Numerical Investigation on the Interaction of Local and Global Buckling in Cold Formed Steel Lipped Channel Columns

M. Anbarasu, R. Padmavijayan

Abstract— This paper reports a numerical investigation concerning the post-buckling behaviour of cold-formed steel lipped channel columns under axial compression affected by the interaction of local and global buckling. Three types of lipped channel cross section profile have been chosen for the study, using CUFSM software by trial and error method to obtain local/global interaction. A non-linear finite element model is developed and verified against the experimental data available in literature on cold-formed steel lipped channel columns. Geometric and material non-linearities are included in the finite element model. Static buckling analysis is carried out and buckling modes such as local and distortional are extracted to incorporate the initial imperfections. After the verification of the finite element model extensive parametric study have been carried out by varying the length and thickness. The finite Element Software ABAQUS is used for the study. The column strengths predicted by the finite element analysis are compared with the design column strengths predicted by DSM - AS100:2007, AS/NZ: 4600- 2005. Based on this study the influence of local/global interaction on ultimate strength are discussed and presented.

Keywords- Columns, Buckling, Local/Global Interaction, Axial compression member etc.,

I. INTRODUCTION

The use of cold formed steel structural members in civil engineering application has increased considerably in recent years, primarily due its high strength to weight ratio, and stiffness to weight ratio compared to hot rolled steel members. The compression members may undergo local, distortional, overall and mixed modes of buckling, the accurate prediction on the member strength of thin walled sections becomes more complex. Finite element analysis of cold-formed structures plays an increasingly important role in engineering practice, as it is relatively inexpensive and time efficient compared with physical experiments. In the past, researchers have investigated the various buckling modes of commonly used cold-formed steel sections. Hancock [1] presented a detailed study of a range of buckling modes (local, distortional and flexural-torsional) in lipped channel sections. He showed that the distortional mode of buckling may control the design for certain geometries, especially those with rear flanges or lipped rear flanges. Lau and Hancock [2] provided simple analytical expressions to allow the distortional buckling stress to be calculated explicitly for any geometry of cross-section of thin-walled lipped channel section columns.

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Lau and Hancock [3] provided design curves for sections where the distortional buckling stress and yield stress were approximately equal. Kwon and Hancock [4] studied simple lipped channels and a lipped channel with intermediate stiffener under fixed boundary conditions. They chose section geometry and yield strength of steel to ensure that a substantial post buckling strength reserve occurs in the distortional mode for the test section. Young and Rasmussen [5] studied about the lipped channel columns. Ben young and Jintang Yan [6] studied the lipped channels columns undergoing local, distortional, and overall buckling. Ben young and Jintang Yan [7] studied the design of channels with complex edge stiffeners by direct strength method. The reliability of the direct strength method is evaluated by reliability analysis. Ben Young and Hancock [8] conducted the compression tests on channels with inclined simple edge stiffeners at different angles for both outwards and inwards. Distortional buckling strength of few innovative and complex geometrical sections has been studied by S. Narayanan and M. Mahendran [9]. Ben Young and Ehab Ellobody [10] proposed a design rules for cold-formed steel lipped angle columns. Schafer [11] studied the cold-form member design by direct strength method. Yap and Hancock [12] proposed new design methods for the effects of interaction of local and distortional buckling modes for cross-shaped section. Kwon et al[13] conducted compression tests on high strength cold-formed steel channels with buckling interaction. M.V. Anil Kumar and V. Kalyanaraman [14] studied the evaluation of direct strength method for CFS Compression members without stiffeners. The aim of this paper is to present and discuss numerical result concerning the ultimate capacity and buckling behaviour of simply supported cold-formed steel lipped channel columns under axial compression affected by local and global mode interaction. In order to address this problem, three types of cross section profiles were chosen from the preliminary study conducted by CUFSM software. A validated finite element model of simply supported cold-formed steel columns under axial compression was used in this parametric study to obtain the ultimate capacities of cold-formed steel lipped channel columns by varying parameters such as thickness, section geometry and span. The finite element model was verified against the column tests conducted by Young and Rasmussen [5]. The accuracy of current design rules AS/NZS 4600 [15] Direct Strength Method (DSM)[16] was investigated using the ultimate capacity results from the parametric study.

