Review on Web Crippling Capacity of Cold Formed Steel Sections

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Abstract -*Cold formed steel constructions are common in nowadays due to its benefits including light weight, faster construction and high strength. Major cold formed steel sections used construction activities include channel sections, perforated channel sections, SupaCee sections, Lite steel beam sections etc. However due to the limited thickness of CFS section, they are vulnerable to web crippling. Web crippling is a localized failure occurs when concentrated loads are acting on the section. This paper aims to provide a review in detail about the web crippling capacity analysis for different CFS channel sections along with experimental and FEM modeling of the sections and also describes the major parameters which affect the web crippling capacity of sections.*

Key Words: Cold Formed Steel, Web Crippling Capacity

1. INTRODUCTION

Cold formed steel is more popular than hot rolled steel due to its faster construction, light weight etc. Use of these CFS steel can lead to material savings because of having high strength to weight ratio. Nowadays these CFS section can be used in purlins, floor joists, prefabrication floor and wall panels, trusses and in steel racks. The CFS sections are usually designed as slender members because of having high width to thickness ratio. While subjecting to reaction forces or loading forces the section may get failed due to their limited thickness. The failures include web crippling failure and bending of the sections. Among these web crippling failures are common in which a localized failure occurs when the section is subjected to concentrated loads.

Fig -1: Cold Formed Steel Structures

2. WEB CRIPPLING

Gatheeshkar et al. [5] from his study define web crippling is a localized bearing failure occurs when cold formed steel beams are subjected to concentrated loads. Three main classification of cold formed steel section includes:

1) Single Web
2) Multi Web
3) I Sections

Depending on the load cases and failure locations web crippling failure of cold formed sections with a single web is classified into four types

1) ETF (End Two Flange),
2) ITF (Interior Two Flange Loading),
3) EOF (End One Flange) and
4) IOF (Interior Two Flange Loading).

Janarthanan et al. [8] stated that if failure occurs within 1.5 d_1(where d_1 is the depth of flat portion of web element) from the specimen edge then the load case is termed as end loading and if failure occurs at a distance more than $1.5d_1$ then it is termed as interior loading case. Web crippling strength for a section with lower thickness is lower for ETF load cases than other three cases. Web crippling capacity of section mainly depends on factors including shear area under bearing plate, inter laminar shear strength and shear stress distribution.

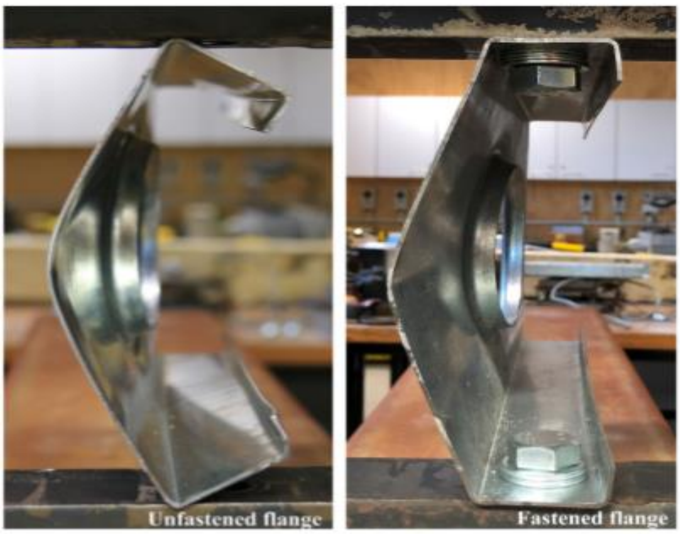
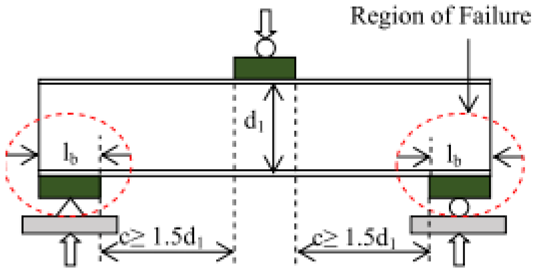


