CHAPTER - 4

DESIGN OF STEEL COMPRESSION MEMBER

4.1: Common Shapes of Compression Member:

4.1.1: Introduction:

Pure compression members are structural elements subjected to axial compressive forces only. Axial compressive force means force is applied along the centroid of a longitudinal axis of the cross section. Columns are the structural member whose longitudinal dimension is comparatively more than its lateral dimensions and they are predominantly subjected to compression in the direction parallel to longitudinal axis.

A strut is defined as a structural member subjected to compression in a direction parallel to its longitudinal axis. The term strut is commonly used for compression members in roof trusses. A strut may be used in a vertical position or in an inclined position in roof trusses. The compression members may be subjected to both axial compression and bending.

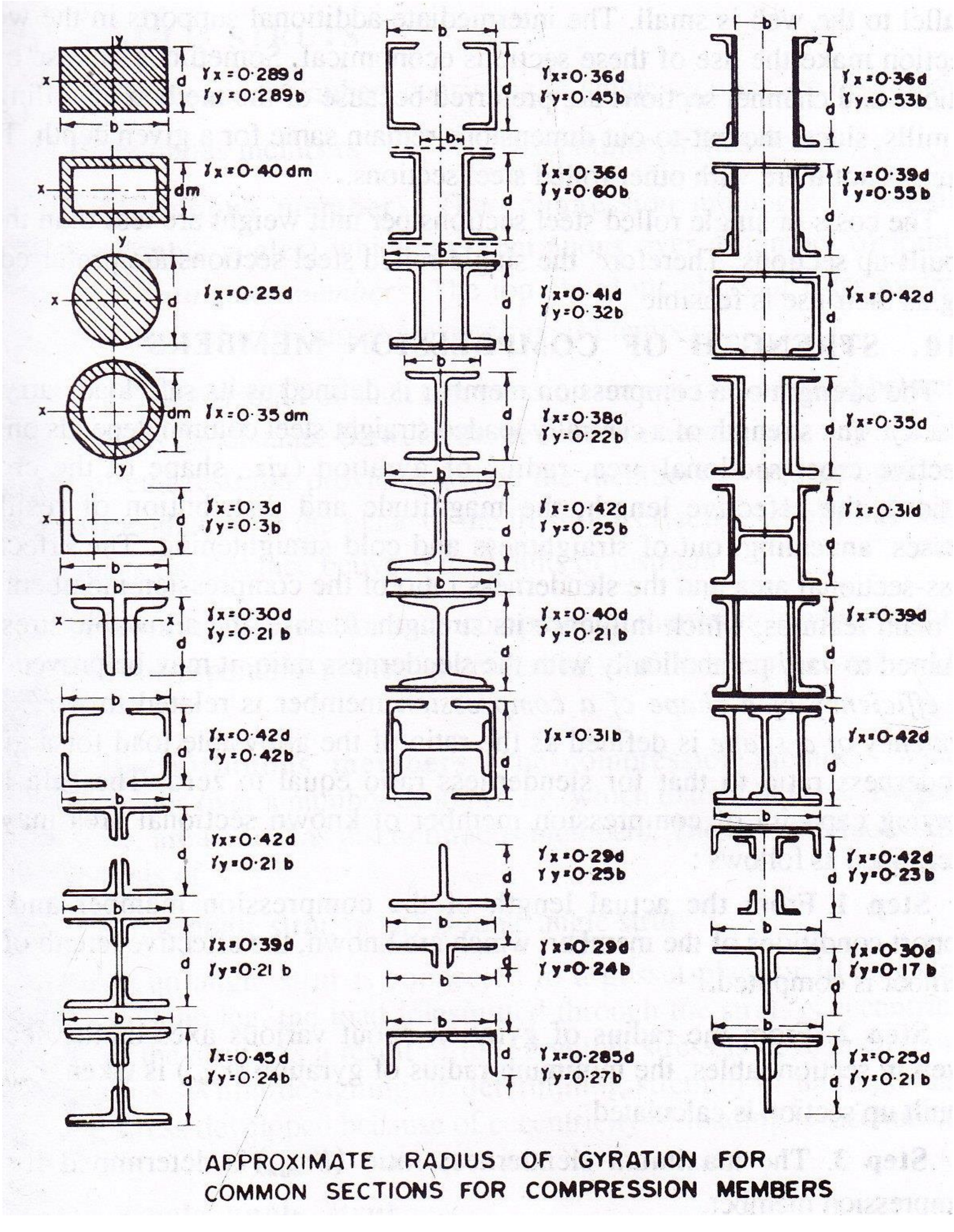
Failure of a compression member may be due to any of the following causes;

