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A Study on Castellated Beams with and Without Stiffeners

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ABSTRACT
The use of castellated beams in many types of constructions is quickly gaining popularity. This is a result of the section's enhanced depth without adding weight, excellent strength-to-weight ratio, low maintenance requirements, and low cost of painting. Increased vertical bending stiffness, ease of service provision, and appealing appearance are the main advantages of castellated beams. Castellated beams are made by zigzagging cutting I sections, then re-joining them to increase the depth of the parent I sections. When castellated beams are loaded, their increased depth makes them more susceptible to web post buckling and lateral torsional buckling failure. There are numerous other forms of failure that must be considered, such as the development of flexure mechanisms, lateral torsional buckling, and vierendeel mechanisms, rupture of the welded joint in a web post, and shear buckling of a web post. A study demonstrates how using stiffeners in the beam's web part can reduce these failures. As a result, a thorough analysis of the stiffeners' quantity, size, and readily available positions in the castellated beam's web part is required. In order to explore the experimental and analytical behaviour of the castellated beam with stiffeners, an attempt has been undertaken in the current paper.The result indicates that use of end stiffeners at end portion of castellated beams helps in increasing the strength and also minimizing the deflection.

Keywords
Castellated beams, Buckling, Stiffener.

1. INTRODUCTION
Such structural elements are called castellated beams, and they are created by flame cutting a rolled beam down the centerline, cutting the two halves in half, and then welding them back together. This increases the overall depth of the beam by 50%, improving its resistance to bending. Structural engineers have made numerous attempts since the Second World War to discover fresh strategies for lowering the price of steel structures. The great strength qualities of structural steel are not always optimally used because of restrictions on the minimum permitted deflection. As a result, numerous novel techniques were developed to increase steel member stiffness without increasing the weight of the steel. One of the better options is the cast-coated beam. TheresponsibilityofaStructuralEngineerliesinnotmerelydesigningth estructurebasedonsafetyandserviceability considerations but he also has to consider the functional requirements based on the use to which the structure is intended. While designing a power plants tructureora multi-storied building, the traditional structural steel framing consists of beam sand girders with solid webs. These hinder the provision of pipelines and air conditioning ducts, electricalwiringrequiredforsatisfactoryfunctioningforwhichthestruc tureisputup.

Rerouting services results in additional costs and is often unacceptable. Another option is to raise the floor height during the design phase to accommodate them. It is now considered standard engineering practice to supply beams with web apertures, which reduces the possibility that a service engineer will later drill holes in the wrong places. Even if there are various options to solid web beams, such as stub girders, trusses, etc., beams with web openings can be cost-effective in some situations. The services are placed within the girder depth at the most suitable locations, maintaining a smaller construction depth. The inclusion of an opening in the beam's web affects both the member's collapse behavior and the member's stress distribution.

- Web Post: The cross-section of the castellated 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.

2. LITERATURE SURVEY
Resmi Mohan & Preetha Prabhakaran (2016), In this study, finite element analysis was used to compare the deflection of an ISMB 150 section steel beam with and without web holes. The analysis was conducted using ANSYS 14.5. Results showed that steel beams with apertures performed better than solid beams in terms of load carrying capacity and deflection. The section's strength increased as a result of the section's increased depth. Additionally, the web portion's openings can aid in allowing services to travel through the beam without reducing its strength, and as provisions are also offered through the web parts, this will aid in lowering the effective floor depth [5].Konstantinos Daniel Tsavdaridis and Theodore Papadopoulos (2016) present a thorough finite element (FE) analysis of extended end-plate beam-to-column connections with single and multiple circular web openings introduced along the length of the beam under the cyclic loading suggested by the SAC protocol from FEMA 350. (2000). The three-dimensional (3D) FE solid model was evaluated using FE and experimental data, and the configuration that was selected could accurately depict the structural behavior of a link that was partially restrained without having to idealize it as being totally fixed. The interaction of these linkages and the mobilization of stresses from the column to the perforated beam are the main topics of the study [3]. The solid I section beam with hexagonal cavities (openings), according to P. D. Pechora, Dr. N. D. Mittal, et al. (2011), has many advantages over traditional rolled sections. because they are robust, light, affordable, and attractive. Since transporting pipes across beams is not a problem, the opening in the web makes the installer's and

