Analysis & Comparison of Castellated Beam with Diagonal Stiffeners Within & Outside Opening by Using ABAQUS & Experimental Work

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Abstract- Now-a-days the use of castellated beam has been admired due to its beneficial functions like light in weight, easy to erect, economical and stronger. The castellated beam is manufactured from its parent solid I beam by cutting it in zigzag pattern and again joining it by welding, so that the depth of the beam increases. Hence, due to increase in depth of beam load carrying capacity of the parent I section is increased with same quantity of material. The increase in depth of castellated beam leads to web post buckling and lateral torsional buckling failure when these beams are subjected to loading. There are many other modes of failure like formation of flexure mechanism, lateral torsional buckling, and formation of vierendeel mechanism, rupture of the welded joint in a web post and shear buckling of a web post which needs to be taken care of. Study shows that use of stiffeners in the web portion of beam helps in minimizing these failures.

The optimization of the design for the proper combination of size position and thickness of stiffener with castellated beam is not yet completed. Though codal provisions provide design of opening sizes but yet data related to stiffener is not satisfactorily incorporated in the provisions

I. INTRODUCTION

Use of Perforated beams in steel constructions are rapidly increasing due to its very advantageous properties like light in weight, ease in construction, advanced load deflection characteristics, more strength and stiffness and also due to aesthetic view offered by perforated beam. Usually pre-engineered buildings are safe as far as strength parameters are considered. But, these sections does not satisfies the serviceability requirement i.e. check for deflection. The beam having more depth can be satisfying these requirements. Hence, instead of choosing the section of more depth the beam can be fabricated in such a way that the depth of the beam increases. This can reduce the cost as the depth required is obtained in same material. Perforated webbed beams are also called as castellated beam, when the openings provided are of hexagonal or octagonal shapes. Also cellular beams i.e. the beams having circular openings are used frequently due to its aesthetic features. Also some producer in recent time has developed the new openings like diamond, sinusoidal, square.

Castellated beams are classified according to the openings provided in the web portion. Following are some castellated beams provided with different openings.

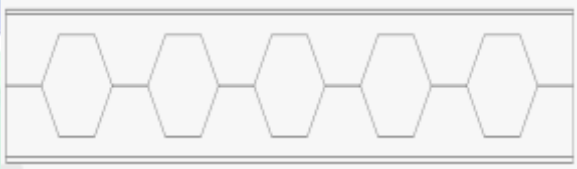

Figure No 1: Castellated Beam with Hexagonal Opening

Castellated beams are manufactured by cutting the web portion of the parent I-section in zigzag pattern and again reuniting them those two halves in such a way that the depth of the beam is increased.

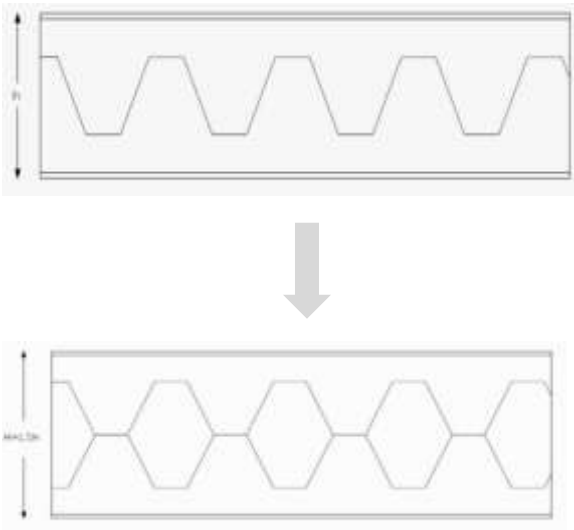

Figure No. 2: Castellation Process Of Castellated Beam With Hexagonal Opening

II. ANALYSIS OF CASTELLATED BEAM

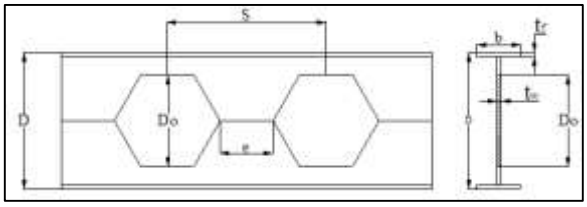

Figure No. 3: Typical Cross Section Of The Beam

Table No 1: Dimensions of Castellation Beam

Original Section Length	Length of Side of Hexagonal	Depth of opening provided	Overall depth of the opening	Width of flange of I beam	Thickness of flange of I beam	Thickness of web of I beam
	a	D_o	D	b	t_f	t_w
150	86.6	150	225	50	5	5

