ASCE
FLORIDA SECTION
ANNUAL CONFERENCE

July 12-13th, 2018

St. Petersburg, FL

FDOT Fiber-Reinforced Polymer (FRP) initiatives for bridge structures

Steve Nolan, P.E. (State Structures Design Office)

FDOT FRP initiatives for bridge structures

ABSTRACT:
FDOT will present the latest developments for fiber-reinforced polymer composite materials for structural applications, primarily for use in bridges. Deployment of external FRP for retrofit, repair and strength restoration began in the 1990's. Application of internal FRP systems for new construction have been researched for at least this long, but practical implementation for bridges and related structures has been limited in Florida to several projects in the last few years. Adoption of FRP for transportation infrastructure has been accelerating nationally as the commercial options and competition expand, and the design guidelines and specifications mature. With the release of ***ASTM D7957***, the update to the ***2009 AASHTO LRFD Guide Specification for GFRP reinforced concrete***, and the new ***AASHTO LRFD Guide Specification for CFRP Prestressed Concrete*** developed under ***NCHRP Project 12-97***, the use of FRP for bridge applications is primed to accelerate significantly in the next few years. The demand for resilient, sustainable infrastructure is increasing beyond just the initial procurement cost. The significant benefits of non-corrosive structural systems with a longer maintenance-free service-life will be highlighted, and the FRP systems that can provide these feature will be identified. Several recently completed FDOT bridge projects will be exhibited, and the Department's efforts for broader FRP deployment under the "***Invitation to Innovation***" and other initiatives will be summarized.

Overview

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

History of FRP at FDOT

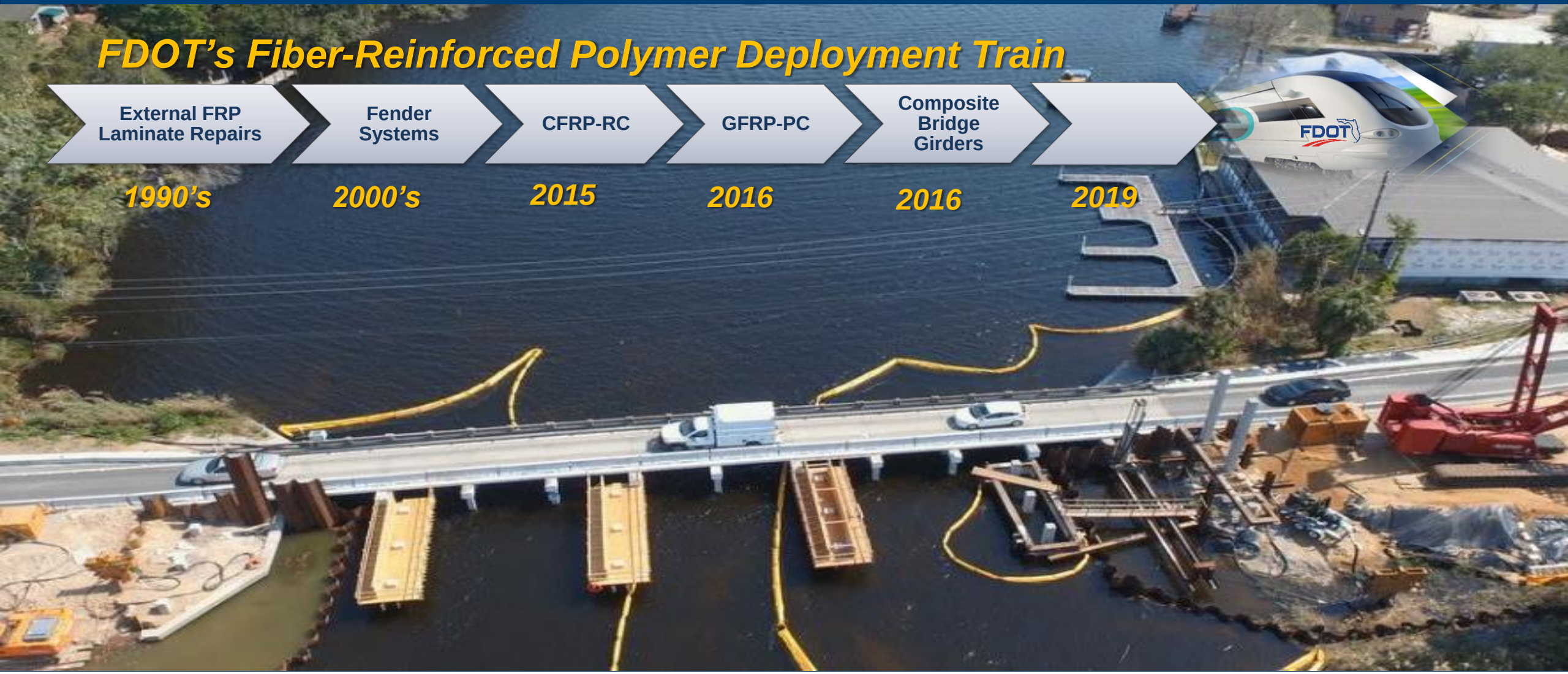


Photo Courtesy of Astaldi Construction Corp.
– Halls River Bridge under construction (FDOT FRP-RC/PC & HCB Demonstration project), April 2017.

History of FRP at FDOT - Repair/Strengthening Operations

FDOT's Fiber-Reinforced Polymer Deployment Train

External FRP Laminate Repairs

1990's

Now considered routine practice for some applications

FDOT currently references **ACI 440.2R**-08 (with modifications); **AASHTO Guide Spec.** (2012) is also available.

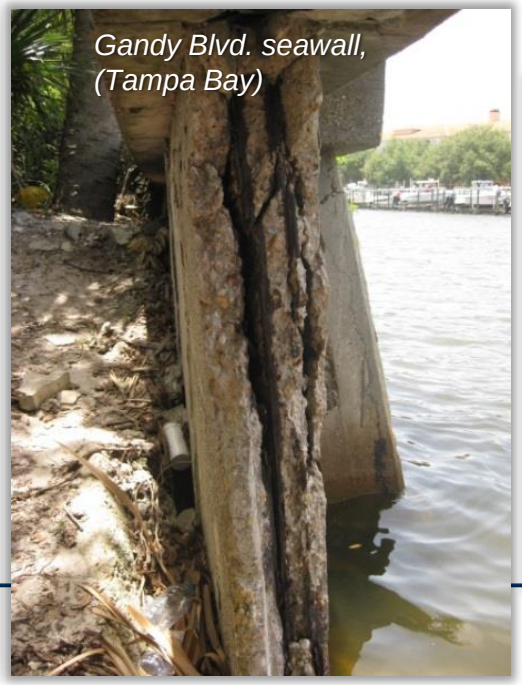
History of FRP at FDOT - Need for Corrosion Protection

FDOT's Fiber-Reinforced Polymer Deployment Train

1990's 2000's

- FRP can increase Durability
- Extend maintenance-free Service-Life
- Mitigate long-term Risks


Old St. George Island Bridge Piling

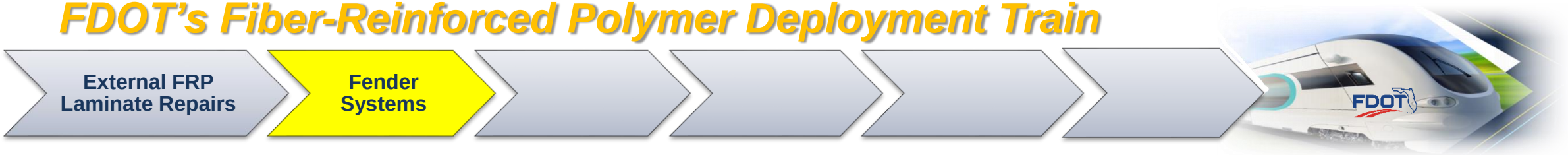

Gandy Blvd. seawall, (Tampa Bay)


Courtney Campbell Causeway, seawall (Tampa Bay)


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

History of FRP at FDOT - Bridge Fender Systems

FDOT's Fiber-Reinforced Polymer Deployment Train



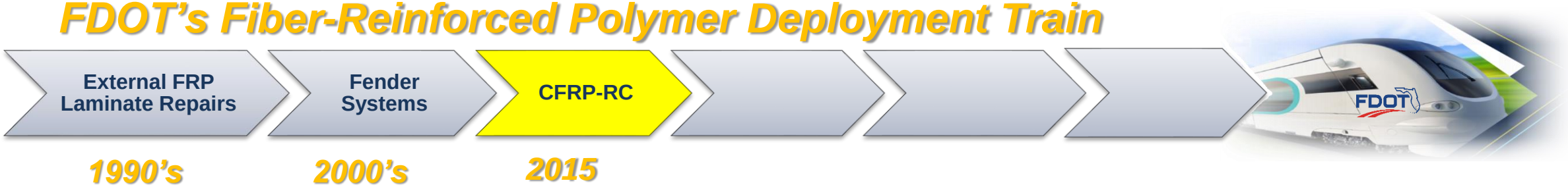
Fully implemented on FDOT projects.

FRP systems strongly recommended - see ***SDG 3.14*** and ***DS Index 21930*** *or* ***SP Index 415-030***)

(Photos Courtesy of Creative Pultrusion)

History of FRP at FDOT – Carbon FRP-PC

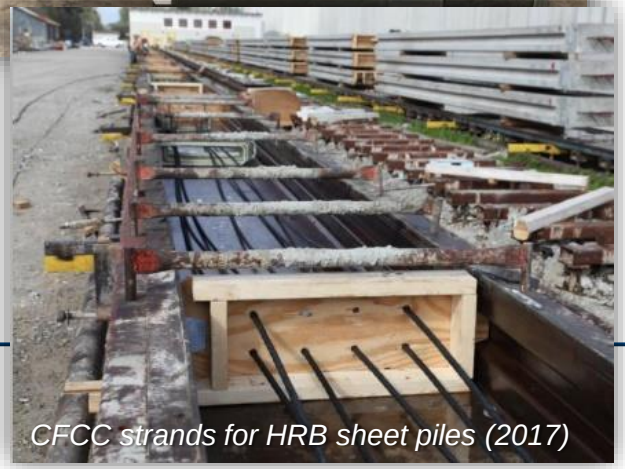
FDOT's Fiber-Reinforced Polymer Deployment Train




Gate Precast (2017)


Halls River Bridge 18"x18" bearing piles (2017)

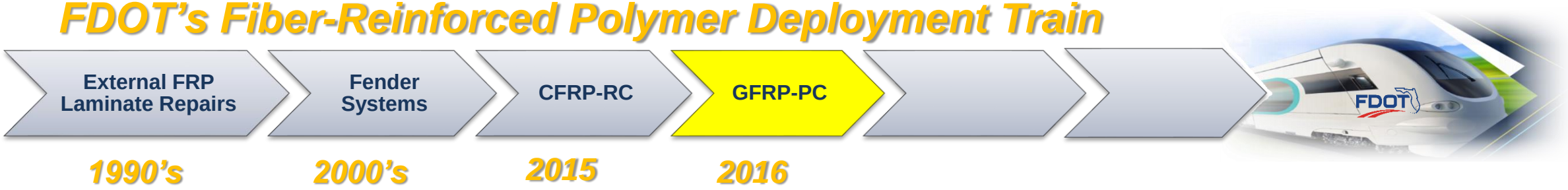

Coupling of CFCC to jacking strands


CFCC strands for HRB sheet piles (2017)

- CFRP-PC Bearing Piles
- CFRP-PC/GFRP-RC Sheet Piles

History of FRP at FDOT – Carbon FRP-PC & Glass FRP-RC

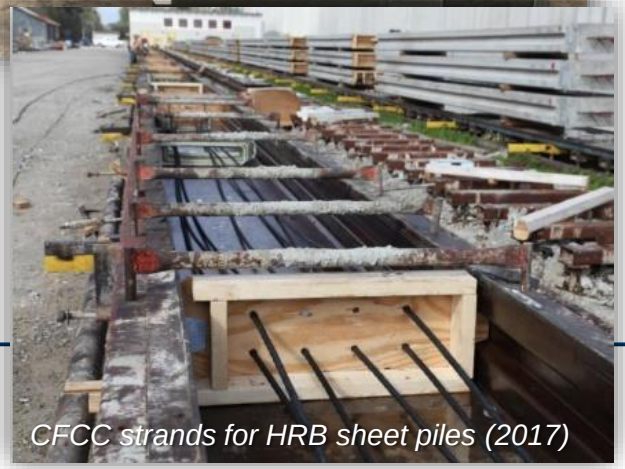
FDOT's Fiber-Reinforced Polymer Deployment Train




Gate Precast (2017)


Halls River Bridge 18"x18" bearing piles (2017)


Coupling of CFCC to jacking strands


CFCC strands for HRB sheet piles (2017)

- CFRP-PC Bearing Piles
- CFRP-PC/GFRP-RC Sheet Piles
- GFRP Caps, Deck, App. Slab…


HRB GFRP-RC Bent Cap (2017)

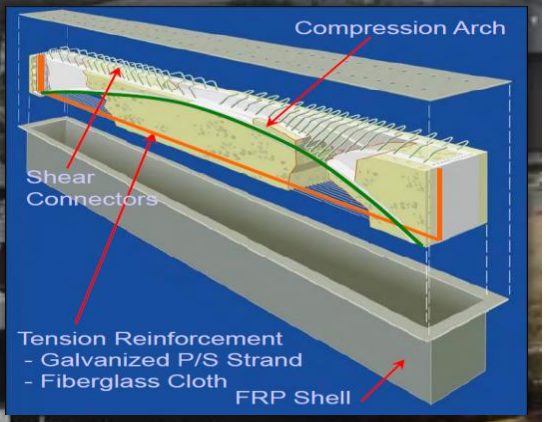

HRB GFRP-RC Deck Casting (2018)

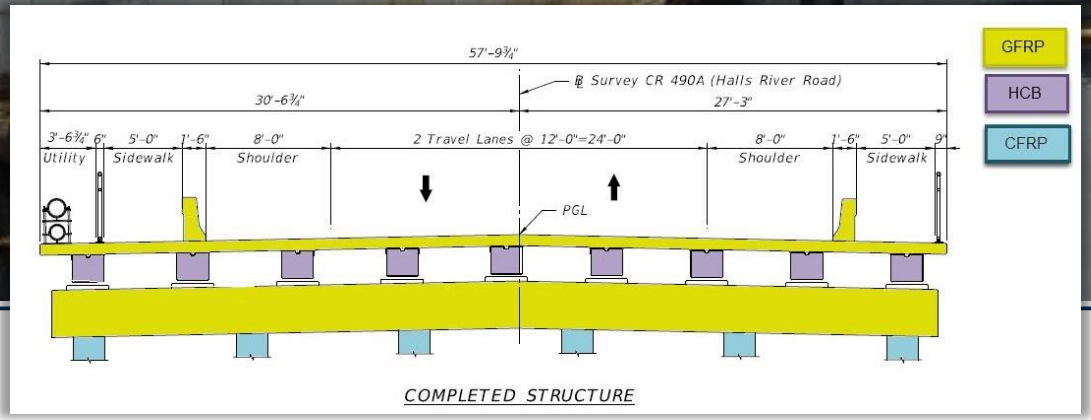
History of FRP at FDOT – Composite Bridge Girders

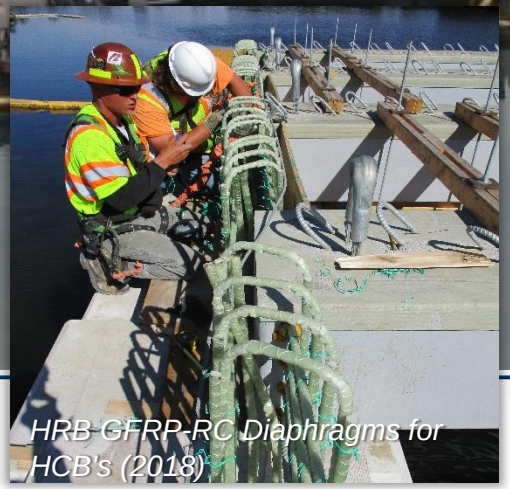
FDOT's Fiber-Reinforced Polymer Deployment Train

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

HCB





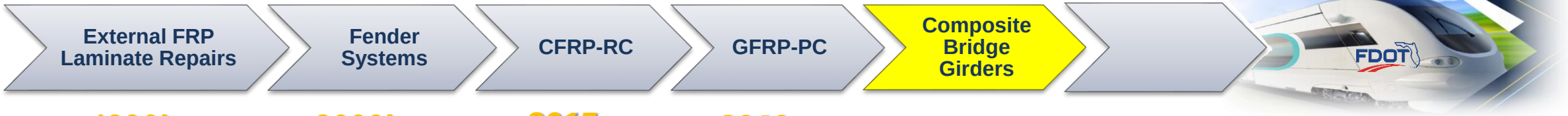


HRB GFRP-RC Diaphragms for HCB's (2018)

HRB Hybrid Composite Beams (2017)

History of FRP at FDOT – Composite Bridge Girders (cont.)

