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Pultruded FRP Reinforcement For Bridge Repair

by Fabio Matta, Antonio Nanni, Thomas Ringelstetter, Lawrence Bank, Bruce Nelson, Brian Orr, and Spencer Jones

More than 156,000 bridges out of the 595,000 included in the 2005 U.S. National Bridge Inventory (Federal Highway Administration, 2005) do not meet the standard safety requirements. In particular, 76,000 bridges are classified as "structurally deficient" and are in need of rehabilitation or, in the worst cases, replacement. Corrosion of the steel reinforcement in concrete decks and safety appurtenances is by far the major instrument of degradation, accruing from the routine use of deicing salts on roads and exposure to harsh environments. Higher traffic demands and load requirements further emphasize the need of upgrade of our transportation infrastructures. Increasing investments are being made to support the development of durable structural systems for rapid bridge construction, primarily under the sponsorship of the Federal Highway Administration, the American Society of State Highway and Transportation Officials, the Transportation Research Board, and several state Departments of Transportation.

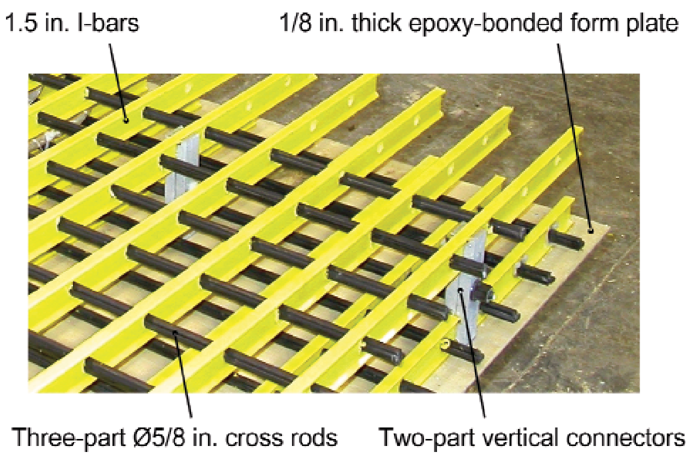


Figure 1.
Close-up of prefabricated FRP SIP deck reinforcement panel.

What is the Problem?

Bridge owners need solutions to rapidly build long-lasting bridges, thereby reducing costs associated with the rehabilitation/replacement of relevant portions of the bridge inventories, including that from road closures, traffic disruption, and periodic inspection and maintenance. Prefabricated stay-in-place FRP reinforcing panels take advantage of advanced composites' versatility, light weight, and corrosion resistance, to make the construction of durable bridge decks faster, safer, and competitive.

FRP Deck Reinforcement Solution

The solution is quite simple: the FRP internal reinforcement for concrete bridge decks consists of very large-size prefabricated panels that integrate a pultruded grating with stay-in-place (SIP) forms, as shown in Figure 1 (see page 18). The two-layer reinforcement is prefabricated by assembling three off-the-shelf pultruded glass/vinyl ester profiles (Bank et al., 2006), which are normally used in grating applications for corrosive environments. The components are:

- I-bars (38 mm) running continuously in the direction perpendicular to traffic;
- Three-part cross rods running through pre-drilled holes spaced at 100 mm on-center in the I-bars web in the direction parallel to traffic; and
- Two-part vertical connectors that space the grating layers 100 mm apart.

The panels are typically fabricated 23.2 ft. wide and 8 ft. long and weigh 900 lb. (4.85 lb/ft^2). The width is that of the bridge deck to be constructed, i.e., 24 ft., minus that of the drip edges to be formed on-site in a traditional manner. The

Table 1.
Limiting full-section properties for FRP reinforcing materials*

Material Property	ASTM Test	GV1 Material (Cross-rods)	GV2 Material (I-bars)
Mechanical Property			
Longitudinal Tensile Strength	D3039, D5083, D638, D3916	95.0 ksi	80.0 ksi
Transverse Tensile Strength	D3039, D5083, D638	N.A.	4.0 ksi
Longitudinal Compressive Strength	D3410, D695	75.0 ksi	60.0 ksi
Transverse Compressive Strength	D3410, D695	N.A.	10.0 ksi
Long. Short Beam Shear Strength	D2344, D4475	6.0 ksi	5.0 ksi
Stiffness Property			
Longitudinal Tensile Modulus	D3039, D5083, D638	5.5 msi	4.5 msi
Longitudinal Compressive Modulus	D3410, D695	N.A.	4.0 msi
In-Plane Shear Stiffness	D5379	N.A.	0.40 msi
Major (Longitudinal) Poisson Ratio	D3039, D5083, D638	N.A.	0.25
Physical Property			
Fiber Volume Fraction	D3171, D2584	55%	45%
Barcol Hardness	D2583	50	50
Glass Transition Temperature	E1356, D3418, E1640	203°F (95°C)	203°F (95°C)
Water absorption (immersion at 50°C [122°F] for 48 hours)	D570	0.50%	0.75%
Longitudinal Coefficient of Thermal Expansion (max)	D696, E831	6×10^{-6}/°F (1.08×10^{-5}/°C)	6×10^{-6}/°F (1.08×10^{-5}/°C)
Transverse Coefficient of Thermal Expansion (max)	D696, E831	N.A.	30×10^{-6}/°F (5.4×10^{-5}/°C)

