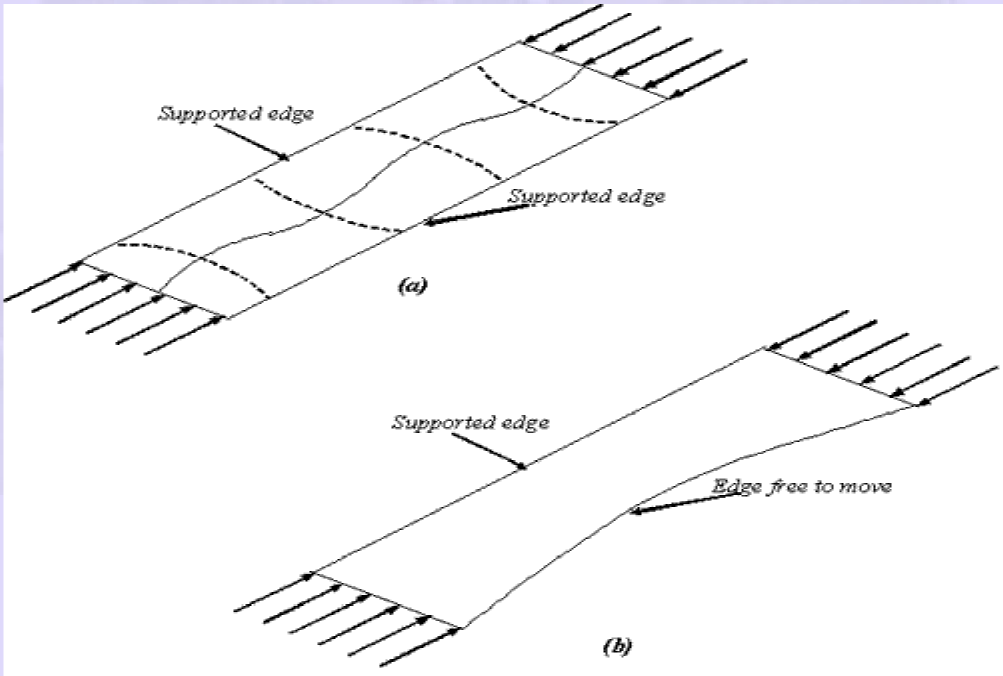
5.3 Local buckling

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. Thinner the plate, the lower will be the load at which the buckles will form.

5.3.1 Elastic buckling of thin plates

It has been shown in the chapter on "Introduction to Plate Buckling" that a flat plate simply supported on all edges and loaded in compression (as shown in Fig. 5.3(a)) will buckle at an elastic critical stress given by

$$p_{cr} = \frac{K\pi^2 E}{12\left(1-v^2\right)}\left(\frac{t}{b}\right)^2 \qquad \textbf{\textit{(5.1)}}$$

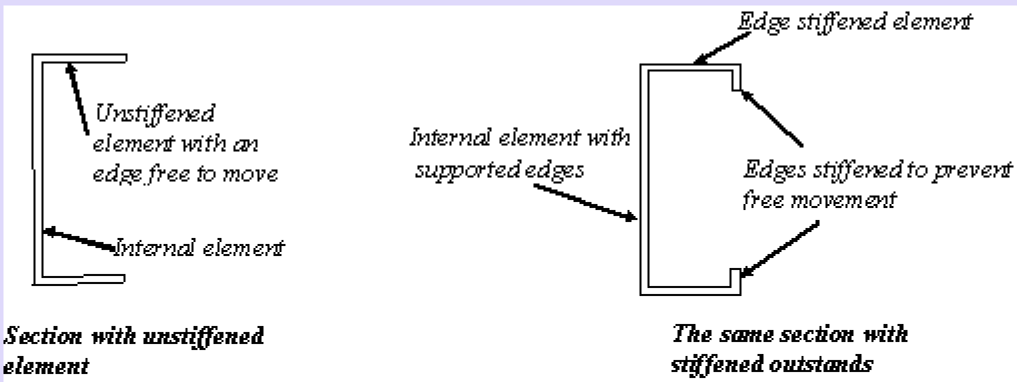


5.3 (a) Axially compressed plate simply supported on all edges

5.3 (b) Axially compressed plate with one edge supported and the other edge free to move

