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Study on the effect of ties in the intermediate length Cold Formed Steel (CFS) columns

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Abstract. This work aims to study the effect of stiffener ties in the behavior of intermediate length open section Cold-Formed Steel (CFS) Columns under axial compression. A comparative study on the behaviour and strength of Cold Formed Steel Columns by changing the direction of projection of lips (i.e., inwards or outwards) are also done. In this work two types of sections were considered Type-I section with lip projecting outwards (hat) and Type-II section with lip projecting inwards (channel). The length of the columns is predicted by performing elastic buckling analysis using CUFSM software. The theoretical analysis is performed using DSM - S100;2007, AS/NZ: 4600-2005 and IS: 801-1975. The compression tests are carried out in a 400 kN loading frame with hinged-hinged end condition. The non-linear numerical analysis is performed using Finite Element software ANSYS 12.0 to simulate the experimental results. Extensive parametric study is carried out by varying the width and spacing of the stiffener ties. The results are compared; the effects of stiffener ties on behaviour and load carrying capacity on both types of columns are discussed.

Keywords: cold-formed steel; columns; pallet racks; axial compression member; thin walled members; distortional buckling; stiffener ties

1. Introduction

In compression, cold formed open cross-section can exhibit three modes of instabilities: local, distortional and flexural or flexural-torsional buckling. Local modes and global modes (i.e., flexural and flexural-torsional buckling) are largely covered in the main design codes by means of effective widths for the plate elements and by column design equations for global buckling. Interaction of local and global modes is also considered in these codes. Distortional buckling plays an important role in the use of open cold formed steel columns. Generally, the following buckling modes were encountered from the earlier research works.

- Local Buckling [(a) in Fig.1]
- Distortional Buckling [(b) in Fig.1]
- Overall Flexural Buckling [(c) in Fig.1]

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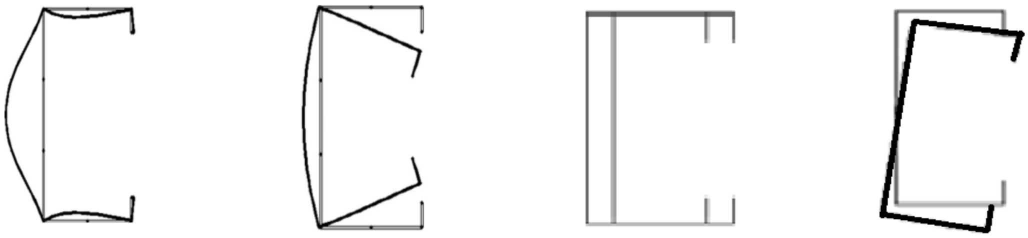
- Overall Torsional Buckling [(d) in Fig.1]
- Overall Flexural-Torsional Buckling

The various buckling modes are clearly portrayed for the basic channel section below in Fig. 1.



(a) (b) (c) (d)

Fig. 1 Various buckling modes

Cold-formed steel upright section members, whose section is thin-walled, open and mono symmetric are used in pallet rack systems. Such sections are prone to loss of stability by interaction of two or more instability modes, such as local buckling of each component plate and overall buckling. Interaction mode between local and overall buckling is called distortional buckling. The occurrence of the distortional buckling depends on the sectional geometry and the length of the member. Distortional buckling occurs at intermediate length between the lengths where local and overall buckling occurs.

In the past, many researchers (Lau and Hancock 1987, Kwon and Hancock 1992, Hancock *et al*. 1996) had investigated the various buckling modes of commonly used cold formed steel section. The extensive literature survey indicates that local buckling and flexural / flexural- torsional buckling behaviour of cold-formed steel sections have been extensively studied in the past. Also, distortional buckling strength of few innovative and complex geometrical sections has been studied by Narayanan and Mahendran (2003). For intermediate length pallet rack columns, the distortional strength was studied by providing spacers to connect the flanges of upright sections by Talikoti and Bajoria (2005). The partly closed thin walled steel columns were studied by Veljkovic and Johanson (2008). Anil Kumar and Kalyanaraman (2010) studied the evaluation of direct strength method for CFS Compression members without stiffeners. Shi *et al.* (2011) conducted tests and finite element analysis on the local buckling of 420 MPa steel equal angle columns under axial compression. Besevic (2012) has experimentally studied to find the residual stress, initial imperfections and material properties of cold-formed steel open cross sections.

