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Behavior of an adhesive joint under weak-axis bending in a pultruded GFRP bridge deck

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ABSTRACT

It has been more than twenty years since the application of GFRP bridge decks in construction fields. Recently, a few studies by governments and individual researchers have investigated in-use GFRP bridge decks. Areas of trouble include the problems of cracking, spalling and the de-bonding of the pavement or the wearing surface on GFRP bridge decks, all of which affect the long-term durability and serviceability of these new construction materials. Related to these problems, reflective cracks on asphalt pavement are directly related to pultruded GFRP bridge decks.

In this paper, the behavior of an adhesive joint under weak-axis bending was investigated to identify the causes of pavement cracks in in-use pultruded GFRP bridge decks. In detail, this paper initially describes a designed section of a pultruded GFRP deck tube while accounting for the effects of the section geometry through bending tests and for the connections to the girders. The study also describes connection methods of creating adhesively bonded joints between GFRP tubes and panels and presents possible sources of pavement cracks on the GFRP decks. The flexural stiffness and the load-carrying capacities in strong and weak axes are measured during bending tests on pultruded GFRP decks. Next, tensile local failures of an epoxy adhesive due to the concentration of deformations at adhesive joints are identified via a weak-axis bending test. Finally, the tensile failure of an epoxy adhesive due to the local concentration of deformation at an adhesive joint under weak-axis bending is verified through a finite element analysis.

The bending tests and FE analyses of a pultruded GFRP bridge deck under weak-axis bending show that local deformations are prone to concentrate at the adhesive joints which form a flexible and weak region due to the relatively low elastic modulus and strength of the epoxy adhesive. Strong-axis bending has a dominant influence on the global behavior of a deck subjected to bi-directional bending. On the other hand, weak-axis bending, which affects the behavior of adhesive joints, also has a strong influence on pavement cracks. Reflective cracks on the pavement of pultruded GFRP bridge decks can occur due to the local concentration of deformations at adhesive joints on the surfaces of GFRP decks under weak-axis bending, even before the tensile failure of the epoxy at the edges of the adhesive joints due to the higher elastic modulus and the lower tensile strength of the asphalt pavement compared to these properties of the epoxy. To prevent reflective cracks on the pavement of pultruded GFRP bridge decks, design improvements or reinforcing measures for deck connection structures which distribute and minimize the concentrated local deformation on adhesive joints are required.

1. Introduction

Glass-fiber-reinforced plastic (GFRP) has excellent properties, such as a light weight, high strength and high durability. Thus, this material has been applied to constitute structural and non-structural members in many fields. Bridge decks are good application examples of GFRP materials. GFRP bridge decks are used for constructing new traffic and pedestrian bridges, for upgrading bridges without strengthening their substructures, for extending the widths of walkways/bikeways, and for replacing deteriorated bridge decks made of conventional materials such as concrete, steel and wood. In Korea, the research on and development of GFRP bridge decks started in 2000, being supported by the Korean government. By January of 2013, 13 traffic bridges (a total area of 20,094 m^2) and 23 pedestrian bridges (a total area of 30,332 m^2) had been built with GFRP bridge decks [1–3]. Applying prefabricated GFRP decks to

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bridges allows us to reduce the construction time, the substructure materials, and thus the construction costs because GFRP decks are as much as one-quarter of the weight of concrete decks and their strength approximate the strength of normal steel. GFRP decks also offer elongated service lifetimes, reduced maintenance costs and thus minimized life-cycle costs due to their good durability [4]. Load and resistance factor design (LRFD) which considers structural safety and deflection serviceability could be applied as the design basis for widespread use of this new material system [5].

Recently, pavement problems such as the cracking, spalling and de-bonding of pavement and wearing-surface have been observed and reported with regard to in-use GFRP bridge decks. According to a report prepared by Telang et al. for the TRB's National Highway Research Program (NCHRP), many in-use GFRP decks show cracking or spalling of the overlay materials and the wearing surfaces caused by improper installations, environmental swings, or excessive loadings [6]. Triandafilou and O'Connor discussed undesirable performance issues pertaining to in-use GFRP composite bridge decks while focusing on the cracking of pavement and the debonding of wearing surfaces through an investigation of field issues associated with the use of GFRP composite bridge decks and superstructures in harsh environments. They concluded that the reflective cracking and spalling of adhesively bonded pavement or of a wearing surface can be caused by improper material selection and application, low structural integrity of the GFRP substrate, and/or movement by or the flexibility of the GFRP deck [7]. These pavement cracks can cause water leakage in the GFRP deck, which adversely affects the durability of the bridge structure. Repeated local deformation at the adhesive joints due to repeated wheel loads can cause fatigue failure at these joints. Sebastian et al. investigated influence of polymer concrete surfacing on the response of GFRP decks under concentrated loading [8]. They focused on the actual load capacities of surfaced deck and their failure modes by localized load distribution by performing tests on surfaced and unsurfaced deck systems.

