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Comparison of a steel column design buckling resistance between the South African/Canadian (SANS 10162-1:2005/CAN/CSA-S16-01:2005), Eurocode 3 (EN 1993-1-1:2005) and Australian /New Zealand (AS4100:1998/NZS3404:1997) standards- Part II: South African Hot-Rolled I- Section

Jean Claude Tchamba[1], Théodore Gautier L. J. Bikoko[2]
[1] *Civil Engineering Laboratory, ENSET, University of Douala,P.O.Box: 1872, Douala, Cameroon*
[2]*School of Civil and Environmental Engineering, University of The Witwatersrand, Johannesburg, South Africa*

Abstract:*Columns are reserve for the main vertical members carrying loads from the roof, beams, floors and the walls in buildings.As an overview, a short, stocky stanchion column fails by squashing or crushing; and for long slender stanchion column failures occur by overall buckling. The capacity/ buckling resistance of a column largely depends on its slenderness, material strength, cross sectional shape and method of fabrications. This paper compares the design buckling resistance (capacity) for a hot-rolled I-steel column section between the South African/Canadian standard (SANS 10162-1:2005/CAN/CSA-S16-01:2005), European code (Eurocode 3) and Australian/New Zealand (AS4100:1998/NZS3404:1997) standard. The results show that by increasing the slenderness ratio of the column section, the design buckling resistance decreases. The differences in capacity between specifications vary with the slenderness ratio of the column. The Eurocode 3 is the most unconservative than SANS 10162-1:2005/CAN/CSA-S16-01:2005 and AS4100:1998/NZS3404:1997 specifications.*

Keywords: *AS 4100:1998/NZS3404:1997,axes convention,design buckling resistance,EN 1993-1-1:2005,SANS 10162: 1-2005/ CAN/CSA-S16-01:2005, slenderness ratio.*

I. Introduction

Columns are usually thought of as straight vertical members whose lengths are considerably greater than their cross-sectional dimensions. An initially straight column, compressed by gradually increasing equal and opposite axial forces at the ends is considered first. Columns are termed "long" or "short" depending on their proneness to buckling. If the column is "short", the applied forces will cause a compressive strain, which results in the shortening of the column in the direction of the applied forces. Under incremental loading, this shortening continues until the column "squashes". However, if the column is "long", similar axial shortening is observed only at the initial stages of incremental loading. Thereafter, as the applied forces are increased in magnitude, the column becomes "unstable" and develops a deformation in a direction normal to the loading axis. The column is in a "buckled" state.

Buckling behaviour is thus characterized by deformations developed in a direction (or plane) normal to that of the loading that produces it. When the applied loading is increased, the buckling deformation also increases. Buckling occurs mainly in members subjected to compressive forces. If the member has high bending stiffness, its buckling resistance is high. Also, when the member length is increased, the buckling resistance is decreased. Thus thebuckling resistance is high when the member is "stocky" (i.e. the member has a high bending stiffness and is short) conversely, the buckling resistance is low when the member is "slender".

Columns and their strength and behaviour constitute a subject area that has received much study and discussion over the years. Experimental and theoretical investigations have been performed to study the interaction of local and overall buckling. The finite element method to analyze the non-linear response of I-sections under axial compression and obtained the interaction buckling loads for them by an overall bifurcation analysis of a locally buckled section.

This paper compares the design buckling resistance (capacity) for a hot-rolled I-steel column section between SANS 10162-1:2005/CAN/CSA-S16-01:2005, Eurocode 3 and AS4100:1998/NZS3404:1997 on the one hand, and on the other hand the axes convention is also compared. The buckling resistance calculation procedures are treated. Illustrative worked example is proposed. Results and discussion are presented, after which conclusions are drawn.

II. Axes Convention

A certain degree of caution must be noted when comparing SANS 10162: 1-2005/ CAN/CSA-S16-01:2005; EN 1993-1-1:2005 and AS 4100:1998/NZS3404:1997, particularly when using section tables.