1. Direct compression
2. Bending
3. Bending combined with Compression and Twisting

4.1.2: Common Shapes of Compression Member:

Rolled steel sections are generally used as compression member. A column or a compression member may be made of many different sections to support a given load. Few sections satisfy practical requirement in a given case. A tubular section is most efficient and economical for the column free to buckle in any direction. The radius of gyration r for the tubular section in all the directions remains same. The tubular section has high local buckling strength. The tubular sections are suitable for medium loads. However, it is difficult to have their end connections. Single angle sections are rarely used except in light roof trusses, because of eccentricity at the end connections. Tee-sections are often used in roof trusses. The single rolled steel I-section and single rolled steel channel section are seldom used as column. The value of radius of gyration r, about the axis parallel to the web is small. The intermediate additional supports in the weak direction make the use of these sections economical.

The choice of a particular section depends on it’s availability in the market, problem to connect with other structural components and slenderness ratio.



4.2: Buckling Class of Cross Sections, Slenderness Ratio:

4.2.1: Buckling class of Columns:

Buckling:

Buckling is defined as sudden bending, warping or crumpling of compression member under

Compressive force. Due to buckling, deformation developed in a column occurs in a direction or plane normal to the direction of loading. Buckling resistance depends on magnitude of the applied load, bending stiffness of the member and length of the member.

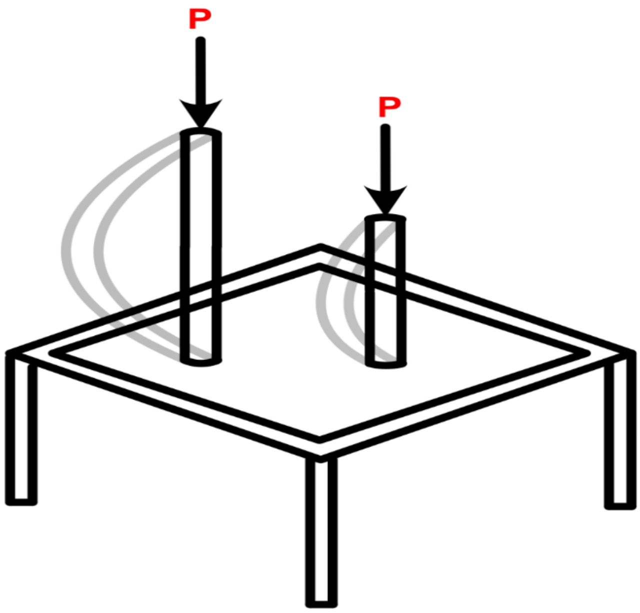
The mean compressive stress at buckling f_{cr} is given by

4.2.2: Slenderness Ratio:

Slenderness ratio is a geometrical parameter, defined for a compression member (column). It is the ratio of effective length and lateral dimension of the compression member. It is also a measure of the structural vulnerability to the failure of the structure.

Slenderness ratio can also be defined as the ratio of effective length of the column to the minimum radius of gyration. Generally we design the columns to resist the axial compression load. Sometimes a combination of bi-axial/ uni-axial moment acting on it.

To understand the concept of slenderness ratio, let's consider a **simple demonstration**. Imagine two thin rods made of the same material, one that is very tall and one that is very short. When you apply a load to the top of the rods, you will notice that the taller rod is more likely to bend or buckle, while the shorter rod remains more stable (see the figure below).



A simple demonstration with two rods of different heights and same material

This difference in behaviour can be explained by the concept of slenderness ratio – the taller rod has a higher slenderness ratio, making it more prone to bending, while the shorter rod has a lower slenderness ratio, making it more resistant to bending.

Slenderness ratio can be written as, $\lambda = l_r/r = Kl/r$

(the maximum value of effective slenderness ratio is given in Table – 3 of IS 800 : 2007)

4.2.3Effective length of column

The effective length of a column is the distance between its points of zero moment or the distance between the inflection points. It is an important parameter in the design of columns because it determines the critical buckling load of the column.

The effective length depends on various factors, such as the end conditions of the column, the type of loading, and the material properties. The following steps can be followed to calculate the effective length of a column:

