Investigation of Buckling Failure of Mild Steel and Validation of Results by ANSYS

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Abstract - *This Paper presents Investigation of buckling failure of mild steel and validation of results with ANSYS 18.2.*

Long column is fixed at both ends and an axial load is applied at one of these ends. Just buckle condition of the column is found using an experimental method and compared it with Euler's formula Method. Validation of results obtained from experimental method is done with ANSYS Static Structural Analysis.

***Key Words*: Long Column, Crippling Load, Crushing stress, Slenderness Ratio, Euler's Theory, ANSYS 18.2**

1. INTRODUCTION

In the modern world there are huge number of tall buildings all over the world. The columns supporting huge structures are subjected to enormous loading over it. As an engineer, we must consider several possible modes of failure when designing a structure. When subjected to axial load the column can deform and can be buckled under variety of loading conditions. So that there is necessity of investigation of buckling failure of various materials.

Columns or struts are defined as, a member of structure which is subjected to axial compressive load. If the member of structure is vertical and both of its ends are fixed rigidly while subjected to axial compressive load, the member is known as column. For example, a vertical bar, one or both of its ends are hinged or pin joined, the bar is known as strut. Examples are connecting rod, piston rod, etc. Columns which have lengths less than 8 times their respective diameters or slenderness ratio less than 32 are called as short columns. The buckling of the short column subjected to compressive load is neglected and the buckling stress is found to be very small as compared with direct compressive stress. Therefore, it is assumed that short column is always subjected to direct compressive stress only. The columns having their lengths more than 30 times their respective diameters or their slenderness ratio more than 120 are called as, Long columns. Long columns are usually subjected to buckling stress only. Direct compressive stress is very small as compared with buckling stress and hence it is neglected [1].

If the axial compressive load on short column is gradually increased, the stage will reach, when the column will be on the point of failure by crushing. The stress induced in such a short column corresponding to this load is known as crushing stress and the load is called as crushing load. All short columns fail, because of crushing. A column is known as Long column, if the length of column in comparison to its lateral dimension is very large. Such long columns, cannot be fail only by crushing but also by bending (also known buckling) . The load, at which the column just buckles is known as, buckling load or critical just or crippling load. The buckling load is less than crushing load for long column [2].

Actually, the value of buckling load for long column is low, whereas as for short column the value of buckling load is relatively high. The column will fail, when maximum stress is more than the crushing stress, but in case of long columns the direct compressive stresses generated are negligible as compared to buckling stresses , hence very long columns are subjected to buckling stresses only [3].

Hence, we classify the columns into short and long columns, based on the parameter called as slenderness ratio. Ratio of actual length of a column to least radius of gyration of the column is known as slenderness ratio. The effective length is defined as, the length of column between the lateral supports. The radius of gyration defined as the root of the ratio of moment of inertia to cross section area.

1.1 Assumptions of Euler's column Theory

- The column is initially perfectly straight and the load is applied axially.
- The cross section of column should be uniform throughout the length.
- The column material is perfectly elastic, isotropic

and homogeneous obeys Hook's law.

- The length of column is very large as compared to lateral dimension.
- The direct stress is very small as compared to bending stress.
- The column will fail only by buckling .
- The self-weight of column is considered to be negligible.

According to Euler's formula for crippling /buckling stress crippling stress is given by,

Crippling Stress $=\Pi^2E \div (Le/k)^2$
Where, Le =Effective length, E =Young's Modulus of elasticity, K= Radius of Gyration.

Hence, crippling stress is directly proportional to Young's modulus of elasticity and square of radius of gyration of corresponding martial and inversely proportional to square of effective length of column. So that effect of each parameter on crippling stress is find out by fixing other parameters

1.2 Finding Limiting Condition for Euler's Law Le/k Ratio

For a column with both ends hinged Le=l, hence crippling stress becomes as $=\Pi^2E \div (l/k)^2$ where l/k is slenderness ratio.

If the slenderness ratio is small, the crippling stress (or the stress at failure) will be high. But for the column material, the slenderness ratio is less than a certain limit, Euler's formula gives a value of crippling stress greater than the crushing stress. For limiting condition the value of slenderness ratio for which crippling stress is equal to crushing stress.

For example, for a mild steel column with both ends fixed

Crushing stress=330 N/mm^2

Young's modulus, $E=2.1*10^5$ N/mm^2

Table -1: Properties of Mild Steel.

Properties	Mild Steel
Young's Modulus (MPa)/(N/mm^2)	$2.1*10^5$
Poisson's Ratio	0.3
Density(kg/m^3)	7850
Tensile Yield Strength (MPa) Or (N/mm^2)	330

Equating the crippling stress to the crushing stress corresponding to the minimum value of slenderness ratio, we get

Crippling stress=Crushing stress

Let, p is the load applied axially on both ends of long column ,which is fixed at both ends of effective length Le, Young's Modulus of elasticity E, and moment of inertia I, radius of Gyration K, cross sectional area A.

