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The effects of splices and bond on performance of bridge deck with FRP stay-in-place forms at various boundary conditions

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ABSTRACT

An investigation is conducted on a novel system of Fiber Reinforced Polymer (FRP) stay in place (SIP) structural formwork for concrete bridge decks. The deck system is composed of FRP composite ribbed panels, spanning between girders and acting as both permanent formwork and bottom slab reinforcement. The testing, conducted at 1:2.75 scale, consisted of ten bridge deck sections and examined several critical parameters, namely: varying of the width (w) of the deck specimens relative to their spans (s), and varying interface bond condition, concrete strength and loading location on the deck. It was shown that as the width (w) is increased relative to span (s), the performance of the deck approaches the actual built performance. An aspect ratio (w/s) of greater than 1.6 was found to adequately represent performance and avoid overly conservative results produced at lower aspect ratios. Varying concrete strength from 17 MPa to 42 MPa in identical decks resulted in 20% increased capacity but did not influence stiffness. Applying adhesive bond at FRP–concrete interface to create a fully composite section increased the deck strength and initial stiffness by 30% and 73%, respectively. In decks with adhesive bond, loading directly above the FRP splice resulted in a 20% lower strength than loading half-way between splices. This is an opposite trend to that observed in decks without adhesive bond.

1. Introduction

The state of transportation infrastructure in North America has been deteriorating for some time. This has necessitated a substantial investment in research to improve the durability and longevity of new concrete infrastructure. Much of this work has been focused on bridge decks, which are particularly susceptible to deterioration due to their extreme exposures to environmental conditions and, in the North, chloride attack from road salt. Fiber Reinforced Polymer (FRP) composites have been recognized as a promising solution to this problem in all-FRP configurations and as internal reinforcement for bridge decks [4]. Recently, FRP has been investigated as a stay-in-place (SIP) formwork system for bridge decks, combining the durability advantages of FRPs with the inherent constructability advantages of SIP formwork [6,17]. Various FRP-SIP geometric configurations, including corrugated plates were explored [9,15]. Numerical investigations of such composite systems has been conducted, including work on slabs [8] and beams [11]. The experimental work related to these systems has largely been focused on testing or modeling discrete bridge deck sections, with width-to-span (w/s, see Fig. 1) aspect ratios typically less than one. These tests can justifiably be expected to produce conservative results as compared to actual decks constructed in the field, due to the discontinuities at the free edges, but there is no literature or guides on this margin of conservatism. This fact has not been a drawback for testing which has predominantly been conducted to validate individual field projects, but is an impediment to research where the goal is to evaluate the performance of the system under field conditions. In addition, testing on FRP SIP form deck system has been conducted almost exclusively with the load applied directly over the seam, presuming that this is a conservative practice. It has been established that the level of in-plane restraint provided to bridge decks impacts their performance [5], making this a critical parameter. The study described in this paper addresses these concerns by targeting several parameters using scaled bridge deck specimens. A total of 10 decks were constructed examining the following parameters for decks with FRP-SIP forms, specifically, along with a control steel-reinforced deck:

(a) *The effect of aspect ratio*: a variety of aspect ratios were chosen from narrow to very wide with all other parameters held constant. This isolated the effect of specimen width in discrete deck panel tests and enabled the determination and recommendations of critical aspect ratios.
(b) *The effect of concrete compressive strength*: the series of widths mentioned above were tested at two different concrete strengths. This is an important parameter, given that failure is expected by punching shear and the strength is governed by in-plain restraint.

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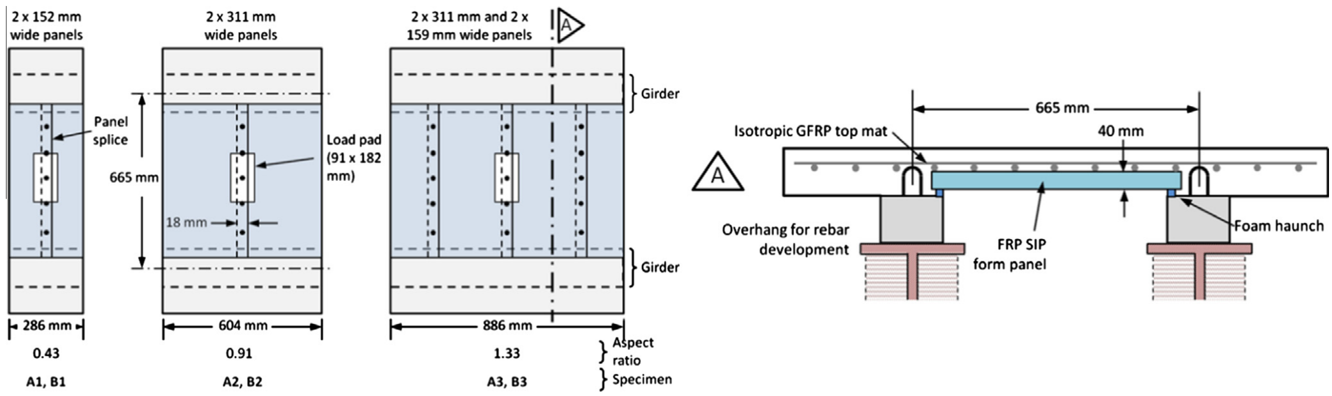

Fig. 1. Layout of specimens A1–A3 and B1–B3.

