



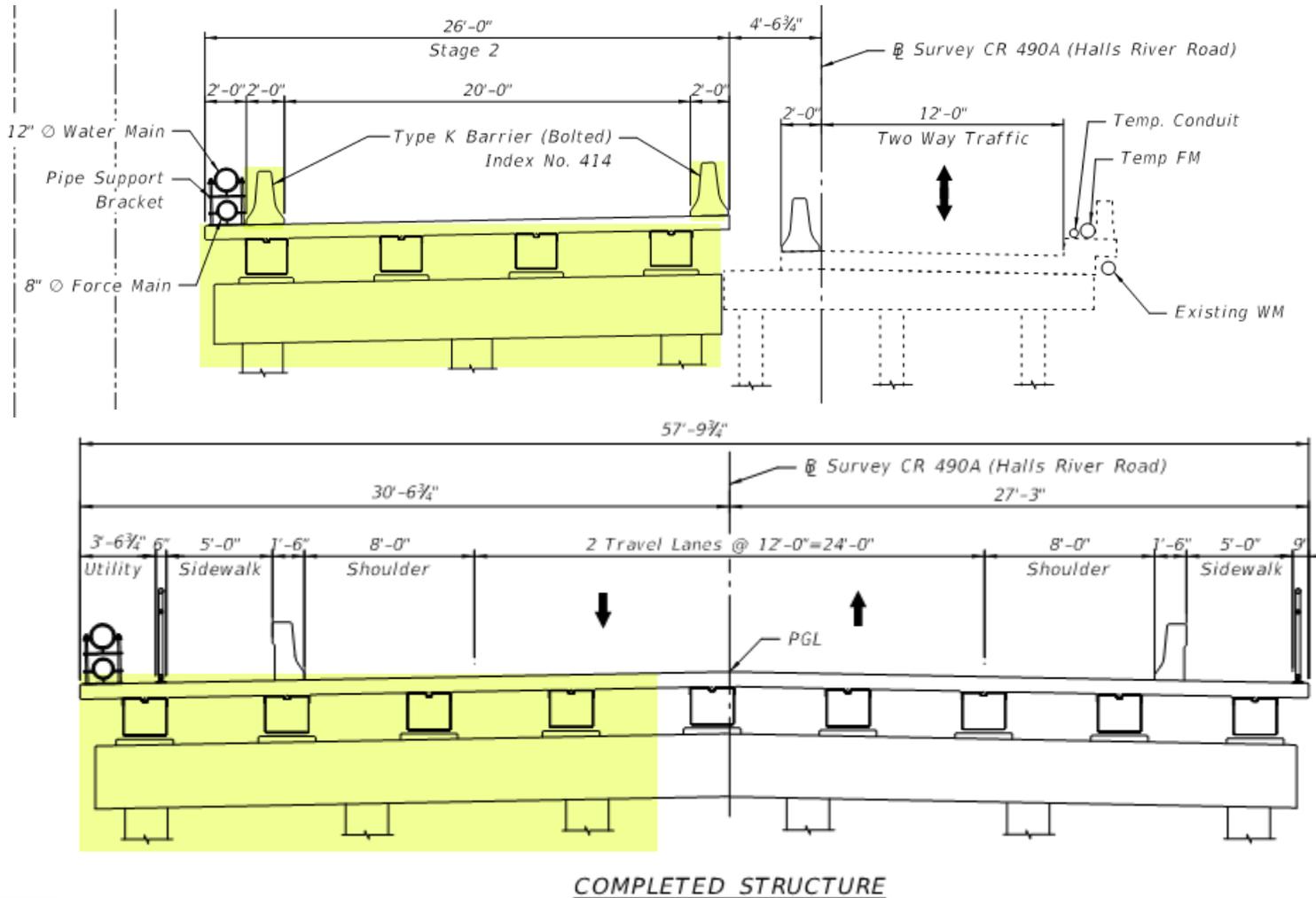
Beyond Halls River Bridge: *FRP-RC/PC Infrastructure Solutions*

Steven Nolan, Felix Padilla, Sam Fallaha, Chase Knight

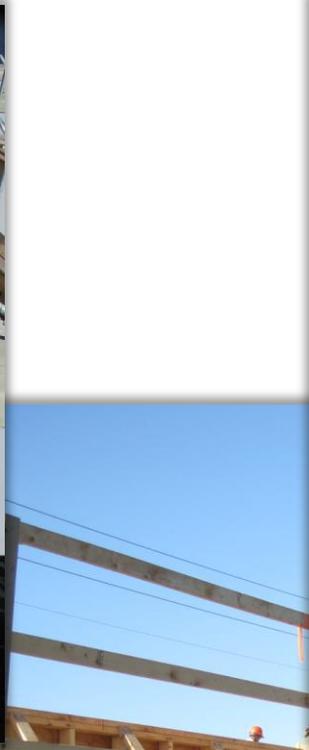
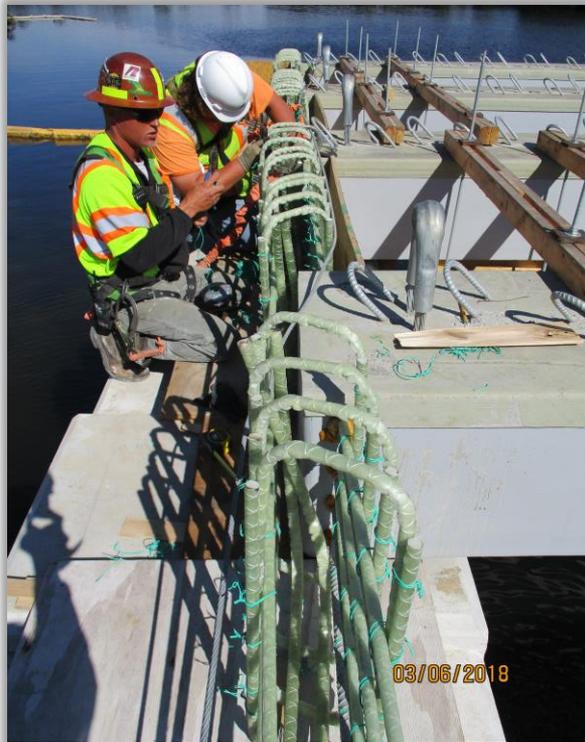
Overview

1. Halls River Bridge progress
2. Goals for broader Deployment
3. Specifications
4. Design Tools
5. Project Identification & Delivery
6. Uniform Standards
7. Advancement

Halls River Bridge progress



Halls River Bridge progress



Halls River Bridge challenges



Goals for Broader Deployment

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

Goals for Broader Deployment



Top 5 Long-Term Goals

- Stewardship
- Confidence
- Competency
- Consistency
- Codification



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)

Participants/Collaborators



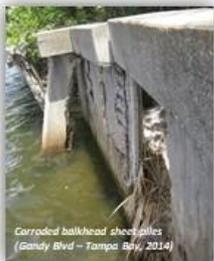
TOKYO ROPE MFG. CO., LTD.

