.470	14.52	10.89	985.09	82.09	8.24	13.71	4.14	0.97



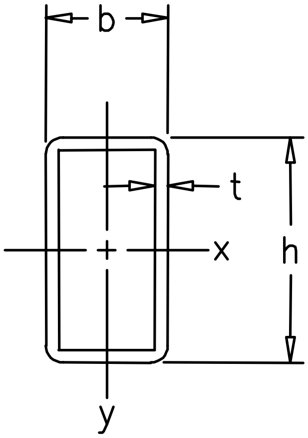
Square Tubes

Width or Depth (h)	Thickness (t)	Area	Weight	X-X Axis or Y-Y Axis		
				I	S	r
in	in	in^2	lbs/ft	in^4	in^3	in
1.00	0.125	0.42	0.32	0.05	0.11	0.36
1.25	0.250	0.93	0.69	0.16	0.26	0.42
1.50	0.125	0.67	0.51	0.21	0.28	0.56
1.50	0.250	1.24	0.93	0.33	0.44	0.52
1.75	0.1250	0.80	0.60	0.35	0.40	0.66
1.75	0.250	1.48	1.11	0.57	0.67	0.62
2.00	0.125	0.92	0.69	0.53	0.53	0.76
2.00	0.250	1.73	1.30	0.89	0.89	0.72
2.11	0.200	1.48	1.11	0.91	0.86	0.78
2.50	0.250	2.24	1.68	1.90	1.52	0.92
3.00	0.250	2.74	2.05	3.47	2.31	1.13
4.00	0.250	3.73	2.80	8.75	4.37	1.53



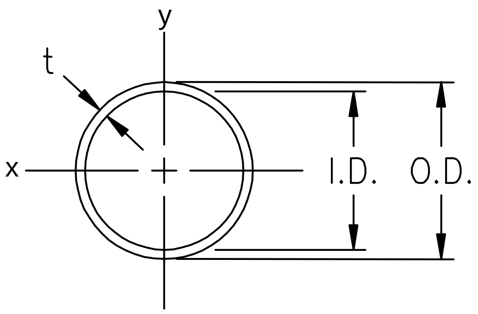
Rectangular Tubes

Depth (h)	Width (b)	Thickness (t)	Area	Weight	X - X Axis			X - X Axis		
					I	S	r	I	S	r
in	in	in	in^2	lb/ft	in^4	in^3	in	in^4	in^3	in
4.40	1.43	0.125	1.38	1.03	2.89	1.31	1.45	0.49	0.68	0.59
4.74	1.72	0.125	1.57	1.17	4.20	1.77	1.64	0.79	0.91	0.71
5.00	0.75	0.125	1.37	1.03	3.15	1.26	1.52	0.11	0.31	0.28
5.07	2.00	0.132	1.80	1.35	5.65	2.23	1.77	1.23	1.23	0.83
6.00	2.00	0.125	2.39	1.79	9.34	3.11	1.98	1.61	1.61	0.82
6.00	4.00	0.250	4.62	3.46	22.31	7.44	2.20	11.84	5.92	1.61
7.00	4.00	0.250	5.20	3.90	33.61	9.61	2.54	13.91	6.95	1.64
7.00	4.00	0.375	7.63	5.73	47.58	13.60	2.50	19.25	9.63	1.59
7.30	1.27	0.190	3.02	2.26	15.37	4.21	2.26	0.80	1.26	0.51
7.75	1.75	0.188	3.38	2.53	20.86	5.38	2.49	1.82	2.08	0.73
8.00	1.00	0.125	2.45	1.84	14.14	3.54	2.40	0.40	0.81	0.41
8.00	1.00	0.250	4.39	3.30	24.62	6.16	2.37	0.58	1.16	0.36
8.00	4.00	0.250	5.70	4.27	46.80	11.70	2.87	15.67	7.83	1.66
8.00	4.00	0.375	8.38	6.29	66.63	16.66	2.82	21.73	10.86	1.61



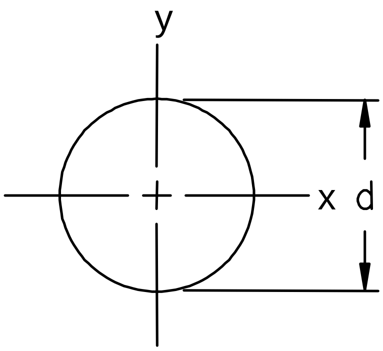
Round Tubes

Outside Diameter (OD)	Inside Diameter (ID)	Thickness (t)	Area	Weight	X-X Axis or Y-Y Axis		
					I	S	r
in	in	in	in^2	lbs/ft	in^4	in^3	in
0.75	0.56	0.0937	0.19	0.14	0.01	0.03	0.23
1.00	0.75	0.125	0.34	0.26	0.03	0.07	0.31
1.25	0.88	0.1875	0.63	0.47	0.09	0.15	0.38
1.25	1.00	0.125	0.44	0.33	0.07	0.11	0.40
1.25	1.00	0.0937	0.34	0.26	0.06	0.09	0.41
1.50	1.00	0.250	0.98	0.74	0.20	0.27	0.45
1.50	1.25	0.125	0.54	0.41	0.13	0.17	0.49
1.75	1.25	0.250	1.18	0.88	0.34	0.39	0.54
1.75	1.50	0.125	0.64	0.48	0.21	0.24	0.58
2.00	1.50	0.250	1.37	1.03	0.54	0.54	0.63
2.00	1.75	0.125	0.73	0.63	0.33	0.33	0.66
2.50	2.00	0.250	1.77	1.33	1.13	0.91	0.80
2.50	2.25	0.125	0.93	0.70	0.66	0.53	0.84
3.00	2.50	0.250	2.16	1.62	2.06	1.37	0.98
3.50	2.94	0.280	2.84	2.13	3.71	2.12	1.14



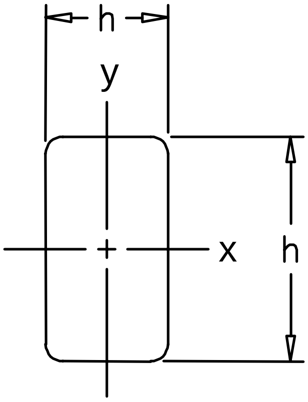
Solid Round Tubes

Diameter (d)	Area	Weight	X-X Axis or Y-Y Axis		
			I	S	r
in	in^2	lbs/ft	in^4	in^3	in
0.125	0.010	0.008	<0.001	<0.001	0.031
0.1875	0.028	0.021	<0.001	0.0010	0.047
0.250	0.049	0.037	<0.001	0.0020	0.063
0.3125	0.077	0.058	<0.001	0.003	0.078
0.375	0.110	0.083	0.001	0.005	0.094
0.500	0.196	0.147	0.003	0.012	0.125
0.625	0.307	0.230	0.008	0.024	0.156
0.750	0.442	0.331	0.016	0.041	0.188
0.8125	0.519	0.389	0.021	0.053	0.203
0.875	0.601	0.451	0.029	0.066	0.219
1.000	0.785	0.589	0.049	0.098	0.250
1.250	1.227	0.920	0.120	0.192	0.313
1.500	1.767	1.325	0.249	0.331	0.375
2.000	3.142	2.356	0.785	0.785	0.500
2.500	4.909	3.682	1.918	1.534	0.625



Solid Bars

Depth (h)	Width (b)	Area	Weight	X-X Axis			Y-Y Axis		
				I	S	r	I	S	r
in	in	in^2	lbs/ft	in^4	in^3	in	in^4	in^3	in
0.25	0.25	0.06	0.05	<0.001	0.002	0.07	<0.001	0.002	0.07
1.00	0.50	0.50	0.37	0.04	0.08	0.29	0.01	0.04	0.14
1.25	0.75	0.93	0.70	0.12	0.19	0.36	0.04	0.12	0.22
1.00	1.00	0.99	0.74	0.08	0.16	0.29	0.08	0.16	0.29
1.23	1.23	1.51	1.13	0.19	0.31	0.35	0.19	0.31	0.35
1.50	1.50	2.25	1.69	0.42	1.36	0.43	0.42	1.36	0.43
1.46	1.46	2.12	1.59	0.37	0.51	0.42	0.37	0.51	0.42
2.00	2.00	3.98	2.98	1.31	1.31	0.57	1.31	1.31	0.57



SECTION 6

SAFETY FACTORS USED IN DESIGNING WITH FIBERGLASS SHAPES

Safety Factors

Safety factors are defined as the ratio of the ultimate stress to the maximum allowable stress.

Safety Factor (S.F.) = Ultimate Stress (U.S.)/ Allowable Stress (A.S.)
Therefore, A.S. = U.S./S.F.

Safety factors compensate for:

- allowable tolerances of the part
- uncertainty of the anticipated loading (magnitude, type or placement)
- assumptions in methods of analysis
- fabrication tolerances (squareness of cuts, normal tolerances, etc.)
- fatigue and creep considerations

The safety factors used in the various design equations were chosen to prevent "first deformation" of the part. First deformation is defined as the first visible deformation including local flange or web buckling, twisting, crushing, etc. The recommended safety factors used for design are:

LOADING TYPE	RECOMMENDED SAFETY FACTORS
Flexural members, beams	2.5
Compression members, columns	3.0
Tension members	2.5
Beam shear	3.0
Connections	4.0

MODULII	RECOMMENDED SAFETY FACTORS
Modulus of Elasticity	1.0
Shear Modulus	1.0

NOTES:

1. The safety factors given above are for **static load conditions only**. Safety factors for impact loads and dynamic loads are typically **two times** the static load safety factor. Long-term service loads, which result in creep deformations, will require even higher safety factors to insure satisfactory performance. For creep effects, see *Structural Plastics Design Manual*, American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017, Vols. 1 and 2, September 1981.

These recommended safety factors are not the only safety factors that may be used in design. The designer may choose to adjust the safety factors based on particular applications and considerations including margin of safety, costs, confidence of loads or materials, etc.

Ultimately, the final selection of a safety factor is the designer's responsibility.

SECTION 7

EFFECTS OF TEMPERATURE ON FIBERGLASS STRUCTURAL SHAPES

Effects of Temperature on Allowable Stresses and Modulii

Pultruded structural shapes experience some loss of structural stiffness from continuous exposure to elevated temperatures, and therefore, it is strongly recommended that this effect be considered when performing a structural design with fiberglass pultrusions. Table 7-1 provides the retention of ultimate stress for the Pultex® products resulting from exposure to elevated temperatures while Table 7-2 provide the retention of modulus of elasticity and to shear modulus:

Table 7-1 Temperature Stress Reduction Factors (T_f) at Varying Temperatures

Temperature	**Pultex® 1500/1525 Series Strength Retention (T_s)**	**Pultex® 1625 Series Strength Retention (T_s)**
80° F	100% (1.0)	100% (1.0)
100° F	85% (0.85)	90% (.9)
125° F	70% (0.7)	85% (0.85)
150°F	50% (0.5)	80% (0.8)
175° F	Not Recommended	75% (0.75)
200° F	Not Recommended	50% (0.5)

Table 7-2 Temperature Modulus Reduction Factors (T_m) for Modulus of Elasticity and Shear Modulus at Varying Temperatures

Temperature	**Pultex® 1500/1525 Series Modulus Retention (T_m)**	**Pultex® 1625 Series Modulus Retention (T_m)**
100° F	100% (1.0)	100% (1.0)
125° F	90% (0.9)	95% (0.95)
150° F	85% (0.85)	90% (0.9)
175° F	Not Recommended	88% (0.88)
200° F	Not Recommended	85% (0.85)

When calculating the Critical Local Buckling Stress or the Critical Global Buckling Stress when designing a beam or a column, use the full, unaffected values of the modulii, then apply the Temperature Stress Reduction Factor T_s to the calculated Critical Buckling Stress. For example, if the operating temperature is 125 degrees-F, and σ_x^{cr} is determined to be 6,500 psi using the full unaffected modulii on Series 1525 material, the actual σ_x^{cr}' would be 0.7 x σ_x^{cr}, or 4,550 psi**. Do not use the Temperature Modulus Reduction Factor T_m to calculate stress-related values – this would be a double-dip.** The only time the Temperature Modulus Reduction Factor T_m is used is for the calculation of deflection— T_m is applied to both the modulus of elasticity E_x and to the shear modulus G_{xy}.

In applications requiring greater strength retention, it is possible to select a higher performance resin system specifically designed for elevated temperatures. An example is Pultex® 1625 Series Vinyl Ester, which has better strength retention at elevated temperatures. Additional resin systems can be supplied to achieve even higher temperature ratings, if required.

