Finite Element Analysis of Cold-formed steel channels subjected to Web Crippling under End One Flange loading

Litty Sunny[1], Sangeetha S[2]

[1]*PG Student, Holy Kings College of Engineering and Technology, Pampakuda, Muvattupuzha*
[2]*Assistant Professor, Holy Kings College of Engineering and Technology, Pampakuda, Muvattupuzha*

Abstract - *Cold-formed steel members subjected to web crippling below highly concentrated loads or reactions once there is no stiffener on the members. A nonlinear finite element analysis is performed on cold-formed steel channels subjected to web crippling under end one flange loading condition. ANSYS software system is used for this finite element analysis. The finite-element results demonstrate the web crippling strength, web crippling failure modes, and web deformation. The verified finite-element models are then used for a constant study of web holes with and without vertical stiffeners. The influence of stiffeners on the ultimate stiffened web crippling strength was assessed using the data from the numerical modelling of specimens. It is demonstrated that the verified finite-element models give a good and time efficient suggests that to predict web crippling strengths of cold-formed steel members.*

Key Words: Cold-formed steel channels, Web crippling strength, Web holes, Stiffeners.

1. INTRODUCTION

Cold-formed steel members are usually so thin with respect to their widths, these thin elements may buckle at stress levels less than the yield point if they are subjected to compression, shear, bending. Flexural members such as purlins and decks are subjected to concentrated loads and reaction forces. These loads or reactions are concentrated over a short length of flange of a beam. Stress concentration occurs at the junctions of web and flange of the beam. Due to this stress concentration, the web near the region of stress concentration tends to fold over the flange, causing failure. This type of failure is denoted as web crippling. When such a member is subjected to a concentrated load or reaction, its web may cripple due to the high local intensity of the load. Web crippling behavior is identified as a localized failure of web elements just under the bearing loads. Common to sections with unreinforced webs, web crippling is identified by large out-of-plane deformations near the point of loading. Web crippling is a complex problem for theoretical analysis because it is highly dependent on the load positioning, the section geometry, support conditions, and other member cross-section parameters. Web crippling can be prevented by spreading load over large portion of flange. The other remedy is provide stiffeners which bear against flanges at load points and are connected to web to transfer force to it gradually. The other remedy is to make the web thicker.

1.1 Load Cases for Web Crippling

Web crippling may occur under various loading conditions; these loading conditions are defined based on the position of the load or reaction applied, and depending on whether the web is loaded through a single flange or both flanges. The four load cases are End-One-Flange (EOF) loading, Interior-One-Flange loading (IOF), End-Two-Flange loading (ETF), and Interior-Two-Flange loading (ITF).

One-Flange loading refers to a concentrated load being applied to just one flange. Two-Flange loading refers to concentrated loads being applied to both the top and bottom flanges at the same time. When two loads are applied in opposite directions to opposite flanges, and are applied within 1.5 times the height of the member from each other, then two-flange loading occurs. If the loads are separated by a distance greater than 1.5 times the height (measured from the inside edges of bearing plates), then two separate one-flange loadings are said to occur. Similar to IOF and EOF cases, the ITF and ETF cases refer to a Two-Flange loading placed somewhere within the span and a Two- Flange loading located at the end of the span, respectively.

1.2 Objectives of Study

a) To develop and verify the behavior of cold-formed channels subjected to web crippling under end one flange loading (EOF) condition.

b) To compare the behavior of cold-formed unlipped channel sections having web holes with and without stiffeners subjected to web crippling.

2. NUMERICAL INVESTIGATION

The non-linear general purpose finite element program ANSYS was used for the numerical investigation to simulate the web crippling behavior of channel sections having holes with and without vertical stiffeners. The sizes of web holes were varied in order to investigate the effect of web holes on web crippling behavior. Circular web holes with a nominal diameter (a) ranging from 47mm to 231mm were considered in the numerical investigation. All the test specimens were fabricated with circular web holes located at the mid-depth of the webs. The specimens consisted four different section sizes; having nominal thickness ranging from 4mm to 6mm; the nominal depth of the webs and the flange width ranged from 125mm to 300mm. Two length of bearing plates (N) were used: the full flange width of the channel and half flange width of the channel. The web crippling strength was primarily influenced by the ratio of diameter of web holes to depth of flat portion of the web, a/h. The specimen consisted of four different section sizes, having thickness ranging from 4mm to 6mm. The ratios of diameter of web holes (a) to the depth of flat portion of the web (h) were 0.4 and 0.8.

