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Buckling Analysis of Column Made of 4140 Alloy Steel with Different Cross Sections in Fixed Free Condition

G. Panduranga[1], P.Sukumar[2]

[1]*Assistant Professor, Pragati Engineering College, Andhra Pradesh, India*

[2]*Associate Professor, Pragati Engineering College, Andhra Pradesh, India*

Abstract— In this paper the buckling analysis of a 4140 alloy steel with different cross sections like I-section, C-section and T-section is done in a fixed free conditions. Columns are the basic parts of a many engineering structures, they may be aero structures or civil structure or any other mechanical load carrying structures. The columns majorly take the axial loads and try to resist the bending caused due to the applied axial loads. It is to show that the actual application of the axial loading governs the buckling behavior of the column. The critical buckling load is calculated for the three columns with different cross sections according to theoretical formulation. From the critical buckling load calculations, it is observed that the critical buckling load values are different for different cross sections. Conservatively it is taken the minimum load value to do the safe analysis. In this paper the maximum deflections and maximum stresses are compared with the three columns with different channel sections made of same material subjected to same load. The solid models are designed in CATIA V5 tool and the buckling analysis is carried out in ANSYS software.

Keywords—Critical buckling load; CATIA V5 and ANSYS, Channel sections;

I. INTRODUCTION

Alloy steels are generally using as columns in many engineering applications which are subjected to compression and bending loads. The theory of buckling of columns was made early by Euler in 1744. The columns may be failed by buckling when their critical loading is reaching. The buckling may be explained by pressing the opposite faces of a column towards one another. For small amount of loads, the process is a elastic and there is no failure in the structure because there is no buckling displacements after removal of load. But once the load is reaching the critical value we can observe the bulges or waves or ripples commonly encountered in the structure. The buckling analysis of the column can be done by the general formula is

$$P_{cr} = \frac{n\pi^2 EI}{L^2}$$

Here,

P_{cr} = Critical buckling load

n = Factor accounting for the end condition

E = Young's modulus of the material

I = Moment of inertia of cross section of the column

L = Length of the column

The factor accounting for the end condition (n) is depending on the type of the contion of the column. The conditions are four types, they may be the following.

· Column with both the ends fixed

· Column with both the ends hinged

· Column with one end is fixed and other end is hinged

· Column with one end is fixed and other end is free

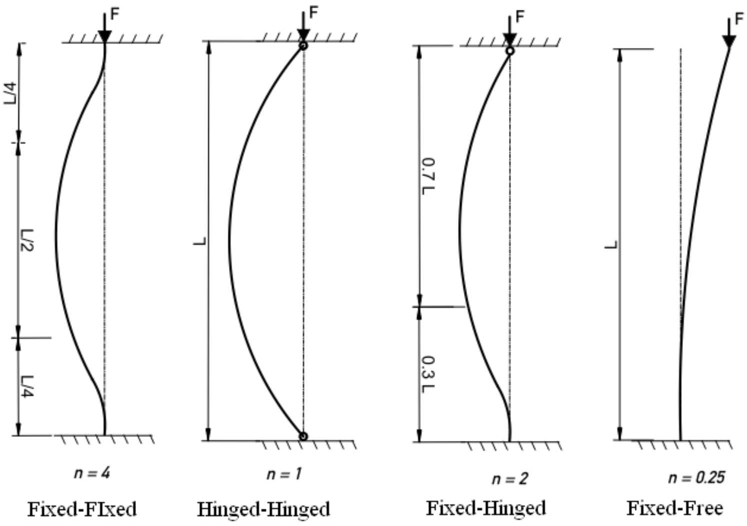

Figure 1: Column with different end conditions

II. MODELING

The modeling of the column is done by using CATIA V5 software. The basic geometry of the Channels for this analysis is given below for each I-section, C-section and T-sections respectively.