The research in case of intermediate length columns is limited. Also in recent times no studies have been reported on effect of stiffener ties on the behaviour and strength of intermediate length cold formed steel open section columns. This paper describes the details of such a study.

The main aim of this paper is to study the effect of stiffener ties in the behavior of intermediate length open section Cold-Formed Steel (CFS) Columns under axial compression. Stiffener ties are the transverse elements of CFS sheet used to connect the lips of the open section columns. A comparative study on the behaviour and strength of CFS Columns by changing the direction of projection of lips (i.e., inwards or outwards) are also done.

For this work, two types of sections are considered Type-I section with lip projecting outwards (hat) and Type-II section with lip projecting inwards (channel). For both the sections theoretical analysis, numerical analysis and the experimental investigation are done. The theoretical analysis is performed using various codal provisions such as Direct Strength Method - S100;2007 (North American AISI Specifications), Australian/New Zealand Standard Code - AS/NZ: 4600-2005 and by Indian standard (IS: 801-1975). The experimental investigation has been carried out on all the specimens with the help of 400 kN loading frame. The numerical model is developed using Finite Element software ANSYS 12.0 including both material and geometric nonlinearity to simulate the experimental results. Thereby, extending the parametric study by varying the width and spacing between the stiffener ties.

The conclusions are arrived based on the comparison of results obtained by various analysis. The effect of provision of stiffener ties, effect of number of stiffener ties or distance between the stiffener ties and effect of width of the stiffener ties are discussed.

2. Experimental investigation

The dimensions of the cross section are finalized based on the guidelines given in codal provisions of IS 801:1975. The length of the columns is 1600mm for both the type of sections. The length of the column is chosen in the range where distortional buckling occurs by performing elastic buckling analysis using CUFSM software. Fig. 2 shows the typical buckling plot of Type-I specimen obtained from CUFSM software.

The dimensions and the section configuration for Type-I and Type-II Columns are shown in Fig. 3(a) and Fig. 3(b) respectively.

8 numbers of columns 4 Nos of Type-I and 4 Nos of Type-II are fabricated with 1st fully opened, 2nd fully closed, 3rd one stiffener tie and 4th two stiffener ties. The details of the specimen and their labelling are given in Table 1. The representation of the labelling is the first term ‘T1’ denotes the type of column, second term ‘H’ the cross section type, third term ‘S0’ the number of stiffener ties and the last term ‘b-50’ the breadth of stiffener tie. Also, the second letter “C” indicates channel section; “SC” indicates stiffener plate closed section.

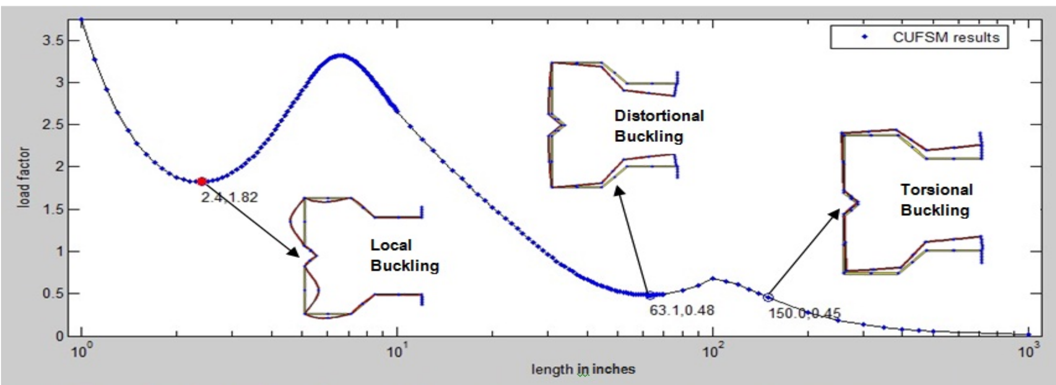


Fig. 2 Typical buckling plot for Type-I (Hat) section columns

Table 1 Specimen details

Specimens for the entire work			
Type-I (Hat) columns		Type-II (Channel) columns	
Description	Labelling	Description	Labelling
Fully Opened	T1-H-S0-b50	Fully Opened	T2-C-S0-b50
One Stiffener tie	T1-H-S1-b50	One Stiffener tie	T2-C-S1-b50
Two Stiffener tie	T1-H-S2-b50	Two Stiffener tie	T2-C-S2-b50
Fully Closed	T1-H-SC-b50	Fully Closed	T2-C-SC-b50

