FRP Design Tools, Composite Bridge Beam Implementation & Pedestrian Bridges

TRB 2020 – AFF80 Workshop on FRP Deployment in Transportation Infrastructure
(January 12, 2020)
Presenter: Steven Nolan
FRP for Concrete and Composite Structures

1. Introduction
   • Where are we?... Where do we want to go?... How do we get there?

2. Design Rules & Tools for CFRP-PC and GFRP-RC
   • Standards
   • Tools
     • Design
     • Justification
     • Delivery

3. Design Rules & Tools for FRP Members (Composite Bridge Beams and Other Structures)
   • Standards
   • Tools
   • Bidding Strategies

4. Composite Pedestrian Bridges
   • Girder Systems
   • Truss Systems

Introduction – Roadmapping Rules and Tools for Transportation Infrastructure

Progression of Implementation:
• Repairs and Strengthening - 1990’s ➔
• FRP Structural Members (mostly Pultruded and VARTM) - 2008, 2012 ➔
• CFRP-PC strands & FRP-RC rebar (Glass) - 2017 & 2012/17 ➔ Basalt?

Putting it all together:
• Rules, Tools, and Implementation Strategies

“Mainstreaming”:
• Codes & Standards
• Certification (Products, Systems, & Producers)
• Training (Designers, Inspectors, & Contractors)
Introduction - Roadmapping FRP for Transportation Infrastructure

Where Are We?

• Southeast (FL, LA, KY, VA, WV)
• Northeast (ME, NY)
• Mid-west (MI, OH)
• Southwest (TX)
• West (OR)
Introduction - Roadmapping FRP for Transportation Infrastructure

Where do we want to go?

• AASHTO LRFD BDS Integration
• Individual Guide Specs vs Broader Guidelines?
• ASTM vs. AASHTO Materials Specs
• Manufacturer/Producer Certification?
Introduction - Roadmapping FRP for Transportation Infrastructure

How do we get there?

• AASHTO LRFD BDS Integration
• Individual Guide Specs. vs Broader Class Guidelines?
• ASTM vs. AASHTO Materials Specs
• Manufacturer/Producer Certification?
Design Rules & Tools for CFRP-Prestressed Members

- Standards
- Design tools
- Cost Guidance
Design Rules & Tools for CFRP-Prestressed Members

• Standards
  • ACI 440.4R-04
  • FDOT Spec 933; Michigan DOT Special Provisions for CFCC;
  • NCDOT Demo (Harkers Island Bridge Replacement);
  • VDOT FHWA/VTRC 19-R1 (Nimmo Parkway/West Neck Ck) & I-64 High Rise Bridge;
  • FDOT Standard Prestressed Piles (Index 455-100 & -440 series)

• Design tools
• Cost Guidance
Design Rules & Tools for CFRP-Prestressed Members

• Standards

• Design tools
  • FDOT Prestressed Beam Program (Mathcad)
  • Michigan DOT/LT CFRP Design Guidelines & Program - select “Modeling Bridge”
  • FB MultiPier (piles) - pending material libraries

TRB Webinar: Advanced Structural Materials for Concrete Bridges (December 3, 2019)
Design Rules & Tools for CFRP-Prestressed Members

- Standards
- Design tools
- Cost Guidance
  - FDOT SDG 9.2 (piles)
  - ~$3 premium/ft. strand

### 9.2.1 Substructure (Rev. 01/20)

#### A. Prestressed Concrete Piling: cost per linear foot (furnished and installed)

<table>
<thead>
<tr>
<th>Size of Piling</th>
<th>Driven Plumb or 1” Batter</th>
<th>Driven Battered</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-inch w/ carbon steel strand^2</td>
<td>$90</td>
<td>$125</td>
</tr>
<tr>
<td>24-inch w/ carbon steel strand^2</td>
<td>$100</td>
<td>$140</td>
</tr>
<tr>
<td>30-inch w/ carbon steel strand^2</td>
<td>$150</td>
<td>$210</td>
</tr>
<tr>
<td>18-inch w/ CFRP or Stainless Steel Strand</td>
<td>$135</td>
<td>$160</td>
</tr>
<tr>
<td>24-inch w/ CFRP or Stainless Steel Strand</td>
<td>$150</td>
<td>$210</td>
</tr>
<tr>
<td>30-inch w/ CFRP or Stainless Steel Strand</td>
<td>$225</td>
<td>$280</td>
</tr>
</tbody>
</table>

1. When highly reactive pozzolans are used, add $6 per LF to the piling cost.
2. When heavy mild steel reinforcing is used in the pile head, add $250.
Design Rules & Tools for FRP-Reinforced Concrete Structures

• Standards
• Design tools
• Cost Guidance
• LCC & LCA
Design Rules & Tools for FRP-Reinforced Concrete Structures

