High Performance Materials For Civil Engineering Structures

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SUMMARY

An overview is presented of the testing conducted on various high performance materials and their deployment in civil engineering structures, primarily concrete bridges. The materials include fiber reinforced polymer composites (FRP), stainless steel clad (SSC) rebars, microcomposite multistructural formable steel (MMFX) rebars, etc. The primary advantage of these materials is their resistance to corrosion and/or their lack of magnetic interference. Corrosion hastens the degradation in civil engineering structures and reduces their life span. This leads to increased costs and frequency of repairs, and reduces the monetary return on the investment. The lack of magnetic interference is highly beneficial in the construction of magnetic resonance imaging (MRI) rooms in hospitals, in certain transmission towers, computer chip production facilities, etc. Carbon FRP fabrics and laminates as well as steel reinforced polymer (SRP) fabrics are becoming very popular in the repair and strengthening of existing structural elements. Case studies are presented to highlight the deployment and monitoring of these materials.

1. INTRODUCTION

The use of high performance materials (HPM) for infrastructure applications offers, in certain applications, both economical and structural advantages, and improved performance. For new structures, the use of HPM provides the advantage of corrosion resistance, and/or high strength to weight ratio, and/or magnetic transparency, etc. For repair and rehabilitation, HPM, especially carbon FRP fabrics and laminates [1,2], are becoming the primary choice for strengthening damaged concrete structural components or for upgrading structures. HPM field applications in concrete bridges are highlighted in this paper.

2. THE ROGER'S CREEK BRIDGE DECK - GFRP REBARS

A bridge deck 11.2 m long and 11.0 m wide was constructed in 1997 across Roger's Creek in Bourbon County, Kentucky with GFRP rebars in a region of the top reinforcing mat as shown in Fig. 1 [5]. The remainder of the top mat was reinforced with epoxy coated steel (ECS) 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 [6].

Fig. 1: Concrete placement on the Roger's Creek bridge deck

3. THE TWO MILE CREEK BRIDGE DECK - CFRP REBARS

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 Fig. 2 is reinforced with Carbon Fiber Reinforced Polymer (CFRP) reinforcement [7]. All longitudinal and transverse reinforcements in both the top and bottom mats are CFRP bars (Figs. 3-5). 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 [3].

