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ARTICLE

IMPACT OF BOLTED SHEAR CONNECTOR SPACING IN COMPOSITE BEAM INCORPORATING COLD-FORMED STEEL OF CHANNEL LIPPED SECTION

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ABSTRACT

Background: *Composite construction with traditional Hot Rolled Steel (HRS) sections has been known to perform much better than with Cold-Formed Steel (CFS) sections for decades; as observed by extensive rules and requirements for their design as prescribed in current design codes. However, only 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. However, composite construction of CFS with Self-Compacting Concrete (SCC) using bolted shear connector has not been established yet. Therefore, this paper presents the behavior of bolted shear connector used with SCC and CFS to form a composite beam system where the impact of longitudinal spacing was studied. Full-scale test specimens of longitudinal spacing of 250 mm and 300 mm with bolted shear connector of grade 8.8 installed with single nut and washer on the CFS flange and beneath were fabricated, cast and tested till failure occurred. The experimental test results showed that the bolted shear connector possessed good ultimate strength and ultimate moment capacities with an increase in the longitudinal spacing of the bolted shear connector from 250 mm and to 300 mm respectively. It was therefore concluded that longitudinal spacing between bolted shear connectors had significantly influenced the shear connector strength capacities.*

KEY WORDS
Cold-formed steel, composite construction, bolted shear connection, push-out test, longitudinal

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INTRODUCTION

Construction practices and philosophies at present time has becoming more advance in which innovation in construction industries played an important role [1-3]. In construction, main constituents of materials are concrete and steel with steel is more vulnerable to corrosion. Corrosion in steel could be resisted by using corrosion inhibitors [4,5]. Corrosion in the reinforcing steel could cause concrete to crack thus, leading to crushing of the whole concrete mass in the structure [6,7]. 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 [8]. But, in light-weight composite construction the Cold-Formed Steel (CFS) section used is prevented from corrosion by coating. CFS sections are lightweight materials that are produced by bending of a flat steel sheet at a room temperature [9] into a desired shape that can withstand more load than the flat sheet itself; and are suitable for building construction owing to their high structural performance [10-13]. The most common sections of CFS are channel lipped C and Z sections, and the typical thickness ranged from 1.2 to 6.4 mm with a depth range of 51 mm to 305 mm [14]. In steel and construction industry, Hot-Rolled Steel (HRS) and CFS are two distinguished known steel sections that are used. But, among the two steel sections, HRS is the most familiar among the building contractors and engineers. Some studies reported on the potentials of using CFS sections in composite construction and significant improvements in terms of strength were demonstrated. An extensive study was conducted by [15,16] on the use of CFS section as a composite beam in cast-in situ and precast concrete slabs. Tests were conducted on push-out and full-scale flexural tests. Varied in the push-out test using the in situ concrete were the shear enhancements consisted of screwed channel (CS), welded channel (CW) and screwed deck (DS) connectors of the same CFS section embedded in the concrete slab. For the precast specimens, screwed bolt connections and through bolted connections were used. The results showed that the connection methods were effective for attaining the desired capacity and the CFS composite slabs responses were ductile. [17] [18] [20] Investigated on the strength capacity of different types of shear transfer enhancement which consisted of pre-drilled holes, pre-fabricated bent-up tabs created on the flange surface of the CFS section, self-drilling screws and surface bond between the CFS section and the concrete. The results showed that reduce in deflection and significant increase in strength capacity were notably observed in specimens with shear transfer enhancements when compared with the specimens relying only on the surface bonding between the steel and the concrete to provide the shear resistance. In this paper, the use of CFS channel lipped section is reported with bolted shear connector used at designated longitudinal intervals of 250 mm and 300 mm and spaced laterally at 75 mm to possibly establish the influence longitudinal spacing could have on the shear connector ultimate strength capacity. The shear connection system is not suggested for welding of stud on thin flanges of CFS as it is not practically feasible. Therefore, this study aimed at addressing the concept of using CFS section in composite construction, although very few technical information is available on composite system that

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incorporates the use of CFS section. It can be concluded that the shorter the distant between the bolted connection, the higher the moment resistance of the composite beam.

EXPERIMENTAL PROGRAM

Full-scale 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 fabrication and installation process are the same as in the push-out test program. [Fig. 1] shows the preparation of the test specimens.

(a)

(b)

(c)

Fig. 1: (a) Samples formwork, (b) Samples casting, (c) Finished samples.

