Full Paper

RESISTANCE OF BUILT-UP COLD-FORMED STEEL CHANNEL COLUMNS FILLED WITH CONCRETE

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Graphical abstract

Abstract

Cold-formed steel (CFS) channel infilled with concrete could increase its ability and stiffness by avoiding failure due to local buckling. Besides, the built-up bolted CFS channel column could serve as permanent formwork, decreased waste material and yet increase economical construction. This study aims to investigate the strength of built-up CFS channel columns infilled with concrete. Two CFS channel sections are situated face to face, connected and strengthen by using M10 bolts and nuts. Then, the 900 mm built-up column is filled with normal concrete of grade C30. Six samples with different end and central bolt spacing were tested. Material properties of CFS and concrete, and the mechanical properties of bolts are also investigated. From the result, the column with concrete on shortest end bolt spacing gave highest ultimate load and reported 68 – 78 % different when compared to similar column without concrete infilled. The failure mode of the column is global buckling and supports yielding, and the concrete is failed due to cracking and breaking. Equation of the relationship between bolt spacing either at the end or central and ultimate load is established.

Keywords: Built-up section, Cold-formed steel, Column, Concrete

1.0 INTRODUCTION

Cold-formed steel (CFS) and sometimes known as thin-walled structure is recognised in structural engineering as structural and non-structural material. CFS is made of steel coil and formed into various shapes by using the roller in ambient temperature. Nowadays, the utilisation of CFS is broad due to the material is thin, lightweight, termite resistance, corrosion resistance etc. Common designs standard e.g. Eurocode 3 and AISI are used for the stability and safety checking. The design standards do not provide a detailed reference for complicated CFS sections, such curved section and built-up section. Improvement and new ideas are reported by

researchers to provide the sufficient data on top of the existing design data.

The built-up section is established to produce the new section with high strength, symmetrical and stable when compared with one section. Generally, the built-up section is produced by using fasteners such as self-drilling, self-tapping screw, bolts and nuts, welding etc. Many researchers proposed new built-up section profiles and studied their behaviour in term of the beam and column [1 - 3]. Georgieva *et al.* [3] mentioned about the advantages of the built-up section in higher strength, symmetry, out-of-plane movement resistance and economic section, however practical design rules for strength is lacking. Current standard and design guide for CFS built-up

section is not sufficient; sometimes the mechanical properties of the built-up are merely the multiplication of two individual sections.

The built-up CFS section with concrete is a type of composite structure that could be used for higher load resistance structure. The composite section provides high strength and stiffness, and reduced construction time by eliminating the timber formwork [4 – 5]. The composite section is also capable to deduct the effects of imperfections and local buckling of cold-formed steel or built-up section. The built-up section on the outer surface of the concrete is effectively in tension and could resist bending moment of the structure [6]. Dabaon *et al.* [6] reported that the stiffness of composite section could be improved because of the location of the steel far from the centroid i.e. contribute higher moment inertia. Concrete in the built-up section is reacting as a core of the structure to sustain the compression load and delay or resist the local buckling of the steel in early stage [6]. So in the built-up CFS section filled with concrete is proving to be high strength, stiffness, ductile, durable and avoid the failure of the concrete.

To date, researchers have studied about the steel column filled with special concrete such as geoplymeric recycled concrete [7], concrete with crushed crystallized slag [5], fibre reinforced concrete [8], recycled aggregate concrete [9]. Other researchers are investigating the cold-formed steel filled with normal concrete [10 – 11]. This column is proposed in future as fire proofing structure material in buildings. Cold-formed steel is normally known as non-combustibility material that not contributed to fire spread quickly. The performance of concrete to protect fire damage is in a good way because the concrete ingredient such as cement and aggregates is classified as poor thermal conductivity. Lastly, both advantages of the fire improvement structure is recommended for further study on built-up bolted cold-formed steel channel column of fire or proposed a new cross-section of built-up cold-formed steel.

The main objective of the study is to investigate the force behaviour of the built-up bolted cold-formed steel column under axial load. In addition, the bolt spacing along the height of the column is analysed and the relationship with an ultimate load of the column is compared.

2.0 EXPERIMENTAL SPECIMEN PREPARATION

Cold-formed steel lipped channel as described in Table 1 was selected. The design grade of the CFSC is 450 MPa. CFSC was cut into 900 mm height and semi-rigid end connections of the column are proposed. CFSC was placed face to face and fastened by M10 bolt with distance 120 mm. The M10 bolt is not only reacted as a connector, but served as a medium to strengthen the bond between concrete and steel. Additionally, the bolt is organised to reduce possible brittle crack that normally occurs in concrete. Six samples with the different bolt arrangement was equipped and tested. The slenderness ratio of the columns was calculated and they are categorised as a short column. The bolt arrangement of the built-up bolted cold-formed steel channel column (BBCFSCC) is separated into two parts as shown Figure 1. The first part is represented as the end bolt spacing, 'e' that located at the end of the column on both sides. Second part is central bolt spacing, 'c' which situated at the centre point of the column. Selection is made by bolt arrangement to the distance, 'e' which is closest to the support, the long and medium distance, 'e' of the support, the distance, 'e' and 'c' with the same length and lastly the greatest distance of 'c'. The ultimate tensile load and stress of the bolt is 30240 N and 385.10 MPa that are taken from the experiment by using Universal Testing Machine (UTM). The overall pictures of the experimental testing were demonstrated in the Figure 2. There are two phases of the experimental testing, which covered material properties and mechanical properties.

