Buckling Behaviour of Cold Formed Steel Channel Section

Paurin J. Shah #, Utsav K. Koshti *

Civil Engineering Department, Institute of Technology, Nirma University, Gujarat, India

* *Civil Engineering Department, Institute of Technology, Nirma University, Gujarat, India*

Abstract— **In the field of structural engineering the design of cost efficient structure is highly important. This led to development of cold-formed steel structures. Cold formed steel members have been widely used in residential and commercial buildings as primary load bearing structural elements. They are often made of thin steel sheets and hence they are more susceptible to local buckling. The present study focuses on understanding the importance of "lip" in cold formed steel sections. As per IS: 801 - 1975, design solution is developed for flexure member design. An experimental program is performed, to gain information on flexural capacity and buckling behaviour of member. Suitable finite element models are then developed to simulate the behaviour of tested beams and are validated using test results. All the ultimate load capacity results for local buckling are compared with codal provisions as well as results obtained by experimental program. This paper mainly focuses on to investigate load carrying capacity and buckling behaviour of two different cold formed steel channel sections i.e., with lip and without lip, by analytically(by developing design solutions),experimentally as well as by finite element analysis(by using ABAQUS software).The 'lip' is not taking part anywhere in calculation of bending moment capacity. It is important regarding to buckling behaviour of cold formed steel sections. All the specimens are tested under Universal Testing Machine (UTM) and subjected to two point load system. Results are showing that members subjected to pure bending, with 'Lip' channel section is subjected to web buckling. Channel sections with 'lip' is showing 28.7% higher than without 'lip' sections. In contrast, without 'Lip' channel section is subjected to flange buckling. With 'lip' channel section has high load carrying capacity compared to without 'Lip' channel section. Analytical, experimental and finite element results are showing close to each other.**

Keywords— **Cold formed steel, channel section, lip, buckling behaviour, FEM analysis**

I. INTRODUCTION

Specialized applications for engineered systems may require unique solutions and special properties. The future civil engineering applications may make use of increased number of composites and highly engineered materials.

There are two types of steel sections i.e. hot rolled steel sections and cold formed steel sections. The well known sections are of hot rolled heavy section family. Very less popular and of growing importance, is the other family of steel sections known as `Cold Formed Steel Sections', manufactured from steel plate or at steel not thicker than 12.5 mm by either press-braking or cold-rolling or forming machines. The Indian counter part for this is IS 801-1975, i.e., "Code of Practice for Use of Cold-Formed Light Gauge Steel Structural Members in General Building Construction."

II. LITERATURE REVIEW

Shanmuganathan Gunalan et al. [1], performed the experimental and analytical work carried out to investigate local buckling behavior and strength of cold formed steel compression members at ambient and uniform elevated temperatures. Two series of experimental studies were conducted to investigate the behavior of cold-formed steel compression members subject to local buckling at ambient temperature (20ºC) and uniform elevated temperatures up to 700ºC. The results were compared with finite element analysis. Author recommended the use of effective area at elevated temperatures in predicting the local buckling capacities of cold-formed steel columns at elevated temperatures. Peter Hegyi & Laszlo Dunai [2], carried out an experiment to gain information on flexural behavior of PAC(Polystyrene Aggregate Concrete)braced CFS(Cold Formed Steel sections). They concluded that PAC had beneficial effect on the post buckling behavior of specimen, since it did not let the steel core to produce great deformations. It could be increased the ultimate load level by 30-45% depending upon parameters. John Dawe & James Wood [3], performed experimental work on scale roof trusses which were fabricated from cold-formed steel and tested to ultimate capacity. Each specimen was subjected to a single point load at the ridge. One series of specimens was fabricated with a hinge connection. They concluded that increasing the thickness of the top chords from 33 to 43 mils resulted in a 50% increase in ultimate strength. Iman Hajirasoulihaet al. [4], carried out an analytical research on CFS(Cold Formed Steel sections) moment resisting connections using MATLAB as per EN1993-1-3(EC3) prepared different prototype sections to measure bending capacity. To compare the result, ABAQUS software was used to determine bending capacity. They concluded that folded flange section gave the high moment capacity compared to standard section.

III. EXPERIMENTAL INVESTIGATION

To know the importance of "lip" in channel section, experiment was carried out. 3 channel section with lip and 3 channel sections without lip i.e., total 6 specimens were tested to measure maximum load carrying capacity. In Fig.1,the photograph of the section is shown. Rectangular Channel section with lip, 100 mm x 50 mm x 20 mm x 3.15 mm of length 1200 mm and Rectangular Channel section without lip , 100 mm x 50 mm x 3.15 mm of length 1200 mm were tested. In Fig. 2, the cross section of test specimen is shown.

