Castellated Beam: A trending know-how

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Abstract: Now a day, use of castellated steel beams has become very admirable as well as in demand due to its advantageous implementations in the construction of buildings. Castellated beams are trending currently and have multiple options to display too. The key part is, it is having openings in its web portion. These Beams are those which are fabricated from standard hot rolled steel I- sections by cutting along its web in "zigzag" pattern and thereafter rejoining the two halves on one another by welding together to form a castellated beam, so that generally the depth of a section will be increased by 1.5 or 1.33 times overall depth of the standard beam. Equal strength in tension & compression, easy construction, permits large span construction, real initial & life-cycle cost, strength, the speed of construction are the main factors for using steel as a building material. The aim is to compare between Standard I section and castellated beam with the hexagonal opening for different span length and for that find out the optimum size of the beam and compare its weight and deflection.

IndexTerms **- Castellated Beam, Standard I-section Beam, Deflection, Weight.**

I. INTRODUCTION

In the era of fast construction, and the prefabricated structure (PEB), structural engineers had developed design and construction of steel and composite buildings to determine the most suitable castellated beam section that can produce of desirable strength without compromising engineering performance and minimum possible self-weight so the overall cost can be reduced. Standard I-beam can be modified by providing web openings. Web openings with the different geometrical shape have been used to increase the floor height, aesthetic view, reduce the cost of construction, lower the maintenance ratio, easy to install at the construction site without increasing the weight of the beam.

The Castellated beam can be made by cutting the web of a Standard Steel I-beam in a certain pattern and then one plate slide and re-welding the two parts to each other. By this process the overall beam depth increases which increase the capacity of the original section. The new section with holes will have a depth of at least 50% more and its section modulus is increased by 2.25 times than the original section. The most common structure types built using these beams are office buildings, car parks, shopping centers and any structure with a suspended floor. Web-expanded beams provide a very economical solution for producing tapered members, which have been used immensely in big sports stadiums.

The Castellated beam is made by cutting a Standard I-Section beam of depth (d) in such a way that it creates a regular pattern of holes in the web with increased depth of section (D). A beam with regular openings in its web portion is called a castellated beam. Fig1 shows the step by step castellation process of the castellated beam from the solid I section.

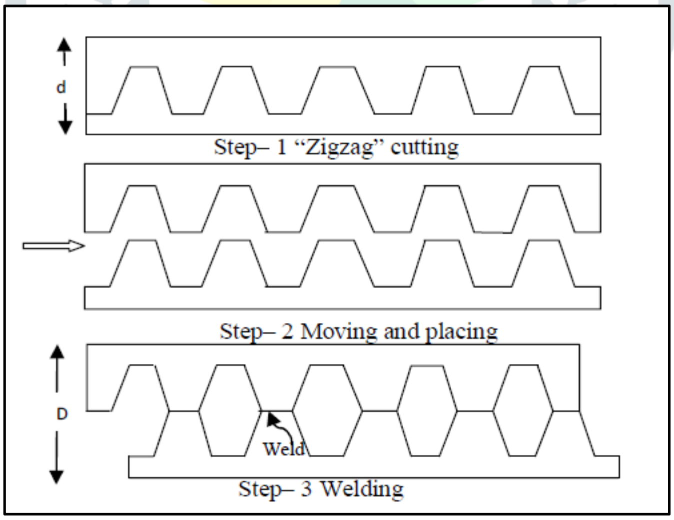

Figure1 Castellated Beam Process

The web of the section is cut by flame along the horizontal x-x axis along a "Zigzag" pattern as shown in Fig.1. The two halves are then welded together to produce a beam of greater depth with the hexagonal opening in the web. Due to the increased depth of section, section modulus is also increased 1.5 times and greater bending rigidity than the original section without any increase in weight. This makes the design even lighter and more cost-efficient steel structures. The usual types of the Castellated beam are as

Hexagonal Castellated Beam, Cellular Beam, Castellated Beam with Diamond Shaped Opening, Castellated Beam with Octagonal Shaped Opening, Rectangular Castellated beam and Square Castellated beam

