# Field application of FRP material in Kentucky

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## Abstract

Repair and rehabilitation utilizing FRP composites, especially carbon FRP fabric and laminates are becoming the primary choice for strengthening damaged structural components or for upgrading structures. The deployment of FRP materials in a number of bridges in Kentucky are presented along with a discussion on long term durability. The highlighted field applications include the use of: (1) FRP rebars – both glass FRP (GFRP) and carbon FRP (CFRP) in bridge decks; (2) FRP sections – a pultruded FRP composite I-girder pedestrian bridge and suspension bridge with a GFRP superstructure; (3) CFRP fabric – retrofitting of reinforced concrete box-beams, repair of concrete bridge pedestals, retrofit of precast prestressed I-girders and strengthening of concrete piers; (4) SFRP fabric – steel FRP used to repair crack locations in RC beams and PC I-beams; and (5) CFRP laminate – normal modulus laminates for strengthening reinforced concrete girders as well as ultra high modulus laminates for strengthening steel girders. A discussion of the lessons learned along with recommendations is also presented.

**Keywords:** FRP, composite materials, reinforced concrete, flexural strength

# 1. Introduction

Bridge infrastructure in the U.S. is aging rapidly and according to the Department Transportation National Bridge Inventory Database (Federal Highway Administration, 2008), there are reportedly 599,766 bridge structures in the United States. Of this number 72,524 are classified as "*structurally deficient*" and 79,792 are "*functionally obsolete*". This indicates that an estimated 25 percents of the U.S. bridges are in need of repair or replacement. The same database also reveals that 4,290 of 13,637 bridge structures in the State of Kentucky are in either category. The use of high performance materials such as fiber reinforced polymer (FRP) structural systems for infrastructure applications offers, in certain applications, both economical and structural advantages, and improved performance.

For new structures, the use of advanced Fiber Reinforced Polymer (FRP) composites have the advantage of corrosion resistance, high strength to weight ratio, magnetic transparency, etc. For repair and rehabilitation, FRP composites, especially carbon FRP fabric and laminates are becoming the primary choice for strengthening damaged structural components or for upgrading structures. Ten field applications of FRP composites in Kentucky will be highlighted.

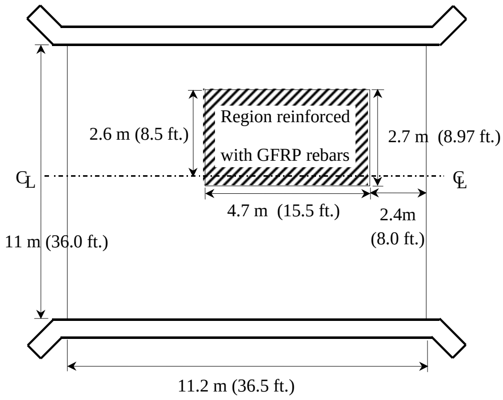
# 2. FRP Rebars

The corrosion of steel can be a significant problem in bridge decks in which the reinforcing and prestressing steel are accessible to deicing salts. The combination of moisture, temperature and chlorides through cracks lead to concrete deterioration and loss of serviceability. Fiber Reinforced Polymer (FRP) rebars have emerged as one alternative to steel reinforcement in such corrosive environments (near the sea shore, chemical plants). FRP rebars can not only withstand corrosive environments they do not interfere with magnetic fields. Consequently, these rebars are being used in structural and architectural components in areas where magnetic interference from the structure must be eliminated (magnetic resonance imaging facilities, special test facilities, etc.). The following are two examples of using glass FRP (GFRP) rebars and carbon FRP (CFRP) rebars in bridge decks that are subjected to salt in the winter months to avoid freezing on the deck surface.

## 2.1 Roger's Creek Bridge Deck

A bridge deck 11.2 m long and 11.0 m wide was constructed in 1997 on US460 over Roger's Creek in Bourbon County, Kentucky with GFRP rebars in the region of the top reinforcing (Deitz et al., 2000). The remainder of the top mat was reinforced with epoxy coated steel (ECS) bars. The bridge is being monitored on a monthly basis to evaluate crack formation, crack width and propagation between the GFRP reinforced area and the ECS reinforced area.

