PREFABRICATED MODULAR GFRP REINFORCEMENT FOR ACCELERATED CONSTRUCTION OF BRIDGE DECK AND RAIL SYSTEM

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ABSTRACT

There is an increasing interest by Departments of Transportation in the development and implementation of durable structural systems for accelerated bridge construction. The main objective is to minimize construction costs, and the impact of the economic and social costs associated with rehabilitation or replacement of a significant portion of the US bridge inventory. This paper reports on the development of an innovative glass fiber reinforced polymer (GFRP) reinforcement for the rapid construction of concrete bridge deck and parapet systems. The deck reinforcement comprises prefabricated modular stay-in-place (SIP) panels (gridforms), consisting of two-layer, three-dimensional grating made of off-the-shelf pultruded shapes, with an epoxy-bonded bottom formwork plate. Pre-assembled GFRP rebar cages are utilized as reinforcement for the open-post concrete parapet. Detailing and construction procedures have been addressed to improve safety and constructibility. Laboratory testing demonstrated the structural adequacy of gridform reinforced slabs under design service loads, and of a first post/deck connection configuration. The system will be implemented in the construction of the new Bridge 14802301 in Greene County, MO, scheduled for completion in November 2005.

INTRODUCTION

Over one quarter of the US bridges are classified as either structurally deficient or functionally obsolete (1). 23% of them, i.e., about 37,000 bridges, are concentrated in the states of Texas, Pennsylvania, Oklahoma, and Missouri. A major instrument of degradation is the corrosion of metallic structural members and steel reinforcement within concrete decks and connections with safety appurtenances, accruing from the routine use of deicing salts on roads and exposure to harsh environments. Increased load requirements further emphasize the need for substantial structural upgrades. The impact of the economic and social costs of such operations calls for the development of competitive and durable structural systems that can be rapidly installed.

The effectiveness of prefabricated pultruded FRP gratings as internal reinforcement of concrete bridge decks has been demonstrated in a number of laboratory tests (2, 3, 4) and pioneer field implementations (5, 6). In addition to the corrosion-resistance typical of advanced composites,
the key features of the solution are ease and speed of installation. Time consuming tying of reinforcing bars is eliminated, while the lightweight of FRP grating dramatically facilitates handling operations of large-scale panels. Furthermore, the use of a SIP configuration, not always practical when adopting conventional metallic forms due to corrosion related issues, would eliminate the need for extensive falsework.

In the project presented herein, large-size GFRP SIP grating panels comprising a double-layer three-dimensional grating and a formwork plate, denoted as gridform, and pre-assembled GFRP rebar cages for both post and rail beam, have been developed and integrated to construct the concrete deck and a newly designed Modified Kansas Corral Rail (MKCR) of the new Bridge 14802301 in Greene County, MO. The structure is scheduled for completion in November 2005. Replacement of the current slab-on-girder superstructure is needed because of its precarious conditions and increased load requirements. The current load rating is 4.3 ton from an original estimate of 11.7 ton, due to extensive degradation of the concrete deck, with through thickness holes up to 1.5’ diameter, and diffuse thickness loss of the top flange up to 30%. The deterioration of the connections between deck and safety appurtenances also poses safety concerns. The new superstructure has four spans of 37’ exterior and 35’ interior, for a total length of 144’. A closed expansion joint at the center support separates the two-span continuous steel girders. The cross section comprises four W24×84 girders spaced at 6’ on-center, and acting non-compositely with a 7” thick deck (clear cover of 1.5”). The out-to-out deck and clear roadway width are 24’ and 22’, respectively. Design, detailing and construction procedures have been addressed to ensure structural adequacy and improve safety and constructibility during installation, in a joint effort between the Center of Infrastructure Engineering Studies at the University of Missouri-Rolla, the University of Wisconsin-Madison, the Greene County Highway Department, Great River Engineering of Springfield (engineer-of-record), Hartman & Co. (contractor), Strongwell (manufacturer of the gridform deck panels) and Hughes Brothers (manufacturer of the GFRP rebars for rail reinforcement).

