2017 First International Workshop on GFRP Bar for Concrete Structures

July 18, 2017

Sherbrooke, QC, CANADA

FDOT GFRP-RC Implementation - Current Status, Projects and Challenges

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Current Status, Projects and Challenges

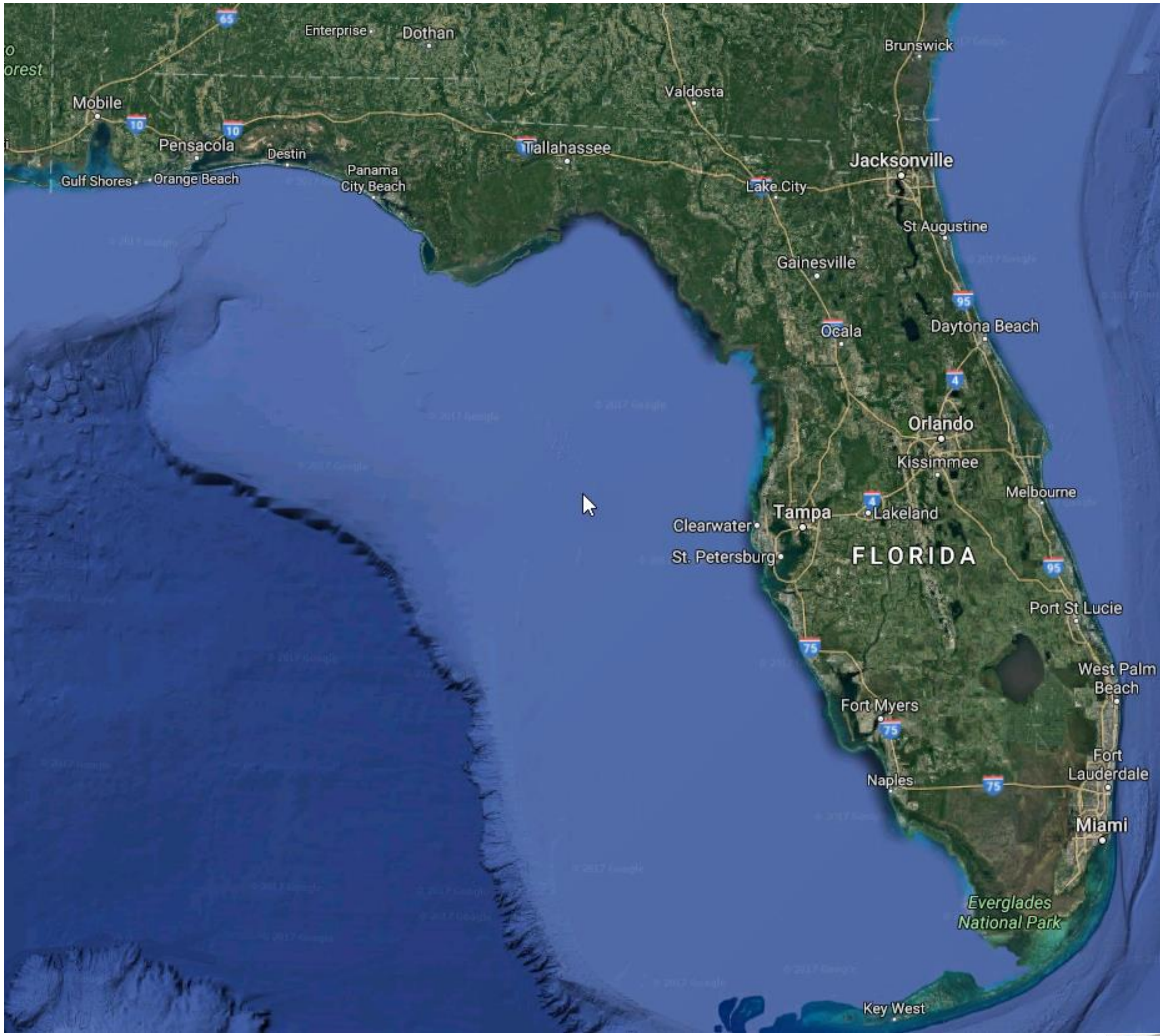
Part 1:

- The Need – Why Composites?
- Available Documentation
- FDOT Research
- Projects
- Looking Forward

Part 2:

- Challenges
- Focus Areas

The Need – Why Composites?



FDOT GFRP Deployment Train

The Need – Why Composites?

- Avoiding Corrosion
  - Durability/Service Life
  - Cost/Benefit Analysis
  - Mitigating Risks

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

Old St. George Island Bridge Piling

Gandy Blvd. seawall, (Tampa Bay)

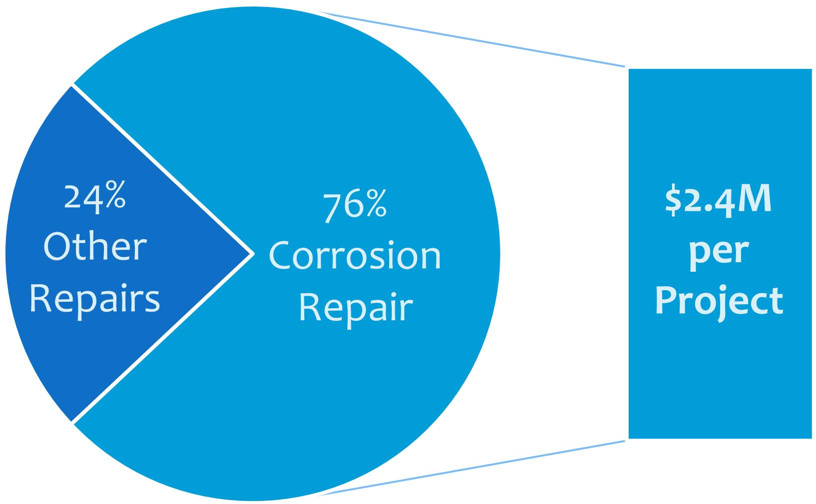
Courtney Campbell Causeway, seawall (Tampa Bay)

The Need – Why Composites?

- Avoiding Corrosion
  - Durability/Service Life
  - Cost/Benefit Analysis
  - Mitigating Risks

The Need – Why Composites?

- Example Costs of Corrosion
  - FDOT District 7 Study
    - Repair cost of bridges
    - 54 Bridge Projects Studied (02/03 to 12/13)
      - 20 Steel and 34 Concrete Bridges



Source: FDOT D7 District Structures Maintenance Office & T.Y. Lin

Available Documentation

Design Documentation

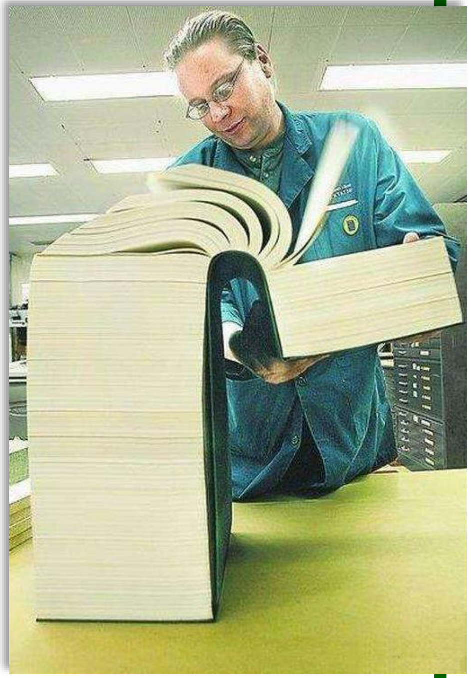
What's available from FDOT?

1. Design criteria –
   a) ***Fiber Reinforced Polymer Guidelines (FRPG)***
   b) ***Structures Design Guidelines (SDG)***;

2. Detailing criteria – ***Structures Detailing Manual (SDM)***;

3. ***Design Standards*** *(drawings)*;

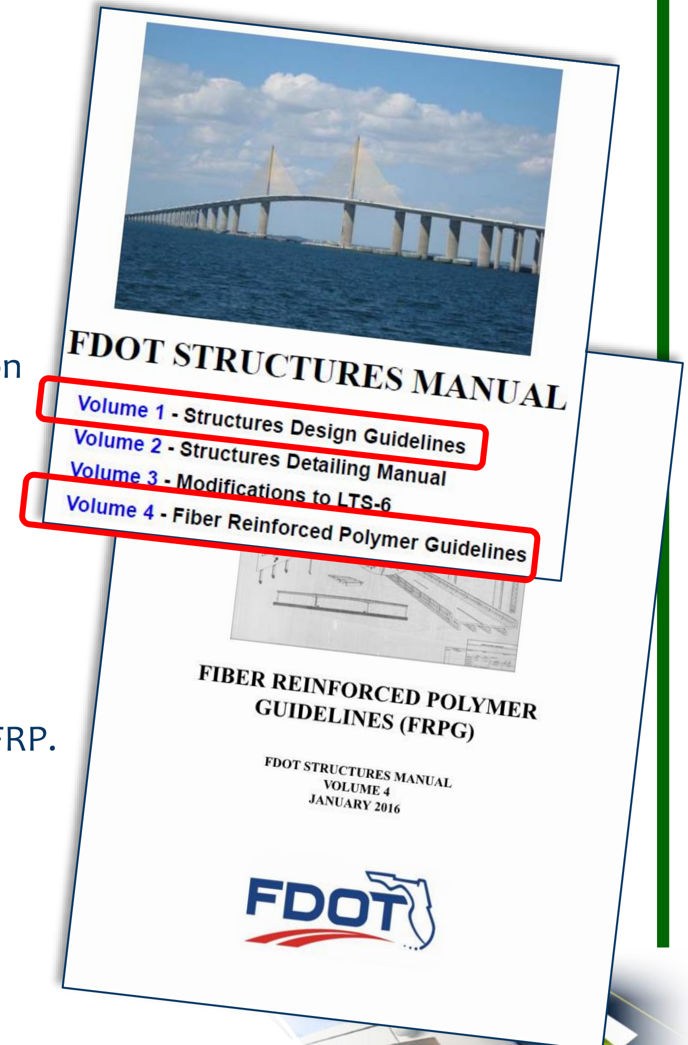
4. ***Specifications*** *(Construction and Materials).*



Available Documentation

Design Documentation

1. Design criteria –
   - ***a)* *Fiber Reinforced Polymer Guidelines (FRPG)***
     - Overall commentary on FRP;
     - Specific design criteria, plan content and Specification requirements;
     - Design review requirements;
     - Approval of use process;
     - Permitted uses for each type of FRP.
   - ***b)* *Structures Design Guidelines (SDG)***
     - Overall design criteria;
     - Revised and/or supplemented by ***Fiber Reinforced Polymer Guidelines (FRPG)*** for given applications of FRP.

