Overview of AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete

By: Steven Nolan, Fabio Matta, Marco Rossini, Antonio Nanni

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ABSTRACT:

The use of corrosion resistant glass FRP (GFRP) bars as internal reinforcement for concrete has become a viable technology for bridge structures particularly in cold regions where de-icing salts are used and in coastal areas. Design principles for GFRP-reinforced concrete (RC) are well established, and guideline documents have been published in North America, Europe, and Japan. In Canada, the use of GFRP bars is specified in the Canadian Highway Bridge Design Code.

In the US, the design of GFRP-RC bridge decks and open-post railings is codified in the first edition of specifications published by the American Association of State Highway and Transportation Officials (AASHTO) in 2009. The need for national standards is paramount for the wider deployment of FRP-RC design. State and local transportation agencies rely on these documents to ensure that federal eligibility for project funding is not jeopardized. To respond to this demand, a task force of researchers and practitioners has developed a draft for the second edition of the AASHTO guide specifications to be submitted for consideration and adoption by the designated AASHTO Committee.

The paper presents the salient contents of these new expanded specifications, which cover relevant bridge superstructure and substructure components. Compared to the first edition, significant changes were introduced to reflect the state-of-the-art from the archival literature. The overarching objectives were to enlist the most recent findings and experience to make the provisions more rationale, offset the overconservativeness of some requirements, and harmonize the design philosophy with those of other existing authoritative codes standards

Outline

1. A Brief History of FRP at FDOT
2. Highway Innovation and Incentive Programs
3. FRP Specifications
4. Specification Harmonization
5. Design Tools
6. Advancements
7. Example FRP Elements
8. Projects
9. FDOT Principles for Broader Deployment

What's in these Programs… involving FRP?

NCHRP:

[Report 503](#) (2003): Application of FRP Composites to the Highway Infrastructure

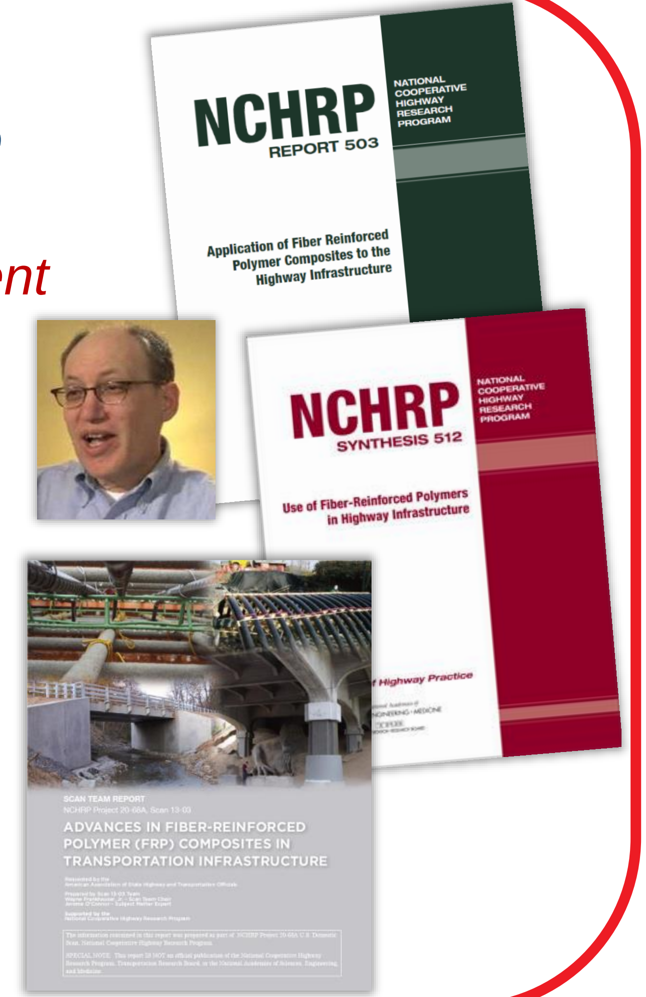
- *Dr. Dennis Mertz (lead author) – "Lack of a clear signal of intent or encouragement from government agencies undermines FRP suppliers' confidence in the viability of a long-term market…"*

[Synthesis 512](#) (2017): Use of Fiber-Reinforced Polymers in Highway Infrastructure

- *State-of-the-art review*

[US Scan Team Report 13-03](#) (2017): Advances in FRP Composite Transportation Infrastructure

- *NCHRP 20-68A program*



http://www.domesticscan.org/13-03-leading-practices-in-use-of-fiber-reinforced-polymer-frp-composites-in-transportation-infrastructure

What else is there… (ASCE Grand Challenge)

- *“Reduce the life cycle cost of infrastructure by 50 percent by 2025 and foster the optimization of infrastructure investments for society”*

Together we can close the infrastructure gap!

What else is there… (nationally / internationally)

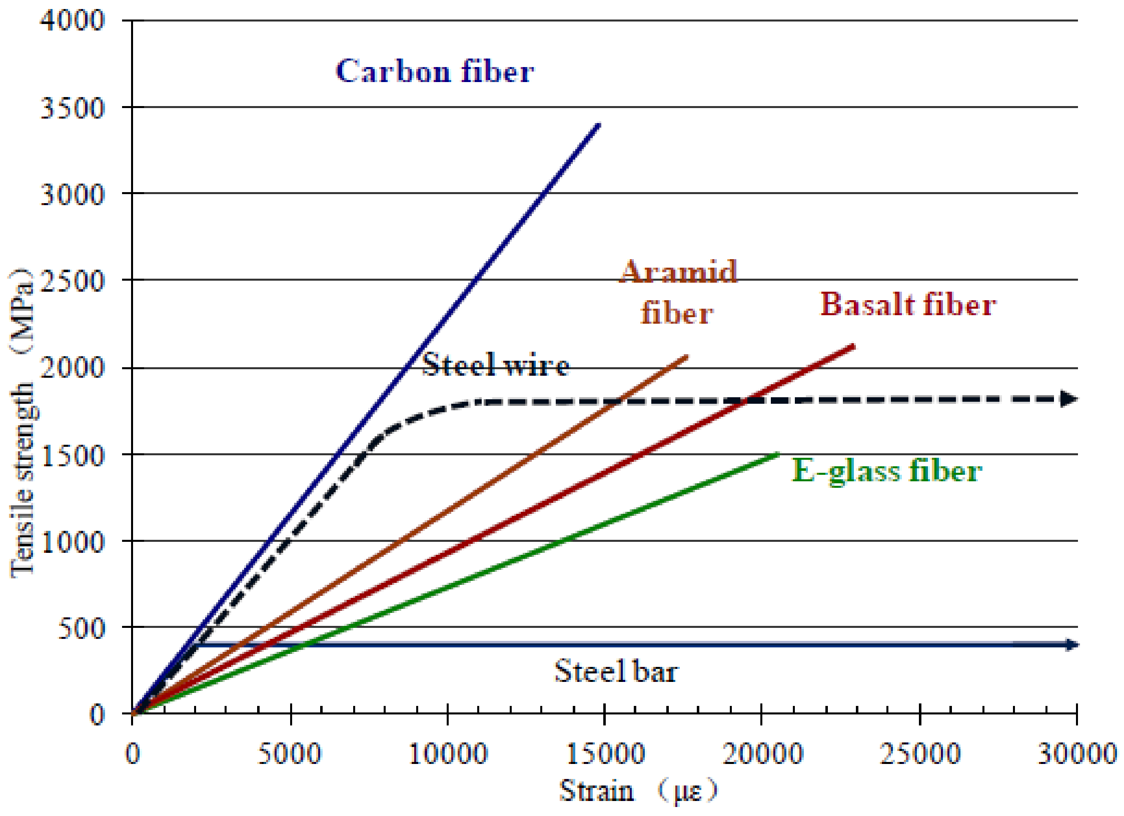
FDOT participation in related technical organizations:

- ***AASHTO Committee on Bridge and Structures – T6 FRP*** *(Member: William Potter)*
- ***TRB AFF80*** *– Structural Fiber Reinforced Polymers (Members: Potter, Fallaha & Nolan)*
- ***ACMA*** *– Transportation Structures Council & FRP Rebar Manufacturers Council (liaisons → John Busel)*
- ***ACI 440*** *– (liaison → Prof. Nanni)*
- ***Canadian Standards Association*** *(liaison → Prof. Benmokrane)*
- ***fib Task Group 5.1*** *– FRP Reinforcement for concrete structures (liaison → TBA)*

What else is there… (locally)

FRP materials of most interest to FDOT (currently):

- ***Carbon FRP strands and laminates*** *(PAN fiber with epoxy or vinyl-ester resin systems)*
- ***Glass FRP reinforcing Bars*** *(E-CR fiber with vinyl-ester resin systems)**;***
- ***Basalt FRP reinforcing bars*** *(melt fiber with epoxy resin systems).*

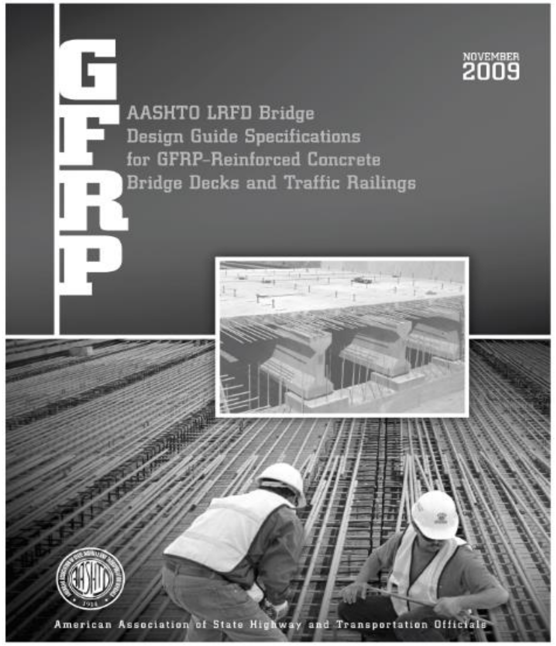


Typical stress-strain relationships of different FRPs compared to steel bars (Zhishen et al., 2012)

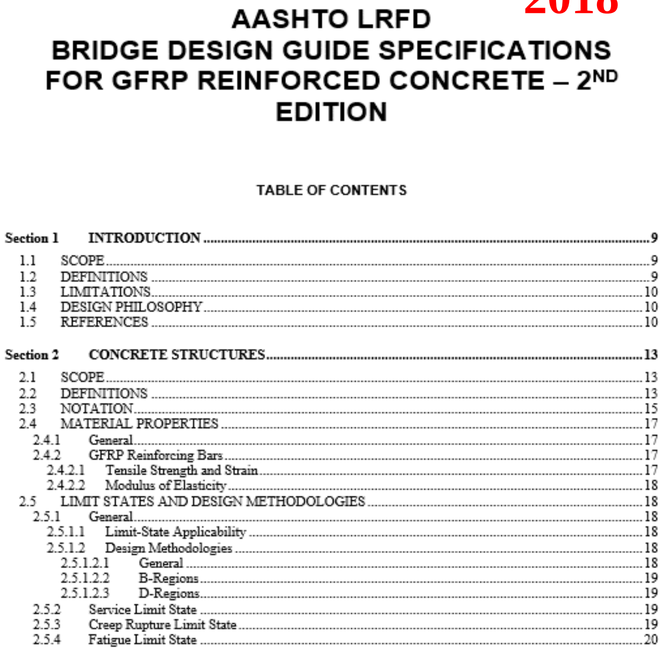
Specifications - GFRP

AASHTO's ***1st Edition*** **on decks and railings has now been updated to a complete** ***Bridge Design Guide Specification (BDGS:GFRP-RC)*** ***2nd Edition*****.**

- Approved 06/28/2018 by ***AASHTO Committee on Bridges and Structures*** (thru ***T-6*** sponsorship).



2018



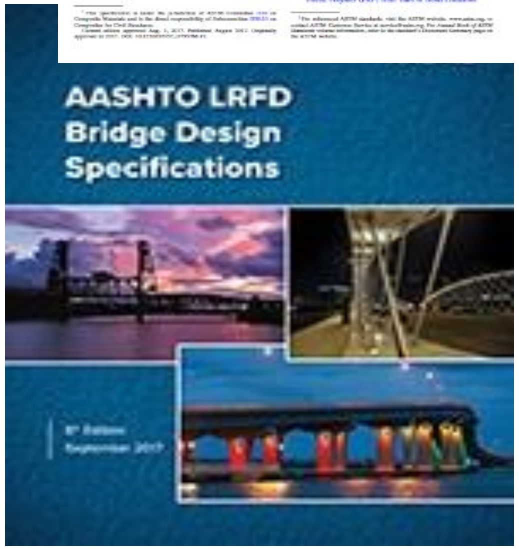
AASHTO LRFD
BRIDGE DESIGN GUIDE SPECIFICATIONS
FOR GFRP REINFORCED CONCRETE – 2ND EDITION

TABLE OF CONTENTS

Specification Harmonization – GFRP-RC

- ***BDGS-GFRP 2nd Ed.*** refers to ***ASTM D7957-17*** for material specifications
  - Only vinyl-ester GFRP / epoxy GFRP round bars allowed
  - Role separation and eased certification

- Design of GFRP-RC bridge elements follows structure of Bridge Design Specifications for steel-RC/PC (***AASHTO-BDS-17, 8th Ed.***).
  - Same language and integration
  - Familiar environment for the practitioner



Specification Harmonization – GFRP-RC (cont.)

- **Inputs** from existing guidelines/codes:
  - ***ACI 440.1R-15*** *“Guide for the Design and Construction of Structural Concrete Reinforced with Fiber Reinforced Polymer Bars”*
  - ***CSA S6-14*** **Section 16** *“Canadian Highway Bridge Design Code: Fibre-Reinforced Structures”*

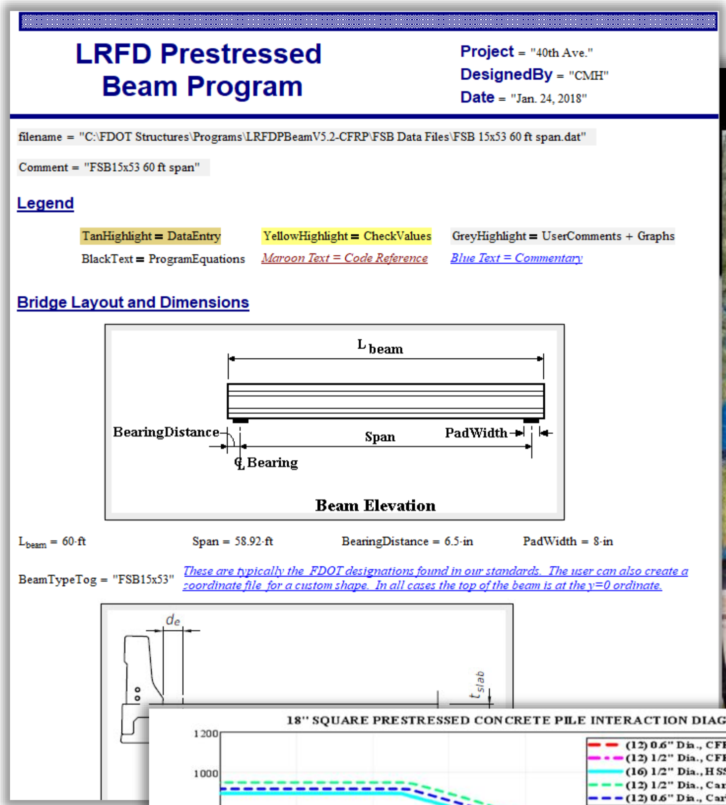
- **Coordination** with next-edition (where possible)
  - ***ACI 440-19*** *“Building Code Requirements for Structural Concrete Reinforced with GFRP Bars”* (under development)
  - ***CSA S6-19*** **Section 16** *“Canadian Highway Bridge Design Code: Fibre Reinforced Structures”* (under development)

