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Push-out Test of Profiled Metal Decking Slabs with Cold-formed Steel Beams and Rebar Shear Connector

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Abstract

New methods to provide shear strength on the cold-formed steel (CFS) lipped c-channel section composite beam encased with concrete partially is proposed using rebars embedded in concrete. The development of research on the CFS composite beams technology with partial encasement shows that the section of the composite beam encased with concrete partially can provide ductile flexural action for the composite beam. The application of profiled metal decking slabs in the composite beam is becoming increasingly popular compared to solid slabs. However, it has a detrimental effect on the structural behavior of a composite beam.

This research is aimed primarily at presenting the behavior of the rebar shear connector to evaluated ductility, shear capacity, and modes of failure. Two samples using a rebar 12 mm in diameter in the profiled metal decking slabs and solid slabs were tested using the standard push-out test till failure. For the composite beam design, the proposed shear connector embedded in the slab concrete and the CFS encased with concrete partially used the test results' shear capacity, greater than the values as proposed by section 3.1, BS 5950. Due to rebars shear-off, the solid slab specimen failed with the highest load of 489.6 kN while the Profiled Metal Decking Slab specimen failed due to the formation of the cracks on the PMDS at 421.1 KN ultimate loading.

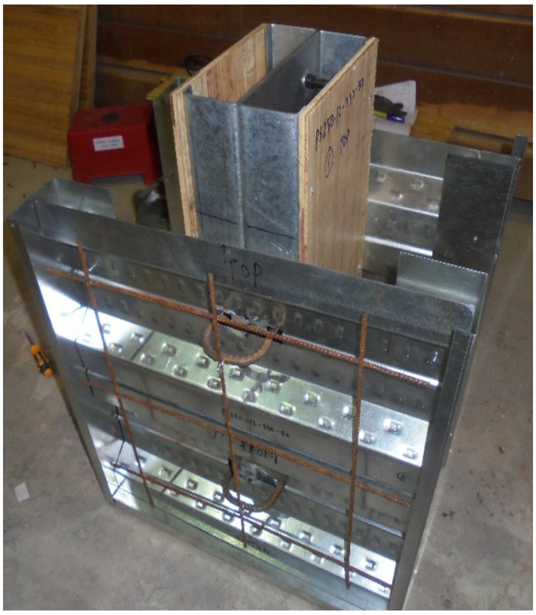
Keywords: Cold-formed steel, Partially encased, Push-out test, Shear connector, Shear capacity

Introduction

Currently, in most developing countries, the usage of Cold-Formed Steel (CFS) composite beam as an I-beam to substitute Hot-Rolled Steel (HRS) has been utilized in floor design for residential buildings, commercial and light industrial design in the construction industry, owing to its lighter weight and simpler to mounted [1]. For a long span, having a steel beam that supports the concrete slab is more economical than increasing the thickness of the slab. Nevertheless, there is a propensity for the composite beam to buckle first before any compression loss of the slab can be accomplished if the CFS is used as a beam. In Indonesia, the use of the CFS section is limited to roof trusses only. The concept of the Industrialized Building System (IBS), which strongly recommended the use of the CFS in wider scope as light steel framing such as beams, floor beams, columns in our construction industry, is yet to be established. The key benefits of such building solutions to improve construction management, higher efficiency and quicker completion, less waste, and environmentally friendly [2].

However, if the beam is encased partially with concrete and fitted with rebars at the tension area, it can increase strength and stiffness. The development of research on CFS composite beam technology with partial encasement continues [3-12] to show that the section of the composite beam with encased partially provided ductile flexural action for the composite beam. In contrast to solid slabs, the use of profiled metal decking slabs in the composite beam is becoming more common for multi-story buildings because it allows for large spans with little or no scaffolding. The profiled metal decking slabs have fewer concrete shapes and are achieved in the formwork. Even if the usage of the profiled metal decking slabs harms the structural conduct of a composite beam utilizing the shear connector, it is widely done because it is cheap and easy to use.