Table No 2: Check For Moment (Flexural) Capacity Of The Beam

Area of upper or lower Tee	Yield stress of steel	Lever arm	Moment capacity of the upper or lower Tee
A_{tee}	P_y	z	M_{pTee}
$((D-D_o)*0.5)*t_w+b*t_f$		D/2	$A_{Tee}\times Py \times z$
437.5	250	112.5	12304687.5

Table No 3: Check For Shear Capacity Of The Beam

Shear area (shear area of whole cross section)	Shear strength of castellated beam	Shear area of Tee	Vertical shear capacity.	Horizontal shear area	Horizontal shear capacity
Av	P_v	A_{wt}	P_{vy}	A_{mwt}	P_{vh}
(D-2tf)×tw	0.6×Py×Av	(D-2tf-Do)×tw	0.6×0.9×Awt	e × tw	0.6×Py×Amwt
1075	161250	325	175.5	300	45000

Table No 4: Check For Flexural And Buckling Strength Of Web Post

Horizontal Shear Capacity	Bending Moment Of Critical Web Post Section	Bending Resistance Of Critical Web Post Section
P_{vh}	M_{max}	M_e
	$P_{vh}\times(Do/2)$	$(t_w\times P_y\times(S-2b)^2)/2$
45000	3375000	7562500

III. ABAQUS MODELLING

In this section, the modelling of castellated beam in ABAQUS is explained in brief. Following are the points which involves in FEA in ABAQUS.

For preparing a model of castellated beam in ABAQUS we have to choose shape of the part as solid and of extrusion type.

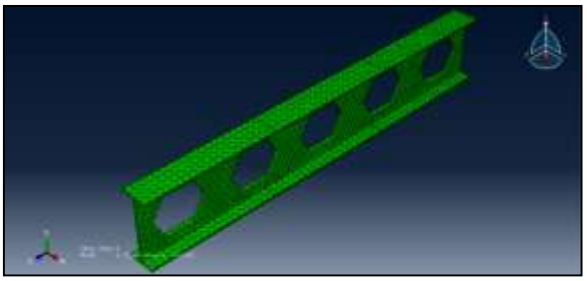

Figure No.4: Part Model Of Castellated Beam Without Stiffener Along With Loading And Boundary Conditions

After creating part model, in the next property module create a material by putting elastic property such as Young's modulus (2 x 105 N/mm2) and Poisson's ratio (0.3) of steel.

It is important to do the assembly of the model in caste of complicated structure. In assembly module create instance by selecting dependent type.

In next step module create step to fix analysis as static general which will perform bending analysis of structure.

In load module concentrated load by selecting point of loading and apply boundary conditions by selecting proper edges. Simply supported condition is taken in consideration.

Meshing is the most important parameter in FEM in ABAQUS, it is very important to select proper mesh size and type of element to get accurate results. In case of castellated beam select the Quad-dominated structured element. Which is S4R doubly curved shell element, which will give accurate results in case of castellated beam with circular perforations.

After meshing has been done, now model is ready for analysis. This is done in job module by creating job and submitting it.

After analysis is completed we can see the results in visualization module. In visualization various types of results are generated from which von-misses stresses and deflection in Y-direction are of our concern, this can be found out in dropdown menu of results as S-Misses and U2 respectively.