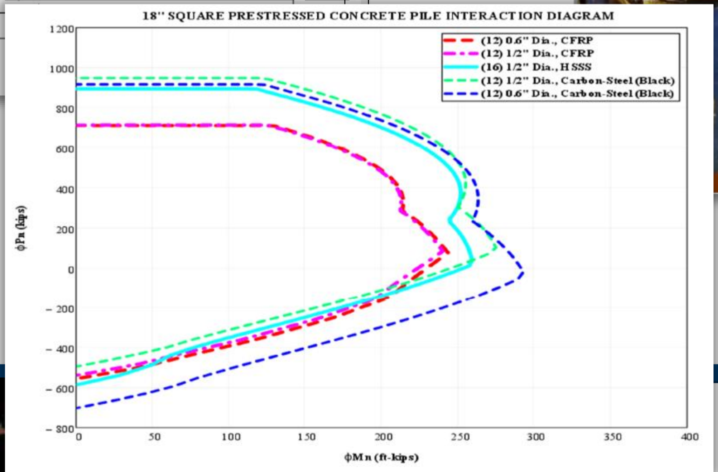
Specification Harmonization – GFRP-RC (cont.)

	AASHTO-GS 2nd 2018	AASHTO-GS 1st 2009	ACI 440.1R 2015 (19)	CSA 2014 (19)	
f_{fu}^*	99.73	99.73	99.73	**95.0** (1)	Strength percentile
Φ_C	**0.75**	**0.65**	0.65	0.75	Res. Fact. concr. failure
Φ_T	0.55	0.55	0.55	0.55	Res. Fact. FRP failure
Φ_S	0.75	0.75	0.75	0.75	Res. Fact. shear failure
C_E	0.70	0.70	0.70	**1.0**	*Environmental reduction*
C_C	**0.30**	**0.20**	0.20 ***(0.30)***	0.25 ***(0.30)***	*Creep rupture reduction*
C_f	**0.25**	**0.20**	0.20	0.25	*Fatigue reduction*
C_b	**0.80**	**0.70** (2)	0.70 (2)	**1.0**	*Bond reduction*
w	**0.028**	**0.020 or 0.028**	0.020 to 0.028	0.020 ?	Crack width limit [in.]
$c_{c,stirrups}$	1.5	1.50	2.0 (3)	1.6 (40mm)	Clear cover [in.]
$c_{c,slab}$	1.0	0.75 to 2.0	0.75 to 2.0 (3)	1.6 (40mm)	Clear cover [in.]

*(1) Characteristic Strength; (2) 1/k_b ; (3) **ACI 440.5-08** Table 3.1; **(19)** proposed for 2019 updates*

Design Tools – FDOT Programs & Design Aids



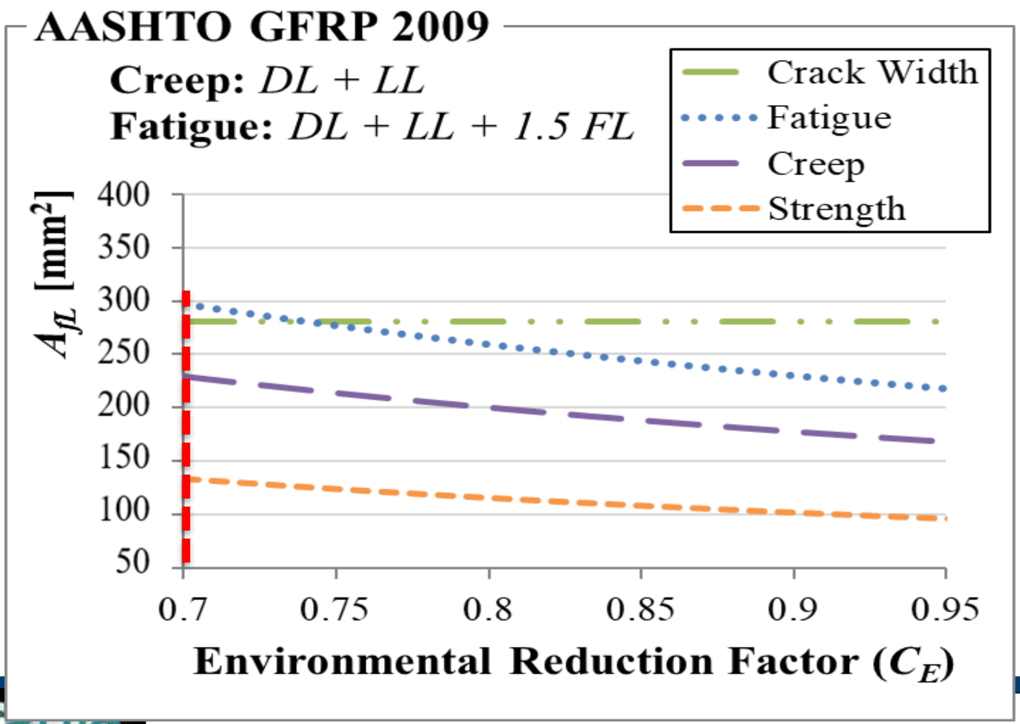


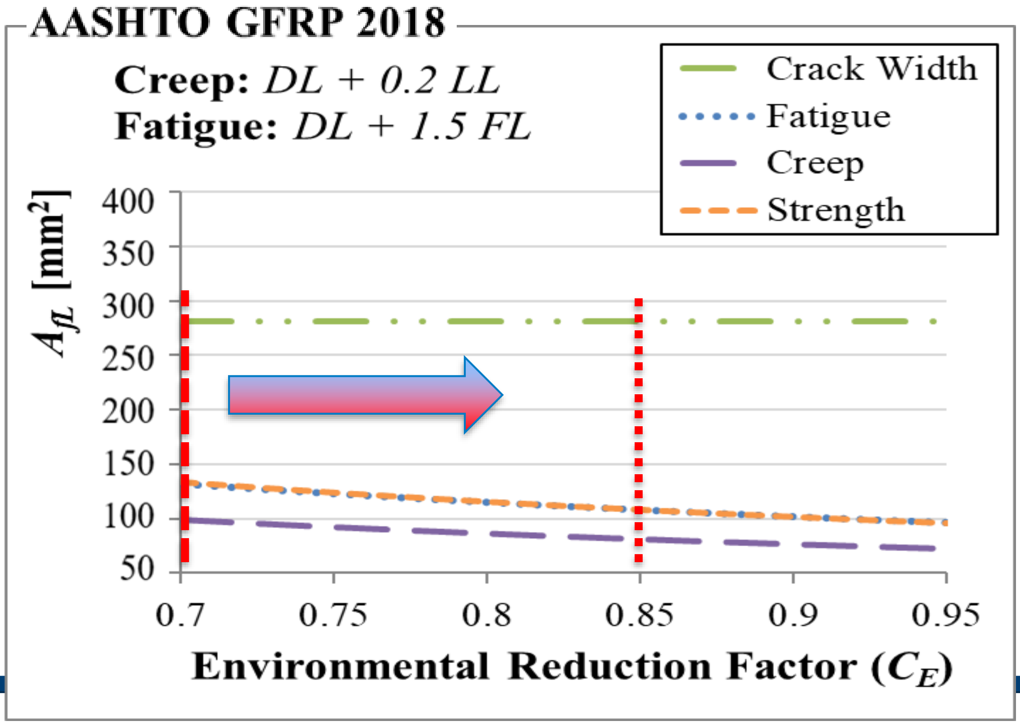
1. **Design Programs**
   - CFRP-PC Beams
   - GFRP-RC Flat-Slab
   - GFRP-RC Bent Cap
   - *Retaining Walls soon!*
2. ***SPI* "Design Aids"**
3. **Project GIS-Map App.**
4. **Under development**
   - Cost Estimating Guidance
   - LCC Analysis Guidance

