Post-Failure Evaluation Of Wood-To FRP Conversion Of A Crossflow Cooling Tower



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ABSTRACT

In 2024, a partial collapse occurred in the wetted section of a crossflow cooling tower less than one year after the structure had been converted from wood to fiberglass -reinforced plastic (FRP) members. A third-party forensic engineering study revealed deficiencies in three critical areas: material properties, structural design, and installation practices. Laboratory testing performed under Cooling Technology Institute (CTI) protocols demonstrated that FRP components failed to meet key mechanical property thresholds. Structural calculations identified undersized members and inadequate connections that did not comply with ASCE7-16 load requirements. Field inspections further revealed missing hardware, misalignments, and the absence of quality assurance and quality control (QA/QC) oversight. Collectively, these deficiencies significantly reduced the tower's load-carrying capacity, resulting in progressive failure. This paper presents the methodology, findings, and engineering recommendations from the investigation, with the goal of informing future FRP retrofit projects and advancing industry best practices.

1. INTRODUCTION

FRP has become an increasingly common choice for structural retrofits in cooling towers, replacing traditional wood framing in both crossflow and counterflow designs. Its popularity stems from well-recognized advantages: excellent corrosion resistance, reduced structural weight, and lower maintenance demands over the service life of the equipment. These properties make FRP particularly attractive for operators seeking to extend asset life while minimizing future repair intervals.

However, FRP retrofits also introduce unique engineering challenges. The mechanical properties of FRP differ significantly from wood and steel, requiring careful consideration in structural design, connection detailing, and field handling. Changes in stiffness, load distribution, and joint performance must be fully accounted for in engineering calculations. Material sourcing and manufacturing variability can further impact performance, making adherence to recognized standards such as CTI-STD-137 critical. Without rigorous quality control, structural reliability can be compromised.

2. TOWER DESIGN & RETROFIT HISTORY

The cooling tower was originally an Ecodyne Series 70 crossflow cooling tower constructed with wood framing. In 2023, a contractor undertook a retrofit project to replace the wetted-section framing of one cell with FRP components. During this process, the original curved louver post design was eliminated and replaced with a straight louver configuration (see Figure 1 below).

In July 2024, less than one year after completion of the FRP retrofit, a partial collapse occurred on the east side of the cell. This was the second structural failure experienced by the tower. At the time of failure, additional cells were also undergoing wood-to-FRP conversion.

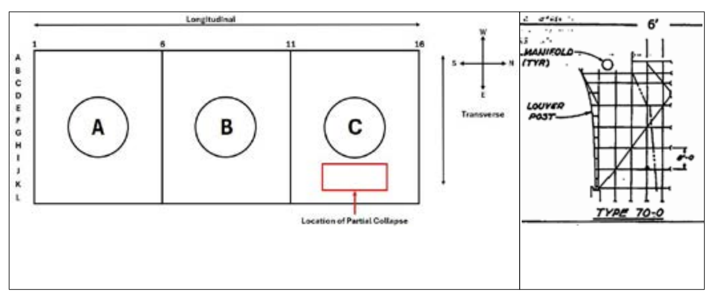

Figure 1: Cooling Tower Overview (left), Curved Louver Column Design (right)

Figure 2: Cooling Tower Undergoing Diagonal Brace Fix (left), Diagonal Brace Fix Overview (right).

3. ROOT CAUSE ANALYSIS & ENGINEERING STUDY

3.1. Problem Identification

Prior to the engineering inspection, the header pipe and hot water basin decking on the collapsed side of Cell C had already been removed by the customer. Our investigation proceeded by inspecting the remaining hot water basin structure from the fan deck downward, removing several bays of fill media to expose and access the damaged framing members. Multiple structural deficiencies were observed, documented, and subsequently presented to the customer. The key findings are summarized below:

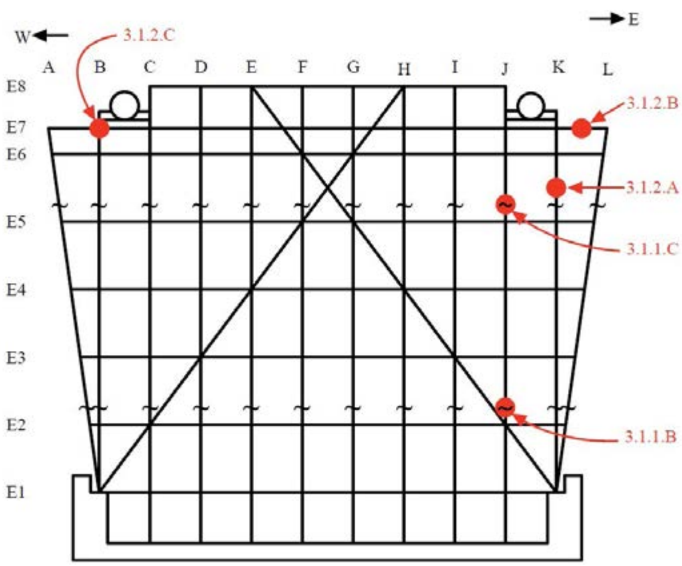

Figure 3: Bent Sketch Illustrating Failure Locations.

3.1.1. Column Design & Installation

a. Several instances of column buckling were identified, including one column that had dropped approximately 127 mm (5 in).

b. At the primary failure location, missing bolts at a column, tie, and brace connection created an unsupported column length of nearly 4.88 m (16 ft), well beyond acceptable limits.

c. Compression failures at column splices were noted in four separate bents, indicating systemic weakness at splice details.

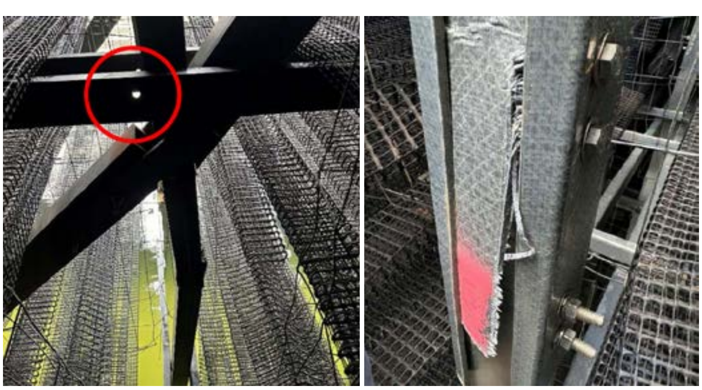

Figure 4: Failed Column Member & Missing Connection Hardware (left), Compression Failure (right).

3.1.2. Hot Water Basin Joist Design & Installation

a. The number of mid-bay nailers was insufficient; joist spans exceeded typical industry spacing, with intervals measured at approximately 0.61 m (2 ft). This lack of adequate lateral restraint increased the likelihood of deflection and connection overstress.

b. Hot water basin joists and their supporting channels spanned approximately 1.83 m (6 ft) without compression blocks between members. Compression blocks are critical in this configuration to prevent inward buckling, distribute load evenly, and provide restraint against torsional rotation under basin water loads.

c. Plowing and cracking were observed on 140 mm (5.5 in) FRP channel joist supports, which were connected to columns with a single fastener instead of the industry-standard double-bolt configuration. The reduced connection capacity contributed to localized overstress and premature material damage.

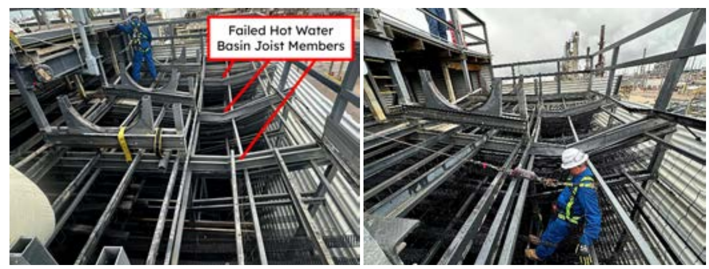

Figure 5: Partial Collapse at Hot Water Basin Level.

Figure 6: Single Bolt Configuration on Hot water Basin Joist.

3.1.3. Material Selection & Quality

a. The FRP material exhibited signs of accelerated degradation despite less than one year in service.”

b. No engineering data or design tables for these materials were available for review.

c. We requested engineering data and design tables for the material, which could not be provided. Third-party laboratory testing was recommended to characterize the material properties per CTI protocols. Independent structural design verification by a licensed professional engineer was also recommended to ensure adequacy of the retrofit design.

3.2. Detailed Inspection

The customer proceeded with the recommended 3rd party material testing and design verification by 3rd party affiliates (list Cooling Technology Institute and a private engineering firm). The customer and the contractor were not able to provide bent sketches for structural design verification.

