Finite Element Investigation of Stress, Deformation and Displacement of I Section and C Section Steel Columns

DR. PETER C OKOYE[1], OLAGUNJU SURAJI J[2], AZODOH KINGSLEY A[3], EWURUM TENNISON I[4]

[1, 3, 4] *Department of Mechanical Engineering, School of Engineering Technology, Federal Polytechnic Nekede, Owerri, Nigeria*

[2] *Department of Metallurgical and Material Engineering, School of Engineering Technology, Federal Polytechnic Nekede, Owerri, Nigeria*

Abstract- The study, Finite element investigation of stress, deformation and displacement of I section and C section steel columns was successfully carried out. Researchers created a model of I section column with 5mm×10mm for both top and bottom flanges and 5mm × 30mm for central member. Similarly, C section column model was also created with 5mm×10mm for the two end attachments and 5mm×10mm for main member. Both columns retained a vertical height of 40mm, with assigned material being Steel Alloy. Each of the columns was subjected to top compressive load of 20 kN, with the base to fixed constraints and simulation was run using finite element analysis software. Von Mises stress was found to be 14581MPa for I section column and 16030MPa for C section column. Since, yield strength of the assigned material is 250 MPa, it suggested that failure of column due to yielding is possible under the given conditions and would be more predominant when C section column is used. Also, the 3rd principal stress for the I section column was 15MPa and 311MPa for C section column. These results indicated that induced stress due to compressive loading is higher in C section column. In addition, maximum stresses induced in columns were found to be 5115MPa for I section and 4346MPa for C section. Since, the maximum compressive stress of structural steel material is 320MN/m2, therefore I section column would experience failure faster compare to C section column under the given conditions. Furthermore, Maximum deformations/strains induced in columns were found to be 0.03244 for I section and 0.02756 for C section. Therefore I section column would experience failure faster compare to C section column under the given conditions. Maximum displacements were observed to be 1.018mm for I section column and 0.2211mm for C section column. These results suggested that the I section column showed lower stability with lower safety factor of 15ul. C section column showed higher stability with safety factor of 16.38927ul.

Indexed Terms- Stress, Deformation, Displacement, Finite element analysis, I section column, C section column

I. INTRODUCTION

Machine parts or structural support members in vertical positions, carrying loads are known as columns. Steel column is a vertical structural member used in construction to provide essential support. They can carry compression loads, bending moments or transmit loads from beams, ceilings, floor slabs to floors or foundation. The failure of such member, column will be due to pure compression, buckling or a combination of both depending upon a slenderness ratio, the ratio of unsupported length of column and radius of gyration of column (Rajput, 2008).

Samadhan et al (2015) explained that I section column is most suitable cross section since it offers more moment of inertia, higher compressive strength with higher section modulus and therefore provides better lateral stability when compare to C section. Although, use of C section column lower project cost.

Finite element analysis here involves the use of simulation to predict and understand stress, deformation and displacement of I section and C section columns under severe load applications of turning moment and constraints. Finite element uses finite element method, which is a numerical technique that cuts the structure of the column into several elements and then reconnects the elements at point called nodes.

Khurmi and Gupta (2014) stated that the principal stress are maximum and minimum value of normal stresses on a plane, 1^{st} principal stress represents stress due to tensile loading whereas 3^{rd} principal stress represents stress due to compressive loading. Stress is force per unit cross sectional area and it induces strain (deformation) and displacement.

Yi Zhu and Tim (2007) stated that the maximum compressive stress of structural steel material is 320MN/m2 and it was found that the use of circular hollow section column was a reasonably good predictor of capacity of slender sections and the deformation capacity of compact sections. Hence, the paper aimed at studying finite element investigation of stress, deformation and displacement of I section and C section steel columns.

