RESEARCH ARTICLE OPEN ACCESS

Study on the Behavior of Cold-formed Channel Sections under Flexure.

Bharat C.Halagalimath*, Kiran Koraddi**
**(Department of Civil Engineering, KLE's Dr. M S Sheshgiri college of engineering and technology, Belagavi.*
*** (Asst. Professor, Department of Civil Engineering, KLE's Dr. M S Sheshgiri college of engineering and technology, Belagavi.*
Corresponding Author: Bharat C.Halagalimath

ABSTRACT
This study mainly focuses on the behavior of Cold-formed steel sections under flexure as per the codes. And comparing them with respect to Indian Standards IS801-1975 i.e. British Standard BS5950-5:1998 and American Iron and Steel Institute AISI-S100-07 both are compared with IS801-1975. The comparison is carried out by assuming three model sections C-10, C-20 and C-30 by increasing their lip depth such that specimen C-10 has lip depth of 10mm, C-20 has 20mm and C-30 has 30mm also all the rest of dimensions and sectional properties are kept the same. Then the effect of variation in lip depth is studied. Also the nature of buckling and the different modes of buckling are studied using Constrained and unconstrained finite strip method (CUFSM) software.
Keywords -Buckling, Channel section, Cold-formed steel, CUFSM, Moment capacity

---

Date Of Submission: 25-08-2019 Date Of Acceptance: 09-09-2019

I. INTRODUCTION

Steel sections are classified into two main groups that are hot-rolled sections and cold-formed sections. The use of cold-formed steel sections in building construction began in 1980's, where United State and Great Britain were the first countries to use this technology. It can be used as individual structure framing member in shape of Channel section, Z-section, I-section etc.The cold formed sections are processed into steel coils of 1-1.25 meters width, the coils are placed longitudinally to the right, then it is tilted longitudinally to the right width with appropriate section required then it is fed into a progressiveness of shapes move the rolls containing male and female bites. The ducts are arranged in pairs and move in opposite direction so that the sheet is sustained through its shape to the required profile. The set of rolls called stages is laid upon its cross-sectional shape and vary from 5 to 15. For the finishing the flying shearing machine cuts the parts into ideal lengths. An alternative method like press-breaking are restricted to short length of about 6 meters and moderately straight shapes. In this process the short lengths of strips are squeezed between a male and female pass. The cold rolling is utilized for enormous quantity of productions.

Galvanized (Zinc coated) coils give an extreme assurance against corrosion in the interior situations. Coating of 275 kg/m2 (total for both faces) is typically standard for inward environment. A 0.04mm thick zinc is coated and significant for the dampness. From the protection of corrosion, pre rolling and post rolling are utilized other than galvanizing. Although, cold rolled products are used world widely after the First World War and it is adapted from 20 years for more utility of lighter load bearing applications.

The properties of cold-formed sections slightly vary from that of hot rolled sections. The material properties of these are Young's modulus E is about $2.03x10^5$ N/mm^2, the Poisson's ratio is 0.3, modulus of rigidity 79 GPa.

There are different kinds in cold formed sections depending upon their shape, built-up sections in structural. The common types of Cold-Formed Steel Sections are as in fig. 1;

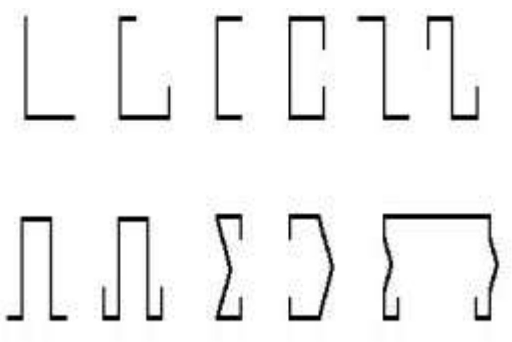

Fig 1: Basic cross sectional elements of Cold-formed steel

1.2 Types of stiffeners in Cold-formed sections

In cold-formed steel sections, the element which is supported along both its longitudinal edges is called a stiffened element. There are two types of stiffener that is 'edge stiffener' which is located at the edge of the element and the other one is called 'intermediate stiffener' which is located internally within a plate. The edge stiffener must possess sufficient rigidity or else it may buckle perpendicularly to the plane of the element to be stiffened. Intermediate stiffeners are extensively used in cold steel member. As with edge stiffeners, the intermediate stiffeners essentially have satisfactory rigidity to avoid deflection in the element in the area of the stiffener.