During this effort:

- Tamper-resistant labels were applied to designated members prior to removal for material testing.
- Two dimensional bent sketches were generated to record framing geometry and sampling locations.
- Inspection procedures included detailed visual assessments, torque checks on bolted connections, and measurement of member spans, alignments, and splices.

Key observations included misaligned columns, improperly field-cut FRP members, missing hardware, and inconsistencies in connection detailing. These findings confirmed that installation quality issues compounded the structural vulnerabilities inherent in the retrofit design.

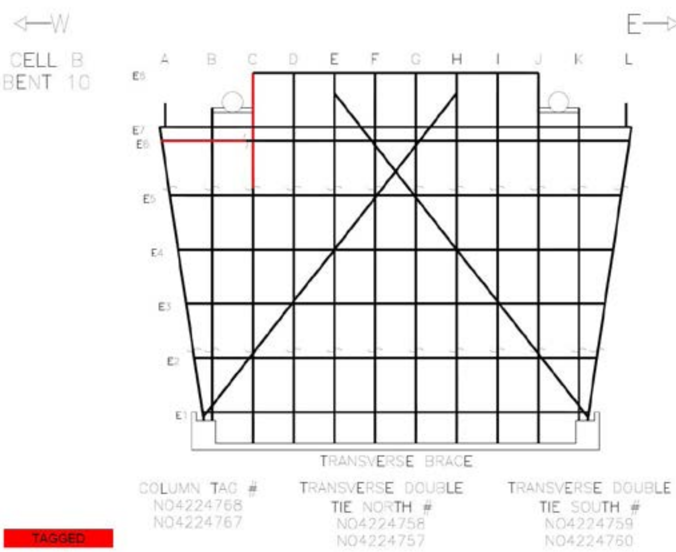

Figure 7: Example Bent Sketch Illustrating Sample Member Location.

4. MATERIAL TESTING ANALYSIS (THIRD-PARTY LAB)

Material samples were extracted from designated structural members and tested under accredited laboratory conditions in accordance with Cooling Technology Institute (CTI) protocols. Testing followed established American Society for Testing and Materials (ASTM) standards to characterize the mechanical properties of the (FRP) components. The scope of testing and the results are included:

Table 1: Summary of FRP Test Results

Property	ASTM Method	CTI Min. Requirement	Test Average	% of Req.	Outcome
Shear Strength	D2344	31.0 MPa (4,500 psi)	26.7 MPa (3,880 psi)	86%	Fail
Bearing Strength	D953	207 MPa (30,000 psi)	180 MPa (26,107 psi)	87%	Fail
Flexural Modulus	D8069	18.0 GPa (2.6×10^6 psi)	23.6 GPa (3.43×10^6 psi)	132%	Pass
Compressive Stress*	D6641	207 MPa (30,000 psi)	413 MPa (59,900 psi)	—	Inconclusive
Compressive Modulus*	D6641	17.2 GPa (2.5×10^6 psi)	29.6 GPa (4.3×10^6 psi)	—	Inconclusive
Water Absorption	D570	≤0.6%	0.58%	97%	Pass

TEST METHODS

The specimens were evaluated at the York, PA facility in accordance with the following:

ASTM D570-22, ***Standard Test Method for Water Absorption of Plastics*****, Section 7.1**

ASTM D953-19, ***Standard Test Method for Pin-Bearing Strength of Plastics*****, Procedure A**

ASTM D8069-17a, ***Standard Test Method for Determining Flexural Modulus of Full Section Pultruded Fiber Reinforced Polymer (FRP) Composite Members with Doubly Symmetric Cross Sections under Bending***

The specimens were evaluated at the Pittsfield, MA facility in accordance with the following:

ASTM D6641/D6641M-23, ***Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture***

ASTM D2334/D2344M-22, ***Standard Test Method for Short Beam Strength of Polymer Matrix Composite Materials and Their Laminates***

All specimens were evaluated for compliance to CTI STD-137, Audit Testing Protocol for Fiberglass Pultruded Structural Products.

Figure 8: Material Lab Testing Methods.

*Results invalid under ASTM D6641 acceptance criteria. Specimens exhibited excessive bending strain (>10% of axial strain) and high variability between tests, indicating non-homogeneous pultrusion. These conditions prevented the data from being considered representative of true compressive performance.