Substituting the values for π, v = 0.3 and E = 205 kN/mm^2, we obtain the value

of p_{cr} as $p_{cr} \approx 185 \, x \, 10^3 \, x \, K \left(\frac{t}{b}\right)^2$ with units of N/ mm^2 **(5.1a)**



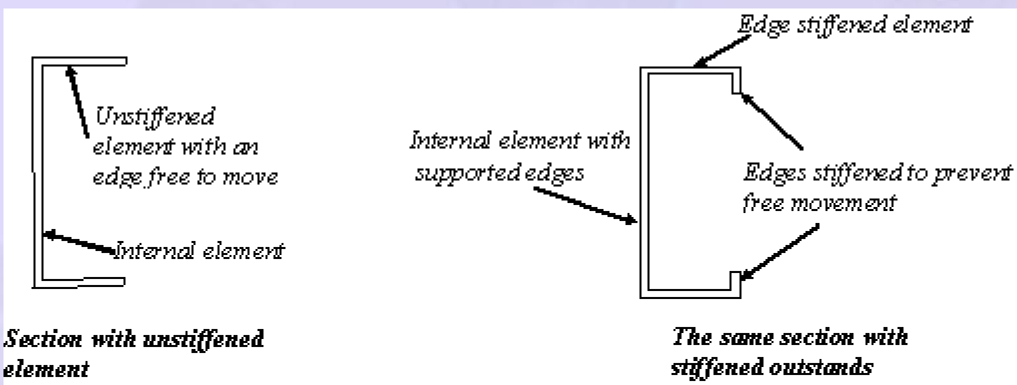


Fig.5.4 The technique of stiffening the element

The value of K is dependent on support conditions. When all the edges are simply supported K has a value of 4.0.

When one of the edges is free to move and the opposite edge is supported, (as shown in Fig. 5.3b), the plate buckles at a significantly lower load, as K reduces dramatically to 0.425. This shows that plates with free edges do not perform well under local buckling. To counter this difficulty when using cold formed sections, the free edges are provided with a lip so that they will be constrained to remain straight and will not be free to move. This concept of stiffening the elements is illustrated in Fig. 5.4.

5.3.2 Post - critical behaviour

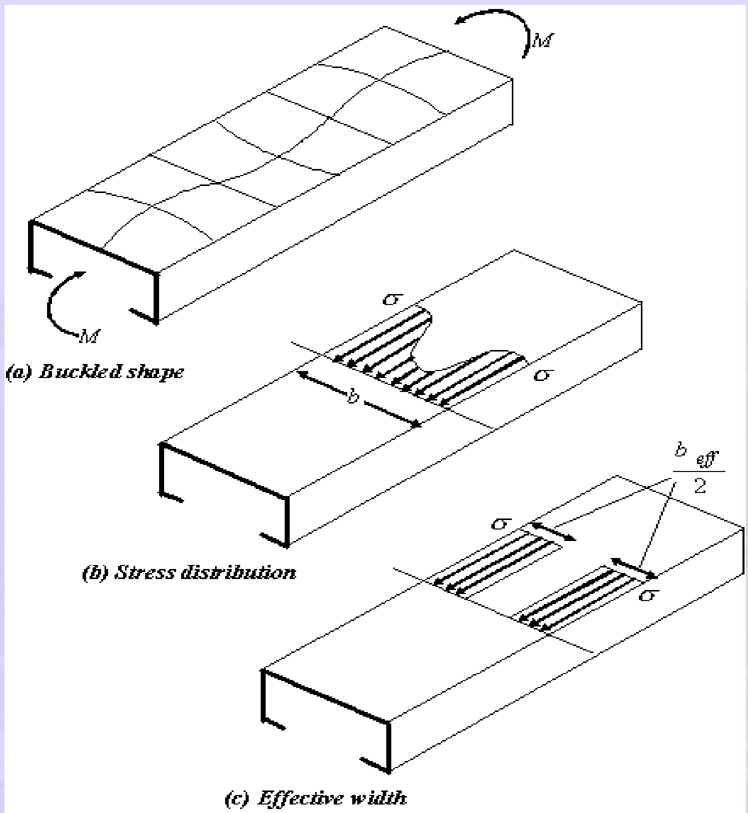


Fig. 5.5 Local buckling effects

Let us consider the channel subjected to a uniform bending by the application of moments at the ends. The thin plate at the top is under flexural compression and will buckle as shown in Fig. 5.5 (a). This type of buckling is characterised by ripples along the length of the element. The top plate is supported along the edges and its central portion, which is far from the supports, will deflect and shed the load to the stiffer edges. The regions near the edges are prevented from deflecting to the same extent. The stresses are non uniform across the section as shown in Fig.5.5 (b). It is obvious that the applied moment is largely resisted by regions near the edges (i.e. elements which carry increased stresses) while the regions near the centre are only lightly stressed and so are less effective in resisting the applied moment.

