A Parametric Study on Cold-Formed Steel Lipped Channel Beam with Web Perforation Subjected to Web Crippling Under ETF Load 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 are 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, 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 placed at a horizontal distance(offset) to the nearing edge of the bearing plate. It was demonstrated that the main factors influencing the web crippling strength are the ratio of the hole depth & thickness 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 is 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.

1.INTRODUCTION

Traditional secondary load-carrying members for a wide range of applications, including roof purlins, well girts, stud walls, and cladding, have been cold formed steel (CFS) structural elements. CFS elements are also increasingly being used as a primary structural member in a more recent trend, particularly in portal frames with short to intermediate spans and low- to mid-rise multi-story buildings. Due to several advantages, including light weight, high flexibility in obtaining various crosssectional shapes, a highly adaptable manufacturing process with relatively little waste, and easier and faster construction, CFS members can potentially provide more economical and efficient design solutions than their hot-rolled counterparts. However, CFS components are more susceptible to local, distortional, and global buckling as well as their interactions due to the fact that their wall thickness is limited by the manufacturing process (usually less than 6-8 mm)

WEB CRIPPLING ANALYSIS:

Web crippling is a vulnerability of CFS members under concentrated reactions and concentrated transverse reactions due to its thin cross sections. Since 1940s, several experimental investigations in the web crippling behaviour of cold-formed steel sections have been conducted by various researchers and web crippling design equations and standards are adopted in the design specifications such as Euro code 3 part 1-3[,AISI S100 and AS/NZS 4600. Besides, the design specifications define the failure modes of web crippling into four categories - Interior-Two-Flange (ITF), End-Two-Flange (ETF), End-One-Flange (EOF) and Interior-One-Flange (IOF) according to these locations of loading, supporting and failure region web crippling behaviour of CFS channel sections were studied. Moreover, web crippling studies were conducted on the lipped channel beam sections with perforation.

USE OF PERFORATION

Web openings could be used in cold-formed steel beam members, such as to improve the buildability of buildings composed of cold-formed steel channel-sections, openings in the web are often required, for ease of installation of electrical or plumbing services

The stress concentration is almost negligible in the centre of the web portion.So we are trying to make the perforation at the centre.

FIG-1.1 CFS SECTION WITH PERFORATION

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), Length of the section > 3d
- End- Two-Flange (ETF), Length of the section > 3d
- Interior-One-Flange (IOF), Length of the section > 5d .
- Interior-Two-Flange(ITF), Length of the section > 5d

Where, d – Overall depth of web.

2.LITERATURES

Cold-formed steel channel sections under end-two-flange loading condition: Design for edge-stiffened holes, unstiffened holes and plain webs Asraf Uzzaman, James B.P. Lim, David Nash, Krishanu Roy

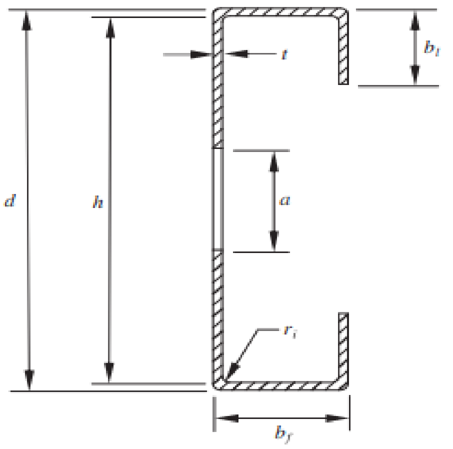
Experimental and numerical investigations of lipped channel sections with plain, circular unstiffened and edge-stiffened web holes subjected to web crippling have been presented. Web holes located at the mid-depth of the web with a horizontal clear distance to the near edge of the bearing plate and down the bearing plates were considered. A series of tests were conducted on lipped channel sections with web holes subjected to the ETF loading condition. 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.

Web crippling behaviour of cold-formed steel channel sections with edge-stiffened and unstiffened circular holes under End-two-flange loading condition Asraf Uzzaman, James B.P. Lim, David Nash, Krishanu Roy-2020

This paper presents a combination of tests and finite element analysis, to investigate the effect of edge stiffened circular web holes on web crippling strength of CFS lipped channel sections under ITF loading condition. For comparison, plain channels and channels with unstiffened circular web holes were also tested. Both the down and offset web holes were considered in this study. A total of 30 specimens were tested under offset and down web holes. In case of offset web holes, it was found that for specimen ITF240x45x15-N50, the web crippling strength was reduced by 38.2% for the unstiffened holes. Similarly, for the same section, the web crippling strength was increased by 18.6% for the edge-stiffened holes. For the down web holes, it was found that the web crippling strength of the same section was reduced by 31.9% for the unstiffened holes and the web crippling strength was reduced by 4.9% for the edge-stiffened holes.

