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Research Paper

Study the effect of intermediate and closer stiffener on the behaviour of the cold - formed steel lipped channel section under axial compression

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ABSTRACT

Cold-Formed steel built-up columns are commonly used as compression member in the industrial roof and long span bridge structures to carry larger load. To improve the strength and stiffness of the cold-formed section, the built-up column with additional stiffeners and lacings are used. This paper reports the results of experimental tests conducted on built-up cold-formed columns, composed with the combination of intermediate and closer stiffeners with pin-ended condition under axial compression. Totally twelve columns with or without intermediate and closer stiffeners were tested to failure. The experimental results aim to quantify the effect of cross-section, intermediate and closer stiffener on the overall performance, including strength, strain and failure modes for the built-up column. The Finite element model was developed by ANSYS software and the model is validated with the experimental results. The built-up column strength predicated by recommended design equations of American Iron and Steel Institute (AISI) exhibited good agreement with the ultimate load of built-up columns obtained both by experimental and numerical. Based on this study a recommendation is proposed to DSM for the CFS built -up columns with intermediate and closer stiffeners.

1 Introduction

In recent days, the use of the cold – formed steel (CFS) built- up columns has started to use in the construction of residential and multi-storey buildings. In multi-storey commercial steel structures, built-up sections are being used by structural engineers in order to resist high axial and flexural load. The CFS built-up sections are also used to withstand the needs of economic construction. Many researchers investigated the behaviour of slender and stub steel columns. A series

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of experiments conducted on cold-formed built-up square sections with intermediate flange and web stiffeners under axial compression with hinges end conditions and proposed design recommendation for calculation of ultimate strength of cold-formed build-up square sections with stiffeners reported by Aruna et.al. (2015). Compression test on twenty-four cold-formed closed built-up columns with intermediate stiffeners to study the ultimate load carrying capacity and compared the failure mode obtained using finite element software ANSYS by Aruna et.al. (2015). The parametric study on cold‐ formed steel lipped channel built‐ up I beam with intermediate web stiffener were carried out using ABAQUS were studied by Manikandan and Thulasi (2019).The design strength prediction by using AISI and Eurocode and for cold – formed steel built – up battened columns made of four lipped angles and also validated the numerical strength with experimental strength by Anbarasu (2020). The built-up CFS lipped channel members were analysed by Cristiane Cruxen (2019) with help of the Generalized Beam Theory in order to identify their buckling loads and modes. The Finite element model developed by ABAQUS software for validation on the behaviour and strength of cold-formed steel web stiffened built-up battened columns and proposed a recommendation to direct strength method (DSM) by Anbarasu et.al (2015). The results of numerical study of 113 different built-up section beams were compared with the predicted strengths using the current direct strength method in the North American Specification were reported by Liping Wang and Ben Young (2019) .The experimentally study on the behaviour of cold-formed steel channel stub columns in axial compressive force in the elastic as well as in the plastic ranges of loading and also compared the design strength calculated using finite element analysis with IS 801, BS 5950 and NAS manual were made by Beulah Gnana Ananthi(2015).

Geometrical imperfection of cold- formed lipped channel sections, with and without intermediate stiffeners in the web with the fixed end conditions were studied by Young et.al (1992). A parametric study carried out to investigate the effect of thickness, depth and spacing of the spacer plate on the strength and buckling behaviour of the specimens were discussed by Manikandan et.al (1992). Detailed nonlinear FE models were developed by Jun Yea et.al (2018) and validated against a total of 36 axial compression tests on CFS plain and lipped channel columns with pin-ended boundary conditions. Experimental investigation on the axial load capacity of four innovative CFS built-up stub columns were carried out by Mohamed Ghannam (2017) and compared the results with predicted values of strength obtained using DS method. The duplex stainless steel columns having square and rectangular hollow sections with fixed end condition, studied using finite element analysis and validated the column strength with the predicted strength using Australian and European code by Ehab Ellobody and Ben Young (2005).Presented the design curve for the calculation of maximum strength of the built-up columns experiencing the distortional and local-distortional buckling by Whittle and Ramseyer (2009).Many researches, Liao et al. (2017), Matsubara et al. (2019), Zhang and Young (2015), Yao and Rasmussen (2017), Tina et al. (2017) and Wang et al. (2016 & 2019), carried out the parametric study on the CFS built column specimens for different cross sections, open and closed column sections and close – to – close and back – to – back channel section arrangements. Tayyab Naqash(2020), Saadi et al.(2021) and Sampson et al.(2021) have discussed about the steel frame with rigid connections.

1.1 Significance of the study

In spite of sufficient literature available on the axial behaviour of cold – formed steel built-up columns with or without intermediate stiffeners. The study was very few to know the effect of combination of closer and intermediate stiffeners on the behaviour of cold-formed steel columns. Thus, the authors aim to study the strength and failure behaviour of built-up columns with intermediate and closer stiffener with pin-end condition. This paper presents the 3D numerical model and recommended design equations which accurately predicts the buckling behaviour of the built-up column subjected to axial compression.

