A Parametric Study of Optimization of Castellated Beam with Stiffener

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Abstract— Castellated beams are steel beams with web opening and they gain its advantage due to its increased depth of section without any additional weight. However one consequence is the presence of web opening which leads to various local effects like shear and deformation. Use of castellated beams is very popular now days to its advantageous structural applications. These beams are fabricated by cutting the web of hot rolled steel I section into zigzag pattern and therefore rejoining it over one another. The opening is made hexagonal, circular, diamond or square in shape. In this study is considering structural performance of the beam, the size and diamond shape of openings is provided in the web are always an important issue concern. the research work is carried out in optimizing size of castellated beam with diamond opening have reported that castellated beams fail mainly by local failure modes and stress concentrations at opening edges. In this paper steel I section ISMB 150 is selected and castellated beams are fabricated such that depth of the beam is 1.5 times of the original depth. The beam is analysed using Finite Element Analysis (ABQUS) also by Eurocode for different opening sizes and results obtained is experimentally validated. Two point loads is applied and load carrying capacity of the beam with and without stiffener is studied. Stiffener is introduced diagonally, double Vertical stiffener in transverse direction on web opening along the shear. The main aim of this study is the behaviour of the castellated beam with stiffeners and further extends to optimization of stiffeners considering position size and its thickness.

Keywords: Castellated beam, Diagonal Stiffener, Double Vertical Stiffener, Finite Element Analysis (ABQUS)

I. INTRODUCTION

In planning for a sustainable infrastructure project, an initial effort should be allocated to identify climate conditions, energy source and costs, water source and costs, and environmental constraints and opportunities. On the other hand design and planning team should consider project's goals and objectives that protect and improve sustainability of the community, the environment, and the region in addition to project economics-related objectives.

A. Rolled Steel Beams

Steel is one of the significant structure materials in construction industry. Different steel members are reproduction in the factor based on their usage. Rolled steel section is in the middle of the initial steel beams which were casted in unremitting casting moulds without any joints. These steel sections which were manufactured in rolling mills and further used as structural members are known as rolled structure steel section. The steel section are named according to their cross sectional shapes. Below image gives idea of different shapes rolled steel section beams like I, T, C, L shape rolled steel beams.

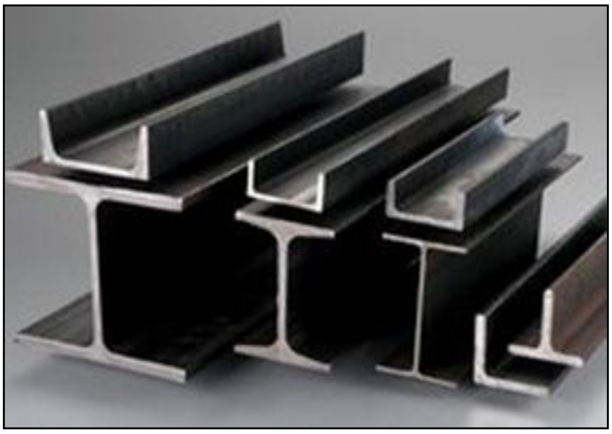


Fig. 1.1: Types of rolled steel section beam

B. Built-Up Beams

Built up beams are used at what time the span , load and corresponding bending moments are of such magnitudes that rolled strengthening beam section becomes inadequate to provide required section modulus. Hence, to increase the depth of beam flat plates of an appropriate shape are chosen and welded together at the top and bottom flange piece to produce beams of the required size. A built-up beam is also known as complex beam. Due to addition of extra steel cover plates over flanges, built up beams became more expensive and heavier at the same time.

Fig. 1.2: Built up beam

C. Plate Girder

When the depth of beam is needed to be increased for increasing the moment of inertia, rolled steel beams failed. Built up beams became a good solution to this problem. But increasing the depth of beam by adding additional cover plates over flanges prove to be costly in addition to also greater than before the self-weight of beam. Another type of shaft of light rafter was fabricated on or after assembles three rectangular tableware and welds them as shown below in figure. The horizontal narrower plates are called flanges and the deeper perpendicular plate is called web. Such girders are called as Plate Girders.

