Numerical Investigation on Cold Formed Steel Column with Stiffeners

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Abstract— **Cold-formed members are typically manufactured as built up sections with perforations to facilitate various services in building construction. To span for more distance and increase the torsional stiffness of column built-up sections were better solution. Some built-up cross sections consisted of two single C sections, such as built-up I and box sections, are commonly used as columns. A built-up column of box section with intermediate stiffener on web was analyzed in this study. When an unusual or new section is optimized from the conventional section it should satisfy the recommendations provided by various country codes. In this study the optimized section dimensions were compared with IS 801 and AISI 2004 recommendations for qualified column cross section. The main objective the study is to define the column cross section parameters such as L:B ratio, Sub element width, stiffener dimensions and edge distance for self-drilling screw connection were according to IS 801 and AISI 2004 recommendations. To determine those parameters numerical analysis (Finite strip analysis) is performed using CUFSM software. The parametric study was conducted in CUFSM software considering for L:B ratio as 1:1.5,1:2,1:2.5,1:3,1:3.5 and 1:4; for stiffener width as 10, 12, 14; for stiffener depth as 5,6,7,8,9,10 and for sub element width as 36,38,40,45,50,55, 60 to a column having a half wave length of 1m under axial compression. By the results obtained from the CUFSM tool the optimum cross section is finalized. The acquired results were compared against IS 801 and AISI 2004 recommendations.**

Keywords—Stiffeners, CUFSM, Built-up column, Overlap section, Cold formed steel

I. INTRODUCTION

In recent years usage of cold formed steel has increased in greater volume. It is often called as Cold rolled sections and light gauge steel. Because of its high strength to weight ratio, Lightness and ease of fabrication cold formed steel was better alternate for hot rolled steel for short spans and light loads. The ease of fabrication of the different shapes and sizes of section that are available leads to the potential use of CFS as a complete building material for primary beams, floor units, roof trusses, stud walls and portions. It can either be in the form stiffened and unstiffened sections.

Built up members are widely used as structural member for an advantage of symmetric and eliminating eccentricity shear and gravity center. Thus, by reducing torsional rotations in the sections. The built-up members were made by available standard single sections. The closed built-up sections have higher load capacity.

CUFSM is a finite strip buckling analysis program for thin walled structures such as beam and columns. It is developed by Benjamin W. Schafer. CUFSM is the short form of **C**ornell **U**niversity **F**inite **S**trip **M**ethod. Finite strip analysis is a general mathematical tool that provides approximate elastic buckling solution with a minimum computational effort and time. FSM is implemented in CUFSM software to analysis the thin walled cold formed section.

II. NUMERICAL INVESTIAGTION

A. Parametric Study

It is proposed to conduct a numerical study in CUFSM software to compare the behavior of the compression member consider the various cross section. The following parametric study done for column (without perforation) shown in figure 3.1 are subjected to axial compression in CUFSM consider as simply supported end condition.

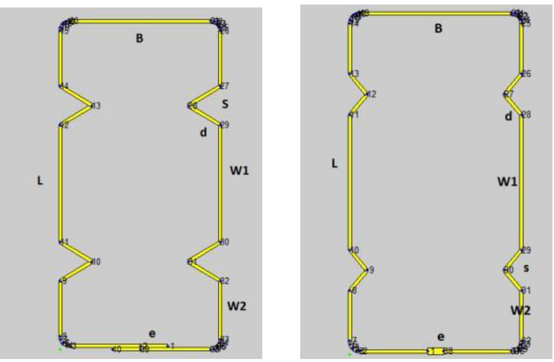

Fig.1 OVERLAP TWICE THICK

Description of notations

W1 – Sub element width d - Stiffener depth
L - Length E - Edge distance
S - Stiffener width B - Breadth

B. Sub Element Width Ratio (W/T)

In the configuration of a new cold formed section each element must be defined properly. IS 801:1975 specified a limit for length of spacing between intermediate stiffener which is known as sub element distance. Sub element length is an important component in the section. Because larger length of sub element prone to local buckling. The parametric analysis was executed in CUFSM by varying the sub element width ratio. The column was subjected to axial compression with simply supported end condition. The load factor for the respective mode of buckling failure was resulted from the CUFSM tool. The parametric study was performed for the sections in the table 3.1