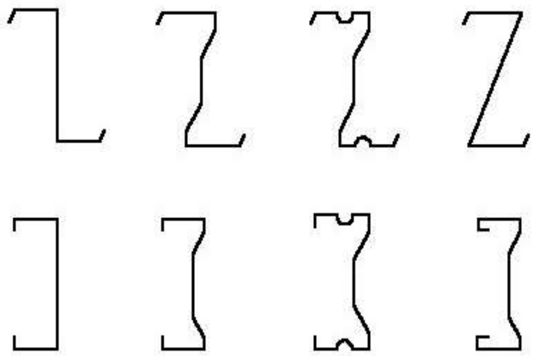

Fig 2: Types of stiffened sections that stiffened at different locations in Z section & C sections [1]

1.3 Behavior of Cold-formed steel

The characteristic behavior of any cold formed light gauge sections is that it more susceptible to buckling.

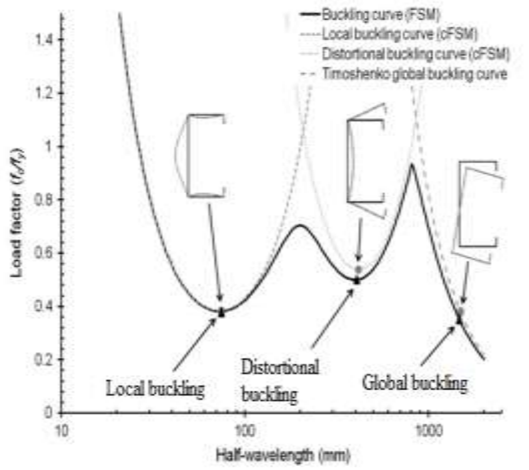

Fig 3: Typical signature curve of buckling of Cold-formed steel derived using CUFSM[2]

Local buckling take place where the axis of the member is not distorted, but the buckling component compromises strength of the cross section. It is an exceptionally important factor of cold-formed steel sections on account of the fact that the very thin elements used regularly buckle before yielding. The thinner the plate, the inferior will be the load at which buckles will form. The distortional buckling comprises both rotational and translational at the corners of the translation. It occurs when the cross section is fragile in torsion and these usually apply to open sections whose thickness is thin. Thin-walled flexural or compression members poised of high strength steel, which are braced against lateral or flexural torsional buckling, may undergo a mode of buckling commonly called distortional buckling.

One of the biggest worries with cold-formed steel design is the hindrance of member buckling. Because of the low thickness to width ratio, it is expected that the members will buckle at stresses that are lesser than the yield stress when compressive, bearing, and shear bending forces are applied. Hence, buckling is a major design consideration for all cold formed steel, which is contrasting the behavior of hot-rolled steel where steel yielding is the major design consideration.

There are two limit states: yielding and overall buckling (see Fig.1). Yielding is mainly an issue for compact and short sections. The yielding of the steel sources the failure of entire member. For longer sections, it is expected that buckling will control rather than yielding of the member. There are numerous factors that can source a member to buckle. The slenderness ratio, which is the member length divided by the least radius of gyration, is the key influence on buckling. However, buckling is impacted by other factors, which include end condition of the member, eccentricity of the load, and limitations within the material.

Buckling can occur both elastically and in-elastically. Inelastic buckling frequently occurs in stocky and intermediate sections since these members have slenderness ratios that are in the small to moderate range. Amongst various buckling modes, distortional buckling is a buckling mode that has recently been inspected. It is a buckling of the compression flange acting as a group of plates rather than as individual plates. Local buckling is often seen as a rippling effect in the web, flange, or lip along the length of the member.

