International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 04 | Apr 2022 www.irjet.net p-ISSN: 2395-0072

A STATE-OF-ART-OF REVIEW ON CASTELLATED BEAM

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Abstract - *The researchers were merely looking for the most efficient way to reduce the usage of steel. Castellated beam is an I beam subjected to a longitudinal cut along the web in different patterns. It is considered as a best innovation of steel beam as it is laid to increase the section's depth to induce an increase in the moment of inertia and the section modulus without the slightest increase in the element weigh. It also have superior strength, weight ratio, and aesthetic appeal. Hexagonal opening is considered to be the best web opening provided. Through web openings on the Castellated Steel Beam (CSB) service pipes, electrical wires, and ventilation ducts could pass through buildings and thereby reduce their floor height.*

This paper aims to study all the features of castellated beam to introduce a strengthening method by encasing castellated beam in concrete with lacing. The optimization study on the different parameters like size, angle, shape and loading of the castellated beam were performed using FEA. All the studies concluded that the introduction of castellated beam can increase the strength of the structure.

Keywords: **Castellated beam, I section, strength, optimization, Vierendeel Mechanism, stress.**

1. INTRODUCTION

"Castellated beam" is commonly used as a type of expanded beam. It is prepared by expanding a standard rolled shape into a regular pattern of holes in the web. As the word means "built like a castle, having battlements, or regular holes are made in the walls, like a castle". It is made by separating a standard rolled shape into two halves by cutting the web in a regular pattern. The pattern of holes in the web presents an attractive appearance for beams exposed to view. The web holes are becoming ever more functional with the increase of piping, conduits and ductwork in modern construction. The greatest advantage, however, is the economy effected by the increased load carrying capacity and stiffness.

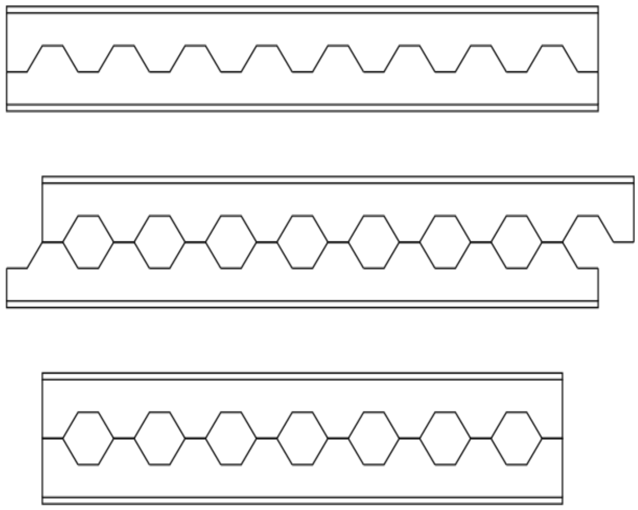

Fig 1: Castellated Beam

Use of steel is gaining greater advantage in the construction industry due to its high strength and ductility. Thus the development of castellated beam has wider advantages over conventional beam. Castellated beam is developed from conventional hot rolled steel beam, by cutting into specific pattern on the web of the WF steel beam profile into 2 pieces, which will later be shifted and welded into one unit, so that it can increase almost 50% of the original profile height. The various advantages includes the beam after creation of holes increases the height of the I section. It creates a T section above and below the opening as shown in (fig.2). Increases the capacity and stiffness of the beam. It provides various applications for the construction techniques.

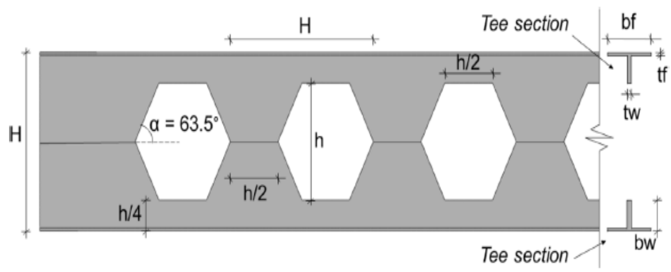

Fig. 2: Tee- section

Another benefit raised is that the castellated beam formed increases the section modulus and moment of inertia without the slightest increase in the weight. Castellated elements have the superior strength, weight ration and the aesthetic appearance. The limitations in conventional beam structure lead to the development of castellated beam. The primary importance of castellated beam is its sufficient flexural capacity. They provide many more advantages over the plain webbed beam that is the bending stiffness, strength to the weight ratio, and contributes the provision of providing passage for all the utilities installed along the large span of the industrial and warehouse facilities, domestic, factories etc.

