# EXPERIMENTAL INVESTIGATION ON BUCKLING ANALYSIS OF CASTELLATED COLUMN WITH SOFTWARE

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## ABSTRACT

*Perforated-web steel sections have been used as structural members since the Second World War in an attempt to enhance the flexural behavior without increasing the cost of the material. Nowadays, such sections are widely used in a variety of geometries suitable for various loading conditions. The study considers a wide range of practical geometric dimensions, as well as, various columns' end conditions. Due to the increase in width of column the radius of gyration of column increase and the slenderness ratio of column get reduce. Due to this effect the buckling load carrying capacity of column increase. Castellated column is defined as the column in which increasing width of column without increasing the self-weight of column. Now a day castellated column is a new technique. A castellated column is fabricated from a standard steel I-shape by cutting the web on a half hexagonal line down the center of the beam. The two halves are moved across by one spacing and then rejoined by welding. This process increases the width of the column and hence the major axis bending strength and stiffness without adding additional materials. Due to the opening in the web, castellated column are more susceptible to lateral-torsional buckling. The main benefit of using a castellated column is to increase its buckling resistance about the major axis. However, because of the openings in the web, castellated columns have complicated sectional properties, which make it extremely difficult to predict their buckling resistance analytically.*

**Keyword** :- *Castellation, Radius of Gyration, Slenderness ratio*

## 1. INTRODUCTION

Castellated column is defined as the column in which increasing width of column without increasing the self-weight of column. Now a day castellated column is a new technique. A castellated column is fabricated from a standard steel I-shape by cutting the web on a half hexagonal line down the center of the column. The two halves are moved across by one spacing and then rejoined by welding. This process increases the width of the column and hence the major axis bending strength and stiffness without adding additional materials. Due to the opening in the web, castellated column are more susceptible to lateral-torsional buckling. The main benefit of using a castellated column is to increase its buckling resistance about the major axis. However, because of the openings in the web, castellated columns have complicated sectional properties, which make it extremely difficult to predict their buckling resistance analytically.

## 2. HEXAGONAL CASTELLATED COLUMN

In the hexagonal castellated column the opening is provided 45' or 60' angle. Hexagonal castellated column give greater resistance to buckling.

**Fig. 1 Hexagonal castellated column**

## 3. OBJECTIVE

- To find out the suitable end condition for the column
- Comparison between practically analysis and software analysis
- To know about the stresses developed in the castellated opening.
- To find out buckling load and deflection of section.

## 4. LITERATURE REVIEW

**DelphineSonck[et al] (2016)** Cellular and castellated members are usually produced by performing cutting and rewelding operations on a hot rolled I-section member. As illustrated in previous work, these operations will influence the residual stresses present in the members in a manner which is detrimental for the flexural buckling resistance.

**G. Panduranga[etal] (2015)** In this paper the buckling analysis of 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.

**Jian-kang Chen [etal] (2013)** This paper presents an analytical solution for the linear elastic buckling analysis of simply supported battened columns subjected to axial compressed loading. The critical buckling load is derived by using the classical energy method. Unlike most of existing work.

**Jeppe Jönsson[et al] (2016)** Eurocode allows for finite element modelling of plated steel structures; however the information in the code on how. to perform the analysis or what assumptions to make is quite sparse.

## 5. METHODOLOGY

### 5.1 *Assembly for various end condition*

There are four end condition given below

- Column with both the ends fixed
- Column with both the ends pin
- Column with one end is fixed and other end is pin
- Column with one end is fixed and other end is free

Assembly for testing of column is prepared from steel material. This is a plate and nut combination assembly which can achieve four end condition of testing.

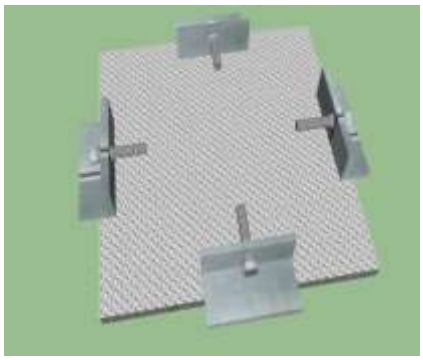


**Fig. 2 Assembly for testing**

### *5.2 Geometry of a typical castellated column*

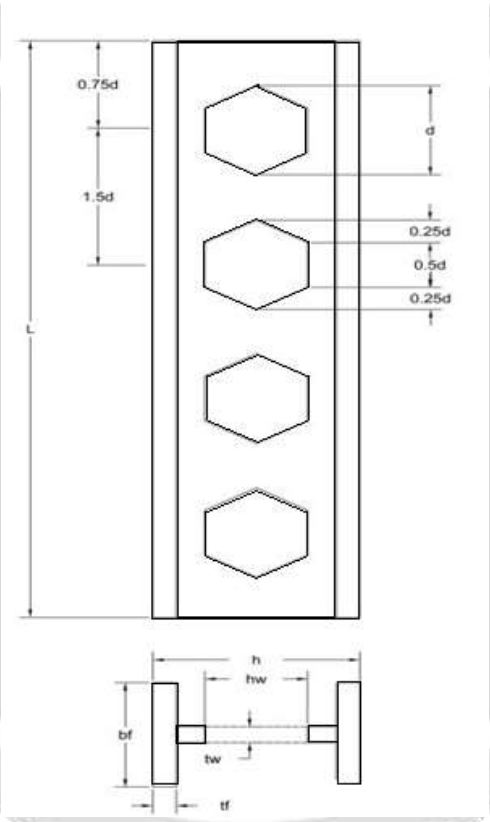



**Fig. 3 Geometry of a typical castellated column**

Typical geometry of modelled castellated columns is presented in Fig. 6. According to this illustration, the typical spacing between castellation is 1.5d, centre-to-centre, where d represents the diameter of the circle enclosing the hexagonal perforation. The gain in the depth of the expanded section, relative to the original depth, is estimated as 0.433h.

