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ANALYTICAL STUDY OF FLEXURAL BEHAVIOR OF COLD FORMED STEEL SECTIONS WITH AND WITHOUT PERFORATION

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Abstract—**This work is about the investigation of flexural behavior cold formed steel member of different cross sections with and without perforation under similar cross sectional area. This work gives idea about the performance of different sections under same loading condition among selected sections and highlights the increasing the flexural strength of member by using stiffener arrangement. In this work three different cross sectional shapes are selected which are C – section, Z – section and Hat shaped section of same cross sectional area analyzed with and without lip under same loading and end condition as well as with perforation. The selected specimens were analyzed analytically using ANSYS Workbench software which shown better comparison among analyzed different geometries of members. Effectiveness of providing edge stiffener to different perforated sections also determined in this work.**

Keywords— **CFS, ANSYS Workbench, FEM, Perforation**

I. INTRODUCTION

In construction, use of steel is mainly due to high tensile strength, economy, ease and speed of construction. Primarily steel is manufactured by two processes one is hot rolled in which steel is made up at elevated temperature and other is cold formed in which steel sheet is made up at ambient temperature. Mainly hot rolled steel used in steel structure industry but for a low or moderate loading use of hot rolled steel becomes uneconomical. The main advantages of cold formed steel are lightness, high strength and stiffness, easy prefabrication, uniform quality, economy in transportation and handling.

Now days in India, cold formed steel (CFS) is gaining more popularity due to its wide application in various engineering field due to its high strength to weight ratio. CFS is widely used in car bodies, railway coaching, storage racks as well as in structural members like purlin, girts, roof trusses etc. Channel and Z sections are mainly used as flexural member due to their ease of construction but also there are other sections available like hat shape, built up I section, box section etc. Many researchers done work on increasing the strength of cold formed steel section using different stiffeners and by shape optimization.

In recent times, use of perforation (holes) in beam increased to provide lightning facilities and other services like piping or anchoring wiring etc. With the use of perforation in beam, dead load of beam reduces and obviously reduces load on column. Due to holes, saving in quantity of steel provides economy in large-scale construction. Instead of such advantages, due to discontinuity created by holes member loses some strength. Researchers done work on effect of spacing of holes, sizes and shapes of holes on performance of particular CFS member. Instead of taking single shape or section of CFS to study, there is requirement to study different section of same cross section with perforation to examine performance of CFS members and to investigate the economic aspects of the CFS as light steel framing system.

In the previous work, **Liping Wang, Ben Young (2014)** have worked on the appropriateness of the current direct strength method on the design of cold-formed steel stiffened cross-sections subjected to bending. An experimental investigation of simply supported beams with different stiffened channel sections has been conducted in this study and the moment capacities and observed failure modes at ultimate loads were reported. For experimental investigation, three point as well as four point bending test were used and their results were compared with numerically analyzed nonlinear finite element model as well as with direct strength method specified in North American specification for cold formed steel structures. From this study, it found that ultimate moments of member subjected to three point bending test are 13% higher than those specimen subjected to four point bending test. It is also found that moment capacity obtained from current direct strength method are quite conservative for the cold formed steel channel sections with stiffened webs subjected to bending. [1] **Ashok M, Jayabalan P and Jaya Prabhakar K (2016)** have studied the flexural behavior of cold formed steel hat shaped beams with different d/b based on codal provisions. In this work, the finite element model used to investigate the effect of factors such as d/b ratio and lip size, which affects the ultimate strength behavior of the hat, shaped section. From this study, it found that load carrying capacity of the hat shaped sections increases with an increase in d/b ratio as well as increases with the lip sizes. [2] **P. Manikandan and S.Sukumar (2016)** have investigated the effect of stiffened element and edge stiffener in the behavior and flexural strength of built-up cold-formed steel beams. In this work, they considered CFS channel sections in four different geometries is conducted, including simple channel sections, a stiffened channel section with or without edge stiffeners. From this study, it is proved that the provisions of stiffened element at the web junction and edge stiffeners at the flanges increasing the flexural strength and improves the behavior. [3] **Sadjad Amir Al-Jallad and Haitham Al-Thairy (2016)** have investigated effects of web opening on the behavior and failure of cold formed thin walled sections (CFS) subjected to axial compressive load as well as effect of shape of opening considered. From this study, it is found that web opening with ratio ratio of opening width to total section width less than to 0.45, the increasing of the numbers of web openings results a decreasing of the column axial compressive strength. It is also seen that circular shape of opening shows less reduction compressive strength of column as compare to other shapes. [4] **Wei-bin Yuan, Nan-ting Yu and Long-yuan Li (2017)** have studied distortional buckling of perforated cold formed steel channel-section beams with circular holes in web. In this research, the influence of the web holes on the distortional buckling behavior and corresponding critical stress and moment of perforated cold-formed steel channel-section beams discussed. In this study they found that the critical moment of distortional buckling of PCFS channel section beam with circular holes in web decreases with increased hole size, but the half wavelength associated with the critical moment increases with increased hole size. [5] **Yerudkar D, Vesmawala G (2017)** have studied the post buckling behavior and ultimate strength cold formed steel member under bending. In this work, they analyzed both stiffened element with flange or web intermediate stiffeners and unstiffened. From this study, it is found that with flange or web stiffeners, performance of cold formed steel member and resistance to local, distortional and lateral torsional buckling improves and also it is seen that after addition of intermediate stiffeners, the linear buckling loads are reducing in sections having flange width to thickness ratio less than 20. [6] **Mohamed Ghannam (2018)** has worked on bending moment capacity of innovative cold formed steel (CFS) built-up beams. In this work, four different built up sections is considered. Each section is composed of combination of two vertical elements. The investigation done by both numerical ANSYS program analytical method. Cross section profile, steel thickness, steel grade, longitudinal spacing between screws (fasteners) are these parameters considered for this study. From this study, it seen that bending moment capacity is directly proportional to the steel yielding strength and the steel thickness and reinforcing webs with stiffeners can increase the moment capacity by more than 15%. [7] **Jinyou Zhao, Kuo Sun, Cheng Yu and Jun Wang (2019)** have investigated flexural behavior of cold-formed steel channel beams with web holes and the reliability of the current direct strength method (DSM) for design of cold-formed steel beams with web holes stipulated in North American Specification (NAS) (2016). In this work, ten groups of specimens with various sizes of web holes and lips were tested under four-point bending and also different hole height-to-web depth ratios were considered. It shown that the web holes change the failure modes of beams from only distortional buckling or only local buckling to distortional-local buckling interaction controlled by distortional buckling or local-distortional buckling interaction controlled by local buckling. From this study, it found that the influence of web holes on beam capacities is relatively small with a maximum reduction value of 7.0% when the hole height to web depth ratio increase from 0 to 0.4, and the dramatic reduction in beam capacities is found with a maximum reduction value of 16.3% when the hole height-to-web depth ratio further increases to 0.8. It is also shown that the current DSM is unconservative to predict moment capacities of cold formed steel channel beams with web holes. [8] The main objectives of this work are as follows

