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Casttellated beam optimization by using finite element analysis.

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ABSTRACT

The Project presents a procedure & software application to optimize the topology, size and shape of castellated beam using finite element analysis method. The Castellated beams are manufactured by cutting and re-welding of hot rolled I sections which are made of regularly spaced web opening. In Castellated beam the height of section is more than the traditional I beam section. So for same weight, castellated beam has more height than regular beam, which increases the moment of inertia of beam and results in high buckling strength of beam. Finite element analysis method is used to evaluate the load carrying capacity castellated beam susceptible to web openings. The parameter studies are also carried out by changing different cross section and to compare the ultimate load behavior. The unit members with hexagonal, rectangular, circular and square web openings are the part of analysis. From architectural and industrial point of view, among the main features the, height of castellated beam is important factor, which resulting in greater strength and stiffness of the beams without the added weight of the beams. The effect of the load at different web openings is also analyzed using FEA. The material properties of flanges, web post sizes and web openings are the critical setting parameters for the optimization of castellated beam.

Keywords— Buckling, castellated, FEA, Optimization.

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I. Introduction

Steel structure building are becoming more and more popular due to their various advantages such as the better satisfaction with the flexible architectural, durability, strength to weight ratio, design, low inclusive cost and environmental protect as steel is manufacture to precise and uniform shapes. Since the Second World War many attempts have been made by structural Engineers to obtain new ways to decrease the cost of steel structures. Due to the limitations on maximum allowable deflections, the high strength properties of structural steel cannot always be utilized to best advantage. As a result several new methods have been aimed at increasing the stiffness or load carrying capacity of steel members without any increase in weight of the steel required. Castellated beams with web openings were one of these solutions. Castellated beams are fabricated from wide flange I-beams. The Castellated beams are manufactured by cutting and re-welding of hot rolled sections which are made of regularly spaced opening. A number of common and practical web openings are considered in the present study on castellated beam, such as circular, square, rectangular, hexagonal. As height of castellated beam will get increase it gives high bending and shear strength as section modulus of castellated beam will get increase. As a result load carrying capacity will get increase and such type of beams also allows to structural work.

II. BACKGROUND

Castellated beams previously had occasional usage for many years, during which time they were produced by simple hand procedures. The Castellated beams initially known as the 'Boyd beam', was first used in 1910, and then these beams are designed and manufactured in the beginning 1930 as roof beams in Czech Republic. The initial inspiration for the elastic and plastic calculation methods were respectively introduced in 1942 and the early 1970s. Castellation is the method of cutting the web of a rolled section in a zigzag pattern. One of the halves is turned round and welded to the other half. Though these fabrication methods were not conducive to broad development, castellated beams have long been identified as advantageous structural members. The pattern of holes in the web presents an aesthetic appearance for beams exposed to view.

III. FABRICATION

The fabrication of castellated beams is a comparatively simple series of operations when adequate handling and controlling equipment is used. This procedure increases the depth of the original beam (Hs) by the depth of the cut (d). As shown in Fig. 1, CSBs are often made from I sections by the castellation process. This shape fits the dictionary definition of castellated as ''castle-like'' The basic reasons for the fabrication of the castellated beams are as follows.

1). Augmentation of section height, resulting in the enhancement of moment of inertia, section modulus, stiffness, and flexural resistance of sections;
2). Decreasing the weight of structures;
3). Optimum use of existing profiles;
4). By passing the used plate girders; and
5). The passage of services through the web opening

Welds are made using CO2 shielded welding process with cored wire electrodes as shown in Fig. 2.

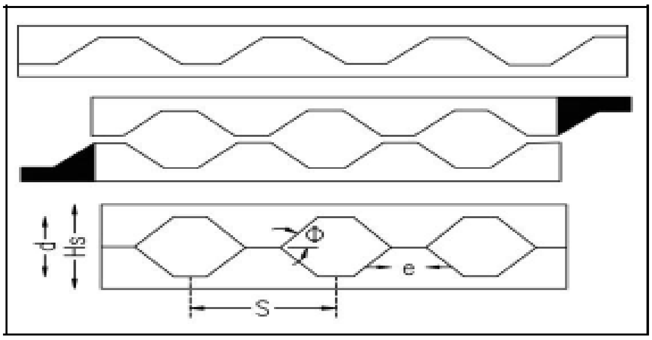

Fig.1. Fabrication of castellated beam.

