

Composite Slab Numerical Strength Test Method Under Partial Connection Approach



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Abstract The present uneconomic strength determination approach for profiled composite slab (PCS) constitutes a serious challenge that contributed significantly to design conservatism. This study seeks to address this challenge by developing and a subsequent experimental validation of a numerical strength determination function for PCS through implementing a rational-based approach. Hence, a procedural algorithm lead to the development of PCS determination function using longitudinal shear estimation method by considering section slenderness and deck characteristics. The strength test performance between the developed scheme and the experiment-based test results indicates high similarity, demonstrating the viability of the proposed strength determination methodology developed.

Keywords Composite slab • Strength load • Longitudinal shear

1 Introduction

Profiled composite slab application in the construction industry has many advantages due to its construction simplicity in comparison to other flooring system. The sheeting deck serves as shuttering by shouldering the concrete weight, for example. This construction method gained popularity due to the elimination of the time-consuming temporary forms—erection and subsequent removal [1–5]. However, investigations [1, 6–8] show the behavior of profiled deck composite slab

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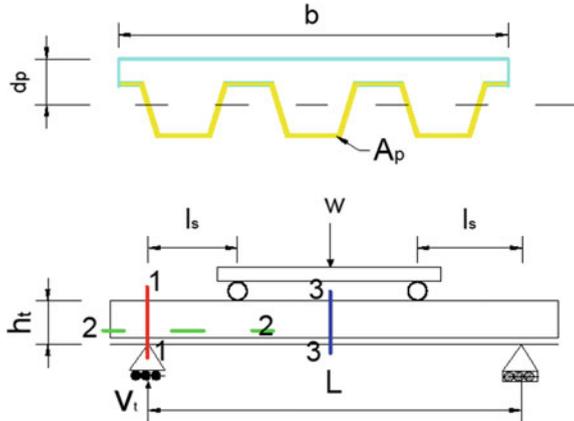
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Fig. 1 PCS failure regions

is affected by the bond failure in the longitudinal direction (see Sect. 2.2 in Fig. 1) more than the other associated failure forms. Intuitively, longitudinal shear capacity defines the ultimate strength of profiled composite slab; typical example is shown in Fig. 1 that demonstrates the three associated failure points [9]. However, a number of issues are known to affect the longitudinal shear capacity; for example the type and level of embossment, the steel strain, shear span length, etc. [10]. These issues have greatly constrained the development of deterministic-based strength capacity for profiled composite slab (PCS) that will replace the current challenge of uneconomic strength determination method. This study is necessitated to address the serious challenges faced especially with the complex interface between the profiled sheeting deck and concrete [11]. Hence, this paper presents a simplified PCS numerical strength function devoid of any complex experimental test, and equivalent experimental validation of the strength determination function.

2 Safety Determinant

Safety indices determination is through the application of a reliability concept through which the failure probability (p_f) is determined. Intuitively, the higher material strength R -value than the demand load Q ; this will definitely guarantee some degree of structural safety than otherwise (unwanted situation). Hence, treating the R and Q as random variables [12], the unforeseen chances for the unwanted scenario is by

$$p_f = R - Q < 0 = p(k < 0) \quad (1)$$

The limit state function k delineates between the desired boundary condition from the failure state condition. The (p_f) value is a real nonnegative number between 0 and 1, but it is usually expressed using reliability index or safety index (β) [3, 13] with the application of the First-Order Reliability Method (FORM).

2.1 Partial Connection Method

Partial connection method for the longitudinal shear strength of PCS takes into account a complete redistribution of longitudinal shear at the concrete-sheeting deck interface [14]. The shear connection degree $\xi (N_c/N_{cf})$ gives the level of redistribution; $\xi = 0$ signifying no composite action and $\xi = 1$ indicating full shear connection while slip and strain values are zero under this case. Similarly, for ξ value between 0 and 1 shows partial shear connection between the sheeting deck and the concrete. The expression given in Eq. (2) returns the longitudinal shear τ_u value in this study, according to literature [15].

$$\tau_u = \frac{\xi_{test} N_{cf}}{b(l_s + l_o)} \tag{2}$$

The parameters l_o and l_s are the overhang and shear span lengths for a given profiled deck width, b that has a yield force value of $N_{cf} = 0.85A_p f_{yp}$ (see Fig. 2). The depth of neutral axis position (x) within the system is as shown by the expression in Eq. (3).

$$x = \frac{N_{cf}}{0.85f_{ck}b} \leq h_c \tag{3}$$

The parameter h_c in Eq. (3) stands for the concrete thickness. Hence, the design bending resistance $m_{p,Rd}$ is

$$m_{p,Rd} = N_{cf} + m_{pr} \tag{4}$$

The plastic resistance moment m_{pr} and the lever arm z functions in Eq. (4) are as follows:

$$\begin{aligned} m_{pr} &= 1.25m_{pa}(1 - \xi) \leq m_{pa} \\ z &= h_c - e_p - 0.5x + (e_p - e)\xi \end{aligned} \tag{5}$$

The deck plastic moment of resistance is m_{pa} , while e and e_p are the centroids distance (see Fig. 2).

