Engineering Structures 33 (2011) 3527–3536

Contents lists available at SciVerse ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Numerical analysis of pultruded GFRP box girders supporting adhesively-bonded concrete deck in flexure

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ARTICLE INFO

Article history:
Received 26 January 2011
Received in revised form
10 May 2011
Accepted 12 July 2011
Available online 15 August 2011

Keywords:
Box girder
Built-up section
Composite
GFRP
Concrete
Load distribution

ABSTRACT

This paper presents the modeling of pultruded glass fiber reinforced polymer (GFRP) box girders consisting of built-up hat-shape sections and flat plates. The study addresses the effect of a thin concrete deck adhesively bonded to the top GFRP plate on flexural performance, as well as the behavior under positive and negative bending that simulates continuous girders. A three-dimensional finite element (FE) approach is proposed to predict the behavior of the GFRP system, including experimental validation. The efficacy of the girders is compared with other metallic box girders: carbon steel and corrosion-resistant metals, namely, stainless steel and aluminum. Failure is generally due to debonding of the concrete deck, and as such, the ultimate strength is not affected much by the girder material used. The study examines the single girder behavior as well as girder-group systems, to assess load distribution. It is shown that the AASHTO LRFD approach for load distribution can reasonably be used for the proposed girder systems. Design recommendations as to material selection are addressed to better use the girder system.

1. Introduction

There is always a need for innovative and durable structural load-bearing systems to accelerate construction, especially in bridges. The application of fiber-reinforced polymer (FRP) materials is gaining a strong momentum in structural engineering applications [1], particularly in bridges which are typically exposed to harsh environments [2]. Pultruded FRP shapes have the potential to replace steel sections for bridges and buildings [3]. For this purpose, glass-FRP (GFRP) is being dominantly used rather than other types of FRPs, such as carbon or aramid FRPs, because of its reasonable cost. GFRP shapes can be used for both load-bearing applications and stay-in-place formwork. Various types of GFRP stay-in-place systems have been developed previously [4–6]. These GFRP applications can compete with conventional corrugated steel decks (e.g., improved durability [7]).

Deskovic et al. [5] proposed a hybrid beam consisting of a rectangular GFRP section with concrete-topping. The GFRP box section functioned as a stay-in-place formwork for the concrete that was adhesively bonded to the top surface of the box. To enhance the flexural stiffness of the system, carbon-FRP (CFRP) sheets were bonded to the tensile soffit of the GFRP section. Various failure modes were examined, including web-fracture, bond-failure, and web-buckling. Dieter et al. [8] evaluated FRP stay-in-place formwork for concrete deck applications. The concrete deck included bi-directional grid reinforcement made of pultruded GFRP composites. The developed deck systems were tested under monotonic and cyclic loads. Bond failure between the GFRP and concrete was observed. The effects of fatigue loads were insignificant on the flexural stiffness of the deck, up to two million cycles. Keller et al. [6] developed an FRP-concrete sandwich deck for bridge superstructure. The core concrete was located in between a ribbed GFRP tension panel and a top compression GFRP flat plate. The assembled specimens were monotonically loaded in flexure. The primary failure mode of the sandwich decks was tension cracking of the core concrete, induced by insufficient composite action with the GFRP. Li et al. [9] tested steel-free composite girder systems consisting of a pultruded GFRP I-shape girder with a concrete slab. The deck was supported by a stay-in-place GFRP plate with ribs. Test parameters included concrete strength and slab thickness. The failure of the system was governed by horizontal shear cracking of the GFRP girder. The specimens with a thick concrete slab exhibited tensile cracking of the concrete because the neutral axis depth was shifted up inside the deck slab.

A recent study supports the significance of deteriorated steel bridges, mainly due to corrosion. It states that over 40% of functionally obsolete or structurally deficient bridges in the United States are made of steel. Sustainability of structures may be improved by using non-metallic girder systems. Fam and

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doi:10.1016/j.engstruct.2011.07.016