

Can Cold-Formed Steel Section Be Use As A Sustainable Structural Member in Building and Civil Engineering Constructions? A Mini Review

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Abstract. Cold-Formed Steel (CFS) section for several decades was not considered as a structural member in building and civil engineering constructions due to inadequate technical information available about its usage, despite the potentials it demonstrated as proven by current research studies. Therefore, this paper aimed at demonstrating the structural capability of CFS section as a sustainable structural member in building and civil engineering constructions. Some research studies conducted reported in this paper shows the possibility of CFS section to be utilized as a structural member in the construction industries. Results from the research studies reported shows that flexural capacities were found to be increased when the CFS section was integrated compositely. In conclusion, and as demonstrated in this paper based on the studies reported, the CFS section can be employed as a sustainable structural member in small and medium size buildings, civil engineering and in lightweight industrial constructions.

Keywords: Cold-formed steel section; sustainable construction; sustainable structural member; flexural capacities; structural member

1. Introduction

For several decades, Hot Rolled Steel (HRS) section is used as a structural member in building and civil engineering constructions as it is shown and proven by the existing codes of practice. However, recently the use of Cold-Formed Steel (CFS) section as a structural member is highly demonstrated as it is also proven by current research works [1-6] conducted to show case its potentials as structurally feasible.



Comprehending the structural behaviour of CFS section was manifested by significant number of research studies [7-9]. It was reported elsewhere in Irwan et al., [10-12] that when two CFS sections were oriented back-to-back, it was observed that lateral-torsional and lateral-distortional buckling were suppressed to a lesser extent and also compressive bending stresses were reported to be reduced. This advantage manifested encouraged the use of CFS sections in a broader range of structural applications both in building and civil engineering constructions.

Therefore, this paper, aimed at demonstrating the structural capability of CFS section as a sustainable structural member in building and civil engineering constructions as proven by current research studies conducted.

2. Previous investigations carried out

Application of CFS sections in concrete composite beams has been reported to be very limited [13-14] as compared with HRS sections in composite construction. However, some research studies were established in literatures due to the potentials demonstrated by CFS sections structurally. Therefore, for structural purposes, CFS sections when employed in connection with other materials become more effective. According to Ghersi, et al., [15], the perfect setting to achieve the structural integrity of CFS is to use it as composite beam in concrete slab. A lot of research studies were conducted using CFS section be it a lone or as a composite entity to demonstrate its capability as a structural member as it is highlighted below. Some selected previous research studies are reported in this paper as presented below.

2.1. Research study conducted in (2000)

An extensive study was conducted by Hanaor [14] on the use of CFS section as a composite beam in cast-in situ and precast concrete slabs. The geometry of the composite beam connection mechanisms are shown in figure 1. Tests conducted consisted of 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 (SC), welded channel (WC) and screwed deck (SD) connectors of the same CFS section embedded in the concrete slab. For the precast specimens, screwed bolt connections and through bolted connections were used. Failure mode of the specimens with bolted connectors was observed to be the spalling of concrete near the drilled holes of the bolt connectors. The results showed that the connection methods were effective for attaining the desired flexural capacity. He concluded that the CFS composite slabs responses were more ductile.

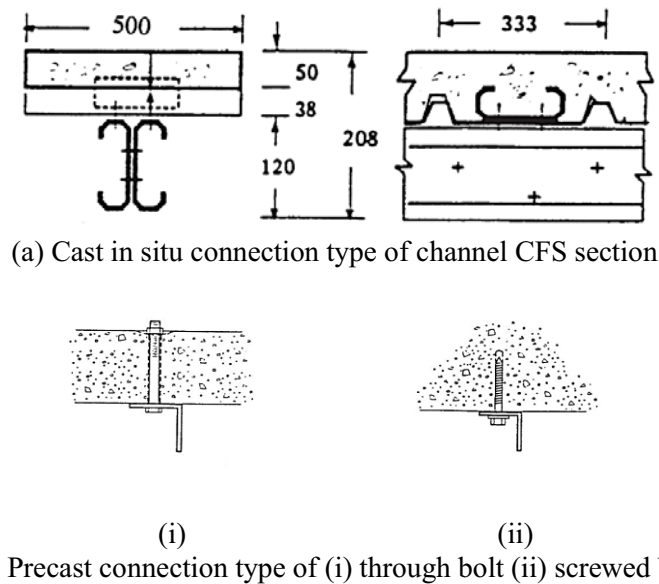


Figure 1. Typical CFS composite beams connection mechanism; Hanaor [14]

2.2. Research study conducted in (2002)

Nakamura [16] conducted a study on a new U-shaped composite bridge girders consisted of CFS section (figure 2). In the study, the CFS section U-shaped girders were compositely made with reinforced concrete slab at the span centre of the bridge girder. And at the intermediate supports of the continuous bridge concrete was poured and made pre-stressed. Flexural bending tests were conducted to evaluate the static bending behaviour of the girder models. The result showed that the new CFS composite bridge girder had sufficient flexural bending strength, good deformation and rotation capacity. He finally concluded that the new bridge girder system was practically feasible and economically viable.

