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Castellated Steel Beams-A Torsional Analysis

A. J. Mehetre, R. S. Talikoti

***Abstract**: Practice of castellated beams (CBs) or perforated beams for several structures speedily gaining petition. This is because of the increased depth in the segment, high strength to weight ratio, light in weight, easy to erect, economical, and stronger. The principal advantages of the castellated beam are an attractive provision, an increase in vertical bending stiffness, & ease of service provision. The CBs is prepared from its virgin sections i.e. I beam by cutting it in a zigzag or any suitable cutting pattern and again rejoined it by welding therefore depth of the resulting section increases. The load-carrying capacity of the parent I section is increased with the same quantity of material and weight, due to an increase in depth of beams. Web post-buckling and lateral-torsional buckling failure occur when these beams are subjected to loading, this is the effect of an increase in depth of the castellated beams. There are five basic failure modes associated with castellated steel beams that need to be taken care of 1) Development of flexure mechanism. 2) Lateral-torsional buckling 3) Vierendeel mechanism 4) rupture of the welded joint in a web post 5) shear buckling of a web post. Therefore, in this research paper, an effort has been made to estimate the torsional moment capacity castellated beam for hexagonal or honeycomb opening with 30^0, 45^0, 60^0 & sinusoidal opening with different fillet radii.*
***Keywords**: Castellated beam, Hexagonal opening, Sinusoidal opening, Torsion.*

I. INTRODUCTION

I-shaped hot rolled steel beams are extensively used as structural components because of their Flexural efficiency about the strong axis. However, in various applications beams are eccentrically loaded and as a result experience tensional loads in combination with bending. Like all solid sections, I-shaped steel beams are very inefficient interaction effects due to torsion, and resisting torsion acting in combination with bending can considerably reduce the capability of the solid beams, and hence CBs are the best solution under this situation. In most of the steel-framed structure, the beam is subjected only bending and not torsion but the situation does arise where torsion effect is significant the designer will also know the value of torsional effect and to consider the resistance of member under the combined bending and torsion Steel beams with an opening in the web part are called castellated steel beams (CSBs). I-shaped section is a very efficient form for carrying both bending and shears loads in the plane of the web. On the other hand, the cross-section has a reduced capacity in the transverse direction and is also inefficient in carrying torsion, for which hollow structural sections are often preferred.

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CBs offer a designer all types of prospects for "cutting to size". For example, in simple straight castellated beams, by changing the cutting pattern the depth can be determined therefore in this technique, the strength of the beam for the occurring loads should be precisely matched. That's what you call optimum construction! In addition to this, a tapered shaped castellated beam easily built, at a slight angle by setting the cutting design not exactly parallel to the length of the castellated beam. After cutting, among two halves, one is reversed and the two halves are then welded together lengthwise. At one end both low sides come together, at the other end both high sides. CBs are such structural supporters, which are prepared by flame cutting a hot rolled steel beam lengthwise its centerline and then rejoining the two halves by welding, and hence the overall depth of the beam is increased by 50% for better structural presentation against bending, flexure, and shear. Commonly, for CSBs hexagonal, rectangular, oval, elongated circular and circular shaped opening are provided, which are distributed at consistent intervals in the web of the CBs. These are finished from I-section (hot-rolled) which is being cut lengthwise with definite configuration and then both halves are moved and re-welded such that results increases in depth. The castellated steel beam achieved is 50% deeper than virgin I-Section i.e. 1.5 times the depth than the original section. Fig. 1 shows CBs with the hexagonal shaped opening, a castellated beam with the sinusoidal opening as shown in Fig. 2.

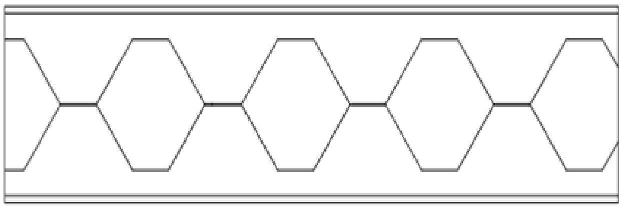

Fig.1. Hexagonal opening CBs.

