Second International Workshop on GFRP Bars for Concrete Structures

January 18-19, 2019
Orlando, Florida

Day 2

Advances in concrete reinforcement

B&B FRP Manufacturing Inc. · Rock Rebar Inc. www.RockRebar · PULTRALL · Olin · Dixie Chemical · Owens Corning · sireg

Session 3: Codes, Standards & Specifications Perspective on the use of GFRP Bars

(8:15 - 10:00pm)

Presentations (2 @ 10 mins)

3.1 Pending Updates to ACI 440-19/20? *(Antonio Nanni)*

3.2 Approved Updates to CSA 807-19 & S6-19 *(Brahim Benmokrane)*

Discussion 3.1 (30 mins)

Presentations (2 @ 10 mins)

3.4 Updates and Advancement for AASHTO GFRP-RC 2nd Edition *(Steven Nolan)*

Discussion 3.5 (30 mins)

Update on ACI Activities related to FRP bars

Document	Doc Ballot by Sub	Doc Ballot by 440 Main	Resolve Negative 440 Main Ballot	Doc to ACI for TAC Review	TAC Review	440 Reply to TAC Comments Ballot	Return to ACI for Layout	In Print
440-H CODE	PI-F15 PII-Su16	PI-S17 PII-S18	PI-S17 PII-S18	Fall 2019				
Bar Const. Spec	Done	Done	Done	Done	Done	Spring 2018		
440.2R Strengthening	One Section Done	One Section Done	One Section Done					
440.7R Masonry	Done	Done	Fall 2018					
Repair Const. Spec	Done	Spring 2018						
Fire TechNote	Done	Spring 2018						
440.4R Prestress	Fall 2018	Spring 2019						
440-J	Pending							

Plan is to get the code balloted at main by spring 2020

Negatives resolved and back to TAC

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Second International Workshop on GFRP Bars for Concrete Structures,

Orlando, FL, January 18-19, 2019

Session 3: Codes, Standards & Specifications Perspective on the use of GFRP Bars

Approved Updates to CSA S807-19 and CSA S6-19

Dr. Brahim Benmokrane, P.Eng.

Professor of Civil Engineering

Tier-1 Canada Research Chair

NSERC/Industry Research Chair

University of Sherbrooke, Sherbrooke, QC, CANADA

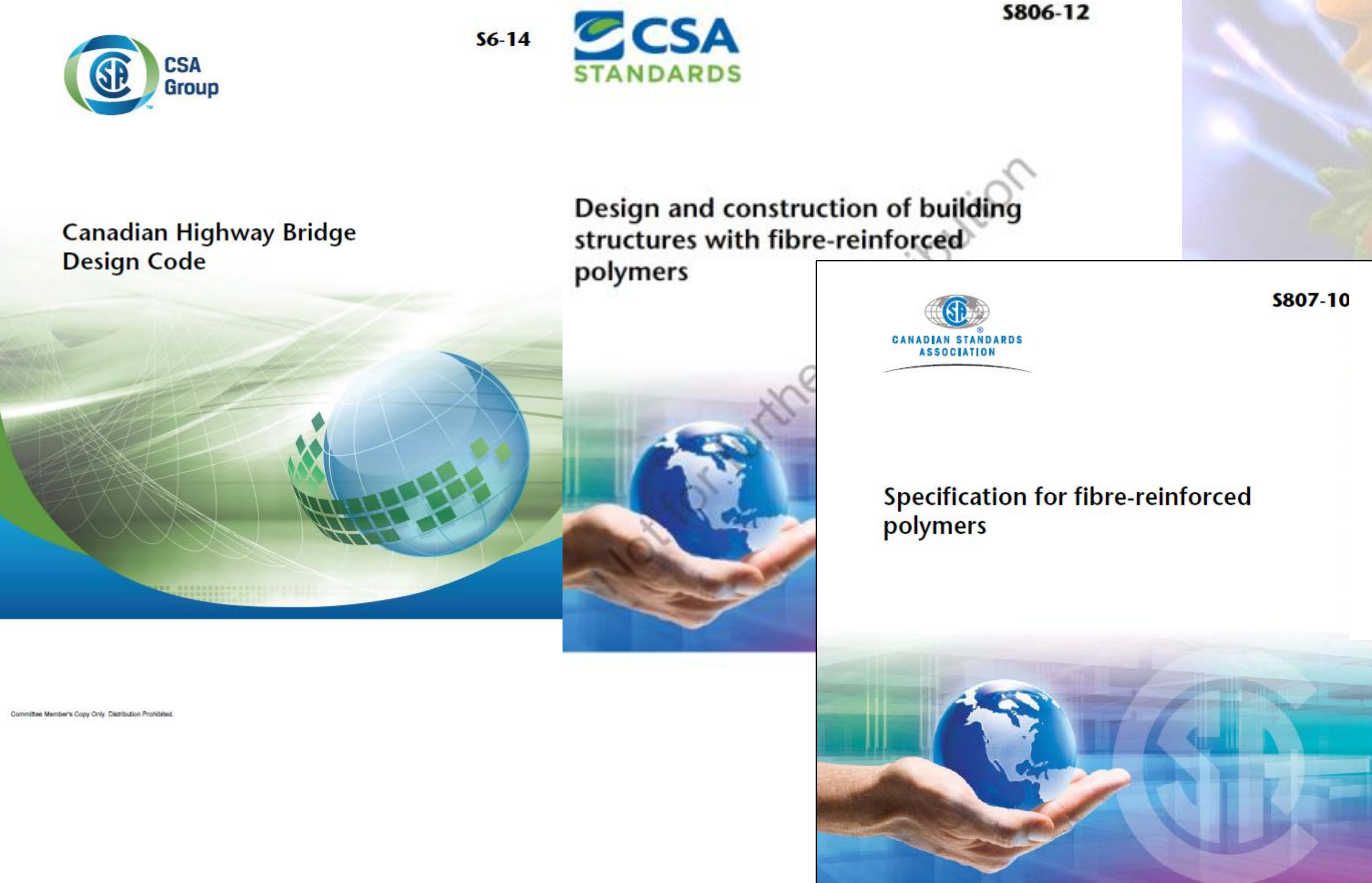
Canadian Codes, Standards & Specifications Related to GFRP Bars (CSA)

1. **CAN/CSA S807: “Specifications for Fibre Reinforced Polymers".** ***1st Edition in 2010; Re-approved in 2015; New Edition will be published in 2019 - APPROVED***

2. **CAN/CSA S6: "Canadian Highway Bridge Design Code", Section 16 "Fibre Reinforced Polymers (FRP) Structures".** ***1st Edition in 2000; 2nd Edition in 2006; Supplement S1, 2010; 3rd Edition in 2014; New Edition will be published in 2019 - APPROVED***

3. **CAN/CSA S806: "Design and Construction of Building Components with FRP“.** ***1st Edition in 2002; 2nd Edition in 2012***

Codes, Standards & Specifications in Canada for GFRP Bars (CSA)



Codes, Standards & Specifications in Canada on GFRP Bars (CSA)

- Design principles of GFRP-RC structures are well established through extensive research and field practice
- Provisions governing testing and evaluation for certification and QC/QA
- Describes permitted constituent materials, limits on constituent volumes, and minimum performance requirements
- Specific properties of GFRP reinforcement, design algorithms and resistance factors, detailing, material and construction specifications
- FRP bar preparation, placement (including cover requirements, reinforcement supports), repair, and field cutting

CSA Design Codes (CSA S6 and CSA S806)

- **Serviceability Limit State** (stress limit, crack-width, short & Long term deflection).
- **Ultimate Limit State** (resistance factor, strength)
- **Fatigue Limit State.**

Design Considerations with GFRP Bars

- The designer should understand that a direct substitution between GFRP and steel bars is not possible due to differences in mechanical properties of the two materials
- One difference is that GFRP are linear up to failure and exhibit no ductility or yielding- Deformability.
- Due to it's lower modulus of elasticity, serviceability limit state of GFRP reinforced concrete sections (such as deflection and crack widths) will govern the design.

