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Experimental Investigation on Castellated steel beam having spacer plates (Litzka Beam)

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Abstract—Constant experiments are conducted by structural engineers to develop better designs to impose desired qualities to the structure. Thus engineers came up with the idea of castellated steel beam. Since castellated steel beam consists of hollow portions it is important to assure its strength & load carrying capability. One of the method to improve the properties is by providing stiffeners. An experimental investigation is conducted by providing stiffeners inside the castellation and also by providing stiffeners along with spacer plates (Litzka beam).

Keywords— Castellated steel beam, Cellular beam, Litzka beam, Castellation, Stiffeners

I. INTRODUCTION

The responsibility of a structural engineer lies in not merely designing the structure based on safety and serviceability considerations but he also has to consider the functional requirements based on the use to which the structure is intended. Engineers are constantly trying to improve the materials and practices of design and construction. One such improvement occurred in built-up structural members in the mid-1930, an engineer working in Argentina, Geoffrey Murray Boyd, is castellated beam. Today the world is advancing in every sector not only in industrialization but also in infrastructure sector. All the metropolitans cities are about to touch the sky with high buildings, offices, malls, bridges, hotels, building floor systems, wide roof or hall covering systems, pedestrian bridges and other structures use rolled section steel beams. Due to population explosion we require more accommodation space on a very limited land. Therefore to fulfill these needs very tall buildings are required. As the construction of high building goes on increasing, the load on the beam also increases. To sustain that increased load the beam should be stronger, stiffer and deeper. With conventional beam these requirements are not satisfied and it leads to modification and development in conventional beam. Castellated beam is the latest development in the conventional beam which fulfills the desired requirement. Due to their design and constructional advantages, engineers are increasingly utilizing castellated beams in their design. Design advantages include a reduced weight per unit length of beam and improved flexural stiffness (lateral section modulus).Constructional advantages include the ability to run utilities through opening.

"Castellated steel beam" is a name commonly used for a type of expanded beam. It is made by expanding a standard rolled steel section in such a way that a predetermined pattern is cut on section webs and the rolled section is cut into two halves. The two halves are joined together by welding and the high points of the web pattern are connected together to form a castellated beam. In terms of structural performance, the operation of splitting and expanding the rolled steel sections helps to increase the section modulus of the beams. The figure below shows the various steps in making castellated steel beam.

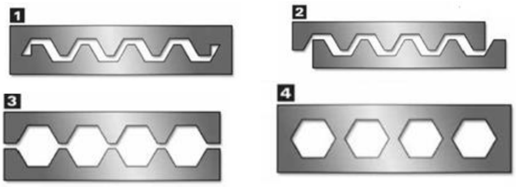

Fig. 1: Fabrication Process of a Castellated beam

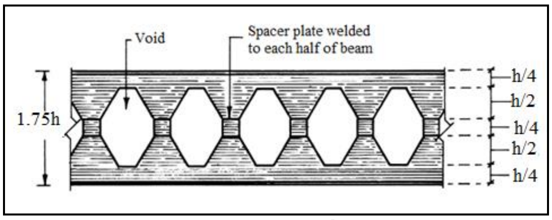

Fig 2 : Litzka Beam

Its depth can be further increased by welding rectangular plates, the increment plates (spacer plates), between the crests of both halves of the original beam. The end product is characterized by octagonal rather than hexagonal openings and is known as the Litzka beam or the extended castellated beam (castellated beam with spacer plates).Various terms used to discuss castellated beam components are given below.

- Web Post: The cross-section of the castellated beam where the section is assumed to be a solid cross-section.
- Castellation: The area of the castellated beam where the web has been expanded (hole).
- 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.

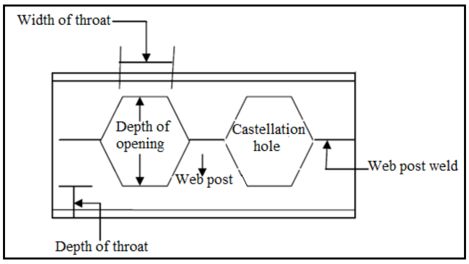

Fig 3: Components of CSB

A. *Failure modes of CSB*

Kerdal & Nethercot 1984, determined there are a number of possible failure modes for castellated beams, which are as follows:

- Vierendeel Mechanism: This occurs due to excessive deformation across one of the openings in the web and formation of hinges in the corners of the castellation.
- Lateral Torsional Buckling of the web: This is caused by large shear at the welded joints.
- Rupture of welded joints in the web: This arises due to excessive horizontal shear at the welded joint in the web.
- Plastic Hinge Formation: This mode of failure occurs when lateral torsional buckling is prevented.
- Web buckling: This is caused by heavy loading and short span of the beam. This may be avoided at a support by filling the first castellation by welding a plate in the hole.

