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Effect of Intermediate Web Stiffener on Buckling Behavior of Axially Loaded C-Lipped Cold-Formed Sections

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Abstract:— **This paper presents the influence of shapes of intermediate web stiffener for improving critical elastic buckling load of cold-formed steel lipped channels under axial compression. From the literature, it is observed that the influence of variation in shapes of intermediate web stiffener has not been studied in detail. Therefore, in the present study, the effect of variation in S1/b ratio (depth of intermediate web stiffener to the depth of web) for triangular and quadrilateral intermediate web stiffener on lipped channel sections of length varying from 0.5 m to 6.0 m have been considered. The thickness of the steel plate is kept constant as 1.50 mm, whereas, the ratio of the depth of intermediate web stiffener to the depth of web has been varied from 0.03 to 0.36. The members have been analyzed with both ends fixed and allow translation in the lateral direction. The elastic Eigen value buckling analysis has been performed on 300 models by using finite element analysis method. Local and distortional failure modes were observed for critical elastic buckling load. From the study, it has been observed that the effect of intermediate web stiffener decreases for member length larger than 2.5 m due change in mode shape i.e. local to distortional. It has also been observed that with the increase in depth of intermediate web stiffener the buckling load increases. However, as compared to triangular shape the quadrilateral shape intermediate web stiffener imparts larger resistance to buckling.**

Index Terms **:-- cold-formed steel, intermediate web stiffener, lipped channel, critical elastic buckling load, local buckling, distortional buckling**

I. INTRODUCTION

Cold-formed steel is commonly used in construction industry due to its various advantages over hot rolled steel. Cold-formed steel structures are gaining popularity due to its availability in various shapes and sizes with attractive color coating. Various national codes like IS: 801 – 1975 (Indian) [1], AISI -2007 (American) [2], AS/NZS 4600:2005 (Australian and New Zealand) [3] and Euro code 3 (part 1.3): (2006) (European Union) [4] are available for the design of cold-formed structures. Substantial research work has been done on cold-formed steel structures since 1939. Professor George Winter has done significant pioneering work in this field and also known to be "father of cold-formed steel" [5]. Cold-formed members are thin and hence problem of local and distortional buckling generally governs the buckling load. To improve buckling capacity of cold-formed members, edge stiffeners known as lip along with intermediate stiffener to web or flange of section are provided which makes the shape complex. Due to complex shapes of cold-formed members it is difficult to predict exact failure modes beforehand. To understand appropriate behavior of cold-formed steel under compression, considerable amount of research has been conducted by many researchers. Rasmussen and Hancock [6] performed compression tests on square and circular stainless steel tubes, for stub as well as for long columns. They proposed the design procedure for cold-formed stainless steel structural members. Dhanalakshmi and Shanmugam [7] performed experimental study on several column specimens, to investigate the performance and ultimate load capacity of non-perforated and perforated equal-angle cold-formed steel stub columns. They proposed simplified design formula to determine ultimate load carrying capacity based on parametric study. Popovic et al. [8] conducted number of compression tests on cold-formed steel equal angles with slender cross section. The angles were tested between pinned ends and loaded axially with eccentric loading, which causes bending parallel with leg. The test data are compared with design rules of the Australian and American specifications for cold formed and hot-rolled steel structures, in addition with ASCE standard. They reported that the code recommended specifications for cold-formed steel structures are very conservative. The cause of conservatism was explained and improved design rules were proposed. Schafer [9] studied effect of depth of lip for different buckling modes and proposed new method which incorporates local, distortional and Euler's buckling. Young and Ellobody [10] studied the performance and design of unequal angles subjected to axial

