Special Note for Carbon Fiber Reinforced Polymer Wrap

The following sections provide the requirements for application of Carbon Fiber Reinforced Polymer (CFRP) wrap, surface preparation requirements, field QA/QC procedures, reporting requirements and Contractor/Testing Subcontractor/Department responsibilities. The purpose of the CFRP fabric is to provide additional shear, flexural, and/or axial capacity to improve the existing bridge load ratings.

References to the “Department” refer to the Kentucky Department of Highways and/or consultants acting on behalf of the Department.

In all cases, the Department reserves the right to request raw data, field notes and/or other available information that may be necessary to evaluate the results of testing specified in this Special Provision. Upon request, provide any available information at no additional cost to the Department.

In all cases, the Department reserves the right to perform testing to obtain independent results of testing specified in this Special Provision. Upon request, provide any assistance required for Department personnel to perform such testing at no additional cost to the Department.

At the request of the Engineer, personnel representing the Contractor (including testing subcontractors) and the Department may be required to attend a pre-test meeting to discuss procedures related to testing, reports, reviews, etc. This meeting will be at no additional cost to the Department.

Unless noted otherwise, the Department will respond to the Contractor regarding acceptability of submittals referenced in this Special Provision within 6 (six) business days. A “Business Day” is defined as any day except Saturdays, Sundays and Holidays, as defined in Section 101.03 of the Standard Specifications.

1.0 Description

This work shall consist of furnishing all materials, labor, equipment and supervision necessary for the installation of a field applied externally bonded CFRP reinforcement, at repair areas shown in the contract plans and as directed by the Engineer. Perform all work in accordance with the Kentucky Transportation Cabinet, Department of Highway's Standard Specifications for Road and Bridge Construction and applicable Supplemental Specifications, the Standard Drawings (Current Editions), this Note, and the associated contract drawings. Section references are to the Standard Specifications.

1.1 Materials

One manufacturer shall supply all material required for the Carbon Fiber Reinforced Polymer (CFRP) system. The manufacture shall be one of the four listed below or approved equal for the CFRP strengthening and protection system. Other suppliers may be approved upon submission to the Division of Structural Design of a portfolio detailing prior similar experience with bridge projects.

Tyfo Fiber Wrap System Fyfe Company, LLC
4995 Murphy Canyon Road Suite 110
San Diego, CA 92123

SIKA Corporation
201 Polito Ave.
Lyndhurst NJ 07071

Quake Wrap
6840 S Tucson Blvd.
Tucson, AZ 85756

HJ3 Composite Technologies
2440 West Majestic Park Way
Tucson, AZ 85705

Provide a high-strength fiber fabric (unidirectional or woven in two or more directions) fully saturated with a compatible epoxy resin that has been tested together as a system in both contact-critical and bond-critical applications. The fabric for the CFRP composite system shall be continuous filament woven fabric. Primary fibers for the fabric shall be carbon. Glass composite systems will not be permitted as a substitute to carbon composite systems. The epoxy shall be supplied by the manufacturer as part of the system designed for use with the selected fabric. Polyester resin shall not be allowed as a substitute for epoxy resin.

Fabric design properties shall be determined from independent laboratory testing and evaluation in accordance with ASTM D3039 and ASTM D7290. Provide cured CFRP systems with a glass transition temperature (T_g) not less than 140°F in accordance with ASTM E1640.

CFRP spike anchors shall be made of the same material used for the CFRP wrap system. The fiber area of the CFRP anchor shall be equal to the area of the CFRP fabric or testing data shall be provided showing that the anchorage system is designed to take 100% of the tensile stress at failure of the CFRP fabric. Alternate anchorage systems compatible with the CFRP wrap system may be submitted to the Engineer for approval.

The contractor shall provide a flexible, waterproofing, non-vapor barrier protective top coating compatible with the CFRP manufacturer's recommendations to protect the CFRP from ultraviolet radiation and heavy abrasion with a design life of 50 years. This protective top coating shall closely match the light gray color of the adjacent concrete.

