Writing Special Provisions for FRP Strengthening Projects

Gregg Blaszak, P.E
Common Strengthening Forms

- Unidirectional Fiber Fabrics
- Bi-directional Fabrics
- Strand Sheets
- NSM Bars
How DOTs use FRP Strengthening Systems

- Environmental protection
- Concrete repair containment
- Repair of impact-damaged AASHTO girders
- Shear and flexural strengthening of pier caps
- Flexural strengthening of decks
- Strengthening of deck edges for new barriers
- Repair of deteriorated beam ends
- Seismic Retrofit
- Others
Shear Strengthening of Pier Cap
Column Confinement
Flexural Strengthening of Bridge Deck
AASHTO Girder End Repairs
Impacted AASHTO Girder Repairs
Greene Street Bridge, City of Spokane
Greene Street Bridge, City of Spokane
Strengthening of Steel Truss
Strengthening of Steel Truss
Strengthening of Steel Truss
SOURCES OF INFORMATION
ACI 440.2R

- Design guide for concrete strengthening since 2002
- 2017 edition includes seismic provisions
- Emphasis on buildings
- Includes provisions for NSM strengthening
AASHTO Guide Specification for FRPs

• Similar to ACI 440.2R

• Includes design equations for flexure, shear/torsion, and axial strengthening

• Designs made with AASHTO are different from those made with ACI 440 (BEWARE)

• Never specify both ACI 440 and AASHTO guides on a project!
ICRI Guide No. 330.2-2016

- Created by the ICRI Technical Committee on Strengthening of Structures
- Committee composed entirely of engineers, contractors, and material suppliers.
- Based largely on the contents of the ACI 440.2R guide and the collective experience of committee members
- It’s a special provision for buildings!
ICRI 330.2R-2016

- Covers “fabric” systems installed using wet lay-up techniques
- Does not cover FRP plates or NSM
- Editable WORD version available from ICRI
- Technical specification that is part of a complete and coordinated project manual (does not address crack injection, spall repair, etc.)
- 3-Part MasterSpec format
- Includes commentary for nearly every section/paragraph
Helpful References

- ICRI 330.2-2016
- ACI 440.2R (Design Guide)
- ACI 440.8R (Material Spec)
- ICC-ES AC125 (Acceptance Criteria for FRPs)
- ACI 562 (Concrete Repair Code)
- ASTM methods
- NCHRP reports
- AASHTO FRP Guide
EOR’s Role

For most projects EOR will always be responsible for the condition assessment and analysis of the structure (except design-build)

• Determine location and magnitude of deficiencies

• Verify that FRP can be used before specifying

  Unstrengthened member checks:
  – ACI 440.2R: \((\phi R_n)_{existing} \geq (1.1DL + 0.75LL)_{new}\)
  – AASHTO: \((R_r)_{existing} \geq \eta_i[(DC + DW) + (LL + IM)]_{new}\)

• Communicate requirements on plans and special provisions

SELECT APPROACH: Prescriptive or Performance Special Provision
If Prescriptive Specification, Then...

*Use when the EOR has done the FRP design and detailing*

- EOR details FRP system
  - Number of plies
  - Ply width
  - Ply orientation
  - Anchors

- EOR specifies acceptable FRP product(s) or minimum properties

- Contractor submits products meeting specification
If Performance Specification, Then...

Use when Contractor/FRP Engineer do the design

- EOR specifies requirements at sections to be strengthened

- EOR provides **ALL** necessary information at sections to be strengthened to complete FRP design.

- EOR specifies minimum properties of generic FRP system or required EA at each section

- EOR requires contractor to submit product data, design calculations and shop drawings

If details are unknown, EOR needs to provide guidance
Include all necessary information to do the FRP design

- Location of all sections to be strengthened
- Dimensions of existing sections and framing plan
- Existing reinforcement layout
- Existing concrete strengths
- Existing and proposed strengths
- Unfactored dead and live load moments/shears
- Possibly shear and moment diagrams
- Sufficient information to be able to do a take-off
- Be careful about including quantities
  - Total area of FRP materials
  - Total coverage area (same as above for one ply)
Submittals

• Only require submittals that will be reviewed

• Product technical data sheets
• Manufacturer’s Installation Guide
• Select Test Reports
  – Alternately, specify an evaluation report (like ICC-ES) or DOT approval (like CALTRANS)
• Quality Control Plan
• Shop drawings (Needed for performance specifications)
• Engineering calculations (Make sure they are really required)