SECTION 8

CORROSION GUIDE FOR THE PROPER SELECTION OF RESINS

Chemical Compatibility Guide

Acetic Acid – Benzene

		Pultex® Structural Profiles	
		1500/1525 Srs.	1625 Srs.
Chemical Environment	Concentration	Temp. Max	Temp. Max
	Percentage	F/C	F/C
ACETIC ACID	0-50	NR	100/38
ACETIC ANYDRIDE	--	NR	NR
ACETONE	100	NR	NR
ACRYLONITRILE	100	NR	NR
ALCOHOL, BUTYL	--	NR	NR
ALCOHOL, ETHYL	10	NR	150/65
ALCOHOL, ETHYL	100	NR	NR
ALCOHOL, ISOPROPYL	10	NR	150/65
ALCOHOL, ISOPROPYL	100	NR	NR
ALCOHOL, METHYL	10	NR	150/65
ALCOHOL, METHYL	100	NR	NR
ALCOHOL, METHYL ISOBUTYL	--	NR	150/65
ALCOHOL, SECONDARY BUTYL	--	NR	150/65
ALUM	100	150/65	150/65
ALUM POTASSIUM	--	100/38	100/38
ALUMINUM CHLORIDE	10	NR	150/65
ALUMINUM HYDROXIDE	5 – 20	NR	150/65
ALUMINUM POTASSIUM SULFATE	100	150/65	150/65
AMMONIA, AQUEOUS	0 - 10	NR	100/38
AMMONIA, GAS	--	NR	100/38
AMMONIUM ACETATE	25	NR	100/38
AMMONIUM BICARBONATE	15	NR	120/49
AMMONIUM BISULFITE	--	NR	120/49
AMMONIUM CARBONATE	25	NR	100/38
AMMONIUM CITRATE	10	NR	120/49
AMMONIUM FLUORIDE	--	NR	120/49
AMMONIUM HYDROXIDE	5	NR	120/49
AMMONIUM HYDROXIDE	10	NR	120/49
AMMONIUM HYDROXIDE	20	NR	120/49
AMMONIUM NITRATE	15	120/49	150/65
AMMONIUM PERSULFATE	5 - 20	NR	150/65
AMMONIUM PHOSPHATE	--	NR	120/49
AMMONIUM SULFATE	15	120/49	150/65
ARESENIOUS ACID	--	NR	160/71
BARIUM ACETATE	100	NR	NR
BARIUM CARBONATE	100	NR	NR
BARIUM CHLORIDE	100	NR	100/38
BARIUM HYDROXIDE	10	NR	NR
BARIUM SULFATE	100	NR	100/38
BARIUM SULFIDE	10	NR	NR
BEER	--	NR	120/49
BENZENE	100	NR	NR

Chemical Compatibility Guide

Benzene in Kerosene – Chromic Acid

		Pultex® Structural Profiles	
		1500/1525 Srs.	1625 Srs.
Chemical Environment	Concentration	Temp. Max	Temp. Max
	Percentage	F/C	F/C
BENZENE IN KEROSENE	5	NR	160/71
BENZENE SULFURIC ACID	5 - 20	100/38	150/65
BENZOIC ACID	5 - 20	NR	100/38
O-BENZOYL BENZOIC ACID	--	NR	160/71
BENZYL ALCOHOL	100	NR	NR
BENZYL CHLORIDE	100	NR	NR
BORAX	5 - 20	100/38	150/65
BRASS PLATING SOLUTION	--	NR	160/71
BUTYL ACETATE	--	NR	NR
BUTYRIC ACID	5 - 30	NR	120/49
BUTYLENE GLYCOL	100	150/65	150/65
CADMIUM CHLORIDE	--	NR	160/71
CADMIUM CYANIDE PLATING	--	NR	120/49
CALCIUM BISULFITE	--	150/65	160/71
CALCIUM CARBONATE	10	NR	100/38
CALCIUM CHLORIDE	10	NR	100/38
CALCIUM CHLORATE	10	NR	100/38
CALCIUM HYDROXIDE	5 - 20	NR	100/38
CALCIUM HYPOCHLORITE	10	NR	120/49
CALCIUM NITRATE	5	120/49	150/65
CALCIUM SULFATE	10	120/49	150/65
CALCIUM SULFITE	--	150/65	160/71
CAPRYLIC ACID	--	NR	160/71
CARBON DIOXIDE	--	150/65	160/71
CARBON DISULFIDE	100	NR	NR
CARBON MONOXIDE GAS	--	100/38	150/65
CARBON TETRACHLORIDE	100	NR	100/38
CARBONIC ACID	10	100/38	120/49
CARBON METHYL CELLULOSE	--	NR	120/49
CASTOR OIL	100	150/65	150/65
CHLORINATED WAX	10	NR	120/49
CHLORINE DIOXIDE/AIR	--	NR	160/71
CHLORINE DIOXIDE, WET GAS	--	NR	160/71
CHLORINE DRY GAS	--	NR	160/71
CHLORINE WET GAS	--	NR	160/71
CHLORINE LIQUID	--	NR	NR
CHLORINE WATER	10	NR	120/49
CHLOROACETIC ACID	0 - 50	NR	100/38
CHLOROBENZENE	--	NR	NR
CHLOROFORM	100	NR	NR
CHLOROSULFONIC ACID	--	NR	NR
CHROMIC ACID	5	NR	100/38

Chemical Compatibility Guide

Chromic Acid – Ferric Chloride

Chemical Environment	Concentration	Pultex® Structural Profiles 1500/1525 Srs. Temp. Max	1625 Srs. Temp. Max
	Percentage	F/C	F/C
CHROMIC ACID	20	NR	120/49
CHROMIC ACID	30	NR	NR
CHROMIUM SULFATE	--	150/65	160/71
CITRIC ACID	5 - 30	120/49	150/65
COCONUT OIL	--	NR	160/71
COPPER CHLORIDE	5	150/65	180/82
COPPER CYANIDE	5	150/65	180/82
COPPER FLUORIDE	--	NR	160/71
COPPER NITRATE	--	150/65	NR
COPPER BRITE PLATING	--	NR	120/49
COPPER PLATING SOLUTION	--	NR	160/71
COPPER MATTE DIPPING BATH	--	NR	160/71
COPPER PICKLING BATH	--	NR	160/71
COPPER SULFATE	--	150/65	160/71
CORN OIL	100	NR	100/38
CORN STARCH- SLURRY	--	NR	160/71
CORN SUGAR	100	NR	150/65
COTTONSEED OIL	--	NR	160/71
CRUDE OIL	100	NR	150/65
CYCLOHEXENE	--	NR	120/49
CYCLOHEXENE VAPOR	--	NR	NR
DEIONIZED WATER	--	150/65	150/65
DETERGENTS SULFONATED	--	NR	160/71
DI-AMMONIUM PHOSPHATE	--	NR	160/71
DIBROMOPHENOL	--	NR	NR
DIBUTYL ETHER	--	NR	120/49
DICHLORO BENZENE	--	NR	NR
DICHLOROETHYLENE	--	NR	NR
DIETHYLENE GLYCOL	--	NR	160/71
DIETHYL ETHER	100	NR	NR
DIMENTHYL PHTHALATE	--	NR	160/71
DIOCTYL PHTHALATE	--	NR	160/71
DIPROPYLENE GLYCOL	100	NR	120/49
DODECYL ALCOHOL	--	NR	160/71
ESTER, FATTY ACIDS	--	150/65	160/71
ETHYL ACETATE	100	NR	NR
ETHYL BENZENE	--	NR	NR
ETHYL ETHER	--	NR	NR
ETHYLENE GLYCOL	100	100/38	150/65
ETHYLENE DICHLORIDE	--	NR	NR
FATY ACIDS	10	120/49	150/65
FERRIC CHLORIDE	10	120/49	150/65

Chemical Compatibility Guide

Ferric Nitrate – Hydrogen Fluoride Vapors

		Pultex® Structural Profiles	
		1500/1525 Srs.	1625 Srs.
Chemical Environment	Concentration	Temp. Max	Temp. Max
	Percentage	F/C	F/C
FERRIC NITRATE	10	120/49	150/65
FERRIC SULFATE	10	120/49	150/65
FERROUS CHLORIDE	--	150/65	160/71
FERROUS NITRATE	--	150/65	160/71
FERROUS SULFATE	--	150/65	160/71
8-8-8 FERTILIZER	--	NR	120/49
FLUOBORIC ACID	--	NR	120/49
FLUSOILICIC ACID	--	NR	160/71
FORMALDEHYDE	5 - 30	NR	100/38
FORMIC ACID	25	NR	100/38
FUEL GAS	--	NR	160/71
FUEL OIL	100	NR	100/38
GAS NATURAL	--	NR	160/71
GASOLINE AUTO	--	NR	160/71
GASOLINE AVIATION	--	NR	160/71
GASOLINE ETHYL	--	NR	160/71
GASOLINE SOUR	--	NR	160/71
GLUCONIC ACID	--	NR	160/71
GLUCOSE	100	150/65	180/82
GLYCERIN	100	150/65	180/82
GLYCOL ETHYLENE	--	150/65	160/71
GLYCOL PROPYLENE	--	150/65	160/71
GLYCOLIC ACID	--	NR	160/71
GOLD PLATING SOLUTION	--	NR	160/71
HEPTANE	100	100/38	150/65
HEXANE	100	100/38	150/65
HEXALENE GLYCOL	--	150/65	160/71
HYDRAULIC FLUID	100	NR	120/49
HYDROBROMIC ACID	5 - 50	100/38	150/65
HYDROCHLORIC ACID	10 - 30	NR	120/49
HYDROCYANIC ACID	--	150/65	160/71
HYDROFLUORIC ACID	--	NR	NR
HYDROFLOUSILIC ACID	10	NR	160/71
HYDROZINE	100	NR	NR
HYDROGEN BROMIDE, DRY	--	NR	NR
HYDROGEN BROMIDE, WET GAS	--	NR	160/71
HYDROGEN CHLORIDE, DRY GAS	--	NR	160/71
HYDROGEN CHLORIDE, WET GAS	--	NR	160/71
HYDROGEN PEROXIDE	--	NR	120/49
HYDROGEN SULFIDE DRY	--	NR	160/71
HYDROGEN SULFIDE AQUEOUS	--	NR	160/71
HYDROGEN FLUORIDE VAPORS	--	NR	NR

Chemical Compatibility Guide

Hydrosulfite Bleach – Myristic Acid

Chemical Environment	Concentration	Pultex® Structural Profiles 1500/1525 Srs. Temp. Max	1625 Srs. Temp. Max
	Percentage	F/C	F/C
HYDROSULFITE BLEACH	--	NR	120/49
HYPOCHLORUS ACID	--	NR	160/71
IRON PLATING SOLUTION	--	NR	160/71
IRON & STEEL CLEANING BATH	--	NR	160/71
ISOPROPYL AMINE	--	NR	100/38
ISOPROPYL PAMITATE	--	150/65	160/71
JET FUEL	--	NR	160/71
KEROSENE	--	NR	160/71
LACTIC ACID	--	NR	160/71
LAUROYL CHLORIDE	--	NR	160/71
LAURIC ACID	--	NR	160/71
LEAD ACETATE	100	NR	120/49
LEAD CHLORIDE	10	120/49	150/65
LEAD NITRATE	10	NR	100/38
LEAD PLATING SOLUTION	--	NR	160/71
LEVULINIC ACID	--	NR	160/71
LINSEED OIL	--	150/65	160/71
LITHIUM BROMIDE	--	150/65	160/71
LITHIUM CHLORIDE	25	NR	120/49
LITHIUM SULFATE	--	150/65	160/71
LITHIUM HYDROXIDE	10	NR	120/49
MAGNESIUM BISUFITE	--	NR	160/71
MAGNESIUM CARBONATE	10	100/38	150/65
MAGNESIUM CHLORIDE	10	100/38	150/65
MAGNESIUM HYDROXIDE	10	NR	120/49
MAGNESIUM NITRATE	10	NR	120/49
MAGNESIUM SULFATE	10	100/38	120/49
MALEIC ACID	100	150/65	150/65
MERCURIC CHLORIDE	10	120/49	150/65
MERCUROUS CHLORIDE	10	120/49	150/65
METHANOL	--	NR	160/71
METHYLENE CHLORIDE	--	NR	NR
METHYL ETHYL KETONE @120F	--	NR	NR
METHYL ISOBUTYL CARBITOL	--	NR	NR
METHYL ISOBUTYL KETONE	--	NR	NR
METHYL STYRENE	--	NR	NR
MINERAL OIL	100	150/65	150/65
MOLYBDENUM DISULFIDE	--	NR	160/71
MONOCHLORIC ACETIC ACID	--	NR	NR
MONOETHANOLAMINE	--	NR	NR
MOTOR OIL	100	150/65	150/65
MYRISTIC ACID	--	--	160/71