New shear strength methods for the CFS Lipped C-Channel Section (LCCS) composite beam partially encased in concrete have been developed as shown in **Figure 1**, rebars embedded in concrete are proposed. The idea of the LCCS composite beam, partly filled with concrete, is regarded as an innovative and feasible solution that requires further analysis of behavior and strength. Although the improvement in strength, as well as the stiffness of the LCCS composite beam with concrete, is very encouraging, the form in which the framework of the proposed LCCS composite beam needs to be well discussed and known in anticipation of any specific construction is recommended for the real construction.



(a) The profiled metal decking slabs

(b) The solid slab specimen

(c) Rebar shear connector

Figure 1 The outline of the proposed shear connector.

Materials and methods

Materials Properties

The LCCS composite beam used in this study was supplied by M Metal PTE LTD Singapore, with an identity as SC25024. The SC25024 is referred to as a steel channel with a 250 mm web depth and the 24 is referred to as the thickness of the steel (i.e., 2.4 mm). The LCCS is predicted to have yield and ultimate strengths of 450 and 510 N/mm^2 by the manufacturer. Properties of the LCCS were obtained by coupon tensile test. The test was carried out to assess the yield and ultimate stresses of the LCCS. **Table 1** shows the effects of the coupon tensile test.

Table 1 Results of coupon tensile test.

Section for	Sample					Average
	CFS1	CFS2	CFS3	CFS4	CFS5	
t, mm	2.32	2.36	2.33	2.34	2.31	2.33
F_m, kN	27.16	27.98	28.04	27.92	27.96	27.81
f_{yb}, N/mm^2	514.73	519.01	535.73	524.72	526.14	524.06
f_u, N/mm^2	585.07	590.76	597.89	592.57	594.65	592.19
E_s, N/mm^2	219883	223242	217391	224189	203032	217547
Elongation, %	15.8	14.3	13.6	10.9	15.0	13.9
f_u/f_{yb}	1.14	1.14	1.12	1.13	1.13	1.13

t: thickness, F_m: maximum load, f_{yb}: basic yield stress, f_u: ultimate stress, E_s: elastic modulus

Figure 2 demonstrates the stress-strain relationships acquired from the examination. All of the coupon specimens failed due to necking. Furthermore, the effects of the coupon evaluation were included in the theoretical estimation, where the basic yield stress, f_{yb} was recorded as 524.06 N/mm^2, ultimate stress, fu was recorded as 592.19 N/mm^2, and Elastic modulus, E_s was recorded as 217547 N/mm^2.

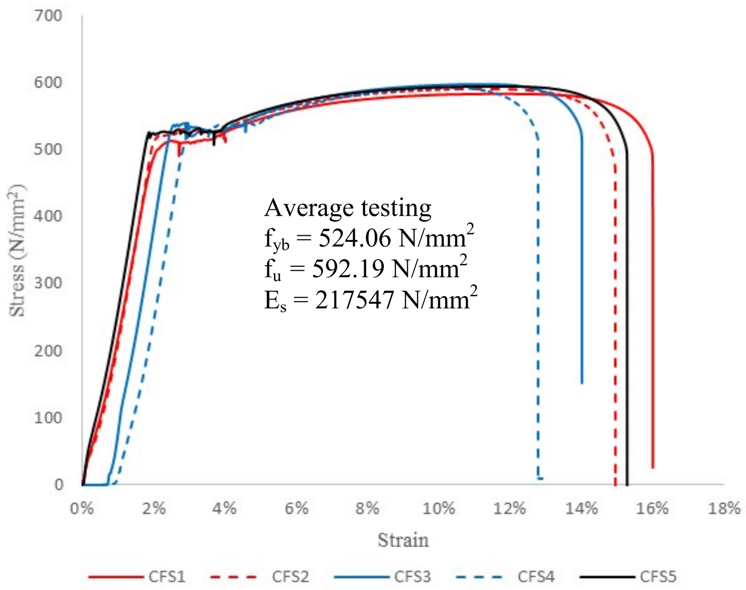
Table 2 Result of rebar tensile test.