UNIVERSITY OF FLORIDA



Strategic Workplan items

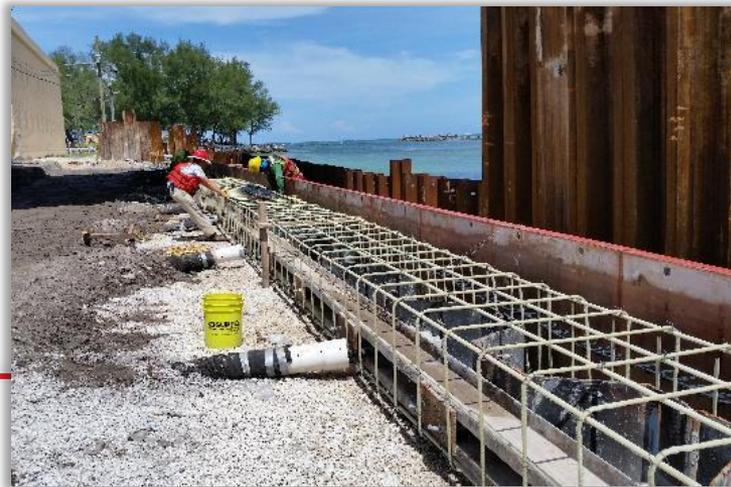
1. Endurance Limits
2. Endurance Characteristic Curves and Testing
3. Establishing Consistency
4. Increasing Material Property Qualification Thresholds and Design Limits
5. Cost Estimating
 - a. OC initiative for ACMA FRP-RMC
 - b. FDOT SDG Chapter 9 update
6. Bar Bends
 - a. Complex Shapes
 - b. FDOT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



Goals for Broader Deployment

1. Stewardship

- Use FRP where it makes sense;
- Maximize material efficiency;
- Identify resources for exploitation.



Goals for Broader Deployment

1. Stewardship

2. Confidence

- Build Stakeholder confidence;
- Supply Chain security.

Goals for Broader Deployment

1. Stewardship

2. Confidence

3. **Competency**

- Designer qualifications/training;
- Design Tools
- Contractor & Inspector guidance



4. Consistency

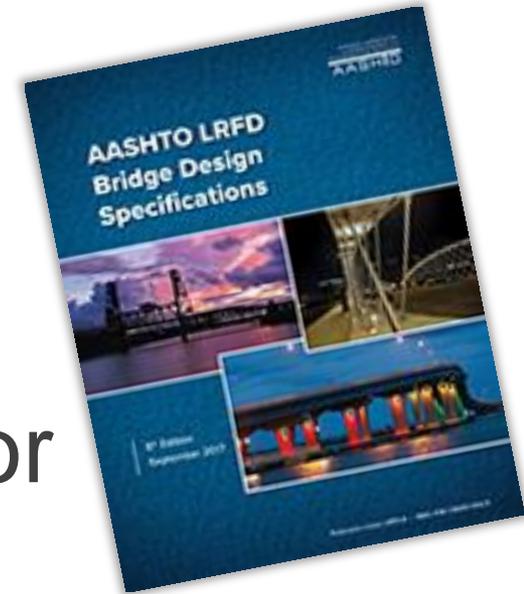
- Material reliability;
- Encourage improved QC;
- Simplified verification testing;
- Bent Bar improvement and capabilities

Goals for Broader Deployment

4. Consistency

5. Codification

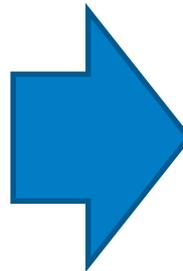
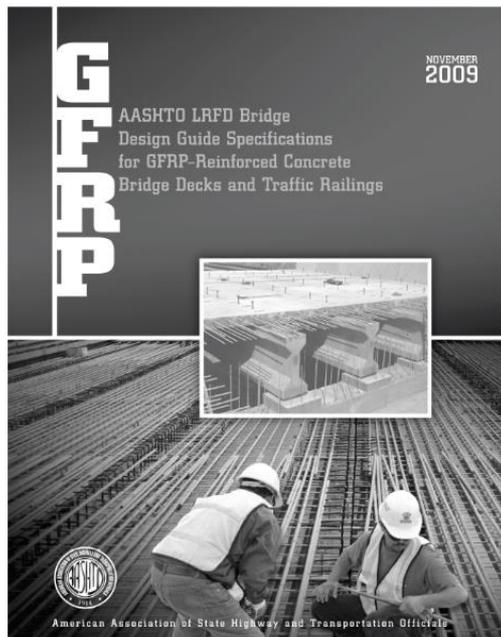
- Establish “**Roadmap**” for **AASHTO** adoption;
- Coordination with **ACI 440**;
- Coordination with international authoritative committees.



Specifications - GFRP

Support update of **1st Edition** on decks and railings to complete **Bridge Design Guide Spec. (BDGS-GFRP) 2nd Edition.**

- To be voted (**06/26/2018**) by AASHTO Committee T6 for adoption.



2018
AASHTO LRFD
BRIDGE DESIGN GUIDE SPECIFICATIONS
FOR GFRP REINFORCED CONCRETE – 2ND
EDITION

TABLE OF CONTENTS

Section 1	INTRODUCTION	9
1.1	SCOPE	9
1.2	DEFINITIONS	9
1.3	LIMITATIONS	10
1.4	DESIGN PHILOSOPHY	10
1.5	REFERENCES	10
Section 2	CONCRETE STRUCTURES	13
2.1	SCOPE	13
2.2	DEFINITIONS	13
2.3	NOTATION	15
2.4	MATERIAL PROPERTIES	17
2.4.1	General	17
2.4.2	GFRP Reinforcing Bars	17
2.4.2.1	Tensile Strength and Strain	17
2.4.2.2	Modulus of Elasticity	18
2.5	LIMIT STATES AND DESIGN METHODOLOGIES	18
2.5.1	General	18
2.5.1.1	Limit-State Applicability	18
2.5.1.2	Design Methodologies	18
2.5.1.2.1	General	18
2.5.1.2.2	B-Regions	19
2.5.1.2.3	D-Regions	19
2.5.2	Service Limit State	19
2.5.3	Creep Rupture Limit State	19
2.5.4	Fatigue Limit State	20

Specifications - CFRP

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

- To be voted (**06/26/2018**) by AASHTO Committee T6 for adoption.

