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STRENGTH CAPACITY OF BOLTED SHEAR CONNECTORS WITH COLD-FORMED STEEL SECTION INTEGRATED AS COMPOSITE BEAM IN SELF-COMPACTING CONCRETE

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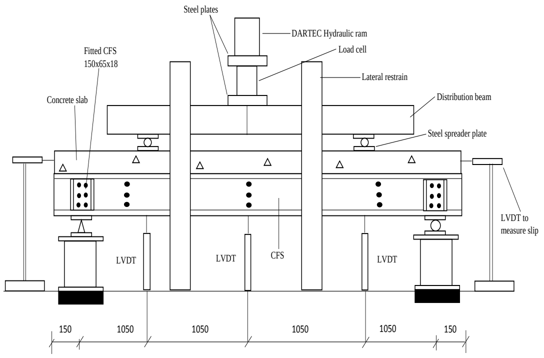
Graphical abstract



Abstract

The use of composite systems comprising of concrete and hot-rolled steel (HRS) sections is well established as observed by extensive rules and requirements for their design as prescribed in current design codes. There is, however, few technical information available about the use of composite systems that incorporates the use of light gauge steel sections, despite the potentials of the system in residential and light industrial constructions. Therefore, this study investigates the strength capacity of bolted shear connectors with cold-formed steel (CFS) section integrated as composite beam in self-compacting concrete. In this paper, four composite beam specimens of dimensions (4500 mm x 1500 mm x 75 mm) with bolted shear connectors of M12 and M14 of grade 8.8 installed on the upper flanges of the coupled back-to-back CFS I-section with longitudinal spacing's of 250 mm and 300 mm centers and spaced 75 mm laterally were fabricated, cast and tested to failure using four-point bending test. Shear connector size and the longitudinal spacing were the varied parameters, and their influence was investigated on the ultimate load and ultimate moment capacities. The results showed that, the ultimate load and ultimate moment capacities were both influenced remarkably by the studied parameters. However, results of theoretical analysis, revealed good agreement between the experimental and the theoretical results. This shows that, the plastic analysis results for the ultimate moment capacity of the composite beams can be estimated efficiently by using the constitutive laws as prescribed by Eurocodes.

Keywords: Cold-formed steel section, strength capacity, bolted shear connectors, composite beam, self-compacting concrete

1.0 INTRODUCTION

Construction practices and philosophies in the present time have become more enormous in which players in the construction industries played an important role [1]. In construction, the main constituents' materials are concrete and steel while steel more vulnerable to corrosion. Corrosion in steel could be resisted by using corrosion inhibitors [2]. Corrosion in the reinforcing steel could cause concrete to crack thus, leading to crushing of the whole concrete mass in the structure [3, 4]. Therefore, to prevent the cracking in concrete structures, self-healing agents are incorporated in the mixing of concrete prior to its application in the construction process [5]. But, in light-weight composite construction the steel section used is prevented from corrosion by coating.

In light gauge steel framing structures, the application of cold-formed steel (CFS) could be one of the factors that can optimizes economical and sustainable construction in the industrialized building system (IBS). The use of hot-rolled steel (HRS) and the conventional headed studs shear connectors in concrete was in practiced for quite a number of decades in composite construction and in the construction of buildings and bridges [6] than with a CFS section. The composite system comprising of concrete and HRS sections is well established as observed by extensive rules and requirements for their design as prescribed in current design codes. There is, however, few technical information available about the use of composite systems that incorporates the use of light gauge steel sections (i.e. CFS section), despite the demonstrated advantages for the system in residential constructions. Therefore, in this paper, the use of CFS section is demonstrated with the use of bolts as shear connectors which could eliminate the dependency on using HRS with headed studs shear connectors as used in the construction of small and medium size buildings. Significant number of researches [7-14] demonstrated the advantages of using CFS and HRS section in the composite construction and remarkable results were manifested.

