IDENTIFICATION OF PERFORMANCE CHARACTERISTICS OF CONCRETE RAILINGS WITH PULTRUDED FRP REINFORCEMENT

SUMMARY

The use of pultruded Glass Fiber Reinforced Polymer (GFRP) internal reinforcement for concrete bridge decks, in the form of either reinforcing bars or gratings, ideally eliminates a major instrument of degradation, i.e., corrosion of the steel reinforcement accruing from the use of deicing salt on roads and exposure to harsh environmental conditions. Recent extensive R&D work funded by the Federal Highway Administration (FHwA) demonstrated the feasibility of using pultruded panels as stay-in-place (SIP) formwork and reinforcement to dramatically reduce construction time.

The development of GFRP reinforced concrete railings is of primary importance to integrate a truly steel-free bridge deck system. From a practical standpoint, the use of composite reinforcement would prevent degradation of the safety appurtenances and their connection with the deck, thereby enhancing the roadway safety. In addition, devising a simple reinforcement layout, combined with the use of lightweight FRPs, would decidedly improve constructability.

A new GFRP deck system comprising large-scale SIP gratings has been selected for the rapid superstructure replacement of a slab-on-girder bridge located in Greene County, MO. To complement the deck system, a modified open-post GFRP reinforced concrete rail was designed. Figure 1 provides an overview of the reinforcement strategies. Experimental validation of the design assumptions is a fundamental step in the transition of an innovative solution from the laboratory to the field. The experimental program proposed herein is aimed at establishing performance characteristics of concrete railings reinforced with pultruded GFRP elements. Identifying the static and dynamic response of the rail, the deck overhang, and the critical detail of the deck/rail connection would provide a basis to evaluate the acceptability of alternative designs. In perspective, GFRP SIP deck gratings may be ideally complemented by a fully integrated rail reinforcement composed of similar pultruded elements.

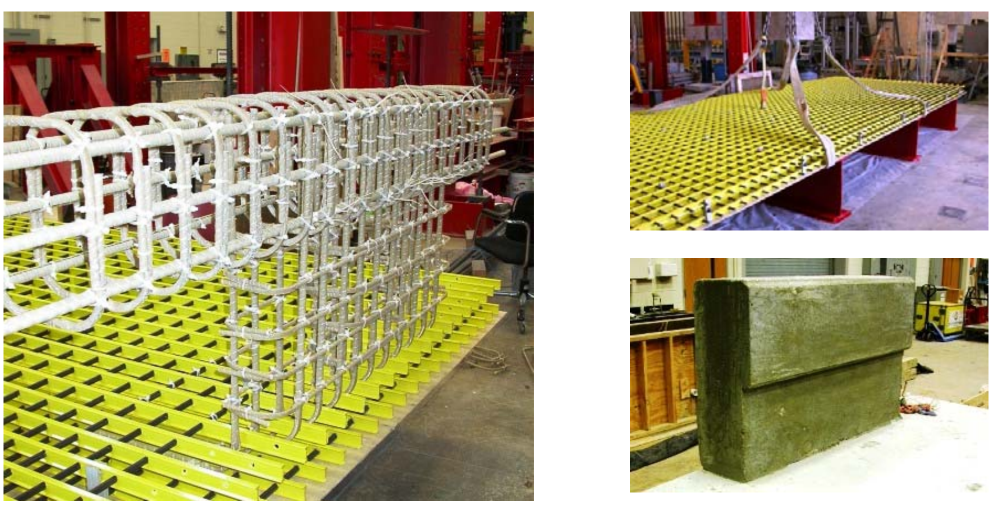


Figure 1 - Strategy for pultruded GFRP internal reinforcement system for concrete deck and railings: 3-D stay-in-place gratings (deck) and GFRP reinforcing bars (rail)

BACKGROUND

Corrosion of the steel reinforcement within bridge decks is a major instrument of degradation, with effects accruing from the use of deicing salt on roads and exposure to harsh environmental conditions. This may ultimately result in severe degradation of deck, girders, and safety appurtenances, as shown in Figure 2.

Figure 2 - Degradation of deck, girder and safety appurtenance of Bridge 148, Greene County, MO

The use of GFRP as a deck and rail internal reinforcement system promises to overcome the issue, and is emerging as a practical alternative to conventional steel reinforcement. However, due to the peculiar physical and mechanical characteristics of composite materials, the design philosophy of FRP reinforced concrete structures is substantially different from that of traditional reinforced concrete. The results of crash testing of a Test Level 3 open-post rail (and deck) reinforced with pultruded GFRP bars, in compliance with NCHRP Report 350 (Ross et al. 1993), provided experimental evidence of the acceptable performance of the system when subjected to vehicle impact load (Buth et al. 2003).

