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Buckling Analysis of Columns

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Abstract: *Column is a vertical structural member in a building frame having its longitudinal dimension exceeds the lateral dimension of the section. The failure modes of column include compression failure for short column, buckling failure for long columns. Column buckling is a unique and inquisitive focus in the area of structural mechanics with which the failure is not related to its strength of the material. The strength of compression members made of any cross-sectional dimensions depends on their slenderness ratio. The buckling analysis is to determine the maximum critical load that the column can support before it collapses. This paper aims to investigate the buckling analysis of varying cross-sectional dimensions of the column with its critical load carrying capacity. The critical load capacity causes elastic instability of a column with varying length and varying cross-sectional dimensions. The critical load solution was determined with Euler's buckling load theory and the theoretical results were compared with simulation studies using ANSYS 19.2 finite element analysis software.*
Keywords: *Column, Euler's buckling load theory, buckling analysis, Elastic instability*

I. Introduction

Columns are used as a major element to support trusses, building frames and sub-structure supports for bridges to support compressive loads from roofs and transmit vertical forces to subsoil [1]. Based on the length to lateral dimension, the columns are classified as short and long column. A long column buckles along with a minimum lateral dimension under smaller axial compressive load than a short column [2]. Even though it is a main structural component which significantly affect the building's overall stability and performance. The failure of the column is hence catastrophic and leads to collapse of the entire structure. The safety factors to be ensured include material irregularities, boundary conditions, construction inaccuracies, workmanship and unavoidable eccentric loading. The failure modes involve yielding or crushing (material) and buckling failure (structural) for short and long columns as shown in Fig.1. Therefore, in the present work, analysis of a column is carried out with varying length and varying cross-section along the height of the column to achieve better rigidity or stiffness of the column. The analysis is carried out by ANSYS software for one end is fixed and other ends free condition and results are validated by Euler's theory for long columns.
There are different cross-section of columns, some of them are:
a) A column of I-section at 200mm
b) A column of Rectangle at 200mm
c) A column of Square at 275mm
d) A column of circle at 300mm dia

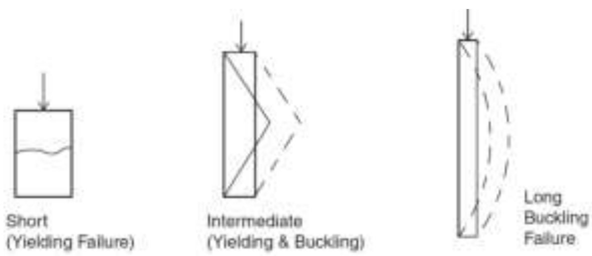

Fig. 1 Modes of failure of columns

1.1. Buckling of column

Buckling is described as a sudden large deformation in a column in which the member is subjected to a slight increase in existing load. A buckling analysis is significant for axial loaded members because the subjected compressive stress at the point of failure is less than the material ultimate compressive stress [3]. The failure of elastic instability of a structure and this type of failure is called buckling. The buckling occurrence may be illustrated using a wooden or metal scale with a compressive load applied at its ends. The consideration only for the material stress level is not to predict the behaviour of such a member [4]. Linear buckling analysis is also called as Eigenvalue buckling or Euler's buckling which involves theoretical prediction of buckling strength of an elastic structure, whereas non- linear buckling analysis predicts more realistic results as shown in Fig. 2. As a result, special consideration is essential for the compressive load and the geometry when designing axial loaded compressive members in order to confirm failure will not occur from elastic instability. The flexural buckling is independent of torsional effect of columns with bisymmetric cross section [5]. This paper determines the critical load of an axial loaded column with varying cross sectional dimensions by buckling analysis using Finite Element Analysis software ANSYS 19.2 and evaluate the results with Euler's theoretical critical buckling load for accuracy. The axial load and different cross section of the columns are made of structural steel. It should be noted that the column is fixed at its one end and is free to deflect at its tip while a load P is applied.

