Behaviour of Castellated Beam with Coupled Stiffener

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Abstract – ***Castellated beam are used as structural members in multistory buildings, commercial, industrial and as well in portal frames Beams which are provided with opportunity in the web segment are not anything other than castellated beams. Generally the opening provided for castellated beams are hexagonal shaped openings, which are dispersed at regular intervals on the web portion of castellated beam. Castellated beams are comprehensively used as flexural members in steel construction. The inexpensive and structural advantages of these rudiments have prompted many researchers to investigate the failure performance of such structures. In this paper steel I section ISMB 150 is selected, castellated beams are fabricated with increase in thickness of stiffener and stiffener is provided between the two openings and beam is analysed with the help of Finite Element Analysis (ABAQUS) software. Experimental testing is conceded out on beam with two points loading. The deflection at centre of beam and various failure patterns are studied. The prevalent use of castellated steel beam as a structural constituent has prompted several exploration in their structural behavior. Castellated beams have proved to be competent for to some extent loaded longer span where the design is prohibited by deflection. The aim of this manuscript to find out increase or decrease the load carrying capacity of optimized stiffener is provided within the hexagonal opening of castellated beam***

Key words: Castellated Beam, Stiffener, Finite Element Analysis

1. INTRODUCTION

Engineers are constantly trying to improve the materials and practices of design and construction. One such improvement occurred in built-up structural members in the mid-1930, an engineer working in Argentina, Geoffrey Murray Boyd, is castellated beam. 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 alongside 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 limits on smallest amount 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 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.

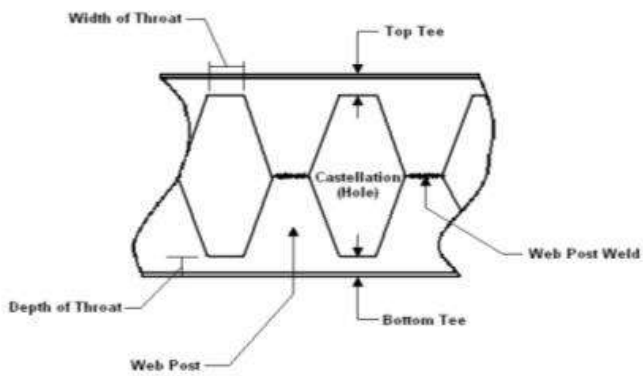

Fig-1: Terminology

- 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.

1.1. Castellated beams

Castellated beams are classified according to their shape of openings provided in the web portion. Most common shapes for the openings are hexagonal, circular also called as 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 optimization of hexagonal and circular shape is done. Following figures gives idea about openings provided for castellated beam.

1.2 Stiffeners

Stiffener are those structural components which are used to strengthen shear and moment resistance of steel plates along the longitudinal, Coupled or/and along the edge of opening. But if the castellated beams are subjected to concentric loading (for example Gantry girders) in such case castellated beam prove to be inappropriate. In such cases castellated beams must be reinforced at the places where these load concentrations occur. For example by inserting plates called as stiffeners, into one or more of the web openings by additional fitting and welding work. It is observed that there is no regulated knowledge of how a beam with web openings would behave if a stiffener is placed.

2. LITERATURE REVIEW

2.1 Shear buckling behaviors of web- post in a castellated steel beam

Shear buckling behaviors of web-post in a Castellated Steel Beam (CSB) with hexagonal web openings under vertical shear were investigated using finite element method. Through treating the upper part of the web-post as a free body under horizontal shear force, whose shear buckling strength can be calculated by the thin-plate shear buckling theory, design equations for the vertical shear buckling strength of the web-post were proposed. Parameters that affected the vertical shear buckling strength of the web-post were studied, which were the opening height to web thickness ratio $h0/tw$, the web-post width to web thickness ratio e/tw, the web height of Tee section above the opening to the web thickness hf/tw, the web thickness tw and the incline angle of the opening edge α. After obtaining the vertical shear buckling strength of a CSB through finite element model, the

shear buckling coefficient k can be obtained through inverse analysis. Research results showed that k decreased nonlinearly with the increase in e/tw and hf/tw and it increased linearly with the increase in α and $h0/tw$. Practical calculating method for k was proposed based on parameter analysis results. The vertical shear buckling strength of the web-post calculated using the proposed shear buckling coefficient k agreed well with that obtained from the finite element simulation.

