

**STATE****OF****TENNESSEE**

March 30, 2020

January 1, 2021

**SPECIAL PROVISION****REGARDING****FIBER-REINFORCED POLYMER MATERIAL****Description**

This work consists of structural strengthening using Fiber-Reinforced Polymer (FRP) composite wrap. Fiber may be either Carbon (CFRP) or E-Glass (EGFRP). Use carbon fiber (CFRP) unless otherwise specified on the plans. Reference is made to *the AASHTO Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements*, *ACI 440.2R Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*, and *ACI 440.8 Specification for Carbon and Glass Fiber-Reinforced Polymer (FRP) Materials Made by Wet Layup for External Strengthening of Concrete and Masonry Structures*.

**Equipment and Materials****A. Material Properties**

Provide a unidirectional, high-strength fiber fabric fully saturated with compatible epoxy resin that has been tested together as a system in both contact-critical and bond-critical applications. A bond-critical application refers to a strengthening or repair application that relies on load transfer from the substrate to the FRP material through bond of the FRP system to the substrate. Bond-critical applications require the FRP to adhere to the concrete to work and include beam or pier cap wraps for flexure or U-wraps for shear. Bond-critical locations are noted on the plans. A contact-critical application refers to a strengthening or repair application that relies on load transfer from the substrate to the FRP material through contact or bearing at the interface. Contact-critical applications require intimate contact with the concrete to work and include column wraps for confinement or beam wraps for shear where the wrap goes all the way around the member. Provide CFRP Cured Laminate Properties and EGFRP Cured Laminate Properties which meet or exceed the minimum requirements in Table 1:

<b>Table 1 FRP Cured Laminate Properties</b>		
<b>Property</b>	<b>CFRP</b>	<b>EGFRP</b>
Design Unit Tensile Strength <sup>1,2</sup>	2.2 k/in/ply	2.8 k/in/ply
Unit Tensile Stiffness <sup>1</sup>	*220 k/in/ply	140 k/in/ply
Design Elongation at failure	1.00%	2.00%
Nominal Fabric Weight	9 oz/yd <sup>2</sup>	27 oz/yd <sup>2</sup>

\*CFRP with Unit Tensile Stiffness in excess of 500 k/in/ply is unacceptable.

1. Verified by ASTM D7565 test procedures

2. Calculate design value by subtracting three standard deviations from the average of 20 or more tensile tests.

Provide FRP lamina with a glass transition temperature (T<sub>g</sub>) not less than 140° F in accordance with ASTM E1640. Provide flexible, waterproofing, non-vapor barrier protective top coating compatible with the FRP manufacturer's recommendations to protect the FRP from ultraviolet radiation and mild abrasion. Match the color and texture of the protective top coating to adjacent concrete, similar to AMS-STD 595A, #36440, Mountain Gray, unless noted as another color on plans.

Provide to the Engineer a copy of the Safety Data Sheets (SDS) for all materials to be used on site and certification that the materials conform to local, state, and federal environmental and worker safety laws and regulations. Include mechanical, physical, and chemical properties, and material specifications for the proposed primer, putty, resin, saturant, fiber, and protective top coating. Provide to the Engineer the manufacturer's maintenance recommendations for the protective top coating and the complete FRP system.

## **B. Equipment**

Furnish all materials, tools, equipment, transportation, necessary storage, access, labor and supervision required for the proper application of the FRP composite system.

## **Construction Requirements**

For all Bond-critical CFRP applications, provide a technical representative from the FRP composite system company at the start of work and until the Engineer is satisfied that the FRP is being properly applied. For all other applications, provide a technical representative from the FRP composite system company at the start of work or provide written certification by the company stating that the Contractor is qualified to install the composite system.

When a technical representative is required, they must be on-site for a minimum of one full working day and three full working days for Bond-critical applications. Written certification from the FRP company must be dated within the last 12 months. In addition, provide the names of the applicator's key personnel (superintendent and assistant) who will perform the actual work with the written verification from the company. The Engineer may suspend the work if an unauthorized composite system is substituted for an authorized composite system, or if unauthorized personnel are substituted for authorized personnel during construction.

