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Experimental Research on Equivalent Rectangular Opening Castellated Beam with Fillet Corner

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Abstract: Nowadays the use of castellated beam has been admired due to its beneficial functions like a light in weight, easy to erect, economical and stronger. The castellated beam is manufactured from its parent solid I beam by cutting it in a zigzag pattern and again joining it by welding so that the depth of the beam increases. Hence, due to an increase in depth of beam load carrying capacity of the parent I section is increased with the same quantity of material and weight. The increase in depth of the castellated beam leads to web post-buckling and lateral-torsional buckling failure when these beams are subjected to loading. There are many other modes of failure like the formation of flexure mechanism, lateral-torsional buckling, and formation of Vierendeel mechanism, rupture of the welded joint in a web post and shear buckling of a web post which needs to be taken care of. Hence, in the present paper, an attempt has been made to evaluate existing literature, concerned with the strength of the beam by providing a rectangular opening and rectangular opening equivalent to diagonal & hexagonal opening with different angles of opening 30^0, 45^0 & 60^0. The fillet radius is provided to the corner of the rectangular opening as a result of a 54% increase in the load-carrying capacity of the rectangular section compared to the regular rectangular section.

Keywords: Castellated beam, Diamond opening, Equivalent fillet corner rectangular opening, Hexagonal opening.

I. INTRODUCTION

Beams that are provided with an opening in the web portion are nothing but castellated beams. Generally, the opening provided for castellated beams are circular shaped or hexagonal-shaped openings, which are dispersed at regular intervals on the web portion of the castellated beam. These are made from hot-rolled I-section which is being cut along a certain pattern and then both halves are shifted and re-welded such that its depth increases. The beam section obtained is 50% deeper than the parent I-Section that is 1.5 times the depth of the original section. Long span structures, as well as vibration characteristics, are served best using the castellated beam. The primary advantage of castellated 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 castellated beams, erection stability must be considered. Fig1 shows the castellation process for hexagonal opening

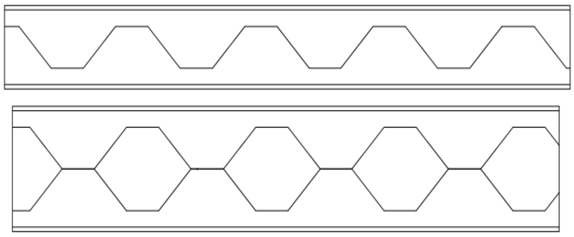

Fig.1. Fabrication process of Castellated Beam with hexagonal opening

Castellated beams are classified according to their shape of openings provided in the web portion. The most common shapes for the openings are hexagonal, circular also called a cellular opening, octagonal, diamond, etc. However, due to simplicity in fabrication mostly hexagonal and circular openings of beams are used in industries. Also, most of the research on the optimization of the hexagonal and circular shape is done. But a very little learning of rectangular opening with fillet corner is going on. As the rectangular opening has the drawback of stress concentration at the corner, it is also called as a Vierendeel failure. To overcome this, in this paper more emphasis is given on a rectangular opening with a fillet corner is considered. Fig 2 shows castellated beam with a rectangular opening, fig 3 shows castellated beam with the diamond opening, fig 4 shows castellated beam with the hexagonal opening.

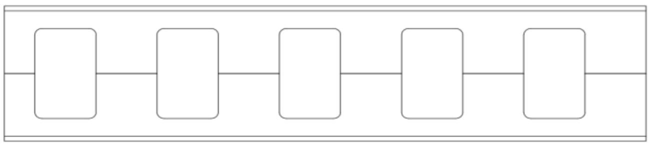

Fig. 2. Castellated beam with a rectangular opening.

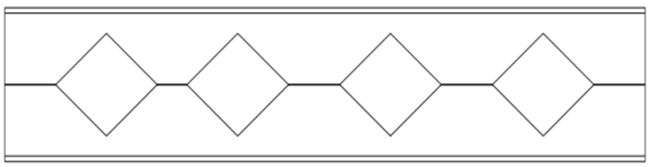

Fig.3. Castellated beam with the diamond opening.