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- To analyze different cold formed steel (CFS) sections of similar cross sectional area with & without lip under flexure.
- To understand flexural response of CFS section with perforation.
- To investigate suitability of CFS section under similar loading condition with perforation.
- To study the performance of CFS sections with edge stiffened holes.

II. METHODOLOGY

The section sizes were decided according to IS 801:1975 first then the material properties were found from work done by P. Manikandan as well as described the process of applying perforation. Initially basic shapes unlipped and lipped solid sections were analyzed and afterwards perforations were introduced in lipped sections with stiffener. All sections were analyzed under same loading and support condition. For analysis, finite element method in ANSYS workbench used.

A. Details of Different CFS Section –

In primary stage the three different basic shapes of same cross sectional area with and without lip are decided. Those are channel section, Z section, hat section. The sizes of the section were decided according to IS 801:1975 guidelines keeping cross sectional area and length of all specimen constant 750 mm2 & 1500 mm respectively. Details of CFS sections are mentioned in Table 1.

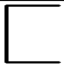
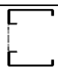
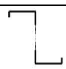
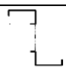
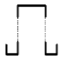
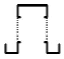
B. Specification of Perforation and Edge Stiffener –

Perforations were introduced in all lipped sections in web area of all three selected geometries. In all sections, similar percentage of area was deducted from web area or total solid area. For the convenience of study, arrangement of holes were provided in middle length of 1413 mm for all sections which follows the following formula.

L=nπd/2, where 'n' is an integer, representing the total number of holes in the web and 'd' is the diameter of hole. This implies that, in the web strip of openings the total opening area is equal to the total solid area.

Dimeter of hole was deiced keeping d/h (Diameter of hole/Height of web) 0.5 for all sections. Center to center spacing between holes were provided as πd/2. Length of edge stiffener for channel and z section kept 12mm while for hat section 6mm was adopted. By fulfilling above requirements, details of perforation are mentioned in Table 2.

Table -1 Details of CFS Sections

Sr. No.	Section ID	Shape of the Cross Section	Section Size (mm)	Thickness (mm)	Length (mm)
1	C1500		150 x 75 x 75	2.5	1500
2	CL1500		150 x 60 x 15	2.5	1500
3	CLP1500		150 x 60 x 15	2.5	1500
4	CLPS1500		150 x 60 x 15	2.5	1500
5	Z1500		150 x 75 x 75	2.5	1500
6	ZL1500		150 x 60 x 15	2.5	1500
7	ZLP1500		150 x 60 x 15	2.5	1500
8	ZLPS1500		150 x 60 x 15	2.5	1500
9	H1500		75 x 75 x 90 x 30	2.5	1500
10	HL1500		75 x 75 x 70 x 25 x 15	2.5	1500
11	HLP1500		75 x 75 x 70 x 25 x 15	2.5	1500
12	HLPS1500		75 x 75 x 70 x 25 x 15	2.5	1500

Labeling For Section Id

Example CL1500

C → Name of Specimen

(C- Channel section, Z- zed section, H- Hat section)

L → Type of Section

(L- Lipped, P- Perforated, S- Stiffened)

1500 → Length of section

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Table -2 Details of Perforation

Sr. No.	Section ID	Depth of web (mm)	Diameter of hole (mm)	Center to center spacing (mm)	No. of holes	Area of Perforation (mm^2)
1	CP1500	150	75	117.75	12	52987.5
2	ZP1500	150	75	117.75	12	52987.5
2	HP1500	75	37.5	58.875	24	52987.5

The material Properties were adopted from previous work done by researcher P. Manikandan on cold form steel obtained from tension coupon test as yield stress 270MPa, ultimate stress 350MPa, tangent modulus 20000 N/mm^2, and modulus of elasticity 2×10^5 N/mm^2 and Poisson's ratio as 0.3.