II. METHODOLOGY

The researchers created a model of I section column with 5mm×10mm for both top and bottom flanges and 5mm × 30mm for central member. Similarly, C section column model was also created with 5mm×10mm for the two attachments and 5mm×10mm for main member. Both columns retained a vertical height of 40mm, with assigned material being Steel Alloy, as shown in Fig 1.0 and Fig 2.0. The model was prepared with the aid of inventor software and imported to; Finite Element Analysis software where stress, deformation and displacement were predicted. Each of the columns was subjected to top compressive load of 20 kN, with the base to fixed constraints. Results were generated and compared to determine the best column sections.

III. MESHING

Meshing was used to divide the column model into section with nodes of 2019 and elements of 1122 for I section column; nodes of 1313 and elements of 717 for C section column. Increasing the number of elements, means more computations and more mathematical formula for the element. Hence, the more precise the results would be. Mesh settings used is shown below in table 1 and table 4.

IV. TABLES AND FIGURES

Table 1: Mesh settings and general objective and settings for I section Column

Design Objective	Single Point
Study Type	Static Analysis
Last Modification Date	9/19/2023, 2:40 AM
Detect and Eliminate Rigid Body Modes	No
Avg. Element Size (fraction of model diameter)	0.1
Min. Element Size (fraction of avg. size)	0.2
Grading Factor	1.5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes
Part Number	I SECTION COLUMN
Designer	EWURUM TENNISON
Cost	$70.00
Date Created	9/19/2023

Table 2: Physical and Material Properties for I section Column

Material	Steel, Alloy	
Density	7.73 g/cm^3	
Mass	0.06184 kg	
Area	4000mm^2	
Volume	8000 mm^3	
Center of Gravity	x=-2.5 mm y=0 mm z=0 mm	
Name	Steel Alloy	
General	Mass Density	7.73 g/cm^3
	Yield Strength	250MPa

	Ultimate Tensile Strength	400MPa
Stress	Young's Modulus	205 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	78.8462 GPa
Part Name(s)	I SECTION COLUMN	

Table 3: Model Operating Conditions

Load Type	Compressive Force
Magnitude	20,000 N
Vector X	0.000 N mm
Vector Y	-20,000 N mm
Vector Z	0.000 N mm

Table 4: Mesh settings and general objective and settings for C section Column

Design Objective	Single Point
Study Type	Static Analysis
Last Modification Date	9/19/2023, 3:16 AM
Detect and Eliminate Rigid Body Modes	No
Avg. Element Size (fraction of model diameter)	0.1
Min. Element Size (fraction of avg. size)	0.2
Grading Factor	1.5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes
Part Number	C SECTION COLUMN
Designer	EWURUM TENNISON
Cost	$55.00
Date Created	9/19/2023

Table 5: Physical and Material Properties for C section Column

Material	Steel, Alloy	
Density	7.73 g/cm^3	
Mass	0.03865 kg	
Area	2650mm^2	
Volume	5000 mm^3	
Center of Gravity	x=2.5 mm y=0 mm z= -0.5 mm	
Name	Steel Alloy	
General	Mass Density	7.73 g/cm^3
	Yield Strength	250MPa
	Ultimate Tensile Strength	400MPa
Stress	Young's Modulus	205 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	78.8462GPa
Part Name(s)	C SECTION COLUMN	

