COOLING TECHNOLOGY INSTITUTE

Structural Design of FRP Components

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FOREWORD

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.

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 2007.

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 Strength Reduction Factors for Temperature

Due to the behavior of composite material strengths in elevated temperature, it is necessary to account for the loss in strength and stability. The resulting loss is related to the resin system used in the construction of the member. The associated reduction factors reflect the percentage of strength and modulus of elasticity retained at that temperature. The following tables present these factors for poly and vinyl resin systems. This temperature reduction factor does not account for loss of strength of the composite material due to moisture exposure. (Comparisons were done dry at elevated temperatures.

Table 1.1-1

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

Table 1.1-2

APPLICATION CONDITION VS. "AVERAGE" MODULUS OF ELASTICITY REDUCTION, ASTM D638(* also reference modulus of elasticity procedure written for this application)		
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 1.1-3

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: Even though the polyester resin system strength is reduced more than a vinyl system this does not mean that a polyester system cannot 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.

1.2 Load Analysis (Dead & 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 and a percentage of fill weight for fill clogging.

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 (add ice/snow loads).

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 Short term maintenance and construction loads.

1.3 Minimum Material Reduction Factors/Deflection Limits

1.3.1 Dead and Operating Loads

1.3.1.1 Bearing Service Factor – 4.0, when applied to a fastener group. Bearing failure defined as a 4% elongation of the fiberglass hole for pinned or bolted joint

1.3.1.2 Shear Service Factor —3.0 min.

1.3.1.3 Bending/Flexural Service Factor – 2.5 min.

1.3.1.4 Compression Service Factor

1.3.1.4.1 Short Column [Material Failure] – 3.0 min.

1.3.1.4.2 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.

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

1.3.1.6 Deck Dead Loads – L/D ratio of 360

∗ Absent a national approved code of standards for FRP materials, service factors indicated here have been derived based on installed tower installations, in service 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.

1.3.2 Short Term Loads and Temporary Construction Loads

Short-term loads include wind, seismic loading, ice/snow loads, and maintenance and construction loads. If possible, member capacity should be determined using full-scale tests. Coupon tests to determine ultimate bearing, bending, and shear stress capabilities may not be reliable. Preferably, pultrusion manufacturers should provide this information to prevent misapplication of a structural shape in any given application. Cooling towers are generally classified as non-occupied structures. Furthermore, short-term loads on cooling towers are nebulous. The largest loads other than short-term loads usually occur when the tower is under construction or refurbishment. Usually the cell/tower is not operating.

1.3.2.1 Bearing Service Factor – 2.5,∗ when applied to a fastener group. Bearing failure defined as a 4% elongation of the fiberglass hole for pinned or bolted joints.

1.3.2.2 Service Factor – 2.0∗

1.3.2.3 Bending/Flexural Service Factor – 2.0∗

1.3.2.4 Compression Service Factor

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

1.3.2.4.2 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.

1.3.2.5 Deflection Limits – L/D ratio of 180

1.3.2.6 Deck Live Load--L/D ratio of 240 ∗. Absent a national approved code of standards for FRP materials, service factors indicated here have been derived based on installed tower installations, in service 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.

1.4 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 derived from full scale testing. However, with improper use problems may occur. For example, if the tower fill is allowed to clog with debris, then the weight of the fill could reach weights 8-10 times the original design weight, which will in most towers cause a structural failure.

1.5 Creep

Creep is the continued deformation that occurs over time after the initial and immediate deformation upon application of load. If higher service factors are used then 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.

1.6 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. If higher service factors are used then 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.

1.7 Glossary of Terms (See Appendix “A”)

2. FABRICATION STANDARDS

2.1 Shop Drawings

Shop drawings shall be prepared by the cooling tower manufacturer in advance of the actual shop fabrication. The shop drawings shall give complete information necessary for the fabrication of the component parts of the structure including the location, size, and tolerance of all cuts, holes, copes and blocks, any cut, drilled, or punched edge sealing requirements, and adhesive preparation requirements as applicable.

2.1.1 Shop drawings shall be developed in conformity to the structural design with best practice and due regard to speed and economy in fabrication and field erection.

2.1.2 FRP ladders, platforms, gratings, etc. – Refer to applicable OSHA, BOCA, UBC, or local building standards for direction or design parameters.

2.2 Equipment

The actual tools and equipment selected by the fabricator is directly dependent upon the type of work, quantity, and the facilities engaged.

For best results, carbide tipped or plated diamond grit saw blades, bits, files, and planers are recommended. It is recommended that adequate dust collection and or ventilation be employed when fabricating FRP structural shapes or plates.

