I.3-8

Research Results

June 2005

repair of buildings & bridges with composites

PRESERVATION OF MISSOURI TRANSPORTATION INFRASTRUCTURE - VALIDATION OF FRP COMPOSITE TECHNOLOGY THROUGH FIELD TESTING

SUMMARY

This project is intended to validate the use of fiber-reinforced polymer (FRP) materials as a means to strengthen existing concrete bridges that are considered structurally deficient. For over a decade, FRP laminates have been used worldwide to strengthen, repair or add ductility to existing concrete bridges and buildings. However, despite all the well-documented benefits of using FRP materials for such applications, including low cost, minimal traffic disruption, and anticipated long-term durability, validation of this technology for bridge retrofit applications on a large scale is required.

The project was conducted in Missouri under a joint Missouri Department of Transportation (MoDOT) – University Transportation Center – Private Sector funding initiative. Five existing concrete bridges (see Figures 1 and 2), located in three districts in Missouri, were strengthened using FRP materials. These bridges will be monitored semiannually over five years including repeated load tests. The data, information and understanding from this validation will be used in the drafting of specifications to be written in AASHTO language for future FRP-related bridge-strengthening projects. This field work will focus on non-destructive evaluation (NDE).

Figure1 Approach and Deck of One of the Strengthened Concrete Bridge

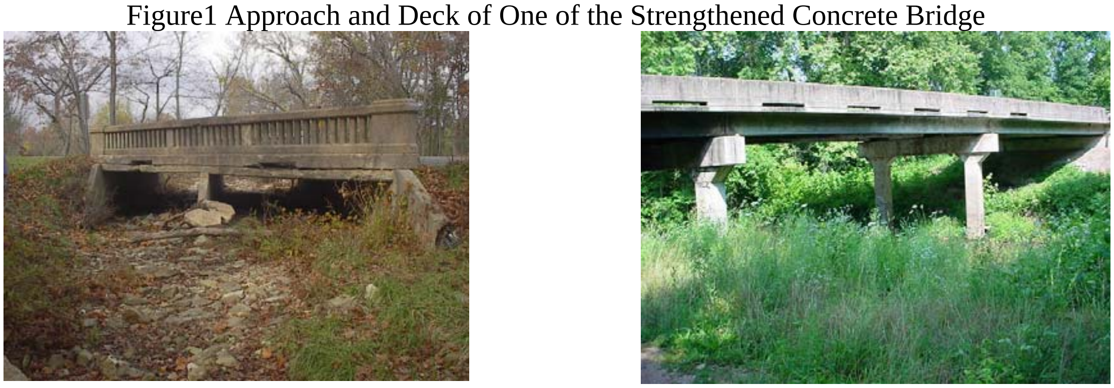


Figure 2 Lateral views of the strengthened concrete bridges: Solid Slab Bridge and T-Beam bridge.

BACKGROUND

The use of composite materials in the form of fiber reinforced polymer (FRP) materials for strengthening, repairing or adding ductility of bridge structures has been successful, because of well-documented benefits such as: low-cost, minimal traffic disruption, rapid execution and anticipated long-term durability. Nevertheless, despite the availability of ACI design guidelines for this emerging technology and the interest of State Departments of Transportation in developing specification written in American Association of State Highway and Transportation Officials (AASHTO) language, validation of this preservation technology for in service existing bridges remains necessary. This project describes a five-bridge strengthening program where five variations of composite technology were implemented to offer MoDOT a comprehensive case study addressing: assessment of deficiency, design, construction, load rating and long-term monitoring. Data and knowledge obtained from this validation is being used to draft specifications, written in standard language, for future FRP-related bridges strengthening projects

OBJECTIVE

- Validation of FRP technology through field installation and evaluation in the strengthening of bridges.
- Recollection of field data for the development of specifications written in AASHTO language to be used in future FRP-related bridge-strengthening projects.
- Develop of reliable and robust methods to detect voids and delaminations of a specified maximum size in FRP repair systems

DESCRIPTION OF THE PROJECT

In order to make these technologies available to bridge owners and practitioners, the University of Missouri-Rolla (UMR) and MoDOT joined in a cooperative research project to perform validation through field testing. A preliminary analysis to demonstrate the feasibility of the strengthening on candidate bridges was carried out, and from an initial list of hundreds of structurally deficient bridges, five load-posted reinforced concrete (RC) bridges, geographically spread over the state (see Figure 3), were selected to be strengthened using composite materials. This selection was based on location, quality of the concrete, accessibility, and the nature of the creek intersected. Four of the bridges are RC "T-beam" type (see Figure 1), and the fifth one is an RC "solid slab" type (see Figure 2). One of T-beam bridges has a four-girder supported deck, while the others have three girders. For the T-beam bridges, the number of spans varies from three to five, with span lengths ranging from 42.5 ft to 52.5 ft. The solid slab bridge consists of two 15 ft spans.

