Finite Element Analysis of Castellated Steel Beam

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Abstract - *This dissertation investigates the various failure patterns and effect of web openings on various structural aspects with the help of Finite Element Analysis software ANSYS WORKBENCH 16.0. The present study deals with the static analysis of single solid web, double solid web, single web and double web castellated beam and nonlinear time history analysis of single web and double web castellated beam. In this research, to design and study the Finite Element Analysis of steel beam with single solid web, double solid web, single web and double web castellated beam is performed and the response in terms of deflection up to serviceability limit by changing the span and section of beam and validate the results by static analysis using ANSYS WORKBENCH 16.0. The beams are simply supported conditions having uniformly distributed loads up to serviceability limit and the spans are 6m, 9m, 12m and 16m. With different parent sections for ISMB 225, ISMB 350, ISMB 400 and ISMB 450 for single solid web, ISDW(Solid Double Web) 225, 350, 400 and 450 for double solid web and also IC 225, IC 350, IC 400 and IC 450 for single and double web castellated beam. Non-linear time history analysis has been carried out by considering earthquake ground motion viz. modified EI-Centro (1940).*

This indicates that up to serviceability limit, castellated beams has more load carrying capacity than its parent sections of beam (i.e. solid beams) The major mode of failure is lateral torsional buckling and that is reduced in double solid web and double web castellated beams than the single solid and single web castellated beams.

Key Words*: *Castellated beam, Deflection, Stress, Finite Element Analysis, single-double web openings.

1. INTRODUCTION

Necessity is the mother of invention. Now a days Engineers are constantly trying to improve the material properties and techniques of design and construction. Use of castellated beam has become very popular due to its advantageous structural applications such as they are light, cheap, they have relatively high resistance, and can be assembled fast at the construction site. These uses take advantage of the increased strength and the economy of castellated beams. Also the different failure modes of castellated beam such as Vierendeel collapse mechanism, buckling of a web post, flexural failure, lateral torsional buckling, shear failure. Therefore these modes of failures are minimized due to providing the double web castellated beam. The available literature does not deal with the behaviour of double web castellated beam with increase in depth of opening. Use of steel for structural purpose in structure is rapidly gaining interest these days. One such improvement occurred in built-up structural members in the mid-1930, an engineer working in Argentina, Geoffrey Murray Boyd, is castellated beam.

Castellated beams are such structural members, which are made by flame cutting a rolled beam along its center line and then rejoining the two halves by welding so that the overall beam depth is increased by 50% for improved structural performance against bending.

Castellated beam reduces the cost of structural steel. Castellated beams having holes or castellation on its web portion. It is made by cutting the web portion of the solid beam in zigzag pattern and then arranging the two halves in such a way that castellation's are made in the web portion. It is the then welded together to form a castellated beam. In castellated beams, one can increase the depth of the beam without any additional steel.

In this work, we are considering a single web castellated beam and double web castellated beam having hexagonal openings. Ansys 16.1 is used for finite element analysis. The beams are simply supported conditions having uniformly distributed loads up to serviceability limit and the spans are 6m, 9m, 12m and 16m. With different parent sections for ISMB 225, ISMB 350, ISMB 400 and ISMB 450 for single solid web, ISDW(solid double web) 225, 350, 400 and 450 for double solid web and also IC 225, IC 350, IC 400 and IC 450 for single and double web castellated beam. Non-linear time history analysis has been carried out by considering earthquake ground motion viz. modified EI-Centro (1940).

2. FINITE ELEMENT ANALYSIS

In this paper, a three dimensional (3D) finite element model is developed to stimulate the behaviour of double web castellated beam having an I-shaped cross section. Various finite element models for determining the Y-directional deformations and von-mises stresses of I-beam with various cross-section and lengths are developed and useful results have been obtained. fixed supported I-beam models have been analyzed and the corresponding deflections and stresses are obtained for a variety of cross sectional geometries, and lengths where d is depth of web opening, D is depth of beam. Modelling is conducted using the general purpose finite element software package ANSYS 16.0.