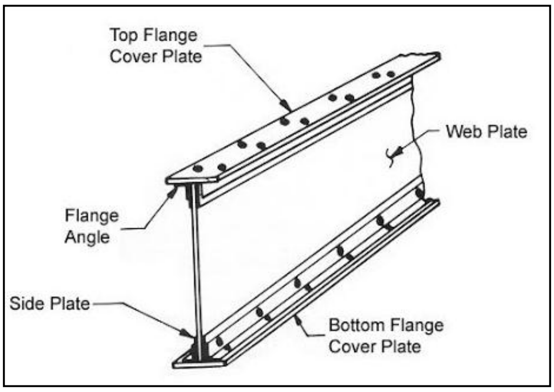


Fig. 1.3: Plate girder

D. Preface of Perforated Beams

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 parameter is considered. But, these sections does not satisfies the serviceability requirement i.e. check for deflection. The beam have 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 occasion 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

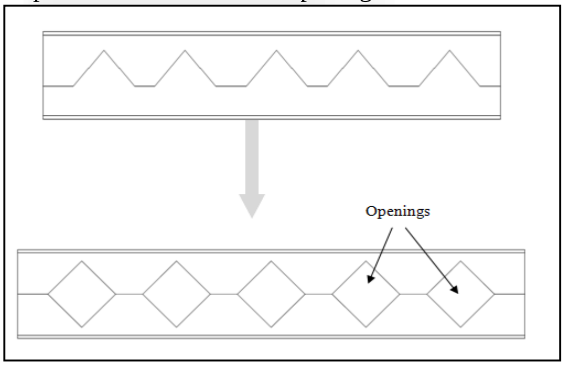


Fig. 1.4: Castellation process of castellated beam with diamond opening

II. NEED OF RESEARCH

Optimization of stiffener for the castellated beam element is predominant issue of the upcoming demand of construction industry to tackle many structural failure problems in castellated beam. The use of castellated beam construction is growing fast as it offers efficient and inexpensive structure with more force and reduced steel quantity of steel. Also, there is decrease in general mass of the frame which helps in pleasing the performance of the structure. The plan events optional by various codes are given in accordance with some empirical formulae. The study of the complex behaviour of the castellated beam with stiffener is not yet completely revealed. Thus current study defines the behaviour of the castellated beam with stiffeners and further extends to optimization of stiffeners considering position size and its thickness.

III. LITERATURE REVIEW

A. Amin Mohebkhah, Mojtaba G. Azandariani (2015)

Lateral–torsional buckling (LTB) resistance of an I-beam depends on the minor axis moment of inertia of its compression flange and torsional rigidity of the section. A practical solution to increase lateral buckling of I-beams is to add two Delta stiffeners between the compression flange and web plates to form a hollow compression flange. Although these beams known as Delta hollow flange beams (DHFBs) have been introduced about half a century ago for bridge construction, however, their LTB behavior has not been investigated, yet. This paper develops a three dimensional finite-element model using ABAQUS for the inelastic nonlinear flexural–torsional analysis of DHFBs and uses it to investigate the effects of unbraced length and central off-shear center loading (located at center, top flange and bottom flange) on their moment gradient factor in different behavioural zones. It was found that the Cb factor and moment resistance curve given by AISC-LRFD in Specification for structural steel buildings are not accurate for intermediate (inelastic) and short plastic DHFBs leading to an unconservative design. Therefore, a modified moment resistance equation is proposed to be used instead of the code equation in inelastic zone for the investigated load cases in this paper.

B. Delphine Sonck and Jan Belis (2015)

The evenly spaced circular web openings in I-section cellular beams have an advantageous effect on the material use if these beams are loaded in strong-axis bending. However, not all aspects of the behavior of such beams have been studied adequately, such as the lateral–torsional buckling failure. For the latter failure mode, the existing design approaches conflict. Furthermore, the detrimental effect of the modification of the residual stresses by the production process, as recently demonstrated by the authors in previous work, was never taken into account. In this paper, the lateral–torsional buckling behavior of cellular beams is investigated using a numerical model that was validated based on experimental results. In this model, the effect of the modified residual stress pattern was aptly taken into account. Using the results of the parametric study, a preliminary design approach was proposed. This approach is based on the currently existing European guidelines for the calculation of the lateral–torsional buckling resistance of I-section beams, but with a modified calculation of the cross-sectional properties and a modified buckling curve selection.