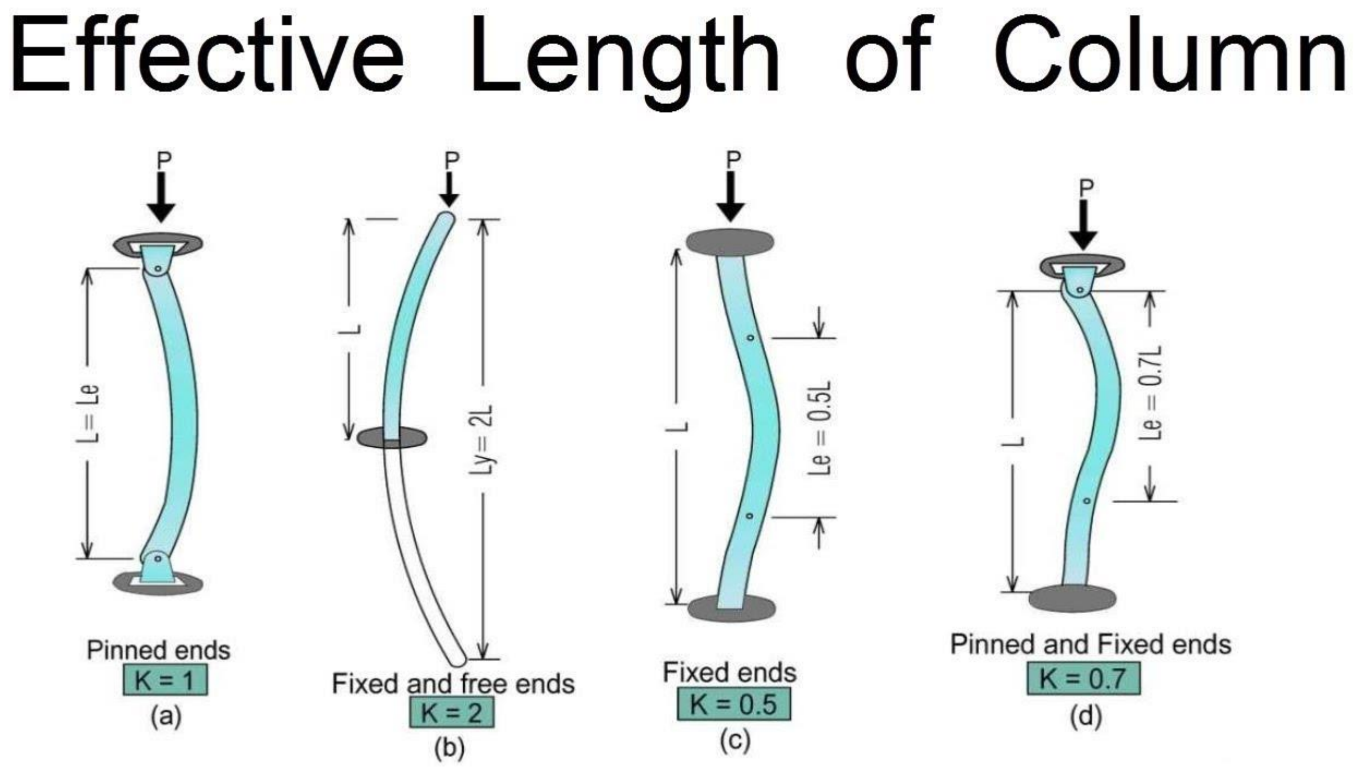
1. Identify the end conditions of the column: The end conditions of the column can be fixed, pinned, or free. These conditions are important in determining the effective length.
2. Calculate the effective length factor: The effective length factor (K) is a dimensionless parameter that depends on the end conditions of the column. It can be found in design tables or calculated using formulas specific to the type of end conditions.

3. Determine the unsupported length of the column: The unsupported length is the actual length of the column between the two points of zero moment. It can be calculated by subtracting the length of the fixed or pinned end connections from the overall length of the column.
4. Multiply the effective length factor with the unsupported length: Multiply the effective length factor with the unsupported length of the column to get the effective length of the column.

Effective length = K x unsupported length

The effective length obtained in this way can then be used to calculate the critical buckling load of the column.

The bending stiffness of the beam meeting at the column, as well as whether the frame is swaying or not, determine the effective length of the column. Whereas a flexible beam will bend readily and not operate as a lateral restraint, a sufficiently stiff beam will not bend considerably when subjected to weights and will fix the column.



4.3: Design Compressive Stress and Strength of Compression Member:

Common hot rolled and built-up steel members used for carrying axial compression, usually fail by flexural buckling. The buckling strength of these members is affected by residual stress, initial bow and accidental eccentricities of load. To account for all these factors, the strength of members subjected to axial compression is defined by buckling class a, b, c or d as given in Table 6.3.

