Strength Study on Castellated Beam

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Abstract

This paper is focussed on the investigation behaviour of shear strength of castellated beam through an extensive FE study (ANYSIS14).Though castellated beams are well accepted for industrial buildings, power plant and multi-storeyed structures, Due to its web opening stress concentration increases at the whole corners and at load application points and also stiffness of castellated beams decrease as the depth of opening increases.

Hence to increase the shear strength of the castellated beam and also to reduce the deflection, shear stiffeners are introduced along the web opening. From the results obtained from ANYSIS, It was concluded that Deflection without stiffeners is 9.75 mm, when stiffeners are provided diagonally it is reduced to 7.85 mm, and it is still reduced to 3.99 mm when stiffeners are provided vertically along with diagonal stiffeners.

Key words: *Castellated beam, Shear, Deformation, Stiffeners.*

1. Introduction

Castellated beam is an open web beam but made up of a single rolled wide flange beam section and is formed by flame cutting the beam section in a predetermined pattern and rejoining the segments by welding to produce a regular pattern of holes in the web. The beam section obtained in such a way can be even 50% deeper than the original section that is 1.5 times the depth of the original section. By increasing the depth, the section modulus is increased by about 2.25 times the section modulus of the original beam section. Thus the load carrying capacity of the beam is increased considerably. A castellated beam has some limitations also, stress concentration occurs near the perforations and the shear carrying capacity is reduced. Stress concentration may be reduced by making perforations near the neutral axis where the stress are small making the cut in a zig- zag way. The shear carrying capacity can be increased by stiffening the web at points of concentrated loads and reactions. Fig-1 shows a castellated beam.

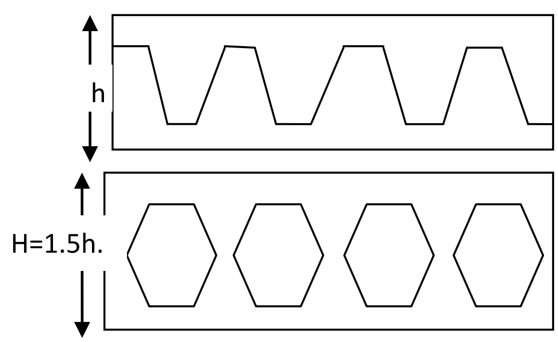


Fig.1. Castellated Beam

2. Objective of Research work

The main focus of the research work is to introduce stiffeners along the web opening so that deflection is minimized and shear failure is controlled. In this investigation the deflection of castellated beam is examined using ANYSIS 14 by providing diagonal and vertical stiffeners.

3. Investigation of Castellated Beam

1. Select the angle of cut to be 45° for a good design
2. The depth of the stem of the T section at the minimum cross section should not be less than ¼ of the original beam section.
3. Calculate 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 sections.
    a. $M_R = A\ \sigma_{at}\ d$
4. The spacing of the castellated beam should not exceed the spacing determined by the equation
    a. $S = \frac{P'}{W'L}$ Where,
    b. S= center to center distance between castellated beams
    c. P'= Net load carrying capacity in N
    d. W= Design load in N/m^2

L= Span of the beam in m

1. Stiffeners are designed at the supports and below the concentrated loads.

2. The beam is checked in shear. the average shear at the end is calculated from

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

$$< 0.4\ f_y$$

Where
R= end reaction in N
d'= depth of the stem of T – section
t= thickness of the stem

3. The maximum combined local bending stress and direct stress in the T Segment is also worked out and should be less than the permissible bending stress.
4. The maximum deflection of the T- section is at the mid span and is due to the net load carrying capacity and local effects.

$$\delta = \delta_1 + \delta_2 \quad < L/325$$

Where
δ_1 - Deflection due to net load carrying capacity
δ_2 - Deflection due to local effects

4. Failure Modes of Castellated Beam

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.
- Lateral Torsional buckling of the overall beam: Castellated beam undergo lateral torsional buckling of the whole span.
- Plastic Hinge Formation: This mode of failure occurs when lateral torsional buckling is prevented. Areas of plasticity are formed in the top and bottom flanges caused by a combination of stresses due to primary flexure and vierendeel action. The hinges may form away from point of maximum bending moment due to the presence of shear and axial forces.
- 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.