The convention of naming the axes of a structural member used in South Africa, Canada, Australia, New Zealand and in Europe is different. The differences can be seen in Figure 1 below. In the South African /Canadian /Australian /New Zealand context, the longitudinal axis is the z-z axes, whilst in the Eurocode method, the longitudinal axis is the x-x axes.

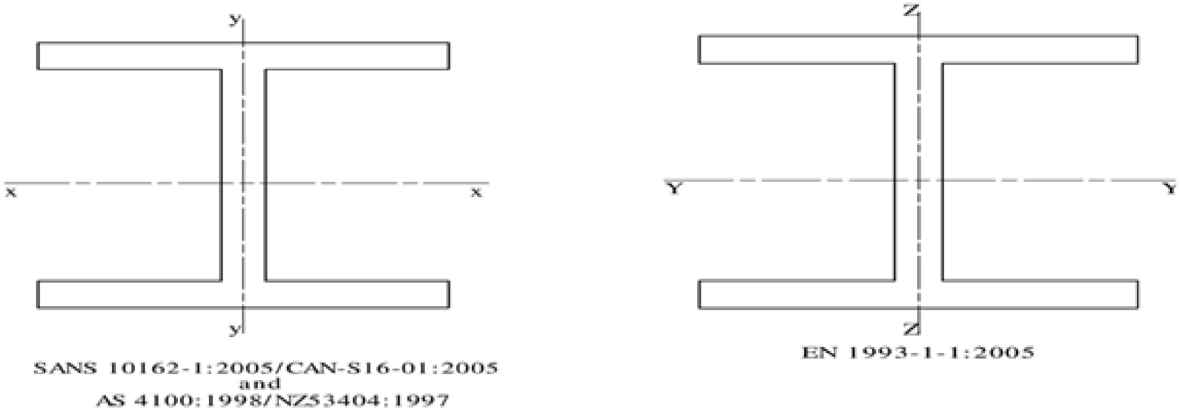

Figure 1: Axes labelling system differences

III. Steel Column Design Buckling Resistance Calculation Procedures

Figure 2 shows the proposed steps required by SANS 10162: 1-2005/ CAN/CSA-S16-01:2005 to calculate the design buckling resistance of the column. Figure 3 shows a flow-chart of the steps required by Eurocode 3. Figure 4 shows the steps required by AS 4100:1998/NZS3404:1997. The approach as well as the steps required differs substantially in these codes. Eurocode 3 requires a much more thorough calculation of the column resistance which turn renders the Eurocode 3 approach much more complex.