Chemical Compatibility Guide

Naptha – Potassium Dichromate

		Pultex® Structural Profiles	
Chemical Environment	Concentration	1500/1525 Srs. Temp. Max	1625 Srs. Temp. Max
	Percentage	F/C	F/C
NAPTHA	100	150/65	150/65
NICKEL CHLORIDE	10	120/49	150/65
NICKEL NITRATE	10	120/49	150/65
NICKEL PLATING: .4% Boric Acid	--	NR	160/71
NICKEL PLATING: 11%Nickel Sulfate, 2% Nickle Chloride, 1% Boric Acid	--	NR	160/71
NICKEL PLATING: 44% Nickel Sulfate, 2% Ammonium Chloride, 4% Boric Acid	--	NR	160/71
NICKEL SULFATE	10	120/49	150/65
NITRIC ACID	5 - 30	NR	100/38
NITRIC ACID FUMES	--	NR	NR
NITROBENZENE	--	NR	NR
OCTONOIC ACID	--	NR	160/71
OIL, SOUR CRUDE	100	NR	120/49
OIL SWEET CRUDE	100	NR	120/49
OLEIC ACID	100	120/49	150/65
OLEUM (FUMING SULFURIC)	--	NR	NR
OILVE OIL	--	150/65	160/71
OXALIC ACID	--	150/65	160/71
PEROXIDE BLEACH: 2% Sodium Peroxide-96% .025 Epsom Salts, 5% Sodium Silicate 42° Be, 1.4% Sulfuric Acid 66°Be	--	150/65	160/71
PHENOL	10	NR	NR
PHENOL SULFONIC ACID	--	NR	NR
PHOSPHORIC ACID	5 - 50	100/38	150/65
PHOSPHORIC ACID FUMES	--	150/65	160/71
PHOSPHORUS			
PENTOXIDE	--	150/65	160/71
PHOSPHOROUS TRICHLORIDE	100	NR	NR
PHTHALIC ACID	100	NR	120/49
PICKLING ACIDS: Sulfuric and Hydrochloric	--	150/65	160/71
PICRIC ACID ALCOHOLIC	--	150/65	160/71
POLYVINYL ACETATE LATEX	--	NR	160/71
POLYVINYL ALCOHOL	100	NR	100/38
POLYVINYL CHLORIDE LATEX: With 35(Parts Drop)	--	NR	120/49
POTASSIUM ALUMINUM SULFATE	10	120/49	150/65
POTASSIUM BICARBONATE	--	NR	120/49
POTASSIUM BROMIDE	10	NR	120/49
POTASSIUM CARBONATE	10	NR	120/49
POTASSIUM CHLORIDE	100	NR	120/49
POTASSIUM DICHROMATE	100	NR	120/49

Chemical Compatibility Guide

Potassium Ferricyanide – Sodium Hexametaphosphates

Chemical Environment	Concentration	Pultex® Structural Profiles 1500/1525 Srs. Temp. Max	1625 Srs. Temp. Max
	Percentage	F/C	F/C
POTASSIUM FERRICYANIDE	--	150/65	160/71
POTASSIUM HYDROXIDE	10	NR	150/65
POTASSIUM NITRATE	10	120/49	150/65
POTASSIUM PERMANGANTE	100	100/38	150/65
POTASSIUM PERSULFATE	--	NR	160/71
POTASSIUM SULFATE	10	120/49	150/65
PROPIONIC ACID	1 - 50	NR	120/49
PROPIONIC ACID	50 - 100	NR	NR
PROPYLENE GLYCOL	100	150/65	150/65
PULP PAPER MILL EFFLUENT	--	NR	160/71
PYRIDINE	--	NR	NR
SALICYLIC ACID	--	NR	140/60
SEA WATER	--	150/65	150/65
SEWAGE TREATMENT	--	NR	100/38
SEBACIC ACID	--	NR	160/71
SELENIOUS ACID	--	NR	160/71
SILVER NITRATE	--	150/65	160/71
SILVER PLATING SOLUTION: 4% Silver Cyanide, 7% Potassium, 5% Sodium Cyanide, 2% Potassium Carbonate	--	NR	160/71
SOAPS	--	NR	160/71
SODIUM ACETATE	--	NR	160/71
SODIUM BENZOATE	--	NR	160/71
SODIUM BICARBONATE	--	150/65	160/71
SODIUM BIFLUORIDE	--	NR	160/71
SODIUM BISULFATE	--	150/65	160/71
SODIUM BISULFITE	--	150/65	160/71
SODIUM BROMATE	--	150/65	140/60
SODIUM BROMIDE	--	150/65	160/71
SODIUM CARBONATE	0 - 25	NR	160/71
SODIUM CHLORATE	--	NR	160/71
SODIUM CHLORIDE	--	150/65	160/71
SODIUM CHLORITE	25	NR	160/71
SODIUM CHROMATE	--	150/65	160/71
SODIUM CYANIDE	--	NR	160/71
SODIUM DICHROMATE	--	150/65	160/71
SODIUM DI-PHOSPHATE	--	150/65	160/71
SODIUM FERRICYANIDE	--	150/65	160/71
SODIUM FLUORIDE	--	NR	120/49
SODIUM FLOURO SILICATE	--	NR	120/49
SODIUM HEXAMETAPHOSPHATES	--	NR	100/38

Chemical Compatibility Guide

Sodium Hydroxide – Tin Plating Solution

		Pultex® Structural Profiles	
Chemical Environment	Concentration Percentage	1500/1525 Srs. Temp. Max F/C	1625 Srs. Temp. Max F/C
SODIUM HYDROXIDE	0 – 5	NR	150/65
SODIUM HYDROXIDE	5 - 25	NR	150/65
SODIUM HYDROXIDE	50	NR	150/65
SODIUM HYDROSULFATE	--	NR	160/71
SODIUM HYPOCHLORITE	10	NR	120/49
SODIUM LAURYL SULFATE	--	150/65	160/71
SODIUM MONO-PHOSPHATE	--	150/65	160/71
SODIUM NITRATE	--	150/65	160/71
SODIUM SILICATE	--	NR	120/49
SODIUM SULFATE	--	150/65	160/71
SODIUM SULFIDE	--	NR	120/49
SODIUM SULFITE	--	NR	120/49
SODIUM TETRA BORATE	--	150/65	160/71
SODIUM THIOCAYNATE	--	NR	160/71
SODIUM THIOSULFATE	--	NR	160/71
SODIUM POLYOPHOSPHATE	--	NR	160/71
SODIUM XYLENE SULFONATE	--	NR	160/71
SODIUM SOLUTIONS	--	NR	160/71
SODIUM CRUDE OIL	--	150/65	160/71
SOVA OIL	--	150/65	160/71
STANNIC CHLORIDE	--	150/65	160/71
STANNOUS CHLORIDE	--	150/65	160/71
STEARIC ACID	--	150/65	160/71
STYRENE	--	NR	NR
SUGAR, BEET AND CANE LIQUOR	--	NR	160/71
SUGAR, SUCROSE	--	150/65	160/71
SULFAMIC ACID	--	NR	160/71
SULFANILIC ACID	--	NR	160/71
SULFATED DETERGENTS	--	NR	160/71
SULFUR DIOXIDE, WET OR DRY	--	NR	160/71
SULFER, TRIOXIDE/AIR	--	NR	160/71
SULFURIC ACID	0 - 30	150/65	160/71
SULFURIC ACID	30 - 50	NR	160/71
SULFURIC ACID	50 - 70	NR	120/49
SULFUROUS ACID	10	NR	100/38
SUPERPHOSPHORIC ACID: 76% P205	--	NR	160/71
TALL OIL	--	NR	150/65
TANNIC ACID	--	NR	120/49
TARTARIC ACID	--	150/65	160/71
THIONYL CHLORIDE	--	NR	NR
TIN PLATING SOLUTION: 18% Stannous Fluroborate, 7% Tin, 9% Flouroboric acid, 2% Boric Acid	--	NR	160/71

Chemical Compatibility Guide

Toluene – Zinc Sulfate

Chemical Environment	Concentration	Pultex® Structural Profiles 1500/1525 Srs. Temp. Max	1625 Srs. Temp. Max
	Percentage	F/C	F/C
TOLUENE	--	NR	NR
TOLUENE SOLFONIC ACID	--	NR	160/71
TRANSFORMER OILS: Mineral Oil Types, Chloro-phenyl Types	--	NR	NR
TRICHLOR ACETIC ACID	50	NR	160/71
TRICHLORETHYLENE	--	NR	NR
TRICHLOROPENOL	--	NR	NR
TRICRESYL PHOSPHATE +A618	--	NR	120/49
TRIDECYLBENZENE SULFONATE	--	NR	160/71
TRISODIUM PHOSPHATE	--	NR	160/71
TURPENTINE	--	NR	100/38
UREA	--	NR	140/60
VEGETABLE OILS	--	150/65	160/71
VINEGAR	--	150/65	160/71
VINYL ACETATE	--	NR	NR
WATER:			
DEIONIZED	--	150/65	160/71
DEMINERALIZED	--	150/65	160/71
DISTILLED	--	150/65	160/71
FRESH	--	150/65	160/71
SALT	--	150/65	160/71
SEA	--	150/65	160/71
WHITE LIQUOR (Pulp Mill)	--	NR	160/71
XYLENE	--	NR	NR
ZINC CHLORATE	--	150/65	160/71
ZINC NITRATE	--	150/65	160/71
ZINC PLATING SOLUTION: 9% Zinc Cyanide, 4% Sodium Cyanide, 9% Sodium Hydroxide	--	NR	120/49
ZINC PLATING SOLUTION: 49% Zinc Fluoroborate, 5% Ammonium Chloride, 6% Ammonium Fluoroborate	--	NR	160/71
ZINC SULFATE	--	150/65	160/71

SECTION 9

DESIGNING FLEXURAL MEMBERS (BEAMS)

This section addresses the following three major topics:

- Local Buckling
- Global Buckling
- Deflection

When designing fiberglass beams, the designer must check all three. Fiber-reinforced composite beams exhibit compressive, flexural, and shear stresses under various load conditions. The dominating failure mode for long span flexural members is typically local buckling of the compressive flange, while short spans are dominated by in-plane shear failures. Because of fiberglass' relatively low full-section modulus of elasticity (as compared to steel), many fiberglass beams are governed by deflection limitations, not by stress. As such, the basic design process should be as follows:

1. Size the beam to meet the deflection requirements,
2. Determine the limiting critical local buckling stress, divide it by the appropriate safety factor, and compare to the actual bending stress,
3. Determine the lateral-torsional (global buckling) buckling critical moment, divide it by the appropriate safety factor, converting it to a bending stress, and compare to the actual bending stress

Be sure to account for the effects of temperature.

Creative Pultrusions, Inc. is credited with the technical content of this section.

Symbols Used for Flexural Design Equations

Δ = Deflection (in)
ζ = Coefficient of restraint of the compression plates
σ_c = Compressive stress (psi)
σ_{cr}^{local} = Critical local buckling stress in (psi)
σ_{cr}^{global} = Critical global buckling stress in (psi)
ν_{xy} = Poisson's ratio (longitudinal or lengthwise)
ν_{yx} = Poisson's ratio (transverse or cross-wise)
A_w = Shear area of profile (Table 2) (in^2)
A' = kA_w, Shear coefficient x shear area of profile (in^2)
b = Half the width of the compression flange for I/W sections (in), $b = b_f/2$ (in)
b = The width of the compression flange for box sections, $b = b_f$ (in)
b_f = Width of the compression flange (in)
b_w = Height of the section (in), (i.e., beam depth)
Δ = Deflection (in)
E_x = Full-section modulus of elasticity LW (psi) (for deflection analyses)
T_m = Temperature Modulus Reduction Factor (Section 7)
T_s = Temperature Stress Reduction Factor (Section 7)
$E_{C\text{-}LW}$ = Compression modulus of elasticity LW (psi) (for local & global buckling analyses)
$E_{C\text{-}CW}$ = Compression modulus of elasticity CW (psi) (for local buckling analyses)
f = Flange
f_b = Flexural stress (psi)
f_v = Shear stress (psi)
G = Shear modulus (modulus of rigidity) (psi)
G_{xy} = Shear modulus (modulus of rigidity) (psi)
$I_{x\ or\ y}$ = Moment of Inertia about desired axis (in^4)
J = Torsion Constant (in^4)
K = Effective length coefficient
k = Shear coefficient (Table 2)
L = Length (inches)
L_u = Distance between points of lateral restraint on the compression flange of a beam (in)
M = Maximum moment (in-lbs)
M_{cr}^{global} = Critical Moment that causes lateral–torsional buckling (in-lbs)
$P_{\mathbf{cr}}^{globa\mathbf{l}}$ = Point load applied at mid-span causing global buckling on a simply-supported beam (lbs.)
D = The approximation of the term EI for non-isotropic materials ($lb\text{-}in^2$)
I_{xx} = Geometric constant used in global buckling formulas ($lb\text{-}in^4$)
p = Constant defined by the coefficient of restraint (ζ) used in local buckling formulas
q = Constant defined by the coefficient of restraint (ζ) used in local buckling formulas
r = Radius of gyration (in)
S_x = Section modulus (in^3)
t_f = Thickness of compression flange (in)
V = Shear Force (lbs.)
Wt. = Weight of profile in lbs./ft
L/D = Ratio of length of the span to the deflection
S.F. = Safety Factor

Beam Deflections - A pultruded beam will be designed for deflection, strength and buckling.

Fiber-reinforced composite beams exhibit both flexural and shear deflections. Shear deflections are most apparent when the span to depth ratios are less than 20. At short spans, the shear deflections comprise a significant portion of the actual deflections; therefore, the designer should always account for shear deflections when designing with composites. Reference Pultex® Fiber Reinforced Polymer Structural Profiles Material Properties Sheets (Section 4) for the appropriate properties of the profiles for which you are utilizing in your design.

