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Non Linear Analysis of Shear Optimization and Strengthening of Light Steel Beams with Stiffened Web Opening

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Abstract *— Light Steel beam (LSB) is a new cold-formed Steel hollow flange channel section produced using a patented manufacturing process. It is commonly used as flexural members in residential, industrial and commercial buildings. Current practice in flooring systems is to include openings in the web element of floor joists or bearers so that building services can be located within them. Test results have shown that the shear capacity of LSBs can be reduced considerably by the inclusion of web openings. A cost effective method of eliminating the detrimental effects of a large web opening is to attach suitable stiffeners around the web openings of Light Steel Beams. In this paper, finite element analysis is done for the shear optimization of Steel beams with openings using stiffeners. ANSYS is used for the analysis.*

Keywords *— ANSYS software, light steel, shear strength, deformation, web openings, stiffeners, lipped channel beams, cold-formed steel structures.*

I. INTRODUCTION

Engineers are constantly trying to improve the materials and practices of design and construction. 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 centerline and then rejoining the two halves by welding so that the overall beam depth is increased by 50% for improved structural performance against bending. Since Second World War many attempts have been made by structural engineers to find new ways to decrease the cost of Steel structures. Due to limitations on minimum allowable deflection, the high strength properties of structural Steel cannot always be utilized to best advantage. As a result several new methods aimed at increasing stiffness of Steel member, without any increase in weight of Steel required. Castellated beam is one of the best solutions. The responsibility of a Structural Engineer lies in not merely designing the structure based on safety and serviceability considerations but he also has to consider the leading to increased floor heights. Pokharel and Mahendran recommended the use of circular web openings in LSBs based on an investigation using finite element analyses. Three standard opening sizes of 60, 102 and 127 mm are used with the currently available LSBs. Keerthan and Mahendran have shown that approximately 88% of the shear force is carried by the main web element of LSB. Hence the use of web openings in LSBs significantly reduces their shear capacity due to the reduced web area. There are many variables that affect the shear capacity of members containing web openings. They include the shape, position and size of web openings. The most practical method is to increase the web thickness. However, this may not be possible with cold-formed Steel sections as the thickness is governed by the manufacturing process. A cost effective way to improve the detrimental effects of a large web opening is to attach appropriate stiffeners around the web openings.