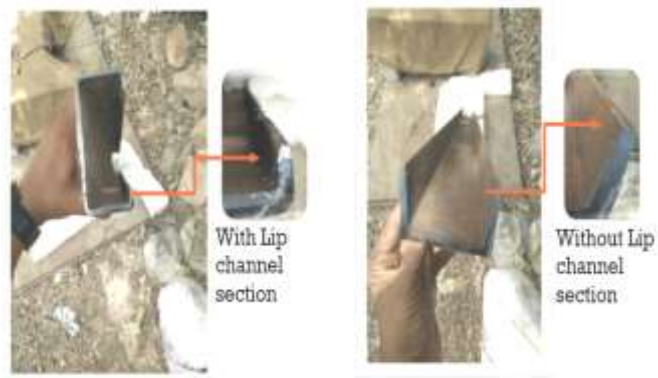


Fig. 1 Test Specimens

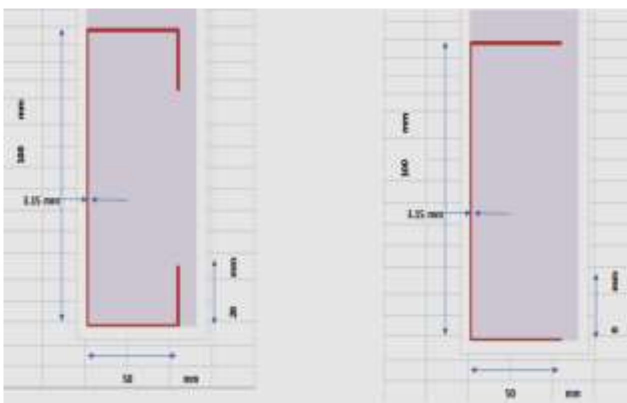


Fig. 2 Cross Section of Test Specimens

Test was carried out on UTM (Universal Testing Machine). For all 6 specimens, test set-up prepared as shown in Fig.3. Two point load system was set up. Buckling of cold forms channel sections with lip and without lip is shown in Fig.4 and Fig. 5 respectively.

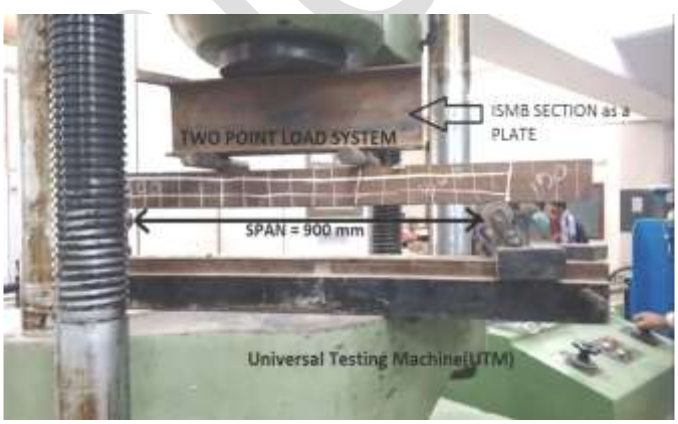


Fig. 3 Test set-up on UTM

Fig. 4 Buckling of Channel section 'with Lip'

Fig. 5 Buckling of Channel section 'without Lip'

Weight of channel section having 'lip' is showing 5.30 kg, while other test specimen consists of 4.65 kg. So, the density was measured as 2507.51 kg/m^3 and 2514.8 kg/m^3. Following table 1 shows the test results in terms of load carrying capacity by experimental program.

Table 1 Results by experimental program

Sr. No.	Rectangular Channel Section with Lip (kN)	Rectangular Channel Section without Lip (kN)
1	28.41	21.05
2	28.50	20.54
3	29.50	19.50
Average	28.80	20.36

IV. ANALYTICAL SOLUTION

Here, Two point load system was done. So, by theoretically calculation we can get designed load carrying capacity as,

$$\frac{P}{2} = \frac{M}{a}$$

where `a' is the distance from the support. So, as per analytically solution,

Maximum ultimate load of Rectangular cold formed channel section without lip can be found by, as per IS 801:1975, the design moment will be,