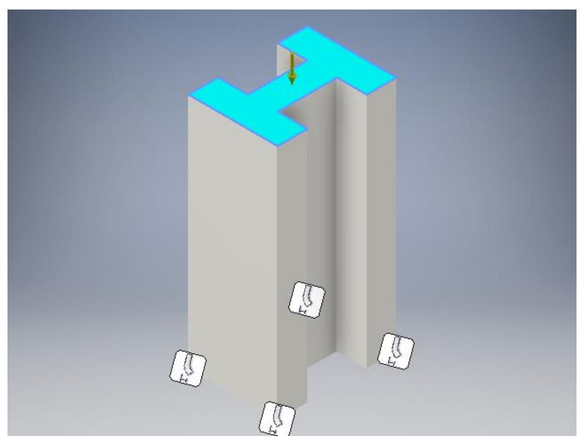

Fig 1.0(a): I section Column with Constraints and Force

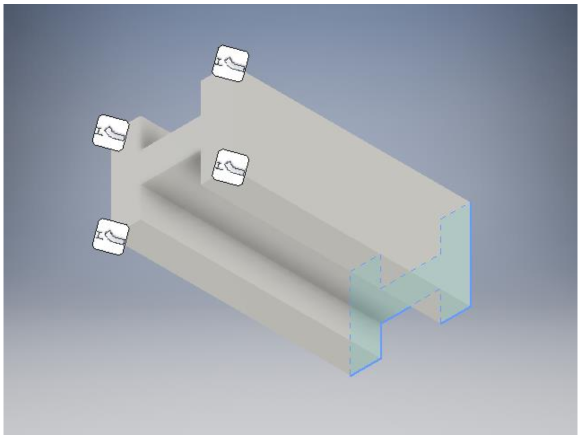

Fig 1.0(b): I section Column with Constraints and Force

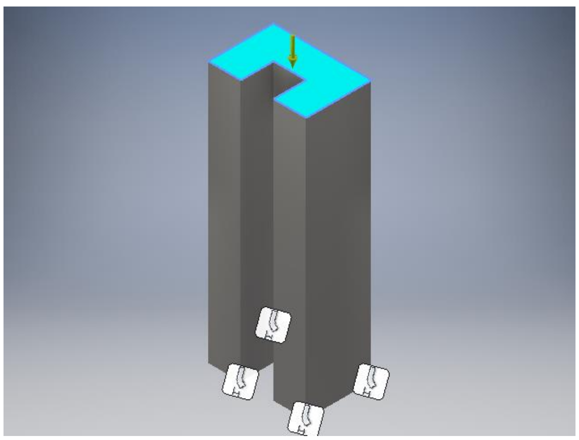

Fig 2.0(a): C section Column with Constraints and Force

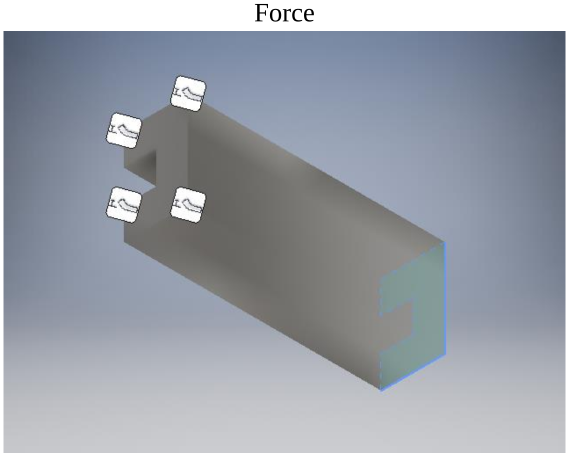

Fig 2.0(b): C section Column with Constraints and Force

V. EQUATIONS

The stress components in an element are given as below.

$$(\sigma_x)_n = \frac{E}{(1+v)(1-2v)}[(1-v)a_n + ve_n] \ldots..(1)$$

(Onyenobi et al., 2022)

$$(\sigma_y)_n = \frac{E}{(1+v)(1-2v)}[va_n + (1-v)e_n] \ldots..(2)$$

$$(\tau_{xy})_n = \frac{E}{2(1+v)}(b_n + d_n) \ldots..(3)$$

$v = Poisson's\ ratio, E = modulus\ of\ elasticity$

The displacement field is shown below.

$$a_n = \frac{\partial u_n}{\partial x} \ \ldots(4)$$

$$e_n = \frac{\partial v_n}{\partial y} \ \ldots(5)$$

$$b_n + d_n = \frac{\partial u_n}{\partial y} + \frac{\partial v_n}{\partial x} \ldots.(6)$$