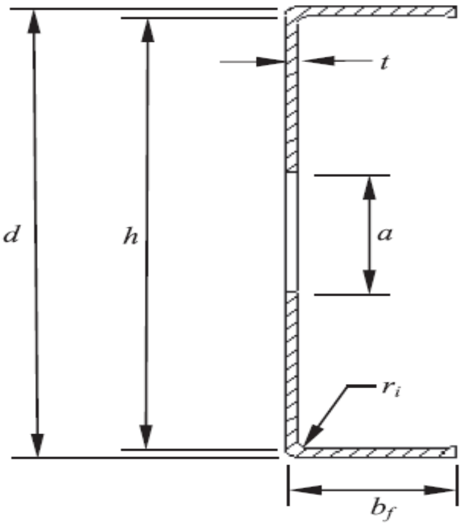

Fig -1 Definition of symbols

2.1 Specimen Labelling

The specimens were labelled such that the nominal dimensions of the specimen, bearing length, ratio of the diameter of the web holes to the depth of the flat portion of the webs (a/h), as well as the stiffened and unstiffened webs could be identified from the label. For example, the labels "125x65x4A0.4S0N65" and "125x65x4A0SRN65" are explained as follows:

- The first three notations indicate the nominal dimensions (dx$b_f$xt) of the specimen in millimeters (i.e. 125x65x4 means d=125mm, b_f= 65mm and t= 4mm)
- "A0.4" represents the ratios of diameter of web holes to the depth of flat portion of the webs (a/h) were 0.4 and 0.8 respectively (i.e. A0.4 means a/h = 0.4) The channel specimens without web holes that are denoted by "A0"
- "SR and S0" indicates channels with and without stiffeners.
- "N65" represents the bearing length in mm (i.e. 65mm)

2.2 Geometry and Material Properties

Cold-formed steel unlipped channel sections were modelled using SHELL181finite elements. It is suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: displacements in the x, y and z directions, and rotations about the x, y and z axes. Bearing plates and load transfer plates were modelled using SOLID186 finite elements.

An effect of large strains, nonlinear behavior, nonlinear contact behavior near the load transfer plates and supports were assessed determining the failure behavior of the specimens subjected to the end one flange loading. The value of Young's modulus of elasticity was 2.03x10^5 N/mm^2 and the Poisson's ratio was 0.3. The material non-linearity was defined in the finite element model by the true values of stresses and strains.

2.3 Loading and Boundary Conditions

The channel specimens were analyzed using end one flange loading condition. The channels are on bonded contact with load transfer block at the central loading point. Two identical bearing plates of same width were positioned at both ends of the specimens. The channels are on bonded contact with the load transfer plates. The flanges of the channels are on frictional contact with a frictional coefficient of k=0.2 with the bearing plates. The stiffeners are on bonded contact with the faces of the channel. The interface between channel section and bearing plate were modelled using the surface to surface contact option. The load transfer plate and bearing plate was the target surface, while the channel sections were the contact surface.

2.4 Parametric Study

The finite element model developed closely predicts the web crippling behavior of channel sections having holes with and without vertical stiffeners. Using this model parametric studies were carried out to study the effect web holes and vertical stiffeners in different cross-sectional sizes on the web crippling strength of the channel sections subjected to web crippling. The specimens with stiffeners were modelled on the end of the channel section and are placed above the center of the bearing plate. A single stiffener with full height was modelled at the expected zone of failure for each of the specimens. The stiffeners are on bonded contact with the faces of the channel section.

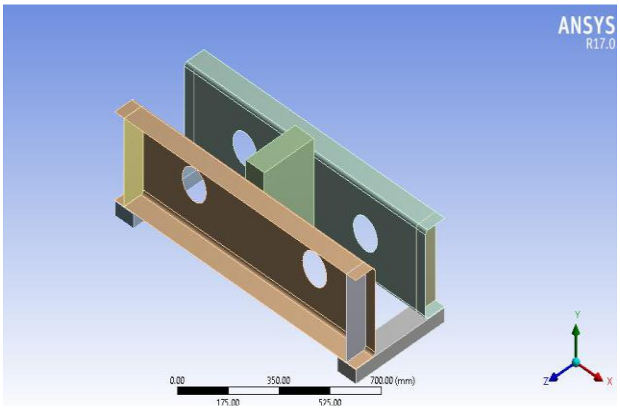

Fig -2: Specimen model: a/h ratio 0.4 with stiffeners

3. RESULTS

Different case studies were carried out on Web crippling resistance on the effect of web holes diameter and bearing length.

