PRESERVATION OF MISSOURI TRANSPORTATION INFRASTRUCTURES

# VOL II:
# Materials and Construction

VALIDATION OF FRP COMPOSITE TECHNOLOGY
THROUGH FIELD TESTING

**Strengthening of Bridge Y-0298**
Pulaski County, MO

*Prepared for:*
*Missouri Department of Transportation*
*University of Missouri-Rolla*
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Strengthening of Bridge Y-0298

## PULASKI COUNTY, MODOT DISTRICT 9

## EXECUTIVE SUMMARY

This report presents the materials and construction for flexural strengthening of the reinforced concrete (RC) bridge Y-0298, Pulaski County, Missouri, using externally bonded reinforcements. The report makes reference to two other documents: a) Master Materials and Construction Specifications, written in AASHTO language, and b) Manufacturer's Literature, that contains the tech data sheets for the materials used in this research program. This document explains the concrete repairs, surface preparation, materials specification, storage, handling, etc, for the five different technologies used in this research program, namely: manual lay-up carbon FRP laminates; near surface mounted (NSM) carbon FRP bars; adhered pre-cured carbon FRP laminates; steel reinforced polymer (SRP) laminates; and mechanically fastened carbon FRP laminates.

Bridge Y-0298 is one of five existing RC bridges, located in three districts, which were strengthened using composite materials. Five different strengthening techniques were used in the entire program but only two were used for bridge Y-0298: manual lay-up carbon FRP laminates and mechanically fastened carbon FRP laminates.

This project was conducted under a joint MoDOT – UMR University Transportation Center – Private Sector funding initiative. The five existing concrete bridges will be monitored twice a year over five years, including repeated load tests. The data, information, and understanding from this validation are used in the drafting of design and construction specifications to be written in AASHTO language for future FRP-related bridge-strengthening projects.

The strengthening schemes were designed in compliance with the ACI 440.2R-02 Design Guide for Externally Bonded FRP Materials where applicable. Both FRP strengthening techniques were easily implemented and showed satisfactory initial performance. The strengthening of this bridge was carried out during one week in November of 2003. The structure has two spans (15 ft = 4.6 m each), and each of them consists of a 7 in (17.8 cm) solid reinforced concrete slab. Each span is considered simply supported on reinforced concrete vertical walls. The total length is 30 ft (9.1 m) and total width of the deck is 24 ft (7.3). The FRP system consisted of manual lay-up carbon FRP laminates and mechanically fastened carbon FRP laminates in both spans.
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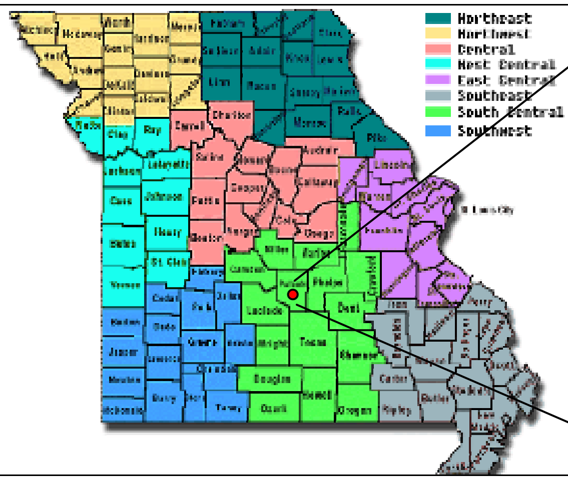
# 1. INTRODUCTION

## 1.1 General description

Bridge Y-0298 is located in Pulaski County, MoDOT District 9. The structure has two equally-spaced spans (15 ft, 4.6 m), each of them consists of a 7 in (17.8 cm) solid RC concrete slab (see Table 1, Figure 1, Figure 2 and Figure 3). Each span is considered simply supported on RC vertical walls. The total bridge length is *30 ft* (9.1) and the total width of the deck is *24 ft* (7.3 m). Two FRP system technologies were used for the flexural strengthening of this bridge.

