Experimental and FE Analysis of Buckling Behaviour of Columns under Different End Conditions

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Abstract: The main objective of this study is to understand the behaviour of circular cross section columns of different materials under gradually increasing axial compressive loads using three different boundary conditions i.e. Fixed-Fixed, Pinned-Pinned and Fixed-Pinned. This paper presents an experimental and FE analysis of buckling behaviour of circular column. Also it includes the study of instability of column under axial compressive loads. Non –linear buckling analysis method is used to calculate critical buckling load when the column is unstable. For the solution of the problem not only experimental analysis has been performed but also FE analysis has been done by using AUTODESK NASTRAN. The results obtained from experimental analysis and FE analysis were compared.

Keyword: Column, Buckling Analysis, Loads, End Conditions

1. Introduction

A structural member, subjected to an axial compressive load, is called a strut. As per definition, a strut may be horizontal, inclined or even vertical. A vertical strut used in building or frame is called column. It has been observed that when a column is subjected to compressive load then the compressive stress induced,

$$\sigma = \frac{P}{A}$$

Where,

       σ =Stress induced on column

       P = Compressive load

       A = Cross section area of the column

Buckling ia sudden failure of a structural member when it is subjected to high compressive load. Due to this high compressive load, the compressive stress in the column is induced. When the load gradually increased on the vertical column will reach a stage, firstly it will be subjected to the ultimate crushing stress. After this stage column will fail by crushing. The Load corresponding to the crushing stress, is called crushing load. It is observed that column cannot completely fail due to crushing, but also by bending i.e.buckling.

But it is happening only with the long columns and short columns are failed due to direct crushing. The load at which the column just buckles is called buckling load or critical load or crippling load. In 1757, mathematician L. Euler gives one statement that "The direct stresses induced in a long column are negligible as compared to the bending stresses". The equation given by the Euler is,

$$P_{cr} = \frac{\Pi^2 EI}{KLe^2}$$

Where,

Pcr = Crippling load

E = Modulus of elasticity

I = Moment of Inertia

Le = Effective length of column

K = constant whose values depends on end conditions

K = 2, For one end fixed and one end fixed

K = 1, For both end pinned

K = 0.5, For both end fixed

K = 0.7, For one end fixed and one end pinned

Stable and unstable equilibrium perform an important role in buckling of column. Stable equilibrium tells thst when energy is added in an object in the form of disturbance (load), the object will return to its original position (things don't change in the end). Unstable equilibrium tells that the energy is added to an object, the object will move and get more disturbed (things change rapidly).

Fig. Experimental Setup

2. Material and Methods used

2.1 Specimen Material

Material plays an important role , we used Iron, Steel, Aluminium as a specimen material. All three materials are ductile in nature and of same material and length.

Sr. No.	Types of material	Cross section	Parameters
1	Iron	Circular	Diameter, ø = 12 mm Length, L = 675 mm
2	Steel	Circular	Diameter, ø = 12 mm Length, L = 675 mm
3	Alumium	Circular	Diameter, ø = 12 mm Length, L = 675 mm

Table No. 1 Different types of material and its parameter

2.2. Method used

Non-linear Buckling Analysis

Non- linear buckling analysis method is based on gradually increasing applied load upto the specimen (column) become unstable (a very small increase in the load will cause very large deflection). This method is used to study and check the unstable behaviour of column under different loading. It is modern technique to check the buckling behaviour of loaded specimen of different materials

3. Practical Calculation

1. Iron

i. Both ends Fixed

Specimen:
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
A = 113.097 mm^2

Piston:
Piston diameter = 60 mm
P = 4 kg/cm^2
= 0.3924 N/mm^2
A = 2827.43 mm^2
F = P x A
= 0.3924 x 2827.43
= 1109.31 N

Deflection (D) = 45 mm

ii. Both ends Pinned

Specimen:
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
A = 113.097 mm^2

Piston:
Piston diameter = 60 mm

P = 4 kg/cm^2
= 0.3924 N/mm^2

A = 2827.43 mm^2
F = P x A
= 0.3924 x 2827.43
= 1109.31 N
Deflection (D) = 70 mm

iii. One end pinned and one end fixed

Specimen:
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
A = 113.097 mm^2

Piston:
Piston diameter = 60 mm
P = 4 kg/cm^2
= 0.3924 N/mm^2
A = 2827.43 mm^2
F = P x A
= 0.3924 x 2827.43
= 1109.31 N