**A. Shop Drawings**

When plans and/or contract documents require shop drawings, provide complete shop drawings for each installation of the composite system to the Bridge Engineer for approval before beginning work. Show details of the widths of strips, number and thickness of layers, orientation of the layers, joint and end details, and locations to be applied in accordance with the plans and specifications. Include anchorage systems providing location and material properties for spikes, ties, or other anchors required for FRP system. Show locations of all gaps and laps.

**B. Calculations**

When plans and/or contract documents require calculations, provide complete calculations to the Bridge Engineer for approval before beginning work. Provide computations in accordance with *ACI 440.2R Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures* to achieve the structural performance shown on the structural drawings for required factored flexure, tension, shear, torsion, axial forces and strain limits. Provide calculations stamped by a Registered Professional Engineer, registered in the State of Tennessee. Include FRP design properties for thickness per ply, ultimate tensile strength, rupture strain, and modulus of elasticity. Use shear designs with a maximum of 4 layers unless otherwise approved by the Bridge Engineer.

**C. Delivery and Storage**

Deliver epoxy materials in factory-sealed containers. Verify that the manufacturer's labels are intact and legible (including brand, system identification number, and batch number) with verification of date of manufacture and shelf life. Store the materials in a protected area at a temperature between 35°F and 100°F. Store products according to the manufacturer's requirements and avoid contact with moisture. Do not use components that have exceeded their shelf life.

**D. Concrete Repairs**

Concrete repairs and epoxy injection shall be performed as shown in project plans. Allow epoxy used for crack sealing to cure in accordance with the manufacturer's recommendations. Place concrete patches to the dimensions shown on the plans and as specified by the Engineer.

**E. Surface Preparation**

Once all concrete repairs are made and cured, prepare concrete substrate surfaces to promote continuous intimate contact between the FRP and the concrete by providing a clean, smooth, and flat or convex surface. Grind away all irregularities, unevenness, and sharp protrusions to provide less than 1/16 in surface profile deviation. Fill all voids or depressions of diameters larger than 1/2 in or depths greater than 1/8 in with a Type II, Grade 1, 2, or 3, epoxy from TDOT QPL 8, or as approved by the fiber-reinforced polymer (FRP) manufacturer. At a minimum, allow all patching materials to cure a minimum of 2 days and reach a minimum of 3,000 psi compressive strength prior to installation of the FRP wraps. Round or chamfer all inside and outside corners and sharp edges to a minimum radius of 1/2 in. Remove all laitance, dust, dirt, oil, foreign particles, disintegrated materials, and any other matter that could interfere with the bond of the concrete to the FRP using abrasive or

water blasting techniques.

#### **F. Application of Composite Fabric**

Ensure that all patch work is complete and cured. Verify ambient and concrete temperatures are between 35°F and 100°F. Maintain epoxy curing temperatures in the temperature range designated for the formulation used. Temperature cure ranges and times to be determined by manufacturer. Protect the composite system from contact by moisture for a minimum of 24 hours. Prepare the epoxy matrix by combining components at a weight (or volume) ratio as specified by the manufacturer. Mix the epoxy as specified. Saturate the fabric to achieve the desired wet-out in accordance with the manufacturer's recommendations. Fabric may be pre-saturated by hand or with a mechanical saturator. Have a properly trained supervisor verify that saturation is correct. Measure and combine the epoxy resin and fabric and deposit uniformly at the rates shown on the approved working drawings and per manufacturer's recommendations.

