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The effect of the compressive concrete strength and perfobond parameters on the structural behavior of the steel concrete composite slab using perfobond shear connectors

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KEYWORDS

Steel profiled sheeting
Perfobond shear connection
Longitudinal shear resistance
The relative slip
The concrete compressive strength

ABSTRACT

The steel sheeting should be able to transfer longitudinal shear to concrete through the interface to ensure composite action of the composite slab. With steel profiled sheeting with smooth surface, the adhesion between the steel sheeting and concrete is generally not sufficient to create composite action. This leads to reduce the shear capacity and increase the relative slip between the steel sheeting and the concrete slab. To overcome this drawback, the steel-concrete composite slab used the perfobond shear connection. An experiment program was conducted to investigate the effect of the concrete compressive strength and perfobond shear connector parameters on the structural behavior of the steel - concrete composite slab by push-out test.

1. Introduction

The steel-concrete composite slab has been popularly used in steel in multi-storey building construction. A composite slab comprises steel decking, reinforcement and cast in situ concrete. The steel sheeting may be used as formwork during construction and tension element after the concrete has hardened. In order to transfer longitudinal shear from the steel sheeting to concrete, the steel sheeting should be deformed the surface to enhance the surface roughness to increase the friction at the contact surface. Some methods used are local deformations (indentations or embossments), holes or incomplete perforation, anchorage element fixed by welding and distributed along the sheet, end anchorage provided by welded studs, or end anchorage by deformation of the ribs.

Many authors also studied the structural behavior of the steel-concrete composite slabs. Baskar. R and Antony Jeyasehar. C studied on experimental and finite element modelling of composite deck slabs with and without embossments [1]. R. Amuthaselvakumar tested simply supported composite slab and conventional slab to compare the structural behavior, load capacity, and the cost [2]. G. Sugila Devi investigated the structural behavior of composite concrete slabs with trapezoidal type profiled steel decking by experimental and theoretical studies [3]. The slab is improved the shear bond characteristics by creating the embossments. Thamilselvi P. et al attempted to quantified the slippage in terms of m-k method and emphasized the need for incorporating composite slab contribution into building design guidelines [4a]. Ali Ibrahim Mohammad Alsarayreh tested four specimens of composite slabs in simply supported conditions [5a]. Author used the m-k method to determine the shear bond capacity of the composite slabs and the experimental test data used in the linear regression analysis were plotted to predict the m-k values. Thanongsak Imjai carried out on fifteen composite slabs to investigates the structural and serviceability performance of composite slabs cast with recycled aggregate concrete [6a]. Different contents of coarse and fine recycled concrete aggregates (RCA) were examined (0 %, 25 %, 50 %, 75 % or 100 %). Keerthana John conducted testing on five new innovative two-way steel-concrete composite slab system [7a]. Three slabs used shear studs, and the remaining two had no shear studs. The test results showed that The slabs failed by flexural failure and shear bond failure, and the composite slabs with and without studs showed comparable load-carrying capacity and two-way action.

Perfobond shear connectors have been popularly used in the steel-concrete composite beams to study effectiveness and applicability in practice [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. Many experiments were carried out to investigate the effect of parameters on the structural behavior of perfobond shear connection. Some of these experiments were bending test on large scale beams [18], other were small specimens using push-out tests. Authors also proposed some formulas for predicted load capacity of shear connection. This kind of shear connection has shown to be quite effective in shear resistance.

This study presents the experimental program of the steel-concrete slabs using perfobond shear connector to evaluate the effect of the concrete compressive strength and perfobond parameters on the structural behavior of the steel-concrete composite slabs. The quantity observed are the load capacity and the relative slip between the steel sheeting and the concrete slabs.

