PRESERVATION OF EXISTING BRIDGES IN KENTUCKY USING ADVANCED COMPOSITES

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Abstract

Three bridge retrofitting projects involving the use of advanced composites – Fiber Reinforced Polymer (FRP) – will be briefly discussed in this paper. These applications of FRP composites include the following areas: repairing and strengthening of RC beams due to shear deficiency; flexural strengthening of RC beams due to increased loads; and repairing of PC beams due to the shrinkage. The success and effectiveness of FRP composites illustrated in the aforementioned projects, due to their tremendous advantages over conventional techniques, will definitely elevate their use in many other structural applications in the near future in Kentucky.

Keywords: Fiber reinforced polymer (FRP) composites, reinforced/prestressed concrete, bridge, retrofit

Introduction

According to the National Bridge Inventory Database (FHWA 2003), there are reportedly 591,220 numbers of bridge structures in the United States. Of this number 81,437 are classified as "*structurally deficient*" and 81,573 are "*functionally obsolete*". This indicates that an estimated 28 percents of the nation bridges are in need of repair or replacement. The same database also reveals that 3,997 of 13,461 bridge structures in Kentucky are in either category.

The use of advanced Fiber Reinforced Polymer (FRP) composites for repair and rehabilitation is rapidly gaining acceptance worldwide due to their resistance to corrosion, high strength-to-weight ratio, flexibility, etc. Some of the common applications involving FRP composites are: strengthening and repairing of RC and PC beams; repairing of seismic deficient RC columns and piers; and retrofitting of walls and slabs (Avramidou et. al. 1999, Hamilton et. al. 1999, Holloway and Leeming 1999, Hutchinson and Rizkalla 1999, Karbhari et. al. 1999, Norris et. al. 1997, Sonobe et. al. 1999, Tan 1997, Yamakawa et. al. 1999, and Zhao et. al. 2002). This paper intends to showcase some of the bridge preservation projects using FRP composites in the state of Kentucky. Three such projects will be discussed in this paper. These projects include the following areas of FRP applications: shear strengthening of precast prestressed concrete box beams; flexural strengthening of cast-in-place reinforced concrete beams due to increased live loads; and

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crack repairs of precast prestressed I-girders due to plastic shrinkage cracking. Conclusions and insights drawn from working with FRP composites will also be included.

Applications on Repair & Retrofit of Existing Bridges Using Carbon Fiber Reinforced Polymer (CFRP) Composites

The Carter County Bridge on KY-3297, Carter County, KY

The retrofitting project of the Carter County Bridge was funded by the Innovative Bridge Research & Construction (IBRC) Program – one of the Federal Highway Administration's (FHWA) Discretionary Programs intended to develop and promote the use of new materials and construction techniques for the repair, rehabilitation, replacement, or new construction of bridges and other structures, and it was also the first full-scale repair project using FRP composites undertaken by the Kentucky Transportation Cabinet, KY. A brief description of the bridge, the problem and the associated retrofitting technique will be discussed in the following sections.

The three-span [68'-98'-42' (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, KY. This bridge was designed based on the Load Factor Design method using HS25 as design live load (i.e. an increase of 25-percent over the existing standard of HS20-44 truck and lane loads) of AASHTO specifications. The bridge plans were completed and approved in February of 1992, and all work was completed in April of 1993.

A first and 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 (see Fig. 1) had formed in all four precast prestressed box beams at both ends of Span 2. Following that an in-depth inspection was scheduled and an investigation to re-evaluate the bridge was launched. Subsequent inspections revealed that the shear cracks in Span 1 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 Carter County Bridge began in September, 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. 2 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. 2d).