TABLE I. LABELING OF CROSS SECTION

SECTION TYPE	**LABELLING OF SECTION**
OVERLAP	OL
TWICE THICK AT OVERLAP	MS2

For each type of sections with varying the sub element width the stiffener also varied. To determine the sub element flat width ratios, the following limiting values were taken into consideration. The values were

Lower limit	**Intermediate limits**					**Upper limit**
36	38	40	45	50	55	60

For each limited sub element width CUFSM buckling analysis was performed and results are tabulated. Above mentioned cross sections were modeled in the CUFSM software by geometry co-ordinates. The ends were assumed as simply supported. The section properties such as area, moment of inertia and radius of gyration were also obtained by CUFSM tool. The failure pattern for trial sections are shown in Fig. 1

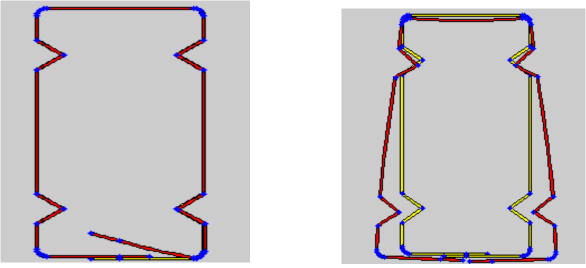

Fig.1. Local Buckling Distortional Buckling

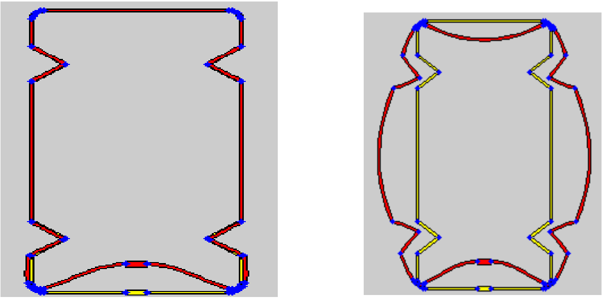

Fig.2. Local Buckling Distortional Buckling

Results for trial sections obtained as signature curve in CUFSM tool. Signature curve which is shown in Fig.3 has been drawn for load factor versus length of the column.

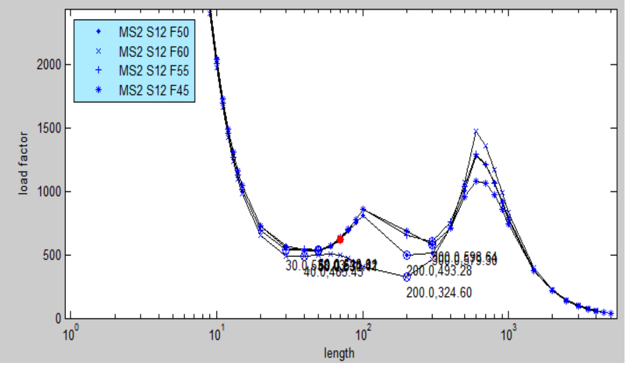

Fig .3. Signature curve for sub element width ratio

Fig.3. shows signature curves of MS2 (Twice thick at overlap) sections having stiffener width as 12mm with varying sub element width ratio. Two modes of failure such as local buckling and distortional buckling failure are occurred. From the results expect flat width ratio 60 critical local buckling load factor (minima point) coincide each other, which indicate the local buckling loads were same as well as higher than the critical load value of flat width ratio 60. Critical distortional buckling load for each type of cross section is varied. When the flat width ratio decreases from 60, the critical load factor value is greater.

