Fiber-Reinforced Polymer (FRP) Deployment for FDOT Structural Applications

Will Potter
Outline

1. The Need – Why Composites?
2. Available Documentation
   - Design Criteria
   - Detailing Criteria
   - Design Standards
   - Specifications
   - Materials Manual
3. Research Efforts
4. Implementation Project – Halls River Bridge
5. Looking Forward
The Need – Why Composites?
The Need – Why Composites?

• Avoiding Corrosion
  – Durability/Service Life
  – Cost/Benefit Analysis
  – Mitigating Risks

- Old St. George Island Bridge Piling
- Gandy Blvd. Seawall, (Tampa Bay)
- New and Old Seven-Mile-Bridge, (Florida Keys)
- 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
The Need – Why Composites?

- Repair/Strengthening Operations
  - Impact, Corrosion, Load Change, Defects, etc.

FDOT currently references **ACI 440.2R** w/ modifications

Considered Routine Practice for Given Applications
The Need – Why Composites?

• Bridge Fender Systems

Fully Implemented and Utilized on Projects
- FRP Heavily Recommended -

(Photos Courtesy of Creative Pultrusion)
Typical FDOT Bridge Components
With Possible FRP
Available Documentation from FDOT

• Where do you get started?
  – Design Criteria
  – Detailing Criteria
  – Design Standards
  – Specifications
    • Material and Construction
  – Materials Manual
Available Documentation from FDOT

• Structures Manual – Design Criteria
  A. Structures Design Guidelines
     • Overall Design Criteria;
     • Covers Fender System Criteria;
     • Revised and/or supplemented by FRPG
  B. Fiber Reinforced Polymer Guidelines
     • 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
  C. Referenced Guides
     • ACI, AASHTO, ASCE…
Available Documentation from FDOT

- **Structures Manual – Design Criteria**
  1. **Structures Design Guidelines**
     - Overall Design Criteria;
     - Covers Fender System Criteria;
     - Revised and/or supplemented by FRPG
  2. **Fiber Reinforced Polymer Guidelines**
     - 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
  3. **Referenced Guides**
     - ACI, AASHTO, etc.
Available Documentation from FDOT

- **Structures Manual – Design Criteria**
  1. Structures Design Guidelines
     - Overall Design Criteria;
     - Covers Fender System Criteria;
     - Revised and/or supplemented by FRPG
  2. Fiber Reinforced Polymer Guidelines
     - 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
  3. Referenced Guides
     - ACI, AASHTO, etc.
Available Documentation from FDOT

- **Structures Manual – Detailing Criteria**
  - Structures Detailing Manual
    - Overall detailing criteria;
    - Revised and/or supplemented by Fiber Reinforced Polymer Guidelines (FRPG) for given applications of FRP

*All reinforcing shall be GFRP #5 bars minimum.*
Available Documentation from FDOT

- **Design Standards**
  - Square CFRP/SS Prestressed Concrete Piles;
  - Precast Concrete CFRP/GFRP & HSSS/GFRP Sheet Pile Wall
  - Fender System Details (wales)

- **Developmental Design Standards**
  - Gravity Wall – Option C (GFRP reinforced);
  - Pultruded FRP Bar Bending Details;
  - GFRP reinforced 32” F-Shape Traffic Railing;
  - GFRP reinforced Approach Slab

### Fender System Details

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<tr>
<th>Code</th>
<th>Description</th>
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<tr>
<td>21830</td>
<td>Fender System - Prestressed Concrete Piles</td>
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<tr>
<td>22440</td>
<td>Precast Concrete CFRP/GFRP &amp; HSSS/GFRP Wall</td>
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### Wall Systems (Corrosion Resistant)

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<td>22609</td>
<td>Notes and Details For Square CFRP &amp; SS Prestressed Concrete Piles</td>
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### Square and Round Concrete Piles (Corrosion Resistant)

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<td>22601</td>
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<td>22612</td>
<td>12” Square CFRP &amp; SS Prestressed Concrete Pile</td>
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<td>22614</td>
<td>Errata</td>
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<td>22624</td>
<td>Errata</td>
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<td>22630</td>
<td>30” Square CFRP &amp; SS Prestressed Concrete Pile</td>
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<td>22654</td>
<td>54” Precast/Post-Tensioned CFRP &amp; SS Concrete Cylinder Pile</td>
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<tr>
<td>22660</td>
<td>60” Prestressed CFRP &amp; SS Concrete Cylinder Pile</td>
</tr>
</tbody>
</table>
Available Documentation from FDOT

