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INVESTIGATION OF DISTORTIONAL AND GLOBAL BUCKLING INTERACTION ON COLD FORMED STEEL LIPPED CHANNEL COLUMNS

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Abstract

The paper presents the investigation on cold formed steel lipped channel columns experiencing distortional and global buckling interaction under axial compression. Five cross sections are chosen based upon the limitations given in the draft IS 801 code. The cross section dimensions and length ensures equal distortional/global critical buckling loads, thus maximizing the distortional/global mode interaction effects through elastic buckling analysis using CUFSM software. The plate slenderness ratio (b/t) is within the limit to avoid local buckling. The ends of the columns are considered as Pinned-Pinned. The Numerical analysis are carried out by the finite element package ANSYS. Finite element model include the geometric and material non-linearities. Geometric imperfections are incorporated in the model by extracting distortional and global modes obtained from buckling analysis. Parametric studies are carried out by varying the yield stress as 250,350 and 550 N/mm2.Theoretical Analysis are carried out by Direct Strength Method DSM-AISI 100-2007 and Australian Standard AS/NZS:4600-2005.The results are compared and the effect of distortional and global interaction on ultimate strength is discussed.

***Keywords**:* Axial Compression, Buckling Interaction, Cold Formed Steel, Distortional buckling, Global buckling and Lipped Channel Columns

1. 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. 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 directstrength 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 cold-formed steel lipped channel columns under axial compression affected by distortional and global mode interaction. In order to address this problem, five types of cross section profiles were chosen from the preliminary study conducted by CUFSM software. A validated finite element model of 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. 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] and Direct Strength Method (DSM)[16] was investigated using the ultimate capacity results from the parametric study.

2. FINITE ELEMENT MODEL

The Finite Element Program ANSYS version 12.0 was used to simulate the experimental behaviour of pin ended cold formed rack columns. The columns were modeled with 4 nodal shell 181 elements with sharp corners neglecting the corner radius according to the clause 3 of ENV1993-1-3(1996). The residual stresses of the sections were not included in the model. The strain hardening of the corners due to cold forming is neglected. A bilinear elastic-perfect plastic behaviour for material was considered. The material and geometric nonlinearity was included in the finite element model.

A linear elastic buckling analysis was performed first to obtain the buckling loads and associated buckling modes. This was followed by a non-linear ultimate strength analysis to predict the ultimate load capacity. In the nonlinear analysis, initial geometric imperfections were modeled by providing initial out-of-plane deflections to the model. The first elastic buckling mode shape was used to create a geometric imperfection for the non-linear analysis.

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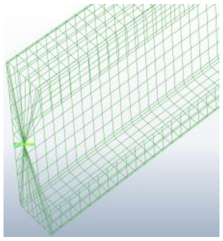

Fig.1 Meshed model

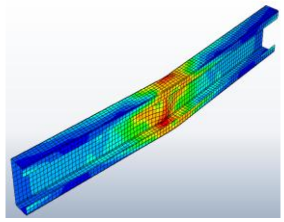

Fig.2 Ultimate failure mode of LC-144-46-24-2-900

3. 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.

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

Table: 1 Comparison of finite element and experimental results of Thin-walled lipped channel columns tested by Young and Rasmussen [3]

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

4. SECTION DESIGN

The objective was to design a lipped channel section which failed through interaction of distortional 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-100-50-10-1.6. 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. The cross-sectional dimensions satisfies the limitations given for pre-qualified sections for columns in Direct Strength method.

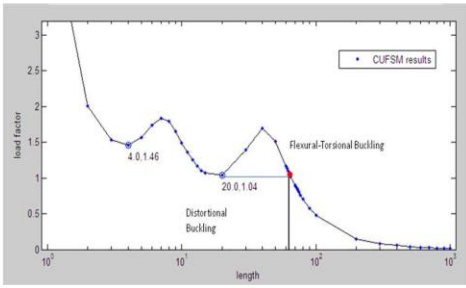

Figure: 3 Buckling plot and modes of the series LC-100-50-10-1.6

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

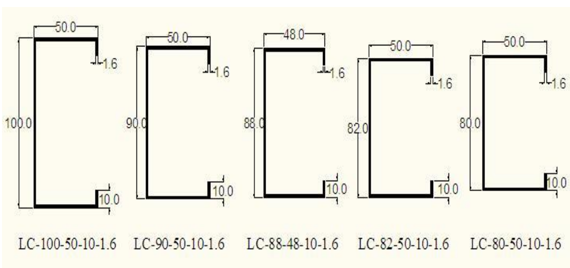

Figure: 4 Geometry and Dimensions of the columns

5. PARAMETRIC STUDY

It is shown that the FEM closely predicted the column strengths and the behaviour of thetested channels. Hence the model was used for an extensive parametric study of cross-section geometries. Five series of cold-formed lipped channel columns compressed between pinned ends were investigated.

The d/b ratio of the selected sections ranges from 1.6 to 2. The plate thickness was 1.6 mm. The column length are in the range of 1500 to 2000 mm. In total 15 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.

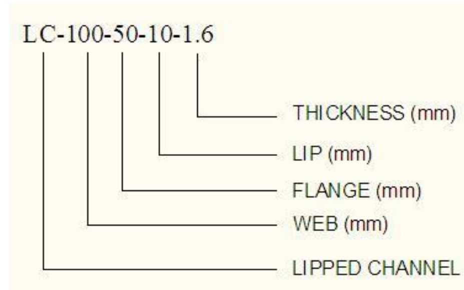

Figure: 5 Typical specimen label for parametric study

The material properties of the lipped channels used in the parametric study values are Yield Stress (f_y) = 350 Mpa, Ultimate Stress (f_u) = 435 Mpa, Young's Modulus (E) = 200 GPa ; Tangent Modulus (E_t) = 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.

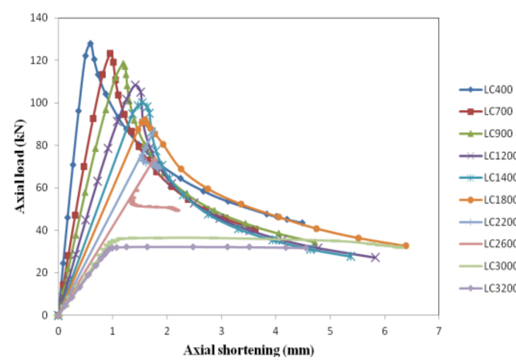

Figure: 6 Axial load vs axial shortening curves for series LC-144-46-24-2

6. 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 distortional/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 - AS100:2007 and AS/NZS Standard are generally unconservative for all lipped channel columns. It is concluded for the study, the interaction of distortional/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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A Brief Author Biography

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