- **Section properties**

ISMB100
A= 1470mm$^2$
h = 100mm
b = 70mm
$b_f$ = 7.5mm
$t_w$ = 4.5 mm

$I_{xx}$ = 2.52 x $10^6$ $mm^4$
$I_{yy}$= 0.35 x $10^6$ $mm^4$
$r_{xx}$ = 41.4mm
$r_{yy}$ = 15.5mm

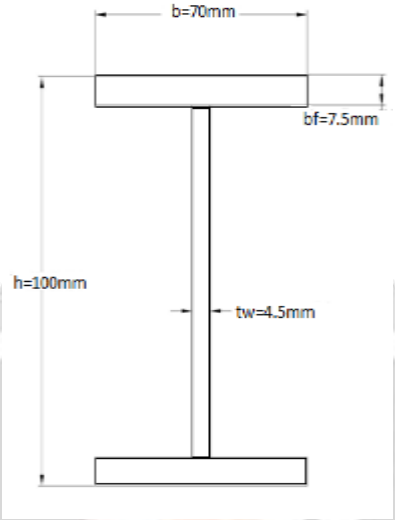



**Fig. 4 Dimension of first original section**

According to above geometry modified section is given below
The diameter of the circle enclosing the hexagonal perforation
d = 0.443h
= 0.443 x 100
= 44.3mm
Centre-to-centre spacing between castellation
s = 1.5d
=1.5 x 44.3
= 66.45mm
End distance of the hexagonal opening = 0.75d
= 0.75 x 44.3
= 33.25mm
Inclined side height of hexagonal opening = 0.25d
= 0.25 x 44.3
=11.07mm

Vertical side height= 0.50d
= 0.50 x 44.3
= 22.15mm

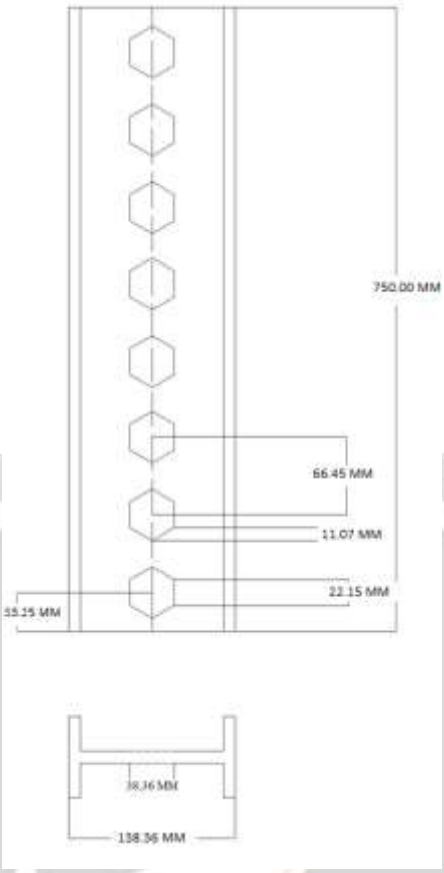



**Fig.5 Dimension of first Modified section**

## 6. CASTING ANDTESTING OF SPECIMEN

### *6.1. Fabrication of section*

The end condition assembly is prepared from the mild steel plate, angle section with bolt. This assebly is used fot the testing of castellated column at various end condition. The castellated section is manufacture from the mild steel I section. Firstly the hexagonal pattern is drawn on the column and by using gas cutter this section is cut into two part. After this two parts are welded each other with the help of gas welding.

**Photo 1 Pattern marking on the section**

**Photo 2 Fabricated section with end condition aseembly**

***6.2. Testing of section***

**Buckling test on regular section (both end fixed)**

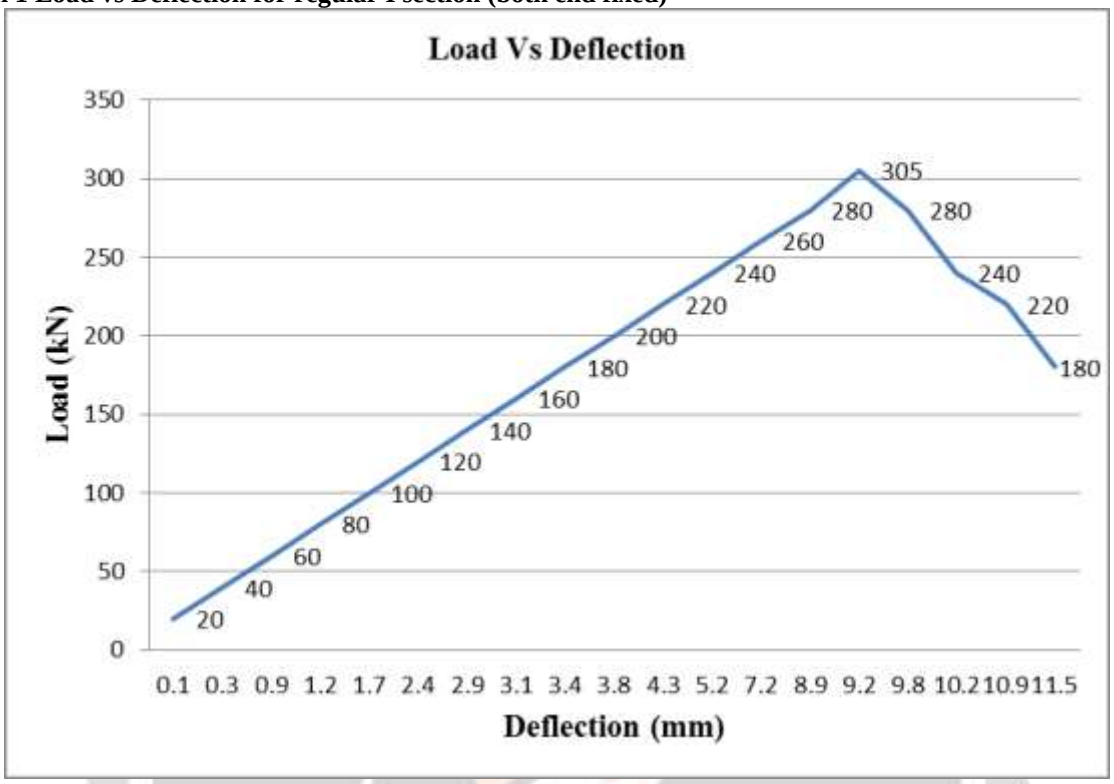
The buckling test on regular section is conducted on Universal testing machine. The test arrangement for test is shown in below photo. The end condition for this testing is both end fixed.

