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Overall interpretation of castellated beam on its dimension and structural behaviour: Review

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Abstract-Every day usage of materials, design performs and construction methodology were trying to improve by introducing new aspect to give away better outcome with reference to current and olden practice. In mid-1930 an engineer Geoffrey Murray Boyd develop the new ideology of castellated beam in which depth of beam is increased with introducing addition section or plate. The objective of this paper is to give overall view of castellated beam on its dimension, its flexural behaviour, stress concentration near opening, deflection of beam. In India practice of new techniques in construction field is less compare to world nation. This paper will stretch overall advantage of castellated beam towards conventional i-steel beam. Providing stiffeners are highly essential in order to prevent web post buckling and to strengthen the weld. While designing castellated beam one has to concentrate on loading nature, deflection and stress concentration.

Key words - Vierendeel mechanism, stress concentration, web post buckling, stiffeners, FEA

I.Introduction

The castellated beams are formed by cutting a beam in longitudinal direction as a hexagonal 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 lad 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 hexagonal) and way it connected (thickness of weld).

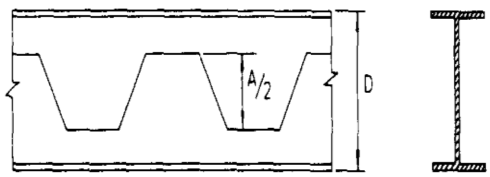

Fig.1 Cutting pattern

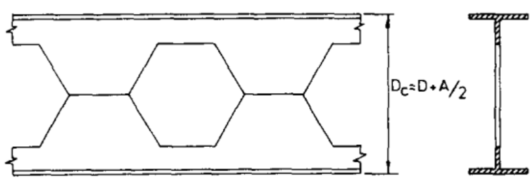

Fig 2 Castellated beam formation

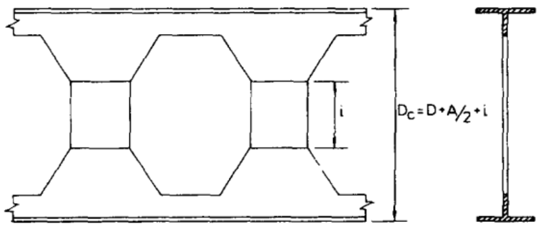

Fig 3 Castellated beam with increment plates

Even though steel in castellated beam utilized efficiently, mode of failure get increased compare to standard I beam. While designing castellated beam proper steps has to be considered in order to prevent the failure of the beam.

A. Benefits on fabricating (3)

i. The increase in sectional height that result in the enhancement of moment of inertia, sectional modulus, stiffness and flexural resistance of the sections.
ii. Decrease the weight of profile which in turns, cut down the weight of whole structure and economized on construction work.
iii. There is no need of plate girder.
iv. The passage of service wires through the web opening

B. Drawback

i. Stress concentration
ii. Shear failure

II.Mode of Failure

Due to the presence of holes in the web, the structural behavior of castellated steel beam will be different from that of the solid web beams. The castellated beam has good carrying capacity towards distributed loads then high concentrated loads. Major mode of failure of castellated beams (1) are

a) Formation of flexural mechanism
b) Lateral torsional buckling of beam
c) Formation of Vierendeel mechanism
d) Web post buckling
e) Rupture of welding in joints

A. Formation of flexural mechanism

The maximum in-plane carrying capacity, Mp, 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.

B. Lateral torsional buckling of beam

The lateral-torsional buckling behaviour of castellated beams is similar to that of plain webbed beams.

C.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. Fig show that plastic hinges form at the comers of the holes and that the openings deform in the manner of a parallelogram. The distortion of the panels is most clearly visible just outside the loading point in the region of varying m o m e n t . It is at these points that the secondary bending m o m e n t s due to the shear force acting at the point of contra flexure have their maximum values

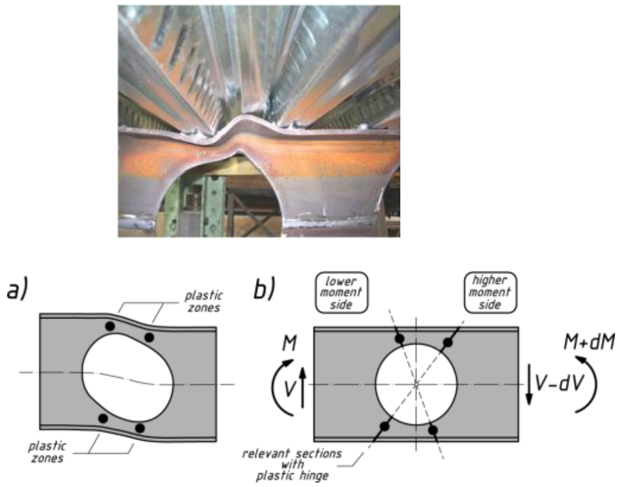

Fig. 4 Vierendeel mechanism

D. Web post buckling

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

E. Rupture of the welded

Rupture of the welded joint can occur if the length of the weld is shortened in order to reduce the magnitude of the secondary moment in the tee-sections.

