

COOLING TECHNOLOGY INSTITUTE

Structural Design of FRP Components



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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers. CTI STD 137, (R2007), Fiberglass Pultruded Structural Products for Use in Cooling Towers, Cooling Technology Institute, PO Box 73383, Houston, Texas 77273, USA is the materials standard to be utilized in conjunction with this guideline.

Approved by the CTI Executive Board.



This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2018.

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Structural Design of FRP Components

Preface

FRP composites structural members are the newest building materials available for constructing cooling towers. As with any new material, designers must understand FRP's unique properties and the performance differences from other structural materials.

This Structural Design Guideline provides minimum design standards and cautionary recommendations to designers of FRP structural cooling towers. STD 137(07) is incorporated in this guideline as the material specification for FRP pultruded structural products and is the basis for the various tables of values.

1. MANUFACTURING STANDARDS

1.1 Design:

Material manufacturers provide allowable loads, design equations, reduction factors and service factors for common shapes and loading. This guideline is provided in lieu of the manufacturers data as a means to determine the design allowable loads. The design allowable provided herein is expressed as follows:

$$\text{Design Allowable} = \frac{\text{Ultimate Strength} \times R_t \times R_m}{\text{Service Factors}}$$

Design Allowable = Maximum allowable stress

Strength = Material ultimate strength as specified in Section 1.1.1 Ultimate Strength or in the case of long columns critical buckling stress.

R_t = Strength reduction factor due to temperature as specified in Section 1.1.2 Strength Reduction Factors

R_m = Strength reduction factor due to moisture as specified in Section 1.1.2 Strength Reduction Factors

Service Factors = Strength reduction factors as specified in sections 1.1.3 Minimum Material Service Factors.

1.1.1 Ultimate Strength:

The minimum ultimate strength may be obtained through the material manufacturer, CTI-STD 137 or testing of pultruded components. Where testing is employed the ultimate strength shall not be less than the 5th percentile value for a weibul distribution with 80% confidence per ASTM D7290-06.

1.1.2 Strength Reduction Factors for Temperature

Composite materials lose strength and stability at elevated temperatures. The resulting strength losses are related to the particular resin system used in fabrication of the member. Reduction factors which reflect the percentage of strength and modulus of elasticity retained at these higher temperatures must be applied to account for this loss of strength. Tables 1 and 2 indicate these

factors for Polyester and Vinyl Ester resin systems. Linear interpolation is permitted for temperatures not shown. These temperature reduction factors do not account for loss of strength of the composite material due to moisture exposure. (Comparisons were done dry at elevated temperatures). Reduction factors for pultruded shapes immersed in water are listed in Table 4 and in CTI STD-137, Table 2.3.

Table 1

APPLICATION CONDITION VS. "AVERAGE" COMPRESSION STRENGTH REDUCTION, ASTM D695 (See footnote #3 below)		
Temperature, °F	REDUCTION FACTOR	
	POLY	VINYL
77	1.0	1.0
100	0.85	0.90
125	0.70	0.85
150	0.50	0.80
175	NR	0.75
200	NR	0.50

- 1) 2004 CTI Paper (TP04-08): "Update on the Impact of Water Immersion for Pultruded FRP"
- 2) 2005 CTI Paper (TP05-03): "The Impact of Veil Thickness and Coating on Cooling Tower FRP Composites"
- 3) These reduction factors are for isophthalic polyester resin shapes.

Table 2

APPLICATION CONDITION VS. "AVERAGE" MODULUS OF ELASTICITY REDUCTION, ASTM D638(* also reference modulus of elasticity procedure written for this application) (See footnote #3 below)		
Temperature, °F	REDUCTION FACTOR	
	POLY	VINYL
77	1.0	1.0
100	1.0	1.0
125	.90	.95
150	.85	.90
175	NR	.88
200	NR	.85

The reduction factor is multiplied by the Ultimate Strengths or Modulus of Elasticity prior to applying service factors. Thus, the location of the member within the tower will dictate the exposure (i.e. fill support beams will be exposed to a lower temperature environment than the hot water distribution piping support beams). If the tower is to experience a short-term hot temperature excursion in excess of the design temperature this would be considered a live load condition. The following example illustrates the use of temperature effects.

