

## Missouri's FRP Composite Strengthening Field Tests Enter Third Year

### Introduction

For more than 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 well-documented benefits, including competitive cost, no traffic disruption, short-time installation, and anticipated long-term durability, validation of this technology for bridge retrofit applications on a large scale has been needed. Since 2002, a research team at the University of Missouri-Rolla (UMR) has conducted field tests to validate the use of fiber-reinforced polymer (FRP) materials as a means to strengthened existing bridges that are considered structurally deficient (Figure 1 and Figure 2).

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 3); near surface mounted (NSM) FRP bars (Figure 4); adhered pre-cured FRP laminates (Figure 5); mechanically fastened FRP laminates (Figure 6); and, steel reinforced polymer (SRP) (Figure 7). 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.

NDT evaluation in this project involves the development of reliable and robust methods to perform quality control inspection and long-term monitoring of FRP strengthening materials. The basic requirements for these detection methods are: 1) simplicity, 2) ease of use in the field, and 3) lack of complex or heavy equipment. Apart from load testing that is 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.



Figure 1 - Bridge P-0962 Dallas County



Figure 2 - Bridge T-0530 Crawford County



Figure 3 – Manual lay-up FRP Laminates



Figure 5 – Adhered Pre-Cured FRP Laminates



Figure 4 – Near Surface Mounted FRP Bars



Figure 6 – Mechanically Fastened FRP Laminates

## 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 of 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 – FRP Technologies Used in Each Bridge

Bridge Code	CFRP Sheets by manual Lay-Up	Pre-Cured CFRP Laminates	CFRP NSM Bars	SRP by Manual Lay-Up	Mech. Fasten. FRP Laminates
T-0530	√	√	---	---	---
X-0495	√	---	√	---	---
X-0596	√	---	√	---	---
P-0962	√	---	√	√	---
Y-0298	√	---	---	---	√

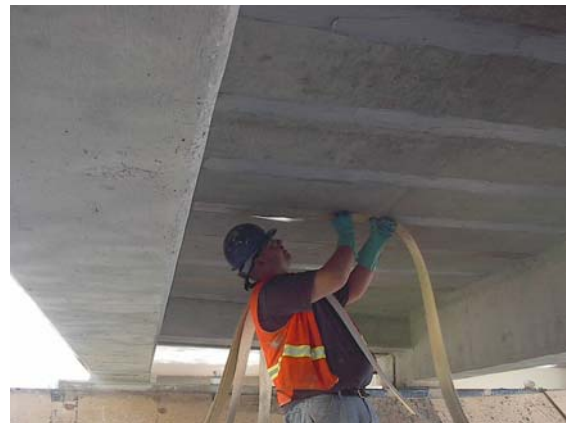


Figure 7 – Steel Reinforced Polymers (SRP)

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.

For strengthening and repairing 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

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 disbands 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 8). 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 8 – Intentional defects in FRP laminates installed for evaluation purposes**

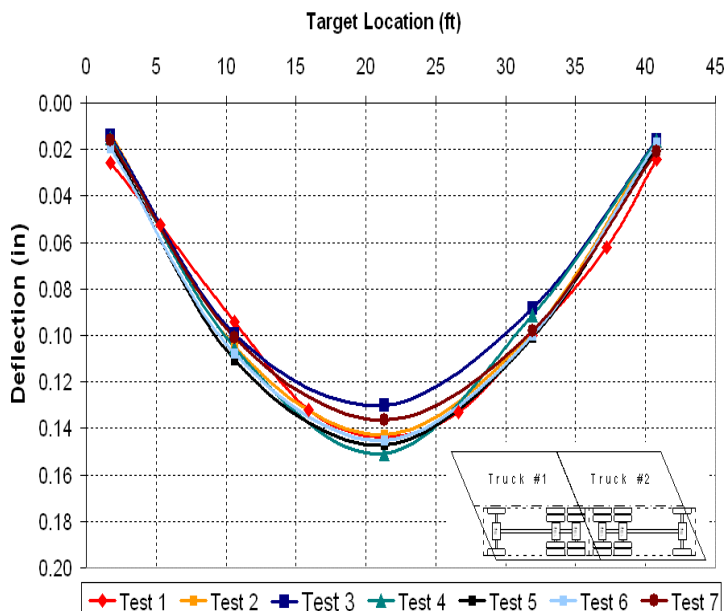
Over time, load testing can show deterioration in the strengthening system or in the original bridge structure as a consequence of a variation in the deflection response of the structure, allowing further more detailed investigation and if necessary, the re-rating and possible repair of the structure. 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 9 – H2O MoDOT Dump Trucks, Total Station and Mounted Prisms during Load Testing**

### In-Situ Load Testing

Periodic structural load testing of the five bridges serves as a vital aspect for the 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 H2O dump trucks provided by MoDOT (Figure 9) and were designed to produce the most demanding conditions for all structural members of the bridge. During the load tests, deflections are measured by a non-contact deflection technique involving the use of sophisticated surveying equipment. Magnet-mounted targets monitored by a Robotic Tacheometry System (Leica TCA 2003) (Figure 9) offer an ideal means of measuring deflections at mid-span and longitudinally along chosen girders. Table 2 reports the load testing schedule for the first seven series of load testing conducted up to date. Load test 1 was conducted before the strengthening of the five bridges and load tests 2 through 7 were conducted after the strengthening. Figure 10 reports the experimental results along one of the external girder prior and after strengthening of the Bridge in Dallas County. Initial measurements show some initial reduction in deflection, i.e., marginally increased stiffness due to the presence of FRP material.