2 Experimental Investigation

2.1 Selection of section

A new stiffened open channel section is chosen for the study. Fig. 1 shows a distinctive cross section of the test specimens with specifications and a detail of the specimens is presented in Table 1.The details of labelling of the specimen are shown in Table 1, the term 'BC' specifies the built-up column, term 'IS' specifies intermediate stiffener(0,1 and 2 number of intermediate stiffener), and the term 'CS' specifies closer stiffener(0,1 and 2 number of closer stiffener). The column specimens zero, one and two intermediate stiffeners are grouped as Series – A, Series – B and Series – C respectively.

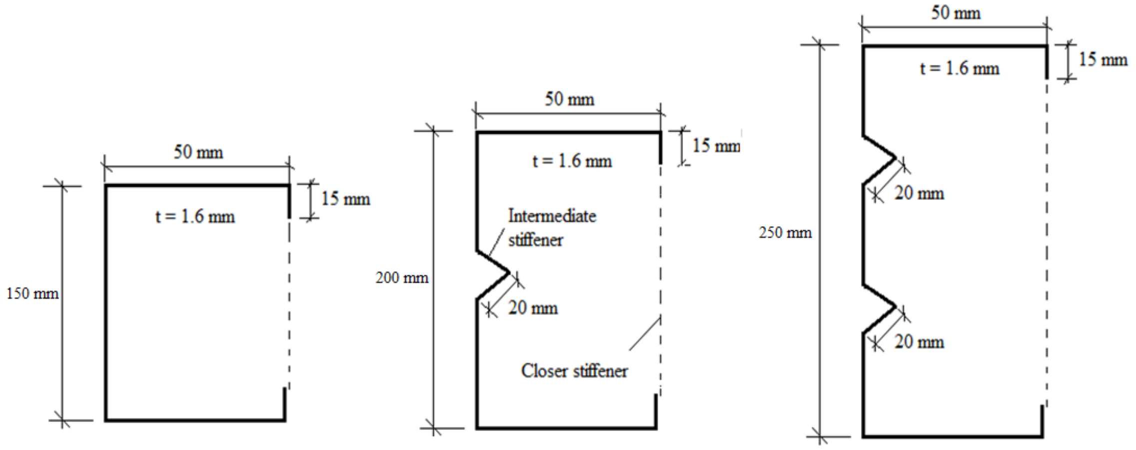

Fig. 1 - Geometry and cross – sectional dimensions of the specimen

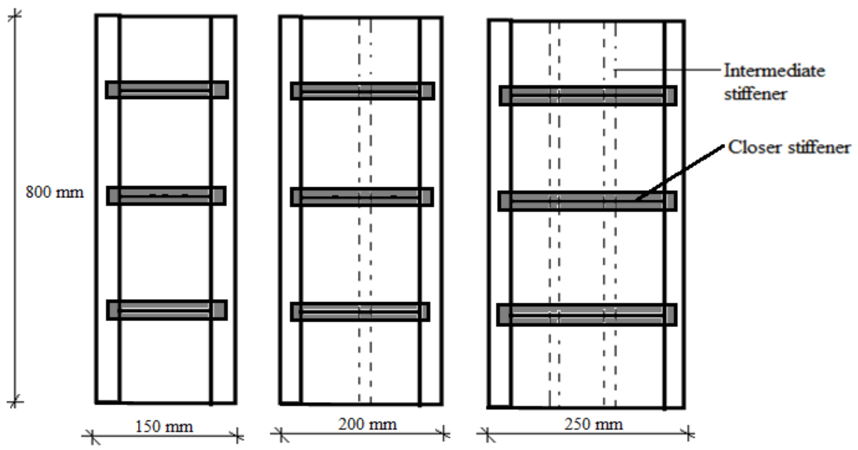

Fig. 2 - Position of the closer stiffener

Table 1 Details of test specimens

Specimen labelling	Cross sectional dimensions			Intermediate stiffener(mm)	No. of Closer Stiffener
	Flange(mm)	Web(mm)	Lip(mm)		
Series - A					
BC - 0IS - 0CS	50.20	150.20	15.10	-	0
BC - 0IS - 1CS	50.10	150.20	15.00	20.10	1
BC - 0IS - 2CS	50.10	150.30	15.10	20.20	2
BC - 0IS - 3CS	50.20	150.10	15.20	20.10	3
Series - B					
BC - 1IS - 0CS	50.10	200.20	15.10	-	0
BC - 1IS - 1CS	50.20	200.10	15.00	20.20	1
BC - 1IS - 2CS	50.10	200.20	15.10	20.10	2
BC - 1IS - 3CS	50.20	200.10	15.20	20.20	3
Series - C					
BC - 2IS - 0CS	50.10	250.10	15.10	-	0
BC - 2IS - 1CS	50.10	250.20	15.10	20.10	1
BC - 2IS - 2CS	50.20	250.10	15.20	20.10	2
BC - 2IS - 3CS	50.20	250.20	15.10	20.20	3

2.2 Experimental setup

Totally, twelve pin – ended built-up columns with or without intermediate and closer stiffener are tested under axil compression. The length and cross-sectional dimensions of the built-up column specimens are selected to resist the local and torsional buckling mode. All the specimens are fabricated using cold-formed steel plate of thickness 1.6 mm under press-braking operation with yield strength of 265 kN /mm2 and Young's modulus of 2 x 105 N/mm2. All the specimens of length 800 mm are tested to failure.

