FRP INTERNAL REINFORCEMENT SYSTEMS FOR CONCRETE DECK AND RAIL: FIELD APPLICATION

SUMMARY

The impact of economic and social costs typically associated with bridge replacement presents the need to develop structural systems that can be rapidly installed, in addition to providing adequate durability under harsh environmental and loading conditions. Recent extensive research and development work funded by the Federal Highway Administration (FHwA) demonstrated the feasibility of using large-scale, pultruded Glass Fiber Reinforced Polymer (GFRP) panels as stay-in-place (SIP) formwork and internal reinforcement for the rapid construction of corrosion-free concrete bridge decks. The technology was successfully implemented in a pilot field application in the U.S. This document summarizes the preliminary study for the application of a new GFRP SIP reinforcement system in the replacement of the superstructure of a slab-on-girder bridge located in Greene County, MO. To complement the deck system, a modified open-post Kansas Corral Rail internally reinforced with GFRP bars was designed. Figure 1 provides an overview of the FRP reinforcement strategies adopted. The design approach is introduced herein. Experimental validation of the design assumptions represents a critical step in the transition of an innovative solution from the laboratory to a field application, and will be undertaken as the following task.

Figure 1 - Overview of FRP reinforcement systems for concrete deck and rail of new Bridge 1480230, Greene County, MO

BACKGROUND

In Missouri, over one half of the 24,000 bridges filed in the National Bridge Inventory (FHwA) have primary structural members made of steel, with a large predominance of slab-on-girder bridges. Almost half of them, i.e., one fourth of the state inventory, are classified as either structurally deficient or functionally obsolete. Corrosion of the steel reinforcement within the deck is a major instrument of degradation, with effects accruing from the use of deicing salt on roads and exposure to harsh environmental conditions.

The superstructure of the seventy-years old Bridge 1480230 (Greene County, MO) needs to be replaced, due to extensive degradation of concrete deck, safety appurtenances, and steel girders, as shown in Figure 2.

Figure 2 - Degradation of deck, girders and safety appurtenances of Bridge 1480230

The new concrete deck is reinforced with 24 by 8 ft GFRP grid panels that also act as stay-in-place formwork. Corrosion resistance is provided by the use of GFRP, while the introduction of lightweight, large scale SIP panels represents a cutting edge solution to dramatically improve the rapidity of installation. The system is complemented by a new Kansas Corral Rail, where traditional steel reinforcement has been replaced by GFRP bars.

OBJECTIVE

To demonstrate the feasibility of using GFRP SIP panels for the rapid construction of bridge decks in a real-case scenario;

To develop a systematic design approach for concrete railings reinforced with GFRP bars based on ACI 440 and AASHTO LRFD provisions;

To gain in-depth understanding of GFRP reinforced concrete rail design and detailing issues, with focus on rail/deck connections.

GFRP SIP REINFORCED DECK SYSTEM

The deck reinforcement, shown in Figure 3, consists of GFRP stay-in-place (SIP) panels with a double-layer grating comprised of four components: a) 1-1/2 in pultruded I-bars (yellow), spaced 4 in center-to-center, which run perpendicular to traffic and are the main load-carrying elements; b) three-part pultruded cross rods (black), spaced 4 in off center, which run parallel to traffic and contribute to the in-plane rigidity of the reinforcement panels; c) two-part shear connectors that provide structural integrity to the double-layer grating, thereby allowing large-scale panels to be lifted in a single pick of a crane and placed on the steel girders; d) a 1/8 in pultruded plate adhesively bonded to the outer face of the bottom I-bars, which does not have structural function and acts solely as a formwork.

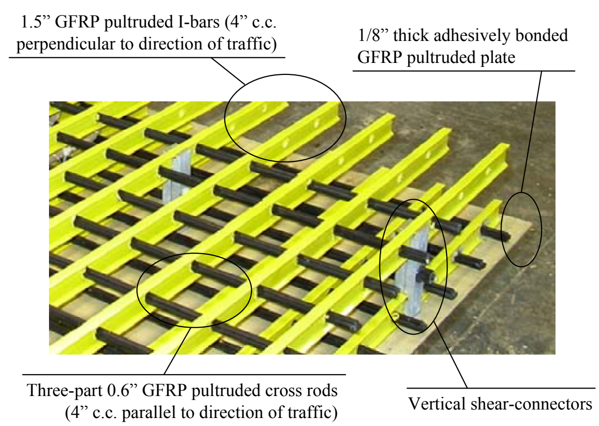

Figure 3 - GFRP SIP deck reinforcement panel

The system has been developed to meet prescriptive material and structural performance specifications, in order to limit stress levels and deformations experienced during the deck construction phases. Extensive experimental work conducted at the University of Wisconsin-Madison demonstrated the ability of a similar GFRP double-layer grating reinforced deck to accommodate HS20-44 truck service design load with a considerable factor of safety against failure.

GFRP REINFORCED CONCRETE RAIL

The open-post concrete rail is reinforced with GFRP pultruded bars, tied in cages using plastic ties. The connection between the post reinforcement and the SIP panels has been specifically designed to allow the deck section adjacent to the post to resist the transversal load required for the correspondent rail class. Figure 4 depicts the reinforcement layout at an intermediate post, which has been considerably simplified with respect to the original steel reinforced counterpart, and a close-up of the connection.

