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Comparison of Compression Capacity of Cold Formed Steel Channel Sections under Concentrated Loading by Analytical Methods

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Abstract: **The objective of this research paper is to determine the capacity of cold formed steel sections under compression subjected to concentrated loading for different lengths. Study under this title includes comparison of mid line and Indian standard design methods to check safe carrying capacity of C-shaped compression members with lips.**

Keywords: **Cold formed steel, Compression member, Mid line and Indian standard design method, Effective width method, Direct strength method.**

1. INTRODUCTION

Cold-formed steel members are widely used in building construction, bridge construction, storage racks, highway products, drainage facilities, grain bins, transmission towers, car bodies, railway coaches, and various types of equipment. These sections are cold-formed from carbon or low alloy steel sheet, strip, plate, or flat bar in cold-rolling machines or by press brake or bending brake operations. Members are usually not thicker than 10 mm. The manufacturing process involves forming the material by either press braking or cold roll forming to achieve the desired shape.

2. DESIGN METHODS FOR COLD-FORMED STEEL STRUCTURAL MEMBERS

2.1 The effective width concept

Since the thickness of individual plate elements of cold-formed steel (CFS) structural members are normally small compared to their width, buckling and postbuckling strength are two major concerns for strength prediction of CFS structural members. Unlike hot rolled structural members, CFS members normally buckle prior to section yielding.

Further, CFS compression elements do not collapse when the buckling stress is reached. Additional load can be carried by the element after buckling, by means of stress redistribution. This phenomenon, termed “postbuckling strength” is most pronounced for elements with high slenderness.

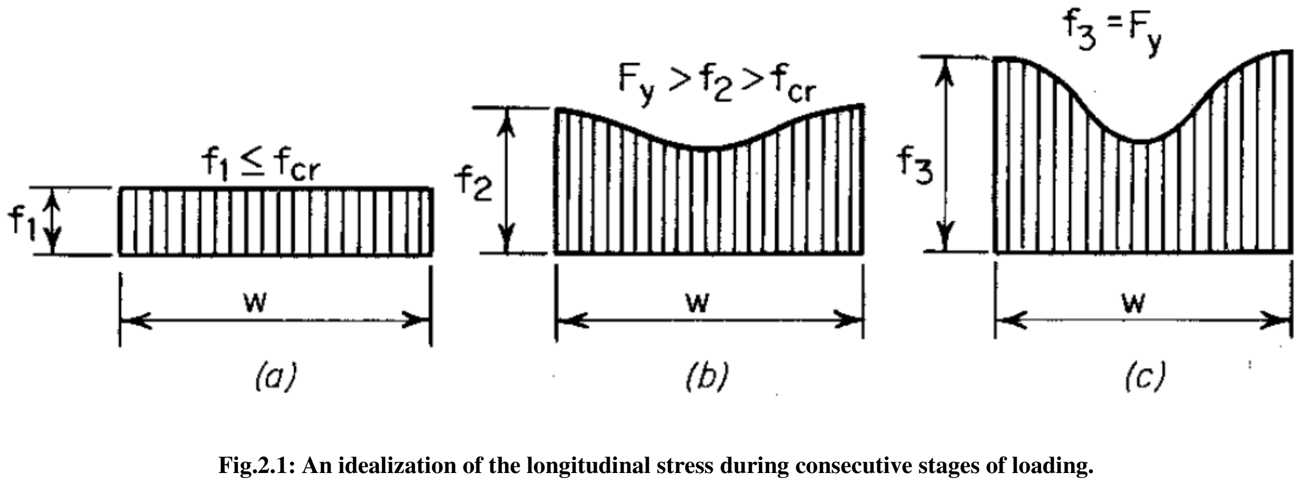


Fig.2.1: An idealization of the longitudinal stress during consecutive stages of loading.

The stress is uniformly distributed at the beginning load stage. As the applied stress approaches the buckling stress, the stress distribution is no longer uniform and the maximum stress increases over the buckling stress until it reaches the yield stress, then the element fails. This ignores the longitudinal variations in the stress, but captures the mean, membrane stress behavior.

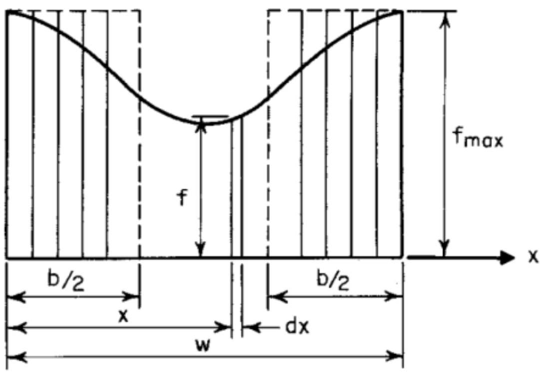


Fig.2.2: $\boldsymbol{f_{\max}}$ **equals the edge stress**

In the Effective Width approach, instead of considering the non-uniform distribution of stress across the width of the element, it is assumed that the total load is carried by a fictitious width b, which is subjected to a uniformly distributed stress $f_{\max}$. Where, $f_{\max}$ equals the edge stress, as shown in Figure 2.2