$v\ and\ u\ are\ velocity\ components\ of\ x\ and\ y$

The principal strains are given below

$e_x = \frac{1}{E}\left[\sigma_x - \frac{1}{m}(\sigma_y + \sigma_z)\right] \ldots..(7)$ (Rajput, 2008).

$$e_y = \frac{1}{E}\left[\sigma_y - \frac{1}{m}(\sigma_x + \sigma_z)\right] \ldots..(8)$$

$$e_z = \frac{1}{E}\left[\sigma_z - \frac{1}{m}(\sigma_x + \sigma_y)\right] \ldots..(9)$$

Von Mises Stress can be given as below.

$$Von - mises\ stress = \sqrt{{\sigma_x}^2 - \sigma_x\sigma_y + {\sigma_y}^2} \ldots. (10)$$

The critical buckling load of column is given in the equation below

$P_C = \frac{\pi^2 EI}{(L_e)^2}$ ……..(11)

$L_e = Effective\ length\ of\ column, E = modulus\ of\ elasticity$

I = Moment of inertia of column

VI. RESULTS

The following results were gotten when simulation was run in finite element software.

Table 6: Reaction Force and Moment on Constraints for I Section

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Fixed Constraint :1	20000 N	0 N	0 N m	0 N m
		20000 N		0 N m
		0 N		0 N m

Table 7: Reaction Force and Moment on Constraints for C Section

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	Component (X,Y,Z)	Magnitude	Component (X,Y,Z)
Fixed Constraint :1	20000 N	0 N	26.9277 N m	10.0034 N m
		20000 N		0 N m
		0 N		-25.0006 N m

