STUDY ON THE BEHAVIOUR OF COLD FORMED STEEL (CFS) RACK COLUMNS

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ABSTRACT

This paper presents the detailed investigation of experimental and numerical studies on the buckling behaviour of cold-formed steel rack columns under axial compression. Compression tests were conducted on four short cold formed rack columns with both end hinged condition. The experimental investigation was focused on the strength and behaviour of cold formed steel rack columns. For each specimen, a shell finite element Eigen buckling and non-linear buckling analysis were conducted using finite element software ANSYS. The finite element analysis included relevant geometric imperfections. It is demonstrated that, the finite element model closely predicts the experimental ultimate loads and the behaviour of the cold-formed rack columns. Comparisons of experimental and numerical results are done. Conclusions and scope for future work is presented based on the results.

Keywords: Cold-Formed Steel Columns, Distortional Buckling, Rack Columns.

INTRODUCTION

The use of cold formed steel structural members in Civil Engineering application has increased considerably in recent years, primarily due to its high strength to weight ratio and stiffness to weight ratio compared to hot rolled steel members. In India, the CFS members are available for the yield stress value ranges from 220 to 350 Mpa. Cold-formed steel sheets have thicknesses ranging from 0.4 to 6.4 mm. Cold forming has the effect of increasing the yield strength of steel, the increase being the consequence of cold working well into the strain-hardening range [5]. These increases are predominant in zones where the metal is bent by folding. The effect of cold working is thus to enhance the mean yield stress by 15% - 30% [1].

Cold formed steel rack column sections are commonly used in rack structures [7]. The compression members undergo local, distortional, overall and mixed modes of buckling, the accurate prediction of the member strength of such sections becomes more complex. Hence, a detailed experimental and numerical investigation on cold-formed steel rack columns under axial compression is discussed in this paper.

Member design for CFS is complicated by the existence of local, distortional, and global buckling modes [3]. In addition, the fundamental modes may interact with one another as well as with material yielding. Two-dimensional compressed plate under different edge conditions will not fail like the one-dimensional members such as columns, when the theoretical critical local buckling stress is reached. The plate will continue to carry additional load by means of the redistribution of stress in the compressive elements after local buckling occurs. This is a well-known phenomenon called post-buckling strength of plates [8]. As a compression member is considered, the length of the columns decides the control of failure mode of CFS members. So based on slenderness ratio, the buckling modes may vary. The rack columns are of structures of having medium length subjected to local and distortional buckling. The rack column sections are good in distortional strength. The rack sections are braced at certain intervals so that, the slender column effect does not come.

1. Literature Survey

In the past, researchers had investigated the various buckling modes of the commonly used cold formed steel section. The most extensive experimental work on the strength of cold-formed steel columns failed in distortional mode is from the University of Sydney; Lau and Handcock (1987) [6], Kwon and Hancock (1992) [4], Hancocok (1985)

[2]. Compression tests were conducted on (a) lipped channels, (b) rack column uprights, (c) rack column uprights with additional outward edge stiffeners, (d) hats, and (e) lipped channels with web stiffeners.

Several Researchers [10-20] experimentally and numerically studied the intermediate length rack columns with lateral ties/connectors to improve the torsional stiffness. Many of them [13-21] extensively studied the buckling characteristics of innovative shapes of cold-formed steel column sections including, rack columns both by numerical and experimental results. The authors used spacers to improve the structural performance of intermediate length columns which are primarily failed in distortional buckling.

2. Aim of the paper

The research in the rack columns with low yield stress value like 250 Mpa is limited. In recent times, no studies have been reported on local and the distortional interaction behaviour of cold formed rack columns with low yield stress. This paper describes the details of such a study. Finite element analysis of cold formed steel structures plays an increasingly important role in engineering practice, as it is relatively inexpensive and time efficient compared with physical tests. However, it is necessary to verify the finite element model against test data in order to provide accurate results. The purpose of this paper is to develop a reasonably accurate finite element model to investigate the strength and behaviour of pin ended cold formed rack columns. The finite element model was verified by column test results. The finite element model includes geometric and material non-linearities.

3. Objective

The objective of the work is to carry out experimental investigations using a UTM and comparing the actual results with Finite Element Model developed using ANSYS Software.