Deflection (D) = 52 mm

2. Steel
i. **Both ends Fixed**

Specimen:
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
A = 113.097 mm^2

Piston:
Piston diameter = 60 mm
P = 4 kg/cm^2
= 0.3924 N/mm^2
A = 2827.43 mm^2
F = P x A
= 0.3924 x 2827.43
= 1109.31 N

Deflection (D) = 50.7 mm

ii**. Both ends Pinned**

Specimen:
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
A = 113.097 mm^2

Piston:
Piston diameter = 60 mm
$P = 4$ kg/cm^2
$= 0.3924$ N/mm^2
$A = = 2827.43$ mm^2
$F = P \times A$
$= 0.3924 \times 2827.43$
$= 1109.31$ N

Deflection (D) = 52 mm

iii. **One end pinned and one end fixed**

Specimen:
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
$A = 113.097$ mm^2

Piston:
Piston diameter = 60 mm
$P = 4$ kg/cm^2
$= 0.3924$ N/mm^2
$A = 2827.43$ mm^2
$F = P \times A$
$= 0.3924 \times 2827.43$
$= 1109.31$ N

Deflection (D) = 55 mm

3 . **Aluminium**

i. Both ends Fixed
Specimen:
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
$A = 113.097$ mm^2

Piston:
Piston diameter = 60 mm
$P = 4$ kg/cm^2
$= 0.3924$ N/mm^2
$A = 2827.43$ mm^2
$F = P \times A$
$= 0.3924 \times 2827.43$
$= 1109.31$ N

Deflection (D) = 71 mm

ii. Both ends Pinned

Specimen:
Cross section: Circular
Diameter: 12 mm

Length: 675 mm
A = 113.097 mm^2

Piston:
Piston diameter = 60 mm
P = 4 kg/cm^2
= 0.3924 N/mm^2

A = 2827.43 mm^2
F = P x A
= 0.3924 x 2827.43
= 1109.31 N

Deflection (D) = 70 mm

iii. One end pinned and one end fixed

Specimen :
Cross section: Circular
Diameter: 12 mm
Length: 675 mm
A = 113.097 mm^2