2.2 A comprehensive FE parametric study

In recent years, researchers study alternative connection designs for steel seismic-resistant frames by reducing the beam section in different ways including that of creating an opening in its web (RWS connections). A similar design is applied in the fabrication of perforated (i.e. cellular and castellated) beams mostly used to support the service integration, as well as the significant mass reduction in steel frames. 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 behaviour 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. The parameters introduced were the distance from the face of the column, S, and the web opening spacing, So, with closely and widely spaced web openings. 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. The design of partially restrained RWS connections should be primarily based on the distance of the first opening from the face of the column.

2.3 Application of structural topology

This paper focuses on the application of structural topology optimization technique to design steel perforated I-sections as a first attempt to replace the traditional cellular beams and better understand the mechanisms involved when subjected to bending and shear actions. An optimum web opening configuration is suggested based on the results of parametric studies. A FE analysis is further employed to determine the performance of the optimized beam in comparison to the conventional widely used cellular type beam. It is found that the optimized beam over performs in terms of load carrying capacities, deformations, and stress intensities. Barriers to the implementation of the topology optimization technique to the routine design of beam web are highlighted.

2.4 Stiffener

Now-a-days the use of castellated beam has been admired due to its beneficial functions like light in weight, easy to erect, economical and stronger. The castellated beam is manufactured from its parent solid I beam by cutting it in zigzag pattern and again joining it by welding, so that the depth of the beam increases. Hence, due to increase in depth of beam load carrying capacity of the parent I section is increased with same quantity of material. The increase in depth of 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 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 of number of stiffeners, size of stiffener and there locations in the web portion of castellated beam needs to be carried out. Hence, in the present paper an attempt has been made to review existing literature, concerned with strength of beam using stiffeners. The literature survey indicates that use

3. MATERIAL AND METHODS

For achieving the aims and objectives of the given research, following methodology was used:

1. For studying behaviour of Castellated beams reinforced with stiffeners, the different shape web openings which were considered as below;
    a. Rectangular Shape
    b. Circular Shape
    c. Diamond Shape
2. The stiffener used in web portion were of following types;
    a. Double Vertical Stiffeners
3. Initially all the castellated beams were modeled in ABAQUS Software with double stiffeners reinforced in web region.
4. After carrying out buckling analysis of all the models, the beam models compare with & without stiffeners.

3.1 Guidelines for openings in web

The openings made in the web are greatly affecting the structural performance of the beam. Therefore, some logical and practical considerations need to be observed while providing web openings in the beam. Following are the general guidelines which are given by Eurocode 3 and some of them are based on the field or practical considerations for obtaining optimum strength of castellated beams. These guidelines are as follows;

Table - 1: Guidelines for Openings In Web

Sr. No	Design	Permissible Values	Project Values	Remark
1.	$1.08 < \frac{S}{D_o} < 1.5$	1.08 to 1.5	1.4	Safe
2.	$1.25 < \frac{D}{D_o} < 1.7$	1.25 to 1.7	1.5	Safe
3.	$D_o \leq 0.8 D$	Less than or Equal to 120	100	Safe
4.	$e \leq 0.4 D_o$	Less than or Equal to 40	40	Safe
5.	Width of end post > 0.5 D	More than or Equal to 50	50	Safe

3.2 Methodology

1. Guidelines for stiffeners according to Euro Code According to Euro code 3 the stiffener should provided at:
    a. Area of stiffener should be equal to 30Ɛ tw provided at spacing 15Ɛ tw.
    b. If 15Ɛt< S then we can provide it at the middle of clear distance between two openings.
2. End stiffeners and stiffeners at internal supports should normally be doubled sided and symmetric about the centerline of the web.
3. Stiffeners at locations where significant external forces are applied should preferably be symmetric.

3.3 Selection of method of analysis

In order to optimize the dimension of the stiffener of the castellated beam, it is very important to decide proper analytical method. Due to complex geometry of castellated beam the finite element analysis (FEA) is the best available to analyze the beam. FEA is done by the simulation software "ABAQUS/CAE 6.13".

3.4 Selection of section for parent hot rolled steel (HRS) I beam

Considering the market availability, economy and inspecting the practical difficulties during the testing section of span was chosen. The span of the section chosen is 1000mm and also by considering the capacity of UTM (1tone) the section was not chosen of greater depth.

