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Importance of Non-Dimensional Slenderness Ratio in the Design of Compression and Shear members as per IS 800:2007

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Abstract - *In steel design, Indian standard code of practice defines a parameter i.e., non-dimensional slenderness ratio, which is defined as ratio of yield strength to the critical stress. When a member is subjected to compressive force then compressive strength is calculated by the column buckling curve and Euler's buckling theory is an important consideration. In this, non-dimensional slenderness ratio is defined as the ratio of effective length to the corresponding radius of gyration. When a beam is subjected to shear force then the shear force is resisted by the web only. For this consideration, shear buckling of the web with or without intermediate stiffeners is considered in the design of the beam. Shear strength of beam is calculated by two methods - Simple Post Method and Tension Field Method. In the simple post method, the non-dimensionless slenderness ratio plays a major role. In the current study, I-sections with varying parameters i.e, length in x, y direction & c/d ratio were designed for Compression and Shear respectively. The design procedure was carried out in the Excel. The results were tabulated for the members designed for compression and shear. The graphs were also plotted for various parameters v/s Slenderness ratio. It is studied that if* $d/t_w > 67\epsilon$ *then the web portion is neglected in the calculation of Moment of Inertia and shear buckling takes place. The results show that the slenderness ratio is indirectly proportional to the c/d ratio in shear members.*

Key Words**:** Steel structures, Non-dimensional slenderness ratio, Simple post method, Compression, Shear, Excel.

1. INTRODUCTION

A structural member which is subjected to compressive forces along its axis is called a *Compression member.* Thus, compression members are subjected to loads that tend to decrease their lengths. Except in pin-jointed trusses, such members (in any plane or space structure), under external loads, experience bending moments and shear forces. If the net end moments are zero, the compression member is required to resist load acting concentric to the original longitudinal axis of the member and is termed as *Axially loaded column,* or simply *column.*

Shear force generally exists with bending moments, the maximum shear stress in a beam is to be compared with the shear yield stress. Since the web of an I-beam is essentially a plate, it may buckle due to shearing stresses which are less than the shearing yield strength of steel. In a plate subjected to pure shear, the shear stresses are equivalent to principal stresses of the same magnitude, one tension and another compression, acting at 45 degrees to the shear stresses. Buckling takes place in the form of waves or wrinkles inclined at around 45 degrees.

1.1 SLENDERNESS RATIO

It is defined as the ratio of the effective length (L_e) of a member to the radius of gyration (r) of the cross-section about the axis under consideration. It is represented as

$$\lambda = L_e/r$$

It also defines the failure mode of the column based on the effective length and the radius of gyration. It is a geometrical parameter, defined for a compression member (column). It is also a measure of the structural vulnerability to the failure of the structure.

1.2 EFFECTIVE LENGTH

The effective length (L_e) is the length between the point of zero moment or successive inflection points. Zero moments is the point at which the moment becomes zero. It is also referred to as the Inflection point. In other words, the effective length of a column in a given plane may be defined as the distance between the points of inflection (zero moment) in the buckled configuration of the column in that plane as shown in below figure. The effect of end restraints on column strength is usually incorporated in the design by the concept of effective length.

1.3 RADIUS OF GYRATION

Radius of gyration or gyradius of a body about the axis of rotation is defined as the radial distance to a point which would have a moment of inertia the same as the body's actual distribution of mass, if the total mass of the body were concentrated there. The distance from an axis at which the mass of a body may be assumed to be concentrated and at which the moment of inertia will be equal to the moment of inertia of the actual mass about the axis, equal to the square root of the quotient of the moment of inertia and the mass.

2. METHODOLOGY

The entire work is divided into two parts i.e., Design of Compression members and Design of Shear members. The design templates were formulated in Excel software. The design procedure in both the cases is done as per Indian Standard code of IS 800:2007. From the obtained design results, draw the buckling curve, various relationship curves i.e, $\boldsymbol{\tau_{cr}}$ v/s $\boldsymbol{\lambda_w}$, $\boldsymbol{V_d}$ v/s c/d etc.

