RDT

Brief

R.I. 02-022 March, 2005

Preservation of Missouri Transportation Infrastructure - Validation of FRP Composite Technology Through Field Testing

Research Development and Technology

Missouri Department of Transportation

2217 St. Marys Blvd.
P.O. Box 270
Jefferson City,
Missouri 65102

Introduction

Under the work of a research team at the University of Missouri-Rolla (UMR), 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 (Figure 1). For over a decade, FRP laminates have been used worldwide to strengthen, repair or add ductility to existing bridges and buildings. Composite materials are strong, lightweight and not susceptible to corrosion. However, despite all their well-documented benefits, including competitive cost, no traffic-disruption and short-time installation, and anticipated long-term durability, validation of this technology for bridge retrofit applications on a large scale is required.

Figure 1 Bridge P-0962 on Rte. B in Dallas County.

Five existing concrete bridges, geographically spread over three MoDOT districts, were strengthened using five different composite technologies that go under the names of manual lay-up FRP laminates (Figure 2); adhered pre-cured FRP laminates (Figure 3); near surface mounted (NSM) FRP bars (Figure 2); mechanically fastened FRP laminates (Figure 4); and, steel reinforced polymer (SRP) (Figure 5). The aim of the present project is to make these strengthening technologies available to bridge owners and professionals through the development of proposed FRP bridge strengthening design, materials, and construction specifications for potential AASHTO adoption. Validation of composites, taking into account durability issues and cost impact, is undertaken with a five-year monitoring program with an emphasis on non-destructive testing (NDT) evaluation.

Figure 2 Manual lay-up FRP laminates and FRP NSM bars.

NDT evaluation in this project involves the development of reliable

Figure 3 Adhered pre-cured FRP laminates.

Figure 4 Mechanically fastened FRP laminates.

Figure 5 Steel reinforced polymers (SRP).

and robust methods to perform quality control inspection and long-term monitoring of FRP strengthening materials. The basic requirements for these inspection and detection methods are 1) simplicity, 2) ease of use in the field, and 3) lack of complex or heavy equipment. Apart from load testing conducted on all bridges throughout the monitoring program, the NDT investigation is concentrated on bridge P-0962 in Dallas County (Figure 1) where instrumentation has been installed to provide long-term monitoring capability.

Strengthening of Five Bridges

Field strengthening, using composite materials, of the five existing bridges located in Morgan, Dallas, Pulaski, Crawford and Iron Counties took place during the summer 2003. Construction was successfully performed under a team-oriented, design-build-verify format involving UMR, Structural Preservation System, and MoDOT. Each bridge used various combinations of composite technologies (Table 1).

Table 1 Composite technologies used per bridge.

Bridge	CFRP Sheets by Manual Lay-Up	Pre-Cured CFRP Laminates	CFRP NSM Bars	SRP by Manual Lay-Up	Mech. Fasten. FRP Laminates
Morgan County X-0596	X	X	-	-	-
Dallas County P-0962	X	-	X	-	-
Crawford County T-0530	X	-	X	-	-
Pulaski County Y-0298	X	X	X	X	-
Iron County X-0495	X	-	-	-	X

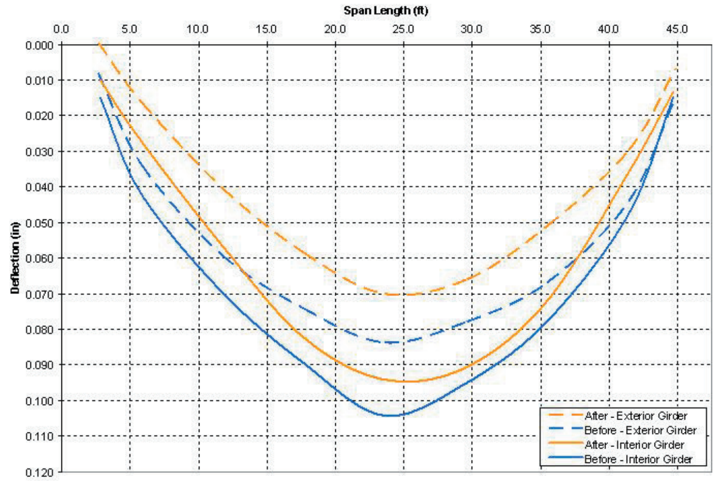
For repair and strengthening of concrete structures with FRP, the load carrying ability of FRP may be affected by surface preparation of the concrete substrate, fiber alignment, air voids created during installation of the externally bonded sheets, and delaminations and disbonds which could occur and progress over time. Prior to installation some concrete repair work was required to remove deteriorated concrete at the bents and deck undersides where FRP material was to be applied. As part of the installation procedure, preparation of the concrete substrate was extremely important to promote a quality bond between the FRP and concrete surface, since such a bond is crucial for the surface-bonded reinforcement technique to be successful. During construction, optimum surface roughness was identified with a UMR developed profilometer utilizing image analysis techniques, which is the first existing roughness measuring device for use in the field. Following installation of the FRP by the contractor, fiber alignment was performed to assure that fibers were installed within 5 degrees of allowable deviation. Since installation, near-field microwave NDT technology and Impact-echo testing have been used to detect delaminations and disbonds between the FRP and concrete. For the purpose of further investigation of the NDT technologies and the composite strengthening technique, some strengthening systems were installed with intentional defects at non-critical locations (Figure 6). These locations will continue to be evaluated over the five-year monitoring program. Pull-off tests, using control plugs installed in various locations have been conducted and will continue for monitoring the bond strength between the composite material applied and concrete surface.

