Journal of Constructional Steel Research 114 (2015) 362–379

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental and numerical study of the bond–slip relationship for post-tensioned composite slabs

Mohammad M. Rana [a,*], Brian Uy [a], Olivia Mirza [b]

[a] Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, The University of New South Wales, Kensington, NSW 2052, Australia
[b] Institute for Infrastructure Engineering, University of Western Sydney, Penrith, NSW 2751, Australia

ARTICLE INFO

Article history:
Received 13 March 2015
Received in revised form 13 May 2015
Accepted 4 August 2015
Available online 27 August 2015

Keywords:
Post-tensioned
Composite slabs
Push tests
Bond stress
Profiled steel sheets
Finite element analysis

ABSTRACT

Post-tensioned composite steel–concrete slabs provide an attractive combination of the structural advantages of post-tensioned concrete slabs and profiled composite slabs in building floor systems. The bond between the concrete and the profiled steel sheets is usually assumed to have a significant effect on the strength, stiffness and ductility of these types of slabs. Push tests provide a less expensive and convenient method to investigate the complex interaction between the profiled steel sheets and concrete, in spite of some obvious differences of behaviour between small scale tests and composite slab bending tests. In this context, this paper presents results from a push test study incorporating post-tensioning at the steel bar to apply precompression to the concrete in order to determine the potential influence of prestress on the bond between the profiled steel sheets and concrete. The parameters investigated in this study were (a) level of prestress and (b) bond length. The results of this study indicated that the prestress has a detrimental effect on the bond between the profiled steel sheets and concrete in post-tensioned composite slabs. This is an important finding which needs to be considered in the ultimate strength determination of post-tensioned profiled composite slabs. This paper also presents a three dimensional nonlinear finite element model of post-tensioned push specimens. The results indicated that incorporating the effects of prestress produces satisfactory results for the overall bond stress–slip behaviour of post-tensioned push test specimens.

1. Introduction

A post-tensioned composite (PTC) slab is a very popular form of building floor system at present due to the economic and technical advantages of using profiled steel sheets as an alternative to conventional timber formwork systems and reinforcement in post-tensioned concrete structures. It consists of a concrete slab, profiled steel sheets, post-tensioning strands and non-prestressed reinforcement (Fig. 1). In this system, profiled steel sheets act as permanent formwork during construction and external reinforcement during service. The combination of post-tensioning and composite action between the profiled steel sheets and concrete in a single building floor system leads to enhanced flexural strength and stiffness of PTC slabs compared with post-tensioned concrete slabs and conventional composite slabs. Limited research studies have looked into the investigation of the behaviour of PTC slabs.

Schravendeel et al. [1] conducted a full scale experimental study on PTC slabs and pointed out the potential advantages in terms of strength and cost. A method to calculate the shear stress distribution at the steel–concrete interface was developed using typical bond stress–slip behaviour available in the literature. Koukkari [2] conducted a test series of columns formed by two pieces of deep steel decking encasing a compressed concrete block. Although this test setup seemed to be similar to the test setup of the current study, the research was to investigate the influence of the location of post-tensioning anchors on the transfer length and concrete failure mode. An ultimate strength test was also carried out as part of this study on a two span continuous composite slab with unbonded tendons to investigate the load carrying capacity. Bailey et al. [3] presented a technique of achieving long span composite floors using prestressed composite slabs. However, in this research, prestressing was applied to the steel deck prior to delivery on site, while in the current study prestressing was applied to the concrete 7 days after pouring, which is a typical Australian construction practice. The bond stress–slip characteristics in both cases are considered to be different due to the two different methodologies of prestressing. Patrick and Lloyde [4] carried out ultimate strength tests of a composite slab, a post-tensioned solid slab and a post-tensioned composite slab and provided design capacity tables for different post-tensioned slab arrangements. This research assured the attainment of enhanced flexural strength of post-tensioned composite slabs over post-tensioned solid slabs and profiled composite slabs. Ranzi et al. [5, 6] presented results of a series of ultimate and long term tests on PTC

* Corresponding author.
E-mail address: m.rana@unsw.edu.au (M.M. Rana).

http://dx.doi.org/10.1016/j.jcsr.2015.08.018
0143-974X/

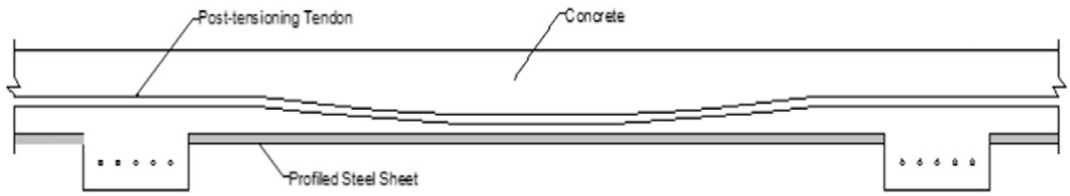

Fig. 1. Typical post-tensioned composite slab (Ranzi et al. [5,6]).

slabs and an analytical model for the determination of the ultimate load carrying capacity of PTC slabs. The novelty of the current research in relation to these previous research studies is to explore the concrete–steel interaction behaviour of the PTC slabs through small scale tests.