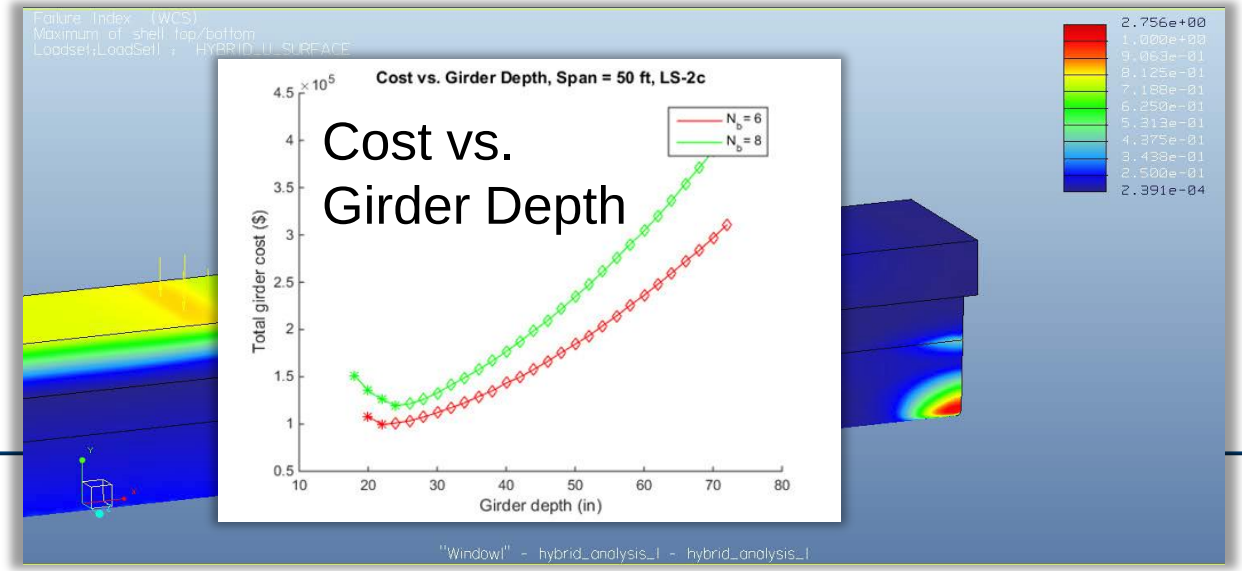
FDOT's Fiber-Reinforced Polymer Deployment Train

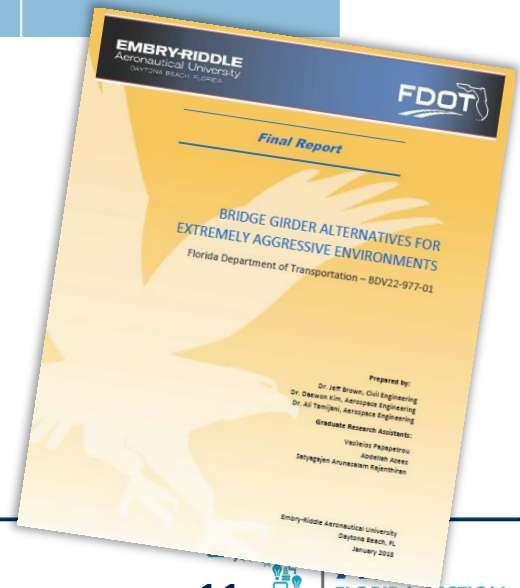


- Non-Proprietary CBG's

Completion Date	Title (Full Report)	Principal Investigator	University / Agency	Project Manager	Contract No. (Summary)
1/31/2018	Bridge Girder Alternatives for Extremely Aggressive Environments	Brown, Jeff	Embry-Riddle Aeronautical Univ.	Potter, William	BDV22 977-01

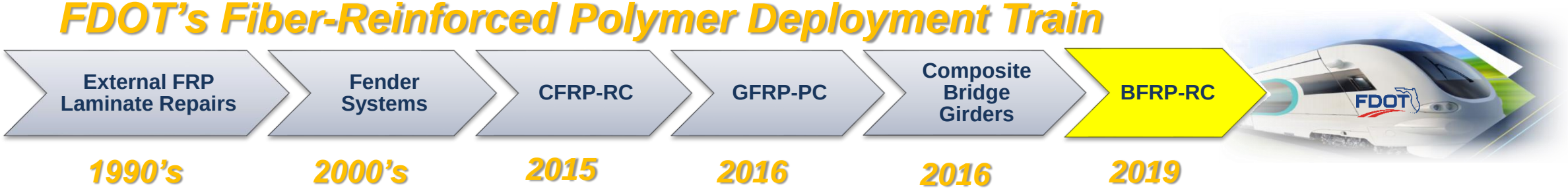
FRP girders await the next step in construction of this bridge.





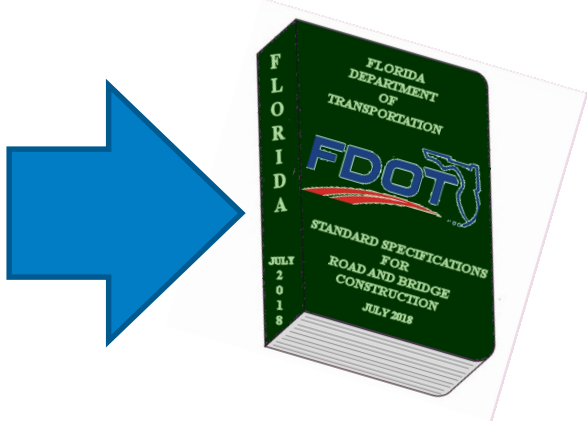
History of FRP at FDOT – Basalt FRP-RC

FDOT's Fiber-Reinforced Polymer Deployment Train



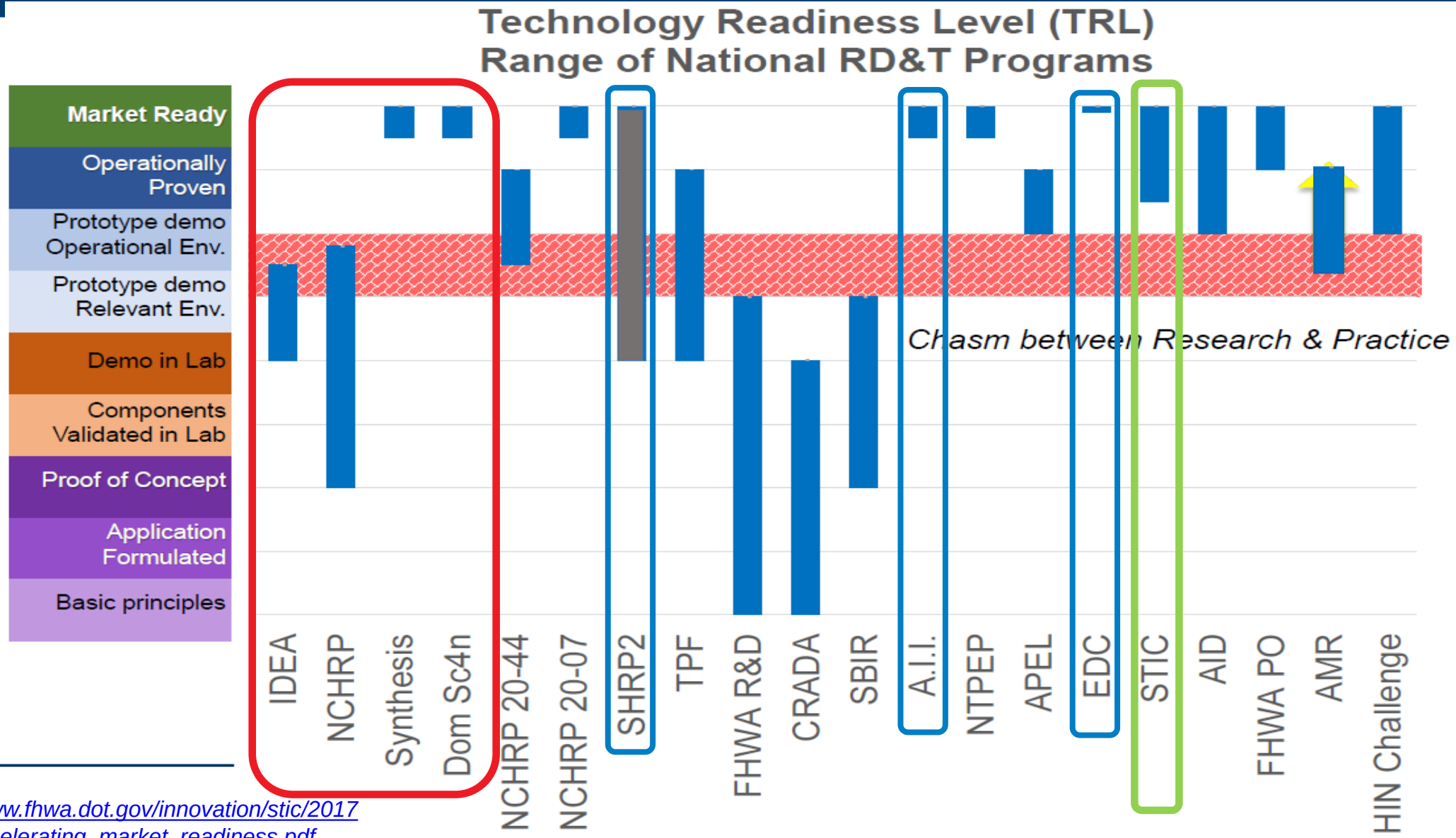
STIC Incentive Project – BFRP-RC Standardization

- Develop ***Standards*** *&* ***Specifications*** for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete.



https://www.fhwa.dot.gov/innovation/stic/state_innovation.cfm

Highway Innovation and Incentive Programs



Source:
https://www.fhwa.dot.gov/innovation/stic/20171019_accelerating_market_readiness.pdf

Highway Innovation and Incentive Programs

STIC Excellence Award Forward *(April 2018):*

"America's highway community faces significant challenges: an aging infrastructure, growing traffic volumes and limited staffing and funding resources. Widespread use of innovation and enhanced business processes is essential to meeting customer needs and increasing the efficiency of project delivery.

Initiatives such as ***Every Day Counts***, the second ***Strategic Highway Research Program (SHRP2)*** Implementation Assistance Program, the ***AASHTO Innovation Initiative***, and others are designed to promote innovations and support the highway community in putting them into practice. Whether through training, workshops, demonstrations, technical assistance or incentive funding, **the result of these initiatives is rapid technology transfer and accelerated deployment of innovation across the nation…**"

https://www.fhwa.dot.gov/innovation/stic/2018_stic_excellence_award.pdf

Highway Innovation and Incentive Programs

Every Day Counts (EDC):

FHWA: PBES → ABC, UHPC, *GRS-IBS…*

Strategic Highway Research Program (SHRP2):

TRB, AASHTO & FHWA:

- Prefabricated Elements-PBES (R04 Report & Toolkit)
- Service Life Design for Bridges (R19A)
- Service Limit State Design Guide Spec./Toolkit (R19B)

AASHTO Innovation Initiative (A.I.I):

AASHTO: Carbon Fiber-Reinforced Polymer Strands

What's in these Programs… involving FRP?

NCHRP:

Report 503 *(2003): Application of FRP Composites to the Highway Infrastructure*

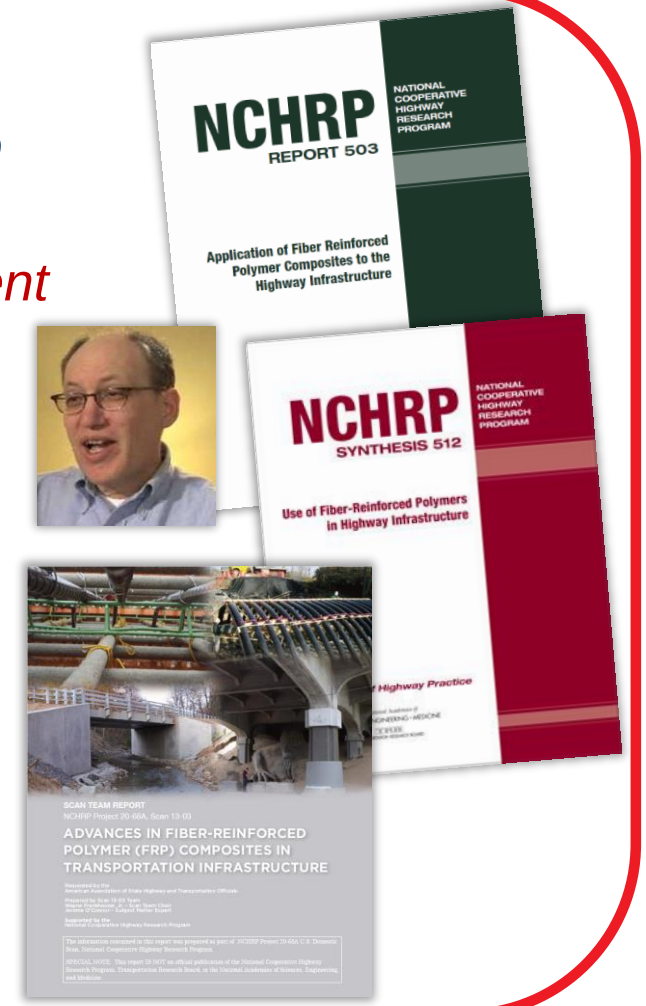
- *Dr. Dennis Mertz (lead author) – "Lack of a clear signal of intent or encouragement from government agencies undermines FRP suppliers' confidence in the viability of a long-term market…"*

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's in these Programs… involving FRP?

Ideas Deserving of Exploratory Analysis (IDEA):

NCHRP (TRB & AASHTO):

- Glass FRP Prestressing Strand (MILDGLASS-2018)

Innovative Bridge Research and Construction (IBRC):

FHWA (1998-2006): FRP Bridges are to be revisited and an update report on status issued;

Innovative Bridge Research and Deployment (IBRD):

FHWA (2006-2017): US 90 over Little River - PBES Bent Caps (used ***SHRP2 R04 Toolkit*** for guidance). FDOT since developed a Mathcad Design Program which includes GFRP-RC elements.

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) SAMTAG

Structural Advance Materials TAG mission:

- Advance the safe implementation and broad deployment of innovative structural materials through advisement to the ***Structures Technical Advisory Group (TAG)*** and coordination with national and international specification development organization representatives…

Members are to support *District Structures Design Engineers (DSDE)* make informed choices:

1 ~ Champion & 1 ~ Backup from each District Structures Office

2 ~ Consultants - structures design community

2 ~ State Materials Office materials experts

2 ~ State SDO facilitators & coordinators

1 ~ Structures Research Center representative

~ Friends of the TAG (Collaborators)

…future Construction and Maintenance representatives?

