Investigation on Innovative Cold-Formed Steel Built-Up Columns Using Lipped and Unlipped Channels

V. A. Veera Vignaesh, S. T. Dhaarini, and C. Manoj Kumaar

1 Introduction

Presently, cold-formed steel (CFS) sections are broadly employed in both commercial and residential structures. Many researchers are coming up with different ideology on built-up sections to provide an economical design for buildings [1–6]. The effective design of compression members for CFS stubs, columns, and beams has been studied with different considerations like with and without stiffeners, varying box sections, fitting screw distance and CFS with lipped and unlipped sections [1, 4, 7–9]. The main advantages of CFS are lightweight, high strength and stiffness, quick and easy erection, uniform quality, more precise details, and cost-effective shipping and handling and they can be manufactured in tiny machine shops and can be fashioned into a wider range of pieces [6, 8–11]. The novelty of work in this paper is a new innovative built-up column consisting of combination of box and I section is developed and connected using screws, while the screw spacing is kept constants for all the heights of the column. The buckling load is used as a design criterion for compression members. The various buckling modes like local, distortional, and global modes decide the ultimate strength of the column. This research aimed at finding the axial load carrying capacity, deformation, and stress distribution in the built-up columns both experimentally by conducting axial compression test and analytically by using Abaqus 4.16 software. Also, the load versus deflection behaviour is compared for all specimens. The experimental and analytical results are compared and validated to derive the suitability of each specimen in the construction industry.

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2 Materials and Test Specimen

2.1 Materials

Cold-rolled sheet of grade IS 513 CR2 of 2 mm thickness is used to build up the columns and Grade M12 screws are fitted vertically throughout the column with equal spacings. Cutting and bending process is carried out in hydraulic machine.

2.2 Test Specimen

For numerical analysis, a total of 18 specimens is analysed using ABAQUS 4.16 software by keeping the cross section dimension and thickness as constant and the height of the column is varied from 300 to 2000 mm by increasing at an interval of 100 mm, whereas for Experimental analysis, 4 specimens of height 300, 500, 1000, and 1500 mm as shown in Fig. 1. are fabricated with cold-rolled sheet of thickness of 2 mm and two plates of size 300 × 300 mm are placed at top and bottom of each column and CO_2 welding is done. This is done for equal transfer of load throughout the whole column. The cutting and bending process is carried out in hydraulic machine. The sections of arranged by heights as per designed cross section and screws are drilled.

Fig. 1 Fabricated built-up columns of height 300, 500, 1000, and 1500 mm

2.3 Geometrical Properties of Sections

A new innovative built-up column is developed by a combination of box and I section joined using screws consisting of two channel sections with lip joined back-to-back along with the web and two channel sections without lip connected around the outer surface of the flanges of the channel section with lip. The screw spacing is kept constant at 100 mm throughout for all heights of the column. Figures 2 and 3 show the cross section of the column and section of the 1000 mm height column, respectively.

Thickness of sheet used $t = 2$ mm
Vertical Screw spacing, $s = 100$ mm
Slenderness ratio = KL/r
According to the AISI and AS/NZS,
Modified slenderness ratio, $(KL/r)_m = \sqrt{(KL/r)_0^2 + (S/r_i)^2}$
When, $(S/r_i) \leq 0.5\ (KL/r)_0$
$(KL/r)_0$—Overall slenderness ratio of the built-up column.
S—Spacing of the intermediate screws
r—Radius of gyration
r_i—Minimum radius of gyration of a single angle section
K—Factor of effective length

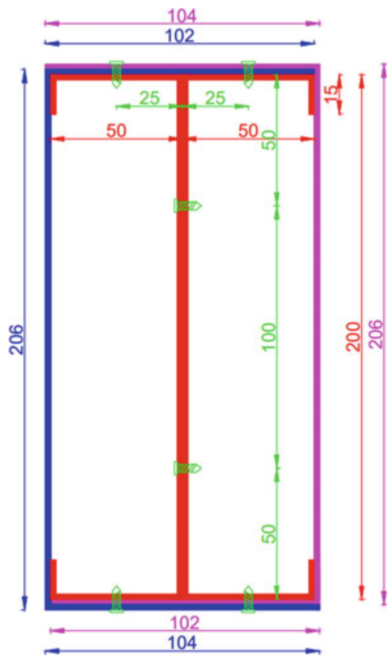

Fig. 2 Cross section of the built-up column

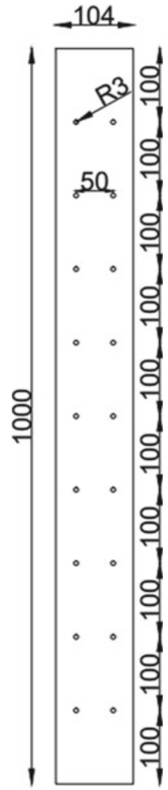

Fig. 3 Longitudinal section of column of height 1000 mm

2.4 Numerical Analysis

The finite element models for the specimen are created and analysed using Abaqus 4.16 software. In finite element analysis, buckling analysis is carried out to study linear behaviour initially. The buckling modes of columns and eigen values are observed. Then using Rik's method, nonlinear behaviour is studied, the curve for load against displacement is obtained for the columns.