For instance, the possibility of using CFS section with headed stud shear connectors welded on the flange of CFS was investigated by Bamaga [11] using push-out test. In the study, a 16 mm diameter headed stud shear connector was used and results attested better performance in strength and ductility. The performance and feasibility of bolted shear connectors as demountable connectors in composite system was investigated by Moynihan and Allwood [14]. Their findings, pointed out that the bolted shear connectors possess good strength capacities and were feasible for use in composite construction. On the other hand, the use of bolted shear connectors in composite construction using HRS section were demonstrated by some researchers [15, 16], and good and promising results were remarkably recorded. For instance, Pavlović *et al*. [15] conducted push-out test on four specimens with bolted shear connectors to evaluate their strength and ductility. Shear connectors of M16 x 140 mm of grade 8.8 were bolted to HEB260 (S235) steel section flange through a bolt hole diameter of 17 mm. The bolt spacings were laterally and longitudinally kept at 100 mm in both directions. The failure observed was sheared-off of the bolted connectors. The authors concluded that the bolted shear connectors achieved a good shear strength resistance and ductility. However, this study aimed at establishing the missing link that exists between using bolted shear connectors with CFS in composite construction when cast in Self-compacting concrete (SCC) and the advantages that could be manifested.

2.0 EXPERIMENTAL PROGRAM

2.1 Material Properties

Materials used in this study are CFS lipped channel section with web depth of 250 mm, width of 75 mm and lipped depth of 18 mm with a thickness of 2.3 mm; bolted shear connectors of M12 and M14 of grade 8.8; welded wire fabric mesh A142 of 6 mm thick spaced 200 mm x 200 mm of deformed bar of strength 460 N/mm^2; and SCC of grade 40 N/mm^2 respectively. The materials were tested in order to obtain their actual strength property using tensile, compression and modulus of elasticity tests respectively. The CFS section attained an average yield and ultimate strength values of 487.43 N/mm^2 and 523.85 N/mm^2 respectively. In the case of the bolts connectors and wire mesh fabric, an average yield and ultimate strength values of 761 N/mm^2 and 843 N/mm^2; 720 N/mm^2 and 807 N/mm^2; 502 N/mm^2 and 595 N/mm^2 for M12, M14 and welded wire fabric mesh respectively. For fresh property of the SCC, i.e. slump flow, its average value was determined to be 625 mm and T500 was 2 sec. Compressive strength and modulus of elasticity were determined to be 40.7 N/mm^2 and 35.4 kN/mm^2 respectively.

2.2 Composite Beam Specimens

The composite beam specimens were 4500 mm length, effectively spanned at 4200 mm between supports. The effective width of the slab was 1500 mm with a depth of 75 mm. The CFS section was oriented back-to-back to form an I-section beam using a self-drilling screws of 5.8 mm diameter. Bolt holes of 13 mm and 15 mm diameter were drilled on the upper flanges of the CFS section. However, for the shear connection to be provided between the concrete slab and the CFS section, bolted shear connectors of M12 and M14 were installed through the holes with single nut and washer at top and bottom of the CFS flange at a longitudinal spacings of 250 mm and 300 mm respectively, spaced at 75 mm laterally. The fabric wire mesh was installed to prevent creeping and shrinkage of the concrete. Figure 1 shows the preparation of the test specimens.


(a) (b) (c)

Figure 1 Preparation of full-scale test specimens [(a) samples formwork, (b) samples casting, (c) finished samples]

2.3 Test Set-up and Procedure

All the composite beam specimens were tested in the same manner using DARTEC jack machine with a load cell capacity of 2000 kN. Test specimen was subjected to four point bending test, where the load from the jack machine was applied at 1050 mm (shear span) from the supports. The specimen was placed as simply supported beam as shown in Figure 2. Deflections of the specimens were monitored at the mid-span and at the quarter spans underneath the bottom flanges of the CFS section using linear variable displacement transducers (LVDT's). Strains in the specimens were monitored on the concrete slab and under the bottom flanges of the CFS section using strain gauges. All LVDT's and strain gauges were connected to the data logger. Due to high concentration of stresses at the supports, premature failure of the CFS may occur; therefore it was prevented by fitting the supports with a CFS section of dimensions 150 mm x 65 mm x18 mm of thickness 2.3 mm (Figure 2(b)). Load from the jack machine was applied on the specimen at a constant rate of 0.2 kN/s through the distribution beam which transfer it to the concrete slab through the line load beams. The line load beams were rested on a steel spreader plates of 200 mm x 150 mm x 12 mm thick, to spread the load as a point load on the concrete slab. The specimen was loaded up to 15% of its predicted failure capacity and then zeroed. This was to ensure that the instrumentation process was okay and that the specimen was in equilibrium state prior to the proper testing. The specimen was loaded again this time not to 15% of its predicted capacity. Load was further increased until failure of the specimen occurred. The failure of the specimen was considered when there was a significant drop in the applied load or when a large deformation of the test specimen was observed. Lateral restrains were provided during the test, this was to prevent the specimen from having lateral torsional buckling failure prematurely.