What else is there… (locally)

FDOT Invitation-to-Innovation

(Design Innovation initiative)

- ***FRP Reinforcing Bar & Strands:*** Basalt, Carbon & Glass FRP Rebar; Carbon FRP Prestressing

FDOT Research:

- ***Materials Research Program:***

7/31/2014	Degradation Assessment of Internal Continuous Fiber Reinforcement in Concrete Environment	A. El Safty	University of North Florida	BDK82-977-05 Summary Report
6/30/2018	Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments	R. Kampmann	Florida State University	BDV30 977-18
3/31/2018	Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements	A. El Safty	University of North Florida	BDV34 977-05
4/16/2014	Investigation of Carbon Fiber Composite Cables (CFCC) in Prestressed Concrete Piles	M. Roddenberry, P. Mtenga	Florida State University	BDK83 977-17
11/30/1998	Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Piles in Marine Environment	M Arockiasamy	Florida Atlantic University	B-9076
8/1/1995	Durability of CFRP Pretensioned Piles in Marine Environment Volume II	R. Sen	University of South Florida	0510642

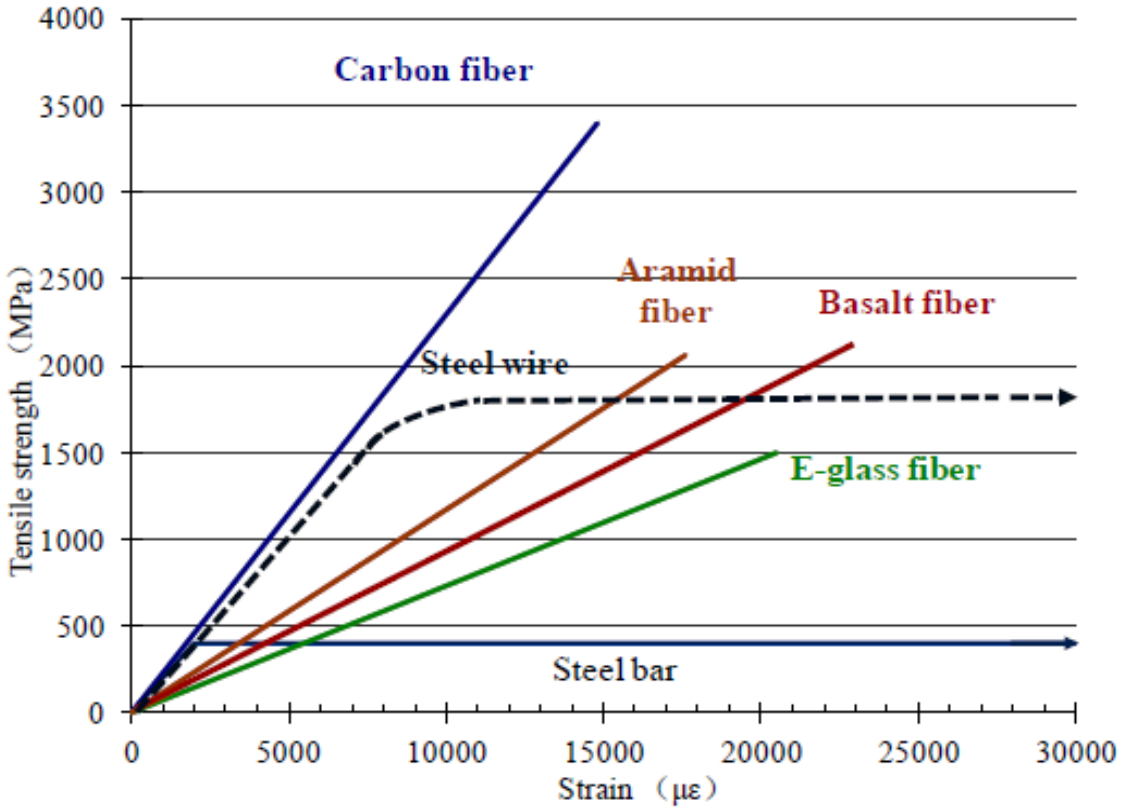
- ***Structures Research Program:***

1/31/2018	Bridge Girder Alternatives for Extremely Aggressive Environments	Brown, Jeff	Embry-Riddle Aeronautical University	Potter, William	BDV22 977-01
3/1/2017	Durability Evaluation of Florida's Fiber-Reinforced Polymer (FRP) Composite Reinforcement for Concrete Structures	Hamilton, Trey	University of Florida	Wagner, David	BDV31 977-01
8/31/2015	Use of Fiber Reinforced Polymer Composite Cable for Post-Tensioning Application	Mirmiran, Amir	Florida International University	Potter, William	BDV29 977-10

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)

What else is there… (locally)

FDOT Standards, Specifications & Projects:

*See **FRP-Design Innovation website** for "one-stop shopping":*

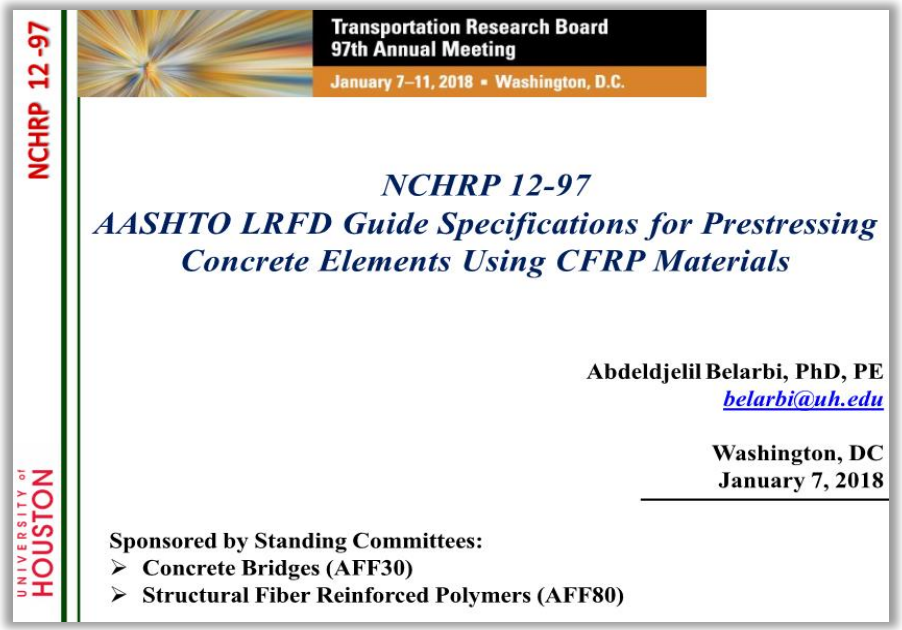
http://www.fdot.gov/structures/innovation/FRP.shtm

- Index^{DS}: 22440, 22600 series, D22900, D21310, D22420;
- Index^{SP}: 455-440, 455-100 series;
- Specifications 400, 410, 415, 450, 471, 932, 933;
- Projects *(shown in later slides)*

Specifications - CFRP

***AASHTO's 1st Edition* for prestressed concrete with FRP strands *Bridge Design Guide Specifications (BDGS:CFRP-PC)*.**

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


NCHRP 12-97

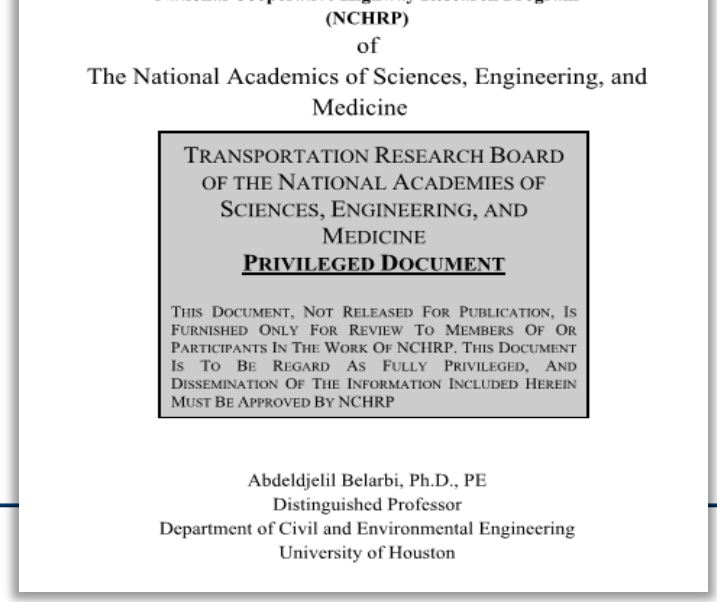
Transportation Research Board
97th Annual Meeting
January 7–11, 2018 ▪ Washington, D.C.

NCHRP 12-97
AASHTO LRFD Guide Specifications for Prestressing Concrete Elements Using CFRP Materials

Abdeldjelil Belarbi, PhD, PE
belarbi@uh.edu
UNIVERSITY of HOUSTON

Washington, DC
January 7, 2018

Sponsored by Standing Committees:
- Concrete Bridges (AFF30)
- Structural Fiber Reinforced Polymers (AFF80)


Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems

DRAFT FINAL [Report]

Prepared for

National Cooperative Highway Research Program
(NCHRP)
of
The National Academics of Sciences, Engineering, and Medicine

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE
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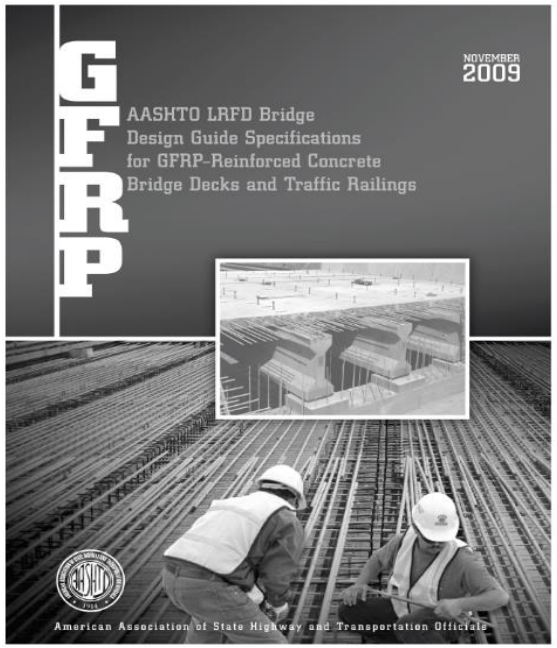
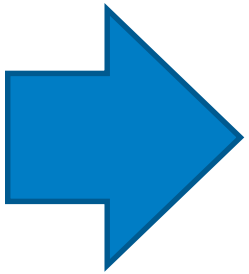
Abdeldjelil Belarbi, Ph.D., PE
Distinguished Professor
Department of Civil and Environmental Engineering
University of Houston

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

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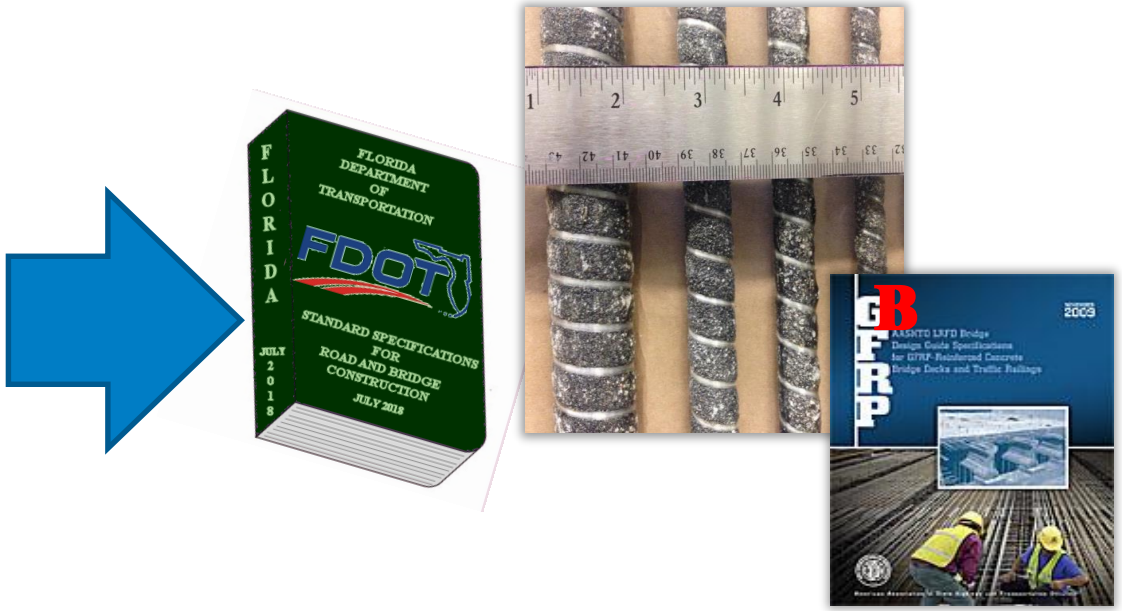
Specifications – BFRP *(in progress)*

STIC Incentive Project – BFRP-RC Standardization

Fed. Project: STIC-004-A (April 2018 - Dec 2019)

FDOT #443377-1; *includes* ***Research Project BDV30 986-01***

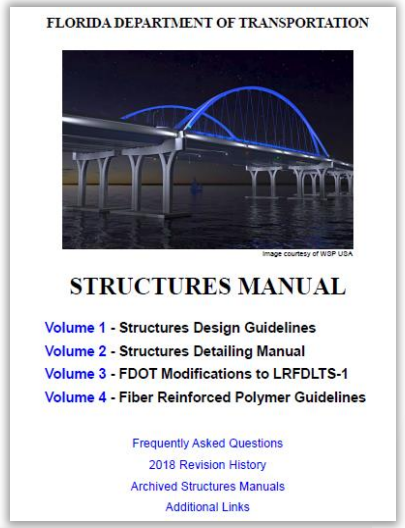
- Develop standard specifications for basalt fiber-reinforced polymer (BFRP) bars for the internal reinforcement of structural concrete.

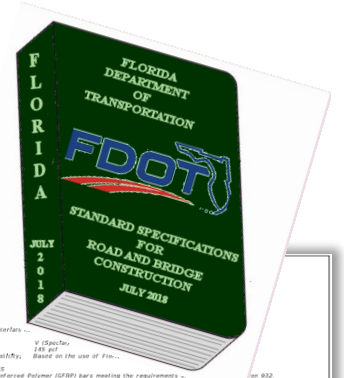


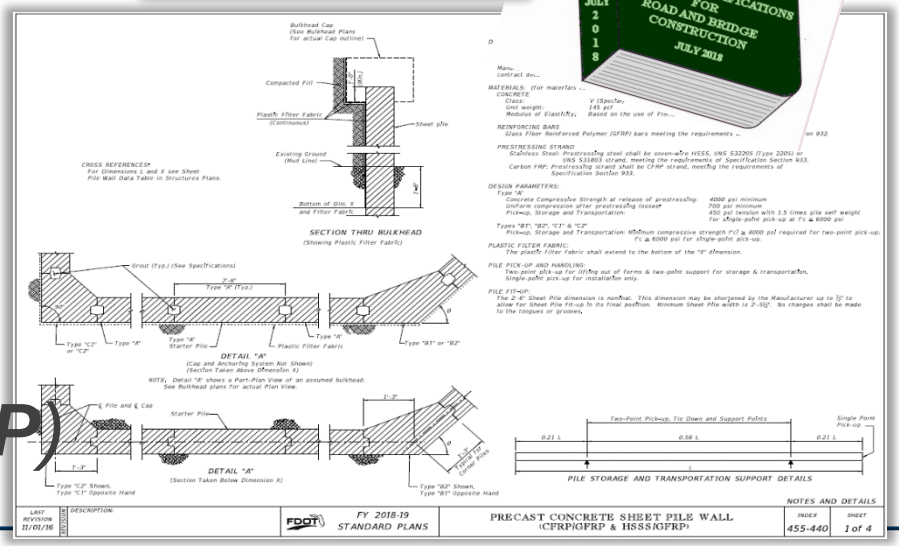
https://www.fhwa.dot.gov/innovation/stic/state_innovation.cfm

Specifications – FDOT

1. **Structures Manual** – Vol. 4 ***(FRPG)***
2. Construction **Specs**. ***(Division II)***
3. Materials **Specs**. ***(Division III)***
4. **Materials Manual** ***(Chapter 12)***
   - Production Facility Approvals
5. **Standard Plans** ***(SP)***
   - SP Instructions ***(SPI)***
   - Developmental Standards ***(DDS** & **DSP)***

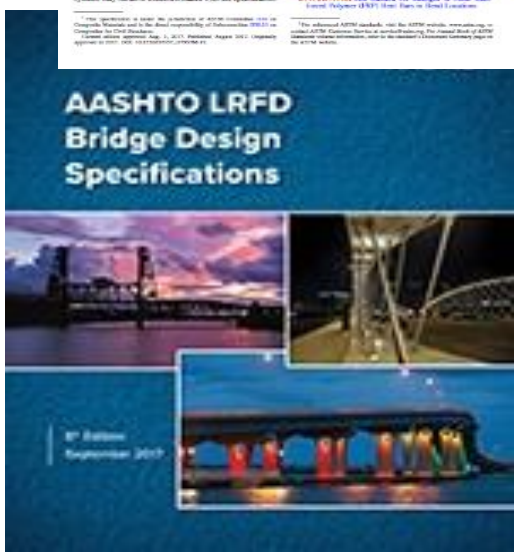






Specification Harmonization – GFRP-RC

- ***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	**0.28**	**0.20 or 0.28**	0.20 to 0.28	0.20 ?	Crack width limit [in.]
$c_{c,stirrups}$	1.5	1.50	2.0 (3)	40	Clear cover [in.]
$c_{c,slab}$	1.0	0.75 to 2.0	0.75 to 2.0 (3)	40	Clear cover [in.]

