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Finite element modelling of demountable precast reinforced concrete deck slabs with external confining system

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ABSTRACT

This paper investigates the enhanced loading capacity and structural behaviour of a transversely confined precast reinforced concrete (RC) deck slab with deconstructable post-installedfriction-grip bolted (PFGB) shear connectors. A detailed 3D non-linearcontinuum-based finite element (FE) model of the deconstructable composite deck with external confining systems (i.e. cross-bracings or ties) and PFGB shear connectors is developed and analysed using the commercial software ABAQUS. The non-linearity of the contacts/interfaces, geometrical and material non-linearities are considered in the FE models. The developed FE models are validated against experimental results and it is shown that the proposed FE model can adequately predict the enhancing effect of arching action in a transversely confined deconstructable precast RC deck slab. Lastly, a parametric study is carried out and effect of different parameters such as compressive strength of concrete, yield strength and proportion of reinforcing bars, clearance between concrete slab and PFGB shear connectors and pretension stress in the PFGB shear connectors on the stiffness and strength enhancement provided by the arching action are evaluated and discussed.

1. Introduction

Development of arching (or compressive membrane) action in conventionally reinforced concrete (RC) beams or slabs with external end or edge restraints can significantly increase stiffness and ultimate strength of the members that in turn can improve structural efficiency and performance of the RC frames, slabs and culverts under static, cyclic and extreme loading conditions [1–9]. In addition to concrete members with reinforcing bars, development of arching action can significantly improve the peak load carrying capacity and fatigue life of the fibre reinforced concrete beams and slabs [10,11].

Various aspects of the development of arching action and its beneficial effects particularly in RC deck slabs and culverts have been investigated experimentally and numerically over the past few decades [8,10,12–14]. The strength enhancement provided by the arching action has been also utilised to develop the concept of transversely confined steel free bridge decks [1,15]. In particular, the steel free decks taking advantage of polymeric fibres/bars in lieu of steel bars have been used to resolve the issues associated with corrosion of the internal reinforcing steel bars and to improve the durability, serviceability and longevity of bridge decks [3,16]. The concept of steel free decks has been also adopted to develop durable rehabilitation strategies for existing RC bridge decks under traffic load [17]. In addition, some bridge design codes recognise the reserve of strength provided by the arching action under ultimate limit state conditions and allow replacing the conventional reinforcing steel bars with external confining systems (in the transverse direction) that mobilise arching action and provide ultimate load capacity comparable to that of conventionally reinforced concrete slabs [18,19]. The transverse confining system usually comprises of ties/straps welded on the top flange of the steel girders and partially embedded in the concrete haunch that separates the slab from the top flange of the steel girders. Furthermore, fully/partially studded straps, threaded bars and cruciform straps can be used in the transverse direction to mobilise arching action. According to Bakht and Lam [1], transverse ties connected permanently to the slab and top flange of the steel beams are the most efficient and the threaded steel bars are the best option in terms of ease of replacement. The steel girders with stud shear connectors welded on their top flange and embedded in the concrete slab can provide a confinement and mobilise the arching action in the longitudinal direction of the deck slabs. However, this traditional construction method in which the shear connectors and confining systems are permanently connected to the steel girders and cast-in-situ slabs are not conducive to deconstruction and their demolition is wasteful, energy-intensive and environmentally-intrusive. To circumvent the shortfalls of the traditional construction practices for bridge deck slabs from an environmental perspective, the use of bridge deck slabs having precast concrete slabs that are attached to the steel girder

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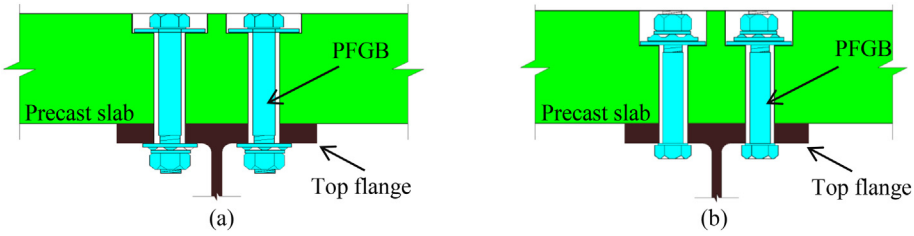

Fig. 1. Post-installed friction-grip bolted shear connection placed in the holes from (a)top and (b)bottom.

by high-strength tensioned friction-grip bolts acting as shear connectors through clearance holes is proposed and numerically examined in this paper.