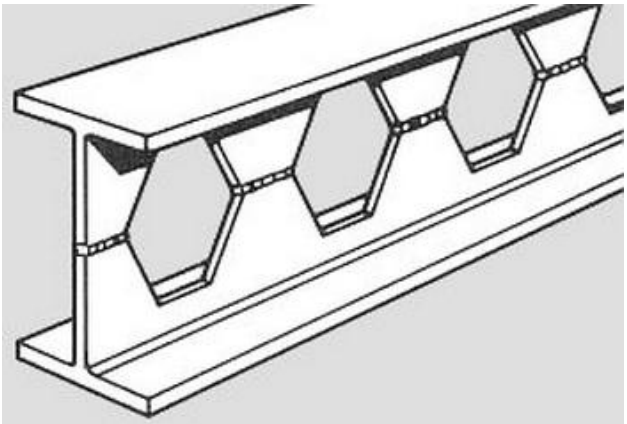

Fig.1. Castellated beam with hexagonal opening.

IV. ASSUMPTIONS FOR ANALYSIS

Castellated beams generally are used as flexural members. However, due to the nature of the section, a beam size cannot be selected solely on the basis of the usual simple procedure of applying the flexure formula to the total beam bending moment. A castellated beam performs like, and may be analyzed as, a Vierendeel truss. In such a member the longitudinal fiber stresses, which govern the beam section used, are influenced both by beam bending moment and vertical shear. The basic design of a castellated beam consists of analyzing the effect of the global and local forces and calculating the stresses illustrated in Fig. 3. Maximum longitudinal fiber stresses occur in the tee section. These stresses may be readily computed on the basis of the following assumptions which are well verified:

A). Vertical shear divides equally between the upper and lower tees.

B). For bending in the tees due to shear, there are points of contraflexure at the vertical centerline through each opening. In a perforated section under a global moment Mo,Sd and a global shear force Vo,Sd, three local actions are induced in the tee-sections above and below the web opening as shown in Fig. 3. These are

1) Axial force in the tee-section, NT, due to the global moment Mo,Sd.
2) Shear force in the tee-section, VT, due to the global shear force, Vo,Sd.

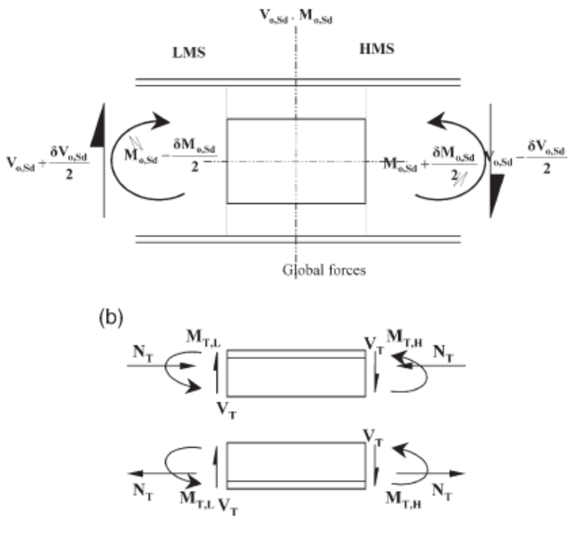

Fig.3. Local and Global forces.

3).Local moment in the tee-section, MT, and due to the transfer of shear force Vo,Sd across the opening length. For beams with given loading and support conditions, the magnitudes of these local actions depend on the shapes, the sizes, and also the locations of the openings.

V. PERFORATED WEB-DESIGN CRITERIA.

According to the codes of practice for the design of framed structures with I-sections having web openings, a number of design criteria have to be taken into consideration.

A. Design Criteria.

1) Shear resistance: The shear resistance of the perforated section should be sufficient to resist the applied shear force at the openings. In general, the shear force at an opening is mainly resisted by the web of the upper web-flange section, because the lower web flange section is often highly stressed in tension.