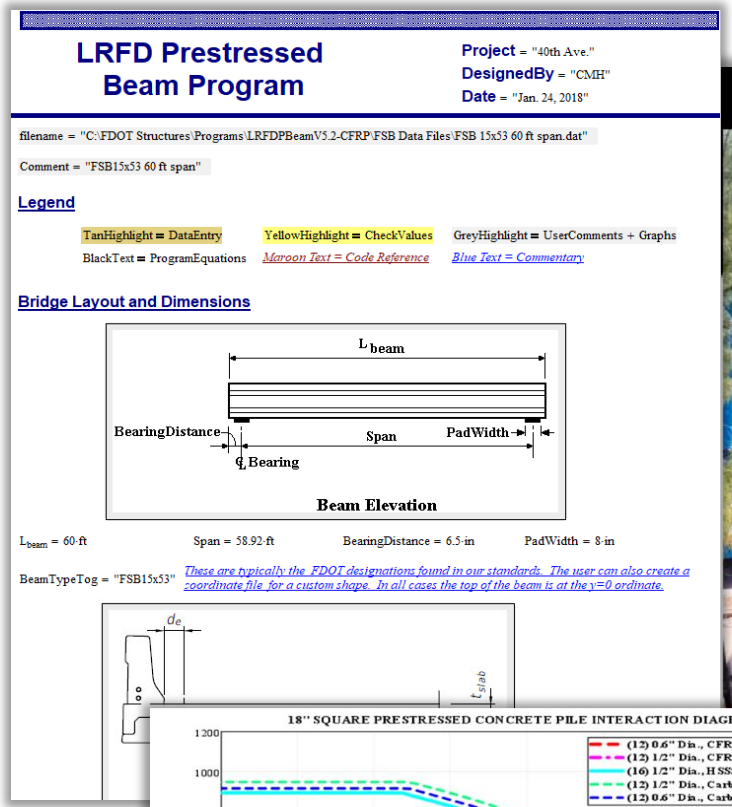
(1) *Characteristic Strength;* (2) *$1/k_b$;* (3) ***ACI 440.5-08*** *Table 3.1;* *(19) proposed for 2019 updates*

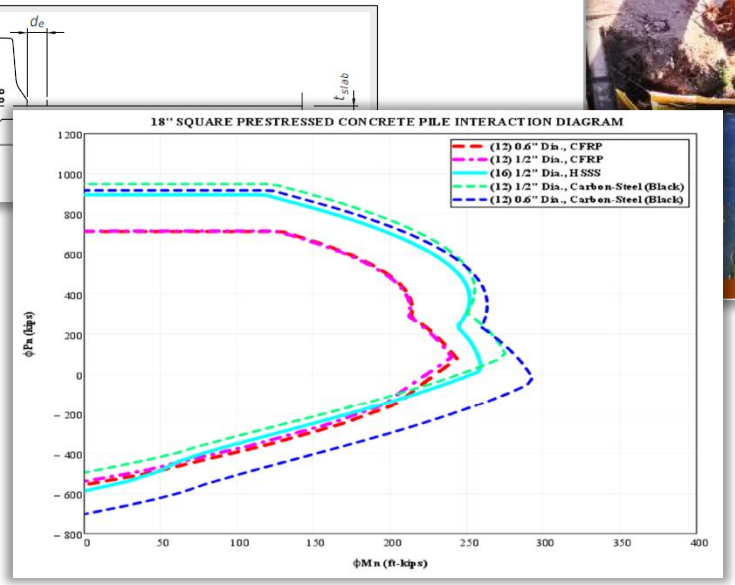
Specification Harmonization – CFRP-PC

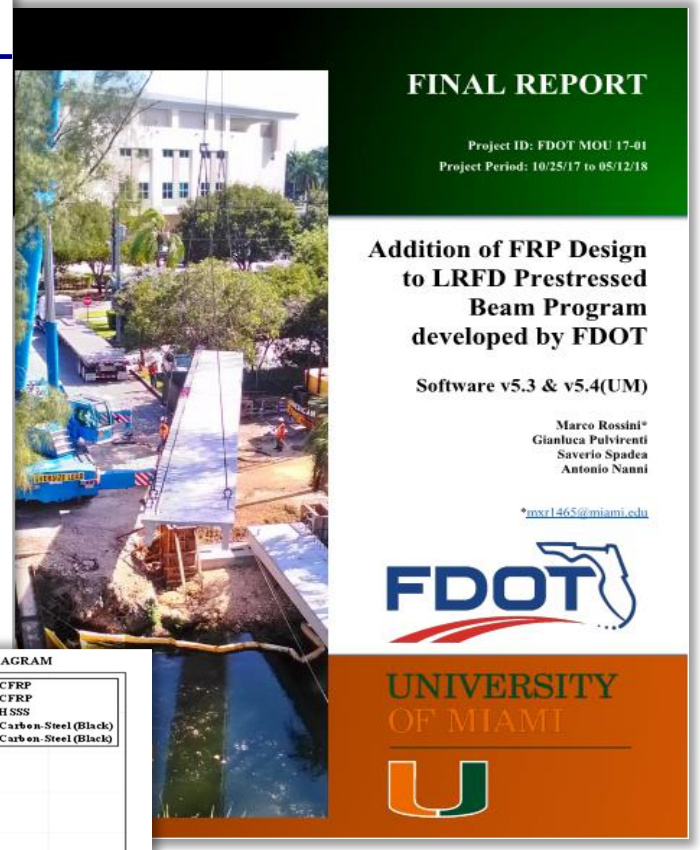
	AASHTO-BDS 8th 2018 (steel only)	*AASHTO-GS 1st* 2018	*ACI 440.4R* 2002 (11)	*CSA* 2014 *(19)*	
f_{fu}^*	99.73	99.73	99.73		Strength percentile
Φ_C	0.75	**0.75**	0.65		Res. Fact. concr. failure
Φ_T	1.00	0.75	0.85		Res. Fact. FRP failure
Φ_S	0.75	0.75			Res. Fact. shear failure
C_E	1.00	1.00 (internal)	0.9 (from 440.1R)		*Environmental reduction*
C_{Ci}	0.75_j / 0.70_{serv}	**0.70_j / 0.65_{serv}**	**0.60**		*Creep rupture reduction*
C_f	0.45	**18 ksi**			*Fatigue reduction / stress*
C_b	n/a				*Bond reduction*
w	n/a				Crack width limit [in.]
$c_{c,stirrups}$	-	-			Clear cover [in.]
$c_{c,strand}$	-	3.5 d_b			Clear cover

(1) *Characteristic Strength; (19) proposed for 2019 updates*

Design Tools – FDOT Programs & Design Aids

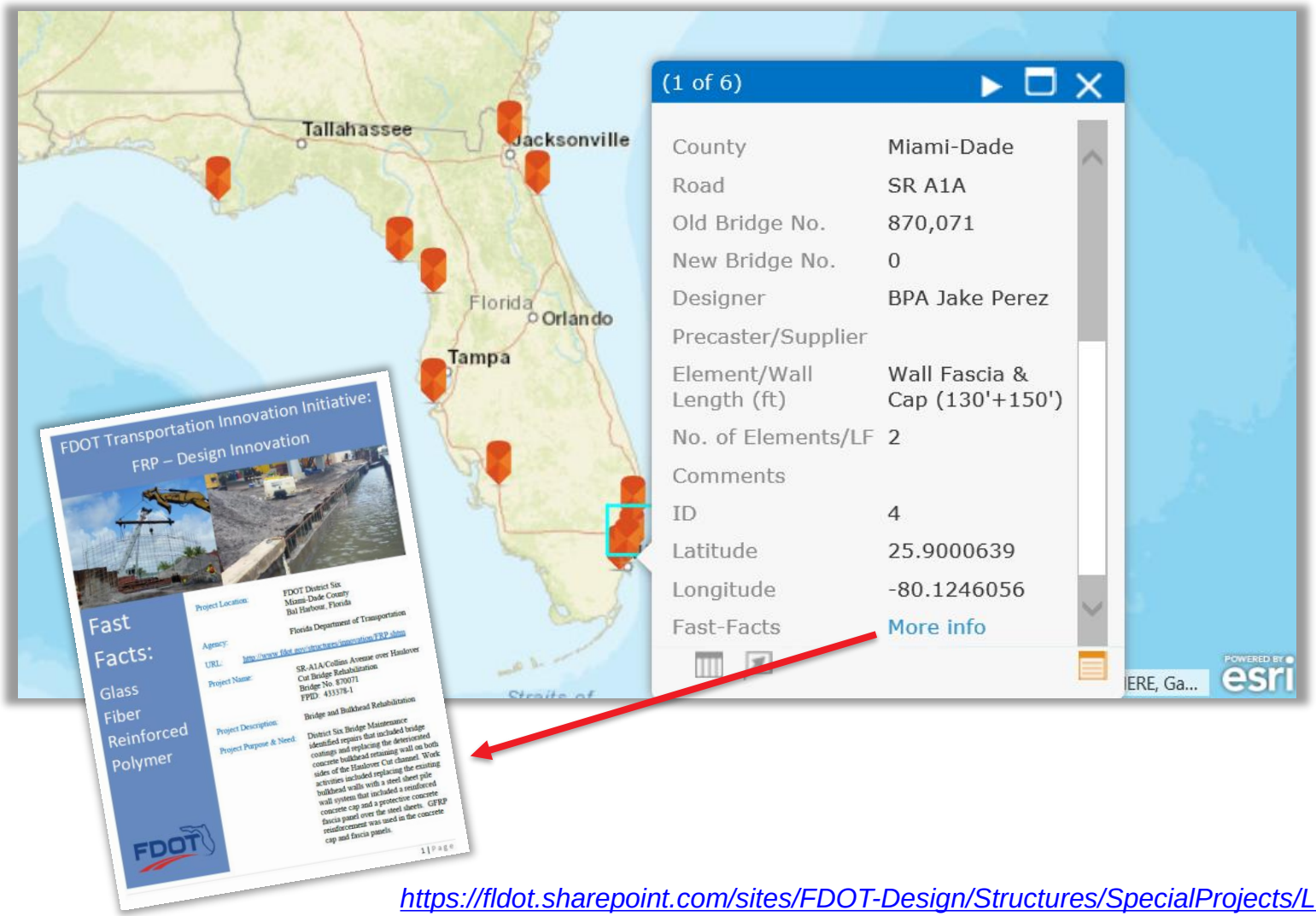






1. **Design Programs**
   - CFRP-PC Beams
   - GFRP-RC Flat-Slab
   - GFRP-RC Bent Cap
   - *Retaining Walls soon!*
2. ***SPI* "Design Aids"**
3. **Project GIS-Map App.**
4. **Under development**
   - Cost Estimating Guidance
   - LCC Analysis Guidance

Design Tools – FDOT GIS-Mapping App.



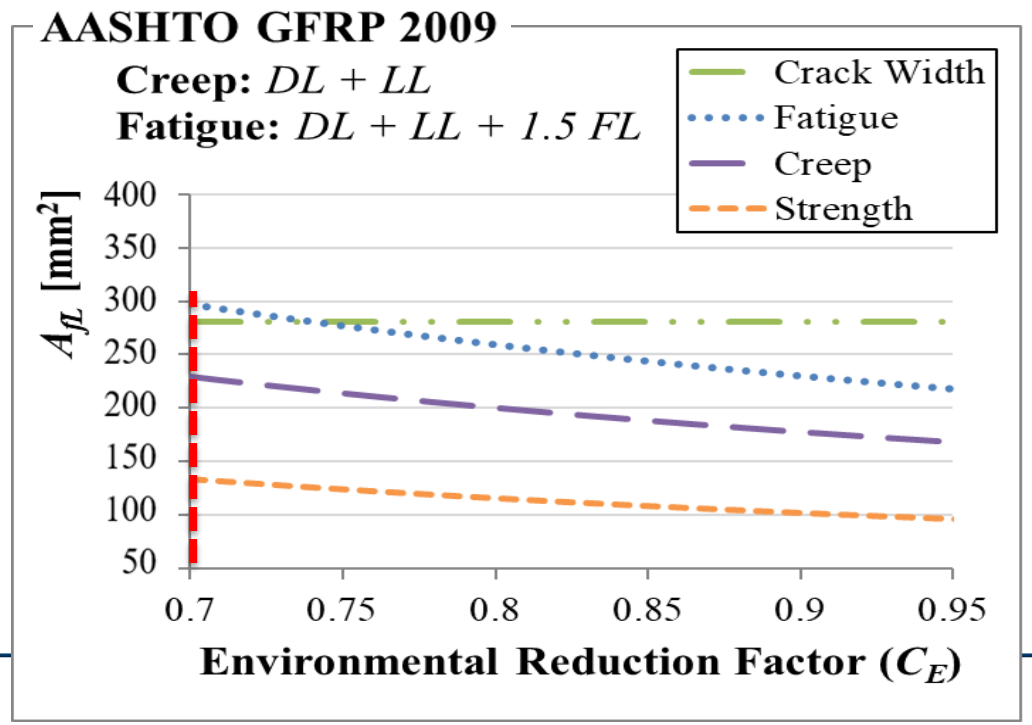
1. **Currently includes:**
   - Active and Completed FRP-RC/PC projects;
2. **Plans to add:**
   - Bridge beam FRP repair/ strengthening projects (25+ year history of wet-layup repairs)
   - FRP-Fender Systems
   - HSSS projects

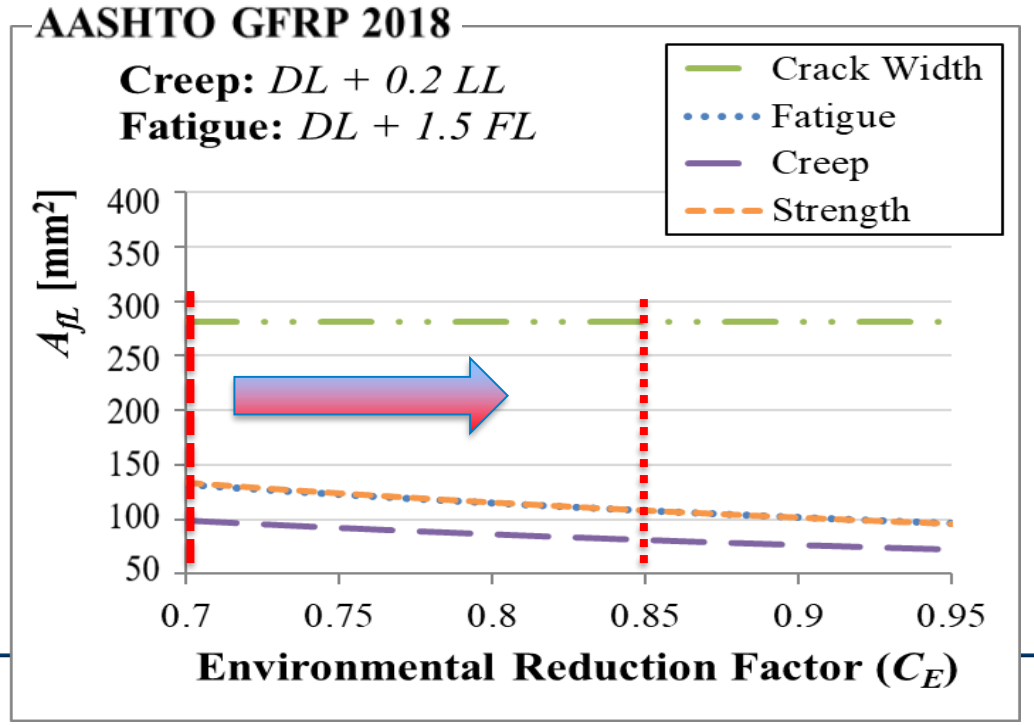
https://fldot.sharepoint.com/sites/FDOT-Design/Structures/SpecialProjects/Lists/FRP%20Rebar%20Project/AllItems.aspx