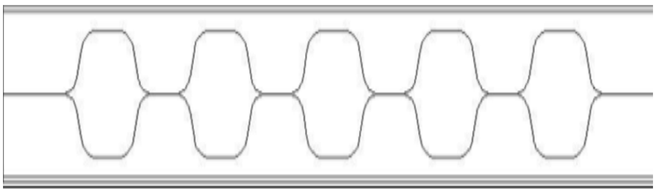

Fig.2. Sinusoidal opening CBs.

II. LITERATURE SURVEY

1. **L.M. Gupta** [etal] carried out experimental investigation & ANSYS analysis on a hexagonal opening castellated beam under constant loading & support condition.

They were also observed deflection pattern at a mid-span of the castellated beam by using different depth of a section & changing the location of hexagons along the length of the beam.

2. **B. Anupriya & Dr. K. Jagadeesan** investigated shear strength analysis on the castellated beam by using ANSYS software. He observed that because of stress concentration at the opening corner more deflection occurred & to reduce this deflection they provided vertical & diagonal stiffener.
3. **Delphine Sonck & Jan Belis** investigated the effect of residual stresses which is occurred due to the fabrication process, which makes design unsafe. They were analyzed results obtained from the numerical model of castellated beam residual stresses & validate it with experimental results.
4. **S. Durif & A. Bouchair** gives the analytical approach based on existing methods for multiple opening and also based on plate buckling theory. They also proposed a formula for calculation of the critical stress coefficient. He compared this study with finite analysis for sinusoidal opening.
5. **Sahar Elaiwai**[etal] investigated the effect of web opening on the transverse deflection of the castellated beam by using analytical method & measured deflection of the castellated beam for varying its length & flange width subjected to uniform loading which is based on the principle of minimum potential energy.

   Research Gap: Most of the research work is undergone with deflection analysis of castellated beam with a different geometrical opening but very less work with torsional analysis of castellated. So these papers mainly focus on the torsional analysis of castellated beam with hexagonal opening & sinusoidal opening.

III. OBJECTIVE & INVESTIGATION

1. To observe the torsional behaviour of the CBs with hexagonal and sinusoidal web opening.
2. To investigate the effect of a number of key parameters on the behaviour of I-shaped castellated steel beams under torsion
3. To compare analytical and experimental investigation.
4. To study different failure mode in a castellated beam
4. To find the most suitable section for more torsional moment carrying capacity as compare to the solid section.

IV. GUIDELINES FOR DESIGN

A. *General Information*

In this chapter the methodology and materials used are discussed in detail. To carry out the castellation process and the testing purpose parent steel section ISMB 150 was used. The table -I shows the properties of the ISMB 150 solid section. Table- II shows the specimen details.

Table- I: ISMB 150 sectional properties details.

Beam type	ISMB 150
A, Area of the section in mm^2	39.72 X 10^2
D, Depth of the section in mm	150
bf, Width of flanged in mm	110
tf, Thickness of flange in mm	11.8
tw, Thickness of web in mm	6.5
I_{xx} mm^4	718×10^3
I_{yy} mm^4	46.8×10^3
Section modulus Z_{xx} (mm^3)	95.07×10^3
Z_{yy} (mm^3)	12.50×10^3

B. *Guidelines for design of castellated beam*

Following guideline are to be followed for fabrication:

• As far as possible the hole should be placed centrally placed in the web so that eccentricity of the opening is evaded

• At least twice the beam depth, D, web opening should be away from the support or 10% of the span, whichever is more.

• Middle half of the span and within the middle third of the web is the best location for the opening.

•The minimum spacing between the centre of the adjacent opening must not be less than 2.5 times the diameter of the larger hole.

• Beam depth D < Clear spacing between.

• Where the shear force is lowest is the best location for opening.

•The provision of stiffening around the opening.