5. Finite Element Analysis

In this paper, a three dimensional (3D) finite element model is developed using ANYSIS-14 for IC 225 and IC 300. Various finite element models and von mises stresses are developed. The introduction of an opening in the web of the beam alters the stress distribution within the member and also influences its collapse behavior. The opening decreases the stiffness of the beam resulting in larger deformation. The strength realized will depend upon the interaction between the moment and shear. The reduction in moment capacity at the openings is small while the reduction in shear capacity may be significant. Hence Shear stiffeners are provided at the opening to improve its shear carrying capacity.

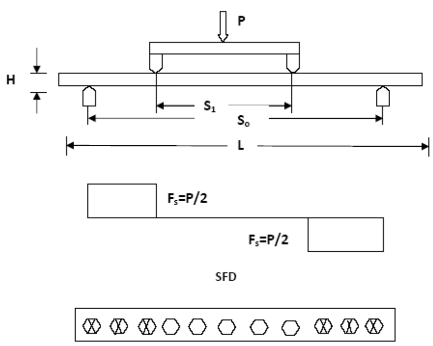
Model 1
IC 225
L=3.2 m, t_F =7.5 mm, t_w =5mm, b_w =80mm, HW=150 mm,
Length of stiffeners =190mm, Width of stiffeners = 15 mm , Thickness of Stiffener = 5mm

Model 2
IC 300
L=3.2 m, t_F =10 mm, t_w =6mm, b_w =100mm
HW=200 mm,
Length of stiffners =260mm, Width of stiffeners = 20 mm , Thickness of Stiffener = 6mm.

6. Analytical Methods

The castellated beams have the disadvantage of reduced shear capacity due to stress concentrations near the openings. This can be alleviated to some extent by providing Stiffeners. Diagonal and vertical stiffeners are provided along the web opening where shear force is low.

Case 1 - Without Stiffeners
Case 2-With Diagonal Stiffeners
Case -3-With Diagonal & Vertical Stiffeners



Case -1 Without Stiffeners

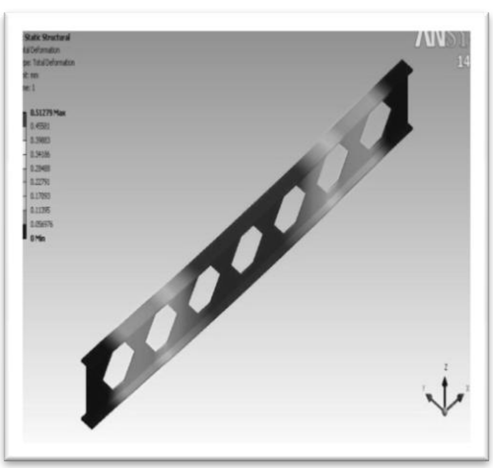


Fig.-2. CB without Stiffeners

Case 2 - With Diagonal Stiffeners

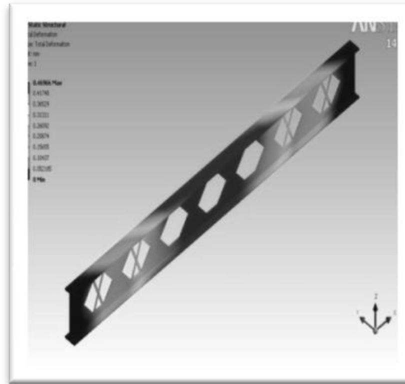


Fig.- 3. CB with Diagonal Stiffeners

Case 3 - With Diagonal & Vertical Stiffeners

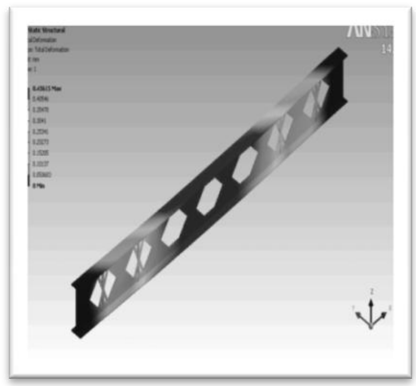


Fig.-4. CB Diagonal & Vertical Stiffeners

Case 1. With Out Stiffeners (IC 225)
Table 1. Load Vs Deflection (IC 225)