Fig -2: Web Crippling Failure

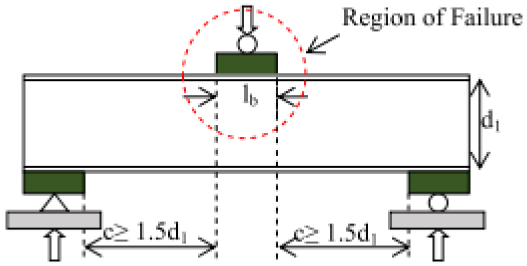
3. LOAD CASES

3.1 End One Flange Loading (EOF)



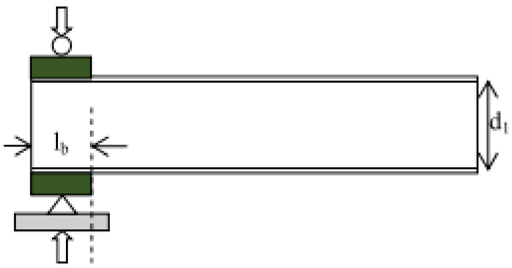
(a) End-One-Flange loading (EOF)

3.2 Interior One Flange Loading (IOF)



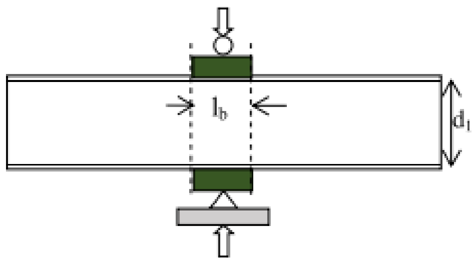
(b) Interior-One-Flange loading (IOF)

3.3 End Two Flange Loading (ETF)



(c) End-Two-Flange loading (ETF)

3.4 Interior Two Flange Loading (ITF)



(d) Interior-Two-Flange loading (ITF)

Fig -3: Load Cases

4. SECTIONS CONSIDERED

4.1 Channel Sections

Various investigations on web crippling capacity of channel sections were conducted by scholars. Channel sections are commonly used in various construction activities today. Channel sections are further classified to lipped channel section and unlipped channel section. Macdonald and Heigentuduwa [15] conducted several investigations on the web crippling capacity of cold formed steel lipped channel beams under all four cases and came to the conclusion that experiment results shows good agreement with FEA results. Janarthanan et al. [8] investigate the web crippling failures in CFS unlipped channel sections by conducting web crippling test on the unlipped channel sections with thickness varying 1.5mm to 6mm and ABACUS was used for FEM modeling.

He also studied the effect of parameters like section thickness, inside bent radius ad bearing length in web crippling capacity. Alsanata et al. [4] studied the behavior of fastened aluminium lipped channel sections subjected to one flange loading conditions and introduce modified design expression given in AS/NSS by taken into account the influence of height and thickness of web in the web crippling capacity.

Fig -4: Channel Sections

4.2 Perforated Channel Sections

Perforated channel sections are provided with the web opening. Usually these openings are important in CFS sections to provide service lines for water supply systems and air conditioning ducts etc. Usually two types of web holes are provided in the channel section

1) centred beneath web holes
2) offset web holes.

The effect of holes in the web crippling capacity were initiated by Yu and Davis by studying web crippling behavior of lipped channel sections with square and circular holes under IOF case In order to know the influence of web openings with different shapes, Sivakumaran and Sielonka

[16] conducted experiment of lipped channel with unfastened support.

4.3 Hollow Flange Section or Lite Steel Beam

Keerthan et al. [13] developed direct strength method equations for Lite Steel beams after conducting 28 web crippling strength tests under two flange load cases. Steau et al.[12] then extend the above analysis by investigate rivet fastened rectangular hollow flange channel beams web crippling behavior under two flange load by conducting 52 web crippling tests.

Hareindirasarma et al.[3] conducted both experimental and numerical analysis to know the effect of circular holes on the web crippling capacity of cold formed Lite steel beams under ITF load case and he studied the effect of parameters including bearing length, yield strength and web opening diameter.