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!***





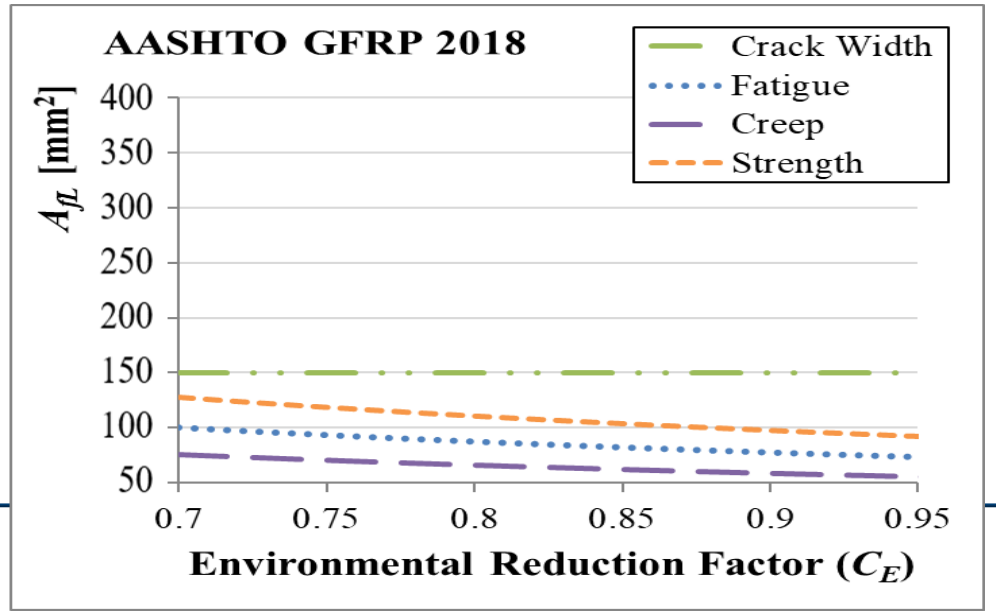
Recent Advancement (cont.) - GFRP-RC Specs

2nd Ed. updates reflect:

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

Now need to:

1. *Rationally increase **Tension-Controlled** Flexural Resistance Φ_t (**0.55** to **0.75 ?**), and*
2. *Increase the minimum **Elastic Modulus…***



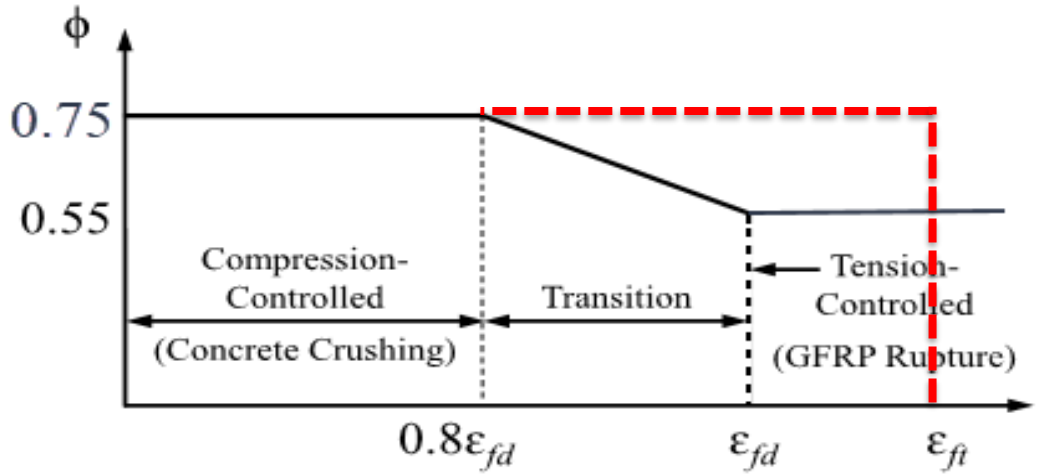
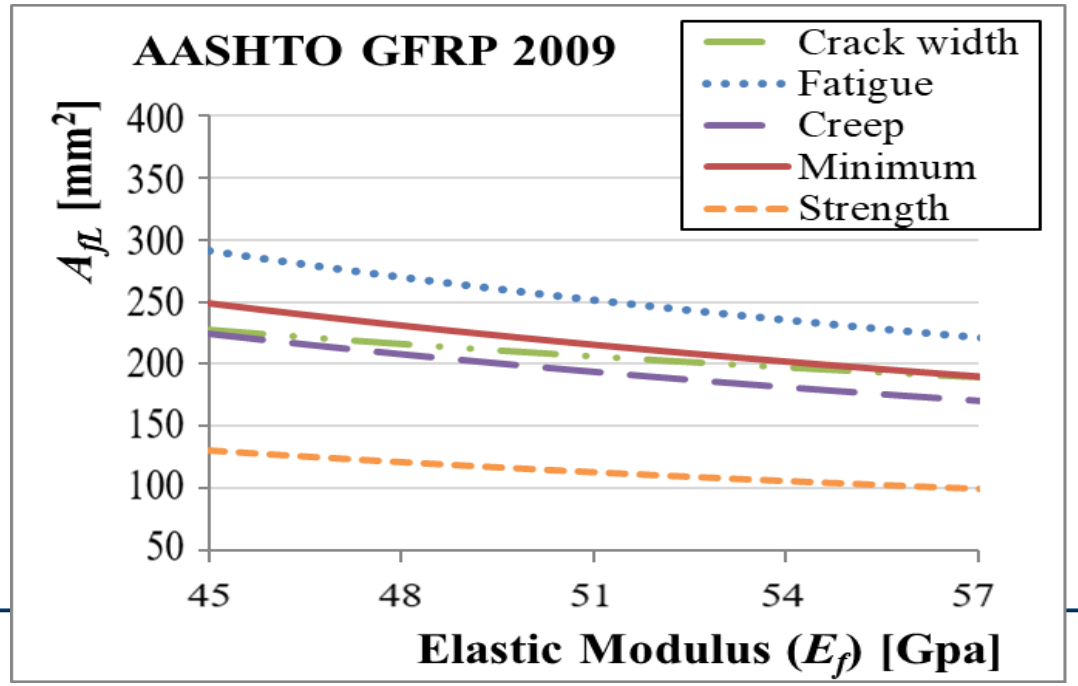
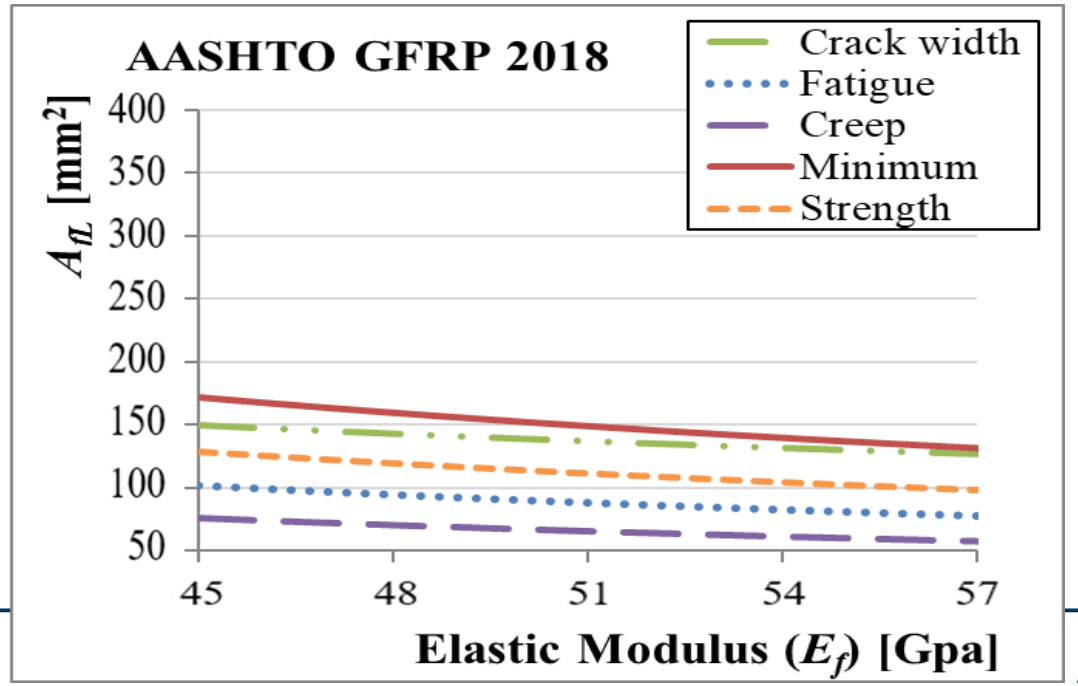


Figure C2.5.5.2-1 – Variation of ϕ with Tensile Strain at Failure, ε_{ft}, in GFRP Reinforcement

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.





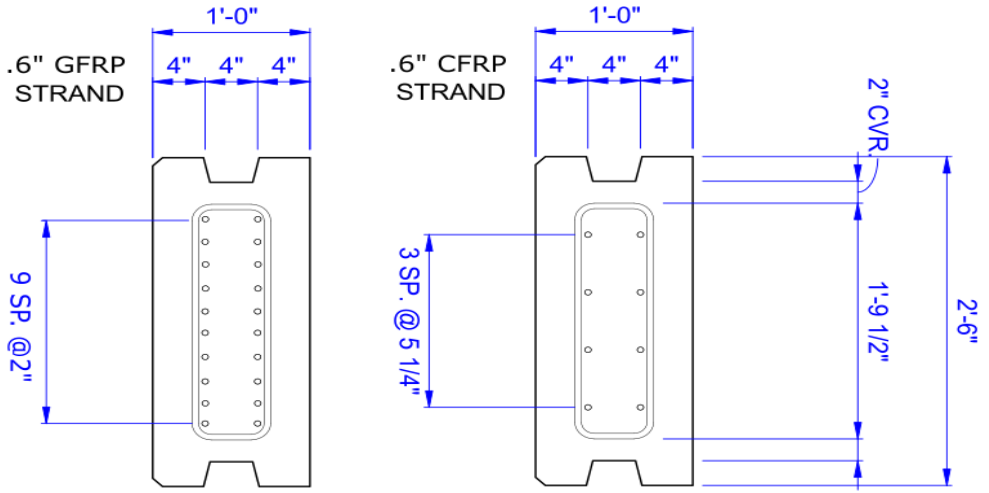
Future Advancement – GFRP-PC twisted strand

1. *NCHRP's* Innovations Deserving of Exploratory Analysis *(IDEA)*

- GFRP Prestressing - **MILDGLASS** *(University of Miami)*;

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

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

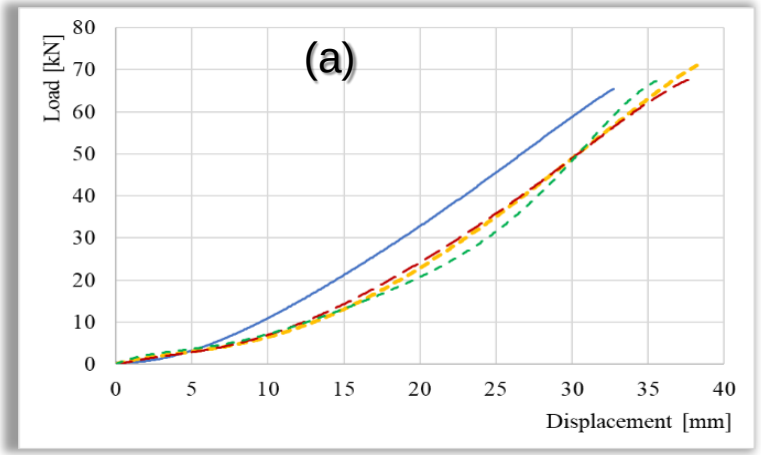


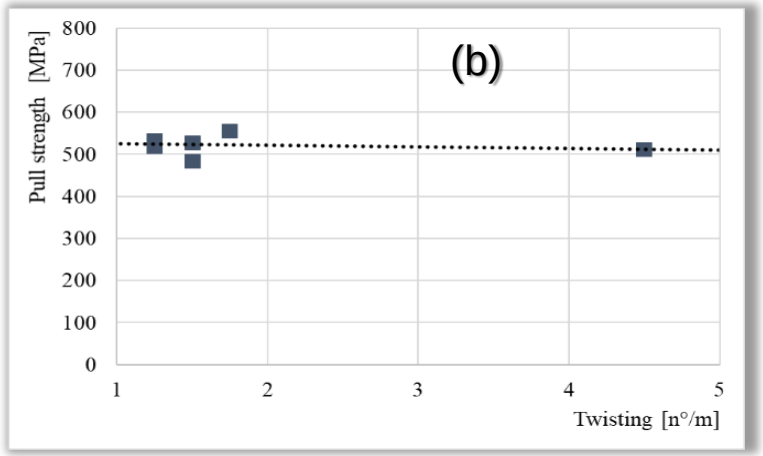
(a) GFRP-PC sheet pile concept (b) CFRP-PC sheet pile design for Halls River Bridge

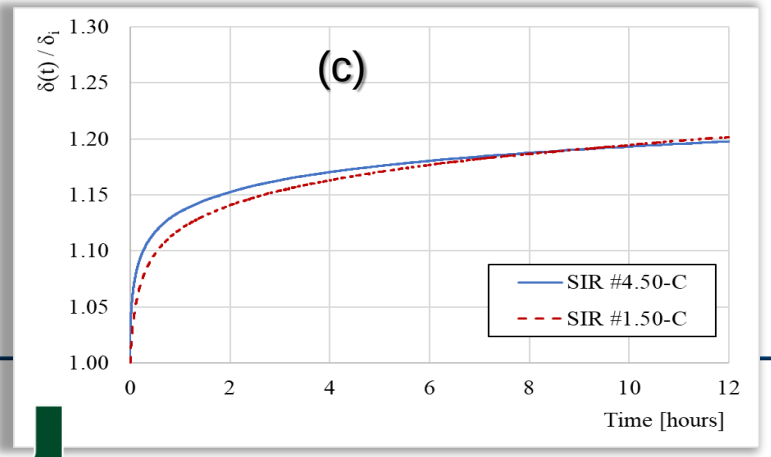
Future Advancement – GFRP-PC twisted strand (cont.)

