EXPERIMENTAL STUDY ON CASTELLATED BEAM WITH AND WITHOUT STIFFENERS

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Abstract—**Castellated beam is widely used due to increased depth of section without any additional weight, high strength to weight ratio, their lower maintenance and painting cost. The principle advantage of castellated beam is increase in vertical bending stiffness. In this study a steel section is selected, castellated beams are fabricated with increase in depth of web openings. Experimental testing is carried out on beam with two point load and simply supported condition. The deflection at center of beam and various failure patterns are studied. Castellated beam has some limitations also, stress concentration occurs near the perforations and the shear carrying capacity is reduced. The shear carrying capacity can be increased by stiffening the web at points of concentrated loads and reactions. Hence to increase the shear strength of the castellated beam and also to reduce the deflection, shear stiffeners are introduced along the web opening and also on the web along the shear zone.**

Keywords—castellated beam, Vierendee mechanisml, Von-mises stress.

I. INTRODUCTION

Long span beams commonly used in steel construction started to use large web openings during the last century in order to reduce the floors depth by passing all services through the web heights. The presence of the large openings changes the local transfer of the internal forces mainly the shear force. In 1978, Redwood presented one of the first experimental studies on beams with large isolated rectangular web openings these tests showed a new local failure mode due to Vierendeel bending. In fact, the shear transfer around the opening is equilibrated by the local bending of both upper and lower members of the opening represented by tee section. This local bending creates local hinges at the four corners of the opening.

II. CASTELLATED BEAM

A. General

The use of perforated steel beams has resulted in longer span floors. Their popularity has also increased because of an architectural emphasis on exposed structures, with cellular, castellated and elongated web openings being typical in structural sections. Sections having webs penetrated by large closely spaced openings over almost the full span are now common. Although the best application of these beams appears to be for long spans which are to carry a light uniform load, some heavy-mass structures, such as bridges, have been constructed using perforated beams for the full span. Also, with greater automation, the cost of their fabrication has been reduced to the level where for certain applications they may be competitive with open-web steel joists

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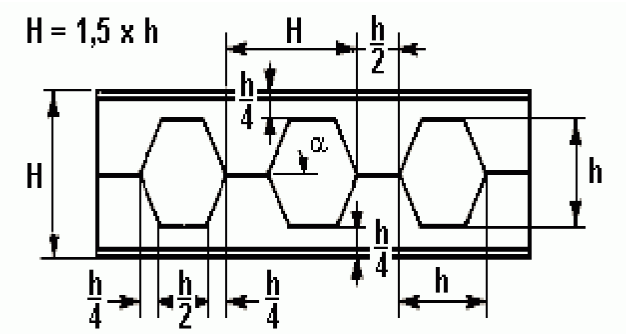
B. Fabrication

Castellated beams are fabricated from wide flange I-beam. The web of the section is made cut along horizontal x-x axis. The two halves are then welded together to produce a beam of greater depth without any increase in the weight. The resulting beam has greater bending rigidity and larger section modulus. The cutting angle varies from 45° to 70° and the commonly used sections are 45° and 60°.



C. Web Post Buckling

Web buckling 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. The horizontal shear force in the web-post is associated with double curvature bending over the height of the post. Many analytical studies on web post buckling have also been reported to predict the web-post buckling load due to shearing force. Based on finite difference approximation for an ideally elastic-plastic-hardening material produced some graphical design approximations for a wide range of beam and hole geometries some correlations between experimental and non-linear finite analysis estimations were found in the works of Redwood (1996).

D. Web Post Buckling due to Compression

A concentrated load or a reaction point applied directly over a web-post causes this failure mode. This mode was reported in the experiments conducted by Toprac and Cook (1959). Husain and Speirs (1973). Buckling of the web post under large compression forces is not accompanied by twisting of the post. as it would be under shearing force. Such a failure mode could be prevented if adequate web reinforcing stiffeners are provided. A strut approach was proposed in the works of (Dougherty 1993) which suggests that standard column equations could be used to determine the strength of the web post located at a load or a reaction point.

III. Advantage and Limitation of Castellated Beams

The primary advantage of this new section is the increased depth of the beam without increasing its weight. In some instances, the depth is increased as much as 50%. By increasing the depth of the beam, strong axis bending strength and stiffness are improved as the strong axis moment of inertia, Ix,, and section modulus, Zx, are increased. Further, the castellation or holes also allow ductwork, plumbing pipelines, and electrical conduits to pass through them ultimately reducing the thickness of the floor assembly.