In this paper, firstly solved some numerically problems for single web castellated beam and double web castellated beam with UDL 13.125 KN/m for different span of 6m, 9m, 12m, and 16m from that results analysis have been done in Ansys 16.0 . ANSYS provides solutions for many type of analysis ANSYS is a widely used commercial general-purpose finite element analysis program

2.1 PRELIMINARY DATA

A three dimensional finite element model is developed to study the behaviour of single solid web, double solid web, single web and double web castellated beam. Beams are of I shaped cross section. Modelling and analysis was done using ANSYS WORKBENCH 16.0.

Table -1: Single Solid Web Beam

Section	h (mm)	bf (mm)	tf (mm)	tw (mm)
ISMB 225	225	110	11.8	6.5
ISMB 350	350	140	14.2	8.1
ISMB 400	400	140	16	8.9
ISMB 450	450	150	17.4	9.4

Table -2: Single Web Castellated Beam

Section	h mm	hc mm	bf mm	tf mm	Tw mm	S mm
Ic 225	337.5	225	110	11.8	6.5	112.5
Ic 350	525	350	140	14.2	8.1	175
Ic 400	600	400	140	16	8.9	200
Ic 450	675	450	150	17.4	9.4	114.2

Table -3: Double Solid Web Beam

Section	h (mm)	bf (mm)	tf (mm)	tw (mm)
ISDW225	225	110	11.8	6
ISDW 350	350	140	14.2	6
ISDW400	400	140	16	6
ISDW450	450	150	17.4	6

Table -4: Double Web Castellated Beam

Section	h mm	hc mm	bf mm	tf mm	Tw mm	S mm
Ic 225	337.5	225	110	11.8	6	112.5
Ic 350	525	350	140	14.2	6	175
Ic 400	600	400	140	16	6	200
Ic 450	675	450	150	17.4	6	114.2

The analysis was performed to determine the deflection of the single solid web, double solid web, single web and double web castellated beams having hexagonal openings. Each I-shaped beam is characterized by its span (L), flange width (bf), flange thickness (tf), depth of parent h, depth of castellated beam (hc) and web thickness (tw). Web perforations were hexagonal in shape, with side (s) spacing between two holes and are uniformly spaced at distance along the span of the beam.

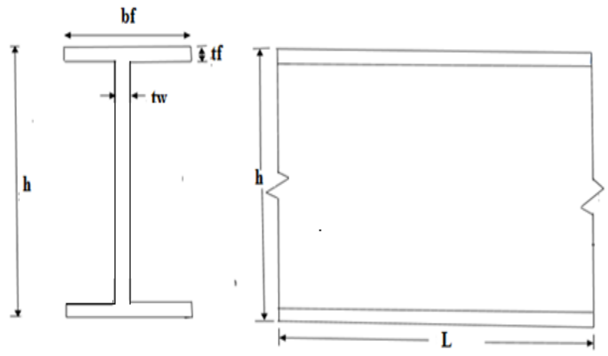


Fig -1: Cross-section for single web solid beam

As per the mathematical expressions the design is carried out for single and double web castellated beams of I shaped cross sections with hexagonal web openings which shown in figures 1 to 4.

