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Finite Element Analysis of 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 CSB consists of hollow portions it is important to assure its strength & load carrying capability. One of the methods to improve the properties is by providing stiffeners. Finite element analysis is conducted by providing stiffeners inside the castellation and also by providing stiffeners along with spacer plates.***

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

1. 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.

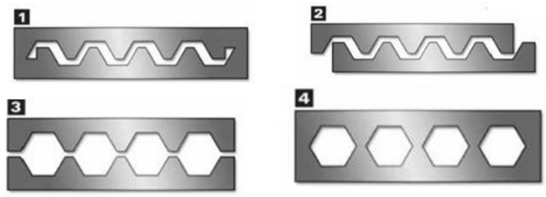

Figure 1: Fabrication Process of a Castellated beam

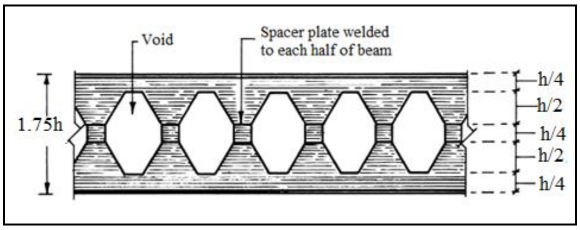

Figure 2: Litzka Beam

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.

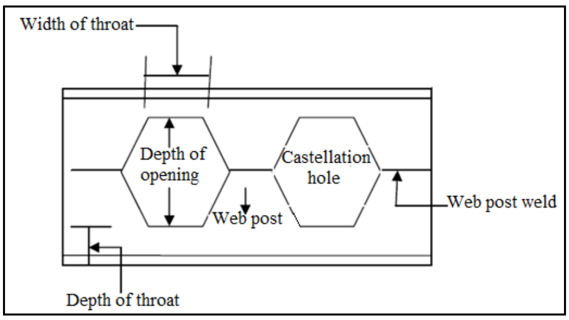

Figure 3: Components of CSB

1.1. Failure Modes of Castellated Beam

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.

1.2. Scope and Objectives

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 finite element analysis for finding the deflection of I beam, Castellated steel beam, Cellular beam & Litzka beam.
- To conduct finite element analysis for finding the deflection of CSB : with diagonal stiffeners, vertical stiffeners, horizontal stiffeners, stiffeners around castellation, stiffeners around castellation along with spacer plates.

1.3. 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.

2. Finite Element Analysis

In order to investigate the structural behaviour of simply supported steel beams a numerical study with the general purpose finite element package ANSYS 14.5 was carried out and fully reported in this paper. ISMB 150 is selected for modeling beams. The length of beam is taken as 3m. SOLID45 is used for the three-dimensional modeling. The boundary conditions used are: on the bottom left side, restrictions to displacements UX, UY and UZ and on the bottom right side, restrictions to displacements UY and UZ. The load is applied at the centre of the beam. A maximum element size of 20mm was chosen for meshing. The following assumptions are adopted for analysis.

1. Yield strength (f_y) = 2.5×10^8 N/m^2
2. Young's modulus = 2×10^{11} N/m^2
3. Poisson's ratio = 0.3
4. Density of Steel = 7830 kg/m^3
5. Plastic Strain = 0

2.1 Beams with various types of perforations

The finite element investigation is carried out on I beam, Castellated beam, Cellular beam & Litzka beam using the FEM software ANSYS 14.5. The dimensions of the beams are shown in the figure below:

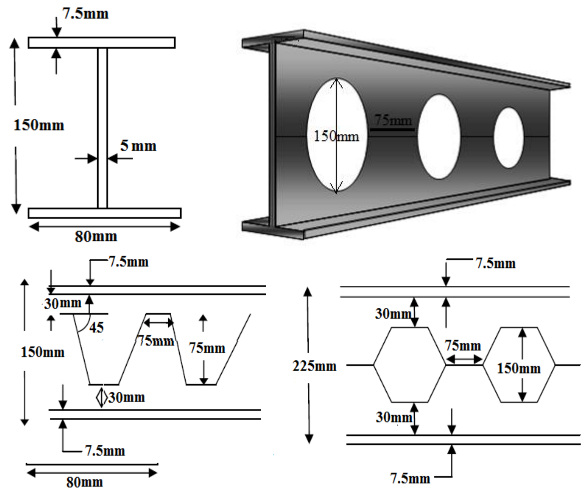

Figure 4: Dimensions used for modelling

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

$$I_{xx} = \frac{bd^3}{12}$$

$$I_{yy} = \frac{db^3}{12}$$

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.

