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ULTIMATE LOAD OF BUILT-UP COLD FORMED STEEL COLUMN

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ABSTRACT

Cold formed steel (CFS) has been used as the primary structure for flexural and compression member due to varieties of advantages such as high strength to weight ratio, high corrosion resistance, and ease of fabrication. The criteria need to be considered in improving the structural strength is the fabrication method. Fast and easy fabrication can produce an efficient structure. Built-up of normal CFS into new member with higher strength can be produced efficiently by attaching the normal steel using self-drilling screw. CFS channel with constant size has been used to produce built-up, back to back (BTB), and box-up (BU) with varieties of length. The constant spacing were used at 400 mm centre to centre along its length and supported by using an angle plate that screw through its web. 18 nos of columns were tested for compression until the column cannot resist any increment of load. The ultimate loads were compared to the predicted buckling load using EC3-1-3. The prediction of column capacity is based on flexural buckling and torsional buckling failure. BTB column results in higher load except for 2.5 m length, while the differences of experimental load are up to 24 % to the experimental. Meanwhile, BU results in higher load for all columns with differences up to 80 % compared to the code and the code is considered too conservative for this column type.

Keywords: cold formed steel, built-up column, buckling strength, back to back column, box-up column.

INTRODUCTION

Built-up CFS is usually a composition of normal CFS - C, Z, □, or hat section to produce a new section. The section is connected by using bolt, screw, or weld. Figure-1 shows a typical built-up section CFS used for compression member and tension member. The built-up section has been used based on their excellent structural behavior. It is widely used as trusses member or space frames. In modern construction, the usage of CFS columns in frame structure has been applied in residential construction for building up to double story. There are many advantages of built-up section. The advantages can be classified into two categories. One is the production and handling such as ease of production. The standard shape - C, Z is fastened by a bolt, screw, or weld to produce new shapes without built special production method. Erection of CFS structure can be faster without heavy lifting equipment that suitable up to two-storey or emergency house. Two is strength and stability. Built-up section can simply gain higher stability and capacity due to double of standard section produce greater cross-section properties, the symmetry of built-up section can eliminate the eccentricity between the shear and the gravity centre of single section consequently eliminate certain buckling effects i.e. distorsional buckling and out of plain movement. The closed box sections allow spanning greater distances between supports and carrying heavier loads than single C-sections [13].

According to research conducted by Reference [2], the BTB is used for strengthening external frame columns while BU is used to support long beam and for a double storey house as shown in Figure-3. The study of built-up CFS has been done in various connection method either by bolt, screw, and welds. Reference [16] has modelled the bolts and the built-up I-shaped section while Reference [14] has tested the built-up I section stud connected using two self-drilling screws spaced at a set of interval. Reference [15] has tested two C10016 lipped channel compression member connected back-to-back using self-drilling screws. Reference [9] determines the compressive capacity of cold-formed steel built-up I sections with pin-ended using the finite element method (FEM) with various screws spacing along the column length i.e. 750 mm, 1000 mm, 1500 mm. Reference [7] has conducted FE model using Ansys for built-up compression members with screw at different spacing. Reference [1] has implemented a point welding to connect the two separate lipped channels for the compression test. Reference [10] has tested built-up box section size 100 mm depth, and modelling of built up I section also made from size 100 mm depth.

a) Close built-up section

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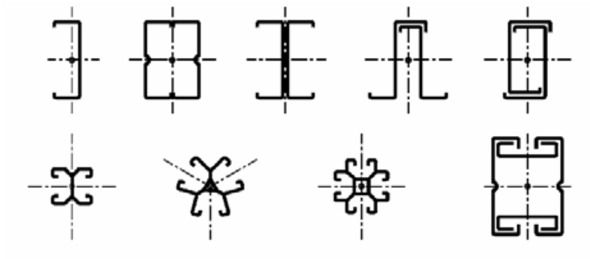

b) Open built up section

Figure-1. A typical type of built-up compression and tension member [4].