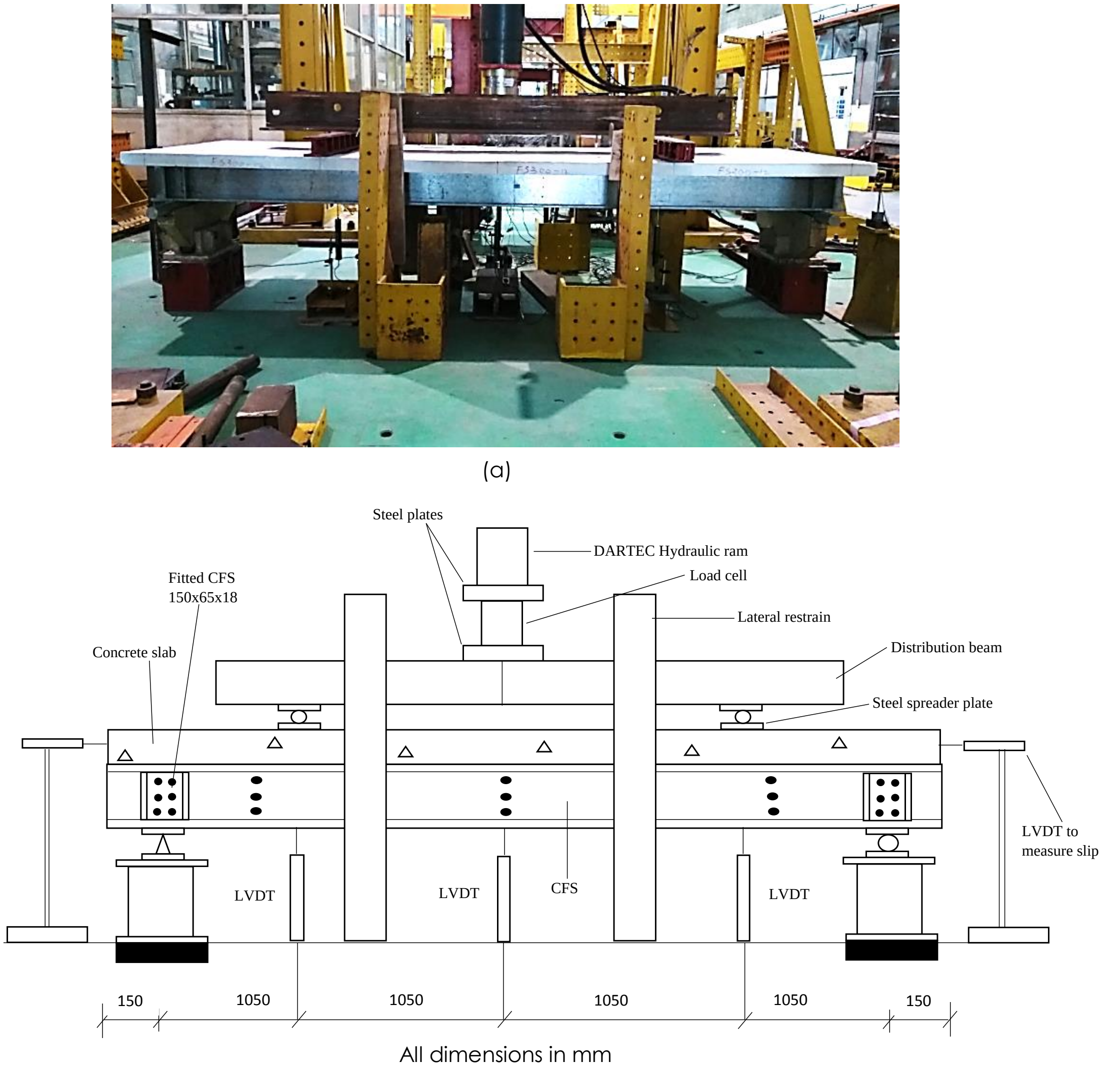


Figure 2 Test set up of composite beam specimens [(a) Testing rig (b) schematic diagram]