Recent Advancement - GFRP-RC Specs

2nd *Ed.* updates reflect:

- Rationally defined creep rupture and fatigue load demands
- Separated ***Creep*** C_c and ***Fatigue*** C_f and aligned to *CSA-14* (0.20 to **0.30 & 0.25 respectively**) – ***Need additional study to improve these conservative limits!***





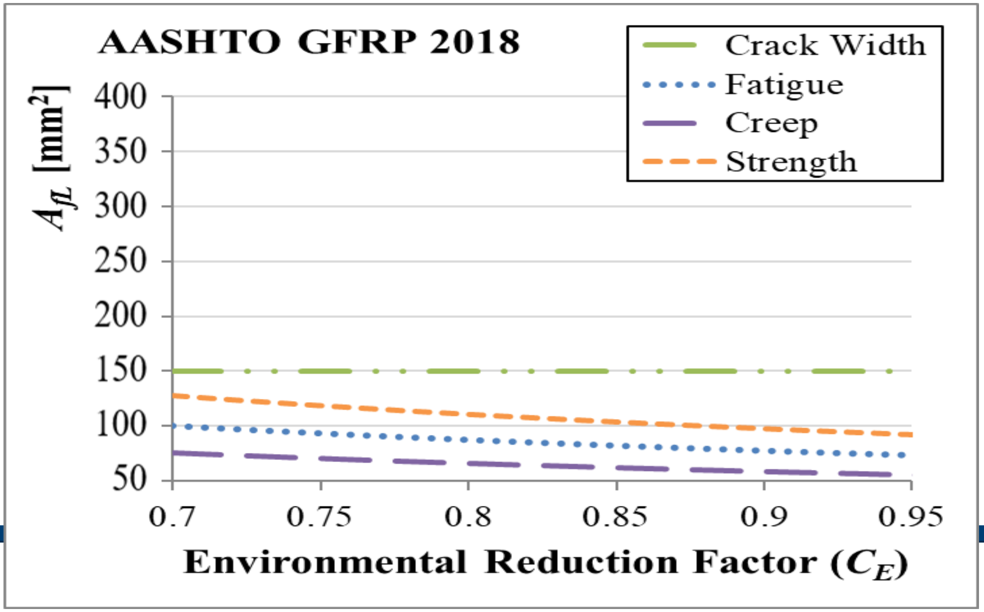
Recent Advancement (cont.) - GFRP-RC Specs

2nd *Ed.* updates reflect:

- Performances of ***ASTM***-certified materials and increase **Compression-Controlled** Flexural Resistance $\boldsymbol{\Phi_c}$ alignment to ***AASHTO BDS-17*** (0.65 to **0.75**);
- Reduced increased Bond Factor $\boldsymbol{C_b}$ (= 1/$\boldsymbol{k_b}$) and max. crack width to 0.028 inches.

Now need to:

1. *Rationally increase **Tension-Controlled** Flexural Resistance* $\boldsymbol{\Phi_t}$ *(**0.55** to **0.75 ?**), and*
2. *Increase the minimum **Elastic Modulus…***



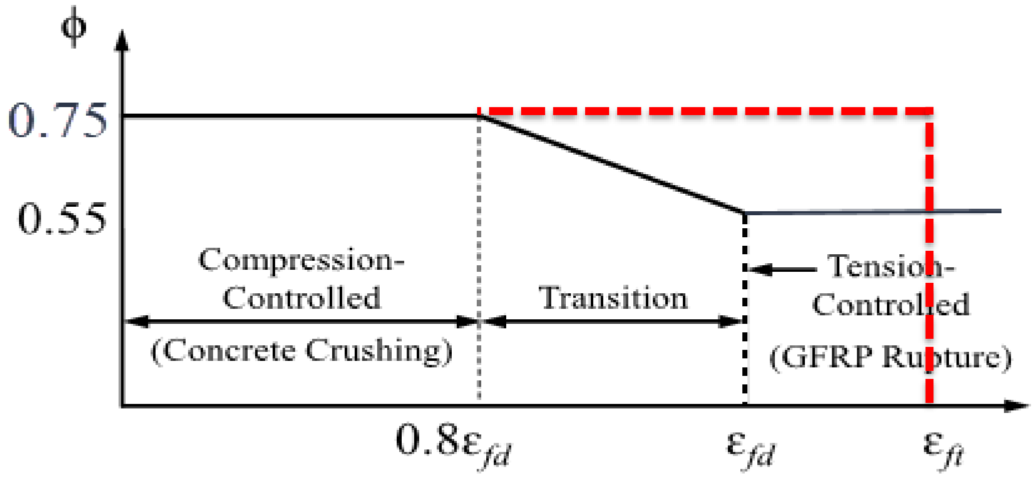
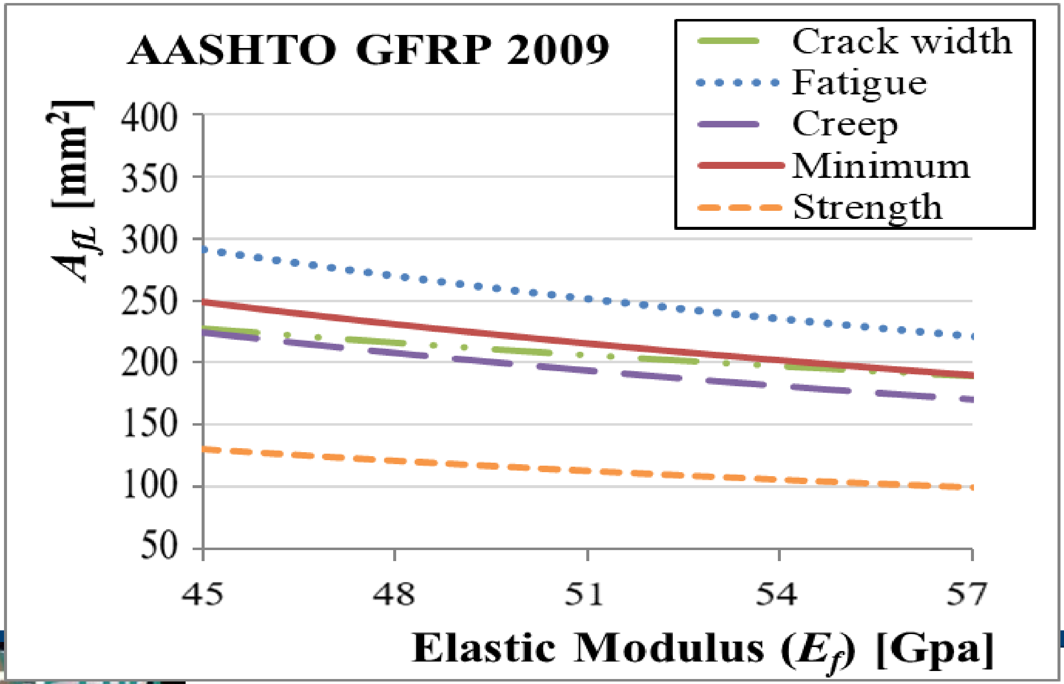
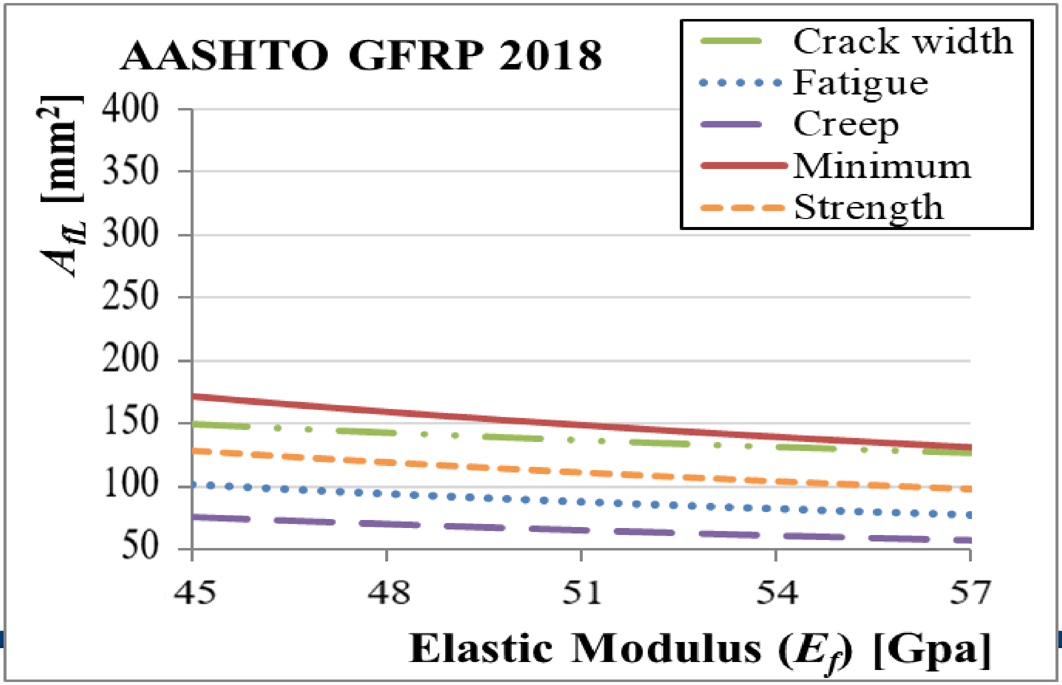


