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Optimization for Various Parameters of Castellated Beam Containing Sinusoidal Openings

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Abstract :
Use of castellated beams has become very popular now a days due to its advantageous structural applications. Castellated beams are those beams which has openings in its web portion. Castellated beams are fabricated by cutting the web of hot rolled steel (HRS) I section into zigzag pattern and thereafter re-joining it over one another. The openings made in the webs are of generally hexagonal, circular, diamond or square in shape. Therefore, considering structural performance of the beam, the shape and size of openings provided in the web are always an important issue of concern. The finite element analysis (FEA) of the beam using Abaqus /CAE 6.13 software and following the provisions of Eurocode 3 has been carried out for different sizes of openings. Von-misses failure criteria is used to finding out failure load on the beam and the results obtained for optimized beam is validated by experimentation.
Keywords: **Optimization, Castellated beam, sinusoidal openings, finite element analysis.**

1. INTRODUCTION

1.1 GENERAL

Use of steel for structural purpose in structure is rapidly gaining interest these days. In steel structures the concept of pre-engineered building (PEB) is most popular due to its ease and simplicity in the construction. Pre-engineered buildings have very large spans but comparatively less loading. Generally, steel sections satisfy strength requirement, the difficulty is that, section have to satisfy serviceability requirement i.e. deflection criteria in safety check. This necessitates the use of beams with greater depth to satisfy this requirement. Use of castellated beams is the best solution to overcome this difficulty. The castellated or perforated web beam is the beam which has perforation or openings in its web portion. Generally, the openings are with hexagonal or square or circular in shapes. The beams with circular openings are called as cellular beams. The advantage of using such beams is that it causes reduction in total weight of the structure and hence requires less quantity of steel. Use of castellated beam with hexagonal opening is very common in recent years because of the simplicity in its fabrication. Castellated beams are fabricated by cutting flange of a hot rolled steel I beam along its centre line and then welding the two halves so that the overall beam depth gets increased for more efficient structural performance against bending.

1.2 Gap analysis:

In earlier study focus has been given on the beams with hexagonal, octagonal, circular, rectangular etc. Opening in web with respect to flexural behaviour. Lot of work also has been done for the optimization of opening for above mentioned shapes. But little work has been done for opening in web with sinusoidal shape. Manufacturing procedure for some non-standard web opening shows benefits in comparison with manufacturing of popular cellular beams. Also it is seen that, literature has mentioned to investigate sinusoidal shape for dimensions such as depth and length of opening. This will improve the structural performance of beam.

1.3 Advantages of castellated beam

There are many advantages of castellated beam from the point of view of architect, engineer, erector and owner. For architect the castellated beam has an built in aesthetic appeal. In addition to aesthetic aspect, sinusoidal shape offer wide range of opening size. After erection the castellated beam allows light to flow through the opening which is not possible for conventional beam. In conventional beam we get lower floor to floor height because of mechanical, electrical and plumbing through the beam. But we get higher floor to floor height in case of castellated beams as we can pass above thing through openings. For the engineer castellated beams provide better load deflections. As mentioned above engineers can increase the depth and strength of beam without additional weight. And be- cause of this advantage the beams are optimal for longer span. For erectors castellated beams are very easy to erect as they are light weight and they can have speedy construction . From the point of view of owner or developer, overall cost gets reduced because of castellated beam.

1.4 Types of castellated beam

Depending upon opening there are different types of castellated beams. Following are the different types of castellated beams.