2. Test program

2.1. Specimens

The test specimen consisted of shaped steel plates, perfobond

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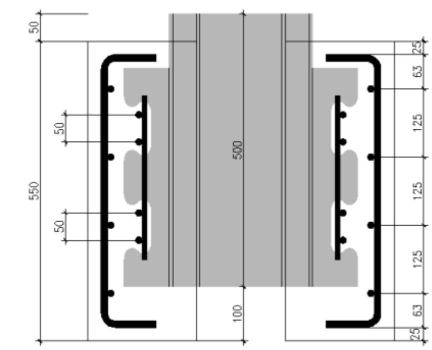
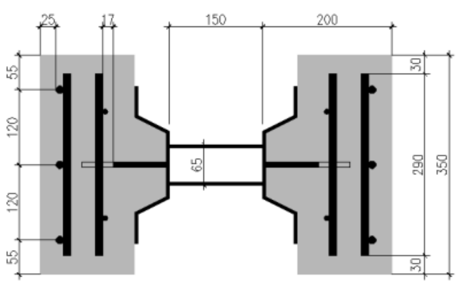
connectors, longitudinal steel bars, transverse steel bars and concrete slabs, as shown in Figure 1, Figure 2 shows the dimensions of perfobond shear connector. Specimens were classified into four different groups based on the compressive strength of the concrete, the thickness of the perfobond, and the number of steel bars passing through the perfobond holes. This groups are presented in Table 1. Specimen before and after concreting is shown in Figure 3.



a. Side elevation



b. Cross section

Figure 1. Detail of specimen.

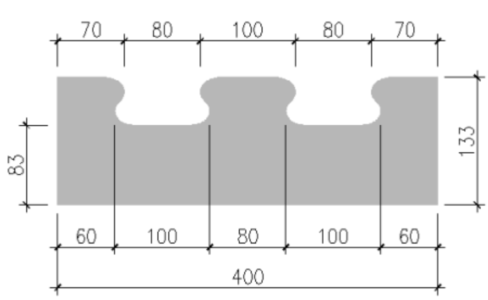
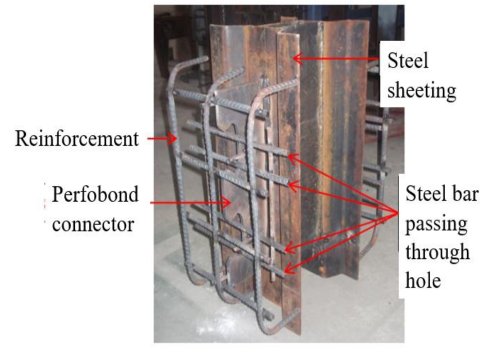


Figure 2. Dimensions of perfobond shear connector.

Table 1. Parameters of specimens.

Specimen	Perfobond thickness	Group	Steel bar	Number of specimens
SP1	6 mm	A	1Ø12	3
SP2	6 mm	A	2Ø12	3
SP3	8 mm	A	2Ø12	3
SP4	8 mm	B	2Ø12	3



a. Before concreting

b. Completed specimen

Figure 3. Specimen before and after concreting.

2.2. Material properties

2.2.1. Concrete

The concrete used in the experiment is divided into two groups, named A and B, with different compressive strength. During the specimen preparation process, concrete was tested to determine compressive strength. These tests were conducted at the same time as the push-out tests. The mechanical characteristics of concrete are presented in the Table 2.

Table 2. Mechanical characteristics of concrete.

Parameter	Unit	A	B
Compressive strength	MPa	35.5	45.0
Elastic modulus	MPa	29×10^3	33×10^3
Elastic deformation limit ε_{elas}	‰	1.8	1.5
Maximum compression limit ε_{limit}	‰	2.24	2.59

2.2.2. Structural steel, plate steel and reinforcement

The structural steel and perfobond were created by plate steel of CT3. The mechanical properties of structural steel and steel bar are presented in Table 3.

Table 3. Mechanical properties of steel.

Parameters	Unit	Plate steel	Steel bar
Yield strength	MPa	330	250
Tensile strength	MPa	500	390
Elastic modulus	MPa	200×10^3	200×10^3
Plastic deformation ε_y	‰	1.8	1.8

2.3. Push-out test

2.3.1. Test installation

To save time until the concrete reached its design strength, the concrete mix included water-reducing and plasticizing additives to accelerate the setting process. After two weeks, the concrete strength will reach the design level and pecimens were tested at that time. Two important parameters recorded throughout the loading process were the force and the relative slip between the concrete slab and the shaped steel plate. The linear variable displacement transducers (LVDT) were attached on specimens to measure the relative slip between the steel sheeting and the concrete slab, as shown in Figure 4.