Reference [2] has done a test on the box-up compression member connected by using self-drilling screw at the flange; the size was 150 mm and 200 mm depth. Reference [18] has done a compression test on built-up closed sections with intermediate stiffeners connected using self-tapping screws also at the flange. Reference [12] has concluded that as the spacing of connectors higher the buckling strength is reduced. Reference [11] has tested the box-up member connected with self-drilling screw made by channel with smaller size 100 mm depth. Meanwhile, Reference [17] was formed a box section by using welded at a thickness of 4.76 mm. The weld is connected at the top and bottom of the section with 50.8 mm long welds and at intermediate locations along the member with 25.4 mm long welds. Reference [13] has using seam welds with different weld spacing to form a box-up member. Reference [8] was tested on built-up and box up member connected by stitch welding.

Reference [5] addressed that EN1993-1-3:2006 are providing a design recommendation for single section only, the longitudinal slip within built up member does not available. Built-up solutions are adopted in practice, regardless of the lack of design rules to predict the member strength [5]. Some of requirement in designing such member is addressed in other code such as in Section D1.2 and C4.5 of the American Iron and Steel Institute (AISI) 2007, "Technical specification for low-rise cold-formed thin-walled steel buildings" (JGJ227-2011), Chinese current code 'Technical Code of Cold-formed Thin-Walled steel structures' (GB50018- 2002), AISC-ASD Specification, and AISC-LRFD Specification. The utilizing of CFS as a column in a building is significant as the built-up column may have variety advantages over normal CFS. The investigation of the built-up column capacity has been required for the standard only available for single section only. Hence, the main purpose of the study is to validate the built-up CFS column to the current design standard EC3-1-3 that wisely use in Malaysia. The objective of the study is to determine the ultimate load of single channel and the built-up column with constant screws spacing along the column length, various lengths, and constant size and compared to buckling load prediction using EC3-1-3.

MATERIALS AND METHODS

Sample Preparation

The CFS is bought from Kemuning Structures (M) Sdn. Bhd. The section is known as KS20020C. The size as shows in Figure-2 and the dimension as tabulated in Table-1.

Table-1. Cross section properties of CFS.

Flange, F	73 mm
Depth, D	200 mm
Lip, L	17 mm
Thickness, t	1.9 mm
Centroid, x	20.379 mm

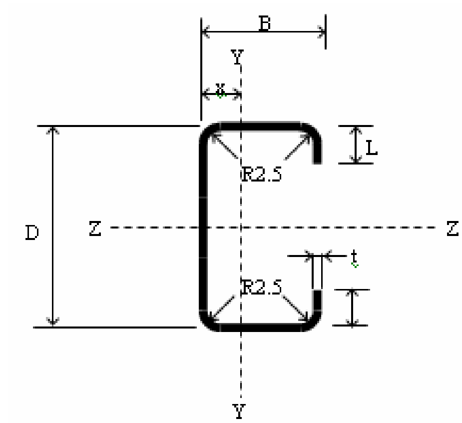

Figure-2. Dimension of CFS.

The tensile coupons test according to BS EN 10002-1:2001 was conducted. The sample was taken from the flanges denoted as samples B and C, and web denoted as sample A. It was cut from CFS in parallel direction of its length. The results of tensile testing of CFS material are in Table-2. It is confirmed that the sample is G450 as the sample A reach maximum stress of 467 MPa.