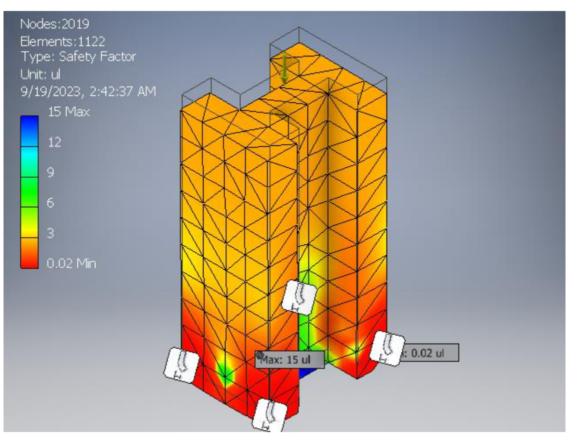

Fig 3: Safety Factor for I Section Column

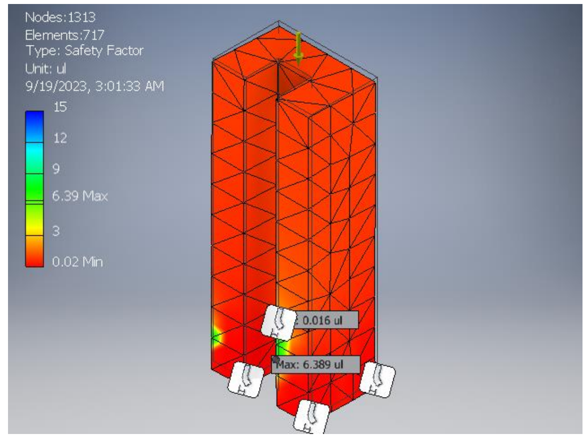

Fig 4: Safety Factor for C Section Column

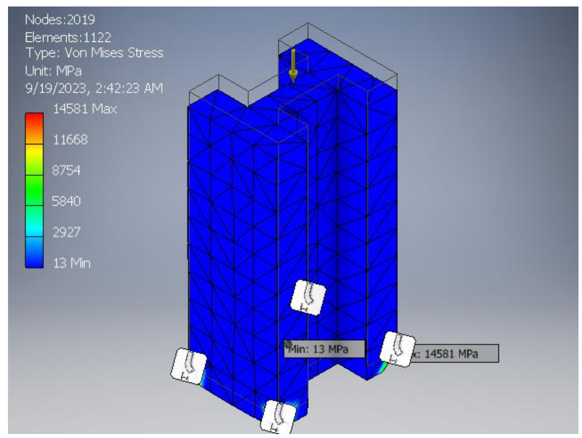

Fig 5: Von Mises Stress for I Section Column

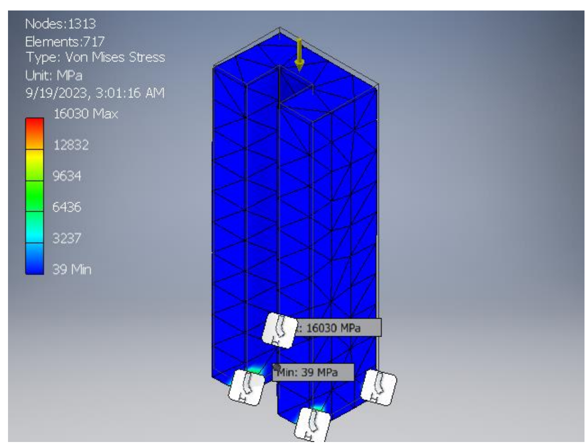

Fig 6: Von Mises Stress for C Section Column

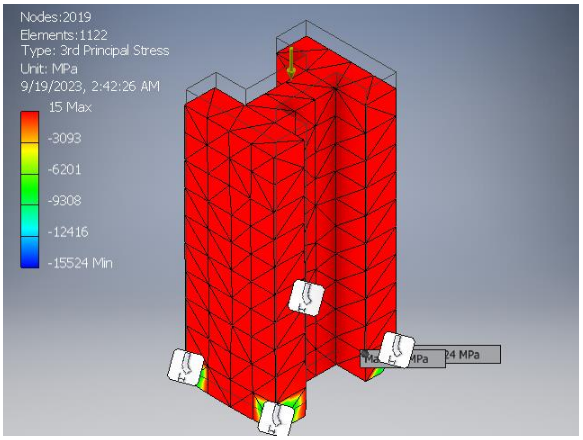

Fig 7: 3rd Principal Stress for I Section Column

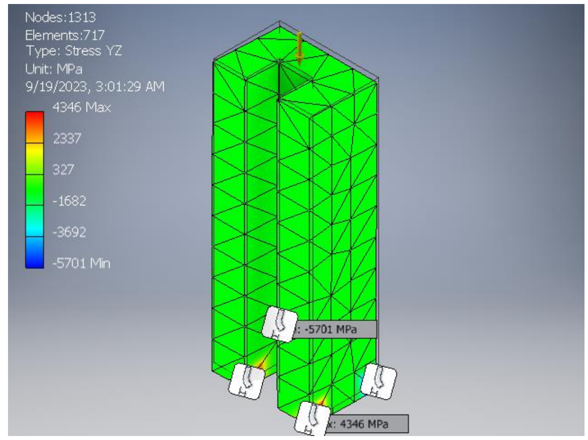

Fig 10: Maximum Stress for C Section Column

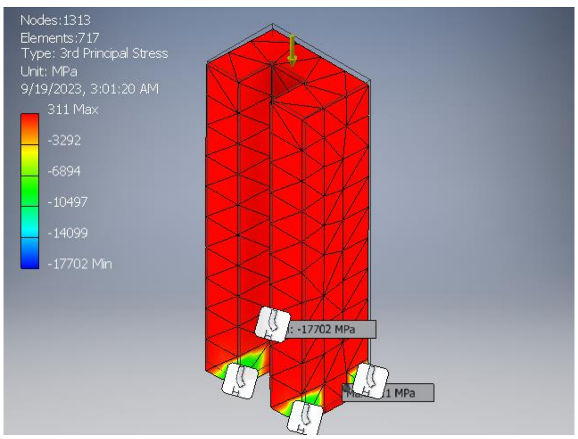

Fig 8: 3rd Principal Stress for C Section Column

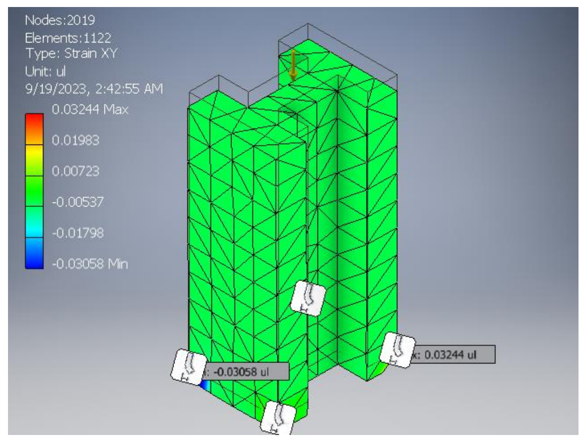

Fig 11: Maximum Deformation for I Section Column

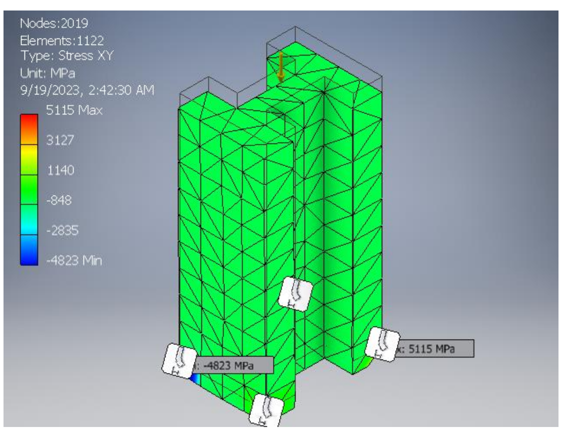

Fig 9: Maximum Stress for I Section Column

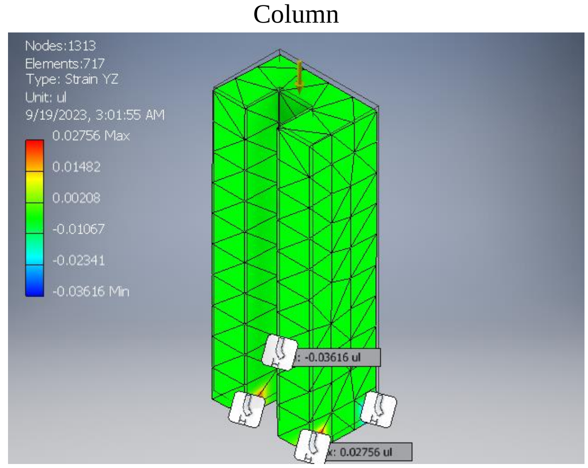

Fig 12: Maximum Deformation for C Section Column

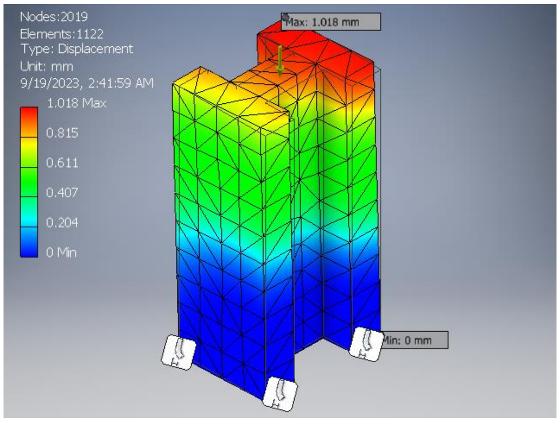

Fig 13: Maximum Displacement for I Section Column

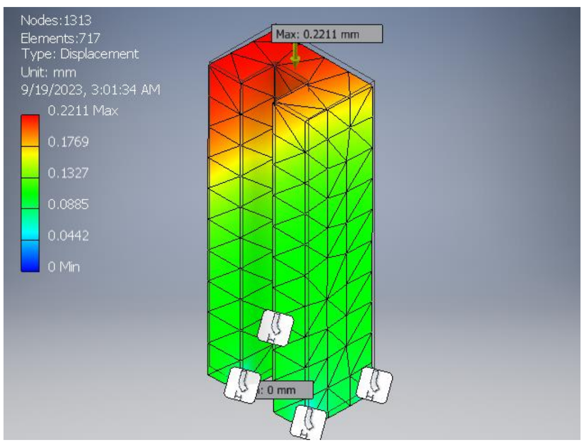