**Photo 3 Testing of regular section**

**Tab. 1 Load vs Deflection for regular I section (both end fixed)**

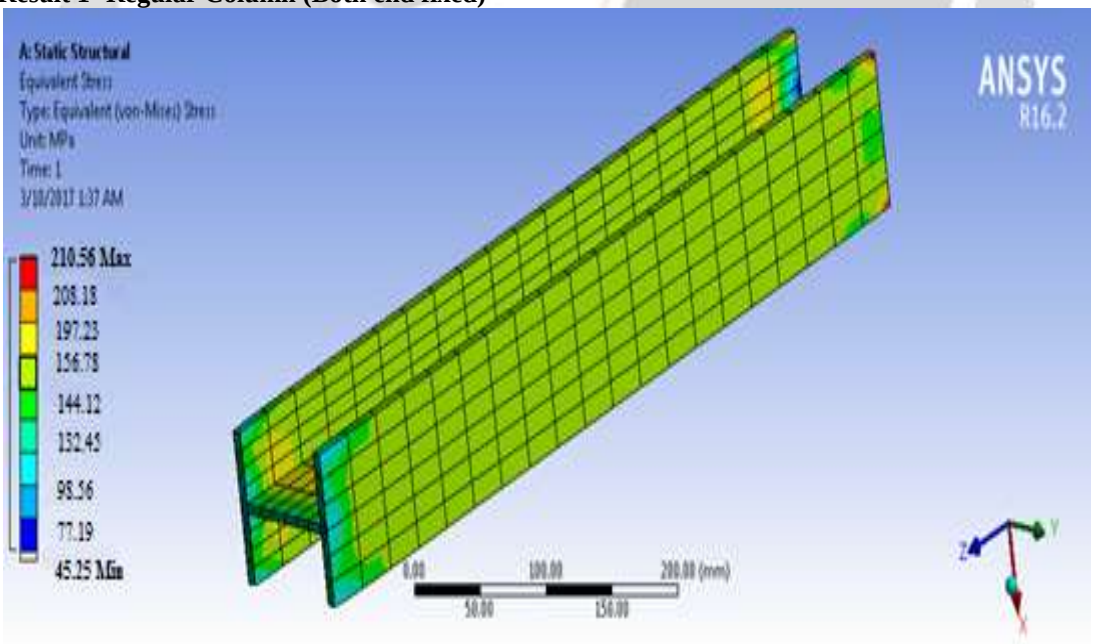
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 20 | 0.1 |
| 2 | 40 | 0.3 |
| 3 | 60 | 0.9 |
| 4 | 80 | 1.2 |
| 5 | 100 | 1.7 |
| 6 | 120 | 2.4 |
| 7 | 140 | 2.9 |
| 8 | 160 | 3.1 |
| 9 | 180 | 3.4 |
| 10 | 200 | 3.8 |
| 11 | 220 | 4.3 |
| 12 | 240 | 5.2 |
| 13 | 260 | 7.2 |
| 14 | 280 | 8.9 |
| 15 | 305 | 9.2 |
| 16 | 280 | 9.8 |
| 17 | 240 | 10.2 |
| 18 | 220 | 10.9 |
| 19 | 180 | 11.5 |

**Graph 1 Load vs Deflection for regular I section (both end fixed)**




From graph the maximum load taken by section is 305 KN at deflection 9.2 mm.

**Ansys Result 1- Regular Column (Both end fixed)**




From Ansys result the maximum stress is 210.56MPa and minimum stress is 45.25 MPa.