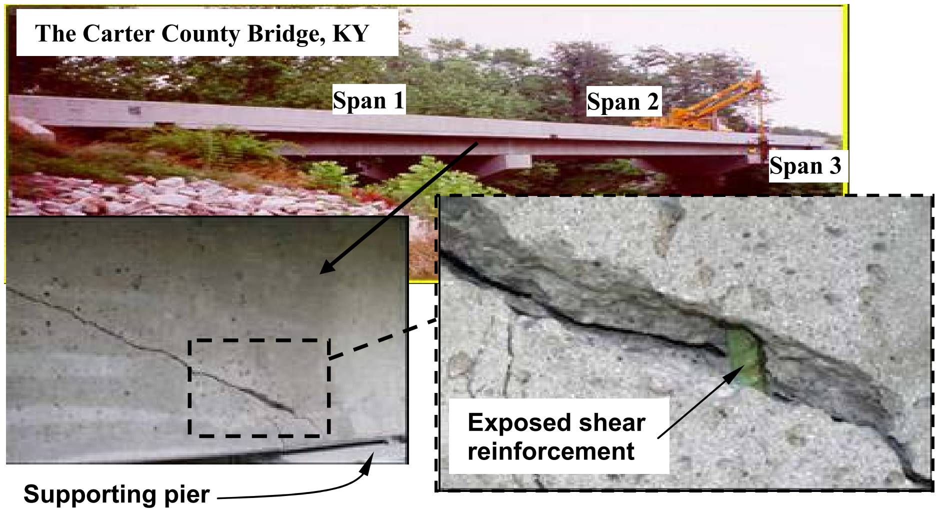


Fig.1 – Diagonal shear crack in span 2 of the Carter County Bridge.

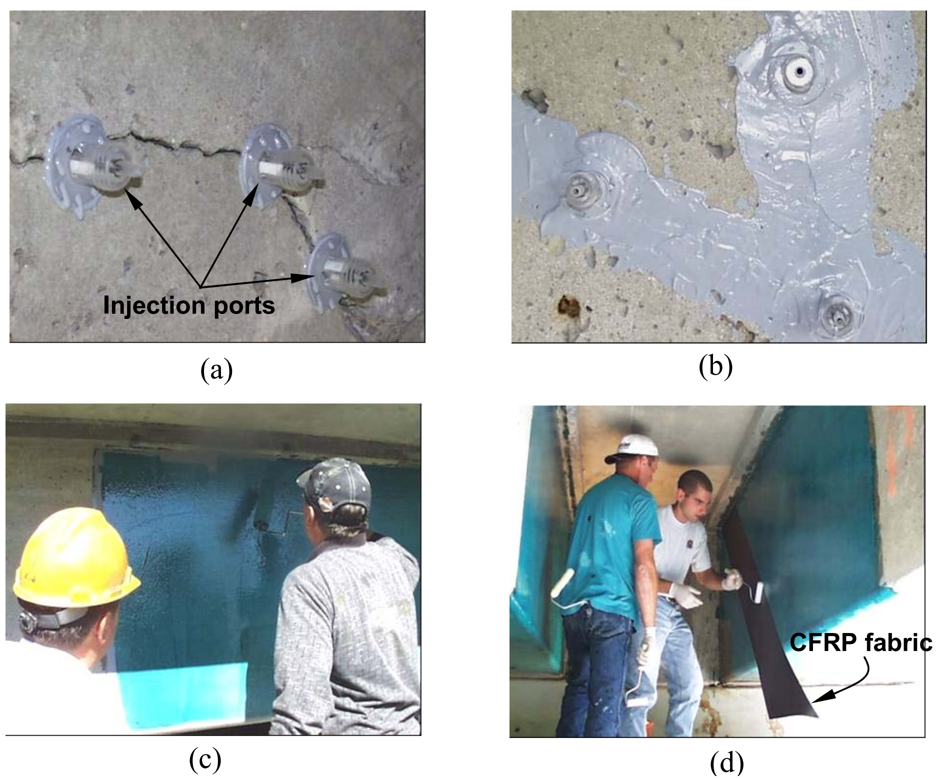
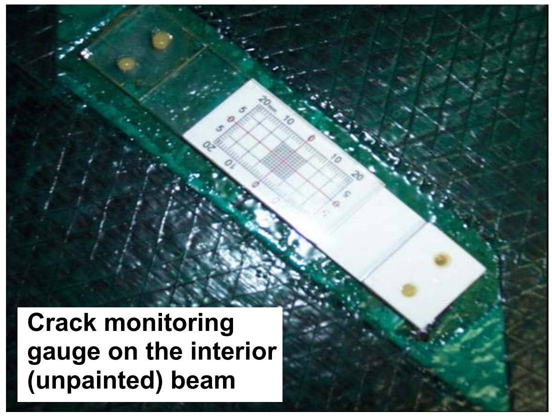