For a given welded I section with the following data, calculate its compression carrying capacity

Overall depth of the beam = 800 mm

Thickness of web = 6 mm

Width of flange = 200 mm

Thickness of flange = 10 mm

Length in X & Y direction is 500, 600, 700, 800, 900, 1000, 1400, 1800, 2200, 2600, 3000, 3500 & 4000 mm

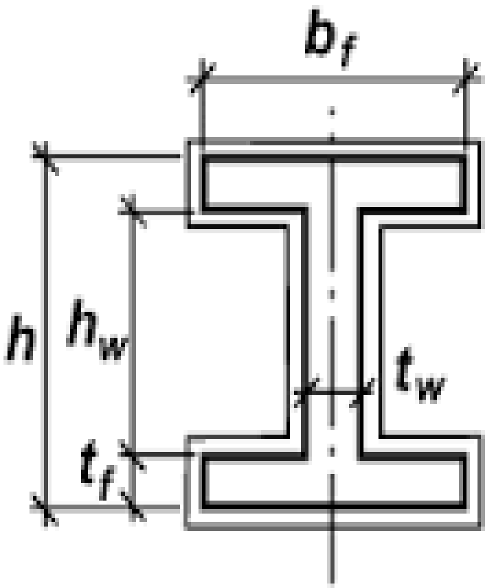

Fig -1: Welded I-section to find out the compression and shear capacity

For a given I section with the following data, calculate its shear capacity

Depth of the beam = 1200 mm

Thickness of web = 10 mm

Width of flange = 275 mm

Thickness of flange = 12 mm

c/d ratio is 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 2.75 & 3.00

3. RESULTS & DISCUSSIONS

The design process was formulated in Excel for compression and shear. The design process was carried out for each trail in all the design procedures. The results thus obtained are tabulated as below. Also, the graphs were plotted for various parameters to study the relationship of non-dimensional slenderness ratio with the other parameters.

3.1 COMPRESSION CAPACITY

The obtained compression capacity designed results were as shown in the tables below.

Table -1: Compression capacity calculations-1

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
d_w	800	800	800	800	800
t_w	6	6	6	6	6
b_f	200	200	200	200	200
t_f	10	10	10	10	10
E	200000	200000	200000	200000	200000
f_{yw}	345	345	345	345	345
γ_{m0}	1.1	1.1	1.1	1.1	1.1
Lx	500	600	700	800	900
Ly	500	600	700	800	900
K	1	1	1	1	1
ϵ	0.85	0.85	0.85	0.85	0.85
b/t_f	9.7	9.7	9.7	9.7	9.7
d/t_w	133.33	133.33	133.33	133.33	133.33
A_g	8800	8800	8800	8800	8800
A_e	5287.1	5287.1	5287.1	5287.1	5287.1
I_{zz}	$9.12*10^8$	$9.12*10^9$	$9.12*10^{10}$	$9.12*10^{11}$	$9.12*10^{12}$
r_{zz}	321.95	321.95	321.95	321.95	321.95
I_{yy}	$1.33*10^7$	$1.33*10^8$	$1.33*10^9$	$1.33*10^{10}$	$1.33*10^{11}$
r_{yy}	50.24	50.24	50.24	50.24	50.24
Along z-z axis:-					
Buckling class	b	b	b	b	b
$(KL/r)_{zz}$	1.55	1.86	2.17425	2.48486	2.79547
$(fcc)_{zz}$	818399.6	568333	417551	319687	252592
$(\lambda)_{zz}$	0.02	0.024	0.02875	0.03285	0.03696
$(\alpha)_{zz}$	0.34	0.34	0.34	0.34	0.34
$(\varphi)_{zz}$	0.47	0.47	0.4713	0.47212	0.47297
$(fcd)_{zz}$	334.0276	333.536	333.046	332.557	332.071
$(Pd)_{zz}$	1766037	1763436	1760845	1758265	1755694
Along y-y axis:-					
Buckling class	c	c	c	c	c
$(KL/r)_{yy}$	9.95	11.94	13.9167	15.9219	17.9121
$(fcc)_{yy}$	19933.32	13842.6	10170.1	7786.45	6152.26
$(\lambda)_{yy}$	0.131559	0.15787	0.18418	0.21049	0.23681
$(\alpha)_{yy}$	0.49	0.49	0.49	0.49	0.49
$(\varphi)_{yy}$	0.491886	0.50214	0.51309	0.52472	0.53706
$(fcd)_{yy}$	324.7251	320.424	316.174	311.958	307.763
$(Pd)_{yy}$	1716854	1694113	1671642	1649355	1627172