Although coupon testing is a good quality control method, composite materials are not homogeneous and will exhibit different properties in the web and flange areas. Deflection predictions should be made with values based on full section testing. Please reference Appendix B per ASTM D198 for full section testing procedure.

The following formula was used to predict the deflections in The Allowable Uniform Load Tables for simply-supported beams subjected to a uniform load:

$$\Delta = \frac{5wL^4}{384\,E_xT_m\,I} + \frac{w\,L^2}{8A'GT_m} \qquad \text{Where } A' = kA_w\ (\text{in}^2) \qquad \text{Equation 9-1}$$

The following formula is used to calculate the deflection of a simply-supported beam with a concentrated load P applied at mid-span of span L:

$$\Delta = \frac{PL^3}{48\,E_xT_m\,I} + \frac{PL}{4A'GT_m} \qquad \text{Where } A' = kA_w\ (\text{in}^2) \qquad \text{Equation 9-2}$$

Refer to the back of the section for other loading conditions, or use standard accepted engineering practices for calculating deflections of beams subjected to other loadings.

A_w = Shear area (in^2) (Ref. Table 2)
k = Shear coefficients (Ref. Table 2)
E_x = Full-section modulus of elasticity, LW (psi)
G = G_{xy} = Modulus of rigidity (Shear Modulus) (psi)
I = Moment of inertia (in^4)
L = Length of span (in)
Δ = Deflection (in)
w = Uniform load on the beam (lbs./in)
P = Concentrated point load applied at mid-span of the beam (lbs)
T_m = Temperature Modulus Reduction Factor (Section 7)

Basic Flexural Stress Formula

Acting Longitudinal Flexural Stress $f_{bx} = M/S_x$ Equation 9-3

Acting Minor Axis Flexural Stress $f_{by} = M/S_y$ Equation 9-4

Allowable Stresses

Fiber reinforced composite beams exhibit compressive, flexural, and shear stresses under various load conditions. The dominating failure mode for long span flexural members is typically local buckling of the compressive flange or global buckling of the compression flange for laterally unsupported beams, while short spans subjected to high concentrated loads are dominated by longitudinal in-plane shear failures.

Safety Factors

Refer to Section 6, Safety Factors Used in Designing with Fiberglass Shapes. For flexural analyses, use S.F. = 2.5.

Local Buckling of the Compression Flange for Wide Flange, I-Sections, Square Tube and Rectangular Tube Sections

The local compression buckling strength of pultruded wide flange, I-Sections, square tubes and rectangular tubes can be determined by utilizing the following equations. The local bucking equations were derived from University research. (Reference Step by Step Design Equations for Fiber-reinforced Plastic Beams for Transportation Structures, by Davalos, Barbero and Qiao)

$$\sigma_{cr}^{local} = \frac{\pi^2}{12}\left(\frac{t_f}{b}\right)^2 \left[\sqrt{q}\left(2\sqrt{\left(E_{C-LW}\right)_f \left(E_{C-CW}\right)_f}\right) + p\left(\left(E_{C-CW}\right)_f \left(\nu_{xy}\right)_f + 2\left(G_{xy}\right)_f\right)\right]Ts$$

Equation 9-5

$$F_b^{local} = \sigma_{cr}^{local}/S.F.$$

Where, σ_{cr}^{local} is the critical stress causing local buckling, and p and q are constants that are defined by the coefficient of restraint (ζ) at the junction of the plates:

I/W sections:

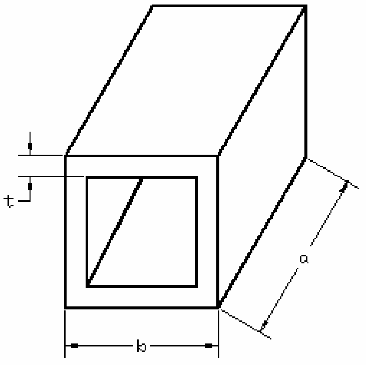
$$p = 0.3 + \left(\frac{0.004}{\zeta - 0.5}\right); q = 0.025 + \left(\frac{0.065}{\zeta + 0.4}\right); \zeta = \frac{2b_w\left(E_y\right)_f}{b_f\left(E_y\right)_w}; b = \frac{b_f}{2}$$

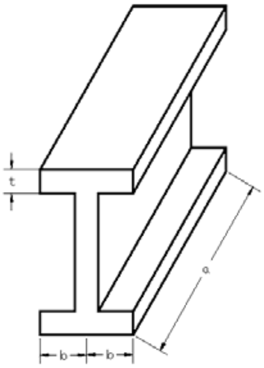
Equation 9-6a, 9-6b, & 9-6c

Box sections:

$$p = 2.0 + \left(\frac{0.002}{\zeta - 1.3}\right); q = 1.0 + \left(\frac{0.08}{\zeta + 0.2}\right); \zeta = \frac{b_w\left(E_y\right)_f}{b_f\left(E_y\right)_w}; b = b_f$$

Equation 9-7a, 9-7b, & 9-7c





σ_{cr}^{local} = Critical local buckling stress in (psi)
b = Half the width of the compression flange for I/W sections (in)
b = The width of the compression flange for box sections, $b=b_f$ (in)
b_f = Width of the compression flange (in)
b_w = Height of the section (in)
$E_{C\text{-}LW}$ = Compression modulus of elasticity for web or flange, LW (psi)
$E_{C\text{-}CW}$ = Compression modulus of elasticity for web or flange, CW (psi)
f = Denotes flange
G_{xy} = Modulus of rigidity (Shear Modulus) (psi) (also G)
p = Constant defined by the coefficient of restraint (ζ)
q = Constant defined by the coefficient of restraint (ζ)
t_f = Thickness of the compression flange (in)
ζ = Coefficient of restraint of the compression plates
w = Denotes web
T_s = Effect of temperature on allowable stress

Local and Global Buckling on Fiberglass Channel Sections

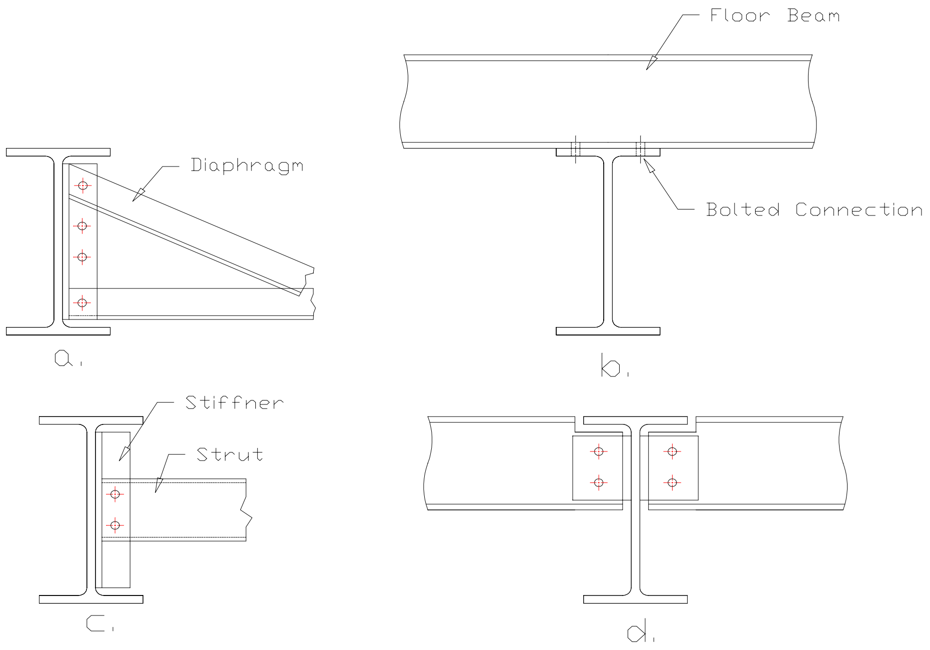
The W-beams, I-beams and Box sections mentioned above are loaded in the plane of symmetry and bend in the plane of loading. Channel sections, however, do not exhibit such behavior unless the loading is applied through the shear center. In normal construction with channel members, such a loading condition is seldom observed; therefore, the top flange of channel sections must be adequately laterally braced to resist rotation due to off shear center loading. The following minimum bracing requirements should eliminate torsional rotation due to off shear center loading:

- 24” for C4’s
- 36” for C6’s
- 48” for C8’s and larger

When checking channels for flexural stress, simply limit the flexural stress to the Flexural Strength LW (33,000 psi) divided by the flexural safety factor of 2.5. Also, when checking channels for shear, limit the shear stress to the In-plane Shear Stress LW (7,500 psi) divided by the beam shear safety factor of 3.0. Be sure to account for the effects of temperature if applicable.

Lateral-Torsional Buckling (Global Buckling)

The degree of lateral support for a structure is difficult to predict. Figures a-d on the next page represent common bracing schemes that are considered to provide adequate lateral support required to prevent global buckling of the compression flange. Note that the bracing intervals must be adequate. In the event that lateral bracing is not used, the designer must investigate lateral torsional buckling criteria, or global buckling. The following formulas provide the designer the tools required to investigate lateral-torsional buckling, also known as global buckling.



Design Equation for Lateral-Torsional Buckling (Global Buckling) For I-Sections or Wide Flange Sections

For long-span FRP beams without lateral supports and with large slenderness ratios, global buckling is prone to happen. From Davaloz, Barbero, and Qiao, 2002, and based on Vlasov's theory (Pandey et al. 1995), a simplified engineering equation for flexural-torsional buckling of an "I" or “W” fiberglass sections under a concentrated mid-span load is expressed as:

$$P_{cr}{}^{global} = \frac{17.17}{(Lu)^2}\sqrt{D\cdot JG}\sqrt{1+\frac{\pi^2}{(Lu)^2}\frac{I_{ww}}{JG}}\cdot Ts \qquad \text{Equation 9-8}$$

where,

$$\text{"}I/W\text{"}:\quad D=\frac{1}{2}(E_{C-LW})_f\, t_f\, b_w{}^2 b_f+\frac{1}{12}(E_{C-LW})_w\, t_w b_w{}^3+\frac{1}{6}(E_{C\_LW})_f\, t_f{}^3 b_f\,,\quad F=(G_{xy})_w\, t_w b_w$$

$$Box:\quad D=\frac{1}{2}(E_{C-LW})_f\, t_f\, b_w{}^2 b_f+\frac{1}{6}(E_{C-LW})_w\, t_w b_w{}^3+\frac{1}{6}(E_{C-LW})_f\, t_f{}^3 b_f\,,\quad F=2(G_{xy})_w\, t_w b_w$$

Equations 9-9 & 9-10

and where,

$$JG=\frac{2(G_{xy})_f\, t_f{}^3 b_f}{3}+\frac{(G_{xy})_w\, t_w{}^3 b_w}{3}\,; \qquad \text{Equation 9-11}$$

$$I_{ww} = \frac{(E_{C-LW})_f t_f b_w^2 b_f^3}{24} + \frac{(E_{C-LW})_f t_f^3 b_f^3}{36} + \frac{(E_{C-LW})_w t_w^3 b_w^3}{144} \qquad \text{Equation 9-12}$$

P_{cr}^{global} is the loading that causes global buckling to occur on a laterally unbraced simple beam with the load applied in the middle of span, L, with an unbraced compression flange length of L_u.

From this, we can calculate the Critical Moment, M_{cr}^{global} by using the formula for moment in a simply-supported beam with a concentrated load applied at mid-span,

$$M_{cr}^{global} = \frac{(P_{cr}^{global})L}{4}, \text{ and further,} \qquad \text{Equation 9-13}$$

$$\sigma_{cr}^{global} = \frac{(P_{cr}^{global})L}{4S_x}, \text{ and} \qquad \text{Equation 9-14}$$

$$F_b^{global} = \sigma_{cr}^{global}/S.F.$$

where σ_{cr}^{global} is the global buckling bending stress.

S_x = Section modulus (in^3)
D = The approximation of the term $E_x Ix$ for non-isotropic materials (lb-in^2**)**
J = Torsion constant (in^4)
M_{cr}^{global} = Moment which causes global buckling on a laterally unbraced beam (in-lbs.)
σ_{cr}^{global} = Bending stress which causes global buckling on a laterally unbraced beam (in-lbs.)
L_u = Unsupported length between flange points that have lateral restraint (in)
E_{C-LW} = Compressive modulus of elasticity LW (lengthwise) (psi)
G_{xy} = Shear modulus (psi)
K = Effective length coefficient (Ref. Table 1)
I_{ww} = Geometric constant of cross-section (lb-in^4)
b_w = Beam height (in)
t_w = Beam web thickness (in)
t_f = Beam flange thickness (in)
b_f = Beam flange width (in)
T_s = Coefficient reflecting the effects of temperature on allowable stress

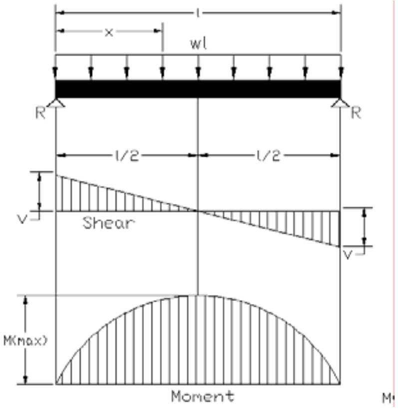
Minor Axis Bending

No test data has been published with regard to minor axis bending of a composite beam. It stands to reason, however, that if the engineer calculates the allowable bending stress F_{bx} for the major axis in accordance with the Equations 9-3 through 9-14, and if the stresses in the minor axis are not permitted to exceed those in the major axis, all would be OK. As such, the allowable bending stress about the weak axis of the beam, F_{by}, is determined by the following formula:

$F_{by} = F_{bx}$; where F_{bx} is calculated in accordance with the Equations 9-3 through 9-14.