To build a pultruded GFRP bridge deck system, deck tubes should be connected to each other by adhesive bonding at the joints. These adhesive joints locally form flexible and weak regions due to the relatively low elastic modulus and low tensile strength of a typical adhesive, thus influencing the behaviors of the GFRP decks in weak-axis bending. Concentrated deformation at these flexible and weak regions under weak-axis bending also causes reflective local cracks on the asphalt pavement of an in-use GFRP bridge deck. Fig. 1.1 shows reflective local cracks on the pavement of a pultruded GFRP deck in a typical steel-plate-girder bridge. The figure also indicates the strong- and weak-axis of the pultruded GFRP deck. Fig. 1.2 shows a picture of reflective cracks on 80 mm-thick asphalt pavement on an in-use GFRP deck of an actual steel-plate-girder bridge, the Gae-Jung Bridge, built in 2004. The reflective cracks in the asphalt pavement occur mainly along the adhesive joints perpendicular to the bridge axis, as shown in Fig. 1.1. From this image, we can assume that the local behavior of the adhesive joints under weak-axis bending, rather than environmental factors, is likely the cause of the reflective cracks. To prevent these cracks, the local behavior of adhesive joints under weak-axis bending should be identified.

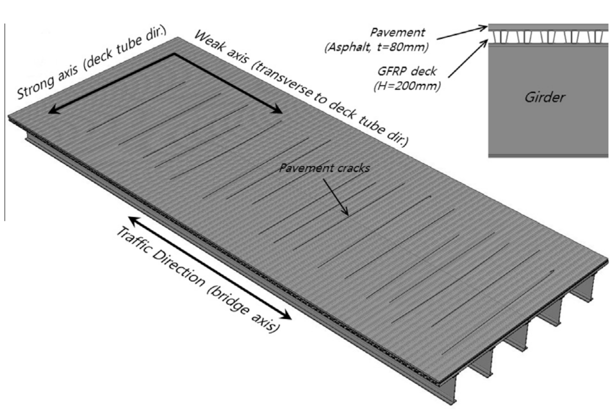

Fig. 1.1. Pavement cracks and strong and weak axes of a pultruded GFRP deck.

Fig. 1.2. Pavement cracks of an in-use GFRP deck (Gae-Jung Bridge).

GFRP decks can be fabricated by pultrusion for mass production after being strengthened with fiber layers having different orientations. These pultruded decks can be assumed as orthotropic plates considering that the pultruded GFRP decks have strong directionality of the stiffness and load-carrying capacity on their strong and weak axes. The orthotropic plate assumption of a pultruded GFRP deck can be explained in terms of two aspects: the shape orthotropic aspect due to the section geometry (e.g. orthotropic steel bridge deck), and the material orthotropic aspect due to the orientation of the fiber reinforcement in each layer of the deck [9]. Both the section geometry and material orthotropic properties of a pultruded GFRP deck should be taken into account in the design of a pultruded GFRP deck. The overall orthotropic behavior depends on the shape orthotropic more than it does on the material orthotropic property of a GFRP deck.

A GFRP deck can be built by assembling modularized deck tubes. This method facilitates the convenient transportation and installation of the GFRP decks. The modularized section geometry should be designed considering the local deformation and deck-to-girder connections. Various geometrical forms of the section significantly affect the weak-axis bending behavior of a GFRP deck. In addition, joining details such as the use of adhesive joints between the deck tubes should be considered in the design of the modularized section geometry. Given that the behaviors of adhesive joints are essentially caused by weak-axis bending, these local behaviors of adhesive joints due to improper designs, installations and material properties can cause local failures at the joints and/or the pavement under weak-axis bending. This behavior of adhesive joints should be properly considered in the design, but it has not yet been investigated in detail to the best of the author's knowledge.

This paper aims to investigate the behavior of adhesive joints under weak-axis bending in order to identify the cause of pavement cracks in in-use pultruded GFRP bridge decks. In detail, this paper (1) describes a designed section of the pultruded GFRP deck tube under consideration by accounting for the effects of the section geometry through bending tests and for the connections to girders, (2) describes connection methods for adhesively bonded joints between GFRP tubes and panels, (3) presents possible sources of pavement cracks on GFRP decks, (4) identifies the