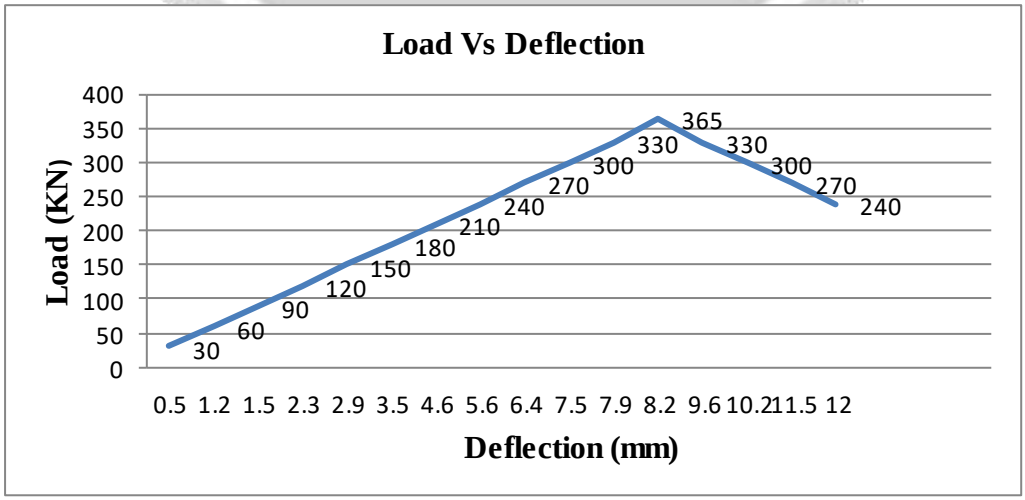
**Buckling test on castellated section (both end fixed)**

**Photo4 Testing of catellated section**

**Tab. 2 Load vs Deflection for castellated I section (both end fixed)**

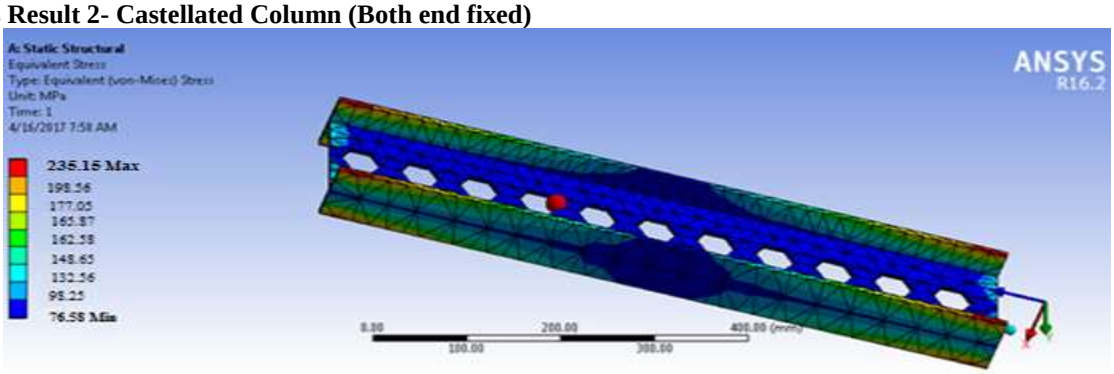
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 30 | 0.5 |
| 2 | 60 | 1.2 |
| 3 | 90 | 1.5 |
| 4 | 120 | 2.3 |
| 5 | 150 | 2.9 |
| 6 | 180 | 3.5 |
| 7 | 210 | 4.6 |
| 8 | 240 | 5.6 |
| 9 | 270 | 6.4 |
| 10 | 300 | 7.5 |
| 11 | 330 | 7.9 |
| 12 | 365 | 8.2 |
| 13 | 330 | 9.6 |
| 14 | 300 | 10.2 |
| 15 | 270 | 11.5 |
| 16 | 240 | 12.0 |

**Graph 2 Load vs Deflection for Castellated I section (both end fixed)**




From graph the maximum load taken by section is 365 KN at deflection 8.2mm.

**Ansys Result 2- Castellated Column (Both end fixed)**




From Ansys result the maximum stress is 235.15 MPa and minimum stress is 76.58 MPa.

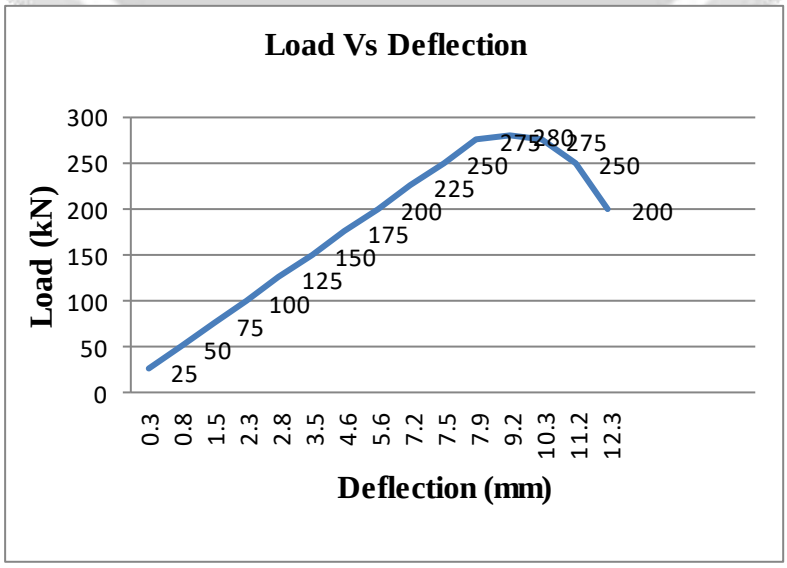
**Buckling test on regular section (one end fixed one end pinned)**