electrician's jobs easier. Study is done on the failure pattern and stresses that resulted from the same loading scenario. 2, 4, and 6 different openings are present in the chosen beam. Both a hexagonal and a circular opening are thought to have the same cross sectional area. The support configurations are fixed, hinged, and roller. A total of 18 instances are examined for the same central point load and span with varying opening spacing. The highest Deflection and Von Mises stress are calculated. ANSYS, a finite element analysis programmer, is used to conduct the comparison study. For the identical support conditions, the deflection likewise rises as the number of openings does. Due to displacements at the ends, the maximum deflection is seen under roller support before being fixed or hinged. When comparing openings of the same area that are circular and hexagonal, the maximum von Mises stress is likewise lower [4]. According to Siddheshwari A. P. and Popat. D. K. (2015), when these beams are loaded, a rise in CB depth causes web post buckling and lateral torsional buckling failure. A study demonstrates how using stiffeners in the beam's web part can reduce these failures. As a result, an effort has been made in the present work to evaluate previous research on the strength of beams utilizing stiffeners. The majority of studies have shown that local failures in the web part have caused web perforated beam failures. To prevent the failure of castellated beams, however, relatively little work has been done. When there is a load concentration in the beam, the strength augmentation is crucial. Therefore, adding stiffeners can lessen areas of concentrated tension at openings [6]. The review report by Mr. Dhanraj K. Shendge and Dr. B.M. Shinde (2015) outlines a method and software application to use finite element analysis to optimize the topology, size, and shape of castellated beams. Hot rolled sections with regularly spaced openings are cut and rewelded to create the Castellated beams. Therefore, a Castellated beam is taller than a Regular beam for the same weight. It is investigated the load carrying capacity of simply supported Castellated steel beams that are subject to web post bucking. Castellated beam's load carrying capacity is assessed using the FEA method. In order to compare the ultimate load behavior, the cross section categorization is also evaluated by parameter studies.

In this paper, the load carrying capacity of castellated beam is reviewed. The unit member with fillet corner opening has a higher load carrying capacity as compared with those with hexagonal, rectangular openings when they have the same opening height, but lower than that with circular opening [2]. This work by B. Anupriya and Dr. K. Jagadeesan (2014) focuses on the investigation of the shear strength behavior of CB with and without stiffeners. In one case, stiffeners are placed on the solid component of the web along the shear zone, and in the other, they are introduced diagonally on the web opening along the shear zone. It has been determined that stiffeners placed on the web's opening are more effective than those placed on the solid part of the web. Since shear across the holes has nowhere to flow and so shear strength across the holes reduces, shear stiffeners placed on the opening of the web are therefore more effective than those placed on the solid portion [1]. As a result, the web begins to collapse, resulting in higher deflection. Siddheshwari A. Patil and Popat D. Kumbhar (2016) used stiffeners to study the analysis of the castellated beam. The ABAQUS programmer is used to conduct the comparative analysis of these stiffeners. In order to conduct the study, stiffeners of two different types—transverse stiffeners and stiffeners attached to the edges of openings—are used. These two kinds of stiffeners were selected to improve strength and lessen stress entry close to the web openings. The transverse stiffener uses less space than the stiffener that runs along the border of the opening. Also, the load carrying capacity of transverse stiffener is considerably more than thes tiffenera long the opening edge. Additionally, the transverse stiffener has a far higher load carrying capacity than the stiffener along the opening edge. Therefore, a transverse stiffener is preferred over an edge stiffener [7].

3. RESEARCH GAP

The majority of studies have shown that local failures in the web part have caused web perforated beam failures. The provision of stiffeners with the right proportions and placements has been suggested, but very little work has been done to prevent the failure of castellated beams. When there is a load concentration in the beam, the strength augmentation is crucial. Although the castellated beam does well with spread weights, it struggles with heavy concentrated loads. Stiffeners must be used in the proper location to verify the behavior and failure modes in order to maximize the beam's effectiveness under the worst stress concentration conditions. While it needs to be thoroughly studied from the other codes and recommendations need to be made for the design of the stiffeners, there are no provisions for the stiffeners for castellated beams in Indian standards. A general concept of the good performance of the castellated beam utilizing stiffeners is provided by the future scope outlined by a small number of researchers in articles. When constructed with stiffeners, this performance will also improve strength and torsional behavior.