Fig. 2 Stress-strain diagram

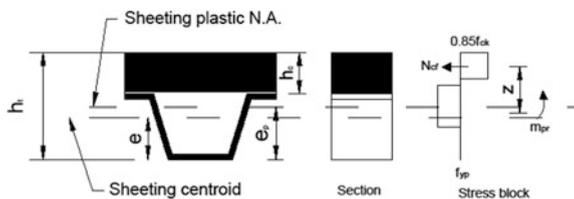


Fig. 3 Partial-connection interaction curve

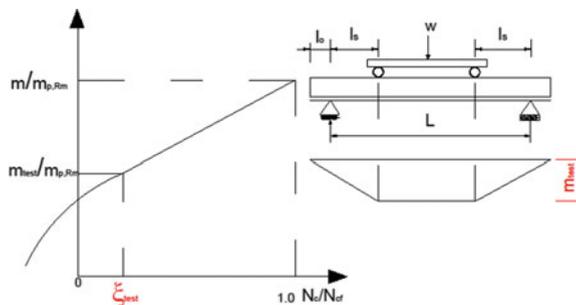


Figure 3 shows the partial interaction curve for the determination of the degree of shear connection. While all the other parameters in that figure are previously explained, the experimental bending m_{test} value is from laboratory test results.

2.2 Performance Function

This study performance function for the determination of the safety index value with the application of FORM method is from the material strength capacity and design load estimation from the shear resistance of composite slab as

$$Q_m - \frac{m_{p,Rd}}{0.5l_s} = R - Q, \quad (6)$$

where Q_m stands for the nominal resistance (Strength tests value over span length), and has a bias factor of 1.0. Furthermore, on the basis of Ellingwood and Galambos [16], the *COV* and statistical distribution type for the b and l_s parameters are 0.17 and log-normal distribution (Bias factor is 1.0 for both parameters). Additionally, the nominal resistance value for the safety value determination is from the literature. Hence, the detailed test specimens properties and their laboratories performance can be found in Marimuthu et al. [2] and Hedao et al. [17].

2.3 Numerical Strength Determination Function

Load ratio l_r in this study is defined as the ratio of experimental PCS strength load (FTL) over design load ζ_{dl} . Hence, the establishment of best-fit relation between the l_r function and the deck performance estimation is highly essential in developing the numerical strength determination function as shown with Fig. 4. The figure provides the mean p_{fmean} value of 0.69 ($\beta = -0.513$). This value led to the development of numerical strength load P_{fl} for predicting PCS performance as shown with Eq. (7) [18].

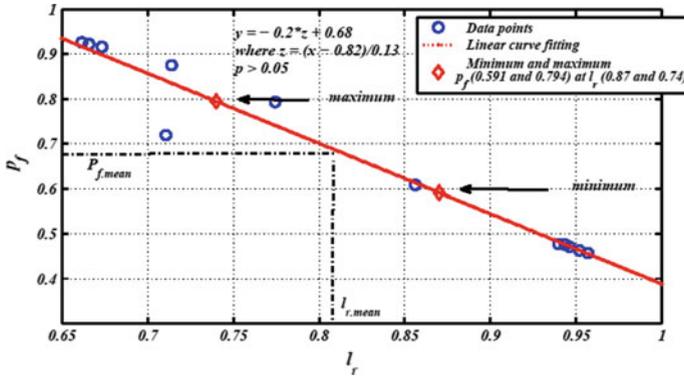


Fig. 4 PCS load-ratio effect on performance

$$P_{fil} = 0.41(A_p f_{yp} d_p / l_s - 3.1) \tag{7}$$

Equation (7) expression computes the performance of PCS without the rigors of the costlier experimental works. However, how good the function can only be confirm if there is close-matched up with an experimental test results for PCS. Therefore, the following section provides details on the experimental validation work.

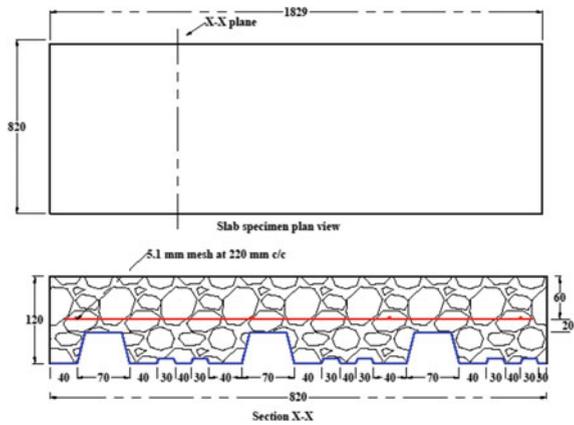
3 Experimental Test Set-up

This study experimental test scope consisted of testing four PCS that includes two specimens for both long and short shear span lengths; 228, 243 mm, and 305, 320 mm, respectively. Hence, these specimens are identified using notations SS and LS; for example, SS-228 and LS-305 represents short and long specimen with shear span length of 228 and 305 mm, respectively. A similar notation also applies to the other test-shear span lengths.

