Arid Zone Journal of Engineering, Technology and Environment, December, 2017; Vol. 13(6):655-661
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Print ISSN: 1596-2490, Electronic ISSN: 2545-5818, www.azojete.com.ng

PROFILED DECK COMPOSITE SLAB STRENGTH VERIFICATION: A REVIEW

K. Mohammed[1]*, I. Abd Karim[2] and K. Bulu[1]

([1] Department of Civil and Water Resources Engineering, University of Maiduguri, Maiduguri, Nigeria
[2] Department of Civil Engineering, Universiti Putra Malaysia, Selangor Darul-Ehsan, Malaysia)
**Corresponding author's e-mail address: engrkachalla@gmail.com*

Abstract
The purpose of this article is to present an overview on alternate profiled deck composite slab (PDCS) strength verification devoid of the expensive and complex laboratory procedures in establishing its longitudinal shear capacity. Despite the several deterministic research findings leading to the development of proposals and modifications on the complex shear characteristics of PDCS that defines its strength behaviour, the laboratory performance testing stands to be the only accurate means for the PDCS strength assessment. The issue is critical and warrants much further thoughts from different perspective other than the deterministic approach that are rather expensive and time consuming. Hence, the development of a rational-based numerical test load function from longitudinal shear capacity consideration is a necessity in augmenting the previous futile attempts for strength determination of PDCS devoid of the costlier and expensive laboratory procedure.

Keywords: Profiled composite Slabs, longitudinal Shear, failure Test load, reliability

1. Introduction

The composite use of steel and concrete has been one of the most popular composite constructions nowadays (Abdullah *et al*, 2015; Chen, 2003; Degtyarev, 2012; Gholamhoseini et al., 2014; Marimuthu *et al*, 2007). The use of such system has a lot of advantages. For instance, the profiled sheeting can serve as shuttering during construction stage, and can serve as tensional force resisting medium within the composite slab system. Other advantages include the effectiveness of the steel sheeting deck and the hardened concrete in carrying any addition loads that may be considered during the design process in addition to supporting their self-weight. Furthermore, unlike the conventional Reinforced Concrete (RC) slab systems, in this construction method, the use of flexural reinforcement steel is seldom required, and the mesh reinforcement mostly provided are for hydration and shrinkage control only. Moreover, the method gains more popularity because of eliminating time-consuming erection and subsequent removal of temporary forms at site, and the gains associated with concrete strength during service (Abbas *et al*, 2015; Gholamhoseini *et al*, 2014). It is for the above reason that this review is presented so that there can be a preponderance of application of this mode of construction here in Nigeria and worldwide too.

1.1 Background of Study

The ultimate strength governs the design of composite slab, and the shear bond strength defines its capacity. Generally, the composite action between the profiled steel sheeting deck and the hardened concrete (
Figure **1**), can be transmitted effectively with the development of longitudinal shear at the steel-concrete interface. The shear bond failure is one of the three, and most common failure modes associated with composite slab (Gholamhoseini *et al*, 2014; Marimuthu *et al.*, 2007), flexural failure and shear at support are the other modes of failures. Many studies (Abbas *et al*, 2015; Burnet and Oehlers, 2001; Tsalkatidis and Avdelas, 2010) show that the behaviour of profiled deck composite slab is affected by the bond failure in the longitudinal direction. Interestingly, recent study (Abdullah *et al*, 2015) result adds the influence of shear span to effective depth ratio on the shear bond strength of the composite slab as very vital consideration in PDCS strength appraisal.

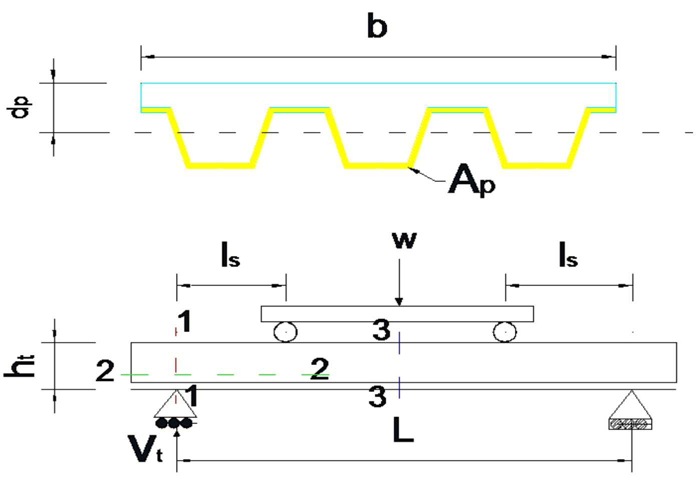

Figure 1: PDCS failure modes (Johnson, 2004)