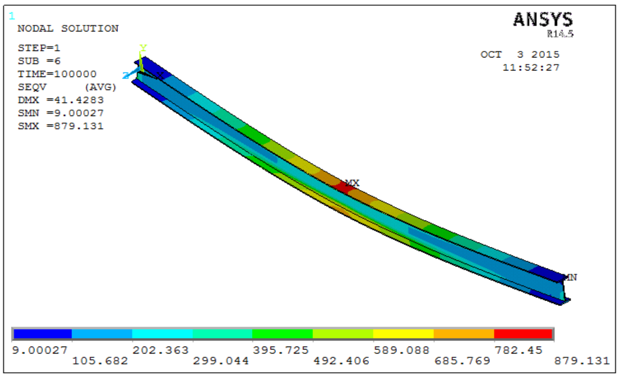

Figure 5: Von mises stress diagram of I beam

Above figure shows the von mises stress diagram of I beam corresponding to 100kN load.It is observed that the maximum value of von mises stress is 879.131N/mm^2.

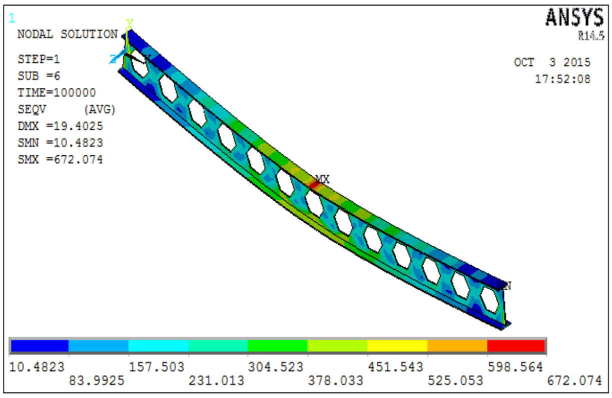

Figure 6: Von mises stress diagram of CSB

Above figure shows the von mises stress diagram of CSB corresponding to 100kN load. It is observed that the maximum value of von mises stress is 672.074N/mm^2.

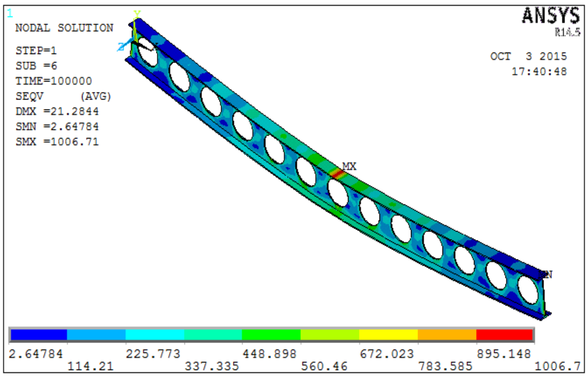

Figure 7: Von mises stress diagram of CB

Above figure shows the von mises stress diagram of CB corresponding to 100kN load. It is observed that the maximum value of von mises stress is 1006.7N/mm^2.

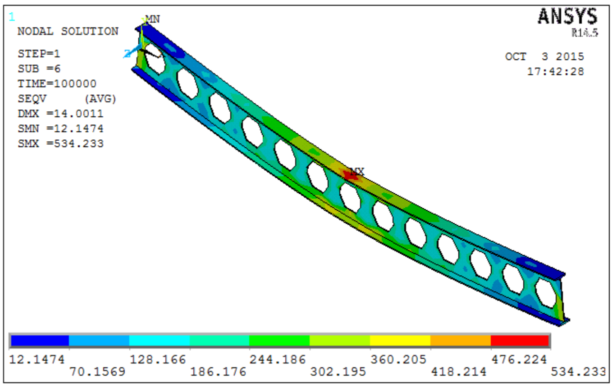

Figure 8: Von mises stress diagram of LB

Above figure shows the von mises stress diagram of LB corresponding to 100kN load. It is observed that the maximum value of von mises stress is 534.233N/mm^2.