#### **G. Installation**

Unless otherwise provided by the manufacturer, install the FRP fabric as follows:

1. Ensure that surfaces are clean in accordance with the requirements of the Manufacturer
2. Use a medium nap roller to apply a primer coat to the concrete surface. Field thickened resins are not allowed to be used as primer coats or between layers of fabric.
3. Ensure the FRP fibers are oriented as noted on the plans.
4. Saturate fabric according to manufacturer's recommendations.
5. Apply saturated fabric to concrete surface by hand lay-up, using methods that produce a uniform, constant tensile force that is distributed across the entire width of fabric. Under certain application conditions the system may be placed entirely by hand methods assuring a uniform, even final appearance. Provide gaps when the length of member to be wrapped exceeds 5 ft . Use 2 in gaps spaced at 2 ft centers. The gaps should only occur parallel to the primary fiber direction (the material would need to be continuous in the primary fiber direction). In cases where the primary direction of the fibers is placed both horizontally and vertically, provide a 2 in square gap every 2 ft in both directions. Ensure that the gaps are completely free of all epoxy resin products used to bond FRP. Provide a lap length of at least 6" at all necessary over-laps in the longitudinal direction of the fabric.
6. Apply subsequent layers, continuously or spliced, until designed number of layers is achieved, per project drawings.
7. Using a roller or hand pressure, ensure proper orientation of fibers, release or roll out entrapped air, and ensure that each individual layer is firmly bedded and adhered to the preceding layer or substrate.
8. Apply a final coat of epoxy. Detail all fabric edges, including butt splice, termination points, and jacket edges, with epoxy.

9. Apply top coat of paint as specified between 24 and 72 hours after final application of epoxy. Use paints that allow vapor transmission at gaps. Remove dust and residue prior to application of paint coats. If after 72 hours the epoxy is cured, the surface must be roughened by sanding or brush blasting.
10. Ensure that anchorage systems are fastened in accordance with the FRP manufacturer's recommendations.
11. Record batch numbers for fabric and epoxy used each day, and note locations of installation. Measure square footage of fabric and volume of epoxy used each day.

#### **H. Testing**

After the initial resin has cured at least 24 hours, perform the following test:

1. Visually inspect for any defects in the FRP wrap.
2. Tap or sound any areas suspected to contain air pockets.
3. For bond-critical applications, perform two direct pull-off tests in accordance with ASTM D7522 for every 1,000 square feet of FRP area installed with a minimum of two tests per day. At the discretion of the Engineer, bond tests may be waved where the FRP is used for protection. No bond testing is required for contact-critical applications. Ensure when testing prestress beams not to score the substrate more than 1/4 in. Accept pull-off tests which fail in the concrete substrate (failure mode G) and not at the interface between the FRP and the concrete. At the discretion of the Engineer, pull-off tests may be performed at locations of similar substrate near the FRP installation area. Prepare test samples using identical application procedures at the same time that the project FRP is installed. Repair the damaged FRP and concrete at test areas after testing is complete.

#### **I. Repairs**

Repair all defects (including bubbles, delaminations, and fabric tears) spanning more than 5% of the surface area as directed by the Engineer. Perform repairs as follows:

1. Inject or back-fill small defects (on the order of 6 inches diameter) with epoxy.
2. Inject bubbles less than 12" in diameter with epoxy by drilling two small holes into the bubble. The holes will allow injection of the epoxy and escape of entrapped air.
3. Repair bubbles and delaminations greater than 12" in diameter by removing and re-applying the required number of layers of the composite and the required finish coatings. Small entrapped air pockets and voids naturally occur in mixed resin systems and do not require repair or treatment.

**Method of Measurement**

The Department will measure Composite Fiber Encasement by the square feet of the total area covered by the applied Fiber-Reinforced Polymer (FRP) regardless of the number of layers required by the plans.

**Basis of Payment**

The Department will pay for accepted quantities, complete in place, at the contract unit price as follows:

<b>Item No.</b>	<b>Description</b>	<b>Unit</b>
604-10.83	Composite Fiber Encasement	Square Feet

Such payment is full compensation for all materials, equipment, labor, and incidentals necessary for proportioning, mixing, delivery, storage, handling, surface preparation, installation, sampling, testing, repairs and curing of the Fiber-Reinforced Epoxy Composite system to be included in the unit price bid for Composite Fiber Encasement. Payment for Type II, Grade 1, 2, or 3 epoxy used for filling small voids or depressions to be included in price bid for Composite Fiber Encasement. Multiple FRP layers are to be included in the Square Feet quantity and should be treated as a single layer for the purpose of payment.