Fig 1 : Castellated Beam with hexagonal opening

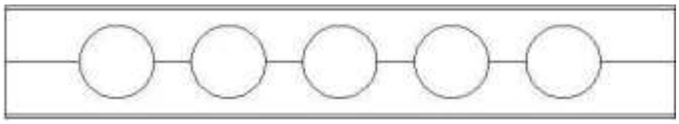


Fig 2: Castellated beam with circular opening

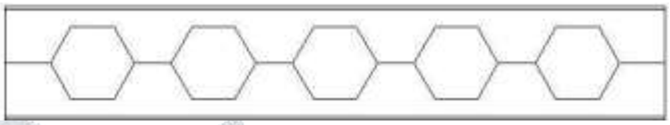


Fig 3: Castellated beam with diamond opening

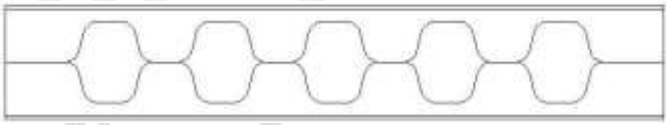
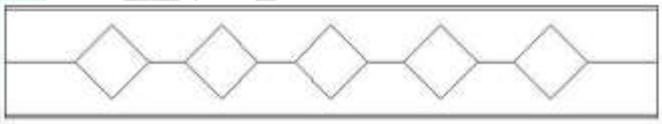


Fig 4: Castellated beam with sinusoidal opening



2. OBJECTIVES

The following are the main objectives of this project

1. To analyse castellated beam of sinusoidal opening by using finite element software and experimentally.
2. To validate result obtained using finite element software with experimental results.
3. To optimize castellated beam with sinusoidal opening for various parameters by using finite element software.
4. To suggest suitable guidelines for optimized sinusoidal shape.

3. LITERATURE REVIEW

Sahar Elaiwi, Boksun Kim, Long yuan Li (2017), "Bending Analysis of continuous castellated beams". In this paper author find out the effect of web opening on transverse deflection. Author used both analytical and numerical method. Analysis has been done by using ANSYS software, validation was done with analytical method. The analysis of beam with hexagonal opening with continuous supports and uniformly distributed load has been done. Analysis was based upon total potential energy method, the effect of web shear deformation also considered. The results obtained from analytical method were in excellent agreement with those predicted from finite element software. Shear effect is very important for short and medium span beam with narrow section. If we ignore the effect of shear we could under estimate the deflection. Effect of web shear on deflection gets reduced for increased length of castellated beams. Comparative study shown that analytical calculation and numerical calculation does not exceed (1.13%-31.94%).

S. Durif, A.Bouchair (2016), "Analytical model to predict the resistance of cellular beams with sinusoidal openings" In this paper experimental study has been done on beams with sinusoidal opening. According to author existing methods for predictions has to improved hence modification has been done for accurate prediction of buckling strength. An analytical approach has presented by studying the existing method for multiple opening and on plate buckling theory. Formula has derived for calculation of critical stress coefficient. Easy method is suggested to considerer additional strength provided by the intermediate web-post to the adjacent web panel. Analytical model has validated with finite element results.

S. Durif et al (2014), "Experimental and numerical investigation on web-post specimen from cellular beams with sinusoidal openings" In this research experimental and numerical exploration has been done for isolated web spaced specimen. Models were tested with symmetric loading and lateral supports are also provided to avoid lateral buckling. Experimental results shown that failure modes two quadrants of opening are similar to those observed in whole beam. Two failure modes were observed one of them is yielding of section at linear part of opening and other one is local buckling of web post in sinusoidal opening. Experimental and numerical exploration has been done for three different geometrical configurations. Analytical approach derived in this paper shown results in good agreement in comparison with numerical model results.

Delphin sonck, janbelis(2014),"Lateral–torsional buckling resistance of cellular beams." In this research, the authors studied lateral torsional buckling behaviour of cellular beams with the help of numerical model. The results were validated using experimental results. The equally spaced circular openings in web have more benefit on material use, when beams are loaded on strong axis. Study was limited to the lateral torsional buckling failure. Preliminary design approach was proposed from the parametric study. This new preliminary approach is based on the currently existing European guidelines with only moderation in calculation of cross-sectional properties and modified buckling curve selection.