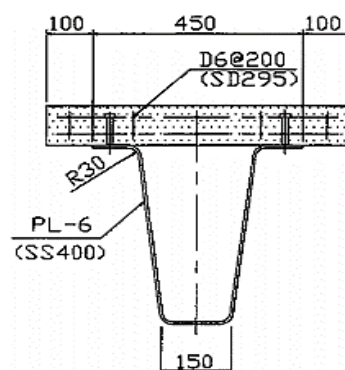


Figure 2. CFS U-shaped composite girder specimen; Nakamura [16]

2.3. Research study conducted in (2003)

Another study on CFS-box section as composite beam with concrete was conducted by Hossain [17], geometry as shown in figure 3. Varied in the study were the enhancement devices as follows:

- (i) Open box section (OS).
- (ii) Open box with welded extension (WE).
- (iii) Open box with welded extension and rod (WER).
- (iv) Open box with reinforced concrete (RC).
- (v) Closed section (CS).

He claimed that the new idea of thin walled composite beam with CFS-box sections with an infill of concrete could be a better option in the construction of small and medium size buildings which could replace HRS sections. In the study, he used normal and light-weight volcanic pumice as concrete infill to evaluate the behaviour of the thin walled composite filled beams. Failure mode of OS beam specimens occurred due to lateral buckling of free open top flanges of the CFS section which caused the steel to separate from the concrete. This was expected because the top flange was under compression and the infill concrete does not provided the flange enough stiffness due to the weakness of composite action that lied only on the surface bonding. He found out that the strength of the beams was limited by compression buckling capacity of the steel plate at the top of the open box section. The results demonstrated that CS beam specimens manifested better strength capacity than WE and OS beam specimens except WER beam specimens. He also observed that similar behaviour was manifested by the specimens filled with normal and volcanic pumice concretes with better strength and deformation capacities demonstrated than beam specimens filled with normal concrete. He concluded that good performance capability could be achieved when light-weight volcanic pumice concrete was used as an infill concrete for thin walled composite beams rather than with the normal concrete.

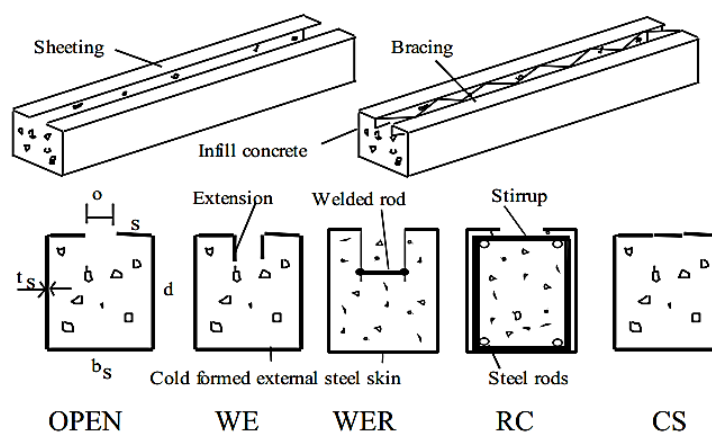


Figure 3. Typical geometry of composite filled beams; Hossain [17]

2.4. Research study conducted in (2006)

The behaviour of composite slab joist consisted of CFS C-section was studied by Lakkavalli and Liu [18]. The study 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 (figure 4) and surface bond between the CFS section and the concrete. Also varied in the study and their influence investigated were thickness of the CFS section and longitudinal spacing of the shear transfer enhancements. The results showed that reduced 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. However, better performance was significantly recorded in the specimens provided with the bent-up shear transfer enhancement than other shear connectors employed. From the longitudinal spacing point of view, specimens employed with bent-up tabs and self-drilling screws shear enhancement attained higher strength capacity as the longitudinal spacing was increased from 150 mm to 200 mm. The lower strength capacity could be attributed to the overlapping of stress fields that existed when the spacing is lower. While the specimens with drilled holes on the CFS flange, the strength capacity was found to increase as the longitudinal spacing between the drilled holes was decreased from 200 mm to 150 mm. This is obvious, because the effect of overlapping of stress fields was not significant as when the shear transfer enhancement is put at stand up position. The same observation was noticed when the CFS section thickness was increased, the ultimate capacity was also found to increased. They concluded that among the four shear transfer enhancements investigated, drilled holes are most industrially viable because of their effectiveness, simplicity and are more economical.



