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A Comparative Study on Lattice Tower Angle Member Capacities as Per Indian, American, and BSEN Standards

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Abstract

The transmission lines and Telecommunication networks are normally supported by lattice towers. Therefore, the reliability of these essentials depends much on the reliability of the towers and their foundations. In Both telecom and power transmission line sectors, the towers are mass-produced and generally based on optimized tower weight and foundation volumes. The weight of a tower is influenced to a great extent by the selection of tower configuration, choice of bracing patterns, choice of steel grade, and profile type. The towers in general are lattice types consisting of main legs, diagonals, horizontals, cross-arm members, and peak members. The telecommunication and power transmission line tower members are generally made of steel equal-angle sections. These tower members are modeled and analyzed as pin-jointed 3-dimensional space truss models and the members are subjected to axial forces, either axial compression or axial tension in nature. Estimation of member compression capacity is the most vital parameter in design as per respective local standards and proving those estimations during full-scale model tower testing if carried out. This paper presents the differences in axial compression capacity of angle members as per Indian, American, and European standards viz., IS: 802 (Part 1/Sec 2)-2016, IS 800-2007, ASCE 10-15 and BS EN 1993-3-1:2006.

Keywords: Compression and Tension Capacity, Member Slenderness Reduction Factor, Slenderness Ratio, Telecom Tower, Transmission Line Tower, Tower Testing

1. Introduction

Currently, India is the world's second-largest telecommunication market and has registered strong growth in the last decade. Due to the increase in subscriber base and demand, a huge number of telecommunication towers have been built in India during the last few decades with the aim of providing efficient communications. India's power sector is one of the most diversified in the world. The growing population along with increasing electrification and per capita usage provided more impetus. An extensive network of transmission line towers has been developed over the years for evacuating power produced by different electricity generation stations and distributing the same to consumers.

Power Transmission and telecom towers are generally analyzed by linear static analysis and the maximum member forces are governed by external loads like wind load on the tower body, conductor loads due to wind and line deviation angle tensions, and accessories like antenna, cables, ladder, and platforms. The members in towers are subjected to tension or compression forces due to external loads. The members are designed based on the prevailing code of practice.

2. Design Practice

In India, Power transmission line towers are designed for ultimate loads using IS 802 standard, and the towers are subjected to full-scale model testing on a test pad, applying all the loads and load combinations which tower has been

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designed one at a time in a particular sequence. Full-scale model testing is recommended to prove the design and detailing after the model analysis and calculations to eliminate all assumptions, unequal force distributions, member eccentricities developed during detailing, etc. For design acceptance by the purchaser, the tower must withstand the applied loads for the duration mentioned in the code.

In India, there is no direct standard available for the design of telecom towers before 2022. Hence Telecom towers are designed for working loads using IS 875 Part 1 to Part 5[1] and members are designed with IS 802 (for angle members) and IS 800 (for circular hollow tubular members) with an overload factor or factor of safety. Full-scale tower model testing is not mandatorily carried out as the towers are designed with overload factor/factor of safety in the design. Recently, the IS17740:2022[2] code has been introduced for design of telecom structures and the member design as per IS800:2007. IS 800 - General steel construction standard, where compression formula is applicable for both angle and tubular members design. Whereas this formula is used for only tubular member design in telecom towers and transmission line towers. The Latest Transmission line tower design standard IS 802 (Part 1/Sec 2) is updated with the circular hollow tubular member design formula of IS 800 in the Appendix as there is a need for transmission line structures with tubes. While it is believed that all standards and formulas are accurately established and expected to produce the same end results. To understand the results, a comparative study has been carried out on compression capacities using different standards and the results are presented in this paper. The standards used to calculate the buckling resistance of compression members in a lattice tower are according to IS 800:2007[3], ASCE 10-1[4], IS 802:2016[5], and BS EN 1993-3-1[6]. The Steel grades used is Mild Steel (MS) and High Tensile Steel (HT) for yield stress of MS 250MPa and HT 350MPa.

3. Literature Review

Seshu M.R. Adluri and Murty K. S. Madugul[7], conducted an experimental investigation consisting of 34 hot-rolled steel angles under concentric compression with a slenderness ratio between 50 and 150. They considered width-to-thickness ratios ranged from 13 to 20 and the results are obtained. The test specimen consists of eight different cross-section sizes and five different lengths. Most of the specimens are failed in torsional-flexural buckling. They recommended that class 4 steel angle sections to be designed as class 3 as per Canadian standards. Gang Shi1, Wen-jing Zhou1, Yu Bai, and Zhao Liu[8], investigated the local buckling of steel equal angle members with different strengths under axial compression. The ultimate local buckling stress of steel equal angle members under axial compression as a function of steel strength and the width-to-thickness ratio was established. They conducted an experiment of local buckling behaviour through FEA, effects of steel strength and width-to-thickness ratio on the ultimate stress were identified. They concluded that when the steel strength is relatively low, ultimate stress decreases slightly with the width-to-thickness ratio. On the other side if width to thickness ratio is small (<10) the ultimate stress increases almost linearly with the strength of the steel which indicates a higher strength of steel could be fully utilized. The width-to-thickness ratio greater than (>10) increase of ultimate stress with steel strength may be the same by local behavior. Considering ANSI/AISC 360-10 and Eurocode[3]. They proposed a formula and compared it better with FEA results. Aljoša Filipović, Jelena Dobrić, Zlatko Marković, Nancy Baddoo, Željko Flajs[9], studied the compressive capacities of stainless steel angle columns with the design procedure presented in Eurocode3. They studied on pin-ended hot-rolled equal angle columns made of austenitic stainless steel grade EN1.4301. They used Finite Element Analysis to assess the appropriateness of buckling curve b used for the design of hot rolled carbon steel equal-leg angle columns. FE Models are selected with slenderness ratio of range 15-256. The compressive capacities of stainless-steel angle columns of FE study are compared with compressive capacities of the equivalent initially straight columns without residual stress. The FE models involves local buckling of angle legs, torsional-flexural mode under combined twisting. The flexural deflection occurs at major axis and flexural buckling about minor principal axis. Wenjiang Kang, F. Albermani, S. Kitipornchai and Heung-Fai Lam[10], studied the behaviour of analytical model of Lattice tower. They investigated the effects of the rigidity of brace end connections of a transmission tower by using Finite element model. They concluded that connection rigidity of main braces to be considered for calculating ultimate capacity of a tower. Nonlinear analysis without consideration of secondary braces may lead to unreliable prediction of the ultimate load capacity of the system. The cross bracing in the secondary bracing configuration can enhance the ultimate load capacity of the structure. Furthermore, there study provides a similar buckling capacity for different types of cross bracings.

4. Objective of Study

To understand the different codal provisions for calculating the compression capacities as per IS 802-2016(Part1/sec2), ASCE10-15, IS 800:2007, and EN 1993-3-1:2006.

- To understand the effect of width to thickness ratio for various angle sections.
- To calculate the compression capacities for different slenderness ratios (L/r) and tabulating the results and graphs using the member slenderness reduction factors for easy reference.
- Member compression capacity = Member slenderness reduction factor (x) Yield stress (x) Area of cross section
- To Compare the member slenderness reduction factors with the respective slenderness ratio as per IS, ASCE, and BS EN Codes.
- To understand the maximum percentage variation between different standards.

5. Determining the Compression Stress

5.1 IS 802(Part-1/Sec-2):2016 Clause 5.2.2 and ASCE 10-15

The allowable Stress Fa in MPa, on the gross cross-sectional area of the axially loaded compression member, shall be

$$a) F_a = \left[1 - \frac{1}{2}\left(\frac{KL/r}{Cc}\right)^2\right] F_y \ when\ KL/r \le C_c$$

$$b) Fa = \frac{\pi^2 E}{\left(KL/r\right)^2} when \frac{KL}{r} > C_c$$

$$C_c = \pi\sqrt{\frac{2E}{F_y}}$$

The above formulae are applicable provided the largest width thickness ratio b/t is not more than the limiting value given by

$$(b/t)lim = \frac{210}{\sqrt{F_y}}$$

$$F_{cr} = \left[1.677 - \frac{0.677\left(\frac{b}{t}\right)}{\left(\frac{b}{t}\right)lim}\right] F_y \ where \left(\frac{b}{t}\right)lim \le \left(\frac{b}{t}\right) \le 378/\sqrt{Fy}$$

$$F_{cr} = \left[\frac{65550}{\left(\frac{b}{t}\right)^2}\right] where \left(\frac{b}{t}\right) > 378/\sqrt{Fy}$$

The Maximum permissible value of b/t for any type of steel shall not exceed 25.

Where,

Fy= Minimum guaranteed yield stress of the material, MPa.

E= Modulus of Elasticity of Steel, that is $2x10^5$ MPa.

KL/r= Largest effective slenderness ratio of any unbraced segment of the member.

L= Unbraced length of compression member in cm.

r= appropriate radius of gyration, in cm.

b= distance from the edge of the fillet to the extreme fiber in mm.

t= thickness of flange in mm.

5.2 IS 800:2007

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

$$f_{cd} = \frac{Xf_y}{\gamma_{mo}}$$

Where,

χ = Stress reduction factor for different buckling class

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

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

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

α = Imperfection factor (0.34 used as specified in the standard) for angle members.

γ_{mo}= Partial safety factor for material strength (1.0 used for this study).

5.3 BSEN 1993:3-1:2006

The buckling resistance of compression members in lattice tower is determined as:

$$N_{b} = \frac{÷Af_y}{ã_{mo}} \text{ for Class 1,2 and 3 cross section}$$

$$N_{b} = \frac{÷A_{eff} f_y}{ã_{mo}} \text{ for Class 4 cross-section}$$

Where χ is the reduction factor for the relevant buckling mode

For constant axial compression in members of constant cross section, the reduction factor χ and the factor Ø to determine χ should both be determined with the effective slenderness ratio $\bar{\lambda}_{eff}$ instead of $\bar{\lambda}$.