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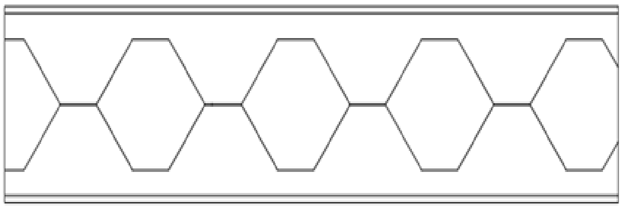


Fig.4. Castellated beam with the hexagonal opening.

II. EXISTING LITERATURE

Peijun Wang[etal] [1] Investigated the Virendeel failure of castellated beam with fillet corner web opening as compared with circular opening castellated beam. He was also proposed that by providing a single cut along centerline, fabrication cost gets reduced. He investigated Virendeel failure of web perforated member in his research. From this research he was concluded that by providing fillet radius stress redistribution is generated which were increases the load-carrying capacity of web perforated beam section.

Resmi Mohan[etal] [2] Investigated the steel beam with or without web opening. In her research work she was prepared castellated beam of different shape opening by providing zigzag cut along a centerline of a parent beam. From her experiment she was concluded that beam with hexagonal opening gives larger load capacity and lesser deflection as compared to solid beam & castellated beam with circular opening. She also work on rectangular opening & she got average results of 42 Kn.

Jamadar A. M. [etal] [3] were observed parametric study of castellated beams with circular (cellular beam) and diamond-shaped openings has been carried out to optimize its size by considering ratio of overall depth castellated beam to the depth of opening provided.

Ajim S. Shaikh[etal] [4] studied the basic behavior of the cellular beam using the finite element method for two-point loading and the boundaries were kept as simply supported. During the research, it was observed that on top of openings and below openings stress concentration was developed in more amounts. So, it was suggested to add extra plates to overcome the stability problem during erection.

Siddheshwari A. Patil[etal] (2015) [5], In this paper a finite element model (FEM) using ABAQUS is developed for analyzing the load-bearing capacity of CSBs by providing transverse stiffener and stiffener placed along an edge of an opening. The study of this stiffener is done by using ABAQUS software. From this research she observed that percentage steel used for transverse stiffener is very less as compared to stiffener provided along edge.

Research Gap- All researchers are worked on castellated beam with regular geometrical opening, but in this research work we are work on an equivalent rectangular web opening with fillet corners that are provided for more load capacity & to avoid stress concentration at the corner of regular rectangular opening.

III. METHODOLOGY

The materials used and methodology are discussed in this chapter. ISMB 150 is used for carrying out the castellation process and also the testing.

Table- II: Properties of ISMB 225

Name of the beam	ISMB 225
Area A (mm2)	39.72 X 10^2
Depth of section D (mm)	225
Width of flanged bf (mm)	110
The thickness of flanged tf (mm)	11.8
The thickness of web tw (mm)	6.5
Moment of inertia I_{xx} (mm^4) I_{yy} (mm^4)	718x10^3 46.8x10^3
Section modulus Z_{xx} (mm^3) Z_{yy} (mm^3)	95.07x10^3 12.50x10^3

A. Process of fabrication of castellated beam -

The fabrication of a castellated beam is a comparatively simple series of operations when an adequate handling section on the side only.

- **Cutting**

This is the first step in the process of fabrication. In this process of a web of a rolled section is cut in the Zigzag pattern, generally with advanced cutting systems in conjugation with CNC-controlled cutting heads. On a small scale, it is done with the help of Gas Cutter as shown in fig. 5

Fig. 5. Cutting of the beam

- **Rearrangement of section –**

After cutting two separate halves section are arranged together in such a way that an opening of required size & the shape is formed as shown in Fig 6

Fig. 6. Rearrangement of Castellated Beam

- **Welding -**

Lastly, welding of the web post back together at the high points is carried out with an automated submerged arc welding process.

Welding is done to join the two cut halves as shown in fig 8.