C. Finite Element Analysis –

The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problem for partial differential equation. It subdivides a large problem into smaller and simple parts that are called finite element. ANSYS Workbench 2016 was used for the numerical simulation of the members which is based on finite element method and CATIA software is used to prepare geometries.

D. NUMERICAL SIMULATION –

After creating geometries of all sections and finding out all material properties numerical simulation was done in ANSYS Workbench. The analysis system was used to carry out the analysis work namely "Static Structural System". For the analysis material non linearity and geometric non linearity was considered. The result of FEA having major impact on result. Therefore, to obtain accurate results in ANSYS workbench size of meshing and no. of element should be considered while calculating result. The meshing size of all the analysis is constant as 12mm.

E. LOADING AND BOUNDARY CONDITION –

For analysis two point loading at L/3 distance from both ends are provided. Load of 7500N was provided on each plate and at both ends all the displacement in X, Y, Z direction are restrained using displacement option in ANSYS workbench. In all sections loading and boundary condition kept constant. For application of two point load 15cm x 15cm x 2 cm rigid body plates were made and placed on beam.

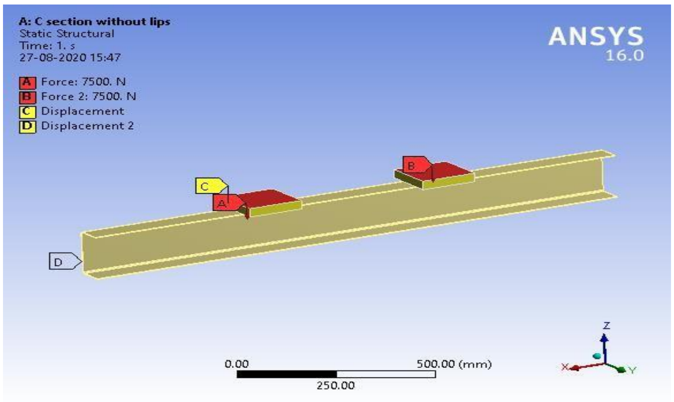

Fig. 1. Loading Arrangement and boundary condition of Channel section in ANSYS

III. RESULT & DISCUSSION

The main objective of this work is to study the behavior of different cold formed steel geometries of same cross sectional area under two point loading with and without perforation. At the end effect of edge stiffened hole or edge stiffener in all perforated sections were evaluated in this study. To achieve objective twelve analysis were performed in ANSYS workbench. A comparative study is made to study the behavior of different sections with and without perforation as well as with edge stiffener in perforated section under flexure on the basis of stress and deformation.

Table -3 Results of Analytical Study

Sr. No.	Section ID	Case	Total Load (N)	Equivalent (von-Mises) Stress (N/mm^2)	Max. Deformation (mm)
1	C1500	Channel section without lips	15000	199.05	1.6607
2	CL1500	Channel section with lips	15000	200.78	1.6358
3	CLP1500	Lipped Channel section with perforation	15000	210.59	2.1333
4	CLPS1500	Lipped Channel section with edge stiffened	15000	206.49	1.9972

		hole			
5	Z1500	Z Section without lips	15000	197.48	1.6716
6	ZL1500	Z section with lips	15000	199.31	1.6363
7	ZLP1500	Lipped 'Z' section with perforation	15000	209.79	2.1718
8	ZLPS1500	Lipped 'Z' section with edge stiffened hole	15000	203.97	1.9872
9	H1500	Hat section without lips	15000	233.53	2.2307
10	HL1500	Hat section with lips	15000	229.99	2.3772
11	HLP1500	Lipped Hat section with perforation	15000	313.66	3.0413
12	HLPS1500	Lipped Hat section with edge stiffened hole	15000	248.53	2.7097