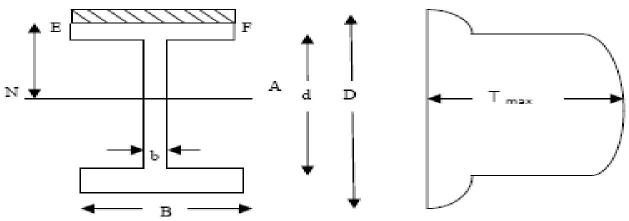
Shear concentrations occurs near the perforations and the shear carrying capacity is reduced by making perforations near the neutral axis where the stress are small making the cut in zig-zag way.

IV. MATERIAL PROPERTIES

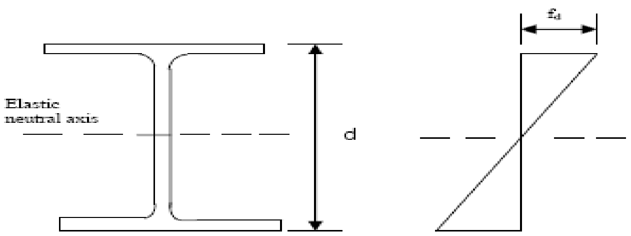
A. *Mechanical Properties Of Steel*

Mechanical Properties	Average Strength
young's modulus (E)	2×10^5 N/mm^2
Tensile strength	410 Mpa
yield stress	250 Mpa
poisson's ratio	0.3
Density of steel	7850 kg/m^3

B. *Distribution Of Stresses In I Section*



Shear stress distribution

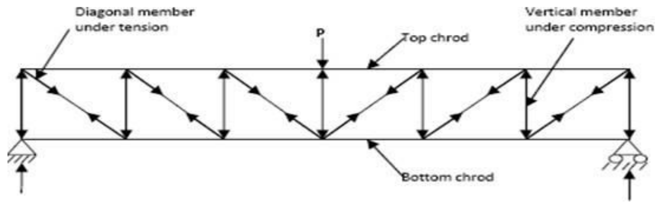


Bending stress distribution

In an I- Section the value of Q which is zero at the extreme fibre increases to a high value at top flange- web interactions and attain maximum value at the neutral axis. From the bending stress distribution diagram Figure 3.2 it can be seen that flanges carries most of the bending stress. From the Figure 3.1 comparison of the shear and flexural stress distributions, it may be observed that the flanges carry a major portion of the flexural load, whereas the web carries most of the shear load. The primary modes of failure of the beam are the local buckling of compression flange and shear buckling of web. Castellated beam depends on web post buckling. That is at high shear locations, normally near the supports and neutral axis; the principal planes would be inclined to the longitudinal axis of the member. Along the principal planes, the principal stresses would be diagonal tension and diagonal compression causes the web to buckle in a direction perpendicular to its action. This problem can be solved by reducing the depth to thickness ratio of the web and we can also provide web stiffeners that would develop tension field action to resist diagonal compression.

C. *Tension Field Action*

Figure shows the tension field action. As the web begins to buckle, the web loses its ability to resist the diagonal compression. The diagonal compression is then transferred to the transverse stiffeners and the flanges. The web resists only the diagonal tension and this behaviour of the web is called tension field action. The behaviour is very similar to a Pratt truss, in which the vertical members carry compression and the tension is carried by the diagonal



Tension field actions

V. NUMERICAL STUDY

D. *General*

Several theoretical approaches are considered to analyze the yielding and buckling failure modes of castellated beams. Elastic finite element analysis is used to predict the ultimate load. Finite element model generation is done using ANSYS.

E. *Design Procedure*

- Guidelines for web perforations

  The limits of applicability are:

  a) $1.08 < S/D0 < 1.5$

  b) $1.25 < D/D0 < 1.75$

  Where, S= center /center spacing,

  Do= Diameter of opening,

  D= Total depth of beam

- The moment of resistance of the castellated section which is the product of the resultant tensile or compressive force and the distance between centroids of T section is calculated by

$$MR = A \sigma st\, d$$

- . The spacing of the castellated beam should not exceed the spacing determined by the equation

$$S = P'/W'L$$

  Where,

  S = Centre to centre distance between castellated beams

  P' = Net load carrying capacity in N

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W' = Design load in N/m^2

L = Span of the beam in m

- Stiffeners are designed at the supports and below the concentrated loads.
- The beam is checked in shear. the average shear at the end is calculated from

$$\tau_{va} = \frac{R}{d't} < 0.4fy$$

Where,

R = end reaction in N

d'' = depth of the stem of T – section

t = thickness of the stem

- The maximum combined local bending stress and direct stress in the T Segment is also worked out and should be lesser than the permissible bending stress.
- Vierendeel bending of upper and lower tees