Fig. 7. Welding of Castellated Beam

- **Grinding -**

Grinding is used to finish workpieces that must show high surface quality and high accuracy of shape and dimension. as shown in fig 8

Fig 8. Grinding of a Castellated Beam

B. Conversion of Diamond & hexagonal opening into the equivalent rectangular opening -

Table- III: Conversion of opening into rectangular

Diamond 30^0	259.94 mm	259.94 mm
Diamond 45^0	150 mm	150 mm
Diamond 60^0	86.6mm	86.6mm
Hexagonal 30^0	334.94 mm	334.94 mm
Hexagonal 45^0	225 mm	225 mm
Hexagonal 60^0	161.6 mm	161.6 mm

IV. EXPERIMENTAL PROGRAM

A. Testing of specimen:

In this work, we have used a two-point loading system, because when used center point loading system beam are failed directly under a point load so we did not get the correct load-carrying capacity of a whole section. In two-point loading, the entire middle one-third of the beam is stressed uniformly and thus the beam failed at its weakest point in the middle one-third of the beam. Typically, the center point results are about 15% greater. In this system, point load is applied at a distance of L/3 from each face of supports are deflection is observed by keeping a dial gauge at mid-span as shown in fig 9 & 10. In this work we are tried for the case of pure bending. For all specimens the length of a beam is kept constant as 1.75 m. Fig 12 shows the shear stress transformation.

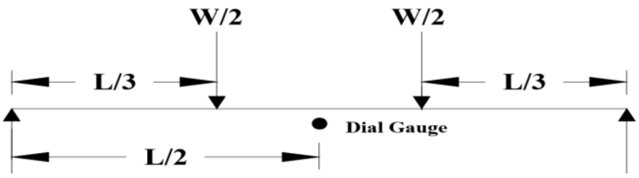
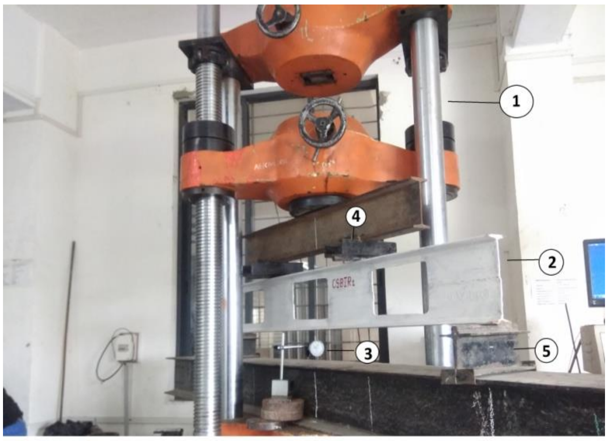


Fig 9. Two-point loading setup



1- Universal Testing Machine.
2- Test Specimen
3- Dial Gauge
4- Two point loading assembly.
5- End supports.

Fig 10: Testing of a Castellated Beam

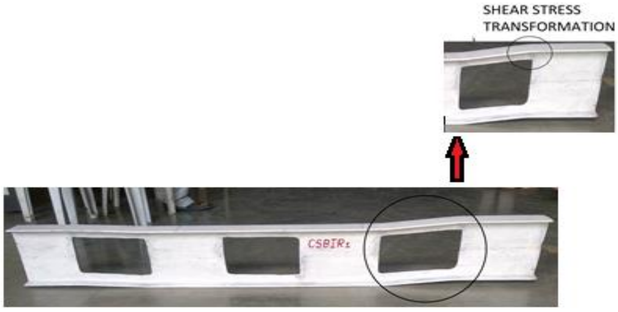


Fig 11: Shear stress transformation due to fillet corner

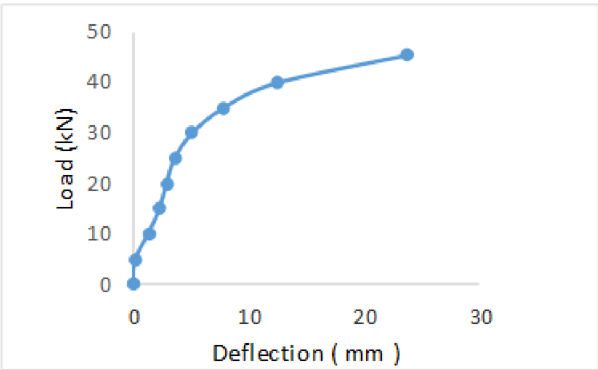
V. EXPERIMENTAL RESULTS

A. Test results for rectangular opening equivalent to diamond shape opening

- **For 30^0 openings:**

Table- IV: Test results for rectangular opening equivalent to diamond 30^0 opening

