STRUCTURAL BEHAVIOUR OF HYBRID CASTELLATED STEEL BEAM WITH HEXAGONAL OPENING

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Abstract— Fabricated beams are used when appropriate hot rolled section is not satisfying the design criteria. The beams are said to be hybrid beams, when the beams are made up of the plates of not the same strength in flanges and web. The steel beam with openings in the web is known as castellated steel beam, which is having high strength to weight ratio. The presence of openings in the web tends to result in different modes of failure such as web-post buckling and Vierendeel mechanism. This paper mainly focused to analyze a hybrid steel beam with hexagonal web openings. In this study, a comparative study of deflection, equivalent stress, maximum principal stress and shear stress is done for homogenous and hybrid castellated steel beam with and without stiffeners.

Keywords— web openings, hybrid steel beam, castellated steel beam, stiffeners

I. INTRODUCTION

Hybrid beam is used in structures to enhance their bending as well as shear strength. The beams are said to be hybrid beams, when the they are made up by means of the plates of not the same strength in flanges and web, usually flange having larger strength than web. Castellated Beam is a type of expanded beam which is made by separating a standard rolled shape into two halves by cutting the web in a regular alternating pattern. The halves are re-joined by welding after offsetting one portion so that the high points of the web pattern come into contact, finally we obtain a beam of higher depth known as castellated beam with openings at web compared to the normal I beam and also the overall beam depth is increased by 50% for improved structural performance against bending. The openings whether they are square as in a castle, rectangular, circular, hexagonal or octagonal or any other shape reduce the weight of the beam without greatly reducing its strength. The result is a beam with a higher strength-to-weight ratio. Due to the presence of openings in the web, stiffness of the beam gets affected, which can be solved by providing stiffeners around the openings. The main failure modes in castellated steel beams are formation of a vierendeel mechanism, lateral-torsional buckling of one or several web posts, rupture of a welded joint in a web post, lateral-torsional buckling of an entire span and formation of a flexure mechanism (hinge). Castellated steel beam with different grades in flange and web is known as the hybrid castellated beam which is having better properties than a homogenous castellated steel beam.

II. OBJECTIVES

- To analyze the behavior of castellated hybrid beam under statically incremental load and examine the modes of failure.
- To analyze the behavior of castellated hybrid beam by providing stiffeners around the openings

III. LITERATURE REVIEW

Various research studies are carried out for analysis and design of homogenous and hybrid castellated steel beam are presented in the following section.

Artificial Neural Network model was applied (Mahmoud Hosseinpoura et al.2020) to predict the ultimate moment of castellated steel beams subjected to lateral distortional buckling. [1]. (Mehdi Shokouhian 2015) presented a new method to determine moment resistance of I-beams with hybrid and homogeneous sections. Flexural tests on six full-scale I-shaped beams, three with hybrid sections and three with homogeneous sections, built up from high-strength steels (Q345 and Q460). The strength of steel beam in the plane of loading depends on its section properties and on its yield stress. [2]. (Mei Liu et al2019) presented numerical investigations on the behavior of a Bolted Castellated Steel Beam (BCSB) with octagonal web openings. The model was meshed using the solid element C3D8R in ABAQUS. Studied parameters of the BCSB included the bolt diameter, the width-to-thickness ratio of the web-post and the bolt layout. The Strut Model was modified to predict the web-post buckling strength of a BCSB with octagonal openings [3]. (Rujuta A. Bhat et al. 2020) analyzed a hybrid steel beam with hexagonal web openings using the software ANSYS. The modes of failure of such beams are compared to their homogeneous counterparts along with the load carrying capacity for each. An optimum ratio of spacing and width of opening is determined to be 1.5 for beams having a depth of opening lower than 60% the beam depth [4]. Numerical modelling approach is used (Richard France et al.2011) for determining opening angle and opening spacing on hexagonal castellated beam [5]. (Samadhan G. Morkhade et al.2019) studied the effect of shape of openings in hybrid castellated beam and the performance of circular and hexagonal openings is found to be excellent [6]. A nonlinear numerical analysis is carried out (Samadhan G. Morkhade et al. 2020) so as to observe the effectiveness of stiffeners provided around the openings using the finite element analysis package ANSYS v12. From the parametric study, it has been observed that by provision of stiffeners around the openings web buckling failure can be prevented [7]. Lateral torsional buckling resistance of castellated steel beam was studied (Sandhi K wani et al.2016) by using collapse analysis and the analysis was done using finite element package ADINA 8.9. The critical moment of castellated beam obtained from the finite element analysis is up to 42.3% lower than critical moment of full beams with same dimensions calculated by using the AISC formula [8].