The critical section for the tee should be determined by using one the methods as described by Olander's or Sahmel's approach. The combined forces in the tee should be checked as follows

$$P_o/P_u + M/M_p \leq 1$$

Where Po and M are forces and moments on the section

Pu = area of critical section

Mp = plastic modulus of critical section for plastic sections

Mp = elastic section modulus of critical section for other sections

- The maximum deflection of the T- section is at the mid span and is due to the net load carrying capacity and local effects which are calculated by

$$\delta = \delta_1 + \delta_2 < \frac{L}{325}$$

Where,

δ1 - Deflection due to net load carrying capacity s

δ2 - Deflection due to local effects

VI. EXPERIMENTAL INVESTIGATION

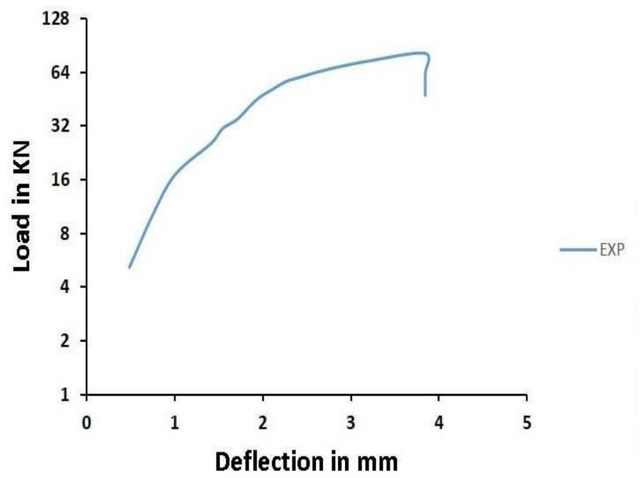
In this paper steel I section ISMB 150 is selected and castellated beams are fabricated such that depth of the castellated beam is 1.5 times greater than the original beam as IC 225 respectively. Experimental test is carried out by applying two point loads and deflection of beam is studied and different failure modes are analysed. Deflection of castellated beam without stiffeners, diagonal stiffeners and vertical stiffeners along the web is noted

A. *Experimental Set Up*

Castellated beams are fabricated for a span of 1.65 m for IC 225. The beam is simply supported (a hinge- base at one end and a roller – base at the other end). The beam is loaded with a two point load at l/3 distance. The load is applied through loading frame of 100ton capacity. The beam is loaded and deflection is measured at the mid span. To record deflection of the beams, dial gauges are mounted at l/3 distance**.**

Experimental Load Vs Deflection IC 225 (WOS)

LOAD(KN)	DEFLECTION(mm)
5.13	0.49
10.26	0.76
17.1	1.01
25.65	1.42
30.78	1.54
34.2	1.69
37.62	1.78
41.04	1.85
46.17	1.96
51.3	2.11
59.85	2.41
66.69	2.75
74.22	3.21
81.74	3.84
62.78	3.84