II. METHODOLOGY

Step 1: Calculation for properties ofsection(as per steel table)
Where A = Area of the section, B_f = Breadth of the flange, t_f =Thickness of flange, t_w =Thickness of web, I_{xx}&I_{yy} = Moment of inertia about 'x' and 'y' axis respectively, Z_{xx}&Z_{yy} = Section modulus about 'x' and 'y' axis respectively

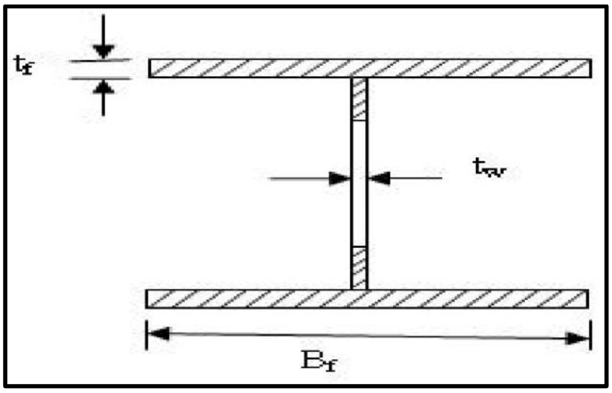

Figure 2 Geometry of Castellated beam

Step 2: Section Classification
Decide section is plastic, semi compact or compact.

Step 3: Load applied over section
Find total load applied on castellated beam and the moment of resistance of the castellated section.

$$M_R = A\,\sigma_{at}\,d \quad (1)$$

Where A = Area of the T-section at open throat, M_R = Moment of resistance, d = distance between the centroids of T-sections

Spacing is determined by,

$$S = \frac{P\prime}{W\prime l} \quad (2)$$

Where S = c/c distance between the castellated beam (m), P' = net load carrying capacity (N), W' = design load (N/m^2), l = Span of the beam (m)

Step 4: Shear check

i. Horizontal Shear:

$$Maximum\ end\ shear = \frac{P\,l}{2} \quad (3)$$

Where P = Load (N/m), l = Span of beam (m)

ii. Vertical Shear:

$$Elastic\ shear\ stress = \frac{VQ}{I_z t} \quad (4)$$

Where V = Shear Force, Q = Static moment of cross section = Aỹ, I_z= Moment inertia about major axis, t = Thickness of web

Step 5: Check for deflection

i. Deflection due to net load carrying capacity

$$\delta_1 = \frac{5Wl^3}{384EI} \quad (5)$$

Where W = Total central load converted from uniformly distributed load, E = Modulus of elasticity, I = Average moment of inertia of the section, l = Span of beam

ii. Deflection due to local effects

$$\delta_2 = \frac{V_{avg}\,p(m+n)^3}{24EI_T} \quad (6)$$

V_{avg}= Average Shear, p = number of perforation panels, m, n = distances as shown in Fig.3

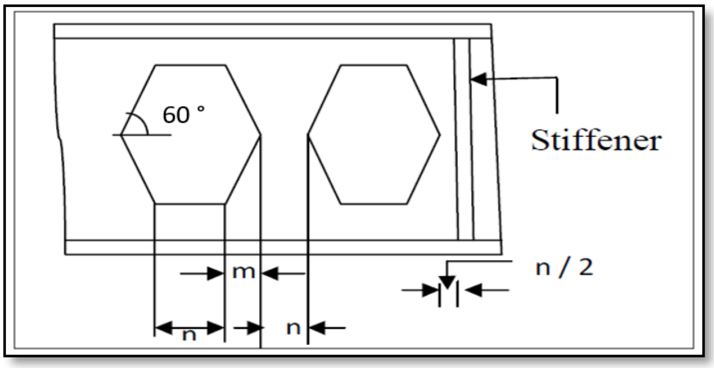

Figure 3 Dimensions of perforations

$$Total\ Deflection = \delta_1 + \delta_2 < \frac{l}{325} \qquad (7)$$

Step 6: Check for Combined Stress

The beam is checked for combined local bending and direct stresses at various locations as shown in Fig.4. The maximum moment and shear effects are combined to give the worst combination at this point and the maximum combined local bending stress and direct stress in T-segments is also worked out and should less than the permissible bending stress.