Summary of Results:

- **Shear Strength:** Average values of 26.7 MPa (3,880 psi) did not meet the CTI minimum requirement of 31.0 MPa (4,500 psi), equating to a ~14% deficiency in shear capacity. This shortfall reduced the ability of diagonal braces and web members (flat, vertical portion of a structural member) to resist in-plane shear forces, increasing the risk of overstress during wind loading and basin water surges.
- **Bearing Strength:** Average of 180 MPa (26,107 psi), below the 207 MPa (30,000 psi) CTI requirement, indicating reduced capacity at bolted connections, particularly critical at diagonal brace splices. This deficiency heightened the likelihood of localized crushing and connection slip, both of which undermine structural stability.
- **Flexural Modulus:** 23.6 GPa (3.43×10^6 psi), exceeding the CTI minimum of 18.0 GPa (2.6×10^6 psi). While this indicates adequate stiffness against bending, it also creates stiffness mismatches when integrated with other components, which can alter load-sharing behavior across the frame.
- **Compressive Strength/Modulus:** Results were inconclusive due to excessive variability within the test data. Non-homogeneous material properties were suspected, raising concerns about pultrusion consistency. Unreliable compressive performance is of particular concern in vertical column applications where uniform axial load resistance is essential.

- **Water Absorption:** 0.58%, within the CTI requirement of ≤0.6%. Although this property met specifications, even small increases in water absorption over time could accelerate long-term degradation, particularly in environments of continuous immersion and thermal cycling.

Overall, the laboratory program confirmed that while certain properties such as flexural modulus and water absorption met minimum thresholds, critical performance parameters for shear and bearing strength fell short of CTI standards. The deficiencies in shear and bearing strength directly reduced member and connection reliability, while the variability in compressive performance raised questions about the consistency of the FRP supply chain. Together, these factors significantly reduced the structural reliability of the FRP members and connections, and they were integral to the collapse sequence.

5. STRUCTURAL / DESIGN EVALUATION (THIRD-PARTY FIRM)

A full structural model of the retrofitted tower was developed using available drawings and load criteria from ASCE7-16. The analysis incorporated dead load, live operational load, hydrostatic basin loads, and wind loading. To capture both theoretical and real-world performance, the model was run twice: first using the minimum FRP property values recommended by CTI-STD-137 and second using the actual laboratory test results obtained from destructive testing of field samples.

The remaining wood structural members had degraded to such an extent that their residual strength could not be quantified without removal and Modulus of Elasticity (MOE) testing, which the Owner advised was impractical for their situation. Therefore, a structural model was developed as if the entire tower was constructed of FRP members.

This approach demonstrated how the tower would have been expected to perform if the FRP material met published CTI-STD-137 minimum standards, and how it actually performed given the properties of the installed components. The comparison revealed that the retrofit design was deficient under both scenarios, but especially when evaluated against the true material data.

The diagonal brace straps, as supplied by this particular vendor, constructed of 76.2mm wide x 9.5 mm thick (3” wide x 3/8 inch thick) FRP, were immediately identified as inadequate. Under ASCE7-16 wind loading, interaction ratios exceeded 1.0 even with CTI baseline properties, meaning the braces were overstressed by design. When laboratory test results were substituted, overstress increased further, confirming that the braces were incapable of resisting lateral loads. Because these members were essential for transferring wind forces and stabilizing the frame, their inadequacy fundamentally compromised the structural system.

Column splices were also problematic. The retrofit omitted bearing plates, requiring the FRP itself to transfer compressive load through localized bearing at bolt holes. The model showed that this detail created high stress concentrations, which aligned with field observations of splice crushing and failures across multiple bents. Without plates, misalignments could not be corrected, and compressive forces were concentrated in vulnerable locations, accelerating failure.

The hot water basin framing was found to be significantly under designed. While the retrofit drawings assumed a 305 mm (12 in) basin depth, the analysis confirmed that member capacity was exceeded at this load. Safe performance could only be achieved at approximately 178 mm (7 in) of water depth, unless additional mid-bay nailers and compression blocks were introduced to provide restraint and stiffness. These reinforcements were absent in the as-built structure, leaving the joists prone to excessive deflection, inward buckling, and torsional instability.