NCHRP 12-97

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

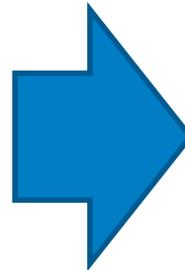
NCHRP 12-97
**AASHTO LRFD Guide Specifications for Prestressing
Concrete Elements Using CFRP Materials**

Abdeldjelil Belarbi, PhD, PE
belarbi@uh.edu

Washington, DC
January 7, 2018

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

UNIVERSITY OF HOUSTON



*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 Academies of Sciences, Engineering, and
Medicine

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES OF
SCIENCES, ENGINEERING, AND
MEDICINE
PRIVILEGED DOCUMENT

THIS DOCUMENT, NOT RELEASED FOR PUBLICATION, IS
FURNISHED ONLY FOR REVIEW TO MEMBERS OF OR
PARTICIPANTS IN THE WORK OF NCHRP. THIS DOCUMENT
IS TO BE REGARDED AS FULLY PRIVILEGED, AND
DISSEMINATION OF THE INFORMATION INCLUDED HEREIN
MUST BE APPROVED BY NCHRP

Abdeldjelil Belarbi, Ph.D., PE
Distinguished Professor
Department of Civil and Environmental Engineering
University of Houston

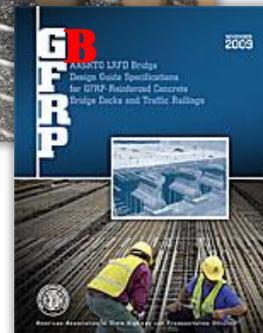
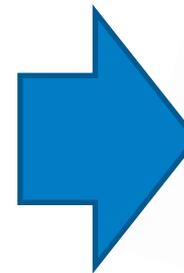
Specifications – BFRP

STIC Incentive Project – BFRP-RC Standardization

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

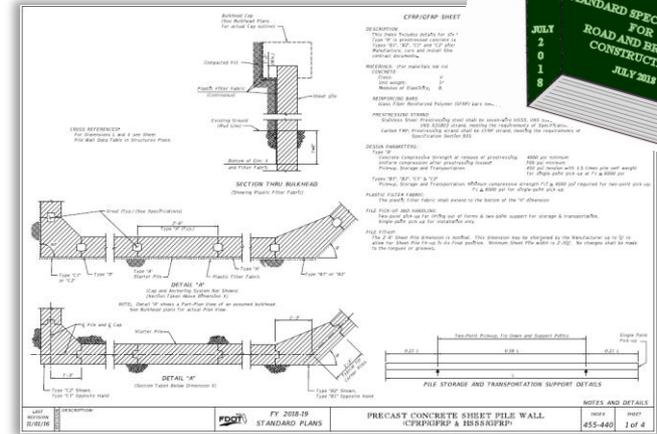
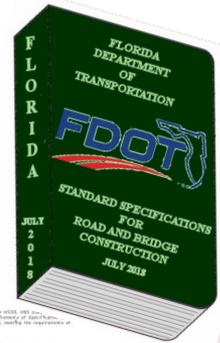
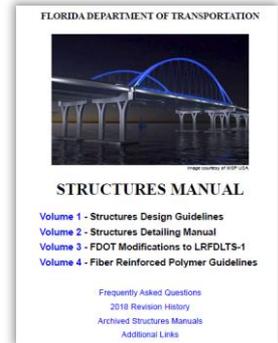
FDOT #443377-1; Research Project BDV30 986-01

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



Specifications – FDOT stuff

1. Structures Manual – Vol. 4 (FRPG)
2. Construction Specs. (Division II)
3. Materials Specs. (Division III)
4. Production Facility Approvals
5. Standard Plans (SP)
 - SP Instructions (SPI)



Design Tools - FDOT stuff

LRFD Prestressed Beam Program

Project = "40th Ave."
DesignedBy = "CMH"
Date = "Jan. 24, 2018"

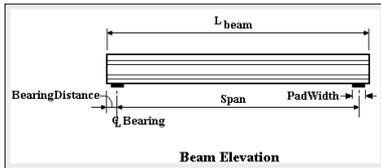
filename = "C:\FDOT Structures\Programs\LRFD\Beam\5.2-CFRP\FSB Data Files\FSB 15x53 60 ft span.dat"

Comment = "FSB15x53 60 ft span"

Legend

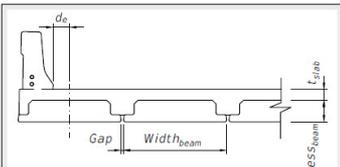
Tan Highlight = Data Entry Yellow Highlight = Check Values Grey Highlight = User Comments + Graphs
Black Text = Program Equations Maroon Text = Code Reference Blue Text = Commentary

Bridge Layout and Dimensions



$L_{beam} = 60$ ft $Span = 58.92$ ft $BearingDistance = 6.5$ in $PadWidth = 8$ in

BeamTypeTog = "FSB15x53" *These are typical; the FDOT designations found in our standards. The user can also create a coordinate file for a custom shape. In all cases the top of the beam is at the $y=0$ ordinate.*



FINAL REPORT

Project ID: FDOT MOU 17-01
Project Period: 10/25/17 to 05/12/18

Addition of FRP Design to LRFD Prestressed Beam Program developed by FDOT

Software v5.3 & v5.4(UM)

Marco Rossini*
Gianluca Pulvirenti
Saverio Spadca
Antonio Nanni

*mrx1465@miami.edu



UNIVERSITY
OF MIAMI

1. Design Programs

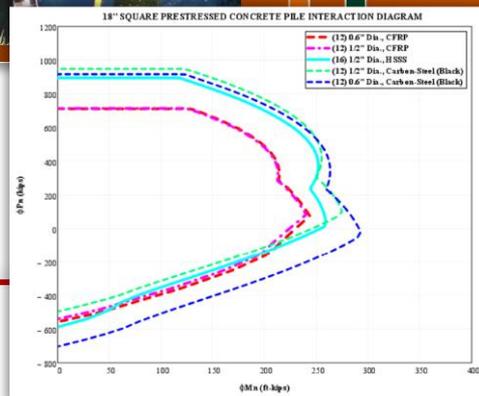
- CFRP-PC Beams
- GFRP-RC Flat-Slab
- GFRP-RC Bent Cap
- *Retaining Walls soon!*

