Review on Buckling Behaviour of Castellated Beam

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Abstract- *Castellated beam fabricated from standard hot rolled section have many benefits including greater bending rigidity, lesser section modulus, optimum self weight depth ratio and economics construction. 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 ingress of piping, conduits and ductwork in modern construction. The principle advantage of the steel beam castellation process is that as increase the depth of a beam to increase its strength, without increasing its weight. So castellated beam is highly steel efficient since it has maximum load carrying capacity for same cross section area of nominal I beam. The widespread use of castellated steel beam as a structural member has prompted several investigation in their structural behavior. Castellated beams have proved to be efficient for moderately loaded longer spans where the design is controlled by deflection. 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. This paper mainly focuses review on buckling behavior of castellated beam. This paper is intended to provide a summary of the past researches related to castellated beam.*

Keywords- Castellated beam, Lateral torsional buckling, Vierendeel mechanism, Flexure mechanism.

I. INTRODUCTION

The castellated beams are formed by cutting a beam in longitudinal direction as any (hexagonal, circular, rectangular) pattern. The top and bottom halves are then staggered and welded together to create a deeper, stronger beam. The word Castellated comes from a Latin word castellum which means structurally fortify. The name coincides due to cutout shape looks like the turrets on a castle. The principle advantage of the steel beam castellation process is that as increase the depth of a beam to increase its strength, without increasing its weight. So castellated beam is highly steel efficient sine it has maximum load carrying capacity for same cross section area of nominal I beam. Due to the unique split construction of the beam, asymmetric design approach can be used – whereby the top half of the beam is lighter weight than the bottom half of the beam. This will increase the load carrying capacity of beam. Longer spans with fewer support columns are typical of a castellated beam project. In addition, mechanical, electrical and plumbing runs are easily integrated, which is not feasible using a solid wide flange beam. Erection time is often faster. The physical properties of the beam can be varied to attain good strength against web buckling, web crippling, local failure. This makes the beam extremely versatile from a design point of view. The customizing of a castellated beam extends to its sectional properties. Sectional properties is one determine the behaviour of the beam. Especially when come to castellated beam strength will depends upon the opening (such as its depth, width, angle of inclination, shape of opening) and way it connected (thickness of weld). Castellated beams are generally classified on the basis of type or shape of perforation made in the web of the beam. The types of hexagonal opening, circular opening, sinusoidal opening, and rectangular openings shown in Fig 1.1

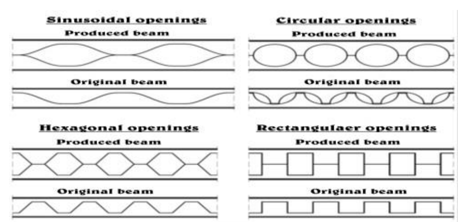

Fig-1.1 Types of Castellated Beam

1.1 Modes of Failure of Castellated Beam

Five potential failure modes associated with castellated beam shown in fig 1.2.

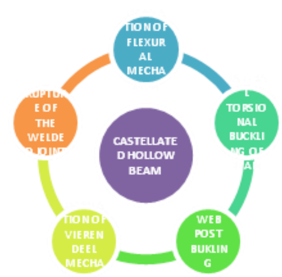

Fig-1.2 Modes of Failure in Castellated Beams

1].Formation of Flexural Mechanism

The maximum in plane carrying capacity of a castellated beam under pure moment loading is equal to the plastic moment of a section taken through the vertical centerline of a hole.

2]. Lateral torsional buckling of beam

The Lateral torsional buckling behaviour of castellated beams is similar to that of plain webbed beams shown in fig 1.3. It is occur in an unrestrained beam. A beam is considered to be unrestrained when its compression flange is free to displace laterally and rotate. when an applied load causes both lateral displacement and twisting of a member lateral torsional buckling has occurred.