Figure C2.5.5.2-1 – Variation of ϕ with Tensile Strain at Failure, ε_{ft}, in GFRP Reinforcement

Future Advancement (cont.) - GFRP-RC Specs

1. Elastic modulus is a game-changer.
2. Increment shall not come from mere sectional area enlargement.
3. Need to operate within ***ASTM D7957-17*** boundaries.
4. Improve quality of the manufacturing process to answer market demand: stiffness, bond performances, durability.

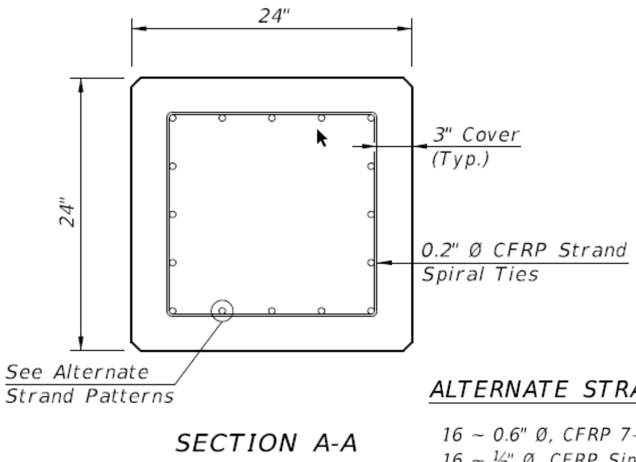




Standardized Elements - Piles

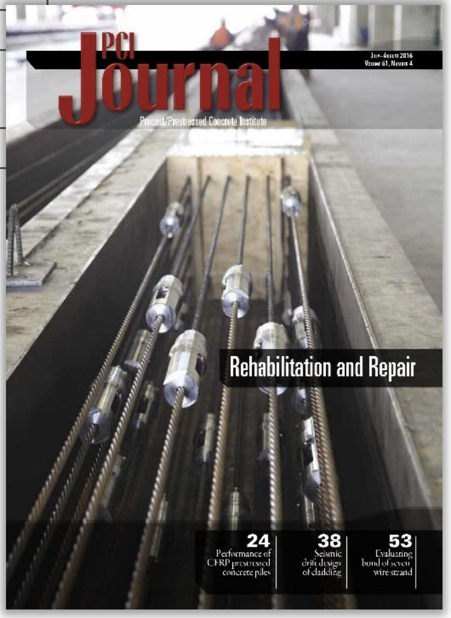
Bridge Bearing Pile Standards

455-101		Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes
455-102		Square CFRP and SS Prestressed Concrete Pile Splices
455-112		12" Square CFRP and SS Prestressed Concrete Pile
455-114		14" Square CFRP and SS Prestressed Concrete Pile
455-118		18" Square CFRP and SS Prestressed Concrete Pile
455-124		24" Square CFRP and SS Prestressed Concrete Pile
455-130		30" Square CFRP and SS Prestressed Concrete Pile
455-154		54" Precast/Post-Tensioned CFRP and SS Concrete Cylinder Pile
455-160		60" Prestressed CFRP and SS Concrete Cylinder Pile



ALTERNATE STRAND PATTERNS

16 ~ 0.6" Ø, CFRP 7-Strand, at 42 kips
16 ~ ½" Ø, CFRP Single-Strand, at 41 kips

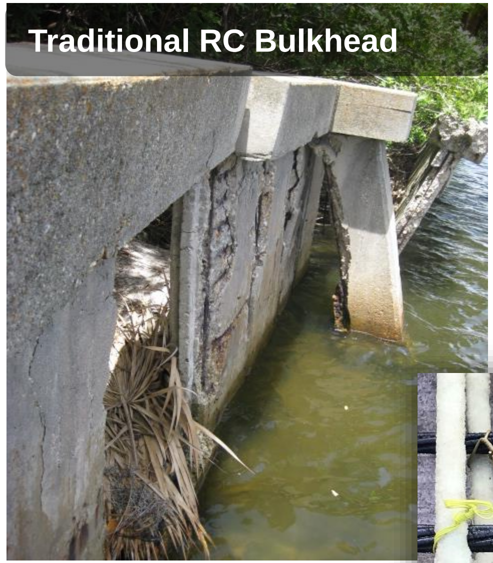


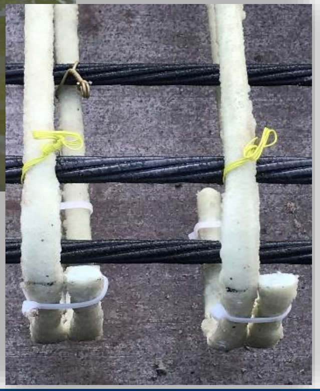
Standardized Elements - Seawall-Bulkheads

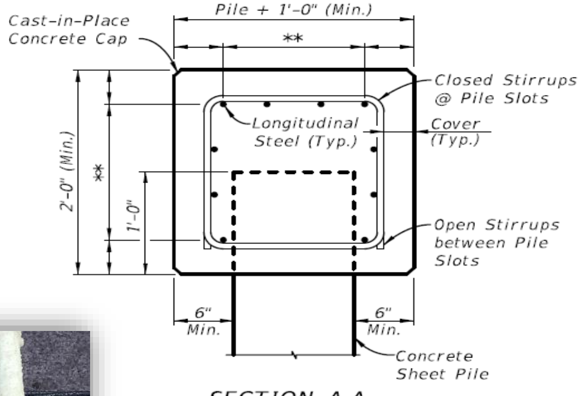
Concrete Sheet Pile Bulkhead Standards


HRB Sheet Pile Installation

		Structures Foundations - Sheet Pile Wall
455-400		Precast Concrete Sheet Pile Wall (Conventional)
455-440		Precast Concrete Sheet Pile Wall (CFRP/GFRP & HSSS/GFRP)