Fig. 2 – Retrofitting of concrete box-beams: (a) mounting of injection ports in cracks; (b) sealing cracks using epoxy; (c) applying two-part resin; and (d) attaching CFRP fabric to concrete.

During the retrofitting process, crack monitoring gauges were mounted directly onto the beams over the repaired cracks (see Fig. 3). As of April 2003, the repaired beams have shown no indication of distress as zero movement has been registered on these monitoring gauges.



(a)

(b)

Fig. 3 – Crack monitoring gauges mounted on repaired beams.

The overall success of the project demonstrated that the use of advanced composites can be an effective retrofitting alternative. Additionally, the Kentucky Transportation Cabinet had reportedly saved approximately $300,000.00 to repair the bridge than to replace the entire superstructure as initially planned.

Louisa-Fort Gay Bridge, Lawrence County, KY

The Louisa-Fort Gay Bridge is located in a small mining community of Lawrence County, Eastern Kentucky. The multi-span bridge has both steel plate girders and concrete RC girders supporting the concrete bridge deck 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. 4.

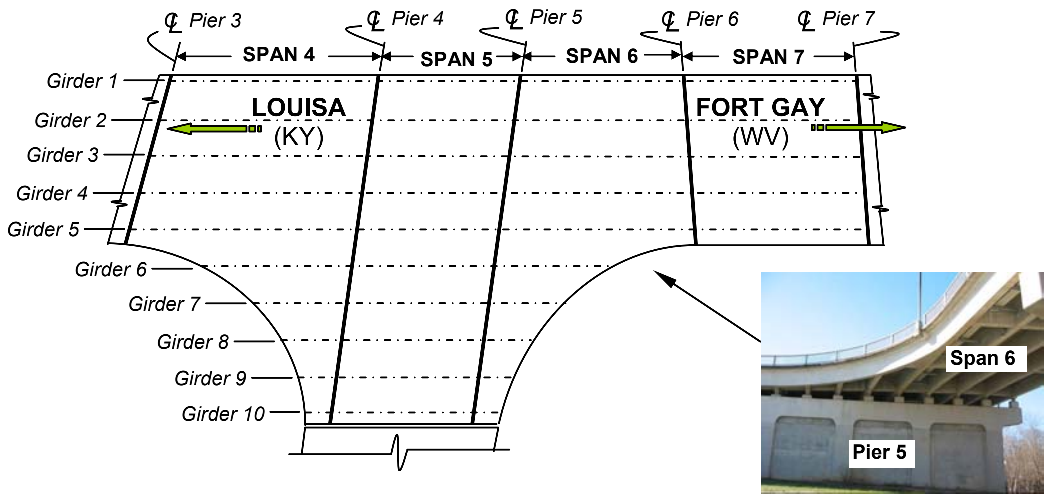


Fig. 4 – The reinforced concrete spans of the Louisa-Fort Gay Bridge.

