Comparison of Buckling Behaviour of Stiffened and Unstiffened Cold Formed Steel Angle Section Subjected to Compression

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Abstract— **A comparison of buckling behaviour of stiffened and unstiffened angle section using cold formed steel members are concentrically loaded subjected to compression members is presented in this paper. The size of stiffened and unstiffened equal angle specimens of various dimensions 40mm x 40mm x 3mm, 60mm x 60mm x 3mm, 80mm x 80mm x 3mm and lip of the specimen is 10mm and the three various lengths of column is 300mm, 450mm, 600mm. are tested between fixed end conditions. Interaction of different modes of buckling behaviours are observed in the column analysis. The limiting values of slenderness ratio for the equivalent radius of gyration with the least radius of gyration are discussed to establish the buckling behaviours of stiffened and unstiffened equal angles. Analytical investigation of with and without lipped equal angles are compared with IS 801:1975 and European standard code provisions.**

Keywords—Buckling behaviour; Cold formed steel; stiffened angle; unstiffened angle; Effective width method; Direct strength method..

I. INTRODUCTION

The main process of cold-formed steel structural elements involves forming steel sections in a cold state from steel sheets of uniform thickness. The thickness of steel members ranges from 0.4mm to 6.0mm.

The cold forming operation increases the yield point and the ultimate strength of the steel sections. Their large strength to weight ratio. Versatility. Non-combustibility with appropriate measures and ease of production has attracted architects, engineers, builders and manufactures of building products with the promise, that it can help them provide improved function and greater aesthetic appearance for many applications at low cost. The wide range of available cold-formed steel products has expanded their use to primary beams, floor units, roof trusses, wall panels and building frames. Cold –formed steel members can be produced in a wide variety of sectional profiles such as angles, channels, hat sections, zed sections and sigma sections.

Angles are the most common structural shape found in almost any structure due to their simplicity and ease of fabrication and erection. Single angles are usually used as web members in steel joists and trusses, members of latticed transmission towers or communication structures and also as bracing members to provide lateral support to the main members. Until recently, the hot-rolled steel members have been recognized as the most popular and are widely used steel group, but since then the use of cold-formed high strength steel structural members has rapidly increased. However, the structural behavior of these light gauge high strength steel members characterized by various buckling modes such as local buckling, distortional buckling, and flexural-torsional buckling is not yet fully understood. Plain sections are finding applications as secondary members: the sections are usually strengthened with flange end stiffeners or web stiffeners in primary structural applications.

II. METHODOLOGY

Buckling behavior of the with and without lipped equal angle section columns are studied here under fixed ended condition with concentrically load application using UTM. Initially theoretical investigation is carried out for the three various size specimen and three various size of length using Effective width method under the reference of Indian standard IS 801-1975 and European standard. 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. But European standard codes comparison with the analytical values get from DSM .

III. BUCKLING BEHAVIOUR OF COLD FORMED STEEL LIPPED ANGLE SECTION

A thin walled member under compression, there is a possibility of local buckling to occur. Besides local buckling, other mode of failure such as:

1. Local buckling mode
2. Distortional buckling mode
3. Global buckling mode

Global buckling modes are consist of

- Flexural buckling
- Torsional buckling
- Flexural – torsional buckling

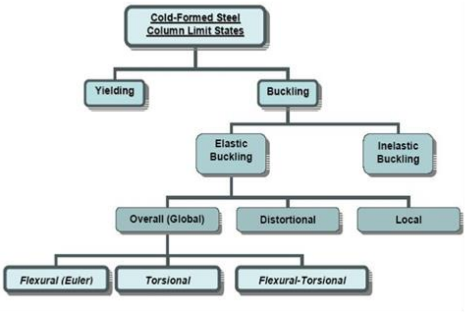

Figure 1 Failure modes of CFS members

Buckling:

When a structure is subjected to compressive stress, buckling may occur. Buckling is characterized by a sudden sideways deflection of a structural member.

Local buckling:

Local buckling is an extremely important facet of cold formed steel sections on account of the fact that the very thin elements used will invariably buckle before yielding.

Distortional buckling:

Distortional buckling 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.

Global buckling:

Global buckling is a buckling mode where the member deforms with no deformation in its cross-sectional shape.

IV. MATERIAL PROPERTIES

The nominal section sizes of with and without lipped Equal angle sections are selected based on the code provision such as IS 811-1995 and IS 801-1975. The sizes of the stiffened and unstiffened equal angle section are same dimensions of 40mm x 40mm x 3mm, 60mm x 60mm x 3mm and 80mm x 80mm x 3mm. Here 40mm and 60mm and 80mm are the web of the section, 40mm and 60mm and 80mm are flange portion of the section and 10mm is lip of the section. The nominal thickness of the section is 3mm. The selection of the section based on the slenderness ratio.