(a) Pre-drilled holes on CFS flange



(b) Bent-up tabs on CFS flange



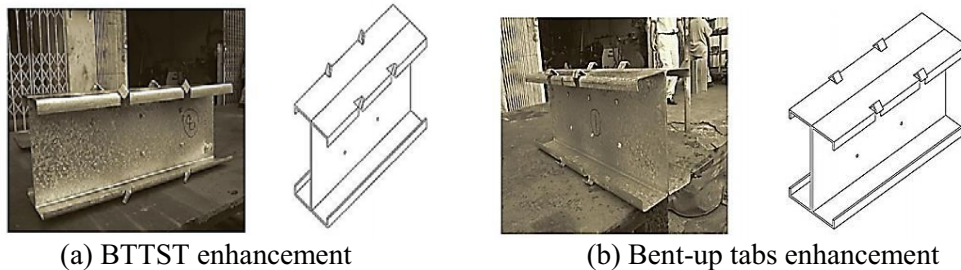
(c) Self-drilling screws installed on CFS flange

Figure 4. Typical shear transfer enhancements; Lakkavalli and Liu [18]

2.5. Research study conducted in (2008 and 2009)

Irwan, et al., [10-11] studied shear transfer enhancement in steel and concrete composite beam system using CFS section (figure 5(a & b)). In the study, shear transfer enhancement of bent-up triangular tab shear transfer (BTTST) were created on the flanges of the CFS section to provide the shear connection mechanism. Varied in the study and their influence investigated were dimension and angle of BTTST, concrete compressive strength and CFS section thickness. Push-out and full-scale specimens were fabricated and tested to establish the strength and ductility of the shear transfer enhancement and flexural capacity of the composite beam specimens respectively. Moreover, similar specimens investigated by Lakkavalli and Liu [18] were also prepared and tested alongside the test specimens for comparison purposes. The failure modes of specimens employed with BTTST using push-out test were observed to be cracking of concrete followed by concrete crushing.

For full-scale beam specimens, specimens employed with larger CFS section failed due to crushing of concrete slab while specimens with smaller thickness of CFS section the failure mode was governed by CFS beam fracture. It was found that the ultimate capacity of BTTST significantly increased with an increased in the angle and dimension of the BTTST, thickness of the CFS beam and concrete compressive strength. The ultimate strength capacity of BTTST was found to be higher than that of Lakkavalli and Liu [18] tested in the study. But, however, the BTTST enhancement failed to meet the ductility requirement of 6 mm or more based on the provision of Eurocode 4 [19]. They concluded that better performance in the ultimate resistance was provided by BTTST enhancement when compared with the bent-up tabs of Lakkavalli and Liu [18].



(a) BTTST enhancement

(b) Bent-up tabs enhancement

Figure 5. Typical shear transfer enhancements; Irwanet *al.*, [10-11]

2.6. Research study conducted in (2011)

Wehbe et al., [20] studied the development of concrete-cold formed steel (CFS) composite flexural members. The study involved experimental and analytical approaches to assess the structural performance and failure modes of the concrete-CFS track composite beams. Investigated in the study were flexural capability, shear strengths, flexural stiffness, and interface shear transfer. Results showed that concrete-CFS track composite beams can be designed for ductile flexural failure.

2.7. Research study conducted in (2013)

Bamaga and Tahir [21] conducted a study using CFS section and concrete as a composite entity. Push-out test on the test specimens was conducted to evaluate the strength and ductility of the proposed shear connectors used. In the study, variety of shear connection mechanisms consisted of single bracket CFS shear connector and HRS plate shear connector were used. Failure mode observed after the test was transverse and longitudinal cracking of concrete slabs tailed by crushing of the concrete slabs. They concluded that the proposed CFS fabricated shear connectors demonstrated a better strength capacity and ductility. The proposed shear connectors are shown in figure 6.



