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Behaviour of Axially Loaded Cold-Formed Steel Built-Up Stub Columns

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Abstract

This paper aims to study the behaviour of axially loaded innovative cold-formed steel (CFS) built-up stub columns. Four innovative CFS built up sections is presented in this paper. Each section is composed of combination of more than two elements as follows: channels, channels with lip, Sigma section and /or plates. The elements of each section are assembled together by using self tapping screws. The axial load capacity of each of the four sections was investigated numerically by using finite element (FE) model using ABAQUS program. The FE model was verified against previous test data. The FE model was used to study different parameters that affect the load capacities of the innovative CFS built-up stub columns, these parameters are: columns profile, steel thickness, steel grade and longitudinal spacing between screws (fasteners), cross sectional area.

Keywords: Cold-formed steel, Built-up stub columns, Axial load capacity.

1. INTRODUCTION

Cold-formed steel (CFS) sections have been increasingly used nowadays in different building construction, such as trusses members, floor joists and wall studs (Zhang and Young 2012), this is owing to the advantages of the CFS section that overcome the rolled sections which is mainly increasing the strength to weight ratio.

Other advantages of the CFS section are: easy construction and flexibility in fabrication, different shapes in cross section that suits different purposes (Z-section C-section Hat-section and ∑- section). Also from the reasons for increasing the use of CFS section are: improved rolling and forming technology, improved connection technology as using blind rivets and self-drilling, self-tapping screws (Davies 2000; Faridmehr et al. 2016).

It was stated that residential and low rise building made of cold formed steel was about 75 000 in 1994 in USA this number increased by five time in 2002 (Davies 2000). Nowadays, there are efforts and researches are being done to use cold formed steel section with larger spans and higher loads (Meza et al. 2015). Analytical study was presented by Dundu (2011) showing an analytical study for using CFS section in a portal frames with span of 12 m and a spacing of 4.5 m.

Using CFS built up section is one of the effective ways to meet the current demand of using cold-formed section. Previously, many researcher study the behaviour of CFS built up section made up of two element, mainly two C-channels back to back or face to face (Dobric et al. 2015; Faridmehr et al. 2016; Lau and Ting 2009; Whittle and Ramseyer 2009; Zhang and Young 2012) with no spacing between the two elements.

However limited researches are available on CFS built up section formed of more than two elements. Meza et al. (2015) presented an experimental investigation of CFS built up stub columns. The research focused mainly on studying the effect of the connector spacing on the behaviour of the built up columns and it was concluded that the connectors spacing has more significant effect on the column behaviour than on the ultimate load capacity. Bujňák et al. (2012) present a stud on the axial capacity of 4 CFS built up columns, the study shows the substantial increase in load capacity compared to other cold formed members.

This paper aims to cover the gap in the field of studying the behaviour of CFS build up section especially, those composed of more than two elements. Four innovative CFS built up stub columns is presented in this paper (0e of these section was presented by Meza et al. (2015). The axial load capacity of the four columns was investigated through numerical and analytical study. It should be mentioned that in this study, axial load capacity refer to the ultimate load capacity of the column where the column can no longer sustain any more load.

The numerical study was carried out by using FE model, which was verified against the test result obtained by Meza et al. (2015). It was very important to develop a FE model as there is a lack of research that provide an accurate FE model for CFS built-up stub columns. The FE model was built using ABAQUS (ABAQUS 2012) FE program. The verified FE model was used to study different parameter that affect the load capacities of the innovative CFS built-up stub columns, these parameters are: columns profile, steel thickness, steel grade, longitudinal spacing between screws (fasteners) and cross sectional area.