Prof. R. R. Jichkaret al (2014), "Analysis of Steel Beam with Web Openings Subjected to Buckling Load." In this paper author uses steel beam having section ISMB 300 with span of 5-meter length with circular, hexagonal and square shape web openings. Author also changed the support conditions and analysed all the openings mentioned above. Firstly, the beam with no web opening was analysed with ANSYS software. Then for next beams number of openings was gradually increased from two to six. Comparison of all

Jamadar A.M., Kumbhar P.D. (2015), "Parametric study of castellated beam with circular and diamond shaped openings." In this paper researcher has done analysis of two types of perforated beams namely circular and diamond shaped. The analysis was done using Abaqus software. Results of hexagonal shape opening in steel I beam were taken from previous papers. Comparison of hexagonal, diamond, circular shape opening has been done. Analysis results shown that diamond shaped opening take more load than other two shapes of opening. Reason behind diamond shape opening carrying maximum load is because of it has more shear transfer area. beams were finally done for deflection and buckling load.

M.R.Wakchaure, A.V.Sagade (2012), "Finite Element Analysis of Castellated Steel Beam." In this castellated I beam was selected to analyse. The beam was loaded with two-point load and is simply supported. ISMB150 was selected for fabrication of castellated beam. Author also gave some guidelines for construction of model for castellated beam. Some of the guidelines were eccentricity of opening should be avoided, corners of rectangle should be rounded, etc. the analysis was done by ANSYS software. Deflection is calculated at midpoint of beam. Beams with increase in depth were compared for serviceability criteria. As per author serviceability criteria can be improved by taking corrective measures. Finite element analysis properly shown different failure mode of all beams. As depth of opening increases stress concentration increases at hole.

S. Durif, A.Bouchair (2012), "Behaviour of cellular beams with sinusoidal openings" In this paper, experimental work has been done on full scale model of cellular beams with sinusoidal openings. Two failure modes were observed by formation of four plastic hinges at the opening corner. For understanding actual resistance of sinusoidal openings, isolated part around the opening has been chosen. Experiments have been performed on different quarter of sinusoidal opening to observe the failure mode.

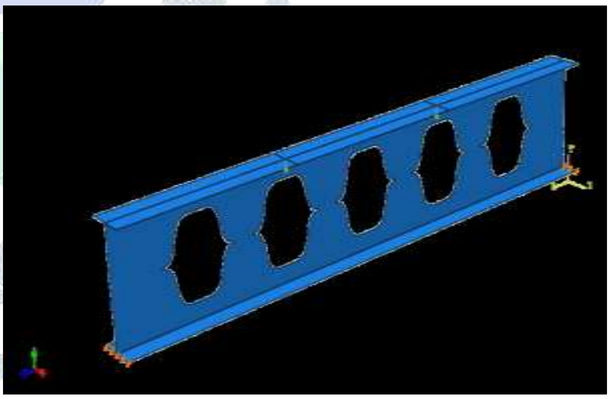
4. METHODOLOGY

Following methodology is adopted for dissertation work:

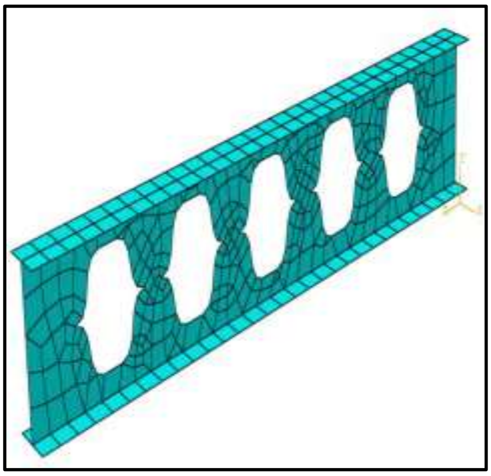
1. Collection and study of literature related to castellated beam with sinusoidal shape opening.
2. Analysis of castellated beam with finite element software and experimentally.
3. Validation of finite element analysis results with experimentation.
4. Optimization of castellated beam with sinusoidal opening for various parameters.
5. Suggest the guidelines for optimization of sinusoidal shape.
6. Submission of dissertation report

5. FINITE ELEMENT ANALYSIS OF CASTELLATED BEAM WITH SINUSOIDAL OPENINGS

FEA of all castellated beams is carried out in Abaqus software to determine the optimum section which fails at greater load.



