Review on Characteristics of Castellated Beam

Gopika S Nair [1], Dr.P.R. Sreemahadevan Pillai[2]

[1]P. G Scholar, Dept. of Civil Engineering, NSS College of Engineering, Palakkad, Kerala, India
[2]Professor, Dept. of Civil Engineering, NSS College of Engineering, Palakkad, Kerala, India

---

Abstract - *A castellated beam is made by providing a longitudinal cut along web of solid beam, following a specific pattern to divide it, and reassembling the beam with a deeper web by taking advantage of the cutting pattern. They gain its advantage due to its increased depth of section. The high strength properties of structural steel cannot always be utilized to best advantage in the case of conventional beam, due to limitations on maximum allowable deflections. 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 are the different modes of failure of castellated beam. With provision of precise number of stiffeners, size of stiffener and their locations in the web portion of castellated beam these failures can be minimized. Also, in addition use of stiffeners in web portion of castellated beams helps in increasing the strength and also minimizing the deflection. This paper is mainly focuses on stating importance of castellated beam as a structural member in construction, its advantages and applications. This paper is intended to provide a summary of the past researches related to castellated beams.*

Key Words: **Castellated beam, *Flexure mechanism, Lateral torsional buckling*, Vierendeel mechanism, Stiffener**

1. INTRODUCTION

Castellated Beam is a type of expanded beam which is made by separating a standard rolled shape into two halves by cutting the web in a regular alternating pattern. The halves are re-joined by welding after offsetting one portion so that the high points of the web pattern come into contact, finally we obtain a beam of higher depth known as castellated beam with openings at web compared to the normal I beam." The name is derived from this pattern of web holes, because castellated means "built like a castle, having battlements, or regular holes in the walls, like a castle".

Castellated beams are I-beams or girders with notches cut from the center member. The notches whether they are square as in a castle, rectangular, circular, hexagonal or octagonal or any other shape reduce the weight of the beam without greatly reducing its strength. The result is a beam with a higher strength-to-weight ratio.

Castellated beams are such structural members, which are made by flame cutting a rolled beam along its central line and then re-joining 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. Structural engineers have made many attempts to decrease the cost of structural steel structures, castellated beams are one solution in it. Castellation parameters and the loading type are the main parameters that determine the strength and modes of failure in castellated beams. Castellated beam is one of the best solutions.

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.

1.1 Parts of Castellated Beams

- Castellation: The area of the castellated beam where the web has been expanded (hole).
- 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.

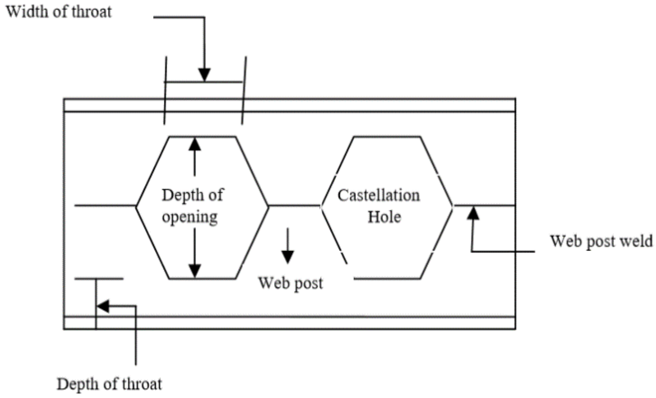

Fig -1: Parts of Castellated Beam

1.2 Modes of Failure of Castellated Beam

Six potential failure modes associated with castellated beams are

1. Formation of Flexure Mechanism: The span when subjected to pure bending moment, the tee sections above and below the holes yielded similar to that of a plain webbed beam, although the spread of yield towards the central axis was stopped by the presence of the holes. Meanwhile the two throat sections had become completely plastic in compression and in tension.

2. Lateral torsional buckling of beam: Non-composite castellated beams are more susceptible to lateral-torsional buckling than composite beams due to lack of lateral support to the compression flange. The lateral torsional buckling behaviour of castellated beams is similar to that of plain webbed beams due to presence of holes in web portion of beam.

3. Local buckling of web or flange: Heavy loading and short span of the beam cause Local buckling of web or flange.

4. Rupture of weld in the web post: Rupture of a welded joint in a web-post can occurs when the width of the web-post or length of welded joint is small. This mode of failure is due action of the horizontal shearing force in the web-post, which is required to balance the shear forces applied at the points of contra flexure at the ends of the upper I-section.