Figure 4. Specimen in incremental load frame.

2.3.2. Incremental loading process

The loading process was carried out according to EC4 guidelines. Accordingly, the applied load is divided into 3 main stages, as shown in Figure 5:

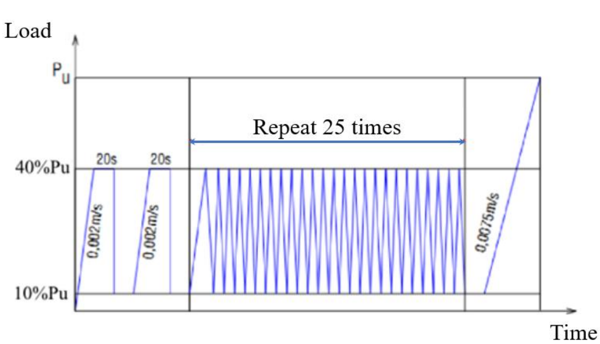


Figure 5. Incremental loading process.

Stage 1: increasing the load to approximately 40 % of the maximum load P_{max} (the expected failure load of specimen), keeping 20 seconds and repeating this twice.

Stage 2: The load is repeated 25 times with a load range of 10 % P_{max} to 40 % P_{max} to reduce friction and adhesion between the concrete and the steel.

Stage 3: After the iteration phase ends, the load will be gradually increased until the specimen is destroyed.

3. Test results and discuss

3.1. Test results

The load capacities and the relative slip between the steel sheeting and the concrete slab are presented in Table 4. In Table 4, P_{1max}, P_{2max}, P_{3max}, and P_{4max} are the failure loads of specimens SP1, SP2, SP3, and SP4, respectively. Load – relative slip curves is plotted in Figure 6. The test results show that the concrete compressive strength and perfobond shear connector parameters affect the load capacity and the relative slip between steel sheeting and concrete slab.

Table 4. The relative slip between the structural steel and the concrete at failure loads of specimens SP1, SP2, SP3, and SP4 δ (mm)

Failure load (kN)	SP1	SP2	SP3	SP4
P_{1max} = 527	2.752	1.494	0.855	0.451
P_{2max} = 564	-	2.173	1.646	0.587
P_{3max} = 624	-	-	6.643	0.912
P_{4max} = 732	-	-	-	6.91

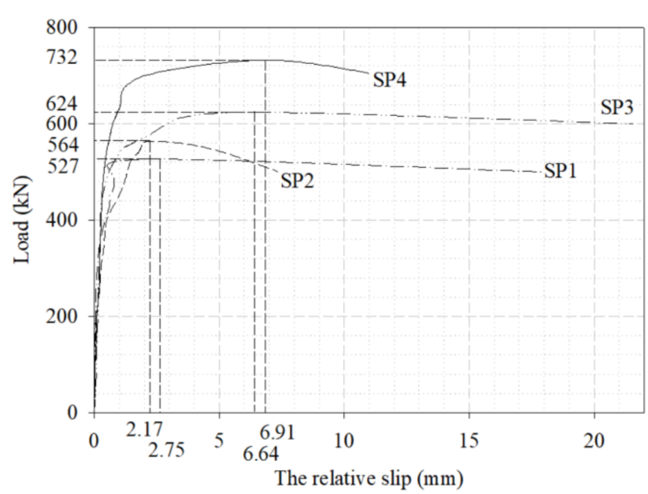


Figure 6. Load – relative slip curves of specimens SP1, SP2, SP3, and SP4.

Figure 6 shows that all perfobond shear connectors have characteristic slip capacity higher than 6 mm, so these shear connectors are considered as the ductile connectors. These curves also show that perfobond shear connectors still behave in elastic region until load level of 80 % P_{max}.

3.2. Effect of concrete compressive strength

Figure 7 presents the load – relative slip between the steel profiled sheeting and the concrete slab of specimens SP3 and SP4 with different concrete compressive strength. The load capacity of specimen SP4, with higher concrete compressive strength, is increased by 17.3 % compared to the load capacity of specimen SP3. At the failure load of specimen SP3, the relative slip of specimen SP4 just equals 13.7 % that of specimen SP3. It is clear that the concrete compressive strength significantly affects the load capacity and the relative slip of the steel-concrete composite slab.

