Web crippling behaviour of LiteSteel Beams with edge-stiffened web openings under End-Two-Flange load case

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***Abstract*— Cold-Formed Steel (CFS) members are widely used with openings in the floor system for various service purposes such as power, telecommunication, and internet cables. Also, web crippling is becoming vulnerable owing to the impact of web openings. However, stiffened web openings are expected to increase the web crippling capacity and redeem a significant percentage of the actual capacity of the section without web openings while allowing the service integration. This paper presents the numerical study on the web crippling capacity of LiteSteel Beams (LSB) with centred beneath stiffened web openings under the End-Two-Flange (ETF) load case. Although Rectangular Hollow Flange beams are investigated with centred beneath web openings, no studies have been carried out regarding stiffened web openings. Therefore, results from previous studies on the web crippling of channel sections with stiffened web openings were validated in terms of strength and failure mode; a good agreement was observed in the validation. Subsequently, parametric study was conducted using Abaqus; Finite Element Analysis (FEA) software, by considering various section depths, bearing plates, yield strengths, web opening ratios, thicknesses, and stiffener lengths of the hole. The FEA results showed much improvement in the web crippling capacity with edge-stiffened openings and the FEA results were analysed with various parameters for better predictions in terms of web crippling strengths.**

Keywords— Cold-Formed Steel, LiteSteel Beam, Web crippling, End-Two-Flange, Finite Element Analysis, Edge-stiffened openings

I. Introduction

Cold-Formed Steel (CFS) sections offer numerous advantages such as high strength-to-weight ratio, lightweight and fire resistance over other construction materials including hot-rolled steel, concrete, and timber [1]. On that note, CFS members are widely accepted for construction purposes all around the world and research studies have been continuously carried out to explore more applications and innovations. LiteSteel Beam (LSB) is considered such an innovation as it showcased exceptional flexural capacity due to its geometry [2]. Vulnerability against web crippling of CFS section is well-known due to its slender profile and it is necessary to address each CFS sections' web crippling capacity considering their empirical nature and the web crippling load cases; End-One-Flange (EOF), End-Two-Flange (ETF), Interior-One-Flange (IOF) and Interior-Two-Flange (ITF) which will influence the web crippling capacity of the CFS sections. Even though web crippling design standards consist of web crippling design equations [3-5], it is mandatory to investigate the web crippling behavior of various sections due to the limitations drawn in the standards. Therefore, the web crippling behavior of LSBs was investigated [2] and equations were proposed to predict the web crippling capacity of LSB. Similarly, various CFS sections such as channel sections [6], Lipped Channel Beam (LCB) [7], and sigma sections [8] have been analyzed for web crippling behavior, and equations were proposed individually.

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The introduction of web openings to accommodate the necessary service integrations such as electrical, heating, and plumbing, will affect its structural capacities. Fig.1 illustrates the utilization of web openings for service integrations. Hence, it is essential to propose equations to predict the capacity and find solutions to overcome the capacity losses. On that note, edge-stiffened web openings are introduced to accommodate the service integration while redeeming the capacity loss due to web openings [9]. Accordingly, Uzzaman et al. [6] conducted experimental studies to investigate the web crippling behavior of CFS channel sections under ETF load case considering unstiffened openings, edge-stiffened openings, and plain sections and proposed equations to predict the web crippling capacity of CFS channel sections. Similarly, the effect of web openings in LSBs on web crippling behaviour under the ETF load case was analyzed by Elilarasi and Janarthanan, and reduction factors were proposed [2]. However, the effect of edge-stiffened web openings in LSBs is unexplored yet. Hence, this paper presents a comprehensive study on web crippling behavior of LSB under ETF load case considering with openings, edge-stiffened openings, and without openings.