Table 1: Comparison of load Vs deflection

Load (kN)	*Deflection(mm)*			
	I beam	*CSB*	*CB*	*LB*
10	4.193	1.942	2.13	1.40
20	8.387	3.880	4.256	2.80
30	12.580	5.820	6.385	4.20
40	16.774	7.761	8.514	5.60
50	20.967	9.701	10.642	7.00
60	25.161	11.641	12.77	8.401
70	29.355	13.581	14.899	9.801
80	33.548	15.522	17.027	11.201
90	37.74	17.462	19.156	12.601
100	41.42	19.402	21.284	14.001

From the above table it can be seen that CSB with spacer plate (Litzka beam) has the least deflection. Increasing the depth of the beam increases the bending strength, so we can gain a lot of stiffness this way**.** However, we start to get limited by things such as buckling when the sections start getting too thin. So we use stiffeners.

Table 2: Percentage variation of Deflection (comparing with I beam)

Sl No.	*Type of beam*	*% variation of deflection(↓)*
1	CB	48.6%
2	CSB	53.15%
3	LB	66.19%

2.2 Csb with various types of stiffeners

Here, various finite element models and von mises stresses are developed. Stress concentration of the beam is studied. Stress concentration is more near the opening leading to shear failure. Hence the webs are stiffened by providing stiffeners on either side of the beam to reduce the stress concentration and to reduce the shear deformation. 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.

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

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

Here we create FE model of CSB by providing diagonal stiffeners(DS), vertical stiffeners(VS), horizontal stiffeners (HS), stiffeners around castellation & stiffeners along with spacer plates for finding out which one is most effective to reduce deflection.

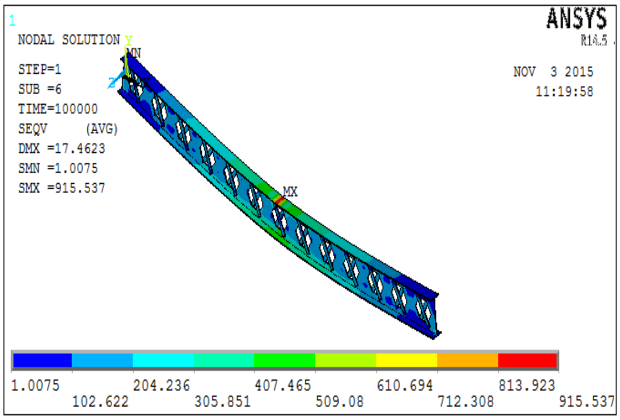

Figure 9: Von mises stress diagram of CSB with Diagonal stiffeners

From the above figure it can be seen that the von mises stress value for castellated steel beam with diagonal stiffeners corresponding to 100kN load is 915 537N/mm^2.

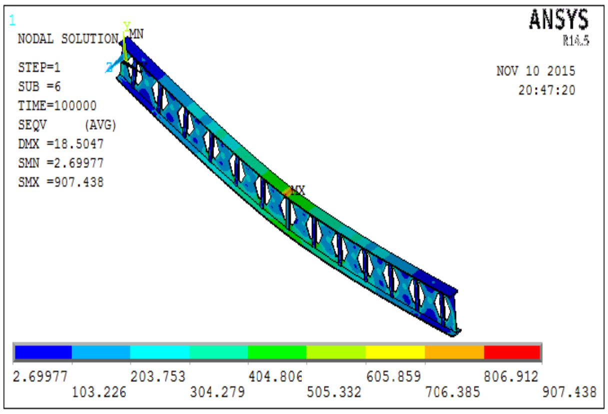

Figure 10: Von mises stress diagram of CSB with Vertical stiffeners

From the above figure it can be seen that the von mises stress value for castellated steel beam with vertical stiffeners corresponding to 100kN load is 907.438N/mm^2.

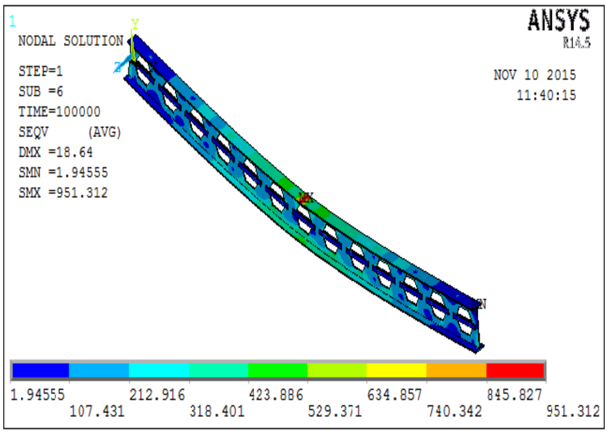

Figure 11 : Von mises stress diagram of CSB with Horizontal stiffeners

From the above figure it can be seen that the von mises stress value for castellated steel beam with horizontal stiffeners corresponding to 100kN load is 856.18N/mm^2.