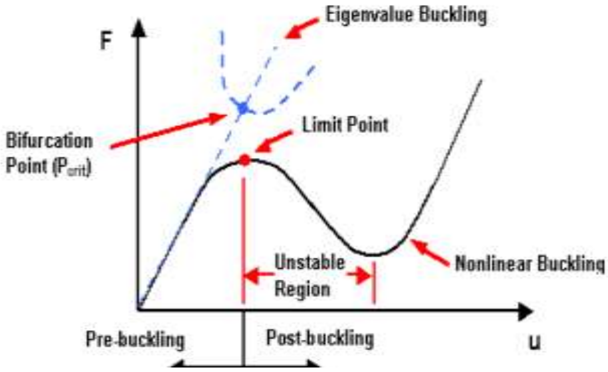

Fig. 2 Linear and Non-Linear Buckling

1.2 Effect of Local Buckling

Local buckling has the significance of reducing the load carrying capacity of columns due to the reduction in strength and stiffness of the locally buckled plate elements. Hence it is desirable to avoid local buckling before yielding of the member. Most of the hot rolled steel sections have sufficient wall thickness to eliminate local buckling before yielding. However, fabricated sections and thin-walled cold-formed steel members generally experience local buckling of plate elements before the yield stress is reached. Local buckling involves deformation of the cross-section in compression members as shown in Fig. 3. There is no shift in the position of the cross-section as an entire as in global or overall buckling.

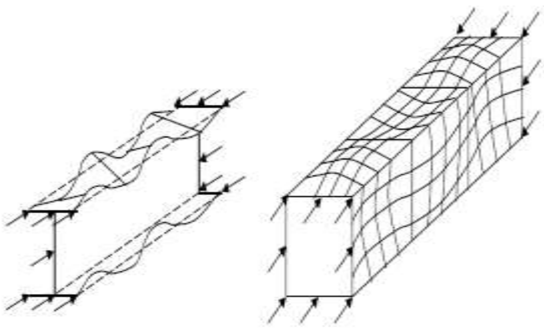

Fig. 3 Local Buckling of Compression members

II. Numerical Analysis

Buckling is a significant failure condition for many types of structure. Accurate estimates of critical load and response modes are difficult unless a structure falls well into the "slender" category. Linear solutions can suit such structures if loads and boundary conditions are carefully assessed. However, for the common of instability prone structures, a full nonlinear analysis is required. This type of analysis is very sensitive to assuming eccentricity and boundary conditions. A methodology is required that will deal with structural softening. The key point method is suggested to identify the onset of instability and subsequent transitional modes.

2.1 Eigenvalue of Buckling Analysis

Eigenvalue buckling analysis calculates the theoretical buckling strength (the bifurcation point) of a perfect linear elastic structure. This method corresponds to the typical approach to elastic buckling analysis: for instance, an eigenvalue buckling analysis of a column will match the classical Euler solution. However, imperfections and non-linearities of the structure to prevent the failure and achieving their theoretical elastic buckling strength. Thus, eigenvalue buckling analysis of column yields unconservative results, and should not commonly be used in actual day-to-day engineering analyses.
Table. 1 Eigen buckling of column

S.no	**Eigen Buckling Value**	**Shape of column**
1	1.0	I-section
2	1.0	Rectangle
3	1.002	Square
4	1.0062	Circular

III. Finite Element Analysis

ANSYS is engineering simulation software used for a variety of engineering applications. ANSYS is capable of both pre and post-processing. Numerical Analysis involves linear buckling analysis on four different types of columns made of structural steel having a height of 10m. Parameters include the boundary conditions as one end fixed and other ends free. The physics for the subject finite element method were modelled by dragging and dropping the static structural and linear buckling modules into the project schematic window within ANSYS workbench 19.2.

