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Fatigue behavior of the foam-filled GFRP bridge deck ☆

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ABSTRACT

Investigated was the fatigue behavior of the foam-filled GFRP bridge deck in the transverse direction which is an intermediate type between the modular type deck and the sandwich type. Four different types of the specimens were prepared and tested with different stress ratios. The failure mode and the change in stiffness by the foam inside the deck was reported. The role of the foam was very clear. It reduced the damage accumulation in the web-flange joint efficiently. Compared to the reference case which was not filled, the endurance of limit of the foam-filled deck was remarkably increased.

1. Introduction

Bridge decks made of fiber reinforced polymers (FRP) are beneficial for maintenance purposes and ease of the replacement of the deck to accommodate any increased traffic demand. Many kinds of FRP decks can be found in these days [1–7]. Most of them can be classified into the modular type or the sandwich type. The former consists of multiple unit modules. A unit module is typically fabricated by the pultrusion process. The modules are bonded in the field to construct a bridge deck. The latter consists of hard skins on the top and bottom surfaces and a soft core between the skins. In practice, the modular type is more preferred than the sandwich type because it is easy to carry such a type economically to the construction site. The behavior of a modular type of deck is greatly influenced by the choice of cross section of the unit module. Although there are various possible cross sections, rectangular sections are well suited for the pultrusion process. In this paper, when we mention modular types, we mean the modular types with a rectangular cross section.

The behavior of the modular types of the bridge decks was tested by many researchers. Because of the characteristics of the pultrusion process, the deck is anisotropic. The direction of the pultrusion is called the longitudinal direction and the other the transverse direction. The behavior of the deck in the longitudinal direction is almost linear before failure. However it is highly nonlinear in the transverse direction [8–11]. It had been believed that the strong nonlinearity in the transverse direction was due to the weak web-flange joint. A strong web-flange joint was tried but it did not improve the nonlinear behavior in the transverse direction [4].

Zi et al. pointed out that the strong nonlinearity is not due to the weak web-flange connection but the shear deformation of the rectangular units [12,13]. They also argued that the failure of the web-flange joint was the major failure mechanism of modular decks with rectangular cross sections although the delamination between two modules was also observed. One may consider that the transverse behavior is not so important as the vehicle load is transferred into the longitudinal direction. However, it is not the case: (1) The failure of the deck when it is loaded in the longitudinal direction is often initiated by local buckling of the web and (2) the moment distribution in the transverse direction is not negligible [14]; see Fig. 1.

Recently, Zi et al. [12,13,15] proposed a new type of cross section, called the foam-filled GFRP bridge deck, where the empty space of the rectangular section was filled by a soft polyurethane foam. This was an intermediate type between the modular type and the sandwich type. The foam-filled inside the space of the deck provided a distributed support to any local buckling of the lamina and mitigated the moment concentration at the web-flange joint. They showed the improvement via a series of static experiments [12,13,15].

This paper is about the fatigue behavior of the foam-filled GFRP deck developed by Zi et al. in the transverse direction. This paper is

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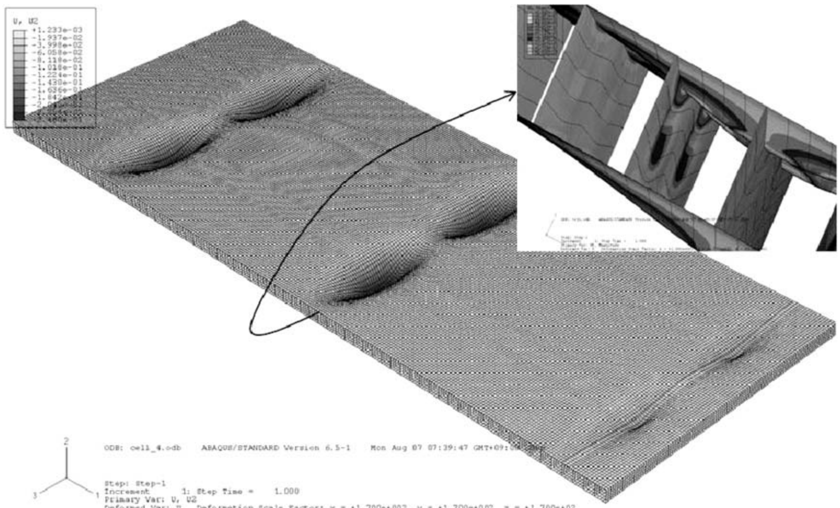

Fig. 1. The principal stress contour with the deformed shape of a typical modular type of GFRP bridge deck subjected to a design wheel load [14].

arranged as follows: the static behavior of the deck is briefly reviewed in Section 2. Then, we describe the procedure of the fatigue test in Section 3. The results and discussions are given in Section 4. We draw conclusions of this paper in Section 5.