III. Design of castellated beam

Design of castellated beam has been well-thought-out in orientation to reference 3 wherein Ajim shapely give the design consideration for castellated beam as such below.

i. The angle of cut is selected to be 45°.
ii. Minimum beam cross-section should not be less than 4 times of the original beam section.
iii. The moment of resistance of the castellated beam should be more the maximum moment. The moment of resistance of the castellated beam
    a. M.R.= A $\times \sigma_{at} \times$ d
iv. The spacing of castellated beam should not exceed the spacing determined by following equation
    a. S = P/ W× l
v. Stiffeners are designed at the supports and below the concentrated loads.
vi. The beam is checked in shear. The average shear at ends is calculated from following equation
    a. τ_{va} = R/d'× t < 0.4 f_y
    b. Where R = end reaction in N, d' = depth of the stem of T section, t = thickness of stem.
vii. The maximum combined local bending stress and direct stress in T Segments is also workout and should be less than the permissible bending stress.
viii. The maximum deflection of T Segment is calculated based on deflection due to net load carrying capacity, deflection due to local effects

IV.Impact of the web-openings on castellated beam

The web opening on beam affect strength of beam where discussed in reference 2 in which Krzysztof stated that the distribution of the bending moments being induced in the critical beam-cross-section depends not only on the value of the polar coordinate but also on the diameter of the hole weakening the beam-web. In addition, this relation, and thus the assumed class of the beam-cross-section, is depended on the effort of that part of the weakened beam-cross section which is subjected to tension. Such dependences are a unique feature of the beam with the web openings, unheard of in any other beams made from the sections of anotherkind. As a result of such beam behaviour the plastic reserve being the consequenceof the redistribution of the bending moment is not available. This meansthat in this case one should assume that the class of the beam-cross-sectionis at most 2.

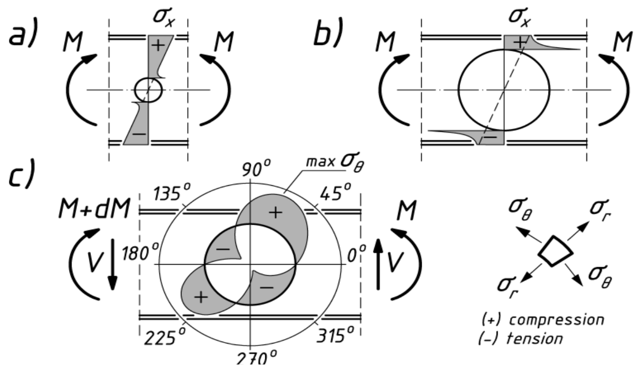

Fig. 5 Stress distribution

V. Effect of additional plate

Ajim (3) concluded from his study that moment of inertia of I-section is directly proportional to the third power of the depth. It gives advantage as increased depth of section without any additional weight, high strength to weight ratio, their lower maintenance and painting cost, the prime advantage of castellated beam is increase in vertical bending stiffness, easy service provision and attractive appearance primarily. There may be local failure which can be rectified by using plate below the concentrated load, provide reinforcement at the weak sections of the beam, to avoid Vierendeel effect corners of the holes are to be rounded are concluded.

VI. Impact of depth of opening

Depth of opening show dynamic part in load carrying capacity of section. It may be due to various local effects in beam under the corner of opening and its circumference. Following consideration shall be considered for determination of depth of hole and position of hole in beam.

i. The hole should be centrally placed in the web and eccentricity of the opening is avoided as far as possible.
ii. Stiffened openings are not always appropriate, unless they are located in low shear and low bending moment regions.
iii. Web opening should be away from the support by at least twice the beam depth, D or 10% of the span, whichever is greater.
iv. The best location for the opening is within the middle third of the span.
v. Clear Spacing between the openings should not be less than beam depth D.
vi. The best location for opening is where the shear force is the lowest.
vii. The clear spacing between such openings should be at least equal the longer dimension of the opening.
viii. Corners of rectangular openings should be rounded.
ix. Point loads should not be applied at less than D from side of the adjacent opening.
x. If stiffeners are provided at the openings, the length of the welds should be sufficient to develop the full strength of the stiffener.
xi. If the above rules are followed, the additional deflection due to each opening may be taken as 3% of the mid-span deflection of the beam without the opening.