C. *Details of a specimen of castellated beam section*

Table- II: Casting details

Notation	*Description*
IP	Parent Section
IH_1	Hexagonal web opening with an angle of opening 30^0
IH_2	Hexagonal web opening with an angle of opening 45^0
IH_3	Hexagonal web opening with an angle of opening 60^0
IS_1	Sinusoidal shape web openings angle of opening with filleted radius1/4^{th}
IS_2	Sinusoidal shape web openings angle of opening with filleted radius1/4^{th}
IS_3	Sinusoidal shape web openings angle of opening with filleted radius1/4^{th}

D. Fabrication procedure for CSBs -

Comparatively simple series of operations for the fabrication of a castellated beam when adequate handling sections are available on the site.

- **Cutting**

In the process of fabrication this is an important step. The zig-zag cutting pattern is being considered to cut a web of hot rolled steel section usually with advanced cutting methods in conjugation with CNC-controlled cutting heads is available otherwise; it is done with the help of Gas Cutter on a small scale, as shown in Fig. 3

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Fig.3. Marking and cutting the parent beam.

- **Separation and Relocation of section –**

After cutting to achieve the required size & the shape of the opening, separated two halves of the section are arranged at their apex points as shown in Fig 4.

Fig.4.Separation and Rearrangement of two halves of section.

- **Rejoining by using welding -**

Finally, welding of the high points of web post back together is done with the help of a gas cutter or an automated submerged arc welding process; to build the required depth of castellated beams as shown in Fig 5.

Fig. 5. Welding of Castellated Beam for hexagonal opening.

V. TESTING PROCESS

A. *Testing Apparatus (Torsion Setup) of Castellated beams on UTM*

Fig. 6: Torsion Assembly of Castellated beams for Torsion Test.

Fig. 7: Assembly of Twist Triangles.

Fig. 8: Specimens of the castellated beam.

Fig.6 showed the testing is carried out by using the torsion test set up in UTM. The twist triangle assembly is shown in Fig.7. The entire fabricated samples are shown in Fig.8.Table- III, and Table-IV show experimental and analytical outcomes. The behavior of all the castellated beams i.e. torsional moment verses angle of twist as presented graphically. Comparisons of all experimental and analytical results presented in graphs 7 and 8.

A. Sample Observation table

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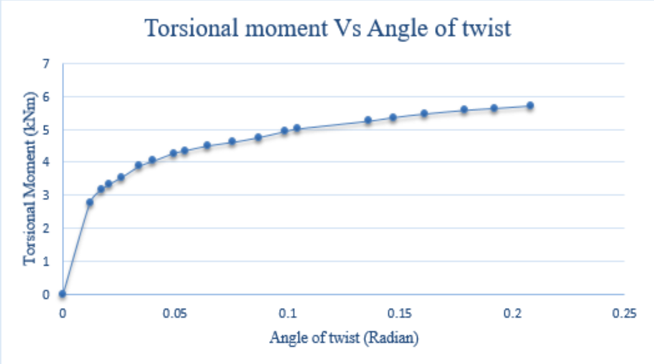
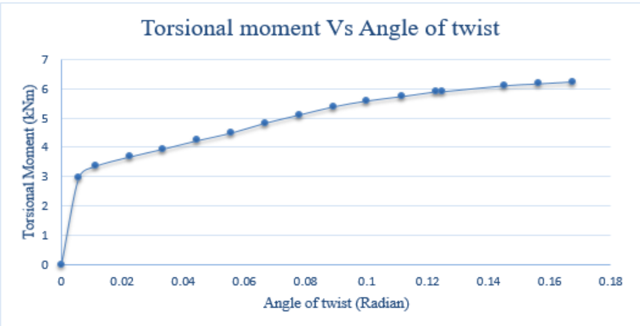
Table No. III- Experimental result