Load vs Deflection curve of WOS

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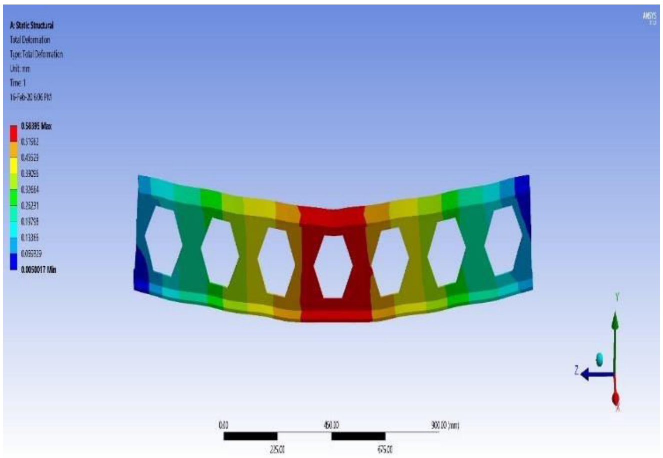
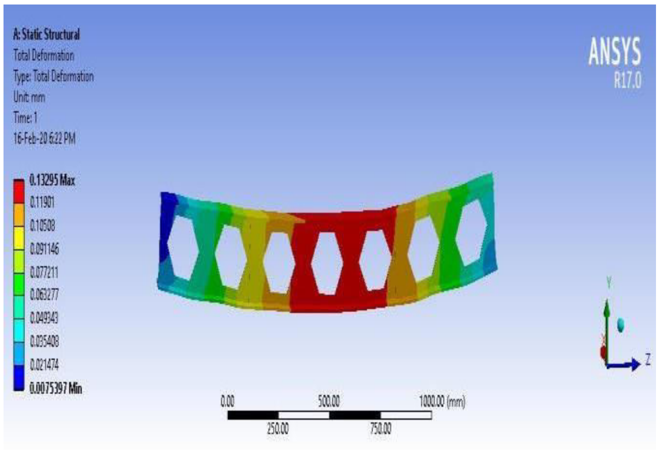


Total Deformation of WOS



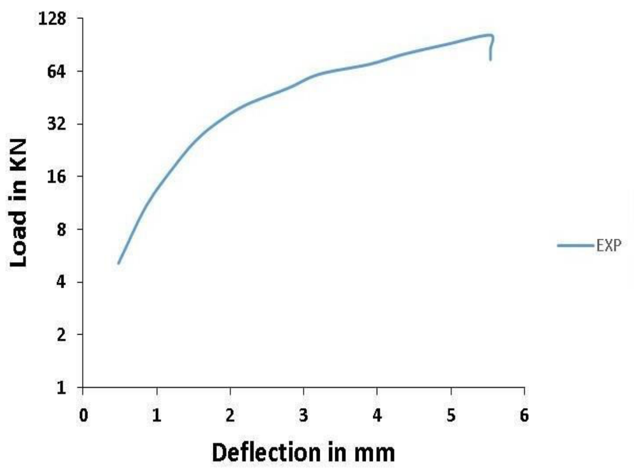
Total Deformation of WVS

Experimental Load Vs Deflection IC 225 (WVS)

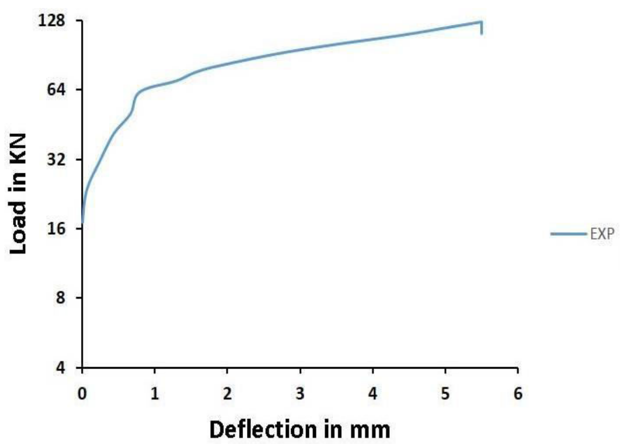
LOAD(kN)	DISPLACEMENT(mm)
5.13	0.48
10.94	0.86
18.81	1.26
25.65	1.53
32.49	1.82
41.04	2.21
51.3	2.79
61.56	3.21
70.11	3.89
80.028	4.36
90.63	4.92
102.94	5.54
86.29	5.54
74.56	5.54

Experimental Load Vs Deflection IC 225 (WDS)

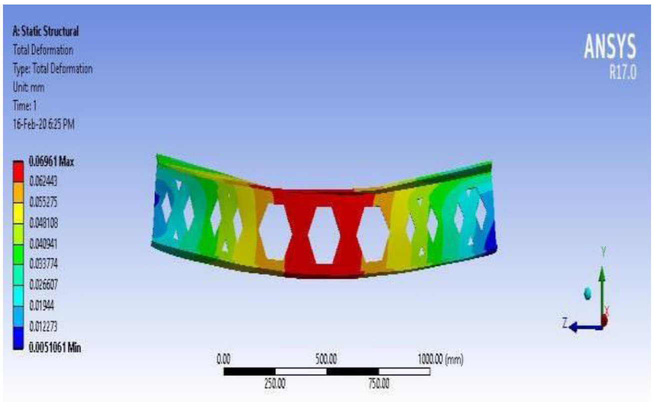
LOAD(KN)	DISPLACEMENT(mm)
17	0.012
21.26	0.04
25.13	0.10
30.57	0.23
41.26	0.44
50.32	0.67
62.78	0.8
75.78	1.54
80.12	1.79
91.47	2.66
100.9	3.50
110.54	4.40
120.65	5.12
126.32	5.50
112.45	5.50
92.97	5.50