A. *Comparative Study of Channel Section*

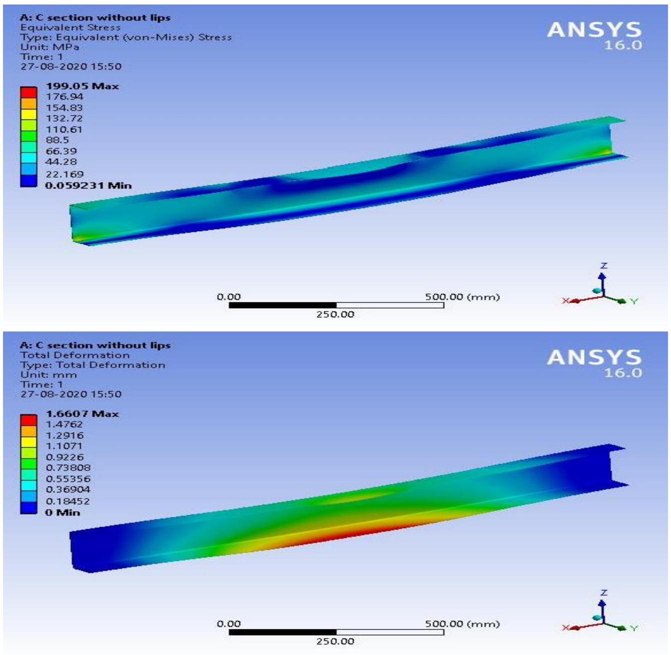

Fig. 2 Deformed shape of C1500

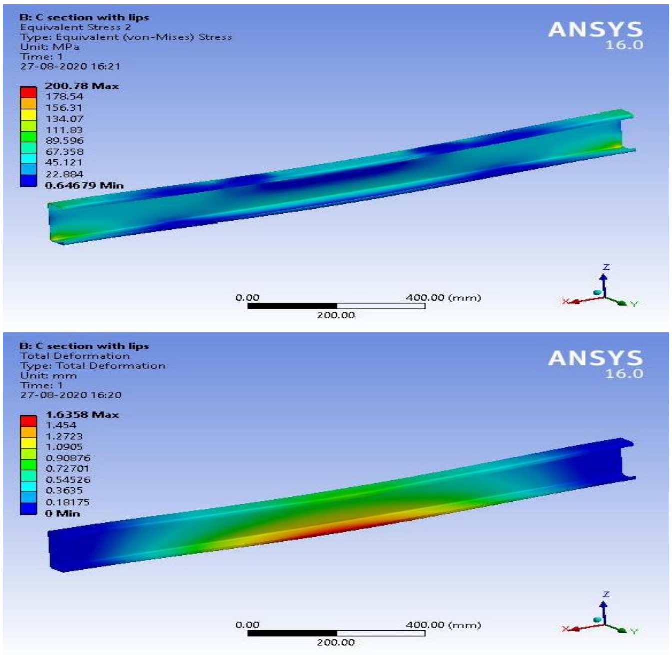

Fig. 3 Deformed shape of CL1500

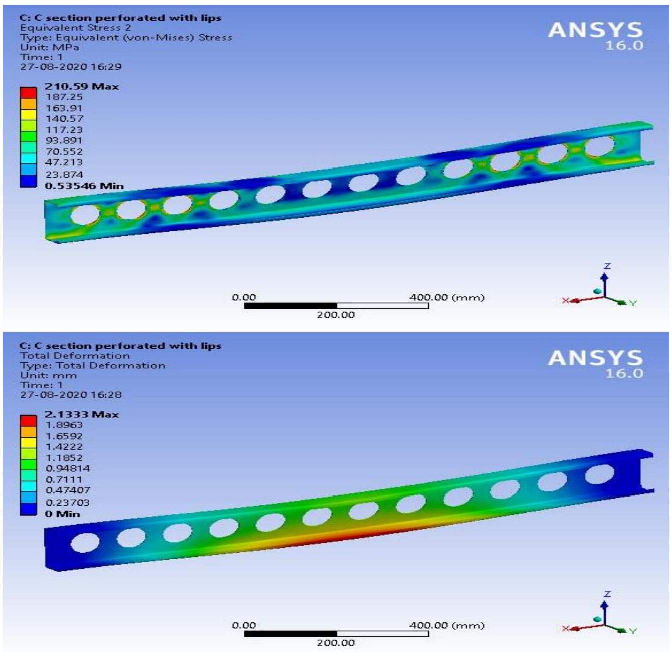

Fig. 4 Deformed shape of CLP1500

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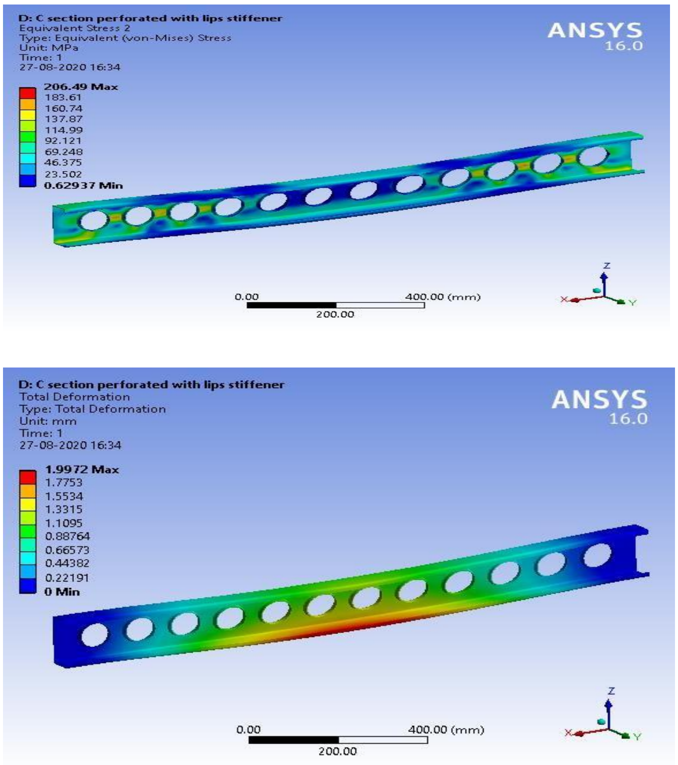
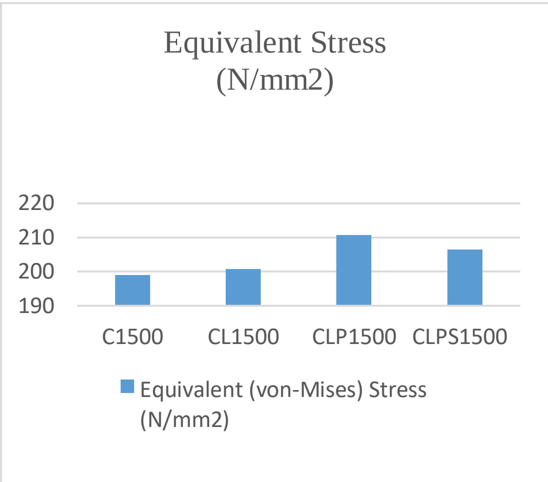


Fig. 5 Deformed shape of CLPS1500



From above graph it is seen that channel section with and without lip under same cross sectional area and same loading doesn't show any significant change in stress value. From graph it is concluded that application of perforation in lipped section shows 5% jump in stress value but also with the use edge stiffened hole stress are reduced.