II. LITERATURE REVIEW

M. R. Wakchaure, A. V. Sagade (2012) concluded that, the Castellated Steel beam behaves satisfactorily with regards to serviceability requirements. Castellated beams have holes in its web, which lead to local effects in the beams. This causes the beams to fail in different local failure modes. As the depth of opening increases, stress concentrations increases at the hole corners. So by taking corrective measures, i.e. by rounding hole corners, providing reinforcement at critical section, providing plate below point load, etc. the serviceability performance of castellated beams can be improved. Flavio Rodrigues, Pedro C. G. da S. Vellasco, Luciano R. O. de Lima, Sebastião A. L. de Andrade (2014) presented finite element models using the ANSYS software to investigate the structural response of Steel beams with web openings in terms of stress distributions, collapse load magnitude and associated failure modes. The use of longitudinal stiffeners welded to horizontal edge of web openings is strongly recommended. The welded longitudinal stiffeners enable a better stress redistribution around the opening region contributing for an increase of the beams ultimate load carrying capacity. The present investigation confirmed that their adoption can double or even triple the ultimate load of beams. Miss Komal S. Bedi, Mr. P.D.Pachpor found out that there is no variation observed in theoretical values and finite element analysis results obtained by Ansys. 1) Formula of the K.F. Chung (2) research Paper can be easily used for different number of web opening for same boundary condition and loading condition. 3) Shear force is more in rectangular opening as compare to Hexagonal and circular web opening 4) Bending moment is less in rectangular opening as compare to Hexagonal and circular web opening 5) In case of circular opening shear force as well as moment capacity is almost equal for all d/D ratios. 6) The shear force reduces as d/D ratio increases whereas bending moment decreases. Fatmir Menkulasi, Cristopher D. Moen, Matthew R. Eatherton, Dinesha Kuruppuarachchi (2015) presented in this paper addressed the need for a design method to estimate the nominal capacity of castellated beams against concentrated loads. Five castellated beam section depths were considered which cover a wide range of the available depths. For each section three load cases were considered: Center of load aligns with the middle of web post, B) center of load aligns with the center of the hole, and C) center of load aligns with a point half-way between the center of web post and center of hole. For each load position two cases were considered; one without a stiffener and one with a full height stiffener. The capacity of the unstiffened beams against concentrated loads as it relates to the limit state of buckling of the web post in compression was increased by addition of stiffeners. Nimmi K. P, Krishnachandran V.N (2016) study the buckling analysis of cellular Steel beams with and without stiffeners has been investigated. The stiffeners can increase the buckling capacity of cellular beams and avoid the failures. Transverse stiffeners are better in resisting the buckling of cellular beam than ring stiffeners.The manufacture of transverse stiffeners would become easier and more economic. The ring stiffeners around the openings reduce the stress concentration and resist from the failure. The transverse stiffeners on the web-post reduced the web post buckling failure. The transverse stiffener, each acts as a single short column which will be a proper link for the load transfer to the bottom flange. Buckling load reduces with increase of aspect ratio of cellular beams. Siddheshwari A. Patil, Popat D Kumbhar (2016) showed volume consumed by transverse stiffener is less than the stiffener along the edge of opening. Also, the load carrying capacity of transverse stiffener is considerably more than the stiffener along the opening edge. In case of transverse stiffener, each stiffener acts as a single short column and hence integrates the load carrying capacity. It also helps in compensating faults of welded joints. Hence, the transverse stiffener is more preferable than the stiffener along the edge. Mahen Mahendran, Poologanathan Keerthan (2017) has presented the details of an experimental investigation into the shear behavior and strength of a new cold-formed hollow flange channel beam known as Light Steel beams with stiffened web openings. Seventeen primarily shear tests were undertaken using a three point loading arrangement. Effects of stiffener types (plate and stud stiffeners) and sizes (thickness, width and height) and screw fastening arrangements on the shear capacities of LSBs with web openings were investigated in detail. It was found that the plate stiffeners based on AISI recommendations are not adequate to restore the original shear strengths of LSBs with web openings. Suitable screw-fastened stiffening systems based on plate stiffeners were developed to restore the shear capacity of LSBs with web openings. The recommended plate stiffener width is d_{wh} + 100 mm where d_{wh} is the web opening depth while its height is the lesser of clear web height (d_1) and d_{wh} + 100 mm. The required stiffener thickness was proposed as a function of the web opening depth to clear web height ratio (d_{wh}/d_1). Test results also provided the required screw fastening arrangement for the recommended plate stiffeners. Simple predictive equations have also been proposed for the dimensions of recommended plate stiffeners. LSB stud stiffeners were also shown to provide 80% of the shear capacity of LSB without web openings when their thickness was the same as the web thickness of the main beam. However, for them to be fully effective, plate stiffeners also have to be used. K.S. Wanniarachchia, M. Mahendrana, P. Keerthana (2017) has presented a detailed investigation into the shear behaviour and strength of cold-formed Steel lipped channel beams (LCB) with unreinforced non-circular web openings (square, rectangular and elliptical) using finite element analyses. Finite element models of LCBs with these web openings were developed and validated using available shear test results. The developed models predicted the shear capacities and associated failure modes accurately. Numerical results showed that the current shear design rules in cold-formed Steel structures design standards are conservative or unsafe. Two sets of new shear design equations were proposed based on a shear capacity reduction factor using the ratios of web opening height to clear web depth (i.e. dwh/d1) and web opening area to full shear web panel area (i.e. Ah/Af). Proposed design equations are able to predict the shear capacity of LCBs with circular and non-circular web openings. Suitable design equations were also developed under the direct strength method.

