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Numerical Analysis and Validation with Experimental Method of Castellated Steel Beams with Hexagonal Web Opening

Devyani Pandey[1*], Toshan Singh Rathour[2]
[1,2]*Department of Civil Engineering, Shri Shankaracharya Institute of Professional Management and Technology, Raipur, India*

***Abstract*: Steel structure are employed in heavy industrial building to provide good strength and also carry tonnes of loads safely. The castellated beams are fabricated by cutting the I section in its web by zigzag pattern and re-joining the two halves by proper welding process, the depth of the section will be increase. The purpose on this study is to validate the finite element analysis result with the experimental method [1] in in the form of deflection and stress or ultimate strength of the CSB also investigate the effect of hexagonal holes parameter in the performance of beams. The total length and ratio of the expansion of the beam are same and only depth of the hexagonal holes are changed. All the parameter of the CSB is taken same as experimental method and compare the behaviour of beams of each group under the similar boundary condition. In order to reach the most optimum design of beam, several models in the form of different profile castellated were tested on the basis of ultimate strength and the most optimum design was selected. Based on the satisfaction of different factors in the form of load bearing capacity, stress induced and deflection the optimum selection of beam was performed. The result obtained by ANSYS software is compared with the experimental result [1] to validate the result of I Beams. In these two different approaches the boundary condition for analysis is same and other parameter is also kept at constant.**

***Keywords*: Castellated beams, Hexagonal web, Web opening, Numerical analysis.**

1. Introduction

The use of steel cellular beams has been growing due to their commercial and visual advantages. Typically, these beams are produced from hot-rolled steel I-sections, and its webs are cut and welded making higher members with regular circular or hexagonal openings along their length. Researchers are always trying to improve the materials property and practices of design and construction. One of the majar improvement occurred in built-up structural members in the mid-1930, an engineer from the Argentina, developed a castellated beam.

Castellated beams are a structural member, which are made by trimming a rolled beam along its center and then reassembled the two halves by welding so that the overall depth of beam is increased by 50% for improved structural performance under the bending. Since the II World War many attempt have been made by civil engineers to find new ways to decrease the cost and increase the utility of steel structures. Due to boundaries on minimum allowable deflection, the high strength property of structural 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 option instead of solid beam.

Fig. 1. Castellated beam with web opening

A. *Web Post Buckling*

Web-post buckling is the loss of stability of the web-post caused by compression stresses due to the shear force. During this phenomenon, the web-post twists over its vertical axis, assuming the shape shown in figure below.

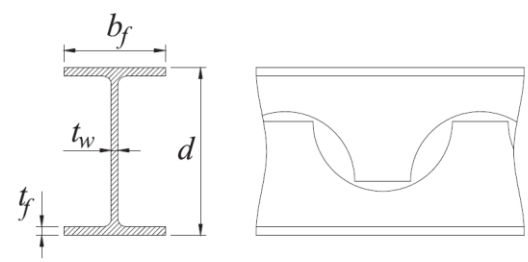

Fig. 2. Web-post twists over its vertical axis

B. *Problem Identification*

The cold formed steel channels failed due to effect of combined bending and web crippling occur when there is highly concentrated interior force on it. The cold formed channel without liped or stiffeners under such loading condition may reduce the ultimate web cripping strength of the channels. Cold rolling of the cold formed sheet makes the final shape of a

*Corresponding author: devyanipandey25@gmail.com

structural member. The element with large flat width ratio uneconomical because they have only very small effective widths. For w/t= 100, less than 50% of the width is effective. For still large w/t ratio, effective width will be still smaller. Here the design of channel width and w/t ratio is one of the crucial parameter and it need proper attention.

The basic objective of the research work is to find out the load carrying capacity by analytical method of two cold formed steel channel assembly and Justify the analytical result by using Numerical method.

2. Methodology

A. Analytical Method

For the analytical analysis and to find out the load carrying capacity of cold formed channel section with lipped edge, we have taken Two channel 200x80 with bent lips are connected with webs to act as beam given below. The thickness of the plate is 2.5 mm and the depth of lip is 25 mm. Also we determine the deflection at the allowable load.

The steel has a yield point of 235 N/mm^2. Take E = 2x105 N/mm^2.