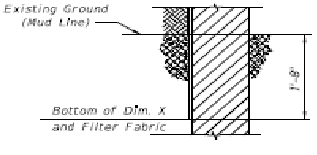

Traditional RC Bulkhead



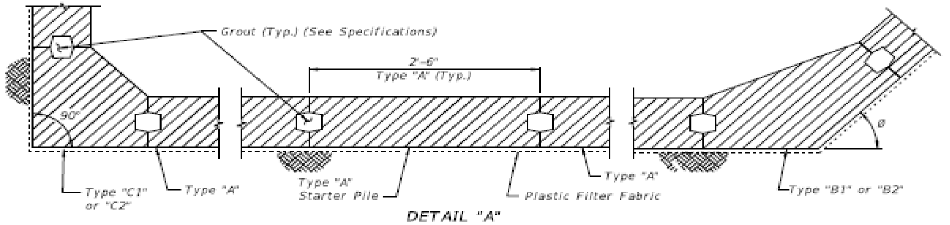


SECTION A-A


Traditional RC Bulkhead Cap



SECTION THRU BULKHEAD
(Showing Plastic Filter Fabric)

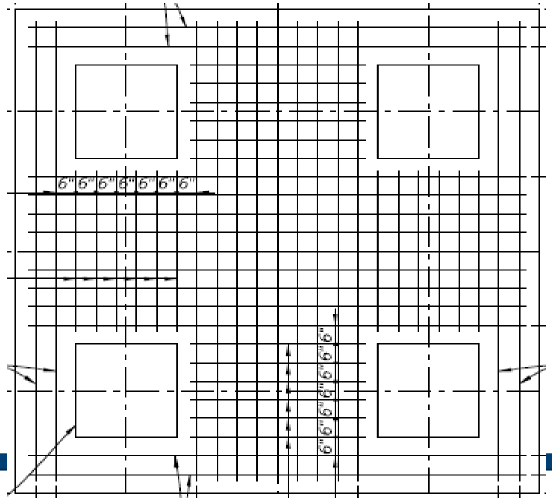


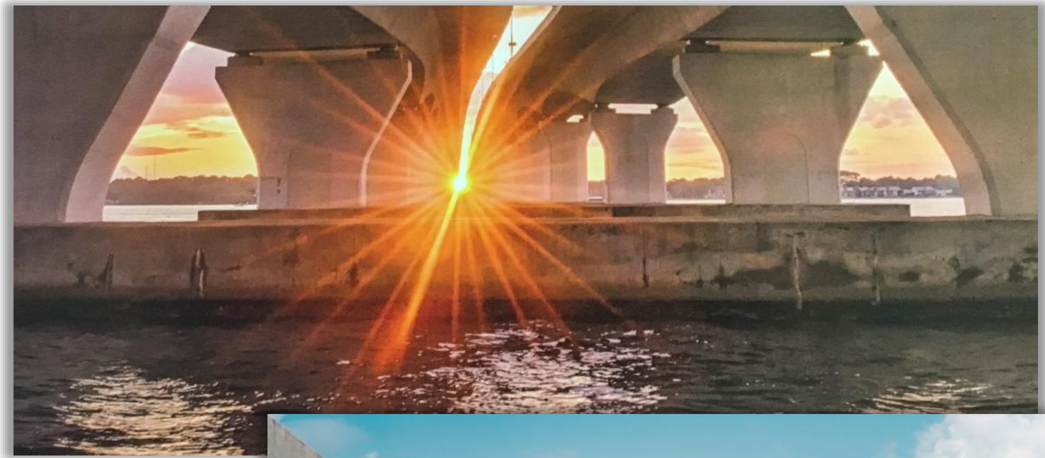
DETAIL "A"

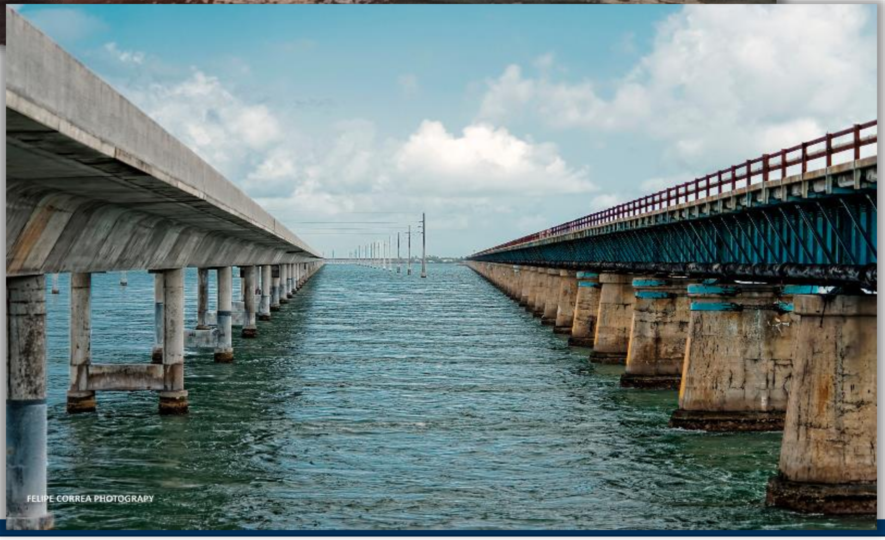
Proposed Elements - Substructures

Waterline footings & columns in saltwater – *need big bars for this!*

#10 bars recognized in
ASTM D7957;
Will need #11 bars in future;
May also need #14 bars?



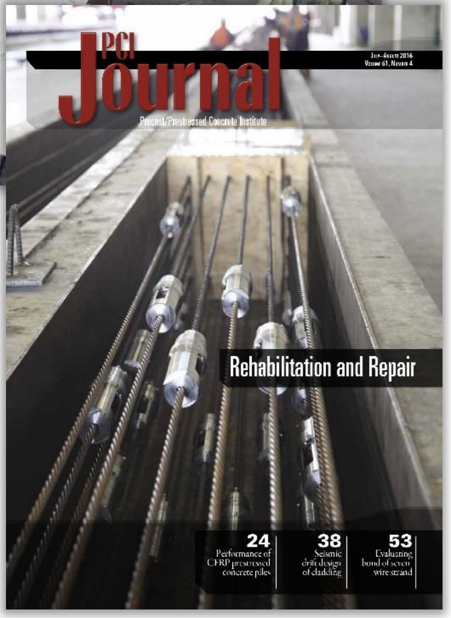




Project Example Elements - Piles

Bridge Bearing Pile Projects

- Halls River Bridge (Homosassa)
- NE 23rd Ave/Ibis Waterway (City of Lighthouse Point)
- C Street Bridge (Cedar Key)
- Barracuda Blvd (New Smyrna)
- 40th Ave. N (St Petersburg)
- iDock (Miami)
- Maydell Dr. (Tampa) ?