CSA Design Codes (CSA S6 and CSA S806)

The current CSA design codes address the durability issue in design of GFRP reinforced sections through a common way considering the following:

- **The material resistance & environmental reduction factors based on fiber type and exposure conditions**
- **Limitation of maximum stress under service load**
- **Limitation of maximum crack-width under service load**
- **Limitation of maximum stress/strain level under sustained load**
- **Concrete cover (fire resistance)**
- **Creep rupture stress limits**
- **Fatigue stress limits**
- **Factor for long-term deflection calculation**

CSA Design Codes (CSA S6 and CSA S806)

As an example for the Canadian Highway Bridge Design Code (CSA S6), the specified values are:

Design Parameter	Design Value
Resistance factor	0.55 for GFRP bars
Stress under service load	25% of the guaranteed tensile strength for GFRP bars
Crack-width	0.5 mm

CSA S807


S807-10

CANADIAN STANDARDS ASSOCIATION

Specification for fibre-reinforced polymers

Table of Contents of S807

List of Tables

List of Annexes

A. Test Method for determination of cure ratio for FRP bars by DSC (normative)

B. Marking (informative)

C. Example of manufacturer's quality control plan (informative)

CSA S807 - Technical Committee

Brahim Benmokrane	**Université de Sherbrooke, Sherbrooke, Québec**	Chair
Baidar Bakht	JMBT Structures Research Inc., Scarborough, Ontario	
Nemkumar Banthia	University of British Columbia, Vancouver, British Columbia	
Bernard Drouin	Pultrall, Thetford-Mines, Québec	
Garth Fallis	Vector Construction Limited, Winnipeg, Manitoba	
Marc-Antoine Loranger	Transports Québec Direction des Structures, Québec, Québec	
Dritan Topuzi	Fiberline Composites Canada, Kitchener, Ontario	
David Lai	Ministry of Transportation of Ontario, St. Catharines, Ontario	
Rolland Heere	Metro Testing Laboratories Ltd, Vancouver, British Columbia	
Ghani Razaqpur	McMaster University, Hamilton, Ontario	
Martin Krall	Ministry of Transportation of Ontario	
Shamim Sheikh	University of Toronto, Toronto, Ottawa	
Jonathan Clavet	Sika Canada Inc., Pointe-Claire, Québec	
Allan Manalo	University of Southern Queesland, Australia	
Didier Hutchison	BP Composites, Edmonton, Alberta	
Ahmed Mostafa	Tem Corp, Toronto, Ontario	
Claude Nazair	Transports Québec Direction des Structures, Québec, Québec	
Ken Phu	**CSA Manager**	

CSA Material Specifications (CSA S807)

Describes permitted constituent materials, limits on constituent volumes, and minimum performance requirements .

Provides provisions governing testing and evaluation for product qualification and QC/QA.

CSA Material Specifications (CSA S807)

Example of Durability Related Provisions:

1. **Limit on Constituent Material, e.g.**
   - Limits on diluents and certain fillers
   - Limits on low-profile additives
   - No blended resins
2. **Lower Limit on Glass Transition Temperature (Tg) & Cure Ratio**
   - Minimum cure ratio and Tg
3. **Material Screening Through Physical & Durability Properties**
   - Maximum void content
   - Maximum water absorption
   - Limits on mechanical property loss in different environment conditioning (Alkali)

CSA Material Specifications (CSA S807)

As an example, the specified limits (acceptance/rejection criteria) are:

Property	Specified Limit
Void Content	Less than 1%
Water absorption	Less than 0.75%
Cure Ratio	Greater than 95%
Glass Transition Temperature	100 °C (DSC)
Alkali Resistance in High pH Solution	Greater than 80% (without load); Greater 70% (with load)
Creep Rupture	greater than 35% of UTS for GFRP bars

CSA Material Specifications (CSA S807)

Table 1: Designation of GFRP individual bars

Fiber	Designated diameter of bar with circular cross-section or width of bar with nominally square cross-section mm	Nominal cross-sectional area (mm^2)	Minimum specified tensile strength Mpa	Designation
Glass	6	32	750	*Ga-Eb-Dc*
	8	50	750	
	10	71	750	
	13	129	650	
	15	199	650	
	20	284	600	
	22	387	550	
	25	510	550	
	30	845	500	
	32	819	450	
	36	1006	450	

CSA Material Specifications (CSA S807)

Table 2 (Grades of FRP bars and grids corresponding to their minimum modulus of elasticity, GPa)

Designation	Grade I	Grade II	Grade III
	Individual bars	Individual bars	Individual bars
AFRP	50	70	90
CFRP	80	110	140
GFRP	40	50	60

CSA Material Specifications (CSA S807)

Table 4 (Determining physical and durability properties of FRPs (all bars sizes for qualification and manufacturer's QC))

Property	No. and details of test specimens required				Test method	Specified limits
	Qualification test	Manufacturer's QC	Owner's QA	Provided at request		
Fibre content	9 tests from 3 production lots 10, 15, 20, and 25 mm or only the sizes manufactured by the supplier	3 tests for each bar size used on project	5 tests for each bar size used on project	N/A	The relevant of the following: (a) bars with glass fibre: ASTM D2584 or ASTM E1131; (b) bars with carbon fibre: ASTM E1131; or (c) bars with aramid fibre: no method is available; provide the theoretical content	Fibre volume fraction ≥55% for FRP bars; fibre volume fraction ≥35% for FRP grids; for ASTM D2584, glass Fibre fraction ≥70% by Weight
Longitudinal coefficient of thermal expansion	N/A	N/A	N/A	5 tests on bar size requested	ASTM E831 at temperature = 0.1-0.3 T_g; or ASTM D696	N/A
Transverse coefficient of thermal expansion	9 tests from 3 production lots 10, 15, 20, and 25 mm or only the sizes manufactured by the supplier	N/A	5 tests for each bar size used on project	N/A	ASTM E831 at temperature = 0.1-0.3 T_g; or ASTM D696	Transverse coefficient of thermal expansion ≤40 x 10-6 °C-1

CSA Material Specifications (CSA S807)

Qualification Tests Per GFRP Bar Size

1. **Tensile Strength:** 24 specimens
2. **Bond Strength:** 24 specimens
3. **Transverse Shear Strength:** 24 specimens
4. **Strength of bent bars:** 24 specimens
5. **Tensile Strength at cold temperature:** 24 specimens
6. **Fibre Content:** 9 specimens
7. **Transverse Coefficient of Thermal Expansion:** 9 specimens
8. **Void Content:** 9 specimens
9. **Water Absorption:** 15 specimens
10. **Cure Ratio:** 15 specimens
11. **Glass Transition Temperature:** 15 specimens
12. **Alkaline Resistance without/load:** 24 specimens
13. **Alkaline Resistance with/load:** 24 specimens
14. **Creep Rupture :** 24 specimens

CSA Material Specifications (CSA S807)

At least six Canadian GFRP bar manufacturers/suppliers qualified their products and obtained approvals from end-users and government authorities (such as MTO and MTQ):

1. **B&B FRP MANUFACTURING INC.** (MSTBAR)
2. **BP COMPOSITES INC.** (TUF-BAR)
3. **FIBERLINE COM POSITE CANADA INC.** (COMBAR)
4. **PULTRALL INC.** (V-ROD)
5. **TEMCORP INC.** (TEMBAR)
6. **PULTRON INC.** (MATEEN)

Hughes Brothers Inc., Marshall Composite Technologies Inc., Composite Rebar Technologies Inc., (USA), FiReP International AG (Switzerland), Asamer (Austria), Magmatech Ltd (United Kingdom), Galen (Russia), etc.

CSA Material Specifications (CSA S807)

Summary of the major changes in the upcoming new edition of CSA S807

- **The new CSA S807 standard includes FRP bars made of basalt fibres.**
- **Only E-CR glass fibers is permitted for GFRP bars. The E-CR glass fibers shall meet the requirements of ASTM D578.**

CSA Material Specifications (CSA S807)

Summary of the major changes/additions in the new edition of CSA S807

Fine Aggregate for Sand Coating:

For sand coated bars, the sand shall be sourced from fine aggregates that are suitable for use in concrete. Fine aggregate sources shall be demonstrably known to be free of reactions with concrete that produce expansion or cracking, owing to the criticality of the sand particles in the bond between the FRP reinforcing bar and concrete.

Without limiting the reactions that may cause expansion and cracking, the fine aggregate sources shall be specifically free of alkali aggregate reactions with concrete, such as alkali-silica or alkali-carbonate, and come from sources that have demonstrated such compliance.

ASTM AND CSA TEST METHODS FOR ALKALI-SILICA REACTION

CSA Material Specifications (CSA S807)

Summary of the major changes/additions in the new edition of CSA S807

Production lot size

The production lot size of straight bars shall be divided in sub-lots of 20,000 m of bars up to a maximum of 60,000 m of bars of the same diameter.

QC tests as indicated in Tables 3 and 4 for the first sub-lot of 20,000 m.

For the two subsequent sub-lots of 20,000 m each, the QC tests shall include:

- fibre content;
- glass transition temperature;
- cure ratio;
- water absorption for one week; and
- apparent Horizontal Shear Strength.

CSA Material Specifications (CSA S807)

Summary of the major changes/additions in the new edition of CSA S807

Production lot size

The production lot size of bent bars of congruent shape and anchor-headed bars shall be divided in sub-lots of 2000 pieces up to a maximum number of 6000 pieces.