IV. MODELLING OF HOMOGENOUS AND HYBRID CASTELLATED BEAM

A three dimensional finite element model of homogenous and castellated steel beam are developed using ANSYS 19.2. The castellated beam and stiffeners were modelled using SOLID 185. Solid 185 structural solids are suitable for modelling general 3-D solid structures. The contact between each layer where provided using 3-D surface-to-surface contact elements CONTA174 and TAGR170. Mesh size provided for both castellated beam and stiffener is 20mm. The details of the specimen are shown in the table1. Figure 1 shows the parent beam and castellated steel beam with the dimensions.

TABLE I: DETAILS OF SPECIMEN USED

Specimen	IC 305
Span (m)	3.2
tf (mm)	8.0
Tw (mm)	5.5
bf (mm)	100
d(mm)	210
h(mm)	105
ds(mm)	37.5
dg(mm)	305

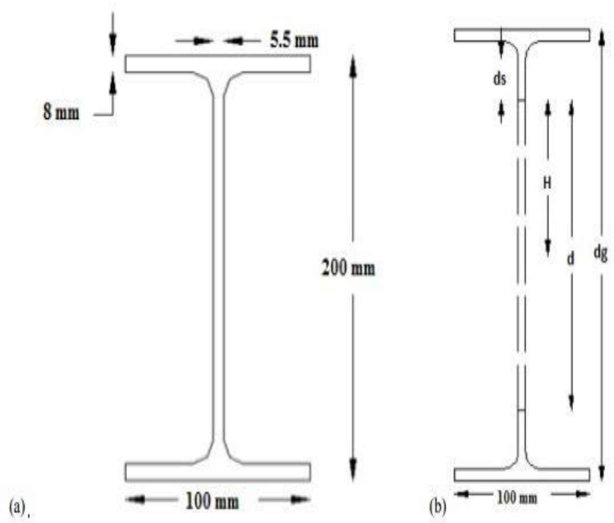

Fig 1. (a)Specimen properties of normal I beam(b)Specimen properties after castellation.

Table 2 shows the material properties used in material modelling of castellated steel beam. Figure 2 shows the finite element model of the homogenous and hybrid castellated steel beams. In this analysis shell 181 element where used.

TABLE: II MATERIAL PROPERTIES

	Modulus of elasticity (N/mm^2)	Poisson's ratio μ	Yield stress(s_y) (N/mm^2)
Homogenous beam	$2X10^5$	0.3	410
Hybrid beam			
Flange	$2X10^5$	0.3	410
Web	$2X10^5$	0.3	250

Finite element modelling of homogenous and hybrid castellated beams are developed and obtained values of deflection, shear, maximum principal stress and von mises stress.

Castellated steel beam (IC 305) is made from standard section (ISMB 200). The span of the beam used is 3.2m. Both homogenous and hybrid castellated beam were provided with seven number of hexagonal shaped openings. Spacing provided between the castellation is 60mm and the depth of opening provided is 0.65 times the depth of beam. Two-point loading is applied at a distance of 1000mm. The beam is provided with simply supported condition. Hexagonal shaped stiffeners were used around the openings. Width of stiffener used is 15mm and thickness is 5mm. Grade of stiffener used is 415 N/mm^2 . Fig 2, Fig 3, Fig 4, Fig 5, Fig 6, Fig 7 and Fig 8 shows model of homogenous castellated beam, hybrid castellated beam, model of hybrid castellated beam, Zoomed view of model of homogenous castellated beam with stiffeners, homogenous castellated beam with stiffeners, respectively.