5. Formation of Vierendeel Mechanism: The transfer of shear force across the opening should be consistent with the rate of change of bending moment otherwise results in local or overall instability

6. Shear Bucking of a Web Post: The horizontal shear force in the web-post is in relation with double curvature bending over the height of the post. In castellated beam one inclined edge of the opening will be stressed in tension, and the opposite edge in compression and buckling will results in twisting effect of the web post along its height.

2. LITERATURE REVIEW

J. P. Boyer (1964) conducted study on very basics of castellated beams mainly its background, assumptions for analysis, fabrication methods, development of design tables and applications and economics.

Richard Fras, Herman Parung (2016) carried out numerical modelling approach for determining optimum opening angle and spacing between two openings on hexagonal castellated beam. Three different angles (50°,60°,70°) with different opening spacing (6mm,9mm,12mm) has been selected. Results demonstrated that, the opening angle and opening spacing which gives better result is 60° and 60mm with deflection at yield is 0.7867, load at yield is 78.4812KN, and von-misses stress is 247.4MPa.

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. ANSYS14.5 was used for the analysis. Results showed that the castellated beam with hexagonal opening showed more load carrying capacity and lesser deflection compared to solid beam and steel beam with circular opening (cellular beam). From the numerical analysis, it was observed that, as compared to solid beam and steel beam with circular opening, steel beam with hexagonal opening showed more load carrying capacity. If diagonal stiffeners are provided along the shear zone of web openings, deflection can further be reduced.

Anupriya et. al (2013) investigated the behavior of shear strength of castellated beams through an extensive finite element study. From the results obtained from ANSYS, it was concluded that deflection reduces when stiffeners are provided vertically along with diagonal stiffeners. Anupriya et. al (2014) investigated the behavior of shear strength of castellated beam with and without stiffeners and concluded that the shear strength of castellated steel beams can be improved by providing diagonal stiffeners along the web opening. Also, it was concluded that the stiffeners provided on the web opening is more effective than stiffeners provided on the solid portion of the web.

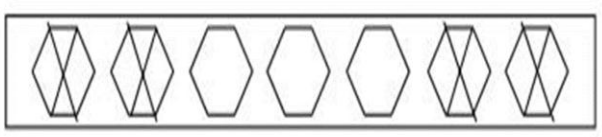

Fig -2: Diagonal stiffener along shear zone

C.Weng (2002) studied experimentally shear splitting failure of composite concrete encased steel beams. Nine full-scale specimens were constructed and tested in this study. Significant horizontal cracks along the interface of steel flange and concrete, referred to as the shear splitting failure, appeared in five tested specimens. Observations from the experiments indicate that the steel flange width ratio, defined as the ratio of steel flange width to gross section width, has a dominant effect on the shear splitting failure of composite beams. The test results reveal that the shear splitting failure occurs when the steel flange width ratio of a composite beam reaches 0.67. The test results also show that the application of shear studs has a positive effect on preventing this type of failure for beams with large steel flange ratio. In addition to the experimental study, a new method for predicting the failure mode of composite beams are proposed. The proposed method gives satisfactory predictions as compared to the test results. Finally, a new equation is derived for the design of the stirrups to prevent shear splitting failure of naturally bonded composite beams.

Hideo Takabatake, et.al., (1991) studied the lateral buckling behaviour of I beam with and without using stiffeners in the web portion of the beam. Along the length of the beam, the beams provided with stiffeners and batten plates. The beam was restrained against lateral translation and twisting. It was observed from the experiment that lateral buckling of I beam was delayed due to web stiffeners and battens.

M.R. Wakchaure and A.V. Sagade (2012) studied the flexural behaviour of castellated beams. Beams were modelled with increase in depth of web openings and analyzed the behaviour of castellated steel beams having an I-shaped cross-section, using ANSYS14. Analysis is carried out on beam with simply supported support and two-point load condition. The study of various failure patterns and deflection at centre of beam are studied. The beams with increase in depth are then compared with each other and with parent section for various parameters and for serviceability criteria. From the finite element analysis results, it is concluded that, with regards to serviceability requirements up to a maximum web opening depth of 0.6h, the Castellated steel beam behaves satisfactorily. For moderately loaded longer spans where the design is controlled by deflection, Castellated beams have proved to be efficient.

M. R. Soltani, A. Bouchair and Mimoune M. (2011) authors prepared a nonlinear numerical model was created to obtain the behaviour of castellated beams with hexagonal and octagonal openings. Also, parametric study is carried out by increasing depth of opening. The numerical results are compared with the existing literature and validated with help of MSC/NASTRAN software. Also, failure patterns of beams with various sizes are studied.