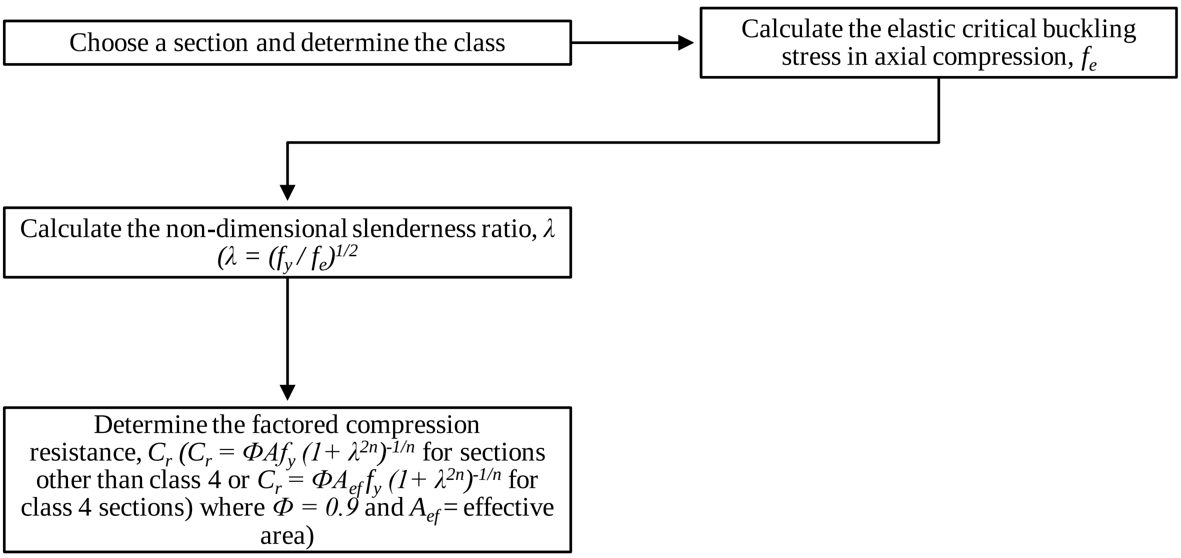

Figure 2: Proposed procedure for calculating column design buckling resistance to SANS 10162: 1-2005/ CAN/CSA-S16-01:2005.