Span Length(mm)	L	900
Yield Strenght (N/mm^2)	F_y	550
Section Properties:		
Depth(mm)	h	100
Width(mm)	b	50
Lip(mm)	c	0
Thickness(mm)	t	3.15
Area of Section(mm^2)	A	587
Centre of Gravity(mm)	C_y	14.2
Moment of Inertia(mm^4)	I_{xx}	9.00E+05
	I_{yy}	1.46E+05
Radius of Gyration(mm)	r_{xx}	39.2
	r_{yy}	15.8
Section Modulus(mm^3)	Z_{xx}	1.80E+04
	Z_{yy}	4.06E+03
Shear Centre(mm)	X_o	30.3
Torsional Constant(mm^4)	J	1.92E+03
Warping Constant(mm^6)	C_w	2.45E+08
Modulus of Elasticity(N/mm^2)	E	205000
Shear Modulus(N/mm^2)	G	78580
Effective Length(mm)	kL	900
	kL/r_{xx}	22.96
	kL/r_{yy}	56.96
Inner Corner Radius(mm)	Ri	4.73
Effective width(mm)	w	34.25
Ratio(w/t)	w/t	10.87
	$453/\sqrt{F}$	24.94
Effective Area condition		Section is FULLY EFFECTIVE
Effective Area(mm^2)	$A_{eff} = A_g - t(w - b_{eff}) - t(h - b_{eh})$	587
Calculate Form Factor as per cl.6.1.1, IS 801 1975	$Q = A_{eff_i}$	1
Calculate Slenderness constant	$C_c = \sqrt{\frac{2\pi^2 E}{F}}$	85.77
Ratio	$\sqrt{\frac{C_c}{Q}}$	85.77
Allowable bending stress as per cl.6.6.1.1 for doubly symmetric sections and cl.6.6.1.2 for singly symmetric sections IS 801 1975 F_{a1}(N/mm^2)	$F_{a1} = \frac{\left[1 - \left(\frac{Kl}{r_{min}}\right)^2 \frac{1}{2C_c^2}\right] F_y}{\frac{5}{3} + \frac{3}{8}\frac{Kl}{r_{min} C_c} - \frac{1}{8}\left(\frac{Kl}{r_{min} C_c}\right)^3}$	299.95

For Sections other than closed doubly symmetric sections check for capacity as may be subjected to torsional flexural buckling mode of failure as per cl.6.6.1.2 of IS 801 1975stress.F_{a2}(N/mm^2)	$\sigma_{ex} = \frac{\pi^2 E}{(Kl/r_{xx})^2}$	3838.32
	$r_o = \sqrt{r_{xx}^2 + r_{yy}^2 + X_o^2}$	52.00
	$\beta = 1 - X_o^2 / r_o^2$	0.66
	$\sigma_t = \frac{1}{Ar_o^2}\left[GJ + \frac{\pi^2 EC_w}{(Kl)^2}\right]$	480.55
	$\sigma_{TFO} = \frac{1}{2\beta}\left[(\sigma_{ex} + \sigma_t) - \sqrt{(\sigma_{ex} + \sigma_t)^2 - 4\beta\sigma_{ex}\sigma_t}\right]$	459.35
	$\sigma_{TFO} > 0.5F_y$ $F_{a2} = 0.522F_y - \frac{F_y^2}{7.67\sigma_{TFO}}$	201.31
		Fa2 is less than Fa1
Calculate allowable bending stress Fb As per cl.6.3 of IS 801 1975 Bearing strength	$A = \frac{L^2 S_{xc}}{dI_{yc}}$	1997.26
	$B = \frac{0.36\pi^2 EC_b}{F_y}$	1324.32
	$C = \frac{1.8\pi^2 EC_b}{F_y}$	6621.61
	F_b	607.81
Moment of Resistance(kN-m)	M	3.62

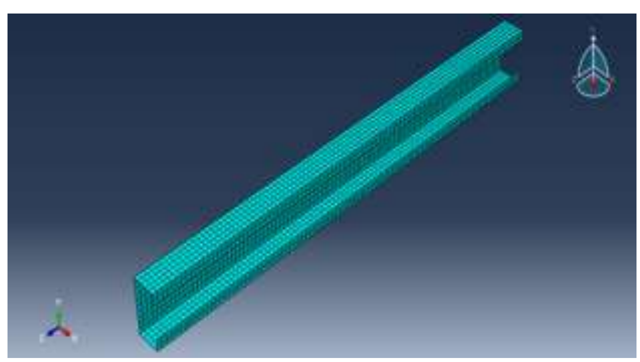
M = 3.62 kNm. In this case, a= 300 mm so,
P= 24.15 kN

Similarly, maximum ultimate load of Rectangular cold formed channel section with lip can be found by, as per IS 801:1975, the design moment will be,

M = 4.28 kNm. In this case, a= 300 mm so,
P= 28.54 kN

V. FINITE ELEMENT ANALYSIS

To know the perfect buckling behavior of cold formed channel section, finite element analysis was carried out using ABAQUS software. Modeling was done using Shell element. Material property was given as Elasticity as well as plasticity by defining Yield stress as 550 N/mm^2. In interaction, reference point was defined by section's C.G. MPC tie constraint was defined. Load and Boundary condition was given as same as test set up. Finer mesh size was given as shown in Fig. 6.