Beam Deflection Formulas

Uniform load on simple beam



$$\text{Total Equiv. Uniform Load} = wl$$

$$\Delta\text{max. (at midpoint)} = \frac{5\,wl^4}{384\,\mathbf{EI}} + \frac{wl^2}{8\,GA'}$$

$$\Delta_x = \frac{w\mathrm{x}}{24\,\mathbf{EI}}\left(l^3 - 2lx^2 + x^3\right)$$

$$R \text{ is } V = \frac{wl}{2}$$

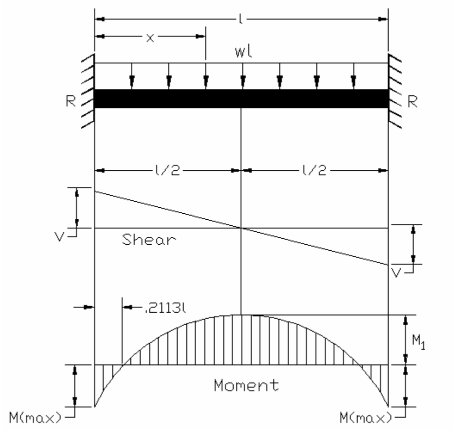
$$V_x = w\left(\frac{1}{2} - \mathrm{x}\right)$$

$$\text{M max. (at midpoint)} = \frac{wl^2}{8}$$

$$\mathrm{M}_x = \frac{w\mathrm{x}}{2}\left(l - x\right)$$

Note: Reference Table 2. Shear Areas and Shear Coefficients for Various Cross Sections A', A' = k A_w.

Uniform load on beam fixed at both ends



$$\textit{Total Equiv. Uniform Load} = \frac{2\,wl}{3}$$

$$\Delta\,\textit{max. (at midpoint)} = \frac{w\,l^4}{384\,\mathbf{EI}} + \frac{wl^2}{8\,G\,A'}$$

$$\Delta_x = \frac{w\,x^2}{24\,\mathbf{EI}\,l^2}\left(l - x\right)^2$$

$$R \text{ is } V = \frac{wl}{2}$$

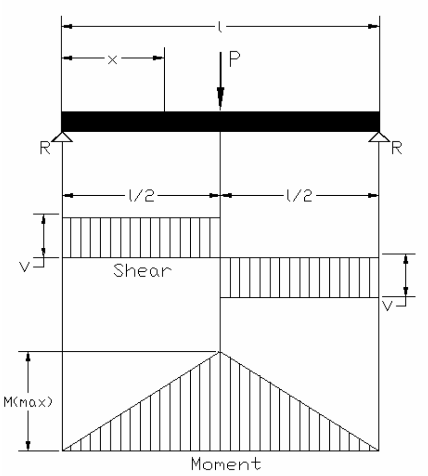
$$V_x = w\left(\frac{1}{2} - x\right)$$

$$\textit{M max. (at ends)} = \frac{w\,l^2}{12}$$

$$M_1\ \textit{(at midpoint)} = \frac{w\,l^2}{24}$$

$$M_x = \frac{w}{12}\left(6\,lx - l^2 - 6\,x^2\right)$$

Point load on simply supported beam



$$\textit{Total Equiv. Uniform Load} = 2P$$

$$\Delta\,\textit{max. (at point of load)} = \frac{P\,l^3}{48\,\mathbf{EI}} + \frac{Pl}{4\,G\,A'}$$

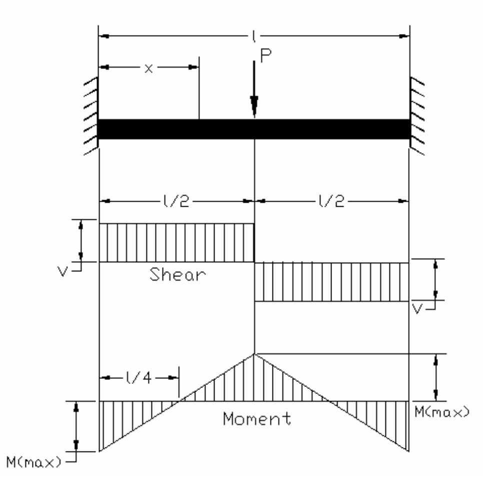
$$\Delta_x\left(\textit{when } x < \frac{1}{2}\right) = \frac{Px}{48\,\mathbf{EI}}\left(3\,l^2 - 4\,x^2\right)$$

$$V = \frac{P}{2}$$

$$\textit{M max. (at point of load)} = \frac{P\,l}{4}$$

$$M_x\left(\textit{when } x < \frac{1}{2}\right) = \frac{Px}{2}$$

Point load on beam with fixed ends



$$\text{Total Equiv. Uniform Load} = P$$

$$\Delta\,\text{max. (at midpoint)} = \frac{P\,l^3}{192\ \mathbf{EI}} + \frac{P\,l}{4\ G\,A'}$$

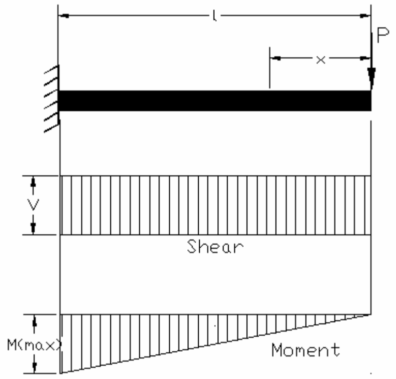
$$\Delta_x \left(\text{when}\quad x < \frac{1}{2}\right) = \frac{Px^2}{48\ \mathbf{EI}\ \ l^2}\left(3\,l - 4\,x\right)$$

$$V = \frac{P}{2}$$

$$M\ \text{max. (at center and ends)} = \frac{P\,l}{8}$$

$$M_x \left(\text{when}\quad x < \frac{1}{2}\right) = \frac{P}{8}\left(4\,x - l\right)$$

Point load on cantilever beam



$$\text{Total Equiv. Uniform Load} = 8P$$

$$\Delta\,\text{max.}\ \left(\text{at free end}\right) = \frac{P\,l^3}{3\ \mathbf{EI}} + \frac{P\,l}{G\,A'}$$

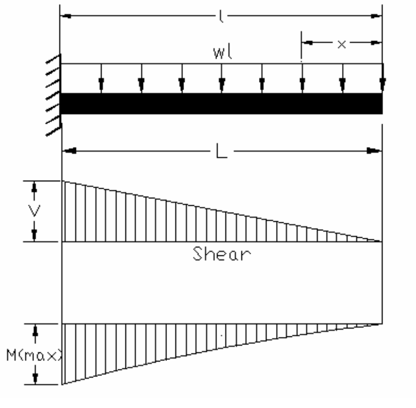
$$\Delta_x = \frac{P}{6\ \mathbf{EI}}\left(2\,l^3 - 3\,l^2 x + x^3\right)$$

$$R\ \text{is}\ V = P$$

$$M\ \text{max.}\ \left(\text{at fixed end}\right) = P\,l$$

$$M_x = Px$$

Uniform load on cantilever beam



$$\text{Total Equiv. Uniform Load} = 4\,wl$$

$$\Delta\,\text{max. (at free end)} = \frac{\mathrm{w}\,l^4}{8\ \mathbf{EI}} + \frac{wl^2}{2\,G\,A'}$$

$$\Delta_x = \frac{w}{24\ \mathbf{EI}}\left(\mathrm{x}^4 - 4\,l^3\,\mathrm{x} + 3\,l^4\right)$$

$$\text{R is V} = wl$$

$$\mathrm{V}_x = wx$$

$$\text{M max. (at fixed end)} = \frac{wl^2}{2}$$

$$\mathrm{M}_x = \frac{w\,\mathrm{x}^2}{2}$$

Two Concentrated Loads Equally Spaced on a Simply Supported Beam

$$\text{Total Equiv. Uniform Load} = \frac{8\ Pa}{l}$$

$$\Delta\,\text{max.}\ (\text{at center}) = \frac{Pa}{EI}\left(\frac{l^2}{8} - \frac{a^2}{6}\right) + \frac{Pa}{GA'}$$

$$\Delta_x\ (\text{when}\ \ x < a) = \frac{Px}{6\ \mathbf{EI}}\left(3la - 3a^2 - x^2\right)$$

$$\Delta_x\ (\text{when}\ \ x > a\ \text{and}\ < (l - a)) = \frac{Pa}{6\ \mathbf{EI}}\left(3lx - 3x^2 - a^2\right)$$

$$R\ \text{is}\ V = P$$

$$M\ \text{max. (between loads)} = Pa$$

$$M_x\ (\text{when}\ \ x < a) = Px$$

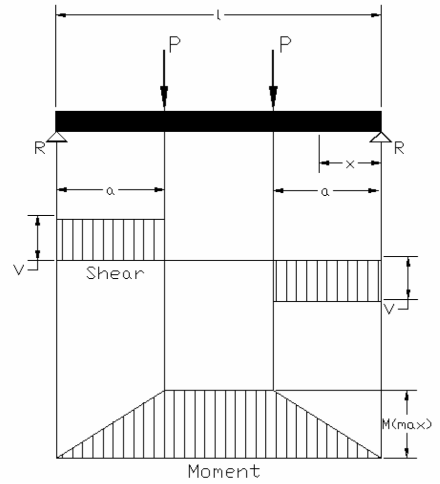
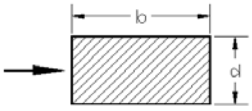
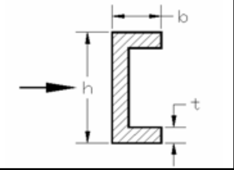
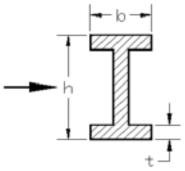
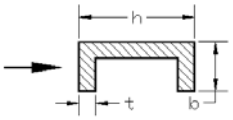
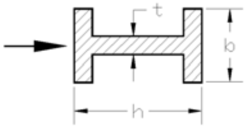
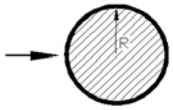
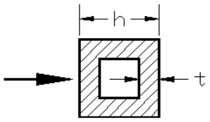
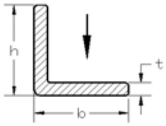
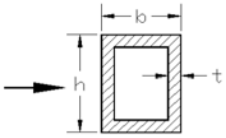
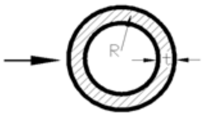


Table 2
For Calculating Shear Component of Deflections

Shear Areas and Shear Coefficients for Various Cross Sections

for calculating A', A' = kA$_w$

Cross Section	Type	Shear Area	k	Cross Section	Type	Shear Area	k
	**Rectangular Section**	**A$_w$= bd**	**5/6**		**Channel Section**	**A$_w$= 2bt**	**5/6**
	**I or W-Section**	**A$_w$= 2bt**	**5/6**		**Channel Section**	**A$_w$= ht**	**1**
	**I or W-Section**	**A$_w$= th**	**1**		**Solid Round**	**A$_w$= π^2**	**8/9**
	**Square Tube**	**A$_w$= 2th**	**1**		**Angle Section**	**A$_w$= th**	**1**
	**Rectangular Tube**	**A$_w$= 2tb**	**5/6**		**Circular Tube**	**A$_w$= 2πRt**	**1/4**

Note: → Arrows indicate direction of shear forces k = Shear coefficient A$_w$ = Shear area

Note: Values are approximated for simplicity. For exact shear coefficients reference ~~Timoshenko's Beam Theory.~~

SECTION 10

DESIGNING TENSION MEMBERS

Tension

Obviously, because there are no buckling concerns with tension members, the design process is quite simple.

Lengthwise Tension
Allowable tensile stress along the major axis (lengthwise, LW) is calculated by using the Tensile Strength LW, $F_{t\text{-}ult\text{-}LW}$ (from Section 4) and divided by the appropriate Safety Factor (see Section 6) and multiplying by the Temperature Factor, T_s.

$$F_{t\text{-}LW} = F_{t\text{-}ult\text{-}LW} * T_s / S.F \qquad \text{Equation 10-1}$$

Problem Example: Calculate the Allowable Tensile Stress, $F_{t\text{-}LW}$ for a W6 x 6 x ¼ SuperStructural (1625 Series) functioning in a 130 degree-F environment as a diagonal brace.