1.2 Equipment

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

1.3 Delivery, Storage, and Handling

The products shall be delivered and stored in original, unopened containers. Containers must be clearly marked with legible and intact labels listing the Manufacturer's name, brand name, product identification and batch number.

Storage of fiber reinforcement and epoxies must be in areas protected from dust, moisture, and chemical exposure. Epoxies must be stored in areas with an ambient temperature between 50°F and 75°F (or according to the manufacturer's recommendations) and away from direct sunlight, flame sources, or other hazards. Epoxy resins must be stored separately from hardeners.

The fiber reinforcement must not be handled roughly. For specific hazards of resin components consult the Manufacturer's Safety Data Sheets (SDS).

2.0 Contractor Submittals

Contractor shall submit the following documentations and obtain approval 7 days before work commences.

2.1 Contractor Qualifications

The contractor shall provide a manufacturer's certification of technical training, CFRP system selected, project supervisor, and documentation showing the contractor has been certified or approved by the manufacturer of the CFRP system. While work is being performed, a trained project supervisor shall remain at the work site to instruct the work crew in the CFRP application procedures. The Engineer may suspend the work if an unauthorized composite system is substituted for an authorized composite system, or if the unauthorized personnel are substituted for authorized personnel during construction.

2.2 Product Data

Manufacturer's product data including physical and chemical characteristics, material specifications for each component, limitations on use of the system, construction or application specifications, maintenance instructions, quality control plan, and general manufacturer's recommendations regarding each system shall be provided. Product data on the proposed primer, putty, resin, saturant, and carbon fiber shall be included. Testing information on the combination of the proposed carbon fiber reinforcement and epoxy when used together as a system shall be provided. The contractor shall provide certifications from the producers of the materials that all materials supplied are in accordance with all the requirements and standards of the appropriate ASTM and other agencies. Manufacturer's SDS for all materials to be used shall be provided.

2.3 Shop Drawings & Design Calculations

Provide to the Engineer complete shop drawings and design calculations for each installation of the composite system for approval before beginning work. Shop drawings shall include the details of types, locations, dimensions, number of layers, splice details, and orientation of all CFRP materials, anchorages, and coatings to be installed. Design calculations for the CFRP system shall be performed according to the *AASHTO Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, 2nd Edition (2023)*, and/or *ACI PRC-440.2-22 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*. Shop drawings and design calculations shall be submitted, signed, and sealed by a Professional Engineer licensed in the state of Kentucky.

3.0 Construction Requirements

3.1 Concrete Repairs

Concrete repairs shall be performed as shown in the contract plans and according to ACI 546R and ICRI 310.2R. Place any required concrete patches to the dimensions shown on the contract plans and as specified by the Engineer. All concrete surfaces where the CFRP system is to be applied shall be sound. CFRP systems shall not be applied to concrete suspected of containing corroded reinforcement. Corroded reinforcement shall be cleaned, and the surrounding contaminated concrete shall be removed. Concrete removal shall extend along the reinforcing steel until there is no further delamination, cracking, or corrosion and the reinforcing steel is well bonded to the surrounding concrete. Any deteriorated concrete is to be patched per the Special Note for Concrete Patching, then cleaned and prepared to the installer's satisfaction prior to the installation of the CFRP system. Allow for minimum 14 days, or as recommended by the manufacturer of the concrete patching material or the manufacturer of the epoxy and fiber system, after all concrete repairs have been installed before applying CFRP wrap system.

Cracks wider than 0.01 inches and with a spacing less than 1.5 in. or cracks wider than 0.03 inches shall be filled using epoxy injection. Allow epoxy used for crack sealing to cure in accordance with the manufacturer's recommendations.