2.1 Dimensions of I-Section:

H= web depth =80mm; b = web thickness = 10mm; B = flange width = 80mm;
h = flange thickness = 10mm; L = Length of the column = 300mm;

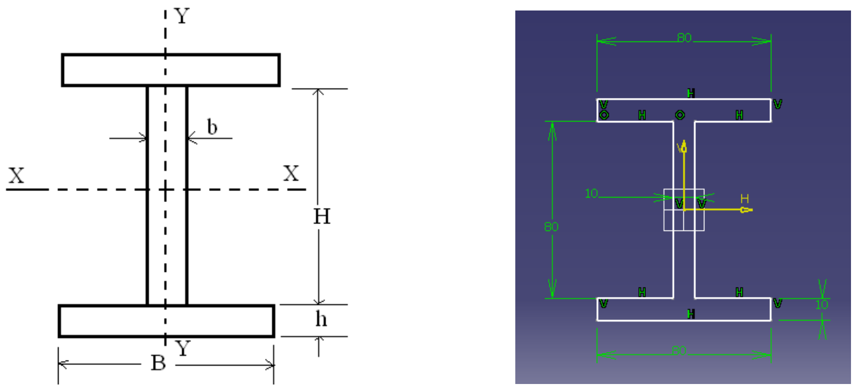

Figure 1: Cross sectional view of the column with I-cross sectional shape

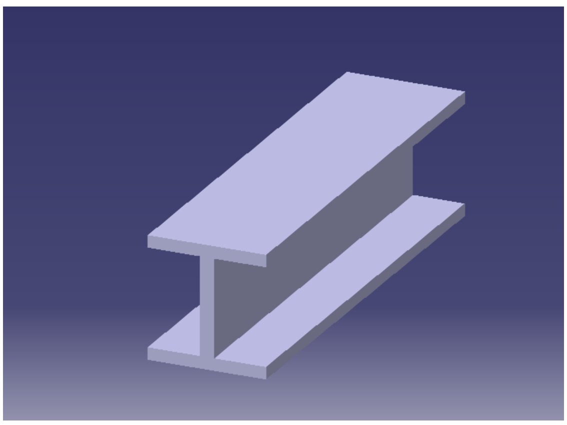

Figure 2: Solid model design of column with I-cross sectional shape in CATIA V5 software

2.2 Dimensions of C-Section:

H= web depth =80mm; b = web thickness = 10mm; B = flange width = 80mm;
h = flange thickness = 10mm; L = Length of the column = 300mm;