Load (KN)	Deflection (mm)
10	1.28
20	2.55
30	3.83
40	5.10
50	6.38
60	7.65
70	8.93
80	10.21
90	11.48
100	12.76

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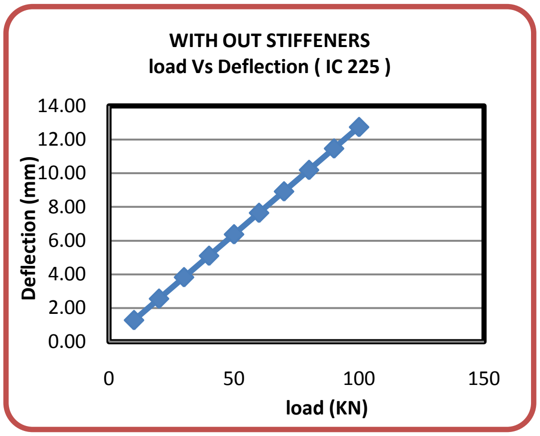
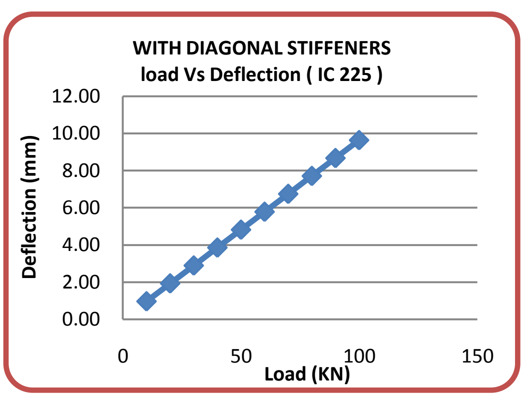


Graph 1. With Out Stiffeners (load Vs Deflection (IC 225))

Case 2. With Diagonal Stiffeners
Table 2. Load Vs Deflection (IC 225)

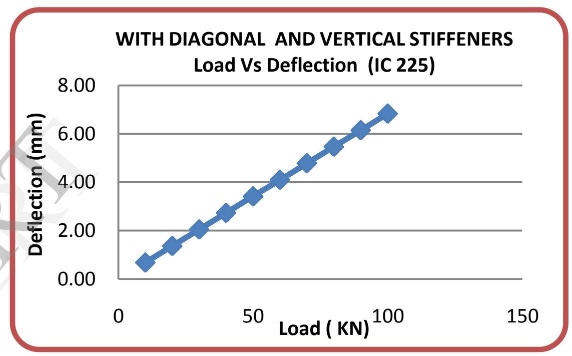
Load(KN)	Deflection(mm)
10	0.96
20	1.93
30	2.89
40	3.85
50	4.82
60	5.78
70	6.74
80	7.70
90	8.67
100	9.63



Graph 2. With Diagonal Stiffeners (load Vs Deflection (IC 225))

Case 3.With Diagonal and Vertical Stiffeners
Table 3. Load Vs Deflection (IC 225)

Load (KN)	Deflection (mm)
10	0.68
20	1.37
30	2.05
40	2.74
50	3.42
60	4.10
70	4.79
80	5.47
90	6.16
100	6.84