From a theoretical stand point, flat plates would buckle instantaneously at the elastic critical load. Under incremental loading, plate elements which are not perfectly flat will begin to deform out of plane from the beginning rather than instantaneously at the onset of buckling and fail at a lower load. This means that a non-uniform state of stress exists throughout the loading regime. The variation of mean stress with lateral deflection for flat plates and plates with initial imperfection, under loading are shown in Fig. 5.6.

This tendency is predominant in plates having b/t (breadth/thickness) ratios of 30-60. For plates having a b/t value in excess of 60, the in-plane tensile stresses or the "membrane stresses" (generated by the stretching of the plates) resist further buckling and cause an increase in the load-carrying capacity of wide plates.

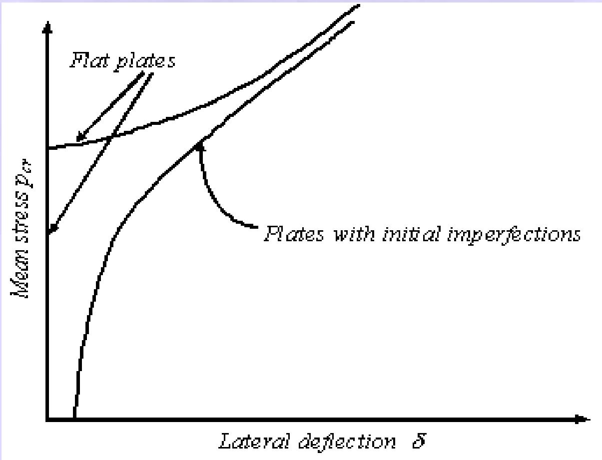


Fig. 5.6 Mean stress Vs lateral deflection relation

5.3.3 Effective width concept

The effects of local buckling can be evaluated by using the concept of ***effective width***. Lightly stressed regions at centre are ignored, as these are least effective in resisting the applied stresses. Regions near the supports are far more effective and are taken to be fully effective. The section behaviour is modeled on the basis of the effective width (b_{eff}) sketched in Fig. 5.5(c).

The effective width, (b_{eff}) multiplied by the edge stress (σ) is the same as the mean stress across the section multiplied by the total width (b) of the compression member.

The ***effective width*** of an element under compression is dependent on the magnitude of the applied stress f_c, the width/thickness ratio of the element and the edge support conditions.

5.3.4 Code provisions on "Local buckling of compressed plates"

The effective width concept is usually modified to take into account the effects of yielding and imperfection. For example, BS5950: Part 5 provides a semi-empirical formula for basic effective width, b_{eff}, to conform to extensive experimental data.

When $f_c > 0.123\ p_{cr}$, then

$$\frac{b_{eff}}{b} = \left[1 + 14\left\{\left[\frac{f_c}{p_{cr}}\right]^{0.5} - 0.35\right\}^4\right]^{-0.2} \qquad \textbf{\textit{(5.2a)}}$$

When $f_c < 0.123\ p_{cr}$, then $b_{eff} = b$ ***(5.2b)***

Where

f_c = compressive stress on the effective element, N/ mm^2

p_{cr} = local buckling stress given by

$p_{cr} = 185{,}000\ K\ (t / b)^2$ N/ mm^2

K = load buckling coefficient which depends on the element type, section geometry etc.