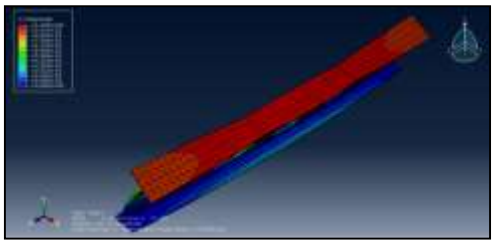

Figure No. 5: Sample results of Eigen Value of castellated beam using diagonal stiffener

IV. EXPERIMENTAL RESULTS

1. Load Carring Capacity by Experimental Result

Table No 5: Load Carring Capacity of Samples by Experimentally

Sample	Load Carring Capacity By Experiment(KN)	Percentage Of Load Increased By Stiffener
Without Stiffener	113.58	-
Diagonal Stiffener Within Opening	114.95	1.21
Both Side Diagonal Stiffener Throughout	166.37	46.48
Both Side Alternate Stiffener	135.91	19.66

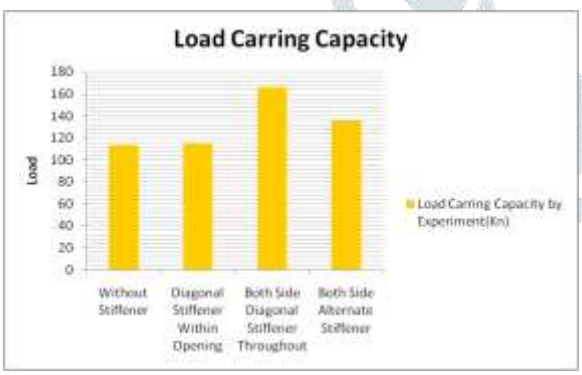

Figure No 6: Load Carring Capacity of Samples by Experimentally

Load carring capacity of various samples by experimentally carried out. It is observed that in case of both sides diagonal stiffener throughout taken more load as compare to others.

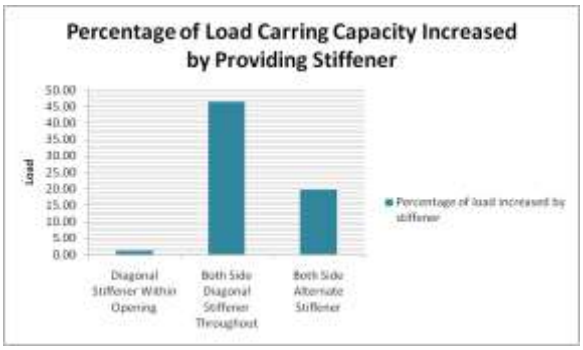

Figure No 7: Percentage of Load Carring Capacity Increased by Providing Stiffeners

Load carring capacity of various samples providing different position stiffeners are carried out. It is observed that in case of both sides diagonal stiffener throughout taken more load i.e. 46.48% as compare to others & stiffeners are provided load carring capacity of sample increases by 22.45% as compare to without stiffener samples.

2. Load Carring Capacity Vs Deflection by Experimental Result

Table No 6: Load Carring Capacity Vs Deflection Curve by Experimental Result

Load (Kn)	Deflection (mm)			
	Without Stiffener	Diagonal Stiffener Within Opening	Both Side Diagonal Stiffener Throughout	Both Side Alternate Stiffener
5	0	0	0	0
10	0	0	0	0
15	0	0.01	0.01	0
20	0.01	0.02	0.07	0.01
25	0.11	0.05	0.07	0.01
30	0.20	0.11	0.15	0.02
35	0.30	0.25	0.27	0.03
40	0.39	0.31	0.38	0.03
45	0.46	0.36	0.47	0.04
50	0.57	0.53	0.56	0.06
55	0.66	0.54	0.70	0.09
60	0.74	0.62	0.84	0.16
65	0.86	0.73	0.99	0.27
70	1.02	0.79	1.15	0.37
75	1.16	0.87	1.32	0.53
80	1.37	0.99	1.56	0.66
85	1.61	1.09	1.77	0.82
90	1.86	1.19	2.03	0.98
95	2.23	1.29	2.30	1.16
100	2.72	1.87	2.47	1.36
105	3.44	2.98	2.53	1.62
110	4.14	3.58	2.62	1.92
115			2.79	2.32