Fig 14: Maximum Displacement for C Section Column

Table 8: Output Summary for C Section Column

Name	Minimum	Maximum
Volume	5000 mm^3	
Mass	0.03865 kg	
Von Mises Stress	39.1281 MPa	16030.1 MPa
1st Principal Stress	-1101.17 MPa	2900.96 MPa
3rd Principal Stress	-17701.8 MPa	310.978 MPa
Displacement	0 mm	0.221143 mm
Safety Factor	0.0155957 ul	16.38927 ul
Stress XX	-5438.42 MPa	671.935 MPa
Stress XY	-5672.26 MPa	3261.16 MPa
Stress XZ	-2259.83 MPa	307.083 MPa
Stress YY	-15369.8 MPa	420.695 MPa
Stress YZ	-5701.39 MPa	4346.46 MPa
Stress ZZ	-4891.03 MPa	839.413 MPa
X Displacement	-0.117769 mm	0 mm
Y Displacement	-0.173129 mm	0 mm
Z Displacement	-0.101178 mm	0.0187614 mm
Equivalent Strain	0.000174221 ul	0.0704694 ul
1st Principal Strain	0.0000758239 ul	0.0248246 ul
3rd Principal Strain	-0.081254 ul	-0.0000471091 ul
Strain XX	-0.0168322 ul	0.0141893 ul
Strain XY	-0.0359704 ul	0.0206805 ul
Strain XZ	-0.0143306 ul	0.00194735 ul
Strain YY	-0.06673 ul	0.00243206 ul
Strain YZ	-0.0361552 ul	0.0275629 ul
Strain ZZ	-0.0144723 ul	0.0141918 ul