(c) *The effect of interface bond*: a specimen was constructed using epoxy adhesive between the FRP panel and concrete to achieve composite action and compared to specimens cast on FRP panels without surface treatment.

(d) *The effect of location of load relative to the splices of FRP panels*: identical decks were constructed where the load was applied either directly above the splice or directly above the panel center, half way between splices.

(e) *The effect of rotational fixity at deck supports on the stiffness and capacity*: one specimen was tested on simply supported rollers to compare with specimens monolithically cast with simulated precast concrete girders.

2. Experimental program

The following sections provide a summary of test matrix, materials, fabrication and test setup and instrumentation.

2.1. Test specimens and parameters

In general, the system under investigation represents a novel FRP composite SIP formwork system, as developed at full scale in an earlier study [15]. The system is composed of a ribbed GFRP plate, produced by the pultrusion method, placed between the girders of a slab-on-girder bridge in such a way as to act as permanent formwork and replace the bottom layer of reinforcement. The panels are placed with the ribbed stiffeners transverse to the direction of traffic and panels are joined to one-another at panel to panel splices located at regular intervals in the traffic direction (Fig. 1). In some cases, surface treatment is provided to the FRP–concrete interface to promote composite action, while in other cases no bonding is provided at the interface.

Table 1 provides a summary of test matrix. As shown in Fig. 1a, specimens A1–A3 were constructed with variable slab widths of 286, 604 and 886 mm, representing deck width-to-span aspect ratios of 0.43, 0.91 and 1.33, respectively. Specimen A4 represents a deck tested earlier by the authors in a parallel study. This deck was identical to the system used for specimens A1–A3, except that it accurately represents a real condition deck of a complete bridge constructed over multiple girders of 4350 mm span. It is added to specimens A1–A3 to represent the case of a virtually infinite width (in this case 4350 mm), giving an aspect ratio of 6.54. Deck A4 has a concrete strength of 40 MPa, comparable to A1–A3, which are 37–46 MPa.

Specimens B1–B3 were similar in design to slabs A1–A3 (Fig. 1), except that they used a very low strength concrete (17 MPa). Low strength concrete filling may present economic advantages and/or permit the use of low density concrete should structural performance be adequate.

Specimens C1–C3 investigated the effect of FRP–concrete bond, loading location relative to FRP splices and support conditions. Unlike specimens A1–A4 which were cast directly on FRP panels without surface treatment, specimens C1–C3 were constructed using a high modulus epoxy adhesive bond at the FRP–concrete interface in order to promote full composite action. While loading was applied directly over the panel-to-panel splice in C1, C2 was loaded half-way between splices as shown in Fig. 2. C1 and C2 were both cast monolithically onto scaled-down simulated CPCI 1200 (AASHTO Type III equivalent) girders to simulate field application. In contrast, C3 was cast independently as a flat slab, and supported on rollers at each end during testing, as shown in Fig. 2. This simulated the conditions under which many deck slabs are currently tested for convenience. Specimens A1 and C1 are identical other than the FRP–concrete interface epoxy, thereby assessing its structural contribution.

Control specimen C4 is a conventional steel-reinforced concrete deck, shown in Fig. 2, used to compare the FRP SIP system to conventional practice. This deck was designed as per CAN/CSA S6-06 [7] requirement and included a top and bottom orthogonal layers of steel bars, with 0.3% steel reinforcement ratio top and bottom in each direction. The thickness of the FRP SIP form specimens was designed to be equal to the depth to the bottom steel reinforcement of control specimen C4.

All specimens had a 665 mm span center-to-center. This span along with all other dimensions of the deck and supporting girders represent a 1:2.75 scale from a prototype full scale deck designed earlier by the authors to represent a 1830 mm (6 ft.) girder spacing commonly used in practice and supported by CPCI 1200 (AASHTO Type III equivalent) precast concrete girders [15].

2.2. Materials

2.2.1. GFRP form panels

The GFRP panels used as SIP formwork in this study can be seen in Fig. 3. They consist of a 4.2 mm thick GFRP plate, stiffened by intermittent T-shaped ribs spaced at 50 mm center-to-center. The total panel depth is 40 mm and the rib web and flange are both 4.2 mm thick. The ribs are oriented transverse to traffic direction when installed. Tensile coupon testing was carried out in both directions according to ASTM D3039/D3039M [3]. It revealed linear longitudinal stress–strain curve with a longitudinal tensile strength of 399 MPa and a modulus of elasticity of 24.7 GPa. In the transverse direction, response was slightly non-linear with a tensile strength of 50 MPa, an initial modulus of 12.7 GPa and a rupture strain of 0.0088. Tensile testing of the web of the ribs