The effective slenderness ratio $\bar{\lambda}_{eff}$ is defined as

$$\bar{\lambda}_{eff} = k\bar{\lambda}$$

Where k is the effective slenderness ratio considered as

$$k=0.8+\bar{\lambda}/10, \bar{\lambda} =\lambda/\lambda_1$$

λ_1 is defined in EN1993-1-1

λ is the slenderness for relevant buckling mode.

γ_{mo} = Partial safety factor for material strength (1.0 used for this study).

χ and factor Ø formulae are same as IS 800 as given above.

Table 1. Limiting ratios for width to thickness

SI. No	IS 800:2007			BSEN 1993-3-1:2006		
	Limiting Values	**MS (250)**	**HT (350)**	**Limiting Values**	**MS (250)**	**HT (350)**
1	b/t = 15.7e	15.7	13.26	h/t ≤ 15e	14.53	12.25
2	d/t = 15.7e	15.7	13.26	h/t ≤ 15e	14.53	12.25
3	(b+d)/t = 25e	25	21.12	(b+h)/2t ≤ 11.5e	11.14	9.418
4	e = $(250/fy)^{1/2}$	1	0.845	e = $(235/fy)^{1/2}$	0.969	0.819

6. Methodology for the Current Study

- We have considered thirty-one different angle sections with grades Mild Steel (MS) and High Tensile steel (HT).
- The study and graphs are divided into two groups depending on the width-to-thickness criteria. The angle sections are within the width-to-thickness limit and the other is exceeding the limit (Highlighted) which are shown in Tables 3 and 4.
- The compression capacities for each angle section are calculated by above stated formulae as per IS, ASCE, and BS EN standards for the slenderness ratio (L/r) ranges of 10 to 330 with an interval of 10.
- From the capacities, the member slenderness reduction factors are calculated for Curves 1 to 6 as per the effective slenderness ratios (KL/r) shown in Table 2.
- Member compression capacity = Member slenderness reduction factor (x) Yield stress (x) Area of cross-section.
- The values of KL/r ratios Clause 6 of IS 802:2016 is used in IS800:2007 for obtaining the Capacities.
- IS 802 and ASCE 10-15 standard compression formulae are the same and hence the resulting compression capacities are the same. The same is reported commonly under "IS 802/ASCE" in tables and graphs.
- Partial safety factor used in calculating IS 800 and BSEN capacities.
- The graphs are plotted between the Member slenderness reduction factors and slenderness ratio (L/r) for grades Mild steel (MS) and High Tensile steel (HT).

Table 2. Effective slenderness ratio (KL/r) for curve 1,2,3 KL/r ≤ 120 and Curve 4,5,6 KL/r >120-250

Curve number	IS 800:2007 and IS 802:2016	BSEN 1993-3-1:2006
1	KL/r = L/r	κ = 0.8+($\bar{\lambda}$/10) for (Symmetrical) Bracing) κ = (0.8+($\bar{\lambda}$/10) *1.2) for (Unsymmetrical) Bracing)
2	KL/r = 30+0.75L/r	κ = (0.7+0.35/ $\bar{\lambda}$) (The reduction factor to be taken on compression strength η = 0.8 for single angle members connected by one bolt at each end, η = 0.9 in case of one bolt at one end and continuous or rigidly connected at the other end.)
3	KL/r = 60+0.5L/r	
4	KL/r = L/r	
5	KL/r = 28.6+0.762L/r	
6	KL/r = 46.2+0.615L/r	

Table 3. B/T limits for Mild Steel (MS)

Section	IS800:2007		IS802: 2016/ ASCE	BSEN	
	Limiting Ratio				
	b/t, d/t =	b+d/ t=	b/t =	b/t, d/t =	b+d/2t=
	15.7ε	25ε	210/, 378/	15ε	11.5ε
	15.7	25	13.282, 23.907	14.53	11.14
40x40x4	10.00	20.00	7.63	10.00	10.00
45x45x4	11.25	22.50	8.88	11.25	**11.25**
45x45x5	9.00	18.00	6.90	9.00	9.00
50x50x4	12.5	25	10.00	12.50	**12.50**
50x50x5	10.00	20.00	7.80	10.00	10.00
55x55x4	13.75	**27.50**	11.13	13.75	**13.75**
60x60x4	15.00	**30.00**	12.00	**15.00**	**15.00**
60x60x5	12.00	24.00	9.70	12.00	**12.00**
65x65x4	**16.25**	**32.50**	**13.63**	**16.25**	**16.25**
65x65x5	13.00	**26.00**	10.70	13.00	**13.00**
70x70x5	14.00	**28.00**	11.60	14.00	**14.00**
75x75x5	15.00	**30.00**	12.60	**15.00**	**15.00**
75x75x6	12.50	25.00	10.33	12.50	**12.50**
80x80x6	13.33	**26.67**	11.00	13.33	**13.33**
90x90x6	15.00	**30.00**	12.58	**15.00**	**15.00**
90x90x8	12.00	24.00	9.70	12.00	**12.00**
100x100x6	**16.67**	**33.33**	**14.25**	**16.67**	**16.67**
100x100x8	12.50	25.00	10.44	12.50	**12.50**
100x100x10	10.00	20.00	8.15	10.00	10.00
110x110x8	13.75	**27.50**	11.50	13.75	**13.75**
110x110x10	11.00	22.00	9.00	11.00	11.00
120x120x8	15.00	**30.00**	12.38	**15.00**	**15.00**
120x120x10	12.00	24.00	9.70	12.00	**12.00**
130x130x10	13.00	**26.00**	11.00	13.00	**13.00**
130x130x12	10.83	21.67	9.00	10.83	10.83
150x150x12	12.50	25.00	10.50	12.50	**12.50**
150x150x16	9.38	18.75	7.63	9.38	9.38
150x150x20	7.50	15.00	5.90	7.50	7.50
200x200x16	12.50	25.00	10.56	12.50	**12.50**
200x200x20	10.00	20.00	8.25	10.00	10.00
200x200x25	8.00	16.00	6.40	8.00	8.00

Table 4. B/T limits for High Tensile steel (HT)

Section	IS800:2007		IS802:2016/ ASCE	BSEN	
	Limiting Ratio				
	b/t, d/t=	b+d/ t=	b/t =	b/t, d/t =	b+d/ 2t=
	15.7ε	25ε	210/ , 378/	15ε	11.5ε
	13.26	21.12	11.22, 20.20	12.25	9.418
40x40x4	10.00	20.00	7.63	10.00	**10.00**
45x45x4	11.25	**22.50**	8.88	11.25	**11.25**
45x45x5	9.00	18.00	6.90	9.00	9.00
50x50x4	12.5	**25.00**	10.00	**12.50**	**12.50**
50x50x5	10.00	20.00	7.80	10.00	**10.00**
55x55x4	**13.75**	**27.50**	11.13	**13.75**	**13.75**
60x60x4	**15.00**	**30.00**	**12.00**	**15.00**	**15.00**
60x60x5	12.00	**24.00**	9.70	12.00	**12.00**
65x65x4	**16.25**	**32.50**	**13.63**	**16.25**	**16.25**
65x65x5	13.00	**26.00**	10.70	**13.00**	**13.00**
70x70x5	**14.00**	**28.00**	**11.60**	**14.00**	**14.00**
75x75x5	**15.00**	**30.00**	**12.60**	**15.00**	**15.00**
75x75x6	12.50	**25.00**	10.33	**12.50**	**12.50**
80x80x6	**13.33**	**26.67**	11.00	**13.33**	**13.33**
90x90x6	**15.00**	**30.00**	**12.58**	**15.00**	**15.00**
90x90x8	12.00	**24.00**	9.70	12.00	**12.00**
100x100x6	**16.67**	**33.33**	**14.25**	**16.67**	**16.67**
100x100x8	12.50	**25.00**	10.44	**12.50**	**12.50**
100x100x10	10.00	20.00	8.15	10.00	**10.00**
110x110x8	**13.75**	**27.50**	**11.50**	**13.75**	**13.75**
110x110x10	11.00	**22.00**	9.00	11.00	**11.00**
120x120x8	**15.00**	**30.00**	**12.38**	**15.00**	**15.00**
120x120x10	12.00	**24.00**	9.70	12.00	**12.00**
130x130x10	13.00	**26.00**	11.00	**13.00**	**13.00**
130x130x12	10.83	**21.67**	9.00	10.83	**10.83**
150x150x12	12.50	**25.00**	10.50	**12.50**	**12.50**
150x150x16	9.38	18.75	7.63	9.38	9.38
150x150x20	7.50	15.00	5.90	7.50	7.50
200x200x16	12.50	**25.00**	10.56	**12.50**	**12.50**
200x200x20	10.00	20.00	8.25	10.00	**10.00**
200x200x25	8.00	16.00	6.40	8.00	8.00

7. Member Slenderness Reduction Factors

7.1 Graphs (B/T Ratio within Limit)

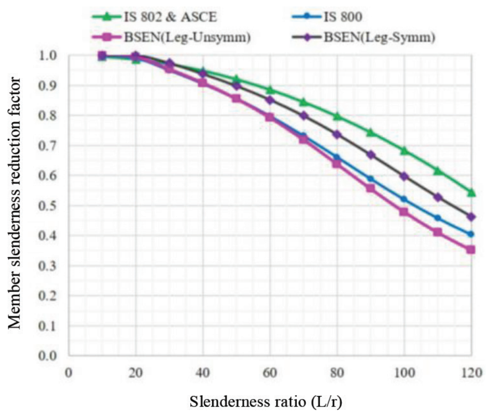

Figure 1. Mild Steel (MS) Graph, Curve-1, b/t within limit.