By using Direct Strength Method explained in AISI 2004, the critical load for each failure mode derived from respective load factor value for each failure mode. Among them minimum critical load value is considered as governing critical failure load and respective failure mode is governing failure mode. The CUFSM results derived by DSM were tabulated in table II

TABLE II. LOAD CAPACITY OF COLUMN

Sub Element Flat Width Ratio	**Local Buckling Critical load (kN)**		**Distortional buckling load (kN)**	
	OL	MS2	OL	MS2
60	58.16	166.47	84.16	119.59
55	57.51	166.64	85.22	117.88
50	56.99	165.92	85.99	116.98
45	56.81	164.46	86.50	117.03
40	56.51	163.73	87.39	117.93
38	56.38	162.94	87.67	118.49
36	56.24	157.38	87.93	119.15

From the critical load values tabulated in table II, it was inferred that for overlap sections (OL) with sub element width ratio 60 t0 36 critical distortional load would be higher than critical local buckling load about 44.7% to 56.36% . In this case local buckling load would be governing design load. Similarly, to the Twice thick sections (MS2) the distortional critical load was 39.43% to 32.08% lesser than local buckling load. Therefore, load corresponds to the distortional buckling are considered as governing load for MS2 section. The following graph in Fig 4 was drawn for design load vs depth of stiffener.

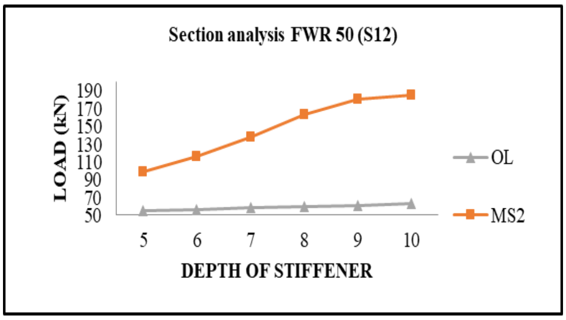

Fig .4. Section analysis graph

From the results obtained from CUFSM and derived using DSM the Fig 4 is drawn for Load versus depth of stiffener by varying cross section type. It was observed that the section considers with twice thickness at overlap has higher load capacity and it resembles actual section behavior taken into the study

The detailed graphical study was done to determine the optimum sub element width ratios. In this study graphs were drawn for load versus depth of stiffener for a different stiffener width and dissimilar flat width ratios. The graphs for each stiffener width was drawn in Fig 5

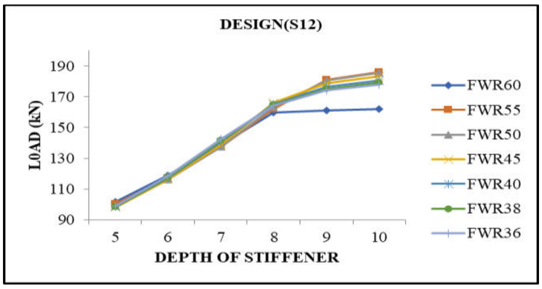

Fig.5. Flat width ratio determination (Stiffener width 12)

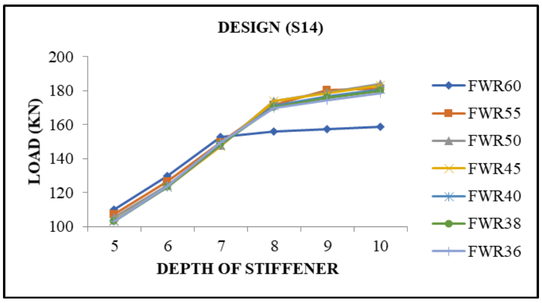

Fig.6. Flat width ratio determination (Stiffener width 14)

From Fig 5 and 6 it was interpreted that the sub element flat width ratio increased from 36 to 55 the load capacity increased. For flat width ratio 60 load capacity is poorly dropped after stiffener depth 7mm.The percentage variation available between the peak capacity (for FWR 50) 0.07% to FWR 50. The percentage drop in capacity occurred in range of 1.5% to 4.6% for FWR 45 to FWR 36 columns.