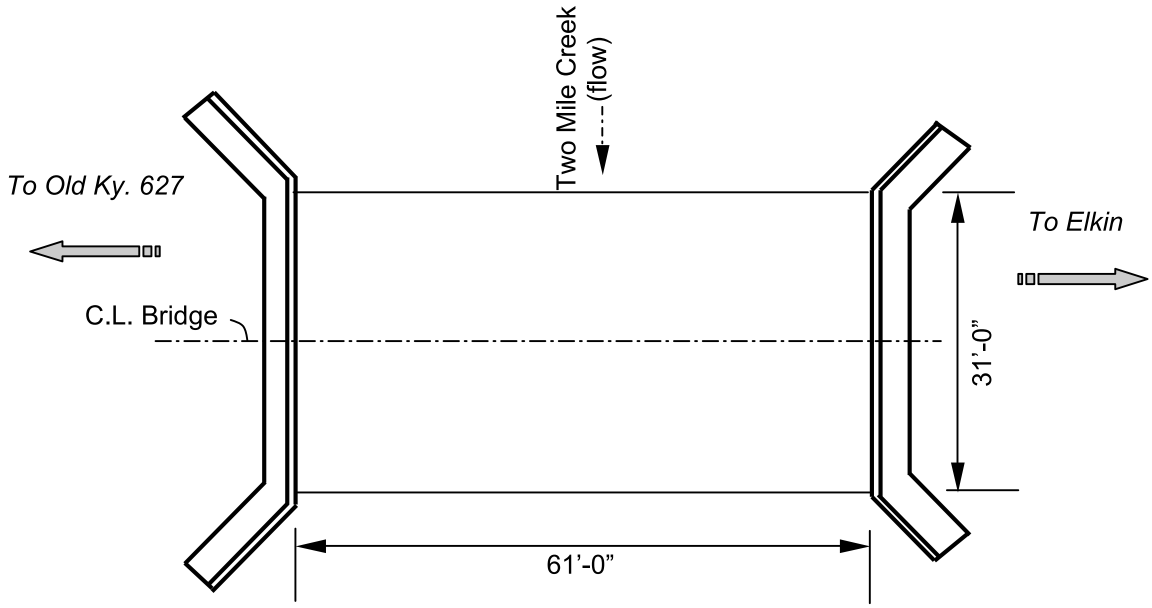


Fig. 2: Plan view of the Two Mile Creek bridge deck

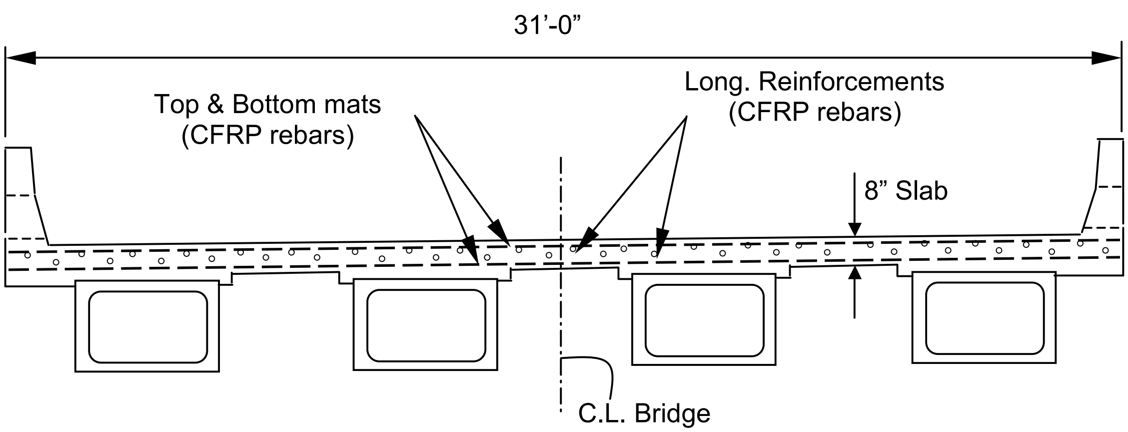


Fig. 3: Typical section of the Two Mile Creek bridge deck

Fig. 4: The Two Mile Creek bridge deck prior to concrete placement

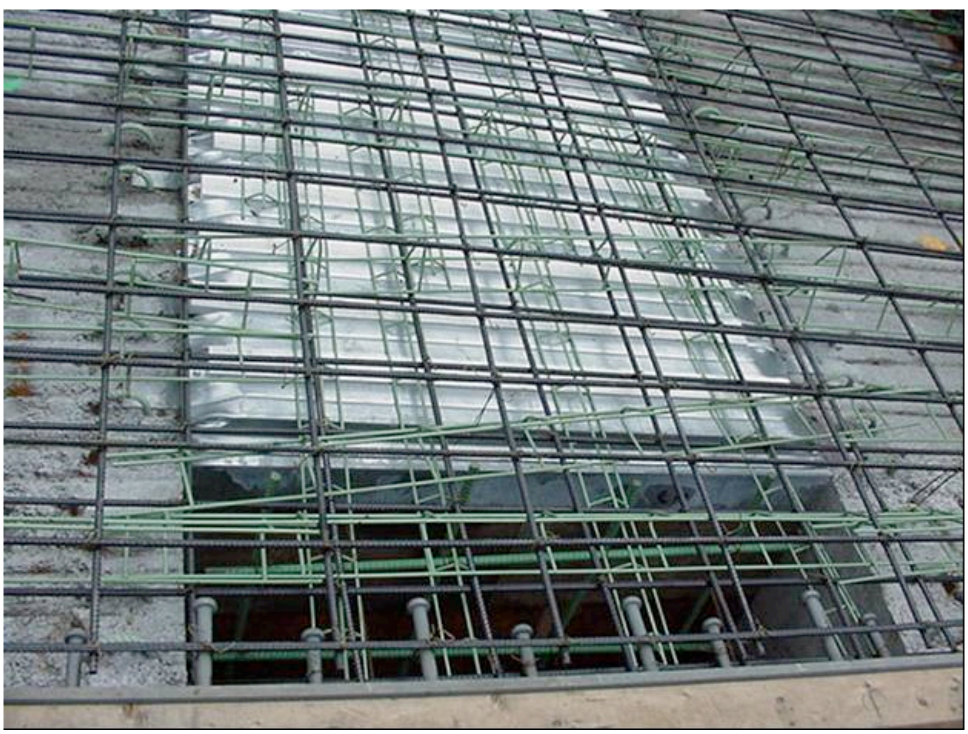


Fig. 5: Longitudinal and transverse reinforcements are CFRP rebars in the Two Mile Creek bridge

4. NORTH ELKHORN CREEK BRIDGE DECK - MMFX REBARS

Microcomposite multi-structural formable steel (hereafter referred to as MMFX) bars possess excellent corrosion resistance, according to its manufacturer, due to the steel unique chemical composition; a combination that minimizes the formation of micro galvanic cells which are the source of the electrochemical process in the steel. MMFX bars tested in 2001 at the University of Kentucky [7] had a tensile strength of approximately 180 ksi (1,250 MPa). The stress-strain relationship of MMFX bars is non-linear particularly at high stress levels. Typical stress-strain relationship of a MMFX bar is shown in Fig. 6. In 2001, MMFX bars were used in the construction of one of the two reinforced concrete bridge decks of the CR 5218 Bridge over North Elkhorn Creek on Galloway Road located in Scott County, Kentucky (Fig. 8).

