BEHAVIOR OF COLD FORMED LIGHT GAUGE STEEL SECTION OF MINIMUM AND MAXIMUM LENGTH COLUMN UNDER AXIAL COMPRESSION LOAD

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ABSTRACT

Cold-formed steel structures has increased rapidly in recent times due to significant improvements to manufacturing technologies and development of thin, high strength steels. The use of cold-formed thin walled steel structures has greater than before in recent years, and some built-up section members are aggravated and widely used for their excellent structural behaviors. The differences of global, local and distortional buckling behaviors among members with built-up and single sections are investigated. In this paper, describes the distortional buckling performance of a series of innovative cold-formed steel columns. More than 12 laboratory experiments were undertaken first on these innovative steel columns of 350 mm and 700 mm length under axial compression. The distortional buckling and non-linear ultimate strength behavior of the columns was investigated in detail using finite element analyses (ABAQUS).

Keyword: - *Cold-formed steel, buckling, finite element analyses (ABAQUS).*

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1. INTRODUCTION

Thin-walled cold-formed steel sections can be used efficiently as structural members of light-weight structures when hot-rolled sections or others are not efficient. However, since the thin-walled sections may undergo local, distortional, overall or mixed modes of buckling, the accurate prediction on the member strength of thin-walled cold-formed steel sections becomes more complex. Until recently, the conventional Effective Width Method (EWM) has been the only way to estimate the member strength for over 60 years. This method can take account of the interaction between local and lateral buckling and the post-buckling strength reserve in the local buckling mode. However, as structural shapes became more complex with additional lips and intermediate stiffeners, the accurate computation of the effective widths of individual elements of the complex shapes becomes more difficult and inaccurate. In order to overcome this problem, the Direct Strength Method (DSM) was developed. North American Specification Supplement 1 and Australian/New Zealand Cold Formed Steel Structures Standard recently adopted the Direct Strength Method as an alternative to the conventional Effective Width Method to estimate the compression and the flexural member strength, which can consider the interaction of local or distortional and overall buckling modes. The method uses the elastic buckling solutions for the whole section rather than for individual elements and the design strength curves developed on the basis of various test results. Research into the distortional buckling mode of thin-walled cold-formed open sections has widely been carried out in recent years.

1.1 Light Gauge Steel History

Cold-formed thin-walled steel structures have been increasingly used in low rise residential buildings, as well as other public Buildings, such as the portal steel frame system. Some built-up Cross sections consisted of two single C-sections, such as built-up I and sections, are commonly used as columns for several advantages:

(a) Comparing to single section, the built-up section can span more distance and carry more loads;

(b) The torsional stiffness of a built-up section, due to biaxial-symmetrical, is much higher than that of a single-symmetrical single section;

(c) Many kinds of built-up sections can be formed by one kind of "standard" single C-section, which is helpful to achieve industrialized production; and

(d) The connection of the members can be more convenient. However, the provisions about the strength design of built-up members in related codes are quite rough up to now.

1.2 Objectives

(a) To design light weight steel sections using the guidelines given in IS: 801- 1975 code for load carrying capacity of the section.

(b) To determine the effect on the load carrying capacity using stiffener elements namely lips, V- stiffener and rectangular stiffener.

(c) Modeling and analyzing columns with and without stiffeners for various lengths by using appropriate FEM based software.

(d) To compare the analytical and experimental results for axial load carrying capacity of columns.

2. METHODOLOGY

2.1 Introduction:

Cold-formed steel members have been widely used in building applications for over five decades. Their markets include the secondary cladding and purlin applications as well as the primary applications as beams and columns of industrial and housing systems. Cold-formed members can be produced in a wide variety of sectional profiles. The commonly used open cold formed sections are the "C" channels and, to a lesser extent, the sections shown in Figure. While plain sections are finding applications as secondary members, the sections are usually enhanced with flange end stiffeners (e.g. the lipped channels) and/or web stiffeners in primary structural applications. With stiffeners, the members benefit from a larger cross sectional effective area and are therefore expected to become better able to resist local and overall buckling. Designers of cold-formed members can also easily vary the profiles' aspect ratio according to their structural or constructional needs; a flexibility that has been made possible by the ease in which cross-sectional dimensions can be changed during manufacturing. However, while this freedom to modify the cross section of cold-formed members provides a commended flexibility to the structural designer, it makes arriving at the optimum section for a given application a difficult and lengthy process. This is especially true when considering the complex nature of the analysis procedure of cold-formed members, primarily because of the combined liability to both local and overall (flexural or torsional flexural) buckling modes of failure. The work presented in this dissertation is part of a long research project at the University of Dundee to simplify the design process of cold-formed members. In this effort, a design tool based on the neural network technology is being built to encompass current knowledge and the latest research conducted on the performance of cold-formed members.

