Engineering Structures 135 (2017) 191–208

Contents lists available at ScienceDirect

Engineering Structures

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

Investigation of the behaviour of reinforcement-free concrete deck slabs restrained by FRP rods

Yu Zheng [a,*], Tao Yu [b], Jianbin Yang [a], You Li [a], Can Sun [a]

[a] Department of Civil Engineering, Dongguan University of Technology, Dongguan, Guangdong Province 523808, PR China
[b] University of Wollongong, Australia

ARTICLE INFO

Article history:
Received 20 April 2015
Revised 25 December 2016
Accepted 2 January 2017

Keywords:
Concrete deck slabs
Reinforcement-free
Experimental test
NLFEA
Arching action

ABSTRACT

This paper presents an experimental and numerical investigation of the structural behaviour of reinforcement-free concrete bridge deck slabs. In the proposed deck structure, a novel load carrying mechanism is introduced to eliminate the need for internal steel reinforcement. This mechanism is a combination utilizing arching action in deck slabs and tying supporting beams together with fiber reinforced polymer (FRP) rods. In this study, a series of one third scale deck specimens were fabricated and tested up to failure with varying several structural parameters, including supporting beam sizes, type of edge beams and spacing of FRP restraint rods. The failure mode of concrete deck slabs under concentrated wheel loads was expected to be punching failure and arching action inside this type of laterally restrained concrete deck slab had a significant effect on the ultimate behaviour. After the comparison of the test results, the influences of these structural variables and arching action on the behaviour were evaluated. Subsequently, a nonlinear finite element analysis (NLFEA) model was proposed to develop further study. The numerical results showed good agreement with the test results. A parametric study using this finite element model was performed to investigate the factors affecting the ultimate capacity and failure mechanism of this type of reinforcement-free bridge deck. The test results and finite element analyses are discussed and conclusions are presented.