Load (kN)	Deflection(mm)
0	0
5	0.2
10	1.3
15	2.3
20	2.9
25	3.6
30	5.1
35	7.8
40	12.4
45.5	23.7

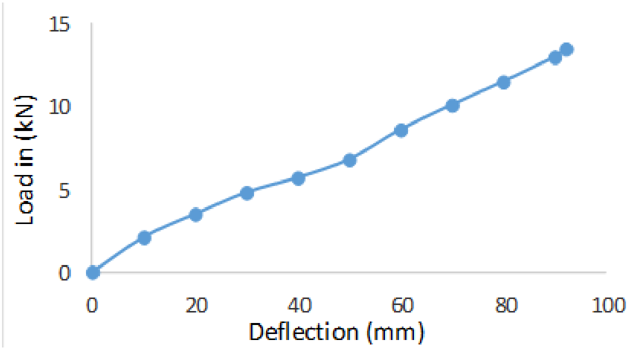


Graph. 1: Load Vs Deflection graph for rectangular opening equivalent to diamond 30^0 opening

- **For 45^0 openings:**

Table-V: Test results for rectangular opening equivalent to diamond 45^0 opening

Load (kN)	Deflection(mm)
0	0
10	2.1
20	3.5
30	4.8
40	5.7
50	6.8
60	8.6
70	10.1
80	11.5
90	13
92.2	13.5

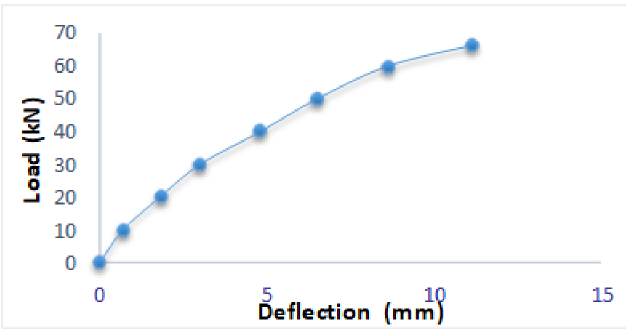


Graph.2: Load Vs Deflection graph for rectangular opening equivalent to diamond 45^0 opening

- **For 60^0 openings:**
-

Table- VI: Test results for rectangular opening equivalent to diamond 60^0 opening

Load (kN)	Deflection(mm)
0	0
10	0.7
20	1.8
30	3
40	4.8
50	6.5
60	8.6
66.6	11.2



Graph.3: Load Vs Deflection graph for rectangular opening equivalent to diamond 60^0 opening

B. Test results for rectangular opening equivalent to hexagonal shape opening

- **For 30^0 openings:**

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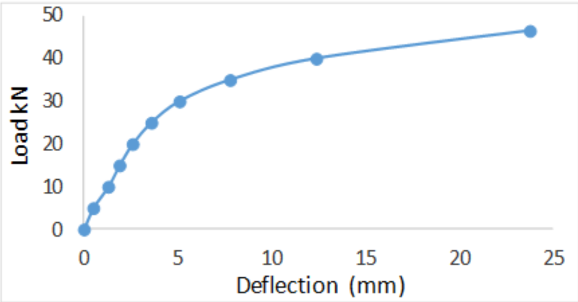
Table- VII: Test results for rectangular opening equivalent to hexagonal 30⁰ opening

Load (kN)	Deflection(mm)
0	0
5	0.5
10	1.3
15	1.9
20	2.6
25	3.6
30	5.1
35	7.8
40	12.4
46.5	23.8

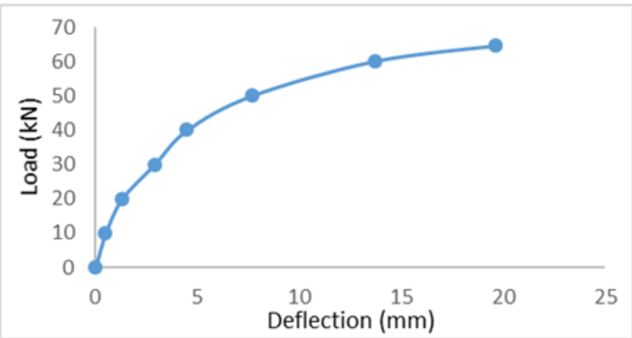


Graph. 4: Load Vs Deflection graph for rectangular opening equivalent to hexagonal 30⁰ opening