The design compressive strength P_d of a member is given by

$P_d = A_e f_{cd}$

Where, A_e = Effective sectional area

f_{cd} = Design compressive stress

4.4: Analysis and Design of Compression Member (Axial Load only):

Method - I

7.1.2.1 The design compressive stress, f_{cd}, of axially loaded compression members shall be calculated using the following equation:

$$f_{cd} = \frac{f_y / \gamma_{m0}}{\phi + \left[\phi^2 - \lambda^2\right]^{0.5}} = \chi f_y / \gamma_{m0} \leq f_y / \gamma_{m0}$$

where

ϕ = $0.5\,[1 + \alpha\,(\lambda - 0.2) + \lambda^2]$

λ = non-dimensional effective slenderness ratio

$$= \sqrt{f_y / f_{cc}} = \sqrt{f_y \left(\frac{KL}{r}\right)^2 / \pi^2 E}$$

f_{cc} = Euler buckling stress = $\dfrac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$

where

KL/r = effective slenderness ratio or ratio of effective length, KL to appropriate radius of gyration, r;

α = imperfection factor given in Table 7;

χ = stress reduction factor (*see* Table 8) for different buckling class, slenderness ratio and yield stress

$$= \frac{1}{\left[\phi + \left(\phi^2 - \lambda^2\right)^{0.5}\right]}$$

λ_{m0} = partial safety factor for material strength.

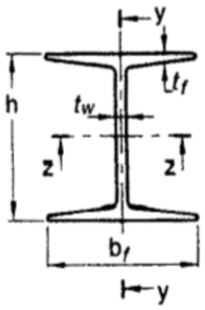
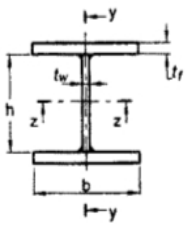
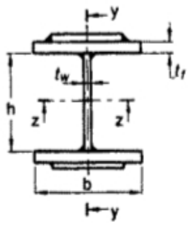
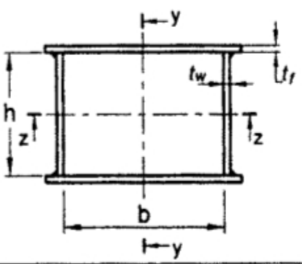
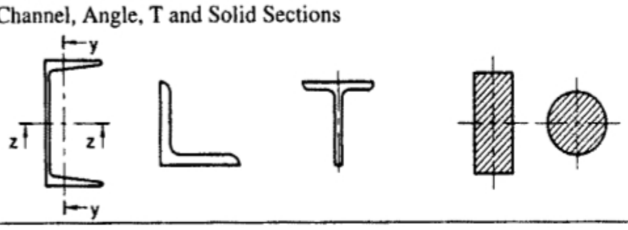
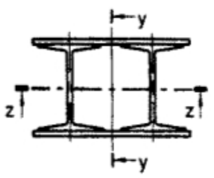
Table 7 Imperfection Factor, α

(*Clauses* 7.1.1 *and* 7.1.2.1)

Buckling Class	a	b	c	d
α	0.21	0.34	0.49	0.76

Table 10 Buckling Class of Cross-Sections

(*Clause* 7.1.2.2)

Cross-Section	Limits	Buckling About Axis	Buckling Class
(1)	(2)	(3)	(4)
Rolled I-Sections 	$h/b_f > 1.2$: $t_f \leq 40$ mm	z-z y-y	a b
	$40 \leq$ mm $< t_f \leq 100$ mm	z-z y-y	b c
	$h/b_f \leq 1.2$: $t_f \leq 100$ mm	z-z y-y	b c
	$t_f > 100$ mm	z-z y-y	d d
Welded I-Section  	$t_f \leq 40$ mm	z-z y-y	b c
	$t_f > 40$ mm	z-z y-y	c d
Hollow Section 	Hot rolled	Any	a
	Cold formed	Any	b
Welded Box Section 	Generally (except as below)	Any	b
	Thick welds and $b/t_f < 30$ $h/t_w < 30$	 z-z y-y	 c c
Channel, Angle, T and Solid Sections 		Any	c
Built-up Member 		Any	c

Method – II

Design compressive stress can also be calculated from the value of effective length of the column depending upon the buckling class of the section as per table 9a, 9b, 9c, 9d of IS 800 : 2007.

Steps for design of compression member:

Following steps can be followed for design of axially loaded compression member;

1. Assume a suitable value of slenderness ratio and determine design compressive stress considering grade of steel and assuming buckling class.
2. Calculate the effective area and choose a trial section from the steel table having higher cross sectional area than the calculated area.
3. Find out the effective length and maximum slenderness ratio considering the end conditions and type of connection.
4. Determine the permissible compressive stress f_{cd} considering the grade of steel and actual buckling class of the section.
5. Compute the design strength of the member.
6. Redesign the section if calculated compressive strength is less than the design load.
7. Check the section for limiting thickness.
   Slenderness ratio may be assumed as per the following table

Type of Member	Slenderness Ratio
Single angle	100-50
Single channel	90-110
Double angles	80-120
Double channels	40-80
Single I -Section	80-100
Double I - section	30-60