C. Hossein Showkati, Tohid Ghanbari Ghazijahani, et al. (2012)

Castellated beams are widely used as flexural members in steel construction. The economical and structural advantages of these elements have prompted many researchers to investigate the failure behavior of such structures. Despite numerous reported researches on the buckling stability of castellated beams, no experimental study is found on lateral–torsional buckling of these elements with elastic bracing. In this paper, the experimental study of nine full-scale castellated beams is reported with the aim of investigation of the performance as well as effect of elastic bracing on the buckling stability of these structural elements. In addition to the presentation of the experimental observations and findings, the current test results are compared with the results of other reported experimental, analytical and numerical studies. Ultimately, the experimental findings and results are evaluated by considering the AISC 360–05 code requirements and predictions.

IV. METHODOLOGY

A. *Terminology in Castellated Beam*

The various basic terms involved in the analysis and design of castellated beam are illustrated in Fig No. 1.5 below,

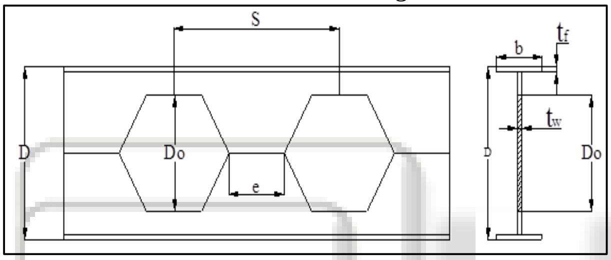


Fig. 1.5: Typical cross section of the beam

Where,

D_o = Depth of opening provided

D= Overall depth of the opening

S = Centre to Centre spacing between the two opening

e = Clear distance between two opening

b = Width of flange of I beam

t_f= Thickness of flange of I beam

t_w= Thickness of web of I beam

B. *Guidelines for Perforations in Web*

The perforation made in the web greatly affects the structural performance of the beam. Therefore, it is essential to make some logical and practical consideration while providing perforations in the beam. Follow are the general guidelines which are given by the Euro code and some of them are based on the field or practical consideration. These standards in web perforations can be distorted or modified without affecting the structural performance of the beam (Lawson R. M. 2011). These guidelines are as follows,

1) $1.08 < \frac{S}{Do} < 1.5$
2) $1.25 < \frac{D}{Do} < 1.75$
3) $Do \leq 0.8 D$
4) $e \leq 0.4 Do$
5) Width of end post $\geq 0.5 Do$

C. *Types of Stiffeners*

Total two types of transverse stiffeners are chosen for the dissertation work in order to reduce the local buckling. Following stiffeners are used,

1) Transverse Stiffener

– Double Transverse Stiffener

– Diagonal Stiffener

Stiffeners which are arranged in normal direction to the span of the beam are nothing but the transverse stiffeners. The basic terms involved in the nalysis and design castelated beam with transverse stiffeners.

D. *Guidelines for stiffeners according to Euro Code*

1) According to Euro code 3 the stiffener should provided at:
   a) Area of stiffener should be equal to 30Ɛ t_w provided at spacing 15Ɛ t_w.
   b) If 15Ɛt< S then we can provide it at the middle of clear distance between two openings.
2) Stiffeners at locations where significant external forces are applied should preferably be symmetric.

E. *Selection of Method of Analysis*

In order to optimize the dimension of the stiffener (placed in transverse and along edge of opening) of the castellated beam, it is very important to decide proper analytical method. Due to complex geometry of castellated beam the finite element analysis (FEA) is the best available to analyze the beam. FEA is done by the simulation software "ABAQUS/CAE 6.13".

F. *Selection of Section for Parent Hot Rolled Steel (HRS) I B eam*

Considering the market availability, economy and inspecting the practical difficulties during the testing section of span was chosen. The span of the section chosen is 1000mm and also by considering the capacity of UTM (1tone) the section was not chosen of greater depth.