1.1 Material Properties

During the process of fabrication, the steel members undergo intense temperature change. It can differ the material properties of the castellated beam. Over the studies it showcased that the use of steel and concrete were considered for experimental and finite element analysis. Steel under room temperature are mostly preferred for analysis. It is considered to be the primary factor affecting in non-linear behavior of castellated beam.

2. LITERATURE REVIEW

Qiao et.al [1] authors focus on experimental and numerical investigation of a substructure with castellated steel beam under a column removal scenario. The catenary action, load transfer mechanism and response to passive collapse were evaluated. Similarly the deformation capacity, vertical forces vs displacement response, failure modes and flexural and catenary actions were investigated using different parameters. Five specimens were tested against a common parent specimen. FEA simulation was done in ABQUS.

Anbarasu et.al [2] focused on the influence of castellation on the bending strength and stiffness of the hot-rolled steel Square Tubular beam and Castellated Tubular beam with simply supported end conditions. Eight specimens were tested which was fabricated according to the Indian Standards. The process improves the aspect ratio leading to an increase in the flexural capacity of the beam.

For specimen STBs 70x70x2.5 series, the flexural strength after castellation with 4 perforations was 6.4KN-m to 7.03KN-m which resulted in an improvement of 9.82% (fig: 3). The finite element model of STB and CTB with both geometric imperfections and material nonlinearity and ultimate flexural resistance, failure modes, load vs mid-span deflection, all results were considered to be in good agreement with teat result.

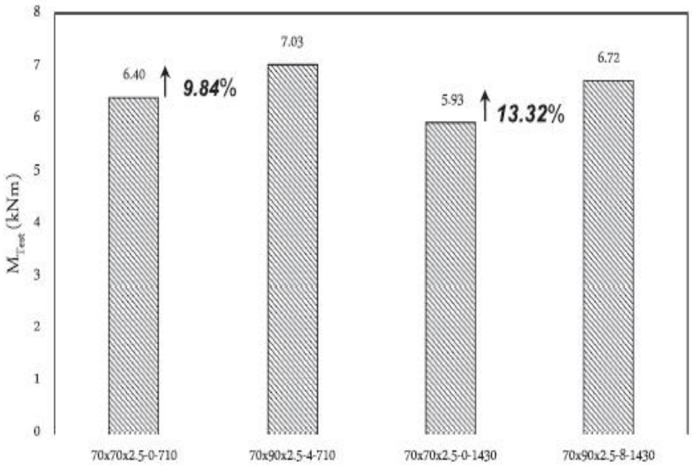

Fig:3 Flexural strength Comparison

Patel et.al [3] The authors focus on the non-linear analysis of curve–in-curve castellated beam for load carrying capacity. The average load carrying capacity increased by 27% in comparison to the parent ISMB 250 section. The parametric study focused on the load displacement variation of the curve-in-curve type castellated beam prepared from ISMB450section for its varying thickness and the length of the opening provided from the end support of the beam. All beams are modeled and analyzed by ABAQUS as a 3D shell element. The analysis confirmed that the arch shaped castellated beam has increased load carrying capacity and state that castellated beam in an effective structural solution.

Deepha et.al [4] The paper focuses on the non-linear behavior of solid I beam and the castellated beam with and without bracings and the effect of fillet radius. The load-deflection nonlinear results show that the load carrying capacity of castellated beam increased upto 1.28 times the parent solid beam. In order to increase the capacity lateral stiffeners are added and the capacity increased by 15% compared to castellated beam. The sharp corners of opening is prone to crack and fail. Hence fillet radius is introduces and it serves in reduction of the stress concentration at corners.

Braga et.al [5] The authors investigate the failure modes of laterally braced litzka type castellated beam using finite element simulation. The mutual influence of the beam parts, interaction of individual modes and post-buckling reserve of strength are evaluated. Parametric study was conducted for understanding the influence of geometry and shear span-to-depth ratio.

Hosseinpour et.al [6] studies on the effect of web distortion on the buckling behaviour of castellated steel beam. A series of nonlinear finite element model were constructed and compared with the experimental results of distortional buckling. Both material nonlinearity and geometric imperfections were considered. The parametric study were investigated to find the effect of beam length, steel grade and cross-sectional dimension on the ultimate buckling features of castellated beam. 480 castellated beams were modelled in ABAQUS for analysis. The first analysis was Eigen-value analysis followed by load-displacement non-linearity analysis. From the model, 436 specimens showed lateral distortional buckling while 20 specimen with lateral torsional buckling and 24 with web distortion.

