RAPID CONSTRUCTION OF CONCRETE BRIDGE DECK USING PREFabricated FRP REINFORCEMENT

Fabio Matta  
(Graduate Research Assistant, University of Missouri-Rolla, Rolla, MO, USA)

Antonio Nanni  
(V. & M. Jones Professor, University of Missouri-Rolla, Rolla, MO, USA)

Thomas E. Ringelstetter  
(Graduate Research Assistant, University of Wisconsin-Madison, Madison, WI, USA)

Lawrence C. Bank  
(Professor, University of Wisconsin-Madison, Madison, WI, USA)

ABSTRACT
The development of durable structural systems for accelerated bridge construction is key to reducing the economic and social costs associated with replacement operations on a large scale. This paper reports on the field application of stay-in-place reinforcing panels, entirely made of glass fiber reinforced polymer components and specifically developed for the rapid construction of concrete bridge decks. The salient features of the system are illustrated, along with significant research and development outcomes. The five-day construction of the cast-in-place deck and open-post rail of Bridge 14802301 in Greene County, MO, is documented, and the major outcomes outlined. The project demonstrates how lightweight and noncorrosive FRP reinforcement is a practical alternative to steel, with the potential of versatile structural forms that add relevant constructibility and economic advantages.

KEYWORDS
Bridge Deck, Fiber Reinforced Polymers, Accelerated Bridge Construction.

1. INTRODUCTION
During the last four years, increasing investments have been made to support the research and development of innovative technologies for accelerated bridge construction, primarily under the sponsorship of the Federal Highway Administration (FHWA), the American Society of State Highway and Transportation Officials (AASHTO Technology Implementation Group), and the Transportation Research Board (TRB Task Force on Accelerating Innovation in the Highway Industry). Emphasis has been placed on improving safety and minimizing traffic disruption while enhancing quality and durability. The issue arises from the urgent need of upgrading and maintaining a significant portion of the bridge inventory while facing inevitable budget restrictions. Redecking operations are rather frequent, since corrosion of steel reinforcement is a major instrument of degradation in reinforced concrete (RC) decks and safety appurtenances. In the case of off-system bridges, cost-benefit analysis, contractors know-how and equipment availability typically result in the adoption of either partial or full-depth cast-in-place (CIP) technologies. The most popular solution limits the use of prefabricated elements to standardized partial-depth precast prestressed concrete panels as structural stay-in-place (SIP) forms between the girders, with CIP concrete topping, as opposed to traditional removable plywood forms. SIP steel metal deck forms, with a full-depth CIP configuration that eliminates the problem of reflective cracks, are less attractive due to three major drawbacks: a) safety concerns due to risks of accidental damage of relatively thin metal sheets, resulting in local buckling problems under wet concrete load; b) corrosion issues under aggressive environments; c) efficient inspection of the underside of the deck is complicated.

In the project presented herein, an innovative prefabricated glass Fiber Reinforced Polymer (FRP) SIP reinforcement
has been selected to construct the replacement deck of Bridge 14802301 in Greene County, MO. Corrosion resistant FRP reinforcement gratings and SIP form plates are integrated into very large-size modular panels. The structural form takes advantage of FRP composites tailorability and lightweight to provide improved constructibility, resulting in enhanced construction speed and safety.

2. PREFABRICATED STAY-IN-PLACE FRP REINFORCEMENT

2.1 Description and Detailing

The FRP SIP panels are prefabricated assemblying off-the-shelf pultruded glass/vinylester components, typically used in floor grating applications in corrosive environments, into a three-dimensional grating made of two (top and bottom) layers (Figure 1). The main load-carrying elements are 38 mm I-bars, spaced at 100 mm on-center, which run continuously in the direction perpendicular to traffic (transverse). Both shape and spacing of the I-bars have been thought to allow ease of walking over the three-dimensional assembly. Three-part cross rods, spaced at 100 mm on-center and running through pre-drilled holes in the I-bars web in the direction parallel to traffic (longitudinal), provide shrinkage and temperature reinforcement, enhance the in-plane rigidity of each reinforcing layer, and constrain the core concrete to ensure mechanical compatibility with the structural I-bars. Top and bottom reinforcing layers are integrated using two-part vertical connectors that space them at 100 mm on-center. The two components forming the connectors are shaped to be epoxy-bonded to the I-bars and then fastened together. The formwork consist of 3.2 mm thick and 1.22 m long plates that are epoxy-bonded to the I-bars in the bottom layer.

The system concept, detailing and construction procedure have been addressed to improve constructibility by introducing original solutions when needed, and constantly seeking input from practitioners. Each SIP panel has a width of 7.06 m, a typical length of 2.44 m (Figure 1(a)), and a weight of about 409 kg (23.7 kg/m²). The width corresponds to that of the bridge deck minus 127 mm per side, to allow a traditional drip edge notch to be formed on-site. The use of large-size and lightweight panels allows easy placement of the SIP reinforcement on the bridge girders with single picks of a crane at four anchorage points. Hence, both time-consuming and labor-intensive setting/removing of plywood forms and tying of rebars are eliminated. Adjacent panels are connected in a non-mechanical fashion by means of 0.30 m overlaps, formed by offsetting the top and bottom grating layers (Figure 1(a)), thereby preserving a degree of continuity in the longitudinal direction (Figure 1(a) and Figure 2(a)). 3.2 mm thick strips are inserted to cover the SIP plate-to-plate butt joints in order to prevent concrete leaking during casting (Figure 2(b)). When using steel girders, each SIP unit is anchored to the top flanges via stainless steel threaded bolts at every 2.44 m, keeping the bottom reinforcing layer in place with 6.3 mm thick FRP washers (Figure 2(c)). Holes in the SIP plate are drilled on site. When composite action is sought between girders and deck, the panels can be supplied with pre-drilled holes with longitudinal and transverse spacing of 10 cm on-center to accommodate welded shear studs. No cambering of the panels is required to match the roadway crown, which is formed using the finishing machine. The length and layout of the end panels are designed to fit the actual bridge length and accommodate the expansion joints. Since glass FRP is easy to saw-cut, adjustments can be readily made on site (Figure 2(d)).