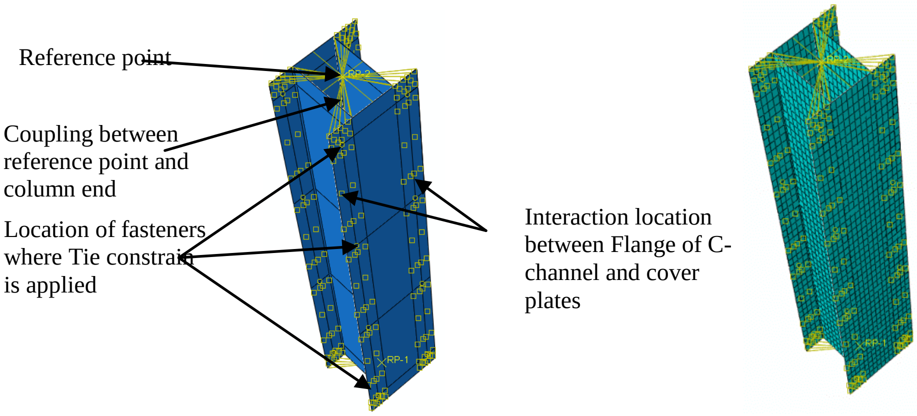
2. FINITE ELEMENT MODEL

It was very important to develop a simplified FE that predicts the axial load capacity of the CFS built-up stub columns, in order to use this model in the parametric study. This section gives a detailed description for the FE model that is developed in this paper.

2.1. Description

The FE model was developed using ABAQUS (ABAQUS 2012) general FE modelling programme. All the CFS built-up section elements are modelled using general-purpose 4 nodded shell elements (S4R) which was chosen from the ABAQUS program library. Fixed end boundary condition was applied to the columns end though two reference point located at the column ends. Each of these reference points is coupled with the adjacent column end as indicated in Figure1. Maximum size of 12 mm was used in meshing with maximum aspect ratio of 2.

The surface-to-surface contact in ABAQUS (ABAQUS 2012) was adopted to simulate the interaction between the CFS element that are composing the built up section. Hard contact in the normal direction and Coulomb friction in the tangential directions were defined in the surface-to-surface contact. Tie constraint was used at the location of fastener that are connecting CFS element together. Full details on the FE model can be found in Ghannam (2017).



(a) Interaction and boundary conditions (b) Meshing

Figure 1. FE model adopted in this study

2.2. Verification of the FE model

The simplified FE model was verified against the test result performed by Meza et al. (2015). Brief details about the test performed by Meza et al. (2015), is introduced in this paragraph. The test program study the axial load capacity of two column profile of CFS built-up stub columns. Three stiffeners spacing were used in each column profile, each test was replicated twice, making a total number of twelve tested columns. The columns profile are indicated in Figure 2, test specimens matrix are shown in Table 1, it should be noted that Table 1 shows the details of specimens with no replication, that is why six columns are only shown in the table, these columns will be used for verifying the FE model. In Table 1, L is the columns length C-1 and C-2 is C-Channel no1 and C-channel no. 2 respectively as indicated in Figure 2, a is the longitudinal fastener spacing, it should be noted that the first fastener in all column is located at 50 mm from the columns end. $P_{U,Test}$ is the ultimate load obtained from the test (Meza et al. 2015) and $P_{U,FE}$ is the ultimate load obtained from the FE model developed by this study.

Figure3 shows a comparison between the load displacement curve of the test results and the FE model, and the Last column in Table 1 shows the ratio between ultimate test load ($P_{U,Test}$) and the ultimate load obtained from the FE model ($P_{U,FE}$). It can be observed that there is a good agreement between the test and the FE model up to the ultimate load. However, there is a difference between the test and the FE model at the failure zone, this can be explained due to the lack of data about the initial imperfection of each column, Meza et al. (2015) provide only the value of maximum and minimum value of imperfection which range from 0.1 and 0.69 for different CFS elements. Another reason, is the lack of information about the residual stress which was not provided by Meza et al. (2015) and was ignored in the FE model.

Figure4 shows a comparison between the failure modes in the test and the failure mode obtained by the FE model, good agreement can be observed between the test results and the FE model. As this study is concerned about the ultimate load value, this simplified FE model is considered to have a good agreement with the test result. If the full behavior of the column (pre and post ultimate stage) is under interest, initial imperfection, residual stresses and corner enhancement should be included in the FE model.

Table 1. Details of the test specimens (Meza et al. 2015) and results comparison.

Column	L (mm)	C-1, Web (mm)	C-1, Flange (mm)	Plate-width (mm)	C-2, Web (mm)	C-2, Flange (mm)	a (mm)	$P_{U,Test}$ (KN)	$P_{U,FE}$ (KN)	$P_{U,Test}/P_{U,Test}$
SC1-2	1100	154.12	53.75	199.78	-	-	333	183.97	180.75	1.02
SC1-3	1100	154.16	53.71	199.4	-	-	250	183.01	188.49	0.97
SC1-5	1100	154.17	53.62	199.79	-	-	167	201.72	225.45	0.89
SC2-2	800	154.09	53.38	-	79.00	36.28	233	213.32	240.88	0.89
SC2-4	800	154.04	53.44	-	79.17	36.45	140	238	245.89	0.97
SC2-6	800	154.24	53.73	-	79.05	36.26	100	232.62	263.71	0.88