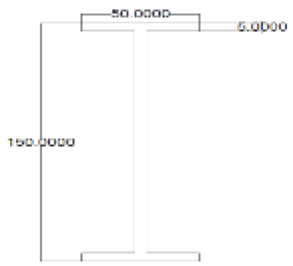

Fig-2: Cross section of the parent I beam

4. RESULTS AND ANALYSIS

4.1 Hexagonal opening without Coupled Stiffener

Table - 2: Result for load carrying capacity of model without stiffener

Hexagonal						
Sr. No	Names	Thickness (mm)	Width(mm)	Area (mm^2)	Load (KN)	Ratio of Load to Area in Percentage
0	0X0	0	0	0	45.754	-

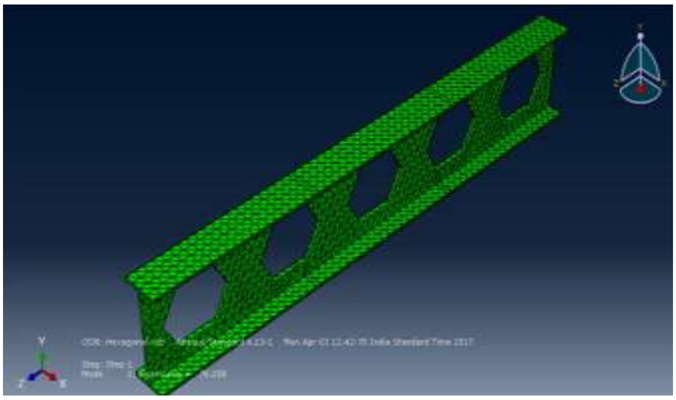

Chart-1: Result for load carrying capacity of model without stiffener

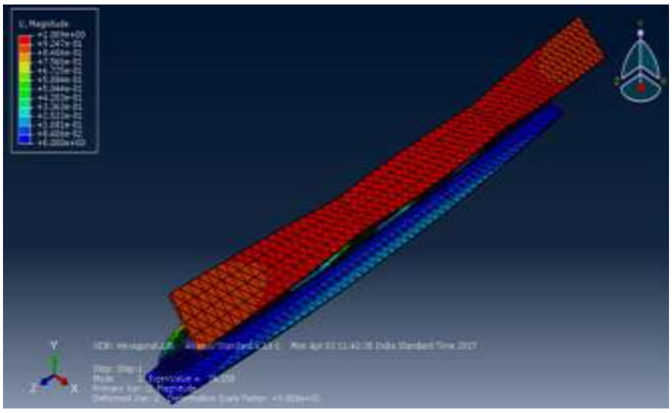

Chart-2: Result for load carrying capacity of model without stiffener

Chart-3:

4.2 Hexagonal opening with Coupled FRP Stiffener

Table - 3: Result for load carrying capacity of model with stiffener (1mm)

Hexagonal Opening With FRP Stiffener						
Sr. No	Names	Thickness (mm)	Width(mm)	Area (mm2)	Load (KN)	Ratio of Load to Area in Percentage
1	1 X 10	1	10	10	45.955	4.60
2	1 X 20	1	20	20	46.248	2.31
3	1 X 30	1	30	30	46.476	1.55
4	1 X 40	1	40	40	46.679	1.17
5	1 X 50	1	50	50	48.328	0.97

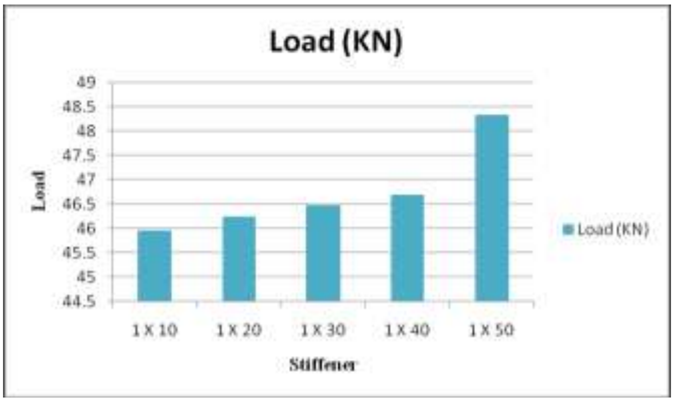

Chart-4: Result for load carrying capacity of model with stiffener (1mm)

Table - 4: Result for load carrying capacity of model with stiffener (1.67)

Hexagonal Opening With FRP Stiffener						
Sr. No	Names	Thickness (mm)	Width (mm)	Area (mm2)	Load (KN)	Ratio of Load to Area in Percentage
1	1.67 X 10	1.67	10	16.7	46.128	2.76
2	1.67 X 20	1.67	20	33.4	46.822	1.40
3	1.67 X 30	1.67	30	50.1	46.886	0.94
4	1.67 X 40	1.67	40	66.8	47.19	0.71
5	1.67 X 50	1.67	50	83.5	47.542	0.57