3.1 Materials Properties and Concreting

The metal deck thickness is about 0.47 mm, and it is 1829 mm long (L), having width (b) value of 820 mm as shown in Fig. 5. Normal grade concrete is prepared using 20 mm aggregate for 120 mm thick concrete. For hydration control, 5.1 mm mild bars are mesh through at 220 mm both ways, and placed 20 mm above the metal deck.

Fig. 5 Test specimen profile

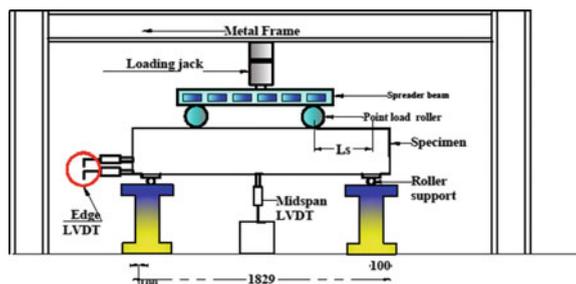


The required necessary laboratory checks on the concrete mix design prior to concreting are fully adhered to according to the ACI-318 standard, and the mix design found to be workable. Moreover, cubes for the determination of the compressive strength from the batch mixes for testing after 28 days by covering concrete surface with Gunny bags, and shows an average compressive strength of 28.5 MPa.

3.2 Test Set-up

Hydraulic jack load is applied upon the test specimen with a two spreader roller weighing about 10 kg each which are placed on top of the slab specimen with the intention of applying the two point load from cross beam that also weigh about 70 kg (Fig. 6). The overhang length is 100 mm from both ends. In determining the slab failure mode during the test procedure, linear variable displacement transducers (LVDT) were at the edges of the decking sheet and the concrete as depicted in Fig. 7. Similar LVDT placements are provided at the mid-span, and a data logger-TDS-530 records all the values for the end-slip, the mid-span deflection

Fig. 6 Specimen set-up



value including the test loads. The testing is halted when the maximum applied load drops by about 20%, or the mid-span deflection value is approaching $l/300$ [19].

The experimental test results are to validate the numerical solution estimation derived as shown with the Eq. (7) for the strength capacity determination of PCS. Hence, possible closeness between the compared results will validate the suitability of the developed model for strength capacity estimation of PCS.

4 Results and Discussion

Figure 8 shows experimental performance of this study's tested slab specimens. The figure provides maximum FTL sustained under each respective shear span length value. A maximum strength tests value of 45.97 kN is recorded with the shortest shear span length, and the lengthiest shear span test value gives 27.97 kN. After the maximum peak failure load, an average of 50% unloading peak load results in a high deflection value. This explains why there is a large jump beyond the peak load values.

Table 1 shows the PCS capacity test results between the experimental test load and approximate estimation from the developed strength test function. The comparative result shows an equal variance between the experimental results and approximate estimation values ($t = -1.67$, $dof = 6$, $p > 0.05$). This implies that the statistical p -value indicates closeness between the strength values. Hence, this paper concludes that the developed numerical strength function will significantly determines the performance of PCS without the rigors of the costly experimental testing procedure that posed serious challenges.



Fig. 7 LVDT arrangements

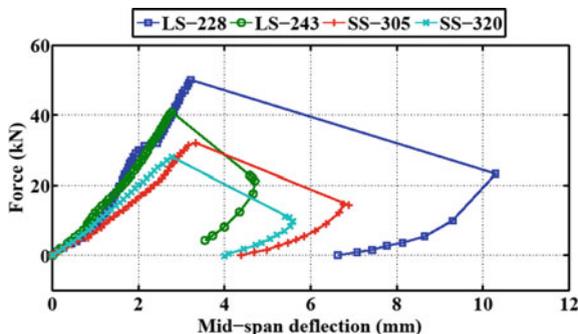


Fig. 8 PCS experimental test performance

Table 1 Experimental and approximate failure test load comparisons

Label	A_p (mm ²)	f_{yp} (MPa)	d_p (mm)	l_s (mm)	l (m)	Experimental FTL (kN)	P_{fit} FTL (kN)
LS-228	496.71	340	100	228	1.83	45.97	41.28
LS-243				243		41.73	52.17
SS-305				305		33.50	41.03
SS-320				320		27.97	38.94

5 Conclusion

This paper shows a development of a rational-based function for profiled deck composite slab strength determination through longitudinal shear capacity using partial connection method. This study aims to address the challenge of costly experimental procedure for PCS strength determination. This leads to develop a numerical strength determination function, and an experimental validation test for confirmation. The litmus strength values comparisons between the experimental results and the numerical estimations of PCS strength capacities shows similar variance indicating the prospect of this study developed model for determining PCS strength capacity.

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