4. EXPERIMENTAL WORK

Transverse and end stiffeners, for example, are optimised, as was covered in the section before this one. Different stiffener sizes and placements are taken into account when optimising Transverse and End stiffeners. Mild steel ISMB 150 was utilised for the experiment. The stiffeners that produced the best results were then cast. Under the guidance of a UTM machine, experimental work was done. It was determined whether the software and experimental data validated one another.

5. RESULTS AND DISCUSSION

Results of Square Shape Web Opening Castellated Beams:

The results demonstrating the load-bearing capability of castellated beams with square-shaped web apertures reinforced with various types of stiffeners are represented graphically in Figure 2 and tabulated in Table No. 1.

Table 1: Load (KN) Carrying Capacity of Square Castellated Beams

Sr. No	Types of Samples	Experimental Results	ABAQUS Results
1.	Without Stiffener	40.39	38.710
2.	Single Vertical Stiffener	45.9	42.431
3.	Double Vertical Stiffener	47.3	45.314
4.	Cut shape Endplate Stiffener	49.06	50.290
5.	Rectangular shape Endplate Stiffener	48.13	50.710

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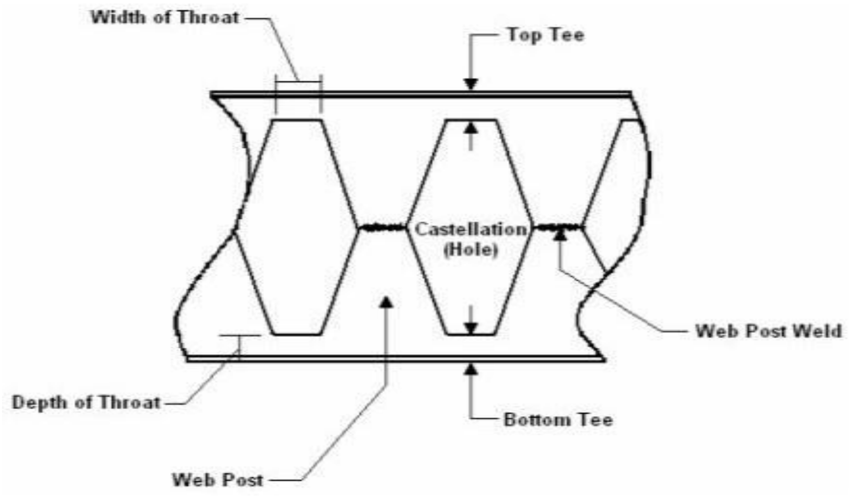

Figure 1: Load Carrying Capacity of Square Castellated Beams

Table 2: Load (KN) Versus Deflection (mm) of Square Castellated Beams

Load	Without Stiffener	Type of Stiffeners			
		Single Vertical	Double Vertical	Cut shape Endplate	Rectangular shape Endplate
0	0	0	0	0	0
5	0.27	0.50	0.61	0.10	0.50
10	0.84	0.77	0.80	0.42	0.98
15	1.03	1.85	1.98	0.70	1.26
20	2.55	2.43	2.58	1.06	1.78
25	4.21	3.86	3.40	1.87	2.31
30	6.26	4.52	4.05	3.66	3.16
35	8.01	5.91	5.48	4.21	4.38
40	12.29	7.67	7.10	5.87	6.50
45		9.91	7.98	7.82	8.42
50				8.16	9.14

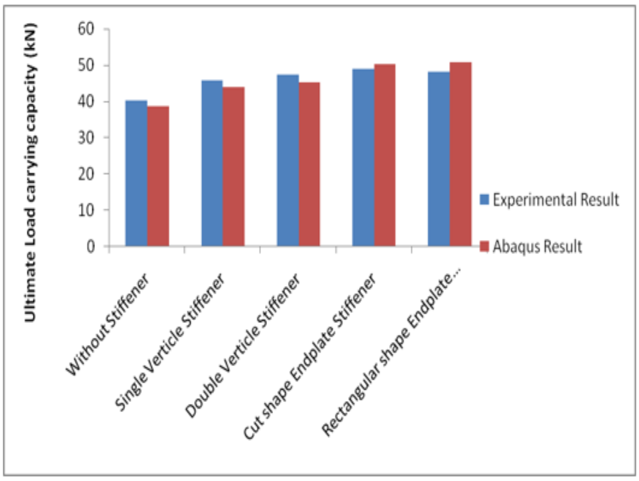

Figure 2: Load Versus Deflection of Square Castellated Beams

There salts showing load carrying capacity of castellated beams of circular shape web opening stein forced with different types of stiffeners are presented in tabular form in Table No 3 and is shown graphically in Figure No 4.

