Experimental and Analytical Study on Strengthening of Deformed Cold-Formed Steel Lipped Channel Section

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***Abstract*— An experimental and analytical investigation of deformed cold formed steel lipped channel section under two point load condition is presented in this paper. The sizes of specimens are 100mm x 50mm, 100mm x 40mm and 80mm x 50mm with lip of the specimen is 15mm and thickness of the sheet is 2mm. The lipped channel specimens are tested under simply supported condition for uniform length 750mm. Flexural behaviour of these conventional beams and deformed beams are observed in the beam tests. The coupon test is carried out to get the exact material properties of these specimens. The Carbon Fiber Reinforced Polymer (CFRP) sheet with 0.5mm thickness is used for strengthening the deformed specimen. Loctite activator and saturant are used for pasting the CFRP sheet on the web section of the specimen. CFRP pasted deformed sections and normal deformed sections are finally compared.**

Keywords—Flexural behaviour; Cold formed steel; CFRP; Lipped channel section; Effective width method; Deformed beam.

I. INTRODUCTION

Two types of structural steel members are being used, namely hot rolled steel and cold formed steel. Cold-formed steel possesses a significant market share because of its advantages over other construction materials and the industries support provided by various organizations that promote cold-formed steel research and products, including codes and standards development that is spearheaded by the American Iron and Steel Institute (AISI). The thickness of the sheet used in cold formed is usually 0.9mm to 6.4mm. Typical cold-formed steel members such as studs, track, purlins, girts and angles are mainly used for carrying loads while panels and decks constitute useful surfaces such as floors, roofs and walls, in addition to resisting in-plane and out-of-plane surface loads. Press braking or cold rolling of the cold formed sheet makes the final shape of a structural member. CFRP consist of very thin filaments of carbon bound together with plastic polymer resin by heat, pressure or in a vacuum. The resulting composite material has both strong and lightweight. Flexural behavior of deformed lipped channel beam section is compared with the strengthened deformed beam using CFRP is compared with the knowledge of theoretical, analytical and experimental investigation.

II. METHODOLOGY

Flexural behavior of the lipped channel section beams are studied here under simply supported condition with two point load application using UTM. Initially theoretical investigation is carried out for the three various size specimen using Effective width method under the reference of IS 801-1975. Analytical investigation is carried out using the CUFSM and ABAQUS softwares. These outputs are calculated using the direct strength method. Surely the values get from Indian standard codes and the analytical values are different. So the main comparison is made with the experimental values get from UTM. Fresh specimen is manually deformed by some impact load under UTM and then those deformed sections are tested under two point condition with and without CFRP sheet on the web section.

III. FLEXURAL BEHAVIOUR OF COLD FORMED STEEL LIPPED CHANNEL SECTION

Lateral torsional buckling may occur in an unrestrained beam. A beam is considered to be unrestrained when its compression flange is free to displace laterally and rotate. When an applied load causes both lateral displacement and twisting of a member lateral torsional buckling has occurred. Figure shows the lateral displacement and twisting experienced by a beam when lateral torsional buckling occurs.

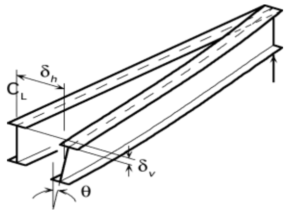

Figure 1 Lateral torsional buckling

The applied vertical load results in compression and tension in the flanges of the section. The compression flange tries to deflect laterally away from its original position, whereas the tension flange tries to keep the member straight. The lateral movement of the flanges is shown in figure.

The lateral bending of the section creates restoring forces that oppose the movement because the section wants to remain straight. These restoring forces are not large enough to stop the section from deflecting laterally, but together with the lateral component of the tensile forces, they determine the buckling resistance of the beam.