From above graph, it is seen that with use of lip under same cross sectional area as compare to unlipped section deformation slightly reduces while use of perforation in lipped section deformation is increased to 30%. With the use of edge stiffener deformation gets reduced by around 6%.

B. *Comparative Study of Z Section*

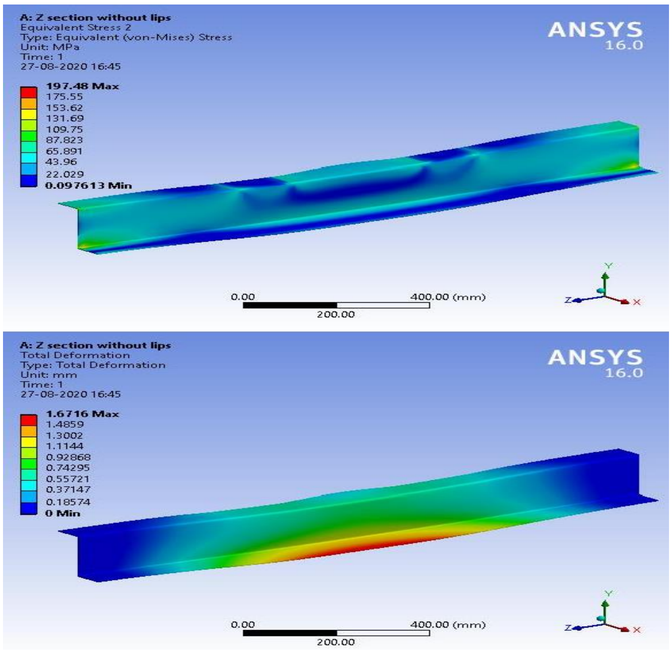


Fig. 6 Deformed shape of Z1500

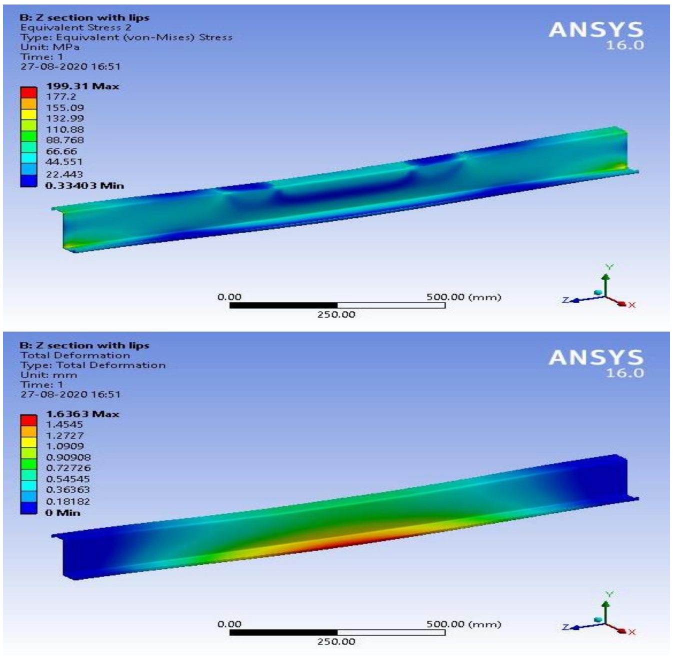


Fig. 7 Deformed shape of ZL1500

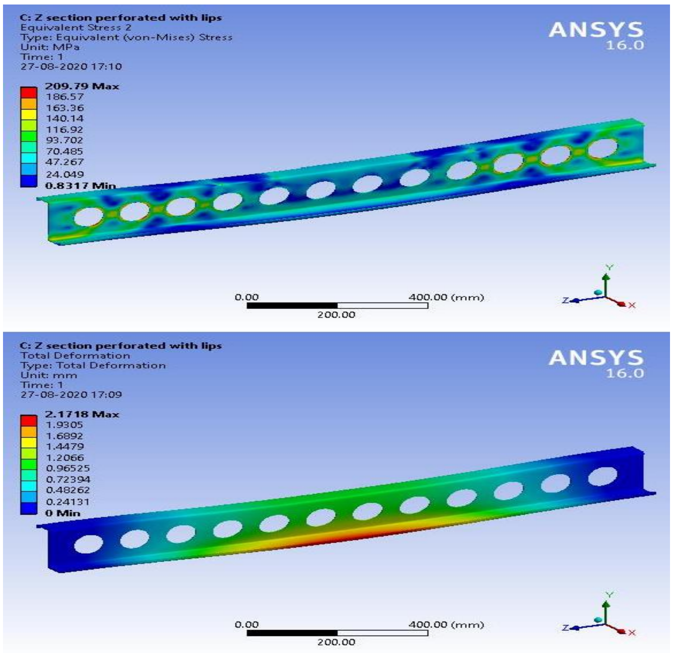


Fig. 8 Deformed shape of ZLP1500

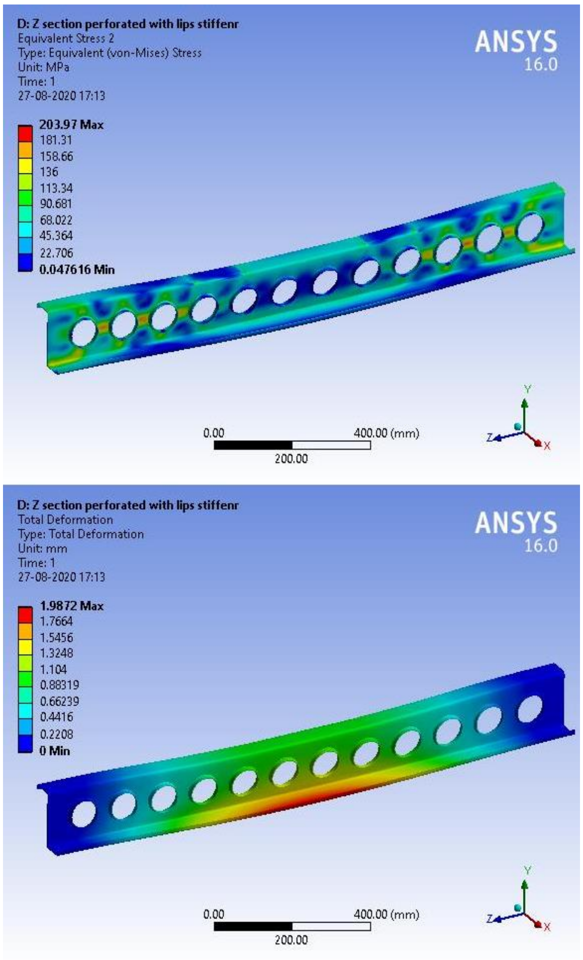


Fig. 9 Deformed shape of ZLPS1500

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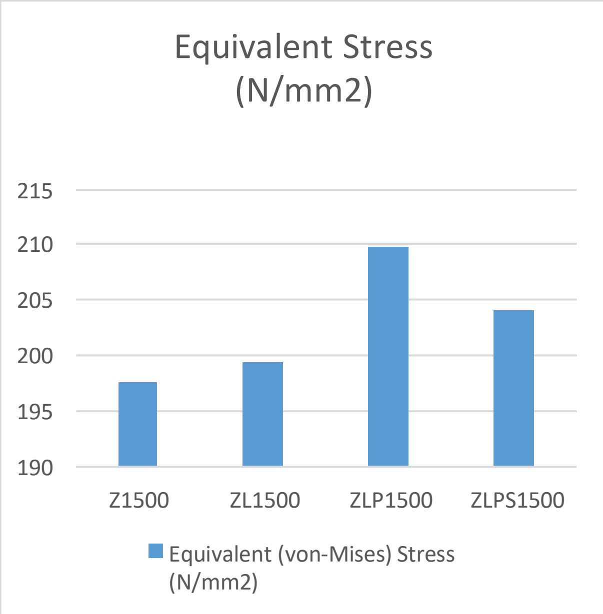

Above graph shows the variation in stress value for different geometries Z section under same cross sectional area and same loading. From above graph it is seen that lipped section shows slightly greater value of stress as compare to unlipped section while use of perforation shows maximum stress value which is 5% more than lipped section but use stiffener shows reduction in stress valueby 2.7%

In above graph it is seen that perforated section shows maximum deformation of 2.1718mm which is 32% more than lipped solid section while use of edge stiffened hole deformation gets reduced to 1.9872mm. It is also seen that use of lip under same cross sectional area and same loading deformation slightly reduces as compared to section without lips.