Test set-up and procedure

All composite beam specimens were tested using DARTEC jack machine with a load cell capacity of 2000kN. Test specimens were 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 [Fig. 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 [see Fig. 2]. 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.

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Fig. 2: Full-scale test arrangement.

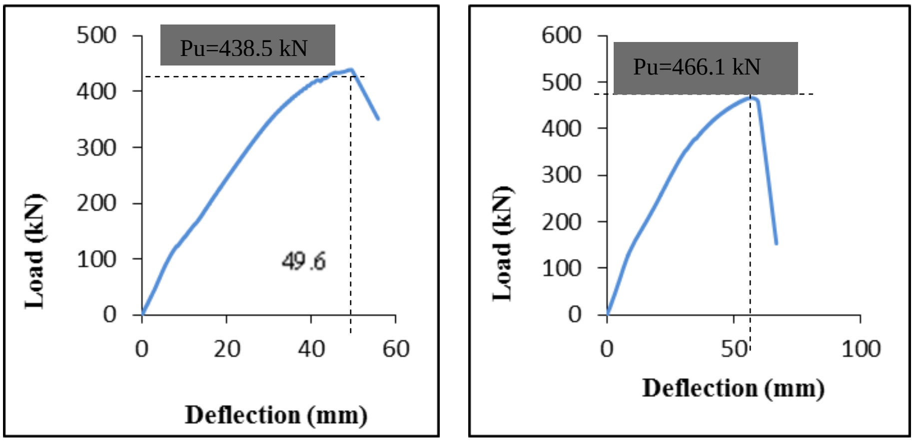
RESULTS AND DISCUSSIONS

The experimental test result of the composite beam specimens is presented in [Table 1].[Fig. 3] shows the load against mid-span deflections of the composite beam specimens. From [Table 1] and [Fig. 3], the ultimate loads (Pu, exp.) attained for specimens FS250-12 and FS300-12 were 438.5kN and 466.1kNwith an initial crack observed at loads level of 185kNand 200kN respectively. Mid-span deflections at ultimate loads level were recorded as 49.6mm and 56.9mm for FS250-12 and FS300-12 specimens respectively. The specimens exhibited the same failure modes by flexure which initiated by longitudinal cracks along the line of shear connector on the slab surface transverse cracks underneath the concrete slab as well as shear connector pull-out from the slab. The shear connector pull-out from the concrete slab could be attributed to the smaller head diameter of the shear connector. The specimens failed as a result of torsional buckling of the CFS section when the ultimate was reached. From the results, specimen with bolt connector at 250 mm attained an ultimate moment capacity of 6.3% higher than that at 300 mm longitudinal spacing. 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 required composite action, considering the load resisted by the specimens [Table 1]. It can be clearly observed that, as the shear connector longitudinal spacing was increased from 250 mm to 300 mm, the ultimate moment capacity attained also increased. This shows that, the shear connector longitudinal spacing influenced the load and moment carrying capacity of the specimens. The influence of the longitudinal spacing of the shear connector on the ultimate moment capacity agrees well with investigation carried out by [17][19] [Fig. 4 (a-c)] shows the failure modes of the test specimens and the shear connector condition after the test.

Table 1: Flexural test result of composite beam specimens

Specimen ID	fck at test day (N/mm^2)	Ultimate load, Pu, exp. (kN)	Deflection at Pu, exp. δu, exp. (mm)	Ultimate moment, Mu, exp. (kNm)
FS300-12	32.6	438.5	49.6	230.3
FS250-12	35.3	466.1	56.9	244.8

FS250-12: Full-specimen @ 250 mm spacing with M12 bolt diameter



(a) FS300-12 (b) FS250-12

Fig. 3: Load-mid-span deflection of composite beam specimens.

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(a) (b) (c)

Fig. 4: (a) Concrete cracks on slab surface, (b) Transverse cracks beneath the slab, (c) Non-deformed shear connector.

CONCLUSIONS

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

- The shear connector showed that the moment capacity of composite action between concrete slab and the steel section was very good as no deformation can be observed on the proposed shear connector.
- The test results showed that the longitudinal spacing of the proposed bolted connecters with self-compacting concrete did not show much difference.
- The use of bolted connector can be used as shear connector to replace the typical shear stud as the composite action between steel and concrete is very promising.

CONFLICT OF INTEREST

There is no conflict of interest.

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FINANCIAL DISCLOSURE

None

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