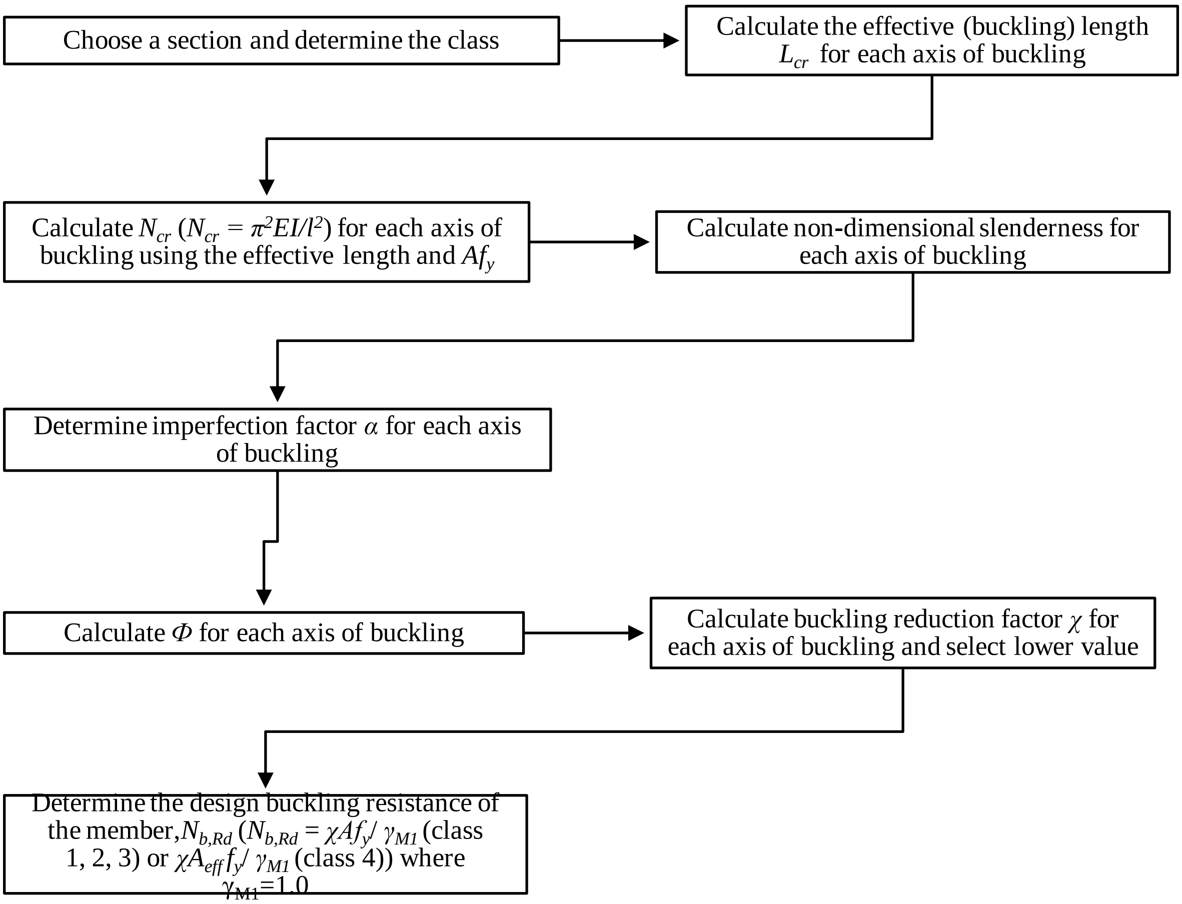

Figure 3: Proposed procedure for calculating column design buckling resistance to Eurocode 3.

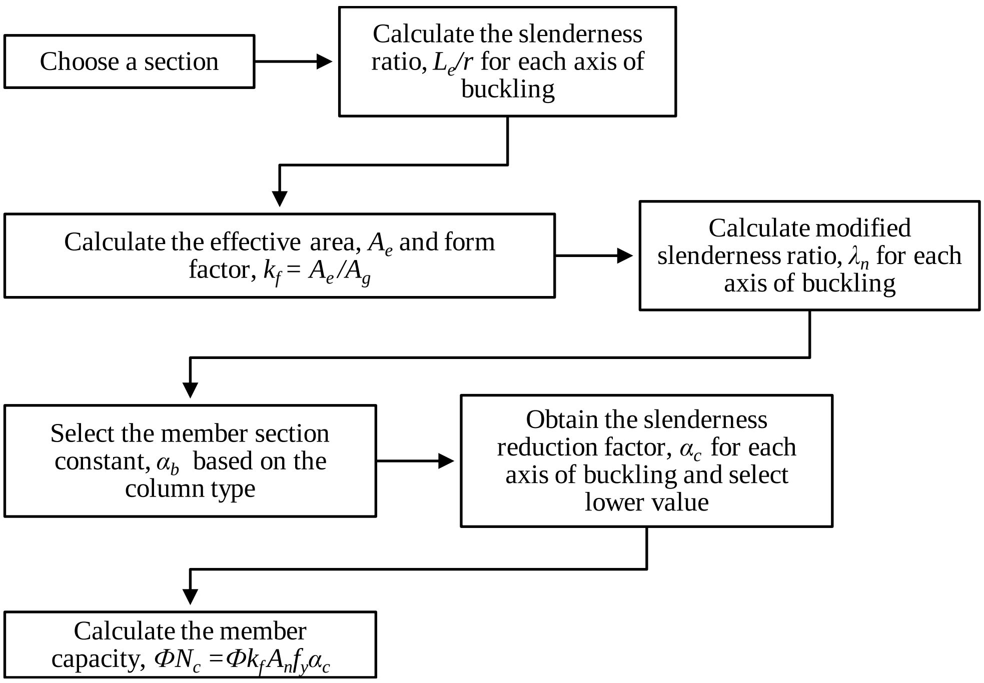

Figure 4: Proposed procedure for calculating column design buckling resistance to AS 4100:1998/NZS3404:1997.

IV. Worked Example

4.1 General

To compare the design compressive resistance between codes it is best to consider same section with same properties;same steel grades;same effective lengths; same modulus of elasticities and same shear modulus.

4.2 Example

Determine the design compressive resistance of a 356x171x67 kg /m I- section in Grade 300W steel. Assume the effective length of 6000mm for buckling about each axis. Take modulus of elasticity E = $200x10^3$ N/mm^2 and shear modulus G = 77000 N/mm^2.