Table 3: Load(KN) Carrying Capacity of Circular Castellated Beams

Load	Without Stiffener	Types of Stiffeners			
		Single Vertical	Double Vertical	Cut shape Endplate	Rectangular shape Endplate
0	0	0	0	0	0
5	1.94	1.47	0.62	0.93	0.99
10	2.23	2.01	1.26	1.65	1.68
15	3.15	3.06	2.35	2.43	2.31
20	4.92	4.66	2.97	3.30	3.15
25	5.26	5.07	3.6	4.18	3.96
30	6.78	6.44	4.25	5.50	5.46
35	7.49	7.05	5.15	5.71	6.62
40	8.54	7.99	7.02	6.04	7.65
45		8.45	7.87	6.46	7.99
50		9.16	8.10	7.01	8.15
55			8.41	7.23	8.74
60			8.67	7.35	9.06
65				8.01	

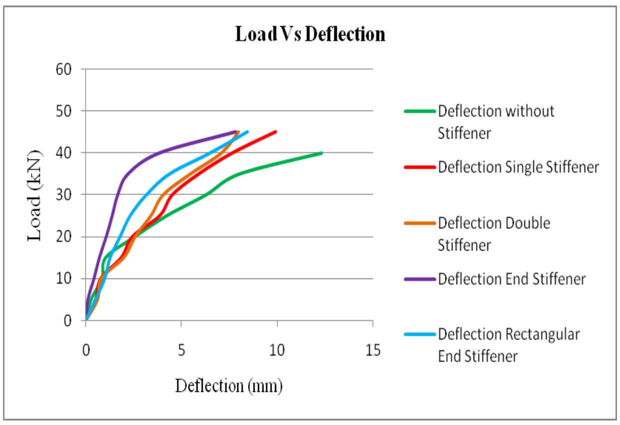

Figure 3: Figure No4: Load Carrying Capacity of Circular Castellated Beams

Table 4: Load(KN)Versus Deflection(mm) of Circular Castellated Beams

Load	With out Stiffe ner	Types of Stiffeners			
		Single Vertical	Double Vertical	Cut shape Endplate	Rectangular shape Endplate
0	0	0	0	0	0
5	1.94	1.47	0.62	0.93	0.99
10	2.23	2.01	1.26	1.65	1.68
15	3.15	3.06	2.35	2.43	2.31
20	4.92	4.66	2.97	3.30	3.15
25	5.26	5.07	3.6	4.18	3.96
30	6.78	6.44	4.25	5.50	5.46
35	7.49	7.05	5.15	5.71	6.62
40	8.54	7.99	7.02	6.04	7.65
45		8.45	7.87	6.46	7.99
50		9.16	8.10	7.01	8.15
55			8.41	7.23	8.74
60			8.67	7.35	9.06
65				8.0 1	