Figure 1: Prefabricated FRP SIP Reinforcement Panels: Longitudinal Section (a) and Close-up (b)

Figure 2: Panel-panel Connection (a, b); Anchoring to Girder (c); End Panels at Expansion Joint (d)
The steel-free reinforcement system is completed with the prefabricated glass FRP rebar cages of a newly designed open post Modified Kansas Corral Rail (Matta and Nanni, 2006). Cut-out pockets in the panels overhang reinforcement facilitate insertion of the post cages at the correct spacing. The continuous top rail reinforcement is made of either 2.44 m or 4.88 m long cages with 1.22 m rebar splices, thought to be rapidly mounted prior to rail forming. Again, the use of lightweight FRP cages greatly simplifies handling and mounting operations, while eliminating on-site rebar tying that is particularly labor-intensive in this case.

2.2 Research and Development

Extensive research and development work during the last 14 years has demonstrated the structural effectiveness of pultruded FRP gratings as internal reinforcement of concrete bridge decks. Two recent pioneer construction projects have been completed in Wisconsin, USA (Bank et al., 2006; Berg et al., 2006). The solution presented herein features the last-generation system, and the first with fully-integrated reinforcement and SIP forms (Ringelstetter et al., 2006). The project Special Provisions included FRP Material Specifications, in compliance with a model specification developed for the FHWA (Bank et al., 2003). Performance Specifications were also defined for the SIP panels by imposing stress and deformation limitations to test panels when simulating typical construction loads, i.e. vertical and lateral loads, in-plane racking, vertical load on overlaps, and wet concrete load (Matta et al., 2005).

The FRP RC open post rail was designed following the ACI 440 guidelines (ACI, 2006) to meet the AASHTO LRFD (AASHTO, 1998) and Standard Specifications (AASHTO, 2002). In the case of the LRFD provisions, where a yield-line approach is recommended to evaluate the equivalent transverse static strength, deformation compatibility was assumed to account for the lack of moment redistribution in FRP RC structures, along with conservative failure scenarios (Matta and Nanni, 2006). In addition, the end posts located at the expansion joints and approach deck, where rail continuity is not provided, were designed to exceed the required crash Test Level 2 strength $F_T = 120$ kN. The deck and rail design was validated through laboratory testing of full-scale deck slabs and rail post/deck connections, which was performed at key steps of the optimization process, and confirmed the significant safety margin of the layout selected for the field implementation (Matta et al., 2005).

3. FIVE-DAY BRIDGE REDECKING

The old Bridge 14802301 (Greene County, MO) slab-on-girder superstructure, built in 1933, was in need of replacement because of severe corrosion-induced degradation of deck and safety appurtenances, and increased load requirements. The load rating was 3.9 t (2004), versus an original design based on a 9.1 t truck load with 30% impact factor. The new superstructure has four symmetrical spans of 11.3 m (exterior) and 10.7 m (interior) length, for a total length of 43.9 m. The cross section comprises four W610×25 steel girders spaced at 1.8 m on-center and acting non-compositely with a 178 mm thick deck. The out-to-out deck and clear roadway width are 7.3 m and 6.7 m, respectively. The girders are continuous over two spans, with a closed expansion joint at the central support.

Transition from research and development to field implementation was conducted in coordination with the manufacturers of the FRP deck and rail reinforcement, and the engineer of record. The construction operations were planned with the contractor parties to minimize the amount of time and work. Construction of the RC deck and railing from the SIP panel installation to rail casting is documented in Figure 3. The job was completed in November 2005 in five days, instead of the typical 2-3 weeks needed for similar steel reinforced bridges built by the contractor. Installation of the deck panels was finalized in six hours during the first day by six workers. During the second day, the 36 rail post cages were mounted, the deck details formed (expansion joints, chamfers, drip edges), and the finishing machine was set. Deck casting and finishing was completed in the third day. The remaining two days were used to mount the open post concrete rail top continuous cages and the formwork, and finally casting.

4. CONCLUSIONS

The first application project of an innovative prefabricated FRP reinforcement for rapid bridge deck construction has been presented. The use of very large-size and lightweight modular stay-in-place panels, comprising a double-layer grating with epoxy-bonded form plates and designed for improved constructibility, eliminates the need of formwork and on-site tying of reinforcing bars. The five-day redecking resulted in over 70% reduction in deck construction time, with a similar reduction in labor cost. Shape and spacing of the reinforcing profiles, devised to facilitate
walking over the three-dimensional assembly, allowed an increase of about 50% in concrete placement productivity while improving safety and working conditions, as confirmed by the field workers.

Figure 3: Bridge Redecking Operations: Panels Installation (a); Mounting of Post Cages (b); Deck Casting (c) and Finishing (d); Mounting of Top Rail Cages (e); Rail Casting (f); Finished Superstructure (g-i)

A conservative cost estimate for the deck as-built is $409/m² ($38/ft²), of which $280/m² ($26/ft²) from the prototype FRP panels delivered to the site. The amount increases to $483/m² ($44.9/ft²) including the cost of the open post railing ($271/m, $82.6/ft). The competitive potential of the proposed system is also enhanced by the durability of FRP reinforcement, with prospective increased service life and reduced maintenance costs.

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6. REFERENCES

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