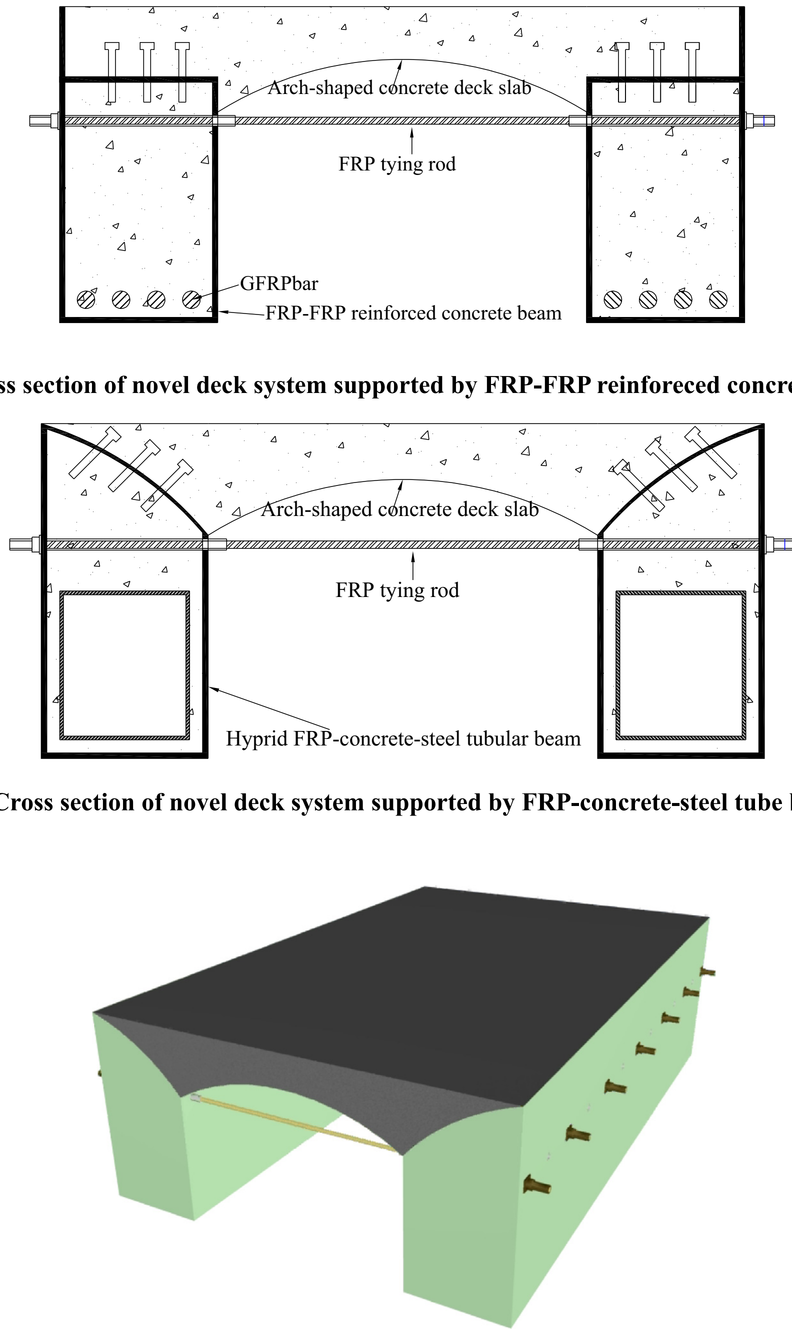
1. Introduction

Currently, more rapid construction and longer durability of infrastructure components are pursed to reduce initial and life-cycle costs. Therefore, some efforts to improve durability have recently been realized by replacing corrosion susceptible steel reinforcing materials with alternative composite materials, such as fiber reinforced polymer (FRP) [1,2]. To accelerate construction and improve durability of concrete bridge deck slabs, this study on the removal of conventional reinforcement and application of FRP materials in deck structures was carried out. As shown in Fig. 1, a novel type of concrete bridge deck slab is proposed, which is an extension to the steel-free deck system previously developed by Mufti et al. [1,3] and Oliva et al. [4,5]. Firstly, to enhance the restraint stiffness from supporting beams, two rectangular edge beams are used in this proposed deck system, in which the torsional and in-plane bending stiffness provided by supporting beams can be increased [6]. In addition, steel restraint straps [1] or steel rods [5] used as restraint components are replaced by glass fiber reinforced polymer (GFRP) rods (see Fig. 1) to avoid the corrosion problems. As shown in Fig. 1, a arch-shaped reinforcement-free concrete slab is designed to be supported by two FRP-FRP reinforced concrete beams or two hybrid FRP-concrete/tubular steel members [2]. This design concept eliminated the need for conventional deck reinforcing and temporary formwork in constructions and improved the durability by using the FRP materials. Therefore, a rapid and sustainable construction can be achieved.

As well reported in the literatures [1,3–5], load carrying mechanism of the reinforcement-free concrete deck slabs resisting concentrated wheel loads is not flexure, but a complex compressive membrane stress referred to as arching action or compressive membrane action [7,8], as shown in Fig. 2. Since arching action was first recognised by Ockleston [9], much research work has been done in topic particularly in the field of concrete slabs, as can be seen in report by Taylor et al. [10]. Currently, it has been reported in the literature that arching action is beneficial in both strength enhancement and serviceability behaviour of concrete bridge deck slabs [6]. Thus, the concept of arching action makes it possible to construct economic and durable concrete bridge deck slabs and has been incorporated specifically into some design

* Corresponding author.
E-mail addresses: zhengy@dgut.edu.cn (Y. Zheng), taoy@uow.edu.au (T. Yu).

http://dx.doi.org/10.1016/j.engstruct.2017.01.005
0141-0296/



(c) 3D view of novel deck structure

Fig. 1. Proposed novel deck system.

guidelines [11,12]. One of the potential applications of arching action is the development of steel-free bridge decks proposed by Mufti et al. [13]. That concept of the steel-free bridge deck included removal of conventional steel reinforcing bars from the concrete in order to prevent corrosion of steel and deterioration of deck slabs subjected to de-icing salts and corrosive environments. Steel straps between beams, externally welded to the bottom of top flanges of the beams, were used to provide added lateral restraint to the decks. Another application of arching action for bridge decks has been in a pilot bridge using a reinforcement-free deck was built in the United States [4,5]. This design concept is similar to the steel-free bridge deck slabs proposed by Mufti et al. [1]. The improved lateral restraint of the deck, archived by tying laterally stiff beams together with steel rods, enhances the ultimate capacity significantly. To improve the durability of deck slabs proposed in this study, GFRP rods were used as restraint components to replace the steel strap [1] or steel rods [5], see Fig. 1. Additionally, rectangular supporting beams were adopted to increase lateral restraint stiffness [14] and arch-shaped concrete slabs were built, which could be beneficial to develop arching action in loading-carrying mechanism.

The research described in this paper was aimed to investigate the structural behaviour of this type of novel reinforcement-free bridge deck structure through experimental tests and nonlinear finite element analysis (NLFEA). In the concept of this deck system, the FRP tube is used as the framework for the precast supporting