2.2 Residual Stresses in Cold-Formed Steel Section

A detailed description of the residual stresses measured from the columns tested in this investigation is to be presented in a subsequent thesis. The following is a brief summary of the observed experimental results:

1. In the longitudinal direction, compression residual stresses were found on the inside surface of the sections, and tension residual stresses on the outside surface.

2. The magnitudes of the surface residual stresses of the section were found to be 25-70% of the yield stress of the material.

3. The magnitudes of the residual stresses on the flat portions of the section were approximately uniform along the perimeter of the section.

4. At the same location, the magnitudes of the residual stresses on the inside and outside surfaces of the flat portions of the section were found to be quite close.

2.3 Parametric Study

An extensive parametric study was conducted in this work to assess the effect of flange and web stiffeners on the behavior of channel members. The study involved a large number of stiffened and unstiffened channel members with the following properties (refer to Fig.):

1. Aspect ratio, b/h, between 0.4

2. Cross-sectional area, A, 1064 mm 2 ;

3. Size of flange stiffener (also called lip) with lip depth/section depth, l/h, being either 0.0 or 0.2;

4. Size of web (triangular) stiffener with stiffener size/section depth, d/h, being between 0.0 and 0.25;

5. Load eccentricity, e, between 0.0 and 250 mm in the weak direction.

All sections had the same effective buckling length, L = 600 mm and 1000 mm wall thickness, t =2 mm and material grade, Fe E280G with yield strength 250 N/mm2, to allow direct comparison of the results obtained. The sections were analyzed according to BS5950, Part 5 to determine their cross-sectional properties, buckling strength and mode of failure. The formulae for the buckling strength of cold formed members according to BS5950.

2.4 Load Carrying Capacity 600 mm Length of I Section

Material Properties: yield stress f y = 250 N/mm2

2.4.1 Computation of Sectional Properties:

Depth (d) = 150 mm

Width (w) = 60 mm

Thickness (t) = 2 mm

Area (A) = 2(532) = 1064 mm2

Span of length (L) = 600 mm

Moment of inertia: I xx =3.66.738X 10^3 mm^4

2.5 Mix Safe Load Carrying Capacity of Section

Ultimate load carrying capacity = [(0.4fckAc) + (0.62fyAsc)

= (0.4x 20x0) + (0.62x250x1064)

= 164.92 KN

Table No.1: Manual Load Carrying Capacity of Section

Sr. No	Depth in mm	width in mm	thickness in mm	Span of length in mm	Area in mm 2	Iyy is less than Ixx. Radius of gyrations Therefore ryy is Minimum.		slenderness ratio	Safe load carrying capacity of section in KN	Fy	fc k	Ultimate load carrying capacity in KN
						ryy	rxx					
1	150	60	2	600	1064	18.03	58.7	32.36	146.23	250	20	164.92
2	150	60	2	700	1064	18.03	58.7	38.82	146.2	250	20	164.92
3	150	60	2	1000	1064	18.03	58.7	55.45	124.00	250	20	164.92

3. EXPERIMENTAL WORK & FEM ANALYSIS

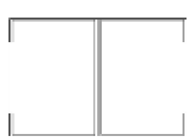
3.1 Section Geometries and Material Properties

Material Properties:

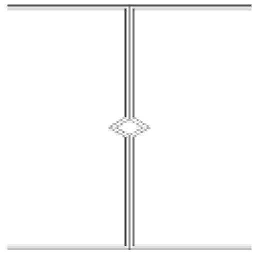
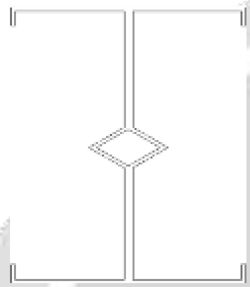
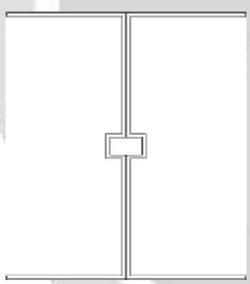
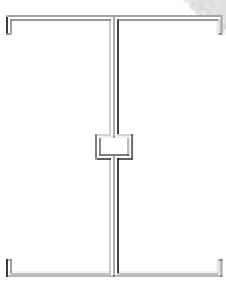
The structural steel grade of the test sections was SGC570 (KSD 3506). The minimum specified yield and ultimate stresses of the test sections of 150x60x2 thickness 2 mm were 350mm and 700 mm length , respectively.