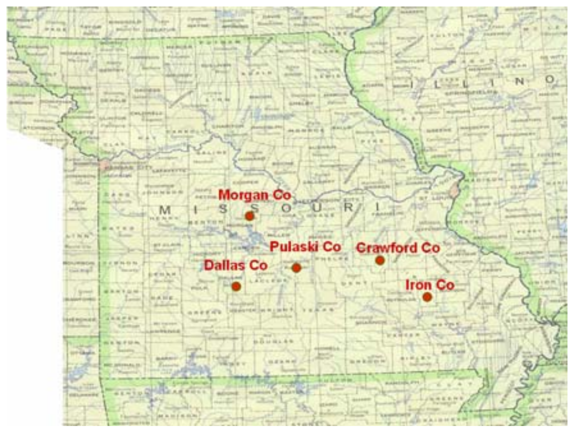


Figure 1 Location of the Five Bridges - Missouri

All bridges have a speed restriction of 15 mph and a load posting restriction that limits trucks over 18 to 21 tons for the T-beam RC bridges and 9 tons for the solid-slab RC bridge.

DESIGN

Load configurations and analysis were consistent with AASHTO Specifications. The analysis of the bridges was carried out for an HS20-44 truck or equivalent lane load. For material characterization, concrete cores were collected at the outset of the project for each bridge and the corresponding average mechanical properties were used for design and load rating. The compressive strength of the concrete ranged from 4.0 ksi to 6.8 ksi. Steel yield strength was assumed to be 40 ksi, as prescribed by

AASHTO, for bridges of that age since no steel coupons could be obtained on site.

The strengthening schemes were designed in compliance with ACI.440.2R-02, where applicable. As an example of the strengthening obtained following the procedure for analysis and design described in ACI.440, Figure 5 shows the envelope for moment demand, the moment capacity before the strengthening (as built) and strengthened moment capacity for the internal girders (half member) for interior girders in Bridge P-0962. Envelope curve is induced by a train of trucks moving from one side to the other of the bridge The strengthening capacity obeys the layout of the SRP flexural strengthening (half member) showed in Appendix A.

From the analysis and design, it was determined that out of the five bridges, the one that required the highest level of strengthening was Bridge P-0962, Dallas County. In this case, the nominal capacity increment corresponded to an increase of live load (since the dead load was not varied) of 30%. It is believed that this capacity upgrade is rather limited and well below the value suggested by the ACI design guide that was originally developed for the safety building structures. For bridge upgrades when the reinforcing steel is of low grade, the most important limiting consideration is that such reinforcement remains below 80% of its yield strength at service.

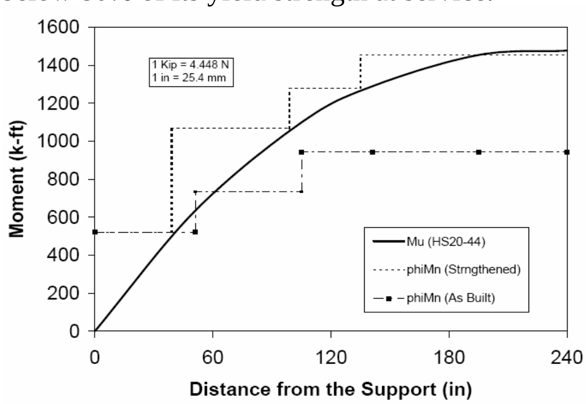


Figure 5 Flexural Demand, and Flexural Capacities (as built and after-Strengthening)

STRENGTHENING

The five bridges were strengthened using four different FRP techniques and a variation named steel reinforced polymer (SRP). More than one strengthening technique was used for each bridge (see table 1).