t = thickness of the element, in mm

b = width of the element, in mm

The relationship given by eqn. 5.2(a) is plotted in Fig.5.7

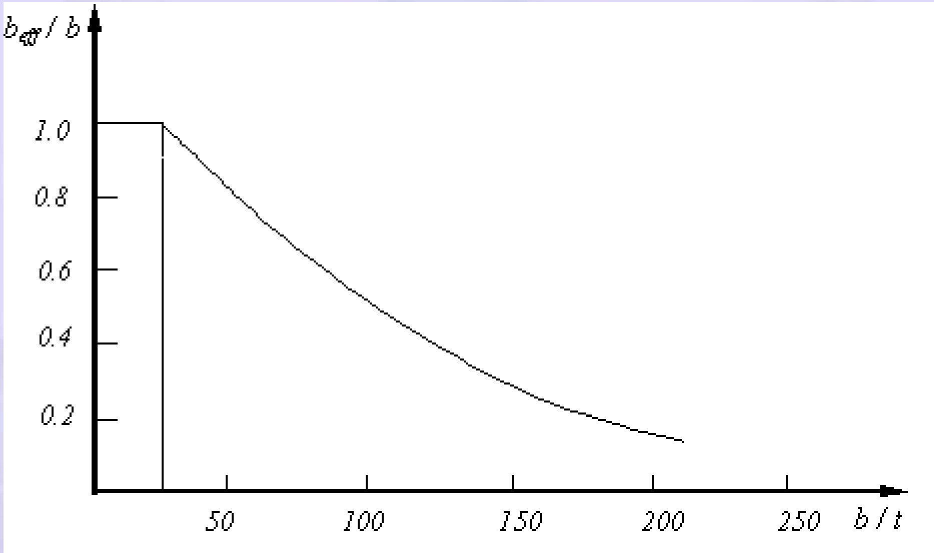


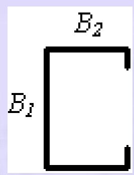
Fig.5.7 Ratio of effective width to flat width (f_y = 280 N/mm^2) of compression plate with simple edge supports

It is emphasised that in employing eqn. (5.2a), the value of K (to compute p_{cr}) could be 4.0 for a stiffened element or 0.425 for an unstiffened element.

BS5950, part 5 provides for a modification for an unstiffened element under uniform compression (Refer clause 4.5.1). The code also provides modifications for elements under combined bending and axial load (ref. Clause

4.5.2). Typical formula given in BS 5950, Part 5 for computing K values for a channel element is given below for illustration. (see BS 5950, Part 5 for a complete list of buckling coefficients).

1. Lipped channel.



The buckling coefficient K_1 for the member having a width of B_1 in a lipped channel of the type shown above is given by

$$K_1 = 7 - \frac{1.8h}{0.15 + h} - 1.43h^3 \qquad \textbf{\textit{(5.3a)}}$$

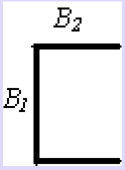
Where $h = B_2 / B_1$

For the member having the width of B_2 in the above sketch.

$$K_2 = K_2 h^2 \left(\frac{t_1}{t_2}\right)^2 \qquad \textbf{\textit{(5.3b)}}$$

Where t_1 and t_2 are the thicknesses of element width B_1 and B_2 respectively. (Note: normally t_1 and t_2 will be equal). The computed values of K_2 should not be less than 4.0 or 0.425 as the case may be.

2. Plain channel (without lips)



The buckling coefficient K_1 for the element of width B_1 is given by

$$K_1 = \frac{2}{\left(1+15h^3\right)^{0.5}} + \frac{2+4.8h}{\left(1+15h^3\right)} \qquad \textit{(5.4)}$$

K_2 is computed from eqn.. 5.3(b) given above.

5.3.4.1 Maximum width to thickness ratios

IS: 801 and BS 5950, Part 5 limit the maximum ratios of (b/t) for compression elements as follows:

- Stiffened elements with one longitudinal edge connected to a flange or web element and the other stiffened by a simple lip 60
- Stiffened elements with both longitudinal edges connected to other stiffened elements 500
- Unstiffened compression elements 60

However the code also warns against the elements developing very large deformations, when b/t values exceed half the values tabulated above.

5.3.5 Treatment of elements with stiffeners

5.3.5.1 Edge stiffeners

As stated previously, elements having b/t ? 60 and provided with simple lip having one fifth of the element width may be regarded as a stiffened element. If b/t > 60, then the width required for the lip may become too large and the lip itself may have stability problems. Special types of lips (called "compound" lips) are designed in such cases and these are outside the scope of this chapter.