II. LITERATURE REVIEW

Narayanan, S. and Mahendran, Mahen (2003)[4]:"Ultimate Capacity of Innovative Cold-formed Steel Sections". This paper defines the distortional buckling behavior of a series of innovative cold formed steel sections. More than 15 laboratory experiments were accepted first on these innovative steel sections of intermediate length under axial compression. All of these sections failed by distortional buckling with very little post-buckling strength. The section and buckling properties of the sections were determined using the finite strip analysis program THINWALL. The distortional buckling and nonlinear ultimate strength behavior of the sections was investigated in detail using finite element analyses. The finite element analyses included relevant geometric imperfections and residual stresses. The deflection and strain results from the experiments compared well with those from the analyses. The ultimate design load capacities were assessed using the provisions of Australian Cold-formed Steel Structures Standard AS/NZS 4600-1996, and were compared with those from experiments and finite element analyses. A series of parametric studies was also carried out by varying the yield strength, thickness and section length. Details of this study and the results are obtained in this paper.

M. Macdonald, M.A. Heiyantuduwa, J. Rhodes (2008)[5]: "Recent developments in the design of cold-formed steel members and structures". In this paper the main types of cold-formed steel members are described, the particular characteristics affecting their design are discussed, as are the ways in which design specifications deal with these characteristics. The various types of buckling which can occur, and which may interact with each other to promote failure at loads substantially less than those, which would be obtained in the absence of these effects. The complications induced by such effects must be taken into account in design, if the potential benefits offered by the use of such members are to be realized, and in recent design specifications this has been realized.

Jia-Hui Zhang, Ben Young (2011)[6]: "Compression tests of cold-formed steel I-shaped open sections with edge and web stiffeners". In this research, a series of section tests on cold-formed steel I-shaped open sections with edge and web stiffeners were conducted. The section specimens were compressed between fixed ends. The sections were failed by local, distortional, flexural buckling and the interaction of these buckling modes. The failure modes and ultimate strengths of the section specimens were presented. The direct strength method in the North American Specification and the Australian/New Zealand Standard was used to calculate the design strengths of the I-shaped open section sections. The appropriateness of the direct strength method for I-shaped open sections with edge and web stiffeners was evaluated. In addition, the reliability of the direct strength method for the I-shaped open sections was evaluated using reliability analysis. It is shown that the direct strength method can be used for cold-formed steel I-shaped open sections with edge and web stiffeners.

Thomas H.-K. Kang, Kenneth A. Biggs, and Chris Ramseyer (2013)[7]: "Buckling Modes of Cold-Formed Steel Sections". This paper aimed at studying different buckling modes, determine the buckling mode and maximum buckling capacity of the built-up C-channels, and evaluate as per the AISI-2001 Specification. For these goals, the following was conducted: 1) different buckling modes of cold-formed steel sections were investigated; 2) previous research on built-up sections and testing rigs for section buckling was reviewed; and 3) the authors' buckling test results of 42 cold-formed built-up sections were examined.

S.A.Kakade1, B.A.Bhandarkar, S.K. Sonar, A.D.Samare (2014)[8]: "Study of various design methods for cold – formed light gauge steel sections for compressive strength". This paper provides an experimental investigation for the compressive strength of Cold – Formed light gauge steel plain (stiffened) tubular sections. The test specimens were brake pressed from high strength structural steel sheets. In addition, the test strengths were compared with the design strengths calculated using the Indian Standard and North American Specification for Cold –Formed steel structures. Compression members are linear members in which axial forces act to cause elongation (stretch). Such members can sustain loads up to the ultimate load, at which stage they may fail by rupture at a critical section. However, if the gross area of the member yields over a major portion of its length before the rupture load is reached, the member may become non – functional due to excessive elongation. I.S. 801- 1975 is in Working Stress Method (W.S.M.) and in (M.K.S.) system, so it is required to study Allowable Stress Design (A.S.D.), Load and Resistance-Factor-Design (L.R.F.D.) and Limit State Method (L.S.M.).It is revealed that the design strengths predicted by the Specification and Standard are generally very conservative. It is observed that some specimen show lower strength than the value predicted by the American Iron and Steel Institute.