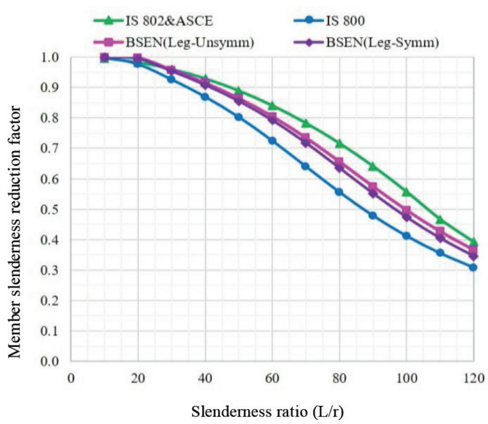

Figure 2. High Tensile (HT) steel Graph, Curve-1, b/t within.

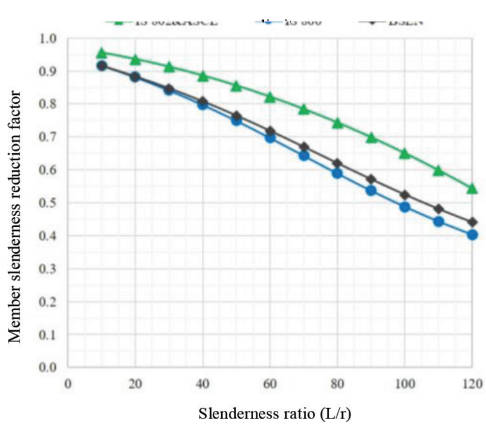

Figure 3. Mild Steel (MS) Graph, Curve-2, b/t within limit.

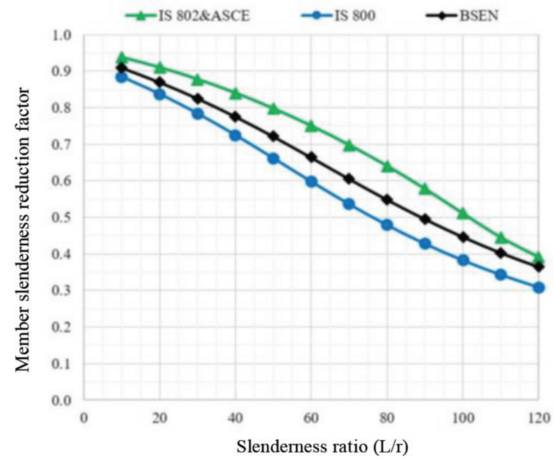

Figure 4. High Tensile (HT) steel Graph, Curve-2, b/t within Limit.

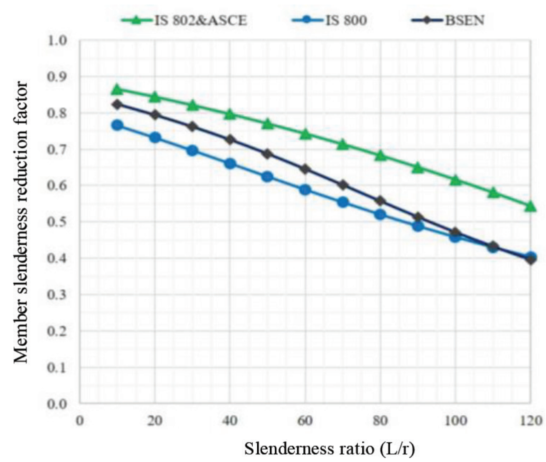

Figure 5. Mild Steel (MS) Graph, Curve-3, b/t within limit.

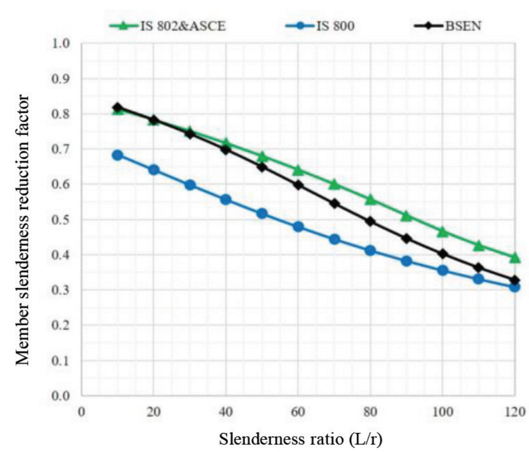

Figure 6. High Tensile (HT) steel Graph, Curve-3, b/t within limit.

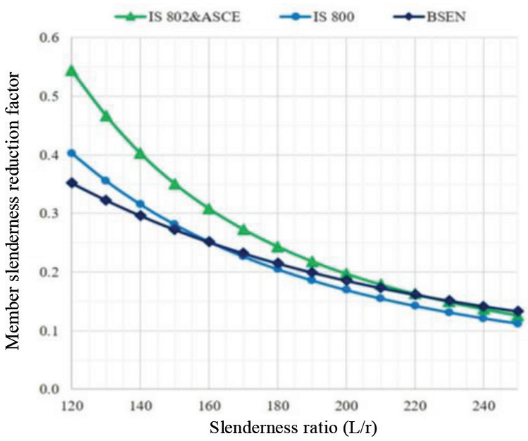

Figure 7. Mild Steel (MS) Graph, Curve-4, b/t within limit.

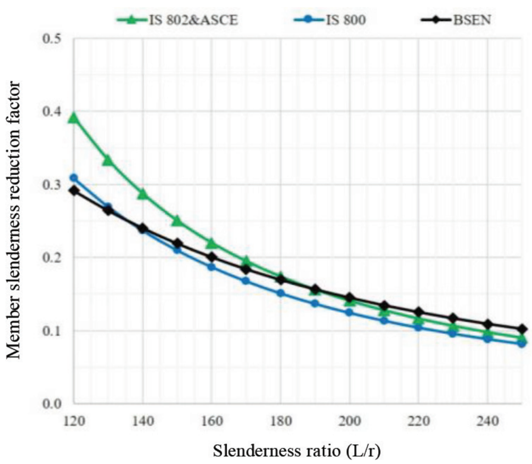

Figure 8. High Tensile (HT) steel Graph, Curve-4, b/t within limit.

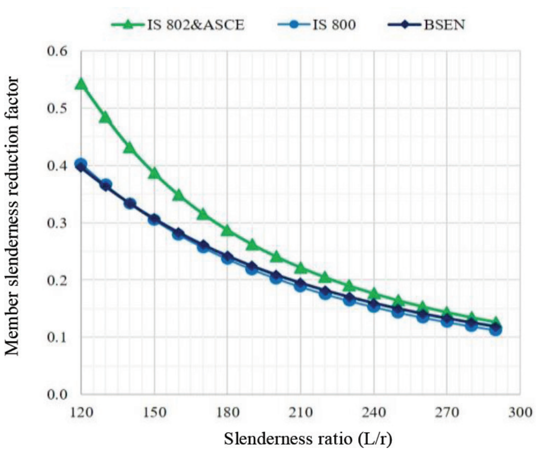

Figure 9. Mild Steel (MS) Graph, Curve-5, b/t within limit.

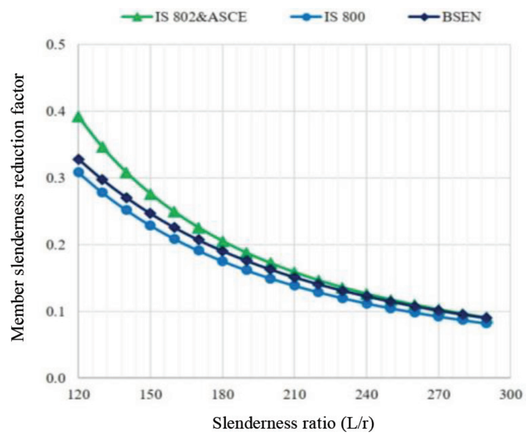

Figure 10. High Tensile (HT) steel Graph, Curve-5, b/t within limit.

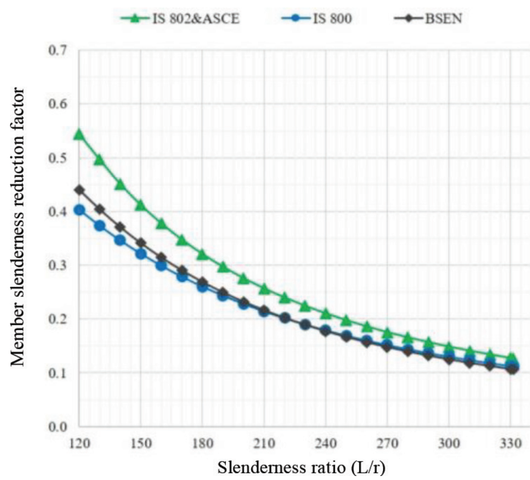

Figure 11. Mild Steel (MS) Graph, Curve-6, b/t within limit.

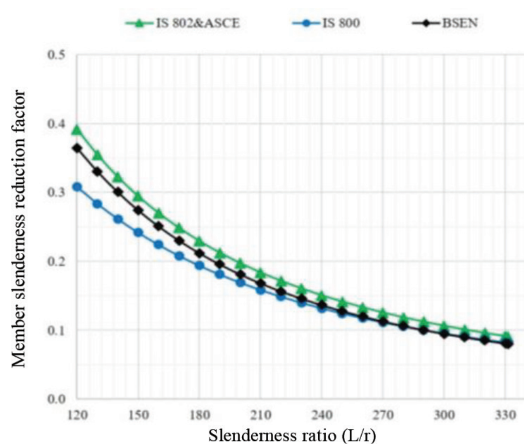

Figure 12. High Tensile (HT) steel Graph, Curve-6, b/t within limit.