B. *Study On Stiffener Dimensions Of Column*

This parametric study majorly to determine the stiffener dimensions in the sense of stiffener depth and stiffener width. Stiffener dimensions effects in distortional buckling behavior of cold formed steel column section. In this study the sub element flat widths were kept between 45 and 50. The section chosen for study was MS1 (Twice thick at overlap). The stiffener dimensions considered for buckling analysis as follows

Stiffener Width	10		12		14	
Stiffener Depth	5	6	7	8	9	10

For the above stiffener depth and width the CUFSM model is developed and analysis is executed under axial compression with simply supported end condition. The results derived as signature curve for various stiffener width is shown in the Fig.7

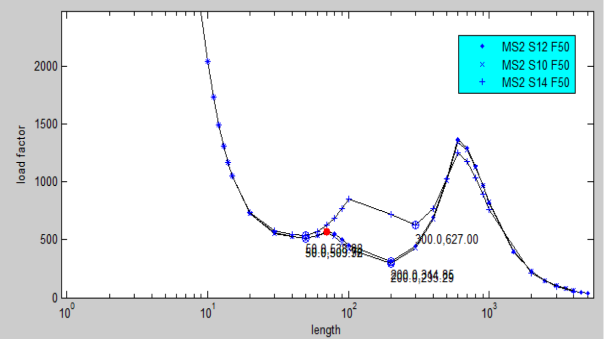

Fig .7 Signature curve for stiffener width

The Fig.7 revealed that the behavior of columns at initial state (i.e) until reach the critical local buckling load factor were similar. After local failure columns with 10mm stiffener width resists higher load before distortional failure. From the resulting curve it was inferred that for columns having stiffener width as 12mm and 14mm distortional buckling load was governing design load.

TABLE III LOAD CAPACITY VARIED STIFFENER WIDTH

Flat width ratio W1/t	**Depth of stiffener (d)**	**Stiffener width (s) load (kN)**		
		S10	**S12**	**S14**
50	5	93.33	98.86	105.22
	6	109.02	116.14	124.42
	7	128.87	137.60	147.74
	8	153.16	163.52	173.71
	9	176.75	180.72	178.79
	10	186.23	185.62	183.85

For the tabulated design load values shown in table III, the graph was drawn for critical load versus depth of stiffener to the varying stiffener width as follows

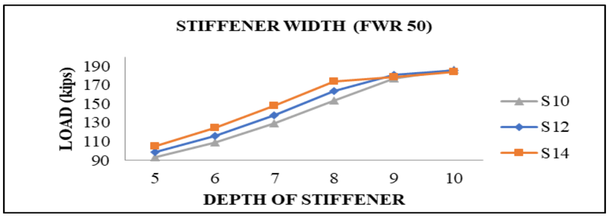

Fig .8 Graph for finding stiffener width

The Fig.8 clearly explained the load capacity variations correspond to change in stiffener width. For a depth of stiffener 5mm, critical load capacity of column having 12mm stiffener width was 5.9% and capacity of column having stiffener width as 14mm 12% was higher than the column with stiffener of 10mm width. Until the stiffener depth varying to 8mm S14 column capacity is higher. After that a sudden drop in capacity occurred in S14 column. But capacity of S12 column is higher than S10 column by 2%.

To determine the stiffener dimensions along with the stiffener width depth of stiffener also an important parameter. To arrive optimum depth the following curve drawn for load against sub element width to stiffener depth ratio.

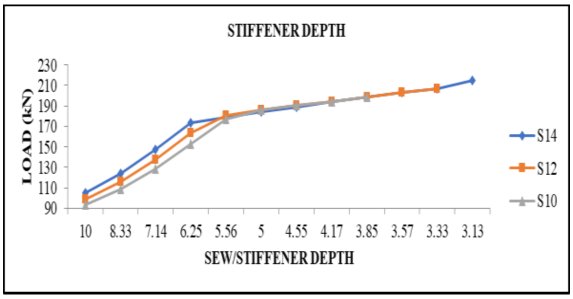

Fig .9 Graph for finding stiffener depth

Load carrying capacity of column for different stiffener depth is presented in the Fig.9. It resulted that varying in capacity is observed between the sub element width to stiffener depth ratio 10 to 5.56. After that 5.56 ratio stiffener dimensions (i.e) stiffener width and depth does not have any significance on capacity of column.

