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Polymer concrete–GRP plate hybrid joints for transverse moment–shear continuity in GRP bridge decks

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ABSTRACT

This paper describes an experimental study of two joint configurations, one with only reinforced polymer concrete (RPC) infill, the other with RPC infill and bonded GRP plates, to overcome shear and moment discontinuities in GRP bridge decks transverse to the bridge's main girders. Fabrication, instrumentation and combined moment/shear force loading of these joints are reported. The joints occupied the full 0.9 m widths and the central 1 m lengths of simply supported deck specimens of span 2.7 m. Cutting out of GRP from the deck to create holes for pouring the concrete into the voids of the deck did not appear to compromise joint integrity under short-term load. Rosettes on the webs of the deck lead to the deduction that over 90% of shear force in the joint was carried by the RPC infill at only 30% of the length of the joint inwards from one end of the infill. Beam theory reliably predicts the neutral axis heights in both joint sections after cracking of the polymer concrete, and also predicts the cracking load for the joint with only RPC infill. For the joint with RPC infill and GRP plates, the test data appear to be elusive in showing a clear cracking load. The GRP plates significantly improved cracked section stiffness beyond that for the RPC alone. A peak load of 500 kN over a 300 mm × 300 mm patch damaged but did not fail the deck specimen with either joint. For the RPC-only joint, an unexplained 45% drop in strain occurred in the compression concrete during sustained load over 80 minutes. Practical fabrication issues and further potential research into these joints are discussed.

1. Introduction

Pultruded fiber reinforced polymer – FRP – cellular systems show huge potential as the decks of traffic bridges owing to the low weights (only 20% that of equivalent reinforced concrete decks), to the corrosion and fatigue resistances, and to the modularity of these FRP systems. Economic considerations commonly dictate the use of glass fiber reinforced polymer – GFRP, or GRP – as the deck material. Two bonded panels of the GRP deck system reported in this paper are shown in Fig. 1(a). The low weights and modularity of such decks permit rapid construction of bridges (and so minimal disruption to traffic flow during construction over live carriageways) with light lifting equipment, while the corrosion and fatigue resistances could lead to reduced inspection/maintenance costs for the bridges in service. The deck panels are laid across the main girders, with connections used between panels as well as between the deck and the girders. The girders may be of steel, fiber reinforced polymer or prestressed concrete. Fig. 1(b) depicts part of a bridge comprising the decking of the present paper with prestressed concrete girders. In all that follows, transverse and longitudinal refer to the width and length respectively of the bridge. Transversely the deck distributes load between girders, while longitudinally the deck can act compositely (as a compression top chord in single span simply supported bridges) with the girders in global bending.

Keller and Gürtler [1,2] came to several scientifically robust conclusions on the structural characteristics of GRP deck–steel girder hybrids based on analyses and large-scale tests. They showed that even flexible adhesives in layers up to 50 mm thick gave full composite action between GRP decks and steel girders, with no damage evident in the adhesive after millions of cycles of realistic fatigue loading. Deck–girder composite action led to quasi-static stiffnesses and strengths well beyond those of the steel girders acting alone. These significant stiffness/strength enhancements from GRP decks may occur with steel girders in bridges up to 25 m span. Keller and Gürtler [1,2] observed that failure occurred by splitting in the deck joints after some yield had occurred in the lower flanges of the steel girders. The webs of the GRP decks were found to provide partial composite action between

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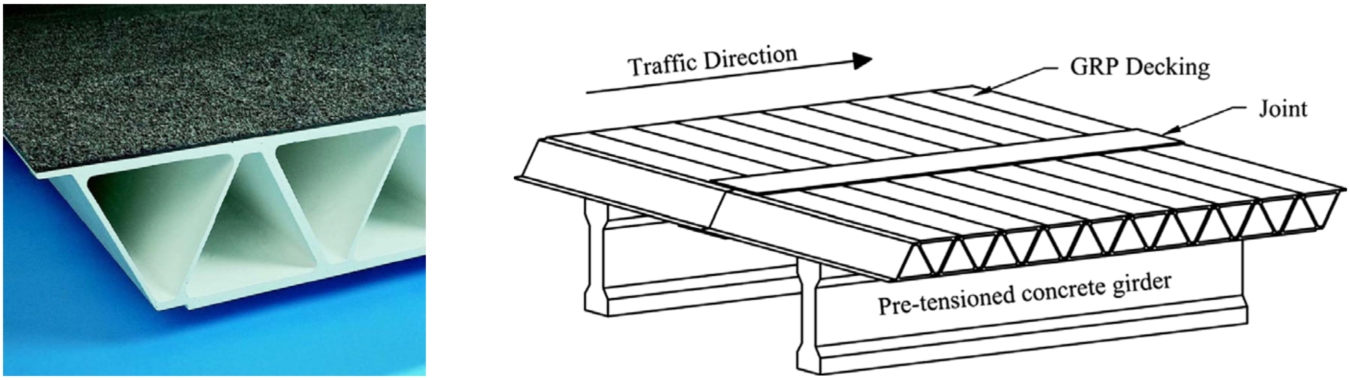

(a) Two bonded GRP deck panels with road surfacing.