3.2 Surface Preparation

Once all concrete repairs are made and cured, prepare the concrete surface to a minimum ICRI-CSP3 concrete surface profile. All concrete surfaces that will be in contact with CFRP shall have all laitance, dust, dirt, oil, curing compound, existing coatings and any other foreign matter removed that could interfere with the bond between the CFRP system and the concrete. Localized out-of-plane variations, including form lines, shall not exceed the smaller of 1/32 inch or the tolerances recommended by the CFRP manufacturer's recommendation. Sharp and chamfered corners shall be rounded off to a minimum radius of 3/4 inch by grinding or forming with the system's thickened epoxy. Variations in the radius along the vertical edge shall not exceed 1/2 inch for each foot of length. The certified and experienced installer responsible shall verify that all required surface preparation has been completed properly and that the CFRP system is cleared for installation.

3.3 Application of CFRP

The CFRP system shall only be installed by individuals certified in writing by the material supplier. The manufacturer shall be required to provide training to the crew that does the actual installation as well as construction oversight throughout the duration of the CFRP installation to ensure the materials are applied according to their design and specific material requirements. The manufacturer must submit the name of the installer's company and provide a certification that the installer meets the quality and experience requirements to perform the work with the bid documents. Installers without the proper certifications and experience will not be permitted to complete this work.

The concrete and atmospheric temperatures shall be between 50°F and 95°F during installation of the CFRP, or as recommended by the manufacturer. The CFRP system shall be applied when the relative humidity is less than 85% and the substrate temperature is more than 5 degrees F above the dew point. The required temperature range shall be constantly satisfied until the composite system has fully cured, according to the manufacturer's recommendations.

The components of the epoxy resin shall be batched in quantities specified by the manufacturer. Epoxy resin shall be mixed by manual stirring or small electrically powered mixing blades for a minimum of 5 minutes and applied uniformly to the fiber at a rate that shall ensure complete saturation of the fabric. Automatic saturators shall not be used to impregnate the fabric. Application shall be carried out within the work time specified by the manufacturer. A properly trained supervisor shall verify that saturation is correct.

The contractor shall maintain a wrapping log. The wrapping log shall be available for review by the Engineer at all times, and upon completion of all wrapping the Engineer shall be given a copy. The log shall provide material traceability and records for the wrapping, including batch numbers for fabric and epoxy used each day, locations of installation, and square footage of fabric and volume of epoxy used.

Application of the CFRP wrap system shall be performed with no live load directly over the beam being repaired until the CFRP wrap system has fully cured, according to the

manufacturer's recommendations. The provisions of Section 3.4 of the *AASHTO Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, 2nd Edition (2023)* may be used to permit traffic on the bridge during application and curing, with approval from the Engineer.

3.4 CFRP Fabric Installation

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

1. Ensure that all concrete surfaces are clean, and devoid of any open cracks, 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 fabrics.
3. Ensure the CFRP fibers are oriented as noted in the approved shop drawings.
4. Saturate the fabric according to the manufacturer's recommendations, prior to installation. Saturation of the carbon fiber in place is not permitted.
5. Apply the saturated fabric to the concrete surface by hand lay-up, using methods that produce a uniform, constant tensile force that is distributed across the entire width of the fabric. Under certain application conditions the system may be placed entirely by hand methods assuring a uniform, even final appearance. Provide a lap length of at least 6 in. 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 the contract plans. Successive layers of composite material shall be placed before polymerization of the previous layer of epoxy is too complete to achieve complete bond between layers. If polymerization does occur between layers, the surface must be roughened using a light abrasive that will not damage the fiber.
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 proceeding layer or substrate. Entrapped air shall be released or rolled over before the epoxy sets. Fibers within the fabric shall not deviate from the horizontal or vertical alignment by more than 1/2 inch per foot.
8. Apply a final coat of epoxy. Detail all fabric edges, including butt splice, termination points, and jacket edges, with epoxy.