II. FINITE ELEMENT MODEL

In this research, ABAQUS standard Version 6.10 was used in the finite element analyses of cold-formed steel compression members subject to local/global buckling interaction. The model was based on the centreline dimensions of the cross sections and the base metal thickness was used. The residual stresses of the channel sections were not included in the model. As the cold-formed steel sections are very thin as compared with their other dimension, plate-shell element available in ABACUS software (S4R5) is generally suitable for modelling. Convergence studies were carried out to find the suitable element size of 10 mm x 10 mm were used to model the lipped channel columns. The geometric and material non linearity was used in the model. In order to account for the Elasto-plastic behaviour, a bilinear stress-strain curve is adopted, having a tangent modulus (Et) of 2000 N/mm2. Axial compression load was defined as a concentrated nodal force at the top. It was then distributed to the ends of the specimen through the MPC as shown in Fig. 1. A node was created in the geometric centroid of the section and it was then connected to the edge of the section through the edge nodes to create the MPC. Each node on the edge of the sections is considered a dependent node. These dependent nodes were then connected to the independent node which was created at the geometric centroid of the sections. They were connected by using rigid beams. The load was applied in increments using the modified RIKS method available in the ABAQUS library. Elastic buckling analyses (bifurcation analyses) were first carried out to find the critical buckling load and associated buckling modes of cold-formed steel compression members. Following this, nonlinear analyses were carried out to obtain the ultimate load. After detailed considerations of the literature, the imperfection imperfection was taken equal to the 0.25 times the plate thickness as recommended by [17] for lipped and plain channels were used to initiate the nonlinear analyses. The pin-end conditions of the columns were modeled with the loaded end prevented from both rotation about the z-axis, and translations in both x and y directions. On the other hand, the unloaded end is prevented from translation in the three directions x, y, and z and from rotation along the z-axis which is along the length of the section.

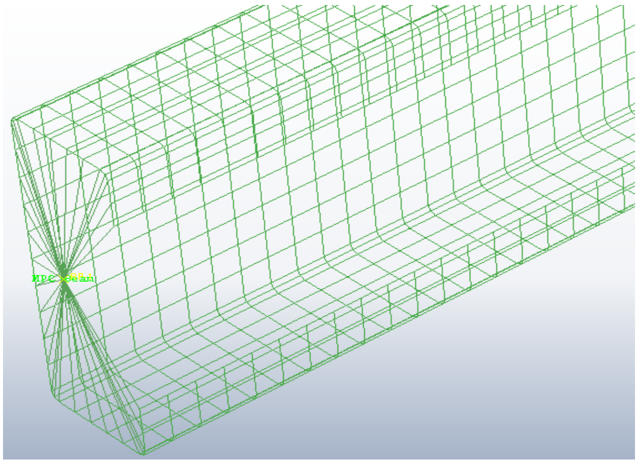

Fig. 1. Meshed model with MPC

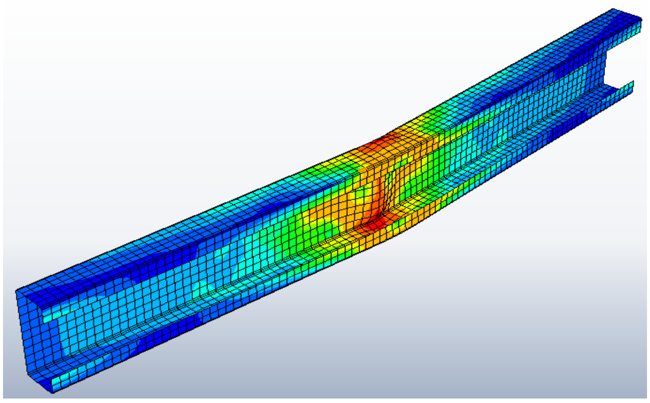

Fig. 2. Ultimate failure mode of LC-144-46-24-2-900

The boundary conditions are introduced to the centroid node and they were distributed to the other nodes through the MPC. Fig. 2 shows the failure mode of the section LC-144-46-24-2-900.

III. VERIFICATION

The accuracy of the used finite element model has been verified by comparing its results to some available experimental studies. The experimental study was conducted by Young and Rasmussen [9], who studied the behavior of cold formed cold-formed lipped channel columns compressed between fixed ends. Six specimens were subjected to axial load from their work were modelled using the finite element computer package. The ultimate load computed by the finite element model has been compared with the values derived experimentally. The comparison between the test results of the ultimate load of the tested specimens, and those computed by the finite element model is presented in Tables 1 and showed a very good agreement between the finite element results and test results.