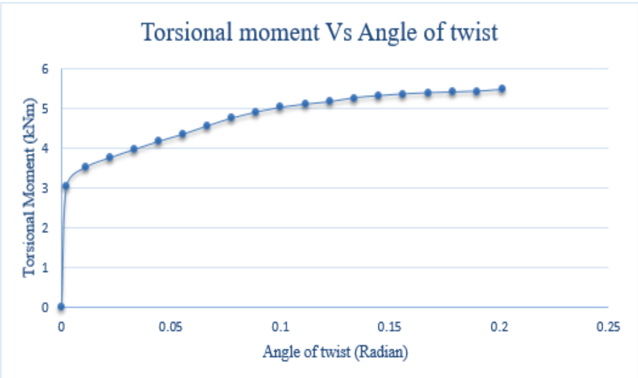
Sr No.	Notation	Load (KN)	Deflection (mm)	Torsional Moment (KN.M)	Angle of twist (Radian)
1	IP	24.5	93	5.5125	0.14719765
2	IH1	27.8	75	6.255	0.167448079
3	IH2	24.3	90	5.4675	0.201357921
4	IH3	32.8	50	7.38	0.111341014
5	IS1	25	118	5.625	0.265
6	IS2	25.9	76.4	5.8275	0.1706
7	IS3	26.9	96	5.06	0.214985573



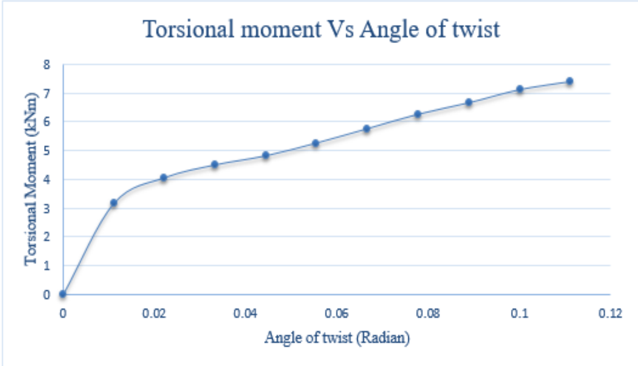
Graph 1: Torsional moment Carrying Capacity of IP V/s Angle of twist.



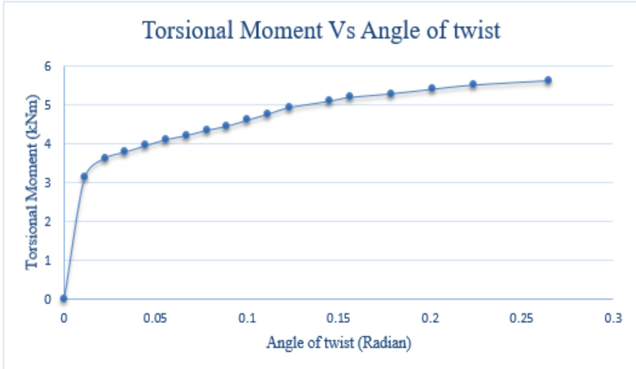
Graph 2: Torsional moment Carrying Capacity of IH_1 V/s Angle of twist.



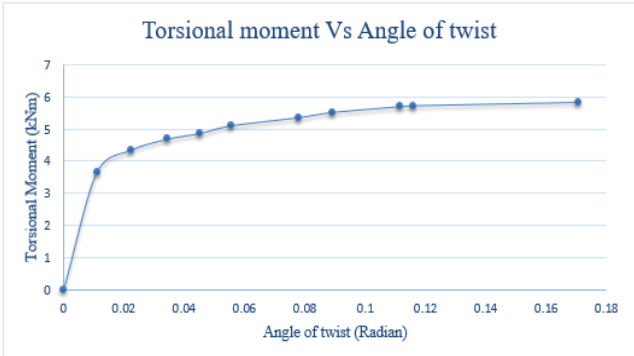
Graph 3: Torsional moment Carrying Capacity of IH_2 V/s Angle of twist.