• Construction and Material Specifications
  – Standard Specifications
    • Implemented previous FRP Developmental Specifications
    • **105** – Contractor Quality Control (FRP Producers)
    • **400** Concrete (includes FRP Bar construction considerations);
    • **415** Reinforcing for Concrete (FRP Bar construction considerations);
    • **450** Precast Prestressed Concrete Construction (FRP Bars/Strand construction considerations);
    • **471** FRP Fender Systems (Design Criteria and construction considerations);
    • **932** Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures (GFRP and CFRP Bars material specs);
    • **933** Prestressing Strand (CFRP Strand material specs)
    • **973** FRP Composite Structural Shapes (material and fabrication requirements)
Material and Producer Requirements

State Materials Office Oversight Role:
• Material Specification
• Sampling and Testing Requirements
• Quality Control Program – Production Facility Approvals
• Conduct and Facilitate Materials Research

State Materials Office (Gainesville, FL)
Available Documentation from FDOT

Material and Producer Requirements

- **Producer Quality Control**
  - Specification Section 105
  - Materials Manual Ch. 12.1
  - Specifications Section 932, 933, and 973

- **Acceptance at the Project Level**
  - Certification
  - Sampling and Testing

- **MAC**
Material and Producer Requirements

- **Producer Quality Control**
  - Section 105 – Contractor Quality Control
  - FRP Producers must meet requirements of Materials Manual
    - Materials Manual Ch. 12.1
    - Specifications Section 932, 933, and 973

- **Acceptance at the Project Level**
  - Certification
  - Sampling and Testing

- **MAC**
Available Documentation from FDOT

Material and Producer Requirements

• Producer Quality Control
  – Specification Section 105
  – Materials Manual Ch. 12.1
  • Production Facility Qualification Process
  • Producer Responsibilities
  • Incoming raw material control
  • Manufacturing quality control
  • QC Inspection
  • Handling, Storage, Shipment
  • Documentation and Record Retention
  – Specifications Section 932, 933, and 973

• Acceptance at the Project Level
  – Certification
  – Sampling and Testing

• MAC
Available Documentation from FDOT

Material and Producer Requirements

- **Producer Quality Control**
  - Specification Section 105
  - Materials Manual Ch. 12.1
  - Specifications Section 932, 933, and 973

- **Acceptance at the Project Level**
  - Certification
  - Sampling and Testing

- **MAC**

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**SECTION 933**
PRESTRESSING STRAND AND BAR

933-1 Strands for Prestressing,
933-1.1 Carbon Steel Strands for Prestressing: The steel strands for prestressing concrete members shall be Grade 270, low-relaxation seven wire strand and shall conform to the requirements of ASTM A416.

933-1.2 Stainless Steel Strands for Prestressing: The stainless steel strands for prestressing concrete members shall be a high strength stainless steel (HSS) conforming to the chemical requirements of ASTM A276, UNS S31803 or S32205 (Type 2205) and the mechanical and dimensional requirements of ASTM A416, except the minimum ultimate tensile strength shall be 240 ksi.

933-1.3 Carbon Fiber Reinforced Polymer (CFRP) Strands for Prestressing: CFRP strand shall meet the requirements of ACI 440.4, following the test methods from ACI 440.3. The CFRP strand shall meet the additional requirements of this Section following the sampling frequency and number of specimens required by ACI 440.6.

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**SECTION 973**
FIBER REINFORCED POLYMER (FRP) COMPOSITE STRUCTURAL SHAPES

973-1 Description.
This Section covers material and fabrication requirements for fiber reinforced polymer (FRP) composite structural shapes.

973-2 Product Acceptance.
Obtain FRP composites from a producer that is currently on the Department’s Production Facility Listing. Producers seeking inclusion on the list shall meet the requirements of Section 105.
Available Documentation from FDOT

Material and Producer Requirements

- **Producer Quality Control**
  - Specification Section 105
  - Materials Manual Ch. 12.1
  - Specifications Section 932, 933, and 973

- **Acceptance at the Project Level**
  - **Certification**
    - Notarized Statement from FRP Producer sent prior to shipment
    - Certificate of Analysis for each LOT sent with each shipment
  - **Sampling and Testing**

- **MAC**
Available Documentation from FDOT

Material and Producer Requirements

- Producer Quality Control
  - Specification Section 105
  - Materials Manual Ch. 12.1
  - Specifications Section 932, 933, and 973

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

- MAC

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Laboratory Test Report

1. REBAR SAMPLE INFORMATION

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>ID/Ref.</th>
<th>Nominal Rebar Denomination</th>
<th>Material Type*</th>
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<tr>
<td>1</td>
<td>N# 342 RW6-A4-64 SUPERSTR. SPANS 1-5 4-461 (P070723CB L=323.36 LF) P.O. (02-08-01/17)</td>
<td>#4</td>
<td>Glass fiber reinforced polymer (GFRP)</td>
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<td>2</td>
<td>N# 221 RW6-A4-65 SUPERSTR. SPANS 1-5 5-251 (P070723CB L=325.09 LF) P.O. (11/18/11/17)</td>
<td>#5</td>
<td>Glass fiber reinforced polymer (GFRP)</td>
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Laboratory Test Report

3.5. TENSILE PROPERTIES


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

Technicians: Guillermo Claro, and Roger Solis.