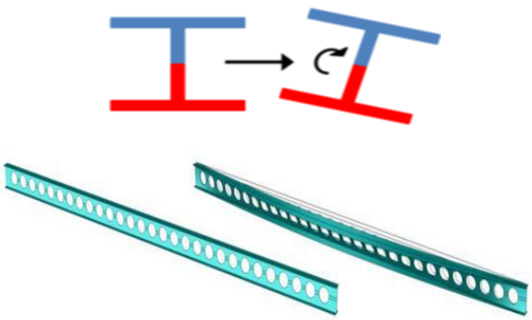

Fig-1.3 Lateral Torsional Buckling of Castellated Beam

3].Formation of Vierendeel Mechanism

This mode of failure is dependent on the presence of a shear force of high magnitude in the span under Consideration. Fig1.4 show that plastic hinges form at the corners of the holes and that the Openings deform of a parallelogram. The distortion of the panels is most clearly visible just outside the loading point in the Region of varying moment.

Fig-1.4 vierendeel mechanism

4]. Web post bukling

The shear force F acting along the welded joint will stress the web post in bending. 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.

5].Rupture of the welded joint

Rupture of the welded joint shown in fig 1.5 can occur if the length of the weld is shortened in order to reduce .

Fig-1.5 Rupture of Welded Joint

II. LITERATURE REVIEW

The Literatures were collected based on the previous investigations in the area of castellated beams with different web openings.

Amin Mohebkhah &Hossein showkati (2005),concluded that the nonlinear lateral–torsional buckling of castellated beams with a wide variety of modified slenderness was studied by means of the FE method. The modified slenderness of these beams appears to have a significant influence on the moment-gradient factor and developed an alternative equation for evaluating the C_b factor for each case in terms of the beam's modified slenderness is proposed. Therefore, it was concluded that evaluating the moment-gradient factor depends not only on loading conditions but also on the modified slenderness of the castellated beams.

Kazemi Nia Korrani et al (2010), concluded that the moment gradient factor does not only depend on the loading type but also on the slenderness of castellated beams. As the beam length decreases and the moment inertia increases, the difference between the computed and suggested moment-gradient factor increases. Accordingly, in the beams with low free span length, the moment-gradient factor obtained from finite element model is lower than that of from building code and using such moment gradient factor may lead to an unsafe design Moreover, a simple relation was proposed to determine gives moment-gradient factor on the basis of loading type.

Ehab Ellobody (2011), The parametric study has shown that the presence of web distortional buckling causes a considerable decrease in the failure load of slender castellated steel beams. The result found shows that the use of high strength steel offers a considerable increase in the failure loads of less slender castellated steel beams. The interaction of buckling modes in castellated normal and high strength steel beams has been investigated and reported in this paper. A nonlinear finite element model for the analysis of simply supported castellated steel beams has been developed. The initial geometric imperfection and nonlinear material properties of steel have been incorporated in the model. The failure loads of castellated steel beams, buckling behaviour, failure modes and load–lateral deflection relationships were predicted from the nonlinear finite element analysis and verified well against published tests. Ninety-six castellated steel beams were analysed in an extensive parametric study highlighting the effects of the change in cross-section geometries, beam length, steel strength and nondimensional slenderness on the failure loads and buckling behaviour of the beams. The parametric study has shown that the presence of web distortional buckling causes a considerable decrease in the failure load of slender castellated steel beams. It is also shown that the use of high strength steel offers a considerable increase in the failure loads of less slender castellated steel beams.

Delphin Snock (2013),studied 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(2013) concluded that 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.

D. Kerdal* and D. A. Nethercott(2014),study that the shear is dominant load in a span it will usually be possible to determine reasonable estimates of the strengths corresponding to any of the three special failure modes which occur with castellated beams. However, while the collapse load due to either lateral torsional buckling of the web posts or to rupture of the welded joint is relatively easy to calculate, the prediction of the load at which a Vierendeel mechanism forms is most readily obtained using a small computer program. No satisfactory method has been identified for the prediction of the load causing vertical buckling of the web post under a concentrated load or at a reaction point.

G. Morkhade & M. Gupta (2015),study the Circular web openings were found to be very effective in all respects, like shows a less stress concentration at the web openings, easy to fabricate and architectural appearance, etc. Rectangular openings were found to be very critical as they show very stress concentration the corner regions. It is also seen that the deformations of the rectangular openings are large compared to the other type of web openings.The rectangular web openings of 0.75*d* have a very high stress intensity compared to the other depth of openings such as 0.62*d* and 0.50*d*. Though structural performance of hexagonal and octagonal openings is found to be similar, openings have good architectural view and are easy for fabrication.