In the experimental study, thickness and length of the specimens are uniform, but variable is cross-sectional dimensions and the number of intermediate and closer stiffener (Fig.1). The distortional buckling strength of the column specimens are increased by connecting closer stiffener to the lip of the sections (Fig.2). All the specimens are tested under universal testing machine of capacity 600 kN. To ensure the uniform distribution of the load to the specimen during the test by placing steel plate one at the top and another at the bottom of the column specimen. The specimens are placed between the plates at both the end. The pin-ended plates allow rotation about their x and y axis, but rotations about the perpendicular z-axis are constrained. The test setup is shown in Fig. 3. The two dial gauges were employed to measure the axial and lateral deflection. The 20 mm strain gauge was subjected to measure the axial strain and recorded the same using five - channel strain indicator.

Fig. 3 - Experimental setup

3 Numerical study

The finite-element analysis of the cold-formed steel built – up column with hinged end conditions was done using the ANSYS software. The non-linear analysis was performed for the built-up columns for axial compression loading similar to the experimental test.

3.1 Modelling

In this study, the built-up columns (intermediate and closer stiffeners) were modelled using a SHELL 181 selected from the ANSYS element library. The assigned element was used to mesh the specimens. The mesh size of the built-up steel column was 10 x 15 mm. The mesh model of the column specimens without closer stiffeners are shown in Fig. 4. A concentrated load is applied at the middle node, thus load distribution to the specimens as pressure at the top end of the built-up column as discussed by Nguyen and Kim (2009). Coupling option was used at the junction of the built-up column and the closer stiffener to get single volume.

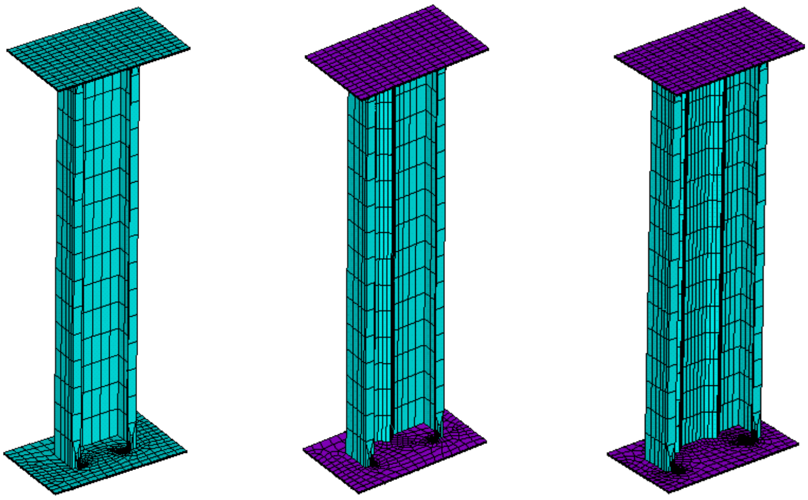

Fig. 4 Finite element model

4 Result and Discussion

All the experimental series of specimens were analysed. The load-deflection (Fig. 5) behaviour of the specimens were compared and shown for all three series of the experimental results.