The next section is tested for one end fixed and other end pinned

**Tab. 3 Load vs Deflection for regular I section (one end fixed one end pinned)**

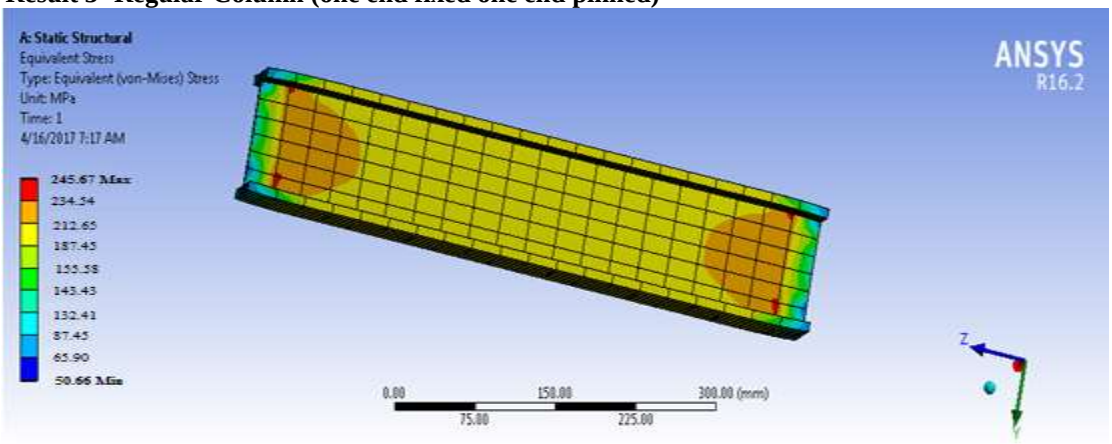
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 25.00 | 0.3 |
| 2 | 50.00 | 0.8 |
| 3 | 75.00 | 1.5 |
| 4 | 100.00 | 2.3 |
| 5 | 125.00 | 2.8 |
| 6 | 150.00 | 3.5 |
| 7 | 175.00 | 4.6 |
| 8 | 200.00 | 5.6 |
| 9 | 225.00 | 7.2 |
| 10 | 250.00 | 7.5 |
| 11 | 275.00 | 7.9 |
| 12 | 280.00 | 9.2 |
| 13 | 275.00 | 10.3 |
| 14 | 250.00 | 11.2 |
| 15 | 200.00 | 12.3 |

**Graph 3 Load vs Deflection for regular I section (one end fixed one end pinned)**



From graph the maximum load taken by section is 280 KN at deflection 9.2mm.

**Ansys Result 3- Regular Column (one end fixed one end pinned)**



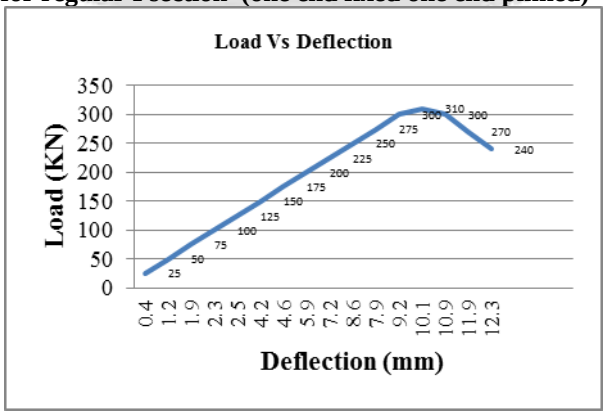

From Ansys result the maximum stress is 245.67 MPa and minimum stress is 50.66 MPa.

**Buckling test on castellated section (one end fixed one end pinned)**

**Tab. 4 Load vs Deflection for regular I section (one end fixed one end pinned)**

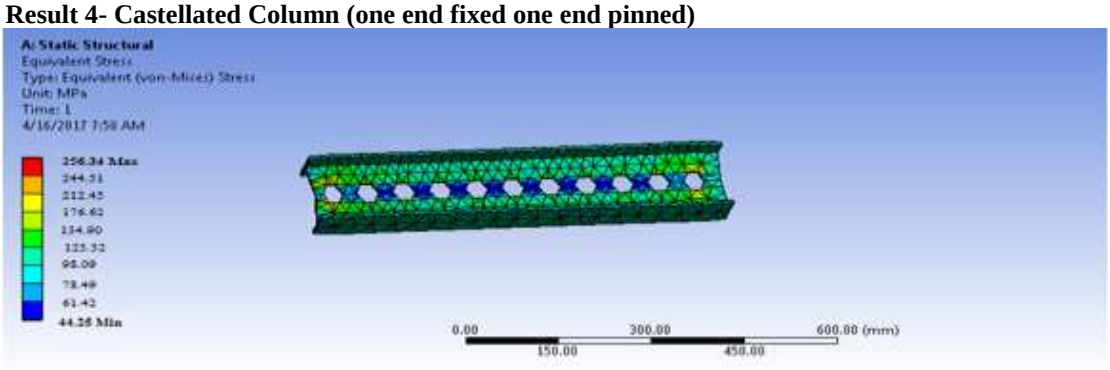
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 25.00 | 0.4 |
| 2 | 50.00 | 1.2 |
| 3 | 75.00 | 1.9 |
| 4 | 100.00 | 2.3 |
| 5 | 125.00 | 2.5 |
| 6 | 150.00 | 4.2 |
| 7 | 175.00 | 4.6 |
| 8 | 200.00 | 5.9 |
| 9 | 225.00 | 7.2 |
| 10 | 250.00 | 8.6 |
| 11 | 275.00 | 7.9 |
| 12 | 300.00 | 9.2 |
| 13 | 310.00 | 10.1 |
| 14 | 300.00 | 10.9 |
| 15 | 270.00 | 11.9 |
| 16 | 240.00 | 12.3 |

**Graph 4 Load vs Deflection for regular I section (one end fixed one end pinned)**



From graph the maximum load taken by section is 310 KN at deflection 10.1 mm.