- **For 45⁰ openings:**

Table- VIII: Test results for rectangular opening equivalent to hexagonal 45⁰ opening

Load (kN)	Deflection(mm)
0	0
10	0.5
20	1.3
30	2.9
40	4.5
50	7.7
60	13.7
64.5	19.6

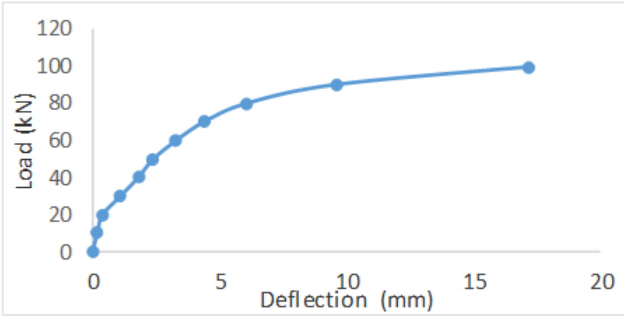


Graph.5: Load Vs Deflection graph for rectangular opening equivalent to hexagonal 45⁰ opening

- **For 60⁰ openings:**

Table- IX: Test results for rectangular opening equivalent to hexagonal 60⁰ opening

Load (kN)	Deflection(mm)
0	0
10	0.2
20	0.4
30	1.1
40	1.8
50	2.4
60	3.3
70	4.4
80	6.1
90	9.6
99.5	17.2



Graph.6: Load Vs Deflection graph for rectangular opening equivalent to hexagonal 60⁰ openings.

Table- X: Interpretation of results for rectangular opening equivalent to diamond & hexagonal opening.

Section	Maximum Load (kN)	Deflection (mm)	Load from previous literature (kN) [2]	Increase in load %
Diamond Equivalent				
30⁰	45.5	23.7	42	8.33
45⁰	64.5	19.6	42	53.57
60⁰	66.6	11.2	42	58.57
Hexagonal Equivalent				
30⁰	46.5	23.8	42	10.71
45⁰	64.5	19.6	42	53.57
60⁰	99.5	17.2	42	136.9

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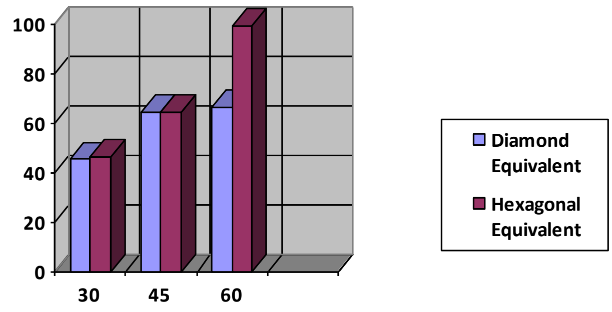

Fig 11: Graphical representation of results

- **Future Scope:** This research is extended by considering the different lengths of opening, height of opening, fillet radius to rectangular opening & changing depth of beam. By considering above dimensional variation, it can be possible to find optimum load carrying capacity of castellated beam.

VI. CONCLUSION & DISCUSSION

- Rectangular opening equivalent to hexagonal opening shows a larger load capacity as compared to a rectangular opening equivalent to a diamond opening.
- Rectangular opening equivalent to hexagonal opening shows lesser deflection as compare to rectangular opening equivalent to diamond opening.
- Rectangular opening equivalent to diamond 60^0 opening shows lesser deflection as compare to other opening sizes.
- Rectangular opening equivalent to hexagonal 60^0 opening shows a larger load-carrying capacity as compared to other opening sizes.
- Experimentation shows that Rectangular opening with fillet corners increases a shear carrying capacity of the castellated beam compared to literature.
- Compare to regular rectangular opening the load capacity of equivalent rectangular opening (Diamond) is about 40.16 % more.
- Compare to regular rectangular opening the load capacity of equivalent rectangular opening (Hexagonal) is about 67.01 % more.

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