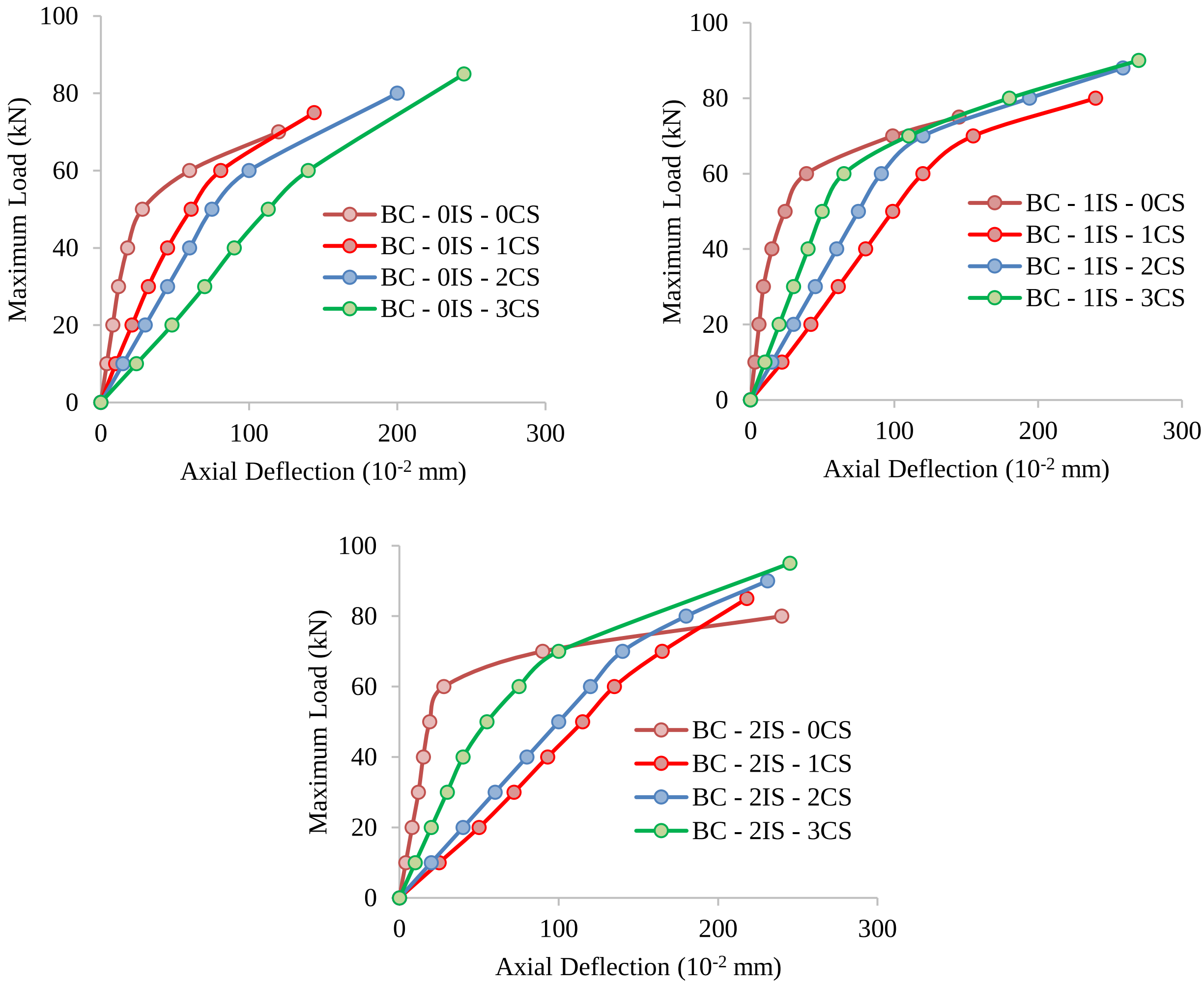

Fig. 5 - Comparison of the load-deflection curve of all the tested specimens

The % increase in the load carrying capacity of built up columns with increase in the number of closer stiffeners from zero to three is 7 % along with or without intermediate stiffener (Fig.6). The strength and axial deformation obtained from the experiment (P_{EXP}) and (δ_{EXP}) are compared with finite element analysis (P_{ANSYS}) and (δ_{ANSYS}), the results are listed in Table 2.

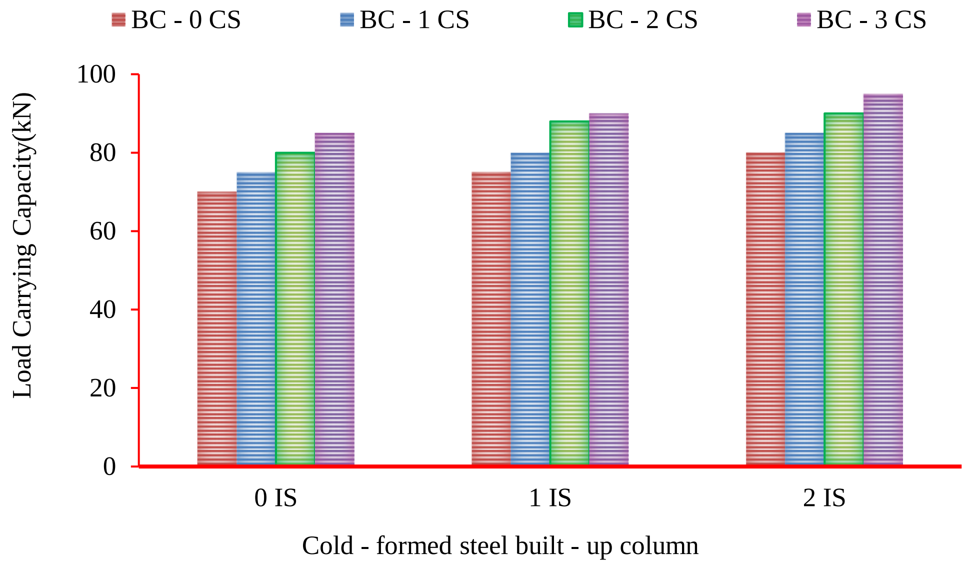

Fig. 6 - Comparison between the load carrying capacity of all column specimens

Table 2 also listed the axial deflection between the experimental and finite element. The ratio between δ_{ANSYS} / δ_{EXP} is less than 1 which implies that the ANSYS model are stiffer due to rigid connections between the column and closer stiffeners. The load-strain (Fig. 7) behaviour of the column specimens were compared and presented for all three series of the experimental results. From the load- strain behaviour the specimens with 2IS are able to take more load and area under the curves gives energy absorption capacity, which is more for specimens with two intermediate stiffeners.