**Ansys Result 4- Castellated Column (one end fixed one end pinned)**



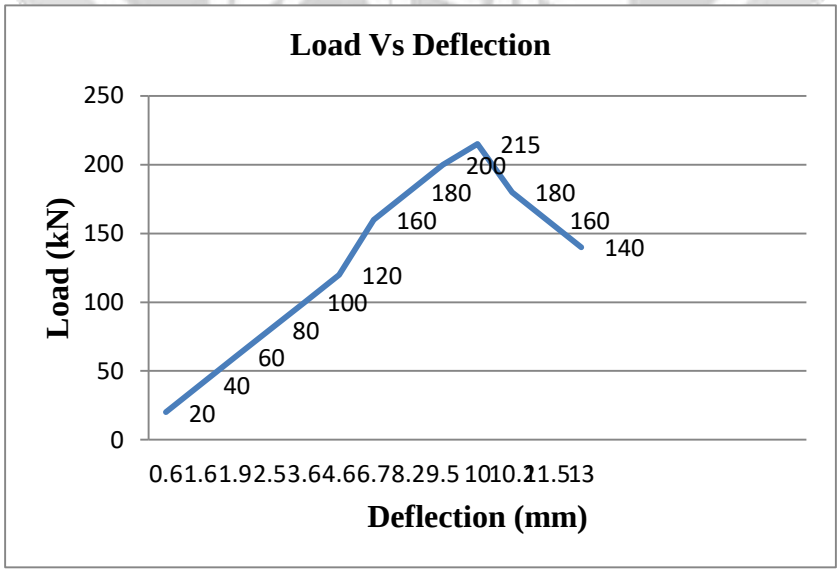

From Ansys result the maximum stress is 256.34 MPa and minimum stress is 44.25 MPa.

**Buckling test on regular section (one end fixed one end free)**

**Tab. 5 Load vs Deflection for regular I section (one end fixed one end free)**

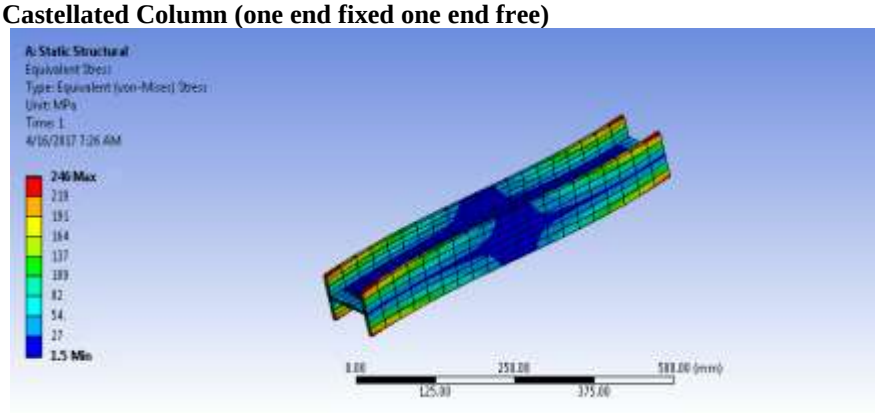
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 20 | 0.6 |
| 2 | 40 | 1.6 |
| 3 | 60 | 1.9 |
| 4 | 80 | 2.5 |
| 5 | 100 | 3.6 |
| 6 | 120 | 4.6 |
| 7 | 160 | 6.7 |
| 8 | 180 | 8.2 |
| 9 | 200 | 9.5 |
| 10 | 215 | 10 |
| 11 | 180 | 10.2 |
| 12 | 160 | 11.5 |
| 13 | 140 | 13 |

**Graph 5 Load vs Deflection for regular I section (one end fixed one end free)**



From graph the maximum load taken by section is 115.00 KN at deflection 10mm.

**Ansys Result 5- Castellated Column (one end fixed one end free)**



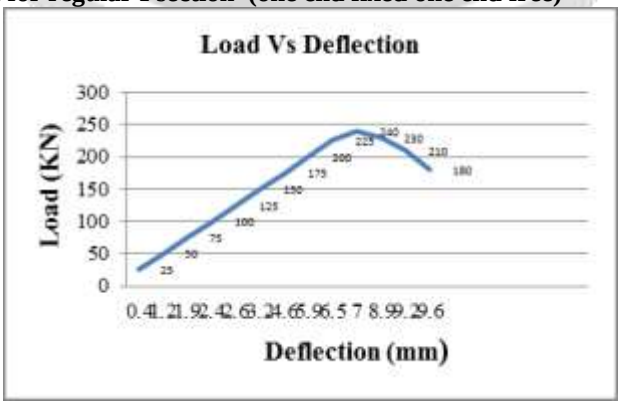

From Ansys result the maximum stress is 246 MPa and minimum stress is 1.5 MPa.