Table 1- Summary Information

| **BRIDGE Y-0298** | |
|---|---|
|  |  |
| **District:** 9 | **County:** Pulaski |
| **Year Built:** 1937 | **Feature Intersected:** Creek |
| **Main Spans Construction:** RC Slab | **Number of Main Spans:** 2 |
| **Total Length:** 30 ft | **Rating (Deck/Sup/Sub):** 5/5/5 |
| **Load Posting:** Trucks over 9 ton (8.16 tons in SI units), 15 mph (24.14 km/hr) on the bridge. | |
| **BRIDGE FEATURES** | |
| **Geometry**<br>• Height of the bridge is 5 ft (1.5 m). Total width of deck is 24 ft (7.3 m)<br>• The thickness of the slab is 7 in. | |
| **Concrete Condition before Strengthening**<br>• Concrete in East slab is in poor condition in areas close to the edges of the bridge.This are caused by water filtering from the top of the deck. In addition, this span shows some deflection. The concrete in the West span is sound. However, some reinforcement is exposed because inadequate concrete cover was provided (Figure 2). Longitudinal cracks were detected (see Figure 3). | |

The FRP systems consist of manual lay-up carbon FRP laminates and mechanically fastened carbon FRP laminates on spans

Figure 1. Approach to the bridge

Figure 2. Condition of deck.
Corrosion of steel reinforcement

Figure 3. Condition of deck. Longitudinal cracks

# 2. MATERIALS

## 2.1 Material Properties

Two commercially-available external composite systems were adopted: (1) externally bonded CFRP laminates installed by manual wet lay-up, and (2) mechanically fastened carbon FRP laminates. The main difference between these two techniques is the preparation necessary before the application of the strengthening. Mechanically fastened carbon FRP laminates do not require any concrete repair neither a surface preparation as manual lay-up technique does. Both FRP techniques have been applied following the Master Materials and Construction Specifications.

The properties of the composite materials and fasteners used in the design are summarized in Table 2, 3 and 4 as reported by the manufacturers (see Manufacturer's Literature).

Table 2 – Properties of CFRP Laminate Constituent Materials

| Material | Ultimate tensile strength $f^*_{fu}$ ksi [MPa] | Ultimate strain $\varepsilon^*_{fu}$ in/in [mm/mm] | Tensile modulus $E_f$ ksi [GPa] | Nominal thickness $t_f$ in [mm] |
|---|---|---|---|---|
| Primer | 2.5 [17.2] | 0.03 | 104 [0.7] | - |
| Putty | 2.2 [15.2] | 0.07 | 260 [1.8] | - |
| Saturant | 8.0 [55.2] | 0.035 | 440 [3.0] | - |
| High Strength Carbon Fiber | 550 [3790] | 0.017 | 33,000 [228] | 0.0065 [0.1651] |

Table 3– Properties Fastened FRP Strip Constituent Materials.

| Material | Ultimate tensile strength $f^*_{fu}$ ksi [MPa] | Ultimate strain $\varepsilon^*_{fu}$ [in/in] | Tensile modulus $E_f$ ksi [GPa] | Cross sectional area $in^2$ [$mm^2$] | Dimensions in×in [mm×mm] |
|---|---|---|---|---|---|
| Epoxy Adhesive | 4.5 [31] | 0.04 | - | - | - |
| Strip | 120 [0.83] | 0.013 | 8,800 [66] | 0.5 [323] | 4×0.125 |

Table 4– Properties of Fasteners

| Material | Ultimate tensile Force per Bolt [Lbs] | Ultimate shear Force per Bolt [Lbs] | Anchor size (in) | Embedment depth (in) |
|---|---|---|---|---|
| Fastener | 5550 | 5110 | 3/8 in | 2-1/2 |

## 2.2 Summary Bill of Material (As Built)

Table 5 and Table 6 presents a summary of materials as used. Table 5 shows the break up for the various reinforcement types.

Table 5– Summary of Bill of Reinforcement as Built

| FRP Type | Reinforcement | Member Location | Span | Quantity | |
|---|---|---|---|---|---|
| Fastened Strips | Flexural | Slab | 1 & 2 | 132*ft* | 40.23 m |
| | | **Total** | | **132 *ft*** | **40.23m** |
| Manual Lay-up Laminates | Flexural | Slab | 1 & 2 | 533 $ft^2$ | 49.5 $m^2$ |
| | | **Total** | | **533 $ft^2$** | **49.5** $m^2$ |

Table 6– Summary of Bill of All Material as Built

| | | | |
|---|---|---|---|
| Fastened Strips | Strip | **132** ft | **40.23** m |
| | Adhesive | **132** ft | **132** m |
| | Fastener | **144** units | **-** |
| Manual Lay-up Laminates | Sheet | **533** $ft^2$ | **49.5** $m^2$ |
| | Primer | **533** $ft^2$ | **49.5** $m^2$ |
| | Putty | **533** $ft^2$ | **49.5** $m^2$ |
| | Saturant | **1070** $ft^2$ | **99.4** $m^2$ |
| | Coating | **533** $ft^2$ | **49.5** $m^2$ |

The detailed compilation for the bill of materials reported in the Tables above is given at the end of this report as Appendix 1.