D. F. Erdal and M. P. Saka (2013) analytically studied the load carrying capacity of optimally designed castellated beam with various number of holes and spacing. With the application of centrally applied point load finite element analysis of same beams is also carried and also failure patterns are studied and verified using ANSYS. It is observed from the study that lateral supports are governing factor for the analysis of beams due to torsional buckling even though the members are relatively short spans. Also, when load is applied above the circular opening then beam fails due to Vierendeel mode and when load is applied on the portion other than prescribed above then beam fails in web post buckling.

M. R. Wakchaure, A.V. Sagade and V. A. Auti (2012) studied validation of the results obtained by the finite element analysis is done by experimentation. Castellated beams with increase in depth (i.e. by increasing depth of perforation) are fabricated and tested under simply supported condition and with two-point bending. The experimental investigation shows beams satisfactory results are obtained for serviceability criteria at the depth of 0.6h. Also, it is observed that Vierendeel failure of beam becomes predominant that with increase in depth of opening.

Fig -3: Flexure Buckling of Beam

Mr. Dhanraj K. Shendge, Dr. B.M. Shinde (2015), the review report presents a procedure & software application using finite element analysis to optimize the topology, size and shape of castellated beam. The study was conducted to obtain Load carrying capacity of simply supported Castellated steel beams susceptible to web post bucking. To evaluate the load carrying capacity castellated beam FEA method is used. The parameter studies are also carried out to assess the cross-section classification to compare the ultimate load behaviour. 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.

Jamadar A.M, Kumbhar P. D. (2014) in the present paper an effort has been made to review various studies carried out to study the flexural behaviour of castellated beam with different size and shape of openings. Also, flexural behaviour of a castellated beam using ABAQUS software (finite element analysis) has been studied and it is found that the results are in good agreement with those results from available literature.

Sung C. Lee, et. al., (2002) analyzed three models of plate girder with and without provision of stiffener using software program. The post buckling behaviour of shear web panel was explained using model called as shear analogy. It was observed that the transverse stiffeners are not subjected to compression force. But the strength of the intermediate transverse stiffener is very important parameter as it provides strength to the web of the beam.

Ehab Ellobody (2011) studied the interaction of buckling modes in castellated beam with hexagonal opening experimentally as well as analytically. 96 models of castellated beam were developed incorporated with all non-linear material properties in ABAQUS (Finite Element programming software). the geometries of the specimen are changed also the length of the beam was considered for study. The strength of the steel and the non-dimensional slenderness of failure mode were also other two parameters considered for the study. It was observed from the study that load of failure of the beam is reasonably reduced due to presence of web distortional buckling.

Ehab Ellobody (2012) analyzed the castellated beam having circular openings by nonlinear analysis, where the combined modes of buckling of these beams were studied. Considering the parameters like imperfection of geometry, remaining stresses and also non-linear material properties of material, the beam behaviour was checked for high strength. The non-linear finite element method aided in predicting deflection, failure modes and also the loads causing failure. The result of parametric study shows the cellular beam fails due to combined action of web distortional as well as due to web post buckling mode which shows considerably decrease in failure load. Lateral torsional buckling was observed in cellular beams with normal strength while distortion of web and also the web post buckling was observed in cellular with high strength.

Peijun Wang using Finite Element Method investigated Vierendeel failure of castellated steel beams with fillet corner web openings. The internal forces around the web openings causes Virendeel failure. When force is applied on the castellated beam it gets transmitted through the web posts, which cause the induction in stresses in the local area. This induced stress is the main cause of the castellated beam failure. Numerical results indicate that castellated beams with the proposed fillet corner web openings have the higher load bearing capacity than those with traditional rectangular or hexagonal openings if they have the same opening height. The fillet radius can promote the stress redistributions around the web openings, which can increase the load carrying capacity of the web-perforated members. According to Wang, the fillet radius which equals to a quarter of the opening web height is the best option for the proposed fillet corner web opening shape.

Delphin Snock investigated the effect of residual stresses in steel castellated beam. The nature of web openings will affect the failure behaviour of castellated beam. New localized failure modes can arise around the web opening. The change in geometry and the influence of production processes gives residual stresses. The residual stresses in the castellated beam plays important role while determining the buckling resistance. Delphin expects that castellated beam members manufactured according to the standard procedure will minimize the residual stresses which in turn give the higher load carrying capacity.