**Buckling test on castellated section (one end fixed one end free)**

**Tab. 6 Load vs Deflection for regular I section (one end fixed one end free)**

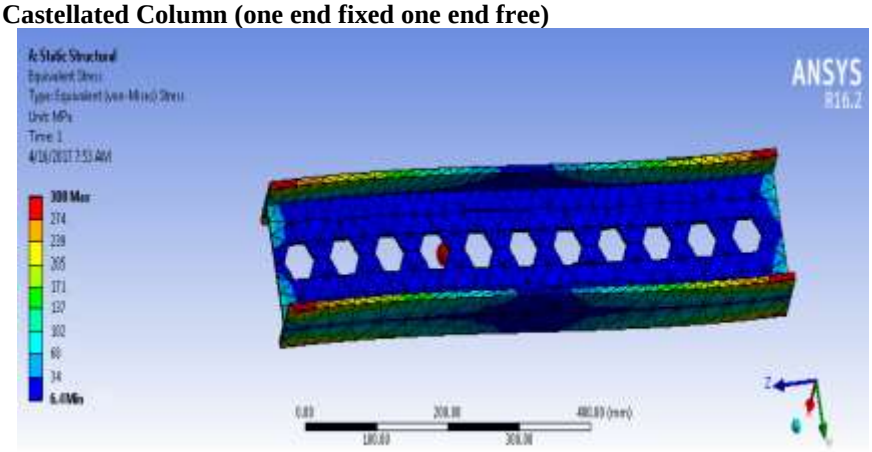
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 25 | 0.4 |
| 2 | 50 | 1.2 |
| 3 | 75 | 1.9 |
| 4 | 100 | 2.4 |
| 5 | 125 | 2.6 |
| 6 | 150 | 3.2 |
| 7 | 175 | 4.6 |
| 8 | 200 | 5.9 |
| 9 | 225 | 6.5 |
| 10 | 240 | 7 |
| 11 | 230 | 8.9 |
| 12 | 210 | 9.2 |
| 13 | 180 | 9.6 |

**Graph 6 Load vs Deflection for regular I section (one end fixed one end free)**




From graph the maximum load taken by section is 240.00 KN at deflection 7 mm.

**Ansys Result 6- Castellated Column (one end fixed one end free)**



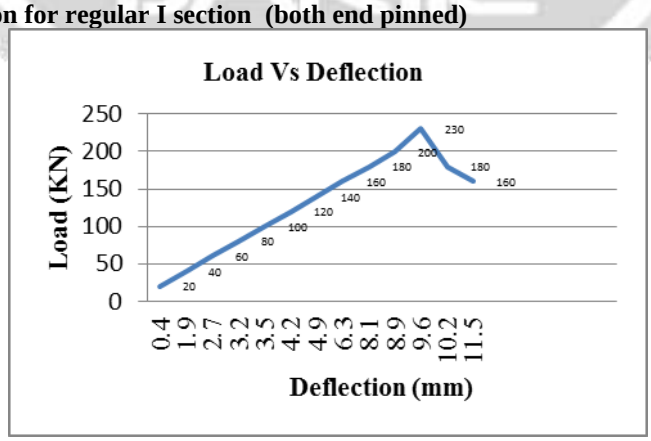

From Ansys result the maximum stress is 308 MPa and minimum stress is 6.4 MPa.

**Buckling test on regular section (both end pinned)**

**Tab. 7 Load vs Deflection for regular I section (both end pinned)**

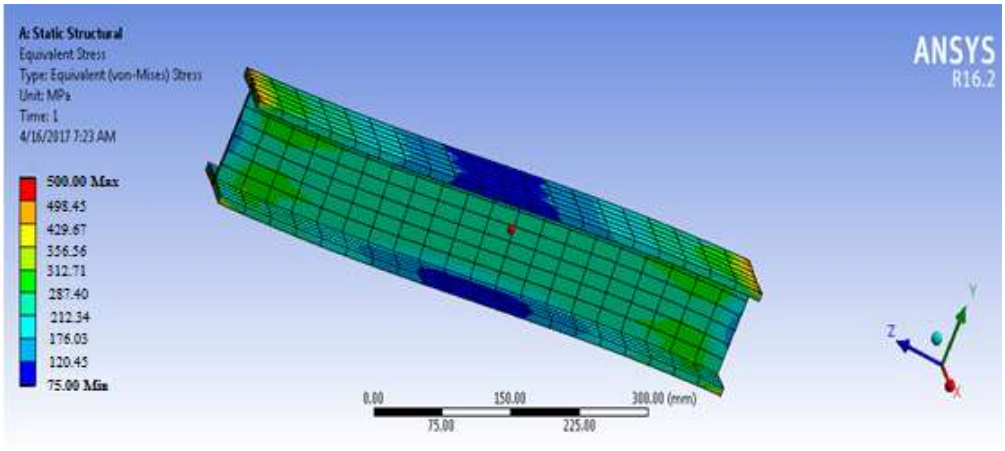
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 20 | 0.4 |
| 2 | 40 | 1.9 |
| 3 | 60 | 2.7 |
| 4 | 80 | 3.2 |
| 5 | 100 | 3.5 |
| 6 | 120 | 4.2 |
| 7 | 140 | 4.9 |
| 8 | 160 | 6.3 |
| 9 | 180 | 8.1 |
| 10 | 200 | 8.9 |
| 11 | 230 | 9.6 |
| 12 | 180 | 10.2 |
| 13 | 160 | 11.5 |

**Graph 7 Load vs Deflection for regular I section (both end pinned)**




From graph the maximum load taken by section is 230 KN at deflection 9.6mm.

**Ansys Result 7- Castellated Column (Both end pinned)**



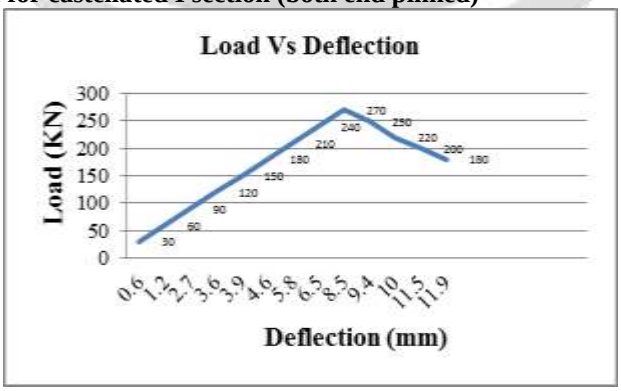

From Ansys result the maximum stress is 500 MPa and minimum stress is 75 MPa.