2. SPI "Design Aids"

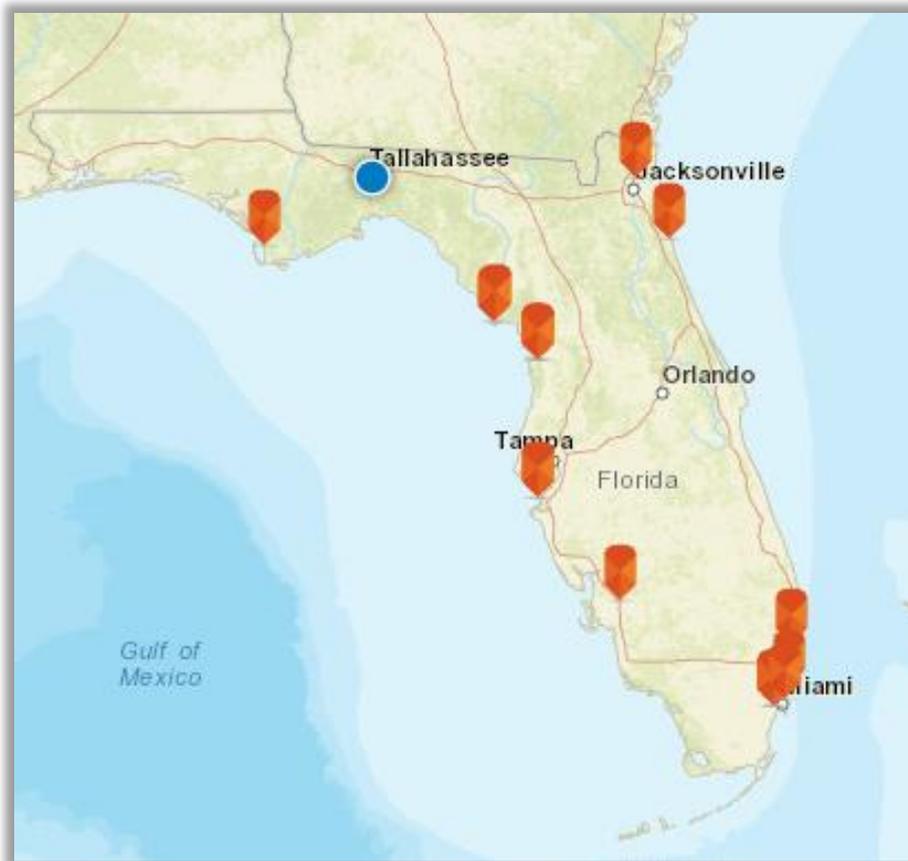
3. Project GIS-Map App.

4. Under development

- LCC Analysis Guidance
- Cost Estimating Guidance



Design Tools – GIS-Mapping



1. Currently includes:

- Active and Completed FRP-RC/PC projects;

2. Plans to add:

- Bridge beam repair/strengthening projects (20+ year history of wet-layup repairs)
- FRP-Fender Systems
- HSSS projects

Project Identification & Delivery

1. Environment Driven

- Durability/Magnetic Transparency/LCC

2. Optional precast alternatives

- Encourage stakeholder buy-in

3. Desire for multiple suppliers

- Redundancy & Supply chain security

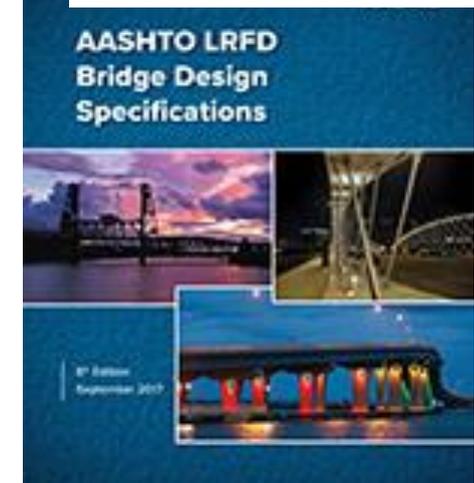
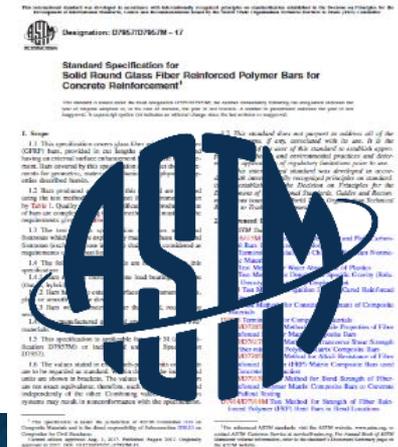
4. Simplify design process/workflow

5. Minimize change for Contractors

- Business as usual...almost

Uniform Standards

- **BDGS-GFRP 2nd Ed.** refers to **ASTM D7957-17** for material specifications
 - Only vinylester 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



Uniform Standards (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 dev.)
 - **CSA S6-19 Section 16** “Canadian Highway Bridge Design Code: Fibre Reinforced Structures” (under dev.)



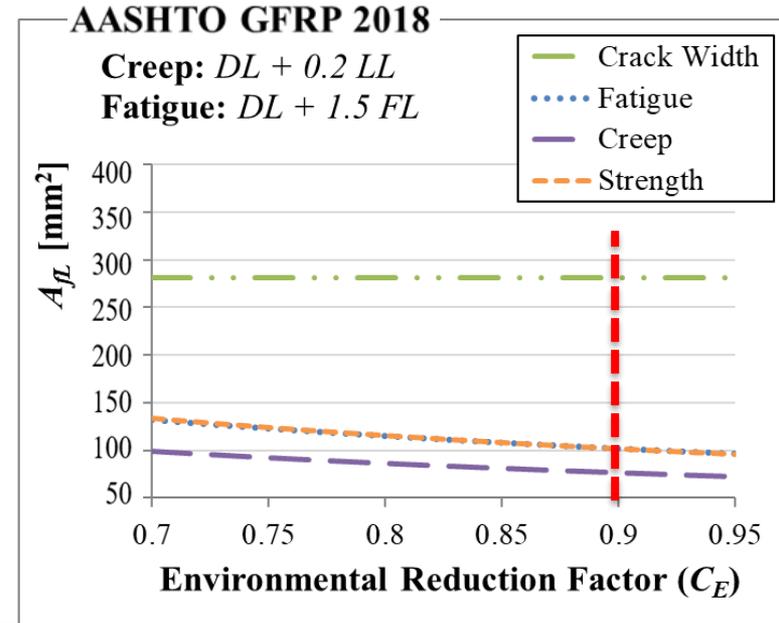
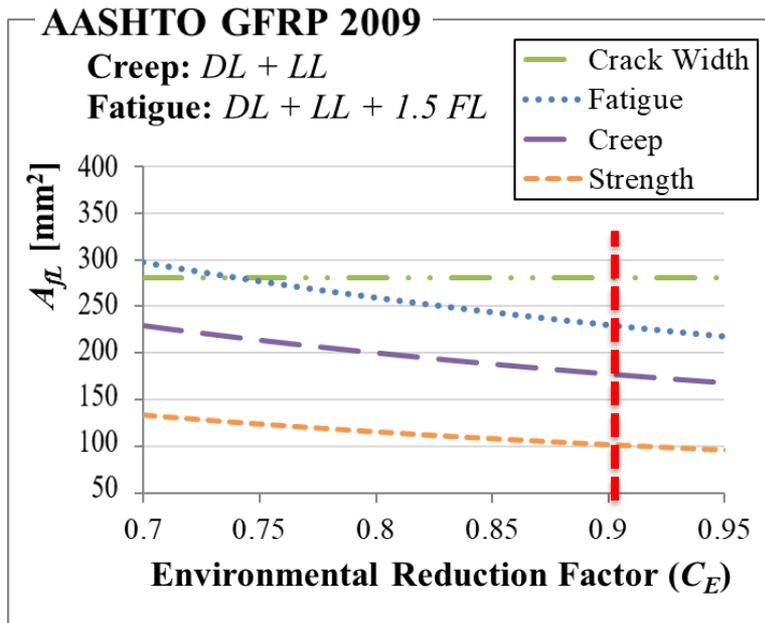
Uniform Advancement

