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Structural Analysis and Design of Castellated Beam in Fixed Action

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***Abstract*— The depth is the most important parameter which governs the sectional property of the section. For the serviceability moment of inertia plays very important role and moment of inertia of I-section is directly proportional to the third power of the depth. Research on cellular beams with circular web openings is very limited and is less developed than Cellular beams which may be attributed to the fact that cellular beams are more complicated to analyze due to their continuously changing section properties around the cell.**

Keyword- structural, Cellular beam, FEA.

I. INTRODUCTION

Cellular beam have been used in construction for many years. Today with the development of automated cutting and welding equipment. These beams are produced in an almost unlimited number of depths and spans. Suitable for both light and heavy loading conditions. In the past the cutting angle of Cellular beams ranged from 45° to 70° but currently, 60° has become a fairly standard cutting angle. Although 45° sections are also available. It should be noted that these are approximate values. Actual angles will vary slightly from these to accommodate other geometrical requirements.

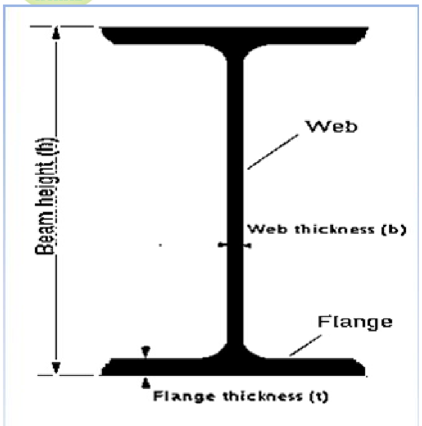
The beam section obtained in such away can be even 50% deeper than the original section by increasing the depth, the section modulus is increased by about 2.25 times the section modulus of original beam section. Thus load carrying capacity of the beam increased by considerably. A Cellular beam has some limitations also viz. stress concentration occurs near the perforations and the shear carrying capacity is reduced. Stress concentration may be reduced by making perforations near the neutral axis where the stresses are small admitting the cut in zigzag way. The shear carrying capacity can be increased by stiffening the web at points of concentrated loads and reaction. The primary advantage of Cellular beams is the improved strength due to the increased depth of the section without any additional weight. However one consequence of the increased depth of the section is the development of stability problems during erection. To fully utilize the engineering advantage of Cellular beams, erection stability must be considered. Cellular beams have been used as structural members in the Europe and the United States since the early 1900's. The theory behind the Cellular beam is to increase the beam's depth and strength without adding additional material. Prior to automated cutting and welding technology, the manufacturing process used to make Cellular beams was to cut the beam apart and weld them back together manually. The resistance of Cellular beams is frequently controlled by shearing forces. These forces may cause excessive stresses in the tee-sections above and below the holes excessive stresses at mid-depth of the web-post between holes or web-buckling involving the web-post.[1,2]

II. CELLULAR BEAM

A) Terminology

Throughout this paper various terms will be used to discuss Cellular beam components and testing results.

- **Web Post:** The cross-section of the Cellular beam where the section is assumed to be a solid cross-section.
- **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.
- **Expansion Percentage:** The percentage change in depth of the section from the root (original) beam to the fabricated Cellular section.



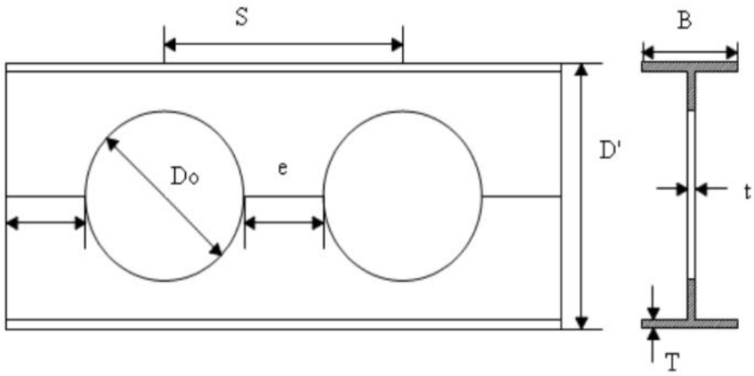


Figure 1. Terminology

B)Design criteria:

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= centre /centre 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:

$Mu \leq Mp = A_{Tee} P_y h$

Where A_{Tee} =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 centre 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:

Po/Pu + M/Mp ≤ 1

Where Po and M are forces and moments on the section at an angle Ɵ from vertical.