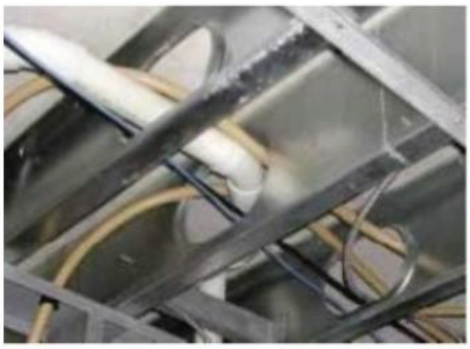

Fig.1: Web opening utilization in buildings

II. NUMERICAL INVESTIGATION

Web crippling behaviour of cold-formed steel LSB sections was investigated using numerical analyses. The finite element software, ABAQUS/CAE 6.20 [10] was used for the numerical studies following proper validation processes. Since the study aims to investigate the web crippling behavior of LSB sections with edge-stiffened openings, the parametric study was mainly conducted for plain sections, unstiffened holes, and edge-stiffened holes. Whilst web crippling study on LSB section [11] was validated for plain sections test data of channel sections [6,12] were used for unstiffened and edge stiffened openings.

In the validation and parametric studies, S4R three-dimensional shell element was applied for the beams while the R3D4 rigid element was adopted to the bearing plates. Test setup and length of the investigated models were incorporated according to the AISI design guidelines standards [13]. The minimum length of the test setup should be 3h, where h is the effective depth of the beam. Web crippling strength is sensitive to the mesh size of the specimens. Mesh sensitivity analysis was carried out for proper mesh selection and mesh sizes of 5 mm x 5 mm, 5 mm x 1 mm, and 10 mm x 10 mm were employed for the flat regions of steel beams, corner regions of steel beams, and bearing plates respectively. Surface-to-surface interaction was generated between the beam and bearing plates. Also, interaction properties of tangential and normal behavior were added between the plates and the beam. Finally, reference points were adopted in both loading and supporting plates in order to apply the boundary conditions similar to the experimental models. The load was applied in the -Y direction with the smooth step of amplitude.

III. PARAMETRIC STUDIES

Table 1. Parametric plan of LSB

Parameters of LSB	Range
Depth of the section (mm)	150, 200, 250
Thickness (mm)	1.5, 3.0
Bearing length (mm)	50, 100, 150
Diameter of the hole to Depth of the section ratio	0.2, 04, 0.6
Yield stress of steel (MPa)	250, 450
edge-stiffener length (mm)	5, 10, 15, 20, 25

Subsequently to the proper validation, parametric study was performed based on the different dimensional and material properties. The dimensional properties, depth of the beam (d), the thickness of the beam (t_w), bearing length (N), web hole diameter to clear web height ratio (a/h), fillet radius between web and edge-stiffener to thickness ratio (r_q/t), and edge-stiffeners length (q) were varied. According to the previous studies, web crippling capacity does not much vary with the corner radius (r_i), flange width (b_f) and flange depth (d_f) of LSB sections. Therefore, flange width (b_f) and flange depth (d_f) were taken as constant values when the corner radius (r_i) was zero. In total, six LSB sections with five different stiffener sizes such as 5 mm, 10 mm, 15 mm, 20 mm and 25 mm were considered in the parametric study and illustrated in Table 1.

IV. RESULTS AND DISCUSSION

Altogether, 540 numerical analyses were conducted to predict the web crippling strength variation of LSB section with various parameters. However, this study mainly focuses on the effect of edge-stiffener lengths (q) on the web crippling capacity. Table 2 shows a few web crippling strengths of LSB sections with unstiffened and stiffened holes. Also, the increment in web crippling strength due to the stiffened edge openings also was calculated and given in the Table 2. The results revealed that web crippling strength can be gained due to the stiffeners.

Table 2. Parametric results for 150 mm sections with 100 mm bearing length

d	fy	t_w	N	a/h	q	FEA	Increment due to the stiffeners (%)
150	250	1.5	100	0.2	0	10.26	-
150	250	1.5	100	0.2	5	15.81	54.16
150	250	1.5	100	0.2	10	16.50	60.92
150	250	1.5	100	0.2	15	16.95	65.29
150	250	1.5	100	0.2	20	17.27	68.41
150	250	1.5	100	0.2	25	18.33	78.72
150	250	1.5	100	0.4	0	8.77	-
150	250	1.5	100	0.4	5	13.64	55.58
150	250	1.5	100	0.4	10	15.15	72.85
150	250	1.5	100	0.4	15	16.09	83.54
150	250	1.5	100	0.4	20	16.70	94.72
150	250	1.5	100	0.4	25	18.20	107.63
150	250	1.5	100	0.6	0	6.28	-
150	250	1.5	100	0.6	5	11.21	78.46
150	250	1.5	100	0.6	10	13.03	107.47
150	250	1.5	100	0.6	15	14.31	127.90
150	250	1.5	100	0.6	20	15.66	149.33
150	250	1.5	100	0.6	25	17.74	182.52