(a) Shear connector type I

(b) Shear connector type II

Figure 6. Push test specimen with the shear connectors before casting; Bamaga and Tahir [21]

2.8. Research study conducted in (2014)

A research study was conducted by Alhajri [22], the study investigated on the structural behaviour of CFS section used as composite beam with ferrocement slab. The composite action was provided using bolted shear connector of 12 mm diameter. Push-out and full-scale flexural beam tests were conducted to evaluate the strength capacity and ductility of the proposed bolted shear connectors, and performance of the composite beam specimens were investigated using a four-point bending test. It was established that the bolted shear connector of M12 used demonstrated sufficient ultimate strength capacity as well as ultimate moment resistance. It was concluded that the proposed composite specimen coupled with the bolted shear connector was strong enough to provide the composite action required.

2.9. Research study conducted in (2015)

Saggaff, et al., [23], conducted a study to evaluate the behaviour of variety of shear connectors cast in ferrocement slab with CFS channel lipped section as composite beam. The study utilized 10 push-out test specimens which were tested to failure. Varied in the study were number of wire mesh layers (2, 4 and 6) and three types of shear connectors consisted of bolts (12 mm diameter), bar angle (10 mm diameter) and self-drilling screw (6.3 mm diameter) as shown in (figure 7). Failure mode observed by the specimens employed with self-drilling screw was sheared-off of the screw connectors and for the with 12 mm diameter bolt the failure mode was separation of the concrete slabs from the CFS beam section with conical concrete (ferrocement) failure with no deformation on the bolted shear connector. The results showed that the 12 mm diameter bolted shear connector achieved better strength capacity than the other connectors. They concluded that experimental results agreed well when compared with the theoretical results based on the provision in [19].



Figure 7. Proposed shear connectors; Saggaff et al., [23]

2.10. Research study conducted in (2016)

A study was conducted by Lawan et al., [24], the study investigated on the use of CFS section with Self-Compacting Concrete (SCC) coupled with bolted shear connectors to establish the system structural capability. Push-out test was conducted to evaluate the strength capacity and ductility of the proposed bolted shear connectors, and performance of

the composite specimens. It was established that the bolted shear connector of M16 used demonstrated sufficient ultimate strength capacity. It was concluded that the composite specimen coupled with the bolted shear connector was strong enough to provide the composite action required. The test set up is shown in figure 8 below.

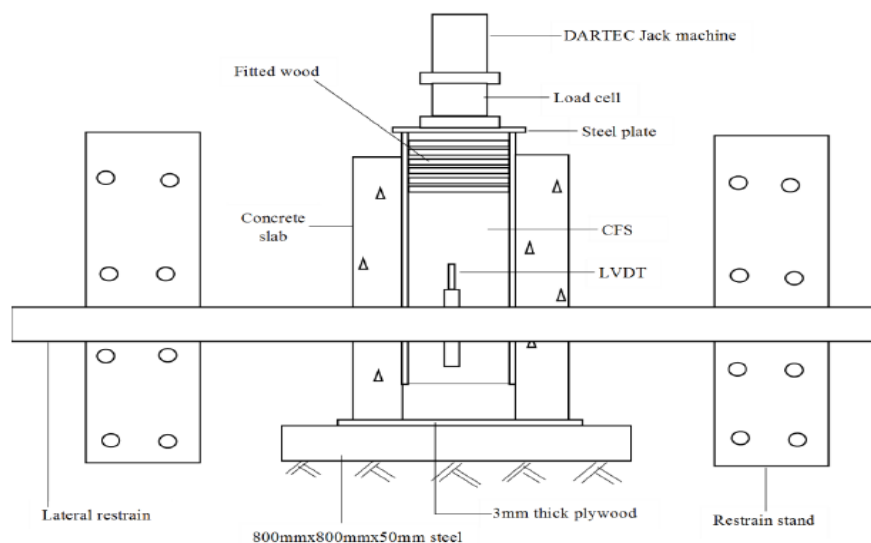


Figure 8. Schematic diagram of push-out test set up; Lawan et al., [24]

2.11. Research study conducted in (2017)

A study was conducted by Kyvelou et al., [25] to see the possibility of developing composite action between CFS joist and timber (wood) based flooring panels. In the study, they proposed an alternative means of shear connection of fasteners and structural adhesive to achieve the composite action. Their result revealed that remarkable degree of shear connection, moment capacities as well as flexural stiffness were significantly increased.