1) Computation of effective width

The section is symmetric about x-x axis hence the stiffened compression flange will govern the design. The effective width of compression flange will be found on the basis of design stress fb = 0.6*fy = 0.6x235 = 141 N/mm^2 Thus f = fb = 141 N/mm^2

For load determination effective width is given by equation,

$$\frac{b}{t} = \frac{658}{\sqrt{f}}\left[1 - \frac{145}{\left(\frac{w}{t}\right)*\sqrt{f}}\right] = \frac{658}{\sqrt{141}}\left[1 - \frac{145}{\left(\frac{45}{2.5}\right)*\sqrt{141}}\right] = 28.98$$

$$= 28.98 * 2.5 = 72.4\ mm > 64$$

$$b = w = 64\ mm$$

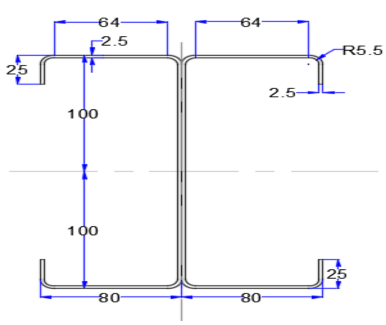

Fig. 3. Cold formed steel section profile

2) Determination of moment of inertia and section modulus

I and Z will be determined by taking b = w = 64 mm

I_{xx} = 4(64+16) * 2.5*(100-1.25)^2 +$\frac{1}{12} * 5$ *(195)^3 +4*2.5*22.5*(100-25-11.25)^2

= 12564570 mm^4,

Z = $\frac{12564570}{100}$ = 125.65X10^3 mm^3

Determination of safe load

M = f*Z= 141x125.65x10^3 =17.72 Kn-m

Let w be the load in kN/m $\frac{w(4)^2}{8}$ = 17.72 kN/m = 8.85

3) Check for web shear

Max. Shear force = $\frac{8.858*4}{2}$ = 17.716 kN

Max. Average shear force $\frac{17.716*1000}{2*2.5*195}$ = 18.17 N/mm^2

Now $\frac{h}{t} = \frac{195}{2.5}$ = 78, $\frac{1425}{\sqrt{fy}} = \frac{1425}{\sqrt{235}}$ = 92.96

For h/t not greater then 1425$\sqrt{f_y}$ then $f_y = \frac{396\sqrt{f_y}}{\frac{h}{t}}$ with a max of 0.40 f_y

Hence the above equation is applicable here,

$f_y = \frac{396\sqrt{f_y}}{\frac{h}{t}} = f_y = \frac{396\sqrt{235}}{78}$ = 77.83 N/mm^2 ≤0.4x236 = 94.4 N/mm^2

Thus fv = 77.83 N/mm^2, which is much greater than the max. Average shear stress of 18.17 N/mm^2, the beam is therefore safe in shear.

4) Check for bending compression in web

$f_{bw'}$ = 141*$\frac{100-2.5}{100}$ = 137.48 N/mm^2 = $\frac{3525000}{(\frac{h}{t})^2} = \frac{3525000}{78^2}$

= 579.4 >137.48 hence safe

5) Determination of deflection

For determination of deflection one may use effective section at max. B.M., however effective width for deflection determination is different from the one found for load termination.

$\frac{b}{t} = \frac{842}{\sqrt{141}}[1-\frac{186}{\frac{64}{2.5}*\sqrt{141}}]$ = 27.65

$b = 27.65 * 2.5$ = 69.1>64 mm

I = 12564570 mm^4

δ = $\frac{5}{384} * \frac{(wL)L^3}{EI} = \frac{5}{384} * \frac{(8.858*10^3*4*(4000)^3}{2*10^5*12564570}$ = 11.7 mm

On the basis of analytical calculation it is found that the cold formed steel channel 200x80x25 lipped section is safe and show vary good response under the loading condition and the generated amount of bending stress 137.48 N/mm2 and deflection 11.7 mm is under safe limit.

B. FEA Method

Geometric Modelling: The finite element analysis is one of the key tools to simulate the problem in virtual environment to find out the nature of the job under the actual working condition. The geometric model of the CFS is prepared in modelling workbench of catia and then assembled in product platform to achieve the required position of both beam.