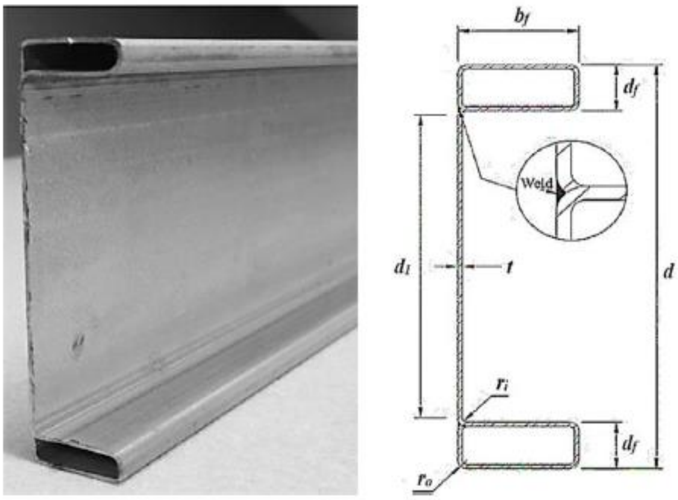


Fig -5: Hollow Flange Sections [3]

Where d is the depth of the section, bf is the flange width , df is the flange depth, d1 is the clear web height ,t is the thickness and r_i is the inside bent radius.

4.4 SupaCee Sections

They are new innovations in the channel sections. The web part of the sections are usually stiffened and provided with lips curved and ribbed web. This ribbed web element make the SupaCee sections more economical than traditional channel sections which are both lipped and unlipped. Usually stiffeners are provided along with the ribbed web. SupaCee sections when compared with lipped and unlipped sections , have enhanced flexural capacities. This channel sections are mainly provided with four web stiffeners which are longitudinally arranged.

Fig -6: SupaCee Sections

5. FEM MODELLING AND ANALYSIS

Due to complexities in plate imperfection, inelastic behavior of web element, non -uniform stress distribution it is not advisable to develop the web crippling capacity equation theoretically. As an alternative, finite element procedures are used by scholars nowadays in order to find the web crippling capacity. Nonlinear static, quasi static dynamic implicit and quasi static dynamic explicit are the FEM analysis commonly used nowadays. From the studies conducted by Natario et al. [10,11] came to the conclusion that nonlinear static procedure is complicated but quasi static dynamic explicit analysis is more easy and accurate.

Ellilarasi et al. [7] stated that for the design of bearing plate, normally use high strength steel with the thickness about 25mm. Two types of length are adopted for bearing plate 1) full flange width of channel section 2) Half width of channel section. The nominal thickness should be varied from 1.3 to 2.0 mm.

For ITF load case, bearing plates were provided in the mid length of specimen and for ETF they were provided in the end of specimen. Length of the specimen has a great influence in the web crippling behavior of sections. Usually the length is taken as twice the height of the channel section. But for accurate results, minimum specimen length can be provided for different load cases based on the equations below:

For EOF and IOF load case $L_{min} = 3(d_1 + \text{bearing length})$

For ETF load case $L_{min} = 3\ d_1$

For ITF load case $L_{min} = 5\ d_1$

Where d_1= clear web height

From the studies conducted by Uzzaman et al. [14] on lipped channel sections under both EOF and IOF cases, provided equation for minimum specimen length for perforated section $3d+ l_b$ for ITF and$1.5d +l_b$ for ETF load case where d is the overall depth of section and l_b is the bearing length.

Mesh sizes play an important role in determining accuracy of results. Fine meshes are usually adopted in corner regions of the section due to transfer of stress from

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the flange to web portion of channel sections. In perforated channel sections, finer meshes are provided around the web opening areas. Displacement control method is used to apply vertical load to the sections. At the nodes of the bearing plate, imposed displacement is applied.