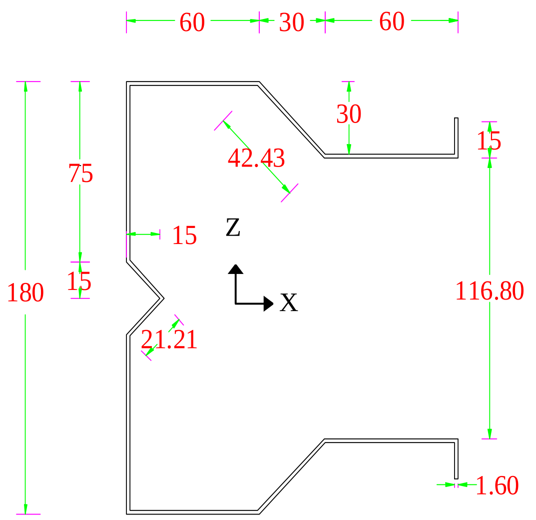


Fig. 3(a) Type-I (Hat) columns

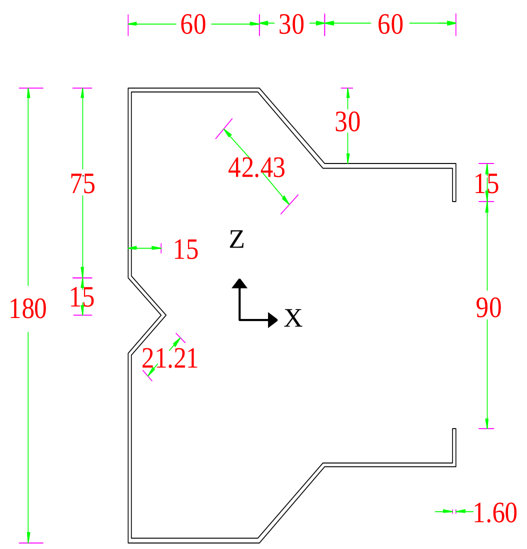


Fig. 3(b) Type-II (Channel) columns

The fully closed specimen is achieved by closing the entire open area of the cross section with the CFS sheet leaving a gap of 5mm at the top and bottom to allow for axial deformation. The CFS sheet is connected to the lip of the sections using 5mm diameter self-driving screws similar to that of the connection of stiffener ties in other specimens. Along the entire height, the closer plate is connected to the specimen by 12 nos of equally spaced screws on each side of the Lip.

2.1 Materıal propertıes

The material properties of specimens are determined by tensile coupon tests confirming to the Indian standard IS 1608-2005 (Part-1). The properties obtained from coupon test are listed below

Yield Stress (f_y)	= 248 Mpa
Young's Modulus (E)	= 200 GPa
Tangent Modulus (E_t)	= 20 Gpa
Poisson's Ratio (m)	= 0.3