Load vs Deflection curve of WVS



Load vs Deflection curve of WDS



Total Deformation of WDS

B. Details of stiffener

Specimen details	Length (mm)	Depth (mm)	Length of stiffener (mm)	Width of stiffener (mm)	Thickness of stiffener (mm)
IC WOS	1650	225	-	-	-
IC WVS	1650	225	210	50	6
IC WDS	1650	225	220	50	6

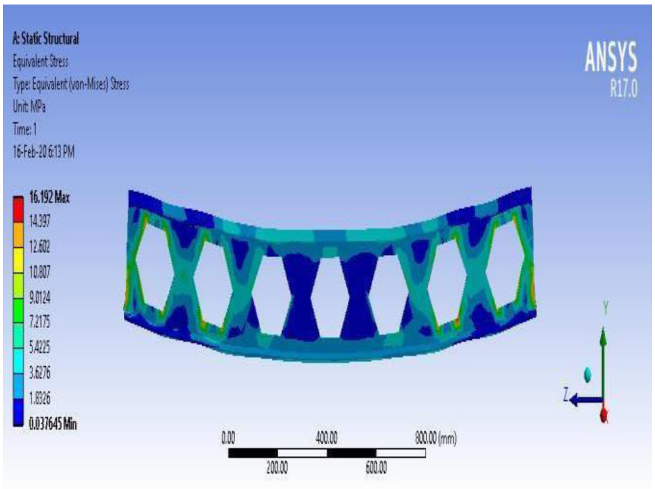
C. Experimental results

SPECIMEN	ULTIMATE LOAD (kN)	DEFLECTION (mm)	FAILURE MODES
WOS	81.74	3.02	Failure of compression flange and vierendeel effect.
WVS	102.94	5.54	Failure of compression flange
WDS	126.32	5.50	Failure of compression flange

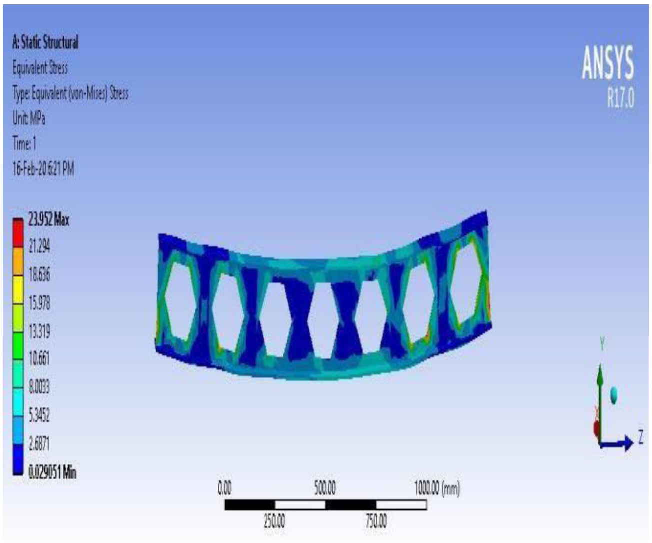
VII. FINITE ELEMENT ANALYSIS

Three dimensional (3D) finite element model is developed using ANYSIS-17 for IC 225. Various finite element models and von misesstresses are developed. Stress concentration of the beam is studied. Stress concentration is more near the opening leading to shear failure