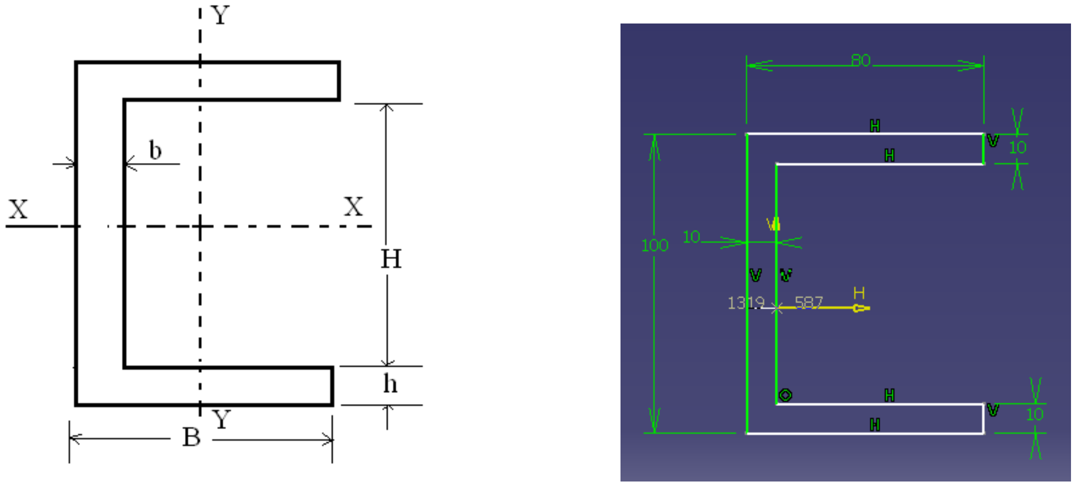

Figure 3: Cross sectional view of the column with C-cross sectional shape

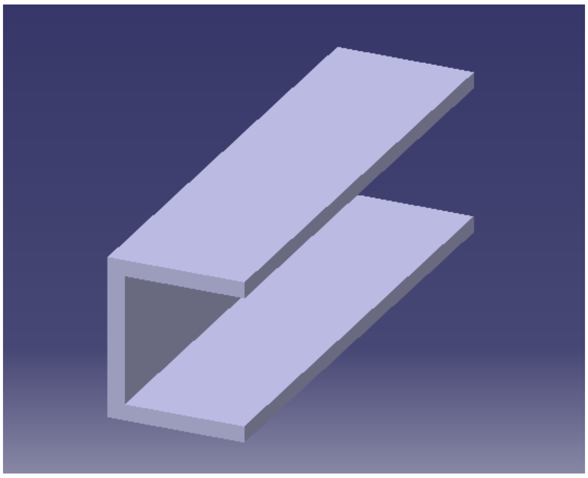

Figure 4: Solid model design of column with C-cross sectional shape in CATIA V5 software

2.3 Dimensions of T-Section:

H= web depth =90mm; b = web thickness = 10mm; B = flange width = 80mm;
h = flange thickness = 10mm; L = Length of the column = 300mm;

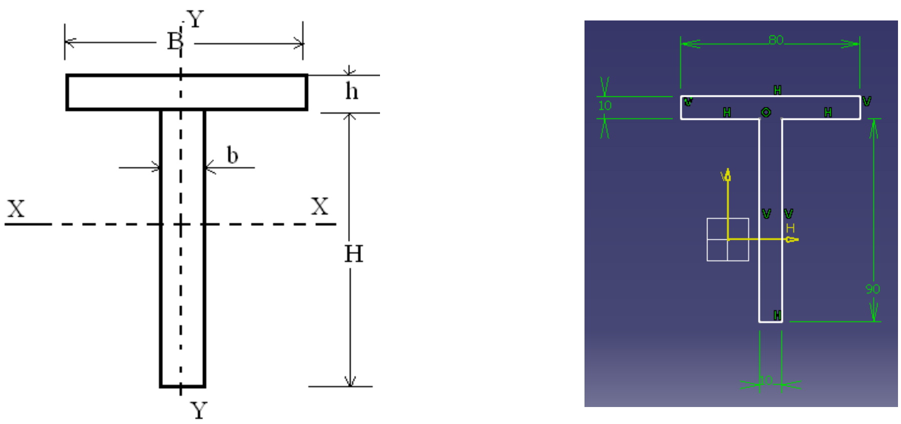

Figure 5: Cross sectional view of the column with T-cross sectional shape

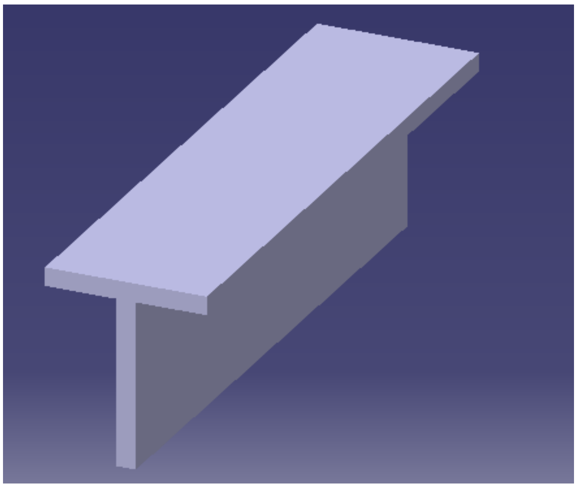

Figure 6: Solid model design of column with T-cross sectional shape in CATIA V5 software

III. CALCULATIONS

3.1 I-Section:

Cross sectional area = A = 2Bh + Hb
= 2*80*10 + 80*10
= 1600+800
= 2400 mm^2

Area moment of inertia about X-X = $I_{XX} = \frac{H^3 b}{12} + 2\left[\frac{h^3 B}{12} + \frac{hB(H+h)^2}{4}\right]$

$= \frac{80^3 * 10}{12} + 2\left[\frac{10^3 * 80}{12} + \frac{10 * 80(80+10)^2}{4}\right]$