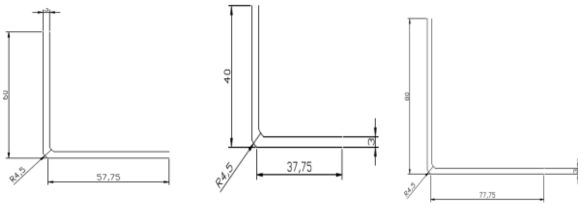

Figure 2 Dimension of unstiffened equal angle specimens

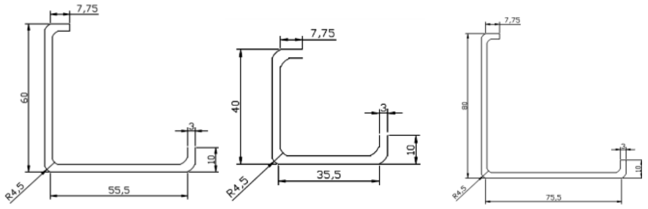

Figure 2 Dimension of stiffened equal angle specimens

The end condition for the compression member is provided by end plates at top and bottom respectively. The end plates are designed for the compressive forces and thickness is arrived as 12mm. the mild steel plate are 80mmx80mmx12mm thick and 120mmx120mmx12mm thick and 160mmx160mmx12mm arch welded at the top and bottom of member.

IV. DESIGN METHODS FOR STIFFENED AND UN STIFFENED COLD FORMED STEEL SECTION

Sections	Length (mm)	Breadth (mm)	Height (mm)	Thickness (mm)
UNSTIFFENED AND STIFFENED (Lip size = 10mm) (Same Dimensions for equal angle)				
40X40X3	300, 450, 600	40	40	3
60X60X3	300, 450, 600	60	60	3
80X80X3	300, 450, 600	80	80	3

Table 1 Dimensions of Equal Angle 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 stiffened and unstiffened equal angle sections are designed as per the IS801-1925 codal provisions

c. Specification

UNSTIFFENED ELEMENT)

Length size: 300mm, 450mm, 600mm

Height of the web, h = 40mm

Width of the flange, w = 40mm

Thickness = 3.0mm

Area of cross section, = 231 mm2

Length of the beam, L S = 300 mm

Moment of inertia on x-axis, Ixx = 3.581 × 104 mm4

Moment of inertia on y-axis, Iyy = 3.581 × 104 mm4

Yield stress, fy = 240 N/mm2

r minimum = 12.45As per IS 801-1975

d. Slenderness ratio

$$\text{Slenderness ratio} = \frac{KL}{r_{min}}$$

$$\text{rmin} = \sqrt{\frac{I}{A}}$$

rmin = 12.45

(As per IS 800-2007 Code book) K value = 0.65

= 15.66

e. Basic Stress

As per IS 801:1975 (Table:2)

f = 0.6 * Fy

f = 1450 kgf/cm2

f. Calculation of effective width

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

a) Flange of Fully effective

$$(b{=}w) \text{ to } \left(\frac{w}{t}\right) \text{lim}$$

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

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

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

= 37.68

b) Flat width ratio

= b - 2t - 2r

(r value Refer IS 811:1987 (Table-11)

= 40-2(3)-2(4.495)

= 42.99/3

= 14.33

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

Hence for effective width

$$\frac{be}{t} = \frac{2120}{\sqrt{f}} * 1 - \left(\frac{465}{\left(\frac{w}{t}\right)\sqrt{f}}\right)$$

$$\frac{2120}{\sqrt{1450}} * 1 - \left(\frac{465}{14.33\sqrt{1450}}\right)$$

be = 8.230X3

be = 24.69mm

g. Effective Area

Ae = be * t * 2 +(Arc area)

Arc area (refer code book IS 811-1987)

Ae = 24.69 * 3 * 2 +(25.85*1)

Ae = 173.99 mm2

h. Determination of from Factor

As per IS 801:1975 (Clause 6.2)

For $\left(\frac{w}{t}\right)$ ratio from 25 to 60

$$F_C = \left(\frac{5600}{\left(\frac{w}{t}\right) X \left(\frac{w}{t}\right)}\right)$$

$$F_C = \left(\frac{5600}{(42.99X42.99)}\right)$$

F_C = 304.089 kgf/cm^2

F - Allowable design stress = 1450 kgf/cm^2

$$Q = \frac{F_C}{f}$$

$$= \frac{304.089}{1450}$$

Q = 0.209

$$\text{Slenderness ratio} = \frac{KL}{r_{min}}$$

$$= \frac{0.65X300}{12.45}$$

$$= 15.66$$

From IS 801:1975

i. Critical stress(C_C)