Pu = area of critical section x Py and Mp = plastic modulus of critical section x Py for plastic sections Or Mp = elastic section modulus of critical section x Py for other sections The value of Mp depends on section classification.

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]

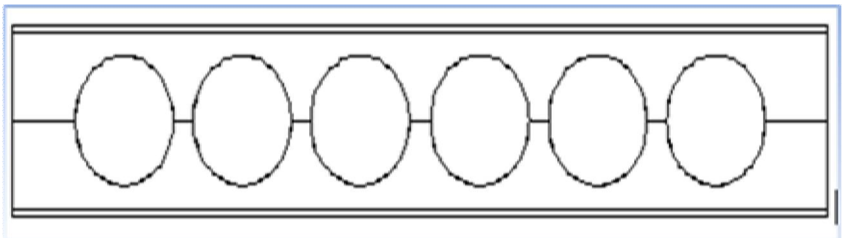


Figure 2 Cellular Beam

C) Fabrication:

Fabrication of Cellular beams is a comparatively simple series of operations when adequate handling and controlling equipment is used. Structural Steel by burning two or more at. a time, depending upon their depth. Splitting is performed by using a component of the oxy-acetylene gas cutter equipment shown in fig.5.1 This is an electrically propelled buggy which runs 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.

Cellular 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, ease of services through the web openings and aesthetic architectural appearance. However, the castellation of the beams results in distinctive 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 postbuckling failure modes. Investigation of these failure modes was previously detailed by Kerdal and Nethercot. Also detailed review of the experimental and theoretical investigations on the failure modes of Cellular beams. However, accurate finite element modelling of the buckling behaviour of Cellular steel beams is quite complicated due to the presence of the initial geometric imperfections, web openings, lateral buckling restraints and loading conditions. Hence, to date, there is no detailed finite element model in the literature highlighting the interaction of buckling modes in Cellular beams, which is addressed in this study.[4]

Figure 3 Experimental Set-up

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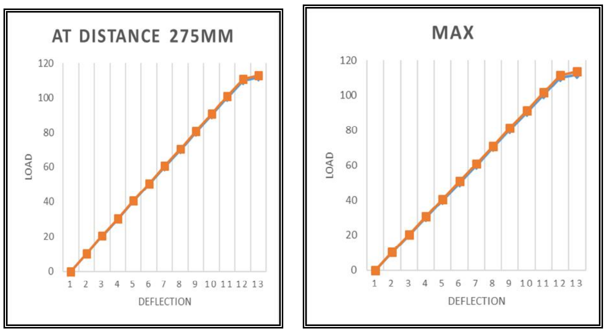
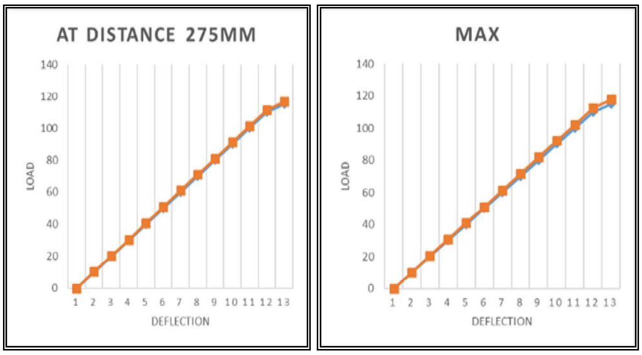
III.ANALYSIS OF FIXED BEAM

Fig.4 Lateral torsional buckling on NPI-125 (Hexagonal)



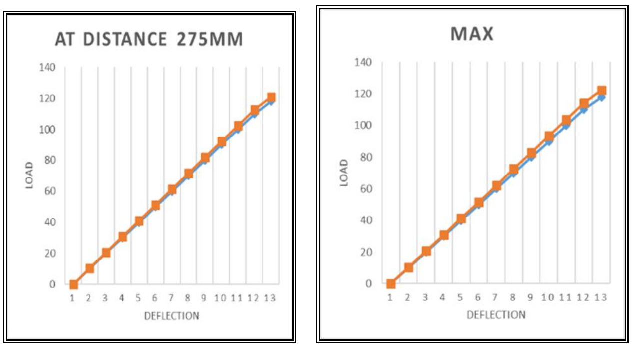
Graph 1 Load vs Deflection Graphics for NPI-125 (Hexagonal)