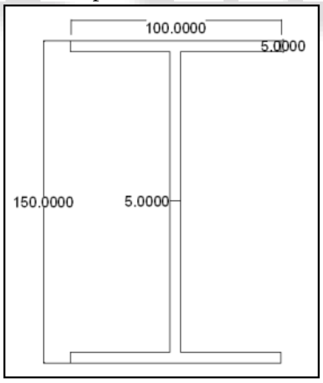


Fig. 1.6: Cross Section of the parent I beam

V. RESULT AND DISCUSSION

A. *Results for Diamond opening with Double Transverse Stiffener*

Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	0x0	0	0	42.425	-

Table 1.1: Load carrying capacity of model without stiffener

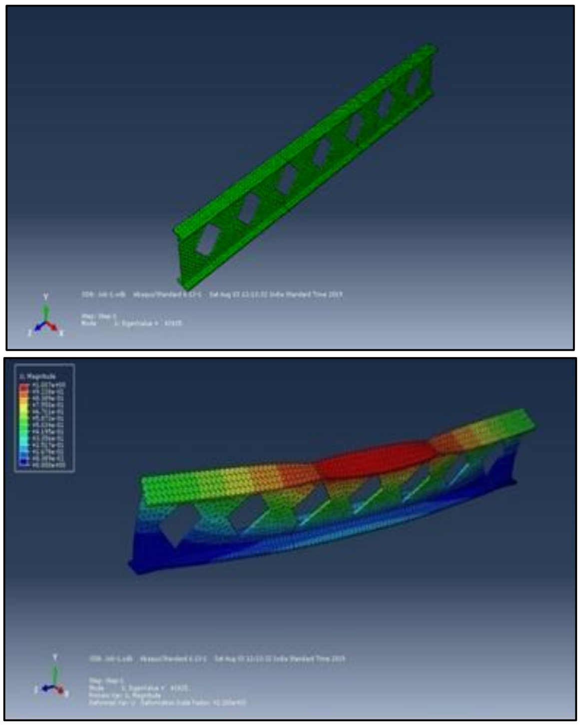


Fig. 1.7: Result for load carrying capacity of model without stiffener

Diamond opening with double transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm³)	Total Volume For 7 (mm³)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	5x10	10	5	11000	77000	45.232	0.59
2	5x11	11	5	12100	84700	41.758	0.5
3	5x12	12	5	13200	92400	45.79	0.5
4	5x13	13	5	14300	100100	45.789	0.46
5	5x14	14	5	15400	107800	48.476	0.45

Table 1.2: Load carrying capacity of model with stiffener (5mm)

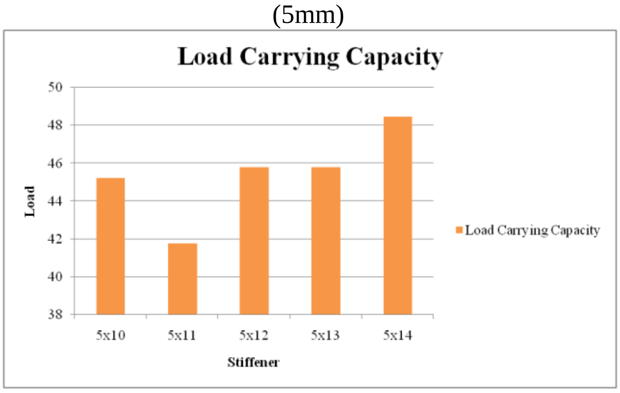


Fig. 1.8: Result for load carrying capacity of double transverse stiffener (5mm)

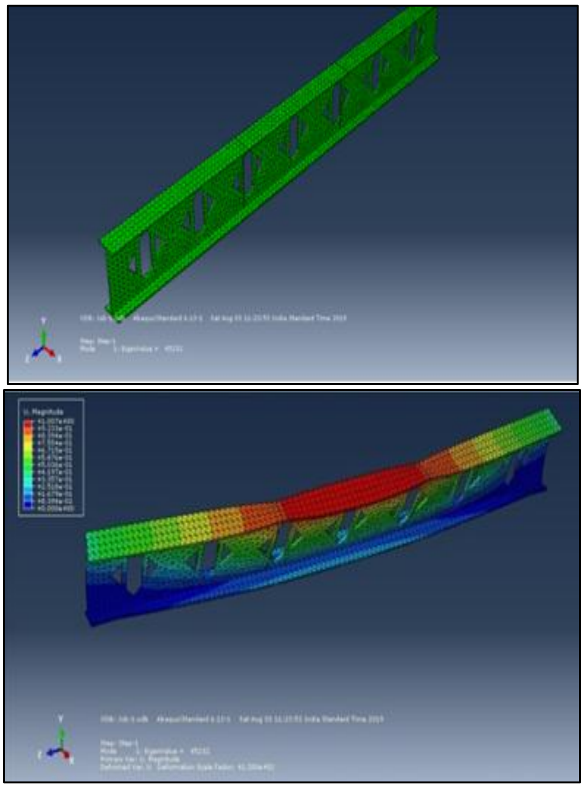


Fig. 1.9: Result for load carrying capacity of double transverse stiffener (5mm)