Table 1 The description of CFSC section (all dimensions in mm)

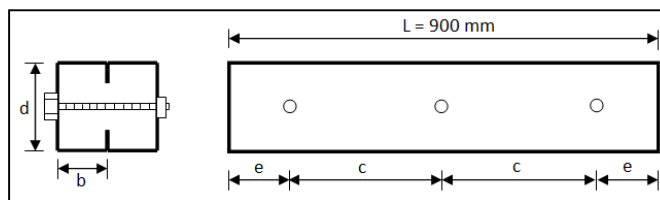| Web, *d*	Flange, *b*	Lipped, *l*	Thickness, *t*	Area, *A*	*b/t*	*d/t*	*d/b*	*L/d*
100.00	50.00	12.00	1.55	329.00	32.26	64.52	2.00	9.00

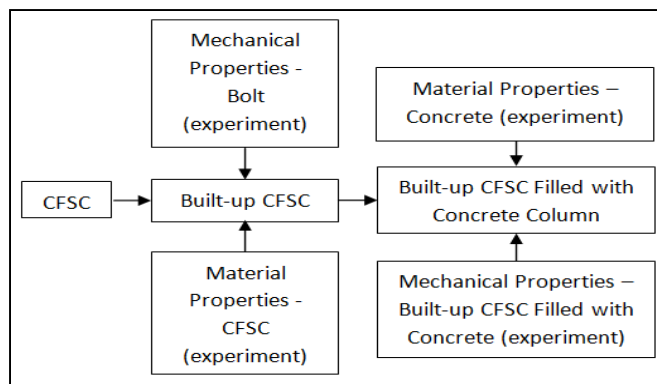**Figure 1** The distance arrangement of the bolts and nuts

Figure 2 The experimental work of the study

3.0 RESULT AND DISCUSSION

3.1 Material Properties of Cold-formed Steel

The CFSC steel was clean and cut into coupon tensile specimens that followed BS EN 10002-1:2001 [12]. The coupon tensile specimens were taken from the web and flange area of CFSC. Extensometer with 50 mm gauge length was situated at the mid span of the coupon tensile specimen, and the specimens were tested on Universal Testing Machine of 100 kN capacity. The results of the material properties are shown in Table 2. Predictably, the yield and ultimate stress of the flange was higher than of the web due to the bending and curving process. The percentage different of ultimate load and extension of the web and flange are 5.82 % and 17.82 %, respectively. The ratio of *fu/fy* and *fu/fyf* of the web was recorded 1.12 and 1.24, respectively; and the ratio of *fu/fy* and *fu/fyf* of the flange is 1.10 and 1.29.

Table 2 The result of the material properties of the CFSC

Sample	Ultimate Load (N)	*fu*, Ultimate Stress (MPa)	*fy*, Yield Stress (MPa)	*fyf*, Yield Stress Factory (MPa)	Modulus of Elasticity (MPa)	Extension on Ult. Load (mm)	*fu/fy*	*fu/fyf*
Web	10,024.79	557.01	497.55	450	207,407.29	5.975	1.12	1.24
Flange	10,643.25	581.47	527.68	450	210,023.57	4.910	1.10	1.29

3.2 Material Properties of Normal Concrete

Normal concrete was proposed by using mix design and calculated of 210 kg/m³ water, 403.85 kg/m³ cement, 686.34 kg/m³ sand and 1119.81 kg/m³ gravel.

The compressive strength of concrete cubes was tested at 3, 7, 28 and 60 days and summarized in Table 3. The results showed the concrete is compliance with quality of grade C30 because the average compressive strength at 28 days is 39.52 MPa.

