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Structural performance of composite sandwich bridge decks with hybrid GFRP–steel core

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ABSTRACT

This paper presents the static and fatigue performance of composite sandwich bridge decks with hybrid GFRP–steel core. The composite sandwich bridge deck system is comprised of wrapped hybrid core of GFRP grid and multiple steel box cells with upper and lower GFRP facings. Its structural performance under static loading and fatigue loading with a nominal frequency of 5 Hz was evaluated. The responses from laboratory testing were compared with the ANSYS finite element predictions. The failure mode of the proposed composite sandwich bridge deck was more favourable because of the yielding of the steel tube when compared with that of all-GFRP decks. The ultimate failure of the composite sandwich deck panels occurs by shear of the bonded joints between GFRP facings and steel box cells. Results from fatigue load test indicated no loss in stiffness, no signs of de-bonding and no visible signs of deterioration up to 2 million load cycles. The thickness of the composite sandwich deck retaining the similar stiffness may be decreased to some extent when compared with the all-GFRP deck. This paper also presents design of a connection between composite sandwich deck and steel girder.

1. Introduction

It was recognized that most of structural deficiencies of bridges were shown in the bridge deck geometry and deck condition. The bridge deck is a structural component that distributes and transfers loads transversely to the girders that bear on piers or abutments. The most commonly used type for slab-on-girder systems is a cast-in-place concrete deck. Structural deficiencies of a bridge deck are related to physical deterioration due to environmental conditions, unanticipated factors like heavy vehicle traffic, fatigue and dynamic responses. They usually cause substantial problems for structural repair and replacement of a concrete deck. For high traffic volume bridges, the speed of construction, especially for the cases of bridge deck repair and replacement, has become a critical issue more than ever. Strong momentum exists for the spread of precast construction for bridges with a push to expand the limits, especially for the use in long-span bridges. One of the promising systems for precast bridge construction has been concrete-decked, precast and prestressed concrete (DPPC) girders for superstructure [16]. The DPPC girder bridge does not need a cast-in-place deck, or any wearing course. By having the concrete deck as an integral member, several benefits are obtained, for instance, an accelerated time frame for construction, a high quality plant-produced concrete deck, and an entire cross section prestressed for enhanced section properties and durability. Despite several major benefits, one of the perceived disadvantages with the DPPC girders is its increased weight in long-span bridges. The writers have been working on finding potential solutions including the use of fiber-reinforced polymer (FRP) decks replacing the concrete deck in DPPC girder bridges [15].

In recent years the interest in using FRP in construction field has significantly increased worldwide. However, the use of FRP panels for bridge decks is still limited, due to the relatively higher cost of the FRP materials than the conventional ones [10,20]. Currently most FRP deck panel systems have the cellular-box geometries fabricated by the pultrusion process [2,9,13,17]. It is believed that innovative designs based on FRP materials could play a great role in extending the application of FRP materials in bridge decks and cutting down the cost. One such design method is to use the hybrid concept. To make the most of FRP materials, combinations of FRP and conventional materials have recently been investigated. Deskovic et al. [7] investigated a hybrid FRP–concrete beam that consists of filament-wound glass fiber-reinforced polymer (GFRP) box section combined with a layer of concrete in the compression zone and a thin carbon fiber-reinforced polymer (CFRP) laminate in

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the tension zone. Burgueno et al. [6] presented a hybrid bridge system with light weight concrete filled circular carbon/epoxy shell girders and an E-glass/polyester deck. They showed that the design is stiffness-driven for the modular composite slab bridge system with the beams of CFRP materials shell type. Lopez-Anido and Han [14] presented the hybrid fiber-reinforced polymer-glulam panels for bridge decks. Mufti et al. [19] developed hybrid FRP–concrete bridge decks using pultrusion and filament-winding fabrication methods. Van Erp et al. [23] developed hybrid FRP–concrete beams for a bridge application in Australia. The hybrid FRP–concrete beam consists of two parts: concrete in the compression zone and GFRP box section in the tensile zone. Additional CFRP laminate was added to the tensile flange of the box section to increase stiffness of the hybrid beam. A layer of concrete is bonded on the GFRP box section by an epoxy adhesive. The weight of the hybrid FRP–concrete beam was claimed to be about 1/3 of that of a reinforced concrete beam. Aref et al. [4] investigated a hybrid FRP–concrete multi-cell bridge superstructure that consists of GFRP trapezoidal box beams combined with a layer of concrete in the compression zone. As stated above, the research on the hybrid structures has been mainly applied to the combinations of FRP and concrete. Ji et al. [11] proposed the composite sandwich deck system with a hybrid FRP–steel core that has the potential to be used with DPPC girders. The main advantages of composite sandwich panels for bridge decks are intended to not only improve stiffness and buckling response by the continuous support of core elements with the face laminates, but also be cost efficient compared to all-GFRP decks.