	AASHTO 2nd 2018	AASHTO 1st 2009	ACI 440.1R 2015	CSA 2014	
f_{fu}^*	99.73	99.73	99.73	95.0 ⁽²⁾	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	<i>Environmental reduction</i>
C_C	0.25-0.30 ⁽³⁾	0.20	0.20	0.25	<i>Creep rupture reduction</i>
C_f	0.25	0.20	0.20	0.25	<i>Fatigue reduction</i>
C_b	0.80	0.70	0.70	1.0	<i>Bond reduction</i>
w	0.28	0.20/0.28	0.28 to 0.20	0.2?	Crack width limit [in.]
$C_{C, stirrups}$	1.5	1.50	2.0 ⁽¹⁾	40	Clear cover [in.]
$C_{C, slab}$	1.0	0.75 to 2.0	0.75 to 2.0 ⁽¹⁾	40	Clear cover [in.]

Advancement

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) – **Now we need to additional study to improve these still conservative limits!**



Advancement (cont.)

2nd Ed. updates reflect:

- Performances of **ASTM**-certified materials and increase **Compression-Controlled** Flexural Resistance Φ_C aligned to **AASHTO BDS-17** (0.65 to **0.75**);

Now need to:

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

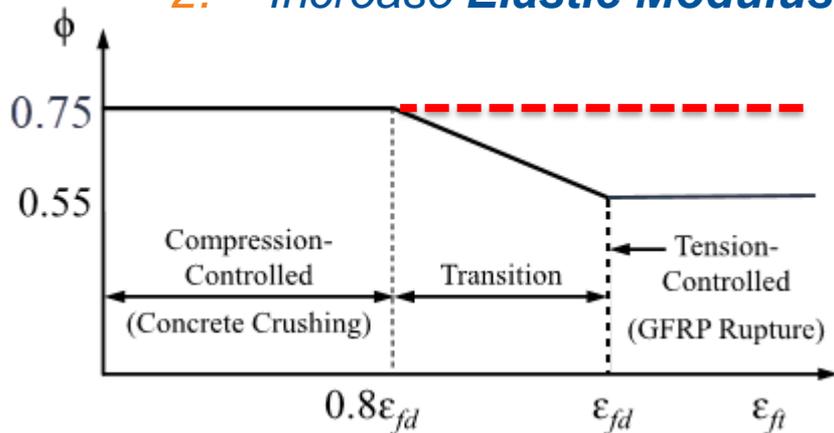
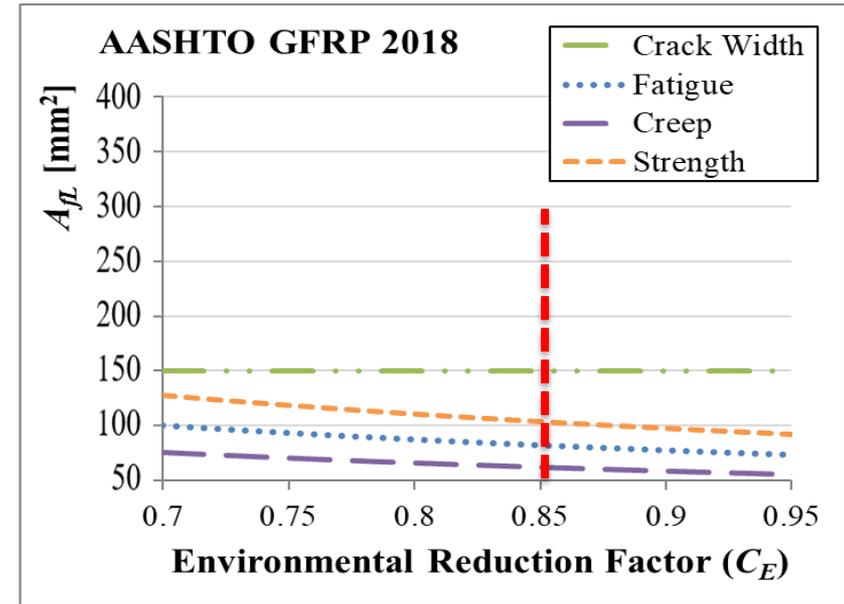
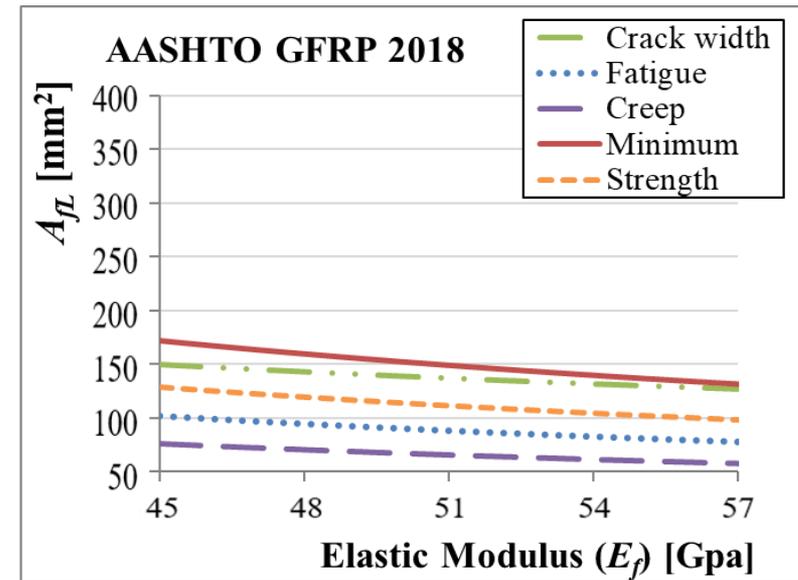
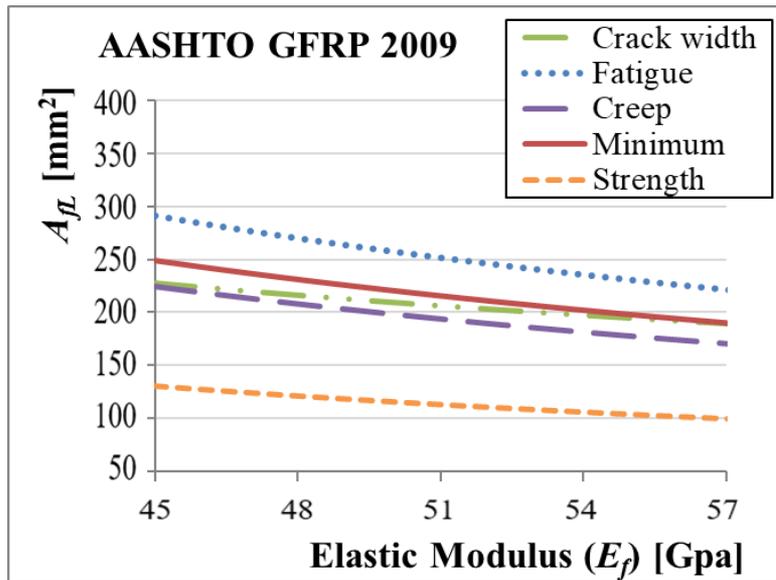


