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EXPERIMENTAL STUDY ON THE BEHAVIOUR OF INTERMEDIATE LENGTH WEB STIFFENED COLD-FORMED STEEL COLUMNS WITH PERFORATED SPACERS

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ABSTRACT

The present work describes the study on the Experimental investigation on the web stiffened intermediate length cold form steel column with perforated spacers under axial compression. In this work the failure modes and ultimate loads are analysed by using perforated spacers at different intervals. Two types of sections are considered for this study. Fourteen columns are experimented out of which, one column from each type is control specimen and others are by providing with one, two and three spacers having width of 50 mm & 20 mm. The section properties and length of the columns are predicted by performing elastic buckling analysis using CUFSM software. The column strength obtained by the Experimental analysis are presented and discussed.

Keywords: Intermediate length columns; cold-formed steel columns; web stiffened lipped channels; thin walled members; distortional buckling; spacers.

1. INTRODUCTION

In compression, cold formed mono symmetric cross-section can exhibit three types of instability modes: local, distortional and flexural or flexural-torsional buckling. Local buckling occurs in lower half wave lengths and global buckling occurs at long half wave lengths. Distortional buckling plays an important role in the use of mono symmetric cold formed steel compression members. The occurrence of the distortional buckling mainly depends on the cross section profile and the length of the member. Distortional buckling occurs at intermediate length between the lengths where local and overall buckling occurs.

Hancock [1] presented a detailed investigations on a range of buckling modes (Local, distortional, and flexural-torsional) in a lipped channel sections. Lau and Hancock [2]

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provided design strength curves for sections where the distortional buckling stress and yield stress were approximately equal. Kwon and Hancock [3] investigated the simple lipped channels and lipped channels with intermediate stiffener under fixed boundary conditions. They choose section geometry and yield strength of steel to ensure that a substantial post-buckling strength reserve occurs in a distortional mode for the test section. Leach and Davis [4] done an experimental verification on the generalized beam theory applied to interactive buckling problems of columns. Narayanan and Mahendran [5] studied the distortional buckling strength of few innovative and complex geometrical sections. Recently, a new idea for improving the distortional strength of intermediate thin walled open column section has attracted by the several researchers (Talikoti and Bajoria, [6]). Similarly, Veljkovic and Johansson [7] proposed an innovative idea for improving torsional stiffness of open thin walled section by making the section partially closed by using spacers/closers.

In continuation of this, a series of experimental, numerical and theoretical studies are reported by Anbarasu et al. over a variety of innovative sections of intermediate length columns for improving distortional buckling behaviour by providing the spacers. Anbarasu et al. [8-13] and his research group attract considerable attention over this topic. This study made an attempt to experimentally study the behavior and strength of web stiffened intermediate length CFS column with perforated spacers. Perforated pacers are the transverse elements of CFS sheet used to connect the lips of the open sections using self-driving screw. For this work, two types of sections are considered one is channel section and the other is hat. Totally fourteen columns are tested (7 Nos. of Channel and 7 Nos. of hat section). The behavior and the strength of the tested specimens are elaborately discussed and presented.

2. SELECTION OF SECTIONS

The cross sections were determined based on the available literature, standard sections, thickness commonly used for structural and architectural applications, elastic buckling analysis (from the CUFSM program) and the constructability of the sections in the Workshop.