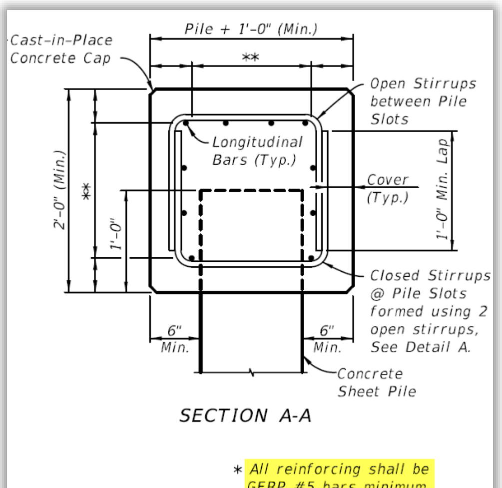


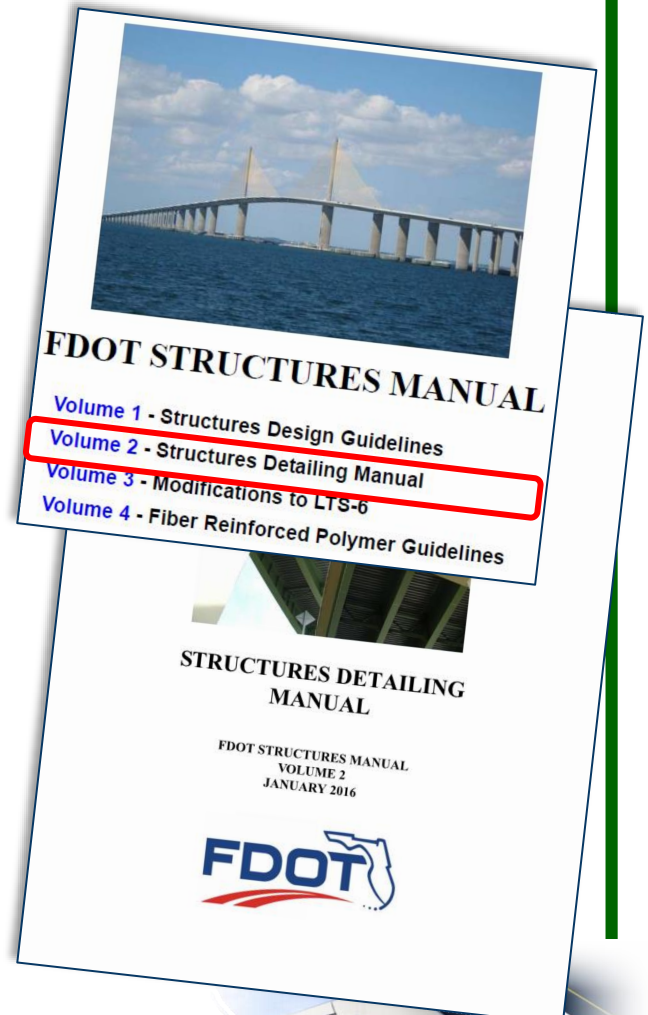
http://www.fdot.gov/structures/StructuresManual/CurrentRelease/StructuresManual.shtm

Available Documentation

Design Documentation

2. Detailing criteria – ***Structures Detailing Manual (SDM)***:
   a) Overall detailing criteria;
   b) Revised and/or supplemented by ***Fiber Reinforced Polymer Guidelines (FRPG)*** for given applications of FRP.





Available Documentation

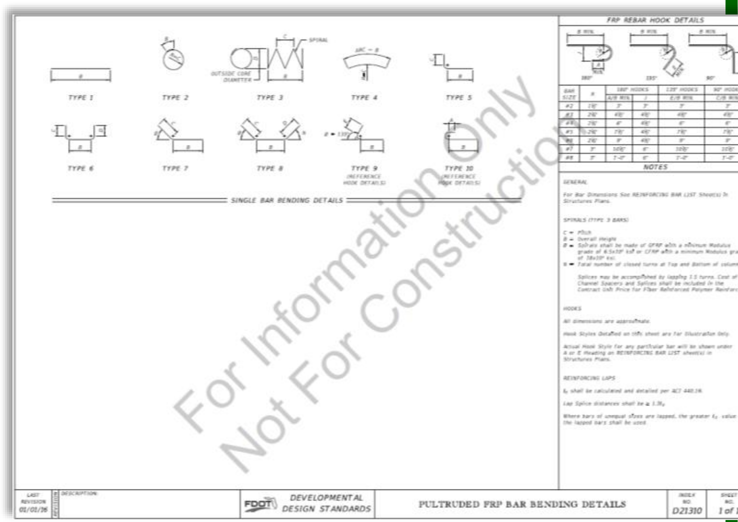
Design Documentation

3. *Design Standards:*

a) FY2017-18 Design Standards:

- ***Index 22600 series*** – Square CFRP & SS Prestressed Concrete Piles;
- ***Index 22440*** – Precast Concrete CFRP/GFRP & HSSS/GFRP Sheet Pile Wall

http://www.fdot.gov/roadway/DesignStandards/Standards.shtm



b) Developmental Design Standards:

- ***Index D6011c*** – Gravity Wall – Option C (GFRP reinforced);
- ***Index D21310*** – Pultruded FRP Bar Bending Details;
- ***Index D22420*** – GFRP reinforced 32" F-Shape Traffic Railing;
- ***Index D22900*** – GFRP reinforced Approach Slab;

http://www.fdot.gov/roadway/DS/Dev.shtm

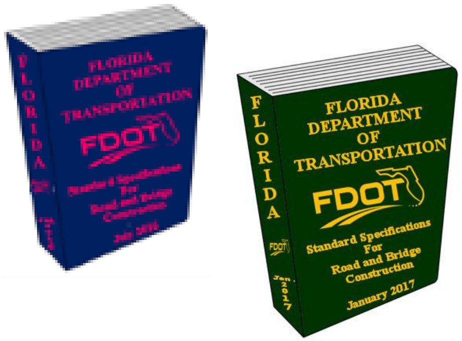
Available Documentation

Design Documentation

4. *Construction & Material Specifications*

a) Standard Specifications (effective July 2016+):

- Implemented previous FRP ***Developmental Specifications.***
- ***400*** Concrete (includes FRP Bar construction considerations);
- ***415*** Reinforcing for Concrete (FRP Bars construction considerations);
- ***450*** Precast Prestressed Concrete Construction (FRP Bars construction considerations);
- ***932*** Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures (GFRP & CFRP Bars material specs);
- ***933*** Prestressing Strand (CFRP Strand material specs);



(Photograph) Hughes Bros. *Coated tie wire.*

http://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm

Available Documentation

Material & Producer Requirements

State Materials Office

State Materials Office Oversight Role:

- ***Material Specifications***
- ***Sampling and Testing Requirements***
- ***Quality Control Program – Production Facility Approvals***
- ***Conduct and Facilitate Research – Durability/Service Life***

Available Documentation

Material & Producer Requirements

1. Producer Quality Control
   a) ***Specifications Section 105***
   b) ***Materials Manual Chapter 12.1***
   c) ***Specifications Section 932 & 933***

2. Acceptance at the Project Level
   a) ***Certification***
   b) ***Sampling and Testing***

3. Materials Acceptance and Certification System (MAC)

Available Documentation

Material & Producer Requirements

1. Producer Quality Control
   a) ***Section 105 – Contractor Quality Control***
      - FRP producers must meet requirements of Materials Manual
   b) *Materials Manual Chapter 12.1*
   c) *Specifications Section 932*

2. Acceptance at the Project Level
   a) *Certification*
   b) *Sampling and Testing*

3. *MAC*

SECTION 105
CONTRACTOR QUALITY CONTROL GENERAL REQUIREMENTS

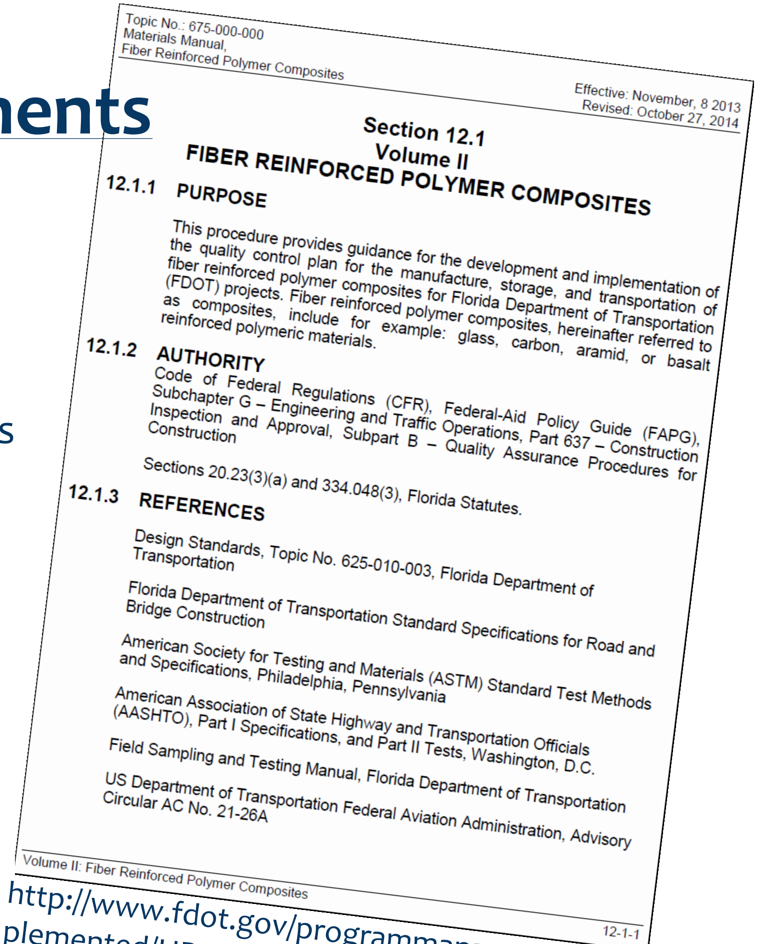
Producers of Fiber Reinforced Polymer Composites shall meet the requirements of Section 12-1, Volume II of the Department's Materials Manual, which may be viewed at the following URL:
http://www.dot.state.fl.us/programmanagement/Implemented/URLinSpecs/Section121V2.shtm.

http://www.dot.state.fl.us/programmanagement/Implemented/SpecBooks/default.shtm

Available Documentation

Material & Producer Requirements

1. Producer Quality Control
   - a) *Specifications Section 105*
   - b) ***Materials Manual Chapter 12.1***
     - Production Facility Qualification Process
     - Producer Responsibilities
     - Incoming raw material control
     - Manufacturing quality control
     - QC inspection
     - Handling, Storage, Shipment
     - Documentation and Record Retention
   - c) *Specifications Section 932*



Topic No.: 675-000-000
Materials Manual,
Fiber Reinforced Polymer Composites

Effective: November, 8 2013
Revised: October 27, 2014

Section 12.1
Volume II
FIBER REINFORCED POLYMER COMPOSITES

12.1.1 PURPOSE

This procedure provides guidance for the development and implementation of the quality control plan for the manufacture, storage, and transportation of fiber reinforced polymer composites for Florida Department of Transportation (FDOT) projects. Fiber reinforced polymer composites, hereinafter referred to as composites, include for example: glass, carbon, aramid, or basalt reinforced polymeric materials.