Figure C2.5.5.2-1 – Variation of ϕ with Tensile Strain at Failure, ϵ_{fi} , in GFRP Reinforcement



Advancement (cont.) - Elastic Modulus

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.

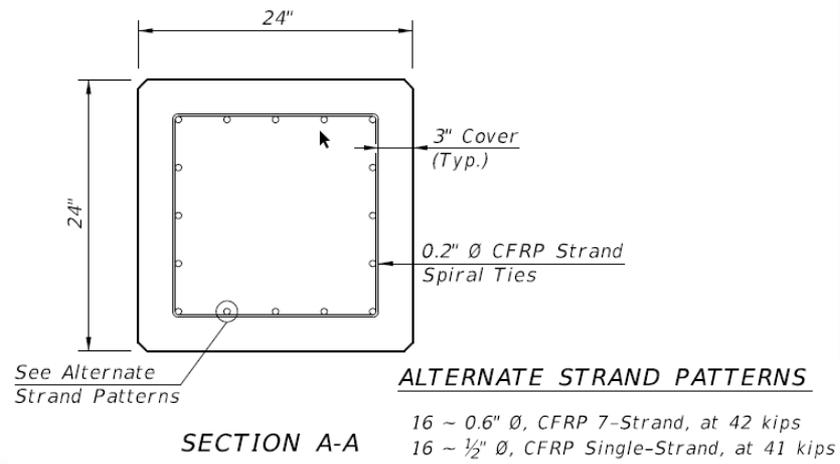


Advancement (cont.) - Piles

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

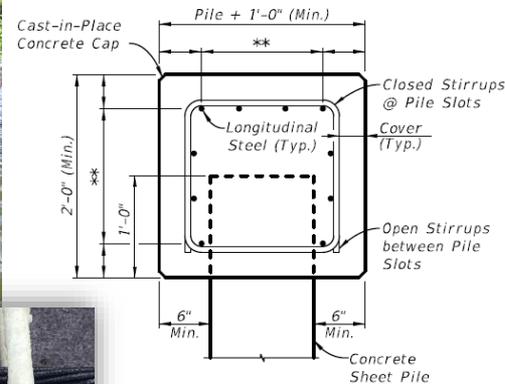


Advancement (cont.) - Seawall-Bulkheads

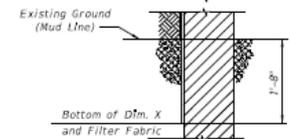
Concrete Sheet Pile Bulkhead Standards



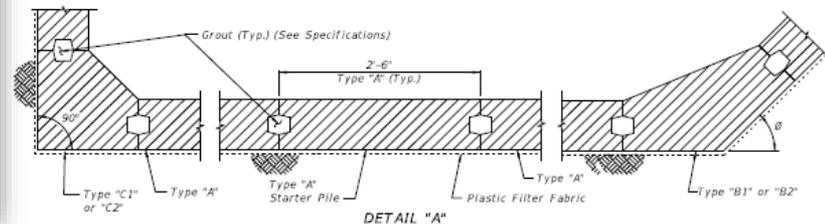
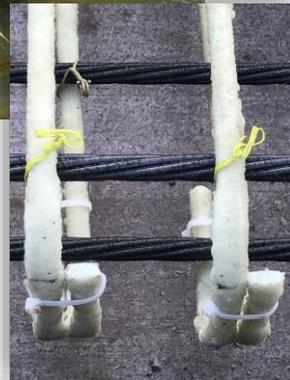
Structures Foundations - Sheet Pile Wall	
455-400	Precast Concrete Sheet Pile Wall (Conventional)
455-440	Precast Concrete Sheet Pile Wall (CFRP/GFRP & HSSS/GFRP)