2) Bending resistance: The bending resistance of the perforated section should be sufficient to resist the applied bending moment. The optimum positions for web openings along the span of the beam depend on the relative proportion of bending moment and shear force. In general, the openings have a greater effect on the shear resistance of the beam than the bending resistance. For web openings with large opening depths under low shear force, flexural failure in the perforated section may be critical.

3) Vierendeel bending resistance: Vierendeel bending results in the formation of four plastic hinges above and below the web opening as shown in Fig. 4. It is a result of transferring shear forces across the opening. The Vierendeel bending resistance depends on the local bending resistances of the web-flange sections. As the global shear forces cause both shear failure and Vierendeel mechanism in perforated sections, the effect of local Vierendeel moments acting onto the tee-sections above and below the web openings may be incorporated through a reduction to the global shear capacities of the perforated sections. For web openings with large opening lengths under high shear force, Vierendeel mechanism is dominant in the perforated section.

4) Local buckling: The edge of the web above an opening,

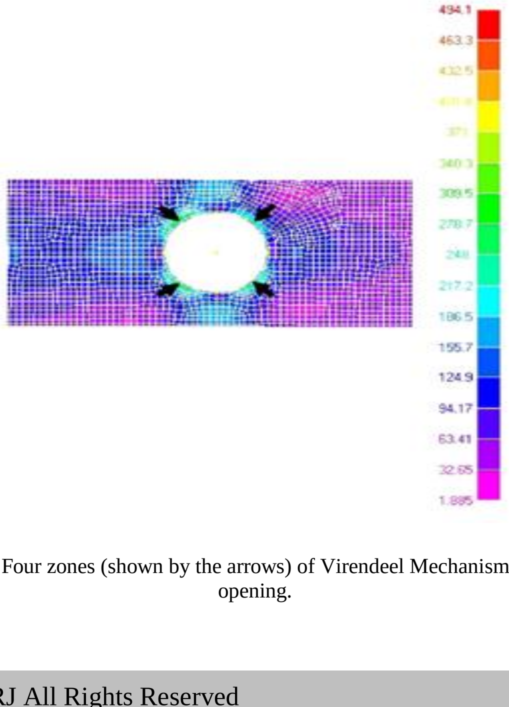

Fig.4. Four zones (shown by the arrows) of Virendeel Mechanism in the opening.

which is often highly stressed in compression, may buckle locally in compression under global bending action.

5). Web buckling:

The transfer of forces around the opening leads to local vertical compression in the web, which may cause buckling if the depth-to-thickness ratio of the web is high.

6). Additional deflection:

Each web opening leads to additional mid-span deflections due to shear and bending effects. Often the additional deflections due to one opening are small, but may be significant when summed over a series of large openings.

B. Design Constaints.

The effects of shape and size of web openings to the structural performance can be correlated to the global shear force and bending moment acting on the perforated sections in relation to the local co-existing forces and moments, acting on the tee-sections above and below the web openings. It should be noted that an increase in the web opening depth always reduces both the shear and the moment resistances of the castellated beam. Therefore, both shear and flexural failures of the beam sections are initially controlled by the size of the opening. However, while the opening length has almost no effect on the local shear and moment resistances of the tee-sections above and below the web openings, any increase in the opening length will increase significantly the local Vierendeel moment acting at the tee-sections. Thus, the Vierendeel mechanism of the castellated beam is essentially controlled by the opening length. Both the opening depth and the opening length are geometrically related, and thus any increase in size in web openings of given shapes will reduce not only the global shear and the global moment resistances of the perforated sections, but also the local axial, shear and moment resistances of the tee-sections. Furthermore, the Vierendeel moment is also increased at the same time. Consequently, it is expected that for beams with web openings of various shapes but of the same opening depths and lengths, i.e. D and In the design castellated beams with web openings the following restrictions in the design of steel beams have to be followed.

1). A good design requires that all web openings should be located along the centerline of the web because in general, the upper section of web-flange resists the shear force, while the lower web-flange section is always highly stressed in tension due to the bending moment and a considerable deviation from the centerline would possibly result in failure of the smaller tee-section.