3. BUCKLING PHENOMENON OF COLD FORMED STEEL ELEMENTS

Axial load is very common and very important type of loading and the requirement to deal with this type of loading in cold formed steel members vary according to type of loading, tension or compression and geometry and use of the member. For axially loaded cold formed steel, compression member should be designed for the following limit states:

1. Local buckling
2. Distortional buckling
3. Flexural buckling
4. Distortional-flexural buckling.
5. Yielding

In the case of light gauge members, the width to thickness ratio (w/t) is quite large and hence failure of member occurs invariably by buckling. For light gauge plate elements, the buckling occurs at low stresses resulting due to compression, or bending or shear or bearing.

The critical stress of a plate in compression is given by

$$f_{\mathrm{cr}} = k\frac{\pi^2 \mathrm{E}}{12(1-\mu^2)(w/t)^2}$$

Where, f_{cr} = critical stress
E = modulus of elasticity
μ = Poisson's ratio
w = width of the plate
t = thickness of the plate
k = constant depends on support conditions

When the edges parallel to the compression stress are simply supported, the value of k = 4. Hence for such case, the critical stress is given by

$$f_{\mathrm{cr}} = \frac{\pi^2 \mathrm{E}}{3(1-\mu^2)(\mathrm{w/t})^2}$$

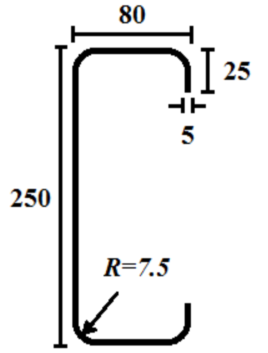
4. CODE PROVISIONS OF BUCKLING OF COMPRESSED PLATES

For effective width of stiffened compression elements other than tubes without intermediate stiffener, Load determination,

for (w/t) upto $(w/t)_{\mathrm{lim}} = 446/\sqrt{f}$, $b = w$
for $(w/t) > (w/t)_{\mathrm{lim}}$, $\frac{b}{t} = \frac{658}{\sqrt{f}}\left[1 - \frac{145}{(\mathrm{w/t})\sqrt{f}}\right]$
Allowable stresses for unstiffened compression elements
for $(w/t) \le 165/\sqrt{f_y}$; $f_c = 0.6 f_y$
for $375/\sqrt{f_y} > (w/t) > 165\sqrt{f_y}$; $f_c = f_y\,[\,0.767 - 10^{-3}(w/t)\sqrt{f_y}\,]$
for $25 > (w/t) > 375/\sqrt{f_y}$; $f_c = 54200/(w/t)^2$
for $60 > (w/t) > 25$
i) angle struts : $f_c = 54200/(w/t)^2$
ii) other sections : $f_c = 134 - 1.93(w/t)$

4.1 Sample calculations by IS 801:1975

Consider 250x80x25x5



250x80x25x5
All dimensions are in mm

1. Sectional properties
h = 250 mm
b = 80 mm
l = 25 mm
r = 7.5 mm
t = 5 mm
A = 2080 mm^2
I_{xx} = 1840×10^4 mm^4
I_{yy} = 156×10^4 mm^4

r_{yy} = 27.39 mm

2. Material Properties

f_y = 240 Mpa
E = 2x10^5 Mpa

3. Computation of effective widths

Radius of curve = 7.5+5 = 12.5 mm

i) For unstiffened element *(lips)*

(w/t) = (25-12.5)/5 = 2.5 < 12
Therefore, $f_c = 0.6 f_y$ = 144 Mpa

ii) For stiffened flanges

$$\frac{b}{t} = \frac{658}{\sqrt{f}}\left[1-\frac{145}{(w/t)\sqrt{f}}\right] = 11$$

Hence b = 55mm

iii) For web, b = 200.55 mm

4. Determination of form factor Q

A_{eff} = 2080-(24.45*5) = 1957.75 mm^2

$$Q = \frac{f_c}{f}.\frac{A_{eff}}{A} = 0.94$$

5. Determination of C_c and $(l/r)_{lim}$

$$C_c = \sqrt{\frac{2\pi^2 E}{fy}} = 128.31$$

$(l/r)_{lim}$ = 132.25

6. Determination of safe load for 1m

$(l/r) = (1000/27.39) = 36.51 < (l/r)_{lim}$

$$f_a = \frac{12}{23}.Q.f_y - \frac{3}{23.E}.\left[\frac{Q.f y.(l/r)}{\pi}\right]^2 = 113.37 \text{ Mpa}$$

Permissible load = f_a. A_{eff} = 235.08 kN.

For different lengths capacity of lipped channel section 250x80x25x5 according to the guidelines of mid line dimensions and IS 801:1975 are as followed.