Note: d - depth; fy - material yield strength; t_w - flange thickness; N - bearing plate length; a/h- web hole diameter to flat portion depth ratio; q - edge stiffener length of the web opening.

The numerical results revealed that web crippling strength can be restored by the edge stiffeners in the web openings. Based on the results given in the Table 2, while web crippling capacity is increasing with the edge-stiffener lengths, the increment rate with edge stiffener lengths is reducing. However, it could be observed there is a sudden increment in the web crippling capacity of LSB sections when edge stiffener lengths change from 20 mm to 25 mm which should be investigated further. A similar pattern was identified in all the remaining sections as well. Moreover, increments due to the 5 mm stiffener for 150 mm section (bearing length of 100 mm, the material strength of 250 MPa, and thickness of 1.5 mm) with web opening ratios of 0.2, 0.4, and 0.6 are 54.16%, 55.58%, and 78.46% respectively. It can be seen that the increment rate due to the stiffener is also increasing with web opening sizes. Increment in the web crippling capacity due to the edge-stiffen hole compared to the unstiffened openings is varying up to 182% to the 150 mm of LSB section with 100 mm bearing length. Moreover, the increment rate is depending on the various parameters of LSB sections which should be investigated further. Edge stiffeners in the web opening of cold-formed steel sections will be a great replacement in the construction industry which will provide adequate strength while delivering enough spaces for mechanical, electrical, and plumbing purposes. Fig.2 shows how web crippling capacity increment varies with different opening sizes.

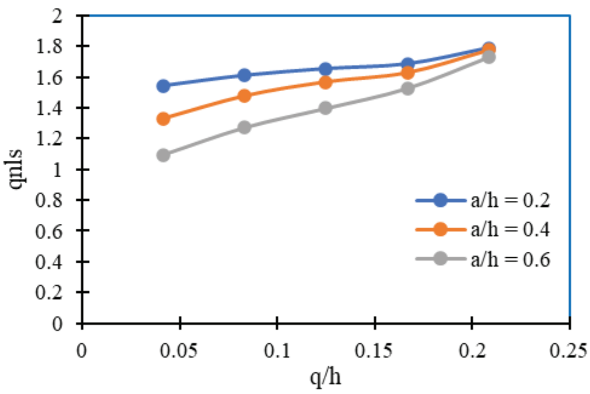

Fig. 2. Effect of edge stiffeners in web crippling capacity of LSB section for various web opening sizes

Note: q/h - edge stiffener length to effective depth of the beam ratio and q_{nls} - web crippling capacity

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increment due to the edge-stiffener openings compared to unstiffened sections.

V. Conclusion

This paper has reported a detailed numerical investigation on the web crippling behavior of LSB sections under ETF load case considering edge-stiffened web openings and unstiffened web openings. A numerical investigation initiated with the successful validation procedure to ensure the modeling properties and progressed to parametric plan development consisting of important parameters including section depth, yield stress, web opening ratio, and stiffened depth. The results obtained from the parametric studies were analyzed and revealed the following findings.

1. Web crippling capacity of LSB section is significantly increasing while adopting edge-stiffeners to the web openings.
2. Web crippling strength is increasing with edge stiffener lengths.
3. The increment rate of web crippling capacity is reduced when edge stiffener length is increasing.
4. Increments due to the edge stiffeners with web opening sizes are also increasing for LSB sections.
5. Increment in the web crippling capacity of the LSB section with 150 mm section depth was noticed to be improved up to 182% due to the edge-stiffened openings.

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