120			2.86	2.86
125			2.93	
130			3.13	
135			3.27	
140			3.36	
145			4.20	

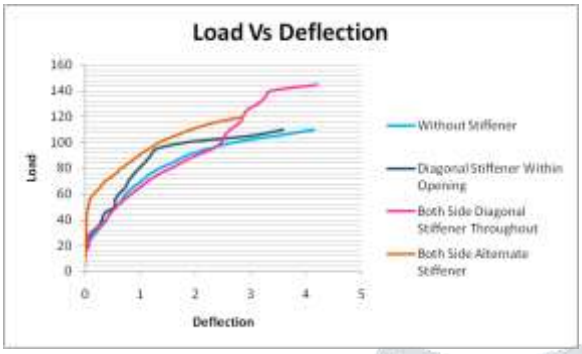

Figure No 8: Load Carring Capacity Vs Deflection Curve by Experimental Result

Load carring capacity Vs Deflection curves of experimental results are plotted. It is observed that load carring capacity increases deflection also increases that is load carring capacity is directly proportion to deflection. Load carring capacity is more in case of both side alternate stiffeners as compare to other cases & less in case of without stiffener as compare to other cases.

V. ABAQUS RESULTS

A. Load Carring Capacity of Diagonal Stiffener within Opening

Table No.7: Load Carring Capacity of Diagonal Stiffener within Opening

Sr No	Thickness	width	Total Volume For 5	Load Carring Capacity	Ratio
1	5	10	72500	108.61	1.50
2		11	79750	108.195	1.36
3		12	87000	109.07	1.25
4		13	94250	108.63	1.15
5		14	101500	109.2	1.08
6		15	108750	112.378	1.03
7		16	116000	113.163	0.98
8		17	123250	114.716	0.93
9		18	130500	114.836	0.88
10		19	137750	113.694	0.83
11		20	145000	113.678	0.78

Figure No 9: Load Carring Capacity of Diagonal Stiffener Within Opening

Load carring capacity of Diagonal Stiffener Within Opening of 5mm thick & various width stiffeners are carried out. It is observed that 5mm thick 18mm width stiffener taken more load as compare to others & 5mm thick 11mm width stiffener taken less load as compare to others.

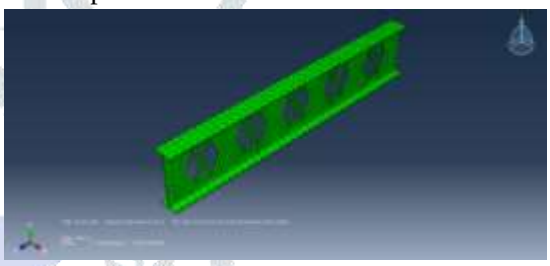

Figure No 10: Load Carring Capacity of Diagonal Stiffener within Opening at 12 X 5mm

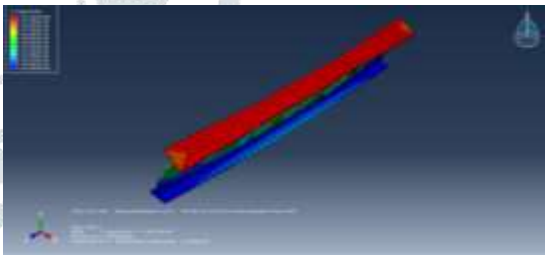

Figure No. 11: Failure of Diagonal Stiffener within Opening at 12 X 5mm: Mode 1

B. Load Carring Capacity of Both Side Alternate Stiffeners

Table No.8: Load Carring Capacity of Both Side Alternate Stiffeners

Sr No	Thickness	Width	Total Volume For 5	Load Carring Capacity	Ratio
1	5	10	150270	127.142	0.85
2		11	165297	128.795	0.78
3		12	180324	130.872	0.73
4		13	195351	132.654	0.68