Table 4.1.1: Theoretically obtained capacity values as per IS 801:1975

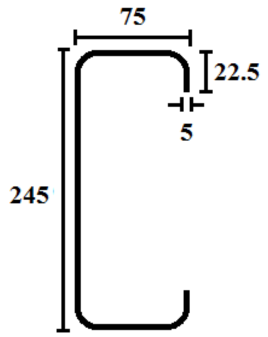
Section	Effective Length	As per IS 801:1975
250x80x25x5	*1m*	235.80 kN
	3m	161.05 kN
	5m	64.32 kN
	10m	16.08 kN

4.2 Sample calculations by Mid Line Dimensions

Consider Section *250x80x25x5*

1. Sectional properties

h = 245 mm
b = 75 mm
l = 22.5 mm
t = 5 mm
A = [245+75*2+22.5*2]*5 = 2200 mm^2
I_{xx} = 2017.65x10^4 mm^4
I_{yy} = 175.14x10^4 mm^4
r_{yy} = 28.22 mm



250x80x25x5
All dimensions are in mm

2. Material Properties

f_y = 240 Mpa
E = 2x10^5 Mpa

3. Computation of effective widths

i) For unstiffened element *(lips)*

(w/t) = 22.5/5
= 4.5 < 12
Therefore, $f_c = 0.6 f_y$ = 144 Mpa

ii) For stiffened flanges

$$\frac{b}{t} = \frac{658}{\sqrt{f}}\left[1-\frac{145}{(w/t)\sqrt{f}}\right] = 15$$

Hence b = 75 mm

iii) For web, b = 206.56 mm

4. Determination of form factor Q

A_{eff} = 2200-(38.44*5) = 2007.8 mm^2

$$Q = \frac{f_c}{f}.\frac{A_{eff}}{A} = 0.91$$

5. Determination of C_c and $(l/r)_{lim}$

$$C_c = \sqrt{\frac{2\pi^2 E}{fy}} = 128.31$$

$(l/r)_{lim}$ = 134.31

6. Determination of safe load for 1m

$(l/r) = (1000/28.22) = 35.44 < (l/r)_{lim}$

$$f_a = \frac{12}{23}.Q.f_y - \frac{3}{23.E}.\left[\frac{Q.f y.(l/r)}{\pi}\right]^2 = 110.3 \text{ Mpa}$$

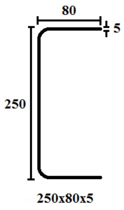
Permissible load = f_a. A_{eff} = 242.66 kN

Table 4.2.1: Theoretically obtained capacity values as per Mid Line Dimensions

Section	Effective Length	As per Mid Line Dimensions
250x80x25x5	*1m*	242.66 kN
	3m	172.63 kN
	5m	72.21 kN
	10m	18.05 kN

Compression capacity of section without lips calculated by both analytical methods is as follows.

Table 4.2.2: Theoretically obtained capacity values for section without lips

Section	Effective Length	As per IS 801:1975	As per Mid Line Dimensions
 x80x5	*1m*	216.08 kN	211.22 kN
	3m	123.86 kN	115.07 kN
	5m	44.94 kN	41.46 kN
	10m	11.23 kN	10.37 kN

5. CONCLUDING REMARKS

In this study, cold-formed C shaped channel sections are studied to get compression capacity under concentrate loading. Two different approaches are used Mid line dimensions and IS 801:1975. For different lengths pinned connections are used so as to have overall length as its effective length. The main conclusions obtained from these results can be summarized as follows.

1. Comparing two design methods first one is according to IS 801: 1975, and another one mid line dimension particularly followed by British standard BS: 5950-5:1998.

2. Even though the base is effective width method consideration of corner effect due to cold forming makes them different.

3. Effective width method is on safer side to find compression capacity of section compared to direct strength method. For a choice of design of a short column direct strength method can be preferred.

4. Comparing capacity values through two different methods it is observed that methodology adopted in IS 801:1975 is more reliable to calculations by considering mid line dimensions. IS 801:1975 is nothing but effective width method which is more tedious than direct strength method but since it depends on Q value that is ratio of effective area by c/s area of sections found to be equal to one for the sections 180x80x25x5 and less than onwards.

5. Channel sections are considered with length variation of 1m, 3m, 5m, and 10m. Therefore, capacity of short columns can be compared to long columns under concentrated loading conditions. It is observed that with increase in length capacity of columns observed to reduce by more than 50% in the range of 3m to 5m and 5m to 10m. Therefore, in case of cold formed structures use of built up columns shall be preferred for longer lengths.

6. The value of form factor Q, which is a ratio of effective area under compression to overall area. Choice of section with lips or without lips doesn't affect the value of Q up to a considerable difference. Not even with the change in its effective length.

7. For channel section with lips, lips are observed to add to the overall stiffness of the section and not to the capacity as much. Change in lip length does not cause any considerable change in compression capacity of the section. Hence, compression capacity obtained by mid line dimension are upper bounded values as compared to those obtained by IS 801:1975.

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