= 3680000mm^4

Critical buckling load = $P_{cr} = \frac{\pi^2 EI}{4L^2}$

$= \frac{\pi^2 * 190 * 10^3 * 3680000}{4 * 300^2}$ = 19,149.534KN

3.2 C-Section:

Cross sectional area = A = 2Bh + Hb
= 2*80*10 + 80*10
= 1600+800
= 2400 mm^2

Area moment of inertia about X-X = $I_{XX} = \frac{H^3 b}{12} + 2\left[\frac{h^3 B}{12} + \frac{hB(H+h)^2}{4}\right]$

$= \frac{80^3 * 10}{12} + 2\left[\frac{10^3 * 80}{12} + \frac{10 * 80(80+10)^2}{4}\right]$

= 3680000mm^4

Critical buckling load = $P_{cr} = \frac{\pi^2 EI}{4L^2}$

$= \frac{\pi^2 * 190 * 10^3 * 3680000}{4 * 300^2}$ = 19,149.534KN

3.3 T-Section:

Cross sectional area = A = Bh + Hb
= 80*10 + 80*10
= 1600mm^2

Centre of gravity of the T-section = (x,y) = (40, 68.52)

Area moment of inertia about X-X =$I_{XX} = bH\left(y - \frac{H}{2}\right)^2 + \frac{H^3 b}{12} + hB\left(H + \frac{h}{2} - y\right)^2 + \frac{h^3 B}{12}$

$$= 10 * 90\left(68.52 - \frac{90}{2}\right)^2 + \frac{90^3 * 10}{12} + 10 * 80\left(90 + \frac{10}{2} - 68.52\right)^2 + \frac{10^3 * 80}{12}$$

$= 1672990.25 mm^4$

Critical buckling load = $P_{cr} = \frac{\pi^2 EI}{4L^2}$

$$= \frac{\pi^2 * 190 * 10^3 * 1672990.25}{4 * 300^2} = 8705.702KN$$

Table 1: Calculated values of the three columns

Column with cross section	**Cross section area (mm^2)**	**Moment of Inertia (mm^4)**	**Critical buckling load (KN)**
I-Section	2400	3680000	19,149.53
C-Section	2400	3680000	19,149.53
T-Section	1600	1672990.25	8705.70

The critical buckling load of three columns with different cross sections in fixed free condition is evaluated. The factor for fixed free end condition of the columns is considered is 0.25. The moment of inertias of the columns with cross sections I and C are high compare to the column with cross section T, so that the critical buckling loads of these columns are high. Conservatively a buckling load of 150KN has been taken to analyze the stresses and displacements of the columns to keep the structure safe. The same load is applied to the three columns so that the stress behavior can be easily observed for the respective cross sectional shapes considered.

IV. ANALYSIS

The analysis has been carried out by using ANSYS 14.5 software. The designed solid model of the columns for the three cross sections imported directly from CATIA file which are saved in igs format. The linear buckling analysis is carried out in ANSYS tool by defining the properties of the 4140 alloy steel. The chemical composition and major mechanical properties of the 4140 alloy steel material for the analysis are listed in the Table 2 & Table 3.

Table 2: Chemical composition of 4140 alloy steel

S.NO	**Element**	**Content (%)**
1	Iron, Fe	96.785 - 97.77
2	Chromium, Cr	0.80 - 1.10
3	Manganese, Mn	0.75 - 1.0
4	Carbon, C	0.380 - 0.430
5	Silicon, Si	0.15 - 0.30
6	Molybdenum, Mo	0.15 - 0.25
7	Sulfur, S	0.040
8	Phosphorous, P	0.035

Table 3: Properties of 4140 alloy steel

S.NO	**Property**	**Value**
1	Tensile strength	655 MPa
2	Yield strength	415 MPa
3	Bulk modulus (typical for steel)	140 GPa
4	Shear modulus (typical for steel)	80 GPa
5	Elastic modulus	190-210 GPa
6	Poisson's ratio	0.30
7	Density	7.85 g/cm^3

In the present analysis the columns are fixed at the one end and other end id free. The separate analysis is carried out for each column. The safe load of 100KN is applied at free end of the column and other is constrained. The same is done to the three columns and stresses and displacements are observed. The major thing in this analysis is the observation of stresses in the columns of the same material with different cross sections. The properties like young's modulus (E) 190GPa, Poisson's ratio 0.3 and density 7.85 g/cm^3 have been taken the input material properties in ANSYS.

