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Finite Element Analysis of Castellated Beam: A Review

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Abstract*— Use of castellated beam has become very popular these days due to its advantageous structural applications. Castellated beams are those beams which are prepared from hot rolled steel I sections by cutting its flange in zigzag pattern in desired shape and rejoining the two halves on one another by means of welding so that overall depth of the beam will be increased. Generally castellated beam are provided with hexagonal, circular and square shaped openings. The finite element analysis is most preferred method for understanding the flexural behaviour of castellated beams. Several researchers have studied flexural behaviour considering hexagonal shaped openings and also by varying the size of openings. However, in order to optimize size of openings, parametric study of castellated beams with circular, square and diamond shaped openings need to be done. Therefore, in the present paper an effort has been made to review various studies carried out to study the flexural behaviour of castellated beam with different size and shape of openings. Also, flexural behaviour of a castellated beam using Abaqus software (finite element analysis) has been studied and it is found that the results are in good agreement with those results from available literature.

***Keywords*— castellated beam, cellular beam, perforated web beam, finite element analysis, web opening, Abaqus.**

I. INTRODUCTION

Use of steel as structural member in structure is rapidly gaining interest now a days. In steel structures, the concept of pre-engineered building (PEB) is most popular because of ease and simplicity in construction. Such pre-engineered buildings have very large spans but comparatively subjected to less loading. So generally, steel sections are safe in strength requirement, however, sections do not satisfy serviceability requirements. So it becomes essential to use beams with more depths so as to satisfy this requirement. Use of perforated web or open web beams is the best solution in order to overcome this difficulty. Perforated web beams are also called as castellated beams when perforations are made of hexagonal or square shapes and those provided with circular openings are called cellular beams [2]. The main advantage of using castellated beams is the reduction in total weight of the structure and hence lesser quantity of steel.

The Castellated beams are prepared from rolled steel I sections. The web of I beam is cut in zigzag pattern along the centreline in desired opening shape, then re-joining the two halves on one another by means of welding. The process of castellation is illustrated in Fig. 1

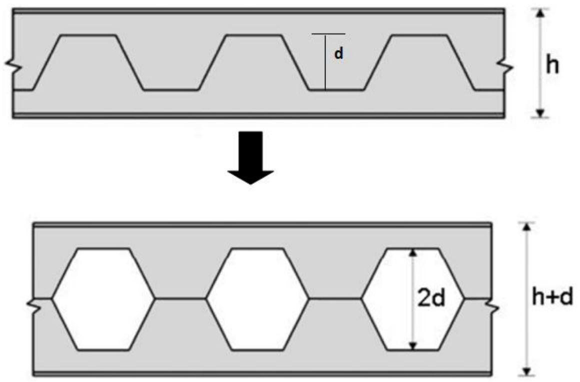

Fig. 1 Castellation Process

Use of castellated beam with hexagonal openings is more common in recent years because of the simplicity in its fabrication. Also, a lot of research has been carried out in optimizing the dimensions of hexagonal shaped openings or perforations [6]. Many researchers have reported that the failure of steel I beam sections with hexagonal openings occur in the web portions, causing the local failures in the form of shear buckling of web post, lateral torsional buckling etc. due to lack of sufficient shear transfer area [9]. Therefore, study of flexural behaviour of perforated steel I beams with openings that will provide sufficient shear transfer area in the web needs to be done.

The perforated steel I beams with openings such as circular, square, diamond etc. provides comparatively adequate shear transfer area due to reduction in number of corners and curvature effect, thus leading to minimizing the local failures in the web portion.

II. PRESENT STUDIES AND THEORIES

In recent times, a lot of work has been done for the design of castellated beam and especially with hexagonal openings. There is no universally accepted design method for castellated beam because of complexity in geometry which is accompanied by complex mode of failure [5]. At present there are possibly six failure modes of castellated beam namely, formation of flexure mechanism, lateral torsional buckling, formation of Vierendeel mechanism, rupture of welded joint, shear buckling of web post, compression buckling of web post [7]. The various research studies carried out for analysis and design of castellated beams by several researchers are given below.

A. M. R. Wakchaure and A.V. Sagade [7]:

These authors studied the flexural behaviour of castellated beams. Beams were modelled with increase in depth of web openings. To analyse the behaviour of castellated steel beams having an I-shaped cross-section, modelling is done using finite element software package ANSYS14. Analysis is carried out on beam with two point load and simply supported support condition. The deflection at centre of beam and study of various failure patterns are studied. The beams with increase in depth are then compared with each other and with parent section for various parameters and for serviceability criteria. From the finite element analysis results, it is concluded that, the Castellated steel beam behaves satisfactorily with regards to serviceability requirements up to a maximum web opening depth of 0.6h. Castellated beams have proved to be efficient for moderately loaded longer spans where the design is controlled by deflection.