12.1.2 AUTHORITY

Code of Federal Regulations (CFR), Federal-Aid Policy Guide (FAPG), Subchapter G – Engineering and Traffic Operations, Part 637 – Construction Inspection and Approval, Subpart B – Quality Assurance Procedures for Construction

Sections 20.23(3)(a) and 334.048(3), Florida Statutes.

12.1.3 REFERENCES

Design Standards, Topic No. 625-010-003, Florida Department of Transportation

Florida Department of Transportation Standard Specifications for Road and Bridge Construction

American Society for Testing and Materials (ASTM) Standard Test Methods and Specifications, Philadelphia, Pennsylvania

American Association of State Highway and Transportation Officials (AASHTO), Part I Specifications, and Part II Tests, Washington, D.C.

Field Sampling and Testing Manual, Florida Department of Transportation

US Department of Transportation Federal Aviation Administration, Advisory Circular AC No. 21-26A

Volume II: Fiber Reinforced Polymer Composites

12-1-1

http://www.fdot.gov/programmanagement/Implemented/URLinSpecs/Section121V2.shtm

2. Acceptance at the Project Level
   - a) *Certification*
   - b) *Sampling and Testing*

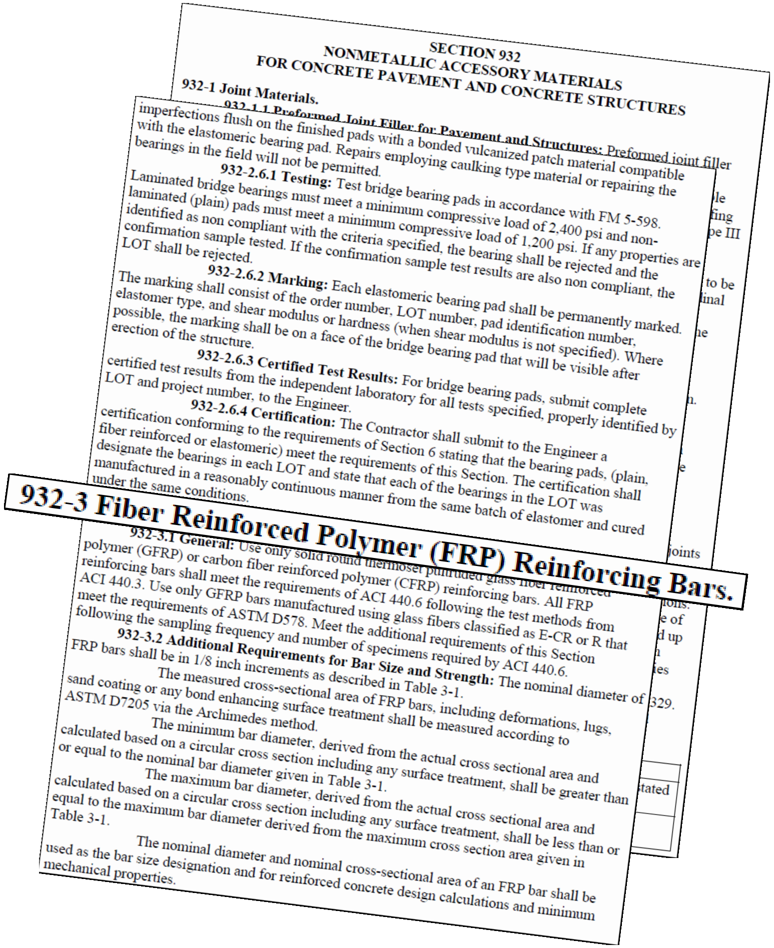
3. MAC

2017 International Workshop on GFRP Bar for Concrete Structures

Available Documentation

Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.1*
   c) ***Specifications Section 932***
      - Since July 2016
      - Sizes and Strengths
      - Physical Property Requirements for Producer Qualification
      - Requirements for Acceptance at the Project Level
2. Acceptance at the Project Level
   a) *Certification*
   b) *Sampling and Testing*


SECTION 932
NONMETALLIC ACCESSORY MATERIALS
FOR CONCRETE PAVEMENT AND CONCRETE STRUCTURES

932-1 Joint Materials.

932-1.1 Preformed Joint Filler for Pavement and Structures: Preformed joint filler

imperfections flush on the finished pads with a bonded vulcanized patch material compatible with the elastomeric bearing pad. Repairs employing caulking type material or repairing the bearings in the field will not be permitted.

932-2.6.1 Testing: Test bridge bearing pads in accordance with FM 5-598. Laminated bridge bearings must meet a minimum compressive load of 2,400 psi and non-laminated (plain) pads must meet a minimum compressive load of 1,200 psi. If any properties are identified as non compliant with the criteria specified, the bearing shall be rejected and the confirmation sample tested. If the confirmation sample test results are also non compliant, the LOT shall be rejected.

932-2.6.2 Marking: Each elastomeric bearing pad shall be permanently marked. The marking shall consist of the order number, LOT number, pad identification number, elastomer type, and shear modulus or hardness (when shear modulus is not specified). Where possible, the marking shall be on a face of the bridge bearing pad that will be visible after erection of the structure.

932-2.6.3 Certified Test Results: For bridge bearing pads, submit complete certified test results from the independent laboratory for all tests specified, properly identified by LOT and project number, to the Engineer.

932-2.6.4 Certification: The Contractor shall submit to the Engineer a certification conforming to the requirements of Section 6 stating that the bearing pads, (plain, fiber reinforced or elastomeric) meet the requirements of this Section. The certification shall designate the bearings in each LOT and state that each of the bearings in the LOT was manufactured in a reasonably continuous manner from the same batch of elastomer and cured under the same conditions.

932-3 Fiber Reinforced Polymer (FRP) Reinforcing Bars.

932-3.1 General: Use only solid round thermoset pultruded glass fiber reinforced polymer (GFRP) or carbon fiber reinforced polymer (CFRP) reinforcing bars. All FRP reinforcing bars shall meet the requirements of ACI 440.6 following the test methods from ACI 440.3. Use only GFRP bars manufactured using glass fibers classified as E-CR or R that meet the requirements of ASTM D578. Meet the additional requirements of this Section following the sampling frequency and number of specimens required by ACI 440.6.

932-3.2 Additional Requirements for Bar Size and Strength: The nominal diameter of FRP bars shall be in 1/8 inch increments as described in Table 3-1.

The measured cross-sectional area of FRP bars, including deformations, lugs, sand coating or any bond enhancing surface treatment shall be measured according to ASTM D7205 via the Archimedes method.

The minimum bar diameter, derived from the actual cross sectional area and calculated based on a circular cross section including any surface treatment, shall be greater than or equal to the nominal bar diameter given in Table 3-1.

The maximum bar diameter, derived from the actual cross sectional area and calculated based on a circular cross section including any surface treatment, shall be less than or equal to the maximum bar diameter derived from the maximum cross section area given in Table 3-1.

The nominal diameter and nominal cross-sectional area of an FRP bar shall be used as the bar size designation and for reinforced concrete design calculations and minimum mechanical properties.

http://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm

3. MAC

Available Documentation

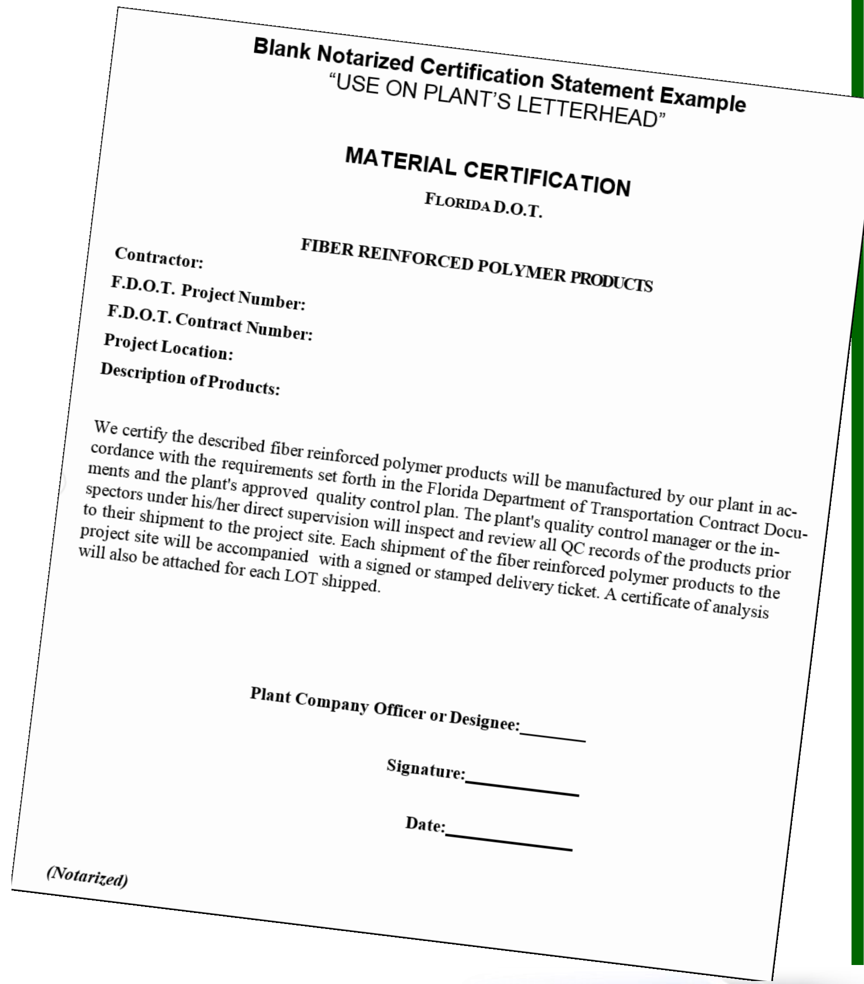
Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.1*
   c) *Specifications Section 932*

2. Acceptance at the Project Level
   a) Certification
   - Notarized Statement from FRP Producer sent **prior to shipment**
   - Certificate of Analysis for each LOT sent with each shipment

   b) Sampling and Testing

3. *MAC*



Blank Notarized Certification Statement Example
"USE ON PLANT'S LETTERHEAD"

MATERIAL CERTIFICATION

FLORIDA D.O.T.