Table 9: Output Summary for I Section Column

Name	Minimum	Maximum
Volume	8000 mm^3	
Mass	0.06184 kg	
Von Mises Stress	11.2369 MPa	26874.8 MPa
1st Principal Stress	-1085.51 MPa	3752.62 MPa
3rd Principal Stress	-29035.8 MPa	108.831 MPa
Displacement	0 mm	1.01836 mm
Safety Factor	0.0093024 ul	15 ul
Stress XX	-7070.45 MPa	960.443 MPa
Stress XY	-9339.04 MPa	2631.14 MPa
Stress XZ	-114.122 MPa	2573.17 MPa
Stress YY	-24030.1 MPa	2593.05 MPa
Stress YZ	-1454.09 MPa	9335.5 MPa
Stress ZZ	-6509.44 MPa	651.035 MPa
X Displacement	-0.899583 mm	0.00538015 mm
Y Displacement	-0.421207 mm	0.0311788 mm
Z Displacement	-0.345338 mm	0.0272821 mm
Equivalent Strain	0.0000475065 ul	0.117782 ul

1st Principal Strain	0.0000286228 ul	0.0463171 ul
3rd Principal Strain	-0.134738 ul	-0.0000409241 ul
Strain XX	-0.0153435 ul	0.0326641 ul
Strain XY	-0.0592232 ul	0.0166852 ul
Strain XZ	-0.000723704 ul	0.0163177 ul
Strain YY	-0.104363 ul	0.0115298 ul
Strain YZ	-0.00922107 ul	0.0592008 ul
Strain ZZ	-0.00541095 ul	0.0173436 ul