* Minimum required values unless specified.

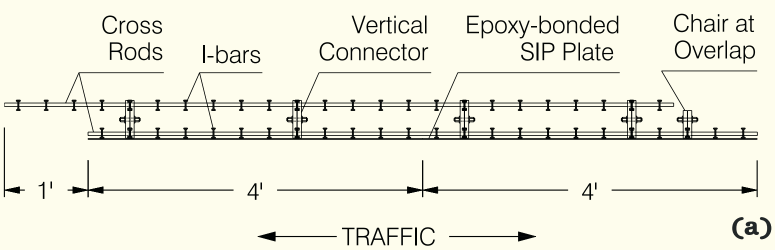
I-bars are the main load-carrying elements and their shape and spacing are designed to make walking over the panels easy and safe. The cross-rods provide shrinkage and temperature reinforcement and constrain the core concrete to ensure load transfer into the I-bars. SIP form plates are epoxy-bonded onto the outer face of the bottom-layer I-bars.

The structural effectiveness of pultruded FRP gratings as internal reinforcement of concrete decks has been proved through extensive research during the last 14 years, leading to recent successful implementations (Bank et al., 2006; Berg et al., 2006). Today's system is the first to provide a fully-integrated reinforcement and SIP formwork (Matta et al., 2005a; Ringelstetter et al., 2006). To complement the deck reinforcement and develop a steel-free system, a new Modified Kansas Corral Rail (MKCR) reinforced with prefabricated glass FRP rebar cages was also developed (Matta and Nanni, 2006).

Advantages of Composites

In addition to the structural (static and fatigue) strength guaranteed by FRP reinforced concrete (RC) decks, the key features of the solution presented herein are:

- Easier and faster construction – the elimination of labor-intensive and time-consuming field operations (formwork setting between the girders, and tying of rebars) by means of large-size prefabricated FRP panels lifted with a single pick of a crane, translates into over 70 percent reduction in construction time from reinforcement installation to deck casting and finishing, as well as into significantly improved working conditions.
- Higher Productivity – the rate of concrete placement is increased by 50 percent compared to traditional steel reinforced decks with similar dimensions.
- Reduced Labor Cost – the reduced need of manpower, faster and easier field operations, and higher productivity translate into over 75 percent reduction in deck construction labor cost.
- Improved safety – the use of very lightweight FRP panels, easy to handle and placed with no need of formwork (as opposed to heavy partial-depth precast prestressed panels commonly used), and the design of the reinforcing profiles to facilitate walking over the top mat, result in improved safety in the work area.
- Enhanced durability – to date, the results of extensive research have demonstrated the superior durability of internal FRP reinforcement for concrete when compared to steel rebars. The corrosion resistance of FRP composites represents a critical advantage for bridge decks, which are highly susceptible to deterioration due to chloride (deicing salts) penetration. This translates into a reduction in bridge maintenance operations, thereby supporting a more efficient bridge management, and prioritization of limited funds.



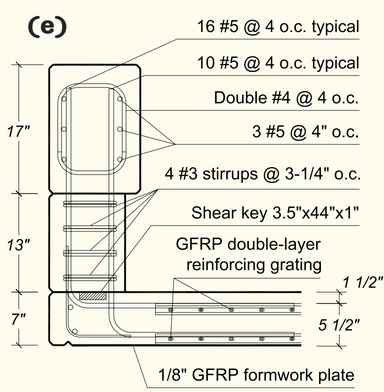


Figure 2. Detailing of FRP SIP panels: longitudinal section with staggered grating layers (a); end panels saw-cut on-site (b); close-up of plate-to-plate butt joint (c); close-up of panel anchor (d); thru-post FRP rail reinforcement (e).