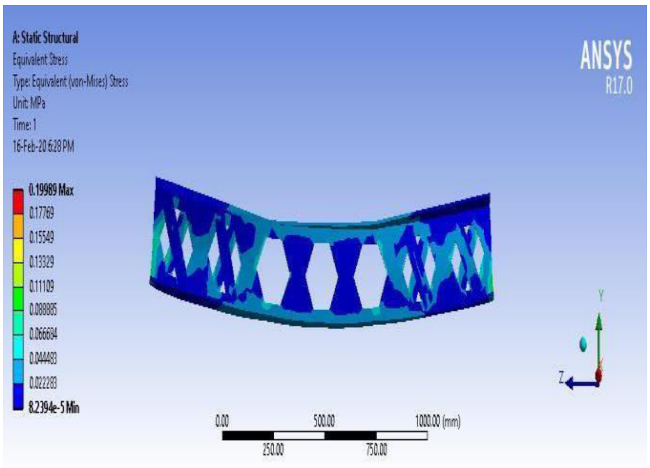
Hence the webs are stiffened by providing stiffeners on either side of the beam along the shear zone to reduce the stress concentration and to reduce the shear deformation. Stiffeners are provided on opening of the web and also on the solid portion of the web. In order to study the effect of stiffeners along shear zone the following three cases are considered Case (I) Without Stiffeners (WOS) on the web opening along the shear zone. Case (II) with vertical Stiffeners (WVS) on the solid web along the shear zone. Case (III) with diagonal Stiffeners (WDS) on the web opening along shear zone.



Von-mises stress of WOS



Von-mises stress of WVS

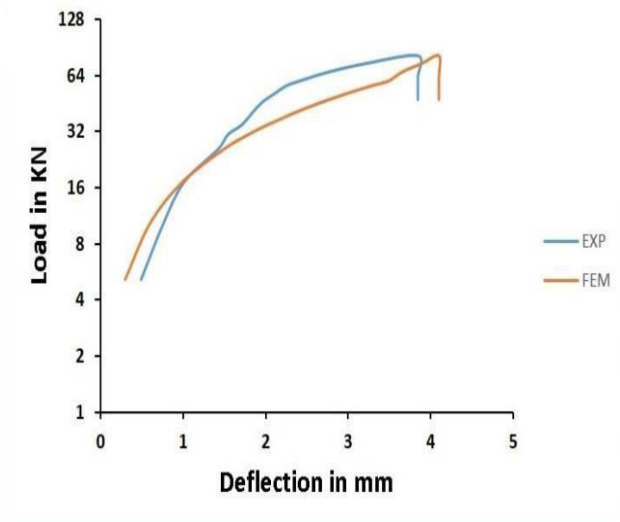


Von-mises stress of WDS

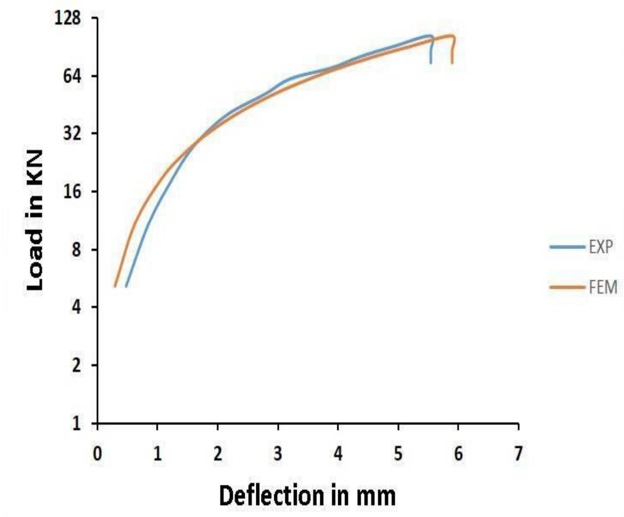
VIII. DISCUSSION OF RESULT

In the result the comparisons between experimental and ansys are compared for three section and comparisons are done by the LOAD vs DEFLECTION curve as shown in the Figure

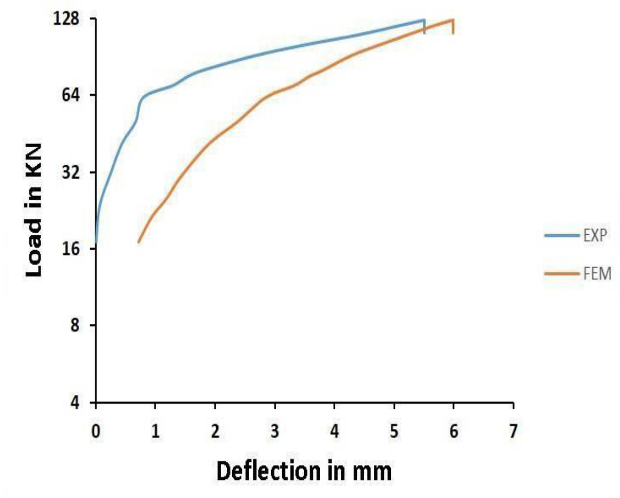
A. *Fem result*



Comparison Result of WOS



Comparison Result of WVS



Comparison Result of WDS

Result comparison of Experimental test and FEM

SPECIMEN	WOS		WVS		WDS	
	EXP.	FEM	EXP.	FEM	EXP.	FEM
ULTIMATE LOAD (kN)	81.74	81	102.94	102.94	126	126
DEFLECTION (mm)	3.84	4.1	5.54	5.89	5.50	5.98
DIFFERENCE BETWEEN EXP. AND FEM IN (%)	6.77		6.31		8.72	

