Structural Analysis and Design of Castellated Beam in Cantilever Action

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Abstract – ***The majority of existing literature on castellated beam is focused on Simply supported analysis, but this paper provides new analytical solution for calculation critical buckling load by the cantilever action. In Simply supported castellated beam the maximum deflection takes place at the mid span of the Beam, but in cantilever castellated beam maximum deflection on the free end. By experimentally it was observed that the value of web shear deformation on the critical buckling load of castellated beam increase with the increase in cross sectional area of the tee section and depth of web opening, but decrease with the length and web thickness. The experimental study of the castellated beam is verified on the cantilever action in the castellated beam the buckling capacity of the web post with fillet corner hexagonal web opening are compared with the circular opening by this opening service pipe can also have passed through this. Comparison Between Castellated Beam and Cellular Beam is executed by different test. A concentrated load or reaction point applied directly over a web-post cause this failure mode, such a failure mode could be prevented if sufficient web reinforcing stiffeners are provided in castellated beam we have to use hexagonal, Square opening and cellular has to kept circular web.***

Use of Castellated beam for various structure rapidly getting appeal. This happens due to increased depth of section without any addition of weight, high strength to weight ratio, their lower maintenance and painting cost. The limitation of castellated beam is Stress concentration occurs near the perforation and the shear carrying capacity is reduced. Stress concentration may be reduced by making perforation near the neutral axis where the stresses are negligible.

Key Words: **structural, castellated beam, FEA.**

1. INTRODUCTION

Cutting and re-welding a solid web steel beam with perforation is a castellated beam not only have higher bending moment capacity but also more effective in terms of passing service wires, pipes and ventilating ducts through opening. Failure of web opening depends on opening shape, opening dimensions, the distance between opening, web post thickness. Modes of Failure -

1. Flexural failure of the section
2. Lateral torsional buckling of beam
3. Local buckling of web or flange
4. Rupture of weld in the web post
5. Vierendeel failure of perforation of section
6. Web post buckling

The cutting of castellated beam may be hexagonal, square, circular, fillet corner hexagon. Three group of castellated steel beam were analyzed to show effect of opening shape on the web post buckling behavior. Castellated beam are such structural members which are made by flame cutting a rolled beam along its center line and then rejoin the two halves by welding so that the overall depth is enhanced by 50% to increase structural performance against bending.

Reasons for fabricating-

a. The increase in sectional height that result in the enhancement of moment of inertia, sectional modulus, stiffness and flexural resistance of the sections.
b. Decrease the weight of profile which in turns, cut down the weight of whole structure and economized on construction work.
c. There is no need of plate girder.
d. The passage of service wires through the web opening

Castellated beams are used as a structural member in multistory building, commercial and industrial building, ware house and portal frames. Consequently, various theoretical and experimental studies reported in a deferent failure modes have been identified and investigated Vierendeel collapse mechanism, buckling of a web post, web weld failure, flexural failure, lateral torsional buckling, shear failure. The Vierendeel mechanism can be defined as “continuous formation of plastic hinges at the ends of four tee sections above and below opening under the combinations of bending moment, local axial force and local shear force.” The

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resistance of castellated beams is continuously controlled by shearing forces. These forces may cause extravagant stresses in the tee-sections above and below the hole's extravagant stresses at mid-depth of the web-post between holes or web-buckling involving the web-post. [1]

2. CASTELLATED BEAM

A) Terminology

Throughout this paper various terms will be used to discuss castellated beam components and testing results. This section introduces the reader to the definition of these terms. Web Post: The cross-section of the castellated beam where the section is assumed to be a solid cross-section.