Sreedhar Kalavagunta1, Sivakumar Naganathan and Kamal Nasharuddin Bin Mustapha (2013) [9]: "Experimental Study of Axially Compressed Cold Formed Steel Channel Sections", In this paper Axial compression tests on cold-formed lipped channel sections were conducted. A total of 27 lipped channel specimens were tested. This paper has outlined two current approaches to the design of lipped channel sections using an extension to the DSM in AISI and EWM in BS5950-5 specifications as well as the test results. The DSM employs gross cross sectional area were as EWM follows effective plate width for calculating cross section capacity. The experimental test results are very close to DSM and EWM methods.

A Jayaraman, et al. (2015) [10]: This paper manages the investigation and conduct of light gauge steel which is also known as cold formed steel using different codes. The Comparative study using different codes such as Limit State Method and Working Stress Method, Euro code was considered to study the bending strength, high loading capacity of the steel area, high load carrying capacity, minimum deflection, minimum local buckling and distortional buckling of the steel section that were conduction and the results were computed using limited state method, working state method. The examples are organized by uniformly distributed loading along with simply supported conditions, Also this study deals with to know which section using which code of the steel section which has good load bearing capacity also which satisfies other strength criteria along with that the most important this is which is economical method to be adapted was fundamental target of this paper, In this paper in the theoretical investigations limit method that in SI method has get high loading, strength, high load carrying capacity , the maximum deflection and minimum local buckling and to the other codes. Also it was observed that the euro code gives solitary estimation of delta condition.

III. OBJECTIVES

1) To study different modes of buckling that occur in Cold-formed steel members that are subjected to flexural loading.
2) To obtain the Finite strip solutions for buckling classes such as global, distortional or local buckling with CUFSM software.
3) To study, design and compare the values of flexural strength as per IS 801-1975, BS5950-5:1998, AISI-S100-07.
4) To observe the effect of lip depth on the moment capacity of a section as per the codes.

IV. DESIGN OF FLEXURAL MEMBERS

4.1 Calculation as per IS Code 801-1975 of practice for use of cold formed light gauge steel structural members in general building construction;

I Specimen: Lipped Channel Section
For length L = 2000 mm with Lip = 10 mm
Computation of sectional properties
Depth d = 250 mm
Width b = 50 mm
Thickness t = 5 mm
Depth of lip D = 10 mm
A_{gross}= 1750 mm^2
I_{xx} = 1395.2 cm^4
x_{cg} = 10.2 mm
Iyy = 35.75 cm^4
r_{min} = 14.3 mm

Calculation of Effective Area
As per clause 6.1, Page No 11, IS 801-1975,
Basic allowable design stress, f = 0.6 Fy
= 0.6 X 250
f = 150 N/mm^2
As per clause 5.2.1.1, Page No 6, IS 801-1975,

$$\left(\frac{w}{t}\right)lim = \frac{1435}{\sqrt{f}} = \frac{1435}{\sqrt{150}} = 36.704$$

For Shorter side:
For 50 mm:

$$\frac{w}{t} = \frac{50-2\,X\,5}{5} = 8 < \left(\frac{w}{t}\right)lim$$

∴ For flange with w/t less than $(w/t)_{lim}$.
Effective width = w = b =50 - 2 X 5 = 40 mm.
For 10 mm:

$$\frac{w}{t} = \frac{10-1\,X\,5}{5} = 1 < \left(\frac{w}{t}\right)lim$$

∴ For flange with w/t less than $(w/t)_{lim}$.
Effective width = w = b = 10 - 5 = 5 mm.

