Behaviour of Castellated Beams with and Without Stiffeners

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Abstract – Uses of castellated beam for various structures are rapidly gaining appeal. 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 benefit of castellated beam is increase in vertical bending stiffness, ease of service provision and attractive appearance. Castellated beams are fabricated by cutting I section in zigzag way and rejoining it in such a way that the depth of the parent I section is augmented. The increase in profundity of castellated beam leads en route for web post buckling and lateral torsional buckling failure when these beams are subjected to loading. There are many other modes of failure akin to 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. Study shows that use of stiffeners in the web portion of beam helps in minimizing these failures. Therefore, a detailed study in respect to number of stiffeners, size of stiffener and readily available locations in the web portion of castellated beam needs to be carried out. Hence, in the present paper an attempt has been made on the way to study the experimental and analytical behavior of the castellated beam with stiffeners. 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

Castellated beams are such structural members, which are made by flame cutting a rolled beam along its centerline and then rejoining the two halves by welding so that the overall beam depth is increased by 50% for improved structural performance against bending. Since Second World War many attempts have been made by structural engineers to find new ways to decrease the cost of steel structures. Due to limitations on minimum allowable deflection, the high strength properties of structural steel cannot always be utilized to best advantage. As a result several new methods aimed at increasing stiffness of steel member, without any increase in weight of steel required. Castellated beam is one of the best solutions.

The responsibility of a Structural Engineer lies in not merely designing the structure based on safety and serviceability considerations but he also has to consider the functional requirements based on the use to which the structure is intended. While designing a power plant structure or a multi-storied building, the traditional structural steel framing consists of beams and girders with solid webs. These hinder the provision of pipelines and air conditioning ducts, electrical wiring required for satisfactory functioning for which the structure is put up.

The re-routing of services (or increasing the floor height at the design stage for accommodating them) leads to additional cost and is generally unacceptable. The provision of beams with web openings has become an acceptable engineering practice, and eliminates the probability of a service engineer cutting holes subsequently in inappropriate locations. Beams with web openings can be competitive in such cases, even though other alternatives to solid web beams such as stub girders, trusses etc are available. This form of construction maintains a smaller construction depth with placement of services within the girder depth, at the most appropriate locations. The introduction of an opening in the web of the beam alters the stress distribution within the member and also influences its collapse behavior.

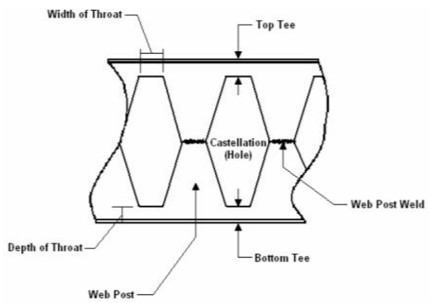

Fig- 1: Terminology

- 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. LIERATURE SURVEY

Resmi Mohan & Preetha Prabhakaran (2016), in this paper, finite element analysis was performed to compare the deflection of steel beam with and without web openings of ISMB 150 section. ANSYS 14.5 was used for the analysis. Results showed that as compared to solid beam, steel beam with openings, showed more load carrying capacity and lesser deflection. The increase in the depth of the section resulted to increase its strength. Moreover the Openings provided in web portion can help for the allowance of passage of services through the beam without any decrement in strength also the provisions are provided through the web portions, so it will help to reduce the effective floor depth [5].
Konstantinos Daniel Tsavdaridis & Theodore Papadopoulos (2016), this paper presents a comprehensive finite element (FE) analysis of extended end-plate beam-to-column connections, with both single and multiple circular web openings introduced along the length of the beam while subjected to the cyclic loading proposed by the SAC protocol

from FEMA 350 (2000). The three dimensional (3D) FE solid model was validated against FE and experimental results and the chosen configuration was capable of representing the structural behavior of a partially restrained connection, without the necessity to be idealized as fully fixed. The study focuses in the interaction of such connections and the mobilization of stresses from the column to the perforated beam. It is found that RWS connections with cellular beams behave in a satisfactory manner and provide enhanced performance in terms of the stress distribution when subjected to cyclic loading [3].

P. D. Pachpor, Dr. N. D. Mittal, et. al. (2011), the solid I section beam with creating hexagonal cavities (openings) has numerous advantages over conventional rolled sections. As they are light weight, strong, cheap and elegant. The opening in the web simplifies the work of the installer and the electrician, since taking pipes across beams presents no problems. The failure pattern and stresses developed under same loading condition are studied. The no of openings is varied as 2, 4 and 6 in selected beam. The shape of opening is considered as hexagonal and circular of same cross sectional area. The support conditions are considered as fixed, hinged &roller. Overall 18 cases are studied for same central point load & span with change of spacing of openings. The maximum Deflection and the maximum VonMises stress are worked out. The comparative study is carried out using software for finite element analysis ANSYS. As the no. of opening increases, the deflection also increases for the same support conditions. The maximum deflection is observed under roller support then fixed or hinged condition due to displacements at the ends. The maximum von mises stress is also less in circular opening as compared to hexagonal opening of same area [4].

