Innovative Solutions for tomorrow’s transportation needs

Design of First FRP Reinforced Concrete Bridge in Florida
Halls River Project

Presenters

FDOT District 7 Structures Design Office:

• Elisha Masséus, P.E.
  Structures Design Engineer

• David Pelham
  Structures Designer & D7 Geotechnical Coordinator

• Cristina Suarez
  Structures Designer
Outline

• Introduction
  • Corrosion Issue
  • Fiber Reinforced Polymer (RFP) Reinforcing
  • Prevention Methods
  • References

• Halls River Project
  • Project Overview
  • Construction

Introduction

• Corrosion Issues
• FRP (Fiber Reinforced Polymer) Reinforcing
• Prevention Methods
• References
Corrosion Issues

- Corrosion of steel reinforcing
  - Premature deterioration of concrete structures
  - Reduction in capacity and service life
  - High costs for rehabilitation and/or replacement

Corrosion Costs

Corrosion Costs

District 7 (FY 02/03 to Present)

54 Total projects:
• 20 Steel
• 34 Concrete

- 24% Other Repairs
- 76% Corrosion Repair

$2.4M per Project

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

Corrosion Issues

• Concrete Alkalinity:
  • Provides initial corrosion protection for steel bars
  • Reduces in aggressive environments
    • Highway Deicers
    • Marine/Coastal Environments
    • Contaminated soils (high chloride/sulfate concentration)

• Concrete Cracks:
  • Due to shrinkage, creep, temperature, settlement, etc.
  • Localized corrosion (where crack intersects rebar)
Prevention Methods

- Existing Concrete Structures
  - Pile Jacket
  - FRP Wrapping
  - Cathodic Protection

- New Concrete Structures
  - Adequate Concrete Cover
  - Concrete Quality
  - Corrosion Inhibiting Admixtures
  - Prefabricated FRP beam: Hybrid Composite Beam
  - Alternative Reinforcements

FRP Reinforcing

- FRP Bar: Fiber-Reinforced Polymer rebar
- Rebar made of fibers embedded in polymeric resin
  - Superior to either component alone
  - Each component retains its own chemical and physical properties
FRP Reinforcing

• Fibers purpose:
  • Strength
  • Stiffness
  • Toughness
  • Durability

• Resin purpose:
  • Holds fibers together
  • Protects fibers from environment/abrasion
  • Transfers load between fibers (shear)

FRP Reinforcing

• Fiber types:
  ✔️ Glass
  • Carbon
  • Aramid
  • Basalt

• Resin (Thermoset) types:
  ✔️ Vinyl ester
  • Polyester
  • Epoxy

Preferred choice for RC applications:
• Balance between cost and strength

Preferred choice for RC applications:
• Good alkali resistance
• Good adhesion to concrete
FRP Reinforcing

Advantages:
• Corrosion Resistant
• High Strength
• Lightweight
• Fatigue Endurance
  • Aramid FRP bars susceptible to fatigue
• Nonmagnetic
• Low Thermal and Electrical Conductivity

FRP Reinforcing

Main Disadvantages:
• High initial cost
• Brittle failure
FRP Reinforcing

Design Considerations:
• Low shear strength relative to tensile strength
• Low modulus of elasticity
• Creep under sustained loading
• Elevated Temperature
• Moisture
• Ultra-Violet Radiation

FRP Reinforcing

Factors Affecting Material Properties:
• Fiber type
• Fiber volume ratio
• Fiber orientation
• Manufacturing process and quality control
• Rate of resin curing
• Temperature
• Void content
FRP Reinforcing

Table 5.2—ASTM standard reinforcing bars

<table>
<thead>
<tr>
<th>Bar size designation</th>
<th>Nominal diameter, in. (mm)</th>
<th>Area, in.² (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>Metric conversion</td>
<td></td>
</tr>
<tr>
<td>No. 2</td>
<td>No. 6</td>
<td>0.250 (6.4)</td>
</tr>
<tr>
<td>No. 3</td>
<td>No. 10</td>
<td>0.375 (9.5)</td>
</tr>
<tr>
<td>No. 4</td>
<td>No. 13</td>
<td>0.500 (12.7)</td>
</tr>
<tr>
<td>No. 5</td>
<td>No. 16</td>
<td>0.625 (15.9)</td>
</tr>
<tr>
<td>No. 6</td>
<td>No. 19</td>
<td>0.750 (19.1)</td>
</tr>
<tr>
<td>No. 7</td>
<td>No. 22</td>
<td>0.875 (22.2)</td>
</tr>
<tr>
<td>No. 8</td>
<td>No. 25</td>
<td>1.000 (25.4)</td>
</tr>
<tr>
<td>No. 9</td>
<td>No. 29</td>
<td>1.128 (28.7)</td>
</tr>
<tr>
<td>No. 10</td>
<td>No. 32</td>
<td>1.270 (32.3)</td>
</tr>
<tr>
<td>No. 11</td>
<td>No. 36</td>
<td>1.410 (35.8)</td>
</tr>
</tbody>
</table>