Combinations

Table No. 2: Geometry of Single Stiffener

Sample	Size in mm	Stiffener size in mm
	150X60X2	No Stiffener
	150X60X2	10
		20
		30

Sample	Size in mm	Stiffener size in mm	Stiffener size in mm	Stiffener size in mm

	150X60X2	10x10		
		10x20		
		10x30		
		20x10		
		20X20		
		20x30		
		30x10		
		30x20		
		30x30		
	150X60X2	10x10 ,10	10x10, 20	10x10, 30
		10x20, 10	10x20, 20	10x20, 30
		10x30, 10	10x30, 20	10x30, 30
		20x10 ,10	20x10 ,20	20x10 ,30
		20X20, 10	20X20, 20	20X20, 30
		20x30, 10	20x30, 20	20x30, 30
		30x10,10	30x10,20	30x10,30
		30x20, 10	30x20, 20	30x20, 30
		30x30, 10	30x30, 20	30x30, 30
	150X60X2	10x10		
		10x20		
		10x30		
		20x10		
		20X20		
		20x30		
		30x10		
		30x20		
		30x30		
	150X60X2	10x10 ,10	10x10, 20	10x10, 30
		10x20, 10	10x20, 20	10x20, 30
		10x30, 10	10x30, 20	10x30, 30
		20x10 ,10	20x10 ,20	20x10 ,30
		20X20, 10	20X20, 20	20X20, 30
		20x30, 10	20x30, 20	20x30, 30
		30x10,10	30x10,20	30x10,30
		30x20, 10	30x20, 20	30x20, 30
		30x30, 10	30x30, 20	30x30, 30

3.2 Compression Tests

A total of twelve cold-formed steel compression members analyzed with fixed-end support conditions. Two types of cold-formed sections (Types A and B sections–lipped I-sections without and with additional lips) were modeled with thicknesses of 2mm, flange width 60mm, web width 150mm and steel grade of G225 columns were tested under axial compressive load to the failure. The specimen lengths chosen were 350 mm and 700 mm. concentric compression tests of lipped channel sections were performed using a UTM, high strength cold-formed channel sections generally have significant post-buckling strength reserve in the local and distortional mode. However, a single symmetric section may have a shift in the line of axial force after local and distortional buckling, if it is loaded between pinned ends. The shift of centroid of sections will affect the ultimate strength of the columns significantly. To avoid this problem, fixed end boundary conditions were used in the tests using the specially designed capping system, which was made of unsaturated polyester resin.

The typical test set-up for the with and without cold formed I section is shown in Fig. Most of the test specimens were painted white and marked black in grid lines so that the complex deformed shapes due to the interaction of local and distortional buckling could be displayed clearly. The loading was applied downward very slowly by using a UTM up to the failure of the specimen. Compression test was conducted by the displacement control method the lateral displacement of the flange center point was measured.

4. RESULT AND DISCUSSION

4.1 Analytical Result for Load Carrying Capacity

(a) Column of Length 350 mm

In following table 3 show that analytical result in load carrying capacity of V stiffener and rectangular stiffener with and without lip. In this result column analyzed in ABAQUS SOFTWARE and table is shown that section, type of stiffener, length of lip, load carrying capacity and load area ratio and highlighted in optimized section. Load carrying capacity of column which is expressed on KN.