Amin Mohebkhah & Mojtaba G.(2015),study the nonlinear inelastic lateral–torsional buckling of DHFBs with a wide variety of overall slenderness under moment gradient was studied by means of the finite element method. The main aim was to investigate the effects of unbraced length and central offshear center loading on the moment gradient factor in different behavioral zones of steel beams. It was found that the Cb factors given are valid just for long-span DHFBs (i.e. elastic beams). The FEM predicted Cb factors for inelastic and short plastic DHFBs are lower than the Cb factors given. Therefore, a modified moment gradient factor (Cbp) as a function of unbraced length was proposed for such beams. Furthermore, it was observed that the AISC moment capacity curve is unconservative for inelastic DHFBs. Therefore, a straight-line transition equation proposed between the points (Lp, Mp) and (Lr, CbpMr) to be used instead of the corresponding AISC equation for DHFBs under the moment gradient case considered in this paper.

Resmi Mohan, Preetha Prabhakaran(2016),Concluded 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.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.

V.Vimleshkumar et al(2017) ,Study the comparing of castellated beam with solid beam it is concluded that solid beam required higher section than castellated beam for same loading and geometric condition. It is also found that higher section required in solid beam is due to the deflection only, because solid beam is safe in all checks like shear, bending, web buckling and web crippling but it is not safe in deflection. To minimize the deflection in solid beam higher section is required. By changing shape of opening in castellated beam (i.e. Hexagonal, Square, Circular), it is concluded that there is no effect of shape of opening on deflection but shape of opening affect on stress concentration. Maximum stress concentration occur in Hexagonal shape of opening. By changing welded length of castellated beam, it is concluded that there is no effect of welded length on deflection. Welded length depends upon depth of hole of castellated beam. By changing ratio of depth of opening to total depth, it is concluded that as ratio increases stresses are also increases. By changing angle of cut in castellated beam, it is concluded that there is no effect of angle of cut in castellated beam but it affects on stresses. Generally 45 degree is minimum angle of cut and70 degree is maximum angle of cut can be provided. In most of castellated beam 45 or 60 degree angle of cut is provided.

Delphine Sonck, and Jan Belis (2019),investigate the LTB behaviour of castellated beams using a numerical parametric study based on a validated finite element model. The suitability of the already existing 2T approach paired with the current EC3 approach for LTB of plain-webbed I-section beams was examined. According to the 2T approach, the all cross-sectional properties are calculated at the center of the web opening. The 2T approach can also be used for the calculation of the LTB resistance M_{rd}. Using a numerical study, a design approach that would fit in the current EC3 approach for the calculation the LTB resistance of plain-webbed I-section beams was determined. In this study, the detrimental effect of the fabrication process on the residual flange stresses, which was previously never considered, was taken into account .The results showed that buckling curve c would be most suited for all sections. Earlier obtained results illustrate that the modification of the residual stress pattern fabrication process of castellated beams will result in resistances that lie approximately one buckling curve lower than the resistances obtained using the original residual stress pattern.

Amol J. Mehetre, R. S. Talikoti(2020),conclued that the Rectangular opening equivalent to hexagonal opening shows lesser deflection as compare to rectangular opening equivalent to diamond opening. Rectangular opening equivalent to diamond 60degree opening shows lesser deflection as compare to other opening sizes. Rectangular opening equivalent to hexagonal 60 degree opening shows a larger load-carrying capacity as compared to other opening sizes. Experimentation shows that Rectangular opening with fillet corners increases a shear carrying capacity of the castellated beam compared to literature. Regular rectangular opening the load capacity of equivalent rectangular opening (Diamond) is about 40.16 % more. Compare to regular rectangular opening the load capacity of equivalent rectangular opening (Hexagonal) is about 67.01 % more.

III. CONCLUSIONS

From reviewing reference, it may have concluded as castellated beam mode failure will be differed from nominal I section steel beam. From the Literature study it was observed that,

1. Behaviour of castellated beam depend on various parameters such as opening shape, cutting angle, welding of length, depth of opening to total depth ect,.
2. The main draw back in castellated beam is stress concentration and failure modes of beam.
3. Castellated beam members manufactured according to the standard procedure will minimize the residual stresses which in turn give the higher load carrying capacity.
4. The method of castellation is simple without using additional material so the cost of construction is reduced.
5. Castellated beam is highly effective for self-weight to depth ratio.

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