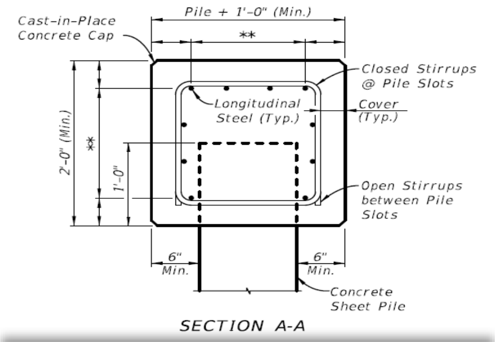


Project Example Elements - Seawall-Bulkheads

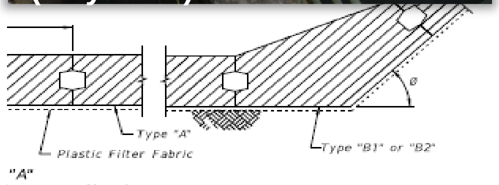
Concrete Sheet Pile Bulkhead Projects


HRB Sheet Pile Walls (2017-18)

- SR24/Channel 3 (Cedar Key)
- Halls River Bridge (Homosassa)
- Bakers Haulover Cut (Miami)
- Skyway Rest Area (Manatee Co.)
- Pinellas Bayway – Structure E
- NE 23rd Ave/Ibis Waterway (City of Lighthouse Point)
- Barracuda Blvd (New Smyrna)
- Maydell Dr. (Tampa) ?
- 40th Ave. N (St Petersburg) ?



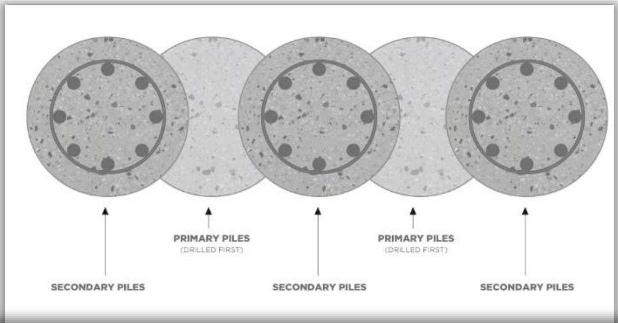
Skyway Rest Area Rehab. (May 2018)



Project Example Elements - Seawall-Bulkheads

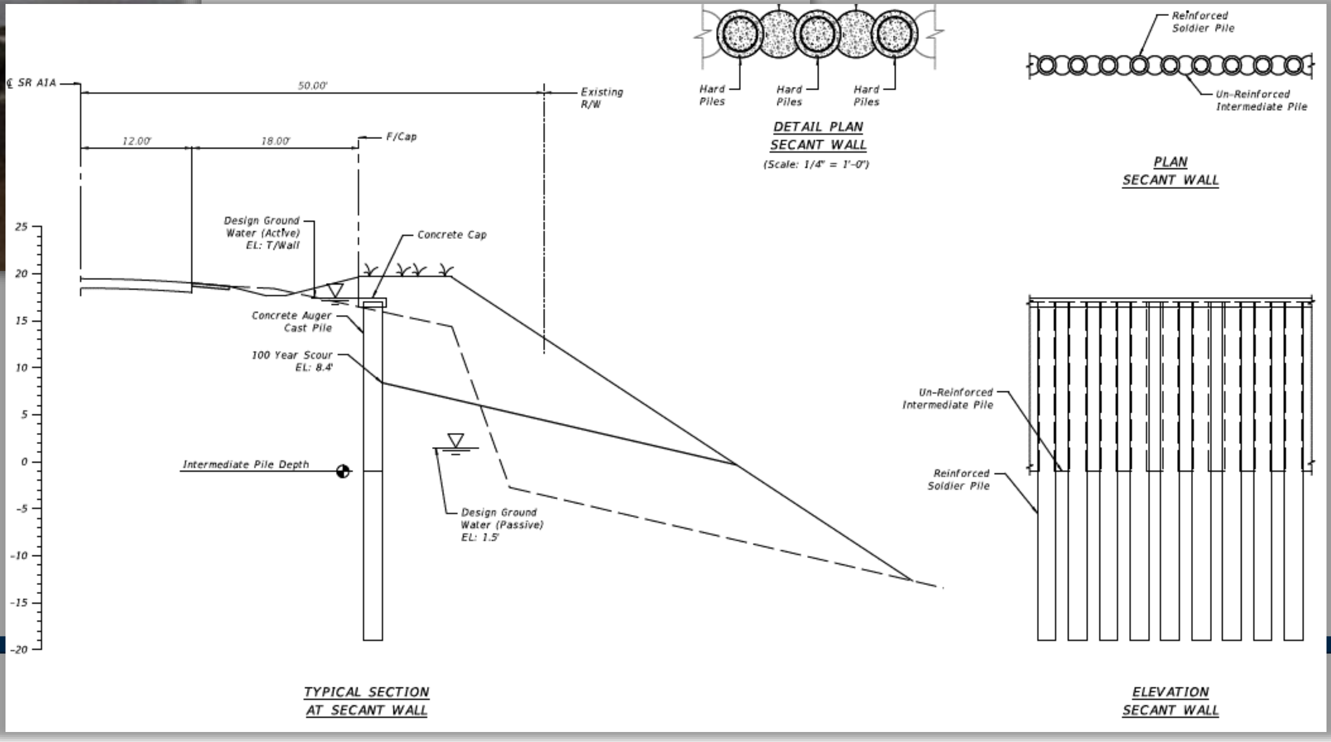
Secant Piles seawall on SR A1A


SR A1A damage after Hurricane Matthew (2016)




GFRP Pile cages (Hughes Bros.)

Secant Wall Concept Rendering

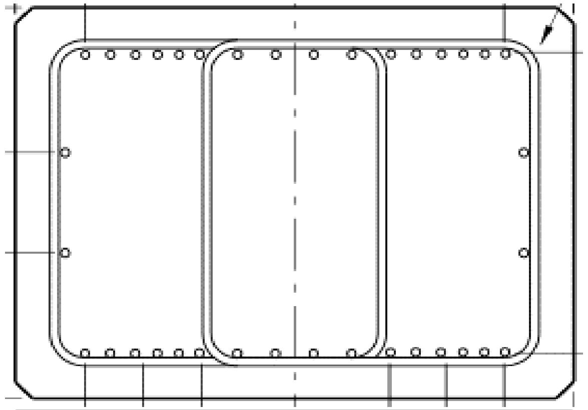


Project Example Elements - Bent Cap

Projects:

- Halls River Bridge (Homosassa)
- NE 23rd Ave/Ibis Waterway (City of Lighthouse Point)
- Barracuda Blvd (New Smyrna)
- iDock (Miami)
- Maydell Dr. (Tampa)?
- 40th Ave. N (St Petersburg)?

HRB GFRP-RC Pile Caps (2017)



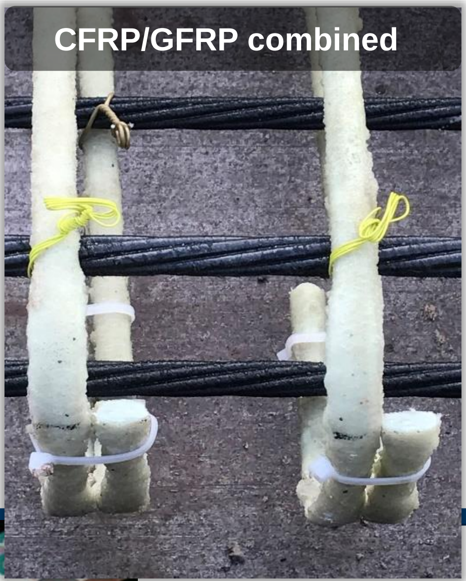
Typical Section from HRB Plans

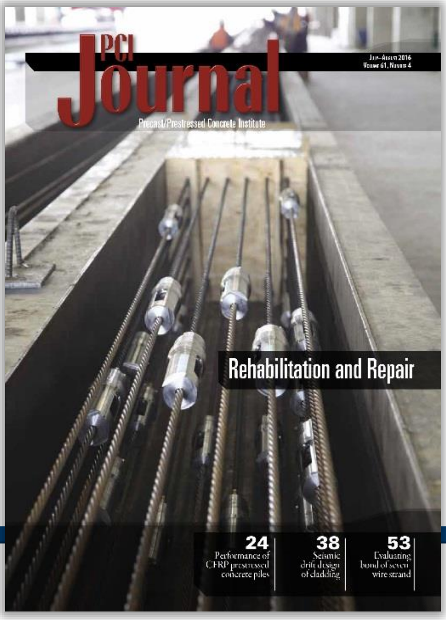
iDock pile bent caps GFRP rebar cages,Coreslab (2018)