Table No 3: Analytical Load Carrying Capacity for Column 350 mm Length

Sr. No.	**Description**	**Type of Stiffener (mm)**	**Length of Lip (mm)**	**Load Carrying Capacity (KN)**	**Area (mm^2)**	**Load/ Area Ratio**
1	I Section Without Lip Without Stiffener	**-**	**-**	**65.17**	**532**	**122.50**
2	I Section With Lip Without Stiffener	-	10	108.58	548	198.14
			20	**139.374**	**568**	**245.38**
			30	142.78	588	242.82
3	I Section Without Lip With V Stiffener	10x10	-	75.759	552	137.24
		10x20		82.651	592	139.61
		10x30		79.461	632	125.73
		20x10		88.853	532	167.02
		20x20		94.936	572	165.97
		20x30		**124.687**	**612**	**203.74**
		30x10		94.376	512	184.33

(b) Column of Length 700 mm

In following table 4 show that analytical result in load carrying capacity of V stiffener and rectangular stiffener with and without lip. In this result column analyzed in ABAQUS SOFTWARE and table is shown that section, type of stiffener, length of lip, load carrying capacity and load area ratio and highlighted in optimized section. Load carrying capacity of column which is expressed on KN.

Table No 4: Analytical Load Carrying Capacity for Column 700mm Length

Sr. No.	**Description**	**Type Of Stiffener (mm)**	**Length Of Lip (mm)**	**Load Carrying Capacity (KN)**	**Area (mm^2)**	**Load/ Area Ratio**
1	I Section Without Lip Without Stiffener	-	-	**72.93**	**532**	**137.09**
2	I Section With Lip Without Stiffener	-	10	114.85	548	209.58
			20	**126.8**	**568**	**223.24**
			30	130.732	588	222.33
		10x10		76.698	552	138.95

3	I Section Without Lip With V Stiffener	10x20	-	80.43	592	135.86
		10x30		89.264	632	141.24
		20x10		105.657	532	198.60
		20x20		110.858	572	193.81
		20x30		**153.983**	**612**	**251.61**
		30x10		110.125	512	215.09

4.2 Comparison of Load Carrying Capacity with and Without Stiffener Column Length 350mm

Table No 5: Comparison of with & without Stiffener

Sr. No.	Description	Type Of Stiffener (mm)	Length Of Lip (mm)	Load Carrying Capacity (KN)	Increase In Load Carrying Capacity (KN)	Actual Increase In Terms Of Ratio
1	I Section Without Lip Without Stiffener	-	-	65.17	-	-
2	I Section With Lip Without Stiffener	-	10	108.58	74.63	0.69
			20	139.374	105.43	0.76
			30	142.78	108.83	0.76
3	I Section Without Lip With V Stiffener	10x10	-	75.759	41.81	0.55
		10x20		82.651	48.70	0.59
		10x30		79.461	45.51	0.57
		20x10		88.853	54.90	0.62
		20x20		94.936	60.99	0.64
		20x30		124.687	90.74	0.73
		30x10		94.376	60.43	0.64
		30x20		110.5	76.55	0.69
		30x30		120.07	86.12	0.72

