Study on Cold-Formed Steel Lipped Channel Beam with Web Perforation Subjected to Web Crippling Under ETF Loading Case

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Abstract: Cold-formed sections are widely employed in steel construction because they are lighter and more economical than traditional hot-rolled members. CFS sections have recently been utilized in construction due to their numerous advantages such as higher load-to-weight ratio, flexibility to shape as well as availability in relatively long spans. CFS channel sections can be used as purlins and joists in the structural system; thus, they are vulnerable to different buckling instabilities including web crippling. Validation of cold-formed steel lipped channel sections with web openings subjected to web crippling was undertaken using finite element (FE) analysis and matched with experimental test results, to investigate the effects of web holes and cross-section sizes on the web crippling strengths of channel sections subjected to web crippling under end-two-flange (ETF) loading conditions. In this loading conditions, the hole was centred beneath the bearing plate. It was demonstrated that the main factors influencing the web crippling strength are the ratio of the hole depth to the flat depth of the web, and the ratio of the length of bearing plates to the flat depth of the web. Web openings could be used in cold-formed steel beam members, such as wall studs or floor joints, to facilitate ease of services in buildings. In this paper a combination of tests using finite element analyses method and experimental test results were used to investigate the effect of such holes on web crippling under end-one-flange (ETF) loading condition. The present paper includes web crippling strength of channel section by numerical study, where the models are validated against the performed experiments.

INTRODUCTION

1.1 GENERAL:

The use of light gauge Cold-Formed (CF) sections as floor joists, decks, wall studs and purlins in residential, industrial and commercial buildings is increasing. These structural members are often subjected to concentrated, localized loads or reactions. All cold-formed steel sections assess many advantages such as enhanced strength to weight ratios and dimensional accuracy.

Compared to their hot-rolled counterparts, CFS members can potentially provide more economical and efficient design solutions due to several advantages, such as light weight, a high flexibility in obtaining various cross-sectional shapes, a highly adaptable manufacturing process with relatively little waste, and easier and faster construction. However, as a result of the nature of the manufacturing process, CFS components are limited in wall thickness (usually to less than 6-8mm), which makes them more susceptible to local, distortional, global buckling, as well as their interactions.

1.2 COLD-FORMED STEEL SECTIONS (CFS)

Cold-formed stainless steel (CFSS) channels are becoming increasingly popular as structural members due to its aesthetic appeal, and favorable material characteristics, particularly for resistance to heat and corrosion Cold-formed steel sections have gained popularity over hot-rolled steel sections because of higher strength to weight ratio, mass production and easy fabrication. The use of light gauge Cold-Formed (CF) sections as floor joists, decks, wall studs and purlins in residential, industrial and commercial buildings is increasing. These structural members are often subjected to concentrated, localized loads or reactions. All cold-formed steel sections assess many advantages such as enhanced strength to weight ratios and dimensional accuracy Cold-formed ferritic stainless steel channels are used in roofing and flooring construction in applications where the surface specific corrosively is sufficiently high to make galvanized coated cold- formed Carbon steel channels unsuitable for use.

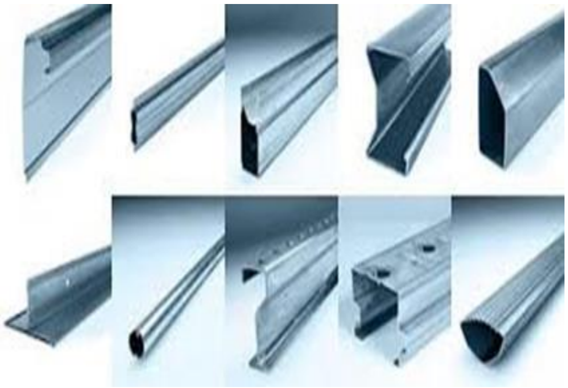


Fig.1.CFS Section

Cold-formed steel sections are increasingly used as bearers in floor systems due to their lightweight and structural efficiency. Cold-formed steel has gained more popularity than hot rolled steel due to its benefits, such as lightweight, high strength, easy transportation, and faster construction. However, most of the cold-formed steel sections are open sections; thus, flexural capacity is reduced due to complex distortional buckling. Cold-formed steel sections have increasingly used in low and medium-rise buildings due to their high strength to weight ratio, ease of fabrication and accuracy in dimensions.