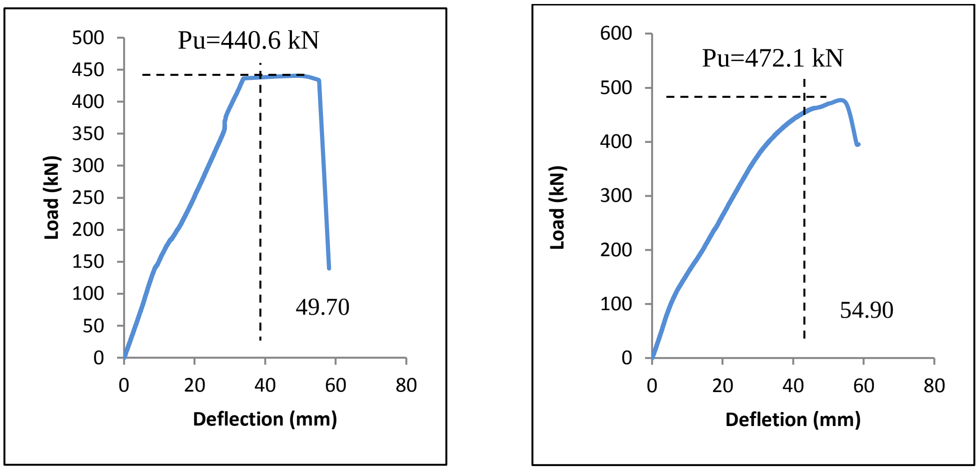
3.0 RESULTS AND DISCUSSIONS

The experimental test result of the composite beam specimens is presented in Table 1. Figure 3 shows the load against mid-span deflections of the composite beam specimens. From Figure 3 and Table 1, the ultimate loads (Pu, exp.) attained for specimens FS250-14, FS300-14, FS250-12 and FS300-12 were 440.6 kN, 472.1 kN, 438.5 kN and 466.1 kN with an initial crack observed at loads level of 205 kN, 222 kN, 185 kN and 200 kN respectively. Mid-span deflections at ultimate loads level were recorded as 49.7 mm, 54.94 mm, 49.6 mm and 56.9 kN for FS250-14, FS300-14, FS250-12 and FS300-12 specimens respectively. Failure modes experienced by the specimens were appearance of a longitudinal cracks along the shear connectors' line on the concrete slab surface and transverse cracks underneath the slab. From the results, specimens with M14 bolted shear connector attained an ultimate moment capacity of 0.4% and 1.3% higher at 250 mm and 300 mm longitudinal spacings than specimens with M12 bolted shear connector respectively. However, this shows that, the moment carrying capacity between the specimens does not differ much. Therefore, this is an indication that the specimens could provide the necessary composite action that is required, considering the load resisted by the specimens (see Table 1). It can be clearly observed that, as the shear connector size is increased from 12 mm to 14 mm diameter, the ultimate moment capacity attained also increases as shown in Figure 4(a). This shows that, the shear connector size influenced the load and moment carrying capacity of the specimens. The effect of size of the shear connector is in agreement with findings of Irwan *et al.* [6]. Similarly, as the longitudinal spacing of the shear connector is increased from 250 mm to 300 mm the ultimate load increases as shown in Figure 4(b). This also agrees well with investigation made by Lakkavalli and Liu [8]. Figure 5 shows the failure modes of the test specimens.