$$C_c = \sqrt{\frac{2\pi^2 E}{F_y}}$$

$$C_c = \sqrt{\frac{2\pi^2 2*10\text{^}5}{240}}$$

$$C_C = 128.25$$

$$\frac{C_C}{\sqrt{Q}} = \frac{128.25}{\sqrt{0.209}}$$

$$= 28.53$$

$$\frac{C_C}{\sqrt{Q}} > \frac{KL}{r_{min}}$$

Allowable Stress & allowable Load

As per IS 801:1975 page No:18

$$Fal = 0.522 * Q * Fy - \left(\frac{Q * Fy * KL/r}{12500}\right)^2$$

$$=0.522*0.209*240 - \left(\frac{0.209*240*15.66}{12500}\right)^2$$

$$= 26.17 \text{ N/mm2}$$

$$\text{Allowable Load} = Fal * Ae$$

$$= 26.17*173.99$$

$$= 4.55 \text{ kN}$$

Section size (mm)	Length (mm)		
	300	450	600
	ALLOWABLE LOAD (KN)		
40x40x3	4.55	4.55	4.55
60x60x3	5.04	5.03	5.03
80x80x3	5.22	5.28	5.28

Table 2 Ultimate load for Unstiffened member as per IS 801:1975

Section size (mm) Lip 10mm	Length (mm)		
	300	450	600
	ALLOWABLE LOAD (KN)		
40x40x3	5.90	5.90	5.90
60x60x3	6.90	6.90	6.90
80x80x3	5.81	5.81	5.81

Table 3 Ultimate load for Stiffened member as per IS 801:1975

2. Design and load calculations for EUROPEAN CODE

The design and load calculations of the stiffened and unstiffened equal angle sections are designed as per the EN-1993 codal provisions

Section size (mm)	Length (mm)		
	300	450	600
	ALLOWABLE LOAD (KN)		
40x40x3	50.4	48.73	46.62
60x60x3	76.58	76.58	75.81
80x80x3	102.76	102.76	102.76

Table 4 Ultimate load for Unstiffened member as per EN 1993

Section size (mm) Lip 10mm	Length (mm)		
	300	450	600
	ALLOWABLE LOAD (KN)		
40x40x3	66.09	62.51	60
60x60x3	89.67	89.67	88.77
80x80x3	122.80	122.80	122.80

Table 5 Ultimate load for Stiffened member as per EN 1993

VI. ANALYTICAL INVESTIGATION

CUFSM is software which is freely available for exploring elastic buckling behaviour for thin walled members. It helps in calculating the buckling stress and buckling mode of various arbitrarily shaped sections. Initially it was developed only for Simply Supported conditions. Recently it has been developed for other boundary conditions such as Clamped-Clamped, Simple-Clamped, Clamped-Free and Clamped–Guided.

Direct strength method (DSM)

The Direct Strength Method is an entirely new design method which was adopted in 2004 as Appendix 1 to the North American Specification for the Design of Cold-Formed Steel Structural Members. It does not rely on effective width calculations, nor require iteration for the determination of member design strength. Instead, the elastic buckling load in local, distortional and global buckling and that which causes first yield are required to be determined and employed in a series of equations to directly provide the strength prediction. It is extensively developed for beams and columns only.

Dsm Procedure For Compression Members

The nominal axial strength Pn is the minimum of Pne, Pnl and Pnd as given below.

Where,

Pne = Nominal axial strength for flexural, torsional or flexural-torsional buckling

Pnl = Nominal axial strength for local buckling

Pnd = Nominal axial strength for distortional

VII RESULT AND DISCUSSION

Length (mm)	Specimen (mm)	UnStiffened	
		European (KN)	Analytical (KN)
300	40x40x3	50.4	55.30
450	40x40x3	48.73	55.34
600	40x40x3	46.62	55.59
300	60x60x3	76.58	84.15
450	60x60x3	76.58	84.14
600	60x60x3	75.81	84.13
300	80x80x3	102.76	112.91
450	80x80x3	102.76	112.86
600	80x80x3	102.76	112.81

Table 6 Comparison for Europe code and analytical (DSM) Unstiffened Loads

Length (mm)	Specimen (mm) LIP 10mm	Stiffened	
		European (KN)	Analytical (KN)
300	40x40x3	66.09	69.82
450	40x40x3	62.51	69.80
600	40x40x3	60.00	69.79
300	60x60x3	89.67	98.61
450	60x60x3	89.67	98.59
600	60x60x3	88.77	98.57
300	80x80x3	122.80	127.48
450	80x80x3	122.80	127.45
600	80x80x3	122.80	127.41

Table 7 Comparison for Europe code and analytical (DSM) Stiffened Loads.

VIII. CONCLUSION

The buckling behaviour and load carrying capacity of the compression members are compared to European code and direct strength method.

The distortional buckling behaviour is observed for the stiffened section only.

Stiffened and unstiffened equal angle section load compared to this paper stiffened section is increased to load capacity.

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