- Castellation: The area of the castellated beam where the web has been expanded (hole).
- Throat Width: The length of the horizontal cut on the root beam. The length of the portion of the web that is included with the flanges.
- Throat Depth: The height of the portion of the web that connects to the flanges to form the tee section. [1]

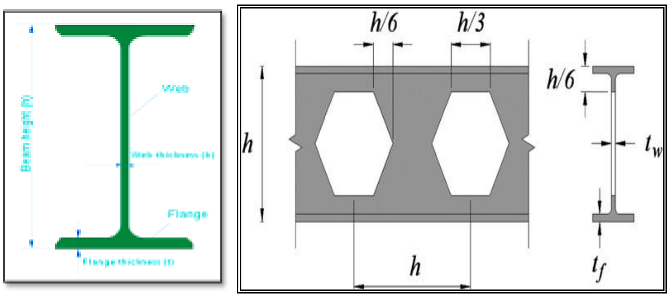

Fig. 1. Terminology

B) Notation-

b Flange width
C_d Coefficient relating relative brace stiffness and curvature
C_L Reduction factor for the initial imperfection
E Modulus of elasticity
G Shear modulus of elasticity
h Full depth of the section
h_o Distance between flange centroids
h_w Clear distance between flanges less the corner radius
I_y Out-of-plane moment of inertia
L Span length
L_b Unbraced length
L_p Limiting laterally unbraced length for the limit state of yielding
L_r Limiting laterally unbraced length for the limit state of inelastic lateral-torsional buckling
M_{cr} Critical moment
M_n Nominal lateral-torsional buckling strength
M_o Elastic critical moment of a doubly-symmetric beam undergoing lateral-torsional buckling
M_p Plastic bending moment
M_r Required flexural strength
P_y Elastic critical buckling load
t_f Flange thickness
t_w Web thickness

C) Fabrication of Castellated Beam and Cellular Beam

Fabrication of castellated beams is a comparatively common events of operations when adequate handling and controlling equipment is used. Structural Steel by burning two or more at a time, depending upon their depth. Division is performed by using a component of the oxy-acetylene gas cutter machine. This is an electrically actuated buggy which function on a fixed track. The buggy has building burning patterns that can be adjusted to any one of live standard longitudinal "module" dimensions and to any hall-opening height.

Castellated steel beams fabricated from standard hot-rolled I-sections have many advantages including greater bending rigidity, larger section modulus, optimum self-weight-depth ratio, economic construction, easy services through the web openings and aesthetic architectural appearance. However, the castellation of the beams results in classifiable failure modes depending on geometry of the beams, size of web openings, web slenderness, type of loading, quality of welding and lateral restraint conditions. The failure modes comprise shear, flexural, lateral torsional buckling, rupture of welded joints and web post-buckling failure modes.

1) In the beginning we cut the I-section into 12 pieces of 1m each.
2) Then we marked the cutting alignment to each three section of hexagonal, square, circular Resp.
3) By using gas cutter, we cut the each nine I-Beam in pre-determined pattern.
4) Then we welded the two Separated I-section face-to-face.
5) Then we observed all the un-Alignment corner parts.
6) Then we filled the un-Alignment parts by welding plates at the corner to make the stability.
7) Then test these prepared Beams on the UTM machine to gain its strengths.[5]

Fig. 2. Fabrication of Castellated Beam and Cellular Beam

D) Design of Cellular Beam

1) Guidelines for web perforations

The limits of applicability are:

a) $1.08 < S/D0 < 1.5$

b) $1.25 < D/D0 < 1.75$

Where, S= center /center spacing,
Do= Diameter of opening,
D= Total depth of beam

2) Ultimate limit state:

To check the beam for the ultimate limit state condition, it is necessary to check the overall strength of the beam the strength of its elements. The following checks should be carried out:

a) Overall beam flexural capacity.

b) Beam shear capacity (based on the reduced section)

c) Overall beam bucking strength.

d) Web post flexure and bucking.

e) Vierendeel bending of upper and lower tees.

3) Overall beam flexural capacity:

The maximum moment under factored dead and imposed loading, Mu should not exceed Mp, where Mp is calculated as follows:

$Mu \leq Mp = A_T P_y h$

Where, A_T =area of lower Tee,
P_y =yield stress of steel,
h = distance between centroids of upper and lower tee.