C. Study On Various Length To Breadth Ratio

This parametric study is carried out to find the optimum length to breadth ratio for a section without perforations. Modified twice thick section is subjected to axial compression with simply supported end condition in CUFSM tool to do this study.

The study extensively done by not only change the L:B ratio and also with other parameter such as stiffener width, stiffener depth and sub element flat width ratio. This parametric study was done for the sub 3element width ratios 45 and 50. Because those two limits were arrived for optimum in study A. Depends upon the section geometry parameters the buckling analysis for axial compression carried out in CUFSM. The results in terms of load factor for different buckling modes were tabulated. By using Direct strength method obtained results were derived to capacity of column. Interpreting the results, the optimum range for the section is arrived.

The L:B ratio considered for this study were

1:1	1:1.5	1:2	1:2.5	1:3	1:3.5	1:4

The CUFSM results for different L:B ratio of sections were arrived was shown in Fig.10

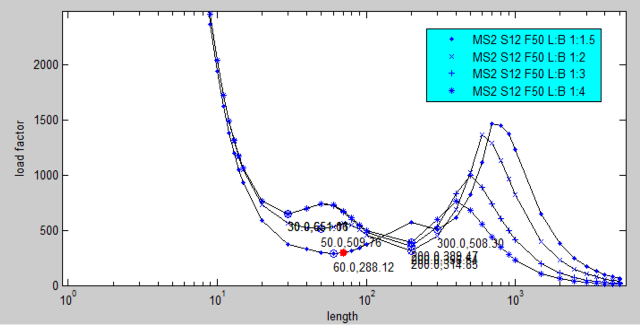

Fig .10 Signature curve for different L:B ratio

Signature curves shown in Fig.10 for each L:B ratio gave us clear indication which is better cross section to carry higher load. In this graph, it was observed that behavior columns were like each other expect column having L:B ratio 1:1.5. The post buckling capacity of column with L:B ratio 1:2 was higher than any other columns. Also, observations made to find the governing design critical load. Most of cases distortion buckling load is considered as design load. The design load values calculated using DSM is tabulated as shown in table

TABLE IV DESIGN LOAD L:B RATIO

Flat width ratio	**Stiffener width**	**d**	**Allowable design load for L:B Ratio (kN)**					
			1;1.5	1;2	1;2.5	1;3	1;3.5	1;4
W1/t 3=50	S12	5	95.27	98.85	99.80	99.82	101.81	102.81
		6	98.53	116.1	116.67	117.6	117.83	118.81
		7	101.2	137.6	137.55	137.47	137.90	138.49
		8	103.8	164.9	164.47	162.08	161.84	162.09
		9	106.5	195.1	189.94	191.06	183.15	166.10
		10	109.1	204.3	205.90	198.31	182.66	161.66
	S14	5	95.48	105.2	106.08	106.69	107.83	108.76
		6	97.75	124.4	124.89	125.18	125.98	126.74
		7	100.1	147.7	147.71	147.54	147.87	148.41
		8	102.6	173.7	174.78	174.05	173.74	173.84
		9	105.2	200.3	199.48	191.87	184.18	178.33
		10	107.7	202.5	200.87	193.36	185.85	178.10

For the above tabulated design load values in the table IV, the graph was drawn for critical load versus depth of stiffener to the varying stiffener width as follows

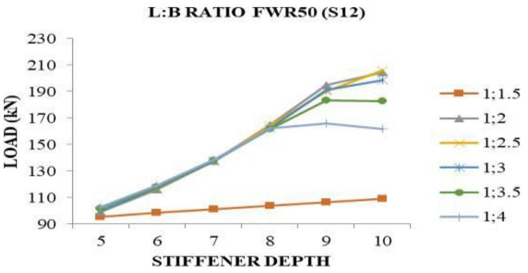

Fig.11 Graph for L:B ratio (S12)