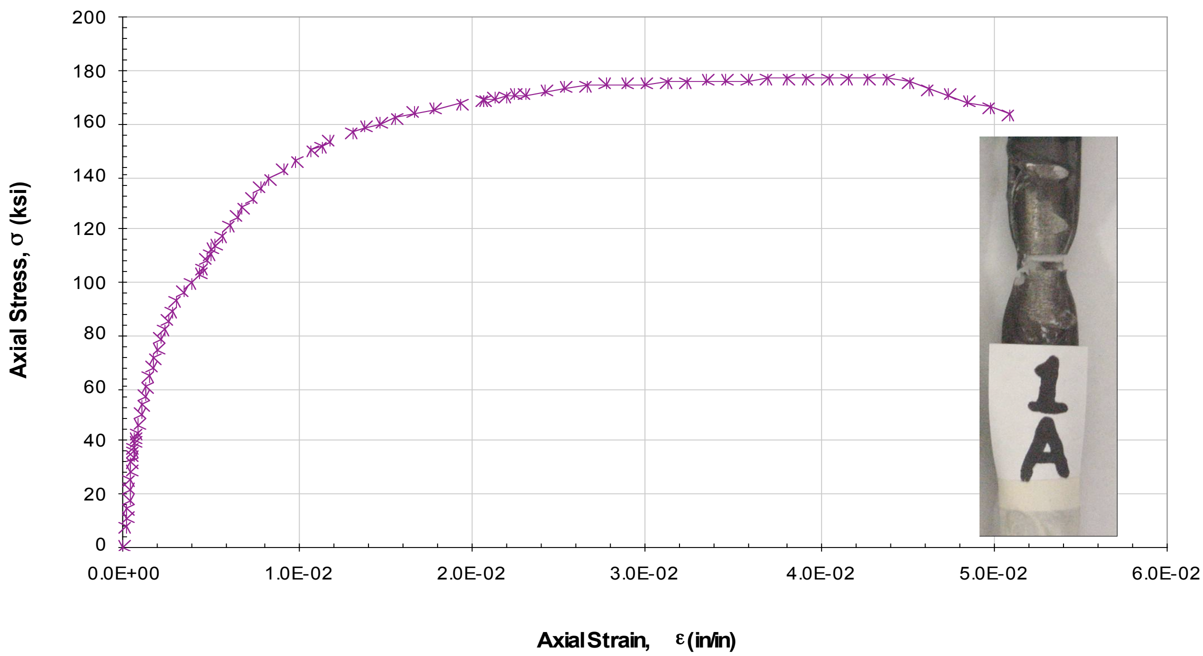


Fig. 6: Stress-strain relationship of a MMFX steel bar

5. NORTH ELKHORN CREEK BRIDGE DECK - SSC BARS

Stainless steel clad (hereafter referred to as SSC) bars are conventional carbon steels (e.g. A615 Grade 40, 60, etc.) with stainless steel serving as exterior protective coating or cladding; much like epoxy coated steels. Stainless steel is essentially a low carbon steel that contains chromium (Cr) at 10% or more by weight. The chromium in steel allows the formation of a rough, adherent, invisible, corrosion-resisting chromium oxide film on the steel surface; this protective film, if damaged, is self-healing. SSC bars are metallurgically bonded by first pressing the carbon steel core into a stainless steel pipe and then hot-rolling the SSC under a specified temperature. Therefore, SSC bars combine most of the advantages of solid stainless steel equivalents and the mechanical properties of their carbon steel core bars. Typical stress-strain relationship of a SSC bar is shown in Fig. 1 [7]. In 2001, SSC bars were used in the construction of one of the teo reinforced concrete bridge decks of the CR 5218 Bridge over North Elkhorn Creek on Galloway Road located in Scott County, Kentucky, USA (Fig. 8).

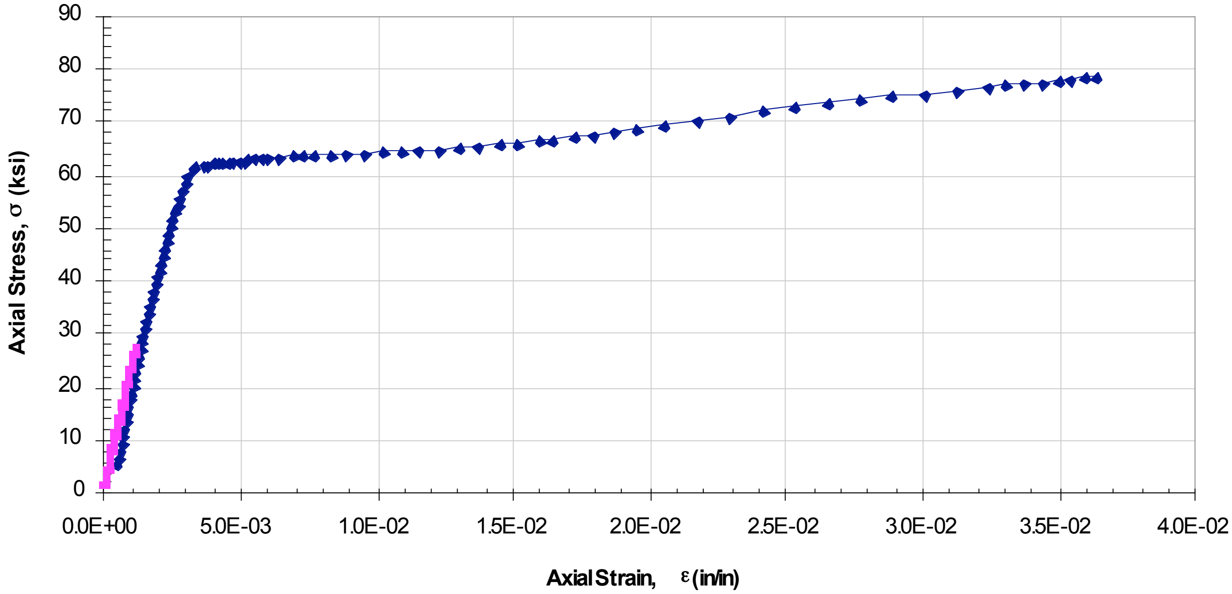


Fig. 7: Stress-strain relationship of a stainless steel clad (SSC) bar

6. THE CARTER COUNTY BRIDGE

The three-span (21-30-13 m) composite precast prestressed concrete box-beam bridge is situated on route KY-3297 crossing the Little Sandy River in Carter County, Kentucky. The bridge was completed in April 1993. A routine inspection 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 (Fig. 9). The cracks formed in all precast prestressed box beams at both ends of 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, further evaluation confirmed that the box beams were indeed under-reinforced in shear.