Section for	Sample			Average
	SC12-1	SC12-2	SC12-3	
d, mm	11.4	11.8	11.3	11.5
F_m, kN	77.9	76.8	77.2	77.3
f_{yb}, N/mm^2	665	660	645	657
f_u, N/mm^2	752	742	746	747
E_s, N/mm^2	211000	189000	240000	213333
Elongation, %	11.1	11.1	12.2	11.5
f_u/f_{yb}	1.13	1.12	1.16	1.14

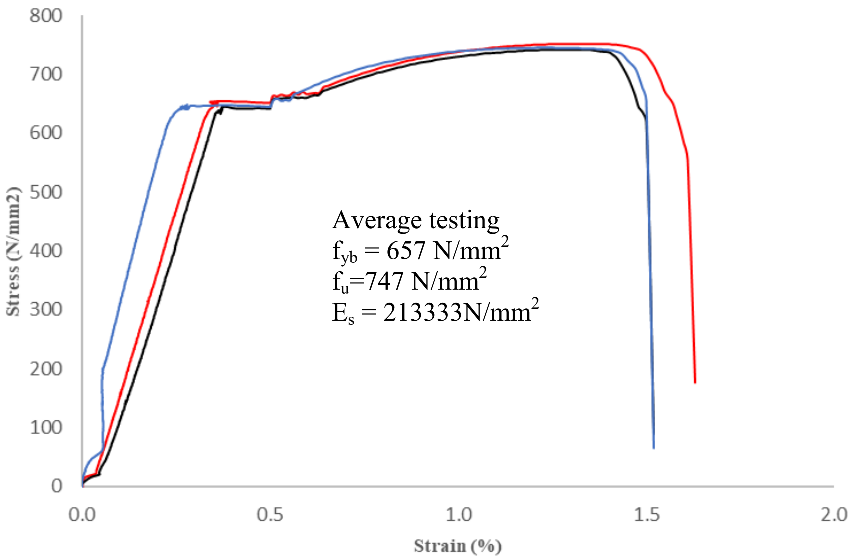
d: diameter, F_m: maximum load, f_{yb}: basic yield stress, f_u: ultimate stress, E_s: elastic modulus

The type of shear connectors used in this study was proposed from the deformation of rebar into U-shaped of different size; the rebar diameters proposed was 12 mm with a specified tensile capacity of 460 N/mm^2 by the producer. **Table 2** shows the yield stress value of tensile testing for deformed rebar at 657 N/mm^2, higher than that of the manufacturer. Based on the outcomes of the experiments, the elastic modulus, Es, is 213,333 N/mm^2. The tensile test findings are seen in **Figure 2** as a stress-strain relationship.

In this experiment¸ Self-Compacting Concrete (SCC) from the supplier at 28 days had a cylinder compressive strength of 43.8 N/mm^2 and an average slump flow of 659 mm. BRC wire mesh was used in this analysis, having an average wire diameter of 5.8 mm and wire spacing of 200×200 mm^2 from the middle to the middle. The producer supplies 460 N/mm^2 steel bars for the wire fabric and then the tensile test is carried out to measure the yield and the final strengths. Tensile tests found that the average yield stress was 709 N/mm^2 and the ultimate stress was 720.5 N/mm^2.