B. M. R. Wakchaure, A.V. Sagade and V. A. Auti [6]:

In this study validation of the results obtained by the finite element analysis is done by experimentation. Castellated beams with increase in depth (i.e. by increasing depth of perforation) are fabricated and tested under two point bending with simply supported condition. The experimental investigation shows beams satisfy serviceability criteria at the depth of 0.6h. Also, it is observed that with increase in depth of opening, Vierendeel failure of beam becomes predominant.

C. M. R. Soltani, A. Bouchaïr and Mimoune M. [5]:

These authors prepared a nonlinear numerical model to obtain behaviour of castellated beams with hexagonal and octagonal openings. Parametric study is also carried out by increasing depth of opening. The numerical results are compared with the existing literature and validated with help of MSC/NASTRAN software. Also, failure patterns of beams with various sizes are studied.

D. F. Erdal and M. P. Saka [3]:

Studied the load carrying capacity of optimally designed castellated beam with various number of holes and spacing. Finite element analysis of same beams is also carried out under the application of centrally applied point load and failure patterns are studied and verified using ANSYS. Study shows that, even though the members are relatively short spans, lateral supports are governing factor for the analysis of beams due to torsional buckling. Also, it is shown that when load is applied above the circular opening then beam fails in Vierendeel mode and when load is applied on the portion other than prescribed above then beam fails in web post buckling.

III. FINITE ELEMENT MODELLING

The finite element analysis of castellated beam by using Abaqus software is carried out and the results are verified with the results of the similar beam illustrated in Indian Standard Handbook for Structural Engineers [4]. The details of modelling using Abaqus software are given in the following sections.

A. Problem Definition

The Castellated beam considered for modelling is derived from Parent steel I beam (ISMB600) with hexagonal openings of depth 300mm. Thus, the depth of castellated beam after perforation becomes 900mm. The flexural behaviour of the parent and castellated beams for deflection and combined axial bending stresses under UDL and considering simple supports is studied. The geometrical details of the castellated beam are given in Fig. 2,

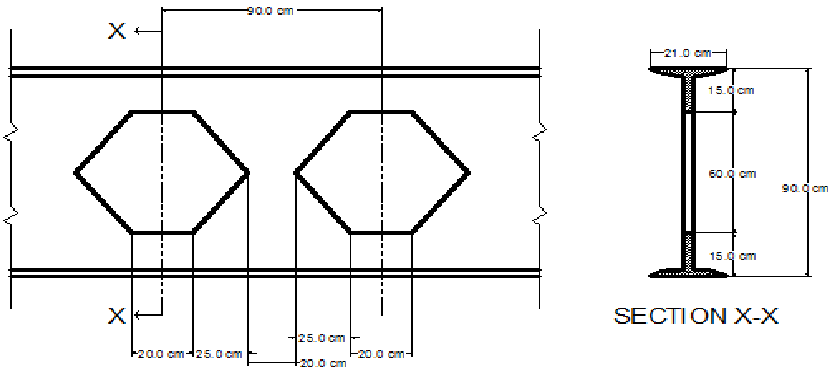

Fig. 2 Cross Section of Castellated Beam [4]

Span of Castellated beam	= 18 m.
Type of material	= Steel
Modulus of Elasticity	= 2 x 10^5 N/mm^2
Poisson's ration	= 0.3
Dead load	= 0.735 kN/m^2
Live load	= 1.65 kN/m^2
Total load	= 2.23 = 2.5 kN/m^2
Spacing of lateral beams	= 7 m
Load on single beam	= Total load x Spacing x Span
	= 2.5 x 7 x 18
	= 315 *kN*
Using ISMB 600, flange width	= 21 *cm*
Load intensity on each beam	= 315 / (21 x 18) = 80 kN/m^2

B. Modelling of parent and Castellated Beam in Abaqus software

Modelling of parent and castellated beams is done in Abaqus software using Solid element. The modelled castellated beams are shown in fig 3(A) and (B) with loading details and support conditions.