1.2 Longitudinal Shear Bond

Longitudinal shear failure for PDCS (
Figure **1**) always occurs before reaching the plastic bending capacity of the composite slab system due to an inadequate shear connection between the profiled sheeting deck and the hardened concrete (Tzaros *et al*, 2010).

An overview of this occurrence shows that several authors (Abbas *et al*, 2015; Abdullah *et al*., 2015; Burnet and Oehlers, 2001; Chen, 2003; Tenhovuori and Leskelä, 1998; Tsalkatidis and Avdelas, 2010) carried out studies on composite slab behaviour as influenced by the bond failure in the longitudinal direction. For example, Marimuthu *et al*, (2007) carried out experimental study on composite slab with the aimed of understanding shear bond behaviours of embossed profiled sheeting deck under simulated variable load after incorporating several strength influencing parameters. The authors' finding revealed that shear span defined the behaviour of embossed profiled composite slab deck (Mäkeläinen and Sun, 1999), and re-affirmed that shear bond failures governed the strength requirement for the embossed profiled sheeting deck. Intuitively, longitudinal shear capacity determines the ultimate strength of composite slab with profiled steel sheeting (Marčiukaitis *et al.*, 2006).

The shear bond analysis obtained from shear bond formulations in codes requires the use of experimental test data on composite slab decks that are obtained through regression analysis on the test data as the case with slope-intercept or the generation of partial interaction curve and subsequent determination of other required parameters as applies to the partial shear connection method. Test data are required to provide input for strength design formulations. There are two methods for the longitudinal shear estimation that are currently useful in deck strength appraisal, and the EC4 (2003) provides the general guide for the bending resistance calculation for composite slab using either of the methods.

1.3 The Slope-intercept Method

The slope-intercept, *m*-*k* method for the longitudinal shear value is from the linear relationship plots of vertical shear, v_t/bd_pagainst shear bond, A_p/bl_s for two groups of test values that comprises a long, *x* and short, *y* specimens (
Figure **2**). These requirements are from the standards. Therefore, the slope (*m*) and the intercept (*k*) are the outcome variables from the plots
Figure **2**.

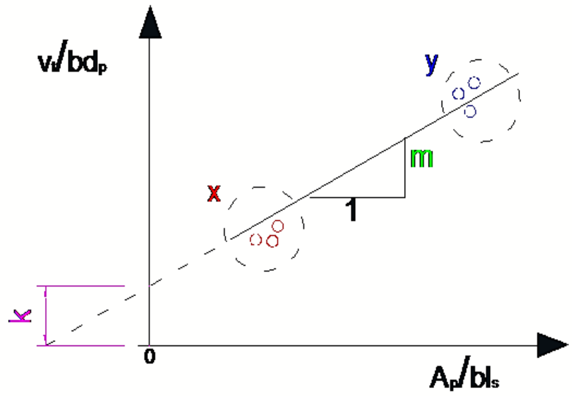

Figure 2: Typical *m-k* parameter determination showing both short and long specimen zones (Johnson, 2004)

In Figures 1 and 2, A_p is the effective sectional area of the sheeting deck with yield strength value, f_{yp}. The parameter d_p is the clear centroid distance to the topmost concrete face that has a width b and l_s is the testing shear span length. Under ductile failure condition, the support reaction, v_t from the failure load, w is (Johnson, 2004):

$$v_t = 0.5w \tag{1}$$

A 20% reduction is applied upon the equation (1) if the failure condition is brittle in nature (Stephen, 2008). Notwithstanding the failure mode type, the ratio l_s/d_p plays a critical role in any of the expected failure modes, and the maximum bending moment occurs at higher ratio. Hence, the vertical shear at equilibrium will be (Johnson, 2004)

$$v_t b d_p = \frac{m}{b d_p l_s} . \frac{A_p f_{yp}}{b l_s} \tag{2}$$

Interestingly, f_{yp} is found to have no significant influence on longitudinal shear (Johnson, 2004), and low l_s/d_p ratio will leads to shear failure. Hence, equation (2) reduces to

$$\frac{v_t}{b d_p} = m\left(\frac{A_p}{b l_s}\right) + k = v_{i,Rd} \tag{3}$$

The design shear resistance $v_{i,Rd}$ is by using Equation(3).