For longer side:

$$\frac{w}{t} = \frac{250-2\,X\,5}{5} = 48 > \left(\frac{w}{t}\right)lim$$

∴ For flange with w/t larger than $(w/t)_{lim}$

$$\therefore \frac{b}{5} = \frac{2120}{\sqrt{1500}}\left(1 - \frac{465}{(48)\sqrt{1500}}\right)$$

∴ b_{eff} = 40.78 X 5
= 203.94 mm
∴ Total Effective area = (5x10) x2+ (5x5) x2+ 46x5
A_{eff} = 380 mm^2

Determination of safe load;
Z_{xx} = 111.6 x 10^3 mm^3
M_r =Z_{xx} x f
=111.6x10^3 x 141
M_r =15.73 kNm
And, $M_r = \frac{wl^2}{8}$
$15.73 \times 10^6 = \frac{w\,x\,2^2}{8}$
w = 31.46 N/mm

Check for web shear;
Max shear force = $\frac{wl}{2}$
= 31.46 kN
Max average shear stress = $\frac{F_{max}}{shear\ area}$
$= \frac{31.46x10^3}{250x5}$
= 25.168 N/mm^2
Determination of deflection;

$$\partial = \frac{5wl^4}{384EI}$$

= 2.34 mm
Permissible; $\frac{Span}{325} = \frac{2000}{325}$

= 6.15 mm

∴ Moment capacity of a lipped channel section with lip 10 mm is 15.73kNm

4.2 Calculation as per British Standard 5950-5:1998: Code of practice for design of cold formed thin gauge section

I Specimen: Lipped Channel Section
For length L = 2000 mm
Computation of sectional properties;
Depth d = 250 mm
Width w = 50 mm
Thickness t = 5 mm
A_{gross} = 1750 mm^2
I_{xx} = 1395.20 cm^4
x_{cg} = 10.2 mm
I_{yy} = 35.75cm^4
r_{min} = 1.43 cm
Z_{xx} = 111.6 cm^3

Limiting stress for stiffened web;

$$p_o = \left\{1.13 - 0.0019\frac{D_w}{t}\left(\frac{Y_s}{280}\right)^{\frac{1}{2}}\right\} X\ P_y$$ Or p_o = p_y

$p_y = \frac{240}{1.15}$ =208.67 N/mm^2

$$p_o = \left\{1.13 - 0.0019\frac{250}{5}\left(\frac{240}{280}\right)^{\frac{1}{2}}\right\} X\ 208.67$$

= 217.46 N/mm^2

Calculation of Effective width of compression flange;

As per clause 4.3 page no. 12, BS5950-5:1998

$h = \frac{B2}{B1}$, = 225/25=9

$K_1 = 5.4 - \frac{1.4h}{0.6+h} - 0.02h^3$

$= 5.4 - \frac{1.4*9}{0.6+9} - 0.02*9^3$

= 10.5 or 4(minimum)

$P_{cr} = 185000 * K1 * \left(\frac{t}{b}\right)$

= 7400 N/mm^2

If $\frac{fc}{pcr}$ < 0.123, $\frac{beff}{b}$ = 1

$\frac{fc}{pcr}$ =0.029<0.123

$\frac{beff}{b}$ = 1

∴ b_{eff} = 25 mm

Moment of Resistance;

$M_{cr} = Z_{xc}*f_c$
= 111.6x10^3 x 202.7= 22.63 kN-m

Buckling resistance moment (M_b);

$M_y = p_y * Z_c$
= 23.28kN-m

Elastic lateral buckling resistance moment;

$$M_E = \frac{\pi^2 AED}{2\frac{LE}{ry}} * Cb\left(1 + \frac{1}{20}\left(\frac{LE}{ry} * \frac{t}{D}\right)^2\right)^{0.5}$$

= 26.43 kNm

Effective Length L_E = 0.85L = 0.85 X 2000 = 1700mm

η is the Perry coefficient and is calculated as,

$$\frac{L_E}{r} = \frac{1700}{14.3} = 139.46$$

For $\frac{L_E}{r}$ > 40C_b, $\eta = 0.002\left(\frac{L_E}{r} - 40\right)$

$\eta = 0.002(139.46 - 40)$

$\eta = 0.199$

$$\therefore \emptyset = \frac{P_{cs} + (1+\eta)P_E}{2} = \frac{23.28 + (1+0.199)\ X\ 26.43}{2}$$