SECTION A-A



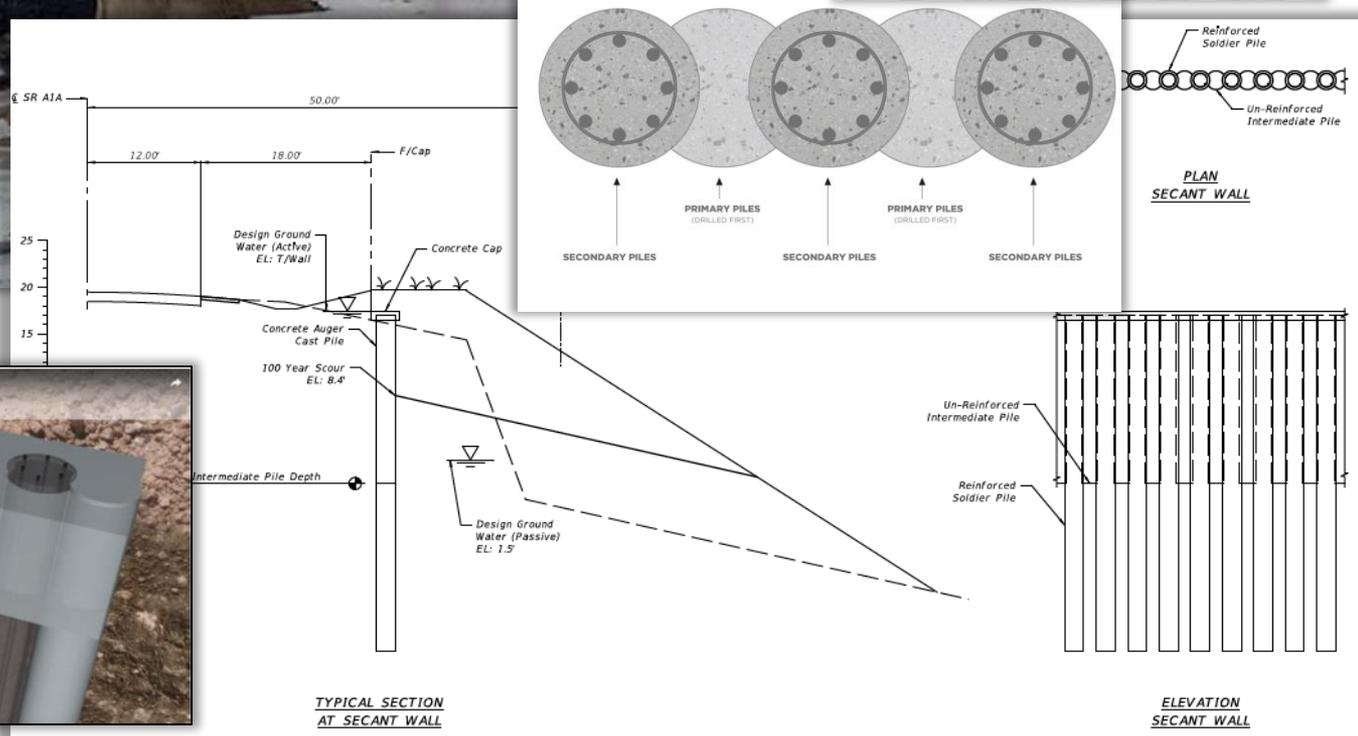
SECTION THRU BULKHEAD
(Showing Plastic Filter Fabric)



DETAIL "A"

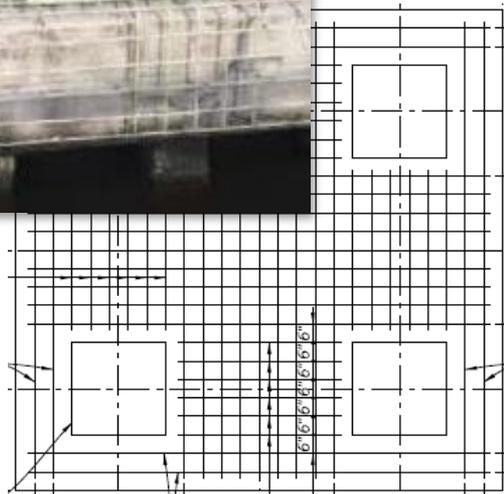
Advancement (cont.) - Seawall-Bulkheads

Secant Piles seawall on SR A1A



Advancement (cont.) - Footings

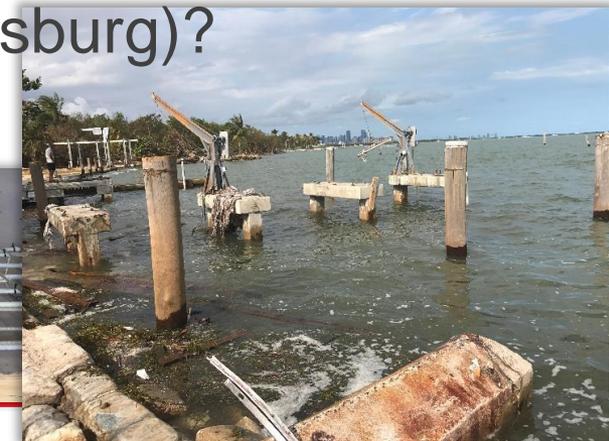
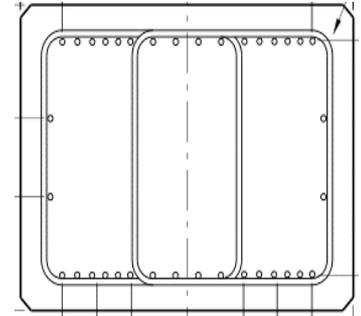
Waterline footings in saltwater – *need big bars!*



Advancement (cont.) - Bent Cap

Projects:

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

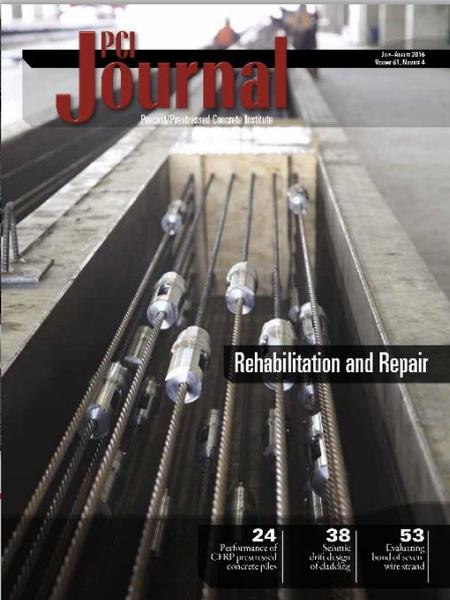
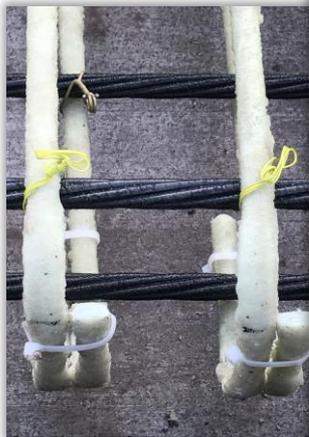


Advancement (cont.) - Girders

Projects:



- Halls River Bridge = **HCB's** (Homosassa)
- NE 23rd Ave/Ibis Waterway = **Flat-Slab** (City of Lighthouse Point)
- US1 over Cow Key Channel = **FSB hybrid** (Key West)
- Maydell Dr. = **FSB's ?** (Tampa)
- 40th Ave. N = **FSB's** (St Pete.)