Source: ACI 440.1R

FRP Reinforcing

Table 3.1—Typical densities of reinforcing bars, lb/ft³ (g/cm³)

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>GFRP</th>
<th>CFRP</th>
<th>AFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>493.00</td>
<td>77.8</td>
<td>93.3</td>
<td>77.8</td>
</tr>
<tr>
<td>(7.90)</td>
<td>(1.25 to 2.10)</td>
<td>(1.50 to 1.60)</td>
<td>(1.25 to 1.40)</td>
<td></td>
</tr>
</tbody>
</table>

Source: ACI 440.1R
FRP Reinforcing

Table 5.1—Minimum modulus of elasticity, by fiber type, for reinforcing bars

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Modulus grade, $\times 10^3$ ksi (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFRP bars</td>
<td>E5.7 (39.3)</td>
</tr>
<tr>
<td>AFRP bars</td>
<td>E10.0 (68.9)</td>
</tr>
<tr>
<td>CFRP bars</td>
<td>E16.0 (110.3)</td>
</tr>
</tbody>
</table>

Source: ACI 440.1R

FRP Reinforcing

Table 3.2—Typical coefficients of thermal expansion for reinforcing bars

<table>
<thead>
<tr>
<th>Direction</th>
<th>Steel</th>
<th>GFRP</th>
<th>CFRP</th>
<th>AFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal, $\alpha_L$</td>
<td>6.5 (11.7)</td>
<td>3.3 to 5.6 (6.0 to 10.0)</td>
<td>-4.0 to 0.0 (-9.0 to 0.0)</td>
<td>-3.3 to -1.1 (-6.0 to -2)</td>
</tr>
<tr>
<td>Transverse, $\alpha_T$</td>
<td>6.5 (11.7)</td>
<td>11.7 to 12.8 (21.0 to 23.0)</td>
<td>41 to 58 (74.0 to 104.0)</td>
<td>33.3 to 44.4 (60.0 to 80.0)</td>
</tr>
</tbody>
</table>

*Typical values for fiber volume fraction ranging from 0.5 to 0.7.

Source: ACI 440.1R
FRP Reinforcing

Table 3.3—Usual tensile properties of reinforcing bars

<table>
<thead>
<tr>
<th>Property</th>
<th>Steel</th>
<th>GFRP</th>
<th>CFRP</th>
<th>AFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal yield stress, ksi (MPa)</td>
<td>40 to 75 (276 to 517)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Tensile strength, ksi (MPa)</td>
<td>70 to 100 (483 to 690)</td>
<td>70 to 230 (483 to 1600)</td>
<td>87 to 535 (600 to 3690)</td>
<td>250 to 368 (1720 to 2540)</td>
</tr>
<tr>
<td>Elastic modulus, ( \times 10^3 ) ksi (GPa)</td>
<td>29.0 (200.0)</td>
<td>5.1 to 7.4 (35.0 to 51.0)</td>
<td>15.9 to 84.0 (120.0 to 580.0)</td>
<td>6.0 to 18.2 (41.0 to 125.0)</td>
</tr>
<tr>
<td>Yield strain, %</td>
<td>0.14 to 0.25 N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Rupture strain, %</td>
<td>6.0 to 12.0 1.2 to 3.1</td>
<td>0.5 to 1.7</td>
<td>1.9 to 4.4</td>
<td></td>
</tr>
</tbody>
</table>

*Typical values for fiber volume fractions ranging from 0.5 to 0.7.

Source: ACI 440.1R
Innovative Solutions for tomorrow's transportation needs

References

FDOT
FIBER REINFORCED POLYMER GUIDELINES (FRPG)
FDOT STRUCTURES MANUAL
VOLUME 4
JANUARY 2015

AASHTO

ACI

Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars
Reported by ACI Committee 440

References

Developmental Specifications

NONMETALLIC ACCESSORY MATERIALS FOR CONCRETE PAVEMENT AND CONCRETE STRUCTURES.
(REV 7-16-14)

Materials Manual Section 12.1, Volume II
FIBER REINFORCED POLYMER COMPOSITES
Section 12.1, Volume II

Technical Specification Provision for HCB

Innovative Solutions for tomorrow's transportation needs
References
Halls River Project

• Project Overview
• Construction
Project Overview: Collaboration

- FDOT Structures Design Office
  - Steve Nolan, P.E.
  - Tom Waits, P.E.
- FDOT Structures Research Center
  - Will Potter, P.E.
- FDOT Materials Office
  - Chase Knight, Ph.D.
- University of Miami – Composite Research Center
  - Antonio Nanni, Ph.D., P.E.
- HCB inventors
  - John Hillman, P.E. and Michael Zicko