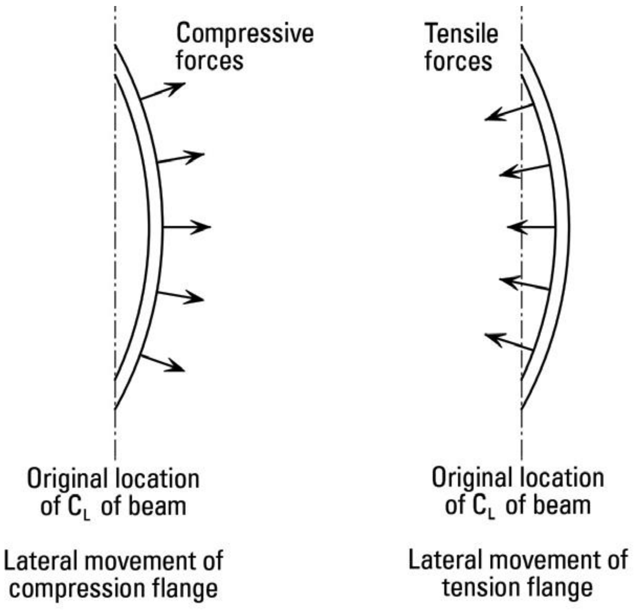

Figure 2 Lateral movements of flanges

The slenderness of a section is used in design checks for lateral torsional buckling. The following factors affect the slenderness of a section:

- Length of the beam
- Lateral bending stiffness of the flanges
- Torsional stiffness of the section.

Design codes need to account for the above factors in the guidance they give for determining the slenderness of a section. The elastic critical moment (Mcr) is used as the basis for the methods given in design codes for determining the slenderness of a section. The elastic critical moment (Mcr) is similar to the Euler (flexural) buckling of a strut in that it defines a buckling load. Euler bucking defines the axial compression that will cause a strut to fail in elastic flexural buckling compared with the elastic critical moment that defines the moment that will result in failure due to elastic lateral torsional buckling of a beam. The Elastic critical buckling (Mcr) and Euler buckling (PE) curves are shown in figure.

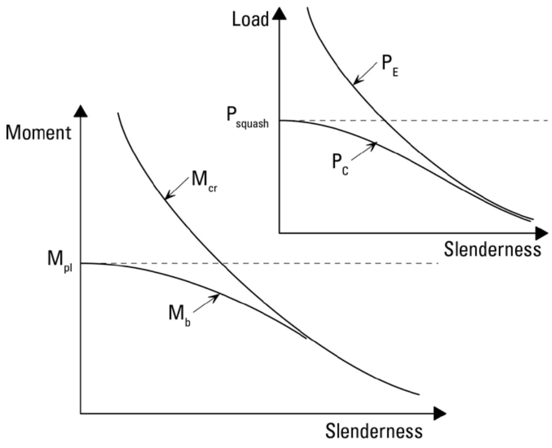

Figure 3 Slenderness graph

The buckling moment of a section is affected by plasticity. Therefore the buckling moment resistance (M_b) cannot be greater than the plastic moment (M_{pl}) of the section. The buckling moment resistance curve shown in Figure shows that;

- very slender sections fail elastically by excessive lateral torsional buckling at an applied moment close to M_{cr}.
- intermediate slender sections fail inelastically by excessive lateral torsional buckling at applied moments less than M_{cr}.
- stocky sections will attain their full plastic moment (M_{pl}) with negligible lateral torsional buckling.

Distortional buckling, also known as “stiffener buckling” or “local-torsional buckling”, is a mode characterized by rotation of the flange at the flange/web junction in members with edge stiffened elements. In members with intermediately stiffened elements distortional buckling is characterized by displacement of the intermediate stiffener normal to the plane of the element. This study focuses on distortional buckling of members with edge stiffened elements.

Distortional buckling may be directly studied by finite strip analysis. Consider the finite strip analysis of a lipped C in pure compression, figure. The analysis proceeds by finding the lowest buckling mode at a variety of different longitudinal half sine waves (half-wavelengths). The minima of the curve reveal different buckling modes that exist for the member. In this case, distortional buckling exists at an intermediate half-wavelength, between local buckling and long half-wavelength flexural or flexural-torsional buckling. This intermediate length is a defining characteristic of distortional buckling.

As figure shows, for a typical lipped C member in pure compression local buckling often occurs at a lower buckling stress than distortional buckling. If the local buckling stress is significantly lower than the distortional buckling stress then it is possible that distortional buckling may be safely ignored.