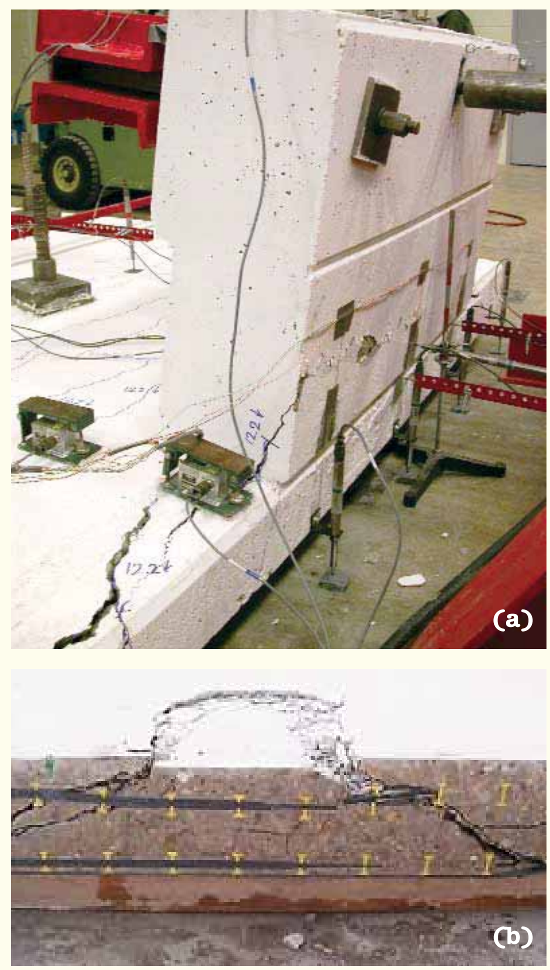


Figure 3. Laboratory testing: section through punching failure surface of deck slab specimen (a); full-scale static test of post/deck connection (b).

Research and Development

The development of this solution was the result of a strict collaboration between academia and industry. The FRP grating used in the RC deck is made of standard pultruded grating that was modified to meet prescriptive specifications for the glass FRP materials used (Bank et al., 2003; 2006), as summarized in Table 1 (see page 18).

For field application purposes, Special Provisions were developed that included Performance Specifications to define limit stresses and deformations in panel test components and subassemblies when subjected to typical construction loads, i.e., vertical loading before and during concrete pouring; lateral loads applied to the top surface; in-plane racking; vertical load on the panel-to-panel splice connection; and wet concrete loading (Matta et al., 2005a). Manufacturers are then provided with a set of acceptance criteria to be met when developing their own FRP SIP systems, including minimum cross-sectional area as well as maximum and minimum spacing for the grating components.

Due to the peculiar physical and mechanical characteristics of composite materials, the design philosophy of FRP RC structures is substantially different from that of traditional steel RC. Design principles are fairly well established (Nanni, 2003) and are reflected in a number of guideline documents published in North America, Europe, and Japan. In the U.S., the ACI Committee 440 "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars" (ACI, 2006) is the primary reference. The R&D work on the FRP SIP system encompassed in-depth experimental validation of the selected configuration, including that of the connection between FRP RC rail post and deck, to assess compliance with both the AASHTO LRFD (1998) and Standard Specifications (2002). The punching shear strength of full-scale slab specimens (Figure 3a) was verified to ensure a safety margin of nearly 6 against HS20-44 truck wheel load with a 30 percent dynamic impact allowance (Matta et al., 2005a,b).

Figure 4. Old Bridge 14802301, Greene County, MO: degradation of concrete deck and steel girders (a), and of safety appurtenance (b).

The equivalent static transverse strength of post/deck connection specimens (Figure 3b) was adequate for the required TL-2 crash test level (Matta and Nanni, 2006).

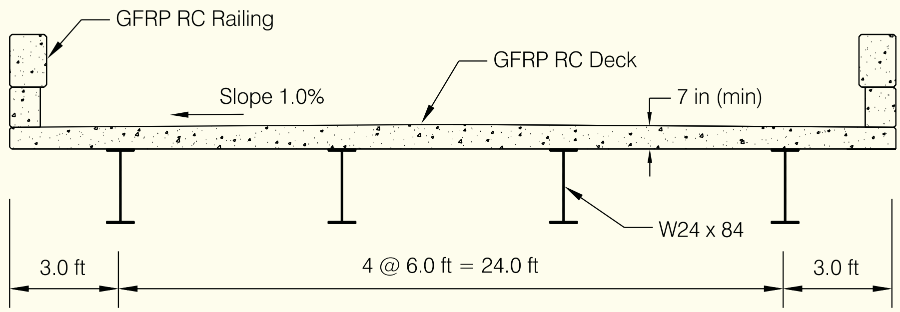


Figure 5. Cross-section of new Bridge 14802301, Greene County, MO.