7.2 Graphs (B/T Ratio Not in Limit)

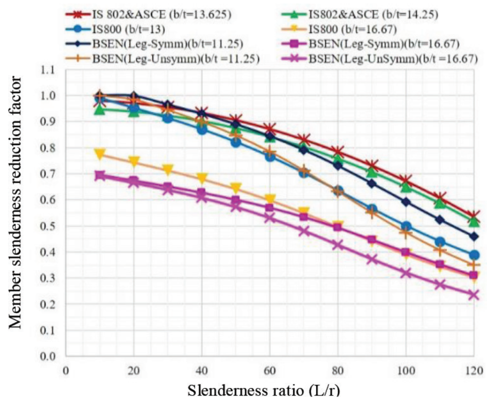

Figure 13. Mild Steel (MS) Graph, Curve-1, b/t Not in limit.

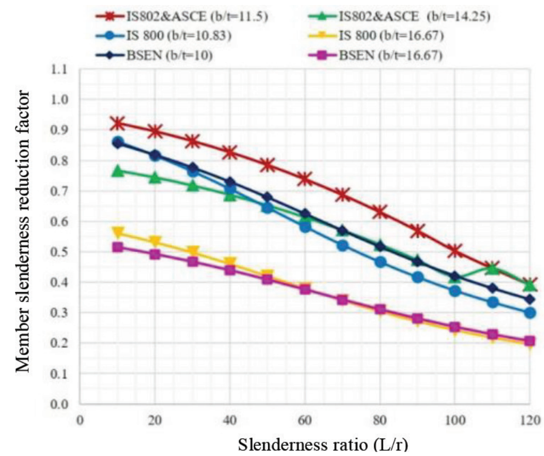

Figure 16. High Tensile (HT) steel Graph, Curve-2, b/t Not in limit.

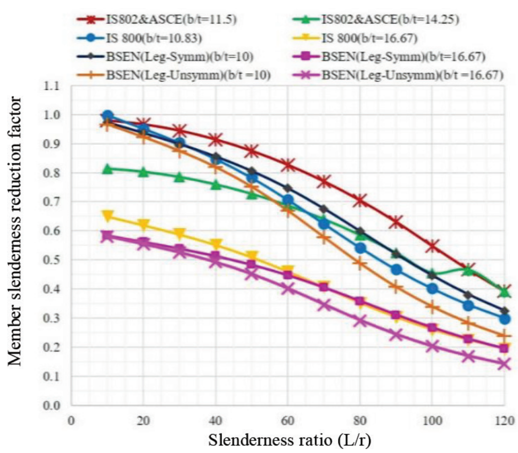

Figure 14. High Tensile (HT) steel Graph, Curve-1, b/t Not in limit.

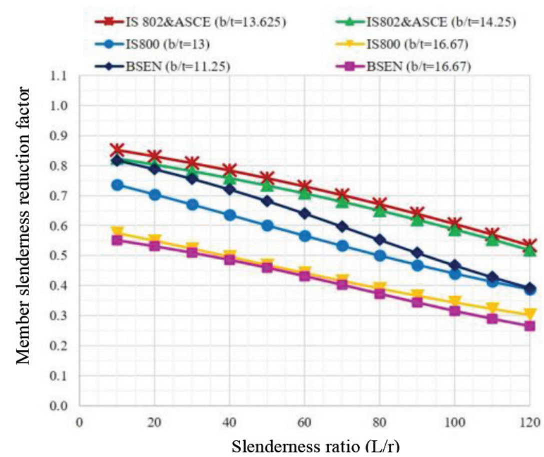

Figure 17. Mild Steel (MS) Graph, Curve-3, b/t Not in limit.

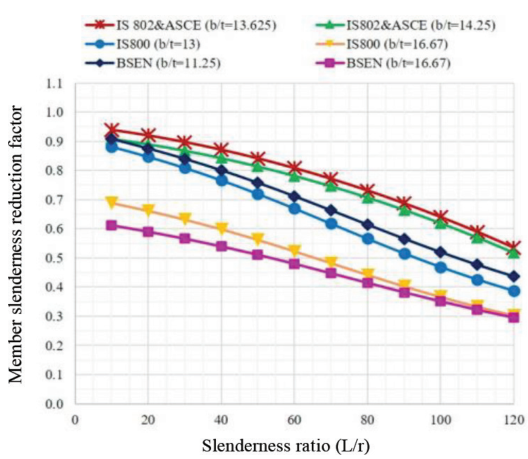

Figure 15. Mild Steel (MS) Graph, Curve-2, b/t Not in limit.

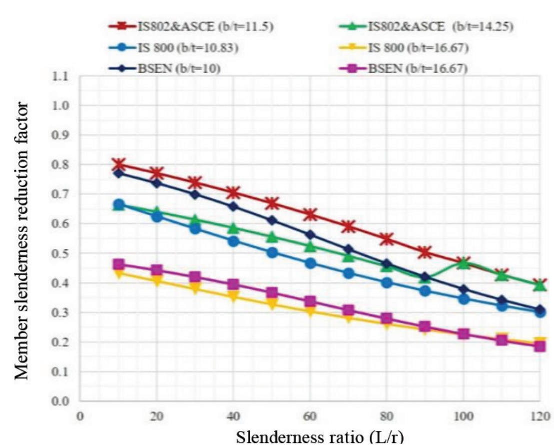

Figure 18. High Tensile (HT) steel Graph, Curve-3, b/t Not in limit.

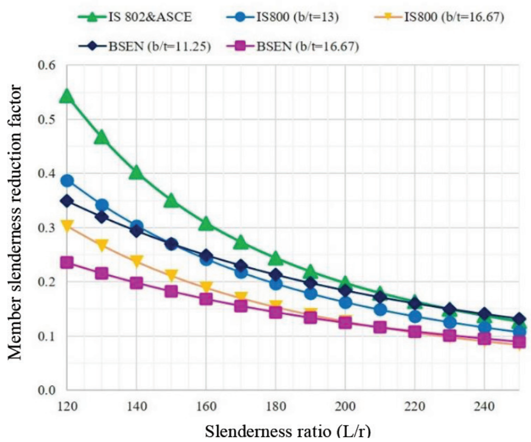

Figure 19. Mild Steel (MS) Graph, Curve-4, b/t Not in limit.

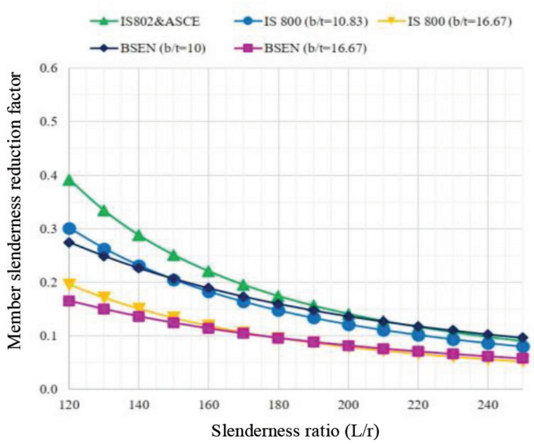

Figure 20. High Tensile (HT) steel Graph, Curve-4, b/t Not in limit.

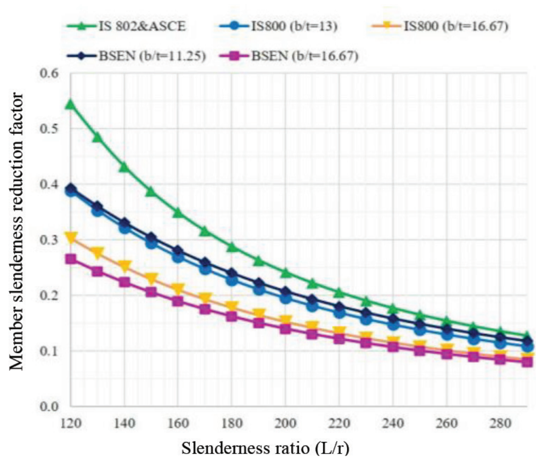

Figure 21. Mild Steel (MS) Graph, Curve-5, b/t Not in limit.

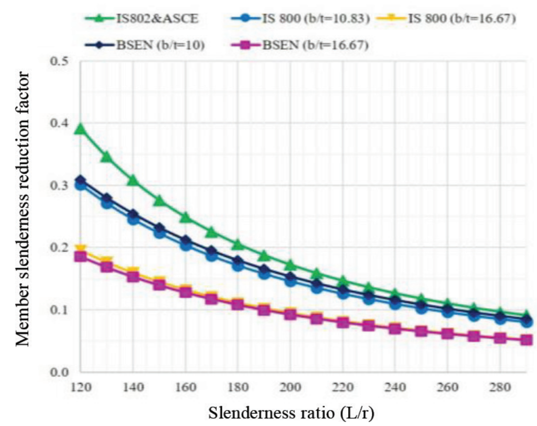

Figure 22. High Tensile (HT) steel Graph, Curve-5, b/t Not in limit.

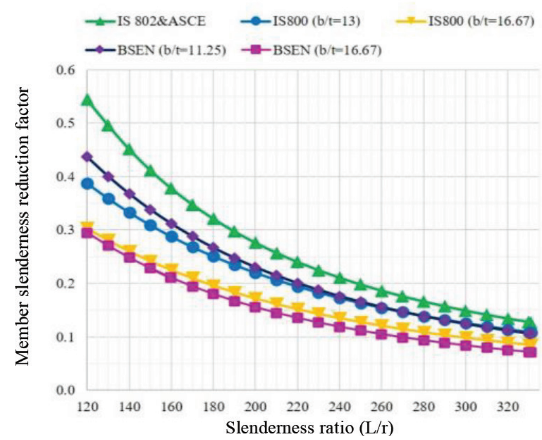

Figure 23. Mild Steel (MS) Graph, Curve-6, b/t Not in limit.