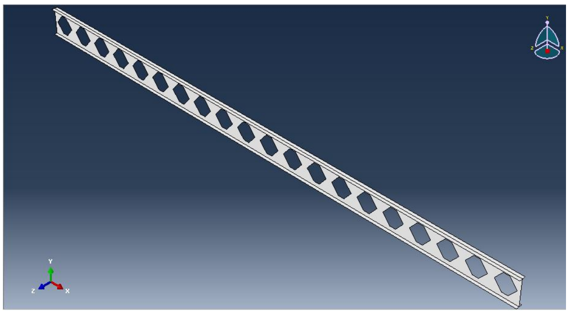

Fig. 3 (A) Modelling of Castellated Beam

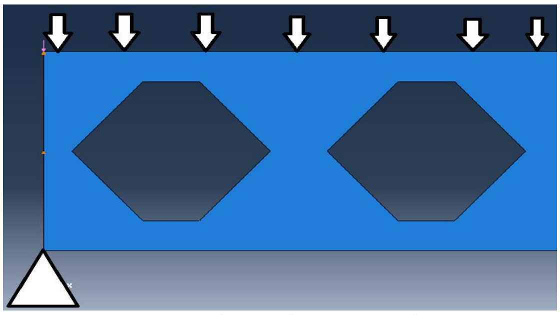

Fig.3(B) Loading And Support Condition

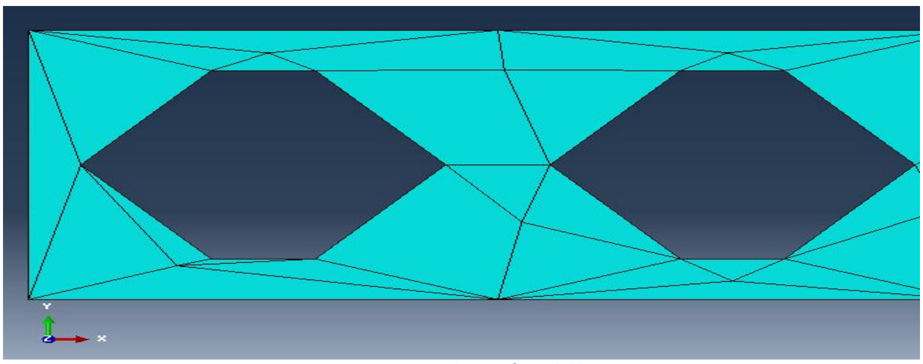

Fig.3(C) Meshing of Modell

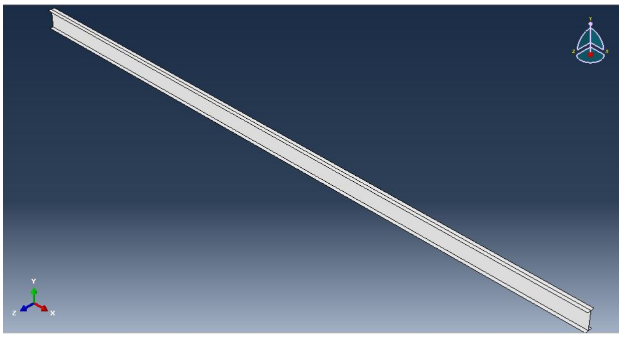

Fig. 4(A) Meshing of Modell

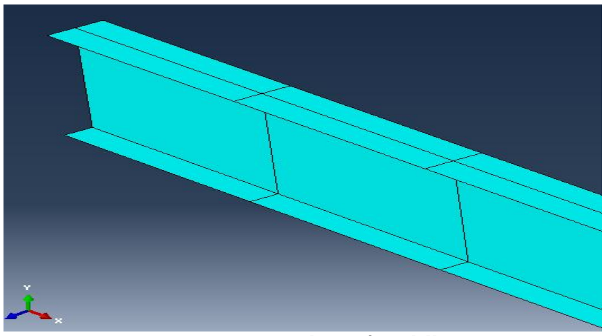

Fig.4(B) Meshing of Modell

IV. RESULTS AND DISCUSSION

The results of the deflection and combined axial bending stresses obtained by analysing the beam by Abaqus software are discussed below.

A. Deflections of the beams by Abaqus software

The values of deflections as obtained by Abaqus software and by IS SP6 [4] are tabulated in Table no. 1 and the deflected shapes of both, parent and castellated beams are represented in Fig. 5. The Limiting value of deflection as per formula given below:

$$\delta = \frac{wl^3}{384EI}$$

= 520 mm

Table No.1 Comparison of results of deflection

Maximum Deflection of Castellated Beam Given in IS SP6 Part 2 (in mm) as in [4]	Maximum Deflection of Castellated Beam obtained from ABAQUS (in mm)	Deflection of ISMB 600 obtained by ABAQUS (in mm)	Limiting Value of Deflection as per standard formula (in mm)
53.6	51.424	135	520