The maximum measured crack width of 0.3 mm (0.013 in) in the GFRP reinforced section meets the maximum allowed by ACI (Section 10.6) and AASHTO (Section 8.16.8.4) specifications in steel reinforced structures for exterior exposure.




(a) (b)

**Figure 1: (a) Roger's Creek Bridge prior to concrete deck placement; (b) Plan view of bridge deck showing the location of GFRP rebars**

## 2.2 Two Mile Creek Bridge

The Two Mile Creek Bridge is located on Elkin Station Road in Clark County, KY. The 9.45 m (31 ft.) wide and 18.6 m (61 ft.) long bridge in Figure 2 is reinforced with Carbon Fiber Reinforced Polymer (CFRP) reinforcement (Hill et al., 2003). All longitudinal and transverse reinforcements in both the top and bottom mats are CFRP bars. The bridge is being monitored on a regular basis (i.e. evaluate crack formation, crack width, crack propagation, etc.). To date, no sign of distress has been reported and the bridge is reportedly in excellent condition.

(a) (b)

**Figure 2: (a) CFRP reinforcements as longitudinal and transverse reinforcement in both the top and bottom mats; (b) concrete placement**

# 3. FRP Sections

FRP sections have generally been produced in the shape of structural steel sections. Although their primary use has been in non-primary load bearing structures, they are popular in structures where corrosion, magnetic interference, and durability are of concern. The following are examples of two pedestrian bridges constructed using FRP structural sections.

## 3.1 Clear Creek Bridge

A pultruded FRP composite I-girder pedestrian bridge (Fig. 3) was constructed in 1996 over the Clear Creek in the Daniel Boone National Forest near Cave Run Lake in Bath County, Kentucky, USA (Szak et al., 1999). The main load carrying members for the bridge are two 61 cm deep hybrid composite I – girders. These girders were made of glass fibers in web and flanges with embedded carbon fibers in flanges. The addition of the carbon fibers in the flanges produced a 128 % increase in the rigidity of the beam, and since the design was controlled by deflection limitations, the number of girders was reduced from four to two. Many new features were incorporated in this bridge. These features include: (i) the use of a hybrid carbon/glass fiber reinforced polymer (FRP) I-beam section; (ii) the use of fiberglass sucker rods as supports for a bridge; and (iii) the use of spliced composite I-girders in a bridge.

(a)

(b)

**Figure 3: (a) Clear Creek Bridge in the Daniel Boone National Forest; (b) Cross section of the flange of the hybrid composite I-beam. The carbon fibers are seen as dark horizontal lines**

## 3.2 Swinging Bridge

A pedestrian swinging bridge that is 128 m long and 0.92 m wide was constructed in April 1999 over the Big Sandy River in Johnson County, Kentucky (Fig. 4). The superstructure in the suspension bridge is made from pultruded GFRP components. The deck is composed of an

open grid resting transverse box section, which in turn rest on longitudinal box sections.

**Figure 4: Swinging Bridge over Big Sandy River**

# 4. CFRP Fabric

CFRP Fabric has been gaining popularity in the retrofit arena of existing concrete structures. The advantage of the fabric is its flexibility, durability, and more importantly, the strength it adds to the retrofitted members. The following are two examples where the CFRP fabric has proven to be an outstanding material for retrofitting existing bridges.