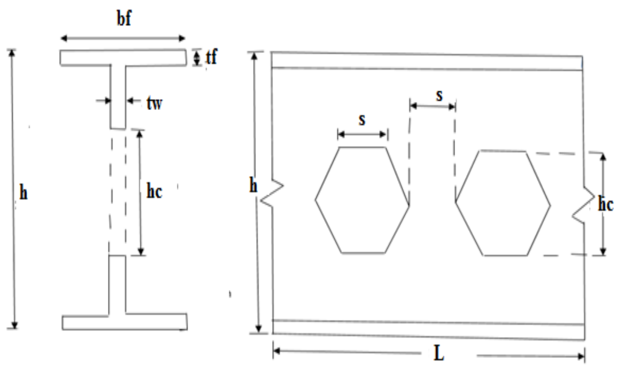


Fig -2: Cross-section for single web castellated beam

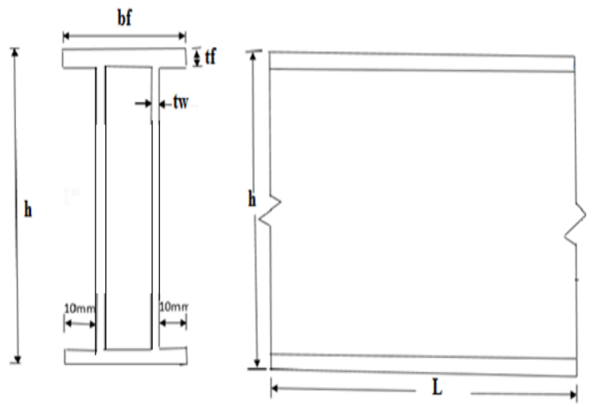


Fig -3: Cross-section for Double web solid beam

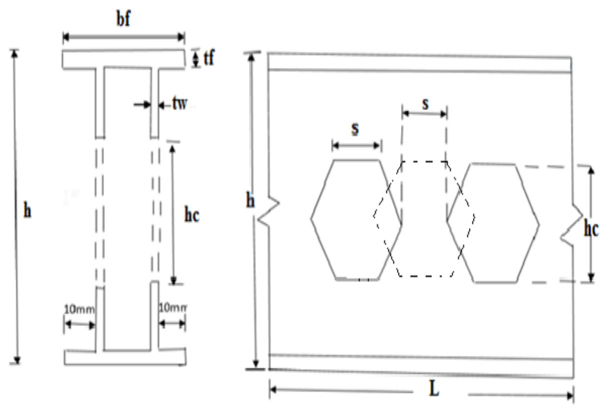


Fig -4: Cross-section for Double web castellated beam

2.2 ANSYS ANALYSIS PROCEDURE

A three dimensional finite element model is developed to study the behaviour of single and double web castellated beam. Beams are of I shaped cross section. Modelling and analysis was done using ANSYS 16.0.

Static analysis was performed to determine the deflection of the single and double web castellated beam and having hexagonal openings. . Each I-shaped beam is characterized by its span L, flange width bf, flange thickness tf, depth of parent h, depth of castellated beam hc and web thickness tw. Web perforations were hexagonal in shape, with side (s) spacing between two holes and are uniformly spaced at distance S along the span of the beam. The size of the elements along the span of the beam is restricted not to exceed twice the size of the element across the flange. Several mesh configurations are attempted until the above-provided limitations are set after providing convergence of the predicted buckling load within reasonable execution time.

The above problem statements are same for single web and double web castellated beam except the web thickness for double web castellated beam is 3mm to 5mm in each cases.

2.3 RESULTS OF ANSYS ANALYSIS

After completed geometry, From Analysis system static structural model is selected and create the ANSYS WORKBENCH 16.0 Model Environment, from that total numbers of models are created for single and double web castellated beam and same for single solid web and double solid web.