Diamond opening with double transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm³)	Total Volume For 7 (mm³)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	6x10	10	6	13200	92400	48.852	0.53
2	6x11	11	6	14520	101640	49.338	0.49
3	6x12	12	6	15840	110880	49.697	0.45

Table 1.3: Load carrying capacity of double transverse stiffener (6mm)

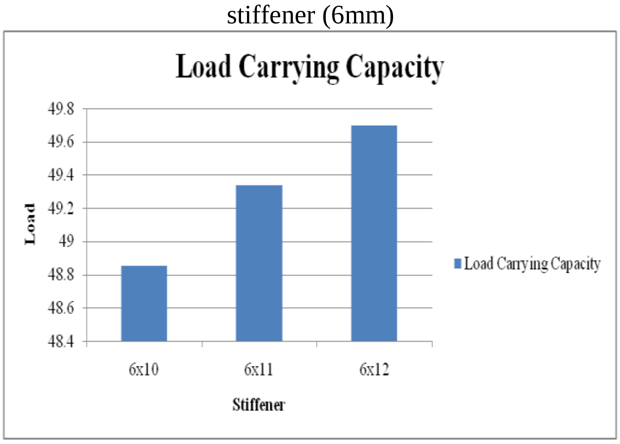


Fig. 1.10: Result for load carrying capacity of double transverse stiffener (6 mm)

Diamond opening with double transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Total Volume For 7 (mm^3)	Load Carrying Capacity KN)	Ratio of Load to Area in Percentage
1	10x5	5	10	11000	77000	49.882	0.65
2	10x6	6	10	13200	92400	50.518	0.55
3	10x7	7	10	15400	107800	51.178	0.48

Table 1.4: Load carrying capacity of double transverse stiffener (10 mm)

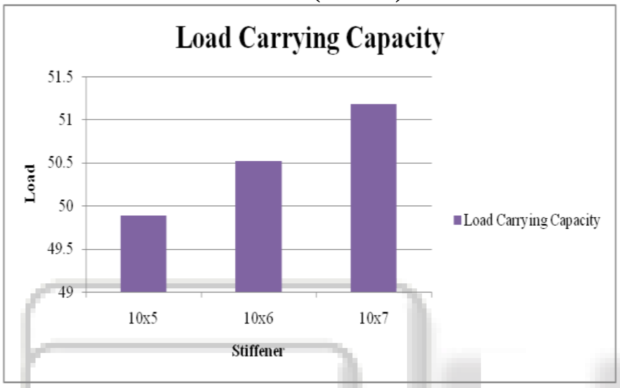


Fig. 1.11: Result for load carrying capacity of double transverse stiffener (10 mm)

Diamond opening with double transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Total Volume For 7 (mm^3)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	12x5	5	12	13200	92400	50.935	0.56
2	12x6	6	12	15840	110880	51.608	0.47

Table 1.5: Load carrying capacity of double transverse stiffener (12mm)

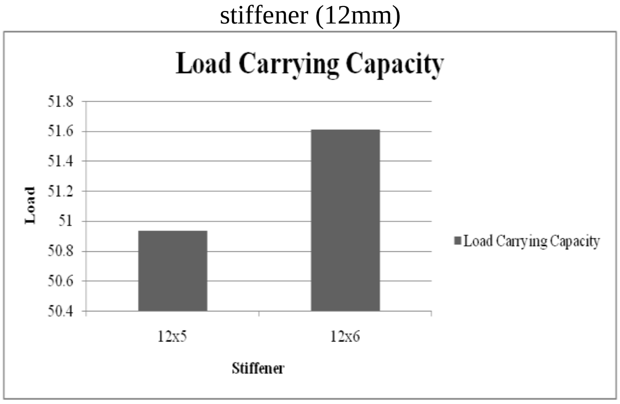


Fig. 1.12: Result for load carrying capacity of double transverse stiffener (12 mm)

B. Results for Diamond opening with Diagonal Transverse Stiffener

Diamond opening with diagonal transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Total Volume For 7 (mm^3)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	5x10	10	5	11000	77000	48.398	0.63
2	5x11	11	5	12100	84700	47.166	0.56
3	5x12	12	5	13200	92400	47.141	0.52
4	5x13	13	5	14300	100100	47.74	0.48
5	5x14	14	5	15400	107800	47.935	0.45
6	5x15	15	5	16500	115500	48.174	0.42
7	5x16	16	5	17600	123200	48.34	0.4