2) The maximum diameter of a circular opening should not exceed 0.75 times the total height of the beam H. The maximum diameter of a web opening should not be extremely large because by increasing the opening height, both shear and moment capacities are reduced and the beam is prone to present shear or flexural failure, respectively. Another disadvantage of large openings is the possibility of Vierendeel mechanism with the characteristic four plastic areas in the corners of the opening, especially when shear force is high. Also, the bigger the hole the more likely the local buckling due to bending appears.

3) The distance between the edges of adjacent openings should not be less than the total height of the beam H. Adjacent openings should not be too close, since the

existence of large horizontal shear forces near the supports may induce web buckling phenomena.

4) The distance between the edge of a web opening and an adjacent point load should exceed D (b > D). The point loads should exceed a minimum distance from the adjacent holes so as not to overstrain the opening's region.

5) The distance between the edge of the web opening that is closer to the beam's support should exceed D (k > D).

Web openings should also be away from supports, as the Vierendeel mechanism is dominant near the support points.

VI. METHODOLOGY AND ANALYSIS PROCEDURE

The the model is prepared using Caria V5 software and is analysed using Ansys software. The Fig 5 shows the methodology for the castellated beam analysis.

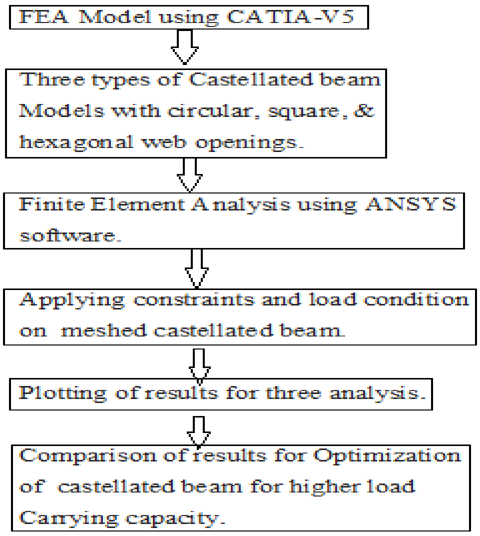

Fig.5 Flow chart showing Methodology

The model used for the parametric study consists of a simply supported beam with an overhang at each support. Both the flanges and the web of the beam are discretized into the shell elements. An opening is formed in the web where the mesh is refined locally. The model takes the advantage of the plane of symmetry at both the mid-span and along the plane of symmetry through the web as local buckling is assumed not to be critical for class 1 or 2 hot rolled steel I sections with concentric large web openings. For simplicity, fillets are not considered in the model. In order to adjust both the applied moment and the applied shear force at the perforated section, a point load V is applied at the mid pan. For ease of comparison, the yield strengths of all sections are assumed to be 275 N/mm2.The modulus of elasticity is taken as 210 GPa. The castellated beam is supported at both ends and load 1000 N is applied at the centre of beam. The results for deflection and shear stresses are shown in Fig. 6 and 7. The results of deflection and induced stresses for castellated beam with circular opening are shown in fig. 8 and 9.

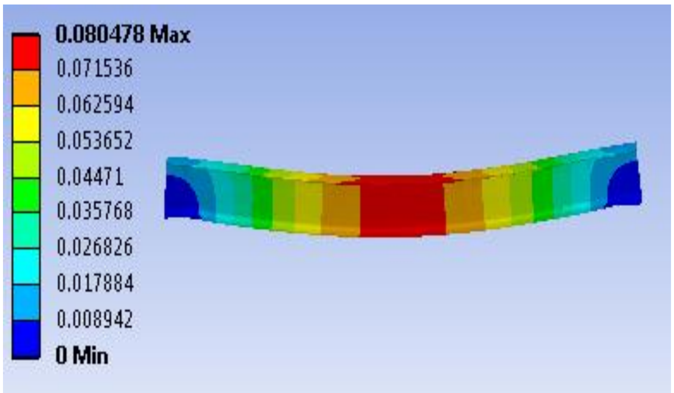

Fig.6 shows the deflection of Traditional I beam.