4) Beam shear capacity:

Two modes of shear failure should be checked. The vertical shear capacity of the beam is the sum of the shear capacities of the upper and lower tees. The factored shear force in the beam should not exceed P_{vy} where:

$P_{vy} = 0.6 \times P_y$ (0.9 $\sum$ area of webs of upper and lower tees)

In addition, the horizontal shear in the web post should not exceed P_{vh} where:

$P_{vh} = 0.6 \times P_y$ (0.9 x minimum area of web post)

Horizontal shear is developed in the web post due to the change in axial forces in the tee.

5) Interaction of axial and high shear forces

In BS 5950 part 1 clause 4.2.6, the interaction between axial forces (or bending moment) and shear in the web of beam is based on a linear reduction of axial or bending capacity for forces exceeding 0.6 P_v. It follows that as the shear force given above approaches P_v, the axial or bending capacity of the web portion of the web tee reduces to zero. This interaction may be taken into account by modifying the web thickness depending on the shear force resisted by the web.

6) Overall beam buckling strength:

To assess the overall buckling strength of a cellular beam, it is recommended that beam properties are determined at the center line of the opening and that lateral torsional buckling strength is then determined in accordance with BS 5950: part 1, section 4. If the compression Flange is restrained sufficiently, this check may not be necessary.

7) Web post flexural and buckling strength

The web post flexural and buckling capacity should be checked using the equation.

8) Vierendeel bending of upper and lower tees:

The critical section for the tee should be determined by using one the methods as described by Olander's or Sahmel's approach. The combined forces in the tee should be checked as follows:

$P_o/P_u + M/M_p \leq 1$

Where Po and M are forces and moments on the section
Pu = area of critical section
M_p = plastic modulus of critical section for plastic sections

M_p = elastic section modulus of critical section for other sections.

9) Serviceability limit state

To ensure an adequate design, the secondary deflections occurring at the opening should be added to the primary deflections due to overall bending of the beam. The total deflection of the beam is found out by summation of deflection due to shear in tee and web post and bending in tee and web post for each opening. The shear force leads to additional deflections. [3]

Fig. 3. Shape of Castellated beam

D) Design of Castellated Beam

1. The angle of cut is selected to be 45°. For a good design the depth of stem of the t-section at the minimum beam cross-section should not be less than by 4 of the original beam section.

2. The load over the section from the roof are a curtained and the maximum bending moments are computed.

3. The cross sectional area of the t-section at the open throat is calculated. Neutral axis of the section is determined and moment of inertia about the neutral axis is calculated.

4. The moment of resistance of the castellated beam which is the product of the resultant tensile or compressive force and the distance between the centroid of T-section is calculated.

$$M.R. = A \times \sigma_{at} \times d$$

Where A = area of the T section at open throat

D = distance between the centroid of T section

The moment of resistance of the castellated beam should be more the maximum moment.

5. The spacing of castellated beam should not exceed the spacing determined by following equation

$$S = P/ W \times l$$

Where S= c/c distance between the castellated beam in meter.

P = net load carrying capacity in N

W = design load in N / m2

l = span of the in meter

6. Stiffeners are designed at the supports and below the concentrated loads.

7. The beam is checked in shear. The average shear at ends is calculated from following equation

$$\tau_{va} = R/d' \times t < 0.4 f_y$$

Where R = end reaction in N

d' = depth of the stem of T section

t = thickness of stem

8. The maximum combined local bending stress and direct stress in T Segments is also workout and should be less than the permissible bending stress.

9. The maximum deflection of T Segment is calculated. This occurs at the mid span is due to the net load carrying capacity load capacity.

Let, δ1 = deflection due to net load carrying capacity

δ 2 = deflection due to local effects

I = average moment of inertia of the section

IT = moment of inertia of T section

P = number of perforation panels in half span

$$\delta 1 = \frac{5 \quad WL3}{384 \quad EI}$$

$$\delta 2 = \frac{VavgP(m+n)3}{24EIT}$$

$$\delta = \delta 1 + \delta 2 < L/325$$ [3]

E) Fabrication of Fixed Support assembly

1) In this project work we have prepared a two Fixed Support assembly

2) Bottom Jaw of a Fixed Support assembly is of size 165mm x 230mm & It works of fixing to movable cross head of a Universal Testing Machine.