Hurricane Irma damage of boat docks (2017)

Project Example Elements - Girders/Slab-Beams


HCB's set on GFRP-RC Pile Caps

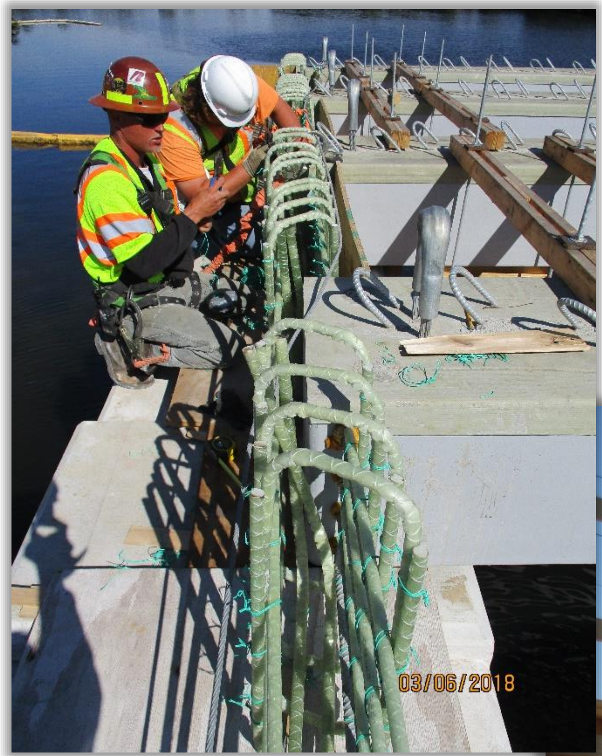

CFRP/GFRP combined



Projects:

- Halls River Bridge = **HCB's** (Homosassa)
- NE 23rd Ave/Ibis Waterway = **Flat-Slab** (City of Lighthouse Point)
- US-1 over Cow Key Channel = **FSB CFRP/GFRP** (Key West)
- 40th Ave. N = **FSB's** ? (St Petersburg)
- Maydell Dr. = **FSB's** ? (Tampa)

Projects - Halls River Bridge progress



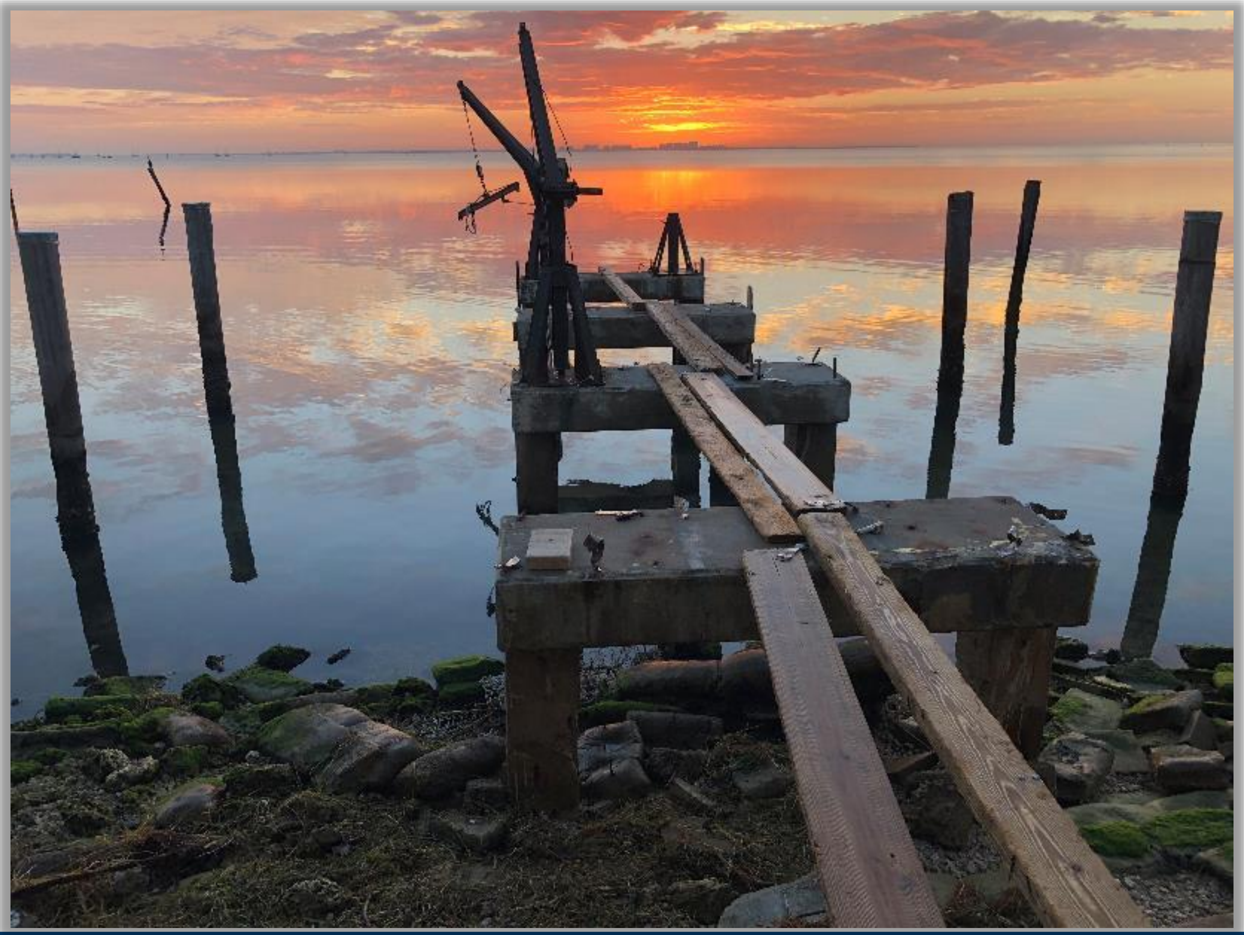
Collaborative Projects

FDOT Collaboration Projects:

- ***SEACON* (2016-2018):** Sustainable Concrete using Seawater, Salt-contaminated Aggregates and Non-Corrosive Reinforcement *(University of Miami & Polimi) – **Halls River Bridge** was one of the two "Demonstrator" projects;*
- ***Arthur Drive Bridge in Lynn Haven (2017):*** Precast GFRP-RC Piles demonstration *(University of Sherbrook & UNF)*
- ***iDock (2018):*** GFRP-RC Piles/Caps/Beams *(University of Miami)*

Collaborative Project Example – iDock

Existing Condition - Dock damaged by Hurricane Irma *(Miami)*



Questions?

FDOT's Fiber-Reinforced Polymer Deployment Train

???	BFRP-RC	Composite Bridge Girders	GFRP-RC	CFRP-PC	Fender Systems	External FRP Laminate Repairs
	2019	2016	2016	2015	2000's	1990's

FDOT

fib 2018

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District Structures Offices:
SAM-TAG representatives
&
District Structures Design Engineers

FDOT's Fiber-Reinforced Polymer Deployment Train

???	BFRP-RC	Composite Bridge Girders	GFRP-RC	CFRP-PC	Fender Systems	External FRP Laminate Repairs
	2019	*2016*	*2016*	*2015*	*2000's*	*1990's*