DISCUSSION

Finite element investigation of stress, deformation and displacement of I section and C section steel columns was achieved. Researchers created a model of I section column with 5mm×10mm for both top and bottom flanges and 5mm × 30mm for central member. Similarly, C section column model was also created with 5mm×10mm for the two attachments and 5mm×10mm for main member. Both columns retained a vertical height of 40mm, with assigned material being Steel Alloy, as shown in Fig 1.0 and Fig 2.0.

Each of the columns was subjected to top compressive load of 20 kN, with the base to fixed constraints and simulation was run using finite element analysis software. According to Fig 5.0 and Fig 6.0, results showed that the Von Mises stress was found to be 14581MPa for I section column and 16030MPa for C section column. Since, yield strength of the assigned material is 250 MPa, it suggested that failure of column due to yielding is possible under the given conditions and would be more predominant when C section column is used.

According to Fig 7.0 and Fig 8.0, the 3rd principal stress for the I section column was 15MPa and 311MPa for C section column. 3rd principal stress represents stress due to compressive loading. These results indicated that induced stress due to compressive loading is higher in C section column. Also, maximum stresses induced in columns were found to be 5115MPa for I section and 4346MPa for C section. Since, the maximum compressive stress of structural steel material is 320MN/m2, therefore I section column would experience failure faster compare to C section column under the given conditions. Similarly, According to Fig 11.0 and Fig 12.0, maximum deformations/strains induced in columns were found to be 0.03244 for I section and 0.02756 for C section. Therefore I section column would experience failure faster compare to C section column under the given conditions.

Fig 13.0 and Fig 14.0 showed that the maximum displacements were observed to be 1.018mm for I section column and 0.2211mm for C section column. These results suggested that the I section column showed lower stability with lower safety factor of 15ul. C section column showed higher stability with safety factor of 16.38927ul.

CONCLUSION

According to the findings, it can be deduced that failure due to stress, deformation and displacement increases in I section columns rather than C section columns. Hence, C section column should be used when higher stability is required.

RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) Use of C section column might reduce stress, deformation and maximize stability.
2) Column material must have higher compressive strength rather than tensile strength, since failure due to compressive stress is predominant.
3) This research could also be done in future using different column design, sizes, loads and other advanced software for generalization.

REFERENCES

[1] Khurmi, R.S & Gupta, J.K. (2014). *Strength of Materials.* New Dehi: Khanna Publishers.

[2] Mohamed, N., Moey, L.K., Ibrahim, A. A., Yazdi, M.H. & Merdji, A. (2022). Stress Analysis of Various Designs of Centrifugal Pump Impellers Using Finite Element Method.

Journal of Engineering and Technological Advances7(1).

[3] Olewuezi, E.C., Gaven, D. V., Oparanozie, G.U., Ahaotu, R. O., & Ewurum, T.I. (2022). Linear Regression Modeling of Induced Stress and Displacement along a Pipeline Due to Fluid Weight: Matlab Approach. *International Journal of Advances in Engineering and Management 4(7), pp. 684-689.*

[4] Rajput, R. K. (2008). *Strength of Materials.* New Dehi: S. Chand Technical Publishers.

[5] Samadhan, G. M & Laxmikant, M. G. (2015). Analysis of Steel I-Beams with Rectangular Web Openings: Experimental and Finite Element Investigation. *Journal of Engineering Structures and Technologies. http://www.researchgate.com*

[6] Yi Zhu, W & Tim. (2007). Finite Element Analysis of Structural Steel Elliptical Hollow Sections in Compression. *School of Civil Engineering Centre for Advanced Structural Engineering. http://www.civil.usyd.edu.au*