2.5 Geometry and Material Property

The three-dimensional geometry of the built-up columns is formed. To account for nonlinearity in material, the values of stresses and strains are assigned to the models. The investigation and validation are carried out using the ABAQUS classic metal plasticity model. To obtain the accuracy of the result, mesh convergence study is performed, hence 10 mm mesh size is applied on all models. The Von Mises yield criterion was used for obtaining the stress–strain curve for the CFS section.

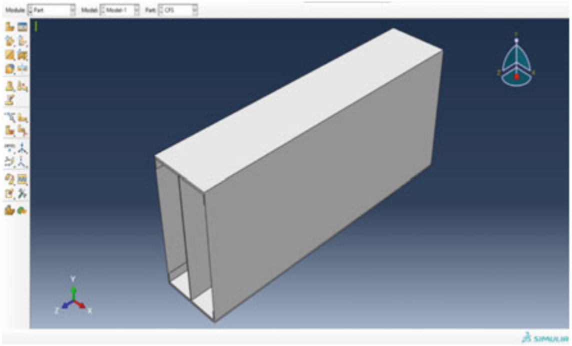

Fig. 4 Geometry and material property

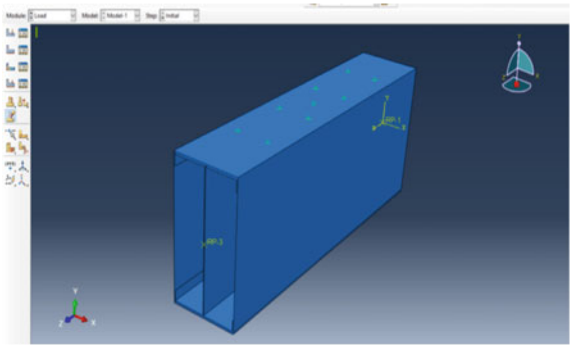

Fig. 5 Boundary condition

The mechanical properties of the section such as Young's modulus of Elasticity as 200,000 MPa, yield strength as 200 MPa, and Poisson's Ratio as 0.3 are assigned. Figure 4 shows the geometry and material property of the FEA model. The boundary conditions as assigned to the model are shown in Fig. 5.

2.6 *Experimental Analysis*

Axial load test is performed for all the four specimens of heights 300, 500, 1000, and 1500 mm are tested for axial loading and at the mid height two dial gauges are placed and end of the columns to determine the deflection for 300 and 500 mm columns. While for the other specimens of height 1000 and 1500 mm, Linear Variable Differential Transformer (LVDT) is used. The specimen of the height of 300 mm was tested using a compression testing machine (CTM), and the specimen of the height of 500 mm was tested using universal testing machine (UTM). Whereas the other specimens of height 1000 and 1500 mm were tested using column loading machine. The four CFS built-up columns of height 300, 500, 1000, and 1500 mm are fabricated and tested under axial load and results are obtained.

3 Results and Discussions

3.1 Results

From the buckling analysis, the eigen values and the buckling modes are derived based on linear analysis as shown in Fig. 6. The nonlinear analysis is performed to study the load versus deflection pattern by Rik's method. The slenderness ratio, modified slenderness ratio, and axial strength for all 18 columns are obtained from numerical analysis and given in Table 1.

An experimental investigation was carried out for the columns of height 300, 500, 1000, and 1500 mm. As a result of axial load test, the failure pattern of buckling is observed in these columns as shown in Figs. 7, 8, 9, and 10 for the column heights of 300, 500, 1000, and 1500 mm, respectively. Figures 11, 12, 13, and 14 show the curve for axial load (kN) versus deflection (mm) for the column heights of 300, 500, 1000, and 1500 mm, respectively. Also, Table 2 gives the comparison of experimental and FEA load values of the columns, respectively.