One of the fundamental aspects on which the strength, stiffness and ductility of composite profiled slabs depends to a large extent is the longitudinal shear transfer between the profiled steel sheets and the concrete slab [7]. The evaluation of shear-bond behaviour in composite slabs has been the focus of extensive research. However, there are no previous studies focused on the evaluation of bond–slip behaviour of post-tensioned composite slabs. For accurate numerical simulation of post-tensioned composite slabs, a bond stress–slip model that accounts for the effects of prestress is required. Moreover, knowledge of the effects of various levels of prestress on the bond–slip behaviour is important to optimise the design of post-tensioned composite slabs.

It is well-known that the longitudinal shear force between profiled steel sheets and concrete is transferred initially by chemical adhesion which is lost as soon as longitudinal slip occurs. The longitudinal shear is then transferred by mechanical interlocking (dowel action) and also by frictional forces [8]. It has been recognised that the mechanism of longitudinal shear transfer between the profiled steel sheets and concrete in composite slabs is complex and difficult to model mathematically [9]. Therefore, the shear interaction property is usually determined using a push test. This behaviour is characterised mainly by the chemical bond and the mechanical bond. Although the chemical bond strength is usually assumed to be controlled mainly by the material strength of chemical adhesion, a push test study conducted by Burnet and Oehlers [10] indicated that it is rather a geometric property in profiled composite slabs and failure of the chemical bond is more akin to a peeling action.

A series of push tests was conducted to gain a detailed insight into the bond stress–slip behaviour of PTC slabs and to determine the possible influences of prestress on this behaviour. This paper conducts an extensive literature review to find out an appropriate push test setup for post-tensioned composite slabs from the existing push test studies in composite slabs [11]. Existing push tests can be categorised into two classes: 1. Push tests setup requiring external lateral restraining forces and 2. Push tests setup without external lateral restraining forces. Finally, a similar push test setup without external lateral restraining forces such as Stark [12] and Burnet and Oehlers [10] was adopted with appropriate modifications to optimise the ease of testing and accuracy of results although the challenge of handling the delamination problem and local buckling at the base of the profiled steel sheets exists. Despite the similarity in the push test setup used by previous researchers and the one presented in this paper, the objective for this research is quite unique when compared with all the previous studies related to PTC slabs.

Numerical modelling and analysis of composite structures using the finite element (FE) method have become a very popular area of research recently due to its advantages of higher efficiency and lower computing costs. Daniels and Crisinel [13] presented a numerical analysis method incorporating pull out test results to predict the behaviour and strength of composite slabs. An and Cederwall [14] conducted a two dimensional finite element analysis of composite slabs using ABAQUS and used the shear stress–slip behaviour from a concrete block bending test. The interaction between the profiled steel sheets and concrete was modelled with spring elements. Veljkovic [15] performed a three dimensional finite element analysis of composite slabs using a nodal interface element available in DIANA. The interaction property was obtained from a push test and modified with a reduction function to correspond with the strain in the profiled sheets. Abdullah and Easterling [16] developed a FE model of composite slabs using connector elements and the interaction property was calculated from the elemental bending test data. The critical observation of these models suggests that success of such an approach depends on the bond–slip constitutive law specified for the interface element.

Some other researchers attempted to model this shear bond behaviour as a nonlinear contact problem using contact elements available in ANSYS. Ferrer et al. [17] developed a FE model to simulate the longitudinal slip mechanism in pull-out tests in order to investigate the effects of the friction co-efficient and geometrical parameters of profiled steel sheets. Tsalkatidis and Avdelas [18] modelled the shear bond interaction in composite slabs as a unilateral contact problem with friction. Chen and Shi [19] performed FE analysis on both the pull-out and bending tests of composite slabs considering adhesion and friction. Both Ferrer et al. [17] and Chen and Shi [19] used Daniel's pull-out test setup [13] which is a laterally restrained type of small scale test. But the push test setup used in this study is a laterally unrestrained type of push test such as those used by Stark [12] and Burnet and Oehlers [10]. Accurate modelling of laterally unrestrained push tests using the contact approach would require significant effort for calibration of cohesion and friction in order to achieve good agreement of the FE model results with the experimental results. Since the incorporation of the effects of prestress in the FE model was the main concern of this paper, the connector element approach was thought reasonable in terms of its accuracy and simplicity.

The finite element analysis, if conducted on post-tensioned composite slabs with different levels of prestress utilising a single shear bond property without considering the effect of prestress on the bond between the concrete and the profiled steel sheets, may lead to an overestimation or underestimation of the ultimate capacity of the post-tensioned composite slabs. Therefore, this paper aims to study the shear bond stress–slip behaviour in post-tensioned push specimens using a FE approach incorporating the effects of prestress on the local bond–slip behaviour. This FE model employed a layer of interface elements between the concrete and profiled steel sheets. The effect of various levels of prestress on the overall bond stress–slip behaviour as observed in the experimental study was incorporated in the local bond–slip properties of the interface element. The objective of this study is achieved by validating the experimental results with the FE simulation results.

2. Experimental programme

2.1. Test specimens

A total of thirty two push test specimens were prepared and tested as a main series of the experimental programme in the Structural Research and Testing Laboratory of the University of Western Sydney, Australia. The push test specimen configuration is shown in Figs. 2 and 3.