Table 1 Strengthening Techniques by Bridges

Bridge	CFRP MLU	Pre-Cured CFRP Laminates	CFRP NSM Bars	SRP MLU	MF FRP Laminates
T-0530	√	√	---	---	---
X-0495	√	---	√	---	---
X-0596	√	---	√	---	---
P-0962	√	---	√	√	---
Y-0298	√	---	---	---	√

The five different composite technologies go under the names of: manual lay-up FRP laminates (Figure 6); adhered pre-cured FRP laminates (Figure 7); near surface mounted (NSM) FRP bars (Figure 6); mechanically fastened FRP laminates (Figure 8); and, steel reinforced polymer (SRP) (Figure 9).

Figure 6. Manual lay-up Laminates and NSM Bars

Figure 7 Pre-cured FRP Laminates

Figure 8. Mechanically Fastened FRP Laminates

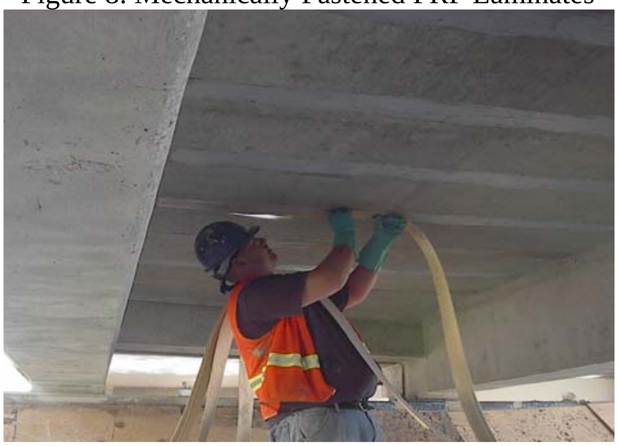


Figure 9. Steel Reinforced Polymer (SRP)

LOAD TESTING

Under the five-year monitoring program, in-situ load testing prior to and after the strengthening was implemented on each structure. The overall performance of the strengthened elements is based on the comparison of the behavior before and after the strengthening to show the improved performance of the bridge; subsequently, semiannual tests over a period of five years will show if stiffness degradation is occurring over time. Monitoring of deflection during the load tests was carried out using a novel non-contact technique based on high performance surveying technique that uses a "Total Station". By comparing the displacement with fixed reference points outside the structure, the operator can determine how much the element has moved. The static load tests were performed using standard trucks. Figure 10 shows the prisms attached to the girders of one of the bridges, the Total Station and loading trucks.

Deflections were measured at several locations, transversely at mid span and longitudinally along an exterior and its adjacent interior girder, using the magnet-mounted prisms. A typical comparison between deflections obtained from load tests performed before and immediately after the strengthening on one of the bridges is shown in Figure 11. As expected, a marginal decrease in deflection was obtained after the application of the FRP reinforcement. Subsequent tests over a period of five years will be compared to these two baselines. Significant changes in the deflection response could indicate the necessity of re-analyzing and re-rating the bridge structure.

Figure 10. Load Testing – Total Station, Reference Point, Prisms and Traffic Control

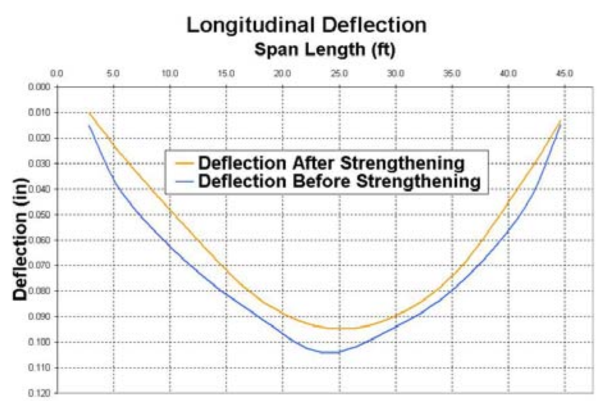


Figure 11. Lateral Deflection (Before and After Strengthening).

LOAD RATING

The safe load carrying capacity of the bridge after the strengthening was determined through load rating. Load rating is performed at two load levels. The first one, operating rating, defines the maximum allowable load to avoid damage on the bridge. The second rating, inventory rating, defines load level that the bridge can carry daily. Load posting is established using 86% of the operating rating. Load rating was calculated for four different truck types, as mandated by MoDOT. For each of these four different load conditions, the maximum shear and maximum moment are computed for each element of the bridge, i.e., deck, girders and bents.