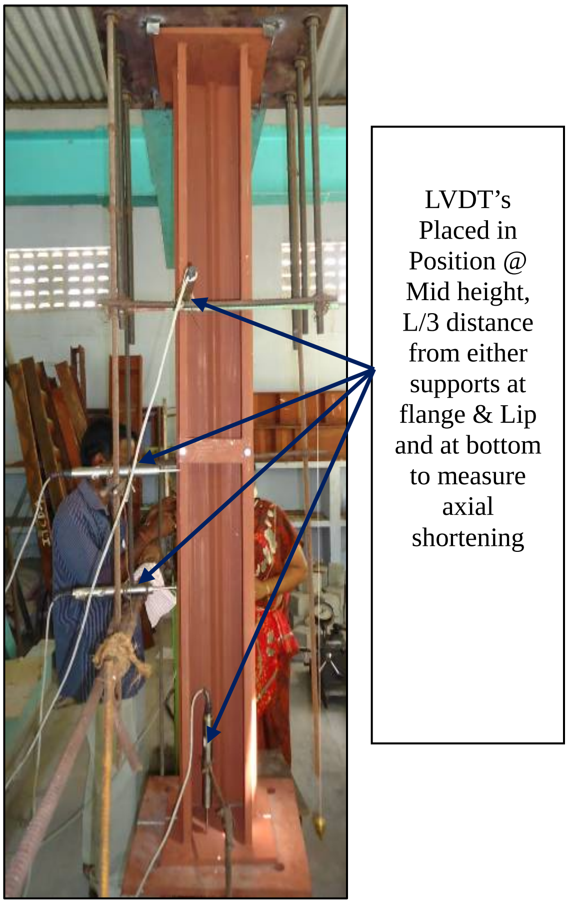


Fig. 4 Experimental setup

Fig. 5(a) Deformed shape of Type-I columns

Fig. 5(b) Deformed shape of Type-II columns

2.2 Test results

The specimens are tested in a Loading Frame of capacity 400kN under hinged end conditions by applying concentric axial load. Axial deformations and lateral deflection at each load step are recorded. The test setup is shown in Fig. 4.

The deformed shape of Type-I and Type-II Columns are shown in Fig. 5(a) and Fig. 5(b) respectively. On observation it clearly indicates that the predominant mode of failure of the fully opened section in case of both types of columns is distortional buckling. Also the mode change from distortional buckling to local buckling is inferred due to the provision of stiffener ties. The two stiffener tie system for both T1 and T2 columns failed under combined local, distortional and flexural buckling. But the predominant mode of failure is Distortional and flexural buckling in T1 and T2 columns respectively. T2-C-S1-b50 is predominantly failed under distortional buckling mode, that is, flanges buckle outward in the bottom half portion and flanges moved inwards in the top half portion. T2-C-S2-b50 is failed under flexural buckling mode in the form of sine wave,

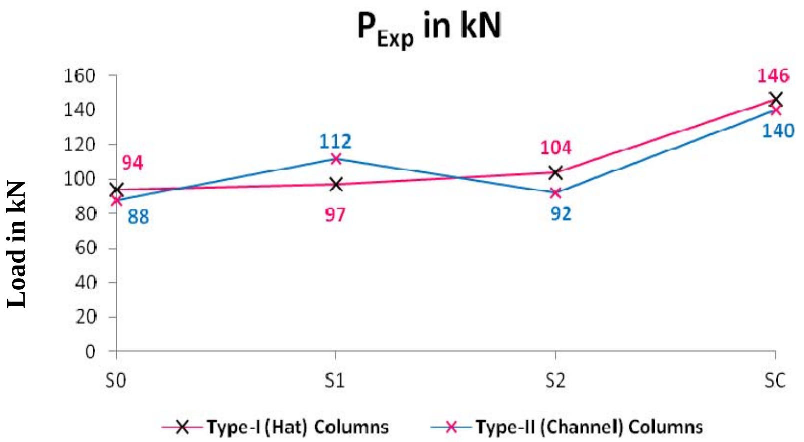


Fig. 6 Test results

both flanges buckled on the same side. Since the flexural buckling has low strength the load carrying capacity is lower than single stiffener tie section. The failure of closed section is not only due to local buckling of closer plate also the local buckling of flange and web are occurred at the same level. The experimental ultimate loads (P_{Exp}) are shown in Fig. 6. The figure shows the variation in distortional strength of both Type-I and Type-II columns with the variation in number of stiffener ties. From the figure it is evident that the provision of stiffener ties increases the load carrying capacity of the columns

3. Numerical analysis

The behaviour of open section rack columns composed of thin walled members is investigated numerically using the finite element software ANSYS 12. Finite element analysis of Type-I and Type-II section without stiffener ties are carried out first and later with stiffener ties at different spacing. All columns are modeled with 4 noded Shell 181 element with sharp corners neglecting the corner radius according to the clause 3 of ENV1993-1-3(1996). The residual stresses of the sections are not included in the model. The strain hardening of the corners due to cold forming is neglected.