# 3. STRENGTHENING

## 3.1 Substrate Repair

The performance of a composite system depends not only on the quality and strength of the concrete substrate but also on the bond between the composite and substrate. A clean and sound substrate is essential for composite repair systems. Nevertheless, for cases where concrete repairs represent a big issue in terms of cost impact over the project, mechanically fastened carbon FRP laminates were used. This technology does not require critical concrete repair.

For both spans, areas where mechanically fastened laminates where installed no concrete repairs were made.

In concrete repair work for the area of manual lay-up installation, sound concrete consisted of  partial-depth repairs of deteriorated concrete for the centered part of the deck, cleaning the area, installing repair materials, finishing and texturing (Figure 4); all concrete surfaces to be strengthened were thoroughly prepared according to the minimum requirement defined in the Master Materials and Construction Specification.

Figure 4. Repair of deteriorated areas on deck

## 3.2 Surface Preparation

To promote continuous intimate contact between concrete and FRP, important issues had to addressed in the surface preparation: concrete surface irregularities, fins, and/or sharp angles that may result in separation and delamination of carbon laminate from the concrete and/or in localized stress concentration. Concrete surface irregularities were removed and smoothed to less than 1 mm.

Abrasive sandblasting was used to clean the concrete surfaces of dust, dirt, laitance, oil and any curing substance. Concrete surface roughness was equivalent to CSP 3 (Concrete Surface Profile number 3) as defined by the International Concrete Repair Institute. The sandblasting must be applied prior to CFRP. All loose particles, oil, dust, cement, paint and other contaminants were contained in accordance with State regulation.

## 3.3 Externally Bonded Composite Reinforcement

Spans were strengthened with manual lay-up laminates and mechanically fastened laminates. The installation process for each technology will be described in the following sections.

### 3.3.1 Manual Lay-up CFRP Laminates

The carbon fabric for the manual lay-up system consists of uni-axial carbon fiber sheets for strengthening the positive moment region of reinforced concrete. In this instance, a high strength carbon fiber was used (Table 2)

#### 3.3.1.1 Primer Application to Fill Voids

Two-component epoxy primer (Table 2) was used to fill voids in the concrete surface. All surfaces to receive the carbon fiber fabric were primed with the penetrating primer

Primer was mixed in accordance with the manufacturer's recommendations (See Manufacturer's Literature) using brushes and rollers. The volume of primer to be prepared at one time was such that could be applied within its pot life. Primer was thoroughly mixed with a hardener at the manufacturer's specified ratio.

Application was uniform in a sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface after full penetration. A four-way method, application in all four directions, was used. When necessary, a second coat was applied after the first coat penetrated into the concrete.

#### 3.3.1.2 Epoxy Filler/Surfacer

Remaining minor surface irregularities and defects were corrected using epoxy filler/surfacer or putty. It is not desirable that the epoxy putty filler cover the entire concrete surface.

A trowel was used to apply the putty in order to fill any surface defect. The material properties of the primer and putty that were used are listed in Table 2.

#### 3.3.1.3 Application of Carbon Fiber Sheets

The carbon fiber sheets were cut beforehand into prescribed sizes using scissors and a simple made-in-place device.

A saturant coating (Table 2) was applied with a medium nap roller after application of the primer and putty. Afterward, the pre-cut fiber sheets were attached according to Contract drawings.

The carbon fiber sheets were installed by manual lay-up method. The sheets were properly aligned and set into the surface saturant.  The fiber plies were aligned on the structural member according to the Contract Documents. Any deviation in the alignment more than 5˚ (approximately 87 mm/m or 1 in/ft) was not acceptable. The sheets were saturated by rolling out the external surface. This operation also removed excess of saturant and bubbles. After appropriate time (10 minutes), a second saturant application over the carbon fiber sheets were applied to a complete impregnation. The saturant was applied in strict accordance with the manufacturer's recommendations (Manufacturers Literature).