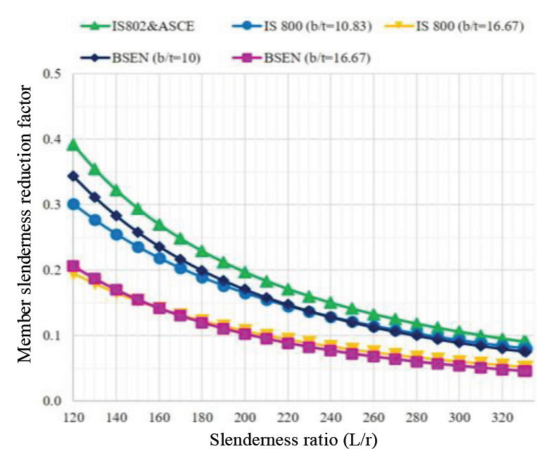

Figure 24. High Tensile (HT) steel Graph, Curve-6, b/t Not in limit.

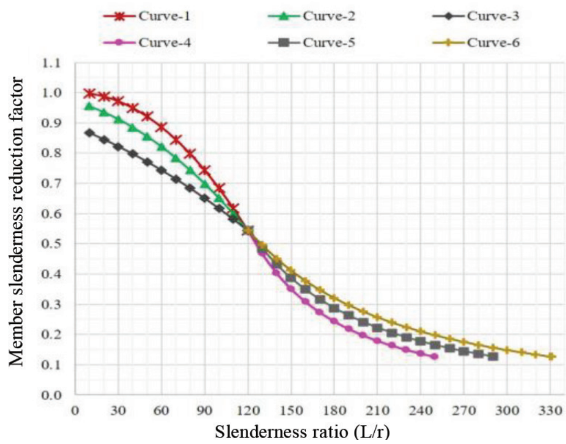

Figure 25. Mild Steel (MS) Graph, IS802/ASCE standard Curves-1-6, b/t within limit.

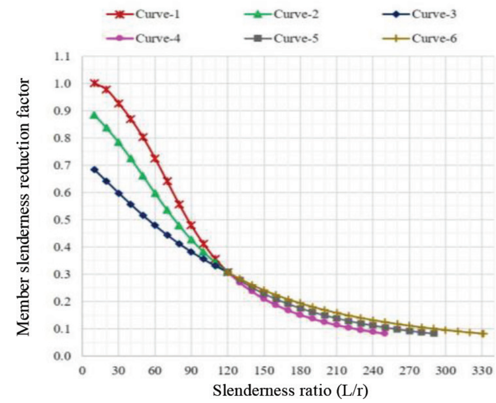

Figure 28. High Tensile (HT) steel Graph, IS800 standard Curves-1-6, b/t within limit.

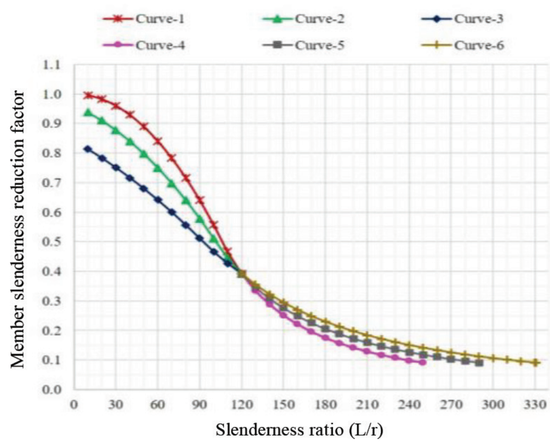

Figure 26. High Tensile (HT) steel Graph, IS802/ASCE standard Curves-1-6, b/t within limit.

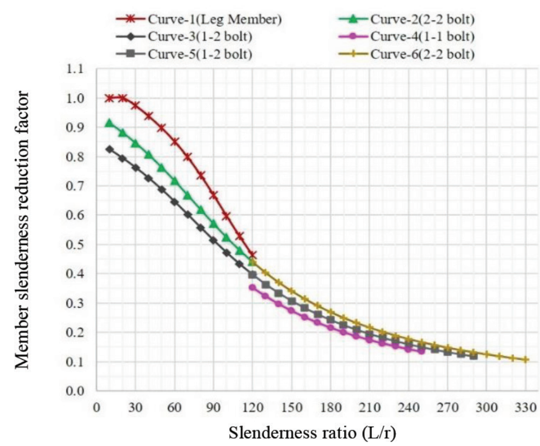

Figure 29. Mild Steel (MS) Graph, BSEN standard Curves-1-6, b/t within limit, symmetrical bracing.

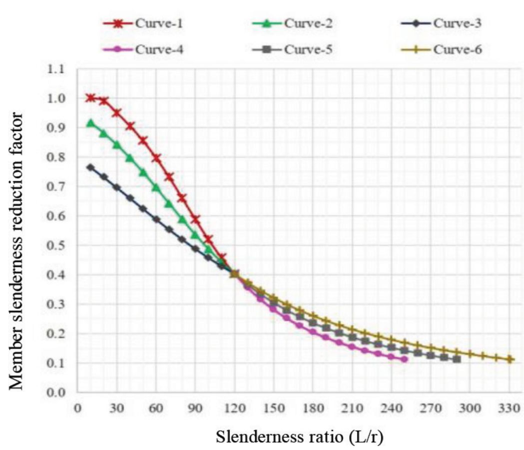

Figure 27. Mild Steel (MS) Graph, IS800 standard Curves-1-6, b/t within limit.

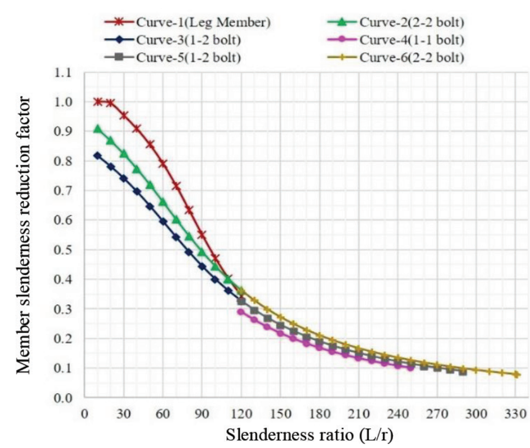

Figure 30. High Tensile (HT) steel Graph, BSEN standard Curves-1-6, b/t within limit, symmetrical bracings.

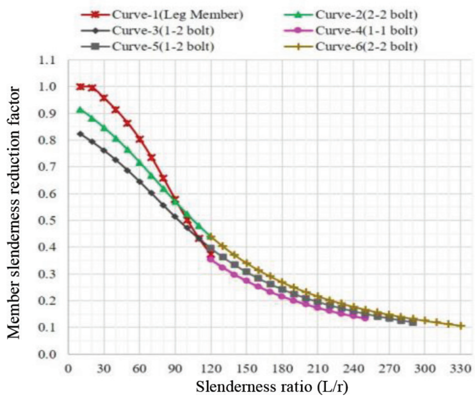

Figure 31. Mild Steel (MS) Graph, BSEN standard Curves-1-6, b/t within limit, unsymmetrical bracing.

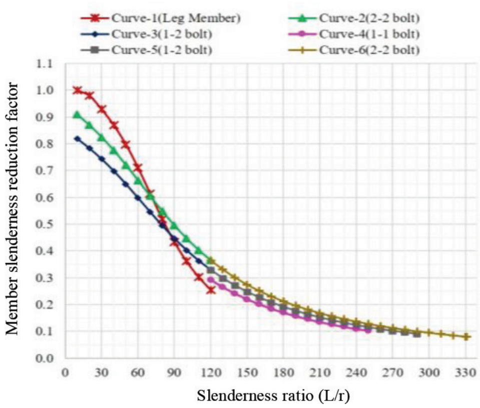

Figure 32. High Tensile (HT) steel Graph, BSEN standard Curves-1-6, b/t within limit, unsymmetrical bracings.

7.3 Observations Inferred Percentage Difference Graphs for B/T Ratio within Limit

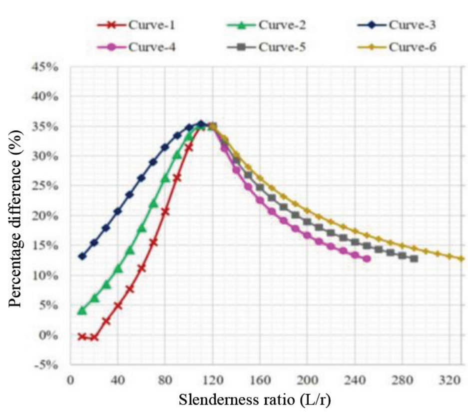

Figure 33. IS802 and ASCE To IS800 percentage difference Mild steel (MS) Graph.

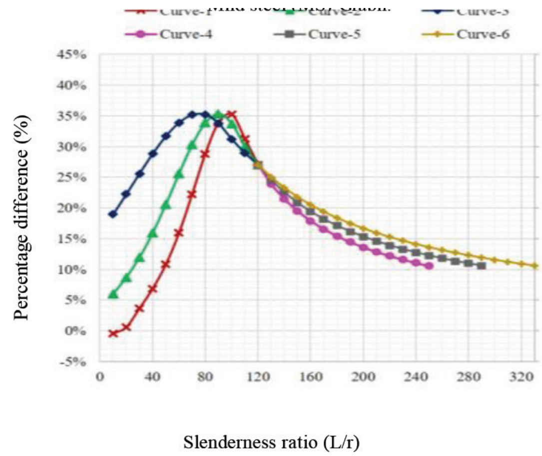

Figure 34. IS802 and ASCE To IS800 percentage difference High Tensile (HT) steel Graph.