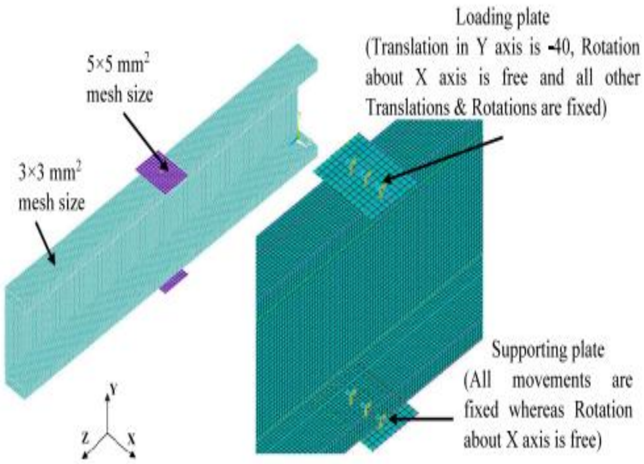


Fig -7: FEM Modeling of Channel Section of ETF load case [3]

Hareindirisarma et al. [3] for their modeling of lite steel beam section they usually used mesh size of 3x 3mm² in the top of the flanges and 5x5 mm² mesh size is applied on the bearing plate or the loading plate. For assigning the support conditions to the bearing plate under ITF load cases, he make X axis rotation is free and the translations and rotations about all the other axis as fixed. For supporting plate he kept X axis rotation is free and all movements about the other axis is fixed. Janarthanan et al. [8] from the modeling of unlipped channel section assigned geometric imperfection magnitude as d/150, but generally takes 0.5tw to t_w as the imperfection magnitude where t_w is the section thickness. He also tested the developed FE models with different coefficients including 0.1,0.2,0.4 and 0.8 and concluded that friction coefficient of 0.8 is used for steel- steel interfaces and friction coefficient of 0.1 for zinc coating. The effect of geometric imperfection on web crippling capacity is very less i.e 2 % for EOF case and 1.23% for IOF case

6. EXPERIMENTAL STUDIES

Uzzaman et al. [14] conducted experimental studies for CFS channel section under ETF loading case. Hinge supports are often provided by using 2 half rounds. Bearing plate is provided for applying load which is act across full flange width. In order to facilitate fastened condition flanges are bolted to the bearing plate. Janarthanan et al. [9] conducted web crippling test in CFS unlipped channel sections for comparing the test results with numerical results. Box beam arrangement is provided for test specimens and the flanges are connected at quarter points by angles. Displacement control method is used for applying mid span load at a rate of 1mm/min.

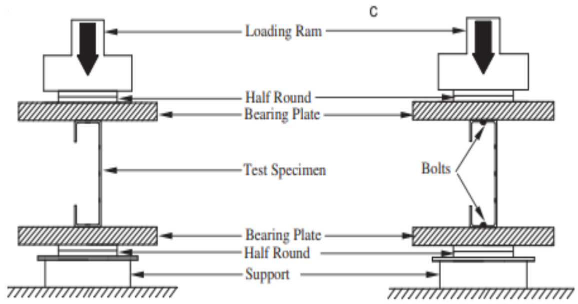


Fig -8: Schematic View of Test Set Up

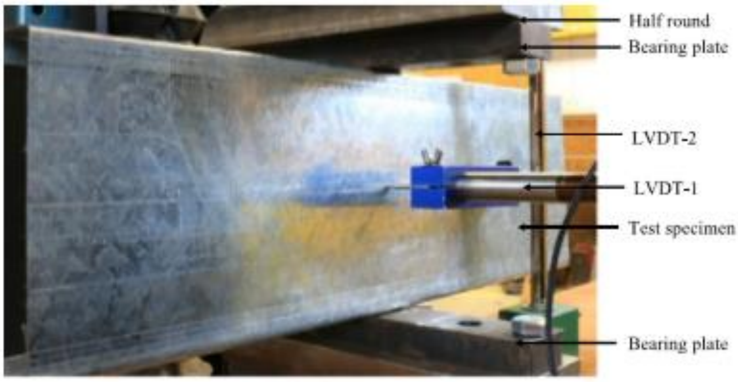


Fig -9: ITF load Case

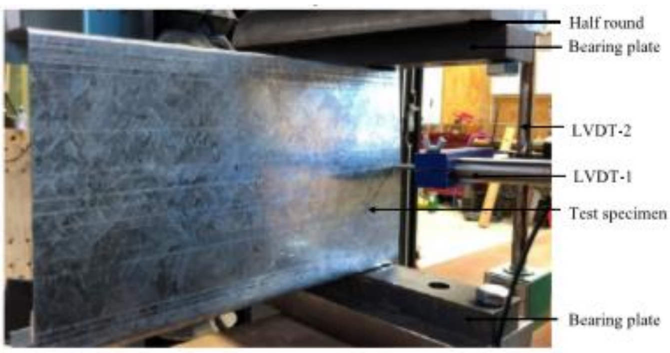


Fig -10: ETF load Case

Fig -11: Web Crippling Test Up [15]