3) Upper Jaw of a Fixed Support assembly is of size 165mm x 170mm and it performs load distribution to the castellated beam.

4) Now by excluding distance 30mm from both side and mark it and drilled the holes of 16.5mm diameter at the center.

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Fig. 4. Fixed Support assembly

5) after that these two Blocks fixed such that the upper Block's comes at the middle of the Lower one.

6) Now mark the upper block at the four corner.

7) after that we drilled former holes on the Both blocks of the Fixed Support assembly.

7) Then we took found foundation Bolt of length 800 mm and gave threads to them at the top and bottom.

8) Now fixed the foundation bolt at corner holes by using threads.

9) Then we passed a steel plate through foundation bolt and tight it by using rubber pad.

10) Then lock the castellated I-Section by steel plates and rubber pad using four bolts.

Fig. 5. Fabrication of Fixed Support assembly

3. TEST SETUP AND EQUIPMENT-

1) In the beginning we performed all the initial adjustment.

2) remove all the fixtures on the lower – cross head of UTM.

3)then put cantilever fixture on the lower-cross head of UTM.

4) after that, fixed the Fixed Support assembly by using Nut-Bolt available at both side of Block.

5) Then fixed cantilever I-section between upper Block & steel plate using Nut-Bolts.

6) Then loading Assembly is fixed on the movable cross head of UTM with the I-Section.

7) put the extensometer Below the castellated I-section.

8) Then start loading taking loading assembly in the middle of cantilever beam.

9) Then noted down the result of Load & deflection.

10) Then, apply all the above step for the hexagonal, circular, square & plane castellated Beam and Note down the Result of Load and deflection.

Fig.6. Lateral torsional buckling on NPI-125 (Hexagonal)

Fig.7. Load vs Deflection Graphics for NPI-125 (Hexagonal)

Fig.8. Lateral torsional buckling on NPI-125 (Circular)

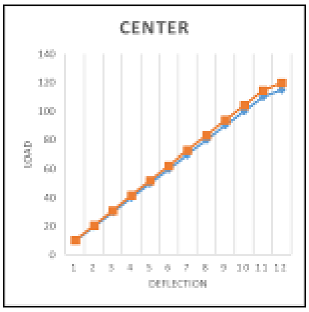

Fig.9. Load vs Deflection Graphics for NPI-125 (Circular)

Fig.10. Lateral torsional buckling on NPI-125 (Square)

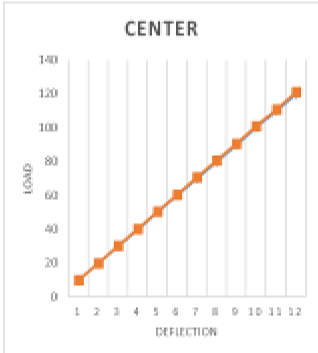

Fig.11. Load vs Deflection Graphics for NPI-125 (Square)

Fig.12. Lateral torsional buckling on NPI-125 (Plane)

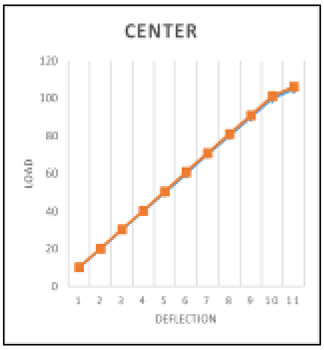

Fig.13. Load vs Deflection Graphics for NPI-125 (Plane)

Fig.14. Experimental Set-up

IV.ANALYSIS BY ANSYS

The finite element software ANSYS was used to investigate the bucking behavior of the web-post. The resulting increased stress towards the edge of the opening, promotes a premature buckling along the web opening.