FIBER REINFORCED POLYMER PRODUCTS

Contractor:
F.D.O.T. Project Number:
F.D.O.T. Contract Number:
Project Location:
Description of Products:

We certify the described fiber reinforced polymer products will be manufactured by our plant in accordance with the requirements set forth in the Florida Department of Transportation Contract Documents and the plant's approved quality control plan. The plant's quality control manager or the inspectors under his/her direct supervision will inspect and review all QC records of the products prior to their shipment to the project site. Each shipment of the fiber reinforced polymer products to the project site will be accompanied with a signed or stamped delivery ticket. A certificate of analysis will also be attached for each LOT shipped.

Plant Company Officer or Designee:________

Signature:________

Date:________

(Notarized)

Available Documentation

Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.1*
   c) *Specifications Section 932*

2. Acceptance at the Project Level
   a) *Certification*
   b) ***Sampling and Testing***
      - Samples selected by Engineer after delivery to project
      - Contractor responsible for verification testing using independent ISO Lab

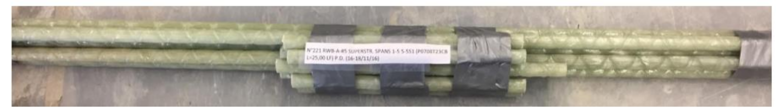
3. *MAC*

Laboratory Test Report

1. REBAR SAMPLE INFORMATION

Sample No.	ID/Ref.	Nominal Rebar Denomination	Material type*
1	Nº 342 RWB-A-#4 SUPERSTR. SPANS 1-5 4-4S1 (P0728T23CB L=32,36 LF) P.D. (02-08/01/17)	#4	Glass fiber reinforced polymer (GFRP)

Sample No.	ID/Ref.	Nominal Rebar Denomination	Material type*
2	Nº 221 RWB-A-#5 SUPERSTR. SPANS 1-5 5-5S1 (P0708T23CB L=25,00 LF) P.D. (16-18/11/16)	#5	Glass fiber reinforced polymer (GFRP)



Laboratory Test Report

3.5. TENSILE PROPERTIES

Test Standard Method: ASTM D7205/D7205M - 06 (2011) Standard test method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars.

Test Description: Determine the ultimate tensile load carrying capacity, tensile modulus of elasticity and computed ultimate strain based on an assumed linear elastic behavior.

Technician/s:

Specimen Preparation: The specimens were cut to the prescribed dimensions. Steel pipe type anchors were installed as indicated in ASTM D7205 using expansive grout after machining the ends of the rebar as to center the bars in the anchors.

Test Data:

Nominal Rebar Denomination	SPECIMEN ID	Peak Load P_{max} lbs	Nominal Area A in²	Ultimate Tensile Strength, UTS f_{fu} ksi	Modulus of Elasticity, E Msi
#4	TNS1-01	27993	0.196	142.6	8.835
	TNS1-02	27963		142.5	8.875
	TNS1-03	29567		150.7	8.963
	TNS1-04	27133		138.3	9.808
	TNS1-05	27352		139.4	8.991
	Average	**28001**		**143**	**9.095**
	S_{n-1}	952		4.85	0.40
	CV (%)	3.4		3.4	4.4
#5	TNS2-01	43959	0.307	143.4	8.593
	TNS2-02	42914		139.9	8.058
	TNS2-03	42517		138.7	8.186
	TNS2-04	42894		139.9	8.203
	TNS2-05	42474		138.5	8.199
	Average	**42951**		**140**	**8.248**
	S_{n-1}	599		1.95	0.20
	CV (%)	1.4		1.4	2.4

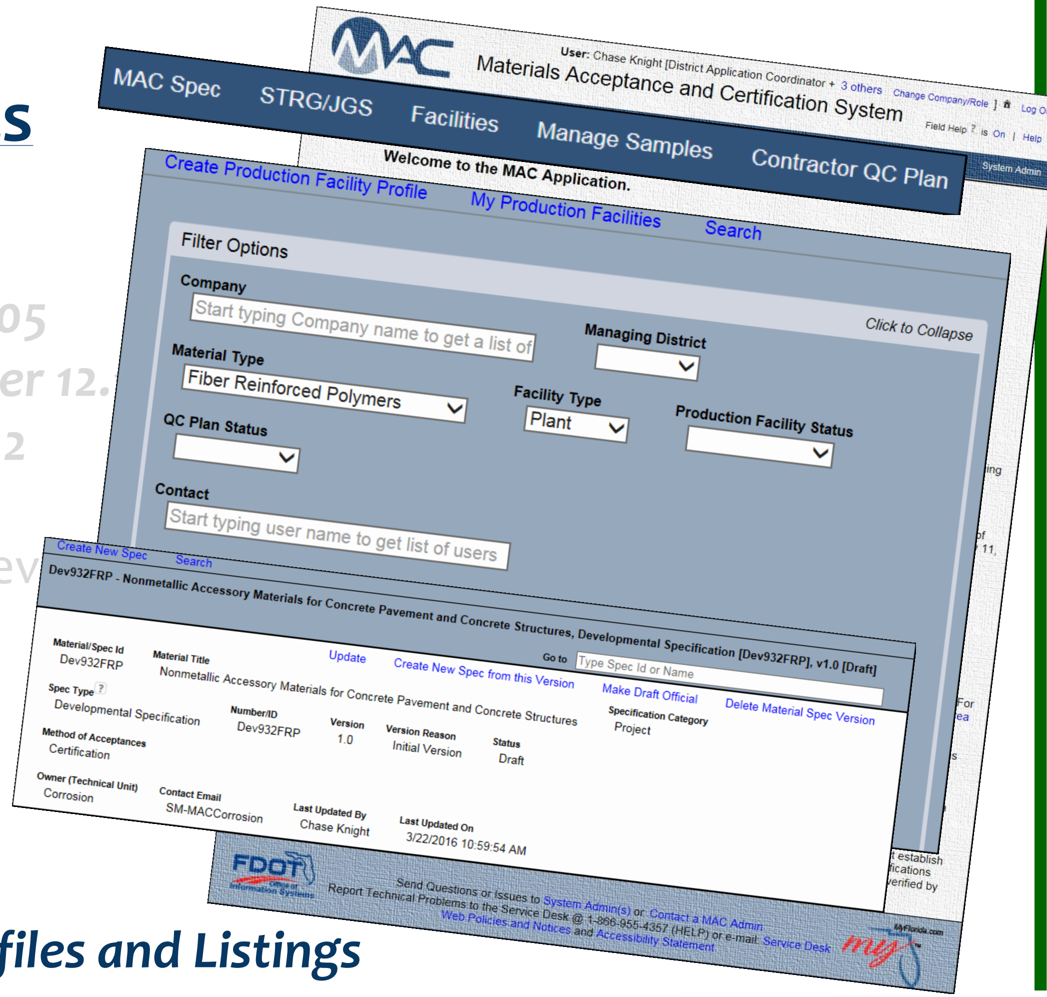
Available Documentation

Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.*
   c) *Specifications Section 932*

2. Acceptance at the Project Lev
   a) *Certification*
   b) *Sampling and Testing*

3. MAC
   a) ***Specifications***
   b) ***Production Facility Profiles and Listings***



https://mac.fdot.gov/smoreports

Available Documentation

Material and Producer Requirements

1. Producer Quality Control
   a) *Specification Section 105*
   b) *Materials Manual Ch. 12.1*
   c) *Specifications Section 932, 933, and 973*

2. Acceptance at the Project Level
   a) *Certification*
   b) *Sampling and Testing*

3. MAC
   a) ***Specifications***
   b) ***Production Facility Profiles and Listings***


Production Facility

- Aggregate Production Facility Listing
- All Producers (Excel)
- Approved Aggregate Products For Friction Course
- Approved Aggregate Products From Mines or Terminals Listing
- Approved Products at Expired Mines or Terminals
- Asphalt Production Facility Listing
- Asphalt Targets
- Cementitious Materials Production Facility Listing
- Coatings Production Facility Listing
- Fiber Reinforced Polymer Production Facility Listing
- Flexible Pipe Production Facility Listing
- Incidental Precast Concrete Production Facility Listing
- Metals Production Facility Listing
- Non Structural Concrete Production Facility Listing
- Precast Pipe and Precast Drainage Structures Production Facility Listing
- Prestressed Concrete Products Production Facility Listing
- Production Facility Listing
- Production Facility Products Listing
- Structural Concrete Production Facility Listing
- Timber Production Facility Listing

Current Research

Projects

- **BDV30-977-18:** "Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments"
  (https://rip.trb.org/view/2016/P/1406946), Est. Completion: 5/31/2018
- **BDV34-977-05:** "Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements"
  (https://rip.trb.org/view/2015/P/1352376), Est. Completion: 3/31/2018
- **BDV30-706-01:** "Inspection and Monitoring of Fabrication and Construction for the West Halls River Road Bridge Replacement"
  (Sample testing and 2 year post-construction monitoring; Est. Completion 11/31/2019)

Past Research
– CFRP Prestressed Concrete Piles

http://www.fdot.gov/structures/structuresresearchcenter/CompletedResearch.shtm

Department of Civil Engineering and Mechanics
The University of South Florida

Durability of CFRP Pretensioned Piles
in Marine Environment
Volume II

Rajan Sen, Satya Sukumar and Jose Rosas
Department of Civil Engineering and Mechanics