From the mesh sensitivity analysis an approximate mesh size of 12 mm × 15 mm (width by length) in all flange and web elements and 7.5 mm × 15 mm in lip are adopted. The elastic modulus (E) and the yield stress of the material (f_y) considered as 200000 N/mm^2 and 248 N/mm^2 respectively. In order to account for the Elasto-plastic behaviour, a bilinear stress-strain curve is adopted, having a tangent modulus (E_t) of 20000 N/mm^2

The end conditions of the columns are pin ended with the loaded end prevented from both rotation about the y-axis, and translations in both x and z directions. On the other hand, the unloaded end is prevented from translation in the three directions x, y, and z and from rotation along the y-axis. A linear buckling analysis is performed to obtain the buckling loads and the associated buckling modes. This is followed by a non-linear ultimate strength analysis to predict the ultimate load capacity. The material and geometric nonlinearity is included in the finite

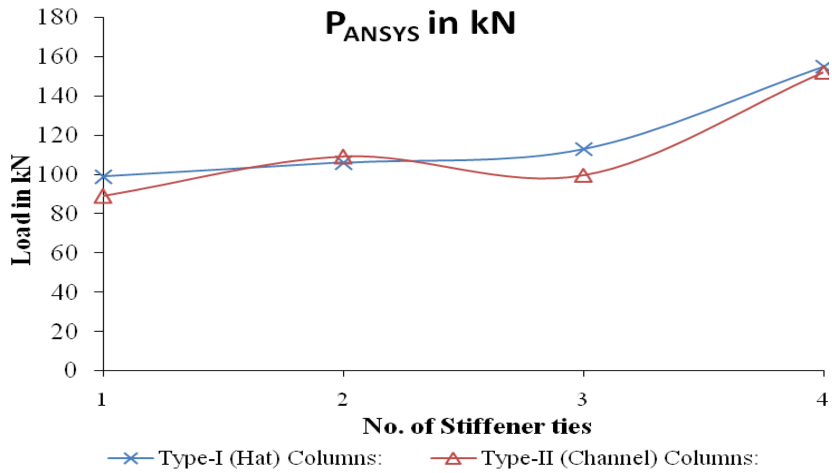


Fig. 7 FEA results

element model. In the nonlinear analysis, initial geometric imperfections are modeled by providing initial out-of-plane deflections to the model. The scaled first elastic buckling mode shape is used to create a geometric imperfection for the non-linear analysis.

The Non-linear Finite Element Analysis is performed for all the tested specimens and the load obtained (P_{ANSYS}) is shown in Fig. 7.

4. Validation of results

Experimental results of all the eight specimens are used to verify the efficiency of the numerical model in predicting ultimate capacities and the corresponding response of the tested specimens.

Fig. 8 shows the correlation of the deformed shape of fully opened Type-I column (T1-H-S0-b50) and double stiffener tie Type-II Column (T2-C-S2-b50). The simulation of response or mode of failure predicted by ANSYS is same as that obtained experimentally. Similar results are obtained for all the specimens.

Table 2 shows the comparison of the test strengths (P_{EXP}) with numerical strength (P_{ANSYS}) for both T1-H and T2-C series. The ratios of the test strength to numerical strength are shown in Table 2. The Comparison of the load displacement relationship for test and numerical results is shown in Fig. 9. It is clear that prediction by the numerical model developed by ANSYS is almost in line with the experimental results

5. Theoretical analysis

The theoretical study involves the analysis of a web stiffened (triangular shape) cold formed steel column for its load carrying capacity. The load carrying capacity is obtained using Indian standards (IS: 801 1975), Australian/ New Zealand Standards (AS/NZS 4600; 2005) and Direct Strength Method by North American Specifications (AISI S100-2007).

Fig. 8 Correlation of FEA with test results

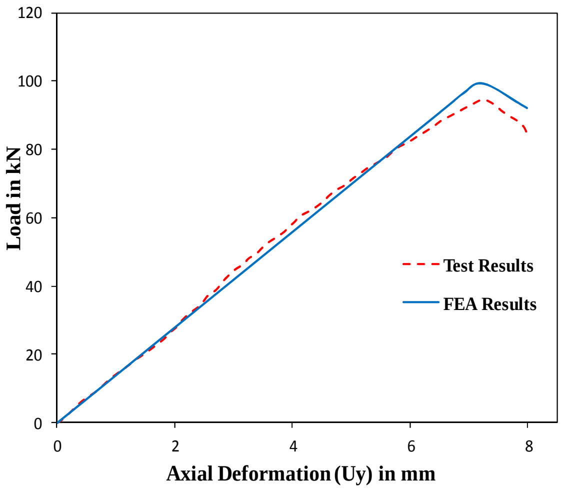


Fig. 9 Comparison of results

Table 2 Comparison of the test strengths (P_{EXP}) with numerical strength (P_{ANSYS})

