CENTER FOR INFRASTRUCTURE ENGINEERING STUDIES

Laboratory and Field Testing of FRP-Reinforced Concrete Bridge

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16. Abstract The work is part of an ongoing effort to develop and promote the use of FRP composite materials in civil engineering structures. Several new bridges have been built using FRP elements and several existing bridges have been repaired or upgraded with FRP reinforcement. Also, laboratory testing of similar structures support the technical development and technology transfer.		
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Laboratory and Field Testing of FRP Reinforced Concrete Bridge

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PROJECT SUMMARY

The work reports the testing of FRP(fiber-reinforced-polymer)-rod-reinforced concrete bridge. This field study was one of three bridges built by an interdisciplinary team of University of Missouri-Rolla (UMR) investigators to demonstrate the effectiveness of new FRP composite in enhancing constructability, life span, and performance. Each bridge deck will feature a different construction technology. The concrete bridge incorporated FRP-rods as reinforcement to otherwise traditional concrete construction and is located on Walters Street, St. James, Missouri. They were constructed in the City of St. James, Missouri using funds from the UMR (UMR-NSF Repair of Building and Bridges with Composites (RB^2C) and the UMR University Transportation Center), the City of St. James, and the Missouri Department of Economic Development. The field testing was enhanced by the installation of permanent fiber-optic strain sensors for a in situ health monitoring capability.

PROJECT DESCRIPTION

Composite Construction Project

This interdisciplinary research project demonstrates the effectiveness of FRP rods as reinforcement in concrete bridge decks for new construction. In particular, the FRP rods are corrosion resistant and should outlive conventional materials. Oden Enterprises, Inc. was awarded the contract through competitive bid for the concrete panels. The bridge details are:

- FRP-rod-reinforced Concrete Bridge – glass and carbon FRP rods as reinforcement in precast concrete panels.

The other three design are listed below.

- Full Composite Bridge – FRP (glass fiber) honeycomb deck.
- Stringer-Supported Deck – longitudinal FRP (glass fiber) panels supported by steel stringers.
- Stringer-Supported Deck – transverse FRP (glass fiber) panels supported by steel stringers.

All bridges will span water crossings and are part of two-lane secondary roadways. The span for each is 24 feet. Traditionally, concrete slab structures would be built for these applications.

Health Monitoring

The research team includes a permanent smart-sensing feature in two of the bridges. This capability allows the bridges to be tested during the first year of operation and periodically in the long term. Strain measurements will be made for key locations at the midspan, within the honey-comb panels, and near the abutment lockdown points. Long term monitoring requires sensors that will not fail during the extended monitoring period and that are easily addressed. The objectives of this health monitoring activity are

- to provide economically strain information during actual use over time and
- to evaluate our methods of smart structural assessment.

The first objective will provide important information regarding the durability of FRP materials for field conditions and will enable optimization of FRP materials for in-use loading. FRP bridge designs are currently in a demonstration phase and are consequently very conservative. Improvements to FRP structural design are needed if FRP applications are to enter the commercial phase. The elimination of over-design features are needed if FRP structures are to be cost competitive with conventional designs. The second objective concerns the effective use of integral sensors. How many sensors are needed, how are they most effectively mounted, and how must sensor data be processed and relayed to adequately understand the health of a structure? Also, the durability of sensors as shown in our laboratory tests must be validated in field tests.

Fiber optic strain sensors based on extrinsic Fabry-Perot interferometric cavity were used for this project. These sensors are commercially manufactured by Luna Innovations and can measure static and dynamic strain accurately over a gauge length on the order of millimeters. In general, fiber optic sensors are ideal for smart civil structures applications because they may be embedded in the FRP materials to measure internal conditions and they can provide absolute measurements without the need for continuous monitoring. Also, they are rugged, small in size, resistant to corrosion and fatigue, immune to electrical interference, and easily multiplexed. They have been shown to be a cost-effective method for monitoring strain conditions at many locations within a bridges and FRP structures. The sensors have an extended lifetime in extreme environments when incorporated properly in a structure.

