Construction and Building Materials 87 (2015) 67–77

Contents lists available at ScienceDirect

Construction and Building Materials

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

Arching behaviour of precast concrete slabs in a deconstructable composite bridge deck

H. Valipour *, A. Rajabi, S.J. Foster, M.A. Bradford

Centre for Infrastructure Engineering and Safety (CIES), School of Civil and Environmental Engineering, UNSW Australia, UNSW Sydney, NSW 2052, Australia

HIGHLIGHTS

- A deconstructable steel–concrete composite bridge deck is proposed.
- Experimental data on arch behaviour of precast RC deck slabs are provided.
- Efficiency of cross-bracing and transverse ties for inducing arch action is studied.
- Application of bolted shear connectors in a deconstructable deck is studied.

ARTICLE INFO

Article history:
Received 4 December 2014
Received in revised form 3 April 2015
Accepted 9 April 2015
Available online 18 April 2015

Keywords:
Arching action
Bolted shear connector
Composite deck
Deconstruction
Rehabilitation

ABSTRACT

This paper describes the results of the testing of precast concrete slabs in a deconstructable composite steel–concrete system for the construction of bridge decks. Benign arching action is utilised to carry the point (wheel) loads to the supports and to develop the required slab capacity; the failure mode and load–deflection response of the precast concrete slabs being investigated in the study. Twelve half-scale precast reinforced concrete slab strips were tested, with the slabs being attached to steel girders using friction grip bolts to provide shear connection between the deck and the supporting steel girders. The systems were tested under a monotonically increasing point load, which simulates vehicle wheel loading. The configuration and proportion of the reinforcing steel bars and the types of transverse cross-bracing and transverse straps were the main test variables. It is concluded that friction grip bolted shear connectors can prevent relative slip between the steel girders and concrete deck slabs, so that the equilibrating tension force in the cross-bracing/transverse straps, required to develop compressive arching in the slabs, can be developed. The arching effect in the slabs is very beneficial, and cannot be ignored in rational structural design processes.

1. Introduction

In reinforced concrete (RC) flexural members, cracking of the section in the tensile zone is associated with a change in the neutral axis (NA) position that, in turn, causes an axial extension of the member as the neutral axis moves away from the centroidal axis and towards the farthest compressive fibre. In steel–concrete composite bridge decks, this axial extension of the RC deck slab can be prevented by adjacent spans and cross-bracing/transverse diaphragms, generating a compressive thrust in the restrained RC deck slab [1]. This phenomenon, known as compressive membrane (or arching) action, can significantly increase the post-cracking stiffness as well as the flexural and punching shear capacities of laterally restrained RC deck slabs [2–10].

The enhancing effect of arching action on the ultimate load capacity of restrained RC deck slabs has been recognised and implemented in some design standards [11,12]. Moreover, to resolve the issues associated with corrosion of the internal steel reinforcing bars and to extend the service life of concrete deck slabs, the concept of mobilising this arching action to develop steel-free deck slabs has been proposed by some researchers [4,5,13]. In existing steel-free deck slabs that rely on the development of arching action, the internal steel bars are typically replaced by external transverse straps with or without cross-bars [14]. The straps rest (or are welded) on the top flange of the steel girders and close to the soffit of the deck slab and the concrete slab is separated from the top flange of the steel girders by a haunch that encases the cross-bars and a small portion of the transverse straps. Alternatively, the lateral restraint/confinement required for the development of arching action in the concrete slab can be provided by threaded bars (*i.e.* steel or CFRP/GFRP) and/or

* Corresponding author. Tel.: +61 2 9385 6191.
E-mail address: H.Valipour@unsw.edu.au (H. Valipour).