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compression. Parametric study was performed on different cross section geometries by using FE model (ABAQUS). Study shows, the current design rules are un-conservative for short and intermediate column lengths. Hence new design rules for cold-formed steel un-equal angle columns are proposed. Macdonald et al. [11] described some recent methods like direct load method, finite element method, finite strip method and generalized beam theory, for rigorous design analysis of cold-formed members and structures. Young [12] studied the behavior of cold-formed steel with open sections for plain and lipped channels, channels with simple and complex edge stiffeners as well as unequal angles with and without lip. Several design recommendations has been proposed. Bedair [13] presented equivalent modelling strategy to stimulate the actual boundary conditions between the channel components. The effect of lip and flange sizes on buckling and post-buckling load was also studied. Considerable enhancement was observed in the post-buckling stiffness of the web and the flange, if geometric interaction between components of channel section were considered. Kwon et al. [14] conducted number of tests on cold-formed lipped channel section for various lengths to study the interaction between local, distortional and overall buckling mode and proposed the formula to determine the design load and compared with test results. Batista [15] proposed the Effective Section Method (ESM) which is beneficial for designers to detect compressive resistance for local buckling failure mode. Vieira et al. [16] conducted experimental work on cold-formed steel lipped C-section columns (studs) with sheathing attached to the flanges for stability and load determination and compare results with AISI and proposed refine codal provision. Nguyen et al. [17] conducted compression tests on cold-formed plain and dimpled steel columns. It has been observed, dimpled sheets increases the buckling and ultimate load up to 33% and 26% greater than the plain steel columns, respectively. Macdonald and Kulatunga [18] presented numerical investigation on the behaviour of cold-formed thin-walled steel structural members with perforations for better understanding the behaviour of the buckling failure. Kalavagunta et al. [19] conducted the analysis and design of axially compressed cold-formed steel channel section through experimental study. Moharrami et al. [20] carried out the optimization on folding of open cold-formed steel cross sections under compression and observed significant increase in compressive load having optimal cross section i.e. more than three times of original designs. They observed that shape of optimal folding greatly influenced by the choice of boundary condition. Dundu [21] conducted experimental investigation on short cold-formed lipped channel columns compressed between pinned ends. Experimental results were compared with South African standard (SAN 10162-2) and observed that code is un-conservative. Yokar and Alandkar [22] compared the mid line and IS design method to check safe carrying capacity of C-shaped compression members with lips. Shifferaw and Schafer [23] conducted the experimental work on cold-formed angle and lipped channel section to discuss about reserve strength in member after global buckling. Proposed new design approach for strength prediction of cold-formed steel angle columns with fixed end boundary conditions. He and Zhou [24] proposed new equation for prediction of distortional buckling load which is extension of equation given in AS/NZS 4600. Ma et al. [25] detected optimal cross section geometry for cold-formed steel elements to achieve maximum compressive strength. Different lengths were considered with effect of shift of neutral axis due to local buckling. Plate slenderness limits and all limits set by the Eurocode, were considered. Finite element models were used to check the gain in capacity by optimization teqnique. From the literature, it is observed that the influence of variation in shapes of intermediate web stiffener has not been studied in detail. Therefore, in the present study, the effect of variation in S1/b ratio (depth of intermediate web stiffener to the depth of web) for triangular and quadrilateral intermediate web stiffener on lipped channel sections of length varying from 0.5 m to 6.0 m have been considered. The thickness of the steel plate is kept constant as 1.50 mm, whereas, the ratio of the depth of intermediate web stiffener to the depth of web has been varied from 0.03 to 0.36. The members have been analyzed with both ends fixed and allow translation in the lateral direction. The elastic Eigen value buckling analysis has been performed on 300 models by using finite element analysis method using ABAQUS software. Failure modes observed for critical elastic buckling load were local and distortional.

II. GEOMETRICAL AND MATERIAL PROPERTIES

Simple lipped channels and lipped channels with intermediate web stiffener of length (l) varying from 0.50 m to 6.0 m with interval of 0.5 m have been considered. The thickness (t) of steel plate is kept constant as 1.50 mm, whereas, the ratio of depth of intermediate web stiffener (S1) to the depth of web (b) has been varied from 0.03 to 0.36. Different triangular and quadrilateral shapes of intermediate web stiffener have been considered. The figures of the section geometries of simple lipped channel and lipped channel with intermediate web stiffener for triangular and quadrilateral shape are given in Fig. 1 (a), (b) and (c). The cross sectional dimensions for simple lipped channels were suitably selected which are within the range manufactured by pennar industries limited.