(a) CFS coupon



(b) Rebars D12

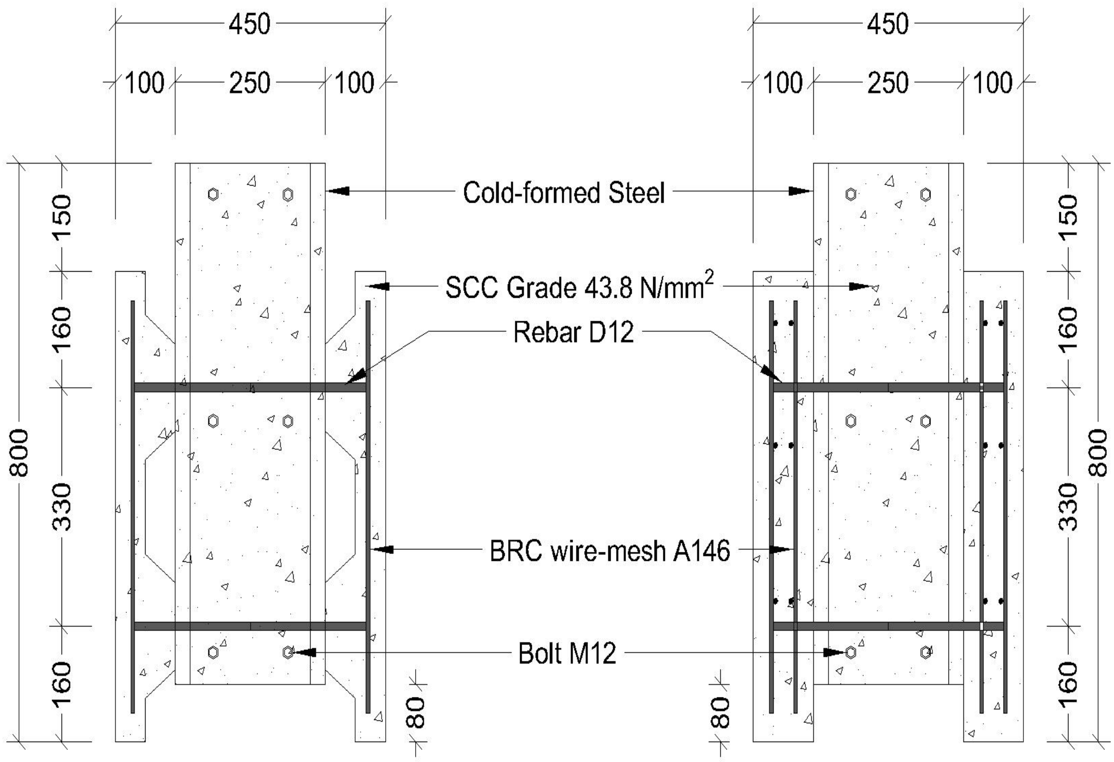
Figure 2 Results of tensile test of rebar D12.

Test method

The key purpose of push-out testing is to investigate the shear capacity and ductility of the proposed shear connector failure modes for shear connections systems of composite beam and load-slip connections. From the push-out test, the slip-load curve of the addition of shear is obtained; strength and ductility of the shear connector are evaluated. **Table 3** and **Figure 3** summarizes the criteria of the tested specimens for the push-out test in detail.

Table 3 Specimens for a push-out test.

Specimen ID	Lipped C-channel section		Rebars shear connector (mm)		Rib height (mm)
	Depth	Thickness	Diameter	Height	
PS250-12-330-50	250	2.4	12	75	50
PS250-12-330-00	250	2.4	12	75	-



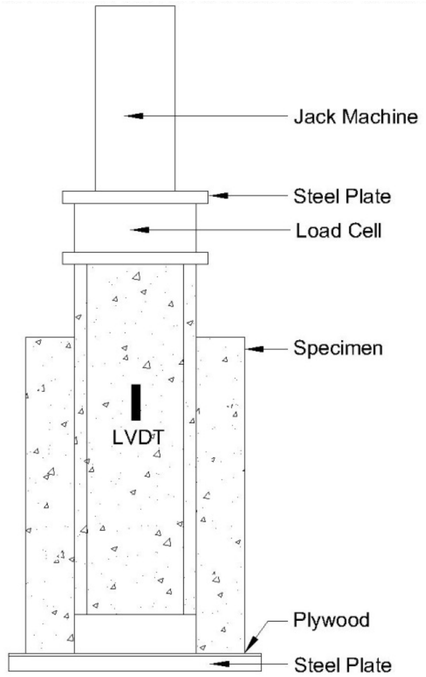
(a) The Profiled Metal Decking Slabs specimen (b) Solid slab specimen

Figure 3 Push-out test specimens.