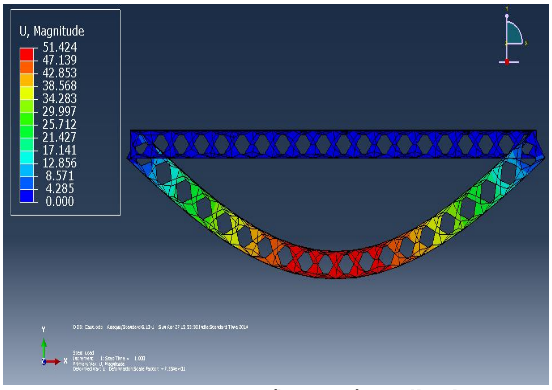

Fig.5(A) Deflection of Castellated Beam

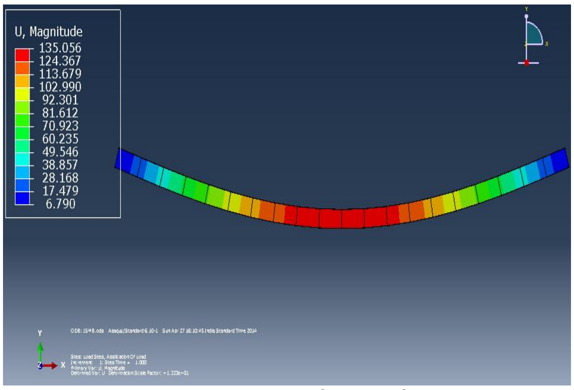

Fig.5(B) Deflection of ISMB 600

B. Combined and axial bending stresses

The values of combined axial bending stresses as obtained by Abaqus software and by IS SP6 [4] are tabulated in Table no. 2 and the deflected shapes of both, parent and castellated beams are represented in Fig. 6.

Table No. 2 Comparison of results of Combined Bending and Direct Stresses

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Combined Bending and Direct Stresses by ABAQUS (N/mm^2)	Combined Bending and Direct Stresses in IS SP6 as in [4] Part 2 (N/mm^2)	Combined Bending and Direct Stresses of ISMB600 by Elastic Analysis (N/mm^2)
163.061	162.92	229.41

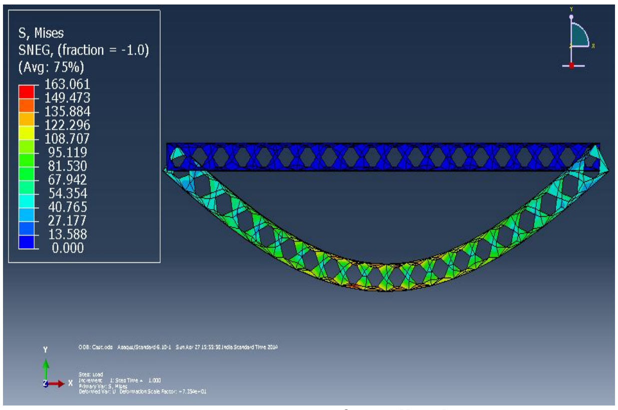

Fig.6(B) Stresses of Castellated Beam 600

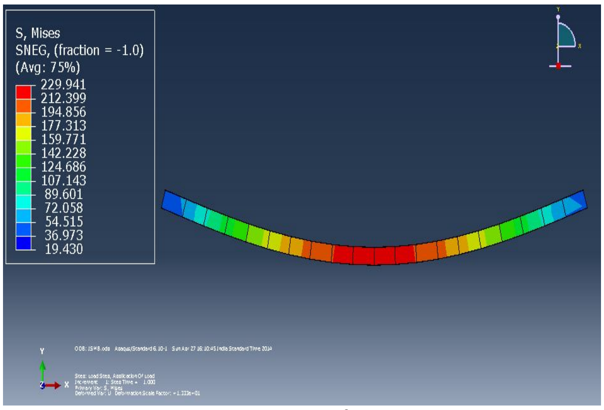

Fig.6(B) Stresses of ISMB 600

From the results of analysis it is observed that, due increased depth of castellated beam there is significant reduction in deflection and combined axial bending stresses as compared to its parent I beam. The stress pattern obtained from analysis shows that stress concentration occurs near the corners and web portion which may leads to local failures.

V. Conclusions

From the review of literature and finite element analysis using Abaqus software following conclusions can be drawn:

A. The local failure of castellated beam is one of the major issues due to lack of shear transfer area in case of castellated beam and hence optimization for shape and size of the openings is essential.

B. The castellated beams with circular, square and diamond shaped openings give better shear transfer area and hence the optimization of castellated beams with such openings needs to be carried out.

C. It is possible to analyze castellated beam using Abaqus software (finite element analysis) as the results are in good agreement with the results obtained by IS code method analysis.

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