Even though load postings have not been removed yet on any of the five bridges and therefore, there is no hard evidence at hand, it is believed that heavier traffic will not cause extensive cracking of the strengthened members and affect the bridge long-term durability.

INSTALLATION CRITERIA FOR FRP TO BE USED FOR FLEXURAL & SHEAR STRENGTHENING

In order to develop guidelines & specifications to investigate the performance of reinforced concrete structures strengthened with FRP composites, non-destructive evaluation (NDE) were planned to be performed under a five-year monitoring program. Another purpose of this investigation was to develop reliable, capable and robust methods to detect voids and delaminations of a specified maximum size in FRP repair systems. The basic requirements for these detection methods were to be simple, easy to apply in the field, and do not involve the use of complex or heavy equipment.

Apart from load testing that is conducted on all bridges, the NDT investigation is concentrated on bridge P-0962 in Dallas County. This investigation covers aspects such as: investigation of fiber alignment and measurement of optimum surface roughness, evaluation of bond properties, and load-induced strain. For delamination detection, strengthening systems were installed with intentional defects at non-critical locations (see Figure 12). Severe environmental conditioning effects, coupled with fatigue loading, will also be addressed. Investigated parameters will be monitored by using advance NDT technologies like echo impact testing (Figure 13), microwave scanning mechanism (Figures 14 and 15), laser profilometer (Figure 16), bond test by disk, fiber optic (Figure 17), and crack sensors.

Figure 12. Intentional defects at non-critical locations

Figure 13. Impact Echo Delamination Testing

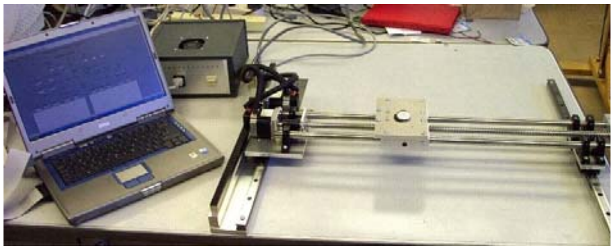


Figure 14 Microwave Scanner

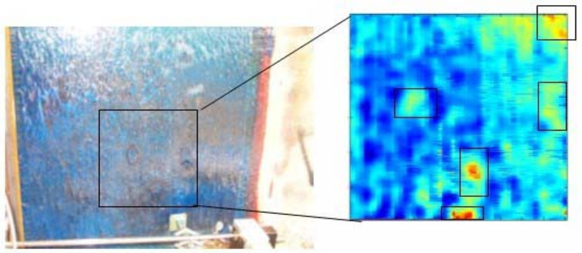


Figure 15. Microwave image of a disband

Figure 16. Laser Profilometer for surface roughness

Figure 17. Strain Fiber

EXPECTED DELIVERABLES AT THE COMPLETION OF THE PROGRAM

1. UPGRADE BRIDGES:

Five upgrade structures candidate for load-posting removal.

2. SPECIFICATIONS:

- Draft Design Guide for FRP Strengthened Bridges (AASHTO language).
- Draft Specification for FRP Strengthened Bridge Rating.
- Draft FRP Materials and Construction Specification (MODOT language).
- Draft Guide for Selection Criteria for Candidate Bridges w/ Cost Estimates.
- Draft Guide for Selection Criteria for Life Expectancy Estimate**.**

NDT TECHNOLOGIES:

- <u>Near-Field Microwave Delamination Detection</u>

Delivery of a unique (compared to the standard available methods) inspection concept and validated method.

- <u>Bond Strength, Surface Roughness, Fiber Alignment</u>

Description of developed field methodologies for testing; optimal surface condition for FRP installation; evaluation of installation procedures.

CONCLUSIONS

The aim of the present project is to make these strengthening technologies available to bridge owners and professionals by creating a comprehensive and authoritative series of documents (specifications and guides) on the technology of composite strengthening of bridge structures. These specifications/guides have been written in standard language for future FRP-related bridge-strengthening projects. The expectation is that the research program can demonstrate that repair/strengthening of bridge structures, using FRP and SRP composites, produces significant savings by prolonging expected service life and by providing a more efficient rehabilitation. Know-how on strengthening and monitoring techniques will be provided to MoDOT personnel, engineering consultants, contractors and public owners of bridges by means of reports, and technology-transfer in the form of software and documents.