5.1. FE model of castellated beam



5.2 Meshing of castellated beam

Sr. No.	Do	D	D/Do	S/Do	Length of Opening	Load at Yield(kN)	Deflection by Software (mm)	Stresses (N/mm^2)
1	80	140	1.75	1.4	89.35	31	1.468	252.913
2	90	145	1.61	1.4	103.91	32	1.309	257.845
3	100	150	1.5	1.4	113.64	32	1.515	251.9
4	110	155	1.41	1.4	121.88	34	1.594	251.03
5	120	160	1.33	1.4	129.95	30.6	1.914	259.026
6	80	140	1.75	1.3	89.66	29.3	1.287	257.242
7	90	145	1.61	1.3	102.34	29.6	1.291	255.771
8	100	150	1.5	1.3	113.31	30.6	1.402	253.179
9	110	155	1.41	1.3	125.92	31	1.353	251.461
10	120	160	1.33	1.3	132.8	29.7	1.59	259.808
11	80	140	1.75	1.2	88.94	14.1	0.584	250.564
12	90	145	1.61	1.2	100.96	14.9	0.614	253.944
13	100	150	1.5	1.2	110.05	21	0.85	251.262
14	110	155	1.41	1.2	121.9	25	1.155	252.25
15	120	160	1.33	1.2	132.06	23	1.03	254.123

FE model of one of such castellated beams with sinusoidal openings is shown in Fig. 5.1 along with loading and boundary condition. The beam is modelled as 3D shell element and the meshing of model is shown in Fig. 5.2. Quad-dominated S4R doubly curved element is used for meshing purpose. The various dimensions of openings along with their loads at yielding, deflections by FEA and their respective stresses for yield load are given in Table 5.1.for sinusoidal shaped openings.

Table 5.1: Results of FEA of castellated beam with sinusoidal openings

From the result of this analysis it is observed that the beam with depth of opening 0.55 times its overall depth behaves satisfactorily in respect of load carrying capacity (32.2kN). In the other words beam with D/Do ratio of 1.41 and S/Do ratio of 1.4 gives more satisfying results than the other. The variation in failure load against the depth of opening is illustrated in graphical format in Fig. 8. While Fig. 9 and Fig. 10 show the variation in stress (maximum 251.03 N/mm^2) and deflection (maximum 1.594 mm) respectively for optimized castellated beam with sinusoidal shaped opening. This optimized beam is highlighted in above Table 5.1.

Fig 5.3. Variation in yield load for different S/Do and D/Do ratio for sinusoidal opening

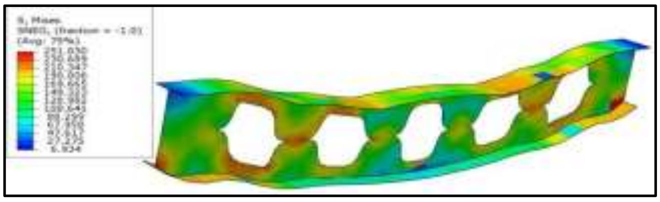


Fig 5.4. Variation in stresses of optimized castellated beam with sinusoidal openings

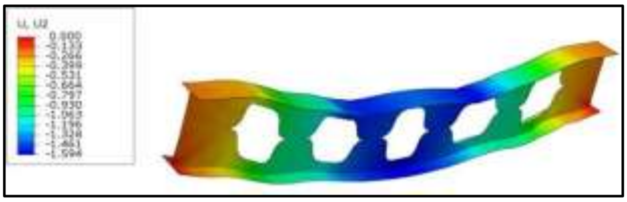


Fig 5.5. Deflection of optimized castellated beam with sinusoidal openings

6. CONCLUSION

This chapter discuss briefly the literature related to the topic,

1. As in case of sinusoidal shaped openings more shear transfer area is available, therefore castellated beam with sinusoidal openings proves to be better than the other shaped openings in respect of taking loads.
2. Sinusoidal openings gives the curved edges instead of corners. Therefore, the stress distribution near the corner portion of opening is uniform resulting in less stress concentration at opening.
3. Results of Abaqus software (FEA) are in good agreement with the results of experimentation and also with method of analysis given by Eurocode.

It is conclude that the castellated beams are well accepted for industrial buildings, power plant and multistoried structures, where generally loads are less and spans are more with its economy and satisfactory serviceability performance.

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