Project Overview: Information

- Category II Structure
  - New bridge using FRP composite materials (1st in Florida)
- FRP Composite Materials
  - Glass FRP reinforcement (deck, bent cap, and bulkhead)
  - Carbon FRP reinforcement (square and sheet concrete piles)
  - Hybrid Composite Beams
Project Overview: Information

- Owner
- Maintaining Agency
- Bi-Annual Inspection
- Design and Build Proposed Bridge

Project Overview: Existing Bridge

Bridge Location
Project Overview: Existing Bridge

Existing Cross Section

Project Overview: Existing Bridge

Existing Spans Configuration
Project Overview: Proposed Bridge

Glass Fiber Reinforced (GFRP) Bars

Hybrid Composite Beam (HCB)

Carbon Fiber Composite Cable (CFCC)
HYBRID COMPOSITE BEAM (HCB)

Project Overview: Proposed Bridge
Project Overview: GFRP Projects

Project Overview: CFCC Projects
Project Overview: HCB Projects

![Map of the United States with HCB Projects locations highlighted.]

Project Overview: Estimated Cost

Cost Per Unit Deck Area

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>$/SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Concrete Bridge (PSB, Steel Reinforcement)</td>
<td>166.00</td>
</tr>
<tr>
<td>Proposed Composite Bridge (HCB, FRP Reinforcement)</td>
<td>282.00</td>
</tr>
</tbody>
</table>
Construction

- Halls River Bridge: Phase Construction
- CFCC Piles
- Hybrid Composite Beam (HCB)
- FRP Bars
  - Handling and Storage
  - Placement and Assembly

Construction: Phase Construction

Phase 1 Sequence

Stage 1:
- Setup traffic (1 lane-2 way) and install Type K Barrier.
- Relocate Sewer Line to temporary location.
- Remove portion of Existing Bridge.

Stage 2:
- Construct Phase 1 of New Bridge.
- Install new Water and Sewer Lines in permanent location.
- Install Type K Barriers for Phase 2 Traffic.
**Construction: Phase Construction**

Phase 2 Sequence

**Stage 1:**
- Shift traffic to Phase 1 of new Bridge (2 lane-2way).
- Construct Phase 2 of New Bridge with Traffic Railing and Pedestrian Railing.

**Stage 2:**
- Shift traffic to Phase 2 of new Bridge (2 lane-2way).
- Construct Traffic Railing and Pedestrian Railing on Phase 1 portion of new Bridge.

---

**Construction: Phase Construction**

Final Configuration
Construction: Phase Construction

Riverhaven Bridge: Construction Phasing
Construction: Phase Construction
Riverhaven Bridge: Utility Accommodation

Construction: CFCC Piles

- FDOT Research:
  - Field Testing:
    - Installation and Behavior.
  - Lab Testing
    - Material and Capacity.
- Pile Production
  - Similar to conventional piles.
  - Handling of CFCC strands to prevent damage.
- Installation
  - Driving method and behavior similar to conventional piles.
  - Research found strength and capacity similar to conventional piles.
Construction: HCB

• Lightweight:
  • 33% less weight than standard concrete beam (includes concrete fill).
  • 80% less concrete than standard concrete beam.
  • 75%-80% fewer trucks required for shipping.
  • Smaller cranes for placement.

  ▶ Accelerated beam installation.

Construction: HCB

• Fabrication
  • Current Locations:
    ➢ Maine
    ➢ Texas
  • New Approved Locations:
    ➢ North Carolina
    ➢ South Dakota
    ➢ Seattle
  • Currently no fabrication plants in Florida.
Construction: HCB

Fabrication

Innovative Solutions for tomorrow’s transportation needs

Handling and Storage

Innovative Solutions for tomorrow’s transportation needs
Innovative Solutions for tomorrow’s transportation needs

**Construction: HCB**

**Transportation**

- HYBRID COMPOSITE BEAMS (Union Street, ME)
  - 9.0 kips x 4 = 36 kips Total
  - 70 ft. beams

- PRESTRESSED SLAB BEAMS (Gospel Island, FL)
  - 25 kips x 2 = 50 kips Total
  - 39 ft. beams

---

**Construction: HCB**

**Installation**

- HYBRID COMPOSITE BEAMS
- STANDARD CONCRETE BEAMS
Construction: FRP Bars

• Minimize damage to FRP bars
• Handling, storage, and placement
  • Similar to coated bar (epoxy or galvanized)
• ACI 440.5-08 “Specification for Construction with FRP Bars”

Handling & Storage

• FRP bars vulnerable to surface damage
Construction: FRP Bars
Placement & Assembly
• Follow Manufacturers’ guidelines

Summary:
• Pilot project
  • Pilot/Experimental project
  • First of its kind in Florida
  • FDOT Central Office and FHWA oversight
  • Long-term monitoring
    • FDOT Structures Research Center and State Materials Office
• Use of corrosion resistant materials
  • Glass FRP rebar
  • Carbon FRP strands
  • Hybrid Composite Beams
• $3.2M estimated costs
Thank you.

Questions?