GFRP STRUCTURAL REINFORCEMENT SYSTEM

Gridform Panels Description and Installation Procedure

Each prefabricated panel has a width of 23’-2”, i.e., the out-to-out deck width minus 5” per side, which will be formed on-site. Typical length is 8’, and thickness 5-5/8”, for a total weight of about 900 lb. The length of the end panels is designed to fit the actual bridge length, and accommodate the expansion joints. The gridforms are made of four pultruded off-the-shelf glass/vinylester components (Figure 1(a)): a) 1-1/2” (38 mm) pultruded I-bars, spaced at 4” on-center and running continuously in the direction perpendicular to traffic (transversal), which are the main load-carrying elements; b) three-part pultruded cross rods, spaced at 4” on-center and running through pre-drilled holes in the I-bars web in the direction parallel to traffic (longitudinal), which enhance the in-plane rigidity of the assembly, mechanically constrain the core concrete to allow load transfer to the I-bars, and provide shrinkage and temperature reinforcement; c) two-part shear connectors, shaped to be epoxy-bonded to the I-bars and fastened with a 3/8” GFRP bolt and nut, which provide structural integrity to the three-dimensional gridform by spacing the grating layers 2.5” apart; and d) 1/8” plates epoxy-bonded to the outer face of the bottom layer I-bars, which act as a formwork.

Cut-out pockets within the overhang reinforcement facilitate insertion of the GFRP rebar post cages at the correct spacing. The detail at a typical thru-section post is illustrated in Figure 1(b), where the I-bars are cut 9” shorter than the form plate at both edges. Upon tying of the post cages, the lightweight gridforms can be lifted with a single pick of a crane (6) at four anchorage points, and placed over the steel girders. The top and bottom grating layers are off-set by 1’, thereby allowing the easy field splicing of adjacent panels by means of non-mechanical overlaps (Figure 1(a)), and providing some continuity in the longitudinal direction. Vertical anchoring is ensured by means of 1” diameter steel threaded rods spaced at 8’ along each girder, used in combination with washer and nut to hold down the bottom layer grating, in order
to stabilize the structure during construction and service life. The rods can be installed either in pre-drilled holes through the top flange thickness, or via automatic end welding if the equipment is available, while drilling of the circular holes through the form plates is done on-site. Deck casting is carried out after forming the 5” concrete drip edge. This solution is preferred since more practical than using pultruded L- or T-shape drip edges connected to the bottom plate, as initially envisaged (7). Concrete leaking between the panels due to girders camber is prevented by inserting 11’-7”x3’x1/8” pultruded strips to cover each butt-joint between the gridform plates. It is also noted that no bending of the panels is required to match the roadway crown, which is formed in place using the deck finishing machine. The rebar cages for the continuous rail beam, pre-assembled with a length up to 16’, are then mounted prior to forming and pouring of the concrete parapet. 4’ long GFRP splice rebars are used to connect adjoining cages.

The project Special Provisions included Material Specifications for the pultruded gridform components, defined in compliance with a model specification recently developed for the FHWA (8), and Performance Specifications for the gridform. Limit stresses and deformations were imposed to individual structural elements, and full-scale test panels, respectively, to be subjected to forces representative of that applied during the construction phases: a) vertical construction loading prior and during concrete pouring; b) lateral loads applied to the top surface; c) in-plane racking; d) vertical load on splice overlaps; and e) wet concrete loading (7).

![Diagram of gridform panels configuration and thru-post reinforcement layout](image)

Figure 1 – Typical gridform panels configuration (a), and thru-post reinforcement layout (b).

The cost of the prototype gridform panels for this project is $26/ft², which is significantly lower than that of earlier SIP generation. The approach proposed may become competitive in case of larger-scale production, and valuing the intrinsic savings due to durability properties, and decisive reduction of time-consuming operations with consequent minimized traffic disruption.

**Open-Post Rail GFRP Reinforcement Design and Layout**

A MKCR internally reinforced with GFRP rebars was designed to complement the deck reinforcement, and develop a truly steel-free bridge deck/rail system. Previous research demonstrated the feasibility of the solution (9, 10). The design objectives were: a) exceed the minimum resistance of Test Level 2 (TL-2) (11), i.e., the category of the open-post rail replaced (12). An equivalent lateral static strength \( F_T = 27 \) kip is required to resist the impact of a 4,500 lb pickup truck at 45 mph, with crash angle of 25°. Measures to upgrade the system to the TL-3 category were also evaluated; and b) devise a simple reinforcement configuration geometrically compatible with the gridform layout, allowing rapid pre-assembling of separate post/connection and longitudinal rail beam cages by trained personnel, and easy installation on-site. 4’ long
posts and openings were used, instead of the original 3’ and 7’, respectively. The cross section replicates that of the MKCR, with a height increased from 27” to 30” to reduce the risk of roll-over. The reinforcement layout is illustrated in Figure 1(b).