Table -2: Compression capacity calculations-2

	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
d_w	800	800	800	800	800
t_w	6	6	6	6	6
b_f	200	200	200	200	200
t_f	10	10	10	10	10
E	200000	200000	200000	200000	200000
f_{yw}	345	345	345	345	345
γ_{m0}	1.1	1.1	1.1	1.1	1.1
Lx	1000	1400	1800	2200	2600
Ly	1000	1400	1800	2200	2600
K	1	1	1	1	1
ϵ	0.85	0.85	0.85	0.85	0.85
b/t_f	9.7	9.7	9.7	9.7	9.7
d/t_w	133.33	133.33	133.33	133.33	133.33
A_g	8800	8800	8800	8800	8800
A_e	5287.1	5287.1	5287.1	5287.1	5287.1
I_{zz}	$9.12*10^{13}$	$9.12*10^{14}$	$9.12*10^{15}$	$9.12*10^{16}$	$9.12*10^{17}$
r_{zz}	321.95	321.95	321.95	321.95	321.95
I_{yy}	$1.33*10^{12}$	$1.33*10^{13}$	$1.33*10^{14}$	$1.33*10^{15}$	$1.33*10^{16}$
r_{yy}	50.24	50.24	50.24	50.24	50.24
Along z-z axis:-					
Buckling class	b	b	b	b	b
$(KL/r)_{zz}$	3.10608	4.34851	5.59094	6.83337	8.0758
$(fcc)_{zz}$	204600	104388	63148.1	42272.7	30266.3
$(\lambda)_{zz}$	0.04106	0.05749	0.07391	0.09034	0.10677
$(\alpha)_{zz}$	0.34	0.34	0.34	0.34	0.34
$(\varphi)_{zz}$	0.47382	0.47743	0.4813	0.48544	0.48985
$(fcd)_{zz}$	331.587	329.666	327.768	325.891	324.03
$(Pd)_{zz}$	1753132	1742975	1732943	1723018	1713181
Along y-y axis:-					
Buckling class	c	c	c	c	c
$(KL/r)_{yy}$	19.9024	27.8633	35.8243	43.7852	51.7462
$(fcc)_{yy}$	4983.33	2542.52	1538.07	1029.61	737.179
$(\lambda)_{yy}$	0.26312	0.36836	0.47361	0.57886	0.68411
$(\alpha)_{yy}$	0.49	0.49	0.49	0.49	0.49
$(\varphi)_{yy}$	0.55008	0.6091	0.67919	0.76036	0.85261
$(fcd)_{yy}$	303.573	286.641	268.984	250.233	230.367
$(Pd)_{yy}$	1605022	1515500	1422145	1323005	1217973

Table -3: Compression capacity calculations-3

	Trial 6	Trial 7	Trial 8
d_w	800	800	800
t_w	6	6	6
b_f	200	200	200
t_f	10	10	10
E	200000	200000	200000
f_{yw}	345	345	345
γ_{m0}	1.1	1.1	1.1
Lx	3000	3500	4000
Ly	3000	3500	4000
K	1	1	1
ϵ	0.85	0.85	0.85
b/t_f	9.7	9.7	9.7
d/t_w	133.33	133.33	133.33
A_g	8800	8800	8800
A_e	5287.1	5287.1	5287.1
I_{zz}	$9.12*10^{18}$	$9.12*10^{19}$	$9.12*10^{20}$
r_{zz}	321.95	321.95	321.95
I_{yy}	$1.33*10^{17}$	$1.33*10^{18}$	$1.33*10^{19}$
r_{yy}	50.24	50.24	50.24
Along z-z axis:-			
Buckling class	b	b	b
$(KL/r)_{zz}$	9.31823	10.8713	12.4243
$(fcc)_{zz}$	22733.3	16702	12787.5
$(\lambda)_{zz}$	0.12319	0.14372	0.16425
$(\alpha)_{zz}$	0.34	0.34	0.34
$(\varphi)_{zz}$	0.49453	0.50076	0.50741
$(fcd)_{zz}$	322.183	319.889	317.605
$(Pd)_{zz}$	1703416	1691285	1679208
Along y-y axis:-			
Buckling class	c	c	c
$(KL/r)_{yy}$	59.7071	69.6583	79.6095
$(fcc)_{yy}$	553.703	406.803	311.458
$(\lambda)_{yy}$	0.78935	0.92091	1.05247
$(\alpha)_{yy}$	0.49	0.49	0.49
$(\varphi)_{yy}$	0.95593	1.10066	1.2627
$(fcd)_{yy}$	209.774	184.116	159.989
$(Pd)_{yy}$	1109094	973440	845880