Table 1.6: Load carrying capacity of double transverse stiffener (5mm)

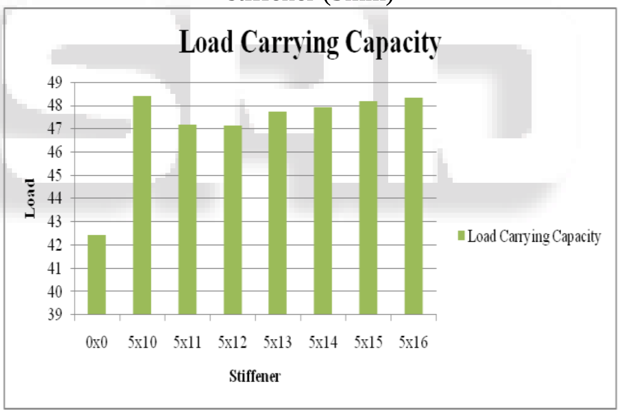
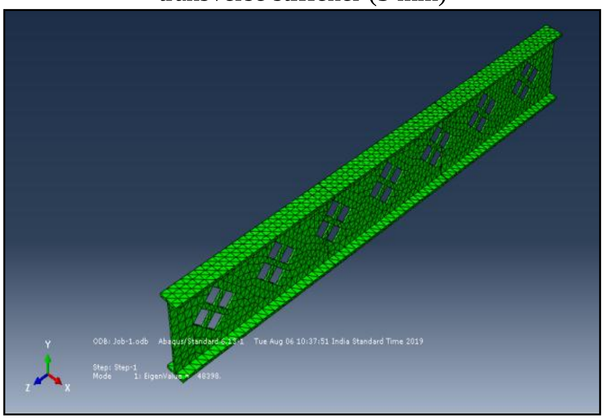


Fig. 1.13: Result for load carrying capacity of diagonal transverse stiffener (5 mm)



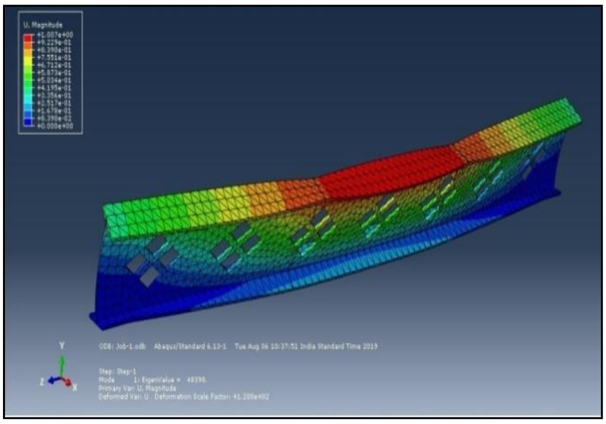


Fig. 1.14: Result for load carrying capacity of diagonal transverse stiffener (5 mm)

Diamond opening with diagonal transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Total Volume For 7 (mm^3)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	6x10	10	6	13200	92400	48.256	0.53
2	6x11	11	6	14520	101640	48.524	0.48
3	6x12	12	6	15840	110880	48.744	0.44
4	6x13	13	6	17160	120120	49.06	0.41

Table 1.7: Load carrying capacity of double transverse stiffener (6mm)

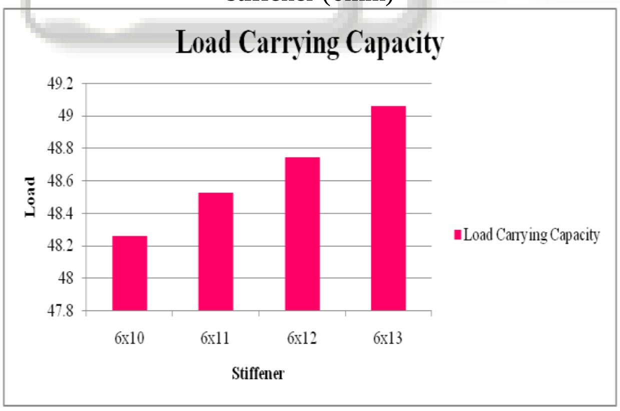


Fig. 1.15: Result for load carrying capacity of diagonal transverse stiffener (6 mm)

Diamond opening with diagonal transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Total Volume For 7 (mm^3)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	8x10	10	8	17600	123200	50.294	0.41
2	10x5	5	10	11000	77000	49.47	0.65
3	10x6	6	10	13200	92400	50.061	0.55
4	10x7	7	10	15400	107800	50.771	0.48
5	10x8	8	10	17600	123200	51.166	0.42

