A Parametric Study on Cold-Formed Steel Lipped Channel Beam with Web Perforation Subjected to Web Crippling Under ITF Load Case

Rajarajeshwari N[1], Jaisurya J[2]

[1]*PG Scholar, Department of Structural Engineering, Government college of Engineering – Salem-11, Tamilnadu, India*

[2]*PG Scholar, Department of Structural Engineering, Government college of Engineering – Salem-11, Tamilnadu, India*

Abstract- Cold-formed steel sections are widely employed in steel construction because they are lighter and more economical than traditional hot-rolled members. CFS 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.

In this phase of this thesis parametric study was conducted to find the effect of web perforations on the web crippling strength of the lipped channel beam under ITF loading condition. The parametric plan was developed to analyze web crippling behavior of lipped channel sections for web holes located at the mid-depth of the web and centered beneath the bearing plates under ITF load case using ABAQUS. Totally 96 numerical analysis was conducted based on two parameters like thickness and perforation ratio. The ultimate web crippling capacity obtained from the parametric study was used to assess the accuracy of the proposed reduction factor given by uzzaman. The assessment revealed that the existing proposed reduction factor was not suitable to predict the ultimate web crippling capacity of cold-formed steel for higher yield stress values under ITF load case. Thus a modified design equation was proposed by comparing the FEA results with uzzaman equation.

1.INTRODUCTION

In steel construction, there are two main families of structural members.

- Hot-rolled shapes members
- Cold formed members

Thin sheet steel products are extensively used in building industry, and range from purlins to roof sheeting and floor decking. Generally these are available for use as basic building elements for assembly at site or as prefabricated frames or panels. These thin steel sections are cold-formed i.e., their manufacturing process involves forming steel sections in a cold state (i.e., without application of heat) from steel sheets of uniform thickness. This is given by the term Cold Formed Steel Sections. Sometimes they are also called Light Gauge Steel Sections or Cold RolledSteel Sections. The thickness of steel sheet used in cold formed construction is usually 1 to 3 mm. The method of manufacturing is important as it differentiates these products from hot rolled steel sections. However, as a result of the nature of the manufacturing process, CFS components are limited in wall thickness. Design of cold formed steel sections is dealt with in IS: 801-1975 which is currently due under revision.

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

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)
- End- Two-Flange (ETF)
- Interior-One-Flange (IOF)
- Interior-Two-Flange(ITF)

2.LITERATURES

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

Experimental and numerical investigations on the web crippling behaviour of cold-formed steel lipped channel sections, with and without circular web holes, under the end-one-flange (EOF) loading condition have been presented.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 behavior

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, the web crippling strength was increased by 16.9% for the edge-stiffened holes. For the down web holes, it is shown for the same channel section that the web crippling strength reduced by 50.0% for the unstiffened holes and strength increased by 37.9% for the edge-stiffened 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

For the case of fastened flanges, the web crippling capacity increased by 71% and 33% on average for the ETF and ITF loading, respectively. Using the validated FE models, an extensive parametric study comprising 912 FE models was conducted to study the effects of web thickness, size of the holes, length of bearing plate and length of edge-stiffener on web crippling capacity of such sections.

3.FINITE ELEMENT MODELLING

ABAQUS 6.13-1 is a general purpose finite element modelling package for numerically solving a wide variety of mechanical problems .These problems include static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems.

The finite element program ABAQUS was used to stimulate the web crippling behaviour of cold formed lipped channel beam with perforation under ITF loading. The beams were modelled using shell S4Relements with sharp corner neglecting the corner radius. The strain hardening of the corners due to cold forming is neglected. An elasto-plastic behaviour for the material was considered. The material and geometric nonlinearity was included in the finite element model.

A linear elastic analysis was performed first to obtain the web crippling loads and its associated modes. The linear elastic mode shape was used to create a geometric imperfections for the non-linear analysis. This wasfollowed by a non-linear ultimate strength analysis to predict the ultimate load capacity.

SPECIMEN PROFILE & LABELLING:

The optimum dimensions of "Lipped Channel" section are taken from Mojtabaei et.al

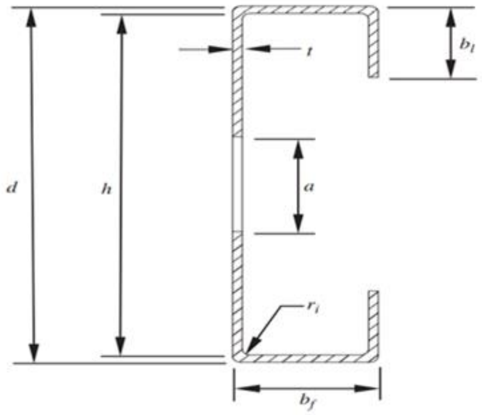


Fig. 3.1. Lipped channel section profile.