4.3 Solution by SANS 10162: 1-2005/ CAN/CSA-S16-01:2005 Method

Section properties of 356x171x67 UB:
A = $8.55x10^3 mm^2$ h_w =312 mm h=364 mm
b =173.2 mm t_f=15.7 mm t_w =9.1 mm
r_x =151 mm r_y = 39.9 mm J= $560x10^3$ mm^4
I_x =195 $x10^6$ mm^4 I_y =13.6x $10^6 mm^4$ C_w =$413x10^9$ mm^6
Calculation of the elastic critical buckling stress in axial compression (f_e) :
The elastic critical buckling stress in axial compression for x-x and y-y axis flexural buckling are determined, by the following expressions:

$$f_{ex} = \frac{\Pi^2 E}{\left(\frac{KL}{r}\right)_x^2} = 1251 \text{ Mpa} \quad (1)$$

and

$$f_{ey} = \frac{\Pi^2 E}{\left(\frac{KL}{r}\right)_y^2} = 87.3 \text{ Mpa respectively.} \quad (2)$$

where$E$ is the Young's modulus, K the effective length factor, L the actual length of the column and r the radius of gyration about x-x or y-y axis.

$$f_{ez} = \left[\frac{\Pi^2 E\ C_w}{(KL)_z^2} + GJ\right] x \frac{1}{A\bar{r}_o^2} = 315 \text{ Mpa} \quad (3)$$

is the elastic critical buckling stress in axial compression for torsional buckling in which E is the Young's modulus,C_w the warping torsional constant, KL the effective length, G the shear modulus,J St. venant torsional constant, A the area of cross-section and $\bar{r}_o^2$ the polar radius of gyration.

f_e = min{ f_{ex} , f_{ey} , f_{ez} }= 87.3 Mpa (4)

is the elastic critical buckling stress in axial compression.
Therefore the factored compressive resistance of member (C_r) is:

$C_r = \Phi A\, f_y\, (1+ \lambda^{2n})^{-1/n}$ (5)

where$\lambda = \sqrt{\frac{f_y}{f_e}}$ = 1.854; Φ=0.9; A=$8.55x10^3 mm^2$; f_y=300Mpa and n=1.34.

$C_r = 0.9x8.55x10^3 x300x10^{-3} (1+ 1.854^{2.68})^{-1/1.34}$

∴ C_r = 590 KN

4.4 Solution by Eurocode 3 Method

Section properties of 356x171x67 UB:
A = $8.55x10^3 mm^2$ d=312 mm h=364 mm
b =173.2 mm t_f =15.7 mm t_w =9.1 mm
r =10.2 mm I_y =195 $x10^6$ mm^4 I_z =13.6 x 10^6 mm^4
Calculation of reduction factor(χ):
The elastic critical buckling loads for y-y and z-z axis are given by:

$$N_{cr,y} = \frac{\Pi^2 E\ I_y}{L_{cr}^2} = 10700680.27 \text{ N} \quad (6)$$

and

$$N_{cr,z} = \frac{\Pi^2 E\ I_z}{L_{cr}^2} = 746303.85 \text{ N} \quad (7)$$

respectively.

$$\overline{\lambda_y} = \sqrt{\frac{Af_y}{N_{cr,y}}} = 0.48 \quad (8)$$

and

$\overline{\lambda_z}= \sqrt{\frac{Af_y}{N_{cr,z}}} =1.85$ (9)

are the non-dimensional slenderness for major and minor axis respectively.

$\Phi_y = 0.5[1+ \alpha_y(\bar{\lambda}_y -0.2) + \bar{\lambda}_y^2] = 0.65$ (10)

and

$\Phi_z = 0.5[1+ \alpha_z(\bar{\lambda}_z -0.2) + \bar{\lambda}_z^2] = 2.49$ (11)

are values to determine the reduction factor for major and minor axis respectively, where α_y= 0.21and α_z= 0.34are the imperfection factors for major and minor axis respectively.

$$\chi_y = \frac{1}{\Phi_y + \sqrt{\Phi_y^2 - \bar{\lambda}_y^2}} = 0.93 \leq 1 \quad (12)$$

and

$$\chi_z = \frac{1}{\Phi_z + \sqrt{\Phi_z^2 - \bar{\lambda}_z^2}} = 0.24 \leq 1 \quad (13)$$

are the reduction factors for major and minor axis respectively.

$\chi = \min(\chi_y, \chi_z) = 0.24$ (14)

is the reduction factor.