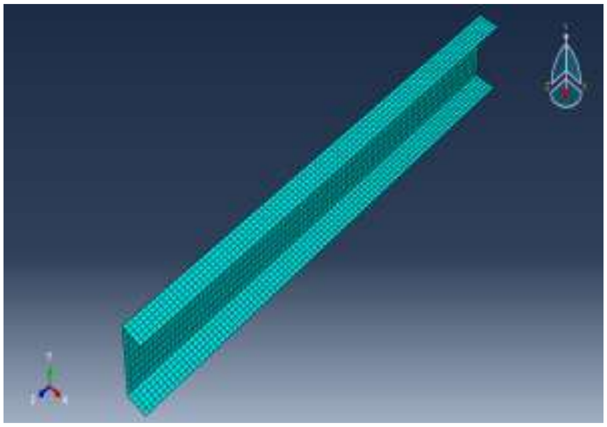


Fig.6 Modeling of Rectangular cold formed channel section

Buckling behavior was showing same as behavior in experimental program. Fig.7 shows the buckling behavior for cold formed channel section with and without lip sections.

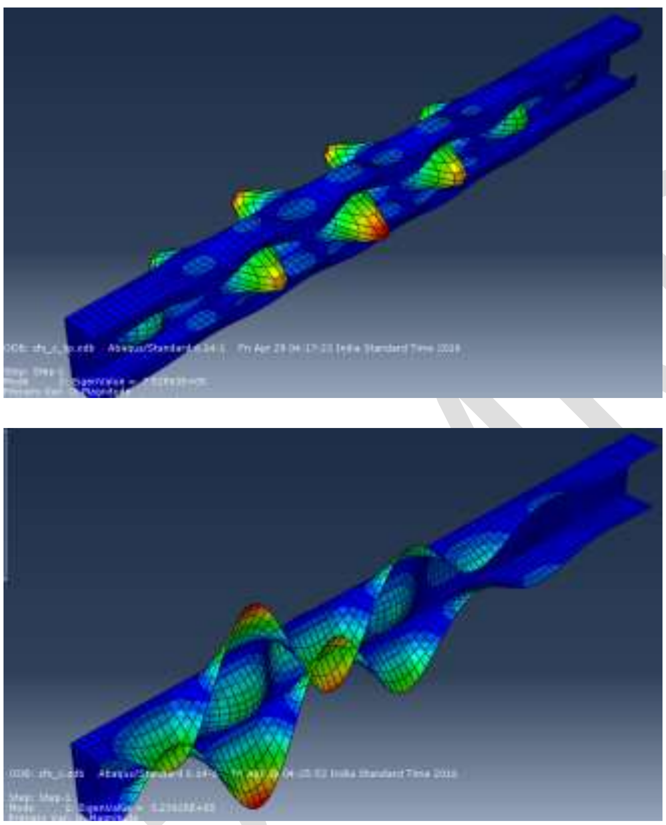


Fig.7 Buckling Behavior of cold formed channel section

VI. DISCUSSIONS

The results by experimental program, analytical solution and by FEM analysis are compared in Table 2.

Table 1 Comparison of Ultimate Load(kN)

Specimen	By Experimental Program(kN)	By Analytical Solution (As per IS 801:1975) (kN)	By Finite Element Analysis (Using ABAQUS Software) (kN)
Cold formed Channel section with lip	28.80	28.54	28.95
Cold formed Channel section without lip	20.36	24.15	21.45

VII. CONCLUSIONS

Results are showing that members subjected to pure bending, with 'lip' channel section is subjected to web buckling; channel sections with 'lip' is showing 28.7% higher than without 'lip' sections. Analytical, experimental and finite element results are showing close to each other.

- The `lip' is not taking part anywhere in calculation of bending moment capacity. It is important regarding to buckling behavior of cold formed steel sections.
- With `lip' channel section has high load carrying capacity compared to without `lip' channel section.
- Members subjected to pure bending; with `lip' channel section will be subjected to web buckling. In contrast, without `lip' channel section will be subjected to flange buckling.

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