4.1 Assumptions:

The following are the assumptions considered while doing the analysis.

- The material is isotopic and initially straight
- Self weight of the material is not considered
- The load is acting on the column axial only
- The column will fail in buckling only
- Imperfections in the material is not considered

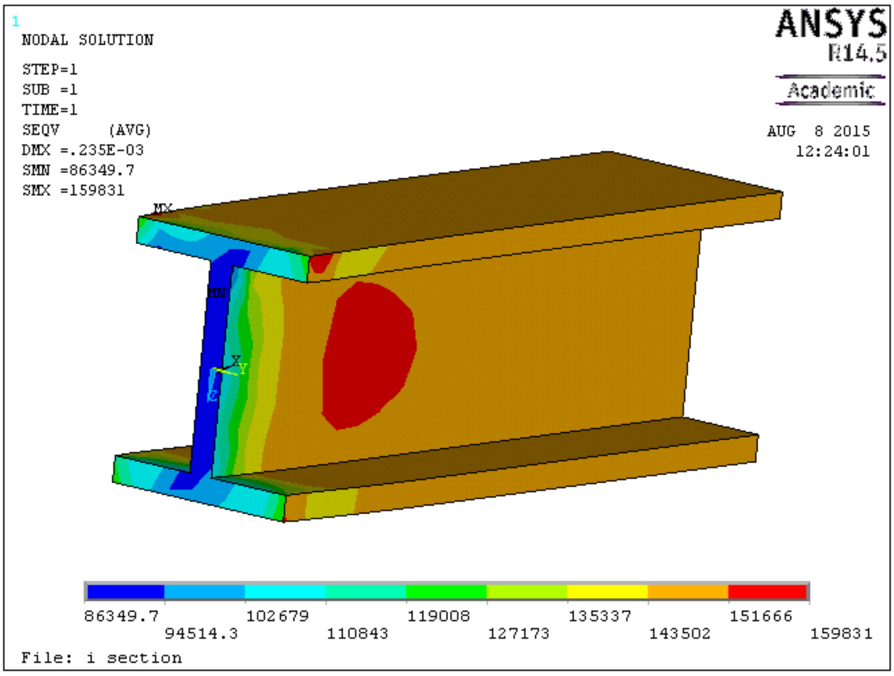

Figure 7: Stress contour for the I-section column

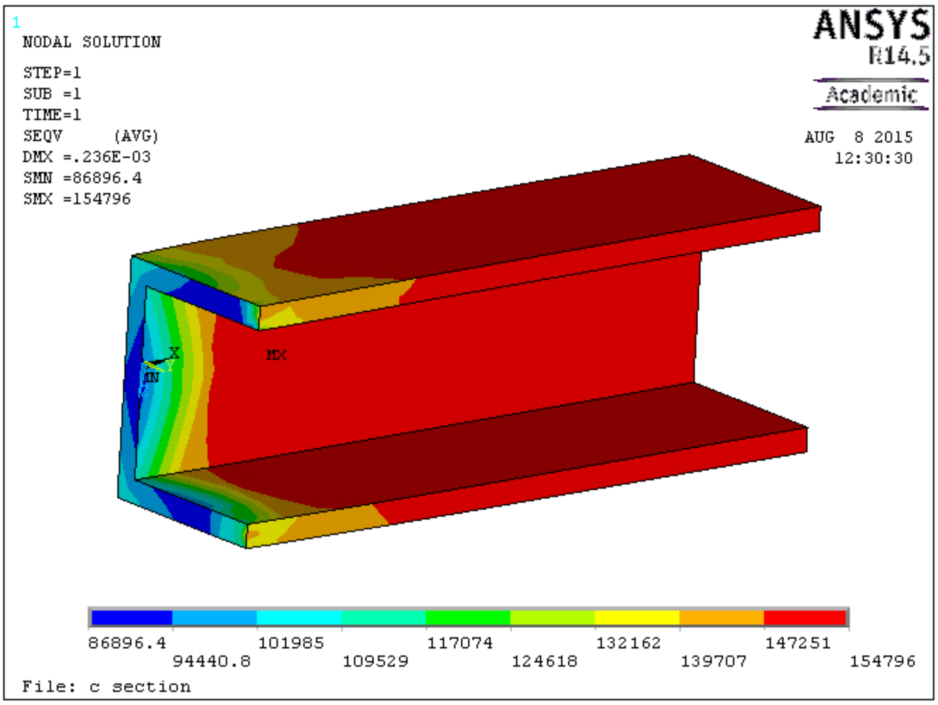

Figure 8: Stress contour for the C-section column

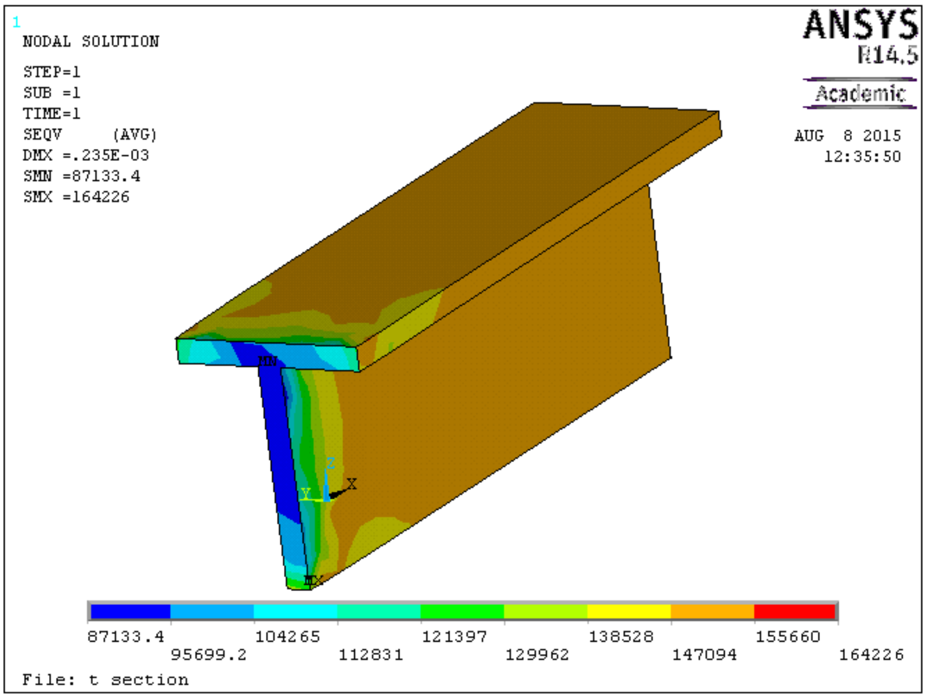

Figure 9: Stress contour for the C-section column

V. RESULTS AND DISCUTIONS

Table 4: Stresses and displacements of the column with different cross sections in fixed free condition

S.NO	Column with	Buckling	Maximum	Maximum

	cross section	Load Applied (KN)	Stresses (KPa)	Displacements (m)
1	I-Section	100	159.83	0.235E-3
2	C-Section		154.79	0.236E-3
3	T-Section		164.22	0.235e-3

From the above results, when a load of 100KN is applied axially to the columns with different cross sections in fixed free condition. it has been seen that the column having the cross section T, experienced the more stresses (164.22 KPa) compare to other two. The displacements in all columns are almost equal and the maximum stresses in the columns with cross section I (159.83KPa) and C (154.79KPa) are near to equal.

VI. CONCLUSIONS

The buckling analysis of the columns with cross sectional shapes I, C and T in fixed free conditions are successfully completed. The critical buckling loads of each column made with same material are calculated by using Euler's equation. To keep the structure safe the conservative buckling load is considered which is lesser than the calculated critical loads. This conservative load is applied to all the columns axially and compared the results by using ANSYS. The maximum stress is observed in case of the column with T-cross section. The displacements in all the columns are almost equal. The stresses developed in the columns of I-cross section and C-cross sections are near to equal. The maximum stress induced in the column with cross section T is less than the allowable yield stress of the material. The cross section and volume of the T-cross sectional column is less than the other two members so that it consumes the less material to manufacture.

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