Specimen ID	P_{EXP} in kN	P_{ANSYS} in kN	P_{EXP} / P_{ANSYS}
Type-I (Hat) Columns:			
T1-H-S0-b50	94.00	99.00	0.95
T1-H-S1-b50	97.00	106.00	0.92
T1-H-S2-b50	104.00	113.00	0.92
T1-H-SC-b50	146.00	155.00	0.94
Type-II (Channel) Columns:			
T2-C-S0-b50	88	89.00	0.99
T2-C-S1-b50	112	109.00	1.03
T2-C-S2-b50	92	99.5	0.92
T2-C-SC-b50	140	152.00	0.92
		Mean =	0.95
		Standard Deviation =	0.0373

For fully opened section, the comparison of the unfactored design strengths predicted using the Australian/New Zealand (4600-2005), Direct strength method (as per North American Specifications) and factored Indian Standard method (801-1975) is shown in Fig. 10. Since the predominant mode of failure of intermediate length columns is distortional, the mode of failure inferred from DSM and AS/NZ specifications was distortional buckling. Whereas in IS method, the mode of failure inferred was flexural-torsional as there is no check for distortional buckling. Hence, the Fig. 10 shows an elevated result for IS method than the other two specifications. So, it is mandatory that the IS code has to be revised incorporating the distortional buckling check.

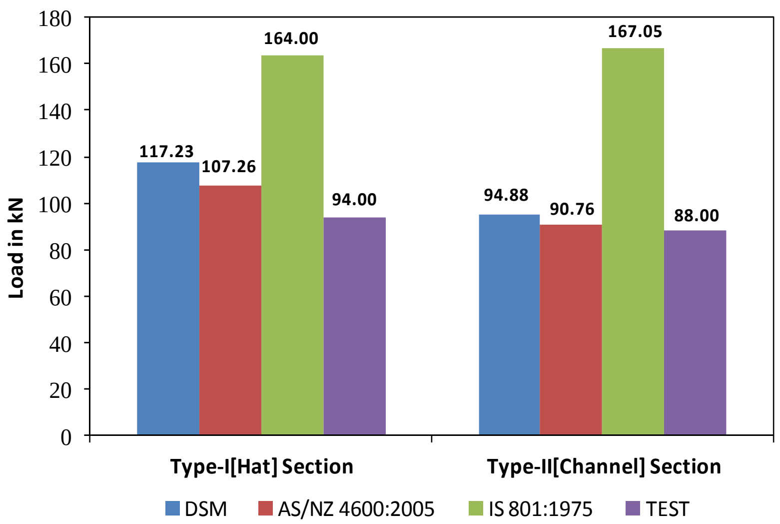


Fig. 10 Theoretical analysis results

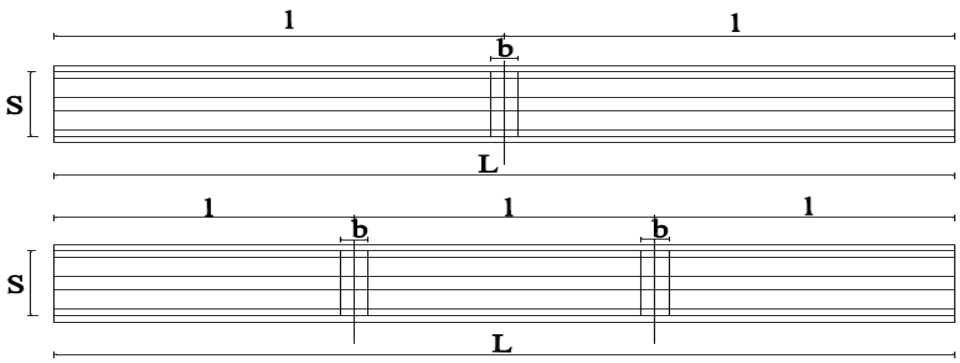


Fig. 11 Geometry of the columns

6. Parametric study

There are several parameters that have direct influence on the response/behaviour of the column. The description of the parameters that are illustrated in Fig. 11 are as follows:

- The overall column length (*L*), which is represented in the form of an integrated slenderness ratio (λ) of the Column.
- The term l/L which is defined as the ratio of the center to center distance (*l*) between stiffener ties-to-the overall length (*L*) of the Column.
- The term *b/S* which is defined as the ratio of the width of the stiffener tie plate-to-the depth of the stiffener tie plate.
- The term t_s/t which represents the ratio of the stiffener tie plate thickness-to-the thickness of the cold formed section.