Connection detailing throughout the retrofit further weakened the system. Joist supports fabricated from 140 mm (5.5 in) FRP channels were connected to columns using only a single bolt. The analysis demonstrated that this configuration could not meet minimum safety factors. The limited bearing area resulted in overstress and was consistent with the plowing and localized cracking observed in the field. Proper double-bolt connections, which distribute load more effectively and provide redundancy, were not used.

Collectively, the structural evaluation demonstrated that the retrofit did not meet the requirements of ASCE7-16, whether evaluated with CTI minimum values or actual laboratory data. The deficiencies identified in bracing, splice detailing, basin member design, and connection configuration produced a system with no acceptable margin of safety. These findings were corroborated by the collapse sequence documented in the field.

Summary of Structural Findings:

- Brace straps were undersized relative to ASCE7-16 wind loads, failing even under CTI minimum values; with laboratory data, overstress ratios increased to approximately 1.33, well beyond allowable limits.
- Column splices constructed without bearing plates developed high stress concentrations at bolt holes, leading to localized crushing and splice failures inconsistent with accepted detailing practices.
- Hot water basin members designed for a 305 mm (12 in) water depth exceeded their load-carrying capacity; analysis confirmed that safe performance was only possible at a reduced 178 mm (7 in) water depth unless compression blocks and mid-bay nailers were added.
- Connection detailing, particularly the use of single-bolt joist supports, was insufficient to meet minimum safety factors and directly correlated with observed plowing and cracking at FRP channels.
- Shear bushings were installed through multiple members in a manner that placed the bushings in shear. Although no failures were observed during field inspections, this detail raised concerns as it could not be reliably tested or analytically validated. The configuration introduces shear demand on the bushing material, representing a potential point of weakness. Refer to Figure 11 below.

6. QAQC & FOLLOW-UP

A formal QA/QC program was not established by either the customer or the repair contractor during the retrofit. In response to this gap, independent oversight was contracted to our team to perform quality checks during and after construction.

Three inspections were carried out between September and November 2024, each producing a findings report with photographic documentation and corrective recommendations.

1. The first inspection, conducted on the east side of Cell C, revealed that brace connections did not match the issued design details, hardware was missing at base anchors, anchor bolts were undersized, bearing plates were absent at column splices, and one tie had been improperly installed. These observations demonstrated both design omissions and construction errors that would have gone unaddressed without independent QA/QC oversight.

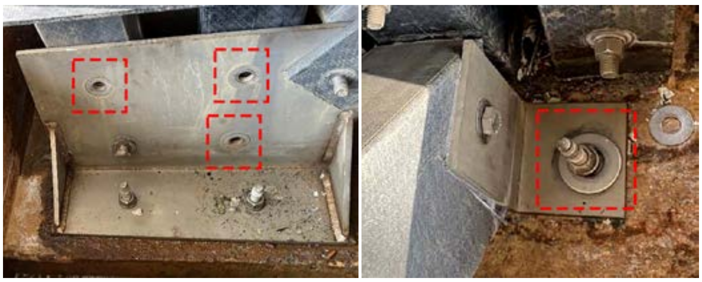

Figure 9: Missing Hardware on Base Anchor (left), Undersized Anchor Bolt (right)

2. The second inspection, covering Cells B and C, confirmed that some corrections were made but also identified outstanding issues. These included an uninstalled header standpipe on the west side, insufficient fastening of the longitudinal air seal wall, and missing fan deck mid-bay supports that represented a safety hazard.

Figure 10: Missing Bearing Plate (left), Uninstalled Standpipe (right)

3. The third inspection, performed on Cell A, reiterated concerns with brace connection details and missing FRP bushings, documented misaligned base anchor hardware, and noted absent bearing plates at column splices. Multiple failed wood ties, though outside the contractor's defined scope, were also recorded as structural concerns. Finally, the fill media review found missing rows of splash fill bars requiring correction.

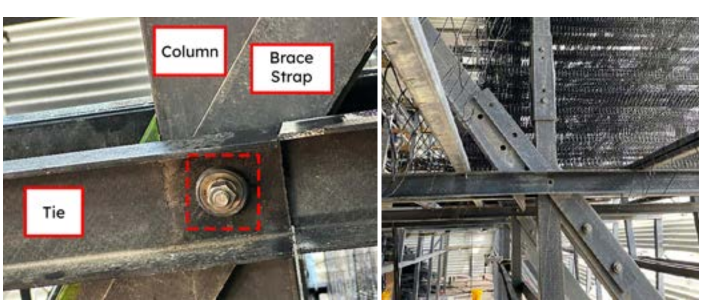

Figure 11: Bushing Installed at Column, Brace and Tie in Shear (left), Brace Strap Missing Hardware (right).