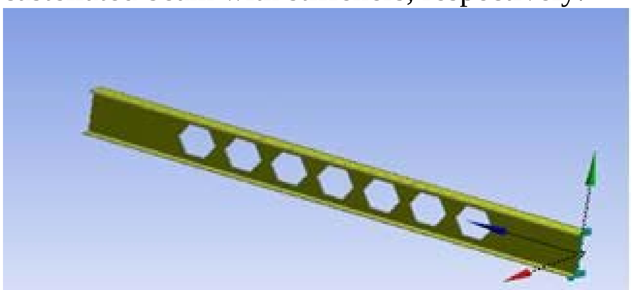

Fig 2. Model of homogenous castellated beam

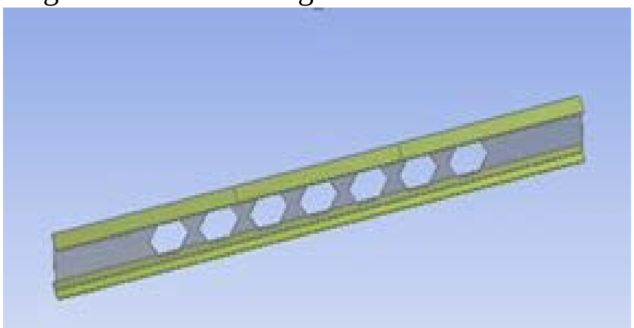

Fig 3.Model of hybrid castellated beam

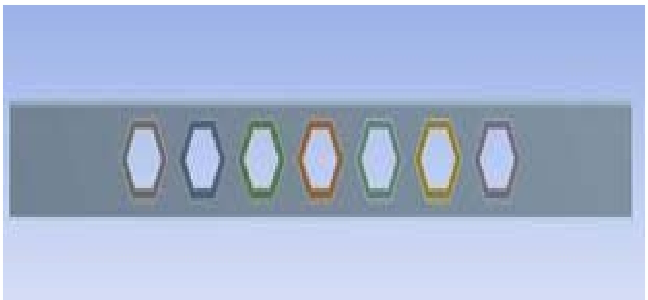

Fig 4.Model of homogenous castellated beam with stiffeners

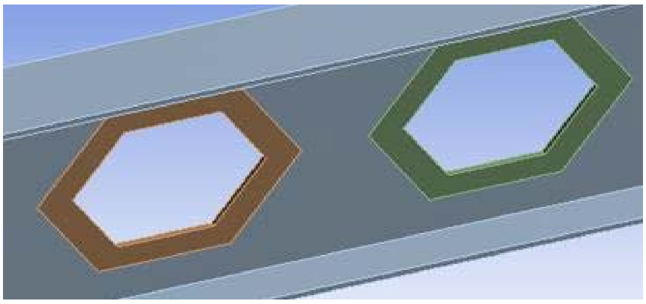

Fig 5. Zoomed view of model of homogenous castellated beam with stiffeners

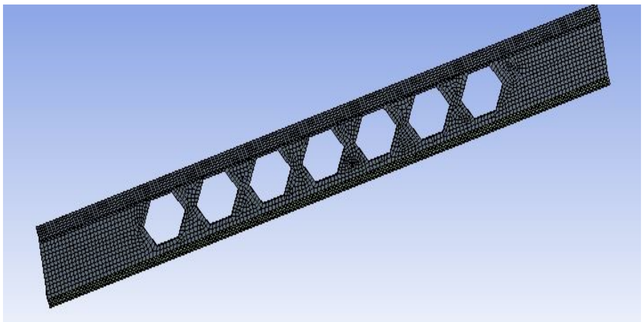

Fig 6. Meshed model of homogenous castellated beam

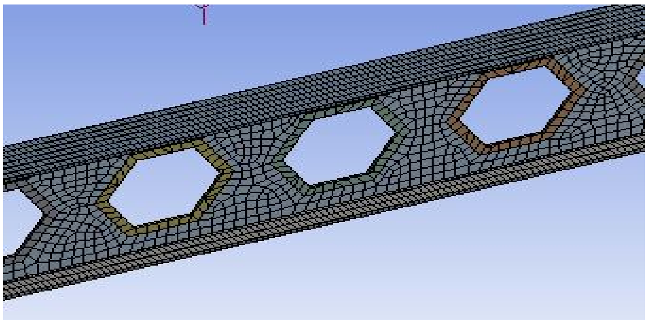

Fig 7. Zoomed view of meshed model of hybrid castellated beam with stiffeners

V. RESU LT AND DISCUSSIONS

Homogenous steel beam and hybrid steel beam having hexagonal openings are analyzed in this study. Table 3 and Table 4 shows the values of deflection, flexure, equivalent stress and maximum principal stress for homogenous and hybrid castellated beam respectively. In order to strengthen these beams, they also analyzed by providing stiffeners around the openings. Deflection for different grades of stiffeners were considered. Table 5 shows Values of deflection for hybrid and homogenous castellated beam with stiffeners having different grades of steel. Fig 8,9 and 10 shows deflection of homogenous castellated beam, hybrid castellated beam and homogenous castellated beam with stiffeners respectively.

