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Behavior of Castellated Beams with and Without Stiffeners

ABSTRACT- Castellated beam applications for diverse buildings are 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 zigzaggingly cutting I sections, then rejoining 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. Therefore, it is necessary to do a thorough analysis of the stiffeners' number, size, and readily available places in the web part of the castellated beam. In order to explore the experimental and analytical behavior of the castellated beam with stiffeners, an attempt has been undertaken in the current paper. The outcome shows that using end stiffeners at the ends of castellated beams increases their strength and reduces their deflection.

KEYWORDS- Raw Water, Disinfection, Pathogens, Chlorine by Products and Distribution System.

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I. 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 innovative strategies for reducing 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 a casted beam.

In addition to designing the structure with safety and serviceability in mind, a structural engineer also has to take into account the functional requirements related to the purpose that the structure is designed for. The classic structural steel frame uses beams and girders with solid webs for power plant structures and multi-story buildings. These prevent the installation of the electrical wiring, air conditioning ducts, and pipes needed for the structure's intended, satisfactory functioning.

Rerouting services or raising the floor height during the design phase to accommodate them results in higher costs. is often unacceptably expensive. 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. This type of building keeps the construction depth down while placing services where they are most needed, inside the girder 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 castellated beam's cross-section, where the cross-section is considered to be solid.
- Throat Width: The length of the root beam's horizontal cut. The distance along the web where the flanges are present.
- Throat Depth: The height of the web's part where it joins the flanges to form the tee section.

II. LIERATURE SURVEY

Resmi Mohan and Preetha Prabhakaran (2016) did a finite element analysis 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 its 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 idealise it as being totally fixed. The interaction of these linkages and the mobilisation of stresses from the column to the perforated beam are the main topics of the study. When subjected to cyclic loading, it is discovered that RWS connections with cellular beams behave well and offer improved performance in terms of the stress distribution [3].

P. D. Pachpor, Dr. N. D. Mittal, et. al. (2011), Compared to traditional rolled sections, the solid I section beam with hexagonal cavities (openings) has many benefits. 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 types of apertures are present in some beams.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 VonMises stress are calculated. ANSYS, a finite element analysis programme, 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].

Siddheshwari A. P, Popat. D. K (2015), When these beams are loaded, the increased depth of CB 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 utilising 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. Thus, adding stiffener can lessen the concentration of stress near apertures [6].

Mr. Dhanraj K. Shendge & Dr. B.M. Shinde (2015), The review report outlines a method and software tool for employing finite element analysis to optimise 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. The load carrying capacity of a castellated beam is assessed using FEA without the additional weight of the beams. In order to compare the ultimate load behavior, the cross section categorization is also evaluated by parameter studies. Architectural details and height are two of these beams' key characteristics since they increase their strength and rigidity without adding to their weight. This paper's workload Review of the castellated beam's carrying capacity. When they have the same opening height, the unit member with a fillet corner opening can bear more weight than those with hexagonal, rectangular, but less weight than those with circular apertures [2].

B.Anupriya, Dr.K.Jagadeesan (2014), The research behavior of CB's shear strength with and without stiffeners is the main topic of this paper. 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. Because shear across the holes has nowhere to go when vertical stiffeners are placed on the solid portion of the web, shear strength across the holes reduces, hence shear stiffeners placed on the opening of the web are more effective than those on the solid portion. Web begins to buckle as a result, increasing deflection [1].

Siddheshwari A. Patil, Popat D Kumbhar (2016), in this paper the analysis of the castellated beam has been studied using the stiffeners. The comparative study of these stiffeners is done by using ABAQUS software. Two different types of stiffener that is stiffeners placed along the transverse direction (transverse stiffeners) and stiffeners placed along the edge of openings are used for the analysis. These two types of stiffeners are chosen in order to increase the strength and to decrease the stress entration near the web openings. The volume consumed by transverse stiffener is less than the stiffener along the edge of opening. Also, the load carrying capacity of transverse stiffener is considerably more than the stiffener along the opening edge. Hence, the transverse stiffener is more preferable than the stiffener along the edge [7].

III. 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. In order to maximise the efficiency of the beam in the worst case scenario of stress concentration, it is required to verify the behaviour and failure modes utilising stiffeners in the proper location. There are no provisions for castellated beam stiffeners in Indian standards. While the beam needs to be thoroughly examined in relation to other codes, guidelines must be created for the stiffener design. A general concept of the good performance

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of the castellated beam utilising 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

IV. 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. Software and experimental results were compared to see if they validated one another.

V. RESULTS AND DISCUSSION

Results of Square Shape Web Opening Castellated Beams
The results showing load carrying capacity of castellated beams of square shape web openings reinforced with different types of stiffeners are presented in tabular form in Table No 1 and are shown graphically in Figure No 2.

