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Experimental studying structural behavior of shear connector in cold-formed steel - concrete composite beam

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KEYWORDS

Structural behavior
Shear connector
The cold-formed steel-concrete composite beam
Relative slip
Failure mode

ABSTRACT

An experimental push-out test was carried out on 12 specimens in 6 groups to investigate the mechanical behavior of shear connectors in cold-formed steel-concrete composite beams. Specimen groups have differences in rivet spacing, shear connector spacing, tab aspect, and rebar through shear connectors. The mechanical behavior was evaluated through quantities such as shear resistance, relative slip between the steel beam and concrete slab, and failure modes. The results show that screw significantly affects the mechanical behavior of shear connectors in cold-formed steel-concrete composite beams.

1. Introduction

Nowadays, the cold-formed steel-concrete composite beam has been used popularly for bearing structures. This structure is suitable for light-loading structures, easy erection, quick construction, and low cost. Many studies have been carried out with large-scale beams in the world. In 2013, Nadim Wehbe et al. carried out a series of experimental studies on full-scale beams under gravity loads [1]. M. A. Youns et al tested on seven composite beams cold-formed steel lipped channel sections to evaluate the effect of shear dowel shape, cold-formed steel thickness, and concrete slab thickness on bending behaviors of composite beams [2]. Ahmed Youssef Kamal and Nader Nabih Khalil investigated the bending behavior of cold-formed steel concrete composite beams to examine the influence of encasing cold-formed steel (U-section) in a reinforced concrete beam on the beam capacities, mode of failure, and ductility [3]. M. M. Tahir experimental observed on full-scale composite beams to investigate the effects of using different types of proposed shear connectors on the behavior of composite beams [4]. Sumiati studied using cold-formed steel as a substitute for reinforcement in lightweight concrete beams to increase the stiffness of the beam, ultimate load, and modulus of rupture [5]. P. Sangeetha tested six specimens to failure with varying numbers of headed stud connectors from 0 to 5 and evaluated the effect of headed studs on the load-carrying capacity of specimens [6]. Before testing large-scale specimens, the authors often carry out small specimens to study the behavior of shear connectors. M.M. Tahir et al carried out a push test on four small specimens with innovative shear connectors used for composite beams with a cold-formed steel section [7, 8]. Anis Saggaff carried out the push-out testing on three specimens until failure to evaluate the effect of rebar on the load capacity of specimens [9]. The results showed that the load-carrying capacity was improved by increasing the diameter of the rebar. In this study, push-out tests were carried out to evaluate the effect of components in specimens on the relative slip between the concrete slab and structural cold-formed steel, as well as the failure mode of specimens.

2. Test program

2.1. Specimens

There are 12 specimens divided into 6 groups. Each specimen consists of two cold-formed steel channels which are combined by screws at their back, called structural steel. The shear connector is a smaller cold-formed steel channel attached at the top of structural steel. The shear connector has some gaps to place rebars through the gaps, as shown in Figure 1. The cross-section and dimensions of the specimen are illustrated in Figure 2. Two steel plates with dimensions of $150 \times 150 \times 15$ mm are reinforced at the top of the specimen to support the applied load. Notation of specimens is described in Figure 3. This study has three types of structural steel named C_1, C_2, and C_3, and two types of bent tabs named bent-in-tab and bent-out-tab.

Figure 1. Specimen before and after concreting.

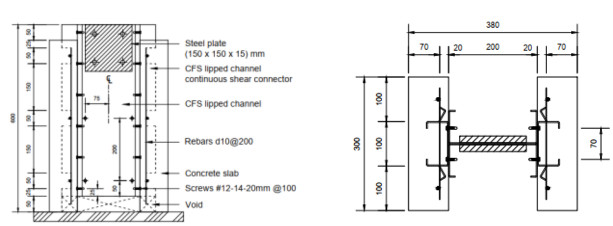

Figure 2. Specimen before and after concreting.

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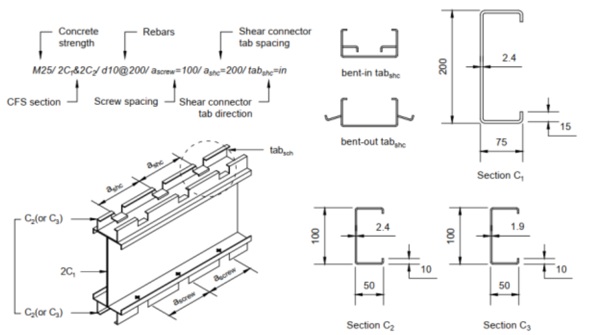


Figure 3. Notation of specimens.

The concrete used for all specimens is M25. Specimens have differences in the spacing of the shear connector gap, rebars through the gaps, and several screws. Table 1 summarizes the classification and notation of specimens.