Figure 6 Intentional defects in FRP laminates installed for evaluation purposes.

Load Testing

Periodic structural load testing of the five bridges serves as a vital aspect for research and validation of the composite strengthening technology. Load testing was carried out on each of the five bridges before and after strengthening and will be repeated every six months over the five-year monitoring program. Static load tests are performed using H20 dump trucks provided by MoDOT with load deflections measured using a non-contact technique involving sophisticated surveying equipment. Magnet-mounted targets monitored by a Leica TCA 2003 robotic total station offer an ideal means of measuring deflections at mid span and longitudinally along chosen girders. Initial measurements (Fig. 7) show some reduction in deflection, i.e., marginally increased stiffness, due to the presence of the FRP material. Over time, load testing can show deterioration in the strengthening system or in the original bridge structure itself. On Bridge P-0962, strains occurring in the substrate, existing rebar, and FRP materials are monitored during load testing using an array of twelve fiber-optic strain sensors and six electrical strain gages specifically installed for long term monitoring. These measurements will be analyzed for changes related to the performance of the reinforcement and for correlation with expected values from calculations.

Figure 7 Initial load test results, before and after strengthening, for Bridge T-0530 on Rte. M in Crawford County.



Summary of Progress to Date

Upgraded Bridges

Since the initiation of this project, the UMR research team has made considerable progress towards achieving project goals and providing expected deliverables. In cooperation with MoDOT, five existing bridges considered structurally deficient have been upgraded by Structural Preservation System using composite strengthening technologies. Post-strengthening load testing and monitoring continue to evaluate the performance and behavior of the in-place FRP materials and existing structures with no indication of deterioration at this time. The five-year monitoring program of the five bridges will conclude in 2008.

Proposed Specifications

As a result of this project and related efforts, the following draft specifications and guidelines have been developed by the UMR research team:

- draft Design Guide for FRP Strengthened Bridges (AASHTO language)
- draft FRP Materials and Construction Specification (MoDOT language)

Development is underway for the following guidelines:

- draft Specification for FRP Strengthened Bridge Rating
- draft Guide for Selection Criteria for Candidate Bridges w/ Cost Estimates
- draft Guide for Selection Criteria for Life Expectancy Estimate

NDT Technologies

This project involves an emphasis on the development and application of NDT technologies to facilitate and improve FRP composite material installation procedures, testing, and long-term performance evaluation. As a result, the following NDT technologies and methods have been successfully advanced as part of this project:

- Near-Field Microwave Delamination Detection - Delivery of a unique (compared to the standard available methods) inspection concept and validated method.
- Bond Strength, Surface Roughness, Fiber Alignment - Description of developed field methodologies for testing; determination and measure of optimal surface condition for FRP installation; effective evaluation of installation procedures.
- Strain Determination by Fiber Optics – Development of database of load-induced strain performance over time and related analysis; description of installation procedures for fiber-optic instrumentation and evaluation of health-monitoring capability.

Technology Transfer Materials

Numerous publications and related-technology transfer materials (video and conference proceedings) have been produced as part of this project. These materials along with draft specifications can be viewed at the UMR-UTC website (*http://campus.umr.edu/utc/*).

For more information, contact:

Antonio Nanni, Ph.D., P.E.
Jones Professor of Civil Engineering
University of Missouri-Rolla
224 Engineering Research Lab
Rolla, MO 65409-0710
(573) 341-4497
email: *nanni@umr.edu*

Bryan Hartnagel, Ph.D., P.E.
Structural Special Assignment Engineer
Missouri DOT
105 W. Capitol Avenue
Jefferson City, MO 65102
(573) 751-0267
email: *Bryan.Hartnagel@modot.mo.gov*