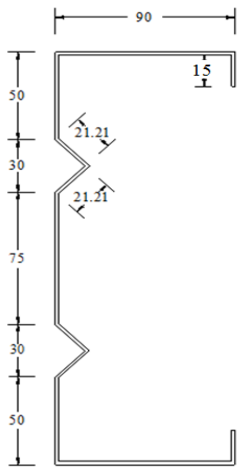


Fig. 1(a). Channel section columns

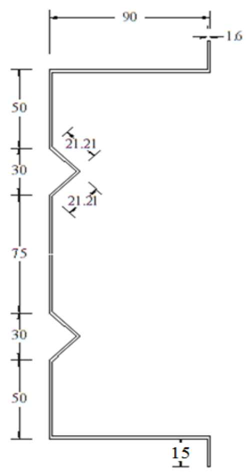
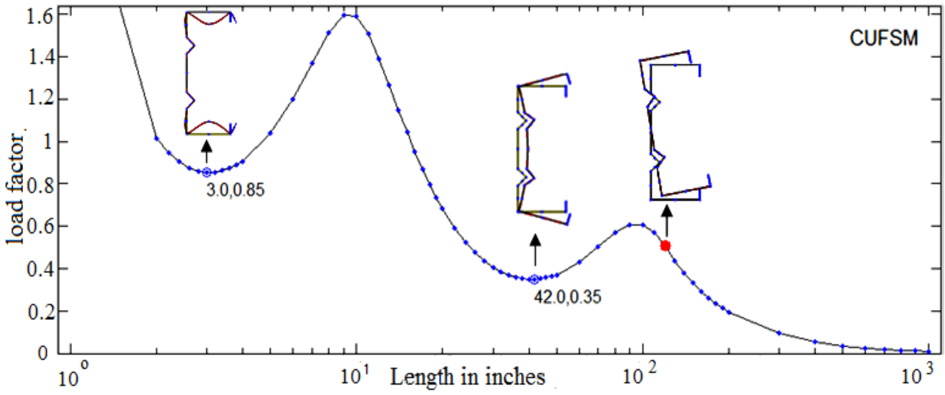


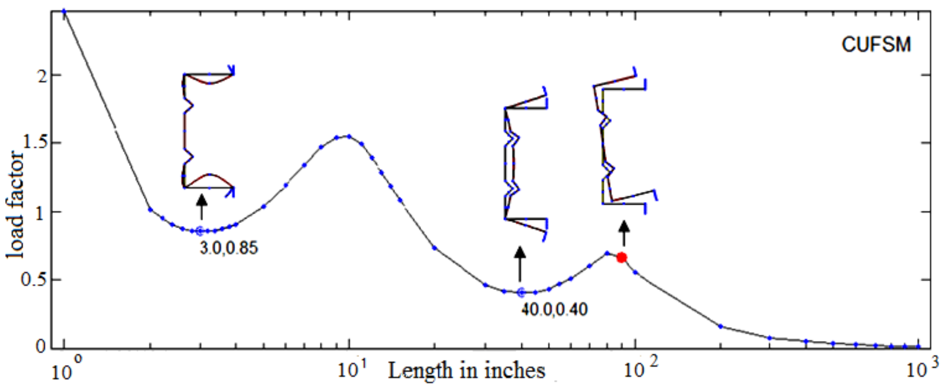
Fig. 1(b). Hat section columns

The dimensions and the section configuration for channel and hat section are shown in Fig. 1.The appropriate dimensions of the cross section are finalized keeping the plate slenderness ratio (b/t) within limits to eliminate local buckling according to IS:801-1975 [14] and AS/NZS 4600-2005 [15]. The selected sections were analysed using CUFSM to ensure distortional buckling, and the buckling plots obtained for channel and hat section column respectively, are shown in Fig. 2(a) and 2(b). The length of the specimen was selected as a multiple of buckling half wave lengths from CUFSM [16] analyses.

Fig. 2 (a) of the CUFSM program results shows that the pure local buckling occurs up to a half wavelength of 76.2 mm and pure distortional buckling from 241 mm to 2413 mm. The minimum elastic distortional buckling stress occurs when the half wave length equals 996 mm. Therefore, the column length was selected as 1000 mm for the channel section of 1.6 mm thickness so that pure distortional buckling would occur. The interaction between local and distortional buckling was expected to occur in the compression tests of the chosen length of column for the channel section. By the same way the hat section column were first designed based on CUFSM program results.



(a) for Channel Section Columns



(b) for Hat Section Columns

Figure 2. Buckling Plot

The elastic buckling analysis results of the channel and hat sections are presented in Table 1.