Table 1: Load (KN) Carrying Capacity of SquareCastellated 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

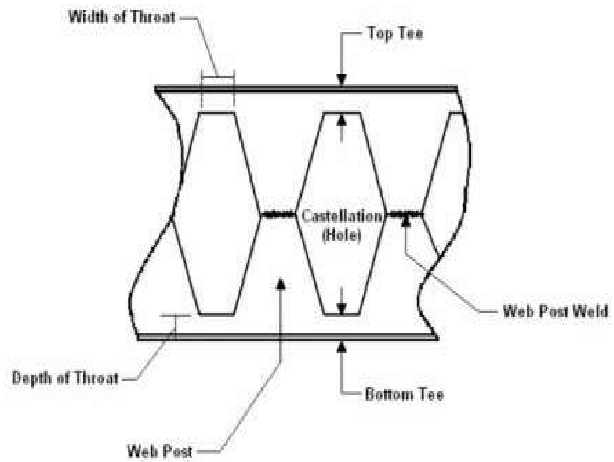

Figure 1: Load Carrying Capacity of Square Castellated Beams

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

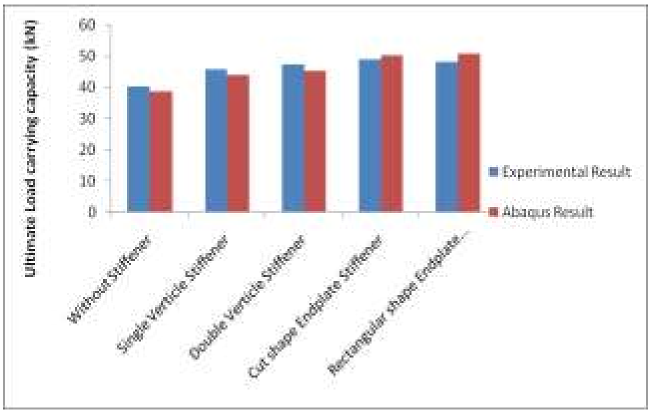

Figure 2: Load Versus Deflection of Square Castellated Beams

A) Results Of Circular Shape Web Opening Castellated Beams

The results showing load carrying capacity of castellated beams of circular shape web openings reinforced 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

Sr. No	Types of Samples	Experimental Results	ABAQUS Results
1.	Without Stiffener	44.14	41.98
2.	Single Vertical Stiffener	49.89	48.27
3.	Double Vertical Stiffener	60.12	56.71
4.	Cut shape Endplate Stiffener	66.18	64.95
5.	angular shape Endplate Stiffener	58.98	58.52

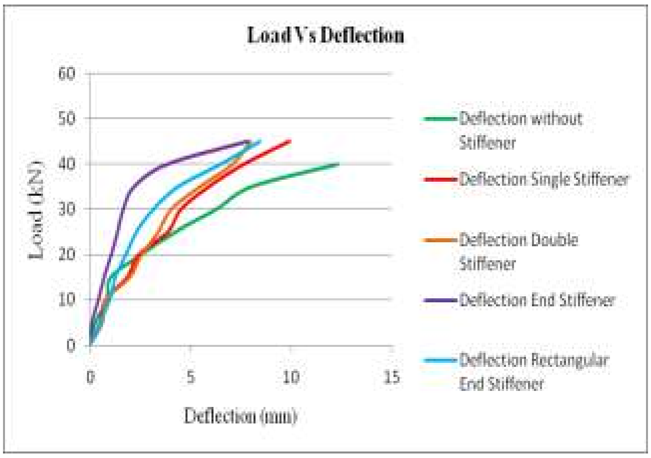

Figure 3: Figure No 4: Load Carrying Capacity of Circular

Table 4: Load (KN) Versus Deflection (mm) 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	

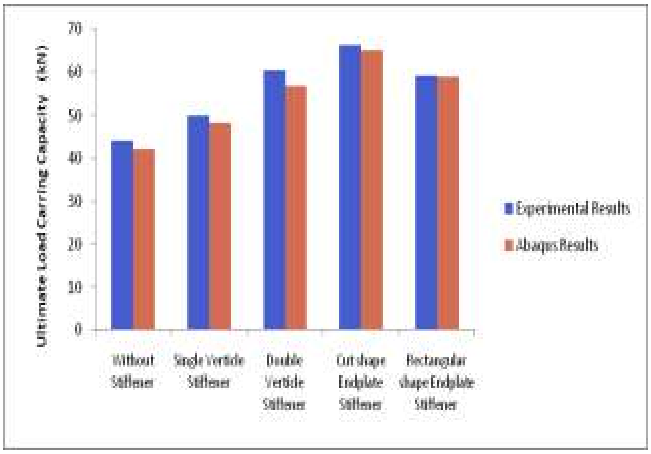

Figure 4: Load Versus Deflection of Circular Castellated Beam

B) 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.	tangular shape Endplate Stiffener	60.29	64.60