Solution: From Section 4, for SuperStructurals we see that $F_{t\text{-}ult\text{-}LW}$ is 46,000 psi, and dividing this by the appropriate safety factor of 2.5, $F_{t\text{-}LW}$ = 46,000/2.5 = 18,400 psi. From Section 7, we interpolate the Temperature Stress Reduction Factor, T_s, between 80% at 125 degrees-F and 85% at 150 degrees-F to be 84% at 130 degrees-F. Therefore,

$$F_{t\text{-}LW} = F_{t\text{-}ult\text{-}LW}/S.F \text{ x } T_s = 46{,}000/2.5 \text{ x } 0.84 = 15{,}456 \text{ psi}$$

Determination of the actual tensile stress is determined by the formula,

$$f_{t\text{-}LW} = P/A \leq F_{t\text{-}LW} \qquad \text{Equation 10-2}$$

where, P = tensile load in the member
A= cross sectional area of the tension member

Cross-wise Tension
Allowable tensile stress perpendicular to the major axis (crosswise, CW) is calculated by using the ultimate tensile strength CW, $F_{t\text{-}ult\ CW}$ (from Section 4) and dividing it by a Safety Factor of 2.5 (see Section 6) and multiplying by the Temperature Factor, T_s. Thus,

$$F_{t\text{-}CW} = F_{t\text{-}ult\text{-}CW} * T_s / S.F. \qquad \text{Equation 10-3}$$

Problem Example: Calculate the capacity of two L6 x 6 x ½ SuperStructural (1525) clip angles x 4" long supporting a hanger from the ceiling in a 75-degree-F environment. The clip angles are mounted such that the hanging force is transmitted through the cross-wise fibers.

Solution: From Section 4, for SuperStructural angles, we see that $F_{t\text{-}ult\text{-}CW}$ is 16,500 psi, and dividing this by the appropriate tensile safety factor. Because the clip angles make up a framing connection, from Section 6 we see that the appropriate safety factor for a connection is 4.0. From Section 7, we find that at 75 degrees-F, the Temperature Stress Reduction Factor, T_s, is 1.0.
Thus, $F_{t\text{-}CW}$ = 16,500/4.0 x 1.0 = 4,125 psi. The area, A, is 2 clip angles x 4" long x ½" thick = 4.00 in^2, therefore the total capacity of the connection is 4.00 in2 x 4,125 psi = 16,500 lbs.

SECTION 11

DESIGNING COMPRESSION MEMBERS (COLUMNS & COMPRESSION BRACES)

This section of the Delta Composites Fiberglass Structural Design Manual is credited to Creative Pultrusions Inc.

Symbols for Compression Members
(Columns)

A = Cross-sectional area (in^2)

b = Width of local flange element; width of angle leg, or ½ width of a wide flange beam flange = $b_f/2$ (in), or width of square or rectangular tube flange = b_f

$E_{C\text{-}LW}$ = Compressive modulus in the lengthwise direction, LW (psi)

F_a = Allowable compressive stress (psi)

I_x, I_y = Moment of Inertia (in^4)

k = Flange stiffness factor = 0.5 for non-stiffened outstanding flange elements of the W-section; 4.0 for stiffened outstanding flange elements of W-sections

K = Effective length coefficient

L = Length of column (ft); (in) when used in KL/r equation

P_a = Allowable axial load (lbs)

r = Radius of gyration of the section (in)

S = Section Modulus (in^3)

t_f = Thickness of local flange element (in)

ν_{xy} = Poisson's ratio (if denoted only as ν, it is to be interpreted as ν_{xy})

Φ = 0.8, a coefficient to account for the orthotropic material of the composite

$F_{brg\text{-}ult\text{-}LW}$ = Ultimate bearing stress of the composite, lengthwise (psi)

$\sigma_{cr\text{-}local}$ = Ultimate local buckling stress (psi)

$\sigma_{ult,Eluer}$ = Ultimate Euler buckling stress (psi)

$\sigma_{ult,f\text{-}t}$ = Ultimate flexural-torsional buckling stress (psi)

Column Load Design Equations

The objective of this Section 11 is to provide engineers with a quantifiable baseline for designing with Pultex® FRP columns. Delta Composites and Creative Pultrusions, through its comprehensive column load test program, provide the most current, thorough manual for the practical design of Pultex® FRP columns. Full section column tests were performed by Professor Robert L. Yuan, Ph.D., P.E., at The University of Texas at Arlington, Arlington, Texas. The protocol of full section column tests included more than 300 structural Pultex® FRP product specimens: I and W shapes, round and square tubes, and angles.

The test protocol required the analysis of short, intermediate and long columns, ranging from one to twenty foot section lengths. The tests were conducted in a reaction frame in the vertical position, using pinned-pinned end conditions, with the corresponding effective length coefficient (K) of 1.0. Column design equations, for practical column applications with various end conditions, are available and completely supported by the extensive column load test results.

The columns were axially compressed, with measurements taken of the axial deflections and lateral center displacements. Axial load versus lateral displacements were plotted and the ultimate loads determined. The ultimate load is defined as the points on the plots, where the loads no longer increase due to local, global or bearing failure.

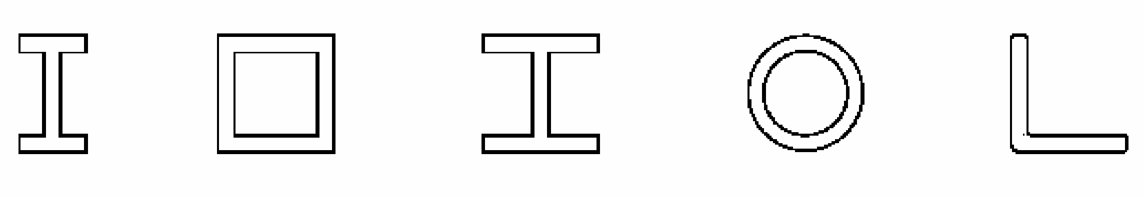
We recognize that some published results by other pultrusion companies for column load information are "inconsistent" within the pultrusion industry. The column load tests conducted by Dr. Yuan, which establishes the basis of this Section 11 of the Design Manual, were predicated by the use of true pinned-pinned end conditions with minimum friction effects. The results of this testing protocol correspond to a strong baseline confidence to which engineers can design and provide conclusions.

Introduction

The research work presented in the Load Tables for Compression Members represents a thorough investigation on the behavior of Pultex® FRP columns, produced by Creative Pultrusions, to be used as supporting members for civil engineering structures.

Five section configurations of Pultex® FRP composite columns are studied in the research, as shown in Figure 1. Two sections have closed configurations: square tube and round tube; the other three are thin-walled open sections: wide-flange, I, and angle sections. More than 300 column members, with three specimens each, were tested.

Figure 1



The thicknesses are 1/8" and 1/4" for square tube sections. The dimensions of the square tubes vary from 1.5" to 4". For round tube sections, the thicknesses are 1/8" and 1/4". The diameters of the round tube are 1.5" and 2". For Wide Flange Sections, the thicknesses of flanges and webs are 1/4" and 3/8". The dimension of the Wide Flange Section ranges from 4" to 10". For I-Sections, the thicknesses of flanges and webs are 1/4" and 3/8". The dimensions of I-Sections are 4" x 2" and 8" x 4". For angle sections, the thicknesses of the flanges are 1/4", 3/8" and 1/2". The dimensions of the angle section are 3" x 3", 4" x 4" and 6" x 6".

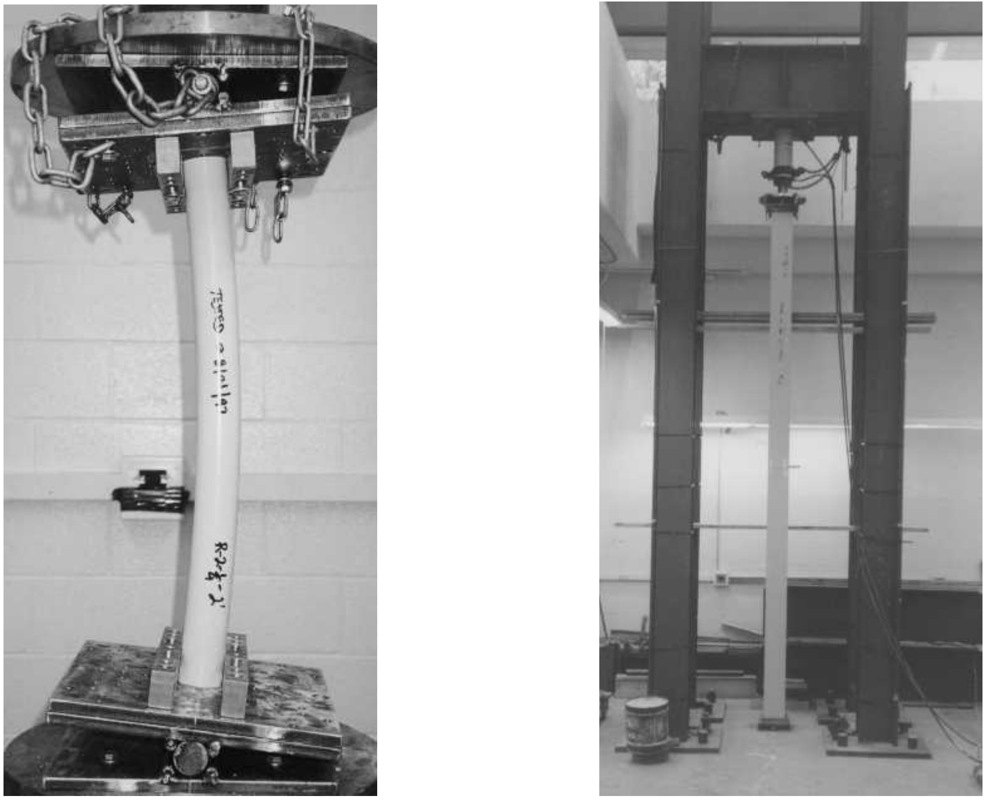
The objectives of the research are to provide:

1. the column load data for five section configurations, taking into consideration the length of the column and the effective length factor, “K”;
2. the allowable compressive stresses;
3. the allowable axial compressive loads;
4. software and/or design equations for predicting load capacity of columns with various section configurations; and
5. written explanations to relate experimental data with the design equations and procedures.

Pultex® FRP Column Test Program

The length of the composite column varies from 1' to 20' to include short, intermediate, and long column members. Full scale column tests are performed by an axial compressive load in a vertical position as shown in Figure 2.

Figure 2



MTS Machine

Reaction Frame

Short vertical column members were tested on a MTS machine; long column members were tested on a 30-ft. reaction frame. During the test, a microprofiler was used to generate the displacement rate of loading at a 0.1 in./min. The measurements included strains, ultimate loads, axial displacements and lateral deflections.

The composite materials for the column members are constructed of polyester-based and vinyl ester-based resin matrices, with and without fire retardancy, reinforced with E-glass fibers.

Analysis and Discussion

Columns with Box Sections (Imperial)

For the short columns with box sections, the ultimate load capacity is a function of the bearing strength of the composite material and the column cross-sectional area. In general, the bearing strength of a structural composite is approximately 30 ksi; therefore, the ultimate strength of short columns with box sections depends upon the cross-sectional area; for a given area, the columns with box sections appear to have the highest ultimate load capacities among the columns with other section configurations. For a given wall thickness of a box section, the ultimate load capacity appears to increase linearly with an increase in the section dimensions, e.g., for thickness t = 1/4", length L = 2 ft., the ultimate load strength was 40 kips for 1 3/4" x 1 3/4" box section; 58 kips for 2" x 2" section; and 88 kips for a 3" x 3" section.

For the long columns, the ultimate column strength is a function of the slenderness ratio KL/r. The column strength decreases with an increase in the slenderness ratio. For columns with box sections, the dividing line at the slenderness ratio for short and long columns appears to be 35. For columns with KL/r less than 35, the bearing strength of the composite controls the ultimate load. For columns with KL/r greater than 35, global buckling strength controls the ultimate load.

Columns with Round Sections

Similar to the columns with box sections, the ultimate load capacity of the short round column is also a function of the bearing strength of the composites and column cross-sectional area. For a given area and length, the ultimate column strength of a short round column is approximately 20% less than that of a short box column.

For the long round columns, the ultimate column strength is a function of the slenderness ratio KL/r. The round column strength decreases with an increase in the slenderness ratio. For round columns, the dividing line at the slenderness ratio appears to be between 30 to 40. For round columns with KL/r greater than 40, the columns have the characterization of an Euler behavior. For round columns with KL/r less than 30, bearing mode of failure dominates the ultimate column strength. At KL/r = 25, the ultimate stress of the round column from test results is less than the bearing strength of 30 ksi of the composites; therefore, the prediction curve in the short round column region becomes an inclined straight line.

Columns with Wide Flange Sections

From experimental results, the ultimate strength of columns with Wide Flange Sections is about 30 percent of the ultimate strength of columns with box sections for a given cross-sectional dimension and member length.