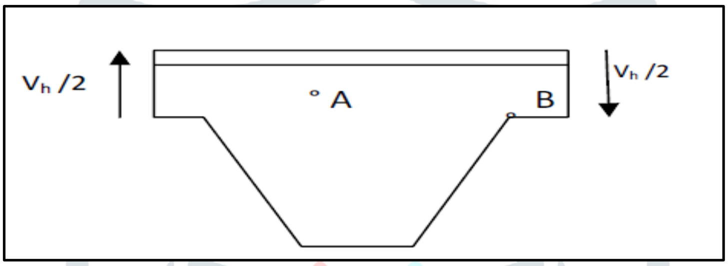

Figure 4 Stresses at various locations

$$Direct\ Stress\ due\ to\ moment\ = \frac{M}{Area\ of\ T * distance\ b/w\ centroid} (8)$$

$$Bending\ Stress\ due\ to\ shear = \frac{V_u * width\ across\ top\ of\ opening}{I_T} (9)$$

Where M = Moment, I_T = Moment of inertia of T-chord, V_u = Shear Force (kN)

$$Combined\ Stress = Direct\ stress\ due\ to\ moment + \ Bending\ stress\ due\ to\ shear \qquad (10)$$

Step 7: Bearing Check

$$n_2 \ = \ 2.5(t_f \ + \ R) \qquad (11)$$

$$f_w = (b_1 + n_2)t_w f_{yw} \qquad (12)$$

b_1 = stiff bearing length, f_w = Bearing capacity, f_{yw} = Design strength of the web, R = Radius of Gyration

Step 8: Web bucking at end

In practice, the end opening will be filled, which is considered as a good detailing practice. Stiffener will be provided for added security at the ends of the beam.

$$F_{wb} \ = \frac{(b_1 + n_1)t_w f_{cd}}{\gamma_{mo}} (13)$$

F_{wb} = Web bucking at end, f_{cd} = Design Compressive stress, γ_{mo} = Partial safety factor against yield stress and bucking

Step 9: End Stiffeners

Stiffeners are designed at the support and concentrated loads. The average shear at end is

$$\tau_{va} = \frac{R}{d' t} < 0.4\, f_y \qquad (14)$$

Where R = end reaction (N), d' = depth of the stem of T-section, t = thickness of the stem

$$Load\ carrying\ capacity = \sigma_{ac} * Area (15)$$

Step 10: Check for bucking of web post of castellated beam

The bending stress in web post in given by,

$$f_{max} = \frac{1.58V_h}{t_{we}} < \frac{f_{yw}}{\sqrt{3}\gamma_{mo}} (16)$$

$$\text{Horizontal shear} = V_h = \frac{Vp}{h} \quad (17)$$

Where F_{yw}= Yield stress of steel

Equivalent slenderness of plate,

$$\lambda_{LT} = 2.8\lfloor\frac{\beta L_e d}{t^2}\rfloor^2 \qquad (18)$$

Where L_e = effective Length, β = 1 = Plastic section, t = thickness of web, d = depth of we post

Form f_y and λ_{LT}, Find the value of f_b (N/mm^2)
f_b = bending stress

III. Result

By computing in tabular format as per Table 1 the weights of Standard I-Beam with Castellated Beam for different spans designed for optimum steel section.

Table 1 Comparison of Weight of beam

	Section		**Weight (kg)**	
Span (m)	**Standard I-Beam**	**Castellated Beam**	**Standard I-Beam**	**Castellated Beam**
5.0	ISMB 250	ISMB 150	186.5	74.5
7.5	ISMB 400	ISMB 225	462.0	234.0
10.0	ISMB 500	ISMB 300	869.0	442.0
12.5	ISMB 600	ISMB 400	1532.5	770.0