III. MODELLING AND ANALYSIS

A. Geometry

200 x 75 x 18 x 2 mm Lipped Channel Section is used.
Length of Specimen: 900 mm
Spacing of bolts in the web side plates: 50 mm
Edge distance of outer bolts: 25 mm.
The two LSBs were then assembled as back to back (30mm distance)
Support: Roller Support

TABLE I. Material properties.

Material	Element Type	Material Properties
Light Steel Lipped Channel Section	Young's Modulus	$2x10^5$ N/mm^2
	Poisson's ratio	0.3
	Yield strength	450 N/mm^2

B. Loading Pattern

Three point loading is applied to the beam considering roller support on both ends. Concentrated load is provided at the center which increase upto the ultimate failure of beam.

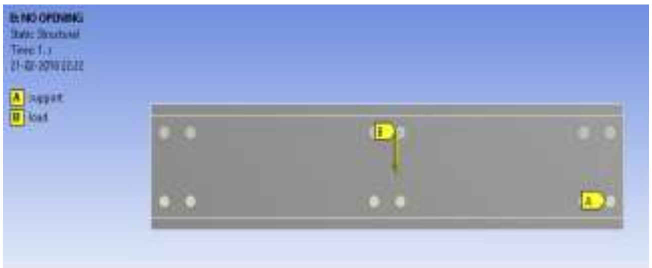

Fig. 1. Loading point on structure.

C. Modelling of Structure

200 x 75 x 18 x 2 mm Lipped Channel Section. The specimen is of length 900 mm based on the spacing of bolts in

the web side plates of 45 mm and the edge distance of outer bolts of 25 mm. The two LCBs were then assembled as back to back LSBs (30 mm distance). The high strength Steel material used for LCBs is of yield strength of 450 MPa. Roller support is provided at both ends.

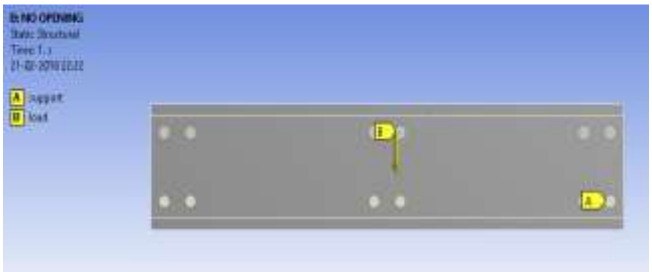

Fig. 2. Lipped channel section without opening.

It is the most important part of an analysis and can determined the efficiency and effectiveness of an analysis. Therefore, a lot of time is given to meshing of complex models. In the present study, 2 sizes of meshes are selected .15mm mesh size for whole body and 5mm mesh size around the openings.

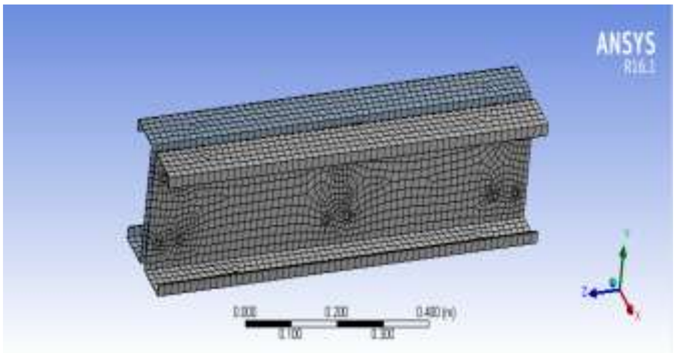

Fig. 3. Meshed view of beam.

For finding the opening which provide maximum shear strength 3 various types of openings, rectangular ,elliptical and circular openings are selected. Size of openings are selected on equal area basis. 3 Different areas are selected. They are 6000 mm^2, 12000 mm^2 and 18000 mm^2. Sides of each openings are calculated corresponds to each area. For 6000 mm^2 area, Rectangular opening of sides 100 x 60 mm is selected . For Circular opening 87.4 mm diameter and for Elliptical opening semi minor axis 30 mm and semi major axis of 63.66 mm is selected. For 12000 mm^2 area, for Rectangular opening 150 x 80 mm sides are selected. For Circular opening 123.6 mm diameter and for or elliptical opening semi minor axis 40 mm and semi major axis of 95.49 mm are selected . For 18000 mm^2 area, for Rectangular opening 200 x 90mm sides are selected. For Circular opening 151.39 mm diameter and for elliptical opening semi minor axis 45 mm and semi major axis of 127.32mm is selected