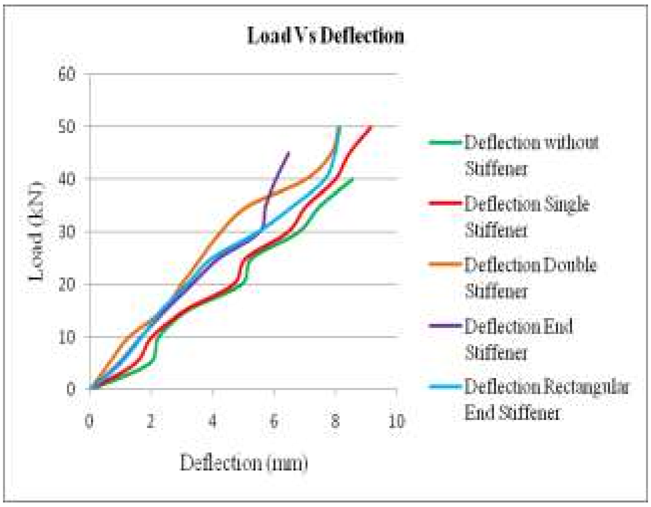

Figure 5: Load Carrying Capacity of Diamond Castellated Beams

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	

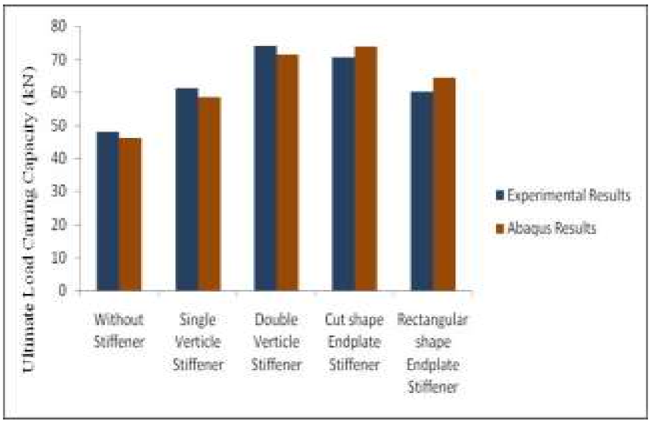

Figure 6: Load Versus Deflection of Diamond Castellated Beams

C) Comparison of Experimental And Analytical Result

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 shap e 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 %

VI. EXPERIMENTAL PERFORMANCE

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. It depends on the stiffeners' shear distribution capabilities if load carrying capability increases even if stiffener area is increased.

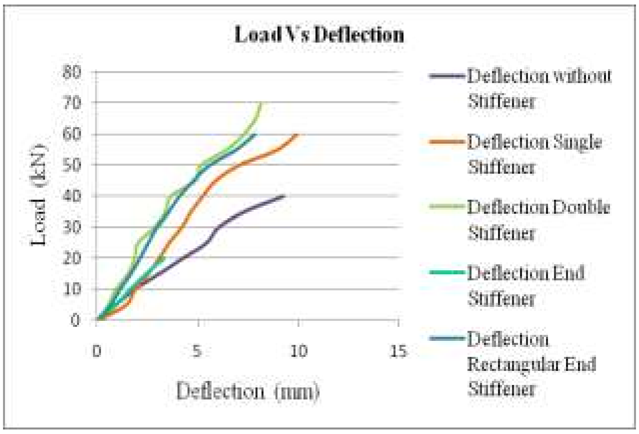

Figure 7: Single Stiffener

Figure 8: Double Stiffener

Figure 9: Rectangle Endplate Stiffener

VII. CONCLUSIONS

From the research done thus far utilising ABAQUS software and an optimised 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.
- It is discovered that the load carrying capacities of castellated beams equipped with various stiffeners under two-point loading are essentially identical to those determined in the ABACUS software, with a percentage difference in load carrying capacity of roughly 4.754%. Thus, it may be said that the Experimental results validate the ABACUS results. m.
- In terms of load carrying capacity and local buckling reduction, the behaviour of optimised castellated beams with stiffeners in transverse within the aperture and with end stiffeners has been examined.

The load carrying capacity of castellated beams with square openings and transverse stiffeners within the opening (single strip) in between openings is found to be more than 13.64% of the beam without stiffener, and the load carrying capacity of castellated beams with square openings and transverse stiffeners within the opening (double strip) in between openings is found to be more than 17.10% of the beam without stiffener.

- Compared to a beam without a stiffener, castellated beams with square openings and end gusset plates have a higher load carrying capacity of 21.46%.
- Compared to a beam without a stiffener, castellated beams with square openings and End Rectangular strips have a higher load carrying capability of 19.16%.

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