Siddheshwari A. P, Popat. D. K (2015), the increase in depth of CB leads to web post buckling and lateral torsional buckling failure when these beams are subjected to loading. Study shows that use of stiffeners in the web portion of beam helps in minimizing these failures. Hence, in the present paper an attempt has been made to review existing literature, concerned with strength of beam using stiffeners. Most of the studies have indicated that the failure of web perforated beams has occurred due to local failures in the web portion. However, very little work has been done to avoid failure of castellated beams. The strength enhancement is important in case where load concentration occurs in the beam. Hence providing stiffener can reduce stress concentration at openings [6].

Mr. Dhanraj K. Shendge & Dr. B.M. Shinde (2015), the review report presents a procedure & software application to optimize the topology, size and shape of castellated beam using finite element analysis. The Castellated beams are produced by cutting and rewelding of hot rolled sections which are made of regularly spaced opening. So for same weight Castellated beam has more height than regular beam. Load carrying capacity of simply supported Castellated steel beams susceptible to web post bucking is studied. FEA method is used to evaluate the load carrying capacity castellated beam. The parameter studies are also carried out in order to assess the cross section classification to compare the ultimate load behavior. Among the main features of these beams can be pointed to architectural features and height which resulting in greater strength and stiffness of the beams without the added weight of the beams. 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].

B.Anupriya, Dr.K.Jagadeesan (2014), this paper is focused on the investigation behavior of shear strength of CB with and without stiffeners. Stiffeners are introduced diagonally on the web opening along the shear zone, and in the other case stiffeners are provided on the solid portion of the web along the shear zone. It is concluded that stiffeners provided on the opening of the web is more effective than stiffeners provided on the solid portion of the web. Hence, shear stiffeners provided on the opening of the web is effective than the solid portion because when vertical stiffeners are provided on the solid portion of the web, shear across the holes does not have any path to flow and hence shear strength across the holes decreases, so web starts to buckle leading to higher 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].

3. RESEARCH GAP

Most of the studies have indicated that the failure of web perforated beams has occurred due to local failures in the web portion. However, very little work has been done to avoid failure of castellated beams, it has been suggested to provide stiffener with proper dimensions and locations. The strength enhancement is important in case where load concentration is observed in the beam. The castellated beam is good in carrying distributed loads but fails to carry high concentrated loads. The behavior and failure modes are necessary to be checked using stiffeners in the appropriate place so that the efficiency of the beam is increased in worst condition of stress concentration. In Indian standards there are no provisions for the stiffeners for castellated beam while it is to be studied in detail from the other codes and guidelines are needed to be developed for the design of the stiffeners. The future scope defined by few researchers in papers give a rough idea of good performance of the castellated beam using stiffeners. Also this performance will enhance strength and torsional behavior when designed with stiffeners.

4. EXPERIMENTAL WORK

As discussed in previous section different types of stiffeners (transverse and end stiffener) are optimized. Transverse and End stiffeners are optimized by considering different sizes and positions of stiffeners. Mild steel ISMB 150 was used for experimental purpose. These stiffeners which gave optimized results were then casted out. Experimental work was carried out under UTM machine. The results of

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software and experimental work were checked if they validated each other.

5. RESULTS AND DISCUSSION

a. 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 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

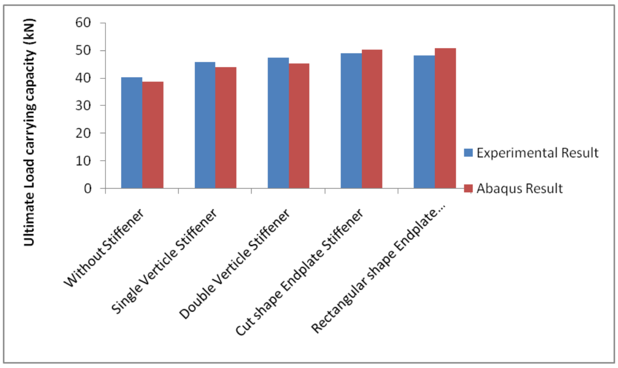

Fig- 1: Load Carrying Capacity Of Square Castellated Beams

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

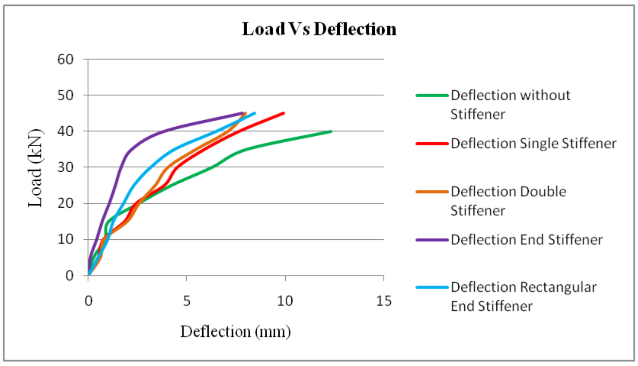

Fig- 2: Load Versus Deflection Of Square Castellated Beams

b. 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.	Rectangular shape Endplate Stiffener	58.98	58.52