Hussien et.al [7] The authors investigated on the structural behavior of castellated beam-column steel element. Twelve specimens were prepared and tested to study the effect of castellation of the beam-column behavior and strength. The experiment was conducted in 3 groups. 1st group focus on axial compression behavior, 2nd and 3rd group focus on axial flexural behavior. ANSYS was used to stimulated the FEA results with experimental results. Both sounds to be in good agreement. For elements subjected to pure axial loading, the castellation has no effect on the linear buckling load. Due to the effect of web deformation the capacity of the castellated element has decreased when compared to the solid web element.

Barkiah et.al [8] The study aims to compare the flexural capacity of conventional beam with the castellated beam of hexagonal opening at varying angles. The study was conducted for soft soil type in South Kalimantan. Soft soil reduces bearing capacity and leads to high soil compression. The study considered the variation in angle ranging from 0˚ to 60˚. ANSYS is used to compare the capacity of the beam. The test object is of span 200mm which is placed on two simple supports with hinged and roller support. Two points load is intended so that the internal force that occurs in the middle of the beam span is pure bending, without any shear forces. The shear between the two points of the load is zero. So that the results are purely due to the force in the moment. The moment of inertia and plastic modulus increases with increase in the angle of the hexagonal opening. Over the analysis, it is concluded that the beam of angle 50˚ has the maximum bending capacity. Hence 50˚ is considered as the optimum hexagonal angle (fig.4)

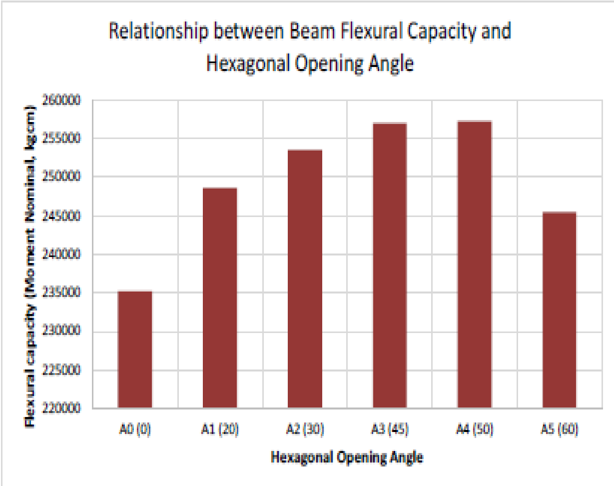

Fig. 4 : flexural capacity based on opening angle

Weidlich et.al [9] The aim of the study is to investigate the instability of castellated beam and the interaction between lateral-torsional and compression of tee local buckling modes. The fully nonlinear finite element analysis considers both material nonlinearity and geometric imperfections. ABAQUS is used for the simulation. Direct Strength Method approach is proposed for a design methodology. Finally DSM based equation is proposed and all required conditions were analyzed.

Liang et.al [10] Apart from regular modeling and analysis of castellated beam here the authors focused on behavior of a bolted castellated steel beam (BCSB). Octagonal web opening is provided and instead of welding the upper and lower tee sections, steel bolts are used for connection. By introducing the bolting mechanism, the transportation cost reduced as well as it became more convenient. The residual stresses induced by welding could also be avoided. The result concluded that BCSB increased the buckling strength of the web-post.

Justino et.al [11] The authors focused on the shear strength of web-post of castellated beam in fire. They considered a hypothetical analysis, where a uniform temperature distribution along the profile and an analogy between the strut model and the compressed diagonal of a web-post subjected to web-post buckling by shear. The analysis occurred in two stages. The first stage consist of an elastic buckling analysis with unit load and eigenvalues associated with buckling is obtained and second stage consist of nonlinear analysis by Riks method. The proposal concluded that the model is satisfactory at ambient temperature and in fire. Hence it could be adopted in design practice with relevant factor of safety.

Zhou et.al [12] The study investigated the residual stresses in castellated beam. In each stage of fabrication, there will be change in residual stresses. This change has impact on lateral torsional buckling. Hence, numerical investigation is carried out and parametric studies are conducted to investigate the effect of thermal residual stresses including flange, web thickness and flange width. According to the thermal stress analysis, the final residual stress in the region where the welding induces residual stress is relatively small. The flange tip which has the large impact of residual stress in the lateral-torsional buckling are far away from welds and kerfs. Therefore the welding induced residual stress will be influenced in same manner

Budi et.al [13] The study discusses the size and distance optimization of litzka type castellated beam. Experimental as well as analytical methods were conducted to compare the result. The results shown that distance of each hole has an influence with the location of maximum stress concentration. The maximum stress concentration is at the corners of opening. From comparative study, angle 60˚ with hole distance between 0.186*ho* to 0.266*ho* (*ho* is the height of the hexagonal hole) are the optimum model considered. Both experimental and FEM analysis has approximately same result.