Table. 2 - Comparison between experimental and finite element analysis results

Specimen Number	Ultimate Load Carrying Capacity		P_{ANSYS} / P_{EXP}	Maximum Axial deflection		δ_{ANSYS} / δ_{EXP}	Failure Mode
	P_{EXP} (kN)	P_{ANSYS} (kN)		δ_{EXP} (mm)	δ_{ANSYS} (mm)		
BC – 0IS – 0CS	70.20	71.32	1.02	1.20	1.04	0.87	D
BC – 0IS – 1CS	75.32	76.21	1.01	1.44	1.13	0.78	L
BC – 0IS – 2CS	80.62	82.31	1.02	2.00	1.81	0.91	L + F
BC – 0IS – 3CS	85.82	87.12	1.03	2.45	2.24	0.91	L + D
BC – 1IS – 0CS	75.32	77.10	1.03	1.45	1.30	0.90	D + L
BC – 1IS – 1CS	80.12	82.32	1.03	2.40	2.28	0.95	D + L
BC – 1IS – 2CS	88.61	90.21	1.02	2.59	2.31	0.89	D + L
BC – 1IS – 3CS	90.06	92.12	1.02	2.70	2.58	0.96	D + L
BC – 2IS – 0CS	80.32	81.92	1.02	2.25	2.18	0.97	D + F
BC – 2IS – 1CS	85.52	86.82	1.02	2.30	2.22	0.97	D + F
BC – 2IS – 2CS	90.40	93.58	1.04	2.36	2.28	0.97	D + L
BC – 2IS – 3CS	95.20	97.32	1.02	2.45	2.36	0.96	D + F
Mean			1.023			0.920	
St. Deviation			0.008			0.056	
Co. of Variance			0.761			6.148	

L=Local buckling, D=Distortional buckling, F=Flexural buckling

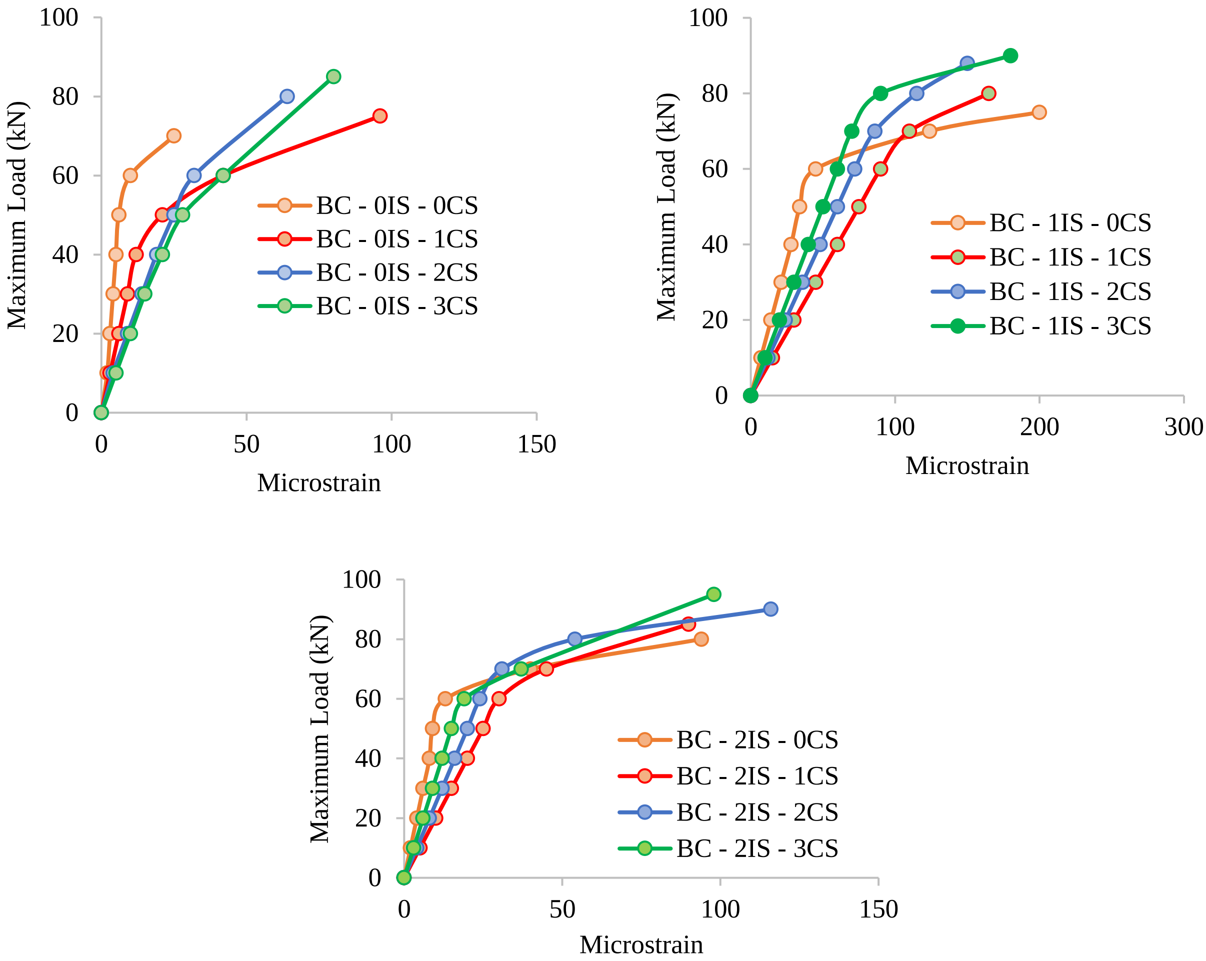

Fig. 7 - Comparison of the load-strain curve of all the tested specimens

The failure modes obtained from the experimental are similar and equivalent to ANSYS model. Fig.8 - 10 shows the good agreement between the ANSYS and experiments and also give confidence to use finite element model to predict the ultimate load and failure mode of the built-up column specimens. The ultimate load and failure modes predicted numerically (P_{ANSYS}) are compared with experimentally (P_{EXP}) as given in Table 2, and a good correlation is achieved. The mean and standard deviation of ultimate strength (P_{ANSYS})/ (P_{EXP}) are 1.023 and 0.008, respectively and similarly the mean and standard deviation of axial deformation (δ_{ANSYS})/ (δ_{EXP}) are 0.920 and 0.056, respectively. From this correlation, it is observed that developed ANSYS model predict the strength and behaviour of the built-up column specimen.