Piston :
Piston diameter = 60 mm
P = 4 kg/cm^2
= 0.3924 N/mm^2

A = 2827.43 mm^2

F = P x A
= 0.3924 x 2827.43
= 1109.31 N

Deflection (D) = 85 mm

4. Simulated calculation

1. Iron
Given data:
i) For both end fixed
Cross section: circular
Diameter: 12 mm
Length: 675 mm

Force (F) = 1109.31 N
 FOS = 3
Deflection (D)=40.64mm

 Stresses = 2.06 MPa
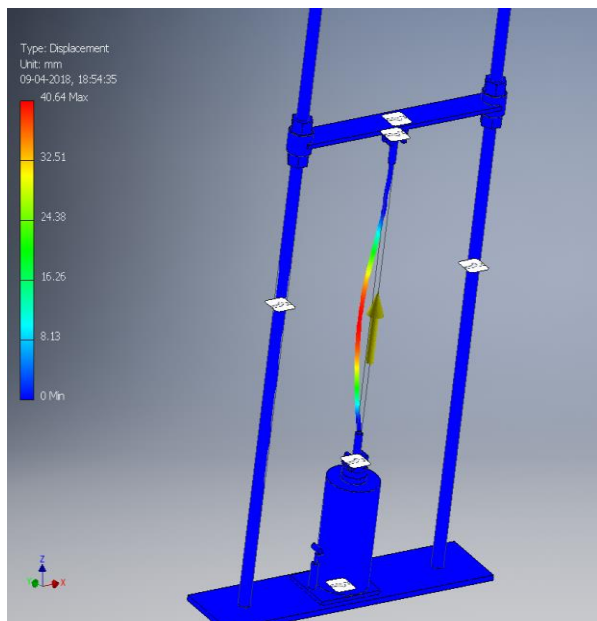
Fig. 6.1 Displacement
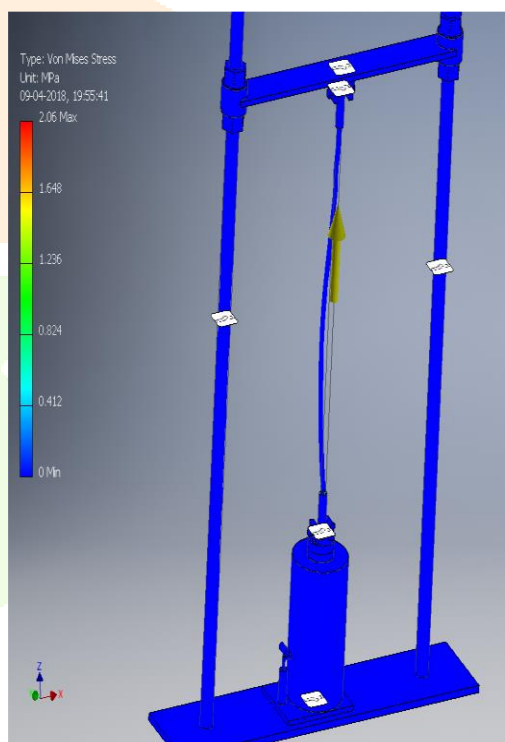
Fig. 6.2 Stress

ii) For both end pinned

Cross section: circular
Diameter: 12 mm
Length: 675 mm
Force (F) =1109.31 N
FOS = 3
Deflection (D) = 40.72 mm   Stresses =2.059 MPa
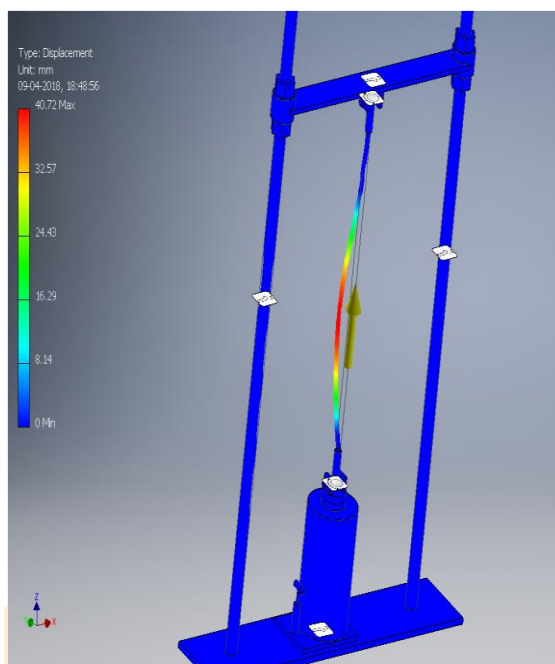
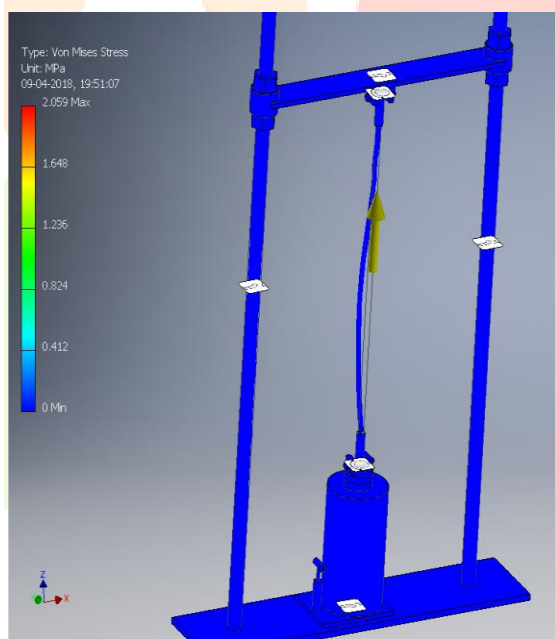Fig.6.3 Displacement

Fig.6.4 stress

iii) For one end fixed and one end pinned

        Cross section: circular
        Diameter: 12 mm
        Length: 675 mm
Force (F) 1109.31 N