PROJECT ACTIVITIES AND FINDINGS

Composite Construction Project

The participants, collaborators, and partners in this project are listed below.

PEOPLE: UMR Faculty Investigators:

PI: Dr. Steve E. Watkins, University of Missouri-Rolla (UMR), Electrical and Computer Eng. Dept. (contact 573-341-6321 or watkins@umr.edu)

Co-PI's Dr. Antonio Nanni, UMR, Civil Eng. Dept.
Dr. Halvard E. Nystrom, UMR, Engineering Management Dept.

UMR Graduate Research Assistants (Thesis):
Danielle Kleinhans Stone, PhD Student, UMR, Civil Eng. Dept.

UMR Graduate Research Assistants (Non-thesis Work):
Josh Corra, MS Student, UMR, Electrical and Computer Eng. Dept.
Pinak Deshmane, MS Student, UMR, Engineering Management Dept.

Collaborators:

UMR Faculty and Staff Collaborators:
John Meyer, UMR, Civil Eng. Dept.
Tom Shipley, Video Communications Center

Partners:

Industry Contractors for Manufacture and Installation of Bridges:
Kansas Structural Composites, Inc. (KSCI), Kansas (FRP slabs)
Oden Enterprises, Inc. (concrete panels)

Outreach Partner
Meramec Regional Planning Commission
Funding Partners for the Smart Composite Bridge
Center for Infrastructure Engineering Studies, UMR
Manufacturing Research and Training Center (Missouri Department of Economic Development),
Missouri Department of Transportation
The City of St. James, Missouri

Composite Construction of Smart Bridges

Four short-span bridges demonstrate the effectiveness of new fiber-reinforced-polymer (FRP) composite material in enhancing constructability, life span, and performance. These field bridges span water crossing and are part of two-lane secondary roadways in St. James, Missouri. Each bridge incorporates a different composite design approach. The designs and construction dates are listed below.

- FRP-rod-reinforced Concrete Bridge on Walters Street – reinforced concrete structure consisting of nine precast concrete panels that are reinforced with glass and carbon FRP rods. Installation began June 18, 2001 and was completed on June 28, 2001. The bridge was opened to traffic on June 18, 2001.
- Fiber-reinforced-polymer (FRP) Slab Bridge on St. Francis Street – fully-composite structure consisting of four prefabricated glass-fiber-FRP honey-comb slabs. Installation began November 13, 2000 and was completed on November 17, 2000. The bridge was opened to traffic on November 29, 2000.
- FRP-Slab Bridge Decks on St. Johns Street and Jay Street – decks consisting of prefabricated glass-fiber-FRP honey-comb slabs on steel stringers. Six lateral panels and four longitudinal panels were used respectively. Installation began September 25, 2000 and was completed on October 4, 2000. The bridge was opened to traffic on October 6, 2000.

The work is funded by the UMR (UMR-NSF Repair of Building and Bridges with Composites (RB^2C) and the UMR University Transportation Center), the City of St. James, and the Missouri Department of Economic Development. This NSF project grant was used to provide health monitoring for the project as discussed in the next section. Kansas Structural Composites, Inc. (KSCI) of Kansas was the industry contractor for fabrication of the FRP slab panels and Oden Enterprises, Inc. was the contractor for the concrete deck panels.

The St. James projects has been extensively covered in the local and regional media (see the Outreach section for details). Danielle Stone, the lead graduate Ph.D. student on the project, was recognized as the 2001 Outstanding Student for the UMR University Transportation Center. The award is sponsored by the U.S. Department of Transportation. Also, the UMR University Transportation Center and its partner, the Meramec Regional Planning Commission, received the 2001 Innovation Award from the National Association of Development Organizations for the St. James project and similar projects.

The field work on the four bridges was supplemented by laboratory characterization of the FRP honey-combed panels and the FRP reinforcing bars.