Figure No.1: Comparison of I Section without Lip with V Stiffener

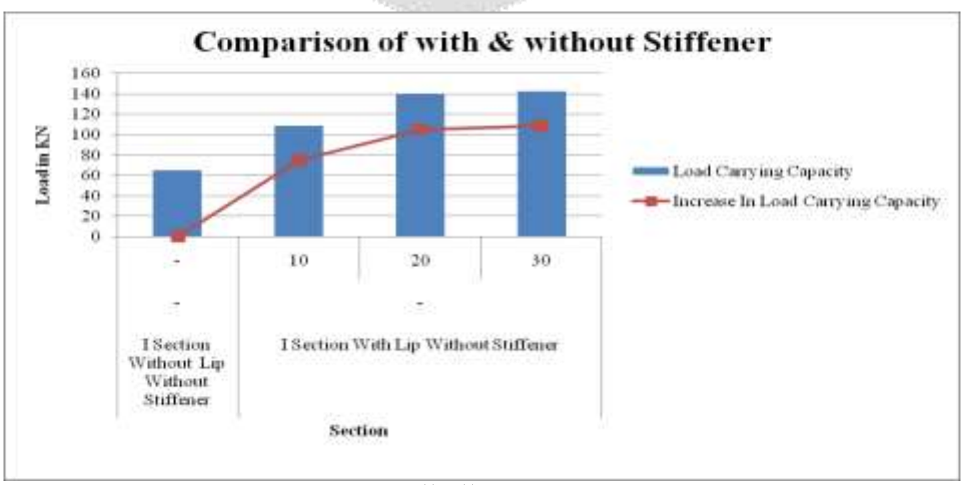
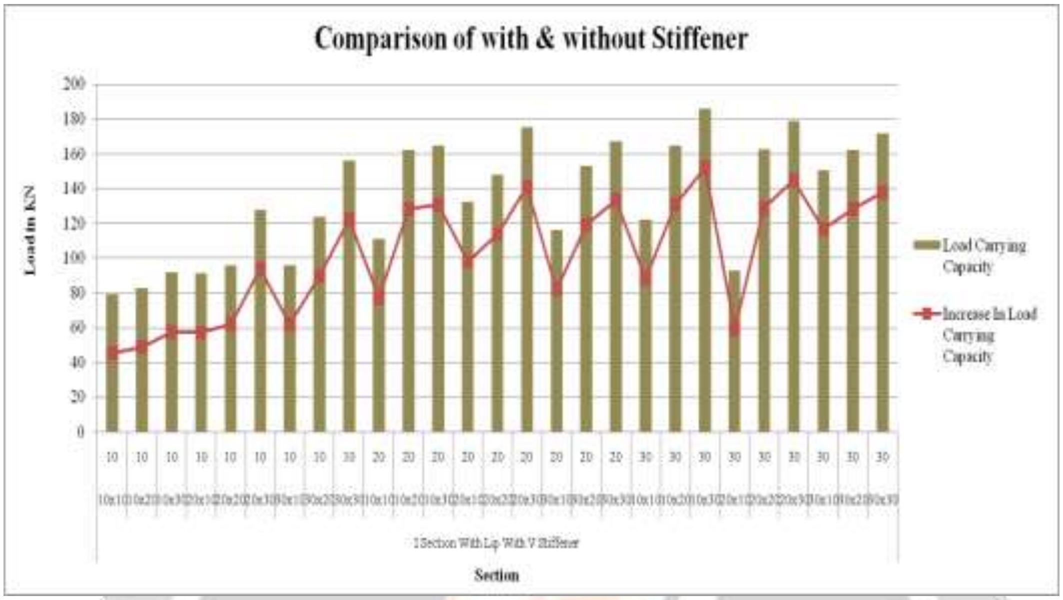