 FOS = 3

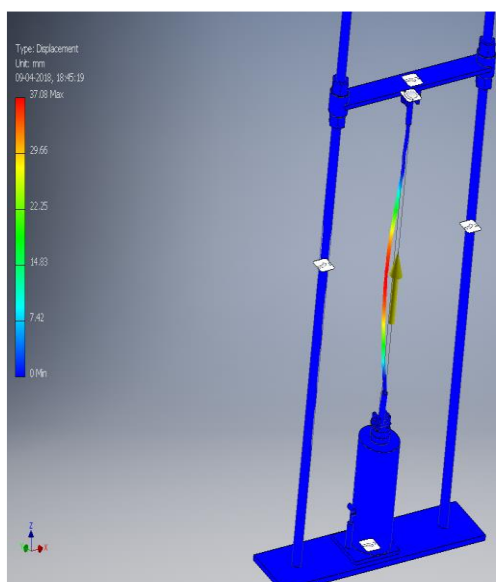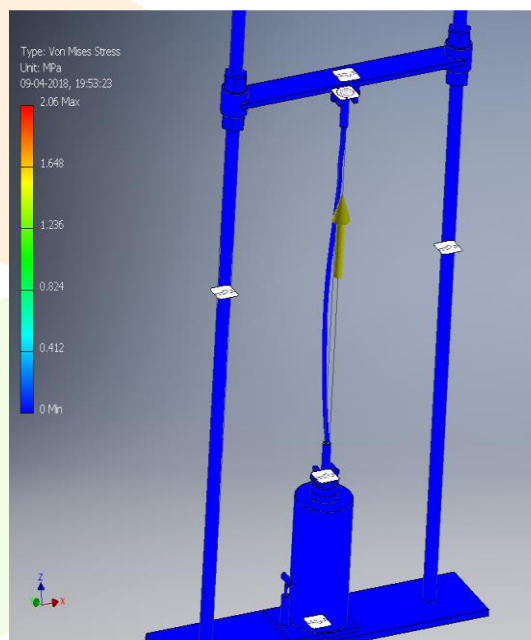Deflection (D) =37.08 mm   Stresses = 2.06 MPa

Fig.6.5 Displacement

Fig.6.6 Stress

2. Steel
Given data:
i)   For both end fixed
Cross section: circular
Diameter: 12 mm
Length: 675 mm

Force (F) = 1109.31 N   FOS = 3

Deflection (D) = 33.38 mm
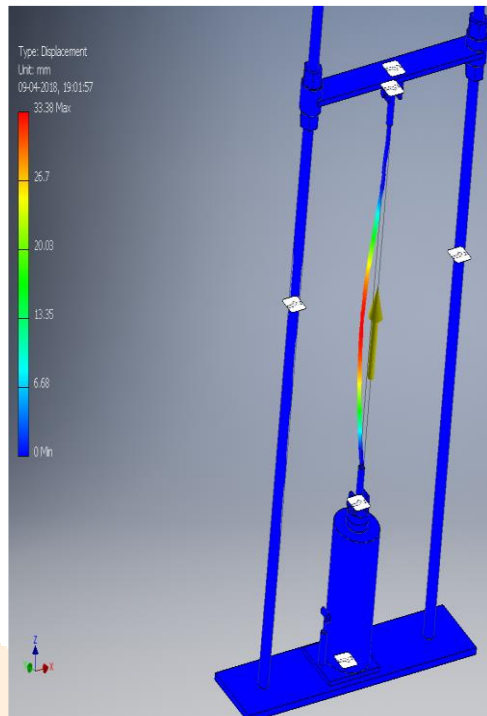Stresses = 1.991 MPa
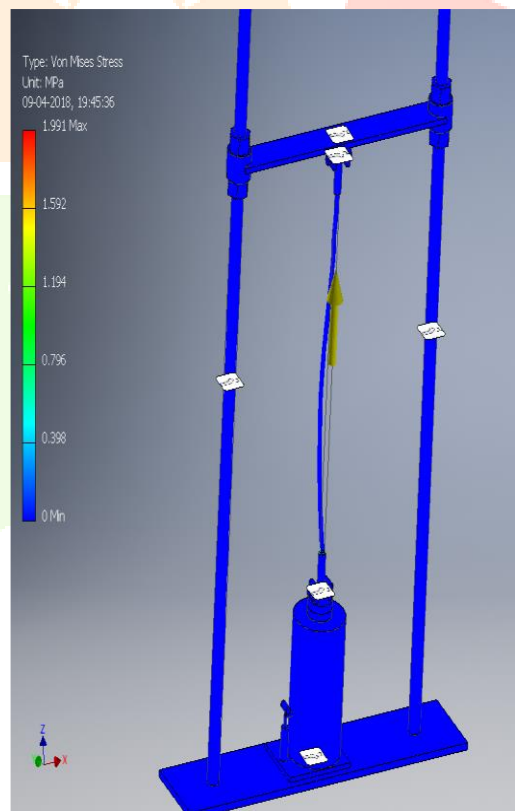
Fig.6.7 Displacement