In-situ Health Monitoring of Bridges

The Fiber-reinforced-polymer (FRP) Slab Bridge on St. Francis Street and the FRP-rod-reinforced Concrete Bridge on Walters Street were instrumented with permanent fiber optic sensors to provide a long-term health monitoring capability. Extrinsic Fabry-Perot

Interferometric fiber optic strain sensors were attached to selected panels and bars during deck assembly at the manufacturers. A permanent access box is attached to the bridge abutments. The installation and initial testing of the bridges are solely supported by this NSF grant. Most of the sensors survived the bridge assembly and installation processes and are available for long-term monitoring.

Preliminary load tests were conducted on the FRP Slab Bridge (St. Francis Street) on March 9, 2001. A loaded tandem-axle truck was placed a various locations on the bridge. The total truck weight was 54,440 lbs. (242.17 kN) with 17,240 lb (76.69 kN), 18,340 lb (81.58 kN), and 18,860 lb (83.90 kN), on each of the three axles from the front to the rear of the truck, respectively. Mid-span deflection and strain were monitored continuously with both internal (fiber optic) and external (LVDT and electrical resistance gage) sensors throughout the duration of each pass of the test. An intermittent problem was discovered with the fiber optic sensors. The signal loss along the sensor leads were excessive and instrumentation errors occurred. Otherwise, the fiber optic sensors generally matched the expected performance. An instrumentation upgrade is needed to boost the fiber optic signal.

Further load tests were performed on October 1-4, 2001. Both the Fiber-reinforced-polymer (FRP) Slab Bridge on St. Francis Street and the FRP-rod-reinforced Concrete Bridge on Walters Street were tested. Fiber optic signals were obtained that were consistent with external sensors. (The intermittent problem prevented comprehensive comparisons.) The test data will be used for future periodic testing using the fiber optic sensors.

PROJECT FINDINGS AND RESULTS

Development of Bridge Technologies

Four short-span bridges were designed, installed, and tested as a field application. Commercial composite contractors were involved in the work. The bridges are on two-lane secondary roadways in St. James, Missouri. The composite components were tested in a laboratory setting to validate the design. Testing indicate that the performance of the bridges exceed the design loading for a HS20-44 AASHTO (American Association of State Highway and Transportation Officials) standard. Constructability details have been demonstrated (see Contributions section for a listing). In addition, two of the bridges were instrumented with permanent internal fiber-optic strain sensors. Most of these sensors are available for permanent health and performance monitoring. Future periodic testing can be accomplished with minimal setup. In addition to demonstrating the capabilities of composite and sensing technologies, the bridge development gives insight into the costs and challenges of incorporating these component technologies in commercial applications.

Associated Student Projects Supervised by the Investigators

The construction and testing of the bridges have provided a variety of educational experiences for graduate students. The following student has performed her doctoral-level research on aspects of the grant activities.

Danielle Kleinhans Stone (Civil Engineering)– Coordination of the construction and testing

The following students have performed graduate research on aspects of the grant activities.

Josh Corra (Electrical and Computer Engineering) – Fiber optic Instrumentation of the bridges

Pinak Deshmane (Engineering Management) – Cost analysis of the bridge construction

A workshop on composite bridge technology was conducted on March 17, 2000. It was sponsored by UMR, the Meramec Regional Planning Commission, and MoDOT for county and state officials. The St. James Bridge projects were used as an example application.

Assessment of Commercial Potential for Composite Bridges

Using the composite bridge development and a related UMR composite bridge project, the anticipated cost for short-span composite bridges are extrapolated. The application of Fiber-Reinforced Polymer (FRP) composite technology to bridges can provide performance enhancements at a time when there is a large and growing need to replace or repair bridges in the U.S. However, current initial costs are significantly higher than with traditional methods, and it is not clear if this technology can be competitive in the standard small bridge market. This study investigates current costs and forecasts future costs to determine how competitive this technology is likely to become, taking into account the expected improvements in manufacturing, transport, and installation and life cycle differences. Based on two demonstration composite bridges and the learning curve approach, the results show that anticipated improvements would not be sufficient to compete on cost with reinforced-concrete (RC) bridges. Unless significant improvement also occurs in the cost of component material, this technology will not be cost competitive for the standard small bridge, and the application of FRP technology will be limited to other niche markets, such as decks and bridge repair.