QC tests as indicated Tables 3 and 4 for the first sub-lot of 2000 pieces.

For the subsequent two sub-lots of 2000 pieces each, the QC tests shall include

- fiber content;
- glass transition temperature;
- cure ratio;
- water absorption for one week; and
- apparent Horizontal Shear Strength.

CSA Material Specifications (CSA S807)

Summary of the major changes in the upcoming edition of CSA S807

New tables for mechanical properties (minimum modulus of elasticity and minimum tensile strength) with distinction between straight and bent bars.

Qualification testing shall be performed on the mechanical, physical, and durability properties relating to both short- and long-term performance of straight and bent bars,

A lower and an upper limit for cross-sectional area of GFRP bars have been defined. The lower limit will be 95 % of the nominal cross-sectional area. The upper limit will be ≤ 120 % of the nominal cross-sectional area for bars of 20 mm and smaller; and ≤ 115 % for bars larger than 20 mm.

CSA Material Specifications (CSA S807)

Summary of the major changes in the upcoming edition of CSA S807

- New tests for the evaluation of durability characteristics of bent and headed GFRP bars are added such as interlaminar shear strength in high pH solution at 60°C and tensile strength retention of headed GFRP bars after conditioning in alkaline solution under sustained load for 120 days at 60°C.

- A new testing method for determining the strength of the bent portion of GFRP bars has been proposed for qualification & quality control testing. This method is viewed as more convenient than the ACI 440.3R B.5.

- Alkali resistance in high pH solution (without load), the tensile capacity retention ≥ increased from 80% to 85% UTS.

- Alkali resistance in high pH solution (with load), the tensile capacity retention ≥ increased from 70% to 75% UTS.

CSA Material Specifications (CSA S807)

Table 1A
Designated Bar Diameter and Nominal Area
(Same as ASTM D7957/D7957M – 17)

Diameter mm	Nominal cross-sectional area (mm2)	Minimum measured cross-sectional area (mm2)	Maximum measured cross-sectional area (mm2)
8	50	48	79
10	71	67	104
13	129	119	169
15	199	186	251
20	284	268	347
22	387	365	460
25	510	476	589
30	645	603	733
32	819	744	894
36	1006	956	1157

.

CSA Material Specifications (CSA S807)

MinimumTensile Strength for GFRP Rebars (Grade III)

Minimum tensile strength for straight bars (#4 to #8) :
1000 MPa (145 ksi)

Minimum tensile strength for straight portion of bent bars (#4 to #8) :
1000 to 850 MPa (145 to 125 ksi)

Minimum tensile strength for bent portion of bent bars (#4 to #8) :
450 to 390 MPa (65 to 57 ksi)

CSA Material Specifications (CSA S807)

Annexes

A (normative) –

Test method for determination of cure ratio for FRP bars by DSC

B (informative) –

Handling and Storage

C (informative) –

Marking

D (informative) –

Example of manufacturer's quality control plan

E (normative) –

Method of test for determining the strength of the bent portion of FRP reinforcing bars

F (normative) –

Evaluation of durability characteristic of anchor headed glass fiber–reinforced polymer Bars

CSA Material Specifications (CSA S807)

Tables

1A - Designated bar diameter and nominal area
1B - Minimum tensile strength for straight bars
1C - Minimum tensile strength for straight portion of bent bars
1D - Minimum tensile strength for bent portion of bent bars
2A - Grades of FRP straight bars and grids corresponding to their minimum modulus of elasticity
2B - Grades of FRP bent bars corresponding to their minimum modulus of elasticity of the straight portion
3 - Determining mechanical properties of FRPs (all bar sizes for qualification and manufacturer's QC)
4 - Determining physical and durability properties of FRPs (all bars sizes for qualification and manufacturer's QC)
5 - Minimum pullout capacity of anchor headed bars

CSA Material Specifications (CSA S807)

Summary of the **major changes** in the upcoming edition of CSA S807

Annex A (normative)
Test Method for determination of cure ratio for FRP bars by DSC

Annex B (informative)
Handling and Storage

Annex C (informative)
Marking

Annex D (informative)
Example of manufacturer's quality control plan

Annex E (normative)
Method of Test for Determining the Strength of the Bent Portion of FRP Reinforcing Bars

Annex F (normative)
Evaluation of Durability Characteristics of Headed Glass Fiber–Reinforced Polymer Bars

Annex E (normative)
Method of Test for Determining the Strength of the Bent Portion of FRP Reinforcing Bars

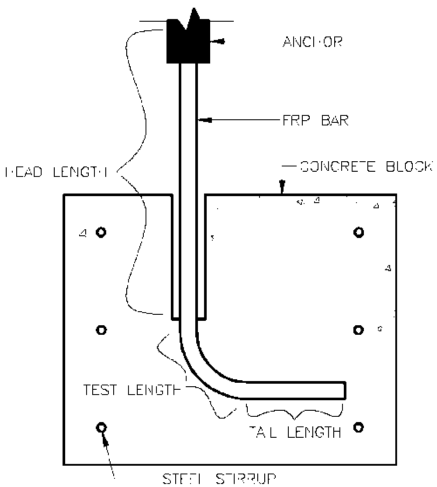


Figure 1 – General Arrangement

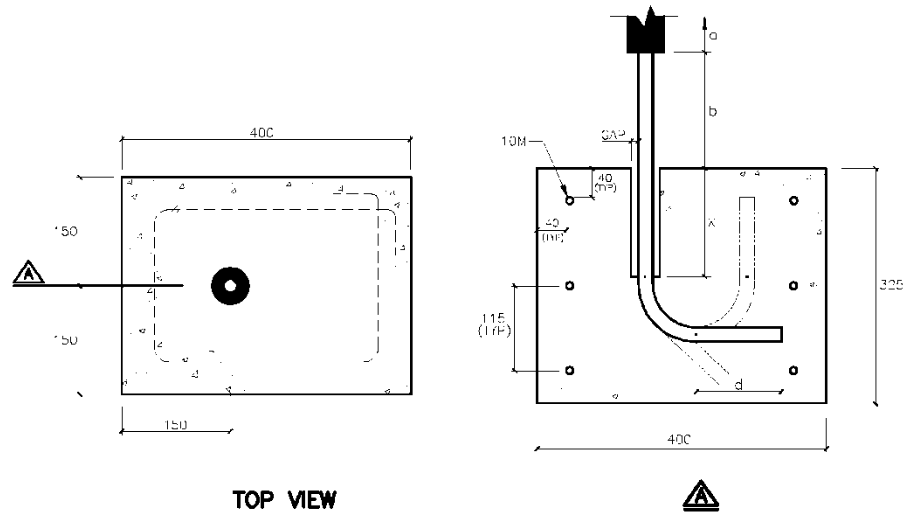
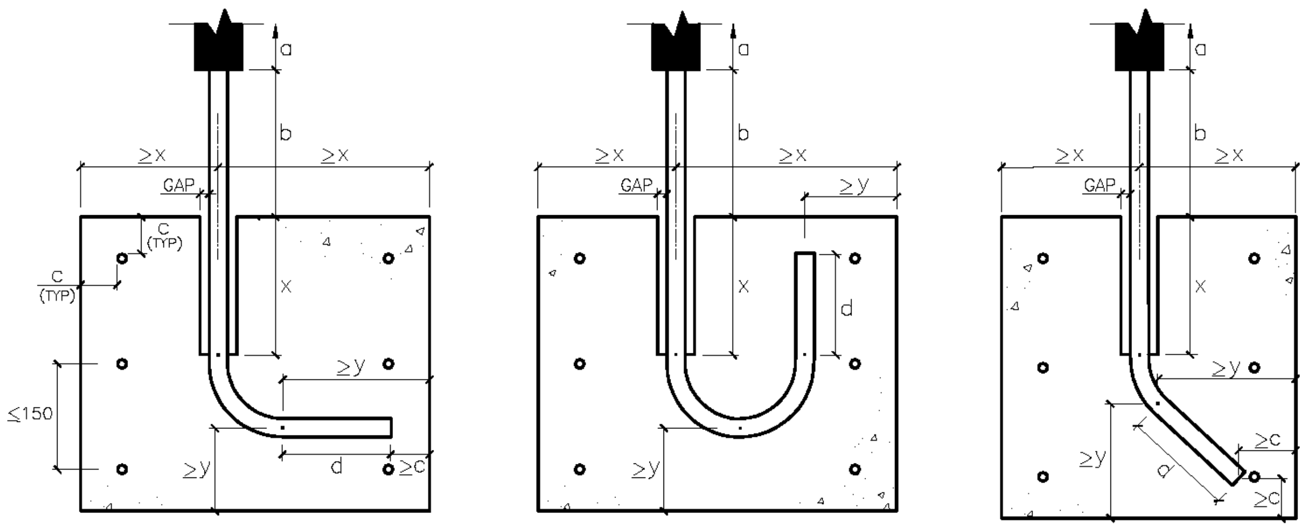