3.2 Discussion

In experimental and numerical analysis, the results axial capacity of columns is obtained. The outcome of this work summaries as follows:

- The difference in axial strength outcomes of the experimental and finite element model is about 3% to 6%. From this, the FEA results show good acceptance with the experimental values, and hence FEA from Abaqus 4.16 software is reliable for the determination of axial strength of the column.
- The slenderness ratio of all the columns analysed lies between 8 and 60. The height of the columns was 300 to 2000 mm with 100 mm increment of each column, respectively. Hence, this cross section of the built-up column can be mainly used as a stub column, short column, and intermediate column only.
- As specified in the cross section, the vertical spacing of the screws was 100 mm which did not fail during the experimental testing of the columns.
- The load versus deflection graphs of the columns show that the maximum deflection of experimental investigation is greater than the FEA results. The deflection variation between experimental and FEA is about 50% for 300 mm column, 44% for 500 mm column, 14% for 1000 mm column, and 10% for 1500 mm column. Therefore, for lateral deflection of the column, FEA results are not reliable.
- On increase of column height, the slenderness ratio is increased, and axial strength is decreased.
- In the case of 300 mm column height local buckling occurred at both top and bottom during both the analysis. Since the height is very small, the load was transferred till the bottom.

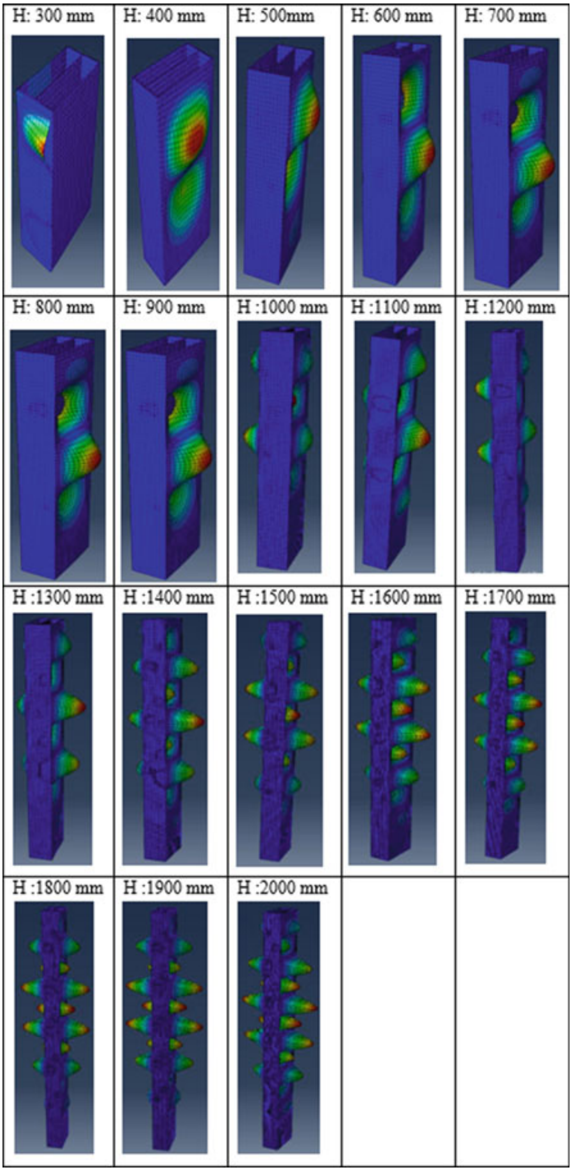

Fig. 6 Buckling of columns from FEM analysis

- In the case of 500 mm column height, local buckling occurred at only at top during both the analysis.
- In the case of 1000 mm column height, local buckling occurred maximum at top and minimum at intermediate during both the analysis.
- In the case of 1500 mm column height, local buckling occurred minimum at top and maximum at intermediate during both the analysis.

Table 1 Numerical results of CFS built-up columns

Column height (mm)	Slenderness ratio $\left(\frac{KL}{r}\right)0$	Modified slenderness ratio $\left(\frac{KL}{r}\right)$m	Axial strength, P_{FEA} (kN)
300	8.84	9.35	534.89
400	11.79	12.18	447.12
500	14.74	15.05	388.57
600	17.69	17.95	361.13
700	20.64	20.86	346.62
800	23.59	23.78	341.09
900	26.54	26.71	340.39
1000	29.48	29.64	340.16
1100	32.43	32.58	339.06
1200	35.38	35.51	333.91
1300	38.33	38.45	329.27
1400	41.28	41.39	324.66
1500	44.23	44.33	322.62
1600	47.18	47.28	319.88
1700	50.13	50.22	317.63
1800	53.08	53.16	315.70
1900	56.03	56.11	314.23
2000	58.97	59.05	312.93