For the long columns, the ultimate column strength is a function of the slenderness ratio KL/r. The column strength decreases with an increase in the slenderness ratio. For columns with Wide Flange Sections, the dividing line at the slenderness ratio for short and long columns appears to be in the range of 40 to 60. For columns with KL/r less than 60, the column ultimate load depends on one-half of the flange width to the flange thickness ratio of $b_f/2t_f$. The higher the $b_f/2t_f$ ratio, the less the ultimate load capacity.

Columns with I-Sections

Similar to the columns with Wide Flange Sections, the ultimate load capacity of the columns with I-sections is a function of the slenderness ratio, KL/r. The column strength decreases with an increase in the slenderness ratio. For columns with I-sections, the dividing line at the slenderness ratio for short and long columns appears to be in the range of 30 to 40. For columns with KL/r greater than 40, the Euler characteristics of the column with I-sections are close to that of the column with Wide Flange Sections; however, for I-section columns with KL/r less than 30, the ultimate stress is significantly higher than the ultimate stress of the Wide Flange Section column due to a smaller b_f/t_f ratio. The crippling of the flange in the testing of I-section columns was not observed. At KL/r = 30, the ultimate stress of the I-section column from test results is less than the bearing strength of 30 ksi of the composites; therefore, the prediction curve in short I-section column regions becomes an inclined straight line.

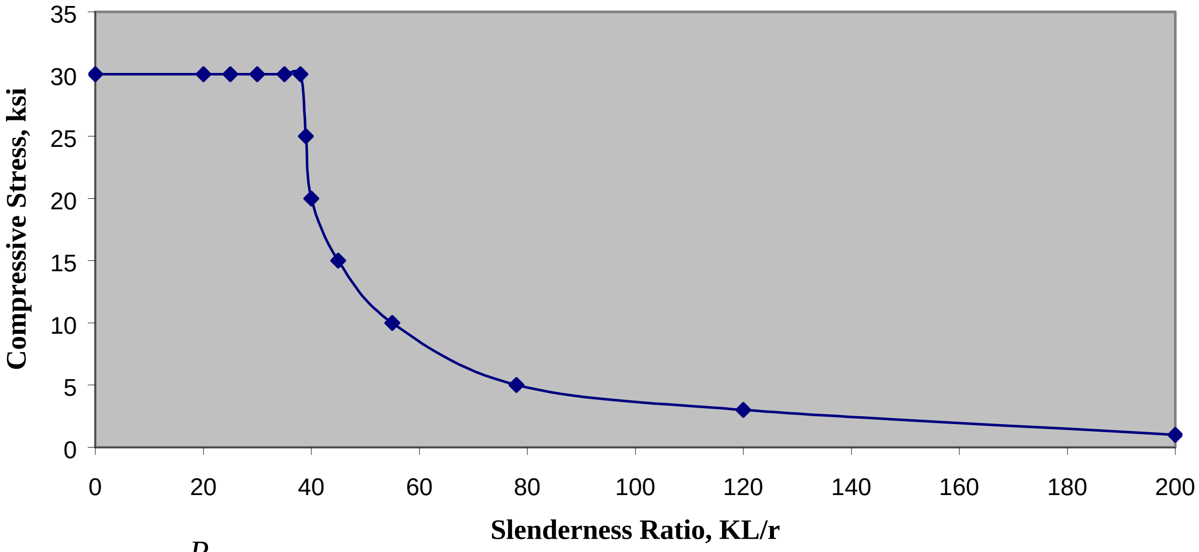
Columns with Angle Sections

Columns with angle sections were axially loaded at the centroid of the section. The ultimate load capacity is a function of the slenderness ratio KL/r. The column strength decreases with an increase in the slenderness ratio. For columns with angle sections, the dividing line at the slenderness ratio for short and long columns appears to be in the range of 45 to 60. For columns with KL/r greater than 60, the Euler characteristics of the column with angle section is close to that of the column with Wide Flange Sections; however, for the angle-section columns with KL/r less than 45, the ultimate stress is significantly lower than that of the Wide Flange Section columns due to a larger b_f/t_f ratio and localized instability. The crippling of the flange in the testing of angle-section columns was observed for all specimens; the local buckling instigated a torsion and global buckling of the column. In the short angle section column region, the ultimate column strength is sensitive to the b_f/t_f ratio. For a b_f/t_f greater than 8, the ultimate strength of the column with angle section decreases significantly.

Column Load Design Equations

The Column Load Design Equations for E-glass reinforced polymer columns are based on a large group of data points from full section tests of composite columns. The observed column failure can be categorized into two modes: bearing failure and/or local instability for short columns, and global instability for long columns. Figure 1. depicts a general behavior for all fiber reinforced polymer columns. The curve can be divided into two groups: short column and long column, as the plotted compressive stress versus slenderness ratio. The short columns generally fail in bearing deformation or local buckling mode; the long columns generally fail in the global buckling mode.

Compressive Stress vs. Slenderness Ratio
Figure 1



$$\sigma_{ult} = \frac{P_{ult}}{A}$$

Design Equations for Box Sections

For short columns with box sections, a bearing failure due to axial compressive loading governs the design equation as follows:

Where P_{ult} = Ultimate axial load (lbs.)
A = Cross-sectional area (in^2)
$F_{a\text{-}ult} = F_{brg\text{-}ult\text{-}LW}$ = Bearing strength of the composite (psi) Equation 11-1
$F_{a\text{-}allow}$ = $F_{a\text{-}ult}$ / S.F. (S.F. = 3.0 for compression)

Columns with Round- and I-Sections

For short columns with round and I-sections, the columns fail due to a combination of axial load and bending moment. The design equations consider the interaction of bearing and flexural buckling failure. A linear equation is developed from the test results for the transition behavior as follows:

$$F_{a-ult} = (30 - \frac{1}{7}\frac{KL}{r}) \cdot Ts \ \text{(ksi)} \quad \text{for short Pultex}^{®}\text{FRP Round} - \text{Section columns} \quad \text{Equation 11-2}$$

$$F_{a-ult} = (25 - \frac{5}{38}\frac{KL}{r}) \cdot Ts \quad \text{(ksi)} \quad \text{for short Pultex}^{®}\text{FRP I} - \text{Section column} \quad \text{Equation 11-3}$$

$F_{a\text{-}allow} = F_{a\text{-}ult}$ / S.F.

Where $F_{a\text{-}ult}$ = Ultimate compressive stress (ksi)
K = Effective length coefficient
L = Column length (in) when used in above equation
r = Radius of gyration of the section (in)

Columns with Wide Flange Sections

For short columns with Wide Flange Sections, local buckling or crippling occurs on the flanges. According to the test results, the ultimate local buckling stress, σ_{cr}^{local} of the Pultex® FRP composite Wide Flange Section column can be predicted by the modified buckling equation of thin plate for isotropic materials as follows:

$$\sigma_{cr-local} = \Phi k \frac{\pi^2 (Ec - lw)}{12(1-\nu^2)} \left(\frac{t_f}{b}\right)^2 Ts \ \text{(psi)} \ \text{for short Pultex}^{®} \ \text{FRP Wide Flange Sections} \ \text{Equation 11-4}$$

Where: $E_{c\text{-}LW}$ = Compression modulus in the loading direction, lengthwise (psi)
ν = Poisson's ratio, lengthwise
t_f = Thickness of the local flange element (in)

b = b_f /2, half the width of the W-flange element = the projecting, unstiffened flange element (in)
Φ = 0.8, a coefficient to account for the orthotropic material of the composite
k = 0.5 is recommended for the non-stiffened outstanding flanges of the Wide Flange Section
k = 4.0 is recommended for the stiffened outstanding webs of the Wide Flange Section

It should be noted that the ultimate local buckling strength needs to be checked against bearing strength. The lower value will be used for the ultimate strength of the short composite column with the Wide Flange Section. Thus for the bearing check of short W-shape beams,

$F_{a\text{-}ult} = F_{brg\text{-}ult\text{-}LW}$ = Bearing strength of the composite (psi) Equation 11-5

Columns with Angle Sections

For short columns with angle sections, the local buckling of the flange occurs, as in the column with the Wide Flange Section. Thus, the design Equation 11-4 and 11-5 can also be applied to predict the ultimate strength of the short columns with angle sections.

Design Equations for Long Columns (Global Buckling)

The flexural buckling, known as Euler buckling, is the general behavior of long, slender Pultex® FRP columns under axial compression loads. According to the test results, the ultimate global buckling strength of long composite columns was in agreement with the Euler buckling equation:

$$\sigma_{ult,Euler} = \frac{\pi^2 (Ec - lw)Ts}{\left(\frac{KL}{r}\right)^2} \text{ (psi) for all long Pultex® FRP columns} \qquad \text{Equation 11 - 5}$$

$F_{a\text{-}allow} = \sigma_{ult,Euler}$ / S.F.

Where: $E_{c\text{-}LW}$ = Compression modulus in the loading direction, lengthwise (psi)
K = Effective length coefficient
L = Column length (in) when used in above equation
r = Radius of gyration of the section (in)
$\sigma_{ult,Euler}$ = Ultimate compressive stress in long composite columns (psi)

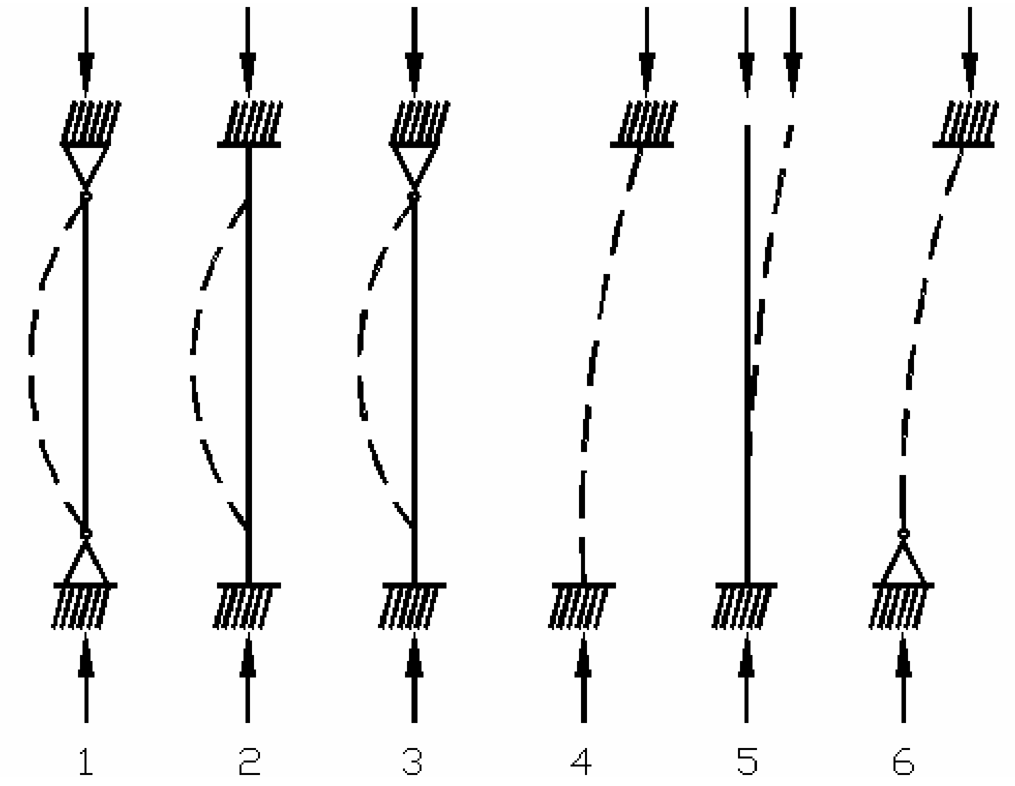
Equation 11-6 can be applied to the long Pultex® FRP composite columns with square-, round-, I-, W-, and angle- sections; however, for columns with angle-sections, flexural-torsional buckling governs the ultimate strength. In the test, the coupling of the flexural and torsional buckling was observed in a form of lateral deflection and global twisting for the angle-section columns. The ultimate flexural-torsional buckling stress can be approximated by the lower value from Equation 11-5 for flexural buckling strength about the weak axis, or from the torsional buckling equation as follows:

$$\sigma_{ult,\ f\text{-}t} = \Phi \, \frac{(E_{c\text{-}LW})}{2(1+\nu)} \left(\frac{t_f}{b_f}\right)^2 T_s \text{ (psi)} \quad \text{for Long Pultex® FRP Angle Columns} \qquad \text{Equation 11-6}$$

Where: $E_{c\text{-}LW}$ = Compression modulus in the loading direction, lengthwise (psi)
ν = Poisson’s ratio, lengthwise
t_f = Thickness of the local flange element (in)
b_f = The total leg width of an angle (in)
Φ = 0.8, a coefficient to account for the orthotropic material of the composite
K = Effective length coefficient
Ts = Coefficient of the effect of temperature on allowable stress

Table 1. Effective Length Coefficient, K-Value

End Conditions	**Recommended K-Value**
1. Pinned-Pinned	1.00
2. Fixed-Fixed	0.65
3. Pinned-Fixed	0.80
4. Fixed-Translation Fixed	1.20
5. Fixed-Translation Free	2.10
6. Pinned-Translation Fixed	2.00



Note: Buckled Shape of Column Displayed by Dashed Line

Tables for Allowable Compressive Stresses and Loads

The following tables provide information for the allowable stresses (Fa) and the allowable loads (Pa) for columns with square tube sections, round sections, Wide Flange Sections, I-sections and angle-sections. The tables represent sections used as compressive members (columns). The tables were developed based on the following criteria:

1. Experimental test results
2. Room temperature (73° F)
3. A safety factor of S.F. = 3.0
4. An effective column length coefficient, K = 1.0
5. A flange stiffening coefficient, *k*, of 0.5
6. A value of $E = 3x10^6$ psi
7. $\nu = .36$ in/in
8. No damages on the composite columns
9. Tables display KL/r values to 200 for reference. It is recommended that KL/r be limited to 120.