TABLE :III VALUES OF DEFLECTION,FLEXURE,EQUIVALENT STRESS AND MAXIMUM PRINCIPAL STRESS FOR HOMOGENOUS CASTELLATED BEAM.

Load (kN)	Deflection (mm)	Equivalent stress (N/mm^2)	Maximum principal stress (N/mm^2)	Shear stress (N/mm^2)
5	0.86	88.00	102.06	6.23
10	1.53	131.30	145.80	12.12
15	2.35	188.00	208.12	16.35
20	3.06	262.00	290.00	24.20
25	3.89	325.00	346.15	29.10
30	4.59	394.00	437.00	36.31
35	5.25	412.00	509.01	41.35

TABLE :IV VALUES OF DEFLECTION,FLEXURE,EQUIVALENT STRESS AND MAXIMUM PRINCIPAL STRESS FOR HYBRID CASTELLATED BEAM.

Load (kN)	Deflection (mm)	Equivalent stress (N/mm^2)	Maximum principal stress (N/mm^2)	Shear stress (N/mm^2)
5	0.51	49.15	62.00	4.63
10	0.78	94.80	99.00	8.58
15	1.13	135.00	136.11	11.31
20	1.53	189.00	198.11	15.00
25	1.89	232.00	236.90	19.21
30	2.30	280.11	297.00	24.70
35	2.91	321.00	343.35	29.13
40	3.45	379.00	397.11	34.30
45	3.98	409.88	460.00	39.11

TABLE :V VALUES OF DEFLECTION FOR HYBRID AND HOMOGENOUS CASTELLATED BEAM WITH STIFFENERS HAVING DIFFERENT GRADES OF STEEL.

Load(kN)	Deflection of homogenous castellated beam (mm)		Deflection of hybrid castellated beam (mm)	
	Without stiffener	With stiffener	Without stiffener	With stiffener
5	0.86	0.60	0.51	0.35
10	1.53	1.24	0.78	0.622
15	2.35	1.79	1.13	0.89
20	3.06	2.48	1.53	1.10
25	3.89	2.99	1.89	1.55
30	4.59	3.72	2.30	1.86
35	5.25	4.22	2.91	2.48