Fig. 7 Buckling of 300 mm column

Fig. 8 Buckling of 500 mm column

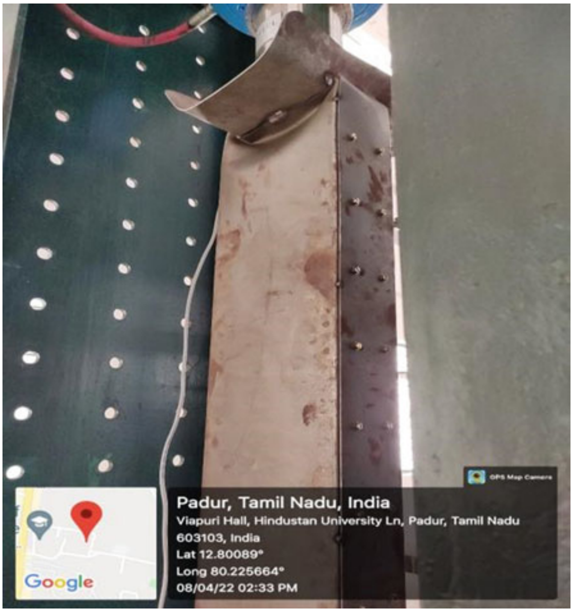

Fig. 9 Buckling of 1000 mm column

Fig. 10 Buckling of 1500 mm column

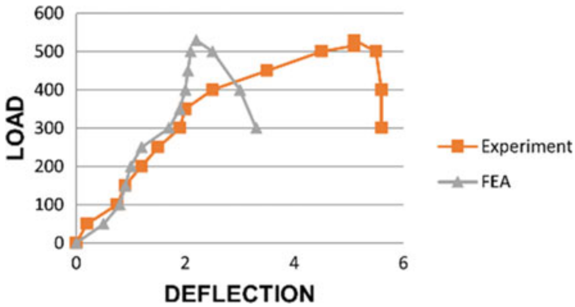

Fig. 11 Comparison of experimental and FEA results of 300 mm height column

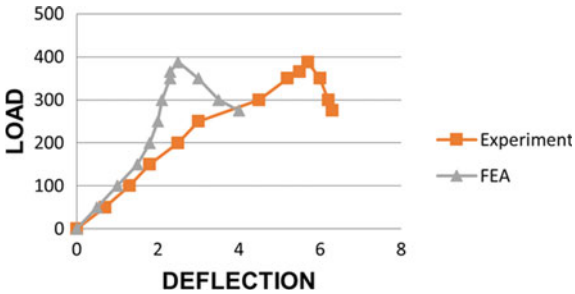

Fig. 12 Comparison of experimental and FEA results of 500 mm height column

- Due to the increase in the slenderness ratio, the change in the failure pattern doesn't seem to improve for all the columns. The failure mode was either local buckling or a combination of local and flexural buckling for all the columns.
- Compared to the previous studies, the axial load capacity of the built-up column has improved without the application of stiffeners.

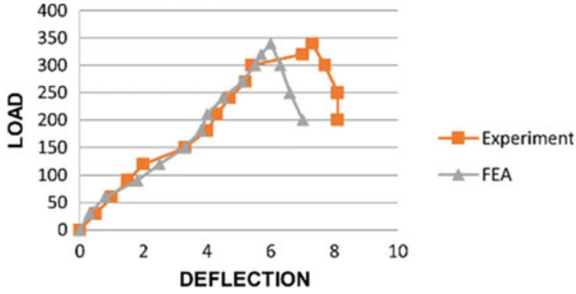

Fig. 13 Comparison of experimental and FEA results of 1000 mm height column

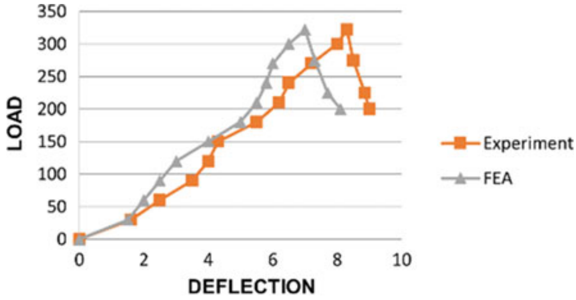

Fig. 14 Comparison of experimental and FEA results of 1500 mm height column

Table 2 Comparison of numerical and experimental load carrying capacities

Height (mm)	FEA load (kN)	Experimental load (kN)
300	534.89	515.5
500	388.57	365
1000	340.16	319
1500	322.62	303

- The performance of this cross section is better when compared to the built-up columns using battens.
- While experimental analysis, on application of load no screw underwent any failure.
- Future study can be performed with varying screw pattern and spacings.
- Further development of this work is to apply the same procedure for long columns and study their axial strength and behaviour.

4 Conclusion

In this research, 4 experimental models and 18 finite element (FE) models of numerical studies were done to understand the axial load carrying capacity and structural behaviour of the designed CFS built-up column with varied heights. The failure modes, axial load carrying capacity, and load against lateral deflection were discussed. The FE model shows good agreement with the experiment outcomes. Since the modified slenderness ratio of the all the columns falls under 8 to 60, the CFS built-up column can be used as stub columns, short columns, and intermediate columns in construction.

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