Each QA/QC findings report was formally submitted and reviewed with plant personnel. While the independent inspections provided critical oversight and led to correction of some deficiencies, several fundamental design omissions—such as the absence of bearing plates and compression blocks—remained unaddressed because they were not included in the contractor's scope of work. The findings demonstrate the necessity of a QA/QC program to ensure proper execution of cooling tower repairs, where craftsmanship and installation quality are as critical as design intent.

7. KEY FINDINGS

The investigation demonstrated that the collapse was not the result of one isolated error but the convergence of deficiencies in material quality, structural design, and installation practices. The following findings summarize the most critical issues identified:

7.1. Material Findings

Independent laboratory testing confirmed that the FRP material did not consistently meet the minimum mechanical property requirements of CTI-STD-137. Shear strength averaged 26.7 MPa (3,880 psi), approximately 14 percent below the required 31.0 MPa (4,500 psi), while bearing strength averaged 180 MPa (26,107 psi), 13 percent below the required 207 MPa (30,000 psi). These deficiencies directly compromised the load transfer capability of brace splices and bolted joints. Compressive strength and modulus testing could not be validated due to excessive bending strain and scatter in the data, indicative of non-homogeneous pultrusion and inconsistent fiber alignment. Such variability renders compressive properties unreliable, a critical issue for vertical column performance. While flexural modulus exceeded requirements, this mismatch in stiffness relative to other components could alter load distribution in unpredictable ways. Collectively, the material findings established that the FRP supply lacked uniform quality and reliable performance, weakening both member and connection behavior.

7.2. Design Findings

The structural evaluation showed that the retrofit design did not meet ASCE7-16 load requirements. The diagonal brace straps, fabricated from 9.5 mm (3/8 in) FRP, were under designed even when evaluated against CTI minimum properties, and overstress was amplified when actual laboratory results were applied. Column splices were detailed without bearing plates, creating localized stress concentrations at bolt holes that led to crushing and splice failures. The hot water basin framing assumed a 305 mm (12 in) water depth, but analysis confirmed members exceeded their capacity at this load. Safe performance was only achievable at approximately 178 mm (7 in) unless compression blocks and additional nailers were introduced, neither of which were present. Connection detailing further contributed to structural weakness: 140 mm (5.5 in) FRP channel supports for joists were attached with only a single bolt, an arrangement unable to provide adequate safety margins and directly linked to plowing and cracking observed in the field. These findings confirm that fundamental aspects of the retrofit design were undersized or improperly detailed, leaving the structure with no acceptable margin of safety.

7.3. Installation and Craftsmanship Findings

Field inspections revealed systemic workmanship deficiencies that compounded the weaknesses in material and design. Multiple fasteners were missing from column, tie, and brace connections, creating unsupported lengths as great as 4.88 m (16 ft). Such omissions directly contributed to column buckling observed at the failure site. Misalignments and improper field cuts of FRP members reduced effective section properties and introduced eccentricities. Torque checks showed that some installed bolts were inadequately tightened, further reducing connection capacity. Single-bolt details, already under designed, were not consistently installed to specification. In several instances, joist supports exhibited plowing damage at the channel lips, a clear symptom of connection overstress. Collectively, these deficiencies demonstrated a lack of consistent QA/QC during installation and highlighted how poor craftsmanship accelerated the progression to collapse.

7.4. Key Findings Summary

The combination of substandard FRP material, under designed retrofit details, and deficient installation practices created a system incapable of meeting minimum structural requirements. Material variability reduced confidence in member capacity, design omissions eliminated key safeguards such as bearing plates and compression blocks, and workmanship errors created conditions for immediate overstress. The interaction of these deficiencies established the root causes of the failure and underscores the importance of treating FRP retrofits as engineered systems requiring rigorous oversight at every stage.

