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Validation of experimental results of cold formed steel built up section with analytical and theoretical analysis

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ABSTRACT

Cold-formed steel built-up sections are commonly used as compression elements to carry larger loads and over longer spans when a single individual section is insufficient. Currently there are no proper design rules for Built-up sections. Therefore, this work proposed to conduct an experimental study on the cold-formed steel built-up sections under axial compression, to explore the buckling behavior and ultimate capacity of built-up sections. The built-up sections have been formed by two identical lipped channels placed back to back connected by using batten plates. The selections of sections are based on the geometric limitations as per the North American Specification for the design (AISI S100-2007) of cold-formed steel structural member-2007 Edition. The spacing between the battens was calculated as per the modified slenderness ratio in clause D1.2 of the AISI specifications (AISI S100-2007). The length of the columns has been varied as per the slenderness ratio. The test results such as column strengths and buckling modes are obtained and the test results were compared with the theoretical results obtained as per the North American Specification for the design (AISI S100-2007) of cold-formed steel structural member-2007 Edition and the obtained results are validated with the finite element method using ABAQUS.

Keywords: Cold-formed steel; Direct Strength Method; lipped channel; Battened Column.

INTRODUCTION

Cold forming steel structures has the advantages of high yield strength of steel, high load resistance, capable to withstand against larger span, durability, light weight, high strength to weight ratio, easy erection and construction. The built up battened columns have unique buckling behavior for which the present codes do not have code provisions. Therefore, the present study describes the behavior and strength of cold-formed steel built up columns with battens.

Ellobody et al. [1] investigated built-up cold-formed steel section battened columns. The measured column strengths was compared with the design strengths calculated using the North American Specification, Australian/NewZealand Standard and European Code for cold- formed steel columns. The investigation exhibited the specifications were unconservative for the built-up cold-formed steel section battened columns failing mainly by local buckling, while the specifications were conservative for the built-up columns failing mainly by elastic flexural buckling.

Hashemi et al. [2] compared the test strengths with the ultimate design strengths obtained using the direct strength method in the North American Specification (NAS 2007) for cold-formed steel structures. The slenderness ratio varies from 20 to 120 for the selected two sections in the parametric study. To evaluate the ultimate strength of the lipped channel built-up columns a design recommendation was proposed for DSM.

Ben Young et al. [3] compared the test strengths with the design strengths obtained using the direct strength method in the North American Specification and Australian/New Zealand Standard for cold-formed steel

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structures. They performed the reliability analysis to assess the reliability of the direct strength method on cold-formed steel built-up closed section columns. It shows that the direct strength method using single section to obtain the elastic buckling stresses are generally conservative and reliable.

EXPERIMENTAL INVESTIGATION

Test specimens

The battened built-up columns were connected by two identical lipped channels placed back to back with a spacing such that I_{xx} equals I_{yy} by using self drilling screws. The dimensions of the built-up columns are selected based on the geometric limitations as per the North American Specification for the design (AISI S100-2007) of cold-formed steel structural member-2007 Edition as shown in fig. 1. The geometric limitations are available for single section only. Based on the single section back to back Built-Up section is selected. The spacing between the battens along the length of the columns was investigated by the modified slenderness ratio in clause D1.2 of the AISI specifications (AISI S100-2007) and it is displayed in table 1. The conservative spacing requirement is expressed as $S/ry \leq 0.5(KL/r_y)_o$. Here S is the spacing between the battens; r_y is the minimum radius of gyration, and $(KL/r_y)_o$ is the overall member slenderness ratio of a built-up section. The Table 1 and figure 2 shows the geometric details of the specimen BC.

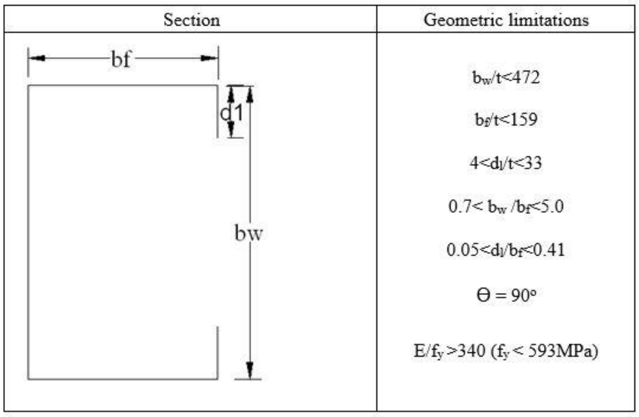
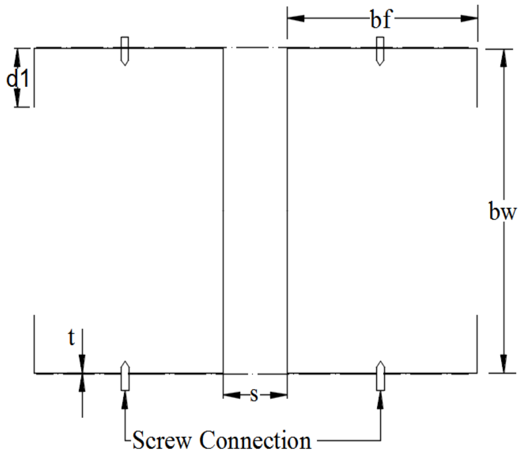