It is shown that the FEM closely predicted the column strengths and the behavior of the tested specimens. Hence the model was used for an extensive parametric study by varying the width of the stiffener tie (*b*) as 25 mm, 50 mm, 75 mm & 100 mm for each type of column. For each '*b*' five specimens are considered by varying the number of stiffener ties from 1 to 5 for each type of column. A total of 40 Nos of specimens (i.e., 20 of Type-I Column and 20 Nos of Type-II columns) were analyzed numerically with the help of the developed model.

In case of Type-I column, the depth of the stiffener tie is 146.8 mm. Hence four group of sections are formulated based on the 'b/S' ratio. They are 0.17, 0.34, 0.51 & 0.68. Since the number of stiffener ties varies in each group from 1 to 5, the '*l/L*' ratio varies from 0.50, 0.33, 0.25, 0.20 and 0.17. Similarly, in case of Type-II column, the depth of the stiffener tie is 120 mm. Hence four group of sections are formulated based on the 'b/S' ratio. They are 0.21, 0.42, 0.63 and 0.83. The variation of '*l/L*' is similar to Type-I columns.

The Slenderness ratio of both Type-I and Type-II column is 30.65. The study is carried out only for 't_s/t' equals to one. The Numerical analysis is carried out for all the specimens and the results are shown in Figs. 12, 13 and Figs. 14, 15 for Type-I columns and Type-II columns respectively.

In the numerical parametric study, it is observed that both Type-I and Type-II open columns failed under distortional buckling. All the columns with number of stiffener tie system and different width failed in combined local and distortional buckling except with two stiffener tie system. The two stiffener tie system in both types of columns failed in combined local, distortional and flexural buckling. But the predominant mode of failure in T1 type of column is Distortional and flexural buckling in T2 columns.

6.1 Effect of depth of stiffener ties (S) and centre to centre length between stiffener ties (l) on the column strength

Fig. 12 and Fig. 13 demonstrates the relationship between the normalized ratio of the centre to centre length between stiffener ties to the overall length of the Column (*l/L*), and the normalized ratio of the ultimate load to the yield load of the column (P_u/P_y) for different values of (*b/S*). Obviously, the centre to centre length between stiffener ties has a significant effect on the strength of columns. As the centre to centre length between stiffener ties increases, the corresponding ultimate load decreases.