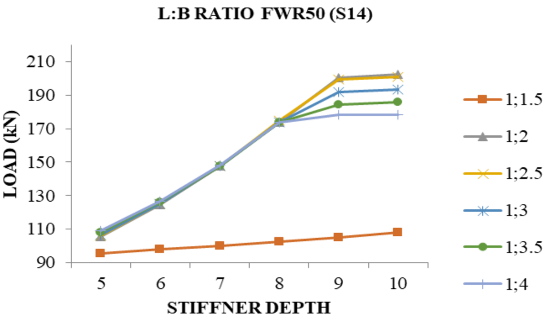

Fig .12 Graph for L:B ratio (S14)

The graphical study explained in the Fig.11 that the load capacity value for L:B ratios expect 1:1.5 were closely equal. io change in capacity was occurred. The column with L:B ratio 1:1.5 capacity largely varied with 1:2 ratio column about 7.9% to 48.9% in case of stiffener width considered to 12mm and in stiffener width 14mm the varying range falls between 9.8% to 65.2%. The capacity of columns for the ratios 1:2 and 1:2.5 were same and the peak capacity is higher than others by 4.3%, 8.7% and 12.37% for ratios 1:3, 1:3.5, 1:4 respectively.

Finalized optimum cross section from the parametric study for further detailed study was given in the figure 3.12

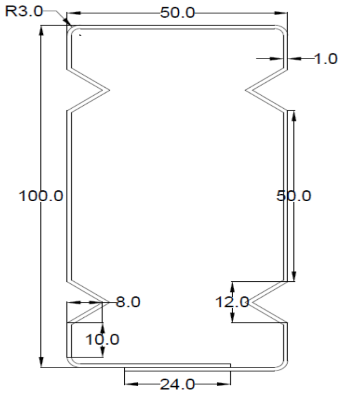

Fig .13 Proposed Model

The load factor, buckling half wave length and critical load for the proposed model considering it as MS1 section was tabulated in table

TABLE V PROPOSED MODEL BUCKLING LOAD

Load factor		**Critical Load (kN)**		**Critical Design Load(kN)**
Local Buckling	**Distortional Buckling**	**Local Buckling**	**Distortional Buckling**	
530.11	493.28	176.99	163.53	163.53

III. CONCLUSION

A detailed review of the literature was carried out to study the buckling behavior of columns, considering the conventional as well as unusual cross sections under axial compression with and without perforations. The detailed numerical analysis was carried out with a help of CUFSM software. From the analysis the following conclusion were arrived to define the optimum cross section.

- To determine the sub element width ratio the investigation was done by considering the various width ratios such as 36,38,40,45,50,55,60. Among them the load capacity of column with flat width ratios 45, 50 and 55 has higher load capacity. Though FWR 55 columns have higher load capacity, fails to satisfy the AISI 2004 recommendation. Since FWR 50 columns have load capacity 1.5% higher than the FWR45 columns for the proposed column cross section sub element flat width ratio is recommended as 50.
- For the determination of optimum L:B ratio for the columns, detailed study was carried out by considering the ratios 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5 and 1:4. The results in terms of load capacity for each type of columns were derived. From these observations it was inferred that the load capacity for columns with ratio 1:2 and 1:1.25 were same higher than the other ratio column capacity. There fore, for the proposed cross section L:B ratio1:2 was recommended.
- In the proposed section the parameter was stiffener dimensions. Stiffener dimensions refer to the width and depth of stiffener. For stiffener width load capacity calculated by changing width as 10, 12 and 14mm. Among them load capacity for column with 12mm stiffener has better buckling behavior than other stiffener width columns. For stiffener depth determination parametric study was done by kept depth as 5, 6, 7, 8, 9 and 10. The load capacity variation for each depth by changing stiffener width was arrived. It describes that load capacity of columns remain same for all the stiffener widths after reaching stiffener depth 8mm. From the above observations recommended stiffener width and stiffener depth for proposed column were 12mm an 8mm respectively.
- The critical design load for the optimum section finalized from this parametric study was 163.53 kN.

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