B. *Scope & Objectives*

Since castellated beams consist of hollow portions it is important to assure its strength and load carrying capability. One of the methods to improve the properties is by providing stiffeners. The main focus of the research work is to study the effect of introducing stiffeners along the shear zone where stress concentration is more so that deflection is minimized and shear failure is controlled. The objectives of this study are

- To conduct experimental investigation to find out the ultimate load carrying capacity of castellated steel bea, castellated steel beam with stiffeners around castellation,

C. *Review of Literature*

Anupriya et al(2014) proved that shear strength of CSB can be improved by providing stiffeners along the web opening. Wakchaure et al(2012) concluded that CSB behaves satisfactory for serviceability up to maximum depth of opening 0.6D. Jamadar et al(2014)concluded that failure of CSB is due to the lack of shear transfer area and CSB with circular, square & diamond shaped openings give better shear transfer area. Wakchaure et al(2012) observed that as the depth of opening increases stress concentrations increases at the hole corners & at load application point.

II. BEAM STIFFNESS

Beam stiffness describes the degree to resist bending or deflection when the beam is loaded. Increasing the depth of the beam increases the bending strength, so we can gain a lot of stiffness this way**.** Mathematically the moment of inertia of a section can be expressed as:

Moment of inertia about x-x axis

$$I_{xx} = \int_A y^2\, dx$$

Moment of inertia about y-y axis

$$I_{yy} = \int_A x^2\, dy$$

Moment of inertia of rectangular section is expressed as

$$I_{xx} = \frac{b d^3}{12}$$

$$I_{yy} = \frac{d b^3}{12}$$

Where, I = Moment of inertia
b = Width of the section
d = Depth of the section

The axes x-x and y-y are passing through the centroid and x-x axes is parallel to the width of the section and y-y parallel to the depth.

The figure below shows the parent I beam (ISMB 150) and the castellated steel beam fabricated from the parent beam.

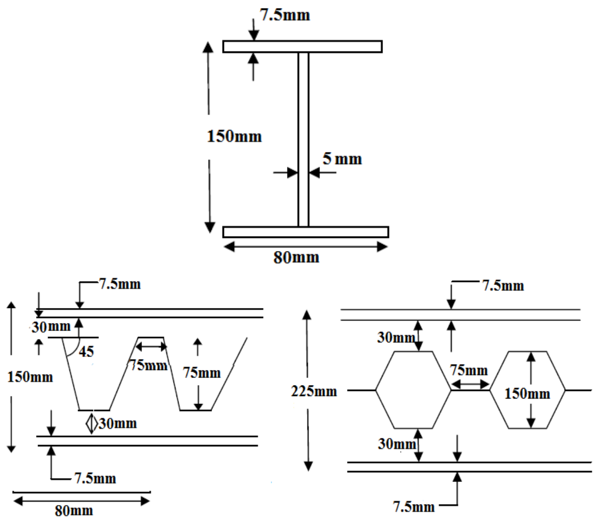

Fig 4: Dimensions of CSB

III. EXPERIMENTAL INVESTIGATION

A. *Fabrication process*

Castellated beams are made by cutting a saw tooth pattern along the centerline of the web of a rolled I-beam section along the length of its span. The two parts of original beam are then welded together to produce a beam of greater depth with halves of hexagonal holes in the steel section. Here we select ISMB 150. Using the equations given below, different values of plate width, b, can be chosen used to solve for the associated values for plate thickness, t. Here we assume b as 25mm.

- a is the spacing of the transverse stiffeners
- t_w is the thickness of the web being stiffened

$$t > \frac{12\, a\, t_w^3 \max\left[0.5\,,\ \frac{2.5}{\left[\frac{a}{h}\right]^2} - 2\right]}{[(2b+t_w)^3] - t_w^3}$$

Here we get t as 4.9mm.