## 4.1 Carter County Bridge

A routine inspection on the 3 span bridge on route KY3297 over Little Sandy River in Carter County, Kentucky conducted in April 1996 found significant diagonal shear cracks that were as wide as 3.2 mm, and 1.8 to 2.4 m long had formed in all precast prestressed box beams at both ends of the center span (span 2). Subsequent inspections revealed that the shear cracks in span 2 were propagating at an alarming rate, and new shear cracks were also beginning to develop in spans 1 and 3. In addition, the re-evaluation confirmed that the box beams were indeed under-reinforced in shear. The retrofitting process for the Bridge using CFRP fabric (Simpson et al., 2006) began in September 2001 and was completed in October of 2001. The process was performed in two phases: (1) crack repairs; and (2) application of CFRP fabric. The goal of crack repairs was to partially restore the capacity of the beams, and the application of CFRP fabric was to strengthen and compensate for shear deficiency.

(a)

(b)

(c)

(d)

**Figure 5: (a) Carter County Bridge; (b) Shear cracking in prestressed box beam; (c) Filling cracks with epoxy; (d) Attaching CFRP fabric to concrete**

## 4.2 I-65 Elevated Highway Bridges

The interstate 65 elevated highway bridges in Louisville span across a number of streets in the heart of Louisville, Jefferson County, KY. The I-65 Expressway required three different types of retrofitting using advanced carbon fiber reinforced polymer (CFRP) fabrics: (1) repair cracked precast prestressed concrete girder spans, (2) repair damaged reinforced concrete bearing pads, (3) repair damaged bridge pier.

A number of cracks had developed on many of the prestressed concrete girders between Jacob Street and Chestnut Street over the years. The cracks were vertical cracks and are located near or at the supporting piers. Preliminary investigations indicated that these cracks may have developed due to shrinkage. The cracks are especially apparent at piers with fixed restraints where the axial shortening of girders is prevented. Prior to retrofitting, the crack locations of two PC girders were instrumented with linear variable displacement transducers (LVDTs) to monitor the vertical and horizontal translations. The damaged PC girders were eventually repaired by wrapping of CFRP fabric (Fig. 6) to limit the translations. After the repair, the two previous crack locations are again instrumented with LVDTs to gauge the effectiveness of the repair.

Several reinforced concrete bearing pads showed signs of damage with some showing severe loss of concrete cover. The subsequent repair involved the wrapping of CFRP fabric around the perimeter of the bearing pads. The edge pier supporting the southbound I-65 over E. Muhammad Ali Blvd. in Louisville, KY had concrete spalling due to corroded rebars. Initially the pier was cleaned and all cracks and voids were filled. 3-D CFRP fabric was used to strengthen the pier to account for the loss of strength due to corrosion of rebars. The fabric is expected to provide confinement as well as ductility to the pier due to its unique fiber orientation.

(a)

(b)

(c)

(d)