Table 1.8: Load carrying capacity of double transverse stiffener (8 &10mm)

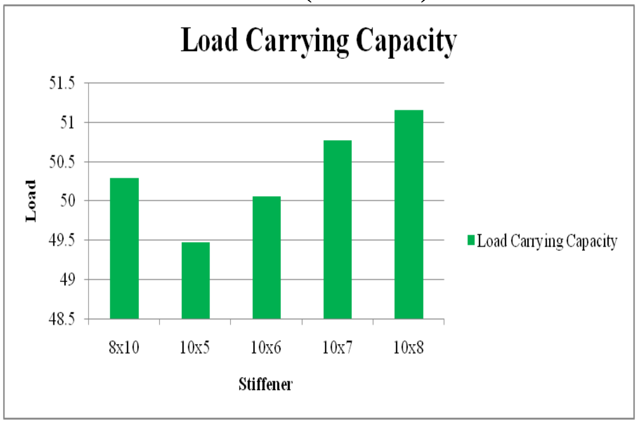


Fig. 1.16: Result for load carrying capacity of diagonal transverse stiffener (8 & 10 mm)

Diamond opening with diagonal transverse stiffener							
Sr. No.	Stiffener (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Total Volume For 7 (mm^3)	Load Carrying Capacity (KN)	Ratio of Load to Area in Percentage
1	12x5	5	12	13200	92400	49.567	0.54
2	12x6	6	12	15840	110880	51.24	0.47
3	16x5	5	16	17600	123200	54.129	0.44

Table 1.9: Load carrying capacity of double transverse stiffener (12&16mm)

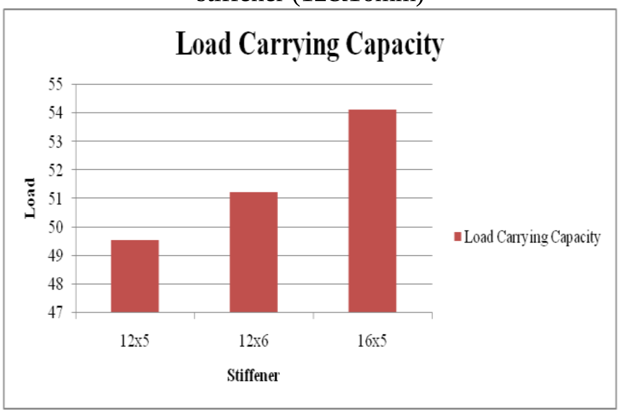


Fig. 1.17: Result for load carrying capacity of diagonal transverse stiffener (12 & 16 mm)

VI. CONCLUSION

Following conclusions cans be drawn from the study so far carried out in respect of behavioural study of optimized castellated beam provided with stiffeners at different locations and using ABAQUS Software.

1) From the analysis and design (Euro Code guidelines) of a castellated I beam provided with stiffeners in transverse and End stiffeners, it is conduced the load carrying capacity of the beam with double transverse stiffeners is found to be more by 9.18% as compared to the beam provided double transverse without stiffeners.
2) From the analysis and design (Euro Code guidelines) of a castellated I beam provided with stiffeners in transverse and End stiffeners, it is concluded that the load carrying capacity of the beam with diagonal transverse stiffeners is found to be more by 11.74% as compared to the beam provided double transverse without stiffeners.

The behavior of optimized castellated beams, provided with double and transverse stiffeners in transverse, has been studied in respect of load carrying capacity and reduction of local buckling. The variation in load carrying capacities as obtained by software analysis is as given below:

1) The load carrying capacity of castellated beam with Diamond opening provided with transverse stiffeners in between openings is found to be 49.882 KN and without stiffener is 42.425 KN. The maximum load area ration for the optimization was noted to be 0.65.
2) The load carrying capacity of castellated beam with diagonal opening provided with transverse stiffeners in between openings is found to be 49.447 KN and without stiffener is 42.425 KN. The maximum load area ration for the optimization was noted to be 0.65.

VII. FUTURE SCOPE

As a future scope, it is recommended to extend the study to understand the behavior of castellated beams in respect of flexural buckling under point load and study the remedial measure to avoid stress attentiveness. Further, it is also recommended to study the effect of torsional buckling of castellated beam with and without stiffeners.

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