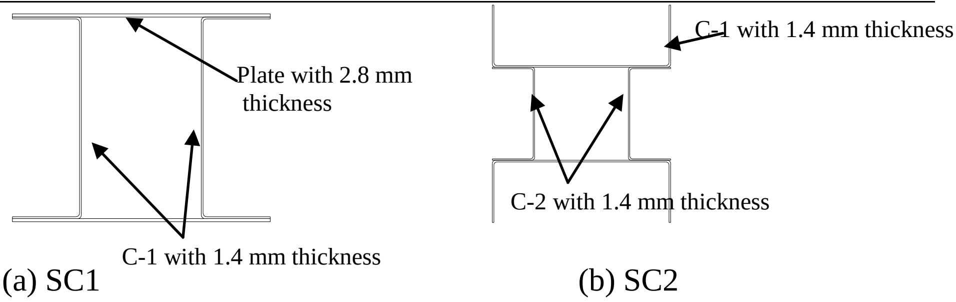


Figure 2. Columns profile used by Meza et al. (2015)

3. PARAMETRIC STUDIES OF COLD-FORMED STEEL (CFS) STUB COLUMNS

Parametric studies on axial load capacities were conducted for four columns profiles of cold-formed steel (CFS) built-up stub columns using the verified FE model as discussed in the previous section. Investigated parameters include, cross section profile (one profile were used as in Meza et al. (2015)

and another 3 innovate profiles), steel yielding strength (f_y) (240, 280 and 360 MPa as per ECP-205 (2008)), thickness of CFS section (t), vertical spacing between fasteners (a), cross sectional area (A). Table 2 gives details for each of the four Profiles. Figure5 presents a schematic diagram for each profile that was used in the parametric studies. It should be mentioned that, five cross sections (S1, S2, S3, S4 and S5) were used in each profile. Each cross section has equal area in the four profiles as indicated in Table 2. For instance, the cross sectional area of S1 = 5612 mm^2 , this cross section area is nearly the same in Profile: 1, 2 3 and 4.

Table 2. Different profiles and sections used in this study.

		Profile 1		**Profile 2**		**Profile 3**		**Profile 4**	
		Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Cross section	**S1**	C400x100x2.5	Pl 530x2.5	Σ 300x90x2.5	C360x100x2.5	C 400x100x2.5	Pl 530x2.5	C300x100x2.5	C360x100x2.5
	S2	C 400x100x4	Pl 520x4	Σ 300x90x4	C 360x100x4	C 400x100x4	Pl 520x4	C 300x100x4	C 360x100x4
	S3	C400x100x1.5	Pl 540x1.5	Σ 300x90x1.5	C360x100x1.5	C 400x100x1.5	Pl 540x1.5	C300x100x1.5	C360x100x1.5
	S4	C270x100x2.5	Pl 510x2.5	Σ 200x65x2.5	C360x100x2.5	C 270x100x2.5	Pl 510x2.5	C 200x71x2.5	C360x100x2.5
	S5	C400x100x2.5	Pl 380x2.5	Σ300x90x2.5	C 250x80x2.5	C400x100x2.5	Pl 380x2.5	C300x100x2.5	C 250x80x2.5

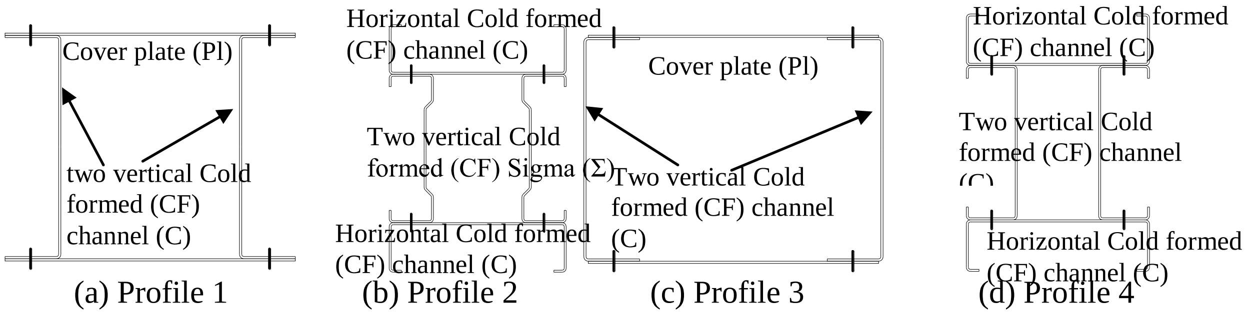


Figure 3. Four Different profiles used in the parametric study.