The retrofitting process for the Carter County Bridge began in September 2001, and 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. Fig. 10 depicts the retrofitting process: (a) mounting of injection ports in cracks; (b) sealing cracks using epoxy through injection ports; (c) applying two-part resin; and (d) attaching CFRP fabric to concrete. Note that the CFRP fabric is attached to both sides of the concrete beams with a 45-degree angle (see Fig. 10d).

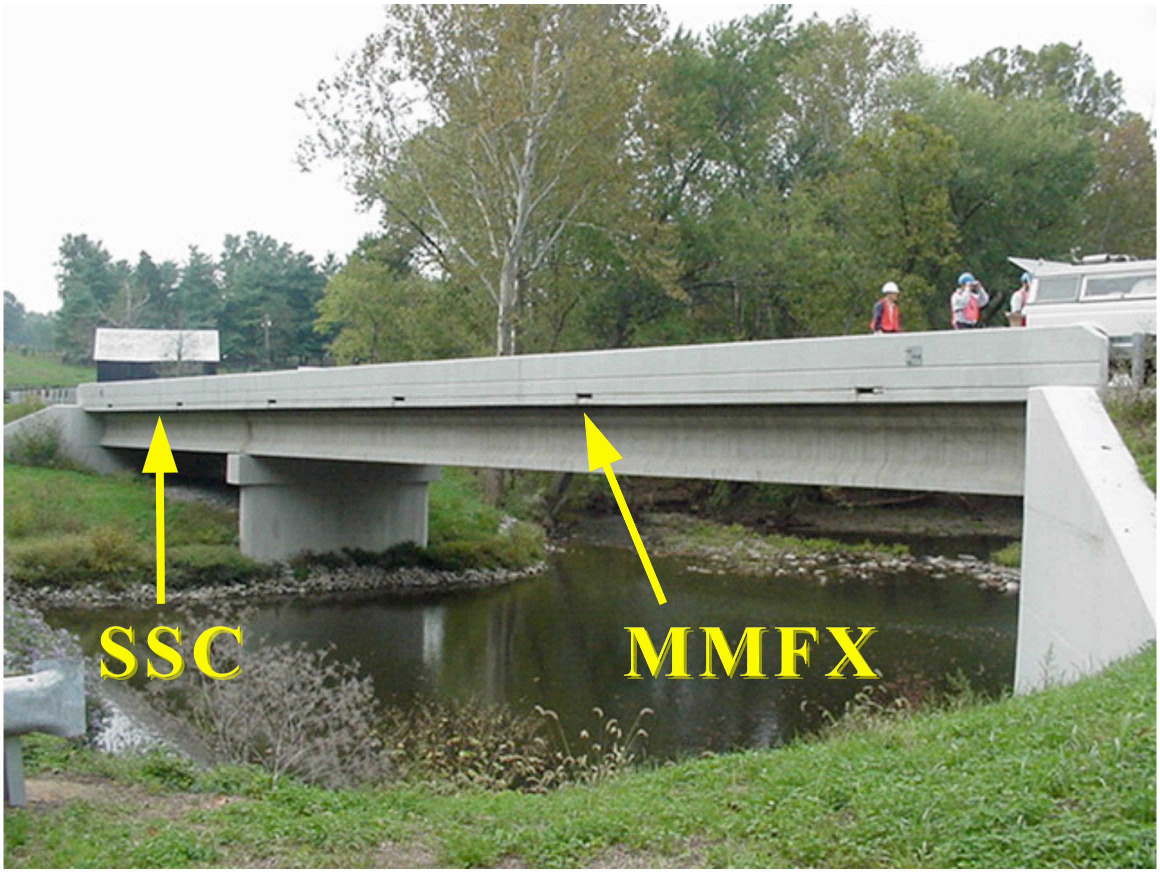


Fig. 8: SSC and MMFX bars were used in the bridge deck of the CR 5218 Bridge in Scott County, Kentucky, USA