Fig. 11 illustrates the plot between the C/L ratio and P_{EXP}/ P_O for the various series (A, B and C) of the test specimens, where P_{EXP} is the experimental column ultimate load and P_O is the ultimate load of the column without closer stiffener. From the Fig.11, it can be observed that the P_{EXP}/P_O ratio decreases with increase in C/L ratio [2].

Fig. 12 shows the plot between b/d ratio to P_{EXP}/ P_O for varying number of closer stiffeners. It is clear from the Fig.12, increasing the value of b/d increase the ultimate load carrying capacity of the built-up columns. From this, it is concluded that the spacing of the closer stiffener decreases, the ultimate strength of the built-up column increases, which enhance their distortional behaviour and ensure the load sharing in the closer stiffener [10]. It is also observed that reducing the spacing between the closer stiffener, increase the ultimate load carrying capacity and which in turn improves the overall buckling of the built-up column.

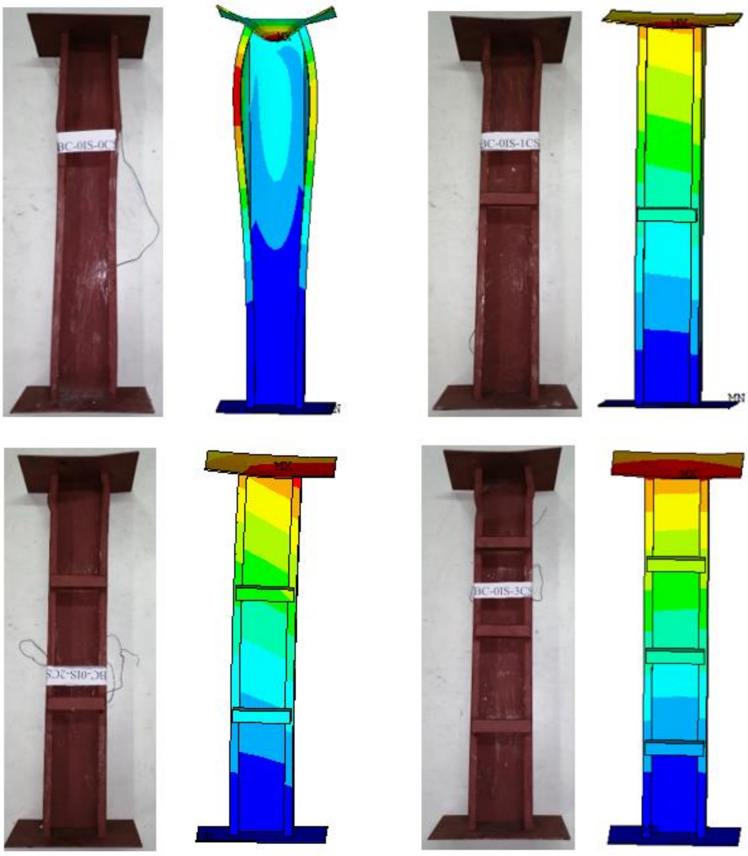

Fig.8 - Comparison on the failure mode of specimen between the experimental and analytical (Series – A)

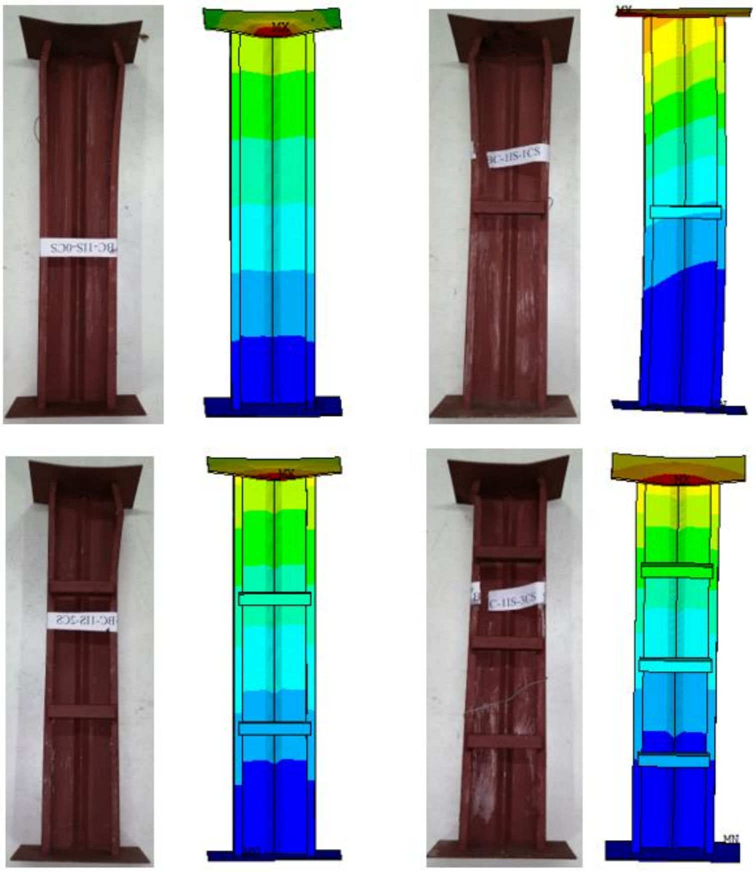

Fig.9 - Comparison on the failure mode of specimen between the experimental and analytical(Series – B)