$P= \Pi^2EI/ Le^2$;

Hence crippling stress σ,

$\sigma=\Pi^2EI/ (Le^2A)$;

$\sigma= \Pi^2Ek^2/ (Le^2)$;

$\sigma=\Pi^2Ek^2/ (Le /k)^2$;

$\Pi^2E \div (Le/k)^2=330$;

Slenderness ratio (s) =Le/k;

Where Le is effective length, here for both end fixed condition Le=l;

$(4\Pi^2*2.1*10^5)/ (l /k)^2=330$;

$(4\Pi^2*2.1*10^5)/ 330= (l /k)^2$;

$(4\Pi^2*2.1*10^5)/ 330=25097.1636$;

Let $I=Ak^2$;

$I= (\Pi/64) d^4$;
$A= (\Pi/4) d^2$;

Therefore, k=d/4;

$(l/k) = (25097.1635)^{1/2}$;

$s = l/ k = 158.42$;

Let $k=d/4$;

$4\ l/d=158.42$

$l/d=39.605$, say 40.

Hence, in case of Mild Steel, Euler's formula for both ends fixed will be valid for slenderness ratio greater than 40.

2. Experimental Setup

Universal Testing Machine (Components and Functions)

A Universal testing machine (UTM) is used to test the mechanical properties (tension, compression etc.) of a given test specimen by exerting tensile, compressive or transverse stresses. The machine has been named so because of the wide range of tests it can perform over different kind of materials. Different tests like peel test, flexural test, tension test, bend test, friction test, spring test etc. can be performed with the help of UTM.

Components of Universal Testing Machine (UTM)

A universal testing machine consists of two main parts:

A) Loading Unit

B) Control Unit

1. Loading Unit

The loading unit of a UTM consists of the following components:

1. Load Frame
2. Upper crosshead and Lower crosshead
3. Elongation Scale

The main components of the control unit in a universal testing machine are:

1. Hydraulic Power Unit
2. Load Measuring Unit
3. Control Devices

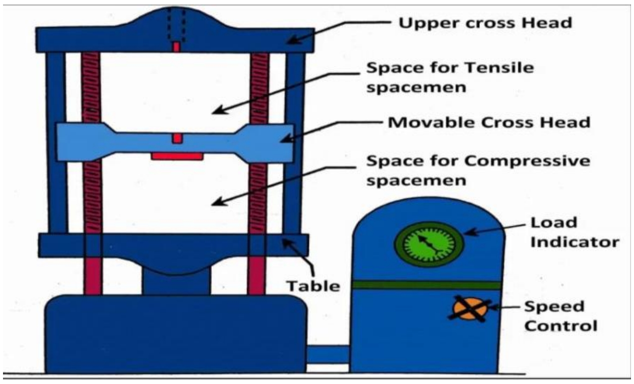


Fig -1: Universal Testing Machine Components.

2.1 Experimental Procedure

Take readings for 8, 10, 12, 16 mm diameter bars of varying cross section area mild Steel bar.

The length of the corresponding bar of particular material also has to be change so that we get the buckling failure modes for various length of particular material.

During the change in diameter and change in the length failure mode criteria, it is necessary to consider the Euler's Law validation condition. So that for particular slenderness ratio the Euler's Law can valid.

Hold the bar of particular material and specific length into the jaw of moveable crosshead and fixture arrangement of the UTM table.

Fig -2: Buckling of Mild Steel bar Fixed at both ends.

Where Le is effective length, here for both end fixed condition Le=l;

$P=4\Pi^2EI/l^2$;

$P=4*(3.14*3.14)(2.1*10^5) I/(l^2)$;

$P=4*(3.14*3.14)(2.1*10^5)((\Pi/64)*d^4)/(l^2)$;