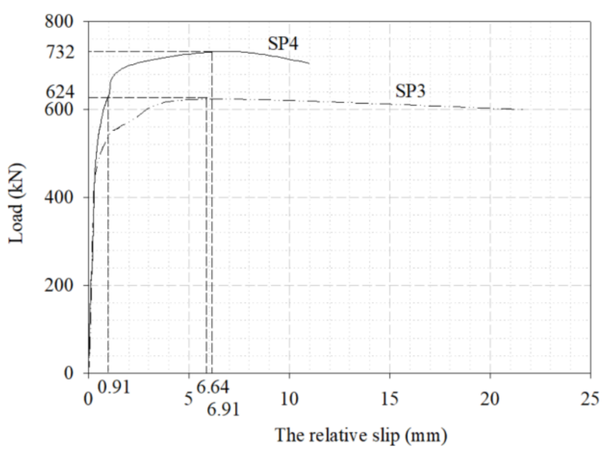


Figure 7. Load – relative slip curves of specimens SP3, and SP4.

In the expreeion for predicting the capacity of the perfobond shear connector of Oguejiofor and Hosain [9], the perfobond shear capacity can be determined as below:

$$q = 0.59A_{cc}\sqrt{f_c^{'}} + 1.233A_{tr}f_y + 2.871nd^2\sqrt{f_c^{'}} \quad \text{(Eq.1)}$$

Where

A_{cc} is the shear area of concrete per connector (mm^2)

A_{tr} is the total area of transverse reinforcement (mm^2)

n is number of perfobond holes

d is the diameter of perfobond hole

f'_c is the compressive strength of concrete (MPa)

f_y is the yield strength of reinforcement (MPa)

In this expresion, the shear capacity of connection depends on the concrete shear area and the concrete dowel in perfobond hole. Therefore, the higher compressive strength of concrete increases the shear capacity of concrete dowel and shear concrete area. perfobond hole, leading to increased shear resistance of the connector dowel.

3.3. Effect of the number of steel bar through the perfobond hole

Specimen SP1 has one steel bar through perfobond hole, while specimen SP2 as two steel bars through perfobond hole. The test result shows that the load capacity of specimen SP2 insignificantly increases in comparison with load capacity of specimen SP1 (only 7.02 %), as shown in Figure 8. At the failure load of specimen SP1, the relative slip of specimen SP2 equals to approximately 54.18 % compared to that of specimen SP1. From Eq.1, the shear capacity of connection also depends on the steel bar passing through the perfobond hole (A_{tr}), so An increased steel bar passing through the perfobond hole will increase the load capacity. However, the increase in load capacity is not considerable because the steel bar area insignificantly increases. The relative slip between the steel sheeting and the concrete slab reduces because of the ductility of steel bar passing through the perfobond hole.

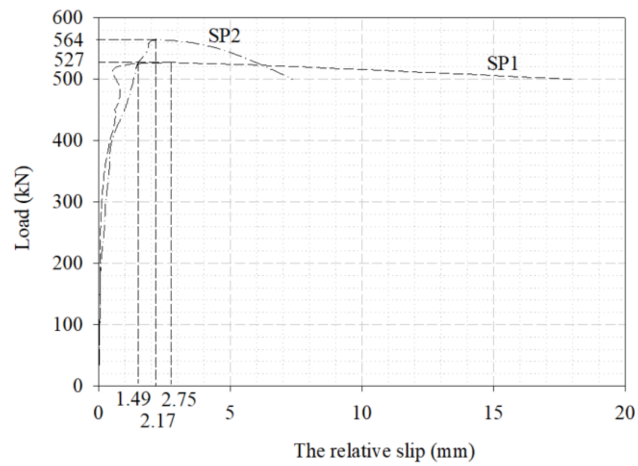


Figure 8. Load – relative slip curves of specimens SP1 and SP2.