Detailing of FRP SIP Panels

The panel details and deck construction solutions were devised with the main objective of improving constructibility, taking advantage of valuable inputs from contractors and practitioners. Full continuity of the main reinforcement elements is preserved by adopting a panel width that replicates that of the bridge deck. An acceptable degree of continuity in the secondary reinforcement is also ensured by the panel-to-panel overlap connection, as allowed by the 1 ft. offset between the top and bottom layers (Figure 2a). The end panels are designed to accommodate the expansion joints, and can be easily adjusted on-site due to the ease of saw-cutting the FRP components (Figure 2b). Glass FRP strips with 1/8 in. thickness are to be inserted between the bottom-layer cross-rods and the form to cover the butt joints between adjacent form plates, thus preventing leaking of concrete during the casting operations (Figure 2c). Each SIP unit can be anchored to the top flanges of steel I-girders by means of stainless steel threaded bolts and FRP washers (Figure 2d); however, in case composite action is required between deck and girders, automatic welded shear studs can be accommodated in holes pre-drilled in the form plates. Mounting of the very lightweight (about 35 lb.), prefabricated FRP rail post cages at the correct spacing is facilitated by the presence pockets cut out in the double-layer grating (Figure 2e).

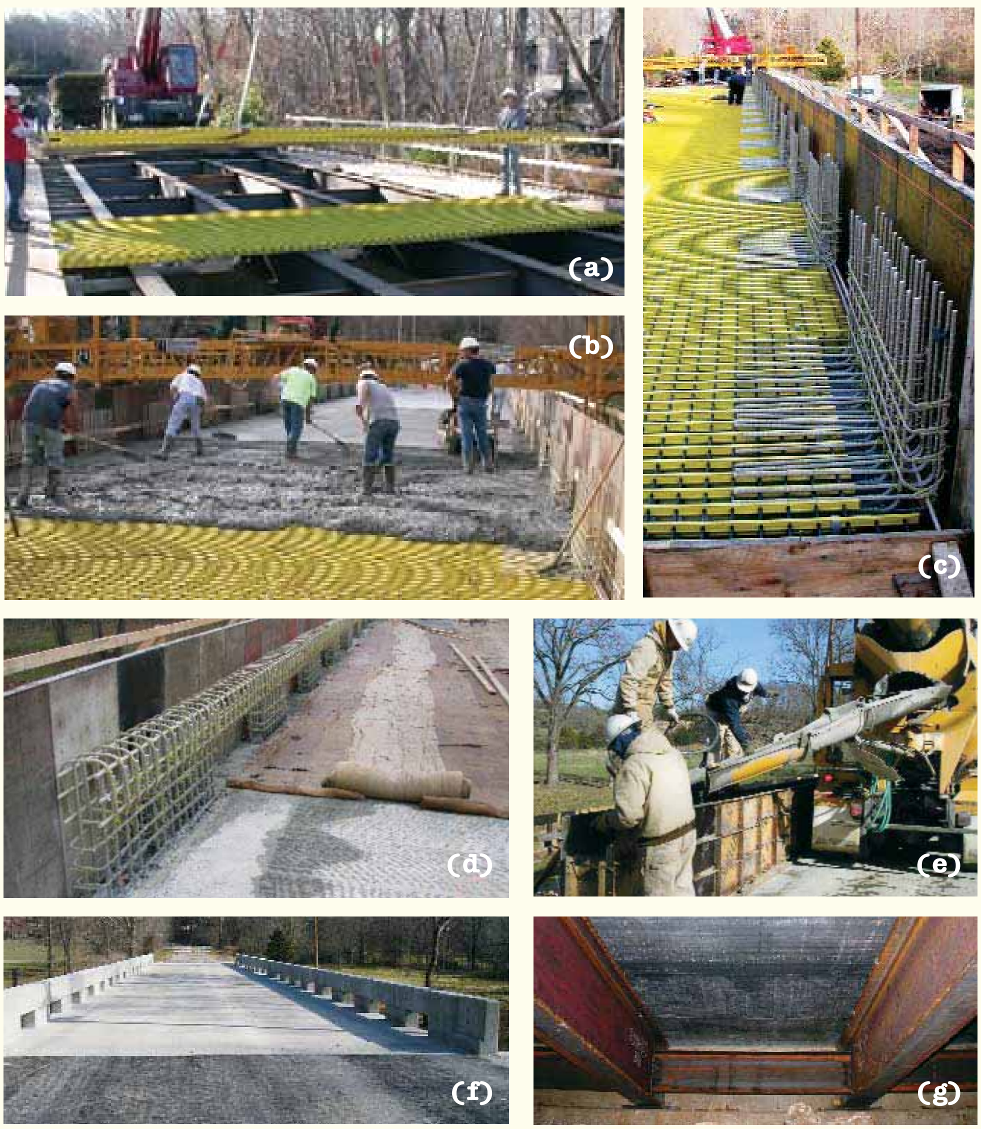


Figure 6. Five-day bridge redecking: installation of FRP SIP panels (a); mounting of rail post cages (b); deck casting (c); mounting of rail top cages (d); rail casting (e); FRP RC deck and rail completed (f-g).

5-Day Installation

The FRP SIP reinforcement system was used in the construction of the new Bridge 1482301 in Greene County, Missouri, completed in November 2005. The County opted for the replacement of the 73-year old posted bridge due to the severe deterioration of the concrete deck, safety appurtenances, and steel girders (Figure 4) that reduced the load rating from the original 10 ton. to only 4.3 ton., forcing the owner to impose vehicle weight restrictions. The new bridge, designed by Great River Engineering of Springfield, Missouri, has the same total length of 144 ft. of the old structure, and consists of four symmetric spans, the exterior ones with a length of 37 ft., and the interior ones of 35 ft. The 7 in. thick RC deck sits on four W24 x 84 rolled steel girders spaced at 6 ft. on-center (Figure 5) and running continuously along the bridge two-span half-length portions, with a closed expansion joint at the central support. The out-to-out deck and clear roadway width is 24 ft.