$\therefore \emptyset = 27.48$

$$Mb = \frac{M_E M_y}{\emptyset + \sqrt{\emptyset^2 - P_E P_{cs}}} \leq M_c$$

$$= \frac{23.28*26.43}{27.48+\sqrt{27.48^2 - 23.28*26.43}} \leq M_c$$

= 9.44 < 22.63
= 9.44kN-m

And, $M_r = \frac{wl^2}{8}$

$9.44 \times 10^6 = \frac{w\ x\ 2^2}{8}$

w = 18.88 N/mm

Deflection;

$$\partial = \frac{5wl^4}{384EI}$$

= 1.409 mm

∴Moment capacity of a lipped channel section with lip 10 mm is 9.44kNm.

4.3 Computation as per AISI S100-07: North American specification for the Design of cold-formed steel structural members

I Specimen: Direct Strength Method
Given Computation of Elastic Local and Distortional Buckling Stresses
From the Confined and Constrained Finite trip Method,
The (M_{crl}) and distortional buckling stresses are using the CUFSM software the graphs are represented as shown in the Fig 4;

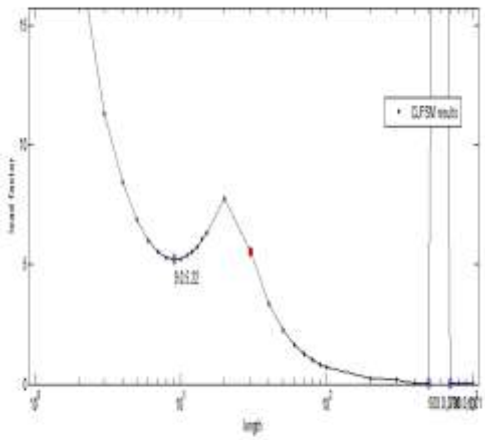

Fig 4: M_{crl} Values of section C10, with the help of the above we directly got the values of M_{crl} and M_{crd} at various lengths

Fig 5: Buckled shape at the length of 30 inches of section C10

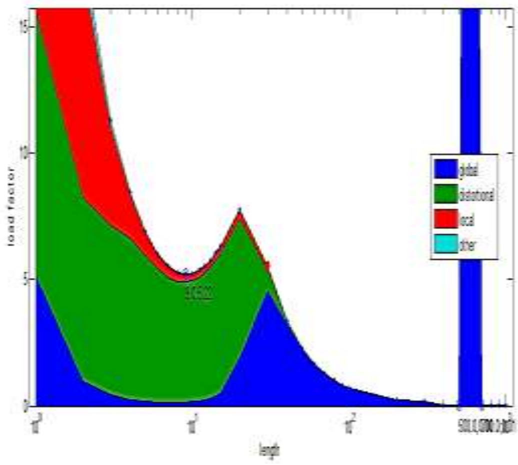

Fig 6: Classification of global distortional and local values at different length of the section C10

Calculations for Direct Strength Method;
F_y = 36.25 ksi
From the CUFSM we got the values of
M_y = 277.02 kip-in
$\frac{Mcrl}{My}$ = 5.22 @ 9 inch half wavelength
$\frac{Mcrd}{My}$ = 5.55 @ 30 inch half wavelength
M_{crl} = 1446.04 kip-in
M_{crd} = 1537.46 kip-in

For Lateral Torsional Buckling;
If $M_{cre} < 0.56M_y$
$M_{ne} = M_{cre}$,
If $2.78M_y > M_{cre} > 0.56M_y$
$M_{ne} = \frac{10}{9}\ My\ (1 - \frac{10My}{36Mcre})$
If $M_{cre} > 2.78M_y$
$M_{ne}=M_y$
M_{ne}=277.02 kip-in