Table 1: Elastic Buckling Analysis Results

Specimen Type	Buckle wave length (mm)		Elastic buckling stress (Mpa)		Length chosen
	Local	Distortional	Local	Distortional	
Channel section	76.20	996.0	297.50	122.50	1000
Hat section	76.20	958.0	297.50	140.00	1000

3. EXPERIMENTAL PROGRAM

3.1 Test Specimens

Totally, 14 pin-ended intermediate length cold-formed steel columns, seven Nos. of channel columns and seven Nos. of hat columns with spacers were tested to failure. The length and cross sectional dimension of the specimens is selected to meet with the distortional buckling mode. All the specimens are fabricated by press braking operation from the locally available cold rolled sheets of 1.6 mm thickness. All the specimens had a length of 1000 mm. A test program was conducted using a column testing machine on cold-formed steel columns subjected to axial concentrated load. The self-driving screw was used as fastener to connect the lip of the section with the spacer plates. The perforated spacers and closed spacers are connected throughout to the lip of the specimen by using self driven screws of 5mm diameter and the spacer thickness is 1.6mm. The required edge distance is provided to avoid the screw connection failure. Seven screws are driven in each side of the specimen.

3.2 Specimen labelling

The representation of the labelling is the first term 'C' or 'H' denotes the type of cross section as channel or hat section, second term 'PS1' indicates the number of perforated spacer, PSC means closed perforated spacer. The last term 'D50' indicates the depth of the spacer as 50 mm.

3.3 Material properties

The coupons were prepared from the CFS sheet used to fabricate the specimens. The tensile coupon tests were carried out in accordance with IS 1608-2005 (Part-1) [17]. The material properties obtained from coupon test are shown in Table 2.

Table 2: Material Properties of the Steel

Sl. No.	Thickness (mm)	Yield Stress f_y (Mpa)	Ultimate Stress f_u (Mpa)	Modulus of Elasticity E (Mpa)	% of Elongation
1	1.6	350	450	2.01×10^5	27

The stress strain curve of a tensile coupon test on a coupon made from the parent CFS sheet is shown in Fig. 3.

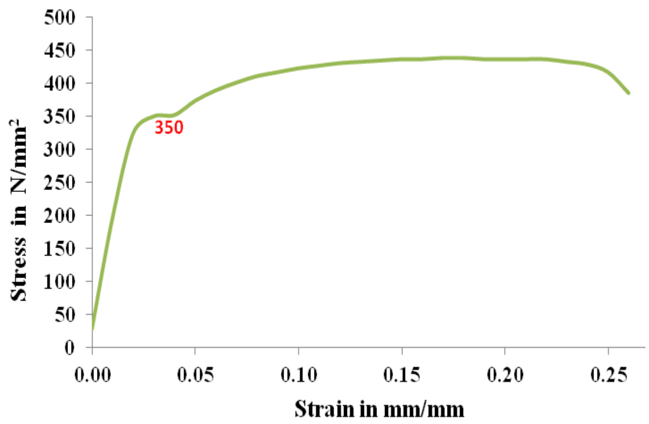


Figure 4. Stress-strain curve

3.3 Test Setup and procedure

The column compression tests are performed with the 400 kN capacity loading frame. The ends of the test specimens were machined to ensure a perfect contact with the end plates and a uniform compression of the column. The specimens made for this research have sharp corners, and the corner radius was negligibly small. The ends of the column specimens is welded with two 10 mm thick carbon steel end plates.