Figure 2 – Dimensional Arrangement of the Block

(nominal diameter of 20 mm or less, bent at an angle between 0 and 180 degrees, and manufactured with a bend-radius-to-bar-diameter ratio of 4 or less)

Annex E (normative)
Method of Test for Determining the Strength of the Bent Portion of FRP Reinforcing Bars



A custom block shall be made for large sizes of bars and bent

Annex F (normative)
Evaluation of Durability Characteristics of Headed Glass Fiber–Reinforced Polymer Bars

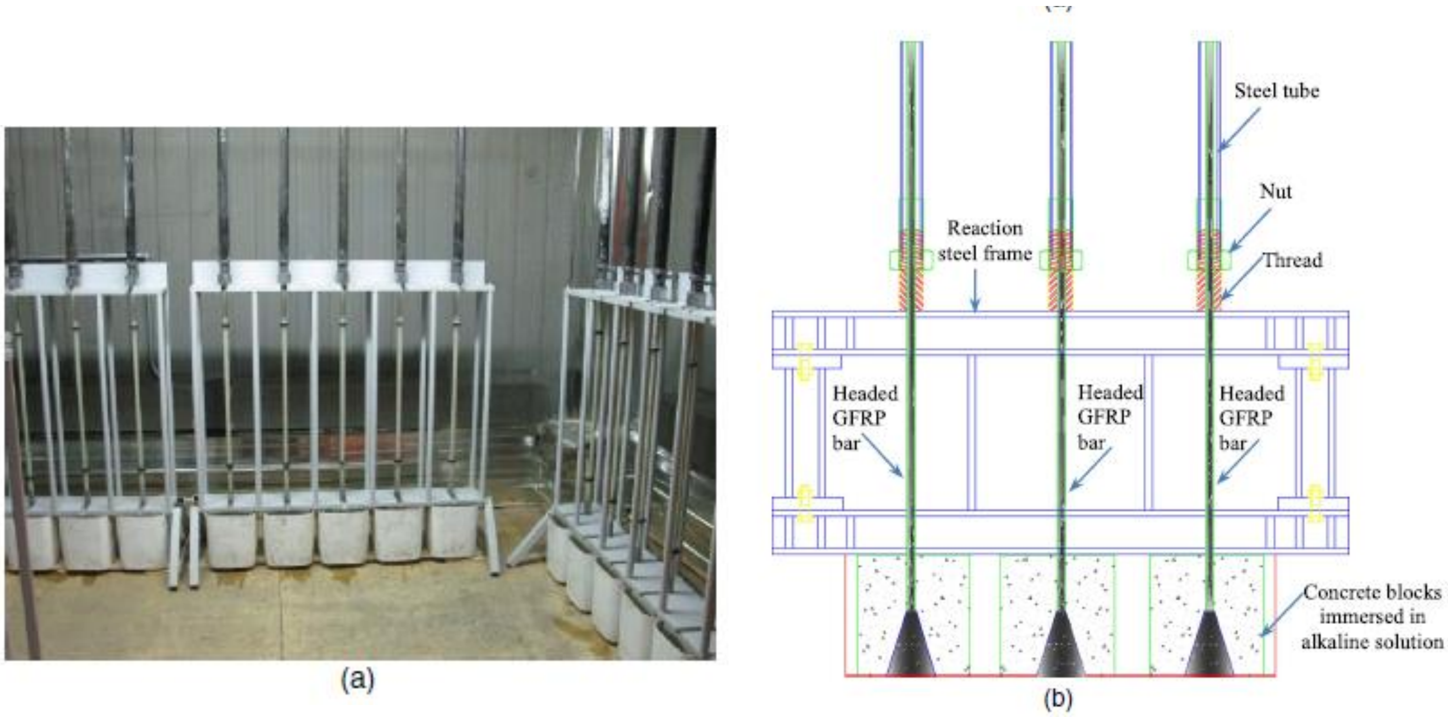


Figure F1. Conditioning of headed GFRP bars in alkaline solution under sustained load (a) test setup; (b) schematic diagram

CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019*

1. **Durability/Material properties/New structural materials**
   (Lead: Benmokrane, Lai, Ben Huh, Mostafa)

2. **Concrete bridge components reinforced internally with FRP reinforcement**
   (Lead: Benmokrane, Sheikh, Bakht, Mufti, Salib, Lai, Galipeau)

3. **Concrete bridge components reinforced externally with FRP reinforcement**
   (Lead: Green, Sheikh, Bakht, Benmokrane, Mostafa, Schaefer)

4. **Concrete bridge components prestressed with FRP**
   (Lead: Svecova, Benmokrane, Green)

5. **Wood bridge components reinforced with FRP**
   (Lead: Bakht, Svecova)

6. **FRP only structures**
   (Lead: Almansour, Benmokrane, Salib, Wight)

7. **FRP formwork**
   (Lead: Almansour, Fam, Green)

CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019 –*

Durability/Material properties/New structural materials

16.5.1 FRP bars and grids

FRP bars and grids shall be manufactured and qualified in accordance with CSA S807.

The properties of FRP bars and grids shall be provided by the manufacturer in accordance with CSA S807.

All of the design properties of FRP bars and grids shall be obtained from tests conducted in accordance with CSA S807.

CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019 –*

Durability/Material properties/New structural materials

16.5.3 Resistance factor (phi factor)

We increased the phi factor of GFRP bar from 0.55 to 0.65

Rational:

Durability of GFRP bars has been enhanced during the last few years:

1. Better manufacturing process and quality control
2. Better constituents : 1) ECR-Glass versus E-Glass; Most of the GFRP bar manufacturers are using boron-free glass fibres (ECR, commercial name Owens Corning), 2) High-performance resins (advances in polymer chemistry)
3. Durability tests in alkaline solution show high strength retentions without load and under loads (CSA S807): 1) greater than 90-95% (without load), 2) greater than 83-90% (with load).
4. Recently the MTQ took cores for in-service bridges (more than 15 years). No degradation.
5. Durability of GFRP versus durability of concrete? The phi for concrete in the CHBDC is 0.75.

CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019 –*

Concrete bridge components reinforced internally with FRP reinforcement

16.8 Concrete beams, slabs and columns reinforced with GFRP bars

New provisions:

1. Development length of FRP bundled bars
2. Development length of FRP bent bar
3. Splice length for FRP bars
4. Anchorage of headed FRP bar
5. Design for shear and torsion
6. Compression components (combined flexure and axial)
7. Strut-and-tie model
8. Barrier walls
9. Recommended practice for repair of damaged bridge barrier walls, curbs, and slabs reinforced with FRP bars

Thank you for your attention

Questions?

Contact:

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Discussion 3.3 (30 mins)

Presentations (2 @ 10 mins)

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Discussion 3.5 (30 mins)

Outline

1. Defining the problem…
2. Are Composites the solution?
3. New Challenges - *SLR, Extreme Weather, Sustainability, Increased Durability Expectations*
4. New Solutions – *SEACON, GFRP-PC*
5. Improving of Creep-Rupture limits
6. Where do we go from here?

What is the Problem?

Need for New Solutions for Corrosion Durability and Sustainability

Avoiding corrosion *"concrete cancer"*

- GFRP or SS rebar
- CFRP or HSSS prestressing strand

i. Cost-Benefit Analysis Justification, LCA/LCC;

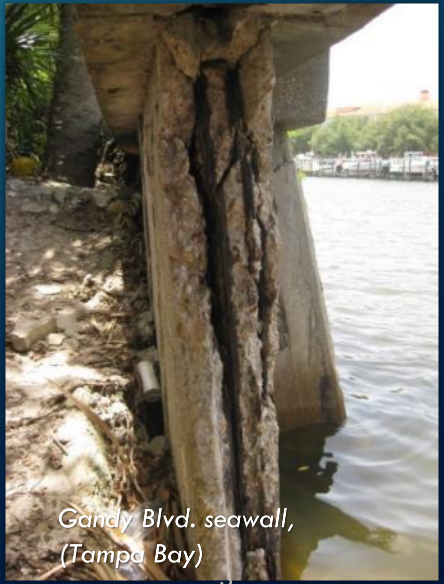
ii. Durability = Long Service Life;

iii. Challenges & Mitigating Risks

- Acquisition Cost
- New material systems;
- Limited suppliers/competition;
- Unfamiliar design criteria;
- Unfamiliar construction practices.