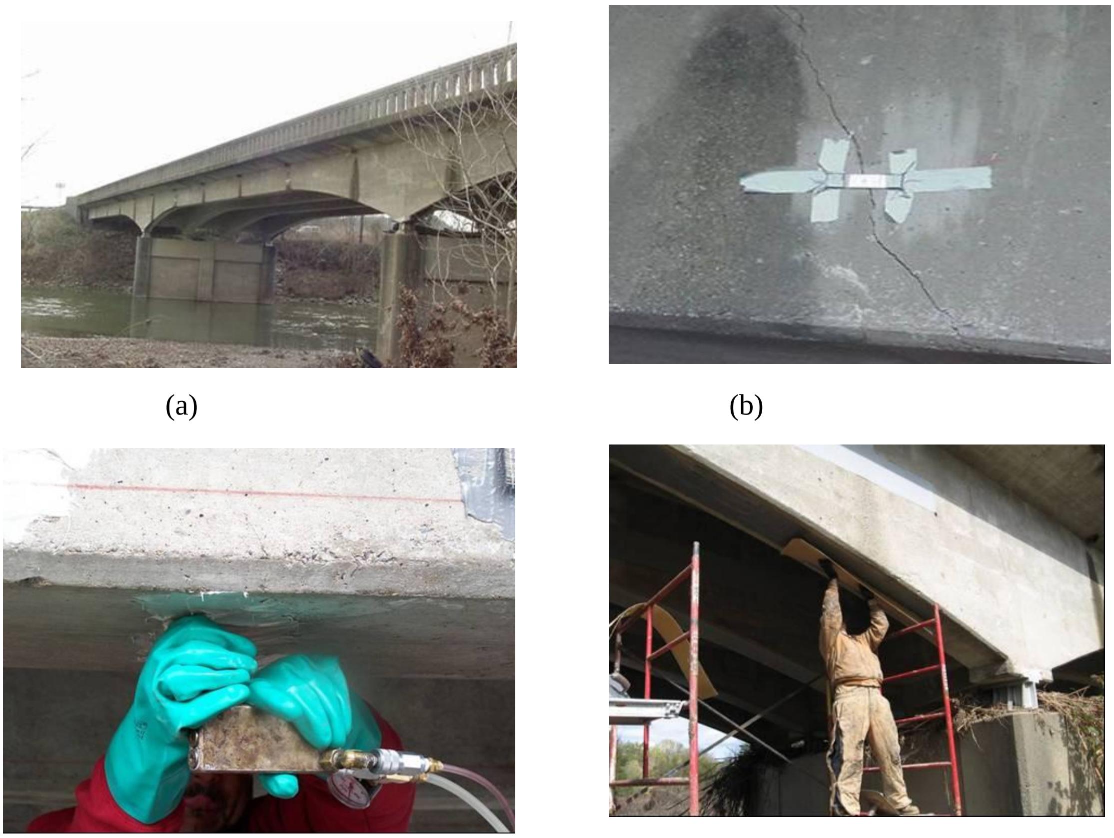
**Figure 6: (a) Crack movement evaluation; (b) Attaching CFRP fabric to concrete beams; (c) Damage to Bridge Pier; (d) Attaching 3-D CFRP fabric to concrete**

# 5. SFRP Fabric

Steel Fiber Reinforced Polymer (SFRP) fabric is woven from strands or wires of high-strength steel. Depending on the strength requirement, several types of SFRP sheets with different density of steel strands or wires are available. Individual steel wires in SFRP offer a stiffness equaling that of conventional steel, with the woven fabric providing the characteristics of high tensile strain, excellent conformability due to its flexibility, and bond-abillity; making them suitable for retrofit projects.

## 5.1 Washington and Nelson County Bridges

The Washington and Nelson County bridges are located on route US 150 in Kentucky. The haunched reinforced concrete girders have developed diagonal cracks near or at the transition of the variable-and-constant depth regions. Steel fiber reinforced polymer (SFRP) sheets were selected for the retrofit. Repair to the reinforced concrete girders was carried out by bonding the SFRP sheets to the vertical and bottom faces. The retrofit was completed in June 2007. Crack gauges have been installed to monitor potential movement and to evaluate the effectiveness of the retrofit.