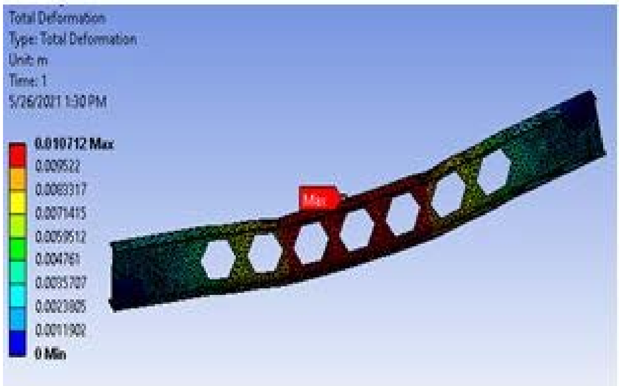

Fig 8. Deflection of homogenous castellated beam

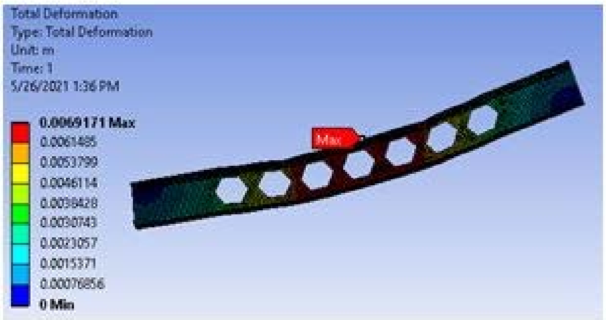

Fig 9. Deflection of hybrid castellated beam

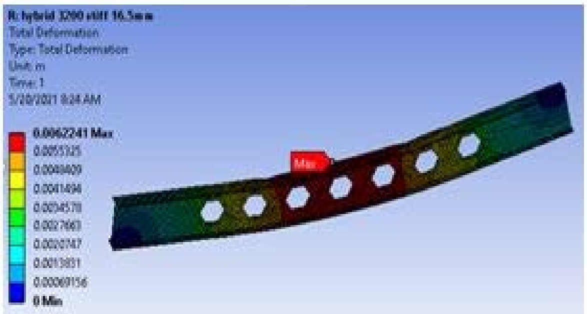

Fig 10. Deflection of hybrid castellated beam with
stiffeners

The charts are prepared by comparing the values of deflection, equivalent stress, maximum principal stress and shear stress for homogenous and hybrid castellated steel beam. Fig 11,12,13, and 14 shows variation of deflection, equivalent stress, maximum principal stress and shear stress with load respectively for homogenous and hybrid castellated steel beam. Fig 15 shows the variation of deflection in reinforced homogenous and hybrid castellated steel beams.