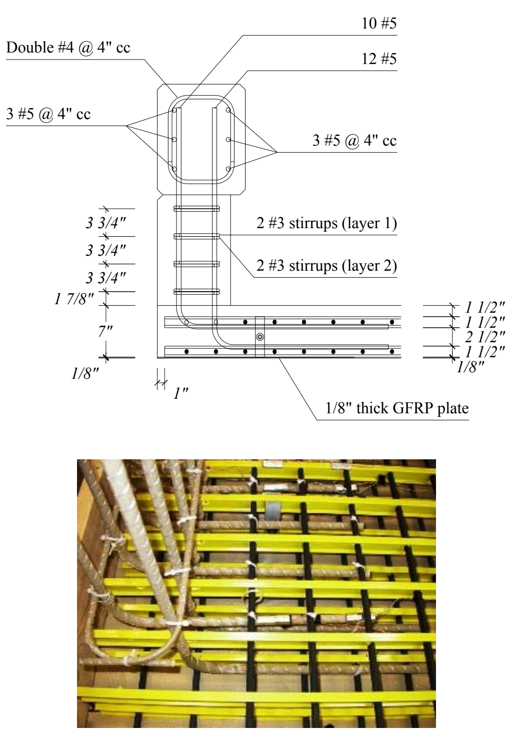

Figure 4 – GFRP reinforcement layout at intermediate post and rail/deck connection

The railing has a typical cross section that replicates that of the Kansas Corral Rail, with a height increased from 27 in to 30 in to minimize the risk of roll-over.

RAIL DESIGN AND ANALYSIS

The yield line method was applied to evaluate the lateral strength of the concrete rail. Upon postulation of possible collapse mechanisms which are compatible with the boundary conditions, the ultimate load is determined via the Principle of Virtual Work, i.e.,

$$F_{T,u}\delta = \sum_i \phi_f M_{n,i}\varphi(\delta, O, P, H_e),$$

wherein $F_{T,u}$ is the ultimate lateral load, applied at a height $H_e \geq 2$ ft from the roadway, and uniformly distributed along $L_T = 4$ ft, which is required to be greater than 54 kip for TL-3 level railings (AASHTO 1998); δ is the average virtual displacement of the rail along L_T; $\phi_f\, M_{n,i}$ is the design moment of the GFRP reinforced section i considered in the collapse mechanism (Table 1), computed as per ACI 440.1R-05, "Guide for the Design and Construction of Concrete Reinforced with FRP Bars", to be released by the American Concrete Institute to supersede ACI 440.1R-03; φ is the rotation at the section i given as a function of δ, H_e, length of opening, O, and length of post, P.

Table 1 - Design moment capacity of rail and rail/deck connection sections

Section	$\phi_f M_n$*
Beam between intermediate posts	27.2 kips-ft
Intermediate post	18.3 kips-ft/ft
Deck edge at intermediate post[a]	11.7 kips-ft/ft
Beam at end posts	44.0 kips-ft
End post	18.1 kips-ft/ft
Deck edge at end post[a]	12.0 kips-ft/ft

* as per ACI 440.1R-05
[a] controls with respect to capacity of post section (no contribution of adjacent deck portions considered)

The resistance against lateral load for the collapse mechanisms considered, which are illustrated in

Figure 5, is summarized in Table 2.

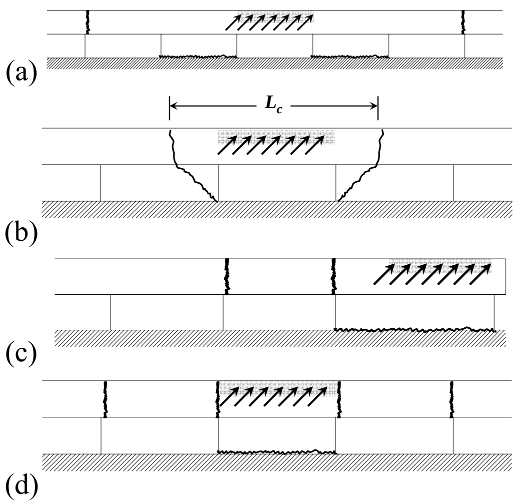

Figure 5 - Failure modes of concrete open-post rail analyzed: 2 post/ 3 span (a); 2 post/ 2 span (b); 1 end post / 1 span (c); 1 post / 2 span (d)

Table 2 - Strength of GFRP reinforced concrete rail as per yield line analysis

Failure mode	$F_{T,u}$* (kips)
2 post / 3 span[a]	58.7
2 post / 1 span	67.3
1 end post / 1 span	55.9
1 post / 2 span	50.5

* No contribution of deck portions adjacent to post is considered in failure mechanisms
[a] Typically accepted for design purposes (Hirsch 1978). Design lateral load F_T = 54 kips (AASHTO LRFD 1998)

Although the 2 post / 3 span failure mode is typically assumed as applicable for open-post concrete railings (Hirsch 1978), other failure modes are considered to provide a better understanding of the overall performance. In particular, the strength of the end portion of the rail, i.e., at the approach deck and at the expansion joint, is verified to exceed the required F_T = 54 kips even when considering a single post (and connected deck) engaged as a resisting structural member. A similar failure mechanism assumed at an intermediate post (1 post / 2 span), without accounting for any contribution from posts nearby, and from deck portions adjacent to the post/deck connection, still yields a theoretical ultimate strength of 50.5 kips.

WANT MORE INFORMATION?

Details on this research project and additional information will be available in the final report.

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