Video Documentation of Composite Applications

A complete video archive of the installation and field loading of the Smart Composite Bridge project has been made in cooperation with the UMR Video Communications Center. This archive will support educational video aids for civil engineering courses, industry demonstrations, planned short courses, etc.

Media Outreach concerning the St. James Bridge Projects

Radio

"University Transportation Center," KUMR Radion Show, Host Richard Cavender of Meramec Regional Planning Commission, Interview of Steve Watkins,, Hal Nystrom, and Randy Mayo Air Date 4/14/2000.

Newspaper

"St. James may be 1st to try new bridge material," Janese Heavin, *St. James News Leader-Journal*, Page 1A, 11/21,/2000.

"St. James will be first Missouri city to install all-composite bridge," *St. James News Leader-Journal*, Page 1A, 6/14/2000 and *Rolla Daily News*, Page 6/15/2000.

"UMR, MRPC receive national Innovation Award," *Rolla Daily News*, Page 11A, 11/4/2001.

"Stone Receives Student Award," *Rolla Daily News*, Page 3A, 4/8/2002.

"Bridges Exceed Expectations," Janese Heavin, *St. James News Leader-Journal*, Page 1, 6/12/2002.

Other Publications and Presentations

Meramec Region Transportation Advisory Committee, Meramec Regional Planning Commission (MRPC), Presentations at Meetings, April 11, 2002; August 10, 2000; June 18, 2000; April 13, 2000; and December 9, 1999.

"A new kind of bridge coming to the Ozarks," *Transportation Issues*, MRPC, December 1999 (newsletter).

"It's just not any bridge," *Transportation Issues*, MRPC, October 2000 (newsletter).

Regional Workshop on Composite Bridge Technology (for county and state government officials and workers), Sponsored by UMR, MRPC, and MODOT, March 17, 2000.

"UMR is Leading New Bridge Technology in Missouri," *Bridge*, Civil Engineering Department, University of Missouri-Rolla, **18**(1), August 2001, pg. 3. (newsletter).

"Smart Composite Bridge at the University of Missouri-Rolla," *UMR Engineer*, School of Engineering, University of Missouri-Rolla, **15**(1), Spring 2002, pg. 6. (newsletter).

WWW

Project Fact Sheets and Project Summaries, *University Transportation Center*, University of Missouri-Rolla (2001). Available WW: http://www.utc.umr.edu/.

PRODUCTS AND PUBLICATIONS

Fiber-reinforced-polymer (FRP) Slab Bridge

The FRP Slab Bridge is a fully-composite working short-span structure on a two-lane secondary roadway. It spans a water crossing on St. Francis Street in St. James, Missouri. This prototype structure consists of four prefabricated glass-fiber-FRP honey-comb slabs with a design rating of HS20-44 (approximately 180 kN) truck loading with deflections within the requirements of AASHTO. The overall span length of the bridge is 26.25 ft (8.00 m) with a bridge width of 27.33 ft (8.33 m). Fiber optic sensors are incorporated in the slabs for a long-term monitoring capability. The bridge is a demonstration of construction techniques and performance that use advanced FRP-based materials and a demonstration of smart sensing techniques.

FRP-rod-reinforced Concrete Bridge

The FRP Concrete Bridge is a working short-span structure on a two-lane secondary roadway. It spans a water crossing on Walters Street in St. James, Missouri. This prototype structure consists of nine precast concrete panels. They are reinforced with glass and carbon FRP rods according to ACI Committee 440 guidelines for reinforcing concrete with FRP bars. The bridges has a design rating of HS20-44 (approximately 180 kN) truck loading with deflections within the requirements of AASHTO. The overall span length of the bridge is 24 ft (7.3 m) long and 25.5 ft (7.8 m) wide. Fiber optic sensors are incorporated in the slabs for a long-term monitoring capability. The bridge is a demonstration of construction techniques and performance that use advanced FRP-based materials and a demonstration of smart sensing techniques.