• Standards
  • **ACI 440.1R-15** *(building code update in process)*
  • Materials - FDOT Spec 932-3; **ASTM D7957-17**
  • Pre-designed Elements: FDOT Concrete Sheet Piles & Bulkhead Caps (Index 455-440)

• Design tools
• Cost Guidance
Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Bidding Strategies

**ACI Committee 440:**
Plan is to get remaining code chapters balloted at main by Spring 2020 and clean up outstanding issues by Fall 2020

Public comment phase
Design Rules & Tools for FRP-Reinforced Concrete Structures

• Standards

• Design tools
  • FDOT Pile Bent Cap Program *(Mathcad)*
  • FDOT CIP Flat Slab Bridge Program *(Mathcad)*
  • FDOT CIP Retaining Wall Program *(Mathcad)*
  • FDOT CIP Box Culvert Program *(Mathcad)*
  • Commercial interest *(DeepEx, FB-MultiPier, etc.)*

• Cost Guidance
Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools

** FDOT Pile Bent Cap Program (Mathcad) **
- Box Culvert v4.0  11/07/2018  
  **GFRP-RC in development!**  
  Exe (Zip) (Mathcad 15)
- Prestressed Beam v5.2  11/07/2018  
  **CFRP-PC Beta version**
  Exe (Zip) (Mathcad 15)
- Bent Cap v1.0  11/07/2018  
  **GFRP-RC included (3b)**
  Exe (Zip) (Mathcad 15)
- Retaining Wall v3.3  11/07/2018  
  **GFRP-RC Beta version**
  Exe (Zip) (Mathcad 15)

- FDOT CIP Flat Slab Bridge Program (Mathcad)
- FDOT CIP Retaining Wall Program (Mathcad)
- FDOT CIP Box Culvert Program (Mathcad)

- Commercial interest (DeepEx, FB-MultiPier, etc.)

** Available on request **

** Available on request **

https://www.fdot.gov/structures/proglib.shtm

CFRP-PC Beta version **

GFRP-RC Beta version **

GFRP-RC included (3b)
Design Rules & Tools for FRP-Reinforced Concrete Structures

• Standards
• Design tools
  • TxDOT IGFRP (Oct, 2019)
• Cost Guidance
Design Rules & Tools for FRP-Reinforced Concrete Structures

- Designer tools/aids
- Producer/Product approval

https://mac.fdot.gov/smoreports
Design Rules & Tools for FRP-Reinforced Concrete Structures

• Standards
• Design tools
• Cost Guidance

D. Reinforcing Bars and Post-tensioning Steel

1. Steel Reinforcing Bars; cost per pound:

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Cost per Pound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel, ASTM A615, Gr. 60 or 75</td>
<td>$1.05</td>
</tr>
<tr>
<td>Low-Carbon Chromium Steel, ASTM A1035, Gr. 100</td>
<td>$1.30</td>
</tr>
<tr>
<td>Stainless Steel, ASTM A955, Gr. 60 or 75, or ASTM A276, UNS S31653 or S31803</td>
<td>$4.05</td>
</tr>
</tbody>
</table>

2. GFRP Reinforcing Bars, FDOT Standard Specifications 932-3; cost per linear foot. Add $1.00 per hook, or bend for stirrups, and $1.00 per revolution for circular spirals.

<table>
<thead>
<tr>
<th>Size</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
<th>#7</th>
<th>#8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>$0.60</td>
<td>$0.95</td>
<td>$1.15</td>
<td>$1.40</td>
<td>$1.80</td>
<td>$2.25</td>
</tr>
</tbody>
</table>
Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Cost Guidance

Recent FDOT Bid Tabs:

<table>
<thead>
<tr>
<th>GFRP Bar Size</th>
<th>AIA Seawall Bid 2018</th>
<th>HRB Bid 2016</th>
<th>NE23rd Bid 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
<td>$1.00</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>$1.45</td>
<td>$1.10</td>
<td>$1.68</td>
</tr>
<tr>
<td>#6</td>
<td>$1.40</td>
<td>$1.68</td>
<td></td>
</tr>
<tr>
<td>#7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td>$1.70</td>
<td>$2.29</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
<td></td>
<td>$4.37</td>
</tr>
</tbody>
</table>

FDOT Corrosion-Resistant Rebar Cost Comparison

- BHC Rehab 2016
- NE23rd Bid 2019
- FDOT Expo 2017
- RS Means 2016
- Mateen 2014 (>40KLF)
- Hughes Bros. 2014
- Pultrall 2014
- Black (FDOT)
- Low-Chromium (FDOT)
- Stainless (FDOT)
Design Rules & Tools for FRP-Reinforced Concrete Structures