Table 1. Specimen classification and notation.

Specimen types	Notation
Group 1	$M25/2C_1\&2C_2/d10@200/a_{screw} = 100/a_{sh} = 200/tab_{shc} = out$
Group 2	$M25/2C_1\&2C_2/d10@200/a_{screw} = 100/a_{sh} = 200/tab_{shc} = out$
Group 3	$M25/2C_1\&2C_2/d10@200/a_{screw} = 100/a_{sh} = 100/tab_{shc} = out$
Group 4	$M25/2C_1\&2C_2/d10@200/a_{screw} = 200/a_{sh} = 200/tab_{shc} = out$
Group 5	$M25/2C_1\&2C_3 = d10@200/a_{screw} = 100/a_{shc} = 200/tab_{shc} = out$
Group 6	$M25/2C_1\&2C_3 = d10@200/a_{screw} = 100/a_{shc} = 200/tab_{shc} = in$

2.2. Material properties

2.2.1 Concrete

A concrete grade of M25 is used in this study. The aggregate gradation component is presented in Table 2. The result of testing concrete compressive strength is listed in Table 3, and the curve of the stress-strain relation is shown in Figure 4.

2.2.2 Cold-rolled steel and round bar

Cold-rolled steel is galvanized with two types of thickness 2.4 mm and 1.9 mm and divided into two groups. Round bars and cold-formed steel were tested to comply with ASTM A370 – 14 [10] to determine mechanical properties. The test results of round bar and cold-formed steel is presented in Table 4 and the stress-strain relation curves of round bar and cold-formed steel are presented in Figure 5.

Table 2. Aggregate gradation component of concrete M25.

Concrete [(1)]	Cement	Stone	Crushed sand	River sand	Admixture	Water
	(kg)	(kg)	(kg)	(kg)	(g)	(kg)
M25	11.2	40.0	12.0	17.3	56.0	7.3
	(311)	(1111)	(333)	(481)	(1553)	(203)

[(1)] Mix capacity is 0.036 m^3, the values in parentheses are designed for $1m^3$ concrete.

[(2)] Admixture is designed with a mass ratio of admixture and cement equal to 0.5 %.

Table 3. Result of concrete compressive strength testing.

Grade	Specimen [(1)]	P_{max}	ft	Elastic Modulus E_c	Poisson's ratio
		(kN)	(N/mm^2)	(N/mm^2)	
M25	1	340.25	19.26	20×10^3	0.19
	2	317.57	17.98		
	3	341.26	19.32		

[(1)] Test was carried out at concrete age of 14 days.

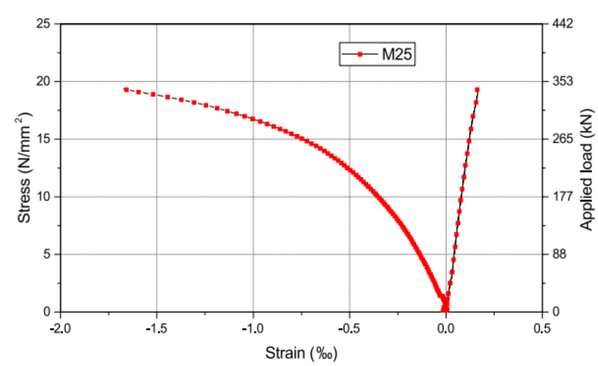
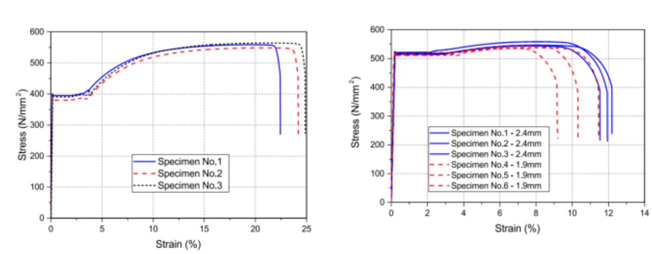


Figure 4. The curve of the stress-strain relation.

Table 4. Result of tensile test of steel.

Steel		Yield strength f_y	Tensile strength f_u	Elastic modulus E_c
		(N/mm^2)	(N/mm^2)	(N/mm^2)
Round bar	10 mm	390	540	190×10^3
Cold-rolled steel	2.4 mm	520	540	190×10^3
	1.9 mm	510	530	

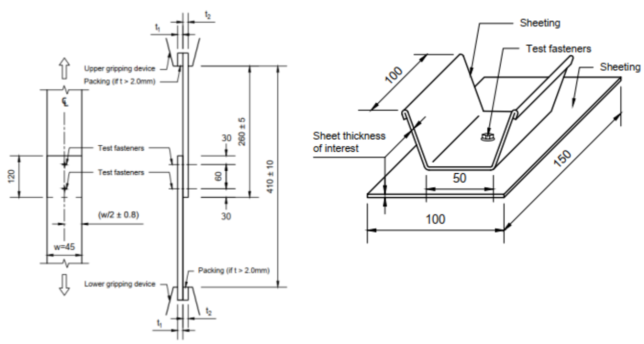


(a) (b)

Figure 5. The stress-strain relation curve of the round bar (a) and cold-formed steel (b).