3.5 CFRP Spike Anchor Installation

CFRP spike anchors shall be installed to prevent premature debonding of the CFRP wrap system. Anchors shall be required on all re-entrant corners as well as the ends of the CFRP wraps on all prestressed concrete I-beams. Additional horizontal strips of FRP shall not be considered adequate anchorage for vertical U-wraps used as shear strengthening. Prior to the application of the CFRP system, use a non-destructive method to determine locations of stirrups and reinforcement in the beams. Adjust the location of the CFRP anchors up to 1 inch in any direction to avoid reinforcement. Notify the Engineer for approval if greater adjustment is required prior to drilling the hole. Drill a hole in the beam at the locations and to a depth shown in the approved shop drawings. Hole diameter shall be 1/8 inch larger than the required CFRP anchor diameter. Round the edges around the lip of the drilled hole to a minimum radius of 1/2 inch. The bend radius at the opening shall not be smaller than specified. Clean and remove all debris from the anchorage hole. The anchorage holes shall be cleaned with compressed air

followed by freshwater spray and again with compressed air after drilling. If compressed air does not remove remnant material, vacuum pressure shall be used.

Install CFRP fabric as indicated in Section 3.4 of this note and as detailed in the approved shop drawings. The fabric shall completely cover the anchor holes. The individual fibers of the saturated CFRP fabric shall be separated by hand in the vicinity of the anchor hole to allow for installation of the anchors. Apply a coat of the same saturating resin used for the CFRP fabric to the inner surface of the anchor hole prior to installing the anchors.

Completely coat the anchors with epoxy saturant. Push the saturated anchors into the predrilled hole. Spread out the anchor fan as shown in the approved shop drawings. The fan shall extend horizontally 1/2 inch past the edges of the CFRP fabric. The CFRP anchor may be replaced with a premanufactured anchor, with approval from the Engineer. Apply a fully saturated CFRP patch covering the anchorage fan with the fibers oriented perpendicular to the main CFRP fabric.

3.6 Topcoat Installation

After the satisfactory completion of any required repairs to the cured CFRP system, apply a topcoat of UV protective coating that is in accordance with the manufacturer's recommendation. Use paints that allow vapor transmission at gaps. Remove dust and residue prior to application of paint coats. If the final epoxy coat is completely polymerized prior to application of final coat, the exterior surface of the CFRP fabric shall be cleaned and roughened by a light abrasive prior to painting. All clean and roughened surfaces shall be dry before painting.

4.0 Field QC/QA

After the initial resin has cured at least 24 hours, visually inspect for any defects in the CFRP fabric prior to applying final protective coating system. Defects include external abrasions or blemishes, delaminations, voids, external cracks, chips, cuts, loose fibers, foreign inclusions, entrapped air, and depressible raised areas or fabric wrinkles. All defects greater than 1" in length or greater than one square inch in area shall be repaired as specified in this note or according to the manufacturer's recommendations.

Tension adhesion testing shall be conducted using ASTM D7522 with the strengths reaching 200 psi. Any failure shall exhibit failure of the concrete substrate before failure of the adhesive. Tension adhesion testing shall cease when strengths reach 200 psi. Any failure of the concrete substrate and/or FRP adhesion shall be repaired at the contractor's expense and as directed by the engineer. Two adhesion tests shall be performed for each bridge component having FRP being applied.

5.0 Repairs

Repair procedures shall be performed in accordance with the manufacturer's recommendations and as specified by the Engineer. All repairs shall be subject to the same application, curing, and quality control specifications as the original work. All repairs shall be approved by the Engineer.

Large delaminations, bubbles, and fabric tears greater than 25 square inches each, shall be repaired by selectively cutting away the affected sheet, reapplying the primer and resin layers, and applying an overlapping FRP patch with an equivalent number of layers and fiber orientation. The patch shall be of the same material and manufacturer as the original defective fabric. Provide 6 inches of overlap in all directions.

Small defects less than 25 square inches each shall be repaired by using a low-pressure injection of the saturating resin, or by the previous procedure specified for large defects.

Repair procedures for conditions that are not specifically addressed in this Special Provision shall be submitted and approved by the Engineer prior to proceeding with the work.

6.0 Measurement

CFRP fabric shall be measured to the nearest square foot based on the area of fabric as detailed in the contract plans. No additional compensation will be given for the use of multiple layers to achieve design strength.

7.0 Payment

The Department will make payment for the completed and accepted quantities under the following:

Code	Pay Item	Pay Unit
25015EC	FRP Wrap	Square Foot

The Department will consider payment as full compensation for all work required herein.