(b) Jointed decking across prestressed concrete main girders.

Fig. 1. GRP cellular decking for bridges.

the upper and lower flanges of the deck, the extent of this intra-deck composite action depending on the angles between the webs and the flanges of the deck. Analytical predictions were developed for the service and ultimate behaviours and were found to compare well with test data.

Zhang and Cai [3] concluded, from test-verified finite element analyses, that deck–girder composite action significantly improves the load distribution and dynamic characteristics of bridges with FRP decks. They recommended that the road surfacing on the deck be kept in good condition, as poor surfacing creates problems with acceleration sensitivity which varies with the type of girder used beneath the FRP deck. They also showed that FRP deck bridges show quite distinct dynamic characteristics from their concrete deck counterparts, and on that basis suggested modified deflection criteria for FRP deck bridges relative to those in existence for concrete deck bridges.

Coogler et al. [4] explained that while transverse strains in GRP decks are repeatable and predictable, longitudinal strains in the deck can be sensitive to small longitudinal shifts of nearby wheel loads and so care should be exercised in using these latter strains for performance assessment. They stated that this strain sensitivity implied significant longitudinal stress ranges in the deck due to passage of wheels, which in turn underpinned the importance of assessing deck fatigue performance.

Keller and Schollmayer [5] showed that while a specific orthotropic FRP deck showed weakly bi-directional behaviour relative to an isotropic plate-strip, increasing the number of bonded deck panels from three to five decreased service deflections by 50%. They showed that this was beneficial to performance at the serviceability limit state, which can commonly be critical for FRP bridge decks.

Alongside the above and related research, FRP decks have been gaining popularity in practice. Solomon and Godwin [6] describe US applications of FRP decks to replace deteriorated decks in existing bridges and also in new bridge construction. One example, an historic steel truss bridge, entailed replacement of the original concrete deck with a new FRP deck to make the bridge lighter and capable of carrying the heavier modern traffic loads while retaining the historic truss. Replacement of timber or steel grating decks in lifting and other bridges are also described. The new bridges cited in the paper [6] comprise FRP decks connected to steel girders via mechanical connections, with one bridge employing prestressed concrete girders under the deck. Luke et al. [7] document the development of the ASSET GRP deck (shown in Fig. 1 and the subject of the present paper) and describe its use with FRP girders in a novel traffic bridge in the UK. Reising et al. [8] compare the performances of four different FRP deck systems used to replace a deteriorating concrete deck along a five-span bridge in the US. Pultruded FRP panels were identified as having the most accurate dimensions, with beneficial consequences for installation. Real truck load tests showed that distribution factors for the FRP decks were broadly similar to those for the original RC deck. However, the FRP decks' thermal characteristics were reported to differ from those of RC decks, with the use of foam cell cores changing internal temperature distributions and so potentially inducing stresses and movements that must be allowed for in detailing the deck-to-girder connections [8].

Zhou and Keller [9] present the underpinning science for deck panel-to-panel and deck-to-girder connections. Bonded, mechanical and hybrid joints are all comprehensively addressed in this paper. Zetterberg et al. [10] describe development of joints between longitudinally adjacent panels for a specific deck system. Adhesive and alternative bolted connections, finite element analyses to examine the structural actions of these connections, then a final steer towards the bonded joints on fabrication and structural grounds are all described.

Joints to provide continuity between FRP deck panels along the girders are well established. One area requiring further attention – and which builds on the work of Zhou and Keller [9] – is a means of overcoming *transverse* discontinuities between FRP deck components. Fig. 1(b) illustrates the issue. Transverse discontinuities may exist between deck components for different reasons. One reason could be the limit on the length of deck which may be transported from factory to site. This can lead to multiple lengths of deck across a wide bridge. Another reason may be the need to keep one lane of an existing two-lane bridge open – to minimise disruption to traffic during new build – while the other lane is demolished then rebuilt using FRP decking on new or existing girders. This introduces discontinuity within the FRP deck halfway across the bridge. If this discontinuity remains, then the structural action of the deck as regards deflections, moments and shear forces associated with load response transverse to the girders can be compromised. It is thus important to introduce transverse structural continuity into the deck at these locations. Fig. 1(b) shows, halfway between girders, a generic joint entailing surface bonded plates to give this continuity. In what follows, transverse joints comprising GRP bar-reinforced polymer concrete infill without and with externally bonded GRP plates are described. The details, fabrication, testing, observations and interpretation of test data are presented for these joints. Automation of fabrication and further research are also discussed. The terms joint and connection are used synonymously throughout the rest of this paper.