Companion Bridges

Two other bridges were constructed on nearby secondary roadways in St. James, Missouri. The St. Johns Street and Jay Street bridges incorporate glass-fiber FRP honey-comb panels supported by steel stringers. The St. Johns Street bridge has six lateral panels and the Jay Street bridge has four longitudinal panels. No long-term monitoring capability is incorporated. The bridges are demonstrations of construction techniques and performance that use advanced FRP-based materials.

Journal Publications

H. E. Nystrom, S. E. Watkins, A. Nanni, and S. Murray, "Financial Viability of Fiber Reinforced Polymer (FRP) Bridges," Accepted for *J. of Management in Engineering*,

Conference Publications

S. E. Watkins, V. M. Eller, Josh Corra, Martha J. Molander, Bethany Konz, R. H. Hall, K. Chandrashekhara, and Abdeldjelil Belarbi, "Interdisciplinary Graduate Experience: Lessons Learned," *Proceedings of the 2002 ASEE Annual Conference,* 16-19 June 2002, Montreal, Quebec. (refereed)

D. Stone, A. Nanni, J. Myers, and S. E. Watkins, "Field and Laboratory Performance of FRP Bridge Decks," *CCC 2001 – International Conference on Composites in Constructions*, Porto, Portugal, 10-12 October 2001.

D. Stone, A. Prota, A. Nanni, and P. Silva, "Field and Laboratory Performance of FRP-Reinforced Concrete Bridge," *CCC 2001 – International Conference on Composites in Constructions*, Porto, Portugal, 10-12 October 2001.

D. Stone, S. E. Watkins, and A. Nanni, "Investigation of FRP Materials for Bridge Construction," 5th National Science Foundation Workshop on Bridge Research in Progress, Minneapolis, MN, 8-10 October 2001.

UMR Theses

Danielle Kleinhans Stone, "Investigation of FRP Materials for Bridge Construction," Doctoral Dissertation, University of Missouri-Rolla, completed May 2002. (advisors John Myers and A. Nanni)

WWW

Project Fact Sheets and Project Summaries, *University Transportation Center*, University of Missouri-Rolla (2001). Available WWW: http://www.utc.umr.edu/.

TECHNICAL CONTRIBUTIONS

Construction Uses of Fiber-reinforced-polymer Materials

The overall project addresses the need for improvement in highway bridge technology. The nation's bridge infrastructure is rapidly aging and many bridges will need to be replaced or repaired in the near future. Fiber reinforced polymer (FRP) composite materials are promising alternatives to traditional construction material in many applications. The use of FRP materials for bridge applications is demonstrated in the field. In particular, use of composites for FRP bridge deck panels and FRP reinforcing bars are shown. The laboratory tests validate the capability of individual components and the on-site load tests show the load capability of the full bridges. All bridges exceeded the design performance targets. Composite material advantages include a reduction in on-site costs and an increase in estimated lifetime. Components for the bridges were prefabricated and transported to the site. The FRP-deck panels were light enough to handle without heavy equipment. Consequently, the on-site installation time and expense was much less than that for conventional short-span bridges. For instance, the on-site installation of the precast/prefabricated bridges were about one week while the installation time using traditional cast-in-place concrete construction would have been three to four weeks.

Developments in Sensing Applications for Bridges

The sensing component of the project addresses the need for enhanced monitoring of highway bridges. The maintenance of bridges can be better managed by the use of quantitative sensing techniques. In particular, fiber optic sensing techniques can provide detailed long-term information about the health and performance of structures. The use of permanent fiber-optic sensors is demonstrated in the field. The sensors generally survived the fabrication and installation processes. Also, the sensors were shown to be compatible with FRP structural elements. Long-term monitoring of the demonstration bridges is planned using the in situ fiber optic network.