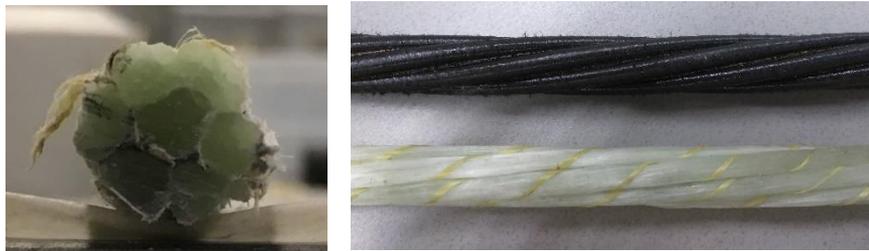
Advancement (cont.) – GFRP-PC

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

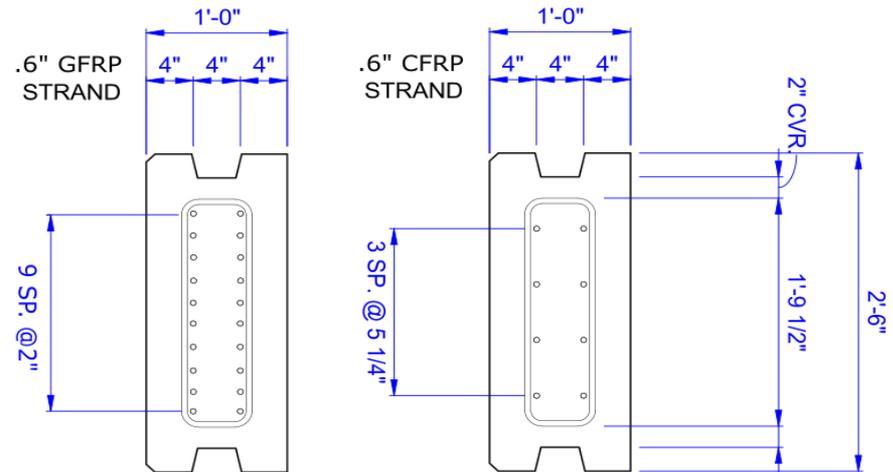
- GFRP Prestressing - MILDGLASS (University of Miami);



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



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

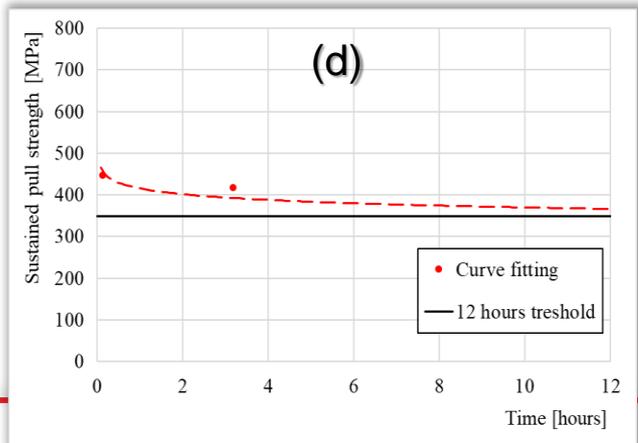
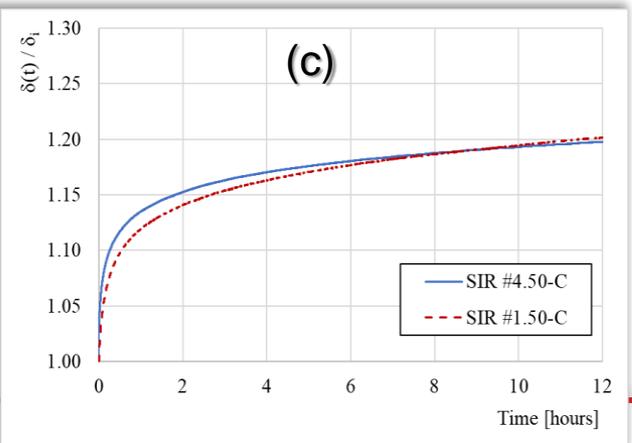
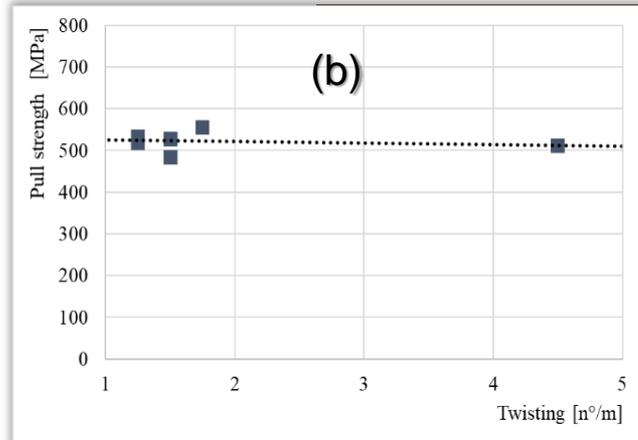
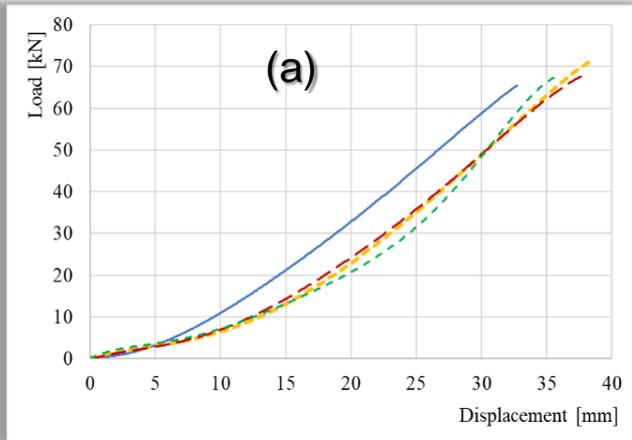


(a) GFRP-PC sheet pile concept (b) CFRP-PC sheet pile design for Halls River Bridge

Advancement – GFRP-PC (cont.)

1. FHWA'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

Advancement (cont.) – **Next**

2. **Next Innovation Deserving of Exploratory Analysis...**

- BFRP Prestressing (perhaps)

Advancement (cont.) – SAM-TAG

Structural Advance Materials - TAG Mission:

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

Members are to support District Structures Design Engineers 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?

Questions?



FDOT's Fiber-Reinforced Polymer Deployment Train



Questions?

FDOT Contact Information:

Structures Design Office:

Steven Nolan, P.E. (FRP Coordinator)
(850) 414-4272

Steven.Nolan@dot.state.fl.us

Structures Design Office:

Felix Padilla, P.E. (FRP Assist. Coord.)
(850) 414-4290

Felix.Padilla@dot.state.fl.us

State Materials Office:

Chase C. Knight, PhD.
(352) 955-6642

Chase.Knight@dot.state.fl.us

FDOT's Fiber-Reinforced Polymer Deployment Train