The test set-up is shown in **Figure 4**. Each of the push-out specimens is placed on a 3 mm thick plywood and on a section of 800×800×50 mm^3 thick steel to properly mount on the concrete slab. The loading using a Jack machine is applied to the top of an LCCS beam where the load cell has a capacity of up to 2000 kN. Each push-out specimen is fitted with a 2 Linear Variable Displacement Transducer (LVDT), each on both sides of the web of the LCCS composite beam partially encased with SCC to measure the slip in the vertical direction between the concrete slab and the LCCS composite beam partially encased with SCC. LVDT and load cell are all connected to the data logger for data collection.

The shear capacity of each shear connector within the specimen is determined based on the assumption that the total load applied was equally resisted and shared by each shear connector within the test specimen. **Figure 5** shows the load-slip curves of test specimens. It can be deduced from the plots that the samples behave elastically at the initial stage of loading, but the behavior changes at the advanced stage of loading and becomes plastic when the ultimate load has been achieved. If the concrete crushes or the LCCS composite beam failed or the rebar sheared-off, the ultimate failure load is achieved.

(a) Specimen for testing



(b) Experimental set-up

Figure 4 Push-out test configuration.

Predicting shear capacity

The estimated strength capacity of the re-bar shear connector is based on the failure of studs and concrete, respectively, according to the BS EN1994-1-1 [13]. Furthermore, 2 calculations were used to measure the expected shear strength potential of the rebar shear connectors. Where the smaller value if the equation is considered as a governing strength capacity of the shear connector. For profiled sheeting with ribs transverse to the beam placement, the reduction factor is given.

If the dimension coefficient is known, $\alpha = 1$, because $h_{sc} / d = (75 \text{ mm}) /(12 \text{ mm}) > 4$, with a partial safety factor, $\Upsilon_v = 1.25$, shear capacity can be predicted to be calculated.

Shank failure of the shear connector:

$$P_{Rd}^{(1)} = \left(0.8\, f_u \frac{\pi\, d^2}{4}\right)\frac{1}{\gamma_v} = \left(0.8\left(747\frac{N}{mm^2}\right)\frac{\pi(12\; mm)^2}{4}\right)\frac{1}{1.25} = 54.1\; kN \quad (1)$$

Concrete failure:

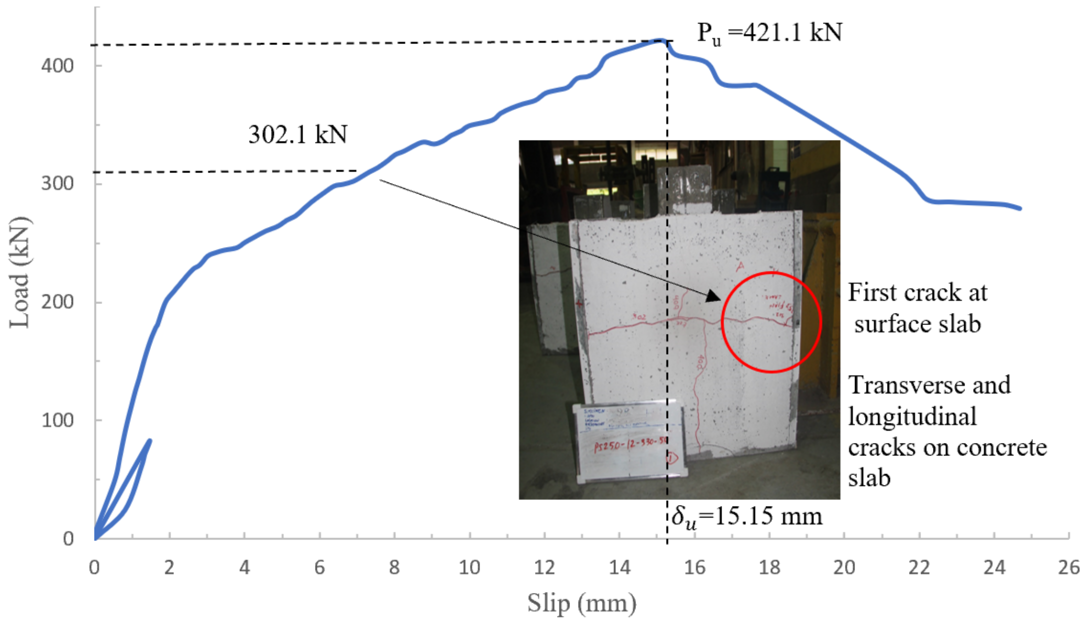
$$P_{Rd}^{(2)} = \left(0.29\;\alpha\; d^2\sqrt{f_{ck}E_{cm}}\right)\frac{1}{\gamma_v} = (0.29\;(1)(12\; mm)^2\sqrt{\left(43.8\frac{N}{mm^2}\right)\left(36\frac{kN}{mm^2}\right)} = 42\; kN \quad (2)$$