2.12. Research study conducted in (2018)

Lawan et al., [3] conducted a research study using CFS section to compare between the two distinct methods of composite design. In the study, the use of doubly oriented back-to-back CFS section coupled with bolted shear connectors in composite floor system was demonstrated. The bolted system of shear connector used provided an alternative to headed stud shear connector with CFS section as welding of the stud connector was practically not possible on CFS section because of its thinness nature. The resulting composite floor system (figure 9) had proven to provide adequate strength and stiffness capabilities under the applied loads. The results have shown that the theoretical value of flexural capacities evaluated agreed reasonably well with the experimental values. They concluded that the composite floor system can be employed in the construction of small and medium size buildings, as well as in light weight construction industries.

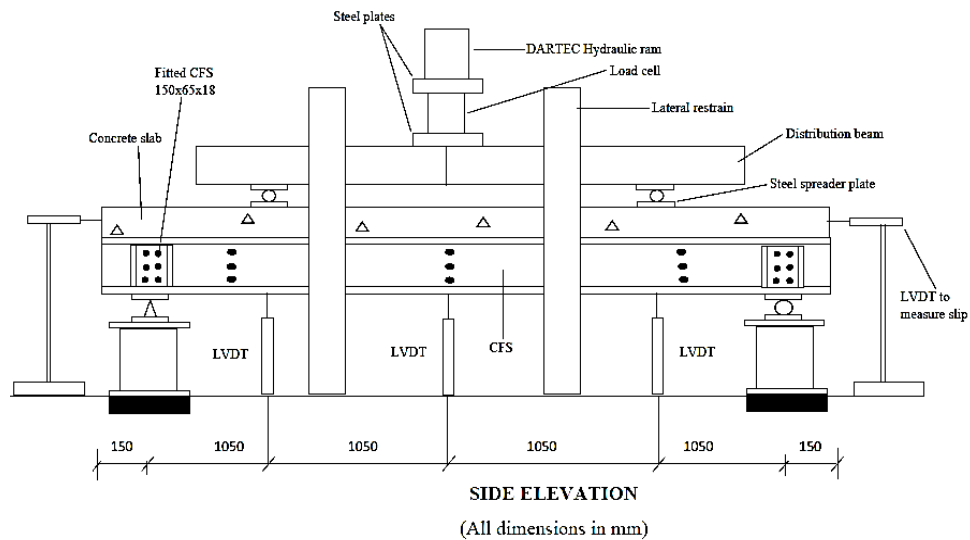


Figure 9. Schematic diagram of composite beam specimen test arrangement; Lawan et al., [26]

2.13. Research study conducted in (2019)

Aguiar et al., [26] conducted a research study that proposed an alternative shear connector for CFS-concrete composite beams. The proposed shear connector was a steel plate with holes placed longitudinally in the middle of the upper flanges of the steel profile that aimed to maximize the support area for precast slabs during assembly as shown in figure 10. The proposed specimens were tested under bending as I-beams consisted of two CFS channel sections. Parameters measured were relative slip between the steel and the concrete, vertical deflection and strains at various locations. Their result manifested that the proposed shear connector assured the shear transfer at the interface of the composite section and that strength of the same magnitude was achieved as obtained by other commonly used shear connectors.

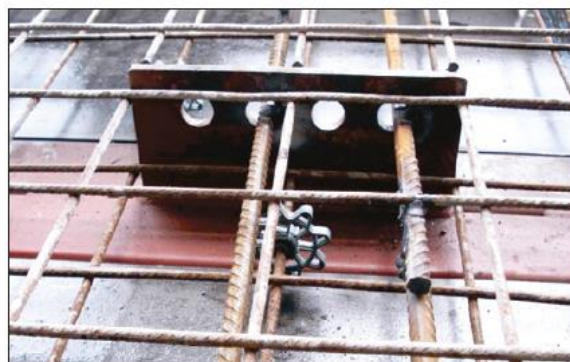


Figure 10. Proposed steel plate shear connector; Aguiar et al., [27]

3. Conclusion

From the reported research studies in this paper, the conclusions can be drawn as follows.

- I. The CFS demonstrated the potentials of been structurally feasible in both building and civil engineering constructions as proven by the research studies reported.
- II. That yes! CFS can be employed and utilized as a sustainable structural member in both building and civil engineering constructions as witnessed in the reported studies.
- III. It is therefore highly recommended that more research studies be conducted to showcase the hidden potentials of CFS as structurally viable.

Acknowledgements

The authors gratefully acknowledge the support provided by Kano University of Science and Technology (KUST), Wudil, Tertiary Education Trust Fund (Tetfund) Nigeria and UniversitiTeknologi Malaysia (UTM Vot Q.J130000.2522.18H02) for the support provided.

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