Experimental Studies of Lipped Channel Beams Subject to Web Crippling under Two-Flange Load Cases Lavan Sundararajah1 ; Mahen Mahendran2 ; and Poologanathan Keerthan

These LCBs are subjected to specific buckling and failure modes, one of them being web crippling. Despite considerable research in this area, some recent studies have shown that the current web crippling design rules are unable to predict the test capacities under endtwo-flange (ETF) and End-two-flange (ITF) load conditions. In many instances, web crippling predictions by the available design standards such as AISI S100, AS/NZS 4600 and Eurocode 3 Part 1-3 are inconsistent, i.e., unconservative in some cases, although they are conservative in other cases. Hence, experimental studies consisting of 36 tests were conducted in this research to assess the web crippling behavior and capacities of high-strength LCBs under two-flange load cases (ETF and ITF). Experimental results were then compared with the predictions from current design rules. Comparison of the ultimate web crippling capacities from tests showed that the design equations are very unconservative for LCB sections under the ETF 9 load case and are conservative for the ITF load case. Hence, improved equations were proposed to determine the web crippling capacities of LCBs based on the experimental results from this study. Current design equations do not provide the direct strength method (DSM) provisions for web crippling. Hence, suitable



design rules were also developed under the DSM format using the test results and buckling analyses using finite-element analyses.

Web crippling behaviour of thin-walled lipped channel beams M. Macdonald, M.A. Heiyantuduwa Don , M. Kote"ko ,n , J. Rhodes

The results showed that the nonlinear finite elements models developed were capable of closely representing the web crippling failure of the specimens considered in this research. An average deviation of 72% of finite element strength from experimental results was observed. The nominal web crippling strength of thirty-six specimens subject to EOF and ETF loading conditions predicted using Eurocode 3, Part 1.3 (equivalent to the Polish code), were compared with the experimental results. The comparisons indicated averages of 34% and 48% underestimations of Eurocode web crippling strength predictions for the EOF and ETF loading conditions, 12 respectively. It was also observed that the length of the load bearing plate, along with the value of corner radii and web depth, all had an effect on the web crippling strength of the lipped channels tested—particularly noted for the IOF and EOF loading conditions. However, no definite trends could be observed for the ETF loading condition. Unloading paths for beams under IOF loading conditions obtained from the plastic mechanism analysis represented the same character of ‘‘brittle failure’’ as experimental results for specimens of small corner radii. Quantitative agreement of theoretical and experimental results was rather unsatisfactory. Theoretical failure curves used in this case in compilation with elastic paths to the upper-bound estimation of the beam ultimate load would give an over-estimation of about 40% in comparison with FE and experimental results. One of the reasons for discrepancies was that the analysis did not account for any strain hardening effect. For sections with large corner radii, failure curves obtained from the plastic mechanism analysis were only capable of representing the global collapse mechanism, which normally occurs well beyond the initial collapse stage.

3. SELECTION OF SECTION

As European Standards(EN-1993-1-3) for the design of cold-formed steel structural members, the flat b/t limits are available for single section. Based on these limitations, suitable section is selected. The dimensions of the Channel section is selected as per Euro code specifications as shown in Fig 3.1. The elements of the sections are chosen by the way the value satisfies the limits provided in Euro code standards for comparison.

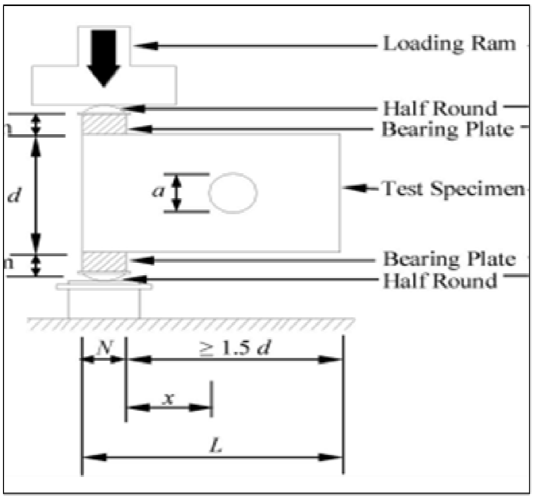


Fig.3.1 Profile of Lipped Channel Beam-Unstiffened web hole Section

Where,

d = Overall Depth of Channel in mm,

h = Plain Height of Web without ri in mm,

b_f = Overall Breath of the Channel in mm,

r_i = Internal radius of the channel in mm,

t = Thickness of the channel in mm,

b_l = Breadth of lip in mm,

a = Diameter of circular web hole.