This paper is focused on the static and fatigue performances of the composite sandwich panels with hybrid FRP–steel core for bridge decks. They were investigated by a combination of experimental and analytical programs. Research has shown that the design of the composite sandwich panels is governed by stiffness and fatigue. This paper also presents the connection design of a composite sandwich deck for a steel I-girder bridge.

2. Experimental program

The experimental program was to investigate the static and fatigue performance of the proposed composite sandwich deck system [11] and to verify that the proposed deck system meets the stiffness requirement and has significant reserve strength. Three different tests in this study were conducted on the composite sandwich deck panels as following: (1) design load test for obtaining flexural strength and structural stiffness of the deck; (2) ultimate load test up to failure; and (3) fatigue load test under service load up to 2 million to inspect the reduction in stiffness or strength due to fatigue.

2.1. Specimen description

The composite sandwich bridge deck system is comprised of wrapped hybrid core of GFRP grid and multiple steel box cells with upper and lower GFRP facings [11]. Fig. 1 shows the cross section of the composite sandwich deck. The design procedure of the composite sandwich deck profile was summarized in [11].The dimension details of the GFRP grid are shown in Fig. 2. The composite sandwich panel specimen used in this laboratory testing is shown in Fig. 3. The detailed manufacturing process of the composite sandwich panel specimens was described in [11].

2.2. Properties of the composite sandwich deck system

The main constituents of the composite sandwich bridge deck system are fibers, resins and steel. Unidirectional E-glass roving, biaxial E-glass roving, continuous strand mat, polyester and vinyl ester resins were selected as the constituents for the GFRP laminates in the composite sandwich panels. The core of steel HSSs in the composite sandwich panel was made of steel, grade KS D3568 steel [18]. The constituents' material properties used for the composite sandwich panels are shown in Table 1. Considering

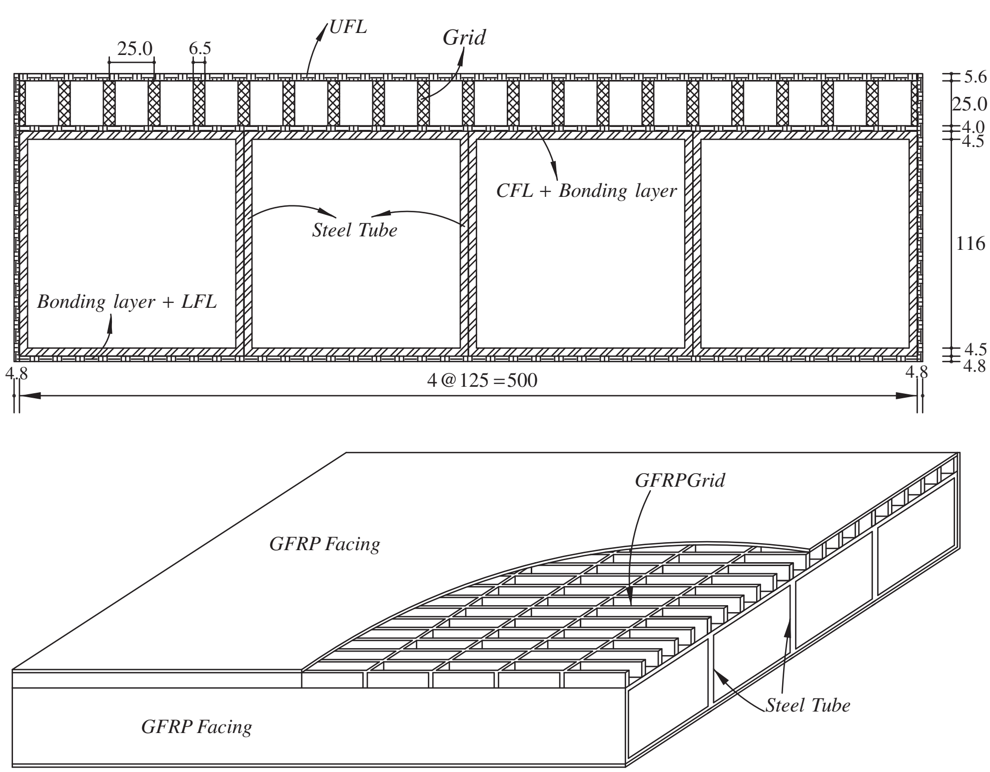

Fig. 1. The proposed composite sandwich deck panel (all dimensions in millimeter).