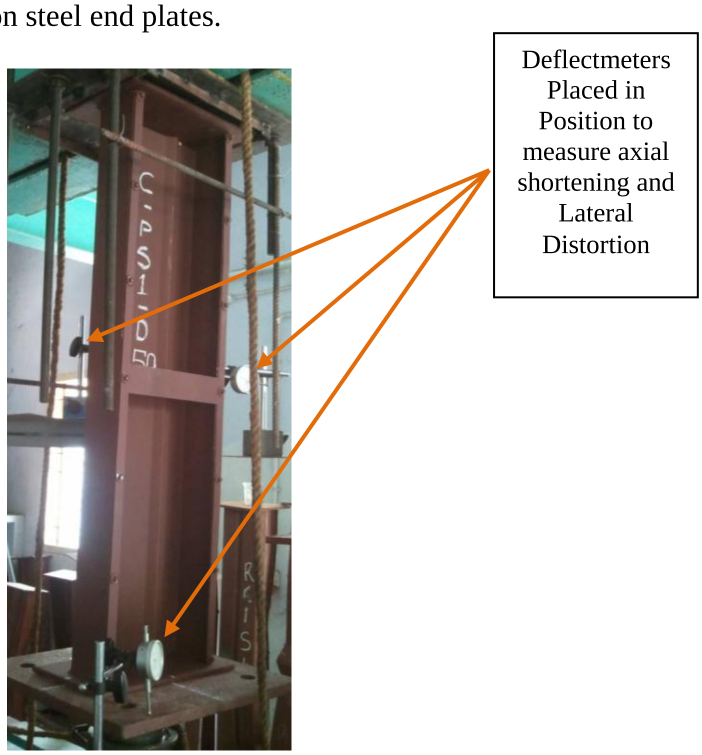


Figure 4. Experimental setup

The specimens are mounted between the platens and its verticality is checked. At either ends between the platens and the end plates of the specimen rubber gasket were placed to facilitate the hinge condition at either supports [8-13]. The experimental test setup for the column tests are shown in Fig.4. Pre-load of less than 5kN was applied so that the specimen is fully in contact with the end plates. This is to hold the test setup in position and to eliminate any possible gap and movements between the end plates and the specimen. The load distribution plate is placed between the load cell and the specimen to avoid the specimen fail by bearing. Dial gauges were placed at mid height on web and flange to measure lateral displacement and one at the lower end to measure the axial deformation. The lateral and axial displacements of the column were recorded after every increment of load. The critical load at which the deflection increased without increase of load is also recorded.

3.4 Test results

The ultimate loads and the corresponding failure modes obtained from the tests are given in Table 3.

Table 3: Experimental Test Results tested Columns

Test No.	Specimen Designation	No. of Perforated Spacers	P_u (kN)	Failure Mode
1	C-PSC	Closer	147.25	L+D
2	C-PS1-D20	1	122.50	D
3	C-PS2-D20	2	158.50	L+D
4	C-PS3-D20	3	173.50	L+D
5	C-PS1-D50	1	138.00	L+D
6	C-PS2-D50	2	168.00	L+D
7	C-PS3-D50	3	178.50	L+D
8	H-PSH	Closer	151.25	L+D
9	H-PS1-D20	1	137.14	D
10	H-PS2-D20	2	161.25	L+D
11	H-PS3-D20	3	177.14	L+D
12	H-PS1-D50	1	139.75	L+D
13	H-PS2-D50	2	167.14	L+D
14	H-PS3-D50	3	183.25	L+D