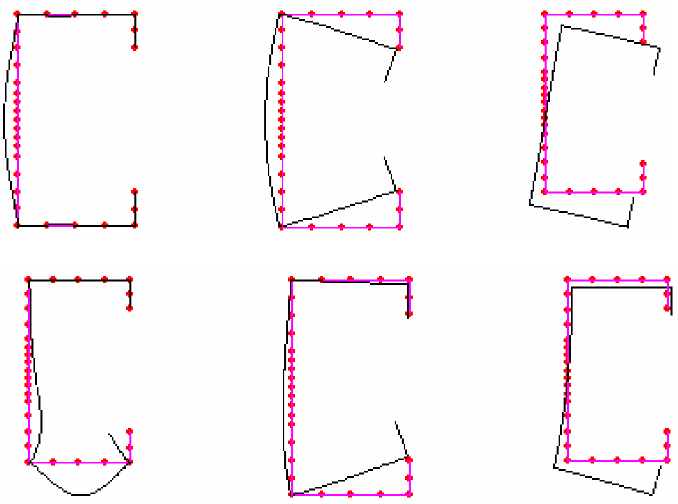

Figure 4 Cross sectional view of lateral torsional and Distorsional buckling

IV. MATERIAL PROPERTIES

The nominal section sizes of lipped channel sections are selected based on the code provision such as IS 811-1995 and IS 801-1975. The sizes of the lipped channel sections are 100mm x 50mm x 15mm x 2mm, 100mm x 40mm x 15mm x 2mm and 80mm x 50mm x 15mm x 2mm. Here 100mm and 80mm are the web of the section, 50mm and 40mm are flange portion of the section and 15mm is lip of the section. The nominal thickness of the section is 2mm. The selection of the section based on the slenderness ratio.

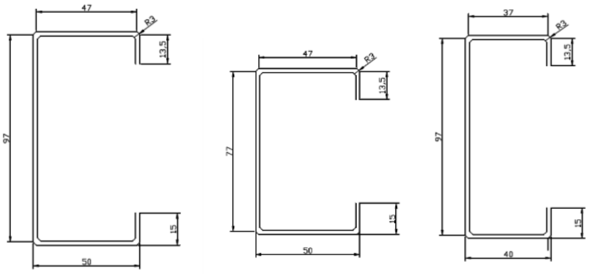

Figure 5 Dimension of lipped channel specimens

Fiber Orientation	Weight (g/m^2)	Density (g/cc)	Thickness (mm)	Ultimate elongation (%)	Tensile strength (N/mm^2)	Tensile modulus (N/mm^2)
Unidirectional	200	1.80	0.50	1.5	3500	$285x10^3$

Table 1 CFRP sheets (carbon fiber reinforcing polymer)

Figure 6 CFRP Sheet

Product	Colour	Pot Life @ 30 Degree	Density(g/cc)	Cure Time
Loctite 30(primer)	Clear	20 min	1.14	7 days
Loctite 324 (saturant)	Amber	120 min	1.25-1.26	5 days

Table 2 Epoxy Adhesive Properties

V. DESIGN METHODS FOR LIPPED CHANNEL COLD FORMED STEEL SECTION

a. Effective Width Method (EWM):

The basis of the Effective Width Method which has been followed in the IS 801 code is that the local plate buckling leads to reductions in the effectiveness of the plates that comprise of cross-section. More formally, this loss in plate effectiveness can be understood as an approximate means to account for equilibrium in an effective plate under as amplified stress distribution as opposed to the actual (full)plate with the actual nonlinear longitudinal stress distribution that develops due to buckling .Each plate in a cross-section was reduced to its effective width and this reduction from the gross cross section to the effective cross-section is fundamental to the application of the Effective Width Method.

b. Design and load calculations

The design and load calculations of the lipped channel sections are designed as per the IS801-1925 codal provisions

c. Specification

Height of the web, h = 100 mm

Width of the flange, w = 50 mm

Depth of the lip, c = 15 mm

Thickness, t = 2 mm

Area of cross section, A = 426 mm^2

Length of the beam, L = 750 mm

Moment of inertia on x-axis, I_{xx} = 67.3×10^4 mm^4

Moment of inertia on y-axis, I_{yy} = 14.5×10^4 mm^4

Yield stress, f_y = 240 N/mm^2

Section modulus on x-axis, Z_{xx} = 13.5 × 10^3 mm^3

Section modulus on x-axis, Z_{xx} = 4.4 × 10^3 mm^3

d. Calculation of effective width

As per IS 801-1975 clause 5.2.1.1 (Pg no.6)