2.2.3 Screw

The screw used for beams was 2.4 mm. The screw was made from stainless steel A2-70 with a nominal diameter of 5.5 mm and screw pitch of 20 mm. Tests of shear and tension were carried out to comply with AISI S905 – 08 [11] to determine the force capacity of the screw. The test model and dimensions of the sample are shown in Figure 6. The result of the screw test is presented in Table 5.



(a) (b)

Figure 6. Layout for the lap-joint shear test (a) and layout for the pull-out test (b) of screw.

Table 5. Result of screw test.

Test	The thickness of cold-formed steel	Strength capacity P_{max} (kN)	Failure mode
Shear	2.4mm	24.3	Split
	1.9mm	15.1	Split
Tensile	2.4mm	4.3	Pull
	1.9mm	3.0	Pull

2.3 Push-out test

12 specimens were tested to evaluate the behavior of shear connectors used for cold-formed steel-concrete composite beams. Push-out tests were carried out at concrete age of 14 days. The parameters that affect the strength capacity of the shear connectors consist of a round bar, the thickness of cold-formed steel, and the spacing of the screw connecting cold-formed steel and the shear connector. The results of the push-out test are used for designing cold-formed steel-concrete composite beams. Figure 7 shows an image of the test setup at Hoang Vinh Technology Research and Construction Consultants Company (Hoang Vinh T.R.C.C). The main components of the specimen consist of:

● Concrete slab had a dimension of 90×300×550 mm. The bottom of the concrete slab has left a gap of 50 mm in height to allow a shear connector without prevention.

● Round bar diameter was 10 mm with a spacing of 200 mm.

● Cold-formed steel beam was formed from two cold-formed steel channels using a screw attached at their back together.

● Shear connection system used cold-formed steel of section C, connecting the back with structural cold-formed steel by screws. The flanges of shear connectors were cut and bent down to create a connector of perfobond shape.

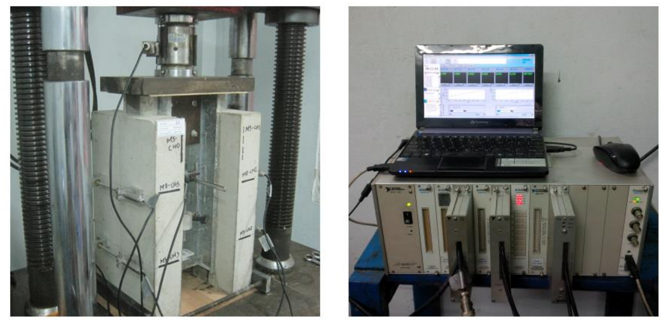


Figure 7. Test setup.

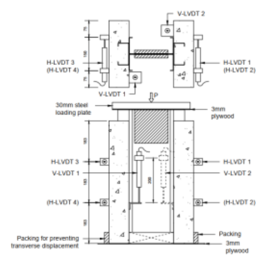


Figure 8. Push-out test arrangement.

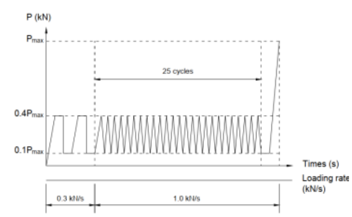


Figure 9. The procedure of incremental loading.

Figure 8 describes a model of the push-out test. In which:

- V-LVDT 1 and V-LVDT 2 were used to measure relative slip between structural cold-formed steel and concrete slab.
- H-LVDT 1, H-LVDT 2, H-LVDT 3, and H-LVDT 4 were used to measure crack development and the width of cracks.
- Compressive load was measured by load cell with a maximum loading capacity of 1000 kN.
- Incremental loading equipment was a pull-push machine with a maximum loading capacity of 1000 kN.
- All test data was recorded automatically with a return period of 2 times per second including six channels of deflection and one channel of load.
- Procedure of incremental loading is complied with Eurocode 4, as shown in Figure 9.

3. Test results and analysis

3.1. *Test results*

The test results of the 6 groups are listed in Table 6. Relation curves of load-relative slip between structural sold-formed steel are plotted in Fig.10. Failure modes are named Type 1, Type 2, and Type 3 and will be presented in the next section.

Table 6. Test results.