5		14	210378	138.456	0.66
6		15	225405	140.134	0.62
7		16	240432	141.224	0.59
8	6	10	180324	134.896	0.75
9		11	198356.4	137.128	0.69
10		12	216388.8	139.865	0.65
11		13	234421.2	142.076	0.61
12	8	10	240432	154.419	0.64
13	10	5	150270	148.626	0.99
14		6	180324	154.638	0.86
15		7	210378	160.967	0.77
16		8	240432	167.31	0.70
17	12	5	180324	167.575	0.93
18		6	216388.8	175.978	0.81
19	16	5	240432	213.866	0.89

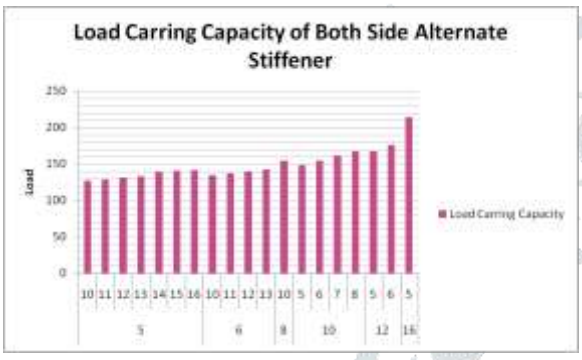

Figure No 12: Load Carring Capacity of Both Side Alternate Stiffeners

Load carring capacity of Both Side Alternate Stiffeners of 5, 6, 8, 10, 12 & 16mm thick & various width stiffeners are carried out. It is observed that 16mm thick 5mm width stiffener taken more load as compare to others & 5mm thick 10mm width stiffener taken less load as compare to others. As per thickness of stiffener increases load carring capacity also increases that is load carring capacity is directly proportion to its geometry.

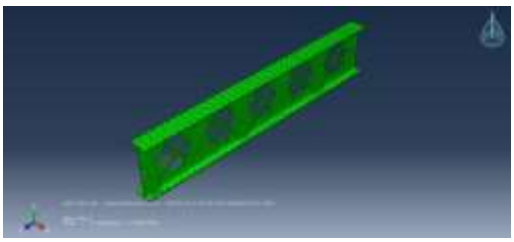

Figure No 13: Load Carring Capacity of Both Side Alternate Stiffeners at 12 X 5mm

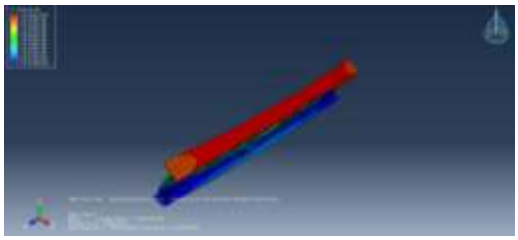

Figure No 14: Failure of Both Side Alternate Stiffeners at 12 X 5mm: Mode 1

C. Both Side Diagonal Stiffeners Throughout

Table No.9: Load Carring Capacity of Both Side Diagonal Stiffeners Throughout

Sr. No	Thickness	Width	Total Volume For 5	Load Carring Capacity	Ratio
1	5	10	150270	155.365	1.03
2		11	165297	159.544	0.97
3		12	180324	154.690	0.91
4		13	195351	168.753	0.86
5		14	210378	172.755	0.82
6		15	225405	177.034	0.79
7		16	240432	181.962	0.76
8	6	10	180324	172.443	0.96
9		11	198356.4	178.08	0.90
10		12	216388.8	184.216	0.85
11		13	234421.2	189.296	0.81
12	8	10	240432	212.885	0.89
13	10	5	150270	192.564	1.28
14		6	180324	206.996	1.15
15		7	210378	221.275	1.05
16		8	240432	234.657	0.98
17	12	5	180324	227.727	1.26
18		6	216388.8	245.485	1.13
19	16	5	240432	327.989	1.36