Flange is fully effective if $\left(\frac{w}{t}\right) \leq \left(\frac{w}{t}\right)_{lim}$

Hence $\left(\frac{w}{t}\right) = \left(\frac{50-2}{2}\right)$

= 24

$\left(\frac{w}{t}\right)_{lim} = \left(\frac{1435}{\sqrt{f_y}}\right)$

$= \frac{1435}{\sqrt{1450}}$

= 37

Therefore $\left(\frac{w}{t}\right) \leq \left(\frac{w}{t}\right)_{lim}$

Hence the entire area is effective.

e. Determination of safe load

Section modulus, Z_{xx} = 13.5 × 10^3 mm^3

Allowable resisting moment, M = Z × f_y

= 13.5×10^3 × 240

= 3.24×10^6 Nmm

For two point load,

$\frac{Pl}{3} = 3.24 \times 10^6$

$P = \frac{3.24 \times 106 \times 3}{750}$

Load, P = 12.96 kN

f. Check for web shear

Maximum shear force, V = P

= 12.9 kN

Maximum average shear stress, F_{max} $= \frac{12900}{426}$

= 30.28 N/mm^2

$\frac{h}{t} = \frac{100-.4}{2}$

= 48

As per Is 801-1975 clause 6.4.1 (Pg no.15)

$\frac{4590}{\sqrt{fy}} = 296.28$

Since $\frac{h}{t} < \frac{4590}{\sqrt{fy}}$

The gross area of flat web, F_v $= \frac{1275 \times \sqrt{fy}}{\frac{h}{t}}$

$= \frac{1275 \times 15.5}{48}$

F_v = 411.72 N/mm^2

F_v must not be greater than F_{max}

F_{max} = 0.6 × f_y

= 0.6 × 240

= 144 N/mm^2

Therefore F_v = F_{max}

Thus, F_v = 144 N/mm^2 is greater than the maximum average shear stress F_{max} = 30.28 N/mm^2.

Hence the beam is safe in shear.

g. Check for bending compression in web

As per Is 801-1975 clause 6.4.2 (Pg no.16)

Actual compression stress at junction of flange and web,

$f_{bw} = f_c \times \frac{w-t}{w}$

$= 0.6 \times 240 \times \frac{50-2}{50}$

= 138.24 N/mm^2

Permissible,

$F_{bw} = \frac{36560000}{\left(\frac{h}{t}\right)^2}$ kgf/cm^2

$= \frac{3586536}{\left(\frac{h}{t}\right)^2}$ N/mm^2

F_{bw} = 1556.65 N/mm^2

Since $F_{bw} > f_{bw}$. Hence safe in bending.

h. Combined bending and shear stress in web

As per IS 801-1975 clause 6.4.3 (Pg no.16)

$$\sqrt{\left(\frac{fbw}{Fbw}\right)^2 + \left(\frac{Fmax}{F_v}\right)^2} \leq 1$$

$$\sqrt{\left(\frac{138.24}{1556.65}\right)^2 + \left(\frac{30.28}{144}\right)^2}$$

0.228 ≤ 1

Therefore it is less than unity. Hence the section is safe.

i. Determination of deflection

$$\delta \quad = \frac{Pa \times (3l^2 - 4a^2)}{24\,EI} \quad < \quad \frac{L}{325}$$

$$= \frac{12960 \times 240 \times (3(750)^2 - 4(250)^2)}{24 \times 210000 \times 673 \times 1000}$$

$$\delta \quad = 1.3739 \quad < \quad \frac{750}{325}$$

$$\delta \quad = 1.3739 \quad < \quad 2.31$$

Hence safe.