Table 1 Comparison of finite element and experimental results of Thin-walled lipped channel columns tested by Young and Rasmussen [5]

Specimen Name	Cross Section Dimension in mm	Length in mm	P_{EXP} (kN)	P_{FEM} (kN)	P_{FEM}/P_{EXP}
Specimen 1	97.1-49-12.2-1.47	300	111.9	112.623	1.006
Specimen 2	97.1-49-12.2-1.47	1000	102.3	105.026	1.027
Specimen 3	97.1-49-12.2-1.47	1500	98.6	99.797	1.012
Specimen 4	97.1-49-12.2-1.47	2000	90.1	97.2	1.079
Specimen 5	97.1-49-12.2-1.47	2500	73.9	70.691	0.957
Specimen 6	97.1-49-12.2-1.47	3000	54.3	54.991	1.013
				Mean	1.016
				COV	0.002

For most of the specimens, the ABAQUS results are slightly higher than the test results. The differences including variability in the ABAQUS model are most likely due to assumed imperfections, residual stress and the rounded corners of the sections are ignored.

IV. SECTION DESIGN

The objective was to design a lipped channel section which failed through interaction of local and overall buckling, with no interference of the distortional mode. The cross-sectional dimensions were obtained based on the buckling plots of the compression members from finite strip program CUFSM. The Fig. 3 displays the buckling plot and modes for the series LC-144-46-24-2. The curve displays two distinct minima. The first minimum, corresponding to the shorter wave length, is associated to the local buckling mode. The second minima indicate distortional buckling corresponding to intermediate wave length. The asymptotic curve for the long wave lengths corresponds to overall buckling. It can be seen that due to the presence of a sufficiently large lip, the distortional buckling load factor is significantly higher than the local buckling load factor. Therefore, interference of the distortional buckling mode is deemed unlikely. The cross-sectional dimensions are also satisfies the limitations given for pre-qualified sections for columns in Direct Strength method.