New and Old Seven-Mile-Bridge, (Florida Keys)

Courtney Campbell Causeway, seawall (Tampa Bay)



Gandy Blvd. seawall, (Tampa Bay)

Are Composites the Solution?

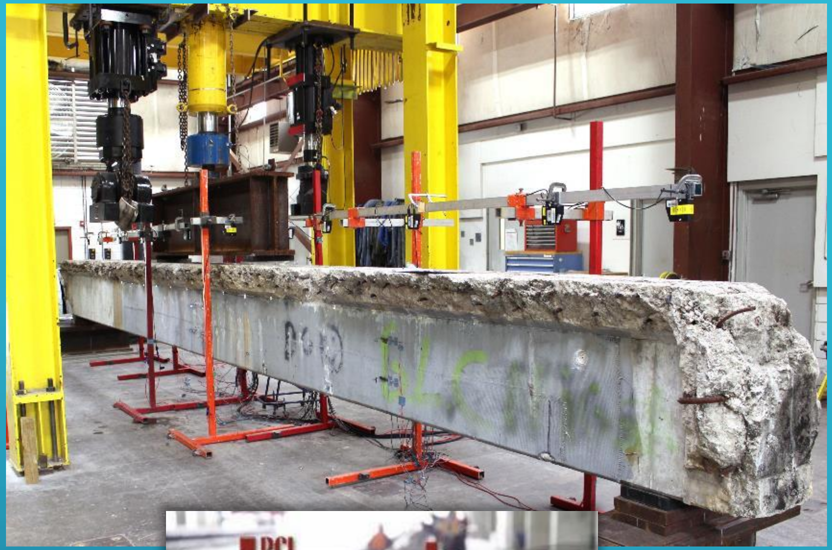
- Service Life Enhancement thru Durability:

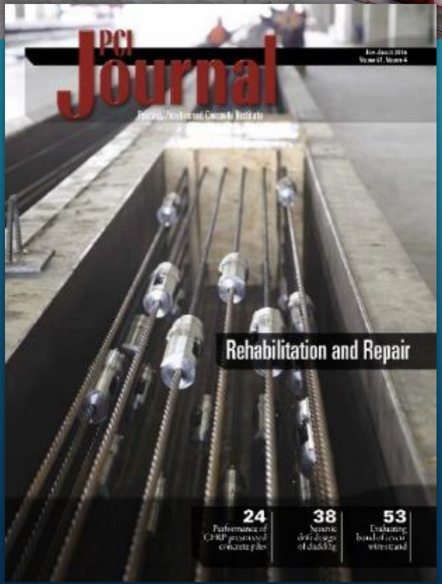
FDOT Research Efforts

1992	Feasibility of Fiberglass Pretensioned Piles in a Marine Environment	Sen, R.	USF
1995	Active Deformation Control of Bridges with AFRP Cables	Arockiasamy, M.	FAU
1995	Durability of CFRP Pretensioned Piles in a Marine Environment – Phase II	Sen, R.	USF
1997	Mechanical and Microscopy Analysis of CFRP Matrix Composite Materials	Garmestani, H.	FAMU/FSU
1997	FRP Composite Column and Pile Jacket Splicing	Mirmiran, A.	UCF
1997	An Analytical and Experimental Investigation of Concrete Filled FRP Tubes	Mirmiran, A.	UCF
1997	Flexural Reliability of RC Bridge Girders Strengthened with CFRP Laminates	Okeil, A.	UCF
1998	Studies of CFRP Prestressed Concrete Bridge Columns and Piles in Marine Environment	Arockiasamy, M.	FAU
1999	LRFD Flexural Provisions for PSC Bridge Girders Strengthened with CFRP Laminates	El-Tawil, S.	UCF
2000	Investigation of Fender Systems for Vessel Impact	Yazdani, N.	FAMU/FSU
2001	Design of Concrete Bridge Girders Strengthened with CFRP Laminates	El-Tawil, S.	UCF
2003	Hybrid FRP-Concrete Column	Mirmiran, A.	NC State
2004	CFRP Repair of Impact Damaged Bridge Girders	Hamilton, T	UF
2009	Thermo-Mechanical Durability of CFRP Strengthened RC Beams	Mackie, K	UCF
2011	Testing of Trelleborg Structural Plastics	Wagner, D.	FDOT

Are Composites the Solution?

FDOT Research Efforts (Cont.)





2012	The Repair of Damaged Bridge Girders with CFRP Laminates	El-Safty, A.	UNF
2014	Investigation of CFCC in Prestressed Concrete Piles	Roddenberry, M.	FAMU/FSU
2015	Repair of Impact Damaged Utility Poles with FRP, Phase II	Mackie, K.	UCF
2015	Use of CFRP Cable for Post-Tensioning Applications	Mirmiran, A.	FIU
2017	Durability Evaluation of Florida's FRP Composite Reinforcement for Concrete Structures	Hamilton, T.	UF
2018	Bridge Girder Alternatives for Extremely Aggressive Environments	Brown, J.	ERAU
2018	Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements	El-Safty, A.	UNF
2018	Testing, Evaluation, and Specification for Polymeric Materials used for Transportation Structures	El-Safty, A.	UNF
2018	Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments	Kampmann, R.	FAMU/FSU
2019	Inspection and Monitoring of Fabrication and Construction for the West Halls River Road Bridge Replacement	Roddenberry, M.	FAMU/FSU
2021	Evaluation of GFRP Spirals in Corrosion Resistant Concrete Piles	Jung, S.	FAMU/FSU
2021	Development of GFRP Reinforced Single Slope Bridge Rail	Consolazio, G.	UF
2019	Performance Evaluation, Material and Specifications for Basalt FRP Reinforcing Bars Embedded in Concrete (STIC)	Kampmann, R. Roddenberry, M.	FAMU/FSU
2021	Testing Protocol and Material Specifications for Basalt Fiber Reinforced Polymer Bars	Kampmann, R. Tang, Y	FAMU/FSU

New Challenges

SLR, Extreme Weather, Sustainability, Increased Durability Expectations

Photos from Hurricane Matthew (2016)

New Challenges

SLR, Extreme Weather, Sustainability, Increased Durability Expectations

(a) Hurricane Damage along A1A *(2008)*

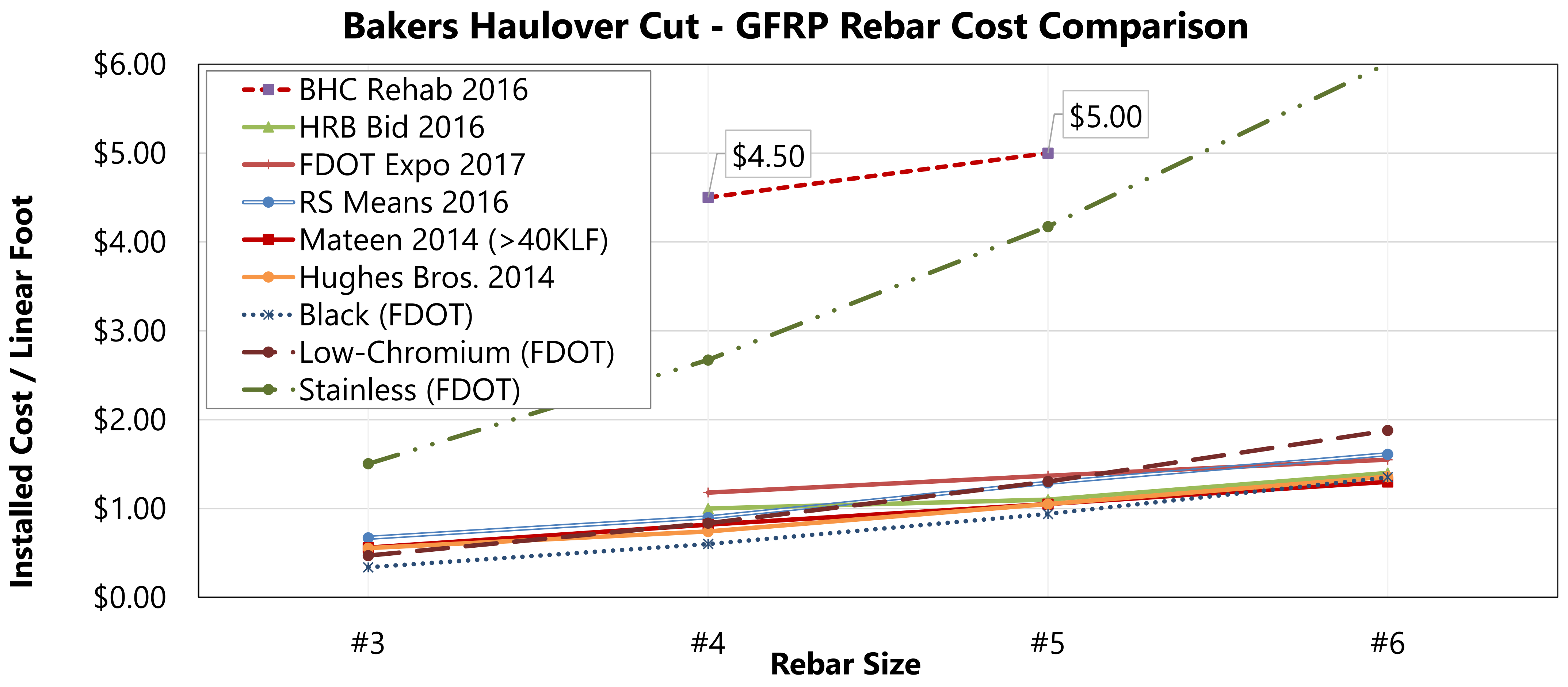
(b) Hurricane Sandy damage along A1A in Fort Lauderdale *(Photo: Susan Stocker, Sun Sentinel, 2012).*