Calculation of Nominal Flexural Strength Mnl, For Local Buckling
Where, $\lambda_L = \sqrt{\frac{My}{Mcrl}}$ = 0.437
For $\lambda_d < 0.776$
$M_{nl} = M_{ne}$
Hence M_{nl} = 277.02 kip-in
For Distortional Buckling,
Where, $\lambda_d = \sqrt{\frac{My}{Mcrd}}$ = 0.42
For $\lambda_d < 0.776$
$M_{nd} = M_{ne}$
M_{nd} = 277.02 kip-in
Design of Nominal Strength
M_n = 277.02 kip-in
For Allowable Stress Design;
Ω_b = 1.67
Allowable Strength Design = $\frac{Mne}{\Omega b} = \frac{277.02}{1.67}$ = 165.88 kip-in.
i.e. 18.74 kNm
And, $M_r = \frac{wl^2}{8}$

$18.74 \times 10^6 = \frac{w \times 2^2}{8}$

w = 37.48 N/mm

Deflection

$$\partial = \frac{5wl^4}{384EI}$$

= 2.79 mm

∴Moment capacity of a lipped channel section with lip 10 mm is 18.74kNm

V. RESULTS AND DISCUSSION

TABLE 1: Moment capacities of sections as per IS Code 801-1975

Channel Section	Moment Capacity	Load Carrying Capacity	Corresponding Deflection
C-10	15.73 kNm	31.46N/mm	2.34mm
C-20	17.10 kNm	34.20N/mm	2.34mm
C-30	18.23 kNm	36.47N/mm	2.34mm

TABLE 2: Moment capacities of sections as per BS 5950-5:1998

Channel Section	Moment Capacity	Load Carrying Capacity	Corresponding Deflection
C-10	9.44 kNm	18.88N/mm	1.41mm
C-20	11.33 kNm	22.66N/mm	1.55mm
C-30	12.26 kNm	24.52N/mm	1.57mm

TABLE 3: Moment capacities of sections as per AISI S100-07

Channel Section	Moment Capacity	Load Carrying Capacity	Corresponding Deflection
C-10	18.74 kNm	37.48N/mm	2.79mm
C-20	20.17 kNm	40.34N/mm	2.77mm
C-30	21.37 kNm	42.74N/mm	2.75mm

5.2 Discussions

1) From the investigation carried out for the cold formed sections, it is clear that the sections with greater lip depth show increased moment capacities. The percentage increase in moment capacities of C20 & C30 compared to C10 with increasing lip depth as per,

IS801-1975 9% and 16% respectively
BS5950-5:1998 20% and 30% respectively
AISI-S100-07 is 8% and 14% respectively.

2) Even though IS801-1975 and BS5950-5:1998 are based on effective width method IS801-1975 considers w/t ratio only while evaluating effective width whereas effective width in BS5950-5:1998 are based on the limiting stresses also.
3) The lateral buckling capacity calculated as per IS800:2007 is in good agreement with the finite strip method for the sections C20and C30. Also the Moment capacities obtained using IS801:1975 are well below the buckling moments calculated according to CUFSM/AISI.
4) The graphical representation of the nominal strengths of the sections is as shown in fig.7;

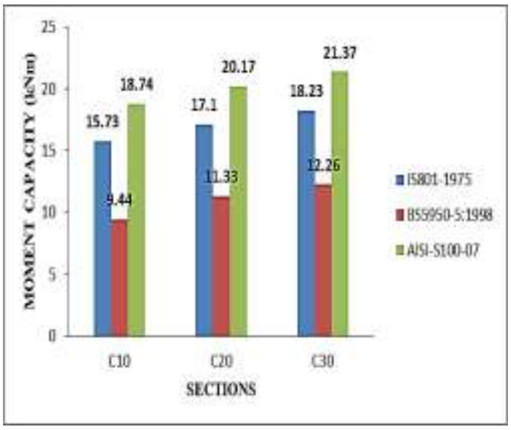

Fig 7: Graphical representation of moment capacities

The moment capacities obtained as per BS 5950 are much lower as compared to IS 801 and AISI this is mainly due to the effective lip width is not being considered in the calculations of moment capacity. The moment capacities as per IS801 and AISI are very close to each other.