7. FACTORS AFFECTING WEB CRIPPLING CAPACITY

Uzzaman et al. [14] studied the effect of offset web holes in the CFS section web crippling behavior. In his study the size of circular holes kept varying from 40 to 240mm. He conducted parametric study by varying the ratio of diameter of holes to depth of flat portion of web from 0.2 to 0.8 and varying the ratio of distance of hole from the edge of bearing plate to depth of flat portion of web from 0.2 to 0.6

After the analysis of model and compared it with the experimental results he introduce a strength reduction factor for accounting the web crippling capacity after conducting study on the offset web holes effect in the CFS sections. Strength reduction factor is used to determine the reduction in web crippling strength under the influence of web holes and they modified the equation for strength reduction factor for both fastened and unfastened case.

Case 1 : Flanges are unfastened to support

$R_p = 0.95 - 0.49(a/h) + 0.17(x/h) \leq 1$

Case 2 : Flanges are fastened to support

$R_p = 0.96 - 0.36(a/h) + 0.14(x/h) \leq 1$

Where a is the depth of hole, h is the flat portion of the web and x is the distance of hole from the bearing edge.

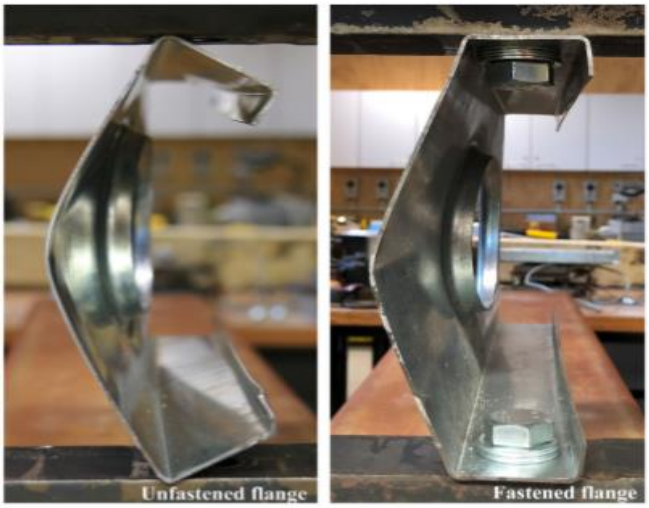
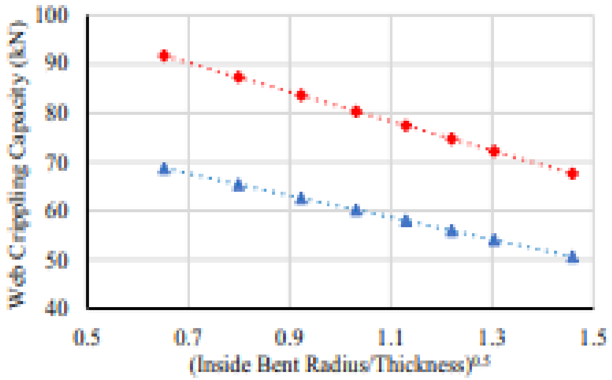
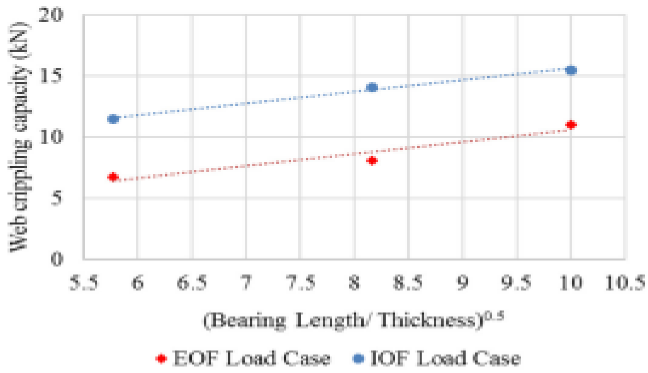