LOADING CONDITION

In this research end two flange(ETF) loading condition is studied as per AISI Standards.

N = Length of the bearing plate.

x = Horizontal clear distance between web holes to the near edges of the bearing plate.
X = Web holes distance ratio (*x* / h)
r_q = Internal radius of the stiffened web hole (r_q = 0,for unstiffened web hole)
q = Length of the web hole edge-siffener (q = 0,for unstiffened web hole)

SECTION LABELLING:
The labelling of the specimens is done in such a way to self-describe the geometrical properties of specimen as ETF – LC d x b_f x b_l - t_w - r_i/t_w – N – A0.0

- Bearing length (N)in mm
- Ratio of internal radius to thickness of web Thickness of the channel (t_w) in mm
- Breadth of lip of the channel (b_l) in mm
- Breadth of the channel (b_f) in mm
- Depth of the channel (d) in mm
- Lipped Channel (LC) , Load Case : ETF- End Two Flange
- Perforation ratio (A), Where A = (a/h)

4.FINITE ELEMENT MODELLING
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 openings in web. In this study, full length were analysed during the validation.

5.VALIDATION

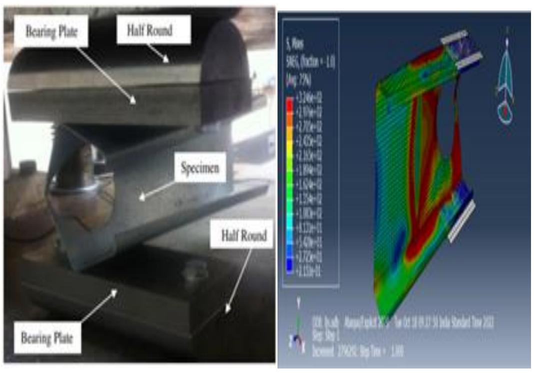


Fig 4.1 Comparison of FEM and experiment

Table 4.1 Validation

S.NO	SPECIMEN	P(kN)	P(kN)-FEM	COMPARISON (FEA/EXP)
1	172X65X13-t1.2N120-A0.25	4.20	4.11	0.9785
2	172X65X13-t1.2N150-A0.25	4.07	3.98	0.9778
3	202X65X13-t1.2N150A0.25	4.97	4.80	0.9657
4	202X65X13-t1.2N150A0.25	4.79	4.49	0.9373

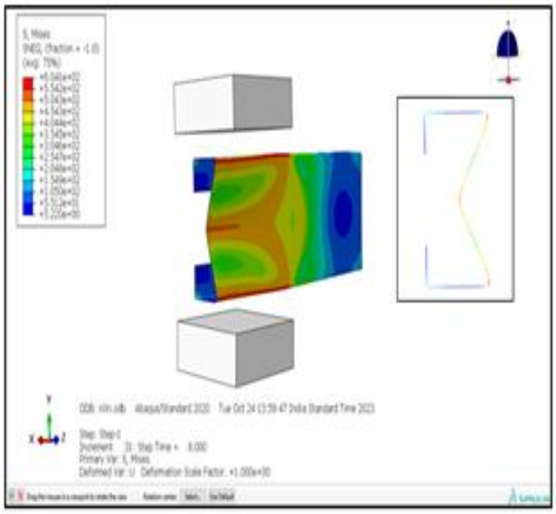
6. PARAMETRIC STUDY

The parametric study was carried out by using the validated procedure for the selected sections. Totally 96 analysis were done on Lipped Channel Beam under ETF loading case. Two different parameters, thickness and perforation ratio is chosen for the parametric study. The bearing length used is 150 mm for all the sections.

Section (d x bf x bl)	Thickness of web (mm)	inside bent radius ri (mm)	Perforation ratio	Number of Models
151x57x34	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24
200x55x11.5	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24
261x79x17	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24
305x50x24	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24

7. NUMERICAL ANALYSIS

The numerical analysis is done using the Abaqus software. The failure modes of one of the specimen is given below.