The process must allow sufficient working time for the rolling of the carbon fiber sheet and saturant to produce a uniform system that is completely free of voids and trapped air. It must be completed within the limits of saturant pot-life.

Because saturant is susceptible to temperature, special care shall be taken to minimize the elapsed time between mixing and application of the saturant. This must be applied to the sheet at least 15 minutes prior to any thickening.

In order to avoid vibrations during the installation, traffic control was used. Speed of the car was limited to 15 mph (24.14 km/hr). Finally, a topcoat was applied to the sheet to provide a cosmetic finish and environmental protection.

### 3.3.2 Mechanically Fastened carbon FRP laminates.

The mechanically fastened FRP laminates system consists of FRP fiber strips, epoxy adhesive and fasteners. The material properties of the bars and epoxy paste used are listed in Table 3.

Installation of Mechanically Fastened FRP systems is generally similar to Pre-cured Strip system. Nevertheless, surface preparation of concrete substrate is not critical, because the mechanism of load transferring from the concrete to the composite laminate is done by the fasteners. Also epoxy contributes in the load transferring, but for bad concrete surface condition, which is the case where a mechanically fastened technique is strongly required, the effect is marginal.

Mechanically Fastened FRP systems was cleaned and cut to the length according to design drawings. For this case, surfaces to receive the reinforcement were scanned with a rebar locator to determine the exact location of steel reinforcement.

A highly adhesive epoxy (Table 3) was applied to the surface for bonding the reinforcing strips. The extra adhesive is squeezed out when the laminate is pressed to the concrete surface (Figure 5)

Figure 5. Installation of mechanically fastened laminates

Holes were drilled in the concrete surface, through the laminates, to a depth of at least ½ in. or one diameter deeper than the embedment required. Special care shall be taken to minimize the elapsed time between mixing and application of the adhesive epoxy, the drilling process and collocation of fasteners (see Figure 6).

Figure 6. Drilling of laminates and concrete surface.

Fasteners were driven through the holes using manual "rotation only" drillers. Normally the fasteners do not require any specific installation torque and the maximum torque is a value normally specified by Contractor (Figure 7 and Figure 8)

Figure 7. Installation of fasteners

Figure 8. Installed mechanically fastened laminates.

## ACCEPTANCE TESTING.

A direct pull-off test based on ASTM D 4541-93 was used by the contractor in this project. This test allows to check the quality of the installation of the FRP. It consists in gluing an aluminum square plate on the strengthened part to be checked; afterwards, a core is drilled close to the aluminum plate through the laminate strip into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. A tension device is then loaded to failure during the test. The tester records the force causing the failure, which, if divided by the core cross sectional area, will result in tensile strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure of the concrete and not at the bond line was the only acceptable failure. The tensile bond strength must be more than 200 psi (1.4 MPa)

One pull-off test was performed every 200 $ft^2$ (20 $m^2$) of area strengthened with carbon fiber strip system or once every deck span.

The results of single tests made on both spans were values of tensile bond strength bigger than the minimum required. Based on these results and that all failures occurs in the concrete and not at the bond line, installation of FRP was considered successful.

# APPENDIX 1

## 1. Fastened Strips

1.1 FLEXURAL REINFORCEMENT

1.1.1 Slab. Spans 1 and 2

$$(2)(6)\ 11\text{ft} = 132\text{ft}$$

## 2. Manual Lay-up Laminates

2.1 FLEXURAL REINFORCEMENT

2.1.1 Slab. Span 1 and 2

$$(2)(2)25\cdot(8\text{in})\cdot(8.0\text{ft}) = 533\text{ft}^2$$

## 3. SATURANT APPLICATION

3.1FLEXURAL REINFORCEMENT

3.1.1 Slab. Spans 1 and 2

$$(2)(2)(2)\ 25\cdot(8\text{in})\cdot(8.0\text{ft}) = 1067\text{ft}^2$$

## 4. PRIMER AND PUTTY APPLICATION

4.1 FLEXURAL REINFORCEMENT

4.1.1 Slab. Spans 1 and 2

$$(2)(2)25\cdot(8\text{in})\cdot(8.0\text{ft}) = 533\text{ft}^2$$

## 5. RESIN (Fastened Strips)

5.1 FLEXURAL REINFORCEMENT

5.1.1Slab. Spans 1 and 2

$$(2)(6)\ 11\text{ft} = 132\text{ft}$$