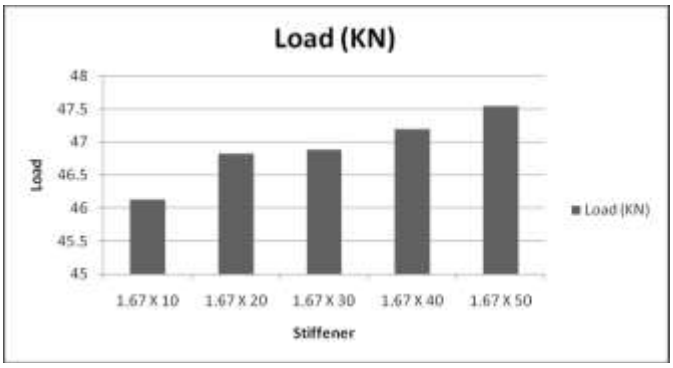

Chart-5: Result for load carrying capacity of model with stiffener (1.67mm)

Table - 5: Result for load carrying capacity of model with stiffener (2mm)

Hexagonal Opening With FRP Stiffener						
Sr. No	Names	Thickness (mm)	Width(mm)	Area (mm2)	Load (KN)	Ratio of Load to Area in Percentage
1	2 X 10	2	10	20	46.181	2.31
2	2 X 20	2	20	40	46.619	1.17
3	2 X 30	2	30	60	47.065	0.78
4	2 X 40	2	40	80	47.444	0.59
5	2 X 50	2	50	100	47.855	0.48

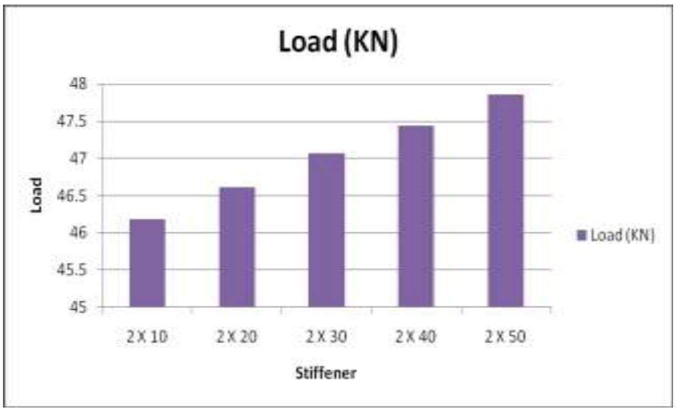

Chart-6: Result for load carrying capacity of model with stiffener (2mm)

Table - 6: Result for load carrying capacity of model with stiffener (1mm)

Hexagonal Opening With Steel Stiffener						
Sr. No	Names	Thickness (mm)	Width(mm)	Area (mm2)	Load (KN)	Ratio of Load to Area in Percentage
1	1 X 10	1	10	10	46.039	4.60
2	1 X 20	1	20	20	46.44	2.32
3	1 X 30	1	30	30	46.774	1.56
4	1 X 40	1	40	40	47.054	1.18
5	1 X 50	1	50	50	48.816	0.98

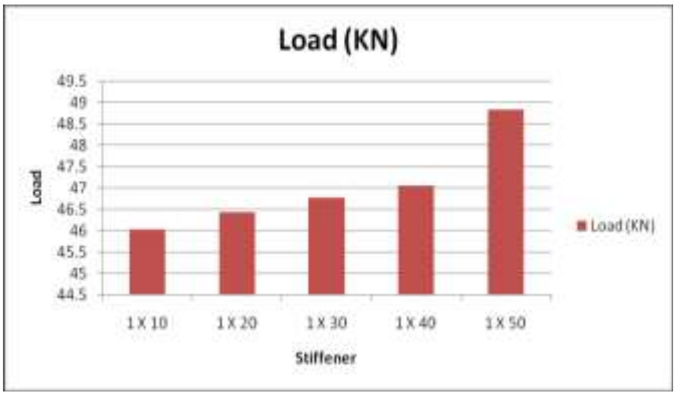

Chart-7: Result for load carrying capacity of model with stiffener (1mm)

Table - 7: Result for load carrying capacity of model with stiffener (1.67 mm)