Table 3 The average compressive strength of the concrete for age 3, 7, 28 and 60 days

Average Compressive Strength (MPa)			
3 days	7 days	28 days	60 days
28.07	34.21	39.52	43.52

3.3 Compression Test of Built-up Bolted CFSC Column

The result of compression test of the column without and with concrete was tabulated in Table 4 and Figure 3. The end spacing with shortest distance is reported to have the highest ultimate load and distance of end spacing produced the second lowest of ultimate load for column with concrete. This is because the end connection of the column with the smallest end spacing would eliminate the yield or initial failure at the end support. It showed that the percentage different for all samples between without and with concrete is in the range of 68 – 78 %. The percentage difference between the highest and lowest value of ultimate load for the column with concrete is approximately 39.13 %. From Figure 3, the initial stiffness of the BBCFSCC1 is the highest, i.e. 77,578.15 N/mm and the lowest value are presented by BBCFSCC2 of

35,433.23 N/mm. When the ratio *c/e* is in a precise value such as 21.50, 3.50 and 1.25, the ultimate load is reported to have higher ultimate load.

Figure 4 (a), (b) and (c) shows the experimental work and the failure of the column. All columns with concrete were failed due to local buckling. Ferhoune [5] has reported that the result of cold-formed steel welded tubes filled with special concrete column is observed having the local buckling. So that, the result that has local buckling is proven. From the figure, column with longer central bolt spacing i.e. in the range 350 to 430 mm failed at the middle of the column. The end bolt spacing with longer distance of range 100 to 225 mm failed due to excessive support yielding (Y) at the top and bottom ends of the column. From the figure also, the concrete with the long end bolt spacing showed that the concrete surface is broken and squashed out. This is due to the bolt can't protect the concrete bonding and existence inner stress of bolt can't transferred directly to the concrete.

By comparing the test samples without concrete with the result of Reyes and Guzman [13], percentage difference between them are 7.46 % for rigid and 2.79 % for flexible end connection. Reyes and Guzman [13] have tested the built-up column with the same dimension, thickness and height of the column but different of connection. The connection that be used in their testing is welded and central bolt spacing for whole column is 100 mm, and without end bolt spacing. For verification, the BBCFSCC1 is designed with Direct Strength Method (DSM) and recorded about 178,800 N resistances for rigid end support. The percentage difference between both methods is 29.94 % and ratio of P_{ult}/ P_{DSM} is 0.70. When verifying with the plastic compression resistance, $N_{pl, Rd}$ of 454,608 N in Eurocode 4 for rectangular or square section, the percentage difference with BBCFSCC 1c is 13.07 %. The ratio of P_{ult}/ P_{EC4} is 0.87.

Table 4 Result of the compression test for Built-up Bolted CFSC Column

Spacing		Ratio c/e	Sample without concrete	Ultimate Load (N)	Sample with concrete	Ultimate Load (N)	Percentage Different	Failure mode
e, End (mm)	c, Central (mm)							
20	430	21.50	BBCFSCC 1	125,260	BBCFSCC 1c	395,204	68.30	LB
50	400	8.00	BBCFSCC 2	66,150	BBCFSCC 2c	254,709	74.03	LB
100	350	3.50	BBCFSCC 3	75,370	BBCFSCC 3c	338,144	77.71	LB, Y
150	300	2.00	BBCFSCC 4	72,180	BBCFSCC 4c	240,559	69.99	LB, Y
200	250	1.25	BBCFSCC 5	78,560	BBCFSCC 5c	353,660	77.79	LB, Y
225	225	1.00	BBCFSCC 6	61,270	BBCFSCC 6c	253,068	75.79	LB, Y

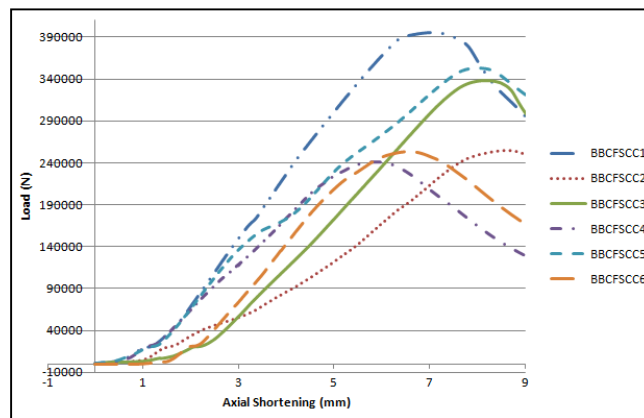Note: LB- local buckling and Y – yielding at support

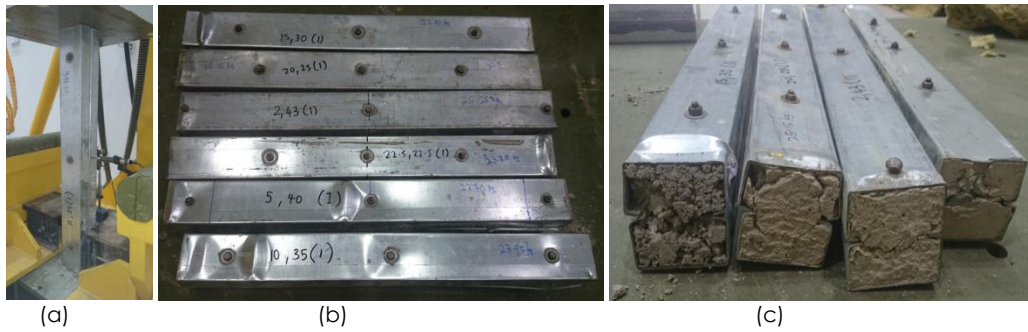**Figure 3** Load versus extension of the column