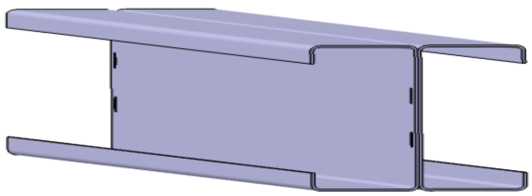

Fig. 4. 3D model of CFS beam

Meshing and boundary condition: After successfully development of 3Dmodel and assembly we move into the static structure workbench to simulate the beam with the help of required boundary condition.

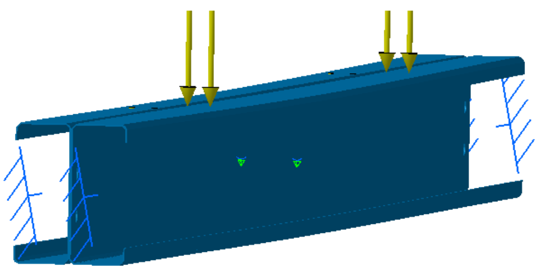

Fig. 5. Boundary condition of CFS beam

3. Result and Discussion

The output of simulation is shown by CATIA in the form of graphical representation with the help of different colour of band. It shows different value for different loading condition and it also provide flexibility to change it according to the requirement. The stress value of beam assembly is calculated with the help of simulation workbench to clearly understand the behaviour of beam assembly under the action of point load.it shown below.

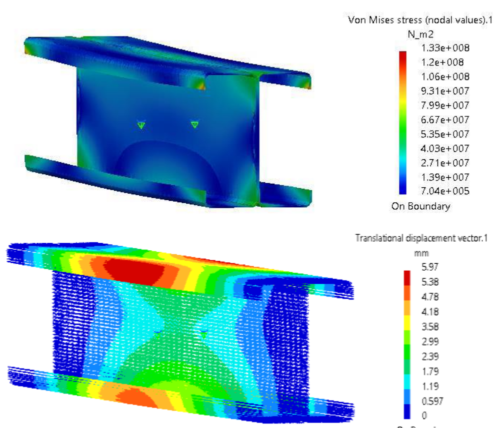

Fig. 6. Stress and deflection distribution in CFS beam

In order to validate the result of analytical method we apply finite element analysis on the cold form steel channel with the same parameter and boundary condition and compared the output result of both approaches in the form of stress and deflection of the beam which is shown in the table below.

Table 1
Comparison of analytical and FEA method

Method	Stress MPa	Deflection Mm
FEA	133	5.97
Analytical	137	11

A. Response of stress and deflection to variations in web and flange by DOE

After applying FEA, Design of experiments is performed for the same model where web and flange were varied in a specific range that is web height between 180 mm to 220 mm & flange between 70 mm to 90 mm. It took approximately 200 minutes to compute the results based on 25 combinations of web and flange.

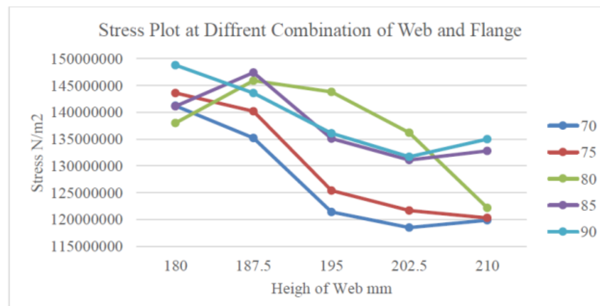

Fig. 7. Stress distribution under different combination of web and flange

B. Optimization by SAA

The optimization with SAA has been performed to find out the optimum combination of web and flange with the given boundary condition. With reference to the Table 4.4 it is to be found that iteration 32nd shown the minimum stress value with the web 203.6 mm and flange 70.7mm. The magnitude of stress for web is continuously going down from iteration number 1 to 10 then it's going up and down till iteration No. 11 to 29 but the average values is almost same.