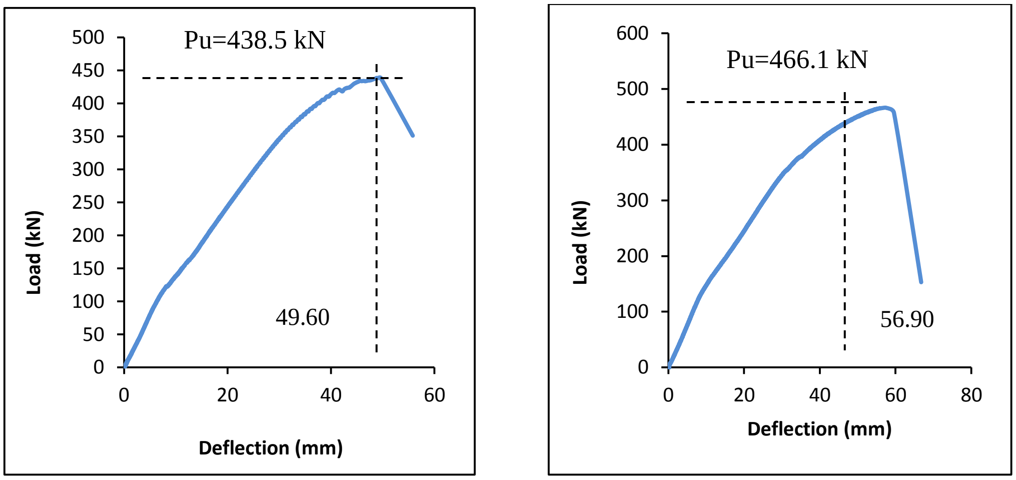
Table 1 Flexural test result of composite beam specimens

Specimen ID	f_{ck} at test day (N/mm^2)	Ultimate load, $P_{u, exp.}$ (kN)	Deflection at $P_{u, exp.}$ $\delta_{u, exp.}$ (mm)	Ultimate moment, $M_{u, exp.}$ (kNm)
FS250-14	34.1	440.6	49.7	231.3
FS300-14	32.6	472.1	54.9	247.9
FS250-12	32.6	438.5	49.6	230.3
FS300-12	35.3	466.1	56.9	244.7