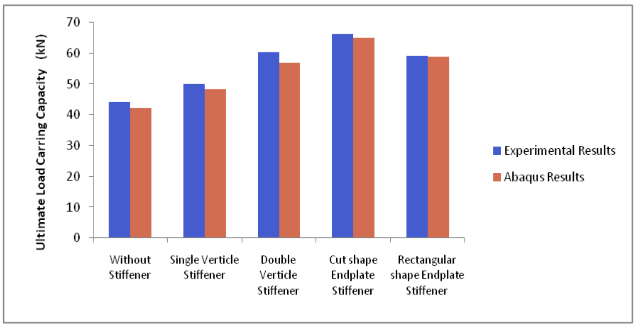

Fig- 3: Figure No 4: Load Carrying Capacity Of Circular Castellated Beams

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	

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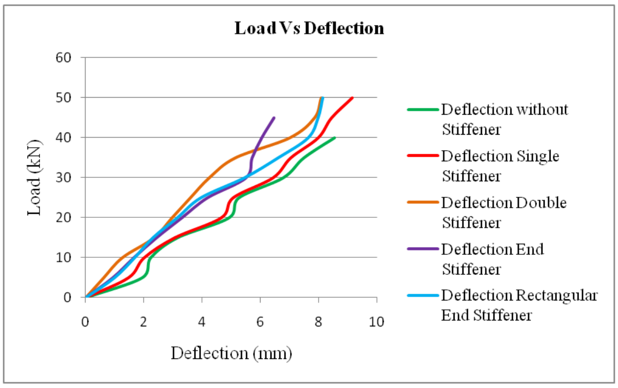

Fig- 4: : Load Versus Deflection Of Circular Castellated Beam

c. 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.	Rectangular shape Endplate Stiffener	60.29	64.60

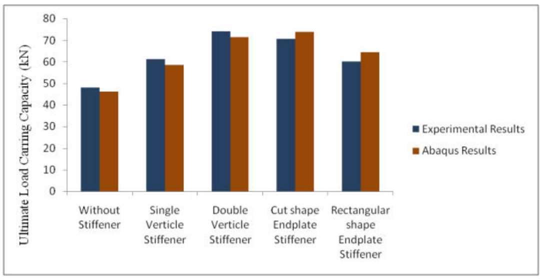

Fig- 5: Load Carrying Capacity Of Diamond Castellated Beams

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	

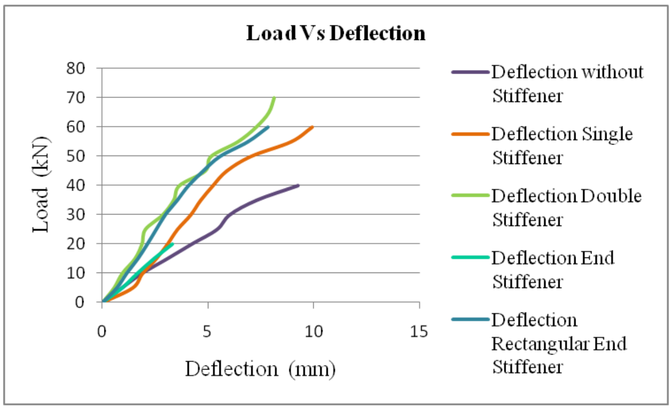

Fig- 6: Load Versus Deflection Of Diamond Castellated Beams

d. 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 PERFORMANCE

Total five models of castellated beam with different size of transverse stiffeners within the opening and end stiffeners were analyzed. From the result of this analysis it can be concluded that the stiffener of thickness 5 mm and width 10mm (5x10) performs good enough in respect of load per area ratio. Also, it is experimental that ratio goes on decreasing as area of stiffener is increased. For Transverse stiffeners each element acts as a single column and will carry the density load coming on the beam opening. Each individual element behaves as the supporting affiliate intended for distributing pressure equally along the opening. Even if we increase the area of the stiffeners it doesn't mean that load carrying capacity increases, it all depends on shear distribution capacity of stiffeners.

Fig- 7: Single Stiffener

Fig- 8: **:** Double Stiffener

Fig- 9: Rectangular Endplate Stiffener

7. CONCLUSIONS

Following conclusions can be drawn from the study so far carried out in respect of behavioural study of optimized castellated beam provided with stiffeners at different locations and using ABAQUS Software.

- From the analysis and design (Euro Code guidelines) of a castellated I beam provided with and without stiffeners in transverse within the opening and End stiffeners, it is finished that the load carrying capacity of the beam with end stiffeners is found to be more as compared to the beam provided with transverse within the opening stiffeners by 3.72%.
- Further, it can be concluded that the provision of end stiffeners helps in increasing shear capacity and reduces the torsion moment but it leads to stress concentration in beam.
- The Experimental results giving load carrying capacities of castellated beams provided with various stiffeners under two point loading, is found to be almost similar to that of the result obtained in the ABACUS software and a percentage variation in load carrying capacity is found to be approximately between 4.754%. Hence, it can be concluded that the results of ABACUS are validated with the Experimental results.
- The behaviour 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 be more 19.16 % than the beam without stiffener.

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