5.3.5.2 Intermediate stiffeners

A wide and ineffective element may be transformed into a highly effective element by providing suitable intermediate stiffeners (having a minimum moment of inertia (I_{min}) about an axis through the element mid surface). The required minimum moment of inertia of the stiffener about the axis 0-0 in Fig. 5.8 is given by:

$$I_{min} = 0.2t^4 . \left(\frac{w}{t}\right)^2 . \left(\frac{f_y}{280}\right) \qquad \textbf{(5.5)}$$

Where w = larger flat width of the sub element (see Fig. 5.8) between stiffeners (in mm)

t = thickness of the element (mm)

f_y = yield stress (N/mm^2)

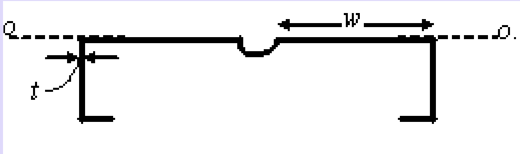


Fig.5.8 Intermediate stiffener

If the sub-element width/thickness ratio (w/t) does not exceed 60, the total effective area of the element may be obtained by adding effective areas of the sub-elements to the full areas of stiffeners.

When (w/t) is larger than 60, the effectiveness of the intermediately stiffened elements is somewhat reduced due to shear lag effects. (Refer to BS5950, Part 5, clauses 4.7.2 and 4.7.3) If an element has a number of stiffeners spaced closely (b/t ? 30), and then generally all the stiffeners and sub elements can be considered to be effective. To avoid introducing complexities at this stage, shear lag effects are not discussed here.

5.3.6 Effective section properties

In the analysis of member behaviour, the effective section properties are determined by using the effective widths of individual elements. As an example, let us consider the compression member ABCDEF shown in Fig.5.9. The effective portions of the member are shown darkened (i.e. 1-B, B-2, 3-C, C-4, 5-D, D-6, 7-E, and E-8). The parts A-1, 2-3, 4-5, 6-7 and 8-F are regarded as being ineffective in resisting compression. As a general rule, the portions located close to the supported edges are effective (see Fig.5.5c) . Note that in the case of compression members, all elements are subject to reductions in width.

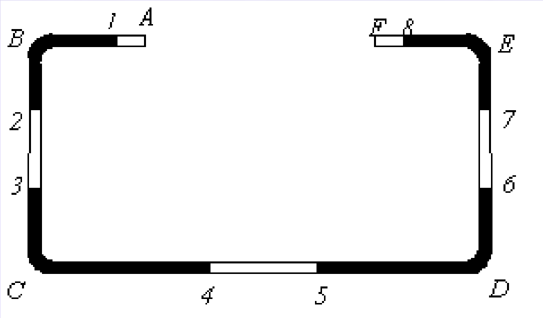


Fig. 5.9 Effective widths of compression elements

In the case of flexural members, in most cases, only the compression elements are considered to have effective widths. Some typical effective sections of beams are illustrated in Fig.5.10.

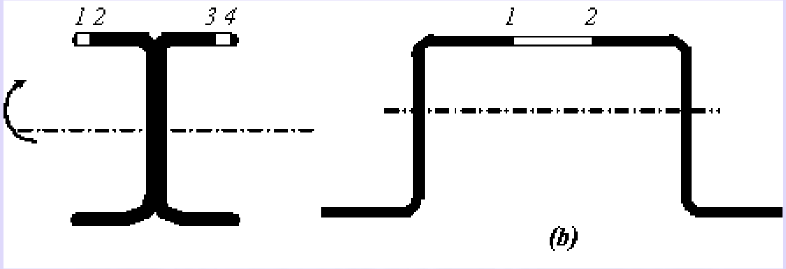


Fig. 5.10 Effective flexural sections

As in the previous example, fully effective sections in compression elements are darkened in Fig.5.10. The portions 1-2 and 3-4 in Fig. 5.10(a) and the portion 1-2 in Fig. 5.10 (b) are regarded as ineffective in resisting compression. Elements in tension are, of course, not subject to any reduction of width, as the full width will resist tension

5.3.7 Proportioning of stiffeners

The performance of unstiffened elements could be substantially improved by introducing stiffeners (such as a lip). Similarly very wide elements can be divided into two or more narrower sub elements by introducing intermediate stiffeners formed during the rolling process; the sum of the "effective widths" of individual sub elements will enhance the efficiency of the section.

According to BS 5950, Part 5 an unstiffened element (when provided with a lip) can be regarded as a stiffened element, when the lip or the edge stiffener has a moment of inertia about an axis through the plate middle surface equal to or greater than

$$I_{min} = \frac{b^3 t}{375} \qquad \textbf{(5.6)}$$

Where t and b are the thickness and breadth of the full width of the element to be stiffened.