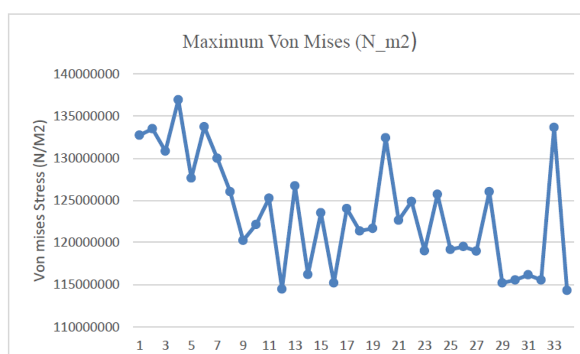

Fig. 8. Variation of Stress as per the iterations via SAA

4. Conclusion

The main aim of the project was to substantially reduce the stress concentration will in-turn help in reducing the overall life of member with cost effective way. This was done with the help of a CAE & CAD software in the form of CATIA where we had analysed the existing steel structure. The structure was analysed in the static structural workbench in CATIA.

We have selected an analytical problem for analysis and alternate solution of existing problem of column and beam connection. The analytical problem guide us to select the parameter of beam under the satisfactory condition. But it was analysis that the FEA result slightly different with analytical solution, due to high stress concentration was found in the web face of the structure. This problem can resolve by changing the size of web in CFS member.

On the basis of results furnished above it is very clear that DOE and Optimization technique emerges to be the most feasible and safe option. It showed a considerable reduction in stress i.e. 114 MPa and the corresponding percentage reduction in mass computed was 14 %.the amount of weight is also reduced around 3% as compare to the previous design of CFS.

References

[1] Jun Ye & et al, Fan “Experimental investigation of local-flexural interactive buckling of cold formed steel channel columns”, 2018.
[2] Mohd Syahrul Hisyam Mohd Sani et al, “Experimental Analysis of Cold-Formed Steel C-Sections with the Notch Subjected to Axial Compression”. KSCE Journal of Civil Engineering (2020) 24(4):1228-1239.
[3] Aamer Nazir & Jeng-Ywan Jeng, “Buckling behaviour of additively manufactured cellular columns: Experimental and simulation validation”, 2019.
[4] Žilvinas Bučmys et al, “analytical and experimental investigation of cold-formed steel beam-to-column bolted gusset-plate joints”. Journal of civil engineering and management.
[5] Asraf Uzzaman et al, “Experimental and analytical studies of cold-formed steel sections with edge-stiffened circular holes subjected to web crippling”. Wei-Wen Yu International Specialty Conference on Cold-Formed Steel Structures St. Louis, Missouri, U.S.A., November 7 & 8, 2018.
[6] V. Chandrikka et al, “Analytical and Experimental Investigation of Cold Formed Steel Sections under Bending”. International Journal of Scientific Engineering and Science Volume 3, Issue 4, pp. 5-10, 2019.
[7] J. Vijayakumar & J. Pavithra, “Experimental and Analytical Study on Strengthening of Deformed Cold-Formed Steel Lipped Channel Section”. International Journal of Engineering Research & Technology (IJERT).
[8] Alex J & Iyappan. G. R, “Experimental Study on Flexural Behaviour of Cold Formed Steel Section”, International Journal of Science Technology & Engineering, Volume 2, Issue 10, April 2016.
[9] Muhammad Firdaus, Et Al, “Experimental Study of Slip-in Haunched Gusset Plate Connection for Double Lipped Cold-Formed Steel Section”. International journal of scientific & technology research, volume 8, issue 12, December 2019.
[10] Paul Makesh A & Arivalagan S, “Experimental and analytical study on behaviour of cold formed steel using angle section under tension members”. International Journal of Engineering Technologies and Management Research, vol. 5, no. 1, January 2018.
[11] M. Prakash et al, “Analytical and experimental study on web-crippling behaviour of cold formed C-section with and without FRP wrapping.” Asian Journal of Civil Engineering, December 2017.
[12] Wei-Xin Ren et al, “Analysis and design of cold-formed steel channels subjected to combined bending and web crippling,” Thin-Walled Structures, 44, 314–320, 2006.
[13] Cristiane Cruxen Daemon d´Oliveira Bastos, “Experimental analysis of built-up cold-formed steel lipped channel stub column.” REM, Int. Eng. J., Ouro Preto, 72(4), 571-579.
[14] Asraf Uzzaman et al, “Experimental and Analytical Studies of Cold-Formed Steel Sections with Web Openings Subjected to Web Crippling,” The 6th International Conference on Coupled Instabilities in Metal Structures, 2016.