Table 3

EXAMPLE: FILL SUPPORT BEAMS DESIGN
TEMPERATURE – 125°F

PARAMETER (Minimum Design Values)	Applicable ASTM	77°F	125°F	
			POLY	VINYL
Ultimate Bearing, PSI	D953	30,000	21,000	24,000
Flexure Strength, PSI	D790	30,000	21,000	24,000
Ultimate Shear, PSI	D2344	4,500	3,150	3,600
Full Section Modulus Elasticity, 10 ⁶ PSI		2.6 and 2.8	2.34	2.66

NOTE: Although polyester resin system strength is reduced more than a vinyl system, polyester systems can be used and still achieve the desired long term behavior. Additionally, the appropriate service factors must be used to minimize long-term creep regardless of which resin system is used. It is recommended that an extra 10°F be added to the maximum design temperatures to compensate for the unexpected short term upset conditions that may occur.

1.1.3 Strength Reduction Factors for Water Absorption

The FRP Committee of the Cooling Technology Institute sponsored a two year study in 2001-2003 which revealed strength property losses for FRP square tubes due to immersion in water. The resulting loss of strength for FRP shapes and plate for water immersion conditions must be taken into account. These reduction factors were developed and are listed in Table 4.

Table 4

TOTAL WATER IMMERSION REDUCTION FACTORS³-R_m	
CONDITION	AVERAGE
SHORT COLUMN	0.80 ^{1,2}
LONG	0.95 ^{1,2}

COLUMN	
ASTM D695 COMPRESSIVE STRENGTH	0.65 ¹
ASTM D695 COMPRESSIVE MODULUS	0.95 ¹

- 1) 2004 CTI PAPER (TP04-08): "Update on the Impact of Water Immersion for Pultruded FRP".
- 2) 2005 CTI PAPER (TP05-03): "The Impact of Veil Thickness and Coating on Cooling Tower FRP Composites".
- 3) These reduction factors are for isophthalic polyester resin shapes.

The reduction factors for Tables 1, 2, and/or 4 depending upon application and engineering judgment. are multiplied by the Ultimate Strengths or Modulus of Elasticity prior to applying service factors. Thus, the location of the member within the tower will dictate the exposure (i.e. fill support beams will be exposed to a lower temperature environment than the hot water distribution piping support beams). If the tower is to experience a short-term hot temperature excursion in excess of the design temperature this would be considered a live load condition.

1.1.4 Minimum Material Service Factors and Deflection Limits.

Note, absent an approved national code of standards for FRP materials, service factors indicated with an asterisk (*) have been derived based on a history of FRP tower installations, in service inspections, and testing of actual FRP tower components by reputable cooling tower manufacturers/designers. These service factors are listed in lieu of the service factors published by FRP material producers.

1.1.4.1 Dead and Operating Loads

1.1.4.1.1 Bearing Service Factor – 4.0, when applied to a fastener group. The commonly reported bearing values obtained per ASTM D953 (Standard Test Method for Bearing Strength of Plastics) for thermoset pultruded shapes are ultimate's, expressed in Megapascals or pounds force per square inch.

1.1.4.1.2 Shear Service Factor —3.0 min.

1.1.4.1.3 Bending/Flexural Service Factor – 2.5 min.

1.1.4.1.4 Compression Service Factor

1.1.4.1.4.1 Short Column [Material Failure] - 3.0 min.

1.1.4.1.4.2 Long Column [Buckling] – 2.0 min.*

Engineering calculations or testing shall model long columns based upon end conditions. Long columns are columns greater than or equal to that length at which the Euler buckling stress is equal to one half the lesser of the material compressive failure stress

or the local buckling stress. Short columns are those shorter than this length.