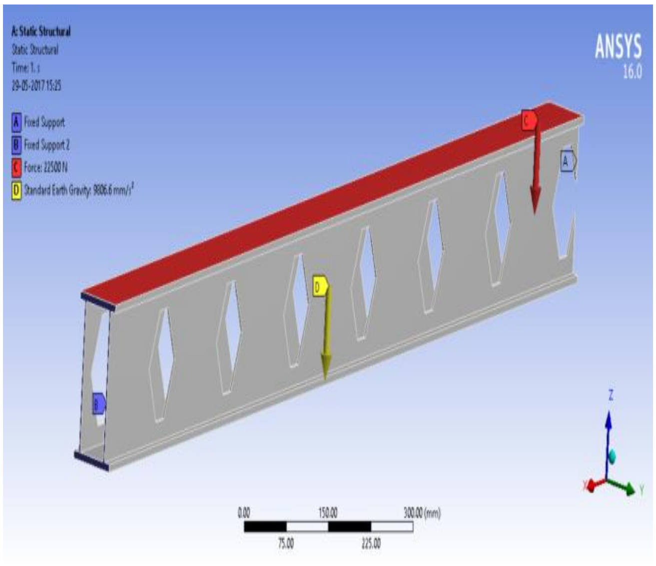


Fig -5: Position of force

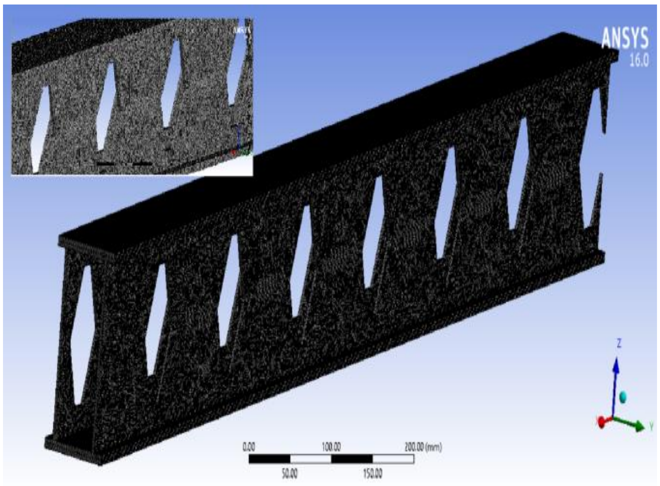


Fig -6: Typical finite element mesh for castellated beam

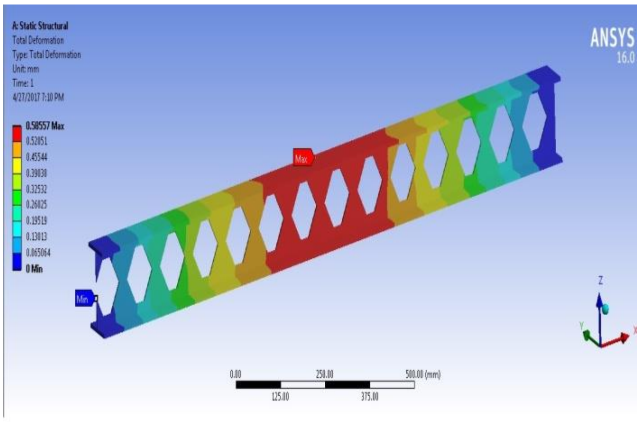


Fig -7: Total deflection of ISMB 225 for Single Web Castellated beam

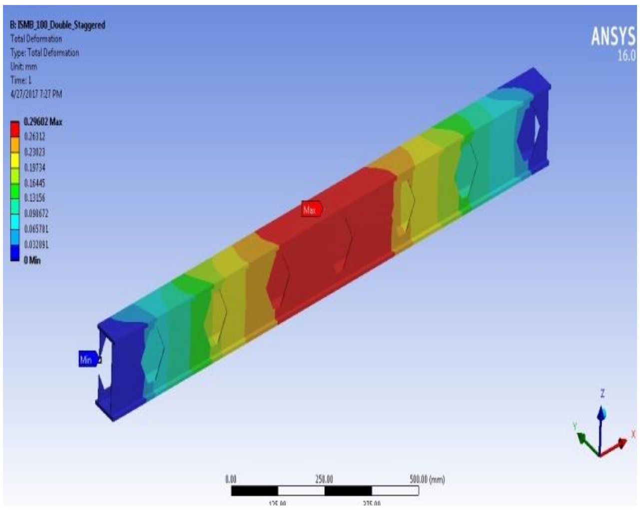


Fig -8: Total deflections of Double Web Castellated beam

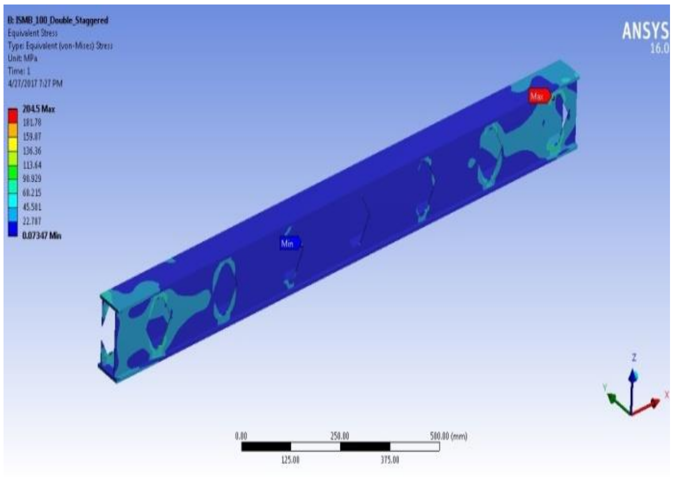


Fig -9: Maximum stress for Double Web Castellated beam

3. RESULTS OF STATIC ANALYSIS AND NON-LINEAR TIME HISTORY ANALYSIS

The Time History analysis was carried out for single web and double web castellated beam for different spans have been analysed. The beams are considered as simply supported conditions over uniformly distributed load and the spans are 6m, 9m, 12m and 16m. With different sections for ISMB 225, ISMB 350, ISMB 400 and ISMB 450 for single solid web, ISDW(solid double web) 225, 350, 400 and 450 for double solid web, IC 225, IC 350, IC 400 and IC 450 for single and double web castellated beam.

Table -5: Comparison of ANSYS results for span 6m with Serviceability Limit of sections ISMB 225, SW Ic 337.5, ISDW 225, DW Ic 337.5

Beam	Defl. ction mm	Load kN/m	Local Mode of Failure	Global Mode of Failure
Single web Solid ISMB 225		7.4	Failure of compression flange and vierendeel effect	Lateral torsional buckling
Single web Ic 337.5	18.4	17.4	Failure of compression flange	Lateral torsional buckling
Double web solid ISDW 225		8.1	Vierendeel effect and Failure of compression flange	Flexural buckling of Web