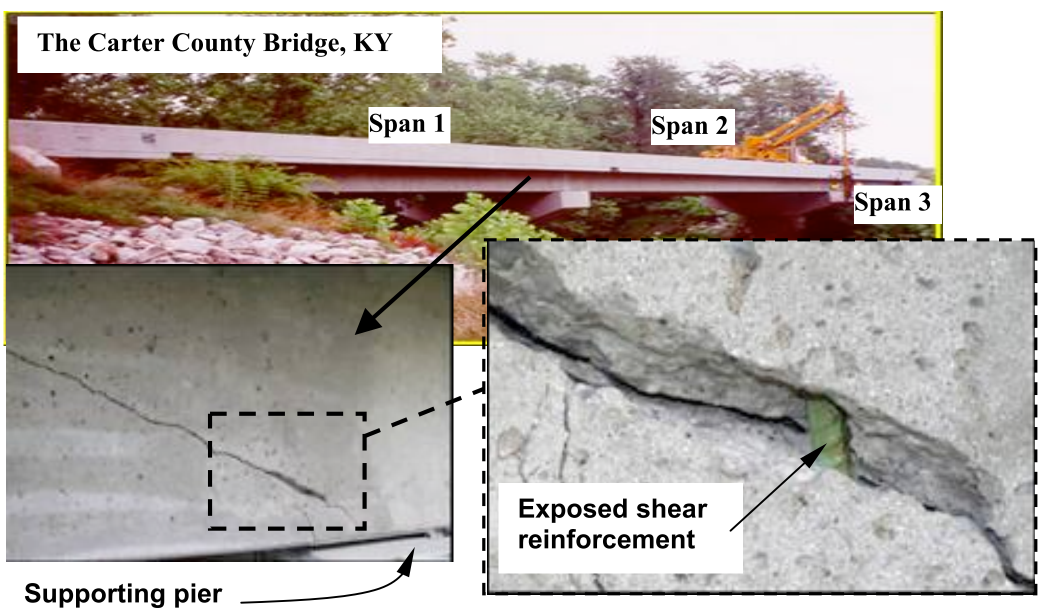


Fig. 9: Diagonal Shear Crack in Span 2 of the Carter County Bridge

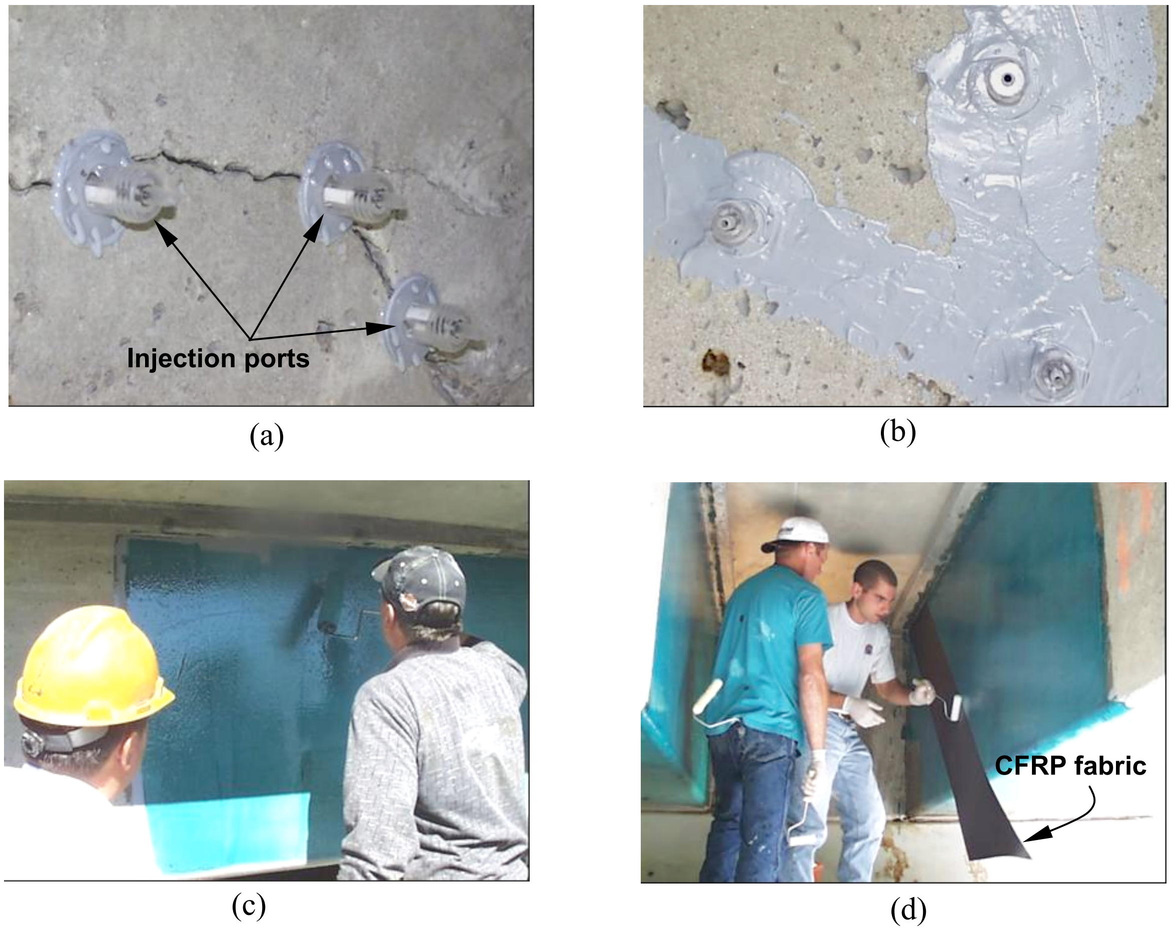


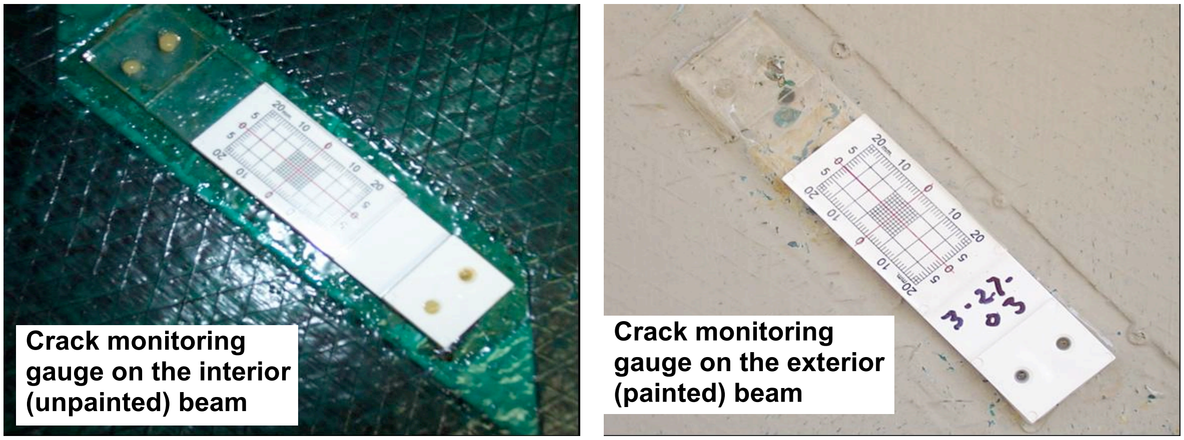
Fig. 10: Retrofitting of concrete box-beams in the Carter County bridge: (a) mounting of injection ports in cracks; (b) sealing cracks using epoxy; (c) applying two-part resin; and (d) attaching CFRP fabric to concrete

During the retrofitting process, crack monitoring gauges were mounted directly onto the beams over the repaired cracks (Fig. 11). As of September 2003, the repaired beams have shown no indication of distress as zero movement has been registered on these monitoring gauges [8].