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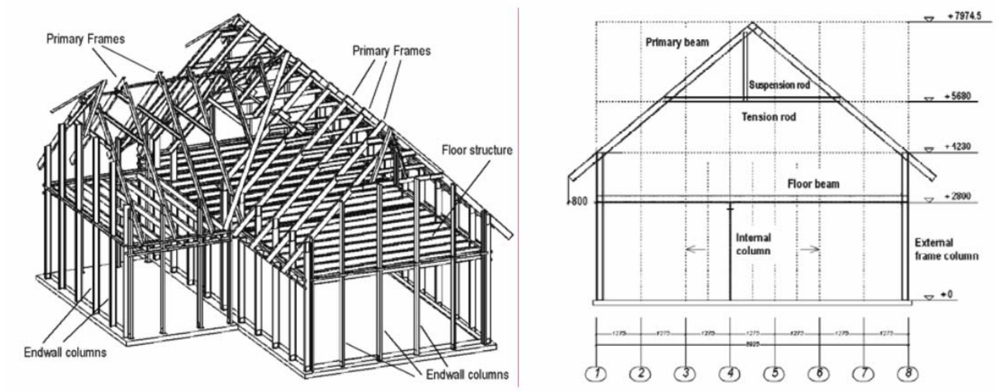

Figure-3. Residential house building frame [2].

Table-2. Material properties of CFS.

Properties	Sample A	Sample B	Sample C
Elastic modulus, E (GPa)	209.257	199.435	233.933
Yield stress (0.2%) (MPa)	403.805	567.504	536.9
% Strain at 0.2% yield	0.4285	0.4615	0.442
Maximum stress (MPa)	467.315	642.345	603.403
% Strain at stress maximum	8.191	8.9585	7.2715

The CFS column is cut into six desire lengths. Single C is tested to get its ultimate strength. The CFS is built-up into two types. The first type is the channel is connected on the web known as back to back (BTB) and the second type is connected at the flange known as box-up (BU). The connection is made with self-drilling screw of 5 mm in diameter bought from Central Bolt and Nut (CBN) Johor Bahru. This connection method is chosen because of the joint is simple without drilling any hole and effective for CFS. The position of the screw at the section is shown in Figure-4. The screw spacing is constant along the length of the column at 400 mm centre to centre (c-c).

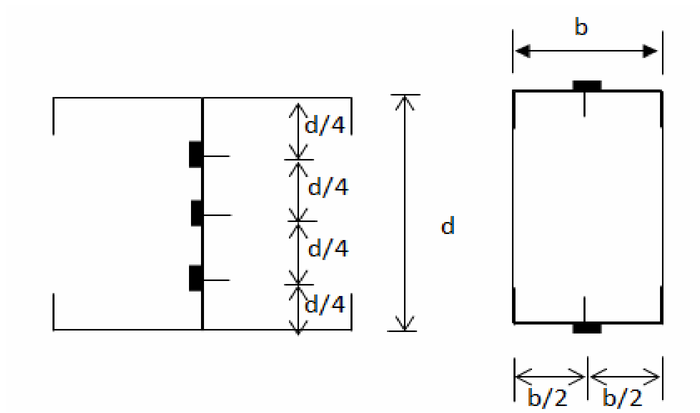

Figure-4. BTB and BU screw position on the column section.

Experimental Setup

The fastener at supports for all columns is by using self-drilling screw. The bolt was not practical for CFS because the thickness of steel is thin, the large hole for bolt may cause the steel tearing due to the high concentrated force of the bolt. The column end was attached to an angle plate using self-drilled screw as shown in Figure-5. This method has been used by Reference [2] on the cold formed steel column. The angle plate is effective to eliminate local buckling failure by thicker the web thickness at the column at the end. The CFS and angle plate were sat on the level plate where the load cell was located. The end level plate was braced laterally at the position of load applied. Loading was applied to the column using hydraulic jack and 500 kN load cell that aligned to the column length. The specimen was cantered

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in the test rig and was aligned using bubble level to ensure that the applied load is axial. The low voltage displacement transducer (LVDT) is placed at middle height of the web and flange specimen, quarter height of the web and on the bottom plate for the axial deformation of the specimen.