Double web Ic 337.5		19.3	Failure of compression flange	Web Buckling

Table -6: Comparison of ANSYS results for span 9m with Serviceability Limit of sections ISMB 350, SW Ic 525, ISDW 350, DW Ic 525

Beam	Defl. ction mm	Load kN/m	Local Mode of Failure	Global Mode of Failure
Single web Solid ISMB 350	27.6	8.7	Failure of compression flange and vierendeel effect	Lateral torsional buckling
Single web Ic 525		20.3	Failure of compression flange	Lateral torsional buckling
Double web solid ISDW 350		9.4	Vierendeel effect and Failure of compression flange	Flexural buckling of Web
Double web Ic 525		21.9	Failure of compression flange	Web Buckling

Table -7: Comparison of ANSYS results for span 12m with Serviceability Limit of sections ISMB 400, SW Ic 600, ISDW 400, DW Ic 600

Beam	Defle ction mm	Load kN/ m	Local Mode of Failure	Global Mode of Failure
Single web Solid ISMB 400	36.9	5.5	Failure of compression flange and vierendeel effect	Lateral torsional buckling
Single web Ic 600		12.8	Failure of compression flange	Lateral torsional buckling
Double web solid ISDW 400		5.85	Vierendeel effect and Failure of compression flange	Flexural buckling of Web
Double web Ic 600		13.7	Failure of compression flange	Web Buckling

3.1 FINITE ELEMENT ANALYSIS OF STEEL BEAM

In this research, to design and study with single solid web, double solid web, single web and double web castellated beam is performed and the response in terms of deflection up to serviceability limit by changing the span and section of beam and then validate the results by static analysis using ANSYS WORKBENCH 16.0.

