Load Carrying Capacity of Cold Formed Steel Section

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Abstract- *Cold-formed steel members are manufactured from thin sheet steel, cold formed steel are susceptible to elastic buckling. Direct Strength Method (DSM) explicitly defines the relationship between elastic buckling and load deformation response with empirical equations to predict ultimate strength. The effort has also been put to extend DSM by Dr. C D Moen (2008) by analysing and studying cold formed steel member with perforations. Particular column section was modelled with finite element method with different height and thickness combinations. Length to width ratio is varied from 0.5 to 5.75 for section and same section was then analyzed by DSM in CUFSM software. Sufficient database was created through this and graph plotted. In this paper shown, though this method gives fairly accurate results (i.e. variation in DSM and finite element method is up to 20%) for columns with the length to width ratio 1 to 3 but the method is not suitable for length to width ratio 0.5 to 1 and 3 to 5.75*

Keywords- cold formed steel, DSM, slender columns, perforation.

I. INTRODUCTION

In India cold formed steel can be proved as very economical and efficient alternative for large production. Cold Formed Steel has advantages as it has Attractive appearance, Fast construction, Low maintenance, Easy extension, Lower long-term cost, Non-shrinking and non-creeping at ambient temperatures, No requirement of formwork, Termite-proof and corrosion proof, Non combustibility. Also it is a recyclable. Effective width method is majorly accepted around the globe but Direct strength method also got reorganization due to its advantages and simplicity.DSM application got broaden by is extension to sections with perforations. This paper deals with the cold formed section with perforation using DSM.

Lots of research is going on to simplify the design of Cold Formed Steel sections so that it will be more reliable and practically acceptable. Addition of perforations serves lot of advantages for the practical purpose but at the same time it generates complications in design. Considerable efforts are required to study the impact of hole on the strength of the member. The aim of the current research is to study and compare the capacity of perforated columns with the DSM equations and Finite Element Method.

II. ANALYTICAL METHODS USED FOR THIN WALLED STRUCTURES

A. Effective Width Method

Effective Width Method is based on effectiveness of the cross section area. Plate buckling leads to reductions in the effectiveness of the plates gross cross-section area. the equilibrium in an effective plate under a simplified stress distribution and the actual plate with a nonlinear stress distribution due to buckling tells the effective cross section which will be carrying load. This reduction from the gross cross-section to the effective cross-section as shown in Fig. 1

B. Direct Strength Method

The direct strength method (DSM) is the simple design method for the predicting strength for local and distortional buckling and with significant limitations. It also applicable for increase the complexity of section shapes and also increase the complexity of the required mathematical models. DSM has design procedure for elastic buckling of cross section. The particular characteristic of this procedure is that it is based post buckling strength.

Cold-formed steel members are manufactured from thin metal sheet steel, and therefore member resistance is influenced by cross-section instabilities like plate buckling and distortion of open cross section compared to hot rolled steel sections which is critical in the global buckling. DSM is a new tool which predict the strength of a member with any general cross section it defines the relationship between elastic buckling and load deformation with empirical equations for calculating buckling strength

