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**ABSTRACT**

Castellated beams are those beams which have openings in their web portion. Castellated beams are fabricated by cutting the web of hot rolled steel (HRS) I section into zigzag pattern and thereafter rejoining it over one another. Use of castellated beams is become very popular now a day due to its advantageous structural applications. This is due to increased depth of section without any additional weight, high strength to weight ratio, their lower maintenance and painting cost. The principle advantage of castellated beam is increase in vertical bending stiffness, ease of service provision and attractive appearance. However one consequence of presence of web opening is the development of various local effects. In this research we have suggest the Indian Standard Code based methodology for designing of castellated beams. So the first objective of this research is to investigate the performance of castellated beam designed by IS code method against which is designed by British Standard and ASTM method. The study of performance is based on deflection, load carrying capacity of castellated beam. We compare the castellated beams design by IS Code method with conventional castellated beams design by British Standard and ASTM based on their load carrying capacities.

**KEYWORDS:** Castellated beam, Circular web opening, Rectangular web opening, Cellular beam etc.

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**INTRODUCTION**

Castellation is a process of fabricating a section with improved section properties from virgin rolled section by increasing depth ultimately improving moment of inertia. There by increase in moment of resistance and controlled on deflection. Since the invention of castellated beams in the mid-1930, they have been frequently used in Europe but commonly over looked in the United States. The first known use of castellated beams in the US was by H. E. Horton of the Chicago Bridge and Iron Works in the 1940's (Dorgherty 1993). G. M. Boyd developed the concept of the castellated beams in 1935 while working for a steel fabricator in Argentina. The idea came to Boyd when posed with a design problem with beam depth restrictions. At the time, the fabricator only had beams of minimal depths available. His first idea was to stack two beams of minimal depth on top of one another to increase depth. Boyd then decided to cut a hot rolled section along the web in a saw tooth pattern, separate the two halves and weld the web posts back together at the high points.

This process increases the depth of the beam by approximately 50%, therefore increasing the strength and stiffness by about 20 to 30% without increasing the weight of the beam. Also the holes in the web allow ductwork to run through beams instead of underneath ultimately reducing the depth of the floor system. Although there are many advantages to using castellated beam, the one disadvantage is fabrication cost. The extra cost of cutting and welding the web is usually the deciding factor for their feasibility. Castellated beams are more popular in areas where the cost of steel is high and labor costs are low. The use of castellated beams in Europe has existed ever since the adoption of the fabrication process developed by LitzkaStahlbau of Bavaria, Germany (Boyer 1964). His equipment and production process is very efficient, making mass production cheaper. Since its adoption in the United States several steel fabrication companies have made castellated beams available.

**Failure Modes**

The design concept for castellated beams is based on typical beam limit states, but the presence of web openings and welds can cause other modes of failure. The potential modes of failure associated with castellated beams are:

- ✓ Flexural Failure Mechanism
- ✓ Lateral-Torsional Buckling
- ✓ Vierendeel Bending Mechanism
- ✓ Rupture of the Welded Joint in a Web Post
- ✓ Shear Buckling of Web Post

### ***Flexural Failure Mechanism***

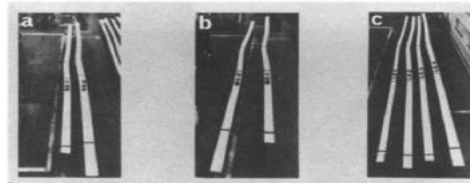
This mode of failure can occur when a section is subject to pure bending. The span subjected to pure bending moment, the Tee-sections above and below the holes yielded in a manner similar to that of a plain webbed beam, although the spread of yield towards the central axis was stopped by the presence of the holes by which time the two throat sections had become completely plastic in compression and in tension.



***Fig. 1 Flexure Buckling of Castellated Beam***

### ***Lateral-Torsional Buckling***

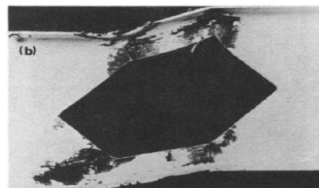
Non-composite castellated beams are more susceptible to lateral-torsional buckling than composite beams due to lack of lateral support to the compression flange. The lateral torsional buckling behavior of castellated beams is similar to that of plain webbed beams. The holes had a significant influence on lateral-torsional buckling behavior.



***Fig. 2 Lateral-Torsional Buckling of Castellated Beam***

### ***Vierendeel Bending Mechanism***

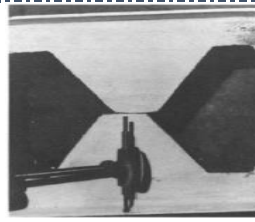
Vierendeel bending is caused by the need to transfer the shear force across the opening to be consistent with the rate of change of bending moment, in the absence of local or overall instability, hexagonal castellated beams have two basic modes of plastic collapse, depending on the opening geometry. The failure is dependent on the presence of a shear force of high magnitude in the holes through span.



***Fig. 3 Vierendeel Bending of Castellated Beam***

### ***Rupture of the Welded Joint in a Web Post***

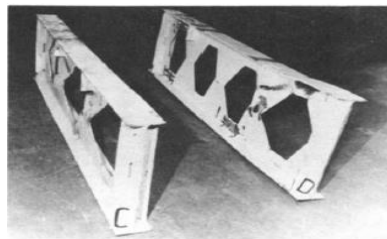
Rupture of a welded joint in a web-post can result when the width of the web-post or length of welded joint is small. This mode of failure is caused by the action of the horizontal shearing force in the web-post, which is needed to balance the shear forces applied at the points of contra flexure at the ends of the upper I-section.