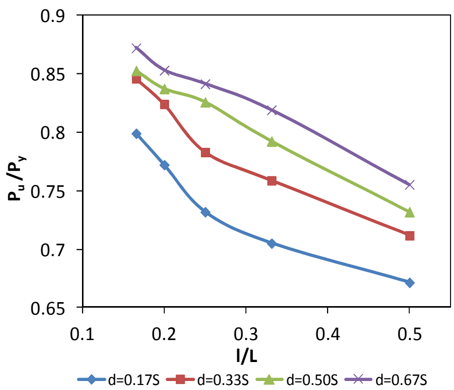


Fig. 12 P_u/P_y Vs *l/L* for T1-H series

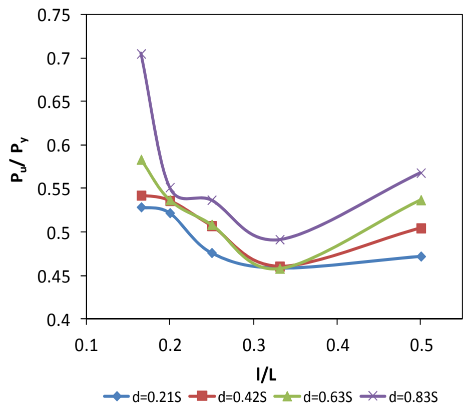


Fig. 13 P_u/P_y Vs *l/L* for T2-C series

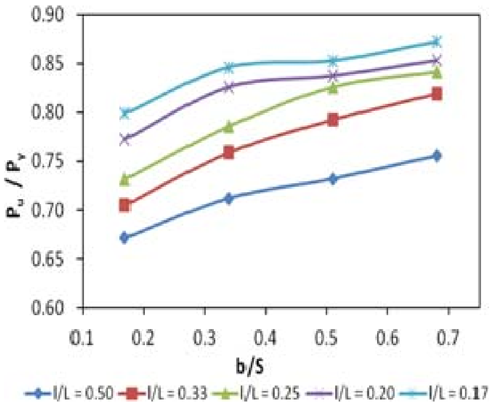


Fig. 14 P_u/P_y Vs *b/S* for T1-H series

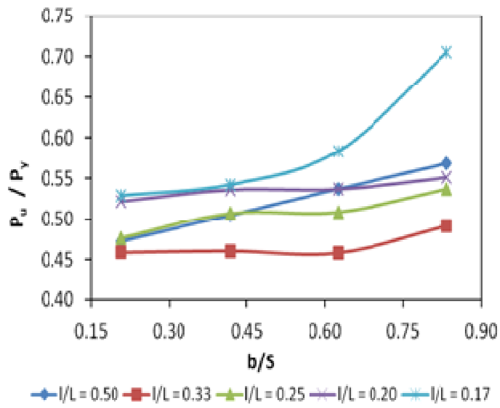


Fig. 15 P_u/P_y Vs *b/S* for T2-C series

6.2 Effect of the centre to centre length between stiffener ties -to-the overall length of the column (l/L)

The influence of varying the number of stiffener ties in both Type-I and Type-II column on its ultimate load is illustrated in Fig. 12 and Fig. 13. Increasing the number of stiffener ties from 1 to 5 improved the ultimate strength of the columns for both the type of sections.

6.3 Effect of the stiffener tie plate width-to- depth of the stiffener tie plate (b/S)

Fig. 14 and Fig. 15 demonstrate the influence of changing the width of the stiffener tie plate on the column strength for a slenderness ratio of 30.65. Apparently, for Type-I columns as shown in Fig. 13 the column strength increases with the increase in width of the stiffener tie plate. Similar pattern is found for Type-II columns also. In Type –II section, two stiffener tie system with different breadth also predominantly fails under flexural buckling in Numerical analysis which shows the similar trend of experiment. Throughout this parametric study the failure of stiffener tie plate is not observed.

7. Sumary and conclusions

The behaviour and ultimate strength of two types of intermediate length cold formed steel columns with stiffener ties are investigated by varying the breadth and spacing of the stiffener ties are presented in this paper. The ends of the columns are considered as pinned. The finite element model including geometric and material nonlinearities has been developed and verified against experimental results. The finite element analysis predictions were generally in good agreement with the experimental ultimate loads of two types of columns. An extensive parametric study of varying the breadth and number of stiffener ties has been performed using the developed finite element model. The following conclusions are derived from the study.

The experimental investigation on all the specimens reveals that the effects of stiffener ties in intermediate length open section columns are

• Changes the mode of failure, from distortional buckling to the interaction of distortional and local buckling with the increase in number of stiffener ties.

• The strength of the column for Type-I section uniformly increases with the increase in number of stiffener ties as it enhances the torsional rigidity of the section.

• The strength of the column for Type-II section non-uniformly increases with the increase in number of stiffener ties

The finite element analysis on all the specimens reveals that

• The mode of failure and load carrying capacity estimated by developed FE-model closely simulates with the results of experimental investigation

Comparison of load carrying capacity of the control specimen (i.e., fully open section) obtained by theoretical, numerical and experimental analysis reveals that

• The results obtained based on the various codal provisions are unconservative.

• The mode of failure predicted by IS codal provision is Flexural torsional and the load carrying capacity is also on the higher side because the code does not provide check for distortional buckling. This means that a further improvement of IS 801:1975 by calibrating the resistance formulae to the experimental data is required

The extended parametric study by varying width of the stiffener ties and number of stiffener ties in case of both Type-I (Hat) and Type-II (Channel) section reveals that

• As the centre to centre length between stiffener ties increases, the corresponding ultimate load decreases.

• Increasing the number of stiffener ties results in improved ultimate strength of the columns

• The ultimate column strength increases with the increase in width of the stiffener tie plate

• The stress reduction factor uniformly increases with the increase in the spacing of the stiffener ties for Type-I section.

• The stress reduction factor non-uniformly increases with the increase in the spacing of the stiffener ties for Type-II section.

• Furthermore, utmost the Type-I Section column performs better than the Type-II Sections with the provision of stiffener ties

The authors intend to pursue additional testing and analysis to determine the capacity of intermediate length columns with stiffener ties, to more closely define the role of stiffener ties and other details

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