Table -8: Comparison of ANSYS results for span 16m with Serviceability Limit of sections ISMB 450, SW Ic 675, ISDW 450, DW Ic 675

Beam	Defle ction mm	Load kN/m	Local Mode of Failure	Global Mode of Failure
Single web Solid ISMB 450	49.2	3.45	Failure of compression flange	Flexural buckling of Web
Single web Ic 675		8.26	Failure of compression flange and vierendeel effect	Lateral torsional buckling
Double web solid ISDW 450		3.64	Failure of compression flange	Lateral torsional buckling
Double web Ic 675		8.52	Vierendeel effect and Failure of compression flange	Web Buckling

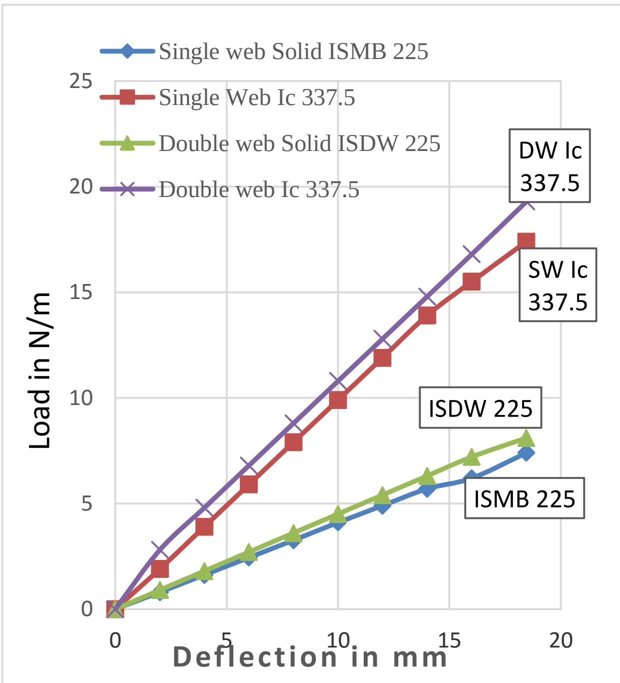
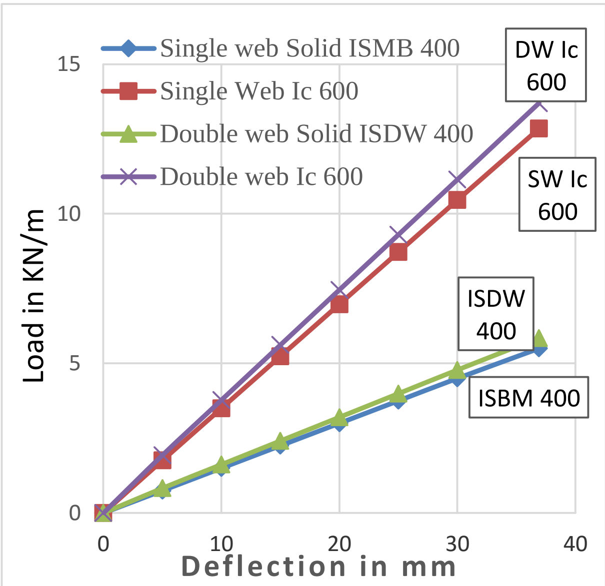


Chart -1: Comparison of ANSYS Results for span 6 m with different sections ISMB 225, SW Ic 337.5, ISDW 225, DW Ic 337.5

Chart -2: Comparison of Ansys Results for span 9 m with different sections ISMB 350, SW Ic 525, ISDW 350, DW Ic 525



Graph -3: Comparison of Ansys Results for span 12 m with different sections ISMB 400, SW Ic 600, ISDW 400, DW Ic 600

3.2 Problem statement

Non-linear time history analysis has been carried out by earthquake ground motion viz. modified EI-Centro (1940).The results for response quantities such as deformation, stresses and failure patterns are presented.