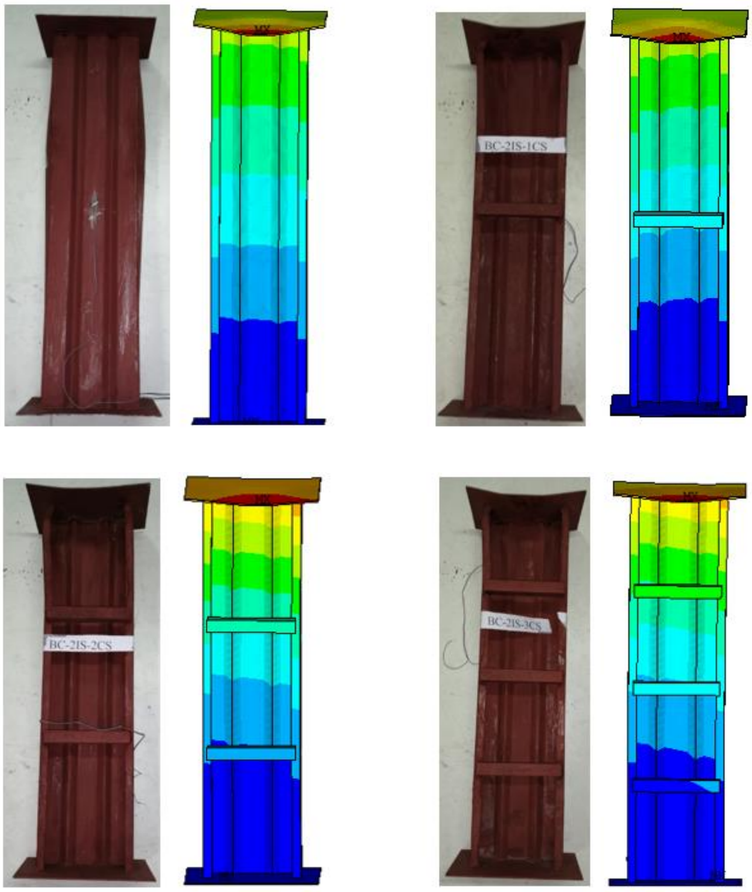

Fig.10 - Comparison on the failure mode of specimen between the experimental and analytical (Series – C)

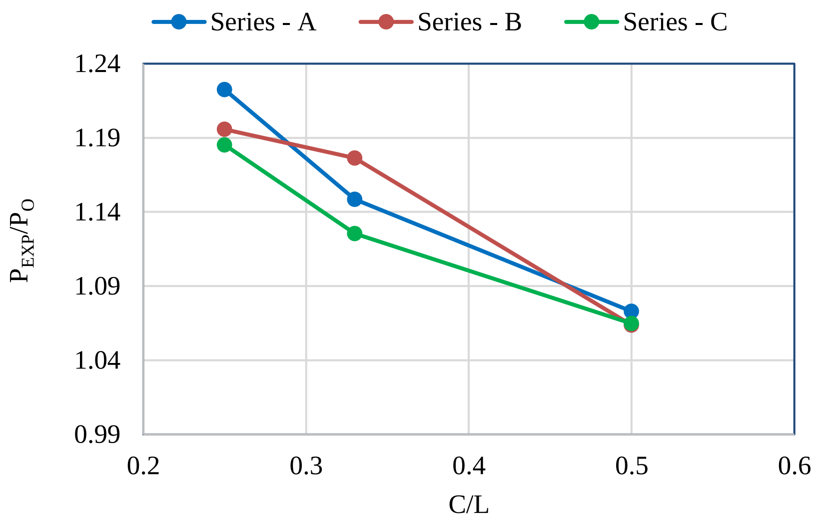

Fig. 11 - Effect of center-to-center distance of closer stiffener to the length of column on to the ratio of the (P_{EXP}/ P_O)