FINAL REPORT

Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Piles in Marine Environment

Principal investigator
M. AROCKIASAMY, Ph.D., P.E.
Professor and Director

Ahmed Amer, Ph.D., P.E.
Research Associate

Submitted to:
Florida Department of Transportation

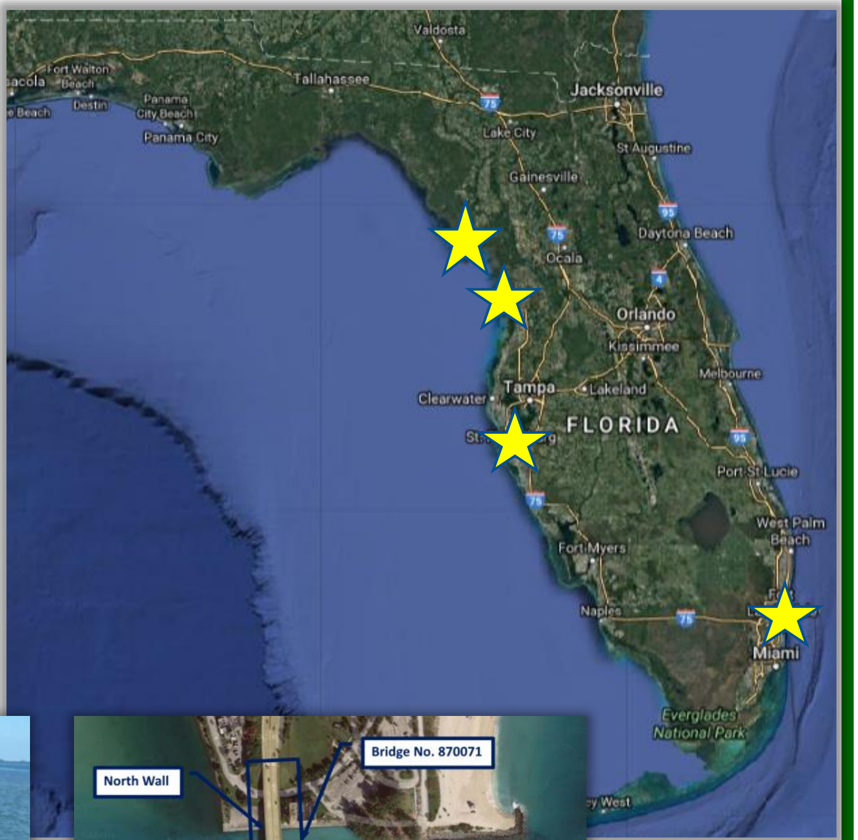
under:
WPI No. 0510698 and Contract No. B9076

Monitored by:
Structural Research Center
Florida Department of Transportation
2007 E. Paul Dirac Drive
Tallahassee, FL 32304

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

FDOT Construction Projects Status

1. ***Cedar Key Bulkhead Cap Rehab.***
   - FPID 432194-1 construction completed June 2016; SMO monitoring.
2. ***Halls River Bridge Replacement***
   - Construction started 1/9/2017;
   - Astaldi Construction Corp.
3. ***Bakers Haulover Cut Bridge Rehab.***
   - Construction started 1/9/2017;
   - Kiewit Infrastructure South Co.
4. ***Skyway South Rest Area Seawall Rehab.***
   - Design Build Procurement;
   - Awarded 2/10/2017;

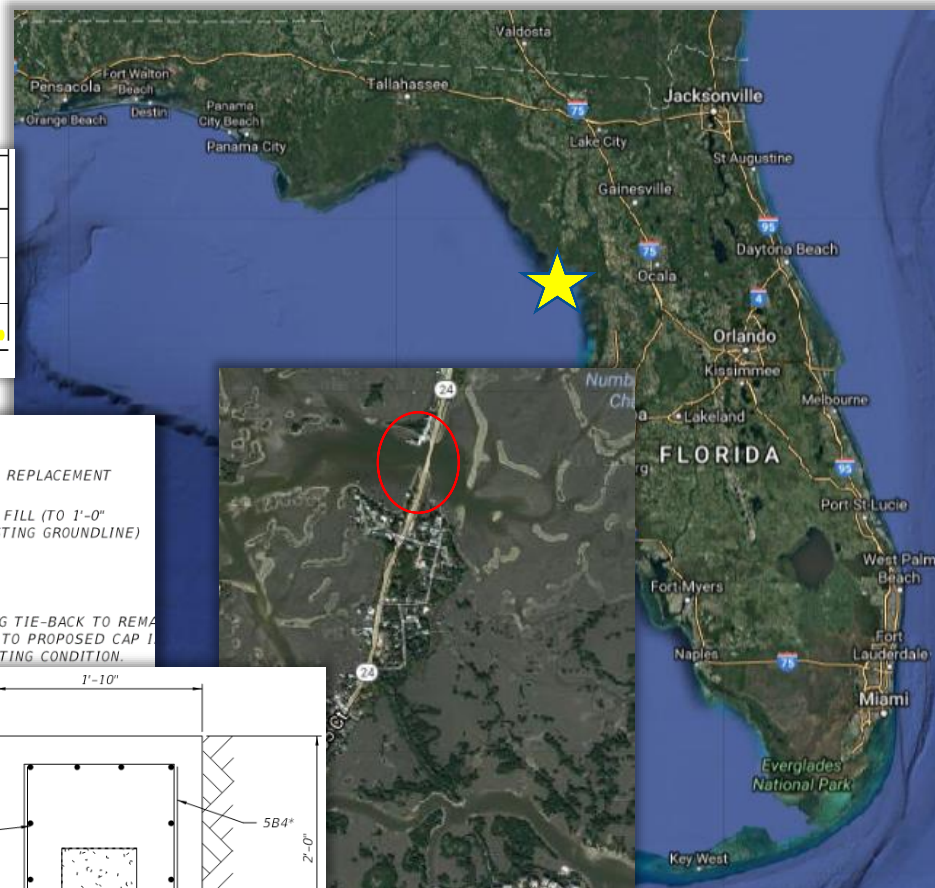


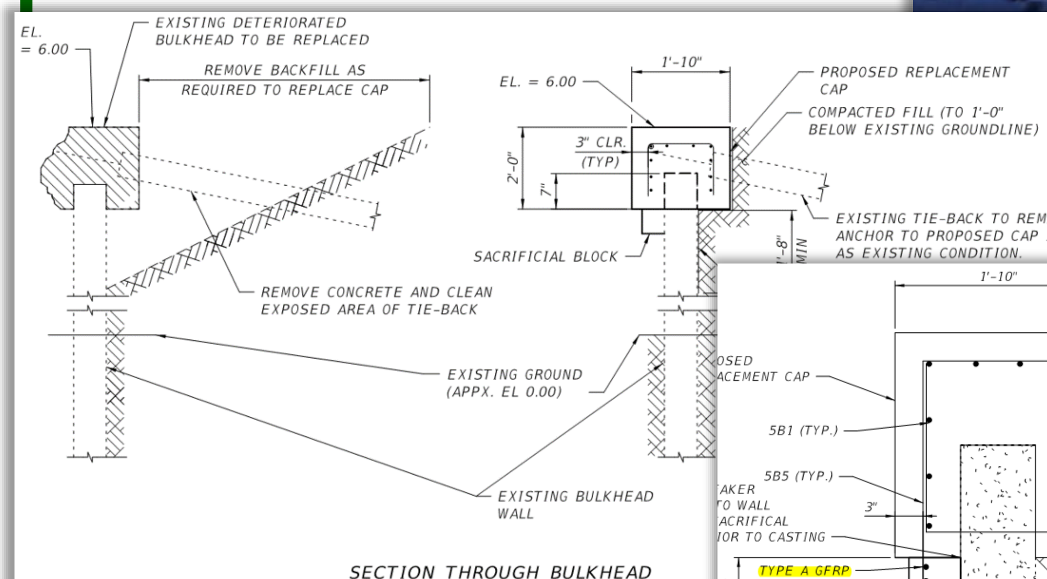
Project Example 1 – *Cedar Key SR24 Bulkhead Rehabilitation*

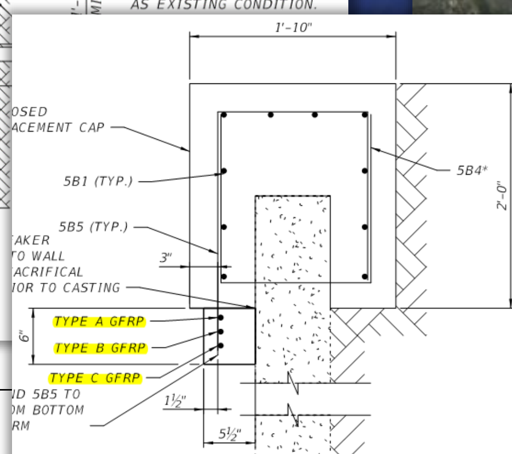
FPID# 432194-1

GFRP BAR TYPE CHART	
TYPE A	SIZE 5 GFRP BAR COATED WITH GRANULAR MATERIAL AND WITH SURFACE INDENTATIONS/DEFORMATIONS CREATED BY HELICAL WRAPPING.
TYPE B	SIZE 5 GFRP BAR COATED WITH GRANULAR MATERIAL AND WITHOUT SURFACE INDENTATIONS/DEFORMATIONS.
TYPE C	SIZE 5 GFRP BAR COATED WITH POLYMER (NO GRANULAR COATING) AND WITH SURFACE INDENTATIONS/DEFORMATIONS CREATED BY SHAPING THE POLYMER COATING (NO EXTERNAL WRAPPING).

TABLE APPLIES ONLY TO REBAR IN SACRIFICIAL BLOCK



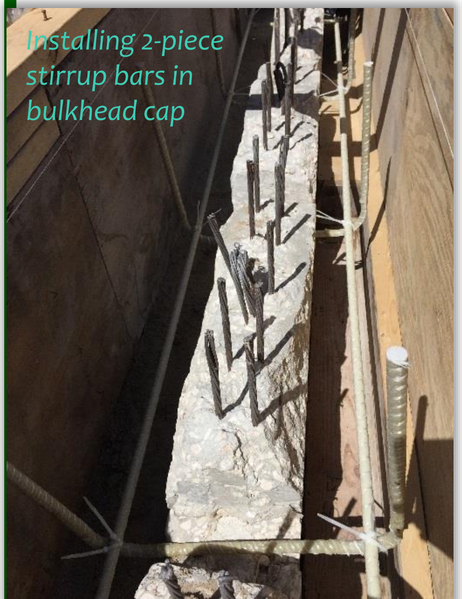


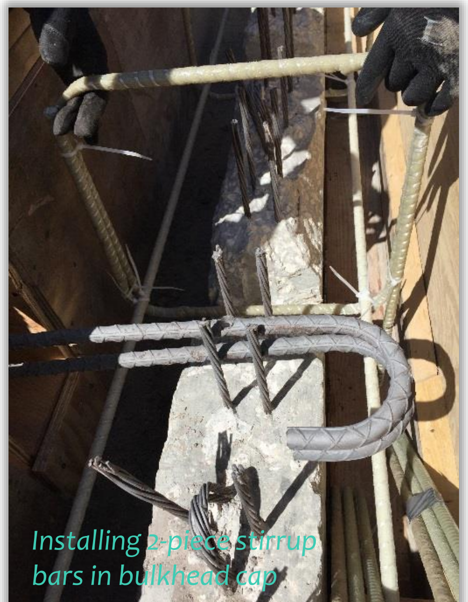


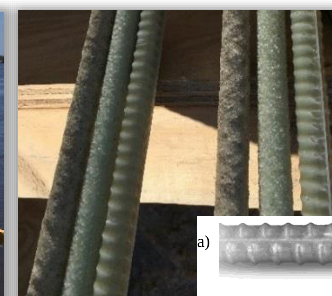
914-415-105	GLASS FIBER REINFORCING POLYMER BAR	ADS	LF	5088
		ED	LF	131