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:

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<tr>
<th>Nominal Rebar Denomination</th>
<th>SPECIMEN ID</th>
<th>Peak Load Pmax lbs</th>
<th>Nominal Area A in²</th>
<th>Ultimate Tensile Strength, UTS ksi</th>
<th>Modulus of Elasticity, E ksi</th>
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<tr>
<td>CV (%)</td>
<td></td>
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Available Documentation from FDOT

Material and Producer Requirements

- Producer Quality Control
  - Specification Section 105
  - Materials Manual Ch. 12.1
  - Specifications Section 932, 933, and

- Acceptance at the Project Level
  - Certification
  - Sampling and Testing

- MAC
  - Specifications
  - Production Facility Profiles and Listings
Available Documentation from FDOT

Material and Producer Requirements

- **Producer Quality Control**
  - Specification Section 105
  - Materials Manual Ch. 12.1
  - Specifications Section 932, 933, and 973

- **Acceptance at the Project Level**
  - Certification
  - Sampling and Testing

- **MAC**
  - Specifications
  - 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
- Precast 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
Research Efforts - Active

• Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments – (BDV30-977-18)

• Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements – (BDV34-977-05)

• Inspection and Monitoring of Fabrication and Construction for the West Halls River Road Bridge Replacement – (BDV30-706-01)

• Bridge Girder Alternatives for Extremely Aggressive Environments – (BDV22-977-01)
### Research Efforts – Past/Completed

<table>
<thead>
<tr>
<th>Date</th>
<th>Project Description</th>
<th>Author(s)</th>
<th>Institution</th>
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<tbody>
<tr>
<td>3/1/2017</td>
<td>Durability Evaluation of Florida's Fiber-Reinforced Polymer (FRP) Composite Reinforcement for Concrete Structures</td>
<td>Hamilton, Trey</td>
<td>University of Florida</td>
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<tr>
<td>8/31/2015</td>
<td>Use of Fiber Reinforced Polymer Composite Cable for Post-Tensioning Application</td>
<td>Mirrnan, Amir</td>
<td>Florida International University</td>
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<tr>
<td>6/30/2015</td>
<td>Repair of Impact Damaged Utility Poles with FRP, Phase II</td>
<td>Mackie, Kevin</td>
<td>University of Central Florida</td>
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<tr>
<td>4/16/2014</td>
<td>Investigation of Carbon Fiber Composite Cables (CFCC) in Prestressed Concrete Piles</td>
<td>Roddenberry, Michelle</td>
<td>Florida State University</td>
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<tr>
<td>10/1/2012</td>
<td>The Repair of Damaged Bridge Girders with Carbon-Fiber-Reinforced Polymer &quot;CFRP&quot; Laminates</td>
<td>El-Saffy, Adel</td>
<td>University of North Florida</td>
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<tr>
<td>1/1/2011</td>
<td>Testing of Trelleborg Structural Plastics</td>
<td>Wegner, David</td>
<td>FDOT</td>
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<tr>
<td>7/30/2009</td>
<td>Thermo-mechanical Durability of Carbon Fiber Reinforced Polymer Strengthened Reinforced Concrete Beams</td>
<td>Mackie, Kevin</td>
<td>University of Central Florida</td>
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<td>8/31/2003</td>
<td>Hybrid FRP-Concrete Column</td>
<td>Mirrnan, Amir</td>
<td>North Carolina State University</td>
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<tr>
<td>7/3/2001</td>
<td>Design of Concrete Bridge Girders Strengthened with CFRP Laminates</td>
<td>El-Tawil, Sherrif</td>
<td>University of Central Florida</td>
</tr>
<tr>
<td>1/1/1999</td>
<td>LRFD Flexural Provisions for PSC Bridge Girders Strengthened with CFRP Laminates</td>
<td>El-Tawil, Sherrif</td>
<td>University of Central Florida</td>
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<tr>
<td>11/30/1998</td>
<td>Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Piles in Marine Environment</td>
<td>Arockiasamy, M.</td>
<td>Florida Atlantic University</td>
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<tr>
<td>12/1/1997</td>
<td>Flexural Reliability of RC Bridge Girders Strengthened with CFRP Laminates</td>
<td>Oks, Ayman</td>
<td>University of Central Florida</td>
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<td>9/1/1997</td>
<td>An Analytical and Experimental Investigation of Concrete-Filled Fiber Reinforced Plastics (FRP) Tubes</td>
<td>Mirrnan, Amir</td>
<td>University of Central Florida</td>
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<td>7/31/1997</td>
<td>FRP-Composite Column and Pile Jacket Splicing Phase II</td>
<td>Mirrnan, Amir</td>
<td>University of Central Florida</td>
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<tr>
<td>8/1/1995</td>
<td>Durability of CFRP Pretensioned Piles in Marine Environment Volume II</td>
<td>Sen, Rajan</td>
<td>University of South Florida</td>
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<td>1/1/1995</td>
<td>Active Deformation Control of Bridges Prestressed with Aramid Fiber Reinforced Plastic (AFRP) Cables</td>
<td>Arockiasamy, M.</td>
<td>Florida Atlantic University</td>
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<td>8/1/1992</td>
<td>Feasibility of Fiberglass Pretensioned Piles in a Marine Environment</td>
<td>Sen, Rajan</td>
<td>University of South Florida</td>
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Implementation Project – Halls River