(c) Hurricane Mathew damage along A1A Flagler Beach, *(2016)*

(d) Brickell Ave under water during Hurricane Irma *(2017)*

New Seawall-Bulkhead Systems

Estimated Cost of Reinforcing Alternatives (in-place):



New Solutions

Reviving an old system with new material - Post and Panel with FRP-RC/PC

2 new FDOT projects in design:

1. NE 23rd Ave Bridge Replacement
2. US 41 over North Creek replacement
3. Possibly… Barracuda Blvd. over Indian River North

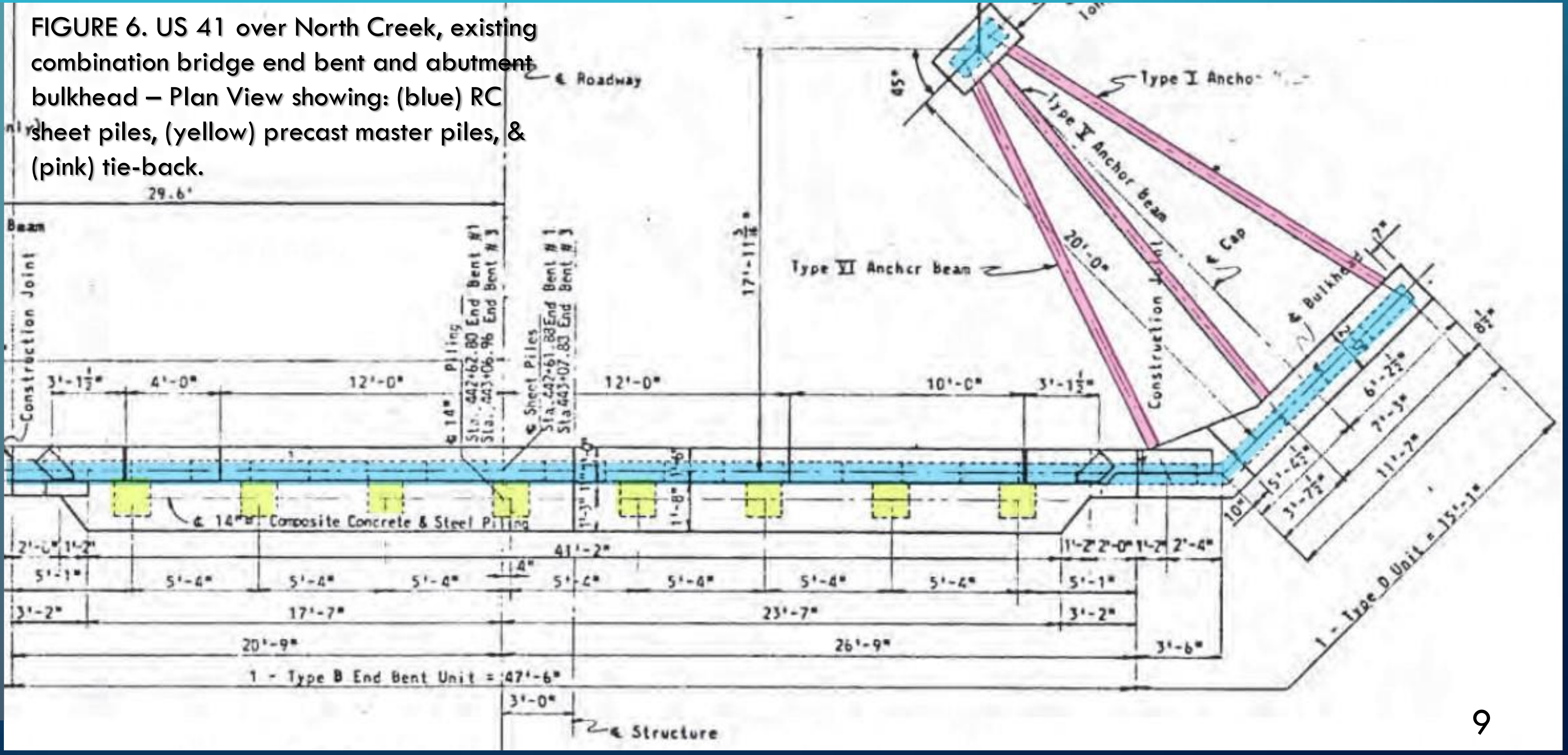
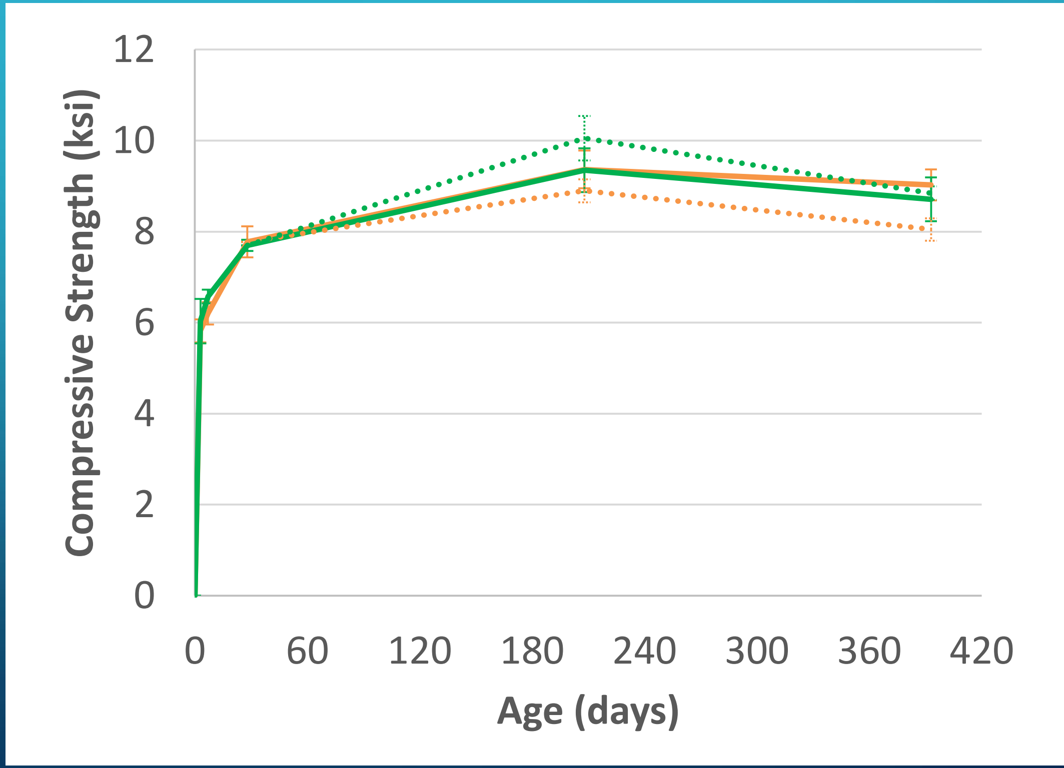


FIGURE 6. US 41 over North Creek, existing combination bridge end bent and abutment bulkhead – Plan View showing: (blue) RC sheet piles, (yellow) precast master piles, & (pink) tie-back.