C. *Comparative Study of Hat Section*

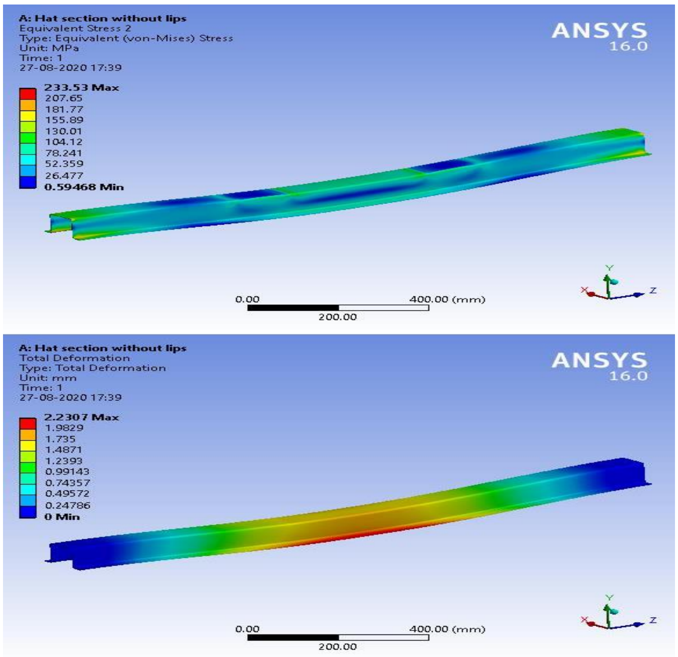

Fig. 10 Deformed shape of H1500

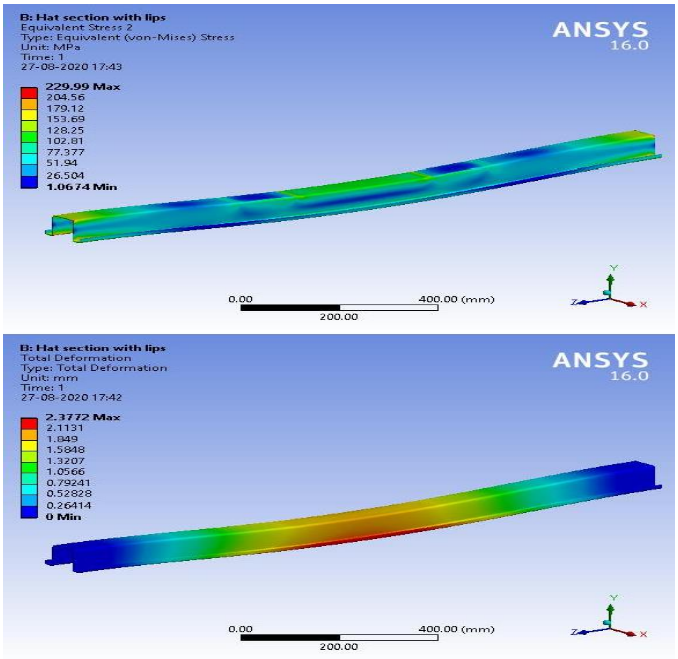

Fig. 11 Deformed shape of HL1500

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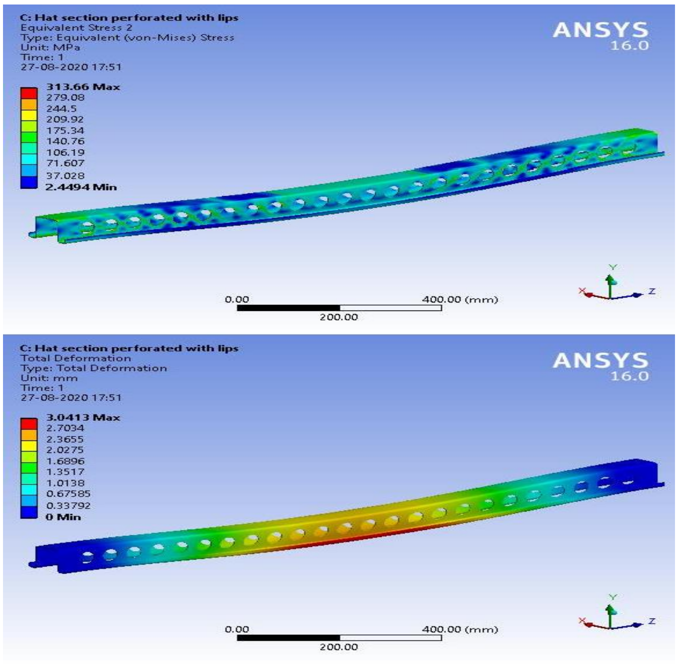


Fig. 12 Deformed shape of HLP1500

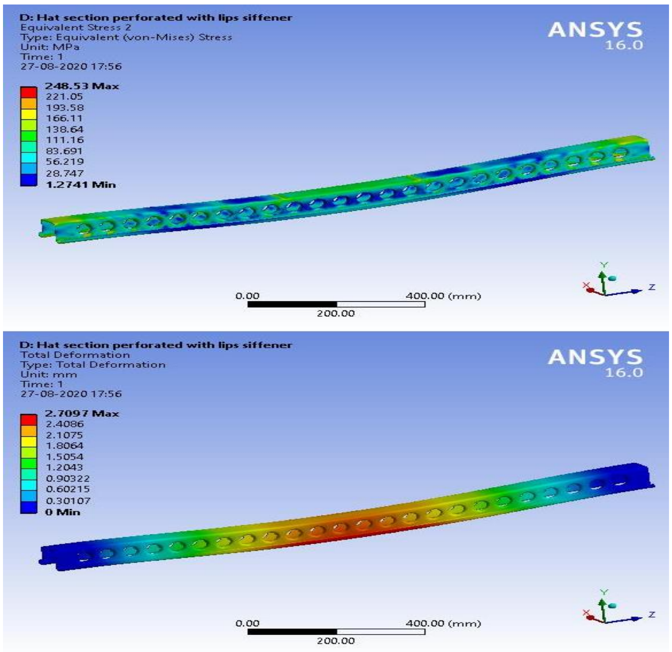
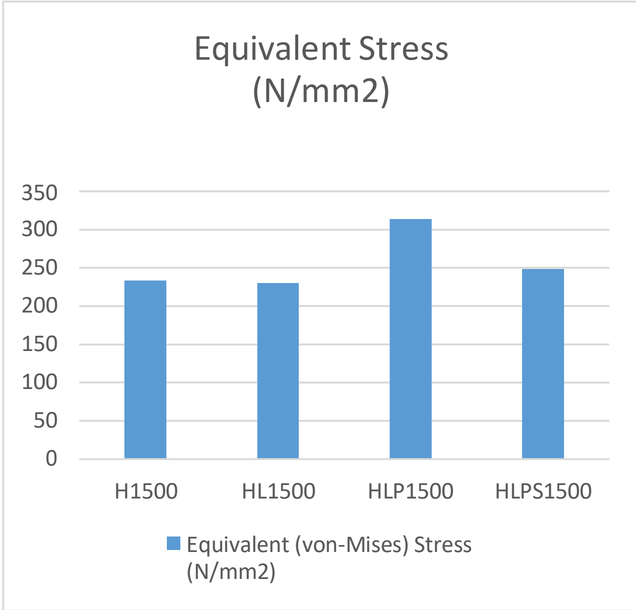