Due to the variety of pultruded GFRP reinforcing elements commercially available, different designs may be considered. In perspective, when using GFRP SIP gratings, a fully integrated rail reinforcement composed of similar pultruded elements would be an ideal alternative. The final target is to develop an economical and safe all-in-one reinforcement system to be rapidly installed prior to casting of the concrete.

Critical steps to make possible solutions competitive are a) defining a systematic approach for the design of FRP reinforced rail and rail/deck connections; b) establishing benchmark performance characteristics to evaluate the acceptability of alternative systems.

OBJECTIVES

- To validate fundamental assumptions for the systematic design of FRP reinforced concrete railings and rail/deck connection according to ACI 440 (American Concrete Institute 2005);
- To evaluate the static and dynamic response of GFRP reinforced concrete rails with respect to steel reinforced counterparts;
- To establish performance characteristics to be used as benchmark to determine acceptability of alternative designs.

WORK PLAN

The research program consists of two tasks, namely:

1. *Preliminary design and detailing of a GFRP reinforced open-post railing and connection with GFRP SIP grating panels;*
2. *Full-scale experimental characterization of*

static and dynamic response of the rail post and deck overhang, with focus on the critical detail of the deck/rail connection.

TASK 1: DESIGN AND DETAILING

Deck: the reinforcement, shown in Figure 3, consists of GFRP stay-in-place (SIP) panels with a double-layer grating comprising 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, with the rail post reinforcing cages already in place, 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.

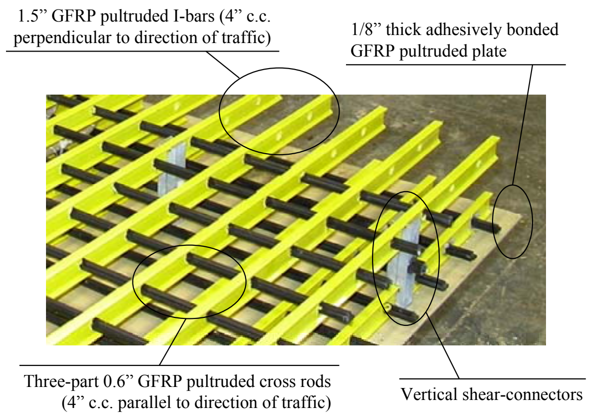


Figure 3 - GFRP SIP deck reinforcement panel

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 (Bank et al. 2004). Equally excellent results are being confirmed by the first results of ongoing testing of the new system.

Railing: 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 a typical thru-post reinforcement layout, which has been considerably simplified with respect to the original Kansas Corral Rail steel reinforced counterpart, and a close-up of the rail/deck connection.

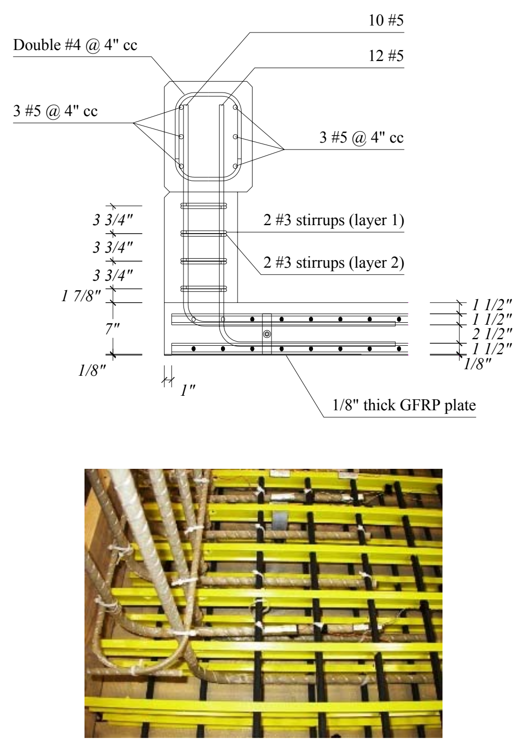


Figure 4 - GFRP reinforcement layout at intermediate post and rail/deck connection

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 further reduce the risk of roll-over.