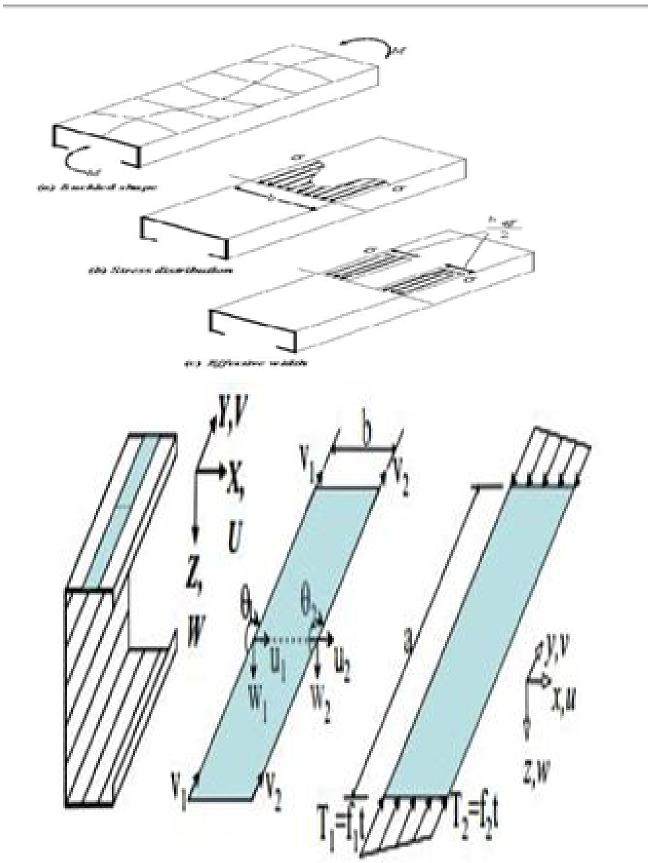

Figure 1: Effective Width Method and DSM

C. Basic Working of DSM

DSM calculate member buckling capacity (Mn) is the minimum of the nominal strengths due to local buckling (Mnl), distortional buckling (Mnd) and global buckling (Me).The nominal strengths of Mnl, Mnd and Mne can be determined using the design equations as provided in the Appendix 1 of the AISI Specification. Safety and resistance factors have been developed both for pre-qualified members and for non-qualified members. Pre-qualified members represent the range of sections used in the development of the DSM design equations and Tables are provided summarizing these dimensions in Appendix 1 of the AISI Specification. The safety and resistance factors provided in AISI Specification Chapter 1.1(b)

To calculate the capacity of cold formed steel member with DSM, finite strip model of section is modeled and the elastic buckling curve is obtained .From an elastic buckling curve elastic buckling properties are obtained for cold formed section.

D. Finite Element Method

Finite element model of the above section was done using ABAQUS - finite element software package. Abaqus is asoftware used for finite element modelling. As far as structural analysis is concerned, the following types of analyses are possible: Static analysis, Modal analysis, Harmonic analysis, Transient dynamic analysis, Spectrum analysis and buckling analysis. The primary unknowns are the nodal degrees of freedom. For structural analysis problems, these degrees of freedoms are displacements. Other quantities such as stresses, strains and reaction forces are derived from the nodal displacements. In general, a finite element solution may be broken into the following three stages.

- Pre-processing: defining the problem.
- Solution: assigning loads, constraints and solving.
- Post processing: further processing and viewing of the results.

III. STRATEGY FOR EXTENDING DSM TO COLUMNS WITH HOLES.

Direct Strength Method can be extended to the columns with perforations by maintaining the assumption that elastic buckling properties of a cold-formed steel column can be used to predict strength. For a column with holes the elastic buckling loads Pcrl, Pcrd, Pcre are calculated including the influence of holes.Moen C. D. has proposed empirical equations for columns with holes to extend DSM method by using finite strip modelling as a part of AISI research program in 2011. These are developed from classical buckling solutions for columns and plates with holes (Moen and Schafer 2009b; Moen and Schafer 2009a). Effect of holes in column section plays an important role in elastic buckling behaviour of column in a Direct Strength approach (Moen 2008).

However, when yielding controls strength, modifications to the existing DSM design. expressions for columns without holes were needed. Engineering intuition tells us that column strength should be limited to the squash load of the column at the net section, Pynet =Anet x Fy, where A is the cross-sectional area at a hole. The net section strength limit i.e. Pynet is used in DSM design expressions f has been taken from experimental analysis from paper (Ortiz-Colberg 1981; Sivakumaran 1987; Miller and Peköz 1994; Abdel-Rahman and Sivakumaran 1998 .)

DSM gives formula for flexural buckling as;

$$\text{For, } \lambda_c \leq 1.5;\ P_{ne} = \left(0.658^{\lambda_c^2}\right) P_y \quad (1)$$

$$\text{For, } \lambda_c\ 1.5;\ P_{ne} = \left(\frac{0.877}{\lambda_c^2}\right) P_y \quad (2)$$

$$\lambda_c = \sqrt{\frac{Py}{Pcre}}$$

$$Py = A_g F_y$$

IV. ANALYTICAL STUDY

The section is selected from S. Narayanan et al. (2003), and analytical study is carried out on it. It is observed that DSM gives very crude results for length to width ratio 0.5 to 1 and 3 to 5.75 of columns with perforations. The section is dimensioned in such a way that it will fail in global buckling only, so that global buckling can be studied thoroughly. Analytical study was carried out by two methods viz. direct strength method and finite element method. Analysis is done through available software packages, CUFSM for DSM which is freely available at http://www.ce.jhu.edu/bschafer/cufsm and ABAQUS for finite element method.

A. Finite Element Modelling

Finite element model of the above section was done using ABAQUS 6.12.1 finite element software package. Abaqus is a general purpose finite element modelling software for numerically solving a wide variety of mechanical problems. For the given model details are:

i. Element type:

Three ABAQUS finite elements commonly employed in the elastic buckling analysis ofthin walled structures are the S9R5, S4 andS4R elements as shown in fig. 2 the S4 and S4R finite elements are four node general purpose shell elements valid for both thick and thin shell problems. Both elements employ linear shape functions to interpolate deformation between nodes. S4R element has been used for meshing the model.