Smaller, The design shear resistance of a reinforcing:

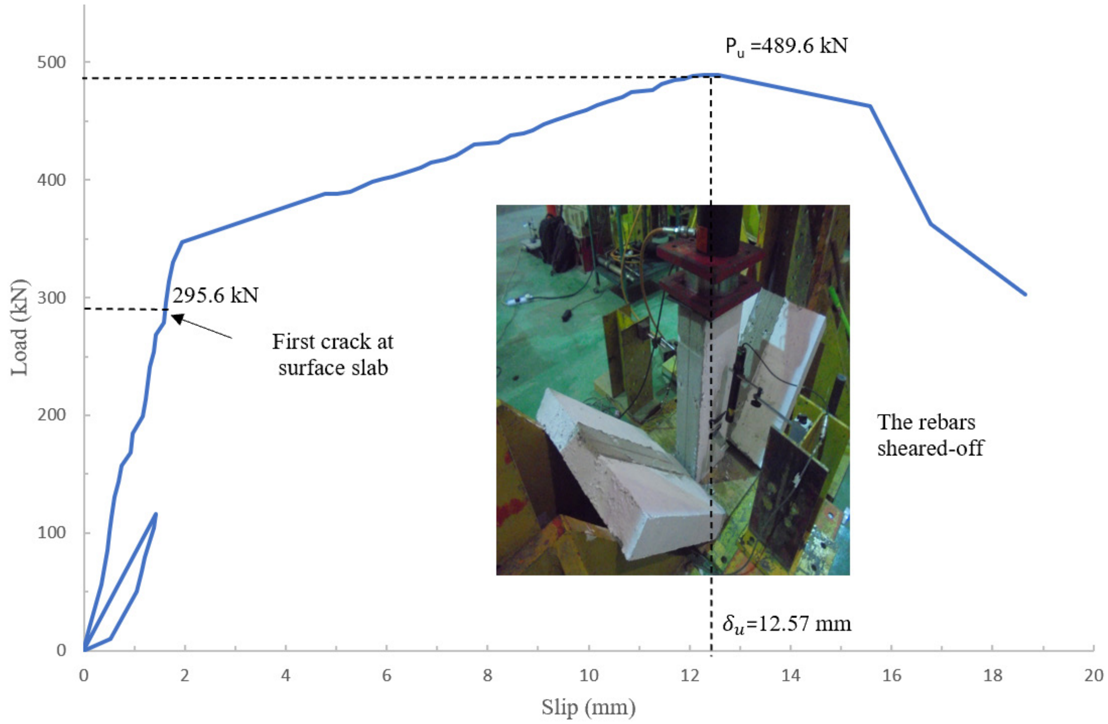
$$P_{Rd} = min\left(P_{Rd}^{(1)}, P_{Rd}^{(2)}\right) = \min(54.1\; kN, 42\; kN) = 42\; kN \quad (3)$$

For profiled sheeting with ribs running transverse to the supporting beams, the reduction factor is given by $k_t = 0.6$, thus:

$$P_{Rd} = k_t min\left(P_{Rd}^{(1)}, P_{Rd}^{(2)}\right) = (0.6)\min(54.1\; kN, 42\; kN) = (0.6)42\; kN = 25.2\; kN \quad (4)$$



(a) PS250-12-330-50 specimen



(b) PS250-12-330-00 specimen

Figure 5 Load-slip curves of the push-out test specimen.