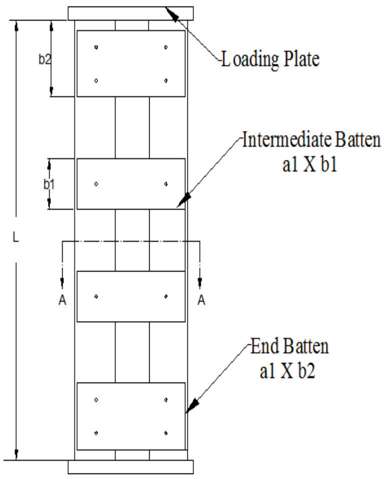
Fig. 1 – Typical details of the specimen

Section Details	b_f (mm)	b_w (mm)	d1 (mm)	t (mm)	a1 (mm)	b1 (mm)	b2 (mm)	S (mm)
120-50-15-1.6	50	120	15	1.6	160	100	75	80

Table 1 Section Geometric Details for the specimen BC (120x50x15)



(a) - Lipped Channel Section A-A



(b) – Lipped channel front view

Fig. 2 – Section Details

Table 2 Shows the spacing selected between the battens for specimen 120x50x15 (BC) based on various codal provisions.

Slenderness Ratio	Length of Column (mm)	Spacing of Battens (mm)			Spacing provided between Battens 'S'(mm)	No.of Battens
		AISI:100-2007	ASCE	EUROCODE		
20	969.27	242.32	363.47	726.95	199.76	4
30	1453.90	363.47	545.21	726.95	361.30	4
40	1938.53	484.63	726.95	726.95	522.84	4
50	2423.17	605.79	908.69	726.95	494.54	5

The spacing between the channels (S) are kept as 80 mm. Each channel had dimensions (bw X b_f X t X d1), as shown in Fig 2. where bw is overall depth, bf is width of flange, t is thickness of channel, d1 is length of lipped member. The intermediate battens had dimensions (a1 X b1) and end battens as (a1 X b2). The Labeling is illustrated in Fig. 3. For example, specimen BC – 30 - B3

BC- Built-Up Columns

30 - The second term indicates the slenderness ratio as 30

B3 – Indicates no. of Battens

NUMERICAL MODELING APPROACH

Finite element models

The commercial software ABAQUS was used to develop numerical models to validate the test results and to perform further parametric analysis. The columns were modeled shell S4R5 elements with sharp corners neglecting the corner radius according to the clause 3 of ENV1993-1-3 (1996). The cold-formed steel sections were created based on the measured cross-section dimensions, as presented in Tables 3. The material nonlinearity and geometric nonlinearity of the cold-formed steel built-up sections were included in the FE models based on the measured results obtained from the tensile coupon tests, and the key parameters are presented in Table 5.

A linear elastic buckling analysis was performed first to obtain the buckling loads and associated buckling modes. This was followed by a non-linear ultimate strength analysis to predict the ultimate load capacity. In the nonlinear analysis, initial geometric imperfections were modeled by providing initial out-of-plane deflections to the model. The first elastic buckling mode shape was used to create a geometric imperfection for the nonlinear analysis. The material properties and dimensions were assigned. The end support conditions of the section were constrained. Mesh size line mesh tool is used to mesh the individual elements into a different number of elements. The coupling was carried out for the coincidence node for joining the spacer to the specimen at the lip, and all degrees of freedom have been constrained.

Validation of test results with FEM approach

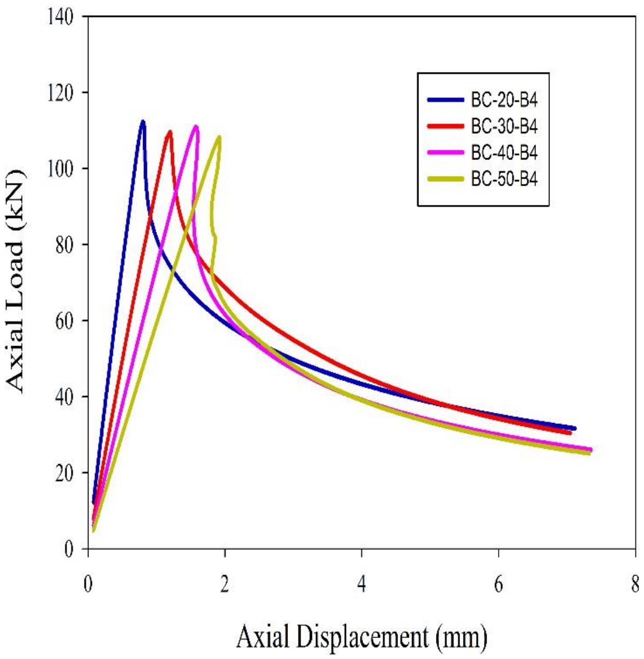
Table 3 Comparison of Loads

S.No.	Specimen ID	PEXP (kN)	PFEM (kN)	PEXP/PFEM
1	BC-20-B4-T1	118	112.16	1.05
2	BC-20-B4-T2	117.54	113.54	1.04
3	BC-30-B4-T1	109.65	109.51	1.00
4	BC-30-B4-T2	110.35	109.65	1.01
5	BC-40-B4-T1	105.26	104.86	1.00
6	BC-40-B4-T2	106.35	105.48	1.01
7	BC-50-B5-T1	103.84	102.85	1.01
8	BC-50-B5-T2	103.54	103.95	1.00
Mean				1.01
Standard deviation				0.02