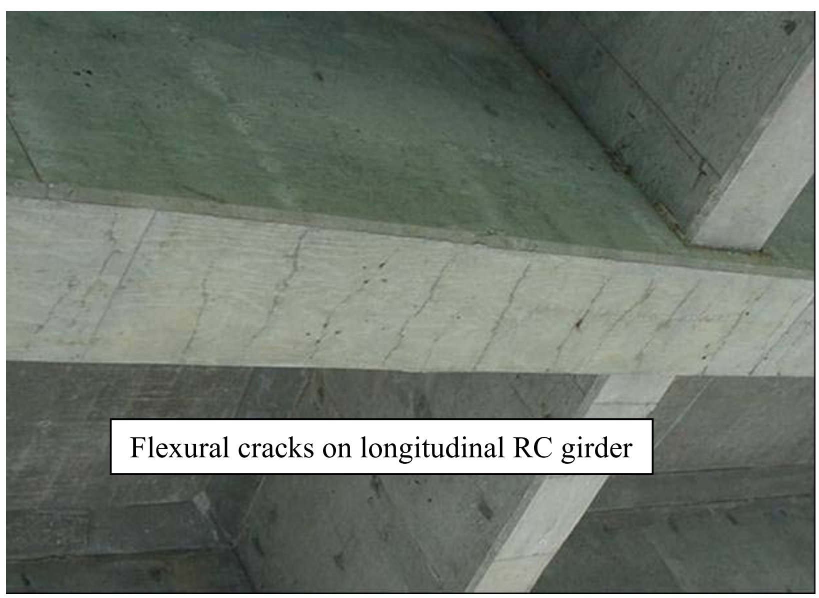


Fig. 5 – Flexural cracks on longitudinal reinforced concrete girders.

Bridge inspection indicated that flexural cracks had developed in the RC girders in Spans 4, 6, and 7 due to heavy truck loads – coal trucks (Type 9) as heavy as 225,000 lbs (1,000 kN) had been recorded [Note: AASHTO HS20-44 Truck is 72,000 lbs (320 kN)]. For illustrative purposes, moment-curvature analysis, as shown in Fig. 6, reveals how much Girder 4 in Span 4 is being overloaded. Strengthened Girder 4 in Span 4 using CFRP laminates is also included in Fig. 6b. The retrofitting process is similar to the one previously described for the Carter County Bridge, except that CFRP laminates will only be mounted to the bottom of the RC girders (see Fig. 7).