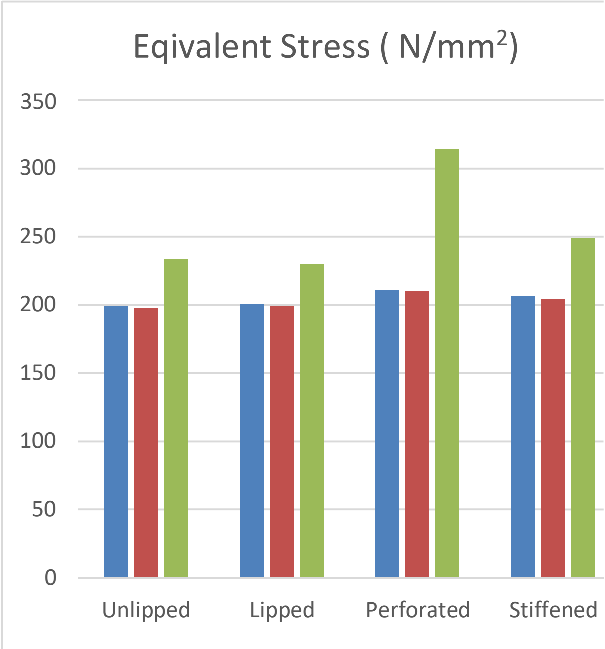
Fig. 13 Deformed shape of HLPS1500



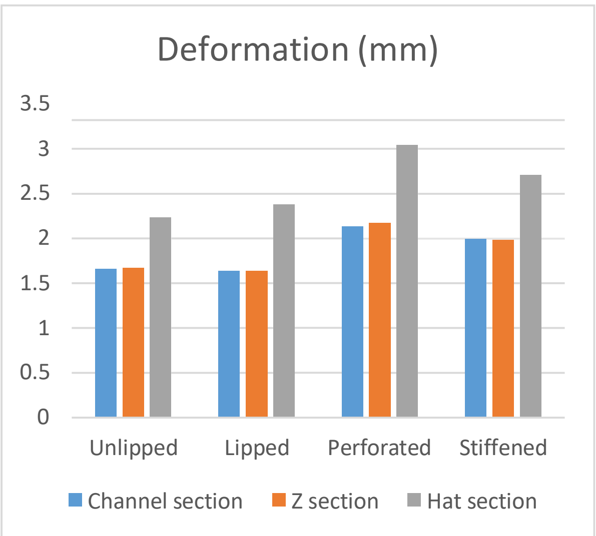
From above graph, it is seen that use of lips in hat section reduces the value of stress as compared to hat section without lips. It is also seen that application of perforation in section increases the stresses by 27% while edge stiffened hole section shows 20% reduction in stress value of perforated section.

Above graph shows the variation in deformation in different members of hat section. From above graph, it is concluded that hat section with and without lip does not show any significant change in deformation value. It is also seen that use perforation shows almost 28% jump in deformation while use of stiffened hole shows almost 11% reduction deformation value as compared to perforated section.

D. Comparative Study of Channel, Z & Hat Section



Above graph shows the variation in stress for channel, Z and hat section beam of same cross sectional area under two point loading. It is seen that channel and Z section doesn't show any significant variation in stress value but hat section shows maximum value of stress of around 17% more than channel and Z section in case of with and without lip while in case of perforation it shows 49.5 % more value of stress. It is also seen that Hat section with edge stiffened hole shows 20% higher value than channel section and 21% higher than Z section with edge stiffened hole.



Above graph shows comparisons of all cases of different geometries in terms of deformation. From this graph it is seen that performance Channel and Z section is better than Hat section. It is clear that hat section shows maximum deformation in case of unlipped sections of around of 34% more than channel and Z section while in case of lipped section and perforated section it shows 45% and 40% higher value. It is also shows 35% more deformation with edge stiffened hole as compared to other sections.

IV. CONCLUSION

In this study, twelve different sections were modelled and analyzed in ANSYS Workbench. Based on results obtained following conclusions were drawn.

- Under same cross sectional area, similar loading and boundary condition performance of channel and Z section is better than Hat section.
- In solid sections Hat section shows maximum deformation of 34% to 40% more than channel and Z section while in terms of stresses Hat section shows 17% higher value as compare to other solid sections.
- Under same cross sectional area, application of lips doesn't shows significant improvement in performance of all three sections.
- In case of perforation, under same area deduction in perforation for all sections Hat section shows significant increase in stress value of 27% while for channel and Z section it is around 5% increase of stresses in solid sections.
- In terms of deformation, Hat section shows 28% jump in deformation value in case of perforation as compared to solid Hat section.
- Use of edge-stiffened holes showed improved performance of all three perforated sections.
- In case of Hat section use of edge stiffened holes shows 20% reduction in stress value of perforated section while 11% reduction in deformation as compare to perforated Hat section.

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