1.3 WEB OPENINGS:

Web openings could be used in cold-formed steel beam members, such as wall studs or floor joints, to facilitate ease of services in buildings. openings in the web are often required, for ease of installation of electrical or plumbing services.

1.4 LOADING CONDITIONS:

The American Iron and Steel institute (AISI) Standard web crippling test method defines web crippling failures under 4 types such as IOF, EOF, ITF & ETF. If the failure occurs within 1.5d1 from the edge of specimen it is called as End Loading (EL) or otherwise it is called as Interior Loading (IL). The AISI standard web crippling test method defines web crippling failures under four types such as,

- End-One-Flange (EOF)
- End- Two-Flange (ETF)
- Interior-One-Flange (IOF)
- Interior-Two-Flange(0ETF)

2. LITERATURE COLLECTION

Various Studies are being conducted on behavior cold formed steel sections by adopting different sections using available design methods. Some of the literatures which are relevant to this study are collected are presented in Chapter – 2.

SELECTION OF SECTION:

The Section dimensions were selected based on north American Specification for the design of cold – formed steel structural members – 2012 edition and Australian / New Zealand Standard code (AS/NZS 4600:2005).

FE ANALYSIS:

The web crippling behaviour of channel sections can be predicted using Finite Element (FE) software using experimental studies available in the literature. The experimental set-up of lipped channel section is simulated using ABAQUS version 6.14 to extend the study on the web crippling of lipped channel sections with ultra-high strength material.

EXPERIMENTAL ANALYSIS

Uzzaman & Liann - Effect of web holes on web crippling strength of cold-formed steel channel sections under end-one-flange loading condition - 2012

The channel section specimens had measured 0.2% proof stress (yield stresses) of 457 MPa, 464 MPa and 479 MPa for the three different section sizes. The web slenderness values ranged from 111.7 to 157.8. The diameter of the web hole was varied in order to investigate the influence of the web holes on the web crippling behaviour.

Uzzaman and Lim - Cold-formed steel channel sections under end-two-flange loading condition Design for edge-stiffened holes, unstiffened holes and plain webs – 2012

A total of 30 specimens were tested under the offset and down web holes. The channel specimens had a 0.2% proof stresses (yield stresses) of 268 MPa and 328 MPa for the two different section sizes. For the offset web holes, it is shown that for the case of specimen ETF-240 - 45 - 15-N50, the web crippling strength was reduced by 29.5% for the unstiffened holes.

Chen & Roy - Web crippling capacity of fastened cold-formed steel channels with edge-stiffened web holes, un-stiffened web holes and plain webs under two-flange loading - 2019

The test results indicated that those specimens with fastened flanges have higher web crippling capacity than those with unfastened flanges. For the case of fastened flanges, the web crippling capacity increased by 71% and 33% on average for the ETF and ETF loading, respectively.

2.2 SPECIMEN PROFILE & LABELLING:

The typical details of “Lipped Channel” section are shown in Fig. 3.1.

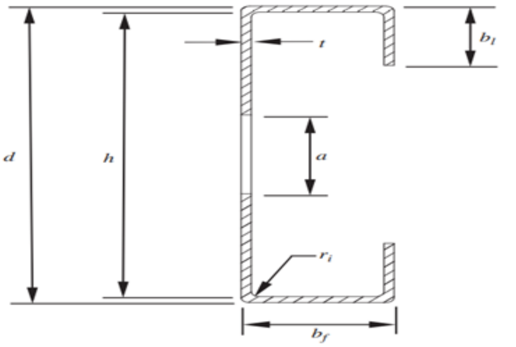


Fig. 3.1. Lipped channel section profile.

Where,

d = Overall Depth of Channel in mm,
b_f = Overall flange width of section in mm,
t = Thickness of the channel in mm,
a = Diameter of circular web holes in mm,
ri = Internal radius of the channel in mm,
b_l = Breadth of lip in mm,

3. SECTION LABELLING

Labelling of the specimens is done in such a way to self-describe the geometrical properties of specimen were labelled such that the nominal dimension of the specimen and the length of the bearing plates, as well as the ratio of the diameter of the holes to the depth of the flat portion of the webs (a/h), could be identified from the label. For example, the labels “LCB - 151X57X34X2.5X1.2X453-N150-A0” ” and “LCB - 151X57X34X2.5X1.2X453-A0.25” The first seven notations define the nominal dimensions ($d \times b_f \times b_l \times r_i$ X t X l) of the specimens in millimetres (i.e. means d=151 mm; bf=57 mm; b_l=15 mm; r_i=2.5mm t=1.2 mm and l=453 mm). “N150” represents the length of bearing in millimetres (i.e. 150 mm)