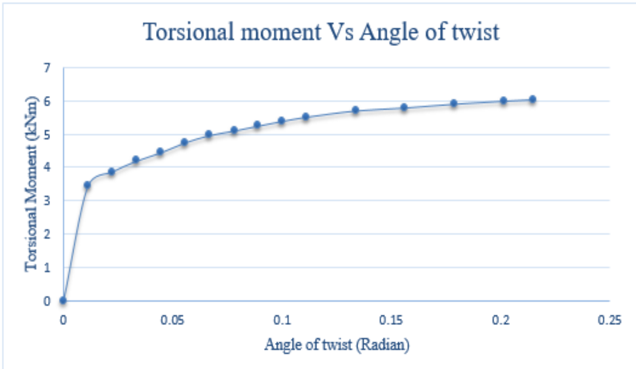
Graph 4: Torsional moment Carrying Capacity of IH_3 V/s Angle of twist.



Graph 5: Torsional moment Carrying Capacity V/s Angle of twist for IS_1 with fillet radius $1/4^{th}$.



Graph 6: Torsional moment Carrying Capacity V/s angle of twist for $IS_2$with filleted radius $1/6^{th}$



Graph 7: Torsional moment Carrying Capacity V/s angle of twist for $IS_3$with filleted radius $1/8^{th}$.

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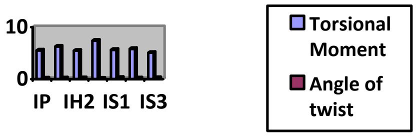
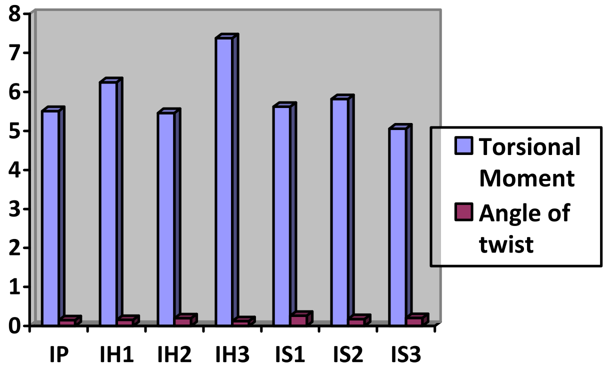


Graph 8: experimental results comparisons of various sections.

Table No. IV Result obtained by ANSYS Software

Sr.No.	Notation	Load (KN)	Deflection (mm)	Torsional Moment (KN.M)	Angle of twist (Radian)
1	IP	24.5	91	5.5125	0.14719765
2	IH1	27.8	92	6.255	0.15394062
3	IH2	24.3	69	5.4675	0.194558449
4	IH3	32.8	54	7.38	0.120289882
5	IS1	25	116	5.625	0.261
6	IS2	25.9	78	5.8275	0.1746
7	IS3	26.9	91	5.06	0.203626494



Graph 9: Comparisons of Analytical results (ANSYS)

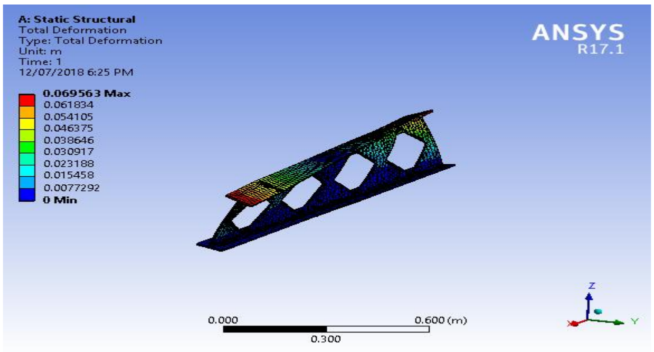


Fig.9: Total angle of twist of IH_1.

VI. CONCLUSIONS

1. Experimental results show that the castellated section increases the torsional moment carrying capacity as compared to the solid section.
2. The hexagonal section with the angle of opening 60^0 shows a 29 % larger torsional capacity as compared to parent sections.
3. Sinusoidal section with the angle of opening 30^0shows 9.5 % larger torsional capacity as compared to parent sections.
4. As per as angle of twist is concern IH_2 and IS_1 showed the maximum angle of twist.
5. All the experiment results are validated by the ANSYS software.

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