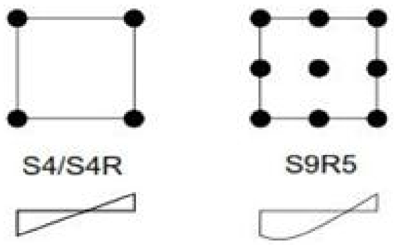

Figure 2: ABAQUS S4\S4R shell element and ABAQUS S9R5 shell element

ii. Boundary conditions and loading:

Boundary condition for the modelled column is pinned-pinned, free to wrap. End cross section nodes are restrained in X and Z direction and nodes at the centre are restrained in Y direction to prevent Rigid Body motion. A reference load of 1 kN is applied as a shell edge load over the perimeter of the column. Column has perforations at 140 cm c/c. Modulus of Elasticity is 212000 MPa and Poission's Ratio as 0.3.

iii. Analysis:

To calculate buckling capacity of section Liner Eigen buckling analysis was performed in Abaqus software and eigen value obtained. It was observed that the convergence was non-monotonic, hence to achieve accuratacy in eigen value, the average value of the models with meshing 30mm and 10mm is obtained and analysis is done.

B. Direct Strength Method: Finite Strip Modelling:

For finite strip analysis CUFSM a freely available program for elastic buckling analysis of thin walled sections is used. The geometry of the section is modelled by giving input as the coordinates of the nodes. Thickness is assigned to nodes.

i. Material Properties:

The following material properties are assigned to the section.

I. Young's modulus = E = 212000 MPa

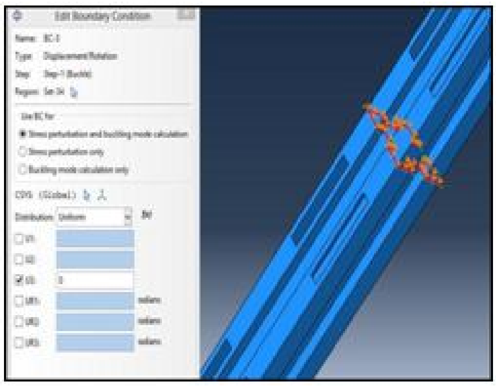

Figure 3: Boundary condition at mid height node

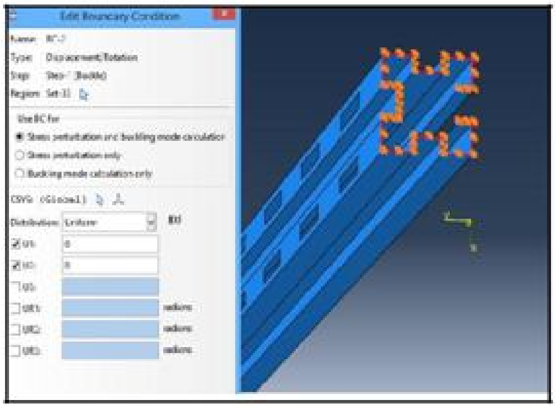

Figure 4: Boundary condition at end nodes

Shear Modulus = G= 8000 MPa
Poison's ratio = v = 0.3

ii. Gross and net section properties:

The gross section and net section properties are calculated with the section property calculator in CUFSM. For net section modelling in CUFSM zero thickness is assigned at the the location of perforation.

To consider the effect of perforation the method suggested by C D Moen and B W Schafer (2011) was adopted and buckling capacity of section was found out.

iii. Procedure For Direct Strength Method:

- Finite strip modelling is done for given column section with the gross section and net section
- Gross section and net section properties are calculated with the section property calculator in CUFSM.
- To determine the net section properties in CUFSM, assign a thickness of zero to the elements at the location of the perforations, but do not delete them.
- For local buckling capacity the gross section of given column section analysed in CUFSM and by taking first minimum on elastic buckling curve
- For distortional buckling capacity as the section does not have distinct local minimum therefore constrained finite strip analysis is performed and reduced thickness is found out and finite strip analysis with reduced web thickness is performed. Reduced web thickness is calculated with Moen and Schafer 2009a
- For global buckling capacity firstly flexural and flexural – torsional buckling capacity is calculated from AISI –S100-07, section C4 and minimum of flexural and flexural – torsional buckling capacity is taken as global buckling capacity.
- By putting above local global and distortional capacity in DSM equation given in AISI section 2.3.5 and by applying suitable factor of safety column capacity of given section is calculated.

V. PARAMETRIC STUDY

A series of parametric study was carried for the given section. The thickness was varied from 0.8mm to 1.8 mm. seven different lengths (1, 1.5, 2, 2.5, 3, 3.1, 4.6 m) were considered for all the thicknesses. Every combination of length and thickness was modelled with Abaqus and CUFSM.