**Designer:** FDOT District 7

**Est. Completion:** Winter/Spring 2018

Owner & Maintaining Agency

Design & Bi-Annual Inspection

Funding & Monitoring

Collaboration Research
Halls River Bridge – Project Overview
Halls River Bridge
Halls River Bridge

- CFRP/GFRP Sheet Pile Wall
  - CFRP Pretensioning
  - GFRP Mild Reinforcement
Halls River Bridge

Proposed Bridge Section

COMPLETED STRUCTURE
Utilized Codes, Standards and References (cont’d)

FDOT Developmental Standards:

– Pultruded FRP Bar Bending Details (Index D21310)
– 18” CFRP Prestressed Piles (Index D22618)
– CFRP Prestressed Piles Splices (Index D22601)
– CFRP/GFRP Sheet Piles Walls (Index D22440)
– Traffic Railing - GFRP Reinforced (Index D22420)
– Approach Slab – GFRP Reinforced (Index D22900)
Halls River Bridge – CFCC Pile Driving
Halls River Bridge – CFRP/GFRP Sheet Piling
Halls River – Hillman Composite Beam
Halls River – Hillman Composite Beam
Halls River – GFRP Reinforced Bent Cap
Halls River – GFRP Reinforced Bent Cap
Halls River Bridge - Summary

• Challenges: More discussion as project progresses…
  – CFCC Pile Cracking
  – Subsurface (soil) Difficulties – Unplanned Pile Splice
  – QA/QC
  – Phased Construction (post-installed traffic railing detail)
  – Material Readily Available – Preapproved Producers

• Demonstration Project with Innovative Materials (FRP)
  – Superstructure: Hillman Composite Beam; GFRP Bars: Deck, Wingwall, Backwall, Barriers, and Approach Slabs
  – Substructure: CFCC Prestressed Piles; Bent Caps: GFRP Bars
  – Sheet Pile Walls: CFCC/GFRP Sheet Piles; Wall Cap: GFRP Bars

• Contractor Bid Cost – $6.01m (Structures = $4.06m)
  – Bridge Cost = $218/sq.ft. (Conventional Est. = $166/sq.ft.)
Looking Forward

• Priority Focus Areas:
  – Increase the variability of bent shapes. The goal would be to duplicate every shape on the FDOT Design Standard Index;
  – Methods/tests to determine expected life of products in place, durability modeling, and predictions;
  – Maintenance inspection of reinforcement embedded in concrete and maintenance guidance for FRP systems;
  – Repair of damaged FRP (rebar, systems, etc.) during construction and when discovered during maintenance inspections;
  – Updating of all design factors, incorporation from ACI to AASHTO;
  – Continue to coordinate with AASHTO and ACMA to develop design codes and test protocols. FDOT is prepared to be active in all stages.
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

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

Technology Transfer (T²)
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 (CRR8) Seminar (July 17, 2012)
- FHWA/NCHRP 20-68A U.S. Domestic Scan T3-03 meeting with FDOT (June 4-5, 2015)
- FDOT-FRP Rebar Industry Workshop (June 15, 2015)
- 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)
- Halls River Bridge Replacement FRP Demonstration Project Workshop (May 3, 2017)
## FDOT Contacts

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will Potter, P.E.</td>
<td>Asst. State Structures Design Engineer</td>
<td><a href="mailto:William.Potter@dot.state.fl.us">William.Potter@dot.state.fl.us</a></td>
</tr>
<tr>
<td>Steve Nolan, P.E.</td>
<td>Structures Standards Coordinator</td>
<td><a href="mailto:Steven.Nolan@dot.state.fl.us">Steven.Nolan@dot.state.fl.us</a></td>
</tr>
<tr>
<td>Chase Knight, PhD.</td>
<td>FRP Coordinator</td>
<td><a href="mailto:Chase.Knight@dot.state.fl.us">Chase.Knight@dot.state.fl.us</a></td>
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<tr>
<td>Rick Vallier, P.E.</td>
<td>Structures Design</td>
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