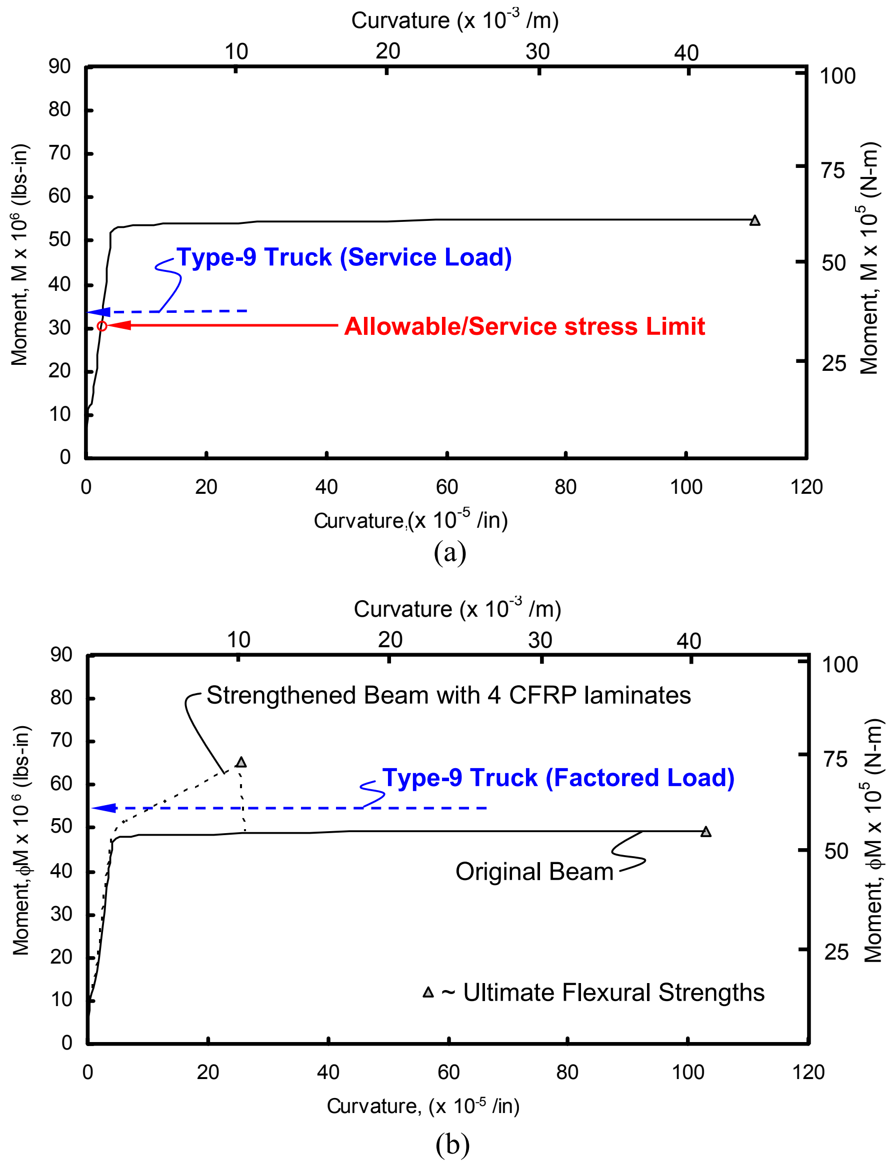


Fig. 6 – Moment-curvature analyses of girder 4 in span 4.

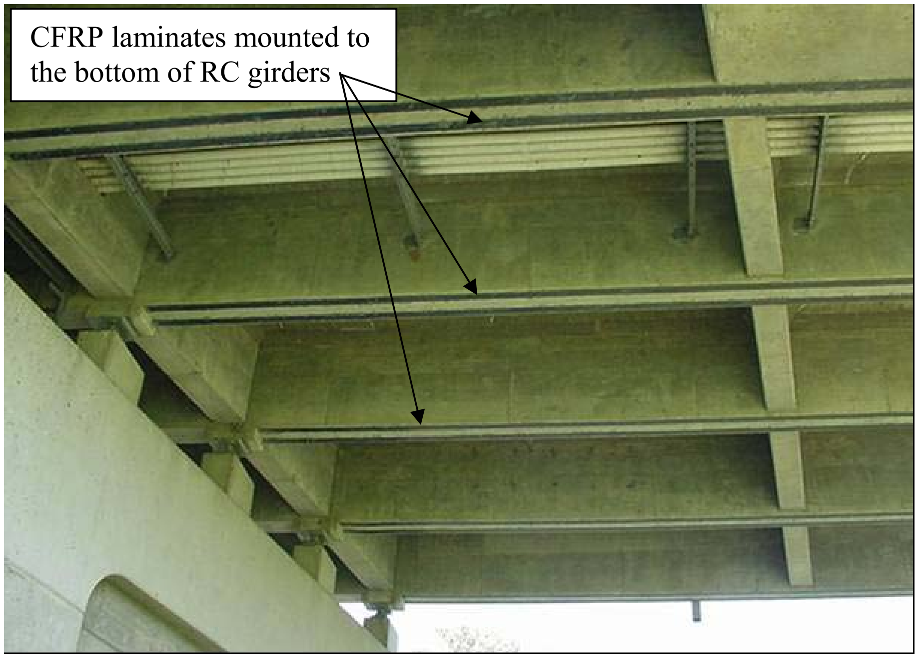


Fig. 7 – Girders in Span 6 strengthened with CFRP laminates.