New Solutions

SEACON…

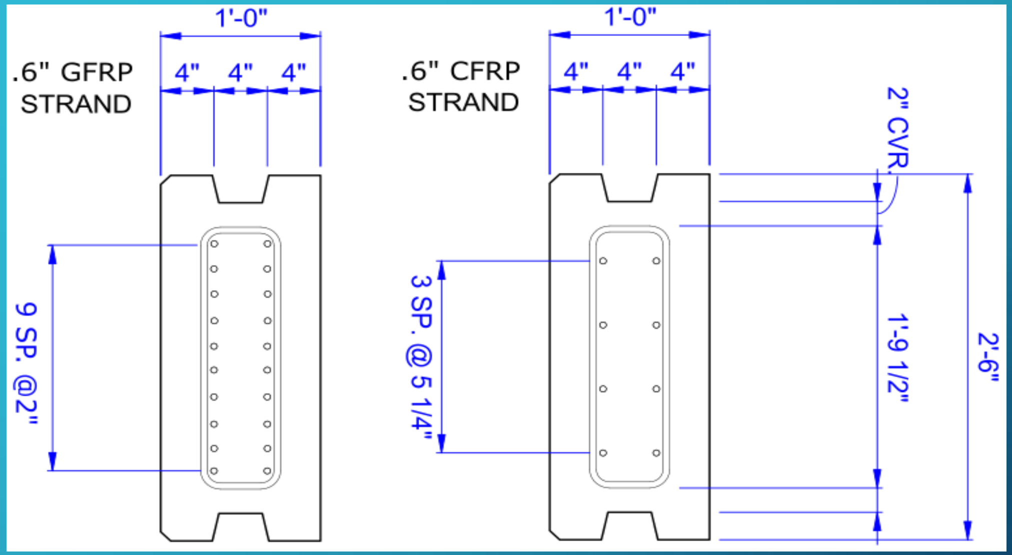
Sustainable concrete using seawater, salt-contaminated aggregates, and non-corrosive reinforcement



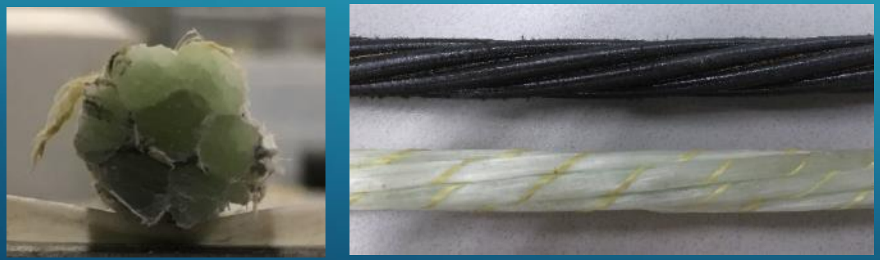
New Solutions

IDEA Project - *MILDGLASS*

(a) & (b) CFRP strand failed during tensioning;
(c) cracking following strands release.



(a) GFRP-PC sheet pile concept (b) CFRP-PC sheet pile design for Halls River Bridge



(a) GFRP strand prototype cross section;
(b) compared to a CFRP alternative.

(a) & (b) Tensioning apparatus for CFRP; versus (c) standard steel HSCS chucks, for GFRP.

New Solutions

- Affordable higher modulus GFRP $\geq$ 65 GPa (9,000+ ksi)
- Adhoc continuous stirrups;
- STIC 2018 Incentive Project
  – *Basalt-FRP Rebar Standardization*

FDOT

STIC
State Transportation Innovation Councils

"Develop standard (guide) design specification, and standard material and construction specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete"

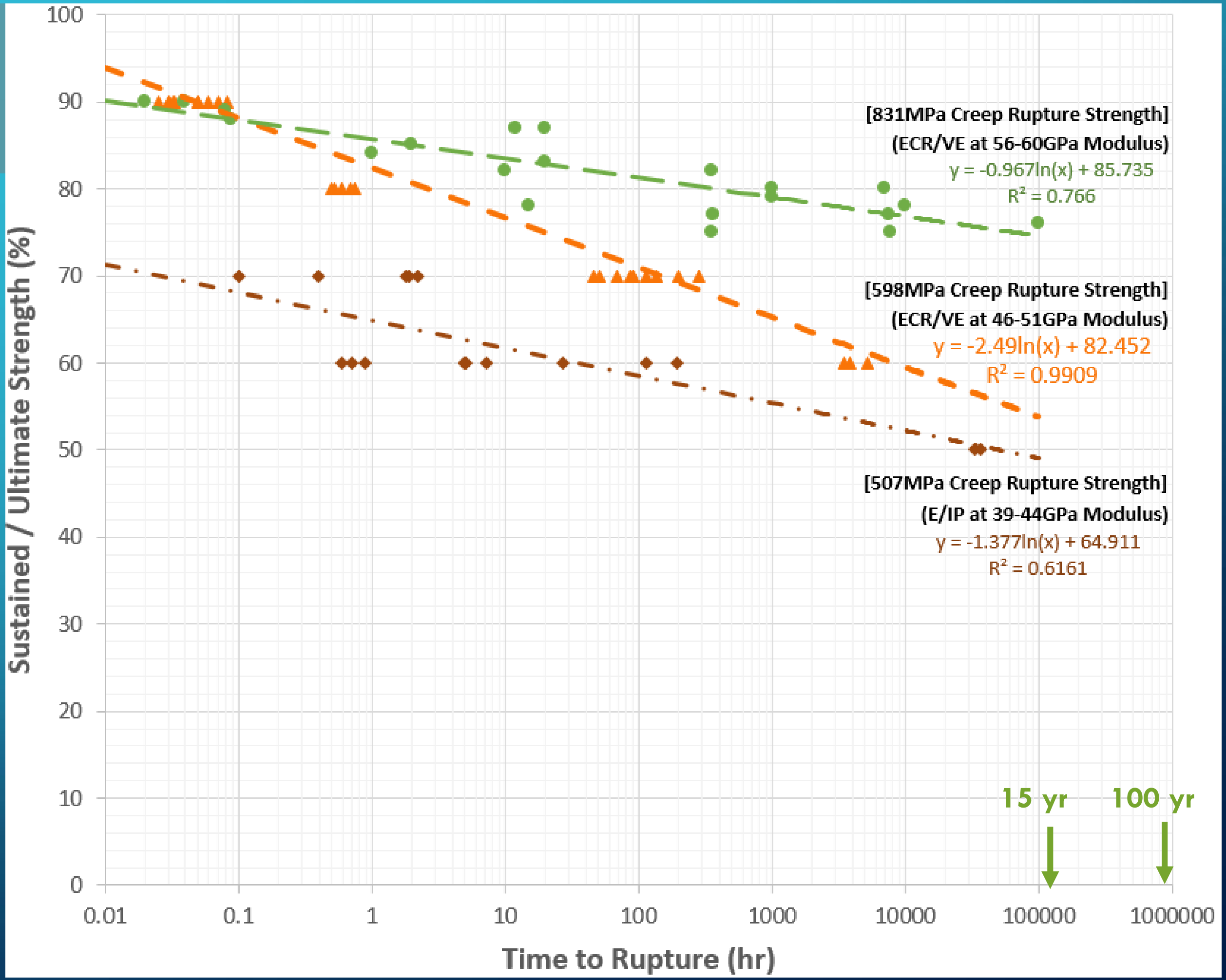
Photo courtesy of Don Smith, RAW Energy Materials (2019)

Why Improve Creep-Rupture Limits?

Enhance AASHTO Specifications and Extend Bridge Service Life

ACI 440.3R B.8 GFRP Creep Rupture Accelerated Testing

1. ACI 440.1R limits the allowable sustained stress for traditional GFRP;
2. Creep rupture limit recently improved C_C = 0.2 to 0.3 in AASHTO BDGS-2;
3. ASTM D7957 GFRP rebar of ECR glass fiber in vinyl ester shows improved creep rupture limit.