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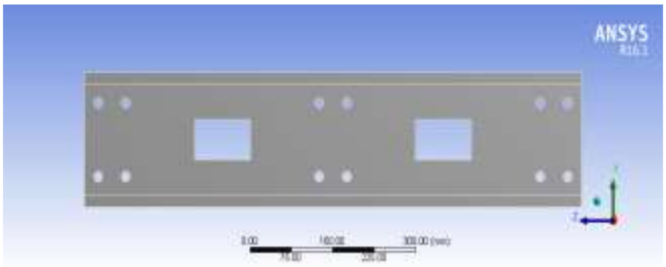

Fig. 4. Lipped channel beams with rectangular opening.

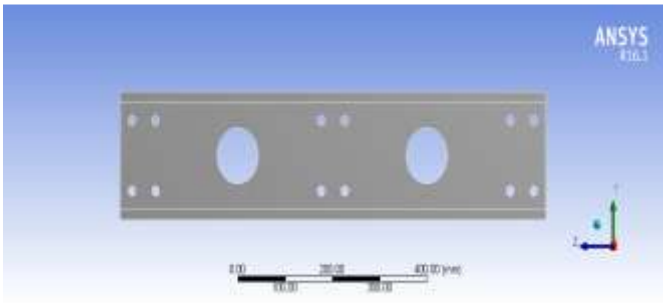

Fig. 5. Lipped channel beams with circular opening.

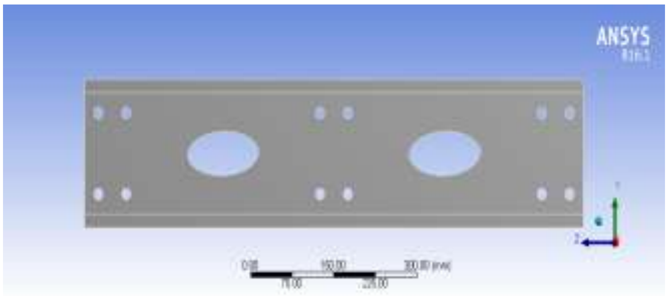

Fig. 6. Lipped channel beams with elliptical opening.

D. Effect of Stiffeners

Stiffeners are provided at the corners of openings 4 different shapes for 3 different openings. Stiffener plates are provided of thickness 1 mm and 75 mm length in direction normal to plate. For arrangement two 2mm thick Stiffener plates are provided at top and bottom of openings. For arrangement four 170mm plate with 15 mm depth at top and bottom and 90 mm length plate with 10 mm width at both sides and 4.25mm thickness is provided for full section.

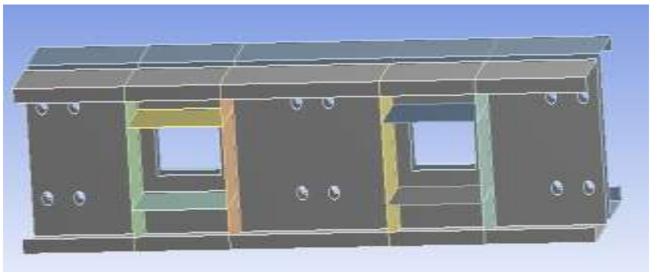

Fig. 7. Rectangular opening with stiffener arrangement 1.

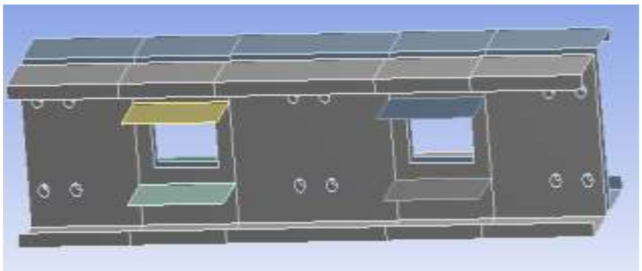

Fig. 8. Rectangular opening with stiffener arrangement 2.