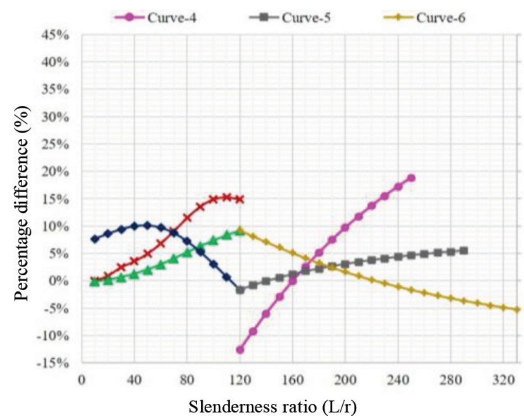

Figure 35. BSEN To IS800 percentage difference Mild steel (MS) Graph.

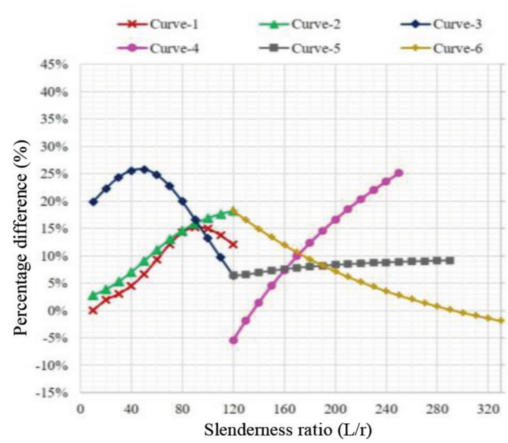

Figure 36. BSEN To IS800 percentage difference High Tensile (HT) steel Graph.

7.4 Percentage Difference Graphs for B/T Ratio Notin Limit

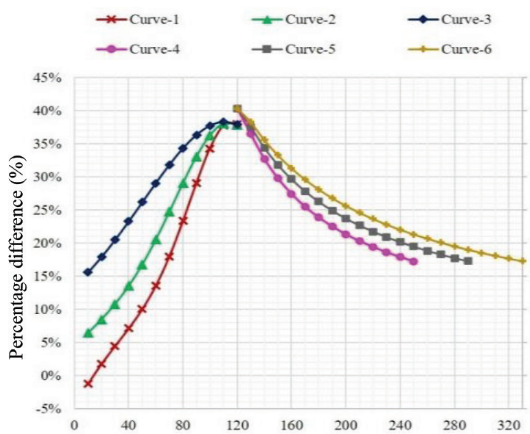

Figure 37. IS802 and ASCE To IS800 percentage difference Mild steel (MS) Graph.

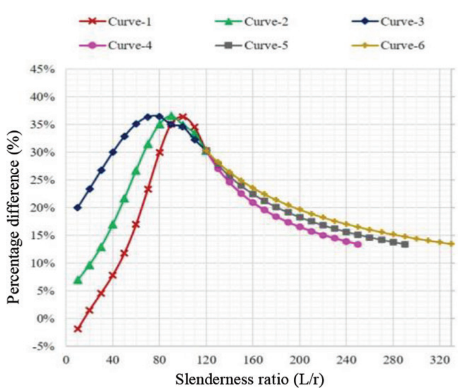

Figure 38. IS802 and ASCE To IS800 percentage difference High Tensile (HT) steel Graph

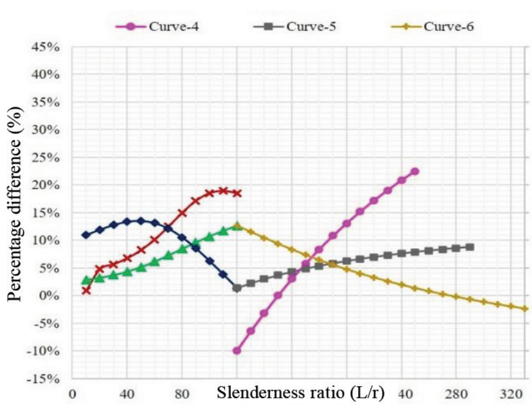

Figure 39. BSEN To IS800 percentage difference Mild Steel (MS) Graph.

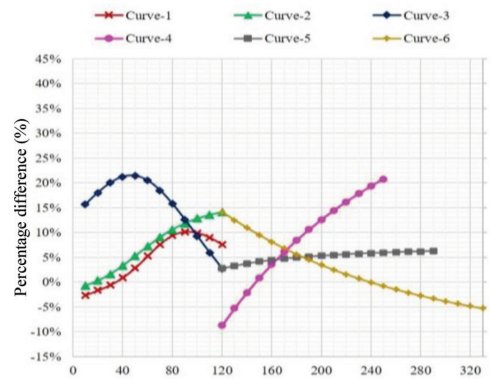

Figure 40. BSEN To IS800 percentage difference High Tensile (HT) steel Graph.

8. Conclusions

1. In the current study compression capacities calculated as per IS 802(part1/section2):2016 gives the maximum when compared with IS 800:2007 and BSEN standards as follows.

A) B/T Ratio within Limit

a) The Compression capacity of IS 802:2016/ASCE is higher compared with IS 800:2007 code in the range of -0.5% to 35% (Figure 33 and Figure 34).

b) The Compression capacity of BS EN is higher compared with IS 800:2007 code in the range of -5% to 26% (Figure 35 and Figure 36).

c) The Compression capacity of IS 802:2016/ASCE is higher compared with BSEN (symmetrical, unsymmetrical) code in the range of -1% to 55%.

B) B/T Ratio not Within Limit

a) The Compression capacity of IS 802:2016/ASCE is higher compared with IS 800:2007 code in the range of -2% to 40% (Figure 37 and Figure 38).

b) The Compression capacity of BS EN is higher compared with IS 800:2007 code in the range of -9% to 22% (Figure 39 and Figure 40).

c) The Compression capacity of IS 802:2016/ASCE is higher compared with BSEN (symmetrical, unsymmetrical) code in the range of -3% to 63%.

2. There are several codes that are relevant in the design of steel angle members. In India, compression capacity of an angle section is calculated as per IS800:2007 and IS802:2016 which can be used for design of steel angular sections. This paper presents the variations between different standards which are shown through graphs. From this paper new reduction factors are obtained by incorporating effective slenderness factor

k to IS 800:2007. The effective slenderness factor k is considered as per IS 802:2016. It is observed that as per IS802:2016 the calculation of angle capacity gives optimum tower weight compared with IS800:2007. Irrespective of design standards, angle members should behave commonly under compression load to a particular slenderness ratio and the resulting axial compression capacity should be the same across all codes. Furthermore, In the current study, both standards show different results for the same angle member due to the difference in assumptions of standards. It is observed that standards of IS 802:2016 and ASCE calculating the compression capacity of angle members, for the KL/r > Cc the effect of width to thickness limit is not considered. The compression capacity design of angle members using IS 800:2007 is very conservative. Moreover, all modern codes including ANSI/TIA-222[11] and AS 3995[12] specifies to mast and tower designs adopting compression formulae in line with IS 802 and ASCE 10-15. The assumption of buckling capacity should be realistic, if not the buckling capacity of a member may either overestimate or underestimate.

9. References

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2. IS17740:2022: Isolated towers, masts, and poles using structural steel-code of practice
3. IS 800:2007: General construction in steel-code of practice.
4. ASCE10-15: Design of lattice steel transmission structures.
5. IS 802 (Part-1/Sec-2)-2016: Use of structural steel in overhead transmission line Ttowers. Sec- 2: design strength.
6. BSEN 1993-3-1:2006: Design of steel structures-Part 3-1: Towers, masts and chimneys- Towers and masts.
7. Adluri SMR, Madugula MKS. Torsional- Flexural buckling strength of steel angles. Can J Civ Eng. 1996; 23:260-71. https://doi.org/10.1139/l96-027
8. Shi G, Zhou W-J, Bai Y, Liu Z. Local buckling of steel equal angle members with normal and high strengths. International Journal of Steel Structures. 2014; 14(3):447-55. https://doi.org/10.1007/s13296-014-3002-0
9. Filipović A, Dobrić J, Marković Z, Baddoo N, Flajs Z. Journal of the Croatian Association of Civil Engineers. 2563-2014.
10. Kang W, Albermani F, Kitipornchai S, Lam H-F. Modeling and analysis of lattice towers with more accurate models. Advanced Steel Construction. 2007; 3(2):565-82. https://doi.org/10.18057/IJASC.2007.3.2.3
11. ANSI/TIA-222-H- Structural Standard for Antenna Supporting Structures, Antennas, and small wind turbine support structures. (Revision of ANSI/TIA-222-G)
12. AS 3995- Design of steel lattice towers and masts- Australian standard; 1994.

10. Member Slenderness Reduction Factors

The Angle compression capacities, b/t ratios within limit can be calculated by using member slenderness reduction factors which are tabulated below

Table 5. IS 802:2016, member slendreness reduction factors

L/r	Mild Steel FY 250			High Tensile FY 350		
	Curve Numbers					
	1	2	3	1	2	3
10	0.997	0.955	0.866	0.996	0.938	0.813
20	0.987	0.936	0.845	0.982	0.91	0.783
30	0.972	0.913	0.822	0.96	0.878	0.751
40	0.949	0.886	0.797	0.929	0.84	0.716
50	0.921	0.856	0.771	0.889	0.798	0.68
60	0.886	0.822	0.744	0.84	0.751	0.641
70	0.845	0.784	0.714	0.783	0.698	0.600
80	0.797	0.744	0.683	0.716	0.641	0.557
90	0.744	0.699	0.651	0.641	0.579	0.511
100	0.683	0.651	0.617	0.557	0.511	0.466
110	0.617	0.599	0.581	0.466	0.446	0.427
120	0.544	0.544	0.544	0.392	0.392	0.392
	Curve Numbers					
	4	5	6	4	5	6
130	0.467	0.485	0.496	0.334	0.346	0.355
140	0.403	0.432	0.451	0.288	0.308	0.322
150	0.351	0.387	0.412	0.251	0.276	0.294
160	0.309	0.349	0.378	0.22	0.249	0.27
170	0.273	0.316	0.348	0.195	0.226	0.248
180	0.244	0.287	0.321	0.174	0.205	0.229
190	0.219	0.263	0.297	0.156	0.188	0.212
200	0.197	0.241	0.276	0.141	0.172	0.197
210	0.179	0.222	0.257	0.128	0.159	0.183
220	0.163	0.205	0.24	0.117	0.146	0.171
230	0.149	0.19	0.224	0.107	0.136	0.16
240	0.137	0.177	0.21	0.098	0.126	0.15

Table 5 continued...

