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

**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.

<table>
<thead>
<tr>
<th>Sections</th>
<th>Length (mm)</th>
<th>Breadth (mm)</th>
<th>Height (mm)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNSTIFFENED AND STIFFENED (Lip size = 10mm) (Same Dimensions for equal angle)</td>
<td>40X40X3</td>
<td>300, 450, 600</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>60X60X3</td>
<td>300, 450, 600</td>
<td>60</td>
<td>60</td>
<td>3</td>
</tr>
<tr>
<td>80X80X3</td>
<td>300, 450, 600</td>
<td>80</td>
<td>80</td>
<td>3</td>
</tr>
</tbody>
</table>

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, \( L \) = 300 mm
Moment of inertia on x-axis, \( I_{xx} \) = \( 3.581 \times 10^{4} \) mm⁴
Moment of inertia on y-axis, \( I_{yy} \) = \( 3.581 \times 10^{4} \) mm⁴
Yield stress, \( f_y \) = 240 N/mm²
r minimum = 12.45 As per IS 801-1975

d. Slenderness ratio

\[
KL
\
\frac{r_{min}}{r}
\]

\( r_{min} = \sqrt{\frac{I}{A}} \)

\( r_{min} = 12.45 \) (As per IS 800-2007 Code book) K value = 0.65

= 15.66

e. Basic Stress

As per IS 801:1975 (Table:2)

\( f = 0.6 \times F_y \)

\( f = 1450 \) 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

\( b = w \) to \( \frac{w}{t} \) limit

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

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

b) Flat width ratio

\( b = b - 2t - 2r \) (r value Refer IS 811:1987 (Table-11)

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

\( = 42.99/3 \)

\( = 14.33 \)

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

Hence for effective width

\[
\frac{be}{t} = \frac{2120}{\sqrt{f}} \times 1 - \left( \frac{65}{\left( \frac{w}{t} \right)_{\text{lim}}} \right)
\]

\( be = 8.230X3 \)

\( be = 24.69 \) mm

g. Effective Area

\( A_e = be \times t + \text{(Arc area)} \)

\( \text{Arc area (refer code book IS 811-1987)} \)

\( A_e = 24.69 \times 3 + (25.85 \times 1) \)

\( A_e = 173.99 \) mm²

h. Determination of from Factor

As per IS 801:1975 (Clause 6.2)

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

\[
F_C = \left( \frac{5600}{\left( \frac{w}{t} \times X \left( \frac{w}{t} \right) \right)} \right)
\]

\[
F_C = \left( \frac{5600}{(42.99 \times 42.99)} \right)
\]

\( F_C = 304.089 \) kgf/cm²

\( F - \text{Allowable design stress} = 1450 \) kgf/cm²

\( Q = \frac{F_C}{f} \)
\[
Q = 0.209
\]

Slenderness ratio \( \frac{KL}{r_{\text{min}}} \)

\[
= \frac{0.65 \times 300}{12.45} = 15.66
\]

From IS 801:1975

1. Critical stress \( C_C \)

\[
C_C = \sqrt{\frac{2 \pi^2 E}{F_y}}
\]

\[
= 128.25
\]

2. Critical stress \( C_c \)

\[
C_c = \frac{C_C}{\sqrt{Q}} \geq \frac{KL}{r_{\text{min}}}
\]

\[
= 28.53
\]

Allowable Stress & allowable Load

As per IS 801:1975 page No:18

\[
\text{Fal} = 0.522 \times Q \times F_y \left( \frac{Q \times F_y \times KL/r}{12500} \right)^2
\]

\[
= 0.522 \times 0.209 \times 240 \times \left( \frac{0.209 \times 240 \times 15.66}{12500} \right)^2
\]

\[
= 26.17 \text{ N/mm}^2
\]

Allowable Load = Fal \times Ae

\[
= 26.17 \times 173.99
\]

\[
= 4.55 \text{ kN}
\]
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**

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Specimen (mm)</th>
<th>European (KN)</th>
<th>Analytical (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>40x40x3</td>
<td>50.4</td>
<td>55.30</td>
</tr>
<tr>
<td>450</td>
<td>40x40x3</td>
<td>48.73</td>
<td>55.34</td>
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<td>600</td>
<td>40x40x3</td>
<td>46.62</td>
<td>55.59</td>
</tr>
<tr>
<td>300</td>
<td>60x60x3</td>
<td>76.58</td>
<td>84.15</td>
</tr>
<tr>
<td>450</td>
<td>60x60x3</td>
<td>76.58</td>
<td>84.14</td>
</tr>
<tr>
<td>600</td>
<td>60x60x3</td>
<td>75.81</td>
<td>84.13</td>
</tr>
<tr>
<td>300</td>
<td>80x80x3</td>
<td>102.76</td>
<td>112.91</td>
</tr>
<tr>
<td>450</td>
<td>80x80x3</td>
<td>102.76</td>
<td>112.86</td>
</tr>
<tr>
<td>600</td>
<td>80x80x3</td>
<td>102.76</td>
<td>112.81</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Specimen (mm) LIP 10mm</th>
<th>European (KN)</th>
<th>Analytical (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>40x40x3</td>
<td>66.09</td>
<td>69.82</td>
</tr>
<tr>
<td>450</td>
<td>40x40x3</td>
<td>62.51</td>
<td>69.80</td>
</tr>
<tr>
<td>600</td>
<td>40x40x3</td>
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<td>69.79</td>
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<td>89.67</td>
<td>98.61</td>
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<td>300</td>
<td>80x80x3</td>
<td>122.80</td>
<td>127.48</td>
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<tr>
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<td>122.80</td>
<td>127.45</td>
</tr>
<tr>
<td>600</td>
<td>80x80x3</td>
<td>122.80</td>
<td>127.41</td>
</tr>
</tbody>
</table>

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.

**ACKNOWLEDGMENT**

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