GRAPH:-

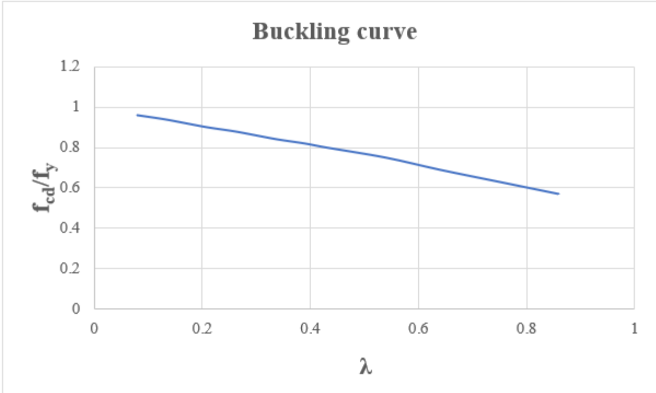

Chart -1: Buckling curve

From the graph as shown in Chart-1, we can see that the curve resembles the Buckling curve c. The buckling class about y-y axis is c and hence it resembles that curve. As the f_{cd}/f_y increases, non-dimensional slenderness ratio is decreasing. It can be seen that both the factors are indirectly proportional to each other. It is due to the lot of imperfections.

3.2 SHEAR CAPACITY

The obtained shear capacity designed results were as shown in the tables below.

Table -4: Shear capacity calculations-1

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
d_w (or) h	1200	1200	1200	1200	1200	1200
t_w	10	10	10	10	10	10
b_f	275	275	275	275	275	275
t_f	12	12	12	12	12	12
E	$2*10^5$	$2*10^5$	$2*10^5$	$2*10^5$	$2*10^5$	$2*10^5$
f_{yw}	345	345	345	345	345	345
μ	0.3	0.3	0.3	0.3	0.3	0.3
γ_{m0}	1.1	1.1	1.1	1.1	1.1	1.1
c/d	0.5	0.75	1	1.25	1.5	1.75
d/t_w	120	120	120	120	120	120
Area in major axis bending	12000	12000	12000	12000	12000	12000
Area in minor axis bending	6600	6600	6600	6600	6600	6600
K_v	25.4	13.51	9.35	7.91	7.13	6.66
$\tau_{cr,e}$	318.844	169.604	117.37	99.294	89.474	83.554
λ_w	0.79	1.084	1.303	1.416	1.492	1.544
τ_b	199.19	153.98	117.37	99.3	89.47	83.55
(V_{cr})major = V_p = V_n	$2.39*10^6$	$1.85*10^6$	$1.41*10^6$	$1.19*10^6$	$1.07*10^6$	$1.00*10^6$
(V_{cr})minor = V_n = V_p	$1.31*10^6$	$1.02*10^5$	$7.75*10^5$	$6.55*10^5$	$5.90*10^5$	$5.51*10^5$
(V_d) major	2172.94	1679.76	1280.4	1083.2	976.08	911.5
(V_d) minor	1195.12	923.87	704.22	595.76	536.85	501.32