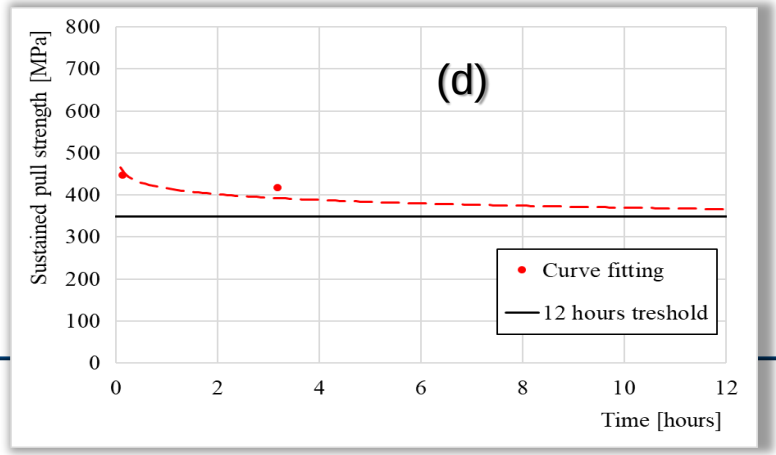
1. *NCHRP's* Innovations Deserving of Exploratory Analysis *(IDEA)*

- GFRP Prestressing - **MILDGLASS** *(University of Miami);*









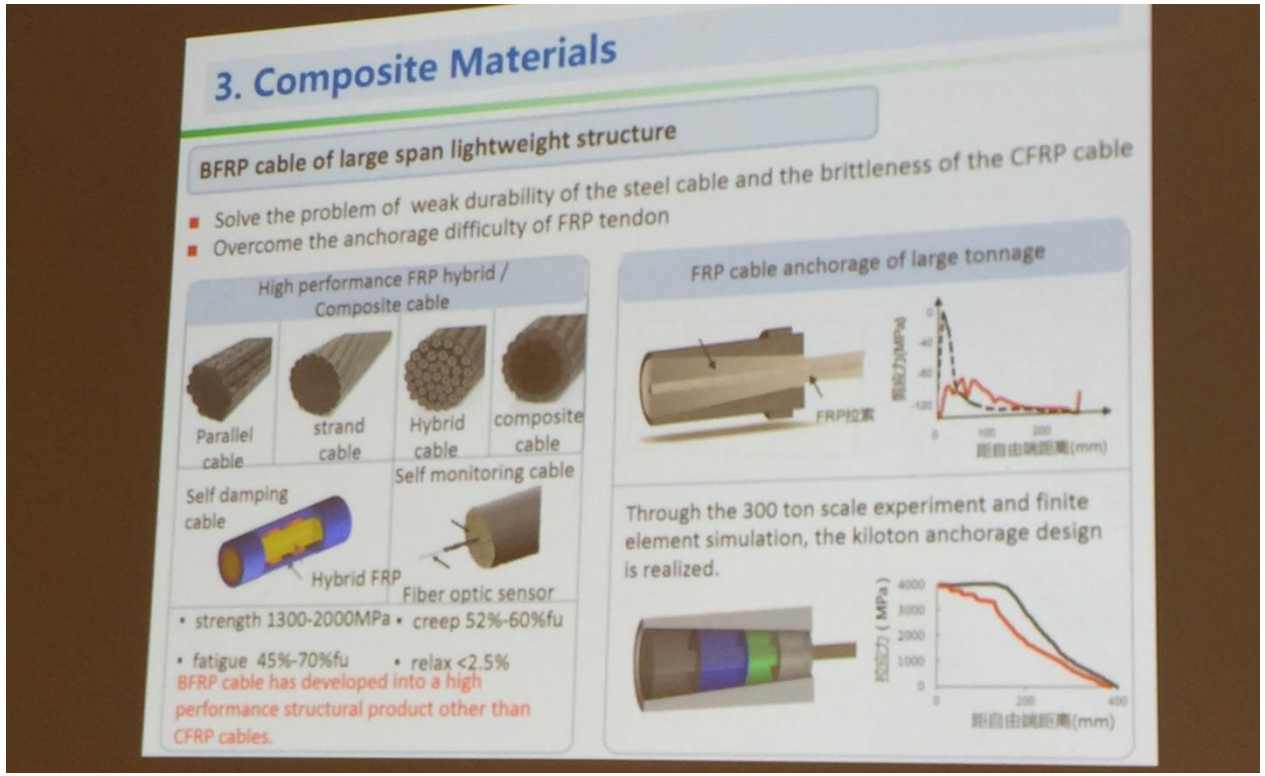
Pull test load:

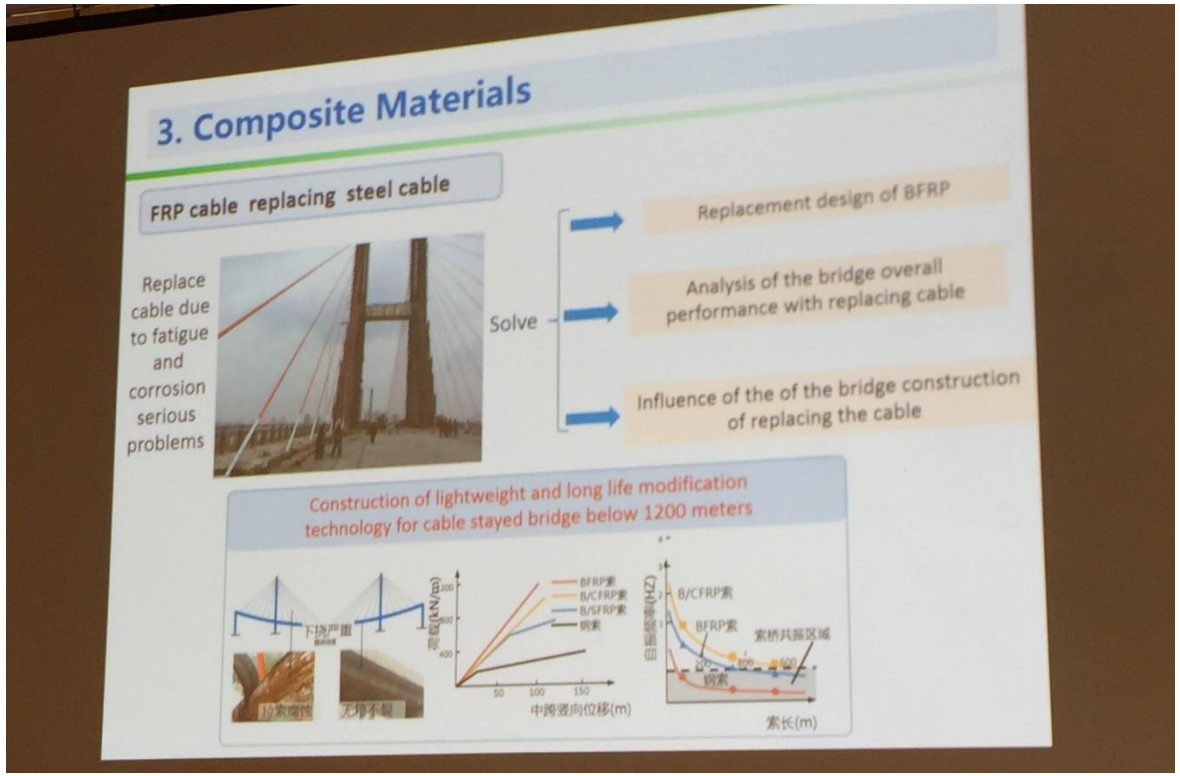
(a) Displacement diagrams;
(b) Pull strength at varying twist per meter;
(c) Creep displacement over initial value;
(d) Creep rupture logarithmic regression

Future Advancement (cont.) – ????...

2. *Next* Innovation Deserving of Exploratory Analysis…

- BFRP Prestressing (perhaps)???

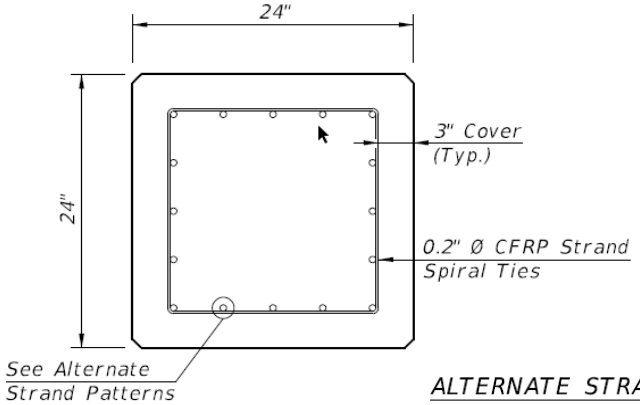




Standardized Elements - Piles

Bridge Bearing Pile Standards

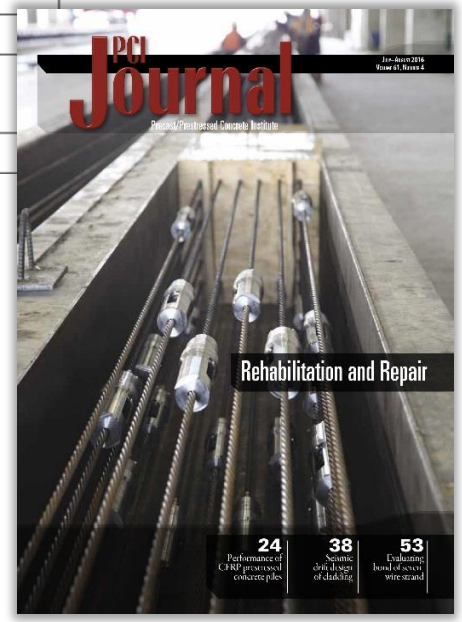
455-101		Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes
455-102		Square CFRP and SS Prestressed Concrete Pile Splices
455-112		12" Square CFRP and SS Prestressed Concrete Pile
455-114		14" Square CFRP and SS Prestressed Concrete Pile
455-118		18" Square CFRP and SS Prestressed 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



SECTION A-A

ALTERNATE STRAND PATTERNS

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

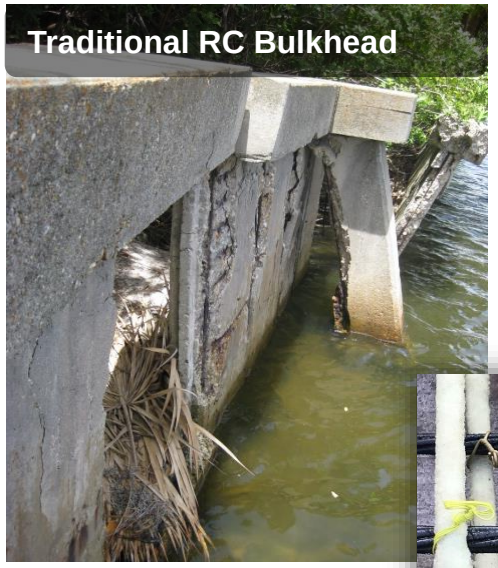


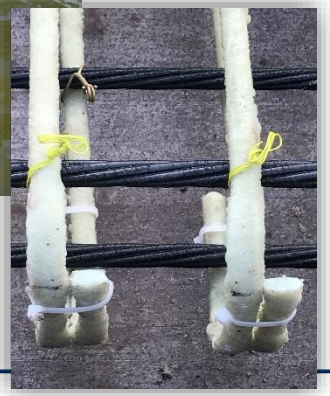
Standardized Elements - Seawall-Bulkheads

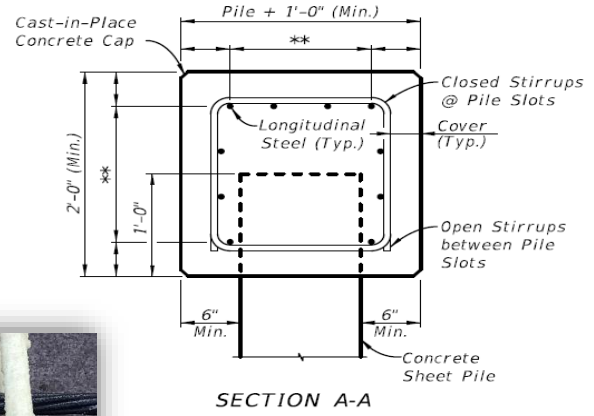
Concrete Sheet Pile Bulkhead Standards


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)

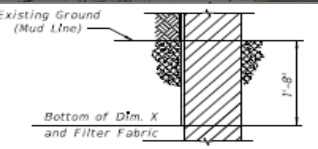

Traditional RC Bulkhead



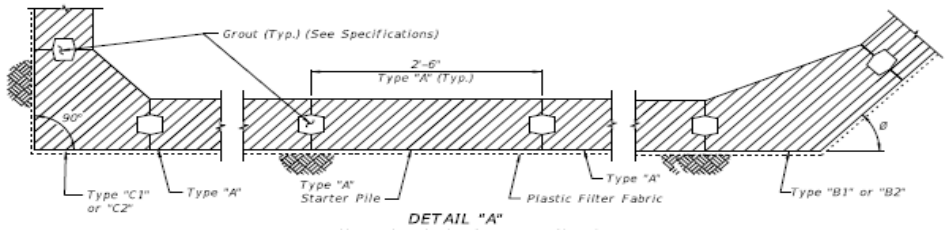


SECTION A-A


Traditional RC Bulkhead Cap



SECTION THRU BULKHEAD
(Showing Plastic Filter Fabric)

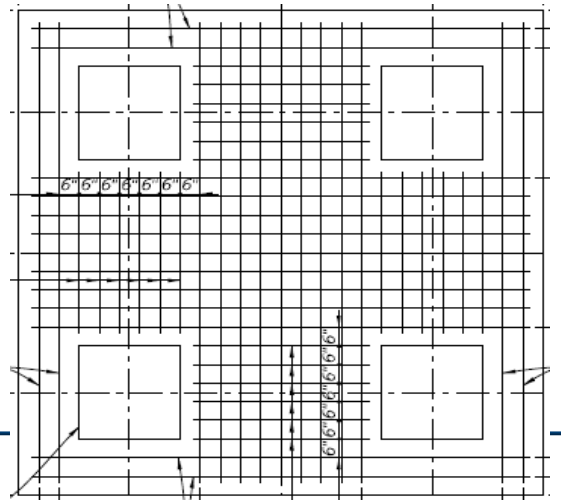


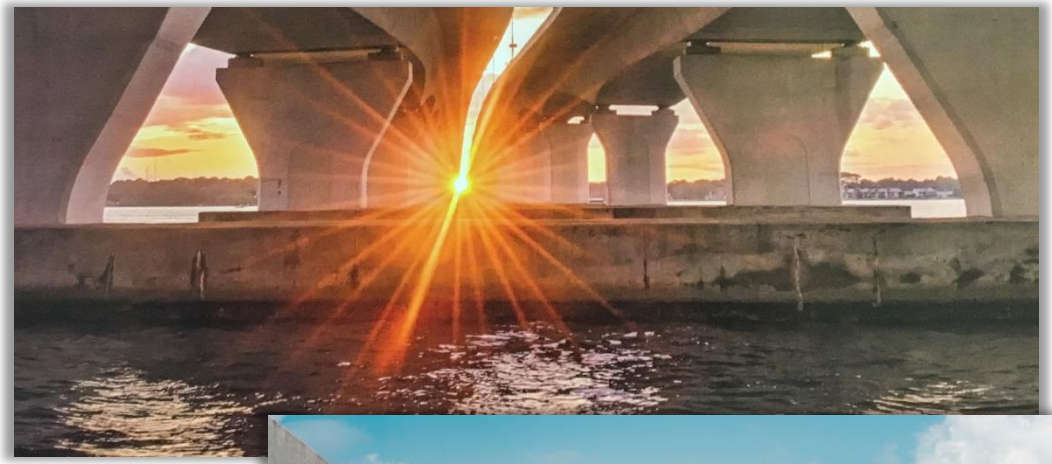
DETAIL "A"

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

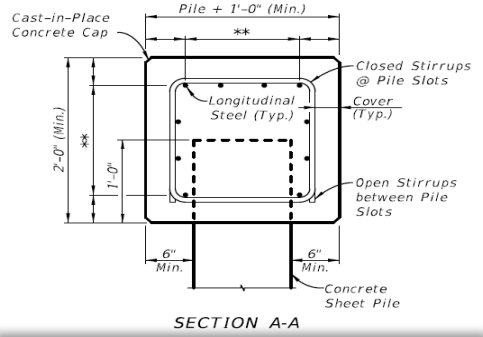
Bridge Bearing Pile Projects

- 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) ?

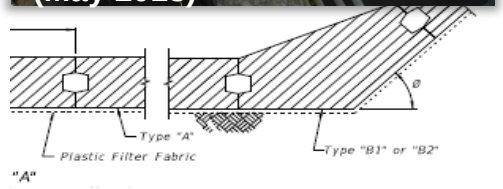
Project Example Elements - Seawall-Bulkheads

Concrete Sheet Pile Bulkhead Projects

- 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) ?