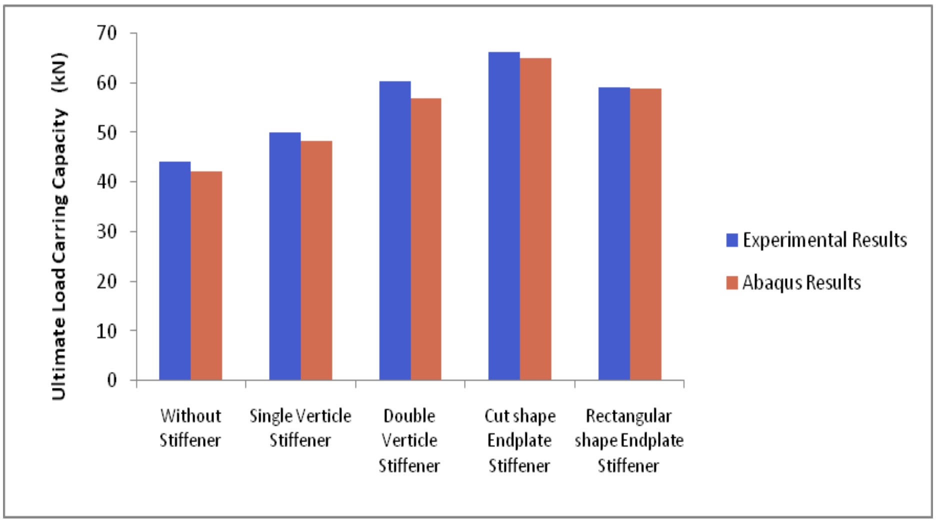

Figure 4: Load Versus Deflection of Circular Castellated Beam

5.1 Results of Diamond Shape Web Opening Castellated Beams

Table-5: Load(KN) Carrying Capacity of Diamond Castellated Beams

Sr. No	Types of Samples	Experimental Results	ABAQUS Results
1.	Without Stiffener	48.13	46.25
2.	Single Vertical Stiffener	61.31	58.84
3.	Double Vertical Stiffener	74.10	71.33
4.	Cut shape Endplate Stiffener	70.55	73.31
5.	angular shape Endplate Stiffener	60.29	64.60

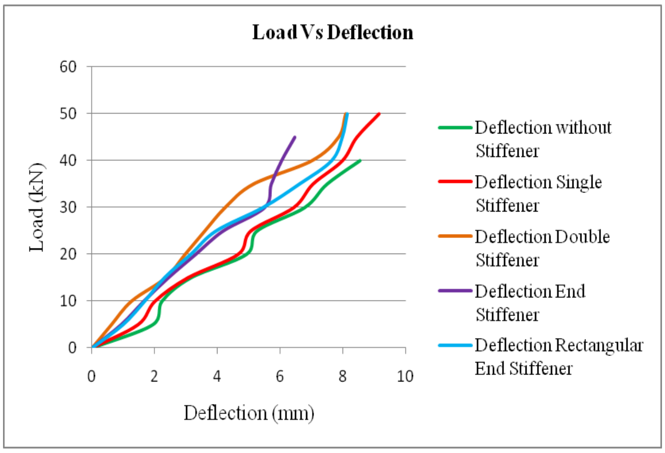

Figure 5: Load Carrying Capacity of Diamond Castellated Beams

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Table 6: Table No 6: Load(KN) Versus Deflection (mm) of Diamond Castellated Beams

Load	Without Stiffener	Types of Stiffeners			
		Single Vertical	Double Vertical	Cut shape Endplate	Rectangular shape Endplate
0	0	0	0	0	0
5	0.92	1.43	0.55	0.93	0.68
10	1.88	1.90	0.94	1.65	1.15
15	3.08	2.55	1.54	2.43	1.68
20	4.24	3.08	1.87	3.30	2.13
25	5.44	3.55	2.03	4.18	2.55
30	6.04	4.18	2.85	5.50	2.98
35	7.32	4.65	3.37	5.71	3.55
40	9.28	5.23	3.64	6.04	4.08
45		5.88	4.86	6.46	4.78
50		7.03	5.14	7.01	5.58
55		8.93	6.41	7.23	6.90
60		9.92	7.27	7.35	7.85
65			7.87	8.01	
70			8.12	8.64	

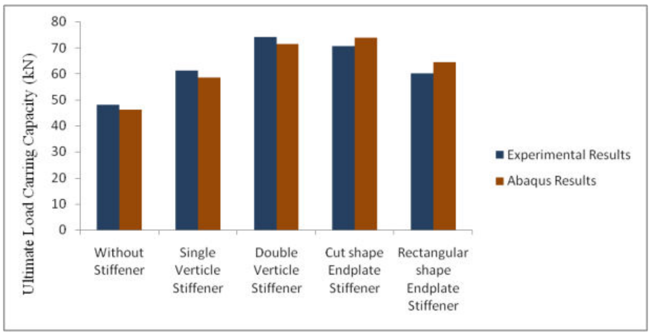

Figure 6: Load Versus Deflection of Diamond Castellated Beams

5.2 Comparison of Experimental and Analytical Results

Table 7: Comparison of Experimental & Analytical Results of Square Castellated Beams