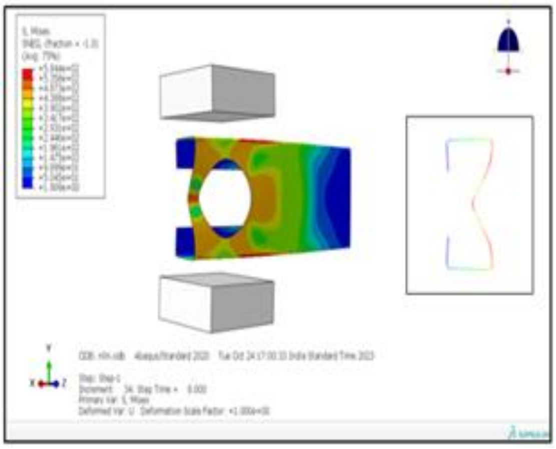


Fig 6.1 Comparison of failure modes of WOP and WP

Web crippling strength increases with thickness and decreases with increasing the web perforation.

8. RESULTS AND DISCUSSION

Uzzaman(2020) has given the strength reduction factor (R_p) using bivariate linear regression analysis for the ETF loading condition. The R_p value is proposed for the yield stress value of 433 MPa to 547 MPa.

For the offset to the bearing plates web holes,

$R_p = 0.98 - 0.11 * (a/h) + 0.01 * (x/h) + 0.05 * (rq/t) + 0.41 * (q/h) \leq 1$ …..(7.1).

Where,

R_p = Proposed reduction factor as per uzzaman.

a = Diameter of circular web hole.

h = Depth of the flat portion of web.

N = Length of the bearing plate.

x = Horizontal clear distance between web holes to the near edges of the bearing plate.

X = Web holes distance ratio (*x* / h)

r_q = Internal radius of the stiffened web hole (r_q = 0,for unstiffened web hole)

q = Length of the web hole edge-siffener (q = 0,for unstiffened web hole)

The limits for the reduction factor (R_p) are h/t ≤ 156, N/t ≤ 84, N/h ≤ 0.63, a/h ≤ 0.8.

The equation (7.1) is inadequate to predict the web crippling strength of the lipped channel sections with ITF loading condition with unfastened supporting condition.

The Uzzaman equation is inadequate due to the usage of yield strength values 433 MPa and 537 MPa, which is greater than uzzaman yield stress values. So the coefficients are proposed for the uzzaman equation.

The coefficients for the proposed equation is arrived by comparing the uzzaman reduction factor with the FEA load factor. The FEA load factor is arrived by taking the ratio of load for with perforation to without perforation. Now the proposed equation for the yield stress value of 433 MPa to 547MPa for ETF load case is given by

$$R_p = 1.0075\left(0.98 - 0.11 * \left(\frac{a}{h}\right) + 0.01 * \left(\frac{x}{h}\right) + 0.05 * \left(\frac{rq}{t}\right) + 0.41 * \left(\frac{q}{h}\right)\right) + .013 \leq 1 \quad (7.2)$$

The limits for the reduction factor ($R_{p,prop}$) are h/t ≤ 203.33, N/t ≤ 100, N/h ≤ 1.08, a/h ≤ 0.7.

9.CONCLUSION

1. The detailed investigation of web crippling behaviour of cold-formed steel lipped channel sections under ETF load case where numerical model was validated with experiment results.
2. The parametric plan was developed to analyse web crippling behaviour of lipped channel sections for web holes located at the mid-depth of the web and centered beneath the bearing plates under ETF load case using ABAQUS.
3. In total, 96 numerical models were developed to obtain the ultimate web crippling capacity of the sections by considering two parameters, thickness and perforation ratio.
4. The web crippling strength increases to 11% to 220% when the thicknesss increases from 1.5mm to 2.5mm. The web crippling strength decreases to 8% to 48% when the perforation ratio(a/h) increases from 0.1 to 0.7.
5. The web crippling results were compared with the literature (uzzaman 2020). Since the comparison discloses that available equation was too conservative to predict the ultimate web crippling capacity under ETF load case for higher yield stress values, so the equation was proposed by comparing the FEA results with uzzaman(2020).
6. Moreover, new design equation was proposed based on the uzzaman(2020) equation. Eventually, this project concludes with a proposed equation with respect to uzzaman(2020), which accurately predict the ultimate web crippling capacity of lipped channel sections with cold-formed steel under ETF load case.

REFERENCE

1. Uzzaman Web Crippling behaviour of cold-formed steel member with web openings, (Ph. D.

Thesis).

2. Sundararajah Web Crippling Studies of Cold-formed Steel Channel Beams, (Ph. D. Thesis).
3. Natário, P. (2015). "Localized failure of thin-walled steel members subjected to concentrated loads: Analysis, behaviour and design." Ph.D. thesis, Instituto Superior Técnico, Universidade de Lisboa, Portugal.
4. Natário, P., Silvestre, N., and Camotim, D. (2016). "Direct strength predictionof web crippling failure of beams under ETF loading." Thin-Walled Struct., 98, 360-374.