$P=4.06338*10^5 d^4$

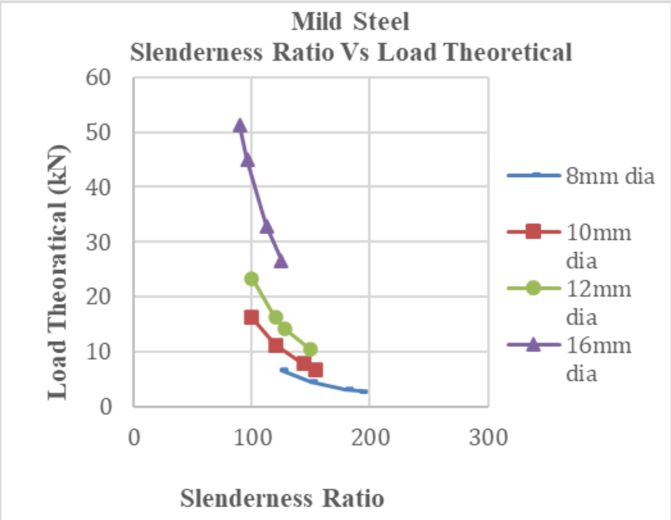


Chart -1: Mild Steel Slenderness Ratio Vs Load Theoretical

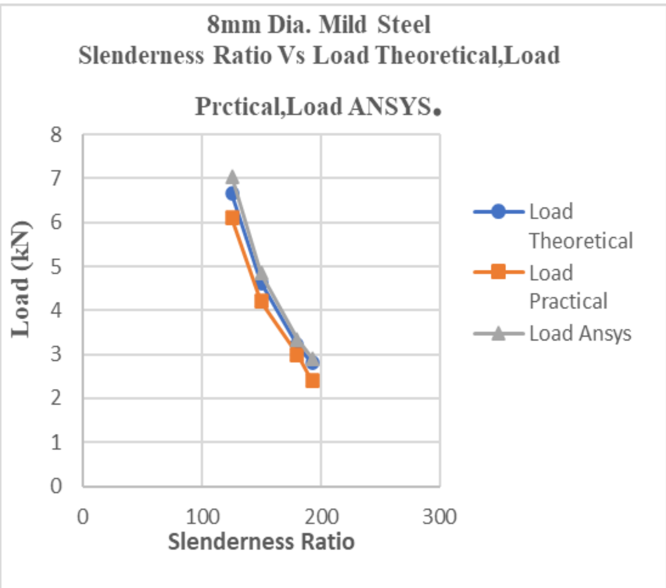


Chart -2: Mild Steel Slenderness Ratio Vs Load Theoretical, Load, Practical, load ANSYS

In case of mild steel critical buckling analysis Euler's formula gives the value of a crippling stress at which the buckling failure just occurs, when crippling load is equal to crushing load. Hence, in case of mild steel with both ends fixed condition Euler's formula is valid only for slenderness ratio greater than 40.

We have plotted the graph of slenderness ratio against load of the column we get the result as follows:

- As slenderness ratio decreases the load required to just buckle the long column increases.
- By experimentation method the values of load required to just buckle the column are 3 to 5 % less than theoretical values obtained from Euler's formula method and results Obtained from ANSYS Structural Analysis.
- In case of long columns as the diameter of column increases (or cross section area increases) load required to just buckle or crippling load increases.
- In other way, load bearing capacity is more for increasing cross section area for same length.

Table -2: Results by theoretical, practical and ANSYS.

Dia. (mm)	C/S Area(mm)	Length (mm)	Slenderness Ratio	Thr.Load (kN)	Prac.Load (KN)	Ansys (KN)	%ERROR (Thr. Vs ANSYS)
8	50.24	770	192.5	2.807	2.4	2.9135	3.7940
8	50.24	720	180	3.21	3	3.341	4.0809
8	50.24	600	150	4.623	4.2	4.8514	4.9405
8	50.24	500	125	6.657	6.1	7.0514	5.9245
10	78.5	770	154	6.853	6.2	7.0861	3.4014
10	78.5	720	144	7.838	7.2	8.1238	3.6463
10	78.5	600	120	11.287	10.8	11.784	4.4032
10	78.5	500	100	16.253	15.8	17.107	5.2544
12	113.04	900	150	10.402	10	10.666	2.5379
12	113.04	770	128.33	14.211	13.9	14.63	2.9484
12	113.04	720	120	16.253	15.9	16.767	3.1624
12	113.04	600	100	23.405	23	24.284	3.7556
16	200.96	1000	125	26.629	26.2	26.806	0.6646
16	200.96	900	112.5	32.876	32.2	33.115	0.7269
16	200.96	770	96.25	44.914	44.3	45.292	0.8416
16	200.96	720	90	51.369	50.9	51.825	0.8876

3. Validation of Results obtained from Euler's formula with ANSYS 18.2

Results obtained by theoretical(Euler's formula) and practical(Experimental) are validated by ANSYS 18.2

Following steps are followed for analysis of columns

Step 1: Draw Geometry of component.

Step2: linking of geometry of component to static structural of→ Analysis system.

Step 3: Fill material properties in data library of Engineering Data.

Step 4: Static structural Analysis of column.

Step 5: Eigenvalue buckling analysis.

Step 6: Make outline of all required parameters.