8. ROOT CAUSE ANALYSIS

While the key findings identified deficiencies in material quality, structural design, and installation, it was the interaction of these deficiencies that produced the collapse. The sequence of failure most likely initiated at a column splice on the east side of Cell C. Missing bolts at the splice left an unsupported length of nearly 4.88 m (16 ft). Without bearing plates to distribute load, stress was concentrated at the bolt holes, accelerating localized crushing. The resulting instability caused the column to buckle, dropping the fan deck by approximately 127 mm (5 in).

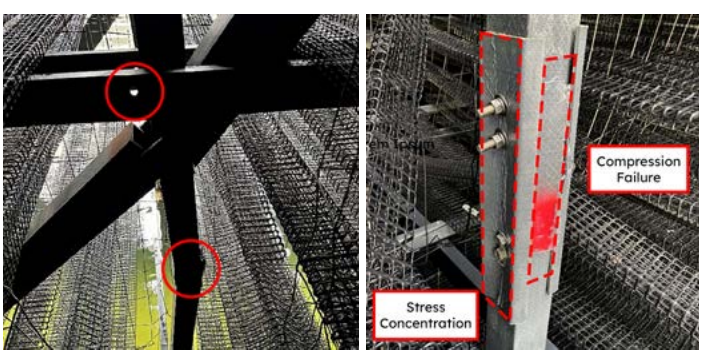

Figure 12: Missing Bolt Contributing to Buckling, Compression Failure at Splice with No Bearing Plate

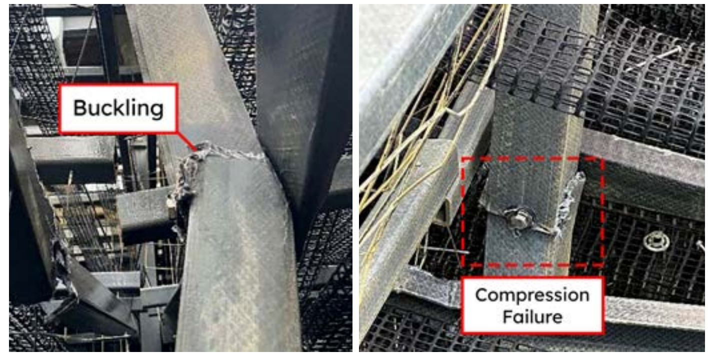

Figure 13: Column Member Exhibiting Buckling (left), Column Member in Compression Failure (right).

As the column failed, loads were redistributed into the adjacent framing system. Basin joists and diagonal braces, already operating near or above capacity under ASCE7-16 loads, were suddenly overstressed. The absence of required hardware at the brace connection attributed to the column buckling. At the same time, single-bolt joist supports began to plow at their channels, and the absence of compression blocks allowed joists to rotate and buckle inward.

Figure 14: Hot Water Basin Joist Exhibiting Plowing (left), Missing Hardware & Plowing of Member (right).

Figure 15: Hot Water Basin Joist Buckling Inward.

This progression produced a cascading collapse: column instability led to overstressed braces, brace failures transferred load to under designed joists, and joist failures allowed the basin framing to deform and twist, ultimately pulling the system into progressive failure across the east side of the cell.

Figure 16: Hot Water Basin Supports Vertical Displacement.

The root cause, therefore, was not a single deficiency but the combined effect of substandard FRP material, under designed retrofit details, and poor installation practices. The deficiencies reinforced one another: weak materials amplified the consequences of design omissions, and workmanship errors accelerated structural instability. The collapse illustrates how an accumulation of deficiencies, each individually significant, can interact to create a catastrophic failure.

9. ENGINEERING RECOMMENDATIONS

The investigation demonstrated that the collapse was caused by an accumulation of deficiencies across material properties, design practices, and installation quality. To prevent recurrence in future retrofit projects, several engineering measures are recommended. These recommendations are presented not as abstract ideals but as practical safeguards rooted in observed failures from this case.

9.1. Material Verification

All FRP components intended for structural use must be certified to comply with CTI-STD-137. Suppliers should provide batch-specific mechanical property data, and lot-by-lot independent testing must be conducted to verify compliance. In this case, the shear and bearing properties of the installed FRP fell short of CTI minimums, while compressive properties could not be validated due to excessive variability. Such material uncertainty directly undermines structural reliability. Future projects must eliminate reliance on vendor claims without third-party validation.