COLUMN LOAD TABLES TO BE ADDED

SECTION 12

DESIGNING FOR SHEAR

SYMBOLS FOR SHEAR CALCULATIONS

A_v = Shear Area (in^2)
$F_{v\text{-ult-LW}}$ = Ultimate In-plane Shear Strength LW (psi)
$F_{v\text{-ult-CW}}$ = Ultimate In-plane Shear Strength CW (psi)
F_v = Allowable Shear Stress (psi)
S.F. = Safety factor (= 3.0 for beam shear, 4.0 for connections)
F_v = Actual Shear Stress (psi)

IMPORTANT!!: WHEN DESIGNING CLIP ANGLES FOR CONNECTIONS, BE AWARE THAT THE SHEAR CAPACITY AT THE THROAT OF THE CLIP ANGLE IS GREATLY REDUCED. SEE SECTION 4 FOR ULTIMATE SHEAR CAPACITIES AT THE THROAT OF CLIP ANGLES.

The allowable shear stress, F_v is calculated by dividing the Ultimate In-plane Shear (LW or CW depending on loading direction-see Section 4 for shear values) by the Shear Safety Factor, 3.0 or 4.0 (see Section 6). The Shear Safety Factor to be utilized when checking beam shear in a beam shall be 3.0. The Shear Safety Factor when calculating beam shear capacity or of a clip angle at a connection shall be 4.0. The engineer shall take into account the direction of loading to properly choose either LW or CW Ultimate In-plane shear values, $F_{Vult\text{-}LW}$ or $F_{Vult\text{-}CW}$.

Thus

$F_v =$, $F_{Vult\text{-}LW}$ or $F_{Vult\text{-}CW}$ /S.F., psi

The actual shear stress, f_v, is calculated by the formula:

$f_v = \frac{V}{A_w}$; Where V is the beam shear force and A_w is the cross sectional area of the web, or webs in the case of a rectangular or square tube.

In short beams subjected to high concentrated loads, shear stress may govern the beam selection as opposed to the flexural stress. Longitudinal shear stresses, $\tau_l = (V*Q)/(I*t)$ must be evaluated to ascertain if the beam flange will remain intact with the beam web, where,

V = beam shear or reaction

Q = Area moment of the section, in^3

I = Moment of Inertia of the section, in^4

t = thickness, in

$\tau_l \leq F_{v\text{-}ult\text{-}LW}$/ S.F.(Ts) Use interlaminar shear, LW

SECTION 13

COMBINING STRESSES FOR UNITY RATIOS

Combined Axial and Bending Stresses

When checking stresses at any given point in a beam or column, the engineer must combine all stresses from major axis bending, minor axis bending, and axial tension or axial compression.

Combining Major Axis Bending with Minor Axis Bending and Tension or Compression

For cases involving both major and minor axis bending, plus axial loading, the Unity Ratio, UR, is calculated as follows:

$$UR = f_{bx}/F_{bx} + f_{by}/F_{by} + (f_a/F_a \text{ or } f_t/F_t) \quad \begin{array}{ll} \le 1.0 & \text{(for operating conditions)} \\ \le 1.33 & \text{(for storm conditions)} \\ \le 1.33 & \text{(for operating conditions with seismic activity)} \end{array}$$

where:

f_{bx} = actual major axis bending stress
f_{by} = actual minor axis bending stress
f_a = actual compressive stress
f_t = actual tensile stress
F_{bx} = allowable major axis bending stress
F_{by} = allowable minor axis bending stress ($= F_{bx}$)
F_a = allowable compressive stress
F_t = allowable tensile stress

SECTION 14

DESIGNING CONNECTIONS

SYMBOLS FOR DESIGNING CONNECTIONS

A_V = Shear Area (in^2)
$F_{Vult\text{-}LW}$ = Ultimate Lengthwise Shear Strength (psi)
$F_{Vult\text{-}CW}$ = Ultimate Crosswise Shear Strength (psi)
F_V = Allowable Shear Stress (psi)
$F_{brgult\text{-}LW}$ = Ultimate bearing stress in the direction parallel to the rovings
$F_{brgult\text{-}CW}$ = Ultimate bearing stress in the direction perpendicular to the rovings
S.F. = Safety factor (4.0 for connections)

IMPORTANT!!: WHEN DESIGNING CLIP ANGLES FOR CONNECTIONS, BE AWARE THAT THE SHEAR CAPACITY AT THE THROAT OF THE CLIP ANGLE IS GREATLY REDUCED. SEE SECTION 4 FOR ULTIMATE SHEAR CAPACITIES AT THE THROAT OF CLIP ANGLES.

Framed Connections

The structural engineer must consider the fact that fiberglass structures are typically designed to be removeable, thus all connections are to be bolted only unless otherwise specified to be epoxied on the construction drawings. Epoxying a joint is analogous to welding a joint in steel--it is permanent. When a joint is epoxied, the flexibility of removal and reinstallation is lost.

When designing a connection, the engineer must know and answer the following question --- Is the joint to be bolted only, or is the joint to be bolted and epoxied, or is the joint to be epoxied only? This question drives the design of the connection.

Per Section 6, **all connections are to be designed using a Safety Factor of 4.0.** From section 4, we obtain the appropriate values for the Ultimate Short Beam Shear Stress (LW or CW) and the Ultimate Bearing Stress (LW or CW). The engineer must take care to know the direction the force is acting and select the correct LW or CW values.

$F_v = F_{Vult\text{-}LW} \text{ or } F_{Vult\text{-}CW}/S.F.$

$F_b = F_{brgult\text{-}LW} \text{ or } F_{brgult\text{-}CW}/S.F.$

Note: When using Pultex® SuperStructural members, the engineer must evaluate if the forces are in the flange section or the web section of W and I shaped members and use the appropriate values for calculating the allowable stress.

It is recommended that, whenever possible, all bolting hardware used should be 316 stainless steel. Avoid, whenever possible, the use of carbon steel (painted or galvanized) because the primary intent for the use of fiberglass structures is to maximize corrosion resistance. The use of fiberglass bolting hardware is recommended only when 316 stainless steel hardware will not withstand the corrosive environment.

Bolted Connections

When designing bolted connections, there are actually seven engineering checks to be performed.

Using the beam reaction load at the joint:

1) Check of beam shear on net throat area of a clip angle, S.F. = 4.0
2) Check of beam shear on the web areas of the beams, S.F. = 4.0*
3) Check of bolt bearing on the web of the beams, S.F. = 4.0*
4) Check of bolt bearing on leg of clip angles
5) Check block shear, web of beams through the bolt, S.F. = 4.0
6) Check of block shear, clip angle legs through the bolt, S.F. = 4.0
7) Check shear capacity of 316 SS bolt using normal steel design procedures.

* Epoxied bearing or shear doubler plates may be required to satisfy the 4.0 safety factor at the connection. Remember, the beam has already been sized for a moment safety factor of 2.5 and a beam shear safety factor of 3.0, but at the connection the beam must possess a shear safety factor

of 4.0 and a bearing safety factor of 4.0. Epoxying these doublers enhances the shear and bearing capacity of the beam web.

1. Checking beam shear on the net throat area of a clip angle:

When checking beam shear on the net throat area of a clip angle, the following steps should be taken.

1. Determine the reaction, R, of the framing beam into the chord. (The chord is the through beam and the framing beam is the beam that is transferring load to the chord).
2. It is strongly recommended that two clip angles be used to frame a joint, one on either side of the framing beam, thus, it is a correct assumption that each clip angle will transfer half the load, or R/2.
3. Using the thickness of the clip angle, t, and the depth of the clip angle, d, calculate the shear area on the throat of the clip angle, $A_v = t \times d$.
4. The allowable shear load, V_a, of each clip angle is calculated as follows:

$V_a = F_v \times A_v \geq R/2$, where $F_v = F_{v\text{-ult-LW}} / \text{S.F.} \times T_s$, where T_s is the stress reduction factor accounting for temperature.

Important: Please note that the $F_{v\text{-ult-LW}}$ through the throat of a clip angle is greatly reduced as compared to the normal beam shear values (Please see separate shear values for clip angles as opposed to beams in Section 4). This is due to the moment introduced due to the eccentricity of loading. Failure to use the proper $F_{v\text{-ult-LW}}$ can have catastrophic results

5. If $V_a < R/2$, increase either the t or d of the clip angle as required to safely carry the load.

2. Checking beam shear on the web of the beams and chords:

When checking beam shear on the web of the beams, the following steps should be taken:

1. From the framing beam shear diagram, determine the beam shear or reaction, R.
2. From Section 5, obtain the web shear area, A_w, where $A_w = d \times t_w$ for the appropriate beam section, with d being the total depth of the beam section, and with t_w being the web thickness.
3. Calculate the allowable beam shear, V_a, of the beam in the following manner:

   $V_a = A_w \times F_v \geq R$, where $F_v = F_{v\text{-ult-CW}} / \text{S.F} \times T_s$ (S.F. = 4.0 for connections)

4. If $V_a < R$, use a beam with more web shear area, and this is achieved by using a thicker web or by using a beam of greater depth, or both. An epoxied web doubler can also be used to increase shear area.

Checking bolt bearing on the web of the beams and clip angles:

When checking bolt bearing on the web of the beams or the clip angles, the following steps should be taken:

1. From the framing beam shear diagram, determine the beam shear or reaction, R.

2. Calculate the beam web bearing area, A_{brg}, as follows:

   $$A_{brg} = t_w \text{ x } \phi_b \text{ x (number of bolts)}$$

   where ϕ_b is the bolt diameter and t_w is the web thickness of the beam or clip angle(s). (Note: If calculating the bearing capacity of the clip angles, bear in mind that, since two clip angles are transferring the load, A_{brg} would be calculated by the formula: $A_{brg} = 2\, t_w \text{ x } \phi_b$ x number of bolts).

3. Calculate the allowable bearing capacity of the connection, P_{allow}, as:

   $$P_{allow} = F_{brg} \text{ x } A_{brg} \geq R, \text{ where } F_{brg} = (F_{brg\text{-}ult\text{-}LW} \text{ or } F_{brg\text{-}ult\text{-}CW})/ \text{ S.F. x } T_s$$

Please note that there is a significant difference between LW and CW shear strengths.

4. If $P_{allow} < R$, the engineer must increase the bearing area, and this is achieved by a combination of, or all of the following-----increase the number of bolts, increase the diameter of the bolts, increase the web thickness of the beam, or adding an epoxied bearing doubler plate, or the use of thicker clip angles if analyzing the bearing capacity of the clip angle system.

Calculating beam shear capacity, block shear of the bolt through webs of beams or through a clip angle:

When calculating the beam block shear capacity, the following procedures should be followed:

1. From the framing beam shear diagram, determine the beam shear or reaction, R.
2. Calculate the beam web block shear area A_{vb} (See attached sketch).
3. From Section 4, obtain $F_{v\text{-}ult\text{-}CW}$ for a beam or $F_{v\text{-}ult\text{-}LW}$ for a clip angle and divide by the safety factor for a connection of 4.0 to obtain F_{vb} ($F_{vb} = F_{v\text{-}ult\text{-}LW}$/S.F. x T_s for a clip angle or $F_{vb} = F_{v\text{-}ult\text{-}CW}$/S.F. x T_s for a beam)
4. Calculate allowable block shear capacity $P_{allow} = F_{vb} \text{ x } A_{vb} \geq R$. If $P_{allow} < R$, add shear capacity by increasing beam depth, increasing web thickness, or by adding a shear doubler as defined above.

Epoxied Connections

When designing an epoxied connection, the engineer must realize that all flexibility for removal of the joint is being lost. However, if the choice to epoxy the joint is made, the following minimum guidelines should be followed.

Standard epoxies used in the FRP industry possess an adhesion strength of 1,000 psi, and using a 4.0 Safety Factor as required in Section 6, the allowable adhesion, F_{adh} = 250 psi. The capacity of the epoxied joint, $P_{allow} = F_{adh} \times A_{adh} = 250 \text{ psi} \times A_{adh}$, where A_{adh} is the surface area of the adhesion.

Please note that the surfaces to be epoxied together must be prepared for epoxying in accordance with the epoxy manufacturer's recommended specifications.

Examples of all of the above types of calculations are provided in Section 15, Design Example.