The yield line method is applied for the preliminary evaluation of the lateral strength of the concrete rail. Upon postulation of admissible collapse mechanisms, 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, computed as per ACI 440.1R-05 (ACI 2005); 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.
The theoretical strength in case of the collapse mechanisms illustrated in Figure 5 is summarized in Table 1.

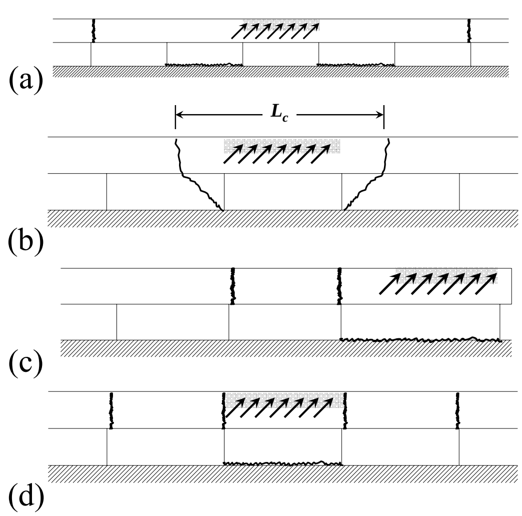


Figure 5 - Failure modes of concrete open-post rail analyzed: 2 post/ 3 span (a); 2 post/ 2 span (b); 1 end post / 1 span (c); 1 post / 2 span (d)

Table 1 - Lateral 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

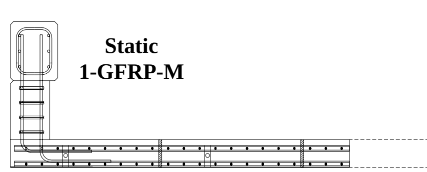
* No contribution of deck portions adjacent to post is considered in failure mechanisms. Environmental reduction factor C_E = 0.7 assumed for design strength of GFRP bars
[a] Typically accepted for design purposes (Hirsch 1978). Design lateral load F_T = 54 kips (AASHTO LRFD 1998)

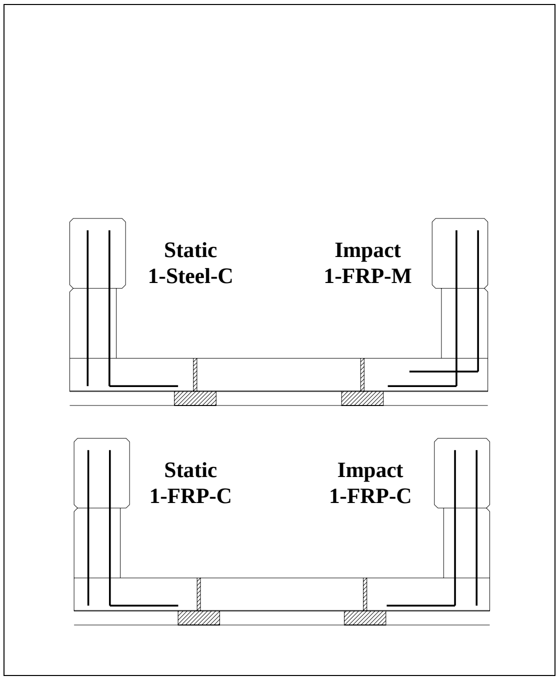
Although the 2 post / 3 span failure mode is typically assumed as applicable for open-post concrete railings (Hirsch 1978), other failure modes are considered to provide a better understanding of the overall performance. In particular, the strength of the end portion of the rail, i.e., at the approach deck and at the expansion joints, 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 adjacent deck portions, still yields a theoretical ultimate strength of 50.5 kips.

TASK 2: LABORATORY TESTING

The proposed test matrix is shown in Table 2. Laboratory tests should be performed on full-scale overhang/rail post specimens under static and dynamic loading, with the latter simulated using a wrecking ball.

Table 2 - Rail test matrix*





* Letters C and M indicate type of rail/deck connection (C = conventional, M = modified)

The performance characteristics are to be evaluated with respect of two main design variables, namely: a) type of reinforcement (steel and GFRP) and b) type of connection (conventional, C, and modified, M).

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BUDGET

Budget for the project will cover support for one graduate student and funds to conduct analytical (Task 1) and experimental (Task 2) studies over a period of one year. The total budget is $25,000. Materials, construction, instrumentation, test setup, and disposal are estimated at $ 15,000.

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