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# Experimental study on the longitudinal shear bond behavior of lightweight aggregate concrete – Closed profiled steel sheeting composite slabs

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## HIGHLIGHTS

- A new type of LWAC – Closed profiled steel sheeting Composite Slab is proposed.
- Specific slab configurations produce better composite actions and a new mode failure.
- The validities of existing methods for the new type of composite slab are confirmed.

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## ABSTRACT

Composite slabs with ordinary concrete and typical profiled steel sheeting are quite common in construction industry. This paper presents full-scale experiments conducted on a new type of composite slab produced from lightweight aggregate concrete and closed profiled steel sheeting (LCCS). A total of 11 simply supported specimens were tested to investigate the structural behavior of this new type of composite slab with special emphasis on their failure modes. Whilst shear bond failure is the common failure type for typical composite slabs with sheet sheeting, a new type of failure was observed herein where slabs failed with showing remarkable bending capacity, and significant end slips was observed in long-span slabs. In addition to *m-k* method and *PSC* method, which are typically used for composite slabs with normal weight concrete, three other techniques such as slenderness method, *PSC* composite beam method and force equilibrium method were used to assess the longitudinal shear bond strength of LCCS. The ultimate carrying capacity and the shear bond stress predicted using slenderness method and force equilibrium method showed very good agreement with test results; *PSC* composite beam method may underestimate the longitudinal shear bond strength, but still can be used as an optional method.


## 1. Introduction

Composite slabs consisting of cold-formed profiled steel sheeting and structural concrete are one of the most popular types of floor system used in steel framed buildings. The main advantages of this concrete-steel composite slabs are the reduction of self-weight and simplification of the construction process. The profiled steel sheeting acts as a permanent formwork before casting and as tension reinforcements after casting; the standard scaffolding and propping systems are not required [1].

Lightweight aggregate concrete (LWAC) is now considered as a useful construction material due to significant reduction in self-weight as well as providing better performance in thermal insulation (low density), fire resistance, acoustic isolation and reduction in lateral force due to earthquake when compared with normal weight concrete (NWC) [2,3]. Hence, introduction of LWAC into concrete-steel composite slabs could produce an improved structural system. However, very limited numbers of studies are currently available on composite slabs with LWAC and profiled steel sheeting, especially those using closed profiled steel sheeting.

The longitudinal shear bond failure is reported to be the most common failure mode in composite slabs. Significant end slips occur between concrete and profiled steel sheeting interfaces well ahead of reaching its ultimate bending capacity [4]. The failure mode is determined by composite actions which are dependent on the transmission of longitudinal shear bond stress due to pure bond, mechanical interlocking and friction as well as several other

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factors including material properties of concrete, geometry and thickness of steel sheeting, slenderness ratio of the slab, loading arrangement and shear connectors [5–7].

In this paper, the failure mode of a new type composite slab with LWAC and closed profiled steel sheeting (LCCS) is investigated. A mixed failure mode is found and defined. The methods (*m-k* method, *PSC* method, slenderness method, *PSC* composite beam method and force equilibrium method) for evaluating the longitudinal shear bong strength are compared and confirmed to be valid on the new type composite slabs.

## 2. Theories of longitudinal shear bond strength

Existing methods for assessing the longitudinal shear bond strengths are mainly based on slabs with NWC and trapezoidal profiled steel sheeting. Eurocode 4 suggests using *m-k* method and Partial Shear Connection method (*PSC*). Both of these two methods require experimental data obtained from full-scale tests because the composite action is strongly dependent on the particular geometry type of the sheeting. In addition to these methods, the current paper also considered Slenderness method, *PSC* Composite Beam method and Force Equilibrium method to check their suitability for the new type of composite slab investigated herein. All considered design rules are briefly discussed in the following paragraphs.

### 2.1. The m-k method

The semi-empirical based *m-k* method was developed by Schuster [8], Porter and Ekberg [9,10], and is adopted in ASCE [11] and Eurocode 4 [12]. The values of *m* and *k* are obtained by using linear regression but are only applicable to specific slab configurations as expressed in Eq. (1).

$$V_{1,Rd} = \frac{bd_p}{\gamma_{vs}}\left(m\frac{A_p}{bL_s} + k\right) \tag{1}$$

where $V_{1,Rd}$ is the design shear resistance; $L_s$ is the length of the shear span; $A_p$ is the nominal cross-section of the steel sheeting; $b$ and $d_p$ are the width and effective depth of slab, respectively; $\gamma_{vs}$ is the partial safety factor i.e. 1.25 for the slab as defined in Eurocode 4.