1.1.4.1.4.3 Beam-Column: Actual stress shall not exceed the following formula for members subjected to combined compression and bending loads by design or construction practices, including eccentrically loaded members.

$$\sigma_c/\sigma_{ac} + \sigma_{bx}/\sigma_{abx} + \sigma_{by}/\sigma_{aby} \leq 1$$

σ_c = Actual compressive stress

σ_{ac} = Allowable compressive stress

σ_{bx} = Actual bending stress for strong axis

σ_{abx} = Allowable bending stress for strong axis

σ_{by} = Actual bending stress for weak axis

σ_{aby} = Allowable bending stress for weak axis

1.1.4.1.5 Deflection Limits – L/D ratio of 180 – total

1.1.4.1.6 Deck Dead Loads – L/D ratio of 360

1.1.4.2 Short Term Loads and Temporary Construction Loads

Short-term loads include wind, seismic, ice/snow, maintenance and construction loads. Construction or refurbishment loads, which occur when a tower or cell is not operating, often may exceed design seismic / wind or other short term loads in combinations with operational loads.

1.1.4.2.1 Bearing Service Factor—2.5*

1.1.4.2.2 Shear Service Factor – 2.0*

1.1.4.2.3 Bending/Flexural Service Factor – 2.0*

1.1.4.2.4 Compression Service Factor

1.1.4.2.4.1 Short Column [Material Failure] –3.0, min.

1.1.4.2.4.2 Long Column [Buckling] –2.0,* min. Long columns are columns greater than or equal to that length at which the Euler buckling stress is equal to one half the lesser of the material compressive failure stress or the local buckling stress. Short columns are those shorter than this length.

1.1.4.2.5 Deflection Limits – L/D ratio of 180

1.1.4.2.6 Deck Live Load--L/D ratio of 240 *.

1.2 Load Analysis (Dead, Live & Operating)

All load combinations shall be per ASCE 7, Design Loads for Building and Other Structures.

1.2.1 Fill Dead Loads – Dry weight of fill material, including water hold up. The estimated weight of fouled fill should be added, should fill fouling be considered probable and the expected fill weight should be stated in the bid documents.

1.2.2 Fill Live Loads – Concentrated loading for maintenance and a live load from fill icing.

1.2.3 Eliminator Dead Loads – Dry weight of eliminators

1.2.4 Eliminator Live Loads – Snow load for region

1.2.5 Distribution System Dead Loads – Distribution system full of water with component weights

1.2.6 Deck Dead Load – Weight of deck materials

1.2.7 Deck Live Load – 60 PSF equally distributed load over entire usable roof deck

1.2.8 Operating Load – Fill Dead Loads, Eliminator Dead Loads, Distribution System Dead Loads, Deck

Dead Loads, Stack Weight, Fan Thrust, all framework including walls and Mechanical Equipment (Dead and Rotational Loads), and Header Thrust Loads.

1.2.9 Short Term Loads and Temporary Construction Loads

1.2.9.1 Seismic Load – Seismic Load factor applied to the operating weight.

1.2.9.2 Wind Load – Wind Load applied to all vertical and horizontal surfaces. The casing will not be considered sacrificial.

1.2.9.3 Ice and Snow Loads -- Consult local codes for time duration loads,

1.2.9.4 Maintenance and Construction loads --- Each horizontal tie line or beam framing level shall be designed for a minimum load of 20 PSF. Every beam and beam to column connection shall be capable of a minimum concentrated load of 600 lbs.

1.3 Life of Structure

A reasonable anticipated life of 30-35 years can be expected from an FRP structured tower with normal loads, proper maintenance, proper sizing of the structural members, and use of proper service factors, with improper use, problems may occur. For example, the fill could reach weights 8-10 times the original design weight if the tower fill is allowed to clog with debris.

1.4 Creep

Creep is the continued deformation that occurs over time after the initial and immediate deformation upon application of load. With higher service factors creep become less of a problem, as overall strain levels are reduced. The stated service factors are sufficient to achieve this behavior for most laminates. The life of the structure then becomes more a factor of normal maintenance, rather than creep.

1.5 Fatigue

Fatigue is the reduced capacity of a member or structure due to repeated cyclical loading. This "continued elastic" reduction will happen primarily when the member is under higher strain levels. With higher service factors fatigue become less of a problem, as overall strain levels are reduced. The stated service factors are sufficient to achieve this behavior for most laminates. The life of the structure then becomes more a factor of normal maintenance, rather than fatigue.