GFRP Deployment Train

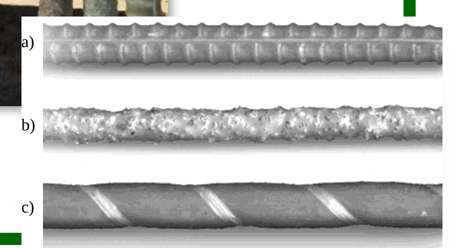
Project Example 1 – *Cedar Key SR24 Bulkhead Rehabilitation*







3 bar-surface types:
a) Ribbed
b) Sand-coated
c) Helically wrapped and sand-coated

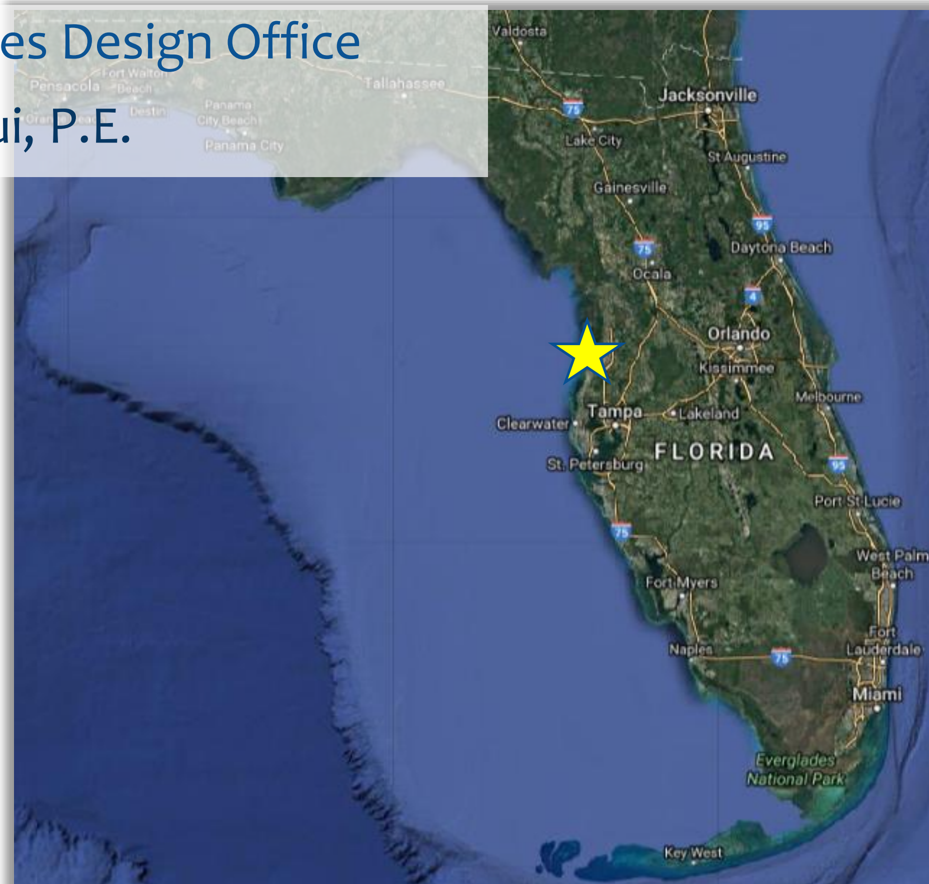


Project Example 2 – *Halls River Bridge Replacement Project*

FPID# 430021-1

Designer: FDOT District 7 Structures Design Office

Structures EOR: Mamunur Siddiqui, P.E.



Owner & Maintaining Agency

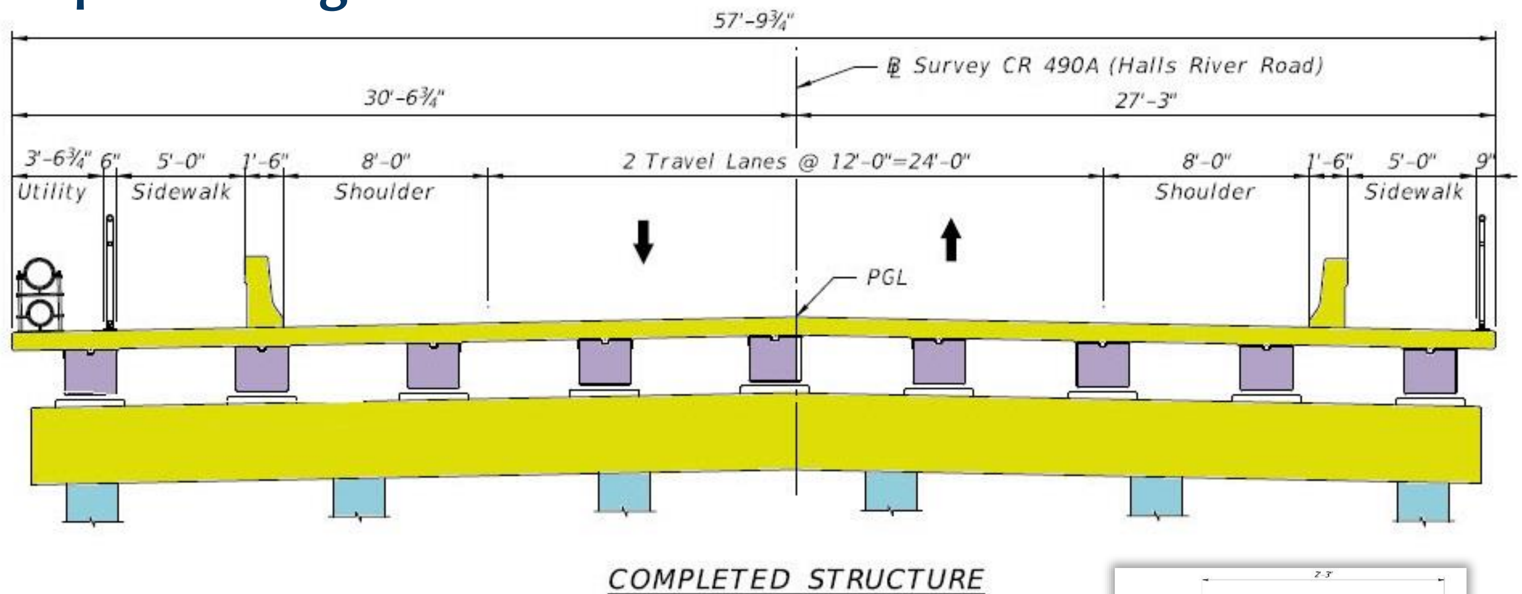
Design & Bi-Annual Inspection

Funding & Monitoring

Collaboration Research

Project Example 2 – *Halls River Bridge Replacement Project*

Proposed Bridge Section

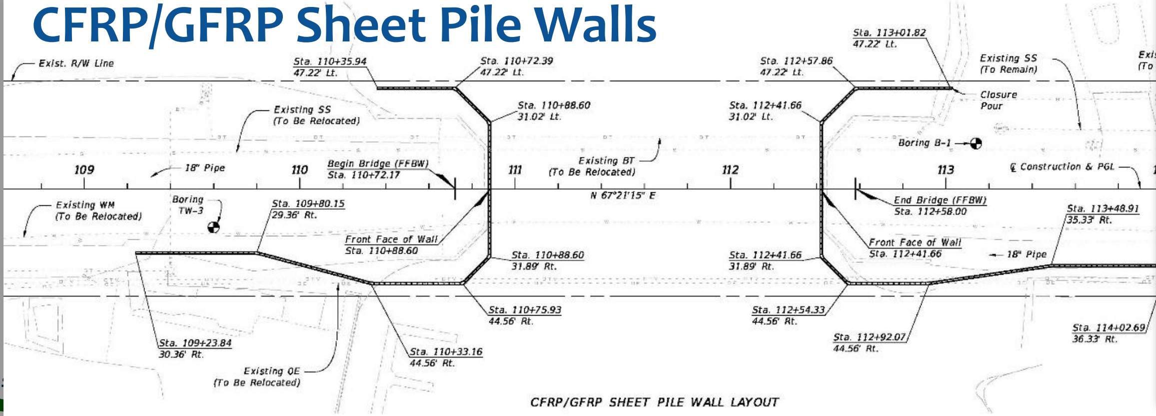


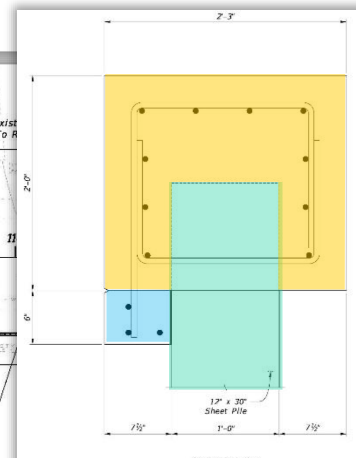
GFRP

HCB

CFRP

CFRP/GFRP Sheet Pile Walls





GFRP

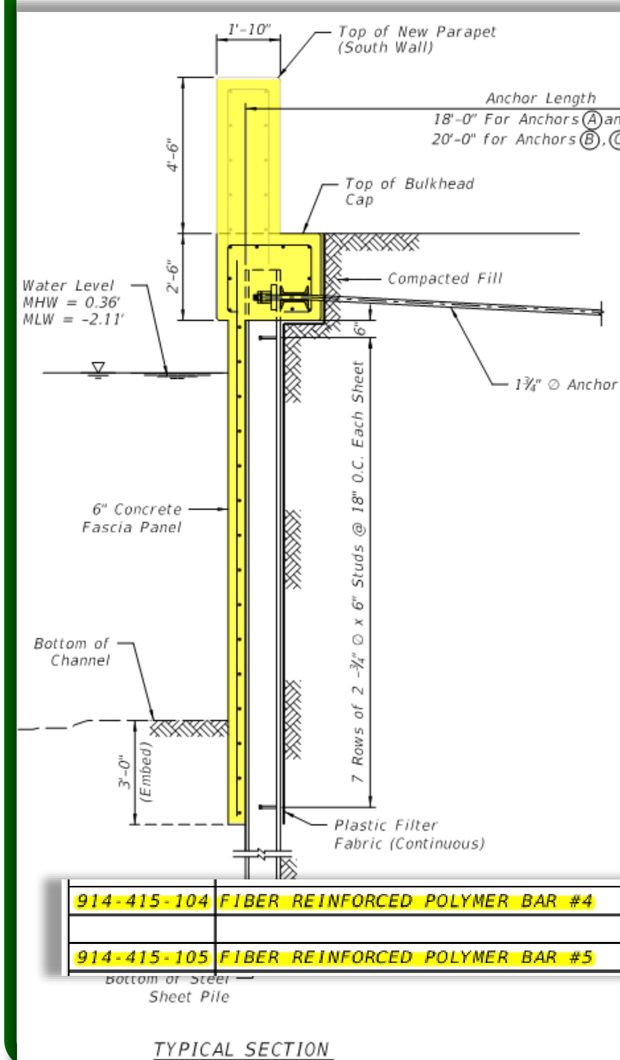
CFCC

Test Blocks

FDOT GFRP Deployment Train

Project Example 3 – *Bakers Haulover Cut Bridge Bulkhead Replacement*

FPID# 433378-1



914-415-104	FIBER REINFORCED POLYMER BAR #4	BULKHEAD CAP, PARAPET & FASCIA PANEL	LF	12,199.32
914-415-105	FIBER REINFORCED POLYMER BAR #5	BULKHEAD CAP, PARAPET & FASCIA PANEL	LF	7,071.14