Group	Streng capacity P_{max}			Slip [(1)]			Failure mode
	Spec. 1	Spec. 2	Average	δ_i	δ_u	δ_u - δ_i	
	(kN)	(kN)	(kN)	(mm)	(mm)	(mm)	
1	458.51	439.51	453.88	1.23	2.37	1.14	Type 2
2	409.69	415.15	412.42	0.95	2.71	1.76	Type 2
3	488.57	454.07	471.32	0.81	3.40	2.59	Type 2
4	340.17	334.85	337.51	2.37	5.85	3.48	Type 1
5	463.17	438.87	451.02	1.22	2.70	1.48	Type 2
6	445.55	437.69	441.62	1.26	5.36	4.10	Type 3

(1) Values of δ_i and δ_u were measured at a load of 90%P_{max} (before and after specimens achieved maximum load).

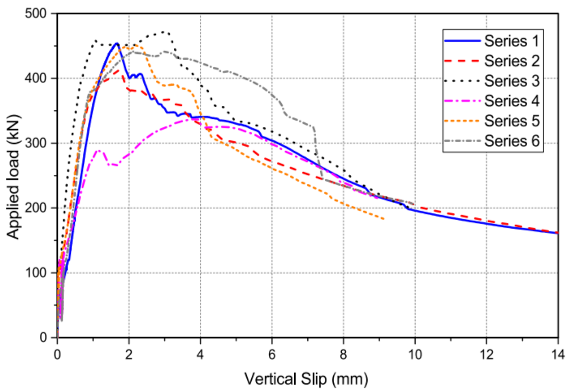


Figure10. Relation curves of load-relative slip between structural cold-formed steel and concrete slab.

3.2. *Failure modes*

Failure modes happened at positions: screws (connecting structural cold-formed steel and shear connector cold-formed steel), or concrete slab. Failure modes are:

- Type 1: Specimen failure happened at the screw, the concrete slab did not occur crack. This failure occurred in group 4. This can be explained that the screw resistance is smaller than that of concrete slab, and specimens have not utilized maximum loading resistance.
- Type 2: Specimen failure happened simultaneously at the screw and concrete slab. Cracks initiated in a concrete slab, relative slip between the concrete slab and structural steel increased result in shear force increased on screws increasing. This failure occurred in groups 1, 2, 3, and 5. With this failure mode, specimens utilized the loading resistance of components.
- Type 3: Specimens failure only occurred at the concrete slab. Cracks developed in a vertical direction from top to bottom. The concrete slab was spalled at the middle slab. This failure mode happened in group 6. This failure mode was supposed by the direction of tabs, this caused concentration stress in the concrete region.

3.3. *Analysis of the effect of parameters on the structural behavior of connection*

3.3.1 Effect of reinforcement

The loading capacity of specimens in group 1 was higher than that of group 2 about 10.1%. The relative slip between the concrete slab and structural steel of group 2 was higher than that of group 1 about 0.62 mm. This reason was supposed that reinforcement in concrete slabs decreased relative slip and resulted in an increased shear capacity of screws.

3.3.2 Effect of shear connection degree

Tab spacing of specimens in group 1 was 200 mm, and that in group 3 was 100 mm. This means that the shear connection degree of group 3 was higher than that of group 1. The shear connection capacity of group 3 was higher than the shear connection capacity of group 1 about 3.8%. The failure mode of these two groups was the same, shear connection capacity did not increase significantly with increasing shear connection degree. Therefore, increasing the shear connection degree did not have much meaning for loading capacity.

3.3.3 Effect of thickness of cold rolled steel

The thickness of shear connection steel of specimen group 1 was 24 mm, and that of specimen group 5 was 19 mm. The results showed that the thickness of shear connection steel did not affect significantly the structural behavior of the shear connectors.

3.4. Investigate the ductile

The values δ_u – δ_i of the six groups presented in Table 6 are ductile of shear connectors. All the ductile groups were smaller than 6 mm, this is also the minimum limit that was considered ductile behavior [12]. The brittle behavior of specimens was similar to the results of Hanaor [13] and J. M. Irwana [14].

At 90%P_{max}, the relative slip values were from 0.95 mm to 1.26 mm, these values were the same as the results of J. M. Irwana [2]. The highest relative slip value was of group 4 at 2.37 mm. It could be realized that in specimens with fewer screws, the relative slip of the specimen was almost formed by screw deformation. The failure load of group 4 was smaller than that of other groups while the ductility of group 4 was higher than that of other groups with more screws.

4. Conclusions

The results obtained from the push-out test partly expressed the structural behavior of shear connectors. The role, advantage, and disadvantage of components in the steel-concrete composite section are also represented through values of P_{max}, failure modes, and the ductile.

Reinforcement increased the load capacity and reduced the relative slip between the concrete slab and structural steel of specimens.

Increasing the shear connection degree did not have much meaning in improving the load capacity of specimens.

The thickness of shear connection steel did not affect significantly the structural behavior of the shear connectors.

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