Different parameters that were used in this study are indicated in Table 3. Steel yielding strength (f_y) was used as in ECP-205 (2008) (240, 280 and 360 MPa). Three values of thicknesses were used; 1.5, 2.5 and 4 mm. Four different value of cross sectional areas were used in each profile as indicated in Table 2 and Table 3. It should be mentioned that sections S4 and S5 has the same cross sectional area but they are different in the value of the moment of inertia (I).

Five values of vertical spacing between the fasteners connecting different element of CFS built up stub columns were used. The locations of the spacing in the horizontal cross section in each profile are shown in Figure5. The value of spacing were chosen for different profiles such that two of the spacing are within the limits that is proposed by AISI-S100 (2007) in the section D1.3 and the other three spacing are outside this limit.

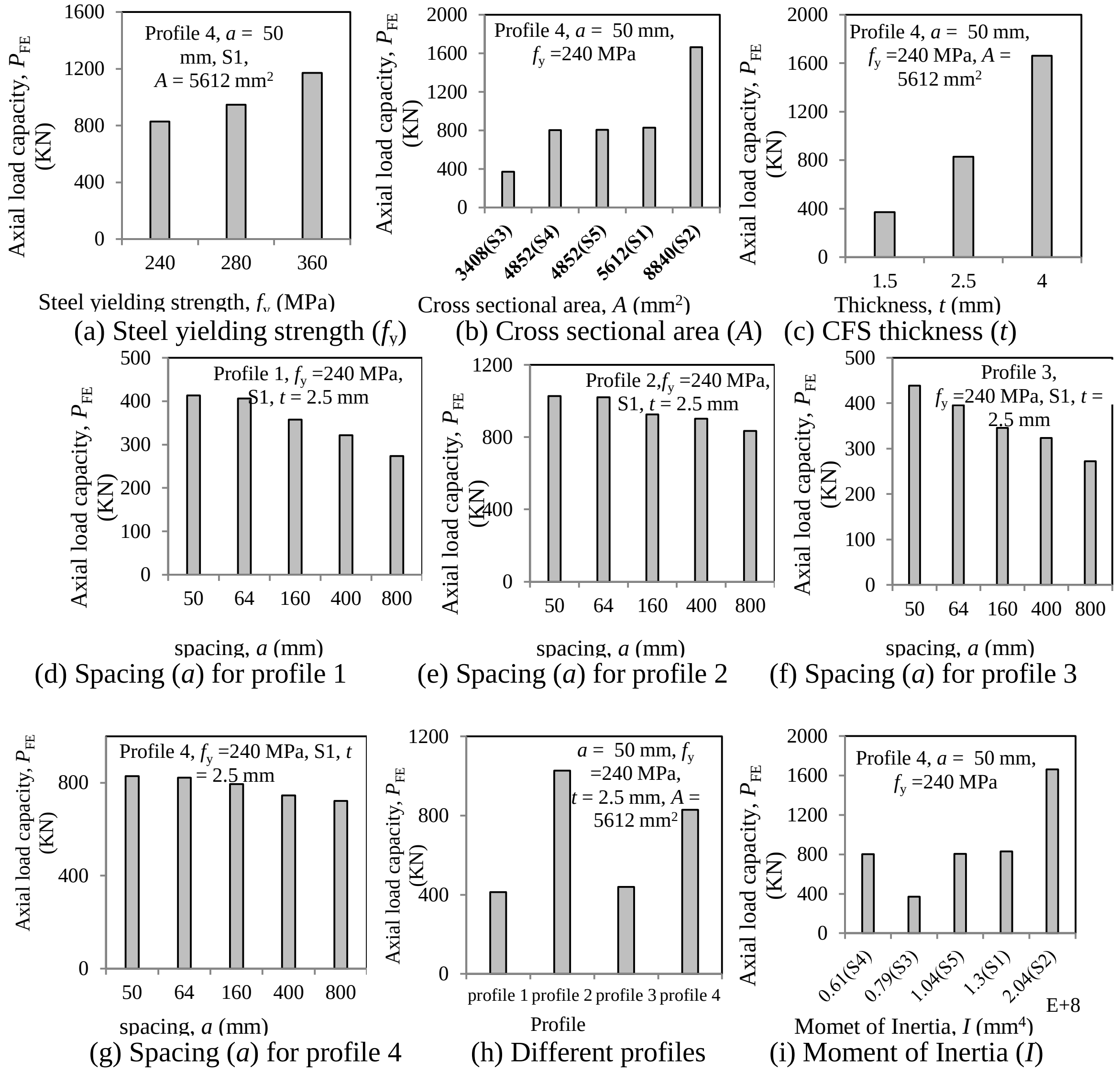
The influences of different parameters on the axial capacity (P_{FE}) of CFS stub columns which was calculated by using the verified FE model are presented in Figure6. As expected it was found that the axial capacity is directly proportional to steel yielding strength (f_y), CFS thickness (t) and the cross sectional area of different profiles.