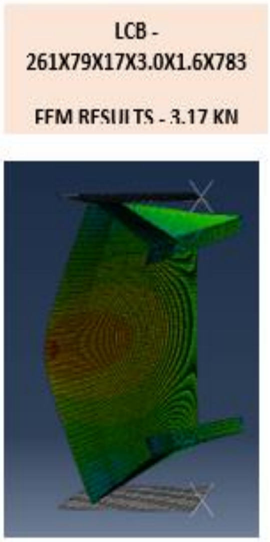
“A0.25”, “A0.35”, and “A0.45” represent the ratios of the diameter of the holes to the depth of the flat portion of the webs (a/h) i.e. A0.2 means a/h= 0.25; A0.45 means a/h=0.45. In all cases, the holes are located at the mid-depth of the web and with a horizontal clear distance to the near edge of the bearing plate (x=0.2h). Tests were conducted on the channel section specimens without web holes are denoted by “A0”.

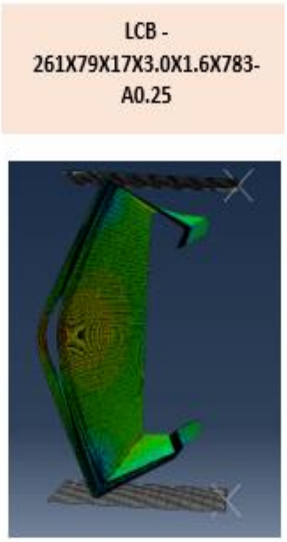
4. FINITE ELEMENT ANALYSIS

The web crippling behaviour of channel sections can be predicted using Finite Element (FE) software using experimental studies available in the literature the test specimens are is simulated using ABAQUS version 6.14 to extend the study on the web crippling of lipped channel sections with ultrahigh strength material. In this study, full length were analysed during the validation

4.1 FINITE ELEMENT MODELING:

Finite element modeling method (ABAQUS) Procedure is validated through the literature experimental investigation lipped channel section form the geometric details of the section of reported in the sundharrajah thesis.(2017). The specimen is modeled, meshed and non-linear analysis was carried out in ABAQUS. The properties of the material are ¬ Yield Strength (fy) for flat is 181 N/mm2 and for Corner is N/mm2 ¬ Young’s modulus (E) is 2.1 E5 N/mm2 (Initial tangent) ¬ Poisson’s Ratio is 0.3.





4.2 EXPERIMENTAL STUDY:

A total of eight specimens have tested and matches with the numerical results. Four specimens with perforation & four specimens without perforation. These sections tested experimentally and compared with FE analysis.

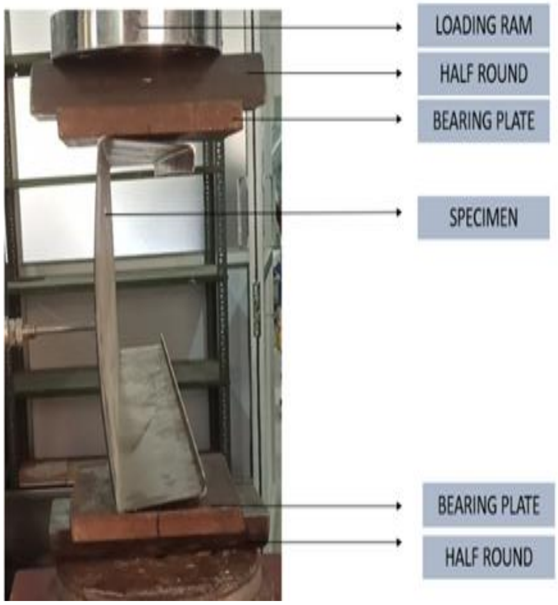


Fig.2.Experimental setup

4.2 VALIDATION BY COMPARISON OF RESULTS

The developed FE models were verified by comparing the i) web crippling failure loads, ii) failure modes and iii) applied load vs. vertical deflection curves with corresponding experimental results. Since the models were generated and validation is presented here. A good agreement was obtained for the model. The comparison based on the web crippling failure load (ultimate load) of the ten experimental studies was carried out for model and presented in Tables 4.2 for lipped channel sections. The validation was conducted for material strength of 180 MPa to 181MPa. The mean and ST.D values for the ratio between the experimental and FE results were also observed as shown in the Tables 4.2. The mean value and ST.D of LCB sections with high strength material for the model was 0.02 respectively. Summary of validation results are given in Table 4.2. The comparison was indicated that developed FE models were capable to predict well the experimental study with reasonable accuracy under ETF loading condition in terms of failure load.