Table -5: Shear capacity calculations-2

	Trial 7	Trial 8	Trial 9	Trial 10	Trial 11
d_w (or) h	1200	1200	1200	1200	1200
t_w	10	10	10	10	10
b_f	275	275	275	275	275
t_f	12	12	12	12	12
E	$2*10^5$	$2*10^5$	$2*10^5$	$2*10^5$	$2*10^5$
f_{yw}	345	345	345	345	345
µ	0.3	0.3	0.3	0.3	0.3
γ_{m0}	1.1	1.1	1.1	1.1	1.1
c/d	2	2.25	2.5	2.75	3
d/t_w	120	120	120	120	120
Area in major axis bending	12000	12000	12000	12000	12000
Area in minor axis bending	6600	6600	6600	6600	6600
K_v	6.35	6.14	5.99	5.879	5.794
$\tau_{cr,e}$	79.711	77.077	75.192	73.798	72.737
λ_w	1.581	1.607	1.627	1.643	1.655
τ_b	79.71	77.08	75.2	73.8	72.74
(V_{cr})major = V_p = V_n	$9.56*10^5$	$9.25*10^5$	$9.02*10^5$	$8.85*10^5$	$8.72*10^5$
(V_{cr})minor = V_n = V_p	$5.26*10^5$	$5.09*10^5$	$4.96*10^5$	$4.87*10^5$	$4.80*10^5$
(V_d) major	869.58	840.83	820.28	805.06	793.5
(V_d) minor	478.26	462.46	451.15	442.79	436.42

GRAPHS:-

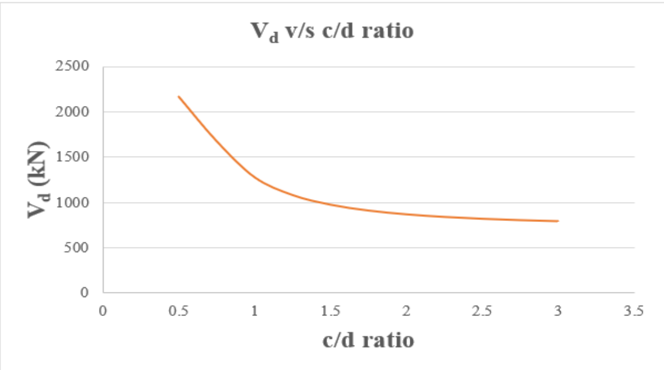

Chart -2: Design shear force (V_d) v/s c/d ratio

We can observe that the design shear force is inversely proportional to the c/d ratio as shown in the Chart-2.

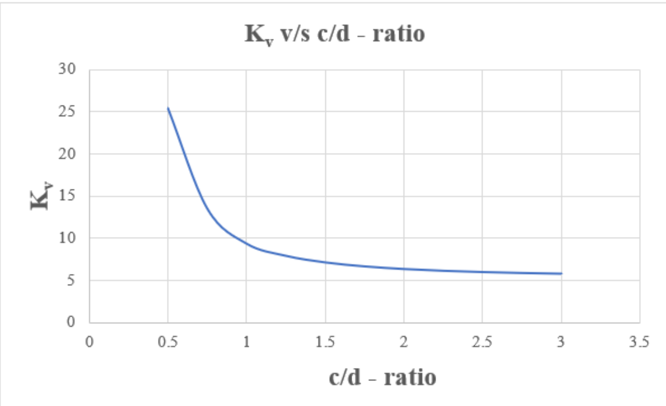

Chart -3: Shear buckling constant (K_v) v/s c/d ratio

From the graph as shown in Chart-3, as the c/d ratio increases, shear buckling constant is decreasing.

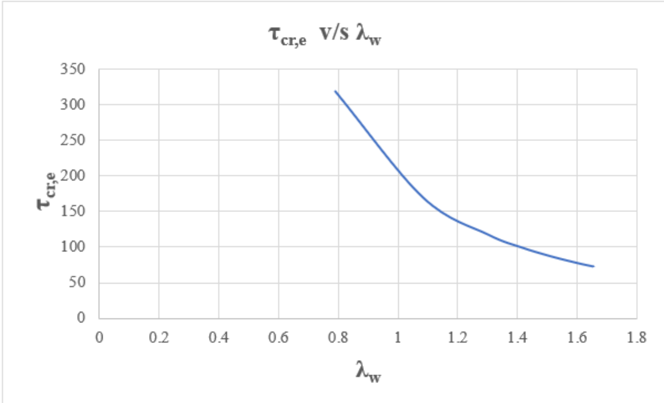

Chart -4: Elastic critical shear stress of the web ($\tau_{cr,e}$) v/s Non-dimensional web slenderness ratio for shear buckling stress (λ_w)

From When slenderness ratio goes on increasing the other parameter elastic critical shear stress of the web is decreasing as shown in Chart-4.