VI. CONCLUSIONS

1) Even though both IS801 and BS5950 are based on effective width method itself, the consideration of cornering effect due to cold forming makes them different.
2) The lips are observed to add up the overall stiffness of the sections.
3) The effect of lip depth is seen on the moment carrying capacities as evaluated by IS801-1975 and AISI-S100-07.
4) The moment carrying capacities obtained by BS5950-5:1998 is much lower compared to IS801-1975 and AISI-S100-07.
5) Mode of failure was due to local buckling in all the three sections as observed from CUFSM analysis.
6) The percentage difference between IS801 and BS5950 is about 40% and that of AISI-S100 with IS801 is 20%.
7) The lip depth of the sections doesn't affect the deflections much.

REFERENCES

[1]. Ljubinkovic, Filip. (2016). "Structural Behavior of Cold-Formed Steel Beams Subjected to Fire". 10.13140/RG.2.1.1507.1760.
[2]. Benoit P. Gilbert, Timothee J-M Savoyat, Lip H. Teh (2012) Self-shape optimisation application: Optimisation of cold-formed steel columns.
[3]. Schafer, B.W. (1998), Cold-formed steel behavior and design: analytical and numerical modeling of elements and members with longitudinal stiffeners,
[4]. S.Narayan and M Mahendran,"Ultimate Capacity of Innovative Cold-formed Steel Columns", Journal of Constructional Steel Research 59(4): pp. 489-508.
[5]. M. Macdonald a,, M.A. Heiyantuduwa a, J. Rhodes, "Recent developments in the design of cold-formed steel members and structures", Thin-Walled Structures 46 (2008) 1047–1053.
[6]. Jia-Hui Zhang, Ben Young (2011): "Compression tests of cold-formed steel I-shaped open sections with edge and web stiffeners". Thin Walled Structures73 (2013).
[7]. Thomas H.-K. Kang, Kenneth A. Biggs, and Chris Ramseyer, "Buckling Modes of Cold-Formed Steel Columns", IACSIT International Journal of Engineering and Technology, Vol. 5, No. 4, August 2013.
[8]. S.A.Kakade, B.A .Bhandarkar, S.K. Sonar, A. D. Samare, "Study of various design methods for cold – formed light gauge steel sections for compressive strength", International Journal of Research in Engineering and Technology, Volume 3, Page No 10-13.
[9]. Sreedhar Kalavagunta1, Sivakumar Naganathan and Kamal Nasharuddin Bin Mustapha (2013): "Experimental Study of Axially Compressed Cold Formed Steel Channel Sections
[10]. A Jayaraman, et al. (2015): "Flexural Behaviour of Light Gauge Cold Formed Steel Members: Comparison of IS Code and Euro Code", Retrieved from International Journal Research in Engineering and Technology ISSN: 2319-1163 Volume 4, Issue 06 June 2015.
[11]. Mohamed Salah, Al-Din Soliman, Anwar Badawy Badawy Abu-sena, Emad Emam Hassan Darwish, Mohamed Saeed Refaee Saleh (2013) retrieved from Ains Shams Engineering Journal (2013),4 433-453.
[12]. Indian Standard IS: 801-1975, "Code of practice for use of cold-formed light gauge steel structural members in general building construction".
[13]. British Standard 5950-5:1998: Code of practice for design of cold formed thin gauge section.

Books:

[14]. American Iron and Steel Institution Committee AISI-S100-07: Specification for the design of cold-formed steel structural members
[15]. Dr. B.C. Punmia, Ashok Kumar Jain, Arun Kumar Jain " Design of Steel Structures" ISBN: 81-70008-093-2
[16]. S.K. Duggal, " Design of Steel Structures" ISBN(13): 978-07-2606893 ISBN (10): 0-007-026068.

Software:

[17]. CUFSM version 4.05 – A general purpose cold formed steel component design software based on North American Standards.

Bharat C.Halagalimath" Study on the Behavior of Cold-formed Channel Sections under Flexure." International Journal of Engineering Research and Applications (IJERA), Vol. 09, No.09, 2019, pp. 36-43