Therefore the design buckling resistance ($N_{b,Rd}$) is:

$N_{b,Rd} = \chi A f_y/\gamma_{M1}$ (15)

for class 1, 2 or 3 cross-sections.

$N_{b,Rd}$ = 0.24x8.55x10^{3}x300/ 1.00=614179.9 N

∴ $N_{b,Rd}$ = 614 KN

4.5 Solution by AS 4100:1998/NZS 3404:1997 Method

Section properties of 356x171x67 UB:

A = 8.55x10^{3}mm^2 d=364 mm t_w =9.1 mm

b_f =173.2 mm t_f =15.7 mm J= 560x10^3 mm^4

r_x =151 mm r_y = 39.9 mm I_x =195 x10^6 mm^4 I_y =13.6x 10^{6}mm^4

Column section is a hot-rolled UB (flange thickness of 15.7 mm) with form factor k_f=1 so from Table of AS 4100:1998/NZS3404:1997, α_b=0.

From Table of AS 4100:1998/NZS3404:1997,α_{cx}= 0.890 (interpolating between values of λ_{nx}= 40 and 45), and α_{cy} = 0.249(interpolating between values of λ_{ny}= 160 and 165).

α_c = min (α_{cx} ,α_{cy}) = min (0.890, 0.249) (16)

∴ α_c = 0.249 where α_c is the member slenderness reduction factor.

Therefore the member capacity (ΦN_c) is:

$\Phi N_c = \Phi k_f A_n f_y \alpha_c$ (17)

ΦN_c = 0.9 x1 x 8.55x10^3 x 300 x 0.249

∴ ΦN = 575 KN

V. Results and Discussion

The section slenderness, slenderness limits and section classification for a rolled I-sectionof each standard/code are listed in Table 1. It indicates that the flange slenderness of the sections in the three standards is very similar. The AS 4100:1998/NZS3404:1997 web slenderness of the sections, flange and web slenderness limits are higher than Eurocode 3 and SANS 10162: 1-2005/ CAN/CSA-S16-01:2005. The web slenderness of Eurocode 3 and SANS 10162: 1-2005/ CAN/CSA-S16-01:2005 are the same.

Table 1: Summary of an I-section slenderness, slenderness limits and section classification.

Standard/ Code	Flange Slenderness	Web Slenderness	Flange Slenderness Limit	Web Slenderness Limit	Section Classification
AS 4100:1998/NZS3404:1997	5.72	40.03	16	45	N/A*
Eurocode 3	4.57	34.38	9.72	36.96	Class 3
SANS 10162: 1-2005/ CAN/CSA-S16-01:2005	5.5	34.3	11.5	38.7	Not Class 4

* Not Applicable

Table 2 shows the comparison results between codes for a 356x171x67 UB for slenderness ratio from 25.06 to 375.93. The positive and negative percentage difference shown in table indicate that applicable standards/code overestimate and underestimate capacity respectively.

Table 2: Summary of differences in capacity between codes for varying slenderness ratios for an I-section. Positive values indicate that applicable standards overestimate member capacity (un-conservative).

	AS 4100:1998 /NZS 3404:1997		**Eurocode 3**		**SANS 10162:1-2005/CAN/CSA-S16-01:2005**	
Slenderness ratio	**ΦN_c(N)**	**% Diff. With EC3**	**$N_{b,Rd}$(N)**	**% Diff. With SANS/CAN***	**C_r (N)**	**% Diff. With AS 4100:1998/NZS 3404:1997**
25.06	2197692	-10.82	2464459	9.21	2237247	1.76
50.12	1929906	-9.12	2123671	9.32	1925744	-0.21
75.18	1530536	-7.32	1651439	10.41	1479520	-3.33
100.25	1101155	-6.47	1177367	8.14	1081532	-1.78
125.31	784890	-6.2	836751.4	5.53	790440.2	0.70
150.4	574816.5	-6.40	614179.9	3.95	589876.7	2.55
175.43	436306.5	-6.54	466878	3.22	451844	3.43
200.5	341658	-6.61	365851.2	2.98	354939.7	3.74
225.56	272403	-7.34	294009.7	3.01	285145.2	4.46
250.62	223924.5	-7.18	241261.8	3.18	233573.8	4.13
275.68	186988.5	-7.18	201457.3	3.42	194557.9	3.89
300.75	159286.5	-6.69	170710.5	3.69	164411.2	3.11
325.81	136201.5	-7.01	146480.9	3.69	140678.3	3.18
350.87	117733.5	-7.33	127055.2	4.22	121684.4	3.24
375.93	101574	-8.7	111245.9	4.48	106260.2	4.41