Fig.6.8 Stress

ii) For both end pinned

Cross section: circular
Diameter: 12 mm
Length: 675 mm

Force (F) = 1109.31 N   FOS = 3
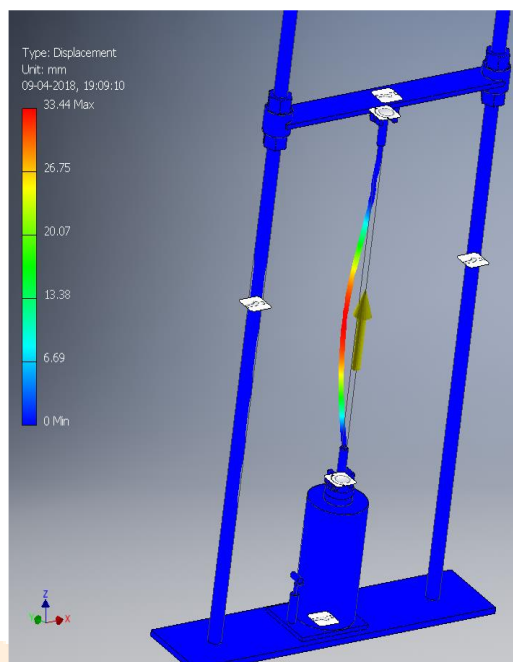Deflection (D) = 33.44 mm   Stresses = 1.989 MPa

Fig.6.9 Displacement

Fig. 6.10 Stress

iii)   For one end fixed and one end pinned

Cross section: circular
Diameter: 12 mm
Length: 675 mm

Force (F) = 1109.31 N   FOS = 3
Deflection (D) = 33.38 mm   Stresses = 1.991 Mpa
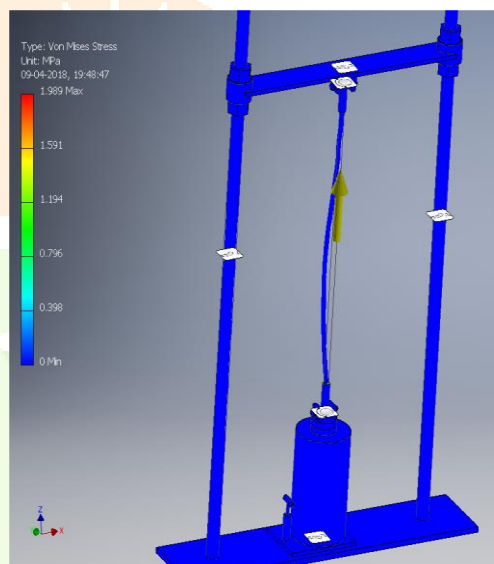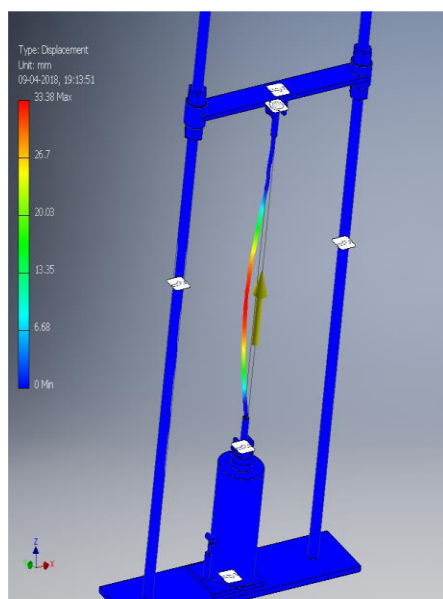
Fig.6.11 Displacement
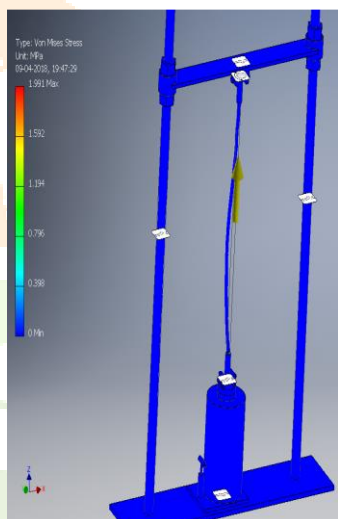