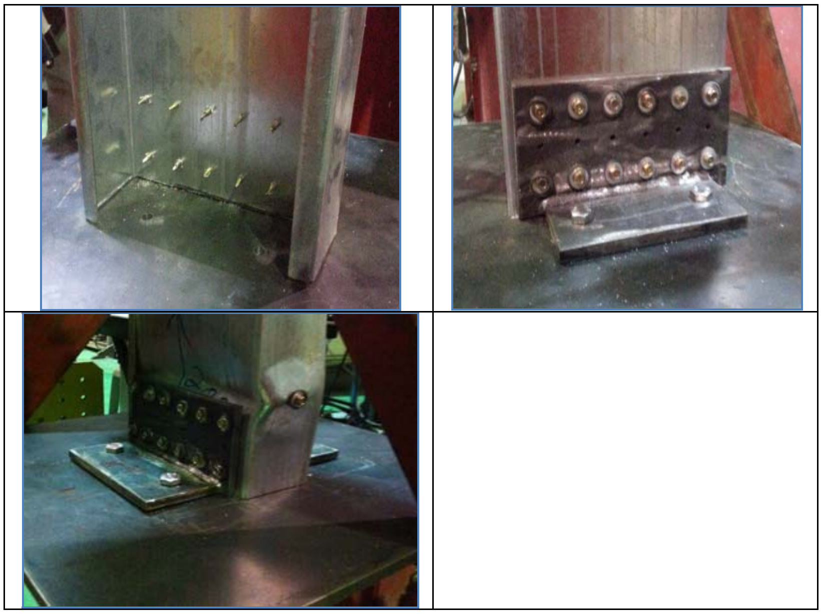

Figure-5. Simple support of self-drill screw through the plate to the web at both column ends.

RESULTS AND DISCUSSIONS

The ultimate load is determined when the column load was dropped. The experiment is divided into three types, C, BTB, and BU. The length of the column was determining the slenderness ratio of the column. The slenderness ratio accounts the geometric of column according to its effective length and its cross-section properties. The design of single channel CFS columns in EC3-1-3 is based on the effective area using effective width method (EWM). The mid-line method is applied to determine the effective width of the flanges, lips, and web of the channel. Hence, using the effective area, the various buckling strength is determined, i.e. flexural buckling, torsional buckling and flexural torsional buckling. In this paper, the safety factors were not included in calculating the buckling strength. The flexural and torsional buckling failures were used for discussion. The theoretical load is selected based on lowest value among these two buckling failures. Two considerations are used in calculating the BTB and BU capacity. First, the CFS is designed as I-section of BTB and box section for BU. Second, both BTB and BU is designed as double of single channel capacity. This consideration is adopted based on [2]. Table-3, Table-4, and Table-5 were tabulated the experimental results and theoretical value of buckling strength of single and built-up column predicted from EC3-1-3. Calculation shows that the I-section and box section yield higher value compared to double of single channel value in term of its buckling capacity.

Generally, as the column lengths were increased the ultimate load was decreasing as expected. However the reality column did not fail in linear relation to its slenderness. Various factors could affect the column strength, such as imperfection in length and imperfection in cross-section of the CFS column. The results of single C are close to the prediction of EC3-1-3 up to 40% difference. The higher differences are found at the intermediate slenderness for length 2000 mm and 2500 mm. BTB section results in 20 % difference compared to the EC3-1-3 prediction. 2.5 m and 3 m length of BTB results in lower ultimate load compared to buckling design load when design as I-section and considered unsafe. Meanwhile, the BU column has resulted in the highest differences in EC3-1-3 prediction up to 80 % difference for 2500 mm length. 3m length of BU results in lower ultimate load compared to buckling design load when design as box section and considered as unsafe. Further analysis of box-up is needed for such columns are not covered yet in the code. The BU columns are observed fail due to yielding of cross-section at a certain point along the column; the experimental load of BU column was higher as it has approached to its compression capacity. The differences in results may be due to the failure of column is not governed by this two buckling mode, especially for intermediate slenderness ratio for all column types. The distribution of column strength verses its slenderness are demonstrated in the Figure-6. The reality column tests are very important to check whether the designs are reliable, safe to be used for the CFS built-up section. The assessment of long column, i.e. 2.5 m and 3.0 m length of both BTB and BU need further investigation by using finite element simulation.