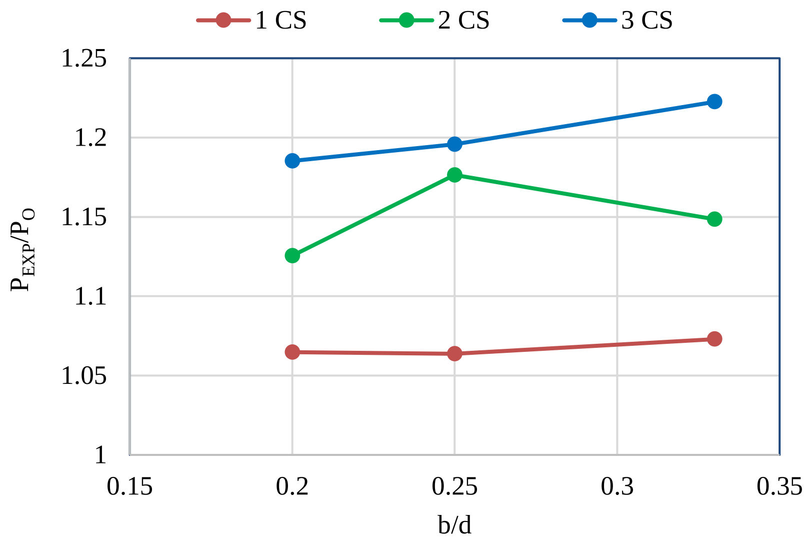

Fig. 12 - Effect of flange width to web depth of the channel section on to the ratio of the (P_{EXP}/ P_O)

4.1 Comparison of experimental results with code specification

The unfactored design strengths of concentrically loaded compression members are calculated using effective width method of the North American Specification AISI - S100 (2016) for cold-formed steel columns is as follow.

$$P_{AISI} = A_e F_n \tag{1}$$

where Ae= effective cross-sectional area in mm^2, F_n=critical elastic buckling stress for flexural bucking. F_n is calculated from equation (1)

$$F_n = \left(0.658^{\lambda_c{}^2}\right) F_y \text{ for } \lambda_c \leq 1.5 \tag{2}$$

$$F_n = \left(\frac{0.877}{\lambda_c{}^2}\right) F_y \text{ for } \lambda_c > 1.5 \tag{3}$$

where λ_c =non-dimensional critical slenderness and can be calculated as follows

$$\lambda_c = \sqrt{\frac{F_y}{F_e}} \tag{4}$$

where F_y is the yield stress, and F_c is the least of elastic flexural, torsional, and flexural-torsional buckling stress calculated in accordance with AISI – S100.The ultimate load for all column specimens calculated using AISI design equation are listed in Table.3. The Table 3 implies that predicted values P_{AISI} are more that the P_{EXP} and the ratio between P_{AISI}/P_{EXP} within the range of 1.10 – 1.15.

Table 3 - Comparison between the column strength of experimental and AISI

Specimen Number	Ultimate Load P_{EXP} (kN)	Ultimate Load P_{AISI} (kN)	$\frac{P_{AISI}}{P_{EXP}}$	Specimen Number	Ultimate Load P_{EXP} (kN)	Ultimate Load P_{AISI} (kN)	$\frac{P_{AISI}}{P_{EXP}}$
BC – 0IS – 0CS	70.20	79.92	1.14	BC – 1IS – 2CS	88.61	97.14	1.10
BC – 0IS – 1CS	75.32	84.12	1.12	BC – 1IS – 3CS	90.06	103.62	1.15
BC – 0IS – 2CS	80.62	92.13	1.14	BC – 2IS – 0CS	80.32	90.16	1.12
BC – 0IS – 3CS	85.82	96.13	1.12	BC – 2IS – 1CS	85.52	96.86	1.13
BC – 1IS – 0CS	75.32	85.14	1.13	BC – 2IS – 2CS	90.40	101.16	1.12
BC – 1IS – 1CS	80.12	91.63	1.14	BC – 2IS – 3CS	95.20	108.61	1.14

An experimental and numerical investigation on the CFS built-up columns, with or without intermediate stiffener subjected to axial compression has been presented. Test on 12 built-up columns were undertaken for three different cross sections by varying the number of intermediate and closer stiffeners. Both the material properties and geometric imperfections under axial compression of the built-up columns were studied. The ultimate column strength, load versus axial deformation, load versus strain and failure mode of the built-up columns were recorded and reported. The numerical models using ANSYS were developed for the built-up columns. The finite element results are found to have good agreement with the experiments results in terms of ultimate load and failure behaviour. The test results were also compared with the design strength calculated using North American Standards (AISI) for CFS built-up column.

The conclusion obtained from the investigation are summarised below:

1. The built-up columns without closer stiffeners fail by distortional and local buckling whereas the column with varying closer stiffeners fails by combination of local, flexural and distortional buckling.
2. The closer stiffener improves the strength, stiffness and torsional rigidity of the built-up column section whereas the presence of intermediate stiffeners affects the failure mode.
3. The different cross-section in terms of depth and increase in the number of closer stiffeners significantly affects the overall performance of the built-up column under axial compression.
4. The developed finite element model stimulates the behaviour of CFS built – up columns with or without stiffeners effectively. The mode of failure between the experimental and numerical are comparable.
5. The increase in centre – to - centre distance (C) of the closer stiffeners to the length of the column specimen (L) appears to decrease the overall capacity of the built-up column. Thus, provision of the closer stiffeners with less spacing between them significantly improves the buckling behaviour of the built – up column sections. Also increase in the ratio flange width to web depth(b/d), improves the strength but fails earlier by local and distortional buckling.
6. The experimental strengths of the built-up column are compared with the design equation currently available for the CFS sections. The prediction using American Iron and Steel Institute are satisfactory with their ratio ranges between 1.1 to 1.15.

Conflict of Interest

The authors declare that they have no conflict of interest.

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