2. Review of the static behavior of the foam-filled gfrp deck

In this section, the static behavior of the foam-filled GFRP bridge deck was briefly summarized and compared with that of ordinary modular decks, which would give important information in understanding the fatigue behavior described in this paper.

The foam-filled GFRP bridge deck consists of a modular type deck and a foam-filled inside the space of the modular type deck [12,13,15]. The foam used by Zi et al. was a polyurethane foam made of PPG and MDI. The elastic modulus was only the order of a thousandth of the homogenized modulus of the GFRP deck but it significantly improved the structural behavior of the deck. More over the mass density was low enough not to significantly increase the weight of the foam-filled GFRP deck.

They confirmed that when the inner space of the modular type deck was filled with the foam, the moment concentration at the web-flange joint was greatly mitigated as shown in Fig. 2. The overall load–displacement relation was also significantly improved; see Fig. 2. According to Zi et al. [13], both stiffness and nominal strength were increased more than 300% with the foam compared to the modular type deck (Fig. 3).

The foam inside the deck changed the failure mechanisms, too. The foam interacting with the web and flange modified the structural system so that the contribution of the flange to the load-resisting mechanism was greater than otherwise. Because of the increased role of the flange, all the foam-filled GFRP decks failed eventually by delamination of the adhesive bond as shown in Fig. 4. The delamination was initiated from the outer surface of the flange.

On the other hand, the results from the investigation of strain distribution along the top and bottom flanges of the modular type deck demonstrated that the positive strain value in the top flange and negative strain value in the bottom flange could be developed and moreover, the maximum strain of the bottom flange developed in the third cell not in the middle of the flange of the deck although the beams were tested in three-point bending as shown in Fig. 5. The reason for the occurrence of an opposite sign of strain was the shear deformation which was one of the key factors governing the transverse behavior of such a modular type of the deck [15]. However, it was also shown that the effect of shear deformation was significantly reduced by the foam-filled inside the deck as shown in Fig. 5.

3. Fatigue testing

Three different types of specimen were tested: the unfilled deck modular deck specimen for the reference and the foam-filled spec-

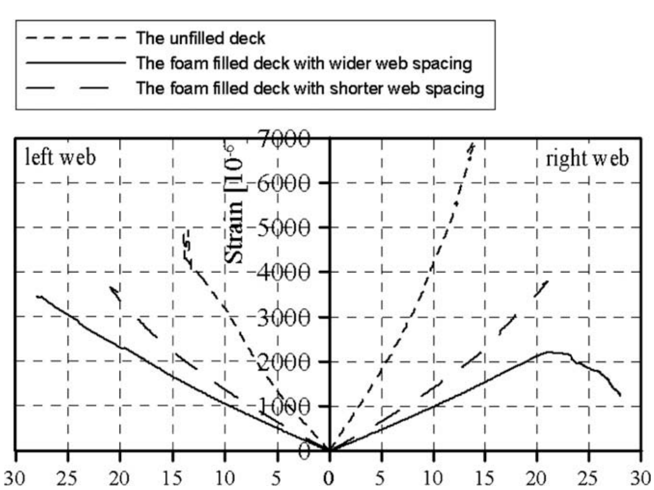

Fig. 2. The strain of the web measured near the web-flange joint.

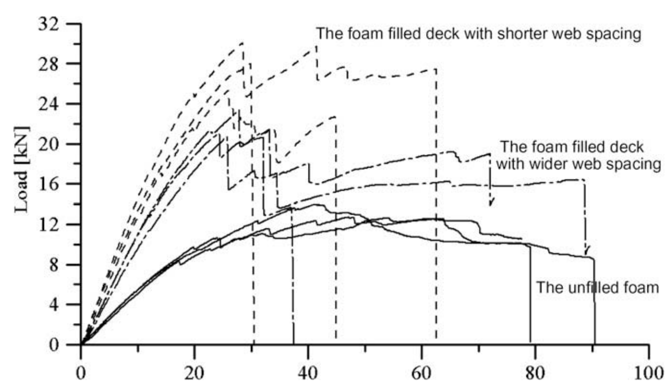

Fig. 3. The load–displacement curves obtained from the static test.