I-65 Elevated Highway Bridges in Louisville, Jefferson County, KY

This interstate 65 elevated highway bridges in Louisville span across a number of streets in the heart of Louisville, Jefferson County, KY. The bridges were completed in 1979, and a number of cracks had developed on many of the prestressed concrete girders over the years. As indicated in Fig. 8, the cracks are 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. In some cases, severe corrosion of steel reinforcements has been detected at the locations of cracks (Fig. 9). As noted in the ACI 224 report (2001), cracking due shrinkage is inevitable in concrete structures, and cracking in these structures must be controlled or otherwise more severe serviceability problems may arise.

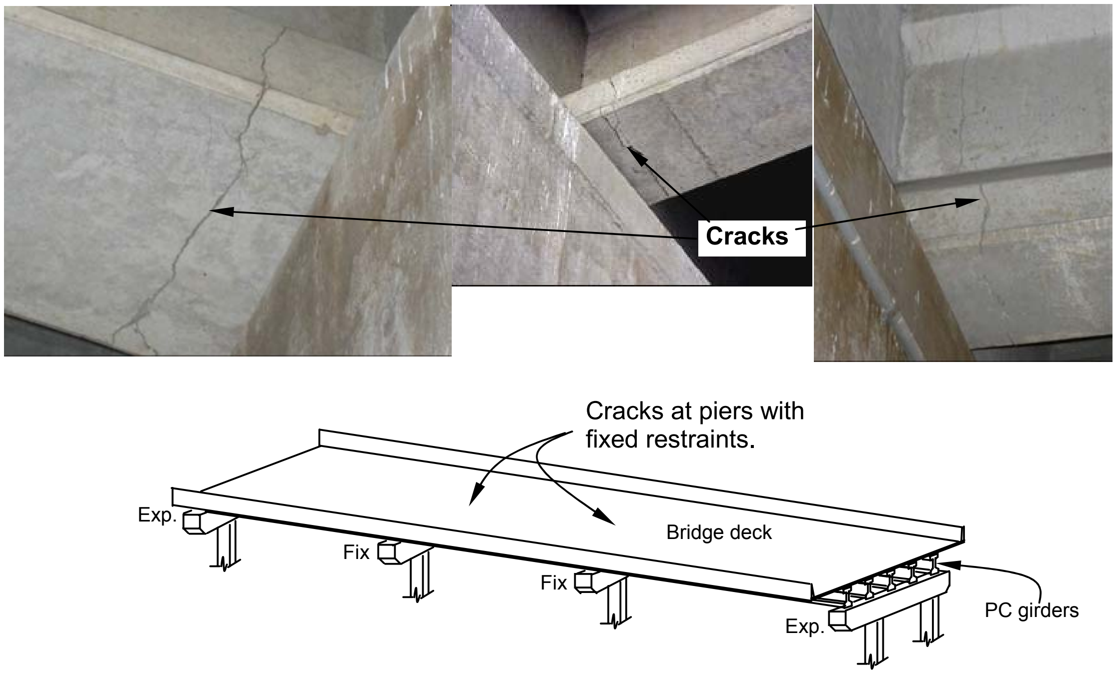


Fig. 8 – Cracks on prestressed concrete I-girders on the elevated portion of I-65 Highway Bridges.

Fig. 9 – Corroded strands at crack location.

Detailed analyses to estimate the restraining tensile forces due to volume change of PC girders had been performed. The primary goal of these analyses is to estimate the amount of FRP composites required for the restoration or strengthening process. In this particular case, FRP composites have been selected as the primary retrofitting material because of their tremendous flexibility and conformity, in addition to their excellent tensile strength. As shown in Figs. 7 and 8, cracks on PC AASHTO I-girders are generally located at hard-to-reach-areas near or at the supporting piers. The retrofit will initiate in Fall 2003 and is expected to be completed in Spring 2004.