250	0.126	0.165	0.198	0.09	0.118	0.141
260		0.154	0.186		0.11	0.133
270		0.144	0.175		0.103	0.125
280		0.135	0.166		0.096	0.118
290		0.127	0.157		0.091	0.112
300			0.148			0.106
310			0.141			0.101
320			0.134			0.096
330			0.127			0.091
331			0.126			0.09

Table 6. IS 800:2007, member slenderness reduction factors

L/r	Mild Steel FY 250			High Tensile FY350		
	Curve Numbers					
	1	2	3	1	2	3
10	1.000	0.917	0.765	1.000	0.884	0.683
20	0.991	0.881	0.732	0.976	0.837	0.64
30	0.950	0.842	0.697	0.926	0.784	0.598
40	0.906	0.797	0.661	0.869	0.725	0.556
50	0.855	0.749	0.625	0.803	0.662	0.516
60	0.797	0.697	0.589	0.725	0.598	0.479
70	0.732	0.643	0.554	0.640	0.536	0.444
80	0.661	0.589	0.520	0.556	0.479	0.412
90	0.589	0.537	0.488	0.479	0.427	0.382
100	0.520	0.488	0.458	0.412	0.382	0.355
110	0.458	0.443	0.429	0.355	0.343	0.331
120	0.403	0.403	0.403	0.308	0.308	0.308
	Curve Numbers					
	4	5	6	4	5	6
130	0.356	0.366	0.373	0.269	0.278	0.284
140	0.316	0.334	0.346	0.237	0.252	0.261
150	0.281	0.305	0.322	0.21	0.229	0.242
160	0.252	0.28	0.299	0.187	0.209	0.224
170	0.226	0.257	0.279	0.167	0.191	0.208
180	0.205	0.237	0.26	0.151	0.175	0.194
190	0.186	0.219	0.244	0.137	0.162	0.181
200	0.169	0.203	0.228	0.124	0.149	0.169
210	0.155	0.188	0.214	0.113	0.138	0.158
220	0.142	0.175	0.202	0.104	0.129	0.149
230	0.131	0.163	0.19	0.096	0.12	0.14
240	0.121	0.153	0.179	0.088	0.112	0.132

Table 6 continued...

250	0.112	0.143	0.169	0.082	0.105	0.124
260		0.134	0.160		0.098	0.117
270		0.126	0.152		0.092	0.111
280		0.119	0.144		0.087	0.105
290		0.112	0.137		0.082	0.100
300			0.13			0.095
310			0.124			0.09
320			0.118			0.086
330			0.113			0.082
331			0.112			0.082

Table 7. BS EN standard, member slenderness reduction factors for, symmetrical, [unsymmetrical] bracing

L/r	Mild Steel FY 250			High Tensile FY 350		
	Curve Numbers					
	1	2	3	1	2	3
10	1.000[1.000]	0.915	0.824	00.995[1.000]	0.870	0.783
20	1.000[0.996]	0.883	0.794	0.995[0.979]	0.870	0.783
30	0.973[0.957]	0.847	0.762	0.954[0.929]	0.825	0.743
40	0.938[0.914]	0.807	0.726	0.909[0.870]	0.776	0.698
50	0.897[0.864]	0.764	0.688	0.856[0.798]	0.721	0.649
60	0.852[0.805]	0.717	0.646	0.792[0.711]	0.664	0.597
70	0.798[0.735]	0.669	0.602	0.718[0.614]	0.605	0.545
80	0.737[0.658]	0.619	0.557	0.635[0.519]	0.549	0.494
90	0.669[0.578]	0.571	0.514	0.552[0.433]	0.495	0.446
100	0.597[0.501]	0.524	0.472	0.473[0.361]	0.447	0.402
110	0.528[0.432]	0.480	0.432	0.404[0.302]	0.403	0.363
120	0.463[0.372]	0.440	0.396	0.346[0.255]	0.365	0.328
	Curve Numbers					
	4	5	6	4	5	6
130	0.323	0.363	0.404	0.264	0.297	0.330
140	0.297	0.334	0.371	0.240	0.270	0.300
150	0.273	0.307	0.341	0.219	0.247	0.274
160	0.251	0.283	0.314	0.201	0.226	0.251
170	0.232	0.261	0.290	0.184	0.207	0.230
180	0.215	0.242	0.269	0.169	0.191	0.212
190	0.200	0.224	0.249	0.156	0.176	0.196
200	0.186	0.209	0.232	0.145	0.163	0.181
210	0.173	0.195	0.216	0.134	0.151	0.168
220	0.162	0.182	0.202	0.125	0.141	0.156
230	0.151	0.170	0.189	0.117	0.131	0.146
240	0.142	0.159	0.177	0.109	0.123	0.136
250	0.133	0.150	0.166	0.102	0.115	0.128
260		0.141	0.157		0.108	0.120
270		0.133	0.148		0.101	0.113

Table 7 continued...

280		0.125	0.139		0.096	0.106
290		0.119	0.132		0.090	0.100
300			0.125			0.095
310			0.118			0.090
320			0.112			0.085
330			0.107			0.081
331			0.106			0.080

The Angle compression capacities with b/t ratios not in limit are calculated by using member slenderness reduction factors which are tabulated below

Table 8. IS 802:2016, member slenderness reduction factors for Mild Steel (MS), B/T ratio not in limit

L/r.	**Curve Numbers**					
	1		**2**		**3**	
	b/t=	b/t=	b/t=	b/t=	b/t=	b/t=
	13.62	14.25	13.62	14.25	13.62	14.25
10	0.979	0.948	0.939	0.908	0.851	0.823
20	0.970	0.939	0.919	0.890	0.830	0.803
30	0.954	0.924	0.897	0.868	0.808	0.781
40	0.933	0.902	0.870	0.842	0.783	0.758
50	0.905	0.875	0.841	0.813	0.758	0.733
60	0.870	0.842	0.808	0.781	0.731	0.707
70	0.830	0.803	0.771	0.746	0.702	0.679
80	0.783	0.758	0.731	0.707	0.671	0.650
90	0.731	0.707	0.687	0.664	0.640	0.619
100	0.671	0.650	0.640	0.619	0.606	0.586
110	0.606	0.586	0.589	0.570	0.571	0.553
120	0.535	0.517	0.535	0.517	0.535	0.517
	Curve Numbers					
	4		5		6	
130	0.467		0.485		0.496	
140	0.403		0.432		0.451	
150	0.351		0.387		0.412	
160	0.309		0.349		0.378	
170	0.273		0.316		0.348	
180	0.244		0.287		0.321	
190	0.219		0.263		0.297	
200	0.197		0.241		0.276	
210	0.179		0.222		0.257	
220	0.163		0.205		0.240	
230	0.149		0.190		0.224	
240	0.137		0.177		0.210	

Table 8 continued...

250	0.126	0.165	0.198
260		0.154	0.186
270		0.144	0.175
280		0.135	0.166
290		0.127	0.157
300			0.148
310			0.141
320			0.134
330			0.127
331			0.126

Table 9. IS 802:2016, member slenderness reduction factors for High Tensile (HT) steel, B/T ratio not in limit

L/r.	**Curve Numbers**					
	1		**2**		**3**	
	b/t=	b/t=	b/t=	b/t=	b/t=	b/t=
	11.5	14.25	11.5	14.25	11.5	14.25
10	0.979	0.814	0.922	0.767	0.800	0.665
20	0.966	0.803	0.895	0.744	0.770	0.640
30	0.944	0.785	0.864	0.718	0.738	0.614
40	0.914	0.760	0.827	0.687	0.705	0.586
50	0.875	0.727	0.785	0.653	0.669	0.556
60	0.827	0.687	0.738	0.614	0.631	0.524
70	0.770	0.640	0.687	0.517	0.590	0.491
80	0.705	0.586	0.631	0.524	0.548	0.455
90	0.631	0.524	0.569	0.473	0.503	0.418
100	0.548	0.455	0.503	0.418	0.466	0.466
110	0.466	0.466	0.446	0.446	0.427	0.427
120	0.392	0.392	0.392	0.392	0.392	0.392
	Curve Numbers					
	4		5		6	
130	0.334		0.346		0.355	
140	0.288		0.308		0.322	
150	0.251		0.276		0.294	
160	0.220		0.249		0.270	
170	0.195		0.226		0.248	
180	0.174		0.205		0.229	
190	0.156		0.188		0.212	
200	0.141		0.172		0.197	
210	0.128		0.159		0.183	
220	0.117		0.146		0.171	

Table 9 continued...