Sarvestani et.al [14] The finite element analysis was conducted over a specimen under standard cyclic loading having lateral drift upto 4%, showed that the steel components except the bolted angles remained intact. There was no fracture occurred in the angle. According to FE buckling analysis, there was no beam-flange buckling as well as no web shear buckling. It has provided a reliable level of energy dissipation.

Soltani et.al [15] The presence of web opening results in failure modes which may affect the shear and buckling resistance of the beam. The failure modes depends on the geometry, web slenderness, loading type, size of opening and the support provisions. The various failures forms are web-post buckling, vierendeel mechanism, fracture at joints. These failures are considered as local failures since they are related to the geometry of the upper and lower tee sections, and the openings. Due to the formation of the four plastic hinges in the upper and bottom tee-section due to the combination of vierendeel moment and global moment, vierendeel mechanism is susceptible to occur. The fracture at the welded joints are caused due to the action of horizontal sear force when the width and length of the web-post and welded joints are respectively small. The major reasons for the local buckling to occur are the vertical instability of the sides of the opening in high shear zone, buckling of the compression flange.

Zirakian et.al [16] The primary parameters affecting the non-linear behavior analysis of castellated beams are bending moment to shear force ratio, slenderness ratio of the web etc. Due to the existence of slender intermediate plate in the web post, the shear resistance with octagonal opening were slightly lower than the circular opening. The other parameters are shape and size, loading condition, different angles etc. The analysis showed that the arch-shaped castellated beams have high load carrying capacity than regular castellated beam. Hexagonal castellated beam with angle 50˚ is optimized for withstanding bending effect. The reinforcement provided on the upper and lower of castellation can improve the strength. The buckling shape of web post with an octagonal or circular opening is 'S' shape.

Showkati et.al [17] Authors focused on the experimental study on lateral torsional buckling of elements with elastic bracings. The objectives of the investigation are distortional buckling of nine simply supported specimen under pure bending (fig.5) and comparison of the result with theoretical results. Generally, the distortional buckling are considered in two 'lateral distortion' and 'restrained distortion' (fig6. a, b). The results conclude that the specimen with lower brace stiffness exhibits half sine-wave buckling mode with maximum out-of-plane deflection along the mid-length. If the stiffness increases, the complete sine-wave buckling mode could develop along the quarter span with maximum out-of-plane deflection.

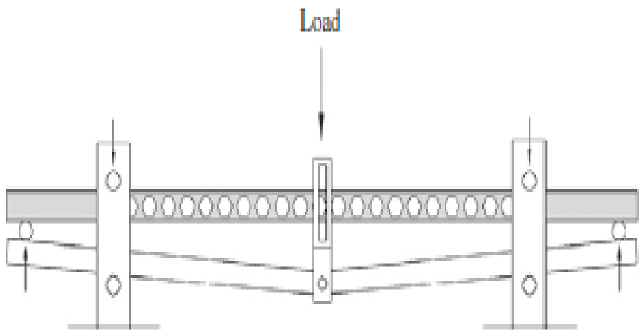

Fig.5 : Loading and Support Conditions

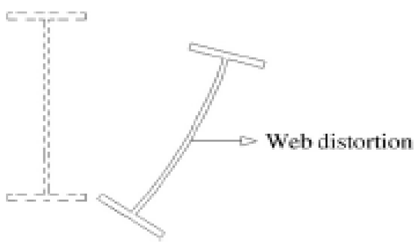

Fig 6 (a) lateral distortional buckling

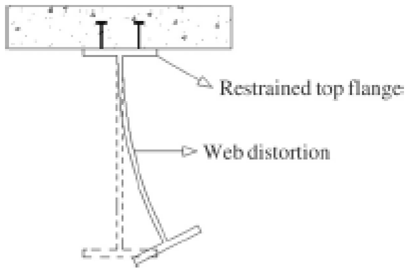

Fig 6 (b) restrained distortional buckling.

3. CONCLUSION

Castellated beams are used as a best structural solution in steel structures. The ultimate strength can be increased to a greater extend by providing strengthening techniques. The fillet corner of the web opening reduces the stress concentration. The castellated beam with high web opening results in web-post buckling. Deeper the tee-section, less accurate result obtained shows that the failure occur in web due to local buckling. The maximum stress concentration occurred at opening edges. Shorter the distance of web-post the stress concentration will move to the weld joint area. Flexural strength also contributes to a good agreement. Strengthening the castellated beam should be given more concentration to exclude all failures.

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