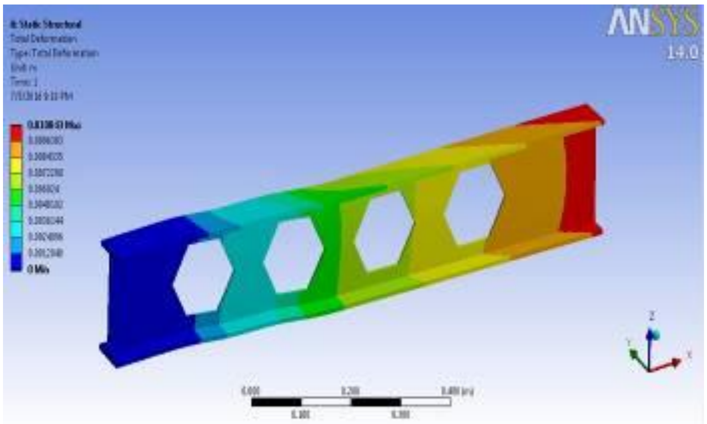

Fig.15 Total Deformation of hexagonal I Section in Cantilever condition

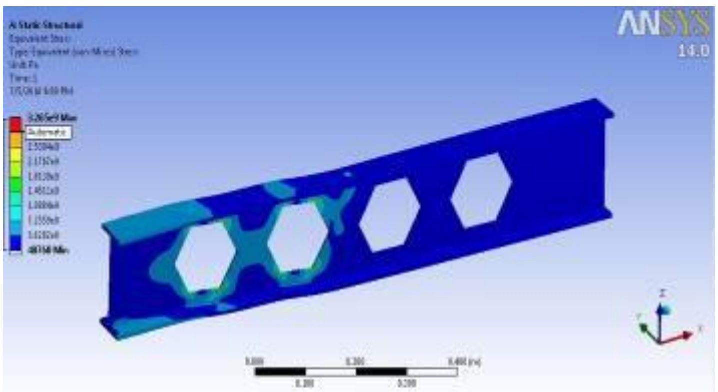

Fig. 16 Equivalent Stress of hexagonal I Section in Cantilever condition

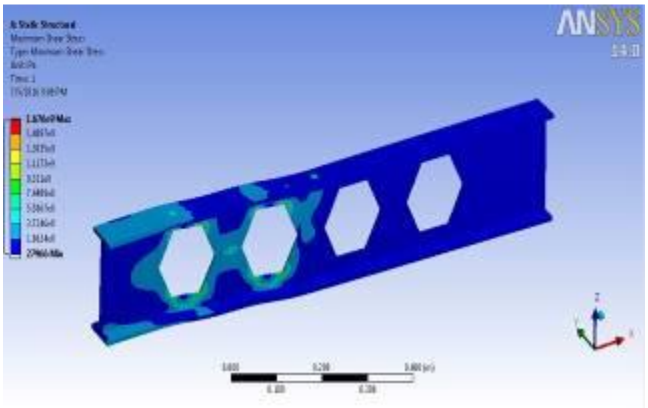

Fig. 17 Maximum Shear Stress of Plane I Section in Cantilever condition

3. CONCLUSIONS

Depth is the most important parameter which regulate the sectional property of the section. For the serviceability moment of inertia plays very vital role and moment of inertia of I-section is directly proportional to the third power of the depth Use of castellated beams and cellular beams for different structures rapidly gaining appeal. This is due to increased depth of section without any additional weight, high strength to weight ratio, their lower maintenance and painting cost, the prime advantage of castellated beam is increase in vertical bending stiffness, easy service provision and attractive appearance primarily. In castellated beam and cellular beam, we increase the depth of the section as discussed earlier up to certain limit and under the consideration of the web shear. In castellated beam to avoid local failure of beam provision of plate below concentrated load, to provide reinforcement at the weak sections of the beam, to avoid Vierendeel effect (to avoid stress concentration) corners of the holes are to be rounded are concluded.
From the test analysis result of this Study the following Conclusion can be reasonably made-
1)The composite moment of inertia of the castellated beam section as found in catalogs.
2)The castellated beam section properties should be used to calculate the flexure strength of castellated beam.

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