Fig -12: Unfastened and Fastened flange

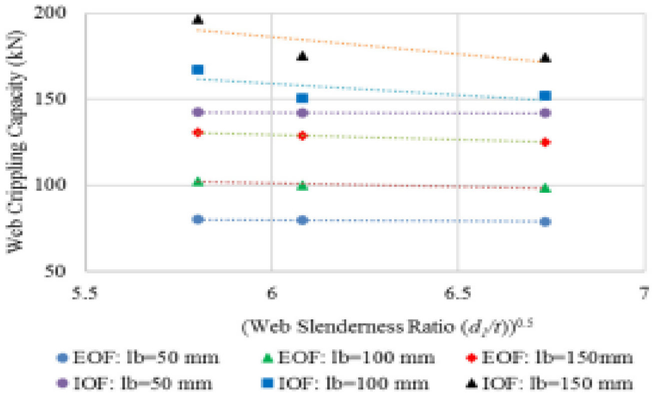
Janarthanan et al. [8] introduce the effect of inside bent radius on web crippling capacity by conducting experiment in unlipped channel section under both EOF and IOF case. In his study the inside bent radius of the unlipped channel section is varied from 2 to 10 mm and stated that with inside bent radius increase there is a decrease in web crippling capacity reduction rate and concluded that there is a reduction in web crippling capacity linearly with the increasing ratio of inside bent radius to thickness of the web. He studied the sections 230x75x6mm,250x90x6mm and 300x90x6mm with different bearing length including 50,100,150mmand concluded that with increase in web slenderness ratio web crippling capacity decrease.



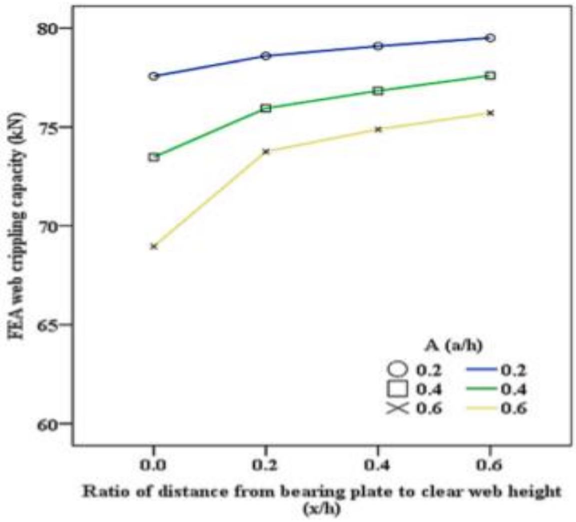
Graph 1: Effect of Inside Bent Radius on Web Crippling Capacity [8]



Graph -2: Effect of Bearing Length in Web Crippling Capacity [8]



Graph 3: Effect of Slenderness ratio in Web Crippling Capacity [8]



Graph 4: Effect of x/h ratio in Web Crippling Capacity [3]

Gatheeshgar et al. [5] stated that web crippling capacity decreases with increase in the web depth of the section while conduct a study to know the combined bending , shear and web crippling capacity of CFS section. In this study lipped channel section is designed for combined bending shear and web crippling and stated that effective width is used to determine the beam bending capacity and the ultimate bending capacity for laterally braced beams is the minimum of bending capacity subjected to two types of failure including local and distortional buckling failures.

The web buckling plays an important role in the determination of shear resistance capacity. Design shear resistance of a channel section is the sum of web shear resistance and flange shear resistance. Web portion of the section contribute a major proportion in the total shear resistance capacity. Four point bending arrangement is provided for conducting bending tests and three point bending arrangement is conducted for analyzing the shear capacity of the section.