9.2. Structural Design Practices

Retrofit designs must account for the unique behavior of FRP, rather than relying on wood-based assumptions. Peer review by an independent licensed engineer should be required before any retrofit is implemented. Critical details include:

- **Bearing Plates at Column Splices**: All splices must incorporate stainless steel bearing plates to distribute load and mitigate misalignment. Their absence in this case produced localized overstress and accelerated splice failure.
- **Brace Sizing for ASCE7-16 Loads**: Diagonal brace straps must be designed to meet or exceed wind loads per ASCE7-16, using laboratory-confirmed FRP properties rather than assumed values.
- **Joist Supports and Compression Blocks**: Joists spanning greater than six feet must be provided with compression blocks to resist inward buckling and torsional rotation. Joist supports deeper than 140 mm (5.5 in) should use double-bolt connections to ensure redundancy and prevent plowing.
- **Basin Load Verification**: Hot water basin framing must be designed for the full operational water depth, not reduced assumptions. In this case, the retrofit was structurally safe only at 178 mm (7 in), while the design assumed 305 mm (12 in).

9.3. QA/QC Protocols

A formal QA/QC program should be included in the scope of all retrofit projects. Contractor self-certification is insufficient. Independent oversight should verify bolt counts, torque values, splice details, and member alignments against approved drawings. As-built documentation should be submitted and retained, including bent sketches and photographs of critical connections. Post-commissioning inspections should be conducted within six months and following major wind events. In this case, QA/QC was not included in the original scope of the contractor or owner and had to be contracted separately, a gap that directly contributed to the persistence of deficiencies in the as-built tower.

10. BROADER INDUSTRY IMPLICATIONS

This case study illustrates the broader risks of cost-driven decision-making in retrofit projects. While FRP has proven advantages as a material, its reliability is contingent on adherence to rigorous engineering practices and quality assurance. When owners or contractors cut costs through uncertified materials, undersized structural designs, or the omission of QA/QC, the result is not savings but deferred risk.

In this project, the initial decision to accept uncertified, foreign-sourced FRP and to proceed without a formal QA/QC program ultimately resulted in catastrophic failure. The collapse forced the rapid mobilization of temporary cooling towers to sustain plant operations. These emergency measures were not part of the original plan and imposed significant additional costs, including both direct expenses for temporary equipment and indirect costs associated with lost efficiency and production disruption.

The lesson for the industry is clear: the cost of failure will always exceed the cost of prevention. Short-term savings achieved through material substitution, reduced detailing, or omission of oversight create long-term risks that jeopardize safety, reliability, and operational continuity. Owners must recognize that proper design review, certified materials, and independent QA/QC are not optional overhead but essential investments. Engineers must resist pressure to accept reduced margins or omit safeguards, and contractors must uphold workmanship standards even when cost or schedule pressures mount.

Ultimately, this case reinforces that FRP retrofits are viable and effective when executed properly, but they demand the same rigor and discipline applied to any primary structural system. Industry-wide adoption of standardized FRP retrofit guidelines—including material acceptance testing, design detailing requirements, and QA/QC enforcement—will be essential to prevent similar failures and to preserve confidence in FRP as a long-term structural solution.”

11. CONCLUSION

The purpose of this investigation was to determine the cause of the partial collapse of a crossflow cooling tower following a wood-to-FRP retrofit and to evaluate the adequacy of the materials, design, and installation practices involved. The outcome of the study confirmed that deficiencies in all three areas—substandard FRP properties, under designed structural details, and inconsistent installation quality—combined to undermine the integrity of the tower and initiate progressive failure. The practical and safety takeaways are clear: FRP can be a durable and effective retrofit material, but only when supported by rigorous design practices, certified material verification, and structured QA/QC oversight. FRP and wood differ significantly in mechanical properties, connection behavior, and long-term performance. A one-for-one substitution cannot be assumed and structural analysis is required to verify adequacy before replacement. Without these safeguards, owners face increased operational risk and the potential for costly unplanned outages. Looking forward, the industry must move toward broader standardization in FRP retrofit QA/QC under the guidance of CTI, ensuring that acceptance testing, detailing requirements, and inspection protocols are applied consistently. Such standardization will not only prevent recurrence of similar failures but also reinforce confidence in FRP as a reliable long-term solution for cooling tower retrofits.

12. REFERENCES

ASTM D638, D790, D2344, D6641, D953, D570

CTI-STD-111, CTI-STD-136, CTI-STD-137

ASCE7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures

Independent forensic evaluations and laboratory testing reports

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