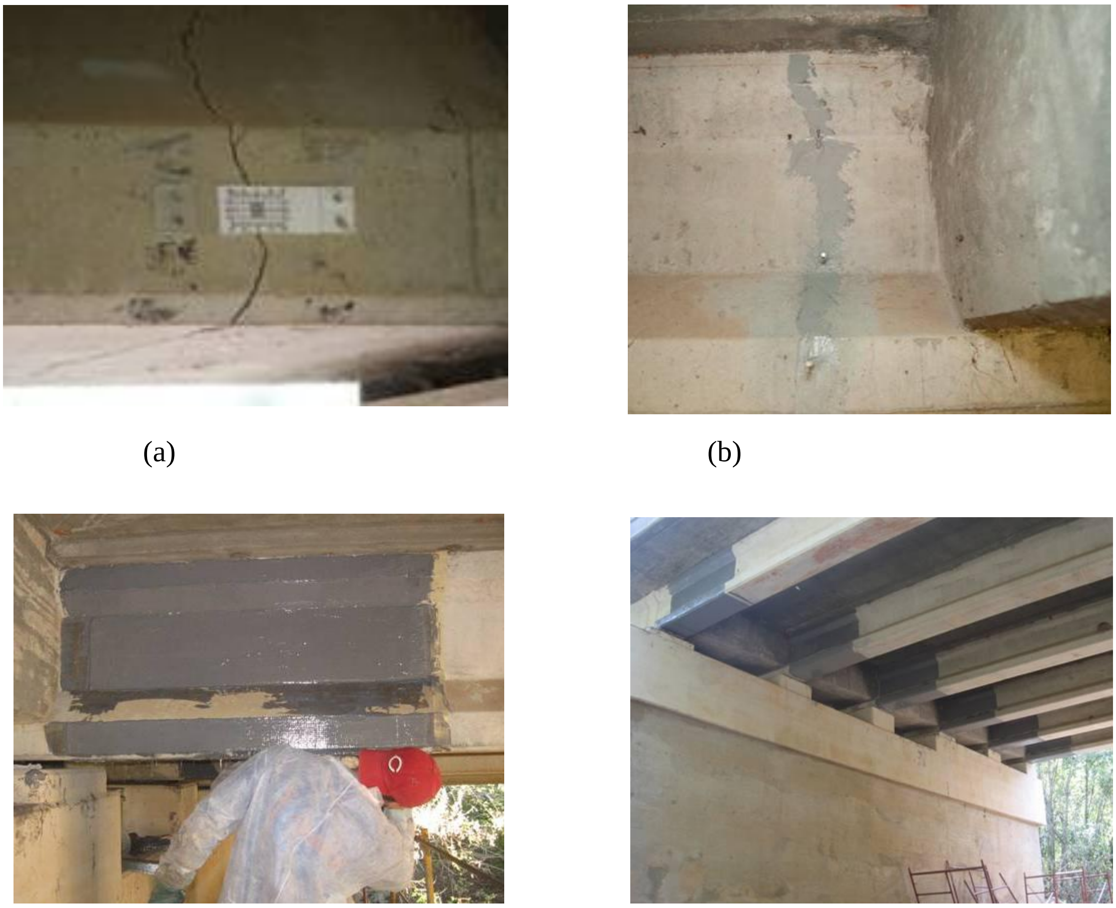
(a) (b)

(c) (d)

**Figure 7: (a) Nelson County Bridge; (b) Diagonal cracking in concrete beams; (c) Crack filling; (d) Attaching SFRP fabric to concrete**

## 5.2 Hart County Bridge

The KY 218 Bridge in Hart County is a three span bridge having 6 AASHTO Type I PC girders in each span. The girders have developed cracks extending from the bottom flange to the web or top flange at various locations in the three spans of the bridge. The cracks were widening with time. High strength steel fiber reinforced polymer (SFRP) fabric was attached to the vertical and horizontal surfaced of the PC beams to halt the growth of cracks.



(a) (b) (c) (d)

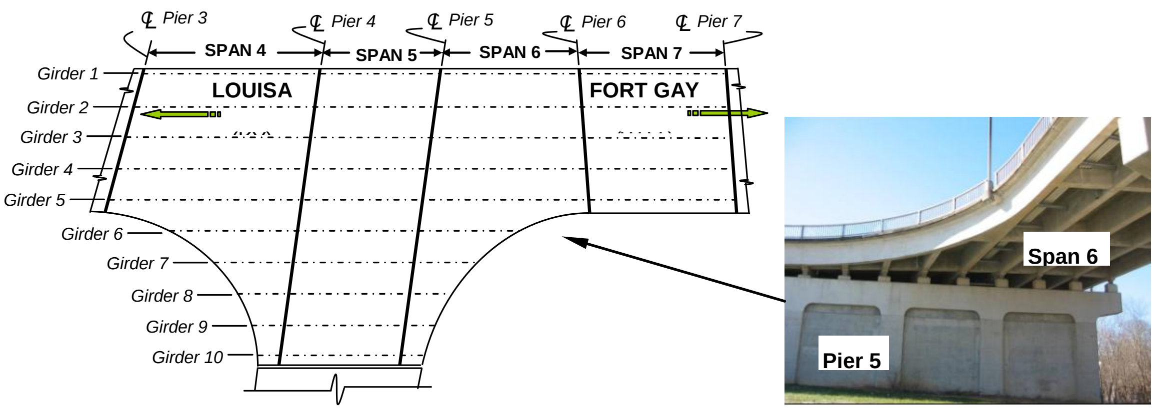
**Figure 8: (a) Cracks in AASHTO Type I girder; (b) Cracks ready to be filled; (c)Application of SFRP on concrete beam; (d) A repaired section of Hart County bridge**