### 2.2. The PSC method

*PSC* method (Fig. 1), which is based on a clear mechanical model, is an alternative to the *m-k* method but should only be used for composite slabs with ductile longitudinal shear behavior as outlined in Eurocode 4.

It is assumed that the mean value for the ultimate longitudinal shear stress $\tau_u$ is constant and is uniformly distributed throughout

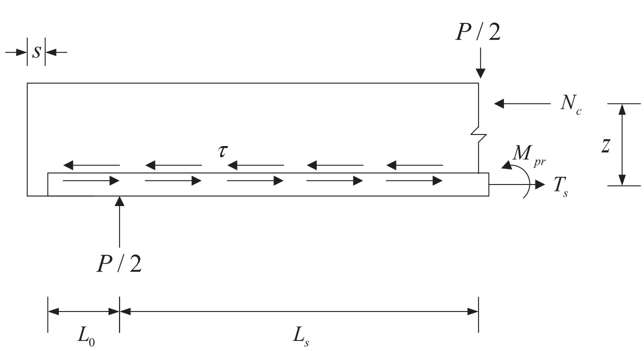


**Fig. 1.** Mechanical model of *PSC* method.

the surface area of the interface between concrete and steel sheeting along the overall length of the shear span, the longitudinal shear bond strength $\tau_u$ can be calculated as:

$$\tau_u = \frac{N_c}{b(L_s + L_0)} \tag{2}$$

If extra support reaction is considered:

$$\tau_u = \frac{N_c - \mu V_t}{b(L_s + L_0)} \tag{3}$$

The partial interaction connection moment resistances of composite slabs $M$ can be calculated by:

$$M = N_c z + M_{pr} \tag{4}$$

$$z = h - 0.5x - e_p + (e_p - e)\eta \tag{5}$$

$$M_{pr} = 1.25M_{pa}(1 - \eta) \tag{6}$$

where $N_c$ is the actual compression force in concrete; $L_0$ is the overhanging length beyond the support; μ is the default value of the friction coefficient to be taken as 0.5; $V_t$ is support reaction under the ultimate test load; $z$ is the moment lever arm; $h$ is the overall thickness of the slab; $e$ and $e_p$ are the distance from centroidal axis and plastic neutral axis of the effective area of the steel sheeting to its lower flange fiber, respectively; $M_{pr}$ and $M_{pa}$ are reduced plastic moment resistance and plastic moment of the effective cross section of the steel sheeting, respectively; $\eta$ is the degree of shear connection defined as $\eta = N_c/N_{cf}$ obtained from test; $N_{cf}$ is the maximum compression force in concrete at fully interaction connection.

### 2.3. The slenderness method

Slenderness method, which is a modified version of *PSC* method, considers the thickness of steel sheeting and the slenderness ratio of slab (shear span length to effective depth of slab ratio, $L_s/d_p$). Considerable studies reported by [6,13,14] showed that the longitudinal shear bond strength $\tau_u$ varies with the slenderness ratio $L_s/d_p$ and is represented as a function of slab slenderness.

The Slenderness method was derived based on the following assumptions:

(1) The moment lever arm $z$, differs very slightly from the effective depth of the slab $d_p$;
(2) The overhanging length $L_0$ doesn't have any considerable effect on slab behavior, and hence is usually negligible.

Eq. (4) can be written as:

$$VL_s = \tau(L_s + L_0)bd_p + M_{pr} \tag{7}$$

Rearranging Eq. (7) and substituting into Eq. (1):

$$\tau d_p = m\frac{A_p}{b}\frac{d_p}{(L_s + L_0)} + \left(\frac{kbd_pL_s - M_{pr}}{b(L_s + L_0)}\right) \tag{8}$$

If the overhanging length $L_0$ is ignored, the second term of the right side in Eq. (8) becomes a constant $s$ regardless of the $M_{pr}$ value as explained by Abdullah [6]

$$\tau d_p = p\frac{A_pd_p}{bL_s} + s \tag{9}$$

Eq. (9) was also obtained by Chen [15] by using a different experimental linear regression method. For a specific type of profiled steel sheeting, the ratio of expansion length $w$ to the width of the slab $b$ is constant, and can be written as $w = ib = A_p/t$, where $i$ is a constant. The new equation changes into: