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

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Abstract-Cold-formed steel sections are widely employed in steel construction because they are lighter and more economical than traditional hot-rolled members. CFS has 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 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 ITF 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 is used to investigate the effect of such holes on web crippling under ITF loading condition. The present paper includes a web crippling strength of the lipped channel beam by comparing the experimental test results with numerical results of 8 sections, where 4 sections are without perforation and 4 sections are with perforation.

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 AND VALIDATION

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

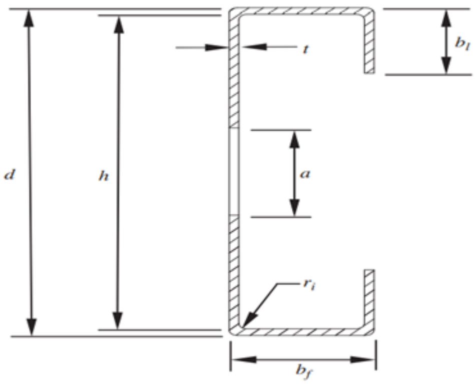


Fig. 3.1. Lipped channel section profile.

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

SECTION LABELLING:

S.No	Specimen Id	Length(mm)
1	151x57x34-t1.2-WOP	755
2	151x57x34-t1.2-WP	755
3	200x55x11.5-t1.2-WOP	1000
4	200x55x11.5-t1.2-WP	1000
5	261x79x17-t1.6-WOP	1305
6	261x79x17-t1.6-WP	1305
7	305x50x24-t1.6-WOP	1525
8	305x50x24-t1.6-WP	1525

Table 3.1. Specimen Details.

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 “151x57x34-t1.2-WOP” and “151x57x34-t1.2-WP” are explained as follows:

The first four notations define the nominal dimensions (d × bf × bl–t1.2) of the specimens in millimetres (i.e. 151 × 57 × 34-t1.2 means d=151 mm; bf=57 mm; bl=34 mm and t=1.2 mm).

“WOP” represents without perforations and “WP” represents with perforation.

In all cases, the holes are located at the mid-depth of web.

4.TENSILE COUPON TEST

The Tensile Coupon Test was conducted to get the material properties. The size of test specimen are in accordance with IS 1608-2005(PART I). These values are given as input to FE Analysis(ABAQUS).

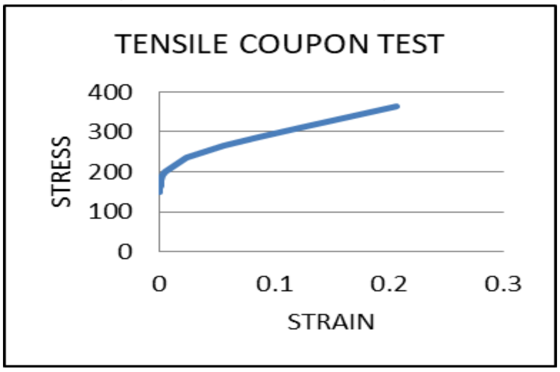


Fig 4.1. Graph obtained from stress-strain curve

5. MATERIAL PROPERTIES USED IN FEM

The elastic properties of the material were assigned to the beam. The value of Young’s modulus (E) is given as $2x10^5$ N/mm^2. The Poisson’s ratio is given as 0.3. The yield stress of the material is 180Mpa. Density of the material is given as $78.5x10^{-6}$ N/mm^3

6.NUMERICAL ANALYSIS

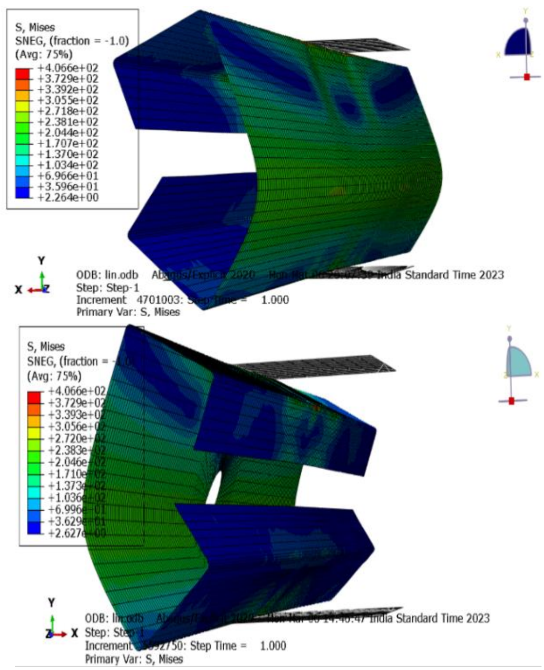


FIG 6.1 - DIFFERENT MODE SHAPES OBTAINED IN ABAQUS

7. EXPERIMENTAL TEST

The experimental test was conducted for 8 different specimens. The experimental set-up is shown in the figure 7.1