Fig.5 Lateral torsional buckling on NPI-125 (Circular)



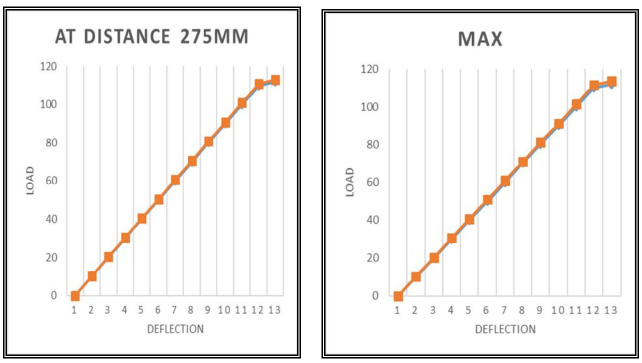
Graph.2 Load vs Deflection Graphics for NPI-125 (Circular)

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



Graph.3 Load vs Deflection Graphics for NPI-125 (Square)

Fig.7 Lateral torsional buckling on NPI-125 (Plane)



Graph.4 Lateral torsional buckling on NPI-125 (Plane)

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IV.ANALYSIS BY ANSYS

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

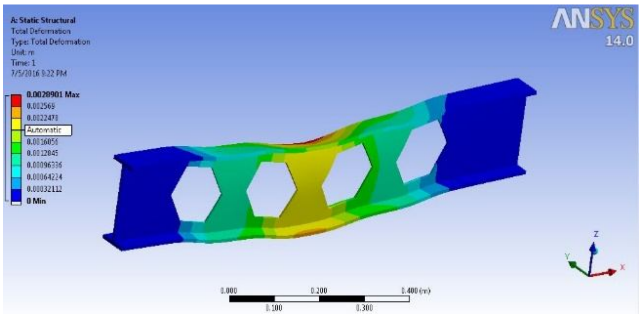

Fig. 8 Total Deformation of Hexagonal I Section in condition

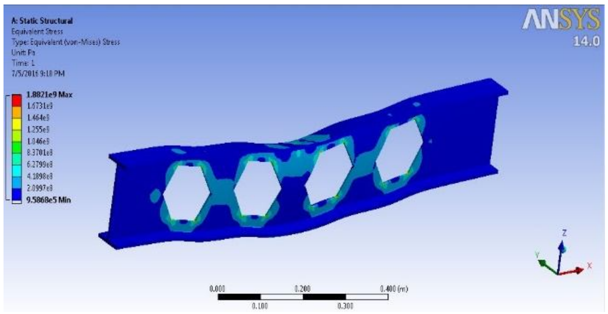

Fig. 9 Equivalent Stress of Hexagonal I Section in Fixed Fixed condition

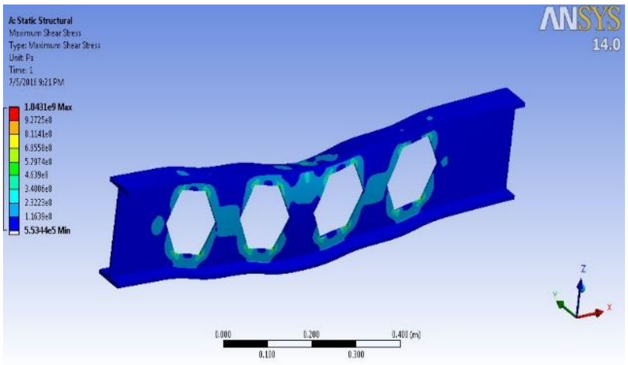

Fig. 10 Maximum Shear Stress of Plane I Section in Fixed condition

V. CONCLUSION

Cellular Beam is also called as Circular perforated web. Main objective of circular perforated web is to increase the depth of section so that the moment of inertia parameter will be increase. Cellular beam have been used in many year. The Cellular beams were firstly used in Europe in 1950s due cheap labor cost. The primary advantages of cellular beam are the improved strength due to increased depth of the section without any additional weight.

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