# 6. CFRP Laminates

The use of CFRP laminates provides a greater fiber volume ratio when compared with multiple layers of CFRP fabric. CFRP laminates are factory pultruded plates consisting of unidirectional carbon fibers in an epoxy resin matrix. Depending on fibers used the elastic modulus of the final laminate plates commonly used in Civil Engineering applications can vary from 150-450 GPa. The emergence of high modulus CFRP plates, with an elastic modulus higher than that of steel, enables researchers to achieve substantial load transfer in steel beams before the steel yields. Two applications of CFRP laminates are presented next, where normal modulus CFRP laminates were used to strengthen reinforced concrete beams, and ultra high modulus CFRP laminates were used to strengthen composite concrete-steel girders.

## 6.1 The Louisa-Fort Gay Bridge

The Louisa-Fort Gay Bridge is located in a small mining community of Lawrence County in Eastern Kentucky. The 12-span continuous bridge structure consists of composite concrete deck-steel girder spans and reinforced concrete middle spans that comprise an intersection for traffic coming from three different directions. Bridge inspection indicated that flexural cracks developed in the RC girders due to heavy coal truck loads. Weigh in motion scales measured trucks weighing in excess to 1000 kN (225 000 lb). The amount of CFRP laminates needed to strengthen the beams was determined via moment-curvature analyses (Choo and Harik, 2007).




(a)


(b) (c)

**Figure 9: (a) Louisa-Fort Gay Bridge; (b) Flexural cracks in RC girder; (c) Beams retrofitted with CFRP laminates**

## 6.2 Scott County Bridge

The KY 32 Bridge over Lytles Creek, located in Scott County KY, is a single span steel girder bridge with a non-composite reinforced concrete bridge deck. A load posting of 12.7 tonne (14 ton) was on the bridge before strengthening. Shear studs were post installed between the steel girders and the concrete deck to make the bridge deck composite with the girders. Following the placement of the shear studs, ultra high modulus CFRP laminates were applied, to the top and bottom, of the bottom flange of the steel girders. Field tests were conducted before and after the installation of the shear studs to verify the effectiveness of post installed shear studs (Peiris et al., 2010). The laminates were applied in April 2010 and field tests were carried out after the laminate application to determine the increase in the load carrying capacity and the reduction in maximum deflection after the strengthening.

(a) (b)

**Figure 10: (a) Bridge girder with post-installed shear studs and ultra high modulus CFRP laminates; (b) Instrumentation for field tests**

# 7. Conclusions

The deployment of FRP composites as components in four new bridge construction projects and as retrofitting elements in six existing bridges in Kentucky was highlighted. The components used in the new bridges were intended for experimental purpose and material evaluation. The six FRP retrofitting projects were chosen because of their economical advantage over other retrofitting alternatives. GFRP and CFRP rebars were found to be excellent replacements for steel rebars in reinforcing concrete bridge decks. CFRP fabric wrapping was found to be an effective method for the repair of concrete piers, pier cap pedestals and also deteriorated or damaged precast prestressed and reinforced concrete beams. SFRP fabric was seen to successfully eliminate crack propagation in reinforced concrete beams. FRP laminates proved to be an efficient strengthening technique for reinforced concrete beams, while testing is underway for the evaluation of their potential in strengthening steel girders. Further use of FRP material in future bridge construction and retrofit projects are recommended for their application to become more established and for developing design and inspection standards.

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