3.1 Effect of a/h ratio on web crippling strength

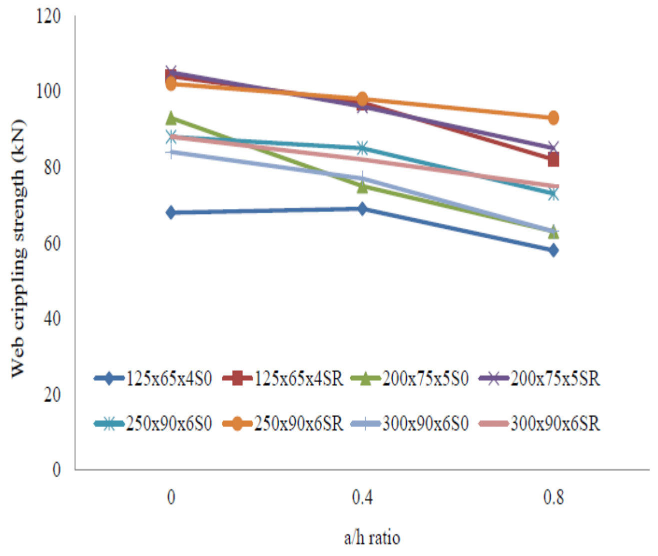

Chart -1: Effect of a/h ratio on web crippling strength, N = b_f

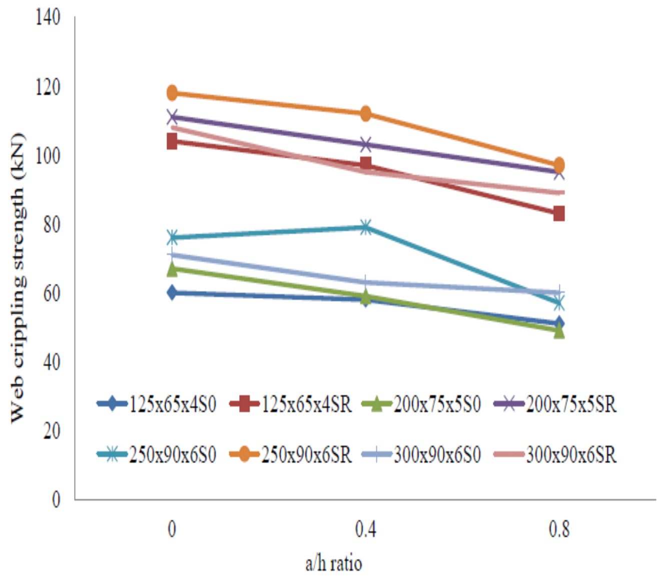

Chart -2: Effect of a/h ratio on web crippling strength, N = 1/2 b_f

As the a/h ratio increases from 0.4 to 0.8 the web crippling strength decreases against the web hole locations. The holes diameter increased from 0.4 to 0.8 it was seen that the ultimate load gets reduced to a small extend and the deformation of the web increased slightly. The stiffened channels show higher crippling strength than unstiffened ones in both bearing lengths. In the case of full flange width as bearing length, there is a slight difference in web crippling strength from 0.4 to 0.8 but in the case of half flange width as bearing length, it shows large decrease in web crippling strength from 0.4 to 0.8.

3.2 Effect of bearing length on web crippling strength

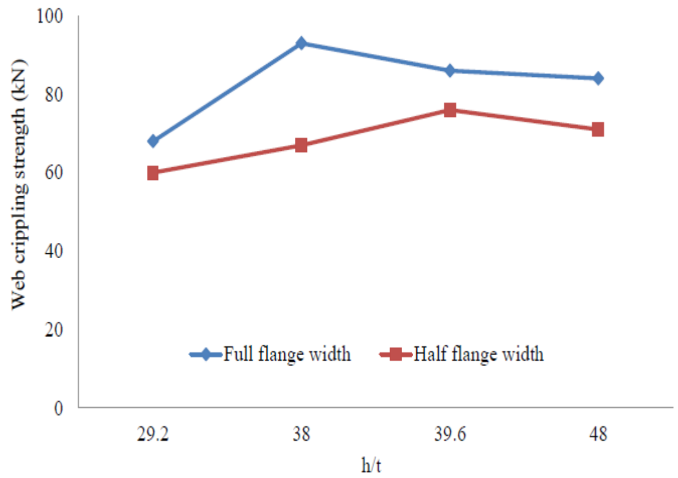

Chart -3: Effect on h/t on web crippling strength without stiffeners

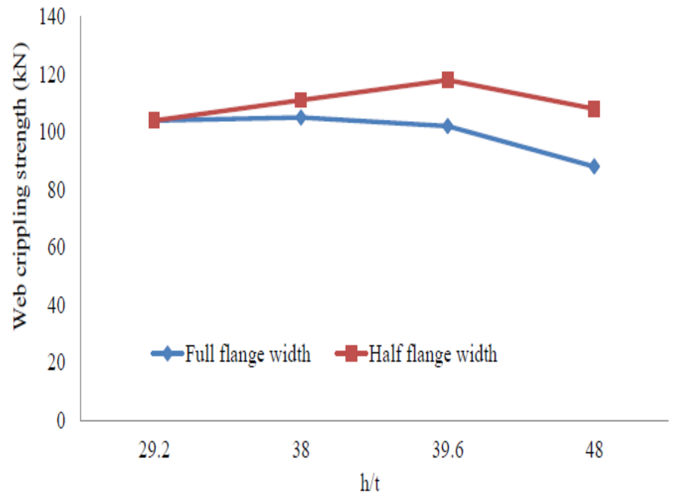

Chart -4: Effect on h/t on web crippling strength with stiffeners

The full flange width bearing length shows higher load carrying capacity in different cross-sections. But the addition of stiffeners the specimens shows better web crippling strength in the case of half flange width bearing length. The full flange width bearing length shows lower strength under stiffened webs.