The field implementation project was developed in a joint effort between academia, government, and industry parties, including the University of Missouri-Rolla (UMR), University of Wisconsin-Madison, Green County Highway Department (general contract and bridge owner), Great River Engineering (engineer of record), Hartman Construction (contractor), Master Contractors LLC (responsible for the assemblage and installation of the MKCR glass FRP rebar cages), Strongwell Corp. (manufacturer of the FRP deck panels), and Hughes Brothers Inc. (manufacturer of the glass FRP rebars for the MKCR reinforcement), and with the assistance of the Missouri Department of Transportation (MoDOT).

The bridge "redecking" operations took only five days to complete, instead of the two to three weeks normally required for similar steel reinforced decks with open-post railings built by the contractor. The construction phases, documented in Figure 6, were as follows.

- **Day 1:** All of the 18 deck panels were set in place and anchored to the steel girders by six workers in a total of six hours.
- **Day 2:** The prefabricated rail post cages were inserted into the cut-out pockets in the SIP panels; the deck details were formed in a traditional manner using plywood, including expansion joints, chamfers, and drip edges; the finishing machine was finally set.
- **Day 3:** The deck was cast and finished in a total of two and a half hours. The roadway crown was formed using the deck finishing machine, which avoided impractical cambering of the FRP panels, and time-consuming preparation of haunches.
- **Day 4:** The prefabricated top longitudinal rail cages were mounted, and the open-post railing formed. Since the temperature was below the minimum required by the County to proceed with casting, the operation was delayed.
- **Day 5:** Casting of the railing was completed.

This project showcased the successful transition of an innovative FRP deck reinforcement technology from the laboratory to the field. The solution eliminates time-consuming and labor-intensive steps such as setting of extensive falsework and tying of rebars. The use of strong and corrosion resistant FRP reinforcement is successfully paired with an innovative panelized approach that takes full advantage of FRP materials tailorability and light weight into an effective structural form, which is inconceivable with more traditional construction materials. As a result, construction of safe and long-lasting bridge decks can be completed in a fraction of the normal construction time.

A conservative cost estimate for FRP RC deck and rail system as-built is \$44.90/ft^2, which includes the \$26/ft^2 cost of the prototype SIP panels delivered to the site. The solution retains a competitive potential due to the rapid construction, which is of critical importance when the indirect costs of traffic disruption are of concern. In addition, the significant savings from reduced labor and equipment costs, increased productivity, and improved safety conditions in the

("Pultruded FRP..." continues on p. 57)

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workzone, together with the minimal maintenance needs provided by internal FRP reinforcement, provide solid benefits to make the system attractive to bridge owners.

Acknowledgements

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