T.C.H. Liu and K.F. Chung done a comprehensive finite element investigation on steel beams with different web openings having various shapes and sizes. All the castellated steel beams with large web openings of various shapes behave similarly on the application of external load. The plastic hinges are formed at both ends of openings at failure. The critical opening length is the most important parameter in the failure of castellated beam. The critical opening length controls the magnitude of local virendeel moments acting on the castellated beam. The transfer of vertical shear forces across the web openings can cause the local bending moments is called as virendeel effect which leads to failure of beam called as virendeel failure. The finite element module is used to examine the effect of fillet corner web openings dimensions on load carrying capacity of castellated beam.

3. CONCLUSIONS

By reviewing the above papers, it can be concluded that

- The method of castellation is simple without using additional material so the cost of construction is reduced.
- A lot of study has been carried out in optimizing the dimensions of perforated web steel beams with hexagonal, octagonal, square, circular, etc opening in respect of flexural behavior.
- very little work has been done to avoid failure of castellated beams, it has been suggested to provide stiffener with proper dimensions and locations.

REFERENCES

[1] J.P.Boyar , "Castellated Beam- New developments", AISC National Engineering Conference, Omah,1964

[2] Richard Fras, Herman Parung, "Numerical modeling of hexagonal castellated beam with monotonic loading", Sustainable civil engineering structures and construction materials, SCESCM,2016.

[3] Resmi Mohan, Preetha Prabhakaran, "Finite element analysis to compare the deflection of steel beam with and without web openings", International Conference in emerging trends in engineering and management (ICETEM),2016.

[4] B. Anupriya and Dr.K. Jagadeesan, Shear strength of castellated beam with and without stiffeners using FEA (Ansys 14), International Journal of Engineering and Technology (IJET), Vol. 6 No 4,2014.

[5] C. Weng, "Experimental Study on Shear Splitting Failure of Full-Scale Composite Concrete Encased Steel Beams", Journal of Structural Engineering,2002.

[6] Hideo Takabatake, Shigeru Kusumoto and Tomitaka Inoue, "Lateral Buckling Behavior of I Beams Stiffened with Stiffeners", Journal of Structural Engineer, Vol.117, pp 3203-3215,1991.

[7] M.R. Wakchaure, A.V. Sagade, "Finite Element Analysis of Castellated Steel Beam", International Journal of Engineering and Innovative Technology, vol. 2, pp. 3744-3755, Jul. 2012.

[8] M.R. Soltani, A. Bouchaïr, M. Mimoune, "Nonlinear FE analysis of the ultimate behaviour of steel castellated beams", Journal of Constructional Steel Research, vol. 70, pp. 101-114, Nov. 2011

[9] F. Erdal and M. P. Saka, "Ultimate load carrying capacity of optimally designed steel cellular beams", Journal of Constructional Steel Research, vol. 80, pp. 355-368, Nov. 2013.

[10] M.R. Wakchaure, A.V. Sagade, V. A. Auti, "Parametric study of castellated beam with varying depth of web opening", International Journal of Scientific and Research Publication, vol. 2, pp. 2153-2160, Aug. 2012.

[11] Mr. Dhanraj K. Shendge, Dr. B.M. Shinde., "Castellated beam optimization by using Finite Element Analysis: A Review", The International Journal of Engineering and Science (IJES), Volume4, Issue6, Pages PP.12-14, June - 2015, ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805.

[12] Jamadar A. M. Kumbhar P. D., "Finite Element Analysis of Castellated Beam: A Review", International Journal of Innovative Research in Advanced Engineering (IJIRAE), ISSN: 2349-2163, Volume 1, Issue 9, October 2014.

[13] Sung C. Lee, M. ASCE; Chai H. Yoo and Dong Y. Yoon,"Behaviour of Intermediate Transverse Stiffeners Attached on Web Panels", Journal of Structural Engineering, Vol. 128, pp 337-345, 2002.

[14] Ehab Ellobody, "Interaction of Buckling Modes in Castellated Steel Beams", Journal of constructional steel research, Vol. 67, pp 814-825. 2011.

[15] Ehab Ellobody, "Nonlinear analysis of cellular steel beams under combined buckling modes", Thin walled structures, Vol. 52, pp 66-79, 2012.

[16] Peijun Wang, Qijie Ma, "Investigation on Vierendeel mechanism failure of castellated steel beams with fillet corner web openings", Journal of Engineering Structures, pp.44-51,2013.

[17] Delphine Snock, Experimental investigation of residual stresses in steel cellular and castellated members, Construction and Building Materials 54, pp. 512–519,2013.

[18]T.C.H Liu, K.F. Chung, Steel beams with large web opening of various shapes and sizes: finite element investigation, Journal of Constructional Steel Research 59, pp.1159-1176,2013.