INVESTIGATION OF FRP MATERIALS FOR BRIDGE CONSTRUCTION

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Research Objectives

The objective of this research project is to examine the use of Glass FRP (GFRP) and carbon FRP (CFRP) materials for bridge construction. In particular, GFRP honeycomb sandwich panels are used as bridge panels and steel-supported bridge deck panels and CFRP and GFRP bars are used as internal reinforcement for a precast concrete slab bridge.

Research Approach

The research program consists of a series of investigations in the field and in the laboratory. First, four short-span bridges are installed so as to outline the construction-related issues associated with the use of these materials. The bridges are located in a residential area of St. James, Missouri and each bridge utilizes FRP materials in a slightly different way, demonstrating the versatility of the materials. Second, in-situ load tests of the constructed bridges illustrate the behavior of the overall structures, both in terms of panel behavior and installation details (e.g., panel-to-panel connections). Moreover, as load tests are conducted over time, examination of the bridges’ long-term performance under real environmental conditions becomes possible. Finally, the third investigative series deals with the laboratory characterization of these materials as reinforcement in concrete and as bridge panels. In each case, the overall panel behavior is investigated in addition to characterizing the individual materials.

Materials utilized: Glass FRP materials are used to construct the FRP honeycomb sandwich panels for the St. Johns Street, Jay Street, and St. Francis Street Bridges. The phrase FRP honeycomb sandwich refers to the construction of the panels themselves, which are comprised of a core of corrugated FRP material “sandwiched” between two faces of solid FRP material. Kansas Structural Composites, Inc. manufactured and installed the bridges. The modulus of elasticity obtained from previous testing conducted by the manufacturer is an average modulus of elasticity for the entire cross-section and was recommended at $1.94 \times 10^6$ psi ($1.34 \times 10^4$ MPa). Figure 1 illustrates the FRP materials utilized for this project.

![Figure 1 (a) Corrugated GFRP core](image1)

![Figure 1 (b) Carbon FRP Bars](image2)

The reinforced concrete (RC) panels for the Walters Street Bridge are reinforced with commercially available CFRP and GFRP reinforcing bars with the following properties. For the
CFRP bars, a guaranteed design tensile strength of 270 ksi (1860 MPa) and a tensile elastic modulus of 15.2 Msi (104.7 GPa) were given by the manufacturer. For the GFRP bars these values were 105 ksi (723.4 MPa) and 6.0 Msi (41.3 GPa), respectively. The panels were designed according to the now available ACI Committee 440 guidelines for reinforcing concrete with FRP bars and were manufactured and installed by Oden Enterprises, Inc.

Bridge details: The St. Johns Street and Jay Street Bridges are both comprised of FRP decks supported by steel stringers. The St. Johns Street Bridge is comprised of six lateral half-width panels, having a thickness of 5.125 in (130.2 mm). The overall span length and width of the bridge are 26.5 ft (8.08 m) and 25.5 ft (7.77 m), respectively. The Jay Street Bridge is comprised of four longitudinal panels, having a thickness of 6.625 in (168.3 mm). The overall span length and width of the bridge are 27 ft (8.23 m) and 25.5 ft (7.77 m), respectively.

The St. Francis Street Bridge is a prefabricated FRP slab bridge, consisting solely of four FRP panels, each 23.625 in (600.1 mm) thick. 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). The Walters Street Bridge consists of nine precast concrete bridge panels, each 1 ft (0.30 m) deep, which are reinforced with the aforementioned FRP bars. The bridge is 24 ft (7.3 m) long and 25.5 ft (7.8 m) wide.

The bridges were designed to carry a standard HS20-44 (approximately 180-kN) truck loading with deflections within the requirements of the American Association of State Highway and Transportation Officials (AASHTO). Additionally, the dead load of the bridge panels was considered in each case with values of approximately 15 lb/ft² (0.72 kN/m²), 16 lb/ft² (0.77 kN/m²), 36 lb/ft² (1.72 kN/m²), and 150 lb/ft² (7.2 kN/m²), respectively for the St. Johns Street, Jay Street, St. Francis Street, and Walters Street Bridges, respectively.