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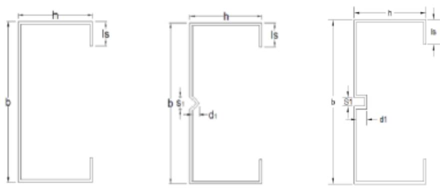


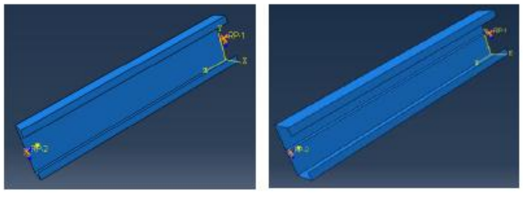
a) Simple lipped channel b) Lipped channel with triangular intermediate web stiffener c) Lipped channel with quadrilateral intermediate web stiffener

Fig. 1. Cross-sectional geometries.

The width of flange (h) of section selected are 50 mm, and the depth of web (b) are 100 mm. The depth of edge stiffener (ls) i.e. lip are 15 mm. The shapes of intermediate web stiffener are varied by varying depth of intermediate stiffener (S1) from 3.0 mm to 36.0 mm with interval of 3 mm by keeping constant width (d1) as 6.0 mm, for both, triangular and quadrilateral intermediate web stiffener. The modulus of elasticity and poisons ratio for the structural steel selected for the analysis are 2.05 x 105 MPa and 0.3 respectively. The yield load of the material are 245 MPa.

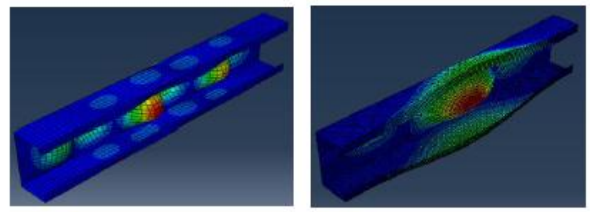
III. METHODOLOGY

The elastic Eigen value buckling analysis has been performed on 300 models by using finite element analysis method using ABAQUS software. Quadratic S8R: 8 noded doubly curved thick shell element was used for discretization of the member with standard function and using reduced integration method. Models were analyzed for various lengths by varying S1/b ratios with both end fixed and allows translation only in the lateral direction. The unit load was applied at the centroid of the section for without and with intermediate web stiffener of channel section as shown in Fig. 2 (a) and (b). Critical mode of failure has been observed for without and with triangular intermediate web stiffener for 0.5 m length of member having *S1/b* ratio as 0.03 as shown in Fig. 3 (a) and (b) and for 3.0 m length of member having *S1/b* ratio as 0.03 as shown in Fig. 4 (a) and (b).



a) without intermediate web stiffener b) with intermediate web stiffener

Fig. 2. Models showing loadings pattern.



a) without intermediate web stiffener b) with triangular intermediate web stiffener

Fig. 3. Critical mode of failure for 0.5 m length of member having S1/b ratio as 0.03.

IV. RESULTS AND DISCUSSION

From the analysis of 300 models, the critical elastic buckling load for the members without intermediate web stiffener (P_{cr}) and with intermediate web stiffener ($P_{cr, is}$) for triangular and quadrilateral intermediate web stiffener with different *S1/b* ratios for various lengths, are plotted in Fig. 5 (a) and (b). Ratios of critical elastic buckling load for triangular and quadrilateral intermediate web stiffener ($P_{cr, is}$) to critical elastic buckling load without intermediate web stiffener (P_{cr}) are plotted in Fig. 6 (a) and (b).

Discussion have been made from the observed results for members without intermediate web stiffener are,

i) Critical mode is local up to 2.5 m and distortional for the length of member from 3.0 to 6.0 m,

ii) Minor reduction in buckling load for the range of lengths from 0.5 to 2.5 m and considerable reduction in the range of lengths from 3.0 to 6.0 m,

iii) Change in mode shape take place from local to distortional and sudden reduction in buckling load in the range of length between 2.5 to 3.0 m.