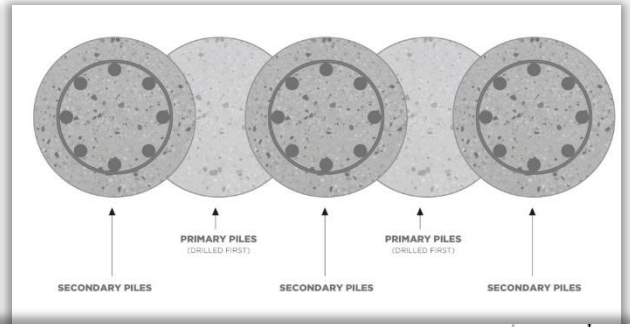
SECTION A-A



Project Example Elements - Seawall-Bulkheads

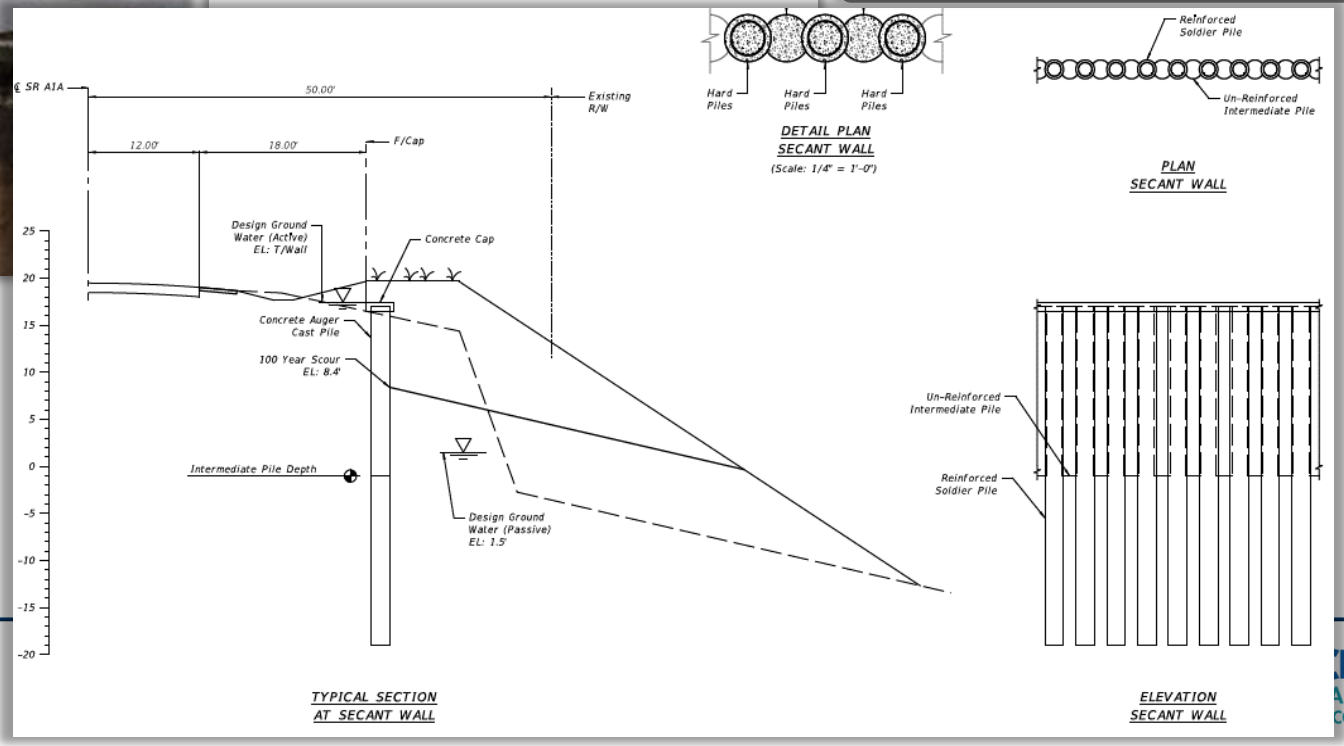
Secant Piles seawall on SR A1A


SR A1A damage after Hurricane Matthew (2016)




GFRP Pile cages (Hughes Bros.)

Secant Wall Concept Rendering

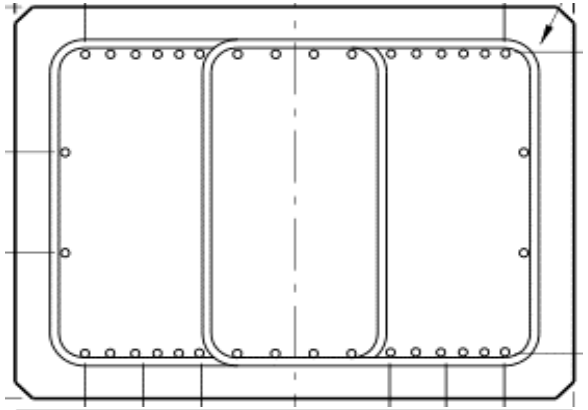


Project Example Elements - Bent Cap

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)



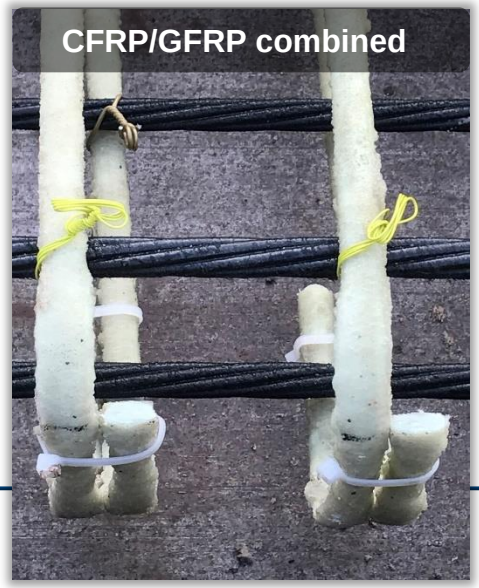
Typical Section from HRB Plans

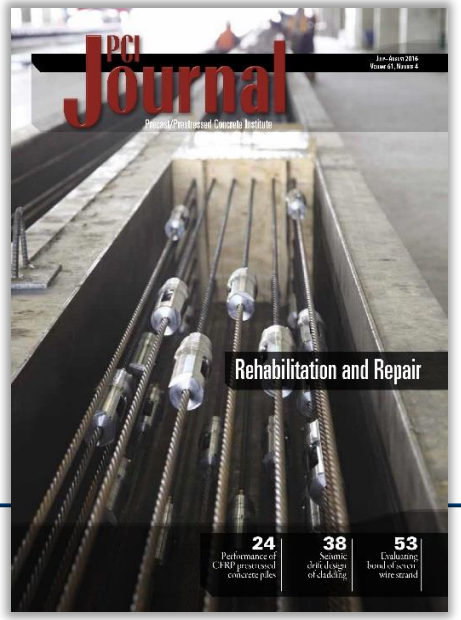
Hurricane Irma damage of boat docks (2017)

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

Project Example Elements - Girders/Slab-Beams


HCB's set on GFRP-RC Pile Caps


CFRP/GFRP combined



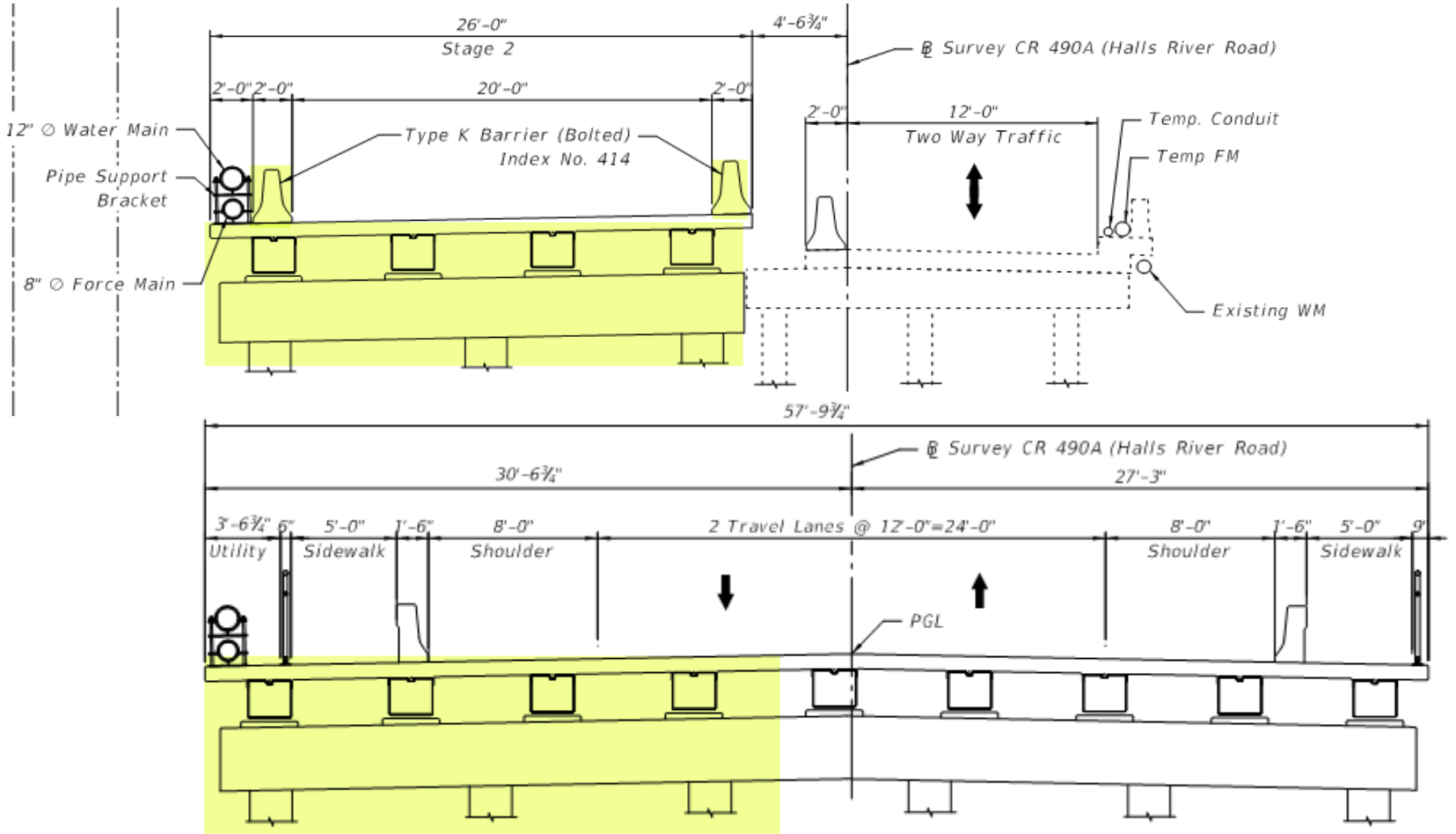
Projects:

- 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)

FDOT Project Identification & Delivery

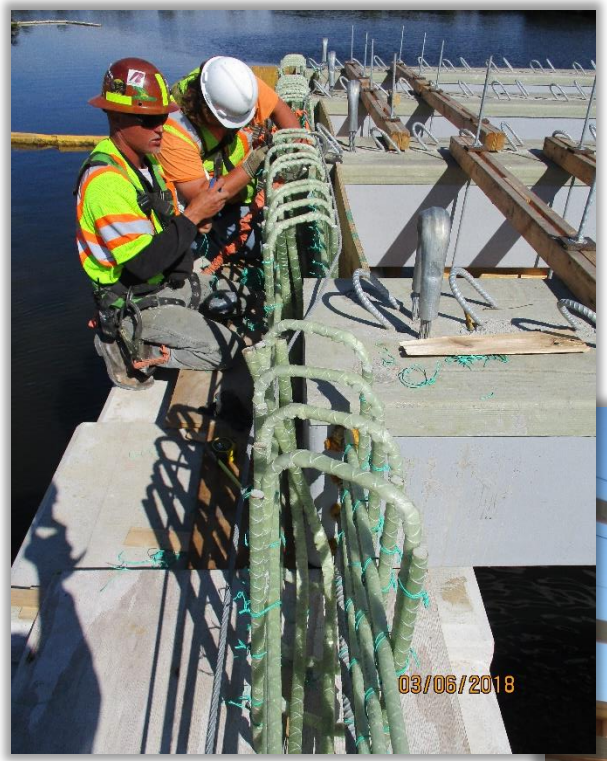
1. **Environmental condition driven**
   - Durability/Magnetic Transparency/LCC
2. **Optional precast alternatives**
   - Encourage stakeholder buy-in
3. **Desire for multiple suppliers**
   - Redundancy & Supply chain security
4. **Simplify design process/workflow**
5. **Minimize change for Contractors**
   - Business as usual…almost

Projects - Halls River Bridge progress



COMPLETED STRUCTURE

Projects - Halls River Bridge progress



Projects - Halls River Bridge progress (challenges)

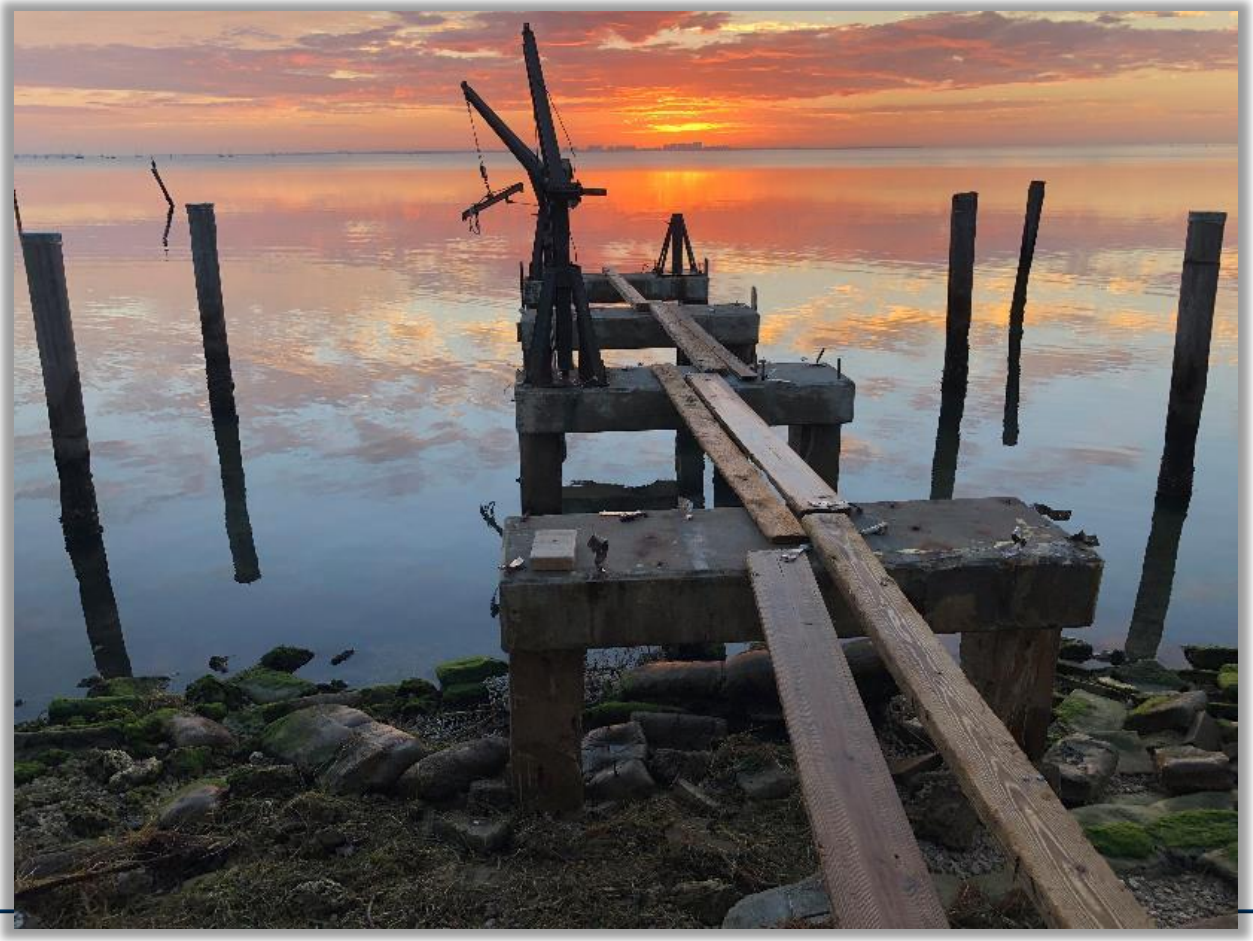
Collaborative Projects

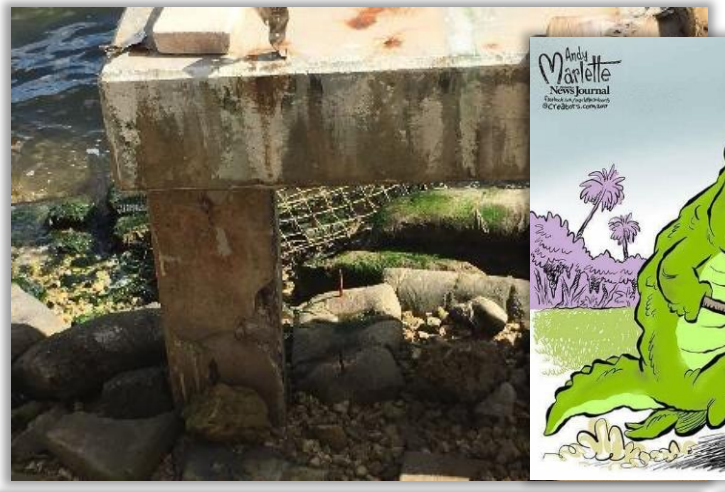
FDOT Collaboration Projects:

- ***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)*



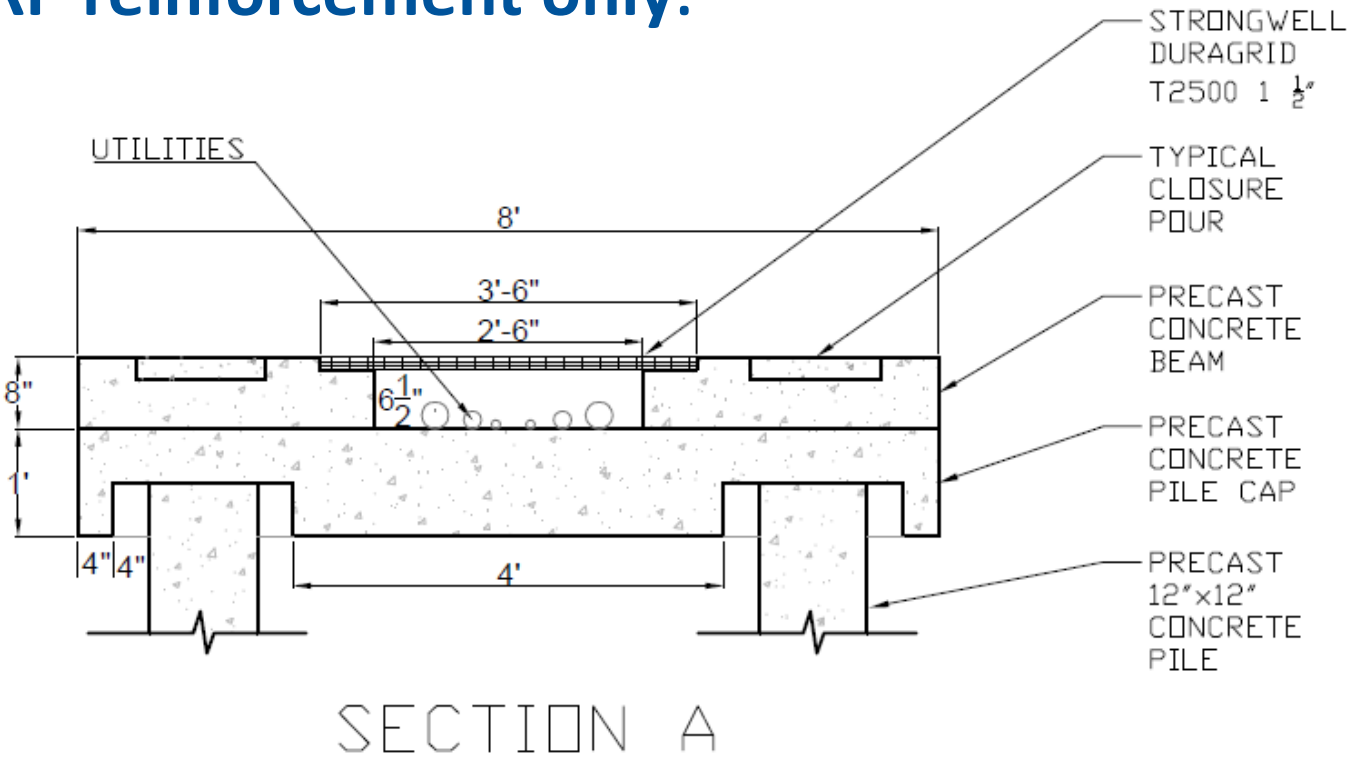


Collaborative Project Example – iDock (cont.)

Proposed Dock -

Precast Elements all using FRP reinforcement only:

1. 8~ Piles: 24’x1’x1’
2. 4~ Pile Caps: 8’x2.5’x1’
3. 8~ Slabs:
   - 1~ unit of 144”x33”x8”
   - 1~ unit of 132”x33”x8”
   - 6~ units of 120”x33”x8”



SECTION A

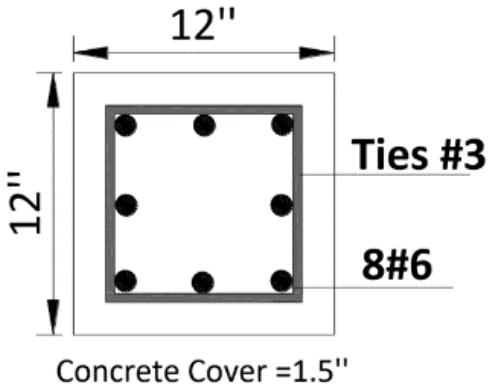
Collaborative Project Example – iDock (cont.)

RC Piles -

Precast piles reinforced with GFRP

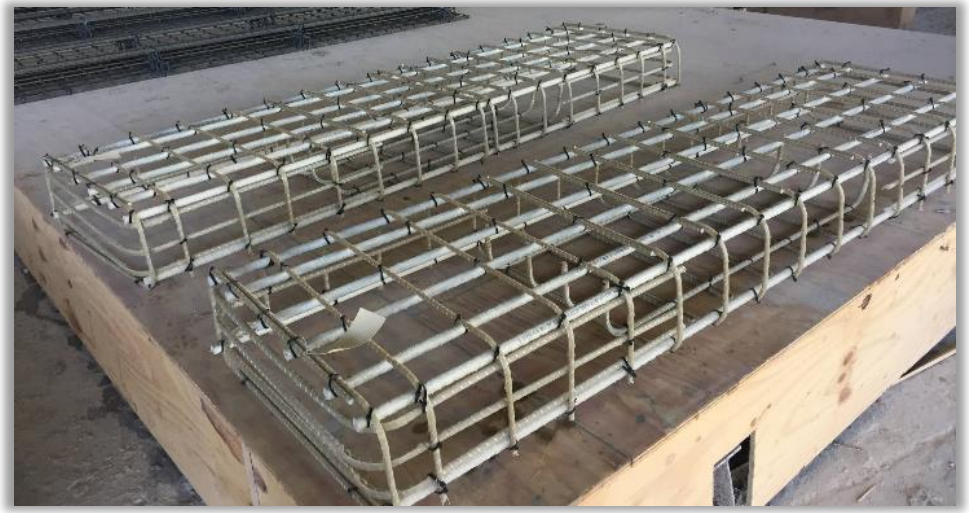
4 types of piles:

1. Type A: 6~#6 with spirals
2. Type B: 6~#6 with square ties
3. Type C: 6~#8 with spirals
4. Type D: 6~#8 with square ties



Collaborative Project Example – iDock (cont.)

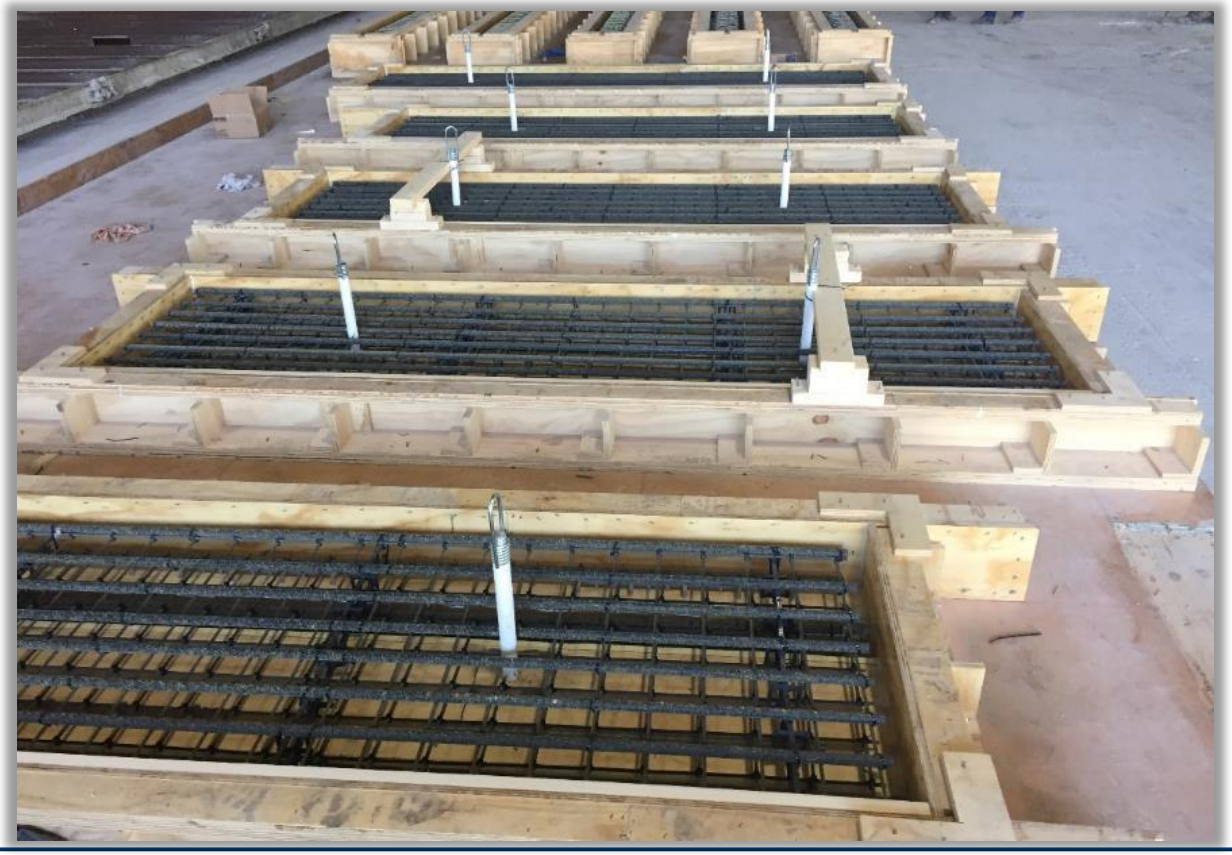
RC Pile Caps - Cages and cages inside formwork with block-outs



Collaborative Project Example – iDock (cont.)

RC Slabs -

Cages and cages inside formwork with lift points



Collaborative Project Example – iDock (cont.)

Completed Precast Elements - Slabs, caps and piles (at the Precaster's yard)

Looking Beyond Halls River Bridge

Photo Courtesy of Astaldi Construction Corp.
– Halls River Bridge under construction (FDOT FRP-RC/PC & HCB Demonstration project), February 2018.

Principles for Broader Deployment

1. **Stewardship**
2. **Confidence**
3. **Competency**
4. **Consistency**
5. **Codification**

NCHRP Report 503 (2003) identified 11 elements for a draft strategic plan as follows:

1. Buy-in from all strategic plan participants;
2. Acceptance, implementation, and revision of the strategic plan;
3. The means to oversee and manage the strategic plan;
4. A study of the relative costs of FRP versus traditional materials;
5. A database of practical infrastructure-based FRP knowledge;
6. Generic bridge-specific material specifications;
7. Generic bridge-specific design and evaluation methodologies;
8. Generic bridge-specific inspection and repair methods;
9. Training on FRP composite materials for practicing engineers;
10. Education on FRP composite materials for graduate civil engineers; and
11. Continuation of FHWA's Innovative Bridge Research and Construction (IBRC) program.

Principles for Broader Deployment

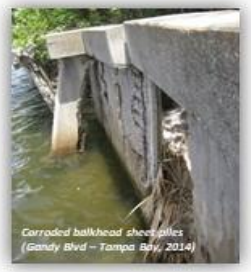
Top 5 Long-Term Goals

- **S**tewardship
- **C**onfidence
- **C**ompetency
- **C**onsistency
- **C**odification

FDOT

Participants/Collaborators

ACMA, Owens Corning, ATP, mafic, Pultrall, Pultron Composites, Tuf-Bar, Miami, UNF, UF, Tokyo Rope MFG. Co., Ltd.

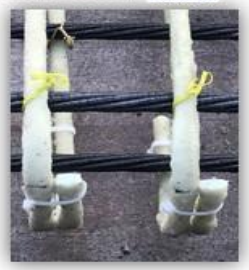


2018 FDOT-FRP Industry 2nd Winter Workshop

Safe Deployment of FRP-RC/PC for Structural Reinforcement

- Next Generation Infrastructure

(eliminating the threat of steel corrosion)



2018 Strategic Workplan items

1. **Endurance Limits**
2. **Endurance Characteristic Curves and Testing**
3. **Establishing Consistency**
4. **Increasing Material Property Qualification Thresholds and Design Limits**
5. **Cost Estimating**
   a. OC initiative for ACMA FRP-RMC
   b. FDOT SDG Chapter 9 update
6. **Bar Bends**
   a. Complex Shapes
   b. FDOT Index D21310
7. **Minimum Bar Sizes for Design Elements**
8. **Life-Cycle Cost Guidance**
9. **Minimum Concrete Class**

http://www.fdot.gov/structures/Innovation/FDOT%202018%20Winter%20FRP-RC%20Workshop/Default.shtm

Principles for Broader Deployment

1. Stewardship

- Responsible use of public funds = specify FRP where it makes sense;
- Maximize material efficiency = strive for constant improvement;
- Identify additional technical resources for exploitation = getting outside of our "silos".

Principles for Broader Deployment

1. Stewardship
2. **Confidence**
   - Build Stakeholder confidence = *owners, designers, contractors, suppliers, inspectors*;
   - Supply Chain security = *redundancy, scalability, sustainability.*

Principles for Broader Deployment

1. Stewardship
2. Confidence
3. **Competency**

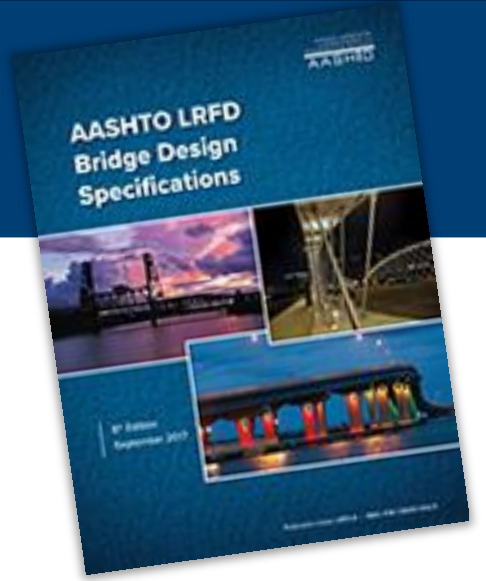
- Designer qualifications/training = *all minor bridge consultants;*
- Design Tools = *calculations & estimates;*
- Contractor & Inspector guidance = *CPAM & training.*

Principles for Broader Deployment

4. Consistency

- Material reliability = *data gathering and curation;*
- Encourage improved QC = *improved reliability;*
- Simplified verification testing = *improved reliability and efficiency;*

Principles for Broader Deployment



4. Consistency
5. **Codification**
   - Establish **"Roadmap"** for ***AASHTO LRFD BDS*** adoption;
   - Coordination with ***CBS T-6***, ***T-10***, & ***ACI 440***;
   - Coordination with other national and international authoritative committees = ***TRB's*** *AFF80,* ***CSA****,* ***fib*** *TG 5.1.*

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*

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&
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FDOT's Fiber-Reinforced Polymer Deployment Train