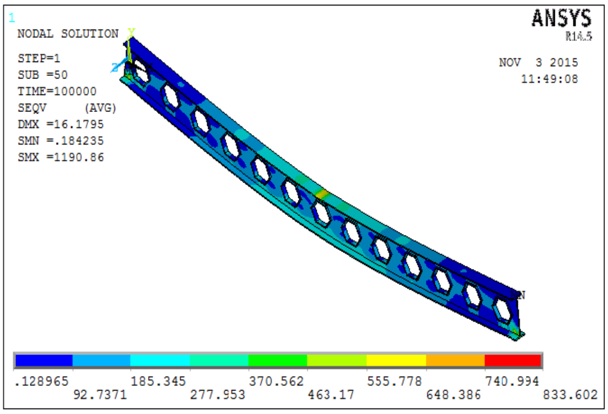

Figure 12: Von mises stress diagram of CSB with stiffeners around hole

From the above figure it can be seen that the von mises stress value for castellated steel beam with stiffeners around hole corresponding to 100kN load is 833.602N/mm^2.

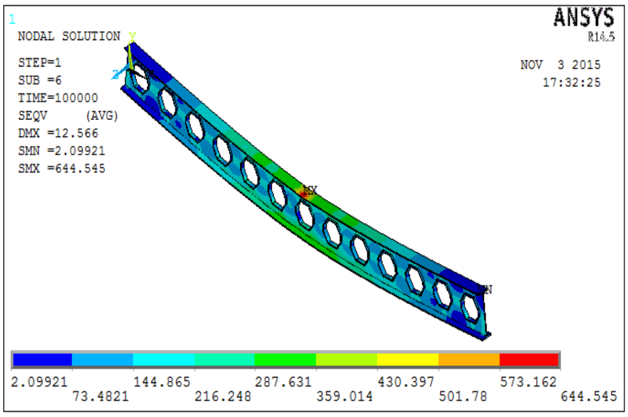

Figure 13: Von mises stress diagram of CSB with stiffeners around hole

From the above figure it can be seen that the von mises stress value for castellated steel beam with stiffeners around hole corresponding to 100kN load is 644.54N/mm^2.

Table 3: Comparison of load Vs deflection

Load (kN)	*Deflection of CSB with(mm)*				
	DS	*VS*	*HS*	*Stfnr around hole*	*Spacer plate & stfnr around hole*
10	1.746	1.850	1.864	1.617	1.256
20	3.492	3.70	3.728	3.235	2.513
30	5.238	5.551	5.592	4.853	3.769
40	6.984	7.401	7.456	6.471	5.026
50	8.731	9.252	9.320	8.089	6.282
60	10.47	11.10	11.18	9.707	7.539
70	12.22	12.95	13.04	11.32	8.796
80	13.96	14.80	14.91	12.94	10.052
90	15.71	16.65	16.77	14.56	11.309
100	**17.46**	**18.50**	**18.64**	**16.17**	**12.566**

From the results of castellated beams with stiffeners it can be concluded that the deflection is less, when the stiffeners are provided around the hole. Again it can be found out that when spacer plate (Litzka beam) is provided along with stiffeners the deflection can further be reduced.

Table 4: Percentage variation of Deflection(comparing with CSB)

Sl No.	*Type of Stiffeners*	*% Variation of Deflection(↓)*
1	Diagonal	9.99%
2	Vertical	5.112%
3	Horizontal	3.92%
4	Around castellation	16.658%
5	With spacer plate & stiffener	35.233%

From the table given above we can see that deflection of Litzka beam with stiffeners around castellation has the least deflection. The percentage in variation when comparing with CSB is about 35.233%.

3. 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. From the results obtained from ANSYS 14.5 it was observed that

1) Among four types of beams (I beam, CSB ,CB ,LB) it can be seen that Litzka beam has the least deflection. Increasing the depth of the beam increases the bending strength by the depth cubed, so we can gain a lot of stiffness this way.
2) The stiffeners provided in the open web causes smooth flow of the shear forces leading to lesser deflection. From various types of stiffeners provided it can be seen that, the stiffeners provided around the castellation is more effective than others leading to lesser deflection.

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