4. Methodology of the Study

Four specimens with the same cross section were manufactured by press braking operation. The specimens were 500 mm long and had four different nominal thicknesses of 1, 1.13, 1.45 and 2 mm. The cross section of the rack column chosen for this study as shown in Figure 1.

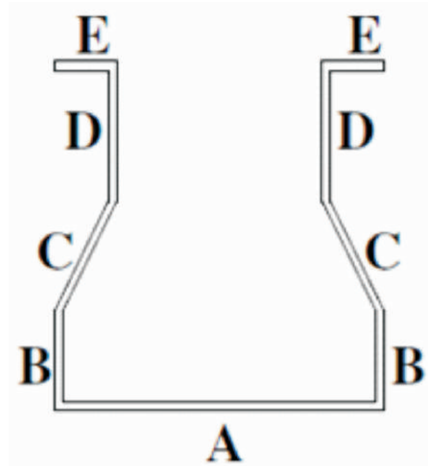

Figure 1. Cross Section of Rack Column

The labeling of the specimens is done in such a way that, the first two characters of the specimen indicate the type of cross section, the second indicated the thickness and the third indicate the length and fourth indicate the end condition.

For Example,

In RC-1.0-500-P section,

RC – indicates Rack Column,

500 – indicates the length of the column = 500 mm, and

P – indicates the pinned end condition

The measured dimensions of test specimens are shown in Table 1.

For the above mentioned 4 number of Columns experimental investigations were carried out using UTM and Numerical investigations are carried using finite element software, ANSYS.

5. Material Properties

The material properties of specimens were determined by tensile coupon tests. The material properties were

Specimen ID	Dimensions in mm				
	A	B	C	D	E
RC-1.0-500-P	80	20.0	29	29	15
RC-1.13-500-P	80	20.4	29	29	15
RC-1.45-500-P	80	20.8	29	29	15
RC-2.0-500-P	80	21.0	29	29	15

Table 1. Measured Dimensions of the Tested Specimens

determined by carrying out standardized tensile tests according to IS 1608-2005 (Part-1).

The material properties are,

Yield Stress (σ_y) = 255 Mpa

Ultimate Stress (σ_u) = 425 Mpa

Young's Modulus (E) = 201 GPa

Tangent Modulus (E_t) = 20.12 Gpa

Poisson's Ratio (m) = 0.3

Percentage (%) of elongation = 27%

6. Experimental Investigation and Results

The buckling half wave lengths that form along the length of the specimens are cross section dependence and can be calculated with the semi analytical finite strip program CUFSM. The finite strip method half wavelengths are useful references to decide the length of the specimens and identify the buckling mode.

The buckling analysis results of the RC-2.0-500-P section obtained using CUFSM is shown in Figure 2.

The local buckling mode for the specimen RC-2.0-500-P has a minimum at around 66.04 mm in half wavelength and the distortional mode has a minimum at around 255 mm in half wavelength. The interaction between local and distortional buckling was expected to occur in the compression tests of the chosen length of the column in the RC-2.0-500-P section. The local and distortional buckling half-wave lengths of all the specimens based on buckling plot are given in Table 2.

Hence, from the above table, the length of the entire four

Specimen ID	Elastic Buckling Half-wave Length	
	Local (L) mm	Distortional (D) mm
RC-1.0-500-P	66.04	228.6
RC-1.13-500-P	60.96	254
RC-1.45-500-P	60.96	254
RC-2.0-500-P	71.12	254

Table 2. FSM Local and Distortional Buckling Half-wave Lengths

specimens is fixed to 500 mm to study the complete interaction between local and distortional buckling.

6.1 Test Setup

The specimens were tested in UTM of capacity 1000 kN under hinged end conditions. Axial deformations and lateral deflection at each load step were recorded. The test setup is shown in Figure 3.