**Fig.4 Rupture of the Welded Joint in a Web Post**

### **Shear Buckling of a Web Post**

The horizontal shear force in the web-post is associated with double curvature bending over the height of the post. In castellated beam one inclined edge of the opening will be stressed in tension, and the opposite edge in compression and buckling will cause a twisting effect of the web post along its height.



**Fig. 5 Shear Buckling of a Web Post**

## **MATERIALS SELECTION**

Selection of section

ISMB 150 is used for carrying out the castellation process and also the testing. Sectional properties of ISMB 150 as follow

Designation	ISMB 150	
Weight (w) kg/m	14.99	
Area (a) cm <sup>2</sup>	19.10	
Depth of section (D) mm	150	
Width of flange (b <sub>f</sub> ) mm	75	
Thickness of flange (t <sub>f</sub> ) mm	8	
Thickness of web (t <sub>w</sub> ) mm	5	
Moment of Inertia	I <sub>xx</sub> cm <sup>4</sup>	717.6
	I <sub>yy</sub> cm <sup>4</sup>	46.8
Radii of Gyration	r <sub>xx</sub> cm <sup>4</sup>	6.13
	r <sub>yy</sub> cm <sup>4</sup>	1.54
Moduli of section	Z <sub>xx</sub> cm <sup>4</sup>	95.7
	Z <sub>yy</sub> cm <sup>4</sup>	12.5
Max Size of Flange Rivet	Φ mm	12

## **EXPERIMENTAL PROGRAM**

ISMB 150 section is selected as the parent section for fabricating castellated beam. The castellated beams are fabricated such that the depth of the beam is 1.5 times the original depth as IC 225. Thickness of flange is 5 mm, thickness of web is 5 mm, depth of opening is 150 mm, and length of the beam is 975 mm. Universal testing machine (UTM) is used for testing the castellated beam.

## **FABRICATION OF CASTELLATED BEAM**

ISMB150 section of depth 150 mm is selected for the fabrication of solid as well as castellated beam then Markings for which cutting should be done was made and then gas cutting machine is used to cut the specimen along its markings. After cutting, the two pieces are welded together to form a castellated beam.

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### TEST PROCEDURE

The specimens are loaded in universal testing machine (UTM) of 1000 KN capacity. The specimen is supported at two ends. All specimens have loaded at its midpoint slowly until buckling. The load corresponding to the failure of specimen is noted. ISMB 150 solid section is also tested to determine the deflection.

### CONCLUSION

Due to presence of the web holes, the failure mechanism of the castellated beams will be different from those of the solid webs. The most predominant failure patterns of the castellated beams include the formation of vierendeel mechanism, web buckling, rupture of web joint weld, and flexure mechanism. It is also expected that most of the beams will stand against the serviceability and strength criteria and can be used for the industrial as well as domestic uses. When the critical span is subjected to an approximately uniform moment, collapse is likely to occur either by lateral-torsional instability in the case of unbraced beam or by the formation of a flexural mechanism for laterally restrained beam.

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### REFERENCES

- [1] Wakchaure M.R., Sagade A.V. and Auti V. A., "Parametric study of castellated beam with varying depth of web opening", International Journal of Scientific and Research Publication, Vol. 2, No.8, pp. 2153-2160, 2012.
- [2] Wakchaure M.R. and Sagade A.V., "Finite element analysis of castellated steel beam", International Journal of Engineering and Innovative Technology, Vol.2, No. 1, pp. 3744-3755, 2012.
- [3] British Standard Institution. (1992), "Design of steel structures. Part 1.1: General rules and rules for buildings", Eurocode 3, ENV 1993-1-1:1992.
- [4] Durif S. and Bouchair A. "Behavior of cellular beams with sinusoidal openings", Steel Structures and Bridges, Procedia Engineering, Vol. 40, pp. 108-113, 2012.
- [5] Amayrey, Saka M. P., "Failure load predication of castellated beams using artificial neural network", Asian Journal of Civil Engineering (building and housing), Vol. 6, (2005), 35-45.
- [6] Khennane A., Introduction to finite element analysis using MATLAB and Abaqus, 1st Edition, CRC Press, New York, 2013
- [7] Lawson R. M. and Hicks S. J., Design of composite beams with large openings, SCI P355, SCI Publication, Berkshire UK, 2011.
- [8] Pachpor P. D., Gupta L. M. and Deshpande N. V., "Analysis and design of cellular beam and its verification", 2013 International Conference on Applied Computing, Computer Science and Computer Engineering, IERI Procedia, Vol. 7, pp. 120-127, 2014.
- [9] Raftoyiannis I. G. and Ioannidis G. I., "Deflection of castellated I beam under transverse loading", Steel Structures, Vol. 6, pp. 31-36, 2006.
- [10] Soltani M. R., Bouchair A. and Mimoune M., "Nonlinear FE analysis of the ultimate behavior of steel castellated beams", Journal of Constructional Steel Research, Vol. 70, No. 2012, pp. 101-114, 2011.
- [11] Redwood R. and Demirdjian S., "Castellated beam web buckling in shear", ASCE Journal of Structural Engineering, Vol. 124, pp. 1202-1207, 1998.
- [12] Zirakian T. and Showkati H., "Distortional buckling of castellated beams", Journal of Constructional Steel Research, Vol. 62, pp. 863-871, 2006.