*SANS 10162:1-2005/CAN/CSA-S16-01:2005

It shows that the differences in capacity between codes vary with the slenderness ratio of the column.

For an I- section the Eurocode 3 values exceeded the SANS 10162-1:2005/CAN/CSA-S16-01:2005 values by about a range of 2%-11 %(See table 2). The difference between SANS 10162-1:2005/CAN/CSA-S16-01:2005 to AS 4100:1998/NZS3404:1997 is minimal and are in the range of 0% -5 %(See table 2). The difference between Eurocode 3 to AS4100:1998/NZS3404:1997 are in the range of 6% -11 %(See table 2). The maximum percentage difference in capacity between Eurocode 3 to AS 4100:1998andNZS3404:1997 is 10.82 %(See table 2) and is occurs at slenderness ratio value of 25.06 (See table 2). The maximum percentage difference in capacity between Eurocode 3 to SANS 10162-1:2005/CAN/CSA-S16-01:2005 is 10.41 %(See table 2) and is occurs at slenderness ratio value of 75.18(See table 2). Eurocode 3 is the most unconservative than SANS 10162-1:2005/CAN/CSA-S16-01:2005 and AS4100:1998/NZS3404:1997.

The curves of figure 5 illustrate the comparison of the column design buckling resistance for varying slenderness ratios ranging from 25.06 to 375.93 of the I- column section. The figure 5 indicates that increasing the column slenderness ratio of each code reduces the column design buckling resistance also the differences in capacity between codes vary with the slenderness ratio of the column.