j. Slenderness ratio

$$\lambda \quad = \frac{K\,L}{r_{min}}$$

$$r_{min} \quad = \sqrt{\frac{I_{min}}{A}}$$

$$= \sqrt{\frac{14.5 \times 10000}{426}}$$

$$r_{min} \quad = 18.45$$

$$\lambda \quad = \frac{1 \times 750}{18.45}$$

$$\lambda \quad = 40.65 < 300$$

k. Maximum lateral buckling stress

As per IS 801-1975, clause 6.3 (Pg no.14)
Maximum lateral buckling stress is determined by

$$F_b \quad = \frac{2}{3}F_y - \frac{{F_y}^2}{5.4\pi^2 EC_b}$$

Where, C_b = bending coefficients considering end conditions

$$C_b \quad = 1.75 - 1.05\,\beta + 0.3\,\beta^2 \leq 2.3$$

$$F_b \quad = 160 - 1.17$$

$$= 158.83\ \text{N/mm}^2$$

l. Moment of resistance

As per IS 801-1975, clause 6.3 (Pg no.14)

$$M_{cr} \quad =$$

$$\frac{\pi^2 \times 426 \times 2.1 \times 10^5 \times 100 \times 2.3}{2 \times 40.65^2}\sqrt{1 + \left(\frac{1}{20}\left[\frac{40.65 \times 2}{100}\right]\right)}$$

$$= 62.62 \times 10^6\ \text{Nmm}$$

Therefore Maximum Design Bending Strength given by this lipped channel section (100 mm × 50 mm × 15 mm × 2 mm) @ 12.9 kN is 62.62 kN.m.

Specimen (mm)	Load (kN)	Maximum shear stress (N/mm^2)	Delection (mm)	Slenderness ratio, λ	Lateral buckling stress (N/mm^2)	Design strength, (kNm)
100×50×15×2	12.9	30.28	1.37	40.65	158.83	62.62
80×50×15×2	9.6	24.87	1.64	40.41	156.28	46.15
100×40×15×2	11	28.6	1.31	50.75	158.28	36.57

Table 3 Comparison of results for three varying lipped channel sections

VI. ANALYTICAL INVESTIGATION

CUFSM software has been successfully used by researchers for finite strip analysis of thin walled sections. The local and global buckling behavior of the cold formed sections was analyzed from this software. In order to calculate input for DSM (say M_{cre}, M_{crl} for flexural members), CUFSM can be used instead of effective width method.

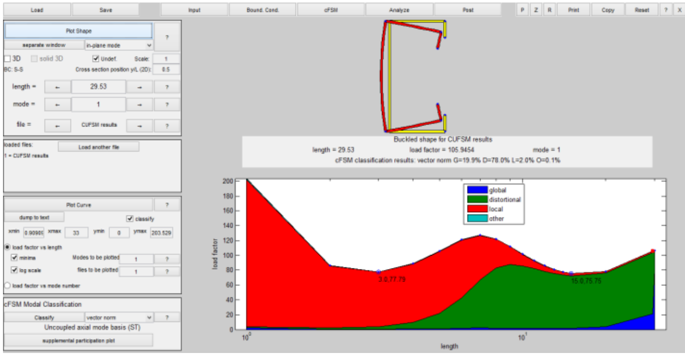

Figure 6 Result get from CUFSM

VII. RESULT AND DISCUSSION

The critical elastic and local buckling moments are analyzed from the CUFSM. Then critical local buckling moment (M_{crl}) and the critical elastic torsional buckling moment (M_{cre}), are presented in the table.

Designation	M_{cre} x 10^6 (kNm)	M_{crl} x 10^6 (kNm)	M_{ne} (kNm)	M_{nl} (kNm)	Design strength (kNm)
CFCS 1	72.06	14.43	7.95	4.22	64.84
CFCS 2	59.04	24.96	3.31	5.17	48.12
CFCS 3	45.69	59.28	2.30	6.16	37.89

Table 4 Critical and Ultimate moments from CUFSM and DSM

VIII. CONCLUSION

- The predominant buckling behaviors of normal section with 3 types of varying sizes are analytically investigated.
- Deformed sections in the structures can be repaired using this method.
- Load carrying capacity is increased for CFRP pasted sections. So it is observed that CFRP increases the strength and load carrying capacity.

IX. PROPOSED WORK FOR FUTURE

The Experimental work consists of the lipped channel beam to be placed in UTM for design load as nominal member and another beam member will load by two point load gradually, while the deform start then the loading will be stopped. The deform member will be covered by

CFRP and then allowed for further loading in UTM. Then the results will be compared with theoretically study.

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