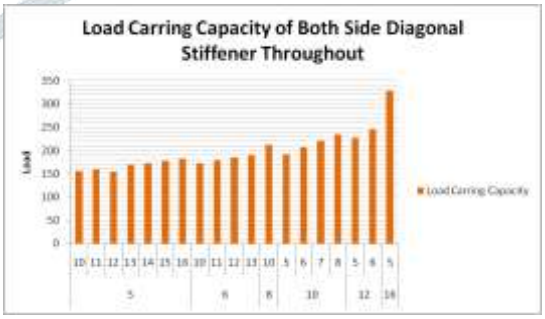

Figure No 15: Load Carring Capacity of Both Side Diagonal Stiffeners Throughout

Load carring capacity of Both Side Diagonal Stiffeners Throughout of 5, 6, 8, 10, 12 & 16mm thick & various width stiffeners are carried out. It is observed that 16mm thick 5mm width stiffener taken more load as compare to others & 5mm thick 10mm

width stiffener taken less load as compare to others. As per thickness & width of stiffener increases load carring capacity also increases that is load carring capacity is directly proportion to its geometry.

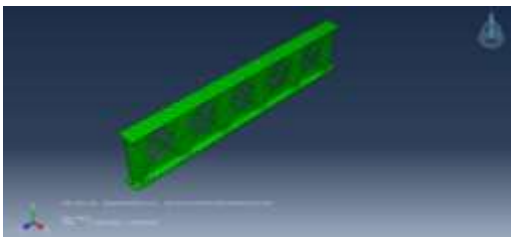

Figure No 16: Load Carring Capacity of Both Side Diagonal Stiffeners throughout at 12 X 5mm

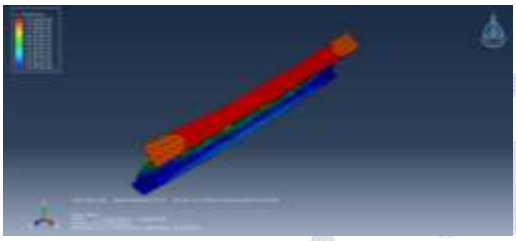

Figure No 17: Failure of Both Side Diagonal Stiffeners throughout at 12 X 5mm: Mode 1

VI. COMPARISON BETWEEN EXPERIMENTAL & ABAQUS RESULTS

Table No 10: Load Carring Capacity of Experimental & ABAQUS Results

Sample	Load Carring Capacity by Experiment (Kn)	Load Carring Capacity by ABAQUS (KN)	Percentage between ultimate load and Abaqus load
Without Stiffener	113.58	103.79	8.62
Diagonal Stiffener Within Opening	114.95	109.07	5.12
Both Side Diagonal Stiffener Throughout	166.37	154.69	7.02
Both Side Alternate Stiffener	135.91	130.872	3.71

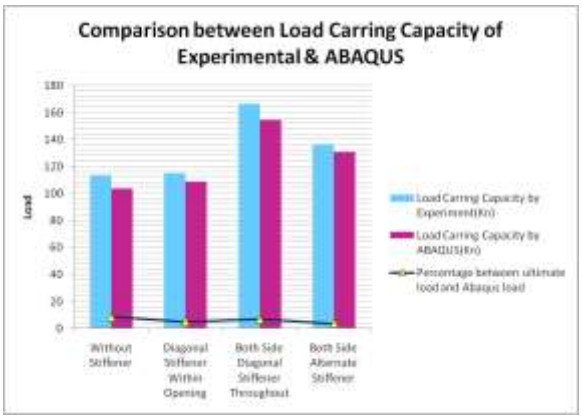

Figure No 18: Comparison between Load Carring Capacity of Experimental & ABAQUS Results

Comparison between Load Carring Capacity of Experimental & ABAQUS Results Load carring capacity of various samples by experimentally & ABAQUS are carried out. It is observed that load carring capacity calculated by experimentally is more i.e. 6.12% as compare to ABAQUS results.

VII. CONCLUSION

After Studying all the related papers and experimental results we can conclude that a Experimental results and Finite element analysis are approximately equal and FEA can validate results for the Experimental work.

Following Results are observed

- Stiffeners are provided load carring capacity of sample increases by 22.45% as compare to without stiffener samples.
- It is observed that in case of Both Side Diagonal Stiffeners Throughout taken more load i.e. 46.48% as compare to others hence it is best option to provide stiffeners in both side alternatives.
- It is observed that load carring capacity calculated by experimentally is more i.e. 6.12% as compare to ABAQUS results.

VIII. REFERENCES

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