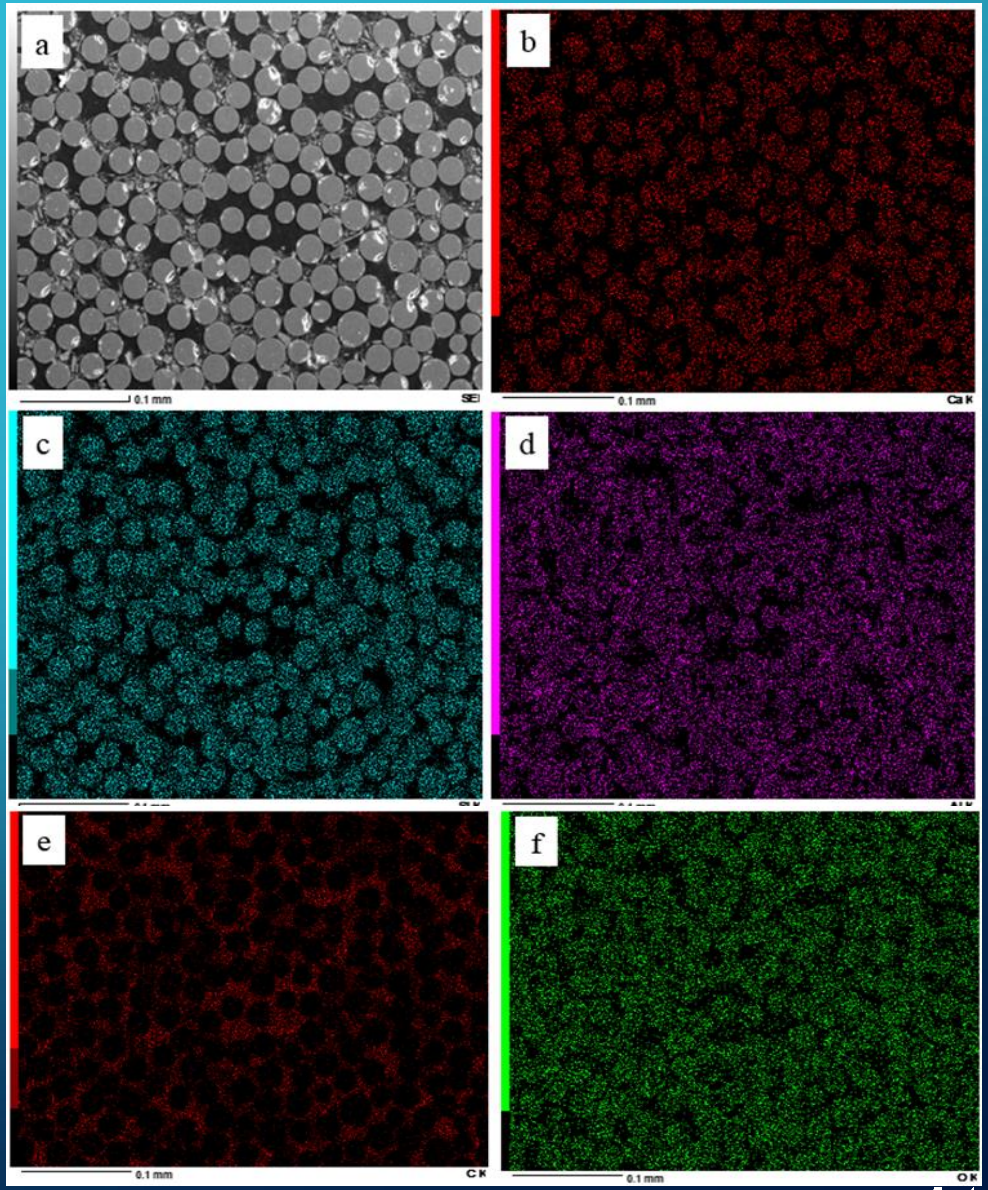


Why Improve Endurance Limits?

Validate With Bridge Service Life

Bridge Core Extraction of 15+ Year GFRP Rebar Samples

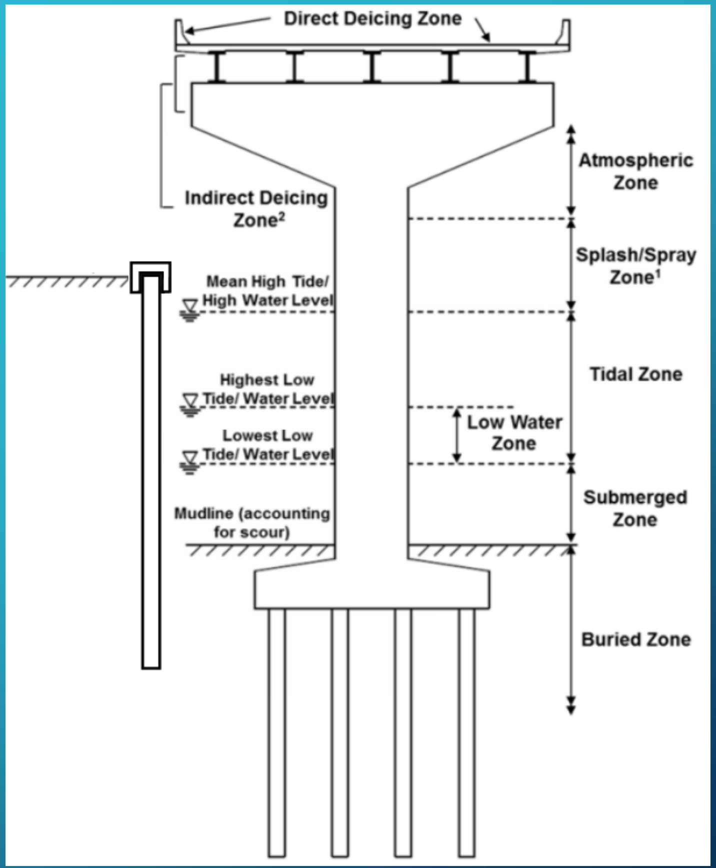
1. Negligible impact in mechanical properties and chemical composition of GFRP fiber and matrix SEM/EDX (300x image fiber, Ca, Si, Al, C, O)
2. GFRP rebar durability in corrosive environments better than predicted by accelerated test methods 0.85 C_E



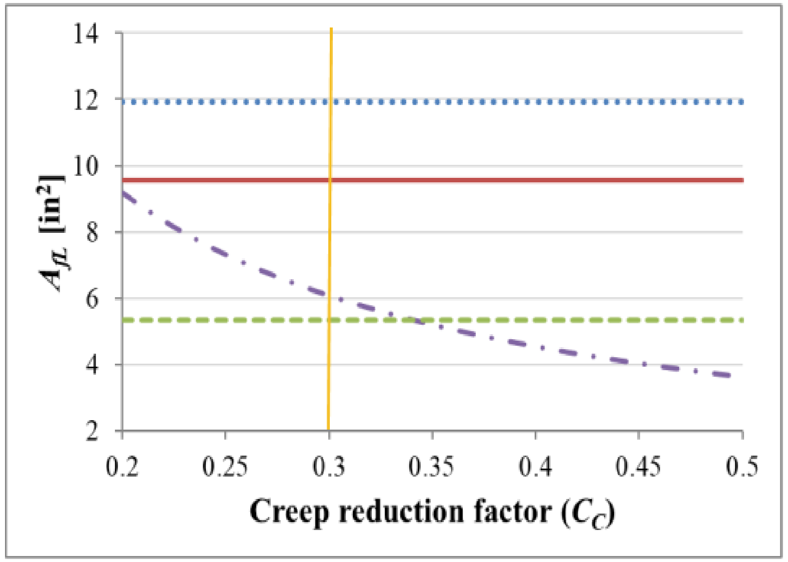
Where do we go from here?

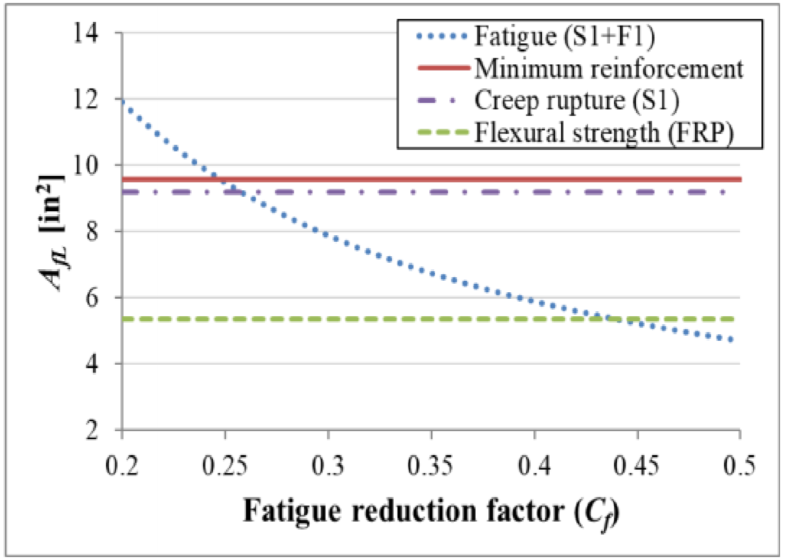
Recommend Endurance Limits to Meet AASHTO LRFD Bridge Design Specification Reliability Requirements

1. Design Limit Refinements
2. Durability Model Refinements
3. GFRP Service Life Design for Tidal and Submerged Concrete Structures
4. Life-Cycle Cost Guidance



Micro-Exposure Zones proposed under NCHRP Project 12-108 for Service Life Design





Proposal to improve endurance limits for 125-year service life and also develop a simple short duration QA verification test method

QUESTIONS ??

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Steven.Nolan@dot.state.fl.us

FDOT's Fiber-Reinforced Polymer Deployment Train

GFRP Prestressing ? → BFRP Reinforcing Bars → GFRP Reinforcing Bars → CFRP Prestressing → Navigation Fender Systems → External FRP Laminate Repairs