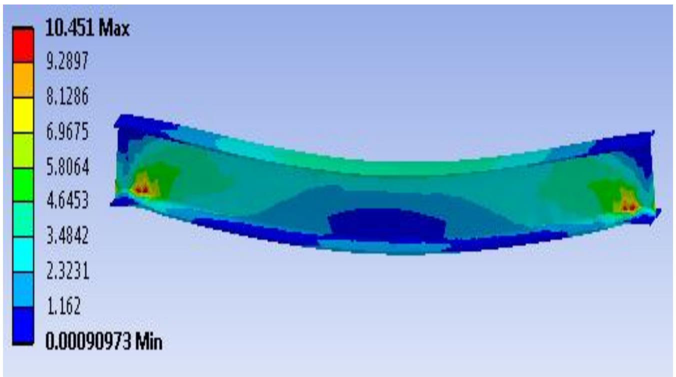

Fig.7. shows the induced stress in Traditional I beam.

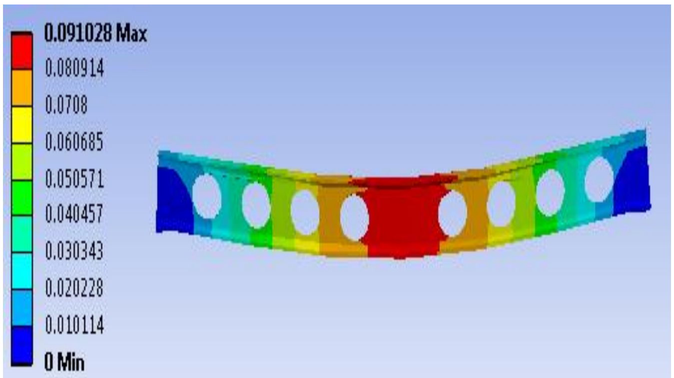

Fig.8 shows the deflection of castellated beam.

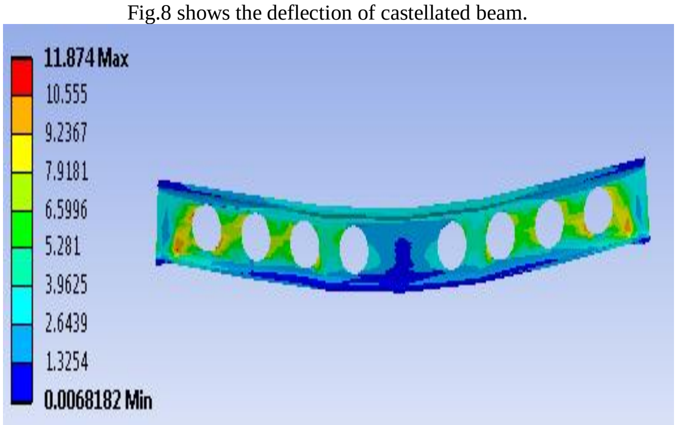

Fig.9 shows the induced stresses in Castellated

VII. APPLICATIONS

Castellated beams have been used in a wide variety of applications, such as roof beams and rafters in both simple span and cantilever construction, and girders for heavy as well as light floor loads. These uses take advantage of the increased strength and the economy of castellated beams. They also demonstrate the interesting appearance and the functional use of the web holes. The fig. 10 and 11 shows the applications of castellated beam for bride and roof structure. The most important advantages of castellated beams are economy. The savings is depending on factors as span of web openings, loading conditions and depth requirements. Even though the castellated beam is an ideal choice for many situations, it would be wrong to contend that it is the best solution in every case. There are some instances in which loads are too small, the spans too short, or the depth limitations too restrictive, to bring out the economy of castellated beams

Fig.10 shows the application of castellated beam for bridge.

However, the efficiency and economy of castellated beams has been well established and, for beams on most spans carrying medium to heavy loads, their use merits consideration.

Fig.11 shows the application of Castellated beam for roof structure.

VIII. CONCLUSIONS

Parameters governing the behaviour of load capacity of castellated beams are loading conditions, minimum yield stress and web thickness.

Load carrying capacity of castellated beam is affected by geometric dimensions and shape of web openings.

The circular web openings have high load carrying capacity than rectangular and hexagonal web openings, because uniform curve can promote the stress distributions around the web openings which can increase the load carrying capacity of the perforated members.

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