Figure No.2 : Comparison of I Section With Lip With Stiffener



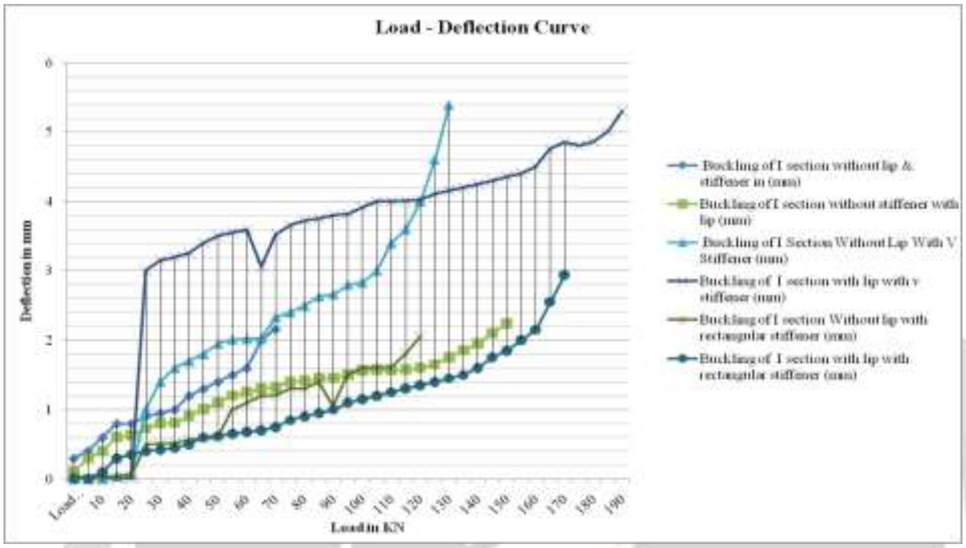
5. EXPERIMENTAL RESULTS

(a) Column Length 350 mm

Table No 6: Experimental Result of Load and Buckling for Column of Length 350mm

Load in KN	Buckling of I Section Without Lip & Stiffener In (mm)	Buckling of I Section Without Stiffener With Lip (mm)	Buckling of I Section Without Lip With V Stiffener (mm)	Buckling of I Section With Lip With V Stiffener (mm)	Buckling of I Section Without Lip With Rectangular Stiffener (mm)	Buckling of I Section With Lip With Rectangular Stiffener (mm)
5	0.3	0.1	0	0	0.05	0
10	0.405	0.3	0	0	0.02	0
15	0.6	0.4	0	0	0.03	0.1
20	0.8	0.6	0.04	0	0.04	0.3
25	0.8	0.63	0.08	0	0.045	0.35
30	0.9	0.73	1	3	0.5	0.4
35	0.95	0.8	1.4	3.15	0.51	0.42
40	1	0.805	1.6	3.2	0.52	0.45
45	1.2	0.905	1.7	3.25	0.565	0.5
50	1.3	1	1.8	3.4	0.585	0.6
55	1.4	1.1	1.95	3.5	0.595	0.62
60	1.5	1.2	2.01	3.55	1	0.65
65	1.6	1.25	2.02	3.59	1.1	0.68

70	2	1.3	2.03	3.06	1.2	0.7
75	2.16	1.32	2.33	3.52	1.205	0.75
80		1.4	2.4	3.65	1.3	0.85
85		1.42	2.5	3.72	1.305	0.9
90		1.45	2.63	3.75	1.4	0.95
95		1.455	2.66	3.8	1.05	1

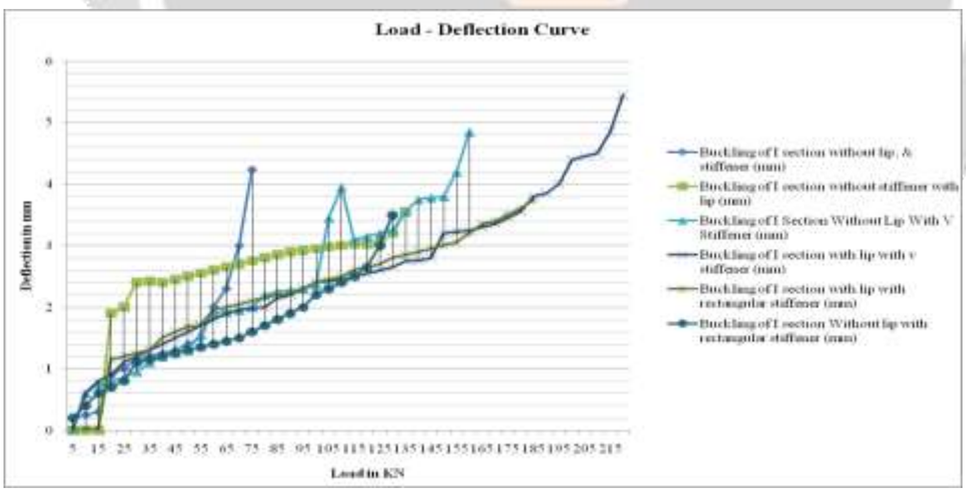


(b) Column Length 700 mm

Table No 7: Experimental Result of Load and Buckling for Column of Length 700mm

Load in KN	Buckling of I Section Without Lip; & Stiffener (mm)	Buckling of I Section Without Stiffener With Lip (mm)	Buckling of I Section Without Lip With V Stiffener (mm)	Buckling of I Section With Lip With V Stiffener (mm)	Buckling of I Section With Lip With Rectangular Stiffener (mm)	Buckling of I Section Without Lip With Rectangular Stiffener (mm)
5	0.2	0	0	0	0	0.2
10	0.25	0	0.6	0.6	0.02	0.4
15	0.3	0	0.75	0.8	0.025	0.6
20	0.9	1.9	0.8	0.9	1.15	0.7
25	1	2	0.85	1.1	1.2	0.8
30	1.15	2.4	0.95	1.2	1.25	1.1
35	1.2	2.42	1.1	1.3	1.3	1.15
40	1.25	2.4	1.2	1.4	1.5	1.2
45	1.3	2.45	1.25	1.5	1.6	1.25
50	1.4	2.5	1.3	1.6	1.68	1.3
55	1.5	2.55	1.56	1.7	1.7	1.35