Expected Products

The expected benefits of this research program are:

- Laboratory characterization of FRP bars and FRP-RC panels
- Laboratory characterization of FRP honeycomb sandwich panels and their constituent materials
- In-situ characterization of FRP-RC panels and FRP honeycomb sandwich panels
- Durability investigation of FRP bars and FRP honeycomb sandwich panels
- Evaluation of construction techniques for FRP-RC panels and FRP honeycomb sandwich panels
- Provide assistance in the development of specifications for bridge construction with FRP materials by adding to the body of knowledge

Preliminary Results

All four project bridges have been installed on the secondary road system in a residential neighborhood. The installation of the St. Johns Street and Jay Street Bridges took place concurrently with the setting of the first panels taking place on September 25, 2000. Installation was completed on October 4, 2000 and both bridges were opened to traffic on October 6, 2000.
Installation of the St. Francis Street Bridge began on November 13, 2000 and was completed on November 17, 2000. The bridge was officially opened to traffic on November 29, 2000. Installation of the Walters Street Bridge began on June 18, 2001. Installation was completed and the bridge was officially opened to traffic on June 28, 2001. Testing thus far has consisted of an in-situ bridge load test of the FRP panel bridge and a test of two identical sections in the laboratory. Preliminary results indicate good agreement between design and experimental material properties.

Load test results: The first load test of the St. Francis Street Bridge, conducted on March 9, 2001, was accomplished with a loaded tandem-axle dump truck placed at various locations on the bridge. The total weight of the truck was 54,440 lb (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 and external sensors throughout the duration of each pass of the test.

Based on the material properties recommended by the manufacturer the theoretical maximum mid-span deflection obtained via conjugate beam analysis is 0.19 in (4.8 mm). The maximum mid-span deflection measured during the load test was approximately 0.16 in (3.96 mm). Possible causes for the smaller measured values could be variations in panel geometry due to the manufacturing process, variations in the locations of load application, stiffness contributions of the wearing surface and guardrails, and/or restraint provided by the connection to the supports and the soil backfill.

Laboratory test results: Two specimens representative of the St. Francis Street Bridge, each approximately 23 in (0.58 m) by 23 in (0.58 m), were tested under four-point bending. The 14–ft (4.27-m) specimens were tested over a clear span of 13 ft (3.96 m) with the equal loads applied approximately 5 ft (1.52 m) from each support, leaving a constant-moment region 3 ft (0.91 m) in length. Deflections at mid-span, quarter-span, and at the supports and strains at mid-span and in the core were monitored continuously throughout the duration of each test.

Based on simple beam theory and a failure criterion of a maximum fiber stress of 9825 psi (67.76 MPa), the failure load of both specimens was approximated at 150,000 lb (667.26 kN). The maximum stress failure criterion of approximately 9825 psi (67.76 MPa) was based on previous testing conducted by the manufacturer; it was also used during the design phase of the project. Another failure criterion prescribed by the manufacturer indicated a span-to-deflection ratio of approximately 100, which would have placed the failure load as high as 245,000 lb (1089.86 kN).

Figure 2 illustrates the load-deflection diagram for both specimens. It should be noted that the dashed line represents the theoretical behavior and the other two lines represent the experimental behavior. Good agreement between design and experimental material properties is exhibited.

Failure of the first beam was observed at approximately 194,400 lb (864.7 kN). The corresponding mid-span deflection was 1.33 in (33.8 mm), which yields a span-to-deflection ratio of approximately 115. Additionally, the maximum bottom fiber stress at failure was approximately 12,600 psi (86.8 MPa), 30% higher than the design failure limit.
Failure of the second beam occurred at a load of approximately 288,100 lb (1281.5 kN) and a deflection of approximately 1.78 in (45.2 mm). The corresponding span-to-deflection ratio at failure is nearly 90. Furthermore, the maximum stress at failure was considerably higher than that of the first beam; with a value of nearly 19,100 psi (131.6 MPa) the failure stress is roughly twice the design failure limit.

The failure mode anticipated, based on experience from previous testing conducted by the manufacturer, was delamination between the face and the core material. Delamination failure occurred between the bottom face and the core initiating at the end of the member for the first specimen. However, for the second specimen delamination initiated near quarter-span at both interfaces of the core and face materials.

In conclusion, to date good agreement between theoretical and experimental material properties has been exhibited. Failure of the specimens occurred where predicted and at a much higher stress than used for design indicating a high factor of safety for the design of the bridges. Future research is planned to investigate the properties of the materials individually, the long-term performance of the FRP materials both in-situ and in the laboratory, and the behavior of the steel-supported FRP deck bridges and bridge deck panels.

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References