**Buckling test on castellated section (both end pinned)**

**Tab. 8 Load vs Deflection for castellated I section (both end pinned)**

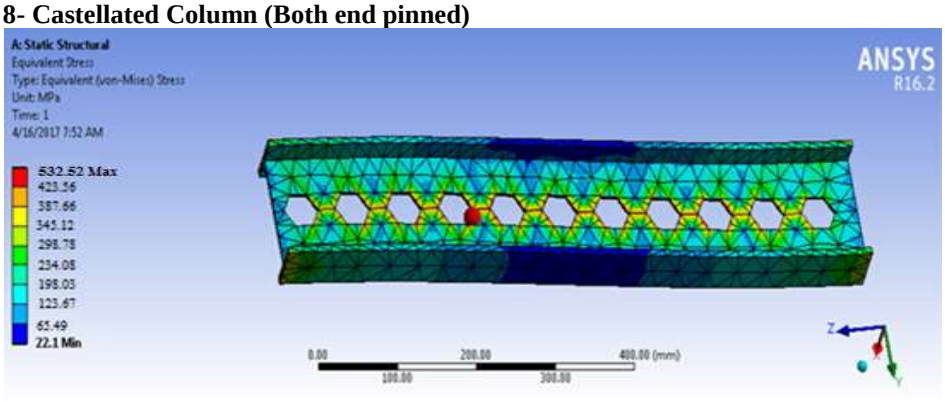
| Sr. No. | Load (KN) | Deflection (MM) |
|---|---|---|
| 1 | 30 | 0.6 |
| 2 | 60 | 1.2 |
| 3 | 90 | 2.7 |
| 4 | 120 | 3.6 |
| 5 | 150 | 3.9 |
| 6 | 180 | 4.6 |
| 7 | 210 | 5.8 |
| 8 | 240 | 6.5 |
| 9 | 270 | 8.5 |
| 10 | 250 | 9.4 |
| 11 | 220 | 10 |
| 12 | 200 | 11.5 |
| 13 | 180 | 11.9 |

**Graph 8 Load vs Deflection for castellated I section (both end pinned)**




From graph the maximum load taken by section is 270 KN at deflection 8.5mm.

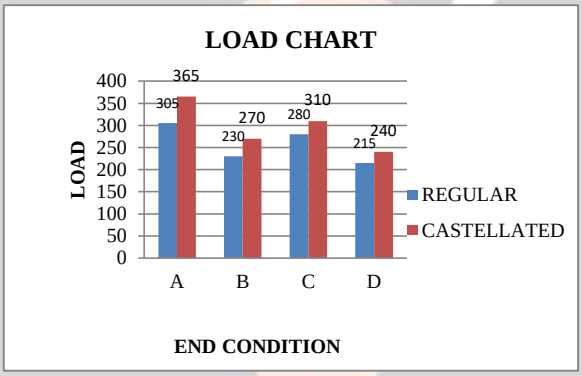
**Ansys Result 8- Castellated Column (Both end pinned)**




From Ansys result the maximum stress is 532.52 MPa and minimum stress is 22.1 MPa.

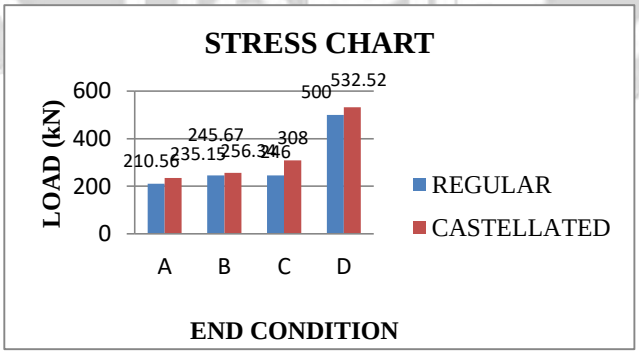
**Graph 9 Load Comparison**

Comparison chart between load for regular and castellated section for all end condition




**Graph 10 Stress Comparison**

Comparison chart between stress for regular and castellated section for all end condition




Where
A= Both end fixed
B=One end fixed one end pinned
C= One end fixed one end free
D= Both end pin

## 7. CONCLUSION

1. The maximum stresses developed in the castellated section are at corner. Both end fixed column carry more load as compare to other end condition.
2. The load taken by the regular column is 305 kN and castellated column is 365 kN for the both end fixed. The castellated column carries 17% more load as compared to regular column. The load taken by the regular column is 230 kN and castellated column is 270 kN for the one end fixed one end pinned. The castellated column carries 15% more load as compared to regular column.
3. The load taken by the regular column is 280 kN and castellated column is 310 kN for the one end fixed one end free. The castellated column carries more 10% load as compared to regular column. The load taken by the regular column is 215 kN and castellated column 240 kN is for the both end pinned. The castellated column carries 11% more load as compared to regular column.
4. From the Ansys result maximum stress developed in regular column is 210.56 MPa and castellated column is 235.15 MPa for both end fixed.
5. From the Ansys result maximum stress developed in regular column is 245.67 MPa and castellated column is 256.34 MPa for one end fixed one end pinned
6. From the Ansys result maximum stress developed in regular column is 246 MPa and castellated column is 308 MPa for one end fixed one end free.
7. From the Ansys result maximum stress developed in regular column is 500 MPa and castellated column is 532.52 MPa for both end pinned.
8. Stresses developed in castellated column are more as compared to regular column. Studying all the end condition it is clear that the both end fixed condition is more suitable for the column.
9. The stiffness of regular column for both end fixed is 32.68 kN/mm and for castellated column is 26.31 kN/mm, so castellated section is more effective than regular section.

## ACKNOWLEDGEMENT

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