The overall success of the project demonstrated that the use of advanced composites can be an effective retrofitting alternative. Additionally, the Kentucky Transportation Cabinet saved approximately $500 000 by repairing the bridge instead of replacing the entire superstructure as initially planned.

7. THE LOUISA-FORT GAY BRIDGE

The Louisa-Fort Gay Bridge is located in a small mining community of Lawrence County in Eastern Kentucky. The multi-span bridge has both steel plate girders and



(a) (b)

Fig. 11: Crack monitoring gauges mounted on repaired beams in the Carter County bridge

reinforced concrete (RC) girders in the end and middle spans, respectively. A schematic plan view of the middle RC spans (Spans 4-5-6-7) is shown in Fig. 12. Fig. 13 shows a section of the underside of the bridge deck with flexural cracks at the bottom of the girders.

Bridge inspection indicated that flexural cracks developed in the RC girders in Spans 4, 6, and 7 due to heavy coal truck loads. Weigh in motion scales measured trucks weighing in excess to 225 000 lb (1000 kN) [Note: the AASHTO HS20-44 Truck is 72,000 lbs (320 kN)]. For illustrative purposes, moment-curvature analysis, as shown in Fig. 14, reveals

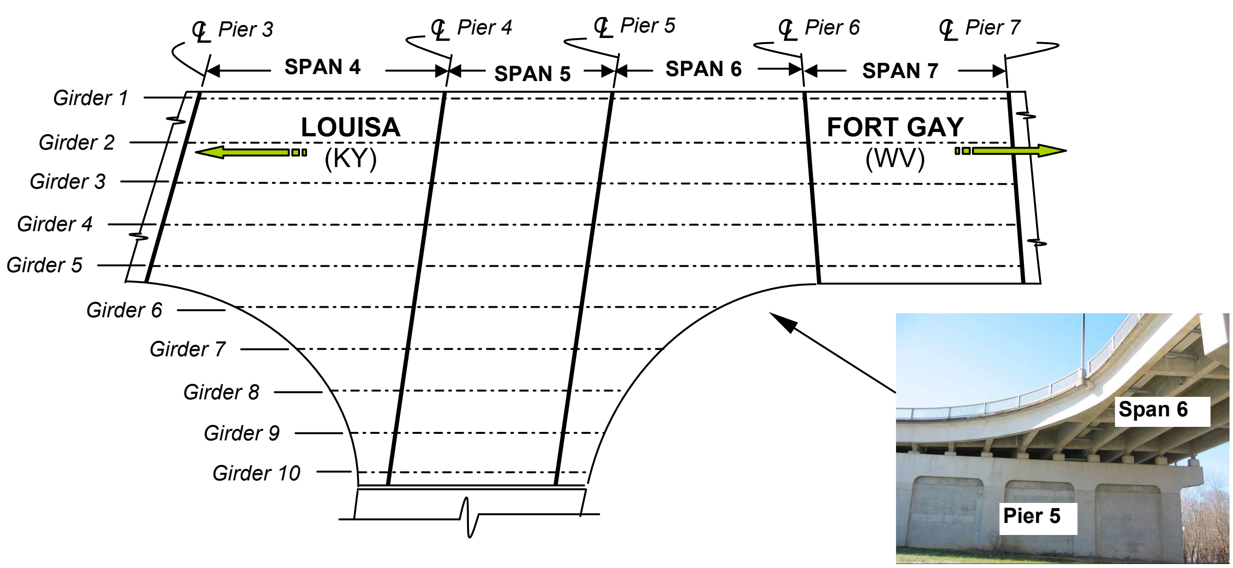


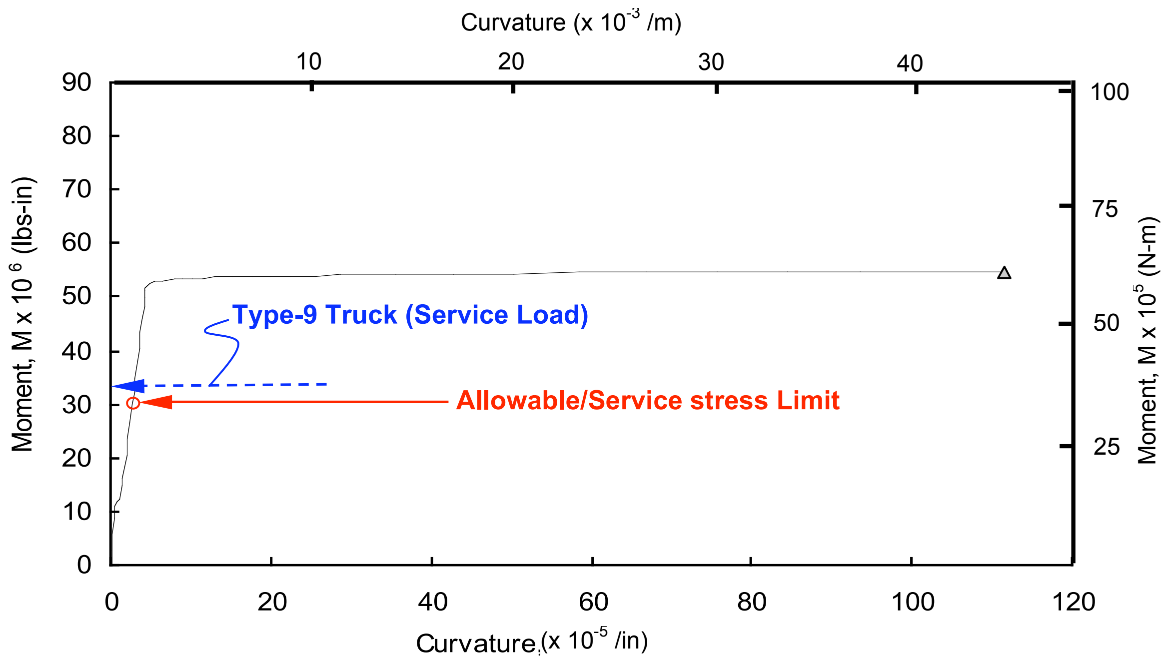
Fig. 12: The reinforced concrete spans of the Louisa-Fort Gay bridge

Fig. 13: Flexural cracks on the longitudinal reinforced concrete girders in the Louisa-fort Gay bridge

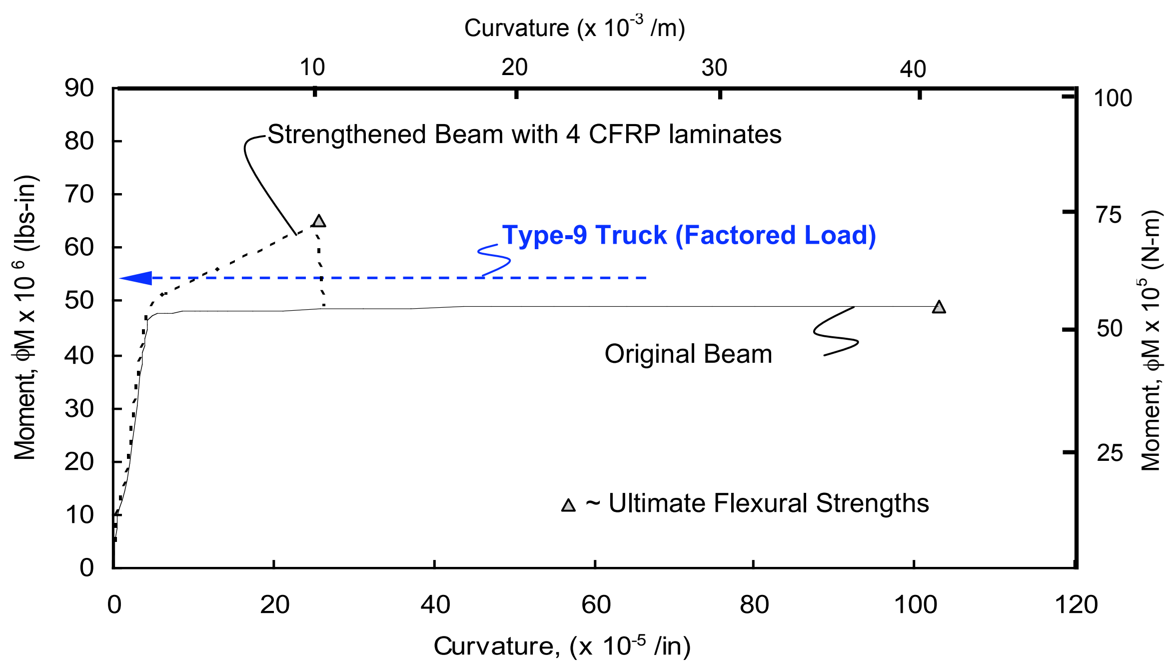
how much Girder 4 in Span 4 is being overloaded. The moment-curvature for the strengthened girder 4 in span 4 using CFRP laminates is presented in Fig. 14b. The retrofitting process is similar to the one previously described for the Carter County bridge, except that CFRP laminates are used as shown in Fig. 15.

10. CONCLUSIONS

The deployment of high performance materials in concrete bridges is presented herein. The components used in the new bridges were intended for experimental purpose and material evaluation. The two bridge retrofitting projects were chosen because of their economical advantage over other retrofitting alternatives.



(a)



(b)

Fig. 14: Moment-curvature analyses of girder 4 in span 4 in the Louisa-Fort Gay bridge