Extensive experimental and numerical investigations on composite beams and beam-to-column joints have been carried out to investigate the feasibility of using deconstructable post-installedfriction-grip bolted (PFGB) shear connections (see Fig. 1) for attaching precast concrete slabs to the top flange of the steel beams/girders [20–34]. All laboratory tests and numerical simulations have demonstrated the adequacy of the PFGB shear connectors for developing composite action between the steel beams and precast concrete slabs. Furthermore, the experimental results have confirmed that composite connections with PFGB shear connectors can be easily disassembled and reassembled, with the slabs and steel girders being reusable in other structural applications [35].

In this paper, the feasibility and structural performance of a deconstructable bridge deck with precast concrete slabs and PFGB shear connectors and a transverse confining system is evaluated. Detailed 3D non-linearcontinuum-based finite element (FE) models of the deconstructable precast deck slabs with transverse ties and/or cross-bracings are developed using ABAQUS [36] software and the FE models are analysed and validated against available experimental results. It is shown that the FE models developed can capture global and local response (i.e. load-deflection, peak load carrying capacity, failure mode and load-strain) of the transversely confined precast deck slabs with reasonable accuracy. The validated FE model is used to conduct a parametric study in which the influence of different parameters including yield strength of reinforcing bars, concrete compressive strength, reinforcement ratio, clearance between concrete slab and PFGB shear connectors and pretension stress in the PFGB shear connectors and thickness of the precast concrete slab on the structural behaviour of the precast deck slabs with external confining system in the transverse direction are investigated.

2. Finite element (FE) modelling

Structural behaviour of the precast RC deck slabs with transverse confining system in a deconstructable composite deck is numerically studied using nonlinear 3D FE models. In the first step, the 3D finite element models of a one-span precast concrete deck slab with transverse ties and/or cross-bracings(Fig. 2) is developed and validated with Moradi, Valipour [12] experimental data.

Commercial software ABAQUS [24] is used to develop and analyse the nonlinear FE models. The non-linearity associated with contacts/interfaces, geometrical and material non-linearity including concrete cracking and crushing, yielding of reinforcing steel bars, bolted shear

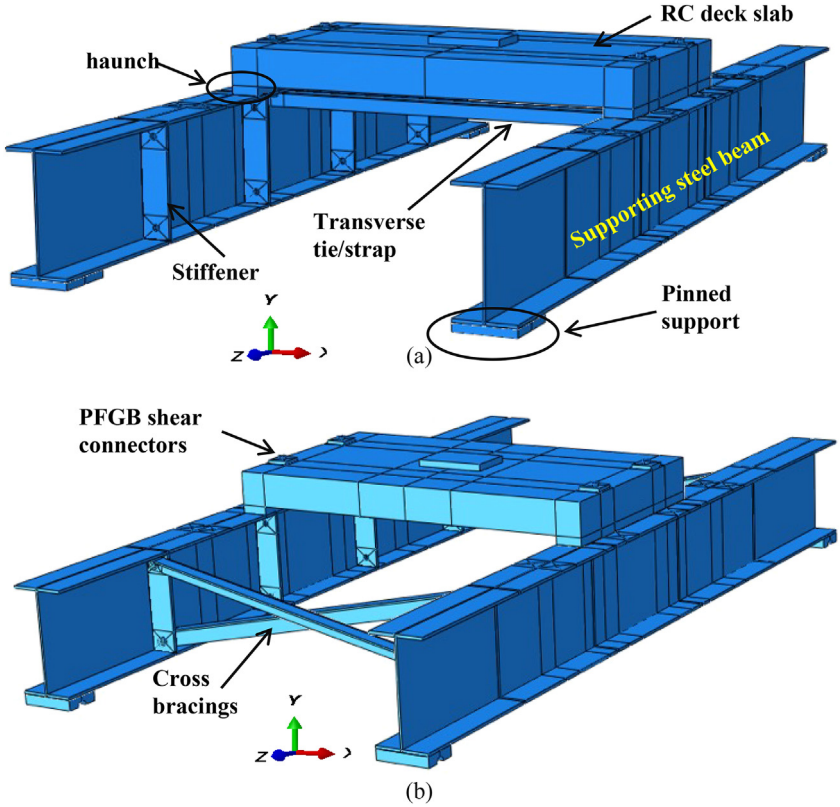

Fig. 2. Outline of the deconstructable composite precast deck slab with external (a)ties/straps and (b)cross bracings in the transverse direction tested by Moradi, Valipour [12].