Hexagonal Opening With Steel Stiffener						
Sr. No	Names	Thickness (mm)	Width (mm)	Area (mm2)	Load (KN)	Ratio of Load to Area in Percentage
1	1.67 X 10	1.67	10	16.7	46.248	2.77
2	1.67 X 20	1.67	20	33.4	47.079	1.41
3	1.67 X 30	1.67	30	50.1	47.218	0.94
4	1.67 X 40	1.67	40	66.8	47.622	0.71
5	1.67 X 50	1.67	50	83.5	48.112	0.58

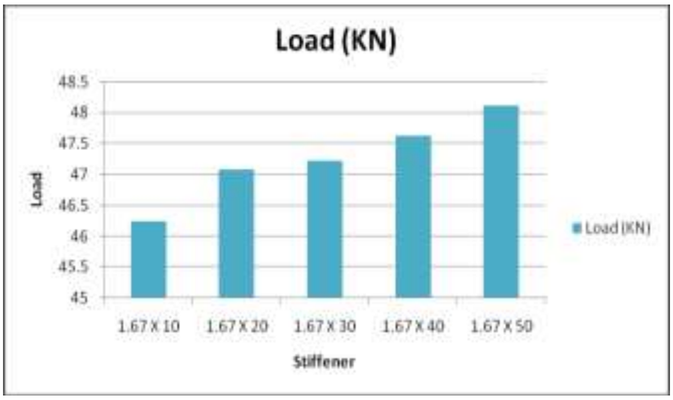

Chart-8: Result for load carrying capacity of model with stiffener (1.67mm)

Table - 8: Result for load carrying capacity of model with stiffener (2 mm)

Hexagonal Opening With Steel Stiffener						
Sr. No	Names	Thickness (mm)	Width(mm)	Area (mm2)	Load (KN)	Ratio of Load to Area in Percentage
1	2 X 10	2	10	20	46.309	2.32
2	2 X 20	2	20	40	46.838	1.17
3	2 X 30	2	30	60	47.404	0.79
4	2 X 40	2	40	80	47.89	0.60
5	2 X 50	2	50	100	48.447	0.48

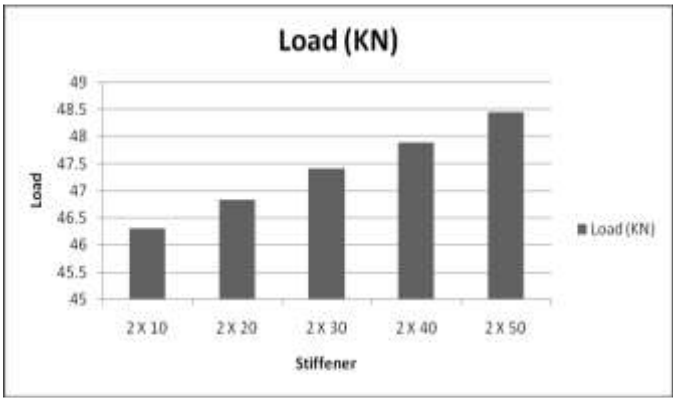

Chart-9: Result for load carrying capacity of model with stiffener (2mm)

3. CONCLUSIONS

Study and optimization of the castellated beam with the coupled Stiffener is done by many researchers. From the research gap we can frame a conclusion that the study of the behaviour of the castellated beam with stiffener is not yet unspoken. But on the other hand over the day by day use of the castellated beam is increasing extensively and demand of good performance of the beam beneath point loading is increasing. This will also give a rise to a new area of optimizing the design of stiffener. From the review of literature following conclusions can be drawn:

- Analysis and design of castellated beam needs to be carried out by using stiffeners in transverse direction and also along the edge of openings in order to minimize web post buckling.
- Optimization of castellated beams with stiffeners by varying the parameters namely, size and positions in web portion is necessary.

Following conclusions can be drawn from the study so far carried out in respect of behavioral 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 stiffeners in transverse stiffeners, it is concluded that the load carrying capacity of the beam with transverse stiffeners is found to be more as compared to the other transverse stiffeners.
- The analytical 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 research paper using software and a percentage variation in load carrying capacity is found to be approximately between 5.21%. Hence, it can be concluded that the results of ABACUS are validated with the results obtained by using software in research paper.
- The behaviour of optimized castellated beams, provided with stiffeners in transverse, has been studied in respect of load carrying capacity and reduction of local buckling. The variation in load carrying capacities as obtained by software analysis is as given below:
    - ✓ The load carrying capacity of castellated beams with hexagonal opening provided with transverse FRP and steel stiffeners in between openings is found to be more than the beam without stiffener. The maximum load area ration for the optimization FRP coupled stiffener was noted to be 4.60

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