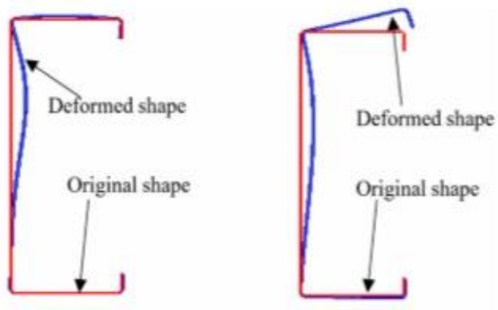


Fig -13: Local and Distortional Buckling

Chen et al.[2] from the study of CFS channel section with edge stiffened, unstiffened web holes and plain webs under two flange loading recognized that edge stiffened web holes have more web crippling capacity when compared with the sections having unstiffened web holes. Sections with fastened flanges have better web crippling capacity compared with unfastened flange. From the study they concluded that there is an increase of web crippling capacity about 71% for ETF load cases and an increase of 30% for ITF load case for fastened flange condition. There is resistance to rotate the flanges when it is fastened to support which will increase the web crippling capacity of the channel section.

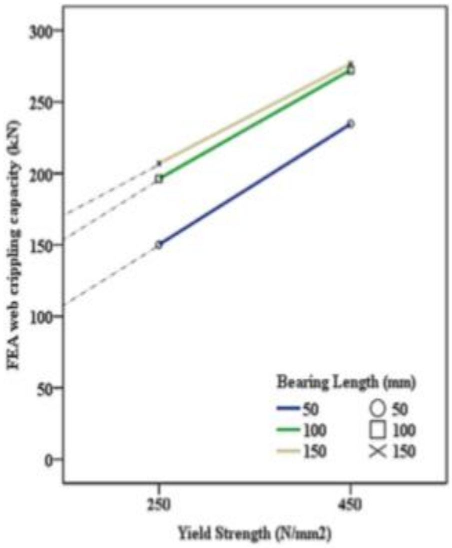
Fig -14: Edge Stiffened Web Hole [2]

Fig -15: Channel Section With Unstiffened Web Hole[2]

Hareindirasarma et al. [3] from their studies on web crippling capacity under the effect of circular holes concluded that web crippling capacity increases with the increase in the horizontal distance from bearing plate to web opening and due to sudden decrease in area with web holes, web crippling capacity decreases, web crippling capacity depends on bearing length to clear web height ratio and web opening diameter to clear web height ratio. Keerthan et al. [13] in their study on web crippling capacity of hollow steel flange the yield strength that he only dealt with is 450 Mpa and he concluded that web crippling capacity linearly vary with the material yield strength. However the study conducted by Hareindirasarma et al.[3] on considering web hole effect in web crippling capacity by varying the yield strength 250 and 450 Mpa and stated that web crippling capacity increases with bearing length and material yield strength. However the relation with web crippling capacity and material yield strength is not in a linear manner and the yield strength factor is proposed

Yield Strength Factor = 1+ Cs $(250/f_y)$

Where fy is the yield strength of the steel



Graph 5: Effect of yield strength in Web Crippling Capacity [3]

Mcintosh et al.[1] by comparing the web crippling capacity of carbon steel, stainless steel and aluminium channels made a conclusion that web crippling capacity of stainless steel is more compared to carbon steel and aluminium channel sections and he stated that modulus of elasticity plays an important role in web crippling behavior of the sections. Aluminium has less web crippling capacity because it has low modulus of elasticity value and due to the strain hardening behavior of stainless steel when subjected to large strain there is an enhancement in web crippling capacity of section

8. CONCLUSION

This paper presents a review on web crippling capacity analysis of different cold formed channel section. It addresses the numerical as well as the experimental web crippling investigations on the Lite steel beam section, channel sections and perforated channel sections considering all four load cases including ITF, ETF, IOF, EOF and the effect of various parameters including bearing length, inside bent radius, web hole diameter and slenderness ratio on the web crippling capacity of the channels considered and came to the conclusion that with the increase in the bearing length, web crippling capacity of a section increase, with the increase in web hole diameter ratio and slenderness ratio, the web crippling capacity decreases.

ABBREVATIONS

CFS- Cold Formed Steel
EOF-End One Flange
IOF- Interior One Flange
ETF- End Two Flange
ITF- Interior Two Flange

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