Where,

d = Overall Depth of Channel in mm,

h = Plain Height Of Web wthout r_i 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,

l_b = Breadth of lip in mm

4.VALIDATION

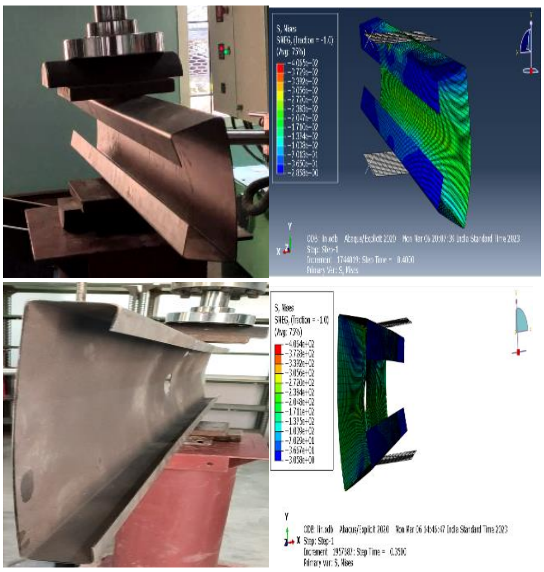


Fig 4.1 Comparison of FEM and experiment

Table 4.1 Validation

S.No	Specimen Id	Length (mm)	P_{TEST} (kN)	P_{FEM} (kN)	P_{TEST}/P_{FEM}
1	151x57x34-t1.2-WOP	755	6.7	6.84	0.98
2	151x57x34-t1.2-WP	755	6.4	6.63	0.97
3	200x55x11.5-t1.2-WOP	1000	5.7	5.74	0.99
4	200x55x11.5-t1.2-WP	1000	5.2	5.45	0.95
5	261x79x17-t1.6-WOP	1305	9.9	9.81	1.01
6	261x79x17-t1.6-WP	1305	9.4	9.48	0.99
7	305x50x24-t1.6-WOP	1525	9.1	9.17	0.99
8	305x50x24-t1.6-WP	1525	7	6.69	1.05
				Mean	0.99
				SD	0.03

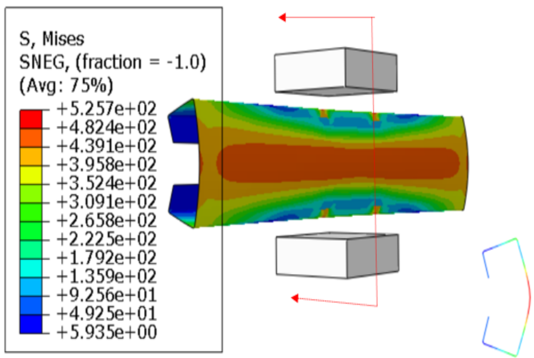
5. PARAMETRIC STUDY

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 ITF 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	Thickness of	inside bent radius ri	Perforation ratio	Number of Model
151 x57 x34	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24
200 x55 x11.5	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24
261 x79 x17	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24
305 x50 x24	1.5, 2.0, 2.5	3, 4, 5	0 to 0.7	24

6. NUMERICAL ANALYSIS

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



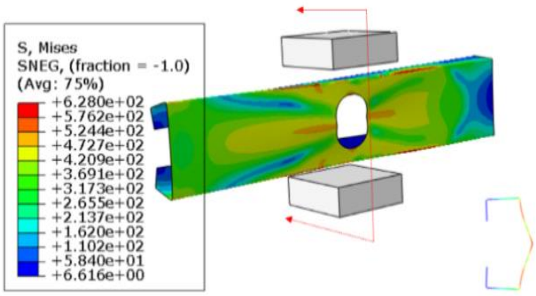


Fig 6.1 Comparison of failure modes of WOP and WP

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

7. RESULTS AND DISCUSSION

Uzzaman(2012) has given the strength reduction factor ($R_{p,uzz}$) using bivariate linear regression analysis for the ITF loading condition. The $R_{p,uzz}$ value is proposed for the yield stress value of 301.8 MPa to 324.6 MPa for web holes located at the mid-depth of the web and centered beneath the bearing plates.

$$R_{p,uzz} = 1.05 - 0.54\left(\frac{a}{h}\right) + 0.01\left(\frac{N}{h}\right) \leq 1$$

Where,

$R_{p,uzz}$ = 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.

The limits for the reduction factor ($R_{p,uzz}$) are $h/t \leq 156$, $N/t \leq 84$, $N/h \leq 0.63$,
$a/h \leq 0.8$.

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(2012) reduction factor with the Reduction factor (Rp). The Reduction factor (Rp) is arrived by taking the ratio of load from FEA analysis (i.e., with perforation to without perforation).

$$R_{p,prop} = 0.9613\left\{1.05 - 0.54\left(\frac{a}{h}\right) + 0.01\left(\frac{N}{h}\right)\right\} + 0.0166 \leq 1 \qquad (7.2)$$

Where,

$R_{p,prop}$ = Proposed reduction factor.

a = Diameter of circular web hole.

h = Depth of the flat portion of web.

N = Length of the bearing plate.

The limits for the reduction factor ($R_{p,prop}$) are $h/t \leq 199$, $N/t \leq 100$, $N/h \leq 1.08$, $a/h \leq 0.7$. Table 7.1 shows the Comparison of Results.

8.CONCLUSION

1. The detailed investigation of web crippling behaviour of cold-formed steel lipped channel sections under ITF 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 ITF 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 15% to 180% when the thicknesss increases from 1.5mm to 2.5mm. The web crippling strength decreases to 5% to 35% when the perforation ratio(a/h) increases from 0.1 to 0.7.
5. The web crippling results were compared with the literature (uzzaman 2012).
6. Since the comparison discloses that available equation was too conservative to predict the ultimate web crippling capacity under ITF load case for higher yield stress values, so the equation was proposed by comparing the FEA results with uzzaman(2012).
7. Moreover, new design equation was proposed based on the uzzaman(2012) equation. Eventually, this project concludes with a proposed equation with respect to uzzaman(2012), which accurately predict the ultimate web crippling capacity of lipped channel sections with cold-formed steel under ITF load case.

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