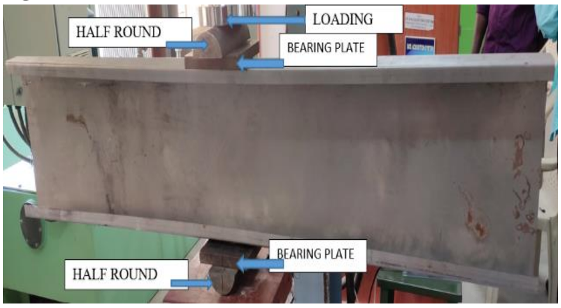
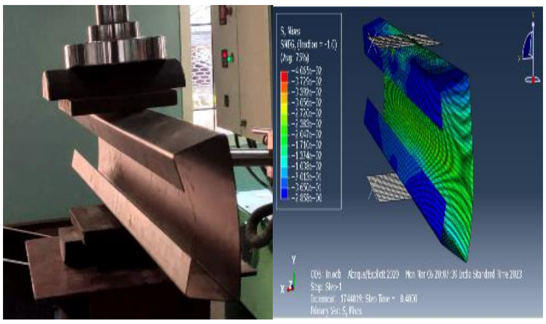


Fig 7.1. Experimental Set up

Fig 7.2 Experimental test for with and without perforation

8. COMPARISON OF ABAQUS (FEM) RESULTS WITH EXPERIMENTAL RESULTS



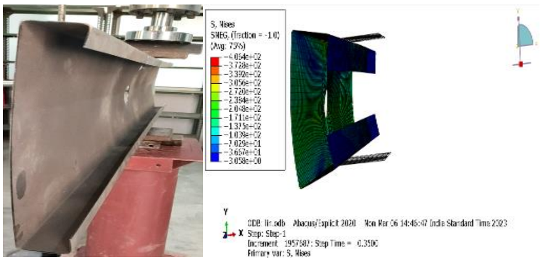


Fig 8.1 Failure mode shapes.

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

9. SUMMARY AND CONCLUSION

In cold-formed steel lipped channels, web perforations are becoming increasingly popular. Such perforations are used to provide access to electric and plumbing lines, however, result in the sections becoming more susceptible to web crippling, especially under concentrated loads/supports reactions applied near the web perforations. This work presents the finite element modeling and validation of web crippling capacity of CFS lipped channels beam with web holes. The finite element software ABAQUS was used to model the cold-formed steel lipped channel sections with web openings subjected to web crippling under ITF loading conditions. The mesh size around the perforation, rigid plate modeling, interaction between the plates and sections and support conditions are carefully modeled to simulate the test results. It is found that the Dynamic Explicit analysis is more suitable to overcome the convergence issues. The developed numerical model was satisfied enough to simulate the test results

The perforation is placed at half the length(L/2) of the specimen for ITF load case. Failure modes of lipped channel under ITF load case with and without web perforation are studied. Local buckling and distortional buckling occurs where the test results nearly matches with the ABAQUS results. As the depth increases, strength reduction also increases. When the depth increases, the strength reduction is 15% to 43% for beam without perforation and 19% to 45% for beam with perforation.

REFERENCE

1. Mojtabaei et al .Development of optimum cold-formed steel beams for serviceability and ultimate limit states using Big Bang-Big Crunch optimisation(2019).
2. Hajirasouliha et al .Optimum design of cold-formed steel beams using Particle Swarm Optimisation method(2016).
3. Sundararajah et al .Experimental Studies of Lipped Channel Beams Subject to Web Crippling under Two-Flange Load Cases(2016).
4. Gardner et al .Description of stress-strain curves for cold-formed steels(2018)
5. Keerthan et al .Improved shear design rules for lipped channel beams with web openings(2014).