Water jet cutting may be utilized; however, precautions must be made for adequately cleaning and preparation of the fabricated part for edge sealing.
Other methods of shearing or punching may be employed provided that the FRP material adjacent to the work is not cracked, crushed, or otherwise harmed or the lubricants that may be required do not contaminate the material.

2.3 Connection Design Criteria

2.3.1 General Criteria - Each of the methods for joining fiberglass has advantages and disadvantages. It should be left to the discretion of the cooling tower manufacturer to determine the best joint for his specific application. In either case the emphasis should be placed on the method of determining the strength of a specific joint. This method should be through full scale testing rather than coupon.

Table 2.2.1-1

Joining Method Considerations
Loads must be transferred, or required joint efficiency fraction of strength of weaker part to be joined.
The region within [the structural elements] where this must be accomplished.
Geometry of members to be joined.
Suitability for fabrication, considering dimensions of components, and numbering of components in production run.
Service environment and life of structure.
Reliability of joint.
Need for disassembly.
Need for fluid or weather tightness.
Aesthetics
Cost target and weight considerations.

Table 2.2.1-2

Comparison of Joining Techniques		
	Mechanical	Adhesive Bonds
Stress concentration at joint	High	Medium
Strength/weight ratio	Low	Medium
Use with non-rigid plastics	Inserts	Yes
Seal (water tightness)	No	Yes
Thermal Insulation	No	Yes
Electrical Insulation	No	Yes
Aesthetics (smooth joints)	Bad	Good
Fatigue Endurance	Bad	Good
Sensitive to peel loading	No	Yes
Non-Destructive Disassembly	Yes	Impossible
Inspection	Easy	Difficult
Skill required of Fabricator	Low	High
Heat and pressure required	No	Yes
Tooling Costs	Low	High
Time to develop strength	Immediate	Long

2.3.2 Mechanical – (Such as bolted, pinned, riveted, sleeved, etc., but not limited to these listed). Bolted connections should be tested for the specific bolt pattern being used and a loading capacity determined based on a 4% elongation of the hole. When bolting hollow members such as square tubes, no cracking of the hollow member should be allowed. If a crack is present, the member has failed and the member should be replaced.

Table 2.3.2-1

Types of Mechanical Fasteners
Bolts
Rivets
Screws
Pin and sleeve or pin and collar fasteners
Spring Clips
Cam Locks
Shrink Fit
Threaded

2.3.3 Bearing Capacity—The bearing capacity of pultruded FRP material around the fastener is affected by edge and end distances and the distance between fasteners in a line (pitch). Unless test data for the FRP material's bearing capacity is provided, Table 2.3.3-1 lists the recommended ratio in minimum distance from the center of fastener to edge/end of member and distance between fastener centers in a line (pitch) to the fastener diameter.

Table 2.3.3-1

Recommended Minimum Fastener Edge Distances to Fastener Diameter (Ratio).		
	Ratio Range	Common Ratio
Edge Distance - End	2.0 to 4.5	3.0
Edge Distance--Side	1.5 to 3.5	2.0
Pitch (Center to center distances of fasteners in a line)	4.0 to 5.0	5.0

2.3.4 Chemical - Bonding of a joint is adhesive specific and the adhesive manufacturer should be consulted as to the proper bonding method, and curing instructions. This should include surface preparation, proper temperature and moisture exposure ranges for application. As with any connection the joint should be tested full scale and tested for the proper application environment. Minimum service factors listed in Section 1.3 are to be applied for chemical bonds/connections as well as mechanical connections.

2.4 Fabrication Tolerances

Fabrication tolerances unless otherwise indicated on the shop drawings shall be as indicated in Table 2.4-1

Table 2.4-1
FABRICATION TOLERANCES

Cut lengths	± 1/8"
Square cuts	± 1° (Measured from face of part)
Hole location	± 1/16" for top side hole on all shapes up to 30' inclusive
Hole location	± 1/16" for bottom side hole on all shapes up to 30' inclusive
Hole location	± 1/8" for topside holes on all closed shapes greater than 30'
Hole location	± 3/16" for bottom side hole on closed shapes greater than 30'
Hole diameters	± 1/32" (Holes ½" to 1" diameter)
Hole diameters	± 1/16" (Holes greater than 1" diameter)
Slot dimensions	± 1/8" (Any dimension)

2.5 Quality Control

The fabricator shall provide quality control procedures to the extent that it deems necessary to assure that all work is performed in accordance with the shop drawings and this specification. In addition to the fabricator's quality control procedures, material and workmanship at all times may be subject to inspection by qualified inspectors representing the purchaser. If such inspection by representatives of the purchaser will be required, it shall be so stated in the contract documents and on the shop drawings. The inspecting agency should provide 24 hours' notice of its intention to perform an inspection.

Notes

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