WANT MORE INFORMATION?

http://campus.umr.edu/utc/research/r098/reports.htm

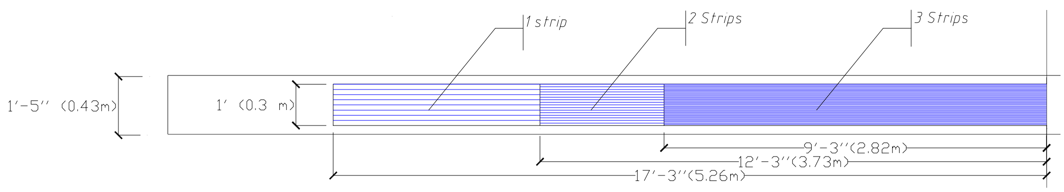
CONTACTS:

Alexis Lopez
PhD Candidate
University of Missouri-Rolla
Tel: (573) 341-4560 Fax: (573) 341-6215
Email: aalkv5@umr.edu

Eli S. Hernandez
PhD Candidate
University of Missouri-Rolla
Tel: (573) 341-6656 Fax: (573) 341-6215
Email: ehd36@umr.edu

Antonio Nanni
V & M Jones Professor of Civil Engineering
University of Missouri-Rolla
Tel: (573) 341-4497 Fax: (573) 341-6215
Email: nanni@umr.edu

APPENDIX A: Steel reinforcement Polymer (SRP) Layout



Appendix A Steel reinforcement Polymer (SRP) Layout

APPENDIX B: Results and deliverables

The following table summarizes accomplishments as of the date of this summary.

	Task	**Activities Accomplished**
		Development of Draft Specifications
	S1. Materials	First draft completed and submitted under the title Master Construction Specifications. Waiting for MoDOT feedback.
	S2. Design (w/ Safety Factors)	First draft completed and submitted under the title Design Guidelines in AASHTO language. The document includes MathCAD platform software for Design. Waiting for MoDOT feedback. Detailed reports (five) presenting analysis and design for each of the strengthened bridges completed and submitted.
	S3. Installation	This task in terms of deliverables has been merged with S1.
	S4. Bridge rating	Analytical part of the task completed. Collection of field data continues and validation to be conducted at the end of the program.
	S5. Inspection & Maintenance	Collection of field data continues in conjunction with the semiannual load tests.
		Development of Draft Guides,
	G1. Selection Criteria for Candidate Bridges w/ Cost Estimates	Data collection on costs for the five bridges completed. Report including expert system software in progress. Trial version expected for end of summer '05.
	G2. Life Expectancy Estimate	Collection of field data continues with emphasis on Bridge P-0962.

Research & Validation	V1. Material Characterization	Detailed reports (five) presenting materials and costs for each of the strengthened bridges completed and submitted.
	V2. Bridge Upgrade	Task completed including some concrete repairs not originally budgeted, but approved during the course of the upgrade.
	V3. Load Tests & Monitoring	Four series of load tests on all five bridges has been carried out. Analysis of the data is in progress. No indication of deterioration at this time.
	V4. Field and Laboratory R&D	<u>Near-Field Microwave Delamination Detection</u> An automated scanning mechanism conducive for on-site inspection of bridge members has been constructed, along with a microwave inspection method capable of automatically removing most of the adverse influences of standoff distance variation over a given CFRP patch. A catalog, consisting of a scan of each patch on the Bridge P-0962 has been completed. Results of periodic future scans of these patches will then be compared to these evaluate changes in the patch properties (e.g., delamination enlargement). <u>Bond Strength, Surface Roughness, Fiber Alignment</u> For repair and strengthening of concrete structures with FRP, the load carrying ability of FRP may be affected by surface preparation of the concrete substrate, fiber alignment and air voids created during installation of externally bonded sheets. During the course of the project the surface roughness was identified with a profilometer, which is the first existing roughness measuring device for use in the field. Following the installation of FRP by the contractor, fiber alignment was performed to assure that fibers were installed within 5 degrees of allowable deviation. In 6 month intervals, forced delaminations have been tested for growth using impact echo method. Control plugs installed in various locations have been used to monitor the bond strength, using pull-off tests. <u>Strain Determination by Fiber Optic</u> No information provided by Co-PI Watkins.
Technology Transfer		Videos developed during construction phases according to TT plan were processed in didactical CDs. Videos cover aspects regarding storage, handling, installation, and required quality procedures for FRP-strengthened bridges. Conducted a one-day TT public event.