3.1 Finite Element Modelling

The Finite element modelling of the column is achieved in ANSYS with two node beam element (BEAM 188). The details of BEAM188 are provided in Fig. 4. The long steel column is discretized with 4 different cross-section beam elements. The material properties of the column are provided in Table-3. The column is loaded with 1N (compressive). The finite element analysis is performed using ANSYS 19.2 and critical buckling load and lateral deflection value are found for these cases. The output data for this case are provided in Table-4. The BEAM188 element is used for analysing slender to moderately stubby/thick beam structures. This element is based on Timoshenko beam theory. The shear deformation effects are included. It is linear beam elements have 2 nodes in 3-D with six degrees of freedom at each node. The degrees of freedom at each node includes translations in x and z directions, and rotations about the x, y and z directions. The including of cross sections is assumed to be unrestrained. The stress stiffness terms provided the elements to analyse flexural, lateral and torsional stability problems (using eigenvalue buckling or collapse studies with arc length methods). BEAM188 can be used with any cross-section having elastic and isotropic hardening plasticity models are supported (irrespective of cross-section subtype).

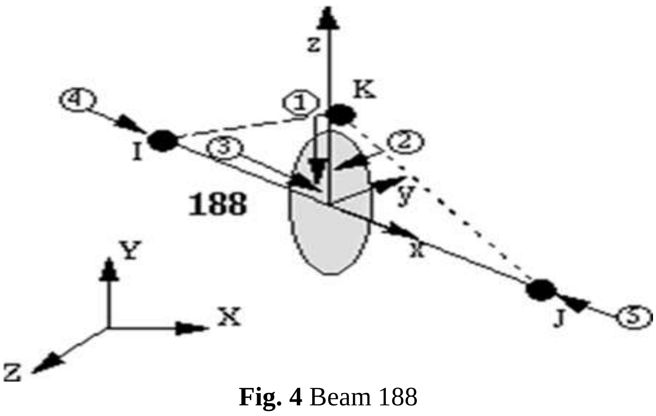

Fig. 4 Beam 188

3.2 Loads and Boundary Condition

Loads and boundary conditions must be applied to accurately model a long column with one end fixed and other end free boundary conditions. The four different cross-sections of the column to apply appropriate load and boundary conditions are shown in a table 2. The 1N compressive point load can be applied by adding a force to the static structural and selecting the vertex at the free end of the column. The constrained degrees of freedom (U1, U2, U3, UR1, UR2, and UR3) will need to be set to 0 within the details of the displacement boundary condition. Fig. 5 & 6 shows the applied load and boundary conditions applied to the FEM.

Table: 2 Column Description and Property

S.no	Column Shape	Column size (mm)	Boundary Conditions
1	I- Section	200x175	BC1- One end Free and other end fixed
2	Rectangular	200x350	
3	Square	275x275	
4	Circular	300 dia	

Table: 3 Mechanical Properties of Column

S.no	Description	Value
1	Density	7800kg/m^3
2	Poisson ratio	0.3
3	Young's Modulus	2x10^{11}

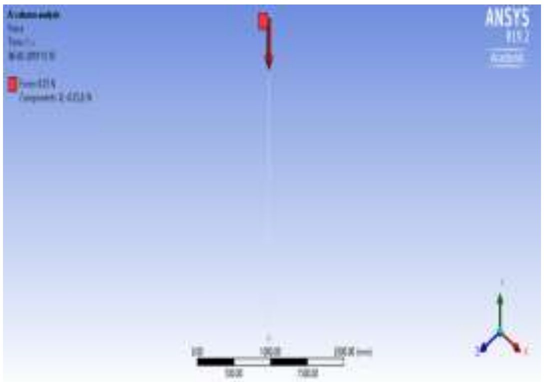

Fig. 5 Applied load to the column

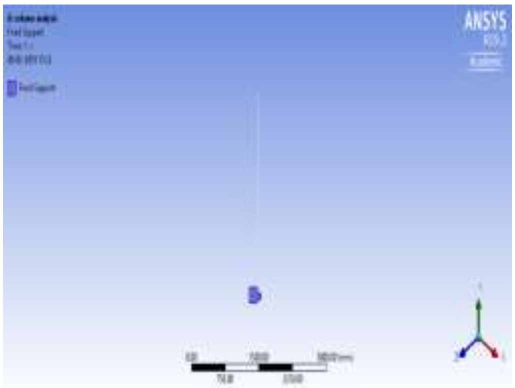

Fig. 6 Boundary Condition to the column

3.3 Critical or Buckling Load

The critical buckling load of a column can be determined by the following equation.