- Standards
- Design tools
- Cost Guidance

- FHWA Presentation 2012 – Industry Meeting
Cost Comparisons (ODOT bridge decks)

<table>
<thead>
<tr>
<th>Anthony Wayne Trail over NSRR (link)</th>
<th>Cost Per Square Foot of Deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Coated Reinforcing</td>
<td>$8.052/SF</td>
</tr>
<tr>
<td>GFRP Reinforcing (GFRP 1st Edition)</td>
<td>$9.587/SF</td>
</tr>
<tr>
<td>GFRP Reinforcing (GFRP 2nd Edition)</td>
<td>$8.736/SF</td>
</tr>
</tbody>
</table>

- Cost information based on Contractor bid prices
- Price of epoxy reinforcing @ $1.00/LB

<table>
<thead>
<tr>
<th>Industrial Drive over the Maumee River (link)</th>
<th>Cost Per Square Foot of Deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Coated Reinforcing</td>
<td>$11.805/SF</td>
</tr>
<tr>
<td>GFRP Reinforcing</td>
<td>$10.609/SF</td>
</tr>
</tbody>
</table>

- Cost information is from Engineer’s estimate
- Price of epoxy reinforcing @ $1.15/LB
- Recent increase in steel cost (15%-20% Increase)

<table>
<thead>
<tr>
<th>I-475 over Dorr Street &amp; Hill Avenue (link)</th>
<th>Cost Per Square Foot of Deck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy Coated Reinforcing</td>
<td>$10.104/SF</td>
</tr>
<tr>
<td>GFRP Reinforcing (w/ Mech. Conn.)</td>
<td>$10.025/SF</td>
</tr>
<tr>
<td>GFRP Reinforcing (w/o Mech. Conn.)</td>
<td>$8.563/SF</td>
</tr>
</tbody>
</table>

- Cost information is from Engineer’s estimate
- Price of epoxy reinforcing @ $1.15/LB
- Recent increase in steel cost (15%-20% Increase)
- Mechanical connectors $20/bar (Assumed)
Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

- Standards
- Design tools
- Bidding Strategies
Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

- Standards
- Design tools
  - HCB worksheet
  - Vendor software
- Bidding Strategies
Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

• Standards
• Design tools
• Bidding Strategies

Potential format: FDOT Index D296 Three sided Concrete Culvert Details IDDS-D296
Design Rules & Tools for FRP Members (Composite Bridge Beams & Other Structures)

• Standards
• Design tools
• Bidding Strategies

“Detail-Build” option:
MnDOT SP 531 Detail-Build Bridge Structure *bid book* describes the process.
- allowing bid options for relatively straight forward bridge projects (or bridge elements)
- requires the contractor to complete the design according to the requirements in SP 531.

For projects with prefabricated elements it allows the contractor select the best option based on cost, product availability and preference; and allows the owner to include proven proprietary products as bid alternates.

Examples:
**Industry, Sawyer Bridge – Detail Build buried structure** (34’ span)
Bid Date: 12/19/2018

**North Berwick, Staples Bridge – Detail Build short span bridge** (40’ span - no FRP option)
Bid Date: 1/8/2020

MnDOT used this process for approximately 10 years with good success with a 4 or 5 week bid period. Avoid any projects with complexities that require in-depth design.
Composite Bridge Systems

- **Girder Bridges**

- **Pedestrian Truss Systems**

95-ft. trail bridge being flown to a remote staging site in Alberta, Canada. *(Photos: Emerald Atlas, courtesy of Dustin Troutman – Creative Pultrusion)*
Needs – Design Tools, Research & Other

• What do we need to get in the Bridge Code?
  • AFF80 Research Needs Statements (priorities)
  • NCHRP options (Scan, Synthesis, Research ?)
  • State DOT research programs vs. Pooled Fund

• Is FHWA’s Every Day Counts (EDC-6) important for FRP (Jan 21, 2020 deadline)?

• FHWA Accelerated Market Readiness (AMR) and other programs (previous BAA Apr 22, 2019, 2020 pending)?
Needs – Design Tools, Research & Other

• What more do we need to get in the Bridge Code?
  • AASHTO RNS (Research)
    • PC Beam Auxiliary FRP Reinforcement submitted
  • Competitive materials: **NCHRP 12-120**
    “Stainless Steel Strands for Prestressed Bridge Elements”
Needs – Design Tools, Research & Other

- What do we need to improve efficiency for Bridge Code?
  - Elastic Modulus
  - Sustained Stress Limits
  - Fatigue Limits


Figure: Parametric analysis of flexural design algorithms per AASHTO GFRP-RC 2nd edition for HRB Bent Cap
Questions?

• What Tools are Still Needed:
  • For Design
  • For Product Acceptance
  • For Contract Delivery
  • For Inspection