3.4. Effect of perfobond thickness

The thickness of specimens SP2 and SP3 are respectively 6 mm and 8 mm. The load capacity of specimen SP3 increases 11.43 % in comparison with that of specimen SP2. At the failure load of specimen SP2 (564 kN), the relative slip of specimen SP3 equals 76.64 % in comparison with that of specimen SP2, as shown in Figure 9.

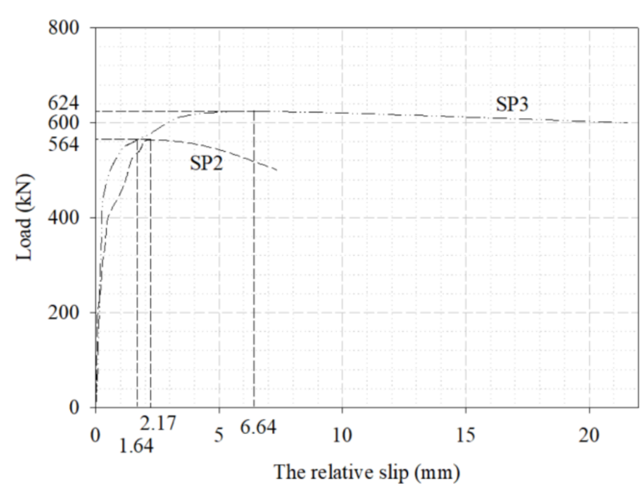


Figure 9. Load – relative slip curves of specimens SP2 and SP3.

Eq. 1 does not present the thickness component, however, the increasing the thickness of the perfobond means increasing the contact surface between the concrete dowel and the perfobond hole. On the other hand, this increases the rigidity of the concrete dowels, so leading to reduce the failure and increase load capacity, this lead to increase the perfobond shear capacity.

3.5. Effect of the number of steel bar through the perfobond hole and thickness of perfobond

The combined effect of perfobond thickness and the number of steel bars passing through the perfobond holes resulted in an 11.84 % increase in the load capacity of the specimen SP3 compared to specimen SP1. The relative slip of specimen SP3 also just equals approximately 31.09 % compared to that of specimen SP1, as shown in Figure 10. Clearly, increasing both components simultaneously significantly reduces the relative slip. However, the increase in load capacity does not yield the expected results.

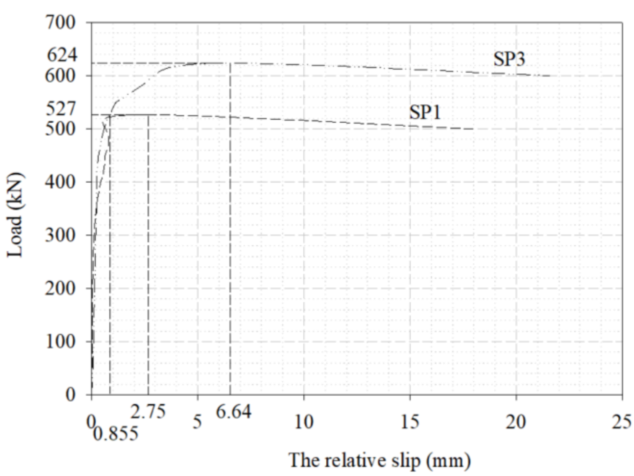


Figure 10. Load – relative slip curves of specimens SP1 and SP3.

4. Conclusions

Experimental investigating the effect of the concrete compressive strength and perfobond shear connectors on structural behavior of the steel-concrete composite slab, some conclusions can be drawn followings:

The compressive strength of the concrete significantly increases the load capacity and reduce the relative slip between steel sheeting and concrete slab.

Increasing concrete compressive strength, perfobond thickness, or number of steel bars considerably reduce the relative slip between the steel sheeting and the concrete slab.

Increasing the number of steel bars passing through perfobond hole does not significantly increase the load capacity, just about 7.02 %.

Increasing the number of steel bars passing through the hole increases the shear capacity of the steel bars but also reduces the shear capacity of the concrete dowel. Therefore, it does not significantly increase the load capacity of the perfobond shear connection. However, this increase is effective in reducing shear deformation due to the ductility of the steel bars.

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