Discussion have been made from the observed results for members with intermediate web stiffener are,

i) Critical mode is local up to 2.0 m and distortional for the length of member from 2.5 to 6.0 m in both shapes of intermediate web stiffener, i.e. triangular and quadrilateral,

ii) Effect of intermediate web stiffener decreases for member length larger than 2 m due to change in mode shape,

iii) With increase in depth of intermediate web stiffener the buckling load increases significantly for short length members, whereas, with increase in member length the effectiveness reduces and beyond 2.5 m the effect diminishes,

iv) As compared to triangular the quadrilateral shape imparts larger resistance to buckling,

v) Members having triangular intermediate web stiffener with *S1/b* ratio of 0.06 shows unexpected reduction in buckling load and is under further investigation.

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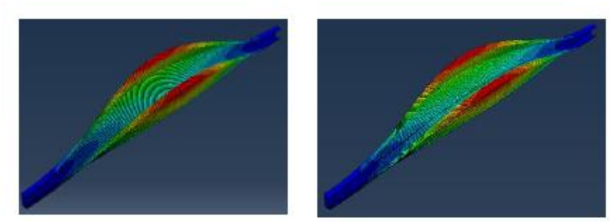
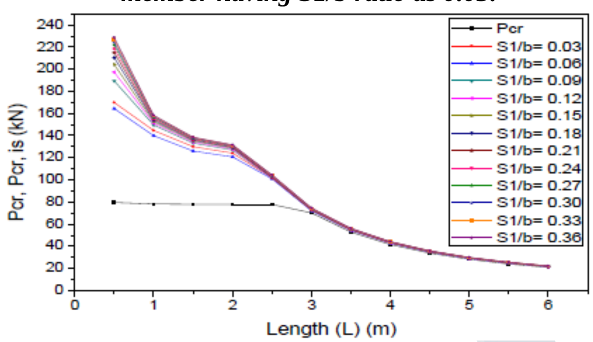
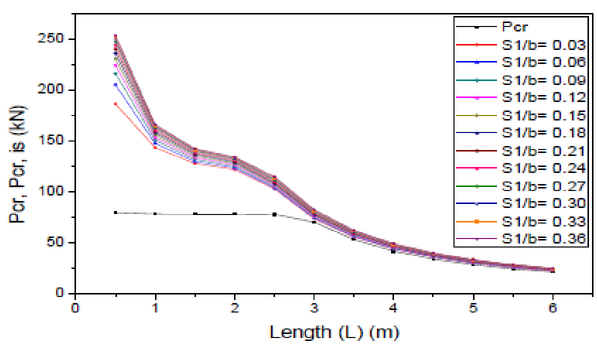


a) Member without intermediate web stiffener
b) Member with triangular intermediate web stiffener

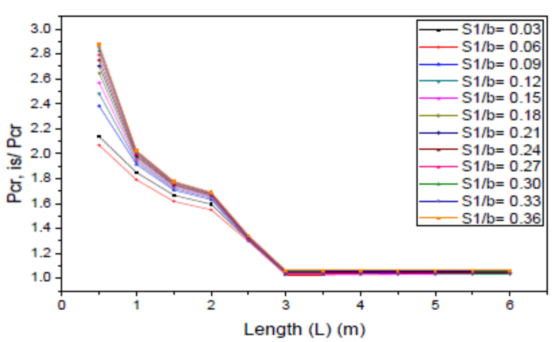
Fig. 4. Critical mode of failure for 3.0 m length of member having S1/b ratio as 0.03.



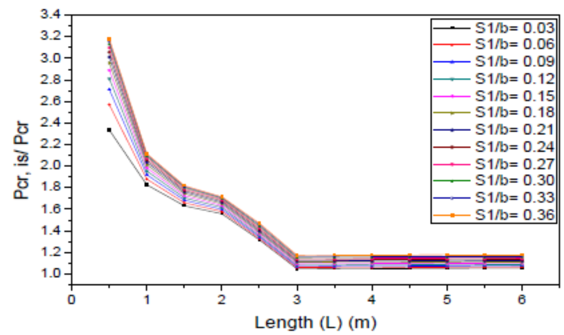
a) Triangular intermediate web stiffener



b) Quadrilateral intermediate web stiffener
Fig. 5. Influence of shape of intermediate web stiffener for various lengths.



a) Triangular intermediate web stiffener



b) Quadrilateral intermediate web stiffener
Fig. 6. Ratios (Pcr, is/ Pcr) shows influence of shape of intermediate web stiffener for various lengths.

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