Fig.6.12 Stress

3. Aluminium

Given data:
i) For both end fixed

Cross section: circular
Diameter: 12 mm
Length: 675 mm

Force (F) = 1109.31 N   FOS = 3
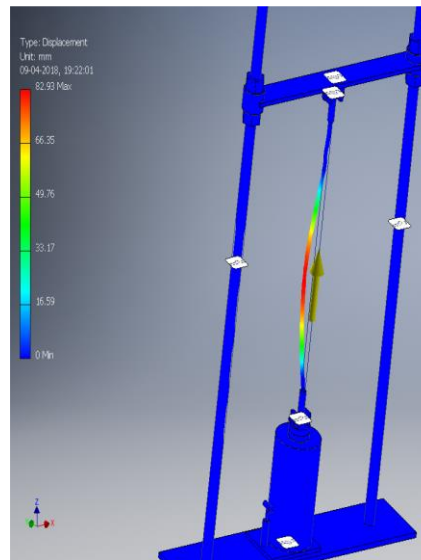   Deflection (D) = 82.93 mm   Stresses =2.211 MPa

Fig.6.13 Displacement

Fig.6.14 Stress

ii) For both end pinned

Cross section: circular
Diameter: 12 mm
Length: 675 mm
Force (F) = 1109.31 N   FOS = 3
Deflection (D) = 83.03 mm   Stresses = 2.21 MPa