Avoid requiring sealed drawings/calculations to be submitted with bid
Warranty

• Majority of projects require 1 year warranty on materials and installation
  – Manufacturer warranties materials
  – Contractor warranties installation

• Avoid unreasonable warranties which will...
  – Unnecessarily raise project cost
  – Reduce competition
  – Invite “desperate” suppliers and installers to “roll-the-dice”

• Avoid vague language like...
  – “FRP system shall be designed to last 50 years”
Payment Basis

• Lump sum is fairly common and should cover all materials, labor, equipment work to complete the job

• Unit price basis may be used.
  – Normally SF of coverage area, not SF of material area
  – Be careful about comparing unit prices from job to job - highly dependent on number of layers, surface prep, etc.
MATERIALS
Specifying FRP Materials (i.e. PRODUCTS)

- Always prescribe material type

- DO NOT list carbon and glass materials. Pick one or specify the type on the drawings.

- OK to list acceptable products but allow for alternates that meet the specification

- Specify “UNIT VALUES” for mechanical properties
  - Tensile Strength per unit width (kips/inch/ply)
  - Tensile Modulus per unit width (kips/inch/ply)
  - Tensile Rupture strain > 1.0% (AASHTO)*

* This requirement will reduce the number of qualified FRP systems
Understanding the Technical Data Sheet

ELEMENTS OF THE TDS

- Fiber Properties

- Design Properties

- Where is the ply thickness specified?

- Always use design properties with the corresponding ply thickness
## Typical Fabric and Fiber Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Type</td>
<td>Carbon</td>
</tr>
<tr>
<td>Color</td>
<td>Black</td>
</tr>
<tr>
<td>Fabric Construction</td>
<td>Unidirectional</td>
</tr>
<tr>
<td>Fiber Tensile Strength</td>
<td>700 ksi (4830 MPa)</td>
</tr>
<tr>
<td>Fiber Tensile Modulus</td>
<td>34,000 ksi (234 GPa)</td>
</tr>
<tr>
<td>Fiber Rupture Strain</td>
<td>2.0%</td>
</tr>
<tr>
<td>Fabric Areal Weight</td>
<td>17.6 oz./yd² (600 g/m²)</td>
</tr>
</tbody>
</table>

**Notes:**
Fiber properties are typical values of the fibers used in the manufacture of the reinforcing fabrics. They are based on proprietary test methods employed by the supplier of the carbon fibers. **Fiber properties shall not be used for design.** They are reported here to provide the designer with a general understanding of the grade of fibers used in the reinforcing fabrics.
The Technical Data Sheet

### Mechanical and Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Design Value</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Thickness$^1$</td>
<td>0.050 in. (1.27 mm)</td>
<td></td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>140 ksi (966 MPa)</td>
<td>ASTM D3039</td>
</tr>
<tr>
<td>Tensile Modulus of Elasticity</td>
<td>10.1 Msi (69.6 GPa)</td>
<td>ASTM D3039</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>1.2%</td>
<td>ASTM D3039</td>
</tr>
<tr>
<td>Tensile Strength/Unit Width</td>
<td>7.0 kip/in./ply (1.23 kN/mm/ply)</td>
<td>ASTM D7565</td>
</tr>
<tr>
<td>Tensile Modulus/Unit Width</td>
<td>505 kip/in./ply (88 kN/mm/ply)</td>
<td>ASTM D7565</td>
</tr>
<tr>
<td>Glass Transition Temperature</td>
<td>145 °F (63 °C)</td>
<td>ASTM E1640</td>
</tr>
</tbody>
</table>

**Notes:**
1. The reported thickness is based on measurements made on panels prepared in the laboratory. Based on experience the typical thickness of a single ply (fibers + saturant), impregnated with RenewWrap™ ESR Saturant is approximately 0.05-0.06 inch. Actual thicknesses measured in the field may vary slightly. As with any FRP strengthening system, the strength/unit width and modulus/unit width should be used for design and for field QC purposes.