Sr. No	Types of Stiffener	ExperimentAL Results	ABAQUS Results	Variations in Results
1.	Without Stiffener	40.39	38.710	4.159%
2.	Single Vertical	45.9	42.437	8.154%
3.	Double Vertical	47.3	45.314	4.199%
4.	Cut shape Endplate	49.06	50.290	2.507%
5.	Rectangular shape Endplate	48.13	50.710	5.360%

Table 8: Comparison of Experimental & Analytical Results of Circular Castellated Beams

Sr. No	Types of Stiffeners	ExperimentAL Results	ABAQUS Results	Variations in Results
1.	Without Stiffener	44.14	41.98	4.883%
2.	Single Vertical	49.89	48.24	3.307%
3.	Double Vertical	60.12	56.72	5.671%
4.	Cut shape Endplate	66.18	64.91	1.930%
5.	Rectangular shape Endplate	58.98	58.70	0.4820%

Table -9: Comparison of Experimental & Analytical Results of Diamond Castellated Beams

Sr. No	Types of Stiffeners	ExperimentAL Results	ABAQUS Results	Variations in Results
1.	Without Stiffener	48.13	46.25	3.896%
2.	Single Vertical	61.31	58.46	4.648%
3.	Double Vertical	74.10	71.55	3.436%
4.	Cut shape Endplate	70.55	73.75	4.539%
5.	Rectangular shape Endplate	60.29	64.43	6.863%

6. EXPERIMENTAL PROGRAM

There were a total of five types of castellated beams that were examined, each with various sizes of transverse stiffeners in the opening and end stiffeners. The analysis' findings lead to the conclusion that the stiffener with dimensions of 5 mm in thickness and 10 mm in width (5x10) works adequately in terms of load per area ratio. Additionally, it is an experimental finding that the ratio gets smaller as the stiffener's surface area grows. Transverse stiffeners have individual elements that each function as a separate column to support the density load coming through the beam hole. Each component functions as a sustaining partner to distribute pressure uniformly along the aperture.

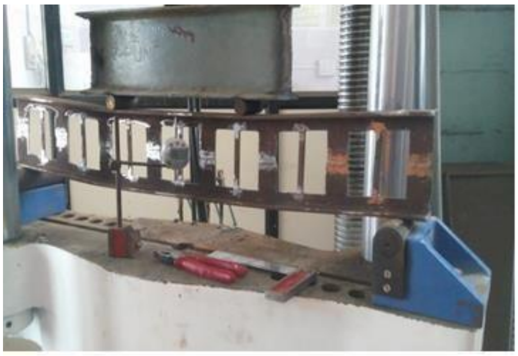

Figure 7: Single Stiffener

Figure 8: Double Stiffener

Figure 9: Rectangular Endplate Stiffener

7. RESULTS AND DISCUSSION

From the research done thus far utilizing ABAQUS software and an optimized castellated beam with stiffeners placed at various points, the following conclusions may be reached.

- The load carrying capacity of the beam with end stiffeners is found to be greater as compared to the beam provided with transverse within the opening stiffeners by 3.72%, according to the analysis and design (Euro Code guidelines) of a castellated I beam with and without stiffeners in transverse within the opening and End stiffeners.
- It may also be deduced that the addition of end stiffeners increases shear capacity and decreases torsion moment but concentrates stress within the beam. The percentage variation in load carrying capacity is found to be approximately between 4.754% and almost identical to the results obtained using the ABACUS software. The experimental results showing load carrying capacities of castellated beams equipped with various stiffeners under two-point loading. Thus, it may be said that the Experimental results validate the ABACUS results.
- The behavior of optimized castellated beams, provided with stiffeners in transverse within the opening and with end stiffeners has been studied in respect of load carrying capacity and reduction of local buckling.
- •The load carrying capacity of castellated beams with square opening provided with transverse stiffeners within the opening (single strip) in between openings is found to be more 13.64 % than the beam without stiffener.
- The load carrying capacity of castellated beams with square opening provided with transverse stiffeners within the opening (Double strip) in between openings is found to be more 17.10 % than the beam without stiffener.
- The load carrying capacity of castellated beams with square opening provided with End Gusset Plate is found to be more 21.46% than the beam without stiffener.
- The load carrying capacity of castellated beams with square opening provided with End Rectangular strip is found to bemore19.16% than the beam without stiffener

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