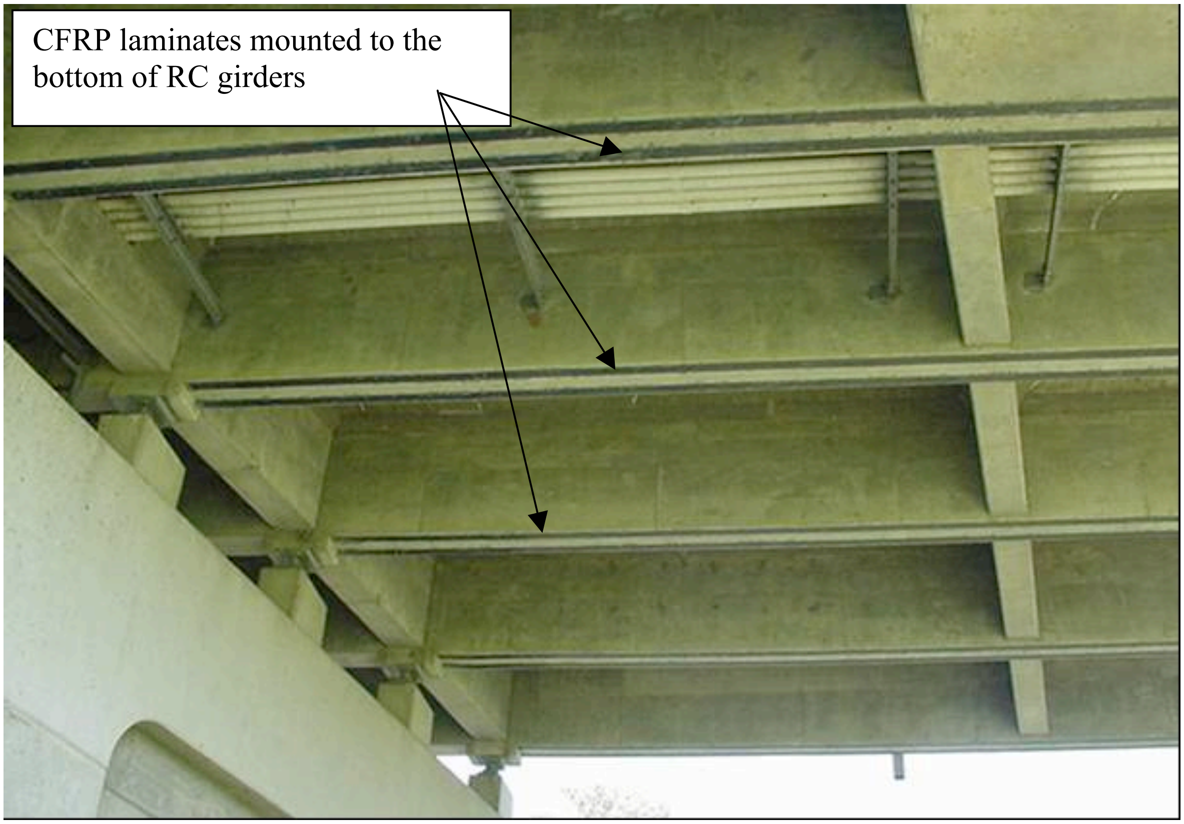


Fig. 12: Girders in span 6 strengthened with CFRP laminates in the Louisa-Fort Gay bridge

ACKNOWLEDGEMENTS

The work reported in this article is a summary of research conducted at the University of Kentucky on numerous research projects. The work was conducted by visiting professors, graduate and undergraduate students, staff members from the Kentucky Transportation Center, and staff members from the Kentucky Transportation Cabinet. The projects were funded by the US Department of Defense, the National Science Foundation, the Federal Highway Administration, and the Kentucky Transportation Cabinet.

REFERENCES

1. Alagusundaramoorthy, P., Harik, I.E., and Choo, C.C., "Shear Strengthening of R/C Beams Wrapped With CFRP Fabric," *Kentucky Transportation Center Research Report No. KTC-01-1, University of Kentucky*, Lexington, Kentucky, August 2002, 30 pp.

2. Alagusundaramoorthy, P., Harik, I.E., and Choo, C.C., "Flexural Behavior of R/C Beams Strengthened With CFRP Sheets or Fabric," *Kentucky Transportation Center Research Report No. KTC-01-2, University of Kentucky*, Lexington, Kentucky, August 2002, 38 pp.

3. Choo, C.C,, and Harik, I.E., "Inspection and Evaluation of a Bridge Deck Reinforced With Carbon Fiber Reinforced Polymer (CFRP) Bars," *Kentucky Transportation Center Research Report No. KTC 06-06/FRT-102-00-1F, University of Kentucky*, Lexington, Kentucky, March 2006, 18 pp.

4. Choo, C.C,, and Harik, I.E., "Performance Evaluation of Concrete Bridge decks Reinforced With MMFX and SSC Rebars," *Kentucky Transportation Center Research Report No. KTC 06-02/FRT-113-01-1F, University of Kentucky*, Lexington, Kentucky, January 2006, 39 pp.

5. Deitz, D., Harik, I.E., and Gesund, H., "GFRP Reinforced Bridge Decks," *Kentucky Transportation Center Research Report No. KTC-00-9, University of Kentucky*, Lexington, Kentucky, November 1999, 225 pp.

6. Harik, I.E., Alagusundaramoorthy, P., Gupta, V., Hill, C., and Choo, C.C., "Inspection and Evaluation of a Bridge Deck Partially Reinforced With GFRP Rebars," *Kentucky Transportation Center Research Report No. KTC 04-21/FRP Deck-1-97-1F, University of Kentucky*, Lexington, Kentucky, August 2004, 102 pp.

7. Hill, C., Choo, C.C, and Harik, I.E., "Reinforcement Alternatives for Concrete Bridge Decks," *Kentucky Transportation Center Research Report No. KTC 03-19/SPR-215-00-1F, University of Kentucky*, Lexington, Kentucky, July 2003, 35 pp.

8. Simpson, J.W. II, Harik, I.E., and Choo, C.C, "Shear Repair of P/C Box Beams Using Carbon Fiber Reinforced Polymer (CFRP) Fabric," *Kentucky Transportation Center Research Report No. KTC 06-01/FRT-114-01-1F, University of Kentucky*, Lexington, Kentucky, January 2006, 39 pp.