Figure 4 (a) Experimental work, (b) Failure of the overall of columns and (c) Failure occurred on concrete surface

The relationship between the end bolt spacing and ultimate load were matched to six-order polynomial line and showed the fine concurrence with the data as illustrated in Figure 5. The equation of the relation line can be determined by using Eq. 1 for a range between 20 - 225 mm. This important to note as the reference for built-up CFSC section for design purpose.
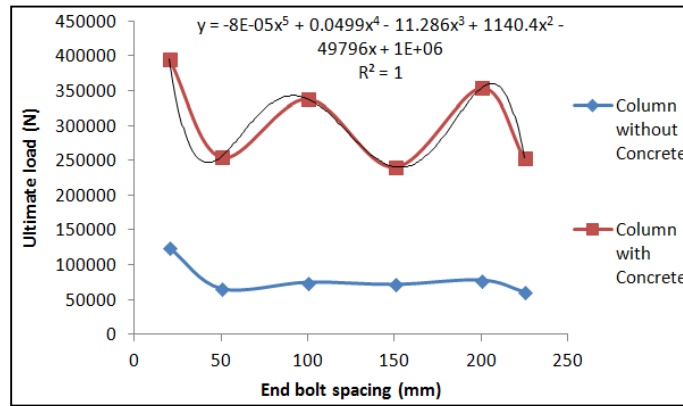

Figure 5 The relationship line between the ultimate load and end bolt spacing

$$20 \text{ mm} < x < 225 \text{ mm}$$
$$P_{ult} = -8E\text{-}05e^5 + 0.0499e^4 - 11.286e^3 + 1140.4e^2 - 49796e + 1E\text{+}06 \tag{1}$$

Where; P_{ult} is an ultimate load of the Built-up Bolted CFSC Column in kN and
e is an end bolt spacing in mm

In addition, the relationship between the Ultimate load and central bolt spacing were also suited to six-order polynomial curve line. It showed the smooth agreement with the data and shown in Figure 6. The important relationship between both these variables are established in Eq. 2 for the range 225 – 430 mm.
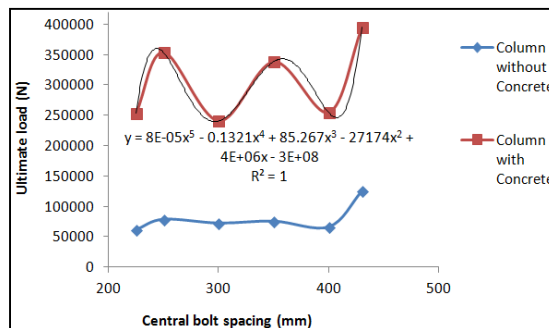

Figure 6 The variation of ultimate load to the central bolt spacing

$$225 < x < 430$$
$$P_{ult} = -8\text{E-}05c^5 - 0.1321c^4 + 85.267c^3 - 27174c^2 + 4\text{E+}06c - 3\text{E+}08 \quad (2)$$

Where; P_{ult} is an ultimate load of the Built-up Bolted CFSC Column in kN and
c is a central bolt spacing in mm

These two equations are important to be a design guide in determining the ultimate load of the built-up bolted CFSC column. End and central bolt spacing that covered in the study also could be an influenced the strength of concrete and the good bonding between concrete and steel.

4.0 CONCLUSION

Built-up cold-formed steel channel column with infilled concrete not only eliminate, the needs of timber formwork during construction, but also provide higher load resistance which lead to cost savings in material usage and waste management. From the experimental work and result, the column with concrete achieved the higher ultimate load when compared with column without concrete. Concrete showed the role of compression load resistance by sharing the load with cold-formed steel that normally weak on local buckling and distortional buckling on the early stage. The percentage difference between the columns without concrete that failed due to local and distortional buckling and the column with concrete is about 63.80 %. Distortional buckling failure does not exist in the concrete infilled CFS built-up columns.

The relationship between the arrangements of the bolt at either end or central spacing is important to establish an ideal performance of the column with concrete. End bolt spacing with short spacing gave higher ultimate load resistance. Whereas, the central bolt spacing is not affected directly and significantly in performing the ultimate load value because the failure of the column occurred near to support or yielding failure. Two equations are produced as a reference in design purpose. Suggestion for future work;
1) Slender columns instead of short column.
2) Effect of different built-up configurations, connectors and grade of concrete or steel.
3) Performance in fire.

Acknowledgement

Reference

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