By comparing the axial load capacity of section 4 and section 5 from different profiles which have the same cross section area but different in there moment of inertia, it was found that both sections give close result to each other, which shows that moment of inertia is not effective for the axial load capacity of stub columns, this is indicated in Figure6(b). This conclusion is verified in Fig.6(i) which shows moment of inertia's effect on the ultimate load capacity. No clear trend can be observed in this Fig.6(i). The main failure mode for stub columns is local buckling failure which depend on the plate slenderness (width to thickness ratio) as indicated in Figure4, for that reason, moment of inertia has no significant effect on the column's load capacity. Moment of Inertia might have a significant effect on the load capacity of the slender columns where the columns may fail due to one or combination of the following failure modes: local, distortional and flexural buckling mode

It can be noted from Figure6 (d, e, f and g), that increasing spacing between fastener decreases the Axial load capacity of the CFS built-up stub columns as a result of increasing the buckling of the individual elements forming up the built up section. Using the spacing within the limits proposed by AISI-S100 (2007) produce no reduction in the axial load capacity. Axial load capacity begin to decrease after increasing the spacing over the value proposed by AISI-S100 (2007) as indicated in Figure6 (d, e, f and g).

The effect of increasing the spacing is more pronouncing in profile 1 and 3 than profile 2 and 4 as indicated in Figure6 (d, e, f and g). This is as a result of using cover plate in profile 1 and 3 which has lower stiffness in x-direction compared to the horizontal C channels used in profile 2 and 4.

Figure6 (h) shows that profile 2 give the highest axial load capacity, followed by profile 4. Profile 1 and 3 give similar values of axial load capacity. This can be explained as profile 2 contains Σ section which has more stiffness compared to the C channel as the web of the Σ section is stiffened and the C channel web is not stiffened. Profile 4 gives higher axial load capacity compared to profile 1 and 3 because the flange of the C channel in profile 4 is stiffened with vertical lipped stiffener and the flange of the C channel in profile 1 and 3 is not stiffened.



(a) Steel yielding strength (f_y) (b) Cross sectional area (A) (c) CFS thickness (t)

(d) Spacing (a) for profile 1 (e) Spacing (a) for profile 2 (f) Spacing (a) for profile 3

(g) Spacing (a) for profile 4 (h) Different profiles (i) Moment of Inertia (I)

Figure 4. Effect of different parameters on CFS built-up stub columns.

4. CONCLUSIONS

In this paper, 4 innovative profile of CFS built-up stub columns (one of them is presented by Meza et al. (2015)) was presented and studied using verified FE model. Detailed parametric study have been carried out on the new profiles based on the axial load capacity of each column profile. Conclusions that are derived from this study are listed below:

1) Axial Load capacity is directly proportional to steel yielding strength (f_y), CFS thickness (t) and the cross sectional area of different profiles. Axial load capacity is inversely proportional with the vertical spacing between fasteners; this effect is more significant with section profiles which contain cover plates (eg. profile 1 and 3).
2) Axial load capacity of stub columns is greatly affected by the stiffened element within the cross section, increasing the stiffeners through the web and the flange increase significantly the axial load capacity.
3) From the profiles presented in this study, profile 2 gives the highest load capacity as the web and flange are both stiffened.
4) CFS built up stub columns can carry axial load more than 2000 KN based on the thickness and the steel type (as in profile 2), this conclusion gives encouragement to expand the use of CFS section in more structures type other than light loaded structure only.

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