From table 5 to 8 it is also seen that the when the section of beam is increasing, deflection of beam is decreasing (deflection for ISMB 225 is more and deflection for ISMB 450 is least.) for each spans and for each beams. If the span of beam is increased, the deflection is also increased.

From graph 1 to 4, it is observed that the local and global modes of failures and the comparison of Ansys results for span 6m, 9m, 12m and 16m with serviceability limit for different sections for single solid web, double solid web, single web and double web castellated beam. This indicates that up to serviceability limit, castellated beams has more load carrying capacity than its parent sections of beam (i.e. solid beams)

Further, it is also observed that the local and global failure for different beams, the lateral tortional buckling is reduced in double solid and double web castellated beams than the single solid and single web castellated beams.

For carrying maximum moment we have to follow following conditions while designing:

- To avoid local failure of beam. (i.e. provision of plate below concentrated load).
- To provide reinforcement at the weak sections of the beam.
- To avoid Vierendeel effect (to avoid stress concentration) corners of the holes are to be rounded. It is observed that the non linear time history analysis for the 6m, 9m, 12m and 16m, and the responce in terms of time period, deformation, stresses are observed 15 to 20% less in double wed castellated beam

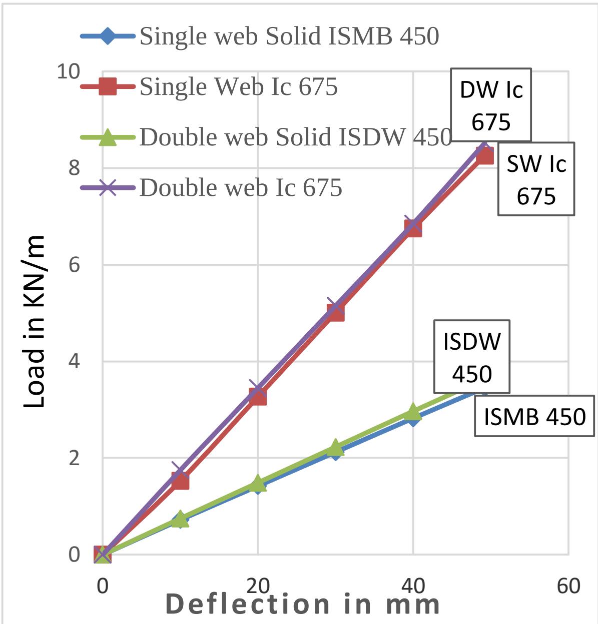


Chart -4: Comparison of Ansys Results for span 16 m with different sections ISMB 450, SW Ic 675, ISDW 450, DW Ic 675

Table -9: Details of percentage error for span 6m, 9m, 12m and 16m

Span in (m)	% Error			
	Single Web Solid Beam	Single Web Castellated Beam	Double Web Solid Beam	Double Web Castellated Beam
6	+ 5.51	5.06	+ 1.31	- 15.61
9	+ 6.15	25.03	- 9.48	8.63
12	+ 4.04	18.16	+ 6.48	1.64
16	+ 2.92	13.21	- 19.14	9.47

4. CONCLUSIONS

From the above results it is concluded that, as the section of beam is increasing, deflection of beam is decreasing (deflection is more for ISMB 225 and deflection for ISMB 450 is least.) for each spans and for each beams. This indicates that up to serviceability limit, castellated beams has more load carrying capacity than its parent sections of beam (i.e. solid beams)

The major mode of failure is lateral torsional buckling and that is reduced in double solid web and double web castellated beams than the single solid and single web castellated beams. We can conclude that castellated beams are well accepted for industrial buildings, power plant and multistore structures, where generally loads are less and spans are more with its economy and satisfying serviceability criteria.

From non-linear time history analysis it is observed that buckling (total deformation), equivalent stress, shear stress are observed 15-20% less in double web castellated beam than single web castellated beam, so it is clear that it should be recommended in higher seismic zone such as north east side (zone V).Also double web castellated beam design should be updated in IS code

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