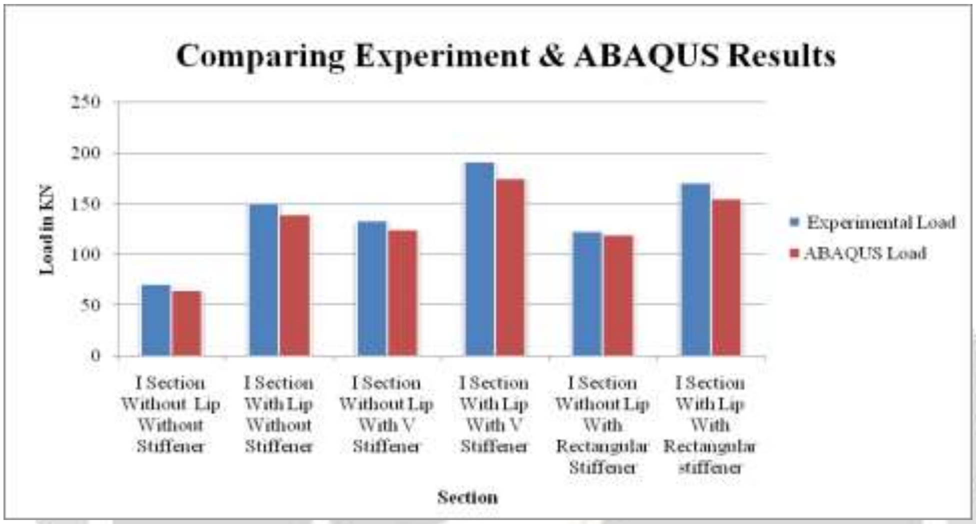
60	2	2.6	1.9	1.8	1.95	1.4
65	2.3	2.65	1.92	1.9	2	1.45
70	3	2.7	1.95	1.95	2.05	1.5
75	4.23	2.75	2	1.98	2.1	1.6
80		2.8	2.2	2	2.15	1.7
85		2.85	2.25	2.15	2.2	1.8
90		2.9	2.275	2.2	2.215	1.9
95		2.92	2.3	2.3	2.3	2
100		2.95	2.35	2.4	2.4	2.2
105		2.98	3.45	2.42	2.45	2.3
110		3	3.95	2.45	2.5	2.4
115		3.02	3.1	2.5	2.6	2.5
120		3.025	3.15	2.55	2.65	2.65
125		3.04	3.2	2.6	2.7	3
130		3.2	3.25	2.65	2.8	3.5
135		3.55	3.55	2.75	2.85	
140			3.75	2.76	2.9	
145			3.78	2.8	2.95	
150			3.8	3.2	3	
155			4.2	3.225	3.05	
160			4.85	3.25	3.2	
165				3.3	3.35	
170				3.35	3.4	



(c) Validation for Load Carrying Capacity by Comparing Experimental and ABAQUS Results

Sr. No	Description	Experimental Load (KN)	ABAQUS Load (KN)	% Difference Between Load Carrying Capacity

1	I Section Without Lip Without Stiffener	71	65.17	8.95
2	I Section With Lip Without Stiffener	151.3	139.374	8.56
3	I Section Without Lip With V Stiffener	133.24	124.687	6.86
4	I Section With Lip With V Stiffener	191.39	175	9.37
5	I Section Without Lip With Rectangular Stiffener	122.89	120	2.41
6	I Section With Lip With Rectangular Stiffener	171.11	155.5	10.04



6. CONCLUSION

The current study has undertaken an experimental and numerical approach to monitor the strength and buckling behavior of stiffened I section under axial load. Totally, 12 specimens are tested and results are comparing numerically. Parametric study is carried out to investigate the effect of thickness, depth and spacing of the spacer plate on the strength and buckling behavior of the specimens. The results acquired from experimental and finite element analysis are compared with the computed resistance by direct strength methods. Based on the results presented herein, it looks reasonable to draw out the following conclusions.

1. Using the smallest size possible of web stiffener leads to significant improvements in the channel members buckling strength under concentric and eccentric forces.

2. The developed finite element model efficiently simulated the buckling behaviour of axially loaded intermediate stiffened partially closed complex channel section.

3. On the other hand, building flange stiffeners into channel sections results in consistent improvements in the member’s buckling strength. This improvement in performance continued to grow with larger flange stiffeners.

4. Load eccentricity in the weak direction leads to significant losses in the buckling strength of channel members. Members with large web stiffeners were particularly sensitive to this effect.

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