$P_{critical} = \pi^2 EI_{min} / 4L^2$

The value of critical or buckling load is calculated manually by using the above formula for the column and is compared with the critical buckling load of the same which is estimated using ANSYS software and validation process is shown in a table. 4. ANSYS finite element analysis is capable to calculate the critical buckling load of the different cross section of column accurately within (0.1- 0.8) per cent of the critical load value.

Table: 4 Manual and Analytical Results

S.no	Theoretical results (N)	Analytical results (N)	Per cent Error [%]	Shape of column
1	$1.92x10^6$	$1.85x10^6$	0.7	I-Section
2	$1.13x10^8$	$1.12x10^8$	0.1	Rectangular
3	$2.35x10^8$	$2.28x10^8$	0.7	Square
4	$7.69x10^8$	$7.61x10^8$	0.8	Circular

IV. Results And Discussions

Buckling load and its corresponding lateral deflection values of the long column under consideration are evaluated under one end fixed and other ends free condition. In this type of long column, which are numerically calculated using ANSYS 19.2 for structural steel section, four different cross-section types and the analysis approach is Eigenvalue. The maximum value of the buckling load is found at mid-height of the column. The variation is found in the lateral deflection of the column.

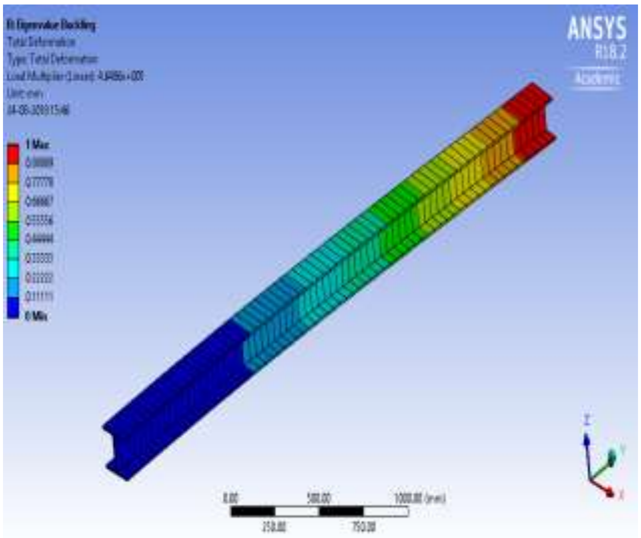

Fig. 7 I-Section column

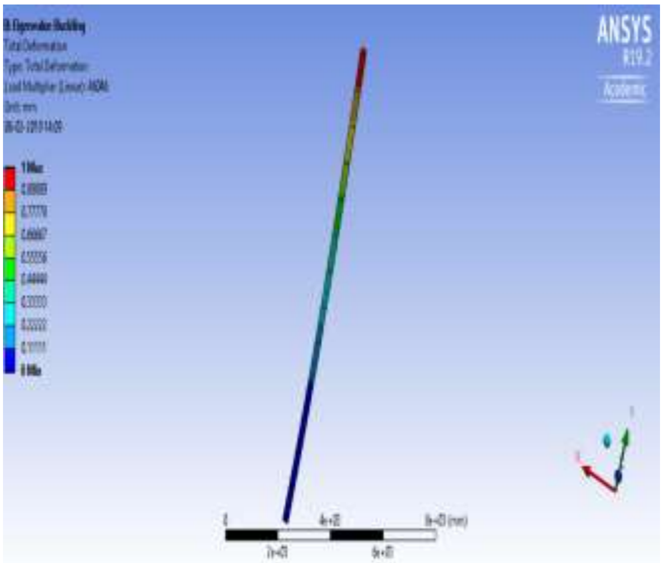

Fig. 8 Rectangle column

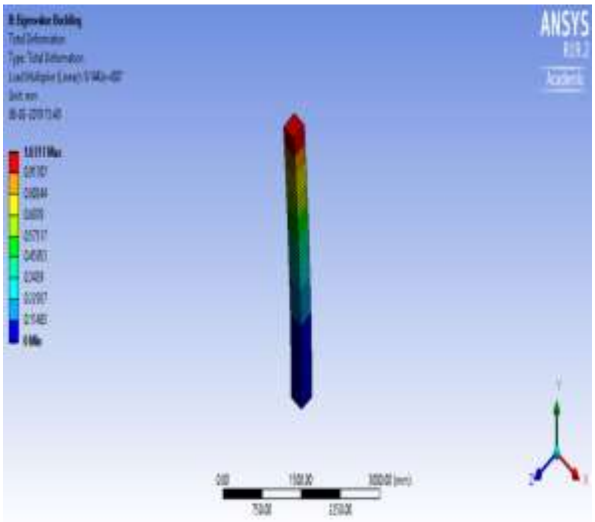

Fig. 9 Square Column

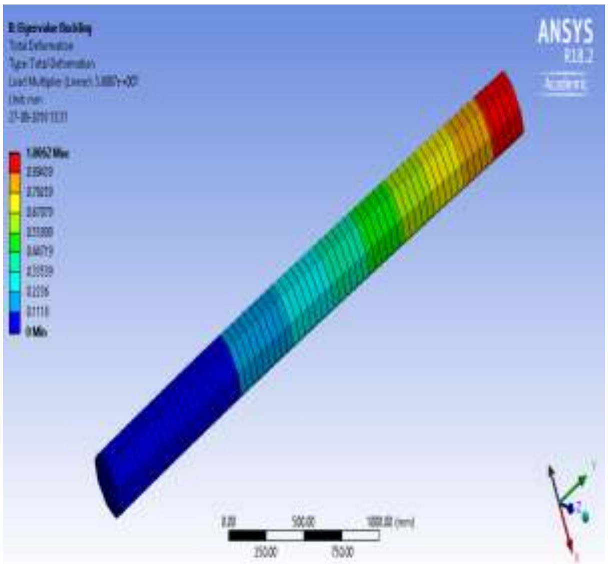

Fig. 10 Circle column

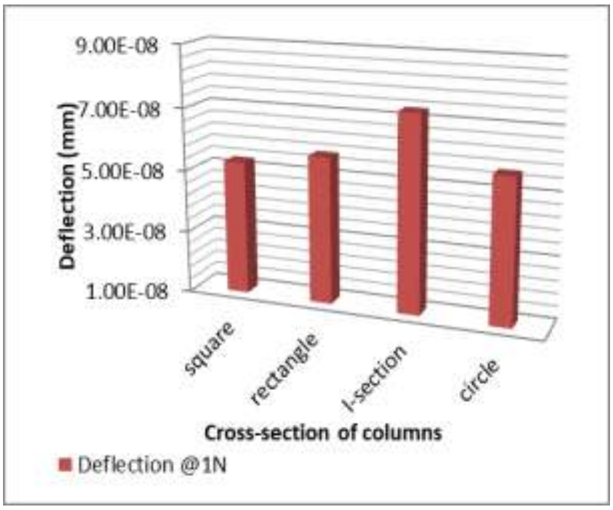

Fig. 11 Deflection of the column at 1N

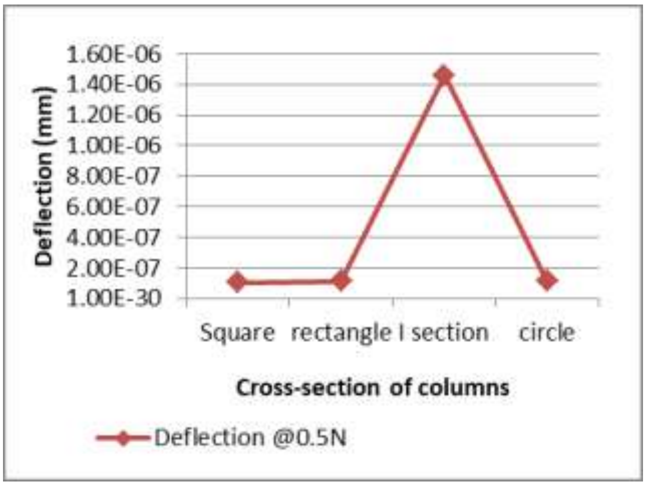

Fig. 12 Deflection of the column at 0.5N

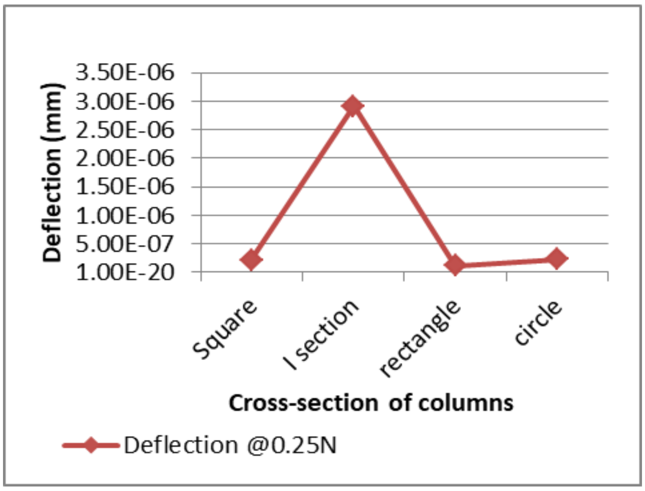

Fig. 13 Deflection of the column at 0.25N

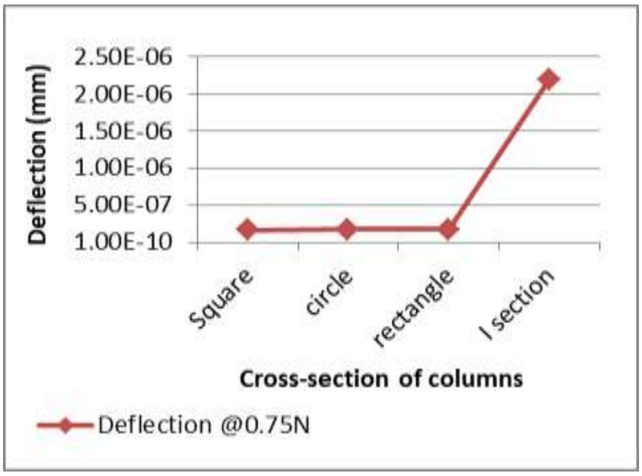

Fig. 14 Deflection of the column at 0.75N

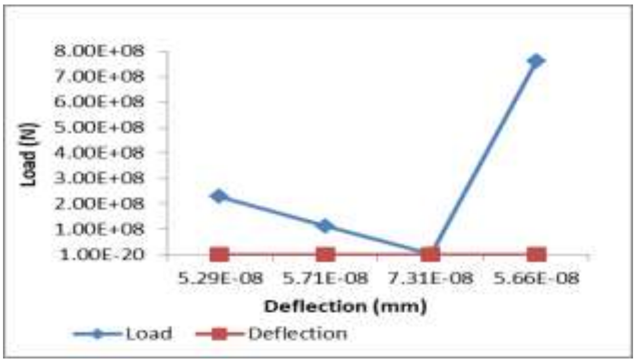

Fig. 15 Load Vs Deflection

V. Conclusion

Buckling analysis is mainly important for axial loaded members because the subjected compressive stress members at the point of failure is less than the materials ultimate compressive stress. As a result, special consideration should be given to the critical load when designing axially compressed members. The analytical critical loads which are determined by Comsol Multiphysics, and ANSYS 19.2 and compared with Euler's theoretical critical buckling load. The number of nodes required to obtain accurate results is very large when compared to the ANSYS finite element analysis which did not utilize tetrahedral elements.

- Buckling loads strongly depends on the material properties and the geometry of the column.
- Buckling loads are directly proportioned with the modulus of elasticity, thickness, outer to inner radius ratio and all the column geometry parameters except the column length.
- The critical load values of different cross-section of column are calculated from the Eigenvalue analysis, which are approximately the same value and the only difference is in percentages which are not exceeded by 0.8 %.
- The numerical solution of the columns is suitable to calculate the critical load due to it used for the total cross sections of the column and with regular shapes.
- There is insignificant variation in lateral deflection of columns is found by the buckling analysis of column with one end fixed and other ends free.
- Finally the maximum deflection of all the cross section of the column at 1N.

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