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The ratio of single to built-up column are greater than 2 were observed for all columns except for 2 m length of BTB, 2 m, and 2.5 m length of BU as tabulated in Table-6. The short column fails due to yielding of cross section, hence is can achieve full effective cross-sectional strength and effective to act as built-up column. The short column capacity can be predicted as doubling of single capacity; however, it will be slightly overdesign. Meanwhile, long column, are fail due to varieties of buckling cause the built-up column difficult to attain its full cross-sectional strength.

Table-3. Single column load.

Length (mm)	Maximum load (kN)	Single C Nb, Rd	Experiment/theory
600	127.5	129.28	0.986
1000	124.75	121.30	1.028
1400	100	112.0155	0.893
2000	139.6	94.40	1.479
2500	109.5	77.68	1.409
3000	64.52	62.33	1.035

Table-4. Back-to-back (BTB) column load.

Length (mm)	Maximum load (kN)	I-section Nb,Rd (kN)	Single Nb, Rd X 2 (kN)	Exp/ Theo I-section	Exp/ Theo (single x 2)
600	305.6	262.66	258.57	1.16	1.18
1000	294.0	250.58	242.61	1.17	1.21
1400	239.1	237.16	224.03	1.01	1.07
2000	234.4	213.36	188.81	1.10	1.24
2500	149.5	189.70	155.37	0.79	0.96
3000	150.6	164.30	124.67	0.92	1.21

Table-5. Box-up (BU) column load.

Length (mm)	Maximum load (kN)	Box section Nb, Rd (kN)	Single Nb, Rd X 2(kN)	Exp/ Theo Box-section	Exp/Theo (single x 2)
600	300.1	263.28	258.54	1.140	1.16
1000	290.8	251.07	242.61	1.158	1.20
1400	298.9	237.76	224.03	1.257	1.33
2000	279.0	213.81	188.81	1.305	1.48
2500	281.1	189.34	155.37	1.485	1.81
3000	150.4	162.34	124.67	0.926	1.21

Table-6. The ratio of single to built-up column.

Length (mm)	Single C Ultimate load (kN)	BU Ultimate load (kN)	Ratio BTB/single	BTB Ultimate load (kN)	Ratio BU/single
600	127.5	300.1	2.40	305.6	2.39
1000	124.75	290.8	2.33	294.0	2.35
1400	100.0	209.3	2.093	239.1	2.39
2000	139.6	279.0	1.99	234.4	1.67
2500	109.5	281.1	2.56	149.5	1.36
3000	64.52	150.4	2.33	150.4	2.33

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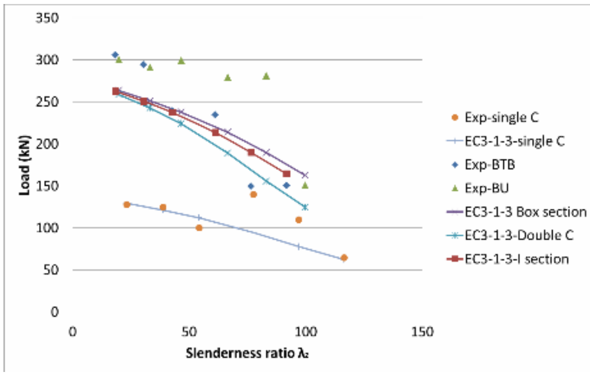

Figure-6. Ultimate capacity of cold formed steel (CFS) column.

CONCLUSIONS

The conclusion can be drawn from this study are the prediction of CFS column based on flexural buckling and torsional buckling using EC3-1-3 of single, BTB and BU results in differences up to 40 %, 20 %, and 80 % respectively. The further analysis of box-up (BU) need to study since utilizing of current code to predict the capacity yield to the smaller amount of capacity and too conservative and some of it considered unsafe. Short column can easily attain its double strength, but the long columns are affected by varieties of buckling results in smaller strength to its double C strength.

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