FS250-14: Full-specimen @ 250 mm spacing with M14 bolt diameter

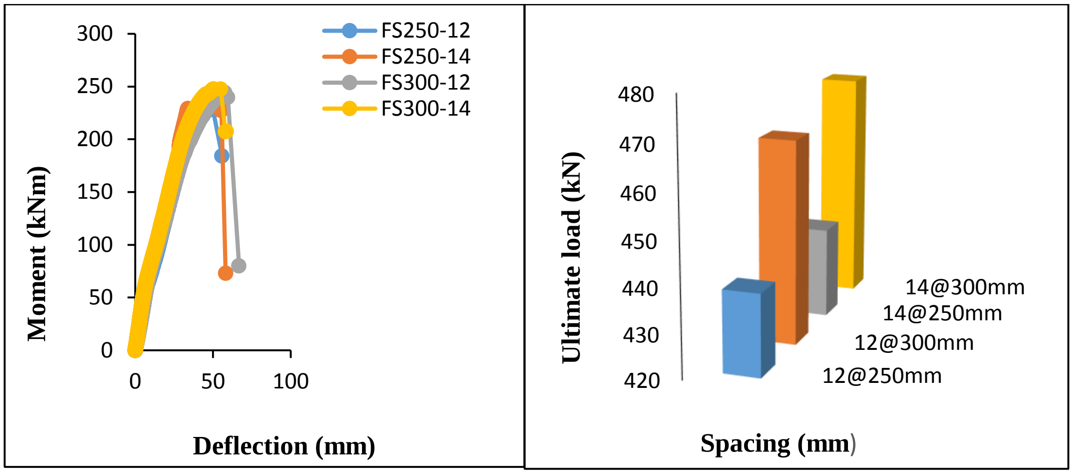


(a) FS250-14 (b) FS300-14



(c) FS250-12 (d) FS300-12

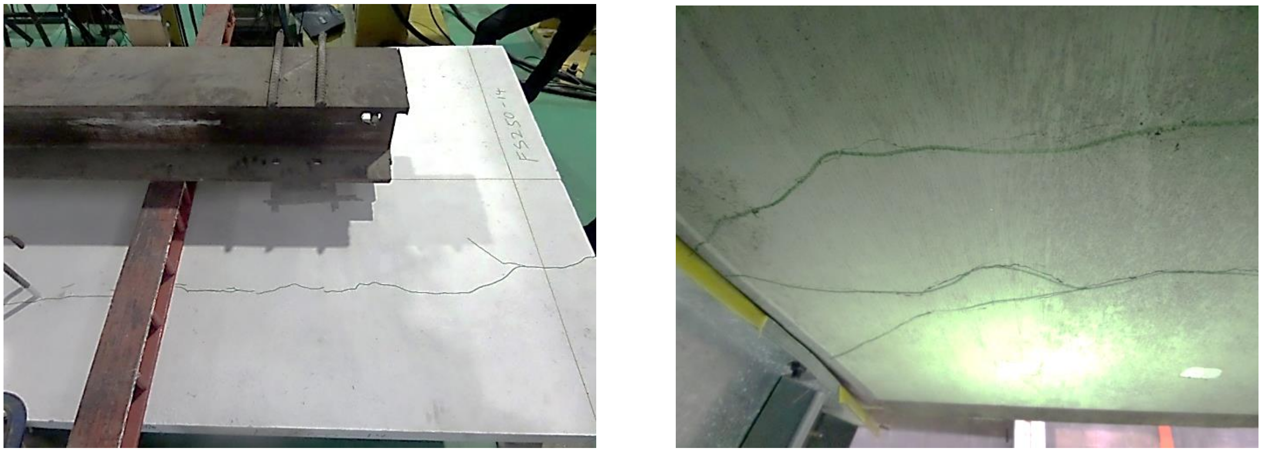
Figure 3 Load-deflection response of composite beam specimens



(a) Size influence

(b) Spacing influence

Figure 4 Influence of shear connector size and spacing of composite specimens



(a) Concrete crushing M14 specimen

(b) Transverse cracks underneath slab M14 specimen

(c) Concrete crushing M12 specimen

(d) Transverse cracks underneath slab M12 specimen

Figure 5 Failure modes of composite beam specimens

3.1 Comparison Between Experimental and Theoretical Results

The experimental results were compared with theoretical results. The theoretical calculation was based on the well-known rigid plastic analysis. From the results of the analysis, it can clearly be seen that, the experimental results values agrees well with the theoretical values based on the analysis approach. The result of the comparison is presented in Table 2. Referring to Table 2, it can be observed that, the ratio of experimental shears to that of theoretical ranges from 1.07 to 1.24 with mean and standard deviation values of 1.16 and 0.07 respectively. However, in terms of moment capacity, the ratios ranges from 1.03 to 1.24 with mean and standard deviation values of 1.13 and 0.09 respectively. This shows that, close agreement between the compared results is well achieved.

Table 2 Results of comparison between experimental and theoretical values

Specimen ID	Experimental results		Theoretical results			
			Stress block method			
	$V_{exp.}$ (kN)	$M_{exp.}$ (kNm)	V_{theory} (kN)	$V_{exp.}/V_{theory}$	M_{theory} (kNm)	$M_{exp.}/M_{theory}$
FS250-14	220.3	231.3	206.0	1.07	225.4	1.03
FS300-14	236.1	247.9	206.0	1.15	224.8	1.10
FS250-12	219.3	230.3	176.8	1.24	186.2	1.24
FS300-12	233.1	244.8	195.8	1.19	211.6	1.16
Mean				1.16		1.13
Std. deviation				0.07		0.09

4.0 CONCLUSION

From the results of the experimental tests, the following conclusions can be drawn:

1. Failure modes exhibited by the composite beam specimens were similar, with crushing of concrete on the slab surface and transverse cracks underneath the slab.
2. Experimental shear capacities (Vexp.) are higher than the theoretical (Vtheory) with a determined ratio above 1.0, hence good agreement acquired.
3. Experimental moment capacities (Mexp.) are higher than the theoretical (Mtheory) with a determined ratio above 1.0, hence good agreement acquired.
4. Strength capacities of the composite beams specimens increases with an increased in the size of the shear connector; therefore, shear connector size had shown to influence the strength capacities.
5. Strength capacities of the composite beams specimens increases with an increased in the longitudinal spacing of the shear connector; this shows that, shear connector longitudinal spacing had shown to influence the strength capacities.
6. The results proved that, the plastic analysis for the ultimate moment capacity of the composite beams can be estimated efficiently by using the constitutive laws as prescribed by Eurocodes and British standards.

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