Project Example 4 – *Skyway South Rest Area Seawall Rehabilitation* FPID# 437973-1 & 438528-1

Design-Build Contractor: *David Nelson Construction Co.*

Example RFP language:

- **FPID 437973-1, South Rest Area Site:**

  - The existing seawall and handrail shall be raised.

  - Extend the seawall southward 285' from the end.

  - Fill behind the seawall to provide for a grassed area and grade for drainage.

  - Metallic reinforcement is not allowed.

  - Non-metallic Reinforcement must meet design criteria and specification

- **FPID 438528-1, Seawall:**

  - Remove and replace the existing seawall cap.

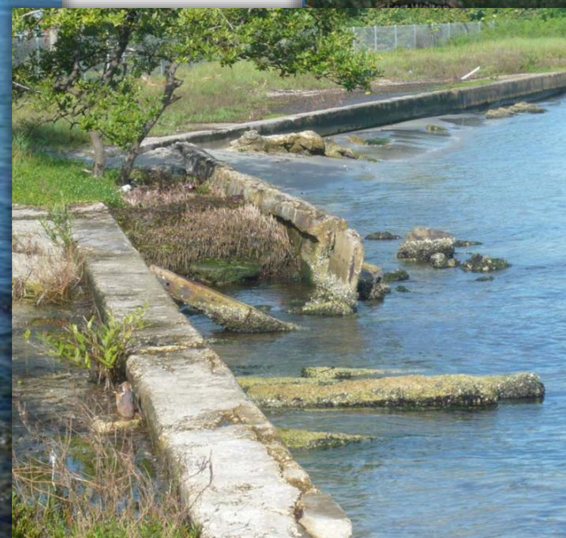
  - Metallic reinforcement is not allowed.

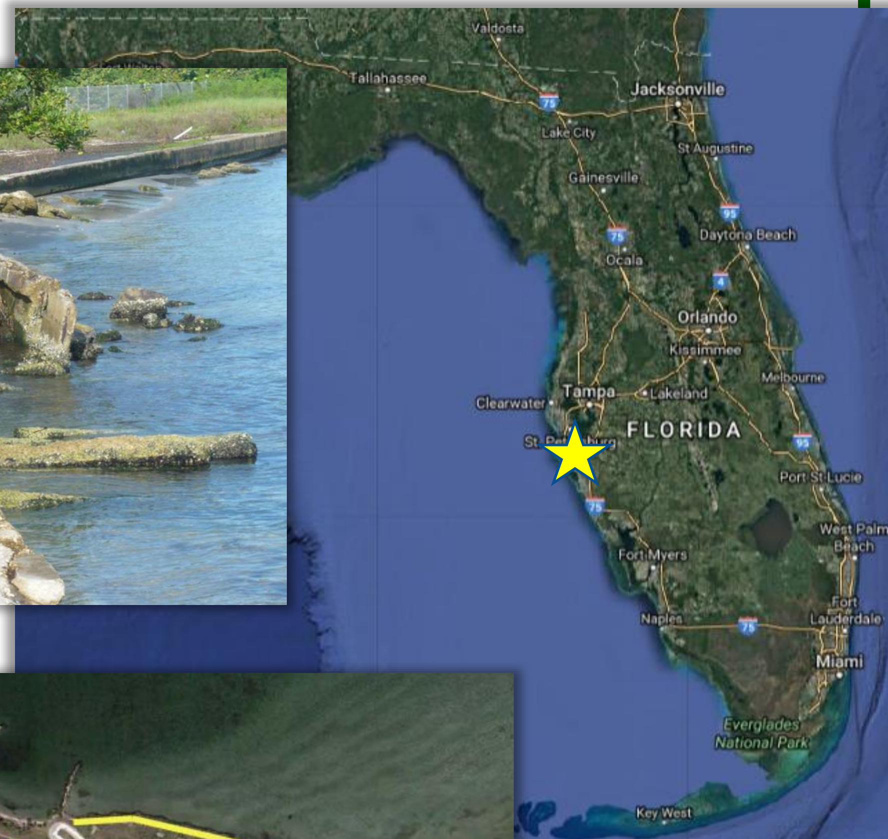
Source: Request for Proposal (Revised August, 2016)

FDOT GFRP Deployment Train

Project Example 4 – *Skyway South Rest Area Seawall Rehabilitation*

Cracking of existing seawall bulkhead cap





Limits of seawall bulkhead cap replacement

Limits of seawall bulkhead cap replacement near Rest Area

FDOT GFRP Deployment Train

Looking Forward

Promote the Use of FRP – Use it where you need it

FDOT Transportation Innovation Challenge

Structures Design Office

Curved Precast Spliced U-Girder Bridges
Fiber Reinforced Polymer Reinforcing
Geosynthetic Reinforced Soil Integrated Bridge System
Geosynthetic Reinforced Soil Wall
Prefabricated Bridge Elements and Systems
Segmental Block Walls

Structures Design - Transportation Innovation

Fiber Reinforced Polymer (FRP) Reinforcing Bars and Strands

Overview
Usage Restrictions / Parameters
Design Criteria
Specifications
Standards
Producer Quality Control Program
Technology Transfer (T^2)
Contact

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

Technology Transfer (T^2)

The following links to FDOT meetings, seminars and workshops are provide as background information for potential users and industry partners:

- FDOT/FHWA Corrosion-Resistant Rebar (CRRB) Seminar (July 17, 2012)
- FHWA/NCHRP 20-68A U.S. Domestic Scan 13-03 meeting with FDOT (June 4-5, 2015)
- FDOT-FRP Rebar Industry Workshop (June 15, 2016)
- Composites-Halls River Bridge Promotional Video for CAMX 2016 (September 26-29, 2016)
- CAMX 2016: FDOT-FRP Deployment for Structural Applications (for new construction) (September 29, 2016)
- ACMA-Transportation Structures Council (TSC) Meeting - FDOT Presentation (Sept. 29, 2016)
- FDOT/FTBA Construction Conference - FRP Presentation Schedule Pending (Feb. 2-3, 2017)
- FDOT-CO Winter FRP-RC Workshop (Feb. 3, 2017)
- Halls River Bridge Replacement FRP Demonstration Project Workshop (May 3, 2017)

Challenges & Focus Areas

See to Part 2 – Do we need a Roadmap for further deployment?

- Challenges to expanded FRP Implementation;
- FDOT Priorities
- Potential Focus Areas;

SDO (RR's) priorities (2/28/2017)

Priority Focus Areas:

1. Increase the variability in bent shapes. The goal would be to duplicate every shape on the FDOT ***Design Standard*** Index 21300;
2. Methods/tests to determine expected life of the products in place, durability modeling and predictions;
3. Maintenance inspection of rebar embedded in concrete;
4. Repair of damaged FRP rebar during construction and when discovered during maintenance inspections;
5. Updating of all design factors (FDOT will approach NCHRP with a recommendation to pursue this as a parallel effort);
6. Continue to coordinate with AASHTO and ACMA-TSC to develop design codes and test protocols (FDOT will continue to participate in all related AASHTO activities);

Questions ?

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Part 2

Do we need a Roadmap?

- Challenges to expanded FRP Implementation
- FDOT Priority Focus Areas
- Potential Focus Areas

Roadmap

Challenges to expanded FRP Implementation:

1. **Material Cost**
    - First cost should include benefits of reduced cover, reduction of concrete additives for durability, and labor/installation savings due to lightweight.
    - Life-Cycle Cost Analysis should to be utilized.
    - SEACON is generating LCC/LCA data that may be helpful.
    - Consider developing example cost comparisons

Roadmap

Challenges to expanded FRP Implementation (cont.):

2. **Lack of confidence in durability for submerged environments (FDOT seeking 75 - 100 year service life)**
    - Accelerated testing could address this issue. OC could update previous tests using samples subjected to sustained load+saltwater+60°C (may need to consider alkalinity also)? The outcome could be a new set of creep-rupture curves that account for environmental effects.
        - *FDOT doing some accelerated testing investigation under BDV30-977-15 "Performance evaluation of glass fiber reinforced polymer (GFRP) reinforcing bars embedded in concrete under aggressive environments" (FSU-UM)*
    - Look at quality of bends compared to straight bars for these conditions.
        - *FDOT proposed SMO research was not advanced last year.*

Roadmap

Challenges to expanded FRP Implementation:

3. **Limitations on the strength due to degradation of properties over time (currently C_E factor = 0.7 for GFRP exterior environments) *[goes with Challenge #2]***
   - Use tests on field-retrieved bars and correlate to accelerate-conditioning tests to develop reliable knockdown factors for 100 years of service life (See Ali & Benmokrane, ***Recommended Value for the Environmental Reduction Factor (C_E) for GFRP Bars in ACI 440-H XXX Code***, for $\mathbf{C_E}$ = 0.9, for 100 year service life GFRP with VE resin, July 2017);
   - Existing sustained stress limit is 0.20 of guaranteed times C_E to account for creep-rupture and fatigue under service loads. *Is the creep-rupture limit actually affected by long-term environmental exposure?*
   - Current FDOT research project: *BDV34 977-05 "Degradation Mechanism and Service Life Estimation of FRP Concrete Reinforcements"*, may provide some answers.