For elements having a full width b less than or equal to 60 t, a simple lip of one fifth of the element width (i.e. b/5) can be used safely. For lips with b > 60 t, it would be appropriate to design a lip to ensure that the lip itself does not develop instability.

A maximum b/t ratio of 90 is regarded as the upper limit for load bearing edge stiffeners.

The Indian standard IS: 801-1975 prescribes a minimum moment of inertia for the lip given by $I_{min} = 1.83 t^4 \sqrt{\left(w/t\right)^2 - 281200/F_y}$ but not less than 9.2 t^4 .

Where I_{min} = minimum allowable moment of inertia of stiffener about its own centroidal axis parallel to the stiffened element in cm^4

w / t = flat width - thickness ratio of the stiffened element.

F_y = Yield stress in kgf/cm^2

For a simple lip bent at right angles to the stiffened element, the required overall depth d_{min} is given by $d_{min} = 2.8t \sqrt[6]{\left(w/t\right)^2 - 281200/F_y}$ but not less than 4.8 t

Note that both the above equations given by the Indian standard are dependent on the units employed.

5.3.7.1 Intermediate stiffeners.

Intermediate stiffeners are used to split a wide element into a series of narrower and therefore more effective elements. The minimum moment of inertia about an axis through the element middle surface required for this purpose (according to BS 5950, Part 5) is given in equation (5.5) above.

The effective widths of each sub element may be determined according to equation 5.2 (a) and eqn..5.2(b) by replacing the sub element width in place of the element width b.

When w / t < 60, then the total effective area of the element is obtained as the sum of the effective areas of each sub element to the full areas of stiffeners.

When the sub elements having a larger w / t values are employed (w/ t > 60), the performance of intermittently stiffened elements will be less efficient. To model this reduced performance , the sub element effective width must be reduced to b_{er} given by,

$$\frac{b_{er}}{t} = \frac{b_{eff}}{t} - 0.1\left(\frac{w}{t} - 60\right) \qquad \textbf{(5.7)}$$

The effective stiffener areas are also reduced when w / t > 90 by employing the equation:

$$A_{eff} = A_{st} \cdot \frac{b_{er}}{w} \qquad \textbf{(5.8)}$$

Where A_{st} = the full stiffener area and

A_{eff} = effective stiffener area.

For w / t values between 60 and 90, the effective stiffener area varies between A_{st} and A_{eff} as given below:

$$A_{eff} = A_{st}\left[3 - 2\frac{b_{er}}{w} - \frac{1}{30}\left(1 - \frac{b_{er}}{w}\right)\frac{w}{t}\right] \qquad \textbf{\textit{(5.9)}}$$

It must be noted that when small increases in the areas of intermediate stiffeners are provided, it is possible to obtain large increases in effectiveness and therefore it is advantageous to use a few intermediate stiffeners, so long as the complete element width does not exceed 500 t.

When stiffeners are closely spaced, i.e. w < 30 t, the stiffeners and sub elements may be considered to be fully effective. However there is a tendency for the complete element (along with the stiffeners) to buckle locally. In these circumstances, the complete element is replaced for purposes of analysis by an element of width b and having fictitious thickness t_s given by

$$t_s = \left(\frac{12\ I_s}{b}\right)^{1/3} \qquad \textbf{\textit{(5.10)}}$$

Where I_s = Moment of inertia of the complete element including stiffeneres, about its own neutral axis.

IS: 801- 1975 also suggests some simple rules for the design of intermediate stiffeners.

When the flanges of a flexural member is unusually wide, the width of flange projecting beyond the web is limited to

$$w_f = \sqrt{\frac{126500td}{f_{uv}}} \text{ x } \sqrt[4]{\frac{100\,c_f}{d}} \qquad \textbf{\textit{(5.10a)}}$$

Where t = flange thickness

d = depth of beam

c_f = the amount of curling

f_{av} = average stress in kgf/cm^2 as specified in IS: 801 – 1975.

The amount of curling should be decided by the designer but will not generally exceed 5 % of the depth of the section.

Equivalent thickness of intermediate stiffener is given by

$$t_s = \sqrt[3]{\frac{12\ I_s}{w_s}} \qquad \textbf{\textit{(5.10b)}}$$