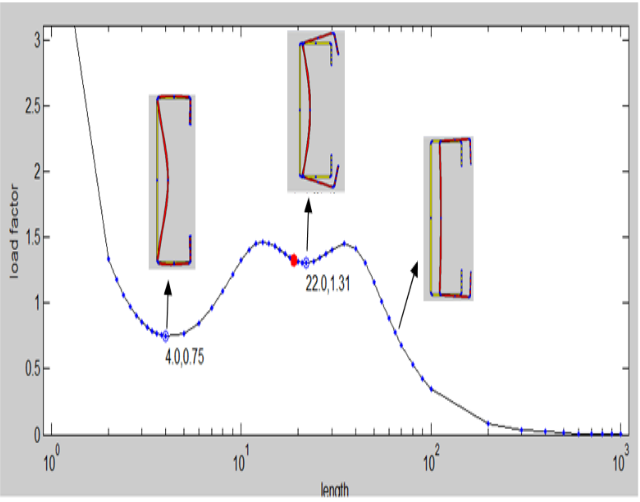

Fig. 3 – Buckling plot and modes of the series LC-144-46-24-2

The chosen dimensions and cross-section profiles are shown in Fig. 4

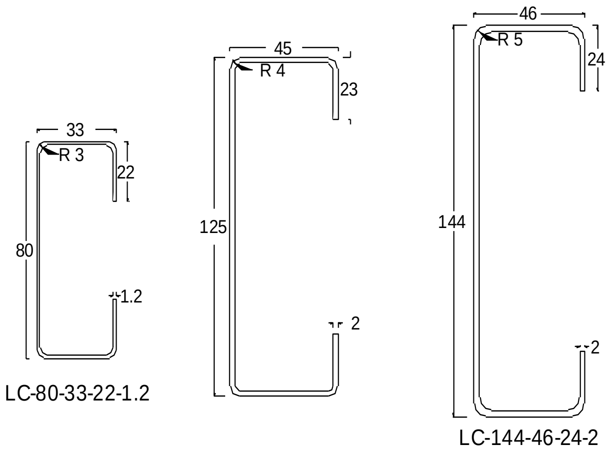

Fig. 4 – Geometry and Dimensions of the columns

V. PARAMETRIC STUDY

It is shown that the FEM closely predicted the column strengths and the behaviour of the tested channels. Hence the model was used for an extensive parametric study of cross-section geometries. Three series of cold-formed lipped channel columns compressed between pinned ends were investigated. The d/b ratio of the selected sections ranges from 2.424 to 3.13. The plate thickness was varied at 1.2 and 2.0 mm. The column length ranged from 400 to 3,200 mm. In total 30 finite element analyses were conducted using the column models. The specimens were labelled such that the type of channels, the width of the web, the width of flange, the lip length, plate thickness and the actual column length could be identified from the label. Fig. 5 explains a typical specimen label for parametric study. Figures and Tables Because the final formatting of your paper is limited in scale, you need to position figures and tables at the top and bottom of each column. Large figures and tables may span both columns. Place figure captions below the figures; place table titles above the tables. If your figure has two parts, include the labels “(a)” and “(b)” as part of the artwork. Please verify that the figures and tables you mention in the text actually exist. Do not put borders around the outside of your figures. Use the abbreviation “Fig.” even at the beginning of a sentence. Do not abbreviate “Table.” Tables are numbered with Roman numerals. Include a note with your final paper indicating that you request color printing. Do not use color unless it is necessary for the proper interpretation of your figures. There is an additional charge for color printing.

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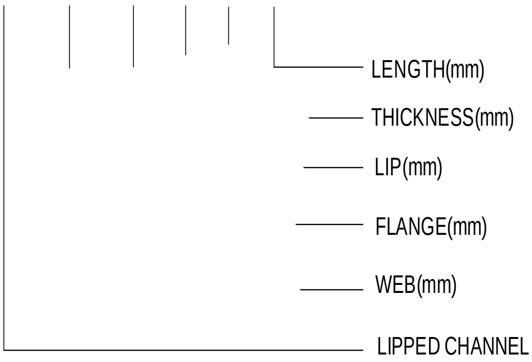

Fig. 5 – Typical specimen label for parametric study

The material properties of the lipped channels used in the parametric study values are Yield Stress (fy) = 350 Mpa, Ultimate Stress (fu) = 435 Mpa, Young's Modulus (E) = 200 GPa ; Tangent Modulus (Et) = 20 Gpa, Poisson's Ratio (m) = 0.3. A scale factor of 25% of the plate thickness of the sections was used in modelling the geometric imperfections of the columns. The finite element mesh used was identical to those used in the FEA. Fig. 6 shows the FEA parametric study results for the series LC-144-46-24-2.

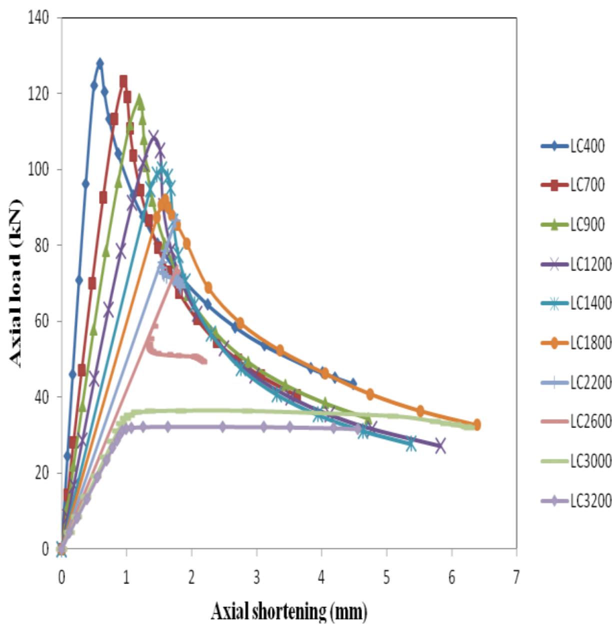

Fig. 6 – Axial load vs axial shortening curves for series LC-144-46-24-2

VI. Comparison of Ultimate Capacities from FEA with Design Column Strengths

The column strengths (PFEA) obtained from the FEA are compared with design curves are shown in Figs. 7–9. The column strengths PFEA obtained from finite element analysis is non-dimensionalized with respect to the squash load (Py) as computed by Py = A fy (Product of yield stress, fy and area of the section.