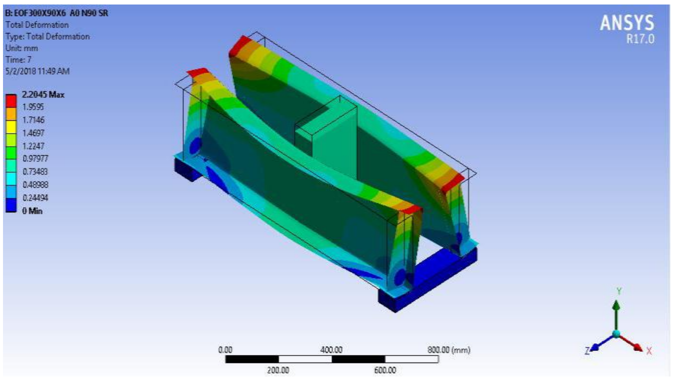

Fig -3: Deformed shape of the channels with stiffeners (b) a/h 0.4 with stiffeners (c) a/h 0.8 with stiffeners

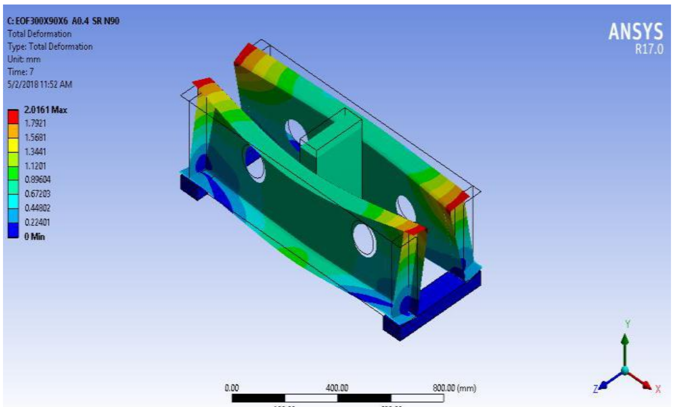

Fig -4: Deformed shape of the specimen having a/h ratio 0.4 with stiffeners (c) a/h 0.8 with stiffeners

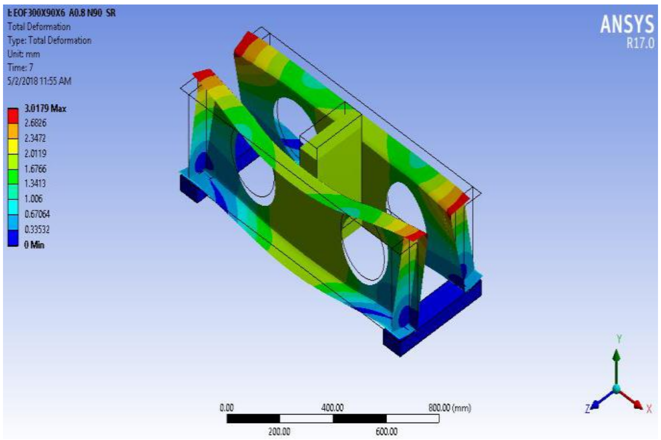

Fig -5: Deformed shape of the specimen having a/h ratio 0.8 with stiffeners

4. CONCLUSIONS

The numerical investigations of unlipped channel sections having circular web holes with stiffeners subjected to web crippling under end one flange loading condition are analyzed. The parameters including diameter of web hole and bearing length are considered in this study. Web holes are located at the mid-depth of the web and the stiffeners are placed on the ends of the channel above the center of bearing length. The finite element results show that the 'a/h' ratios and bearing length influencing the web crippling behavior of the channels with web holes. It was also observed that the cross-sectional dimensions of the channel had an effect on the web crippling strength of unlipped channel sections. The reduction in the web crippling strength was observed at higher web holes diameters. The half flange width bearing length shows good performance of strength on the addition of stiffeners. So the diameter of the holes and the distance from the bearing plates influences the ultimate strength of the section. The provision of stiffeners in channel sections reduces the web crippling to a large extent. The results shows that stiffened webs can significantly improve the web crippling strength of the cold formed steel channel sections.

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