http://dx.doi.org/10.1016/j.conbuildmat.2015.04.006
0950-0618/

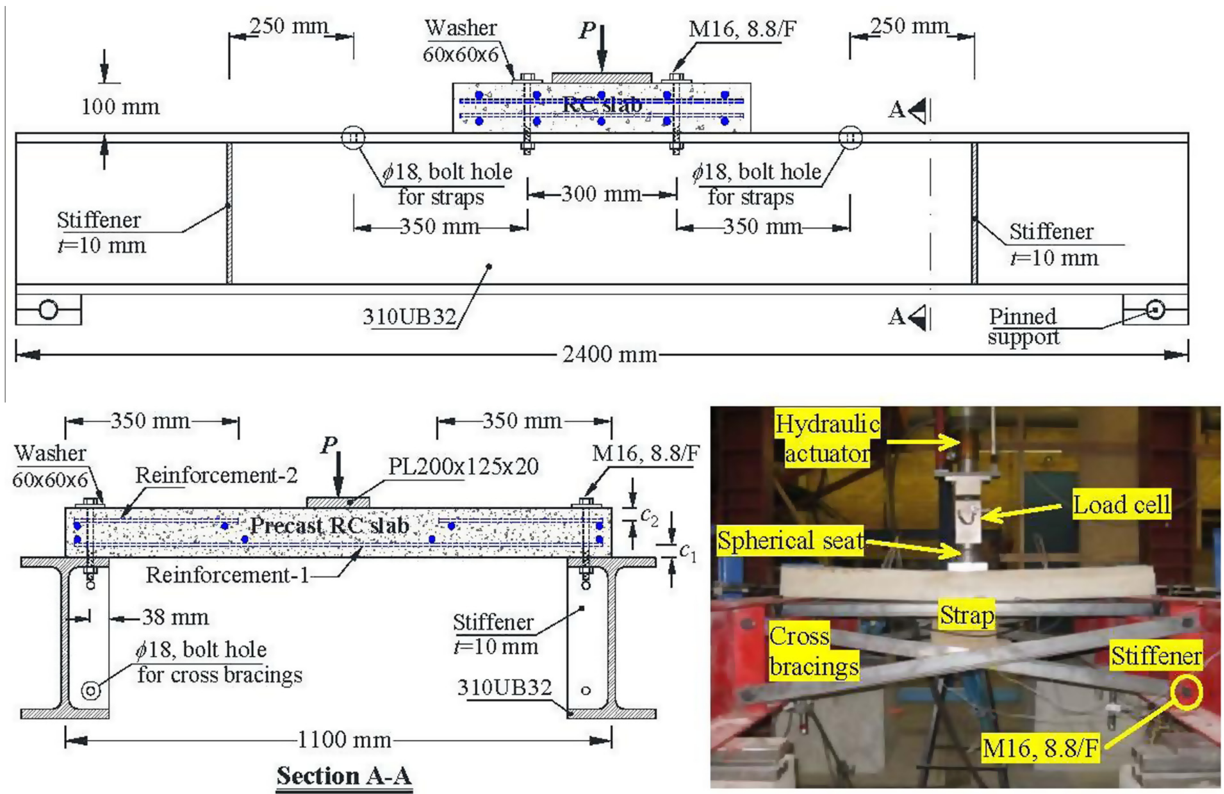

Fig. 1. Geometry, cross-section, configuration of restraining/confining system in transverse direction and test set up for precast RC slabs connected to steel girders using PFBSCs.

Table 1
Designation of specimens, details of flexural reinforcement and bar configuration and transverse confining/restraining system.

Designation of specimens[#]	Reinforcement-1	Reinforcement-2	$\rho = A_{st}/bd$ (%)	c_1 (mm)	c_2 (mm)	Transverse restraining system 45 × 45 × 5EA
M6B	6N10	–	1.5	45	–	Bracing
M4B	4N10	–	1.0	45	–	Bracing
B4B	4N10	4N10	0.7	25	25	Bracing
B6B	6N10	6N10	1.0	25	25	Bracing
M6	6N10	–	1.5	45	–	–
M4	4N10	–	1.0	45	–	–
B4	4N10	–	0.7	25	–	–
M6S	6N10	–	1.5	45	–	Strap
M6BS	6N10	–	1.5	45	–	Bracing + strap
M4BS	4N10	–	1.0	45	–	Bracing + strap
B4BS	4N10	4N10	0.7	25	25	Bracing + strap
B6BS	6N10	6N10	1.0	25	25	Bracing + strap

[#] M*x* and B*x* designations are used for slabs with main flexural reinforcement at middle and bottom layer, respectively and *x* denotes the number of reinforcing steel bars.

intermediate diaphragms [4,15]. Amongst different alternatives, transverse straps permanently connected to the concrete slab and top flange of the steel girder appears to be the most efficient confining system, whilst threaded steel bars can be replaced easily [4].

In current engineering practice, the composite interaction between the concrete slab and steel girders is typically achieved by welded headed shear studs buried permanently in the cast *in situ* concrete or in pockets filled with grout for precast slabs. However, this form of construction is not conducive to deconstruction and it also hinders the speedy and cost-effective replacement of defective slabs and/or the transverse confining system.

The ability of bolted shear connectors in developing efficient composite action between the steel girders and precast concrete slabs has been demonstrated through several studies [16–23]. In particular, recently conducted three-point bending tests on composite beams and push-out tests on composite connections with post-installed friction-grip bolted shear connectors (PFBSCs) have shown that the composite efficiency and fatigue strength of PFBSCs are significantly higher than those for beams having stud shear connectors [19,20,24]. Furthermore, the steel–concrete composite decks with PFBSCs can be deconstructed easily, so that the possibility for future reuse and the recycling of the structural components are maximised [16,17]. Thus, composite bridge decks with PFBSCs can allow for speedy and cost-effective rehabilitation, replacement and repair of deteriorated deck slabs with minimal traffic disruption.

In this paper, the ability of PFBSCs in preventing the relative slip between the precast concrete slabs and steel girders in a transversely-confined steel–concrete composite bridge deck is explored experimentally. The anchoring provided by PFBSCs allows for the development of compressive membrane (or arching) action that