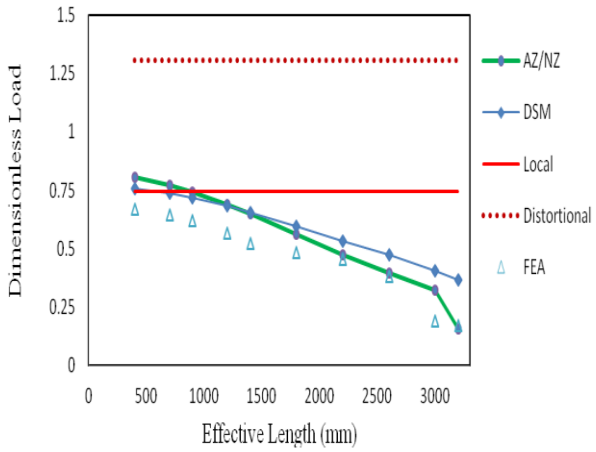

Fig. 7 – Comparison of FEA results with design column strength for series LC-144-46-24-2

The horizontal solid line represents the ratio of the theoretical local buckling load to the squash load against the column length. The horizontal dashed line represents the theoretical distortional buckling load to the squash load against the column length. The design strengths calculated using the two specifications are generally unconservative. The DSM design strengths are unconservative for all channel columns except for length less than 1000mm in the series LC-144-46-24-2. It is found that the DSM design strengths are more unconservative than the AS/NZS design strengths for all channels.

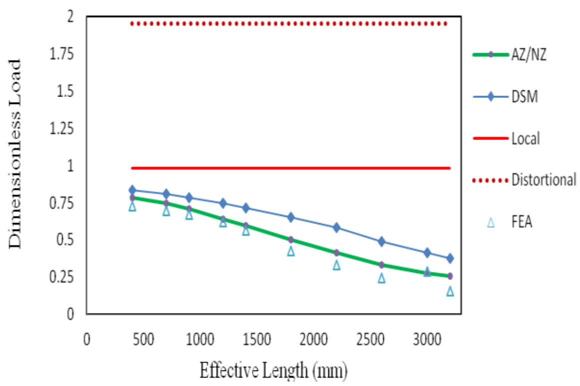

Fig. 8 – Comparison of FEA results with design column strength for series LC-125-45-23-2

For the series LC-80-33-22-1.2, the DSM, AS/NZS design strengths and FEA results are converge after the length of 1800mm.

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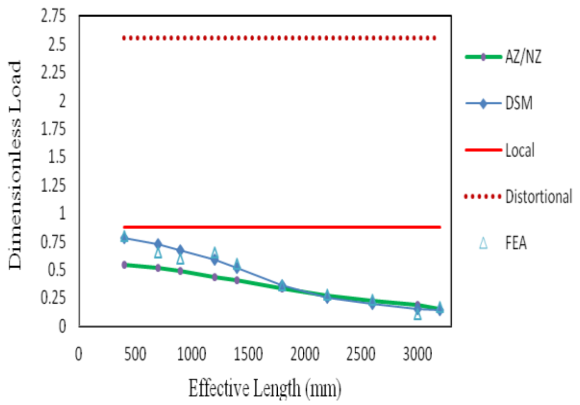

Fig. 9 – Comparison of FEA results with design column strength for series LC-80-33-22-1.2

VII. CONCLUSION

A finite element model for the analysis of pin-ended cold-formed steel lipped channel columns has been presented. The geometric imperfections and strain hardening material properties are included in the finite element model. It is shown that the finite element model accurately predicted the strength and behaviour of lipped channel columns. Hence, a parametric study has been performed to study the effects of local/global buckling interaction on ultimate capacity of lipped channel columns. The column strengths obtained from the finite element analysis in the parametric study were compared with the design strengths predicted by the by DSM - AS100:2007 and the Australian/New Zealand Standard AS/NZS 2005 for cold-formed steel structures. The interaction of local and overall buckling reduced the column strength and made the FEA results lower than the design curves. It is shown that the column design strengths predicted by the by DSM - AS100:2007and AS/NZS Standard are generally unconservative for all lipped channel columns. It is concluded for the study, the interaction of local/global mode leads to premature failure of the members. This investigation has also shown that further research is needed in local/global interaction influence on the ultimate load to be add in the design codal provisions for the design of columns.

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