4. CONCLUSIONS

Based on the research and discussions, the following conclusions were drawn. According to Indian Standard steel code IS 800:2007, when a member is designed for shear and compression then the non-dimensional slenderness ratio λ_w and λ is defined in each case respectively.

COMPRESSION:-

- In compression point of view, there are only semi-compact and slender sections.
- If $\frac{d}{t_w} > 42\epsilon$ then the given section is slender section.
- If the section is slender then we consider the effective area, A_e i.e., $A_e = A_g - \left[\frac{d}{t_w} - 42\epsilon\right] t_w^2$
- For the considered design problem, the flange is semi-compact and the web is slender section. Hence, the overall section which is considered is slender section.
- Least KL/r value gives the maximum design compressive force and the highest KL/r value gives the minimum design compressive force.
- If the non-dimensional effective slenderness ratio is more then we get the minimum design compressive force.

- The least design compressive force which is obtained in the compression design calculation in both Y & Z directions is considered as its design compressive force.
- The buckling class about the y-y axis is c.
- The obtained curve resembles the buckling curve c as shown in Fig. 8 in IS 800:2007.

SHEAR:-

- If $\frac{d}{t_w} < 67\varepsilon$ then no shear buckling takes place.
- If $\frac{d}{t_w} > 67\varepsilon$ then shear buckling takes place.
- If shear buckling takes place use simple post critical method or tension field method.
- In case of shear, when $\lambda_w < 0.8$, $0.8 < \lambda_w < 1.2$, $\lambda_w > 1.2$ then the shear strength is calculated by different formulae according to IS 800:2007
- For the considered design problem, the flange is semi-compact and the web is slender section. Hence, the overall section which is considered is slender section.
- Shear strength is inversely proportional to c/d ratio.
- Slenderness ratio is inversely proportional to elastic critical shear stress.

Based on all the above results and conclusions, we can understand that the slenderness ratio plays an important role in design the members subjected to compression and shear as per IS 800:2007

REFERENCES

[1] Yuhan Nie, Yang Wei*, Linjie Huang*, Ying Liu and Fenghui Dong. (2021). Influence of slenderness ratio and sectional geometry on the axial compression behavior of original bamboo columns. Journal of Wood Science, pp. 1-20.

[2] Iloegbu L. B, Chidolue C. A, Ezeagu C. A (2019). The Effects of Design Methods on Compressive Members in Steel Frame Work. *Iconic Research and Engineering Journals,* Vol.2, Issue 8, pp. 86-94

[3] Vidhi Chopra, Dr. Mohan Gupta (2019). Design aid to IS 800-2007 : Safe load for Angle struts. *International Research Journal of Engineering and Technology (IRJET),* Vol.6, Issue 6, pp. 2812-2816.

[4] Shaiv Parikh (2013). Design Of Steel Compression Members (According To Is: 800). *International Journal of Engineering Research & Technology (IJERT)*, Vol. 2, Issue 11, pp. 1411 - 1417.

[5] Gargi Dandade (2021). A Brief Study on Different Stresses of Steel Structural Member as per Indian Standard Parallel Section. Research and Reviews: Journal of Engineering and Technology (RRJET), Vol. 10, Issue 8, pp. 1-5

[6] IS 800:2007, Indian Standard General Construction Steel – Code of Practice.

[7] Dr. N. Subramanian, "Design of Steel Structures", Oxford higher education, Chennai (2008).

[8] Design of steel structure by S. Ramamrutham.

[9] DR. S.R. Satish Kumar and A.R. Santha Kumar, "Beam column, Structural Engineering Laboratory, Dept., of Civil Engineering, IIT Madras, Chennai. https://www.researchgate.net/profile/Satish-Kumar-19

[10] Theory of Stability of Structures by Alexander ChaJes.

[11] Theory of Elastic Stability by S. P. Timoshenko & J.M. Gere-Mc Graw Hill Publications