IX. CONCLUSION

When stiffeners are introduced diagonally stress concentration along the hole corners are reduced and deflection is reduced to 35% for IC 225 when compared to castellated beam without stiffeners. When stiffeners are provided vertically deflection is reduced to 22% IC 225 when compared to castellated beam without stiffeners. Hence diagonal stiffeners provided on the opening of the web is effective than the vertical stiffeners provided on the opening. Analytical work is carried out using Finite Element Analysis to study the stress distribution of castellated beam and the effect of stiffeners. When the experimental results of castellated beam are compared with analytical work, it correlates with each other and the discrepancy is within 20% and there is a good correlation between experimental and analytical results

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In this thesis the section used is IC 225 the section details, section properties, experimental data's and experimental photographs have been taken from S. Arun Bharathi

REFRENCE.

1. Liu T.C.H & Chung K.F 2003 'Steel beams with large web openings of various shapes and sizes: Finite Element investigation', Journals of construction steel research, vol.59, pp 1159 - 1176.
2. Konstantinos Daniel Tsavdaridis et al 2011 'Web buckling study of the behaviour and strength of perforated steel beams with different novel web opening shapes', Journals of construction steel research, vol.67, pp 1605 - 1620.
3. Ehab Ellobody 2011 'Nonlinear analysis of cellular steel beams under combined buckling modes', thin walled structures, vol. 52, pp 66-79
4. Wakchaure M.R. et al 'Parametric study ofcastellated beam with varying depth of web opening',

International Journal of scientific and research publication, vol. 2, No. 8, ISSN 2250 - 3153.
5. Soltani M.R, et al 2012 ‘Nonlinear FE analysis of the ultimate behavior of steel castellated beams’, Journal of constructional steel research, vol.70, pp 101 - 114.
6. Chapkhanea N.K et al 2012 ‘Analysis of Stress distribution in castllated beam using finite element method & experimental techniques’, Journals of construction steel research vol.124, pp 99-100.
7. Komal S Bedi, et al 2012 ‘Moment and Shear Analysis of beam with different web openings’, International Journals of Mechanical Engineering Applications research, pp 190- 197.
8. S. Durifa and A. Bouchaïra 2012 ‘Behavior of cellular beams with sinusoidal openings’, Procedia Engineering, vol. 40, pp 108-113.
9. Wakchaure M.R., Sagade A.V.2012 ‘Parametric study of castellated beam with varying depth of web opening’, International journals of Engineering and Innovative Technology, vol. 2, Issue 1, pp 365 - 372 .
10. S. Durif , A. Bouchaïr, O. Vassart 2013 ‘Experimental tests and numerical modeling of cellular beams with sinusoidal openings’, Journals of construction steel research, vol. 82, pp 72-87
11. Ramin Vafaeipour Sorkhabia et al 2013 ‘Optimization of the Castellated Beams by Particle Swarm Algorithms Method’, APCBEE procedia, vol. 9, pp 381-387.
12. Peijun Wang et al 2014 ‘ Vertical shear buckling capacity of web-posts in castellated steel beams with fillet corner hexagonal web openings’, Journals of construction steel research, vol. 121, pp 173-184.
13. Delphine Sonck et al 2014 ‘Experimental investigation of residual stresses in steel cellular and castellated members’, Construction and building materials, vol. 54, pp 512 – 519.
14. B.Anupriya, Dr.K.Jagadeesan 2014 ‘shear strength of castellated beam with and without stiffeners using FEA (ANSYS 14)’, IRJET Research journal, vol. 6 No. 4, ISSN : 0975 – 4024, pp 1970 - 1981.
15. Jamadar A. M., Kumbhar P. D. 2015 ‘ Parametric study of castellated beam with circular and diamond shaped openings’, International Journals of Engineering and Technologies, vol.2, pp715 – 722