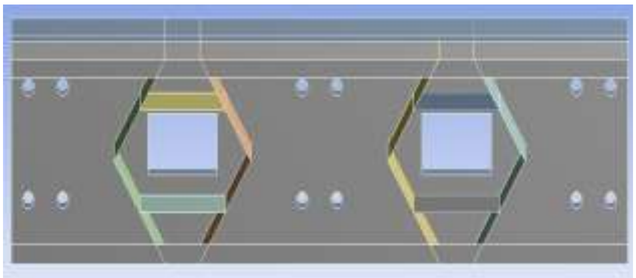

Fig. 9. Rectangular opening with stiffener arrangement 3.

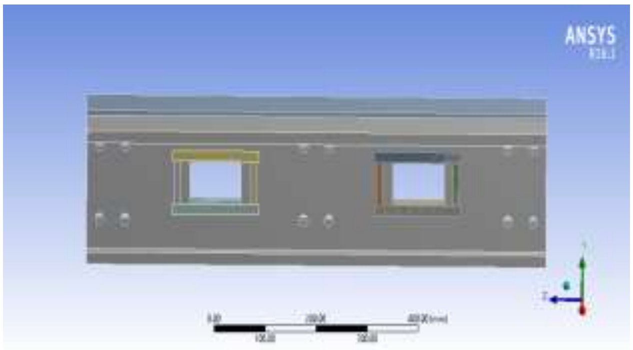

Fig. 10. Rectangular opening with stiffener arrangement 4.

IV. RESULTS AND DISCUSSIONS

The data obtained from the analysis is shown below.

A. Shear Strength for Various Type Openings

TABLE II. Shear strength for various openings.

Area of Opening(mm^2)	Type of Opening	Shear Strength (kN)
6000	RECTANGLE	140.68
6000	CIRCLE	151.18
6000	ELLIPTICAL	153.13
12000	RECTANGLE	97.01
12000	CIRCLE	105.13
12000	ELLIPTICAL	113.31
18000	RECTANGLE	71.39
18000	CIRCLE	71.13
18000	ELLIPTICAL	86.9

B. Effect of Stiffeners

TABLE III. Effect of stiffeners for various openings.

Stiffener Arrangement	Type of Openings	Shear Strength (kN)
ARRANGEMENT 1	RECTANGULAR	181.43
ARRANGEMENT 1	CIRCULAR	179.3
ARRANGEMENT 1	ELLIPTICAL	180.01
ARRANGEMENT 2	RECTANGULAR	146.83
ARRANGEMENT 2	CIRCULAR	156.16
ARRANGEMENT 2	ELLIPTICAL	153.75
ARRANGEMENT 3	RECTANGULAR	194.52
ARRANGEMENT 3	CIRCULAR	193.28
ARRANGEMENT 3	ELLIPTICAL	195.01
ARRANGEMENT 4	RECTANGULAR	169.15
ARRANGEMENT 4	CIRCULAR	161.98
ARRANGEMENT 4	ELLIPTICAL	169.3

V. CONCLUSONS

This paper has presented the details of an analytical investigation into the shear behavior and strength of a new cold-formed hollow flange channel beam known as Light Steel beams with stiffened web openings.Three different types of openings with equal area are analysed.Analysis was done for three different areas.Various Stiffener arrangemants are also tested to find out the better arrangement of Stiffeners which provide maximum Shear Strength. The following summarizes the conclusions:

- Inclusion of openings reduces the shear strength of the Light Steel Beams
- Elliptical openings provide more shear carrying capacity than circular and rectangular openings
- Shear capacity reduced due to inclusion of openings can be increased by providing stiffeners in suitable ways
- Stiffener arrangement 3 with elliptical opening provides maximum shear strength for the structure.
- Suitable arrangement of stiffeners increases the shear strength upto 38.27%.
- Providing stiffeners are effective and economical method for the optimization of steel n structures

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