**Figure 10 – Load Test Results, before and after Strengthening for Bridge P-0962 on Route B in Dallas County**

**Table 2 – Load Testing Schedule**

Bridge Code	T-0530	X-0495	X-0596	P-0962	Y-0298
Load Test 1	7/09/03	7/08/03	8/19/03	8/14/03	10/15/03
Load Test 2	11/03/03	10/29/03	11/10/03	11/17/03	11/12/03
Load Test 3	5/12/04	5/04/04	5/06/04	5/05/04	5/13/04
Load Test 4	10/25/04	10/27/04	11/09/04	11/10/04	11/08/04
Load Test 5	4/25/05	4/27/05	4/20/05	5/04/05	5/02/05
Load Test 6	10/18/05	10/11/05	10/25/06	10/20/05	10/06/05
Load Test 7	4/17/06	5/01/06	4/03/06	4/10/06	4/12/06

## 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 be concluded 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)

*(Be sure to visit the web site listed on page 5.)*

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.

Fieldwork for monitoring focused on non-destructive evaluation. Conditions such as delamination and voids, surface roughness, bond strength, fiber alignment, load-induced strain are determined by using advance techniques (*microwave scanning mechanism, laser profilometer that take picture of roughness surface, bond test by disk, fiber optic*).

As a result, the following NDT technologies and methods have been successfully advanced as part of this project:

- ***Microwave Near-Field Nondestructive Testing and Evaluation of Debond Between CFRP Laminates and Concrete Bridge Members***

The capability of near-field microwave NDT&E techniques for quick, on-site, real-time and repeatable detection of disbonds between CFRP laminates and concrete bridge members has been demonstrated. A new measurement system including a fully automated scanner and signal processing section was designed and its construction will be completed soon. It is expected that this system will enable an operator to quickly attach the microwave probe to the areas of interest in a bridge and produce microwave images for the CFRP-strengthened regions. The system will also be able to record and save these images for future access and for comparison purposes. In addition, wireless transfer of the image data to an off-site location for further scrutiny will be possible as well.

A catalog, consisting 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). To date, no signs of further delamination were documented.

- ***Testing for Bond Strength, Surface Roughness, Fiber Alignment***

For repair and strengthening of concrete structures with FRP, the load carrying ability of FRP may be affect 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. To date neither delamination growth nor bond degradation have been recorded.

- **Strain Determination by Fiber Optics**

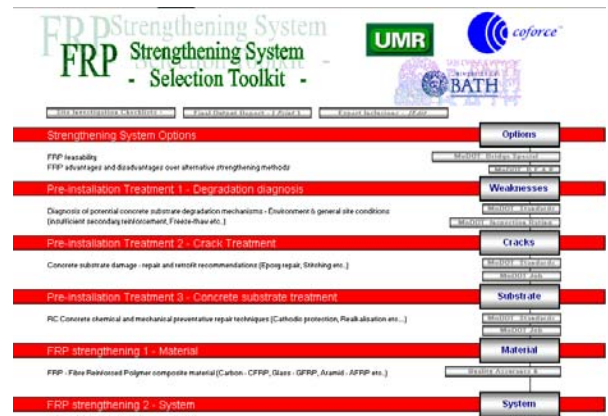
Recently, field tests of the fiber optic sensing abilities have been performed. Beginning in recent years individuals have installed, and tested, sensors on several MODOT bridges. In Dallas, Iron, and Phelps counties bridges have been instrumented to provide a workable group of “in use” field structures for providing data for engineering analysis. Work in Dallas County has centered on the use of fiber optics for bridge rehabilitation. This aspect of the problem is becoming increasingly important in Missouri and other areas. Aging infrastructure that is in need of repair can benefit from sensing methods that fiber optics can provide.

As structures age, and begin to weaken, parts will change in behavior. Sensing methods that are being implemented on these structures can provide a point of evaluation. Evaluation of the structures in regular intervals with sensing permanently embedded allows for comparison to be made and aging components of the system to be identified and replaced. In addition, retrofitting of structures with sensor during repair can allow for a structure to be watched for further signs of damage.

A database of load-induced strain performance over time was created. The comparison between the periodic readings allows determining the safety of the structure overtime. A description of installation procedures for fiber-optic instrumentation and evaluation of health-monitoring capability is also underway. To date, no performance degradation was recorded demonstrating the good performance over time of the FRP strengthening.

### FRP Strengthening System Selection Toolkit Software

In order to facilitate the selection criteria for candidate bridges with cost estimates, a visual basic “expert system” software was developed (see Figure 11). The software provides a superstructure ‘FRP Strengthening System – Selection Toolkit’ defining the extent of required strengthening following diagnosis, and recommendation for pre-installation treatment of the defects and degradation established from analysis of assessment and inspection results. The program and report consciously targets the concerns of largely inexperienced engineers in this field, particularly those of graduate level training, while attempting to meet the knowledge demands of project engineers or MoDOT managers responsible for the development of a preliminary strengthening scheme proposal.



**Figure 11 – Program introduction index (‘main menu’)**

Currently a user-friendly web based new version of the expert system is under development. It will be installed on the UMR server and made available to MoDOT and FRP manufacturers which will be able to input materials properties and costs. The software will allow the selection, design and pricing of the appropriate strengthening technique. A first version of the web-based software will be available by the end of the summer 2006.

### 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.umn.edu/utc/research/r098/index.htm>)

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