1.4 The Partial Shear Connection Method

Partial interaction is also another means other than the *m-k* method that can be used to obtained longitudinal shear strength of profiled composite slab. The method assumed complete re-distribution of longitudinal shear between the sheeting deck and the concrete interface (Stephen, 2008). The degree of shear connection, $\xi = N_c/N_{cf}$ (N_c is the compressive force while N_{cf} stands for the steel yield force) defines the activity level between the sheeting deck and the concrete, and comes under three groups. First, $\xi = 0$, signifying no composite action between the sheeting deck and the concrete. Second, $\xi = 1$, full shear connection exist, slip and strain are assumed to be zero in this case. Finally, if ξ is between 0 and 1, partial shear connection is said to exist between concrete and the sheeting deck. Similar to the expression given in Equation (3) for the *m-k* method, the longitudinal shear, τ for a given value of bending resistance under Partial Shear Connection (PSC), neglecting the support reaction is given by Equation (4).

$$\tau = \frac{\xi_{test} N_{cf}}{b(l_s + l_o)} \tag{4}$$

The variables l_o were the overhung length, and $N_{cf} = 0.85 f_{yp}$ represented the steel yield force. However, in this method, the bending resistance determination is highly dependent on the neutral axis position within the system, and is either within or above the deck with $\xi = 1$. Because of complexity involved with the estimation of the stress block depth *x*, from the neutral axis, the sheeting tensile force is decomposed to equal compressive force. Thus, the design bending resistance, $m_{p,Rd}$ is computed from the expression:

$$m_{p,Rd} = N_{cf} z + m_{pr} \tag{5}$$

Where

$$m_{pr} = 1.25 m_{pa}(1 - \xi) \le m_{pa};\; z = h_t - 0.5x + \frac{(e_p - e) N_c}{N_{cf}} \; and \; x = \frac{N_{cf}}{0.85 f_{ck} b} \le h_c \tag{6}$$

The parameters e_p, h_t and h_c represents distance of plastic neutral axis above the base, overall deck thickness $(80mm)$, and concrete thickness, respectively. These restrictions are to control the minimum fire protection requirement and load concentration resistance for the composite system. The parameter m_{pa} is the design value of the profile sheeting deck plastic moment of resistance, and the manufacturer provides it normally.

The PSC method involves the determinations of all the parameters defined through Equations (4) to (6). However, the task of determining the experimental degree of shear connection, ξ_{test} can only be achieve through the use of partial interaction diagram by plotting, $m/m_{p,rm}$ as depicted in Figure **3**. The m and $m_{p,rm}$ are moments signifying when there are no interaction ($\xi = 0$) and full interaction ($\xi = 1$). Afterwards, with the ratio $m_{test}/m_{p,rm}$ the equivalent ξ_{test} value is located as shown with
Figure **3**. The maximum bending moment m_{test} is determined from the full-scale test (Abdullah et al., 2015). Once, the design shear strength is known, the design envelope for the particular deck profile can be drawn.

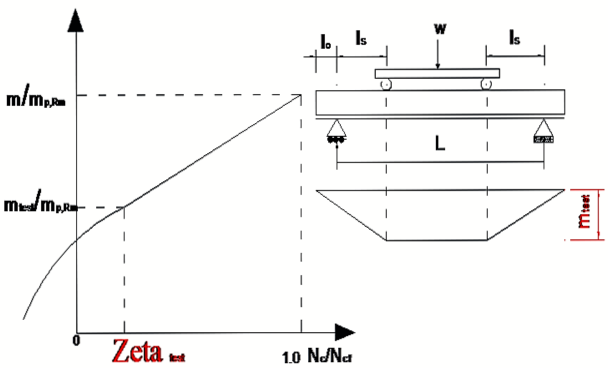

Figure 3: Degree of shear connection determination using PSC method (Johnson, 2004)

It was evident from the two methods for determining the longitudinal shear capacity of PDCS, the experimental failure test is essential in determining the requisite shear parameters (Abbas *et al*, 2015). The process is cumbersome and expensive. However, the volumes of research findings and proposals on the complex shear characteristics of profiled deck composite slab, the laboratory performance testing stands to be the only accurate means for the determination of composite slab strength (Abbas *et al*, 2015). The issue is critical and warrants much further thoughts from different perspective other than the deterministic approach that are expensive and time consuming (Crisinel and Marimon, 2004).