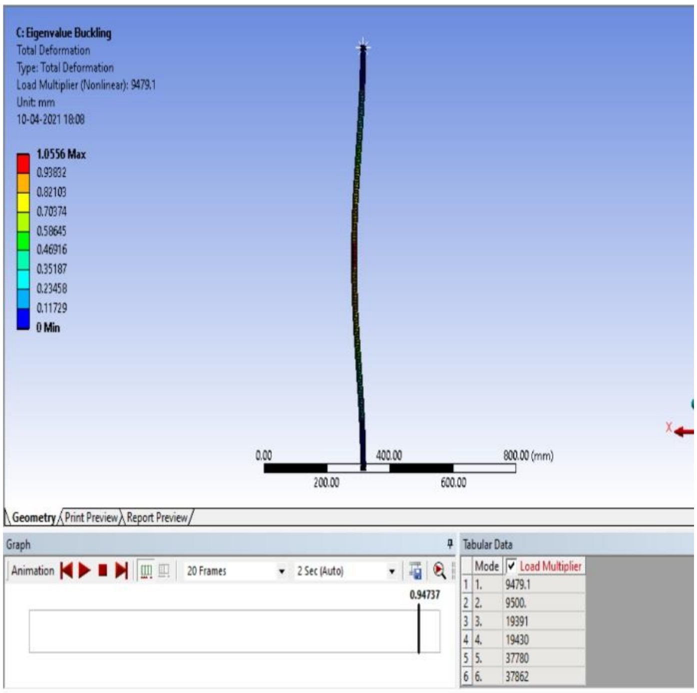
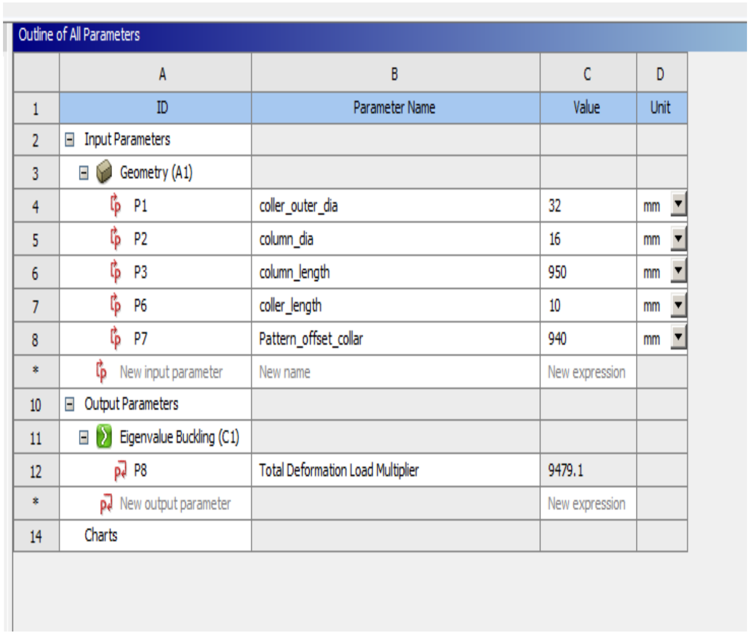


Fig -3:Structural Analysis of Long Column of Mild Steel Fixed at both ends on ANSYS 18.2.



Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Geometry (A1)			
4	P1	coller_outer_dia	32	mm
5	P2	column_dia	16	mm
6	P3	column_length	950	mm
7	P6	coller_length	10	mm
8	P7	Pattern_offset_collar	940	mm
*	New input parameter	New name	New expression	
10	Output Parameters			
11	Eigenvalue Buckling (C1)			
12	P8	Total Deformation Load Multiplier	9479.1	
*	New output parameter		New expression	
14	Charts			

Fig -4: Outline of parameters on ANSYS 18.2.

4. Conclusions

For a particular material and specific slenderness ratio, practical values of load for just buckle the column are less compare to the values calculated by Euler's formula and obtained by ANSYS software Structural Analysis

The various reasons behind these are as follows:

- Diameter taken for experimentation is not exactly same considered in Euler's formula and ANSYS software Structural Analysis.
- The material obtained from the local market is not perfectly same as that of material properties considered for Euler's formula and ANSYS software Structural Analysis. For e.g., Young's modulus of elasticity, crushing stress, tensile yield strength of material.
- In practical experimentation holding length may not be exactly same for considering the calculation for Euler's and ANSYS.
- While measuring the load by using dial gauge on Universal Testing Machine (UTM) error may occurs because of,
  - Human measuring errors.
  - Not properly calibrated dial gauge.

For a particular slenderness ratio material having high values of crushing strength, tensile and compressive yield strength and Young's modulus of elasticity will shows buckling at high loads. As slenderness ratio decreases the load required to just buckle the long column increases.

Results obtained from Euler's formula for buckling of log column are almost same as ANSYS analysis having variation of 3 to 5 %. Therefore, results by Euler's formula and experimentation methods are validated by ANSYS software structural analysis.

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