Summary and Conclusions

Three bridge retrofitting projects involving the use of FRP composites in Kentucky are briefly discussed in this paper. These projects address three different areas of strengthening or repairing: (1) repairing and strengthening of RC beams due to deficiency in shear; (2) flexural strengthening of RC beams; and (3) repairs of PC beams due to shrinkage.

Based on the above experiences, the following advantages offered by FRP composites in the preservation of existing bridges can be observed:

1. It can eliminate or minimize traffic disruption during the retrofitting process.
2. It can eliminate or minimize the use of heavy equipments. Only hand tools and minimal man-power are often required.
3. It offers greater flexibility and conformity. Repairing in areas where other means of repair are difficult to perform
4. It offers a cost-effective alternative.

The success and effectiveness of advanced composites in retrofitting would certainly elevate their use in many areas of applications in Kentucky in the future to come.

References

ACI Committee 224, “Control of Cracking in Concrete Structures,” American Concrete Institute (ACI 224R-01), May 16, 2001.

Avramidou, N., Drdacky, M.F., and Prochazka, P.P., “Strengthening Against Damage of Brick Walls by Yarn Composites,” Proceeding of the 6th International Conference on Inspection, Appraisal, Repairs & Maintenance of Buildings & Structures, Melbourne, Australia. 1999.

FHWA, “National Bridge Inventory,” Bridge Technology – Infrastructure, United State Department of Transportation, Federal Highway Administration. February 2003.

Federal Highway Administration (FHWA, IBRC, 2001). Innovative Bridge Research & Construction Program, USA

Hamilton, H.R., Holberg. A., Caspersen, J., and Dolan. C.W., “Strengthening Concrete Masonry with Fiber Reinforced Polymers,” Fourth International Symposium – Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures, ACI International SP-188, Farmington Hill, Michigan. 1999.

Holloway, L.C., and Leeming, M.B., "Strengthening of Reinforced Concrete Structures using Externally-Bonded FRP Composites in Structural and Civil Engineering," 1st Ed., Cambridge: Woodhead Publishing Limited. 1999.

Hutchinson R.L. and Rizkalla, S.H., "Shear Strengthening of AASHTO Bridge Girders Using Carbon Fiber Reinforced Plastic Sheets," Fourth International Symposium – Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures, ACI International SP-188, Farmington Hill, Michigan. 1999.

Karbhari, V.M., Seible, F., Seim, W., and Vasquez, A., "Post-Strengthening of Concrete Slabs," Fourth International Symposium – Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures, ACI International SP-188, Farmington Hill, Michigan. 1999.

Norris, T., Saadatmanesh, H., and Ehsani, M., "Shear and Flexural Strengthening of R/C Beams with Carbon Fiber Sheets," Journal of Structural Engineering, New York, ASCE, v.123, n. 7. July 1997.

Sonobe, Y., Matsuzaki, Y., Nakamura, H., Iso, M. and Watanabe, M., "Experimental Study on Reinforced Concrete Columns having Wing Walls Retrofitted with Continuous Fiber Sheets," Fourth International Symposium – Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures, ACI International SP-188, Farmington Hill, Michigan. 1999.

Tan, K.H., "State-of-the-Art Report on Retrofitting and Strengthening By Continuous Fibers – Southeast Asian Perspective – Status, Prospects and Research Needs," Non-Metallic (FRP) Reinforcement for Concrete Structures – Proceedings of the Third International Symposium, Vol. 1, 1997.

Yamakawa, T., Satoh, H., and Zhong, P., "Seismic Performance of Hybrid Reinforced Concrete Circular Columns Confined in Aramid Fiber Reinforced Polymer Tube," Fourth International Symposium – Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures, ACI International SP-188, Farmington Hill, Michigan. 1999.

Zhao, T., Zhang, C.J., and Xie, J., "Study and Application on Strengthening the Cracked Brick Walls with Continuous Carbon Fibre Sheet," Advanced Polymer Composites for Structural Applications in Construction, Proceedings of the 1st International Conference, University of Southamption, UK. 2002.