Wakchaure from his study govern that up to maximum depth of opening 0.6D beam satisfactory for serviceability. Further increases of depth of opening may leads to different failure mode which resist the actual load capacity of the section.It makes structure highly indeterminate, which may not analyse by simple methods of analysis. So, we have to design beam to avoid local effects, for improved performance of castellated beam. It is observed as depth of opening increases in Vierendeel effects is prominently observed at the hole corners, so by taking corrective measures (i.e. corners should be rounded, provision of reinforcement) we can expect improvement in performance of beam. I - section fails under lateral torsional buckling whereas castellated beam was fails under web buckling.

Wakchaure conclude that castellated beams are well accepted for industrial buildings, power plant and multi-storeyed structures, where generally loads are less and spans are more with its economy and satisfying serviceability criteria.

VII. Selection of method of analysis

Jamadar confer finite element analysis (FEA) is the best available method to analyze the beams due to complex geometry of the castellated beam. Failure of beam is decided with von -mises failure criteria. The criteria states that, failure of the structure would take place if the von-misses stresses in the structure reaches to the value of yield stress of the material. Hence the material (steel) used has been worked out corresponding to the yield stress of 250 N/mm^2.

From his study it is observed that the beam with depth of opening 0.7 times its overall depth behaves satisfactorily in respect of load carrying capacity (32.5 kN). In the other words beam with D/Do ratio of 1.36 and S/Do ratio of 1.4 gives more satisfying results than the other. Whereas study done by Wakchaurereferredthatdepth of opening 0.6D of beam only satisfactory for serviceability.

VIII. Benefits of stiffeners

Function of Stiffener to strengthen element against shear and moment along the longitudinal, transverse direction or/and along the edge of opening. In Indian standards there are no any specified provisions for the stiffeners for castellated beam while it is to be studied in detail from the other nation codes and guidelines are needed to be developed for the design of the stiffeners.

The various types of stiffeners are used for I Beam or castellated beam are as listed below (7)

i. *Intermediate transverse web stiffener*: Intermediate transverse stiffener may be placed either at one side of web portion or can also be provided on both side of web portion. The buckling strength of web can be increased due to these stiffeners.
ii. *Load carrying stiffener*: Load carrying stiffeners are allowed when the load applied to the section is greater than that of the buckling strength of the web. These stiffeners are so designed that the buckling of web can be avoided, which is caused because of intense loading.
iii. *Bearing stiffener*: Bearing stiffener are placed where the capacity of the web is less than that of the load applied on the flange portion. These stiffeners help to minimize the local crushing which is caused because of the loads applied to the specimen.
iv. *Torsion stiffener:* Torsion stiffener is provided in such manner that the tensile force can be simply transmitted through the web portion.
v. *Diagonal stiffener:* Diagonal stiffeners are provided in order to bear the shear applied which more than that of the web of the beam. The stiffener provided have
vi. different strength that of the web of the beam.
vii. *Transverse stiffener:* These stiffeners are used at end and stiffeners at internal supports should normally be doubled sided and symmetric about the centreline of the web.

Anupriya (5) who done work to overcome the failure of castellated beam due to shear concentration near opening. Utilization of stiffeners where elaborately studied by providing vertical and diagonal stiffeners. With referential to her study, providing diagonal stiffener and vertical stiffeners will reduce the deflection of beam compare to beam without stiffeners.

Siddheshwari (7) drawn following conclusions from his evaluation (i) 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. (ii) Optimization of castellated beams with stiffeners by varying the parameters namely, size and positions in web portion is necessary.

IX. Gap in research

There is no proper analysis method for castellated beam which as to be determine. Steps has to be taken to formulate code provision for castellated beam which is main disadvantage castellated beam and column.

X. Conclusion

From reviewing reference, it may have concluded as castellated beam mode failure will be differed from nominal I section steel beam. Main drawbacks of castellated beam are stress concentration and rupture of weld which cannot prevent by providing any addition member. While designing thickness and length of weld, all factors has to be consider which will create failure in order to avoid local failure of beam? It can be reduced by using following method.

- Provide additional plate below concentrated load.
- Provide reinforcement at the weak sections of the beam.
- To avoid Vierendeel effect (to avoid stress concentration) corners of the holes are to be rounded.
- Castellated beam is highly effective for self-weight to depth ratio.

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