Fig 11. Load vs deflection

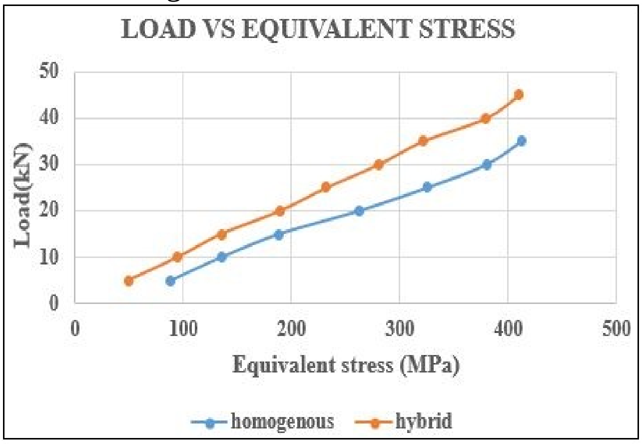

Fig 12. Load vs equivalent stress

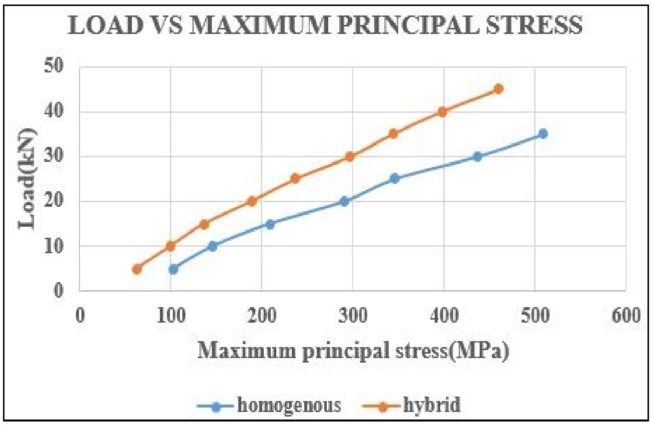

Fig 13. Load vs maximum principal stress

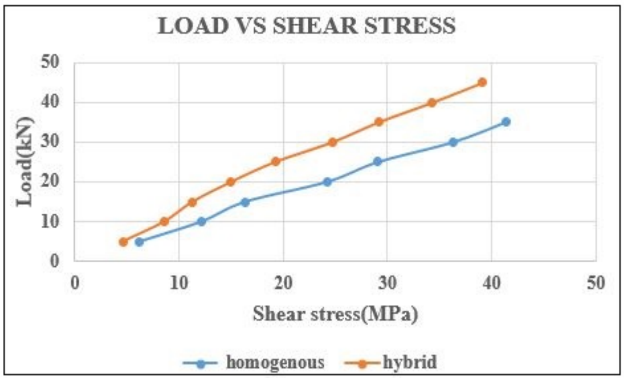

Fig 14. Load vs shear stress

Fig 15. Load vs deflection graph for homogenous beam with stiffener

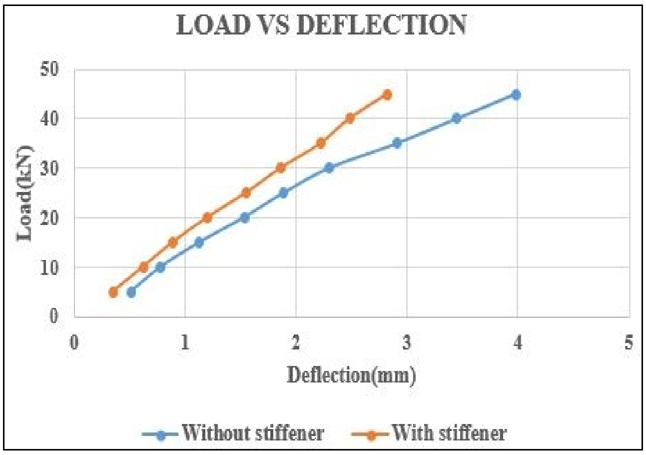

Fig 16. Load vs deflection graph for hybrid beam with stiffener

The load vs deflection for hybrid castellated beam is less as compared to homogenous castellated beam.

The load vs shear stress for hybrid castellated beam is less as compared to homogenous castellated beam.

The load vs equivalent stress and maximum principal stress for hybrid castellated beam is less as compared to homogenous castellated beam.

The load vs deflection for hybrid castellated beam with stiffeners is less as compared to homogenous castellated beam with stiffeners.

By providing stiffeners around the openings the deflection value of homogenous and hybrid castellated beam get reduced.

VI. CONCLUSIONS

In this work the analysis of hybrid and homogenous castellated steel beams with and without stiffeners around the opening of the web have been studied numerically. Deflection, equivalent stress, maximum principal stress and shear stress where found out for statically incremental load. Also effect of change in the grade of stiffener were studied. The following conclusions were drawn from this work.

- Using hybrid beams, the deflection of beam with web opening has been decreased by 48%.
- Equivalent stress of hybrid castellated beam is 33% less than homogenous castellated beam.
- Maximum principal stress is 34% greater for homogenous castellated beam than hybrid castellated beam.
- Using hybrid beams, the shear stress of beam with web opening has been decreased by 31%.
- Deflection of reinforced hybrid beam is 49% less than reinforced homogenous castellated beam
- Providing stiffeners in hybrid beams, deflection is decreased by 23%.

VII. REFERENCES

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