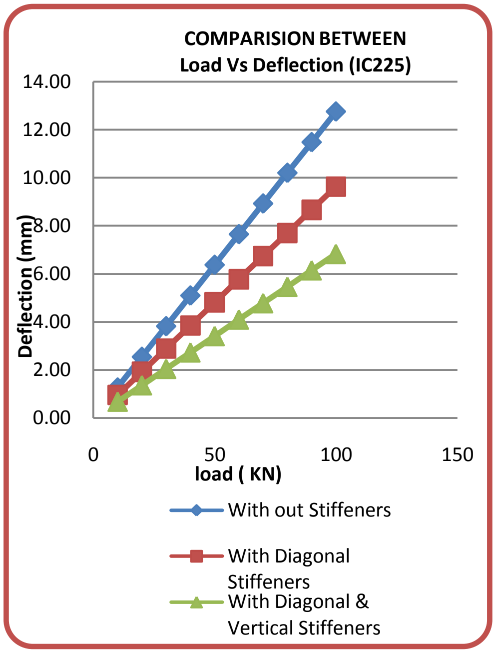


Graph 3. With Diagonal & Vertical Stiffeners (load Vs Deflection (IC 225))

Comparison between Load Vs Deflection (IC225)

LOAD (KN)	DEFLECTION (mm)		
	Without Stiffeners	With Diagonal tiffeners	With Diagonal & Vertical Stiffeners
10	1.28	0.96	0.68
20	2.55	1.93	1.37
30	3.83	2.89	2.05
40	5.10	3.85	2.74
50	6.38	4.82	3.42
60	7.65	5.78	4.10
70	8.93	6.74	4.79
80	10.21	7.70	5.47
90	11.48	8.67	6.16
100	12.76	9.63	6.84

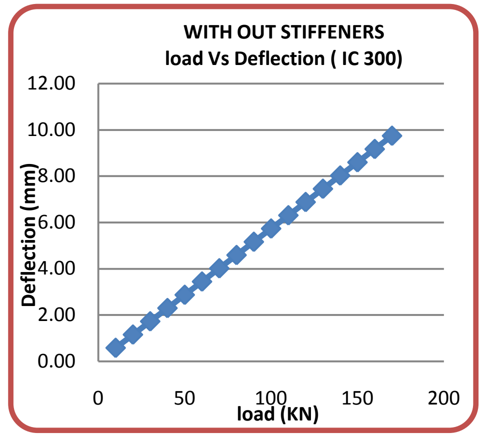
Table5. Load Vs Deflection (IC 225)



Graph 5 Comparision (load Vs Deflection (IC 225))

Case1- With Out Stiffeners (IC 300)
Table 6. Load Vs Deflection (IC 300)

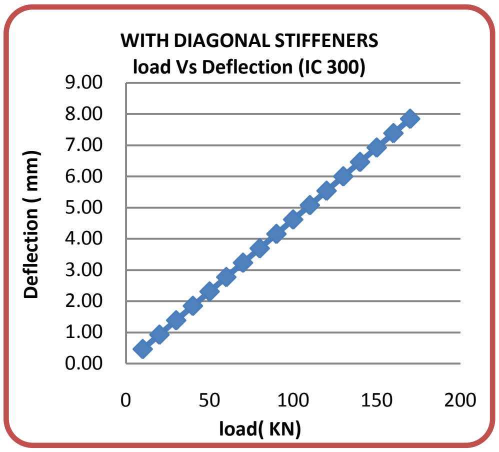
Load(KN)	Deflection(mm)
10	0.57
20	1.15
30	1.72
40	2.29
50	2.87
60	3.44
70	4.01
80	4.59
90	5.16
100	5.73
110	6.31
120	6.88
130	7.46
140	8.03
150	8.60
160	9.18
170	9.75



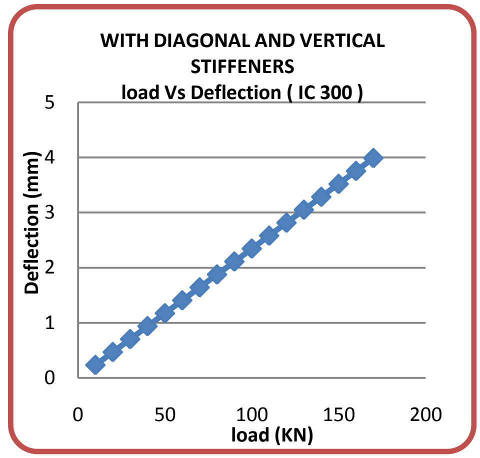
Graph 6 With Out Stiffeners (load Vs Deflection - IC 300)