Fig. 15 Displacement

Fig.6.16 Stress

iii)   For one end fixed and one end pinned

Cross section: circular
Diameter: 12 mm
Length: 675 mm

Force (F) = 1109.31 N   FOS = 3
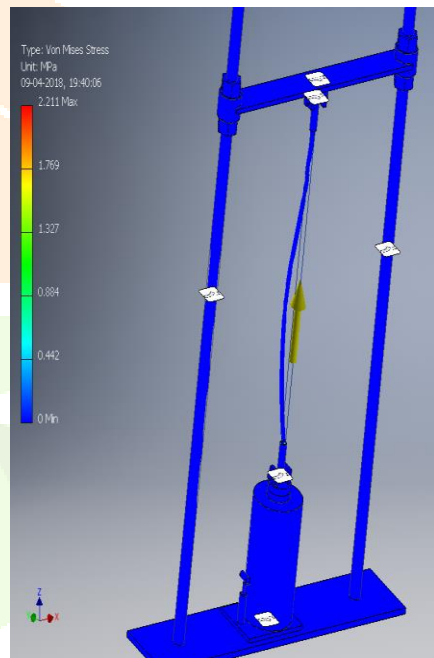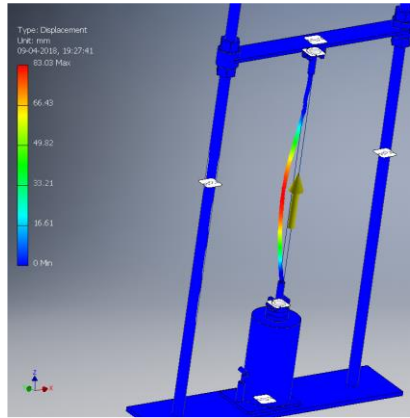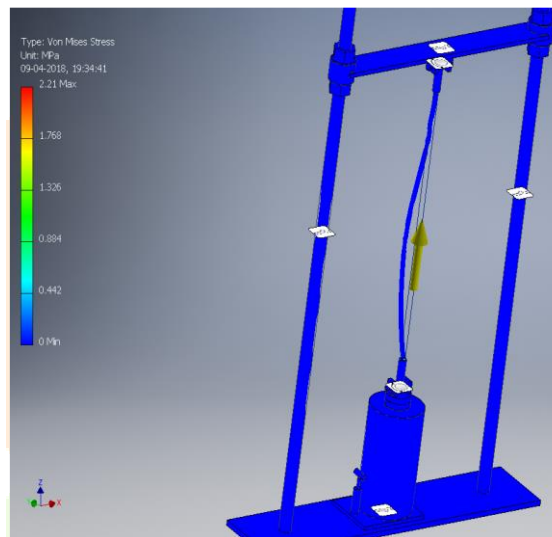Deflection (D) = 82.94 mm   Stresses = 2.211 MPa
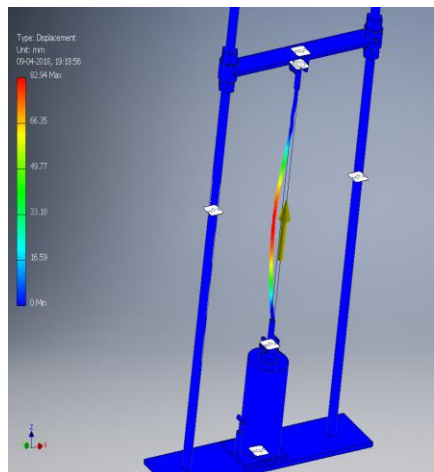
Fig. 17 Displacement
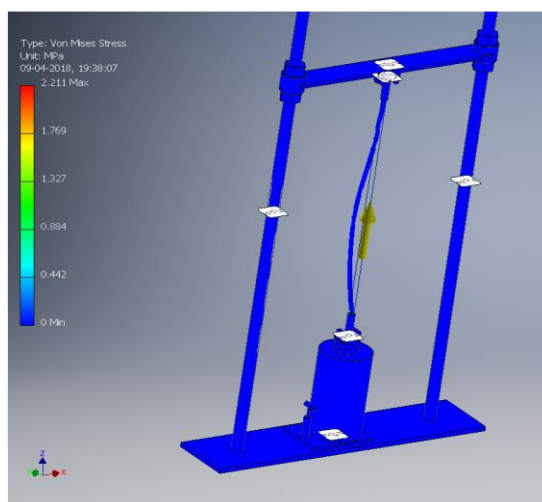
Fig. 6.18 Stress

RESULT and COMPARISON
Software calculation

MATERIAL	FORCE (N)	DEFLECTION (mm)
IRON		
a. Both end fixed	1109.31	40.64
b. Both end pinned	1109.31	40.72
c. One end fixed and one end pinned	1109.31	37.08
STEEL		
a. Both end fixed	1109.31	33.38
b. Both end pinned	1109.31	33.44
c. One end fixed and one end pinned	1109.31	33.38
ALUMINIUM		
a. Both end fixed	1109.31	82.93
d. Both end pinned	1109.31	83.03
e. One end fixed and one end pinned	1109.31	82.94

Practical calculation

MATERIAL	FORCE(N)	DEFLECTION (mm)
IRON		
a. Both end fixed	1109.31	45
b. Both end pinned	1109.31	70
c. One end fixed and one end pinned	1109.31	52
STEEL		
d. Both end fixed	1109.31	50.7
e. Both end pinned	1109.31	52
f. One end fixed and one end pinned	1109.31	55
ALUMINIUM		
g. Both end fixed	1109.31	71
h. Both end pinned	1109.31	70
i. One end fixed and one end pinned	1109.31	85

Conclusion

In the present work buckling of various materials are studied by using different end conditions. The study helped better understanding of the buckling modes and the effect of design or testing parameter on the buckling behaviour. Three experimental specimens with overall lengths ranging between 650 mm to 900 mm were tested. A model was verified by comparing the AUTODESK - NASTRAN results with the experimental tests in addition to previously published experimental tests.

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