The rail system was designed in compliance with ACI 440.1R-05 (13). It is emphasized that the linear elastic behavior of FRP rebars does not allow for moment redistribution following yielding at a section where the full capacity is attained, as in the case of steel reinforced sections. Therefore, the assumption of a given failure mode is admissible as long as both equilibrium and deformation compatibility are verified. For the same reason, in the present case, a failure mode involving a single post and two adjacent 4’ rail beam spans, assumed fixed at the beam/post joint section, is initially postulated in lieu of a generally accepted and less conservative failure mode where two post/deck connections reach their ultimate capacity (14). The main unknown is the moment-rotation response of the connection system, which is affected (not necessarily concurrently) by the developable tensile stress of the bent rebars within the deck, the behavior of the construction joint, the effectiveness of the anchorage of the post tension rebars, and the contribution of adjacent deck portions.

The cost of the pre-assembled GFRP rail reinforcement is $59/lin.ft, which in perspective should not dramatically exceed the total cost of $90/lin.ft of a conventional Federal Lands MKCR (12).

**EXPERIMENTAL CHARACTERIZATION**

**Gridform Reinforced Deck Panel**

A 7’×8’×7” gridform reinforced slab, simply supported at 6’-4” on-center, was subjected to static testing. A concrete design mix with 3/4” maximum aggregate size, and 28-day compressive strength of 4,000 psi, was utilized. A maximum midspan deflection of 0.332” was measured during concrete pouring, corresponding to 0.175” in case of continuous three-span configuration. The value is significantly below the prescribed limit of 0.25” for conventional SIP formwork (11). The specimen included a lap splice positioned flush with the edge of the neoprene loading pad (Figure 2(a)), to assess the response at the weakest area of the reinforcement. The punching shear capacity was 124.9 kip, i.e., nearly six times the 21 kip load corresponding to the 16 kip HS20-44 truck wheel service load increased by a 30% impact factor, as shown in the load-deflection plot in Figure 2(b).

It is noted that the theoretical capacity of 124.1 kip, calculated according to the design equation proposed by Jacobson (15), is in excellent agreement with the experimental value (7).

**Rail Post/Deck Connection**

Full-scale proof test of a post/deck overhang subassembly was performed to assess the connection resistance and actual rotational stiffness. Figure 3(a) and Figure 3(b),(c) show the
connection configuration tested, and the test setup, respectively. The post was cast on a 8’
twice the post length)×9’ gridform reinforced slab, supported over two floor steel beams spaced
3’ on-center, and tied to the strong floor using six dywidag steel bars. The overhang length was
3’ from the center of the exterior support. Preliminary linear elastic finite element analysis was
performed to select test boundary conditions which allowed a deflection profile linearly
proportional to that of a real MKCR under the same load conditions. The assembly was
instrumented with several strain gauges and displacement transducers.

Quasi-static load was uniformly applied at 2’ from the slab surface by means of a 4’ long
restraint beam, using a hydraulic jack tied to a reaction frame. An ultimate load of 15.1 kip was
attained, corresponding to 45% of the nominal bending capacity of a 4’ long slab section,
accounting for the contribution of the GFRP rebars only. First cracking initiated at a load of 7.6
kip due to post shear-off at the post/deck interface, where no shear key was included, in order
to simulate a construction joint often encountered in practice. Fracture developed within the
deck along the concrete/top grating I-bars interface up to a load of 13 kip, followed by an
essentially post-mortem diagonal crack started in proximity of the I-bar ends and progressed
within the deck. Figure 3(d) shows the load-deflection profile as recorded using two string
transducers on top of the rail post (2’-5 3/4” from the slab surface) at the midsection and at 6”
from the edge, respectively. The moment-rotation response of the connection would allow a
theoretical transverse rail resistance of 47.8 kip (34.9 kip considering the nominal concrete
compression strength), assuming a one post-two beam failure scenario. The beam design
flexural strength, \( (\varphi M_p)_{b} \), would be reached at an horizontal deflection of 0.36” (0.26”), and
bending moment at the connection of 11.2 kip-ft (10 kip-ft), i.e., 74% (66%) of the ultimate
capacity. Even though the lateral strength of the configuration largely exceeds the TL-2
requirement, the improved version in Figure 1(b) aims at improving the post/deck continuity by
including a shear key, reducing the congestion of FRP underneath the post by introducing cut-
out pockets, and increasing strength and stiffness by optimizing the reinforcement layout.

CONCLUSIONS

A novel prefabricated modular GFRP reinforcement for concrete bridge deck and rail systems
has been presented. Together with the durability characteristics typical of FRP reinforcement,
the distinct advantage of the proposed solution is the speed of installation. Full-scale proof
testing of deck panel and post/deck overhang specimens provided experimental evidence of
the structural adequacy of the system, which will be implemented in the upcoming superstructure replacement of a slab-on-girder bridge in Greene County, MO.

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