Case2- With Diagonal Stiffeners (IC 300)
Table 7. Load Vs Deflection (IC 300)

Load(KN)	Deflection(mm)
10	0.46
20	0.92
30	1.38
40	1.85
50	2.31
60	2.77
70	3.23
80	3.69
90	4.15
100	4.62
110	5.08
120	5.54
130	6.00
140	6.46
150	6.92
160	7.39
170	7.85



Graph 7. With Diagonal Stiffeners (load Vs Deflection -IC 300)



Graph 8 With Diagonal & vertical Stiffeners (load Vs Deflection -IC 300)

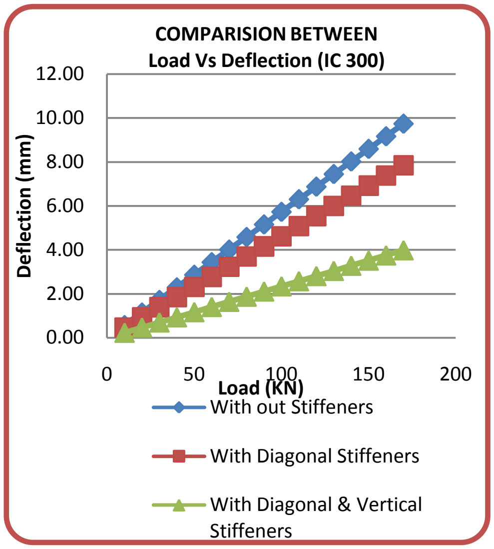
Case3- With Diagonal & Vertical Stiffeners (IC 300)
Table 8. Load Vs Deflection (IC 300)

Load(KN)	Deflection(mm)
10	0.23
20	0.47
30	0.70
40	0.94
50	1.17
60	1.41
70	1.64
80	1.88
90	2.11
100	2.35
110	2.58
120	2.82
130	3.05
140	3.28
150	3.52
160	3.75
170	3.99

Comparison between Load Vs Deflection
Table 9. Load Vs Deflection (IC 300)

LOAD (KN)	DEFLECTION (mm)		
	Without Stiffeners	With Diagonal Stiffeners	With Diagonal & Vertical Stiffeners
10	0.57	0.46	0.23
20	1.15	0.92	0.47
30	1.72	1.38	0.70
40	2.29	1.85	0.94
50	2.87	2.31	1.17
60	3.44	2.77	1.41
70	4.01	3.23	1.64
80	4.59	3.69	1.88
90	5.16	4.15	2.11
100	5.73	4.62	2.35
110	6.31	5.08	2.58
120	6.88	5.54	2.82
130	7.46	6.00	3.05
140	8.03	6.46	3.28
150	8.60	6.92	3.52
160	9.18	7.39	3.75
170	9.75	7.85	3.99

Graph 9 Comparision (load Vs Deflection (IC 300))



Allowable

Deflection = L/325 = 3200/325 = 9.84

Conclusions

From the results obtained from ANYSIS 14, shear failure is more near the wholes than the web, hence shear stiffeners are provided on the opening of the web along the shear zone. Stiffeners are provided diagonally and deflection is noticed. In another case stiffeners are provided vertically along with diagonal stiffeners and deformation is noted.

Deflection of castellated beam without stiffeners, with diagonal Stiffeners, and vertical along with diagonal is given below. For (IC 300) Deflection without stiffeners is 9.75 mm, when it is arrested diagonally deflection is reduced to 7.85 mm, and it is still reduced to 3.99 mm when stiffeners are provided vertically along with diagonal stiffeners. Hence it is concluded that, shear strength of castellated beam can be improved by introducing shear stiffeners along the shear zone.

Specimen Detail	Load (KN)	Deflection (mm)		
		With Out Stiffeners (mm)	With diagonal Stiffeners (mm)	With diagonal & Vertical Stiffeners (mm)
IC 225	100	8.93	6.74	4.79
IC 300	170	9.75	7.85	3.99

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