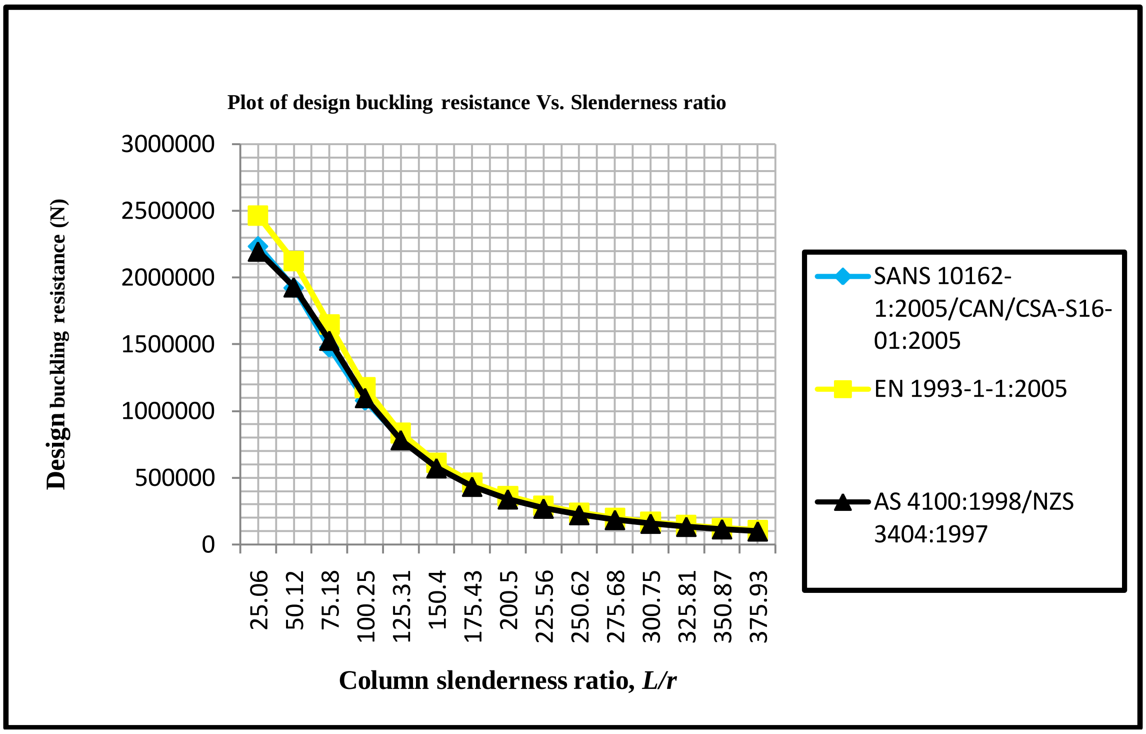

Figure 5: Comparison of an I- steel column section design buckling resistance for varying slenderness ratios.

VI. Conclusions

From this study the following conclusion can be drawn:

1. The Eurocode 3 specification requires a significantly greater calculation effort than that required by AS4100:1998/NZS3404:1997 and SANS 10162-1:2005/CAN/CSA-S16-01:2005 specifications.
2. The differences in capacity between codes vary with the slenderness ratio of the column section.
3. The Eurocode 3 specification is the most unconservative than SANS 10162-1:2005/CAN/CSA-S16-01:2005 and AS4100:1998/NZS3404:1997 specifications.

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Notations

A Area of cross-section
A_e Effective area of cross-section
A_g Gross section area
A_n Net area of cross-section
b Width of a cross-section
b_f Width of a cross-section
C_r Factored compressive resistance of member
C_w Warping torsional constant
d Depth of straight portion of a web
E Elastic modulus of steel
f_e Elastic critical buckling stress in axial compression
f_{ex} Elastic critical buckling stress in axial compression for x-x axis flexural buckling
f_{ey} Elastic critical buckling stress in axial compression for y-y axis flexural buckling
f_{ez} Elastic critical buckling stress in axial compression for torsional buckling
f_y Yield stress
G Shear modulus of steel
h Depth of a cross-section
h_w Depth of straight portion of a web
I_x Moment of inertia about x-x axis
I_y Moment of inertia about y-y axis
I_z Moment of inertia about z-z axis
J St venant torsional constant of a cross-section
k_f Form factor
$K.L$ Effective length
$\frac{K.L}{r}$ Effective slenderness ratio
L_{cr} Buckling length
n Parameter
$N_{b,Rd}$ Design buckling resistance
N_c Nominal compressive capacity of member
$N_{cr,y}$ Elastic critical buckling force for y-y axis
$N_{cr,z}$ Elastic critical buckling force for z-z axis
r Root radius
$\bar{r}_o^2$ Polar radius of gyration
r_x Radius of gyration about x
r_y Radius of gyration about y
t_f Flange thickness
t_w Web thickness
$\overline{\lambda_y}$ Non-dimensional slenderness for major axis
$\overline{\lambda_z}$ Non-dimensional slenderness for minor axis
α_b Member section constant
α_c Member slenderness reduction factor
α_{cx} Member slenderness reduction factor for x-axis
α_{cy} Member slenderness reduction factor for y-axis
α_y EC3imperfection factor for major axis
α_z EC3imperfection factor for minor axis
Φ_y Value to determine the reduction factor for major axis
Φ_z Value to determine the reduction factor for minor axis
χ_y Reduction factor for major axis
χ_z Reduction factor for minor axis
χ Reduction factor
Φ Capacity reduction factor
γ_{M1} Partial factor for member instability
λ_{nx} Modified slenderness ratio for x-axis
λ_{ny} Modified slenderness ratio for y-axis