VI. RESULTS AND DISCUSSION

From the results it is observed that for the DSM results for length to width ratio 0.5 to 1 and 3 to 5.75 are not matching with FEM results for same length to width ratio . So there is need of modifying the formulae in terms of variable parameters such as length, thickness, λ etc.

It is observed that as the the accuracy of DSM decreases for length to width ratio 0.5 to 1 and 3 to 5.75. The existing formula for the P is;

$$\text{For, } \lambda_c > 1.5;\ P_{ne} = \left(\frac{0.877}{\lambda_c^2}\right)$$

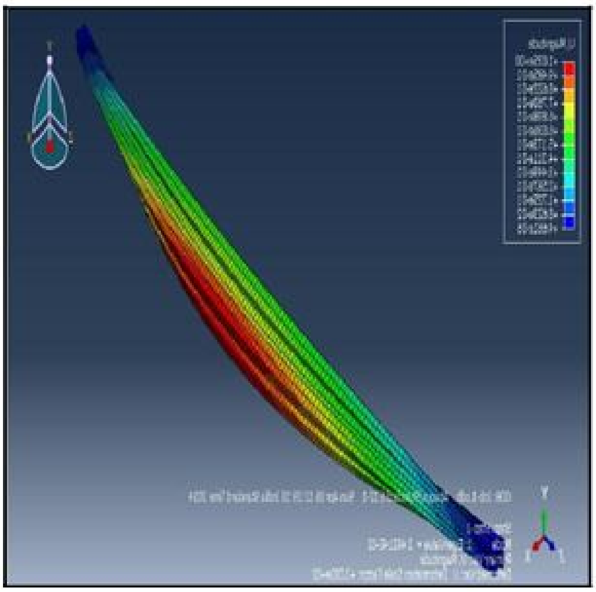

Figure 5: First mode shape of the model

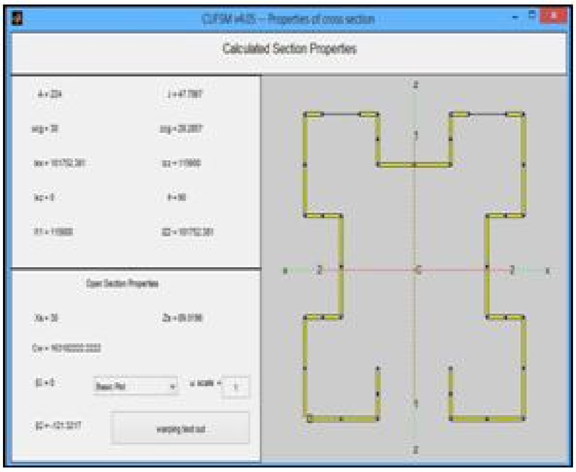

Figure 6: Section geometry of a proposed section

Table 1. Comparison of DSM and FEM

Lengt h (M)	DSM (KN)	FEM (KN)	% DIFF	Capacity With Modified Formula(KN)
1	128.74	264.51	51.33	-
1.5	100.06	130.44	23.29	-
2	70.426	79.206	11.09	-
2.5	46.031	56.597	18.67	-
3	32.1	41.583	22.81	-
3.1	30.107	39.495	23.77	-
4.6	13.875	22.679 01	38.82	21.23939017

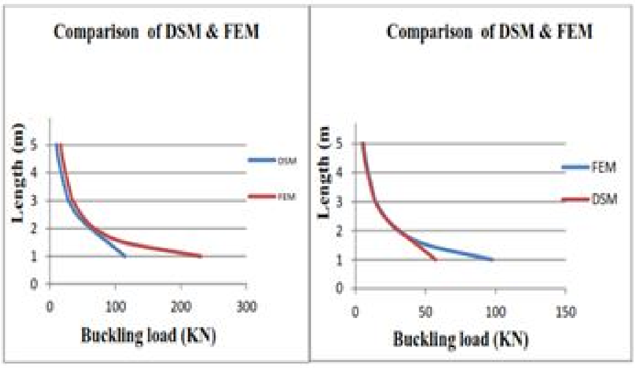

Figure 7: Comparison between DSM and FEM for 1.8 mm and 0.8 mm thick section.

In the existing formula the dependency of P on length, thickness and λ is not considered. But in case of global buckling these parameter plays an important role so t the dependency of length, thickness, λ should be considered in existing formula of P

VII. CONCLUSION

To simplify the design of Cold Formed Steel sections so that to make it more reliable and practically acceptable more efforts in research are taking place nowadays .Cold formed section with perforations are beneficial the practical purpose but it generates complexion in design. More efforts are required to study the effect of perforation incold formed section on the strength of the member

More rigorous study for different sections with different boundary conditions, perforations is needed to carry out to sharpen the existing work on cold formed steel design a so that more accuracy can be attained for predicting buckling capacity of cold formed section.

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