Result and discussion

The failure mode of the PS250-12-330-50 specimens could be attributed to the cracks developed in the concrete slab at the shear connector position in the profiled metal decking slab specimen. The cracks became moderately larger at that position in the profiled metal decking slabs specimen as the applied load were increased, which resulted in the crushing of concrete. The initial transverse crack occurred on the PS250-12-330-50 specimen with a load of 302.1 kN, a slip of 6.9 mm, and a formation of longitudinal crack at an applied load of 402.6 kN. The profiled metal decking slab specimen is crushed at an ultimate load of 421.1 kN with a slip of 15.15 mm, which is higher than 6 mm as recommended by BS 5950 Part 3.1 [14].

For the PS250-12-330-00 specimen, the rebars sheared-off separates from the solid slabs and the LCCS composite beam. The PS250-12-330-00 specimens transverse cracks are found at the top and bottom of the shear connector in the solid slabs with initial cracks of 295.6 kN with a slip of 1.63 mm. The cracks became moderately larger at that same position in the solid slabs as the applied load were increased. Suddenly, at the ultimate load of 489.6 kN with a slip of 12.57 mm, which is higher than 6 mm by 109.5 %, the rebars sheared-off and the solid slab separated from the LCCS composite beam.

Table 4 shows the comparison of experimental and theoretical results of the push-out test, where the PS250-12-330-00 shows a better closeness of the experimental and theoretical comparisons. It is also found that the solid slab has a greater shear capacity than using the profiled metal decking slab specimen.

Table 4 Comparison of experimental and theoretical results of the push-out test.

Specimen ID	$P_{u,exp}$ (kN)	$P_{u,exp}$ per connector (kN)	Slip to failure δ_u (mm)	$P_{u,pred}$ (kN)	$P_{u,exp}/P_{u,pred}$
PS250-12-330-50	421.1	52.6	15.14	25.2	2.09
PS250-12-330-00	489.6	61.2	12.57	42.0	1.46

A comparison between other researchers' results and the results obtained in this study was made based on the push-out test. Research works considered in the comparison were studies conducted by [15-19]. It can be seen that the proposed rebar shear connector of 12 mm diameter using solid slab shows a higher strength capacity of 35.9% over a bolted shear connector of 12 mm diameter used by Bamaga *et al*. [15] with CFS sections of 2.3 mm and 41.2% higher than work done proposed by M.M Lawan *et al.*, M. M Tahir *et al*. and A. Saggaff *et al*. [16-19] with a CFS section of 4 mm thick. However, the rebar shear connectors of 12 mm in diameter used in this study achieved a characteristic slip capacity of more than 6 mm as recommended by BS 5950 Part 3.1 [14].

Conclusions

By proposing a new system of the rebars shear connectors of 12 mm diameter, this research investigated the structural performance of CFS parts encased in high-performance SCC partially. The following are the findings drawn after performing experimental and theoretical research: 1) the PMDS specimen failed due to the formation of a crack in the slabs with a final load of 421.1 kN, while the solid slabs specimen failed due to sheared-off re-bars with a final load of 489.6 kN. 2) since the shear capacity of the test results is greater than values as indicated by BS 5950 Part 3.1, the proposed rebars as a shear connector for partly embedded CFS can be used in the construction of the LCCS composite beams. Because this study only reviews the experimental results of 2 samples, further research is needed to obtain the validity of the data by conducting a series of tests and making a numerical model so that the right formula for configuration performance can be obtained.

Acknowledgement

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