Roadmap

Challenges to expanded FRP Implementation:

4. **Limitations on strength due to low design resistance factors (ϕ factors) related to lack of ductility and strength variability in the FRP materials (currently 0.55-0.65 for tensioned-control to compression-controlled flexural failure modes)**
   - This is a design issue that could be tackled immediately based on reliability.
   - For flexure, revisit existing data and verify proposal by Jawaheri and Nanni (see Table 9).

Table 9—Recommended strength reduction factors for FRP reinforced beams

Limit state	Strength reduction factor (ϕ)
FRP rupture*	0.70
Concrete crushing*	0.75
Shear†	0.75

*Conservatively: $\phi = 0.70$ for both modes; †Shear reinforcement limit is modified as $V_f \leq 3V_c$.

Roadmap

4. Limitations on strength… (continued)

Code comparison prepared by SSDO:

Action	Failure Mode	Phi (AASHTO)	Phi (ACI)	Comment
Conventional Steel Reinforcing:				
Shear	Brittle	0.75	0.75	
Flexure-CC	Brittle	0.75	0.75	
Flexure-TC	Ductile	0.90 (1.00)	0.90	() = prestressed
FRP Reinforcing:		(AASHTO-GS)	(ACI -440)	
Shear	Brittle	0.75	0.75	
Flexure-CC	Brittle	0.65	0.65	non-prestressed
Flexure-TC	Brittle	0.55	0.55	non-prestressed
Flexure-CC	Brittle	N/A	0.65	CFRP-prestressed
Flexure-TC	Brittle	N/A	0.85	CFRP-prestressed

- Prestress resistance factors might be reduced for TC = 0.75 & increased for CC = 0.80 based on new reliability study by Kim & Nickle *(ACISJ Tile 113-S89, Sept-Oct 2016)*
- Could also consider eliminating minimum flexural reinforcing limits when excesses Mcr capacity is provided (maybe 1.5Mcr ??) .

Roadmap

Challenges to expanded FRP Implementation:

5. Limitations on the service limit states due to creep-rupture:

- Existing sustained stress limit is 0.20 of guaranteed strength times C_E to account for fatigue and creep-rupture under service loads.
  - *Is 0.20 f_u too low?*
- Same 0.20 limit for both fatigue (range) and creep (sustained).
  - *New ACI 440.1R-15 under 7.4.2 implies that sustained+range $\leq$ 0.2 f_u, is this valid? If so why even check creep at 0.2fu ?*
  - Is the AASHTO-Fatigue I load case (1.5 x design truck – for infinite life) consistent with the intention under ACI 440.1R for fatigue?
  - AASHTO-GS 2.7.3 creep-rupture limit loading is unclear (should this be just Dead Load at Service I, since what portion of the Live Load would be considered sustained load?)
- Need endurance testing based on modern bar properties.

Roadmap

Challenges to expanded FRP Implementation:

6. **Low Elastic Modulus, resulting in greater deflections and larger crack openings**
   - Not likely we can increase MoE significantly, so…
   - Revisit default k_b factor = 1.4, for crack width estimation, or require testing in Spec 932 to establish a lower value for design (maybe 1.0).
   - Consider combining with FRC to control crack size openings. Would need tools to quantify effect of FRC on crack width (0.02” max.) and deflections.
7. **Shear design:**
   - Shear provisions could be reconciled with Canadian standards method which is much less conservative.

Roadmap

Challenges to expanded FRP Implementation:

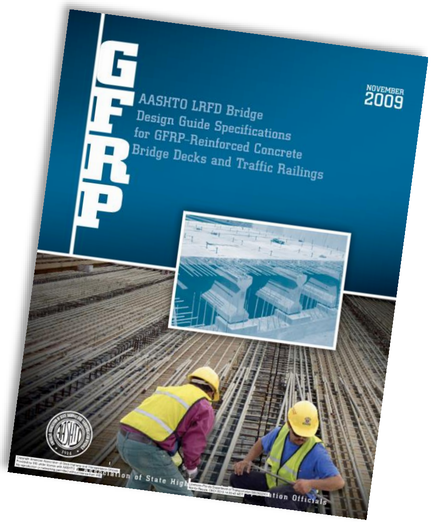
8. Restrictions in bar bending capabilities, and challenges with field modifications to bar shapes

- Manufacturers could propose standardized shape of higher quality revisiting minimum radius of curvature and 60% efficiency.
  - *For design, clarify how the 40% strength reduction is applied for bent shear stirrups?*
- Continuous close stirrups/ties are now possible and allow tight corners, and do not rely on GFRP-concrete bond.
  - *Would test methods differ for these types of stirrups?*
  - *What is the maximum leg length before surface bonding would be required?*
- Consider combining GFRP stirrups/ties with carbon or steel strand in PC applications.
  - *Would need to quantify confinement effect.*

Roadmap

Challenges to expanded FRP Implementation:

9. **Update AASHTO Guide Specification (2009)**
   - This work is underway
10. **Maintenance Inspection Methods**
11. **Repair Methods**



SDO (RR's) priorities (2/28/2017)

Priority Focus Areas:

1. Increase the variability in bent shapes. The goal would be to duplicate every shape on the FDOT standard index ***(Challenge #8)***
2. Methods/tests to determine expected life of the products in place, durability modeling and predictions ***(Challenge #2 & 5)***
3. Maintenance inspection of rebar embedded in concrete ***(Challenge #10)***
4. Repair of damaged FRP rebar during construction and when discovered during maintenance inspections ***(Challenge #11)***
5. Updating of all design factors (FDOT will approach NCHRP with a recommendation to pursue this as a parallel effort) ***(Challenge #2, 3, 4, 5, 6, 7 & 9)***
6. Continue to coordinate with AASHTO and ACMA-TSC to develop design codes and test protocols (FDOT will continue to participate in all related AASHTO activities) ***(Challenge #9+)***

Roadmap

Expanded list of Potential Focus Areas:

1. **(Challenge# 2) Resolution of durability question especially in submerged environments;**
    - SMO projects. (Do we need other testing ?)
        1. BDV34-977-05 Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements, A. El-Safty (UNF), due 3/31/2018
        2. BDV30-977-18 Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments, R Kampmann (FSU), Due 5/31/2018
2. **(Challenge# 3) Refinement of Environmental Reduction factors (CE);**
3. **(Challenge# 4) Rationalization of Resistance Factors (ϕ factors)** used to address lack of ductility and variability in material strength properties**;**
4. **(Challenge# 5) Endurance limits** – refine fatigue and creep-rupture design limits and loading;
5. **(Challenge# 6) Mitigation of lower elastic modulus effects** as related to member deflections and concrete crack widths;
6. **(Challenge# 8) Advancement in bent bar fabrication;**

Roadmap

Expanded list of Potential Focus Areas (cont.):

7. **(Challenge# 9) Improved FRP Industry coordination** especially between ACMA-TSC and AASHTO SCOBS-T6 (FRP) & T10 (Concrete);
8. **(Challenge# 10) Maintenance Inspection/Test methods**
   i. Maintenance inspection of rebar embedded in concrete;
   ii. Non-Destructive Test Methods for identifying deterioration preferable.
9. **(Challenge# 11) Repair Methods**
   i. Repair of damaged FRP rebar during construction and when discovered during maintenance inspections
10. **Investigate hybrid designs –** using GFRP stirrups/rebar with Carbon or Steel prestressing strands;

Roadmap

Expanded list of Potential Focus Areas (cont.):

11. Continued Standardization through:

i. Design Specifications
- AASHTO Guide Spec update (T5) –> LRFD Chapter 5 inclusion (T10);
- ACI 318-GFRP design companion document/address column design;

ii. Material Specifications
- FDOT Specification Sections 932 & 933;
- ACI 440-K/ASTM D30.10: new Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement, WK43339;

iii. Pre-Fabrication
- Cages (ACP, Sheet Piles, Traffic Railings, Precast Caps)
- Closed stirrups
- 2D-Grids/Mats (e.g. Decks and Noise Wall Panels);
- Closed Stirrups/Hoops;
- Headed Anchors;

iv. Pre-designed of Structural Elements (such as **FDOT** ***Design Standards*** Indexes);

Roadmap

Expanded list of Potential Focus Areas (cont.):

13. Guidance on the use of Life Cycle Cost Analysis for FRP justification:

i. Coordinate with SEACON-WP6;

ii. Utilize FHWA/& NCHRP Report 483;

iii. Consider Leveraging Sustainability angle if permitted:

- From **2016 National Bridge Conference**: Jianwei Huang and Chris Strazar, "Sustainability of GFRP RC Bridge Deck: Materials Cost", Southern Illinois University Edwardsville: *This research clarifies the concern of the high initial cost for GFRP RC bridge deck as compared to conventional steel RC deck;*
- **USDOT to require emissions-reduction goals for funding recipients** The US Department of Transportation is working on plans to require highway and transportation funding recipients to set and track carbon dioxide emissions-reduction goals as a condition of receiving money;
- **FHWA proposal: Emissions could gauge success of transportation projects** The amount of emissions, along with congestion, traffic reliability and freight movement, could be used to evaluate the success of a transportation project under new rules proposed by the Federal Highway Administration. The agency has started a 90-day comment period in the proposal.

Roadmap

Expanded list of Potential Focus Areas (cont.):

14. Project Monitoring

i. SMO monitoring Cedar Key Bulkhead rehab – Test Beams under cap (3 surface coatings of GFRP bars);
ii. FSU-UM monitoring Halls River bulkheads, piles, bent caps and deck – Test beams under bulkhead (GFRP, CFRP, and BFRP);
iii. Coordinate with FHWA for monitoring FRP under ***Fixing America's Surface Transportation (FAST) Act***.

15. Outreach and Technology Transfer:

i. FDOT Transportation Innovation - FRP website;
ii. FDOT Design Expos;
iii. Project Case-Studies & Workshops.

****

New items from FDOT-FRP Workshop (Feb 3, 2017)…

ACMA/FRP-RMC Industry Concerns

1. Necessary and required testing today versus years of test data compiled from other installations
2. Identification and selection process of testing laboratories which are ISO qualified. *(Comment: This has been proposed to be changed to "an independent laboratory approved by the Department" for the January 2018 Specs*.)
3. Government agencies and engineers that use products that may be interpreted by some as questionable, un-tested and does not meet the expected standards generated by ASTM, ACI, others
4. First costs versus cost premium impact to overall project cost. How is this handled from the owners stand point. Do life cycle costs play a role as identified in MAP-21?
5. Durability testing: field versus accelerated testing. Which will the DOT feel gives them the results they need? What is the DOT looking for?

Questions ?