2. Overview on the Numerical Approach for Failure Test Method

Generally, steel deck fabricator provides design data for the engineers and builders for the commonly available profiled sheeting deck for composite construction. However, in special cases where the use of non-standard dimensions, which may be because of either choice by design engineer or strict architectural requirement, such privilege information on the steel deck behaviours may not be available. Hence, the need to carry out full laboratory test that is uneconomical and time consuming is unavoidable in order to establish the design parameters necessary for the design and construction of the composite slab. This limitation has led to many research developments using numerical solutions all with the aim of eliminating the uneconomical full-scale test that is required to verify the performance of composite slab (Abbas *et al.*, 2015; Marimuthu *et al.*, 2007).

The quest for replacing the uneconomical and complex strength verification of composite slab, the exploration of numerical approach in solving the problem becomes the only option. Abdullah and Samuel (2009) and Abdullah et al. (2015) presented proposals for new method for modelling horizontal shears in composite slab systems that takes in to account the slab slenderness as a major parameter that influences the horizontal shear bond. In Abdullah and Samuel (2009) experiment, the shear bond-end slip behaviour of composite slab in bending is determined using force equilibrium method. The study result shows that shear bond varies with the slenderness in bending, and the slab slenderness affects the strength of the composite slab. Furthermore, the authors modelled the slab using finite element (FE) analysis with the aim of replacing uneconomical and time-consuming full-scale test on composite slab. However, modelling limitation on the factors affecting the shear bond capacity hinders to yield effective result due to lack of quantitative information on them. On the other hand, Abdullah et al. (2015) finding reveals the slenderness influence the longitudinal shear bond. They presented results of linear interpolation of shear bond that includes the effect of the slenderness, and concluded that it performed satisfactorily.

Furthermore, in a related Finite Element (FE) modelling study on PDCS, the simulation results for long slab specimens reflect true resemblances of the slab performance with previous similar study results. However, comparative behavioural analysis for the short span shows behavioural variations between the modelled slabs from the real (An, 1993; Crisinel and Marimon, 2004). The critics of FE analysis application for shear bond capacity for composite slab is that shear bond is geometry dependent, and this signifies that full-scale experimental testing must be conducted. Hence, FE modelling will become uneconomical since the test has to be conducted before utilizing the data for the modelling (Abdullah and Samuel 2009).To augment the flaws, an approach that does not require the complex and expensive laboratory procedures for PDCS strength verification is still required. This shifts the focus on the use of more rational method, which will be the probability-based design concept, for example.

Literature related to reliability studies on the performance of composite slab are scanty (Degtyarev, 2012), very few areas is indeed covered. Degtyarev (2012) presented reliability based analysis result on composite slab at construction stage to the United State design provision. The author considers the failure analysis of allowable stress design and load resistance factor design using First Order Reliability Method for strength and deflection limit state conditions. The finding reveals high level of conservatism in the US design provision for composite steel deck construction. Notwithstanding the effort, analysis at construction stage may have little or no influence on the deck behaviour, and the much-needed simplification for the PDCS strength determination devoid of the complex and expensive laboratory procedure is still yet to be developed. Therefore, further work in exploring the potential associated with this rational-based approach in order to develop a simplified strength determination function for PDCS is required.

3. Conclusion

Informed by the literature reviewed, the complexity in the design and strength verification of profiled composite slab is largely due to the uneconomical and the mandatory laboratory procedure required for its strength determination. The manufacturer provides the required test data and independent verification of such vital information posed a serious challenge. However, several research findings and proposals on the complex shear characteristics of profiled deck composite slab showed that the laboratory performance testing stands to be the only accurate means for the determination of composite slab strength. The issue is critical and warrant much further thoughts from different perspective other than the deterministic approach that are expensive, uneconomical and time consuming. Therefore, the development of a rational-based numerical test load function from longitudinal shear capacity consideration is a necessity in augmenting the previous futile attempts for profiled composite slab strength determination devoid of the uneconomically expensive laboratory procedure.

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