“Typical” Properties vs. “Design” Properties
Other Properties

Glass Transition Temperature (Tg)
• Typically 140 F is required for the saturant

Durability
• Easiest to require an ICC-ES AC125 report or that FRP systems meet the requirements of ACI 440.8R

• Alternately, can select the appropriate tests from AC125 and retention criteria (carbon=85%, glass=65%)
INSTALLATION AND QC
Substrate Repairs
  • Requirements defined elsewhere

Surface Preparation
  • Bond-Critical
    – Make repairs first
    – Grit-blasting or other means to achieve ICRI CSP-3 or higher
    – Surface needs to be flat
    – Round corners (for U-wraps)
    – Clean surface

  • Contact-Critical
    – Round corners to ½” radius
    – Surface profile needs to promote continuous contact
    – Remove paint or other coatings?
    – Clean surface
Application of FRP

• Wet lay-up or “dry lay-up”
  – Refers to whether a machine is used to wet out the fabric
  – Heavier weight fabrics will usually require a machine to wet them out
  – Specify that fabrics should be wet out in accordance with manufacturer’s instructions

• Environmental conditions
  – Temperature range
  – Moisture vapor transmission (challenging)
  – Protect work area from elements
  – Heating work area - Use clean heat source like electric or propane
EXECUTION

- Nearly all applications are “in accordance with the manufacturer’s recommendations”

- Difficult to prescribe each of the steps...
  - Mix resins
  - Apply primer, if required
  - Apply putting, if required to fill bug holes, voids, level surface
  - Impregnating the fabric sheets with saturant
  - Installing fabric on member
  - Applying multiple fabrics
  - Lapping fabrics
  - Anchors
Field Quality Control and Inspections

- Material certificates of conformance
- Daily reports (what was installed, where, temperature, etc.)
- Tensile tests (witness panels)
- Fabric alignment (< 1”/foot deviation)
- Delaminations
- Cure of resins
- Adhesion strength (for bond-critical)
Witness Panels

- Witness panels are fabricated and cured in the field from the same materials (fabrics and resin) used on the project.
  - Analogous to concrete cylinders.
  - Panel quality varies widely and is challenging to get good test results.
  - Current thinking is that each tensile test result should exceed the reported design value.
  - Avoid specifying for “non-structural” applications.
Delaminations

- Found visually or by acoustic sounding
- Suggested frequency of 1 tap per 0.5 SF
- Small delaminations (<2 in²) are OK provided they...
  - do not exceed 5% of total area
  - there are not more than 10 per 10 SF area
- Large delaminations (>25 in²) need to be cut out
- Mid-size delaminations (>2 in² and <2 in²) may be repaired by epoxy injection

Delaminations due to moisture vapor transmission
Adhesion Strength

• Only for bond-critical applications

• ASTM D7522

• Suggested frequency of one per day per crew or one per 1,000 SF of contact area

• Acceptance criteria:
  – Strength > 200 psi
  – Ideally, failure in the substrate
  – Failures not in substrate are reported to engineer
Concluding Remarks

• DO analyze structure
• DO determine if FRPs are an appropriate method
• DECIDE on prescriptive or performance
• ALWAYS specify material type (carbon or glass)
• INCLUDE all section details for performance specification and EA requirements
• INCLUDE detailed FRP design values for prescriptive specifications
• ALWAYS use FRPs with confidence: They are a good tool!
THANK YOU!

For questions/comments:
Gregg Blaszak, P.E.
Gregg.Blaszak@Milliken.com
864-706-8647
2.2.4.2—Tensile Failure Strain

The characteristic value of the tensile failure strain in the direction corresponding to the highest percentage of fibers shall not be less than one percent, when the tension test is conducted according to ASTM D3039.

1% rupture strain will limit number of systems able to compete
Comments on AASHTO Guide Spec

- Range seems too large to be practical
- Not sure how this could even be measure in the field or how it correlates to lab produced samples versus field applied FRP
- Has this been correlated to performance (i.e. above 10% the equations no longer apply?)
• It appears that the effective strain in the FRP is set to 0.005 independent of concrete strength and laminate stiffness.
• This is similar to the approach taken by ICBO prior to ACI 440
• Can result in projects with an unreasonably large number of layers.
• This requirement appears more academic than practical
• Cannot be quantified in practice
• Suppliers do not report shear modulus values of the resin
• Bondline thickness (while important) is not measured or controlled in the field.
• How to QC this?
4.3.1—Factored Strength

The factored shear strength, $V_r$, shall be defined as:

$$V_r = \phi \left( (V_c + V_s + V_p) + \phi_{frp} V_{frp} \right)$$  \hspace{1cm} (4.3.1-1)

- It appears there is a missing parenthesis
ACI vs. AASHTO Shear Design Method
Complete Wrap ("Fully Anchored")

36" D x 40" W Rectangular Section
f'c = 3000 psi

ACI 440
AASHTO

No. of Layers

Effective Strain
ACI vs. AASHTO Shear Design Method
U-Wrap

Effective Strain

No. of Layers

1 2 3 4 5 6

36" D x 40" W Rectangular Section
f'c = 3000 psi

AASHTO
ACI 440

Comments on AASHTO Guide Spec