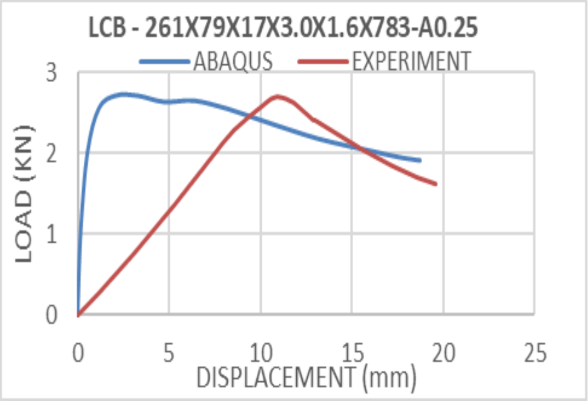
LCB -
261X79X17X3.0X1.6X
783

EXPERIMENTAL
RESULT - 3.10 KN

LCB -
261X79X17X3.0X1.6X7
83-A0.25

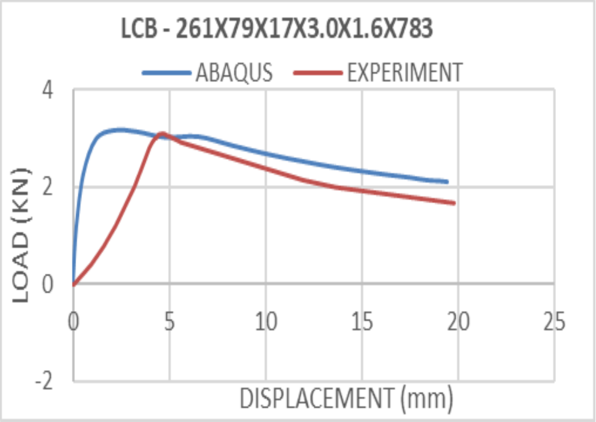
EXPERIMENTAL
RESULT - 2.60 KN

GRAPH 1. COMPARISION OF FE ANALYSIS & EXPERIMENTAL TEST RESULTS OF WEB CRIPPLING STRENGTH



SECTION LCB - 261X79X17X3.0X1.6X783-A0.25

GRAPH 2. COMPARISION OF FE ANALYSIS & EXPERIMENTAL TEST RESULTS OF WEB CRIPPLING STRENGTH



SECTION LCB - 261X79X17X3.0X1.6X783-A0.25

S. NO	SPECIMEN-ID LCB – d X b_f X b_l X r_i X t X l	P_{FEM}	P_{TEST}	P_{TEST}/ P_{FEM}
1	LCB - 151X57X34X2.5X1.2X453	6.92	6.83	0.98
2	LCB - 200X55X11.5X2.5X1.2X600	5.98	5.89	0.99
3	LCB - 261X79X17X3.0X1.6X783	3.10	3.1	0.98
4	LCB - 305X50X24X3.0X1.6X915	2.75	2.75	0.99
5	LCB - 151X57X34X2.5X1.2X453-A0.25	6.13	6.13	0.97
6	LCB - 200X55X11.5X2.5X1.2X600-A0.25	5.29	5.29	0.95
7	LCB - 261X79X17X3.0X1.6X783-A0.25	2.60	2.6	0.99
8	LCB - 305X50X24X3.0X1.6X915-A0.25	2.34	2.32	0.99
MEAN				0.98
STANDARD DEVIATION				0.02

COMPARISON OF ABAQUS(FEM) RESULTS WITH EXPERIMENTAL TEST RESULTS

The comparison is done between the analysis on Abaqus values and experimental test results with a deviation of 0.02.

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[5] LaBoube RA, YuWW, Deshmukh SU, Uphoff CA.Crippling capacity of web elements with openings. Journal of Structural Engineering1999;125:137–41.