Note: Pu = Ultimate load, L = Local buckling, D = Distortional buckling,

(a) Before testing

(b) After testing

Figure 5. Channel section specimens

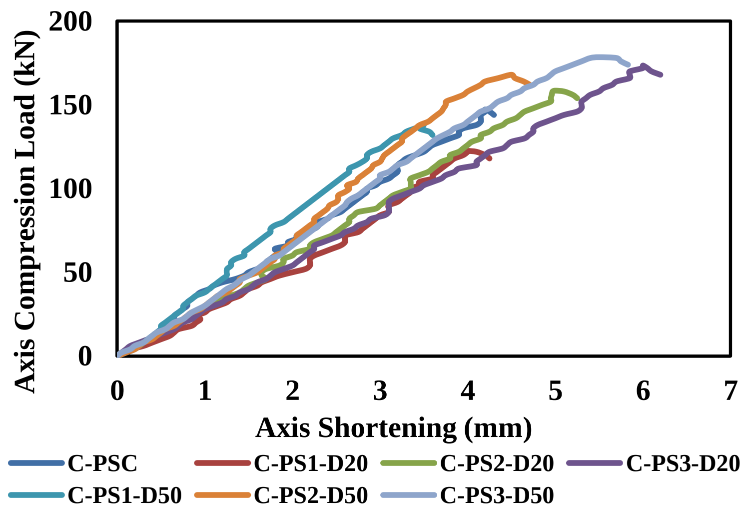
(a) Before testing

(b) After testing

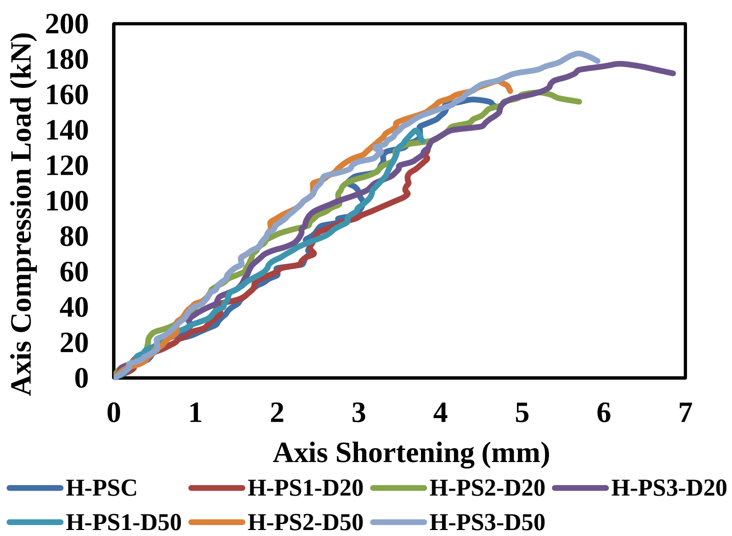
Figure 6. Hat section specimens

Fig. 5 and Fig. 6 show the channel and hat section specimens before and after testing respectively. On observation it clearly indicates that the predominant mode of failure of the section both types of columns is distortional buckling. In the early loading stages (elastic range), all the columns exhibiting a clearly visible distortional buckling deformed configurations. At the last, in the loading steps, the distortional deformation is associated with the local mode. Also the failure mode change from distortional buckling to local buckling is inferred due to the provision of spacers. From the experimental results it is found that the provision of 20 mm spacers is not enough to increase the load carrying capacity and also not able to failure mode from distortional buckling. Fig. 7 shows the representative sample of load vs axial deformation curves obtained from the experimental results are presented.

The Load Vs axial deformation curves for all the tested columns in both series are shown in Fig. 7. With the addition of spacers in both the type of sections, the failure mode shifted from distortional mode to interference of local and distortional mode, since the spacers help in enhancing the torsional rigidity of the section, their by enhancing the load carrying capacity.



(a) For Channel section series



(b) For Hat section series

Figure 7. Load Vs Axial deformation Curve

4. SUMMARY AND CONCLUSIONS

The effect of perforated spacer in the web stiffened intermediate length column with hinged end conditions at both ends is analyzed to study the buckling behaviour and capacity. Experimental Investigation carried out for closed section and section with spacers of size 20 mm and 50 mm for 1to 3 Nos. of spacers. The following Conclusions are derived based on the experimental results.

- The effect of perforated spacers on the ultimate strength under axial compression is found. The provisions of spacers increase the ultimate strength for both types of sections.
- The ultimate strength increases with increase in depth and number of spacers.
- The spacer plate improves the torsional rigidity and increases the stiffness of the section.
- Depth and spacing of spacer plates significantly affect the overall performance of the sections.
- This investigation has shown that the use of spacers at proper width and intervals do help increasing not only load carrying capacity but also vary mode of failure due to enhancement in the torsional rigidity of the sections.
- Hat section with perforated spacer gives better result than channel section with perforated spacer.

This investigation has also shown that further research is needed in this area to add the effect of spacers in the design codal provisions for intermediate length columns.

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