230	0.107	0.136	0.160
240	0.098	0.126	0.150
250	0.090	0.118	0.141
260		0.110	0.133
270		0.103	0.125
280		0.096	0.118
290		0.091	0.112
300			0.106
310			0.101
320			0.096
330			0.091
331			0.090

Table 10. IS 800:2007, member slenderness reduction factors for Mild Steel (MS), B/T ratio not in limit

L/r.	**Curve Numbers**					
	1		**2**		**3**	
	b/t=	b/t=	b/t=	b/t=	b/t=	b/t=
	13	16.67	13	16.67	13	16.67
10	0.991	0.774	0.882	0.688	0.736	0.574
20	0.953	0.744	0.847	0.661	0.704	0.549
30	0.913	0.713	0.809	0.632	0.670	0.523
40	0.871	0.680	0.767	0.598	0.635	0.496
50	0.822	0.642	0.720	0.562	0.601	0.469
60	0.767	0.598	0.670	0.523	0.566	0.442
70	0.704	0.549	0.618	0.482	0.532	0.415
80	0.635	0.496	0.566	0.442	0.500	0.390
90	0.566	0.442	0.516	0.403	0.469	0.366
100	0.500	0.390	0.469	0.366	0.440	0.344
110	0.440	0.344	0.426	0.333	0.413	0.322
120	0.388	0.303	0.388	0.303	0.388	0.303
	Curve Numbers					
	4		5		6	
130	0.342	0.267	0.352	0.275	0.359	0.280
140	0.304	0.237	0.321	0.251	0.333	0.260
150	0.270	0.211	0.293	0.229	0.309	0.241
160	0.242	0.189	0.269	0.210	0.288	0.224
170	0.218	0.170	0.247	0.193	0.268	0.209
180	0.197	0.154	0.228	0.178	0.250	0.195
190	0.179	0.139	0.210	0.164	0.234	0.183
200	0.163	0.127	0.195	0.152	0.220	0.171
210	0.149	0.116	0.181	0.141	0.206	0.161

Table 10 continued...

220	0.137	0.107	0.168	0.131	0.194	0.151
230	0.126	0.098	0.157	0.123	0.183	0.143
240	0.116	0.091	0.147	0.115	0.172	0.134
250	0.108	0.084	0.138	0.107	0.163	0.127
260			0.129	0.101	0.154	0.120
270			0.122	0.095	0.146	0.114
280			0.115	0.089	0.139	0.108
290			0.108	0.084	0.132	0.103
300					0.125	0.098
310					0.119	0.093
320					0.114	0.089
330					0.108	0.085
331					0.108	0.084

Table 11. IS 800:2007, member slenderness reduction factors for High Tensile (HT) steel, B/T ratio not in limit

L/r.	**Curve Numbers**					
	1		**2**		**3**	
	b/t=	b/t=	b/t=	b/t=	b/t=	b/t=
	10.83	16.67	10.83	16.67	10.83	16.67
10	0.998	0.649	0.863	0.561	0.666	0.433
20	0.952	0.619	0.817	0.531	0.624	0.406
30	0.903	0.587	0.765	0.497	0.583	0.379
40	0.848	0.551	0.707	0.460	0.542	0.353
50	0.783	0.509	0.645	0.420	0.503	0.327
60	0.707	0.460	0.583	0.379	0.467	0.304
70	0.624	0.406	0.523	0.340	0.433	0.282
80	0.542	0.353	0.467	0.304	0.402	0.261
90	0.467	0.304	0.417	0.271	0.373	0.242
100	0.402	0.261	0.373	0.242	0.347	0.225
110	0.347	0.225	0.334	0.217	0.323	0.210
120	0.301	0.196	0.301	0.196	0.301	0.196
Curve Numbers						
	4		5		6	
130	0.263	0.171	0.271	0.176	0.277	0.180
140	0.231	0.150	0.245	0.160	0.255	0.166
150	0.205	0.133	0.223	0.145	0.236	0.153
160	0.182	0.119	0.203	0.132	0.218	0.142
170	0.163	0.106	0.186	0.121	0.203	0.132
180	0.147	0.096	0.171	0.111	0.189	0.123
190	0.133	0.087	0.158	0.102	0.176	0.115
200	0.121	0.079	0.146	0.095	0.165	0.107

Table 11 continued...

210	0.111	0.072	0.135	0.088	0.154	0.100
220	0.101	0.066	0.125	0.082	0.145	0.094
230	0.093	0.061	0.117	0.076	0.136	0.089
240	0.086	0.056	0.109	0.071	0.128	0.083
250	0.080	0.052	0.102	0.066	0.121	0.079
260			0.096	0.062	0.115	0.074
270			0.090	0.059	0.108	0.070
280			0.085	0.055	0.103	0.067
290			0.080	0.052	0.098	0.063
300					0.093	0.060
310					0.088	0.057
320					0.084	0.055
330					0.080	0.052
331					0.080	0.052

Table 12. BS EN standard, member slenderness reduction factors for Mild Steel (MS), B/T ratio not in limit, symmetrical, [unsymmetrical]

L/r.	Curve Numbers					
	1		2		3	
	b/t=	b/t=	b/t=	b/t=	b/t=	b/t=
	11.25	16.67	11.25	16.67	11.25	16.67
10	1.000[1.000]	0.695[0.691]	0.907	0.612	0.817	0.551
20	0.998[0.985]	0.674[0.665]	0.875	0.590	0.787	0.531
30	0.965[0.945]	0.651[0.638]	0.839	0.566	0.755	0.510
40	0.929[0.900]	0.627[0.607]	0.800	0.540	0.720	0.486
50	0.890[0.848]	0.600[0.572]	0.757	0.511	0.682	0.460
60	0.844[0.785]	0.570[0.530]	0.711	0.480	0.640	0.432
70	0.791[0.713]	0.534[0.481]	0.663	0.447	0.597	0.403

Table 12 continued...

80	0.730[0.632]	0.493[0.427]	0.614	0.414	0.553	0.373
90	0.663[0.551]	0.447[0.372]	0.566	0.382	0.509	0.344
100	0.592[0.474]	0.400[0.320]	0.519	0.351	0.468	0.316
110	0.523[0.407]	0.353[0.274]	0.476	0.321	0.429	0.289
120	0.459[0.349]	0.310[0.235]	0.436	0.295	0.393	0.265
Curve Numbers						
	4		5		6	
130	0.320	0.216	0.360	0.243	0.400	0.270
140	0.294	0.198	0.331	0.223	0.368	0.248
150	0.270	0.182	0.304	0.205	0.338	0.228
160	0.249	0.168	0.280	0.189	0.312	0.210
170	0.230	0.155	0.259	0.175	0.288	0.194
180	0.213	0.144	0.240	0.162	0.266	0.180
190	0.198	0.133	0.223	0.150	0.247	0.167
200	0.184	0.124	0.207	0.140	0.230	0.155
210	0.171	0.116	0.193	0.130	0.214	0.145
220	0.160	0.108	0.180	0.122	0.200	0.135
230	0.150	0.101	0.169	0.114	0.187	0.126
240	0.141	0.095	0.158	0.107	0.176	0.119
250	0.132	0.089	0.148	0.100	0.165	0.111
260			0.140	0.094	0.155	0.105
270			0.132	0.089	0.146	0.099
280			0.124	0.084	0.138	0.093
290			0.118	0.079	0.131	0.088
300					0.124	0.083
310					0.117	0.079
320					0.111	0.075
330					0.106	0.071
331					0.105	0.071

Table 13. BS EN standard, member slenderness reduction factors for High Tensile (HT) steel, b/t ratio not in limit symmetrical, [unsymmetrical]

L/r.	Curve Numbers					
	1		2		3	
	b/t=	b/t=	b/t=	b/t=	b/t=	b/t=
	10.00	16.67	10.00	16.67	10.00	16.67
10	0.973[0.966]	0.584[0.580]	0.856	0.514	0.771	0.463
20	0.936[0.922]	0.562[0.554]	0.819	0.492	0.737	0.443
30	0.898[0.875]	0.539[0.525]	0.777	0.467	0.699	0.420
40	0.855[0.819]	0.514[0.492]	0.730	0.439	0.657	0.395
50	0.805[0.751]	0.484[0.451]	0.679	0.408	0.611	0.367
60	0.746[0.669]	0.448[0.402]	0.625	0.375	0.562	0.338

Table 13 continued...

70	0.676[0.578]	0.406[0.347]	0.570	0.342	0.513	0.308
80	0.598[0.488]	0.359[0.293]	0.516	0.310	0.465	0.279
90	0.519[0.408]	0.312[0.245]	0.466	0.280	0.420	0.252
100	0.446[0.340]	0.268[0.204]	0.421	0.253	0.379	0.227
110	0.381[0.285]	0.229[0.171]	0.380	0.228	0.342	0.205
120	0.325[0.240]	0.195[0.144]	0.343	0.206	0.309	0.186
Curve Numbers						
	4		5		6	
130	0.249	0.149	0.280	0.168	0.311	0.187
140	0.226	0.136	0.255	0.153	0.283	0.170
150	0.206	0.124	0.232	0.139	0.258	0.155
160	0.189	0.113	0.212	0.128	0.236	0.142
170	0.173	0.104	0.195	0.117	0.217	0.130
180	0.159	0.096	0.179	0.108	0.199	0.120
190	0.147	0.088	0.166	0.099	0.184	0.111
200	0.136	0.082	0.153	0.092	0.170	0.102
210	0.127	0.076	0.142	0.085	0.158	0.095
220	0.118	0.071	0.132	0.080	0.147	0.088
230	0.110	0.066	0.124	0.074	0.137	0.082
240	0.103	0.062	0.115	0.069	0.128	0.077
250	0.096	0.058	0.108	0.065	0.120	0.072
260			0.102	0.061	0.113	0.068
270			0.095	0.057	0.106	0.064
280			0.090	0.054	0.100	0.060
290			0.085	0.051	0.094	0.057
300					0.089	0.054
310					0.084	0.051
320					0.080	0.048
330					0.076	0.046
331					0.075	0.045