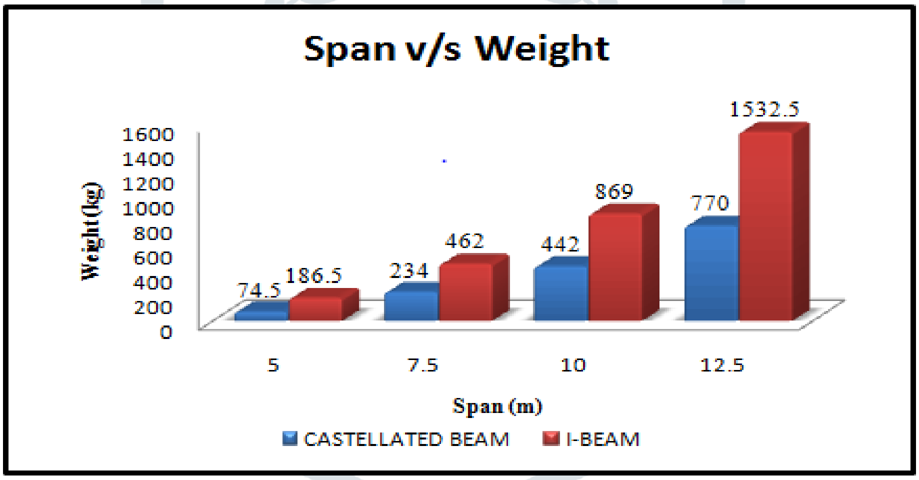

Figure 5 Graph of Span v/s Weight

Also, computing in tabular format as per Table 2 the deflection of Standard I-Beam with Castellated Beam for different spans maintaining the same steel section.

Table 2 Comparison of Deflection of beam

	Section		**Deflection (mm)**	
Span (m)	**Standard I-Beam**	**Castellated Beam**	**Standard I-Beam**	**Castellated Beam**
5.0	ISMB 250	ISMB 250	15.86	12.03
7.5	ISMB 400	ISMB 400	20.14	16.73
10.0	ISMB 500	ISMB 500	28.80	23.76
12.5	ISMB 600	ISMB 600	34.62	30.93

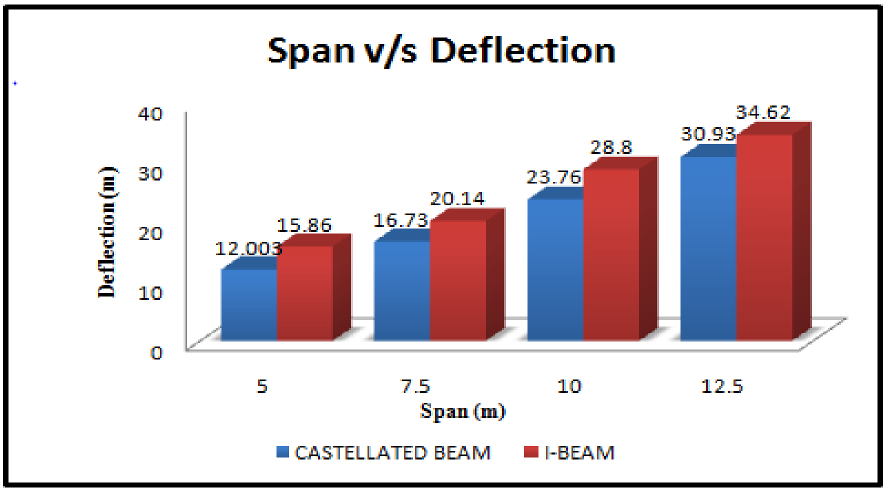

Figure 6 Graph of Span v/s Deflection

IV. CONCLUSION

- The castellated steel beams can be modified by the strength of the standard I-section by simply increasing its height without adding any material and there by maintaining the same weight of section.
- Determining the optimum steel sections, material saving reaches almost 50% to 60% in castellated beam as compare to Standard I-Beam for different span.
- Deflection of same section being used as a Standard I-Beam and Castellated Beam also shows a variation from 10%-25% for different span, the latter being lower one.
- Castellated beams are used for industrial buildings, power plant, etc. where loading is quite less as compared to its huge span will prove to be more economical and satisfy its serviceability criteria.
- Castellated beam reduces the total weight of structure, hence a huge saving in material.
- On the contrarily, it requires skilled labours.

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