Fig 5: I beam after gas cutting

Fig 6 : Welding of the specimen

B. Experimental setup

An experimental program is conducted to evaluate the ultimate strength of castellated steel beam, castellated steel beam with stiffeners, Litzka beam with stiffeners. The specimens were tested using universal testing machine (UTM) of 1000kN capacity. The specimens fabricated for testing has a span of 750mm, of which 50mm was to be kept as an overhanging portion and therefore the effective span of the beam available would be 700mm. The stiffeners has 25 width & 5mm thickness. The specimen were clamped at two ends. All specimens were loaded at its midpoint slowly until failure. Deflection measurements were taken using deflectometer. The support condition for testing was taken as simply supported and the support conditions were set accordingly by providing a hinge and roller support on either sides.

The loading was done starting from 0 kN in steps of 10 kN. Readings for each 10 kN increment in loading was taken. The loading was done until failure load i.e. until the beam specimen failed. At point of failure the proving readings are seen to go in the opposite direction even though load is applied. The load corresponding to this point will be the failure load of the specimen. The experimental results are shown below.

Fig 7: Deformed specimen (CSB)

The figure 7 shows the deflected shape of castellated steel beam without stiffeners. The beam fails at 90kN with a deflection of 1.54mm.

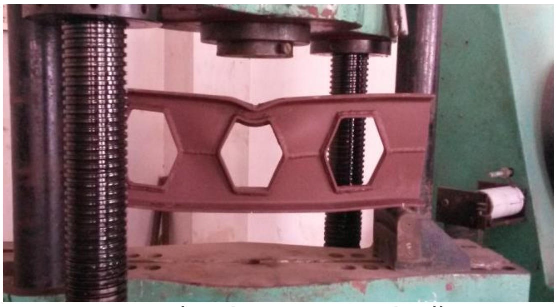

Figure 8 :: Deformed specimen(CSB with stiffeners)

The figure 8 shows the deflected shape of castellated steel beam with stiffeners. The beam fails at 170kN with a deflection of 3.04mm.

Fig 9: Deformed specimen(Litzka beam with stiffeners)

The figure 9 shows the deflected shape of litzka beam with stiffeners. The beam fails at 220kN with a deflection of 3.37mm.

C. FE Analysis

Finite element models were developed to simulate the structural behaviour of castellated steel beams. These models were calibrated against experimental results. The FE model was developed in a commercial FE analysis software package, ANSYS version 14.5. The material properties of the steel beams are same as that of I beam.The loads and supports present in the experimental steel beams were simulated by using restrictions on appropriated nodes in the numerical model. Castellated steel beam of span 750mm is tested for its ultimate load carrying capacity. The beam has three castellations.

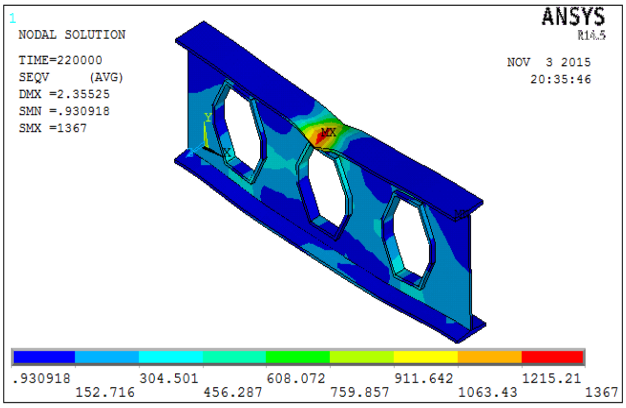

Fig 12 : Figure 6.18 : Von mises stress diagram of LB with stiffeners

TABLE I. PERCENTAGE VARIATION OF DEFLECTION (COMPARING WITH CSB)

Type of Beam	Failure Load (kN)	% variation in load carrying capacity	% variation in weight
CSB	90	-	-
CSB with stiffeners around castellation	170	88.89%	12.6%
CSB with Spacer plate & stiffeners	220	144.44%	17.89%

From the above table it is clear that the castellated steel beam having stiffeners along with spacer plates carries more load before failure.

IV. CONCLUSIONS

Now a days use of castellated beams for various structures are rapidly gaining appeal. This is due to increased depth of section without any additional weight, high strength to weight ratio, their lower maintenance and painting cost.

The stiffeners provided in the open web causes smooth flow of the shear forces leading to lesser deflection.

From the experimental investigation it is concluded that the castellated steel beam having spacer plates (Litzka beam) along with stiffeners around castellation carries more load before failure

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