The Experimental results are used to verify the efficiency of the numerical model in predicting ultimate capacities and the corresponding response of the tested specimens. The test results and numerical results are compared in Table 3. Table 3 shows the comparison of the test strengths (PEXP) with numerical strength (PFEM) for all the Columns. The ratios of the test strength to numerical strength are also shown

Accuracy of the developed finite element model was finally assessed by comparing the failure modes of specimens from numerical analysis and from the experimental tests.

The comparison provides very good agreement between the experimental and numerical results, indicating that the finite element models had the capacity of replicating the structural behaviour of the test specimens. Therefore, the finite element models were approved against the tests and proved to be accurate in terms of failure modes and deformed characteristics.



THEORETICAL ANALYSIS DESIGN RULES

General

The Direct Strength Method and Effective width method as per North American Specifications (AISI S100-2007) were carried out in this study.

Direct Strength Method (North American Specifications)

An alternative method such as "Direct Strength Method" (DSM) for the Design of Cold-formed Steel Structural Members 2007 (AISI S100-07) located in Appendix 1 of the North American Specification. DSM may be used instead of the Main Specification for determining nominal member capacities. Specific advantages include the absence of effective width and iterations, while only using known gross-sectional properties.

Flexural, torsional or flexural-torsional buckling (P_{ne})

for $\lambda_c \le 1.5$

$$P_{ne} = \left(0.658^{\lambda_c^2}\right) P_y \quad (Eq.\ 1.2.1\text{-}1)$$

for $\lambda_c > 1.5$

$$P_{ne} = \left(\frac{0.877}{\lambda_c^2}\right) P_y \quad (Eq.\ 1.2.1\text{-}2)$$

where $\lambda_c = \sqrt{P_y / P_{cre}}$ (Eq. 1.2.1-3)

Local bucklin

for $\lambda_\ell \leq 0.776$

$$P_{n\ell} = P_{ne} \quad (Eq. 1.2.1\text{-}5)$$

for $\lambda_\ell > 0.776$

$$P_{n\ell} = \left[1 - 0.15\left(\frac{P_{cr\ell}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{cr\ell}}{P_{ne}}\right)^{0.4} P_{ne} \quad (Eq. 1.2.1\text{-}6)$$

$$\text{where} \quad \lambda_\ell = \sqrt{P_{ne}/P_{cr\ell}} \quad (Eq. 1.2.1\text{-}7)$$

The column strengths results for P_{DSM-1}, P_{DSM-2} and P_{EWM} and comparisons of finite element results with the column strength using the direct strength method and effective width method are shown in Table 4.

The theoretical strengths obtained has been compared with FEM results and found to be proportionate. Later, The Slenderness ratio will be increased up to 200 in order to study the behaviour of cold formed steel built-up columns.

Table 4 – Theoretical Results of BC specimen

Specimen ID (BC)	P_{EXP} (kN)	P_{DSM1} (kN)	P_{DSM2} (kN)	P_{EWM} (kN)	P_{EXP}/P_{DSM1} (kN)	P_{EXP}/P_{DSM2} (kN)	P_{EXP}/P_{EWM} (kN)
BC-20-B4-T1	118	134.17	136.38	135.45	0.88	0.87	0.87
BC-20-B4-T2	117.54	132.40	135.20	133.38	0.89	0.87	0.88
BC-30-B4-T1	109.65	128.70	132.87	131.81	0.85	0.83	0.83
BC-30-B4-T2	110.35	129.84	131.24	130.55	0.85	0.84	0.85
BC-40-B4-T1	105.26	125.47	128.54	129.46	0.84	0.82	0.81
BC-40-B4-T2	106.35	123.24	126.74	124.52	0.86	0.84	0.85
BC-50-B5-T1	103.84	117.90	119.45	120.89	0.88	0.87	0.86
BC-50-B5-T2	103.54	119.02	121.81	124.31	0.87	0.85	0.83
				Mean	0.87	0.85	0.85

CONCLUSIONS

Based on the experimental investigation, and comparison between FEM and theoretical strength results, the following conclusions and observations has been drawn. An experimental investigation of cold-formed steel built-up section beams with battens has been presented. The built-up sections have been formed by two identical lipped channels placed back to back connected by using batten plates using self-tapping screws. The observed failure modes from the tests included failure modes for those built-up sections battens are validated with the numerical analysis using FEM in this study. The numerical and experimental results are in very good agreement in terms of column strength and failure modes. The behaviour of cold-formed steel under axial compression is significantly influenced by the slenderness ratio. For the slenderness ratio between 20 and 50, the column strengths remain reduced. The analytical results and theoretical analysis are compared in Table 4.

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