6.2 Test Results

The experimental ultimate loads (P_{Exp}) and failure modes of

Figure 3. Test setup

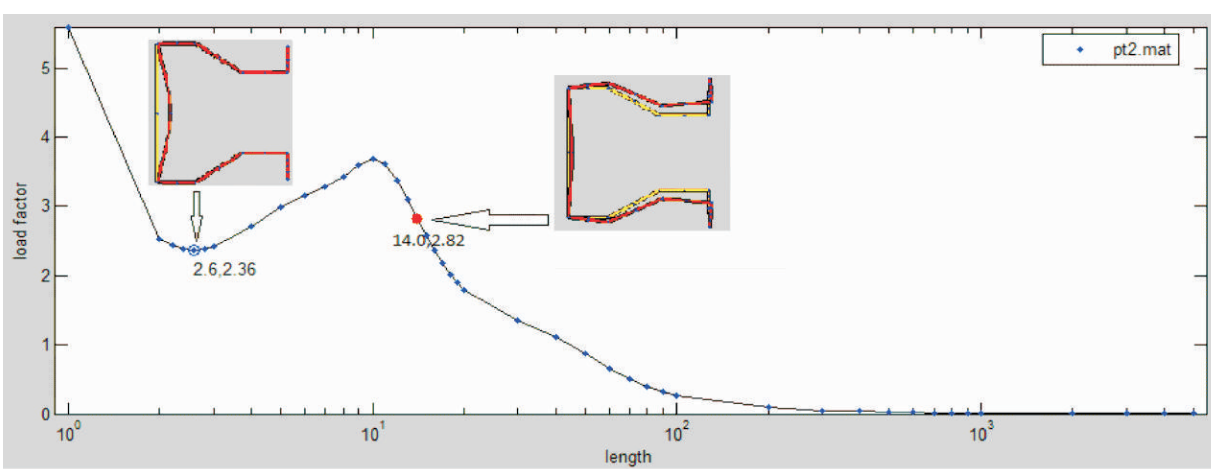

Figure 2. Buckling Plot for RC-2.0-500-P Section

the columns are shown in Table 3.

The failure modes of the ultimate load of the columns involved are local buckling (L) and distortional buckling (D). The failure modes were determined by observation of the deformed test specimens at ultimate load during testing. The tested specimens are shown in Figure 4.

6.3 Numerical Investigation

The finite element program ANSYS version 13.0 was used to simulate the experimental behaviour of pin ended cold formed rack columns. The columns were modelled with 4 nodal shell 181 elements with sharp corners neglecting the corner radius Based on clause 3 of ENV1993-1-3(1996). Appropriate mesh size is chosen after the mesh convergence study. The meshed model and master node is shown in Figure 5.

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-perfectly plastic behaviour of material was considered. The material and geometric nonlinearity were 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 nonlinear analysis.

Specimen ID	Experimental	
	P_{Exp} (kN)	Failure mode
RC-1.0-500-P	47.5	L
RC-1.13-500-P	50	D
RC-1.45-500-P	77	D
RC-2.0-500-P	118	L+D

Table 3. Experimental Ultimate Loads with Failure Modes

Figure 4. Tested Specimens

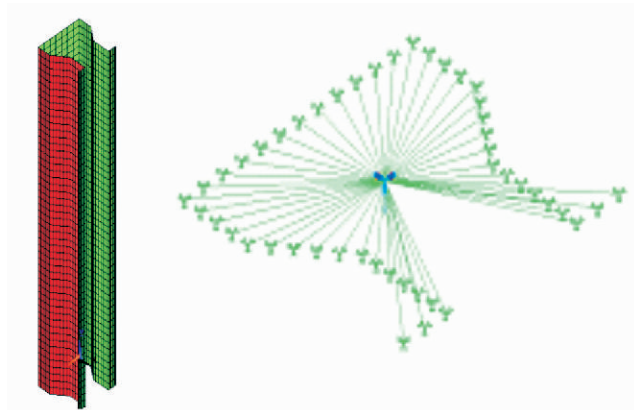

Figure 5. Numerical Model with Master Node

The maximum value of distortional imperfection was initially taken as approximately equal to the plate thickness 't' as recommended by Schafer and Pekoz [9]. Local buckling imperfection was taken as 0.25 times the thickness. Buckled in a local, distortional or mixed mode of local and distortional buckling. This study, therefore did not include any overall imperfections in the finite element analysis. The pin-end conditions of the columns were modeled with the loaded end prevented from both rotation about the y-axis, and translations in both x and z 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 y-axis. A rigid surface was modeled in the loaded end. The load was applied in increment through the master node, which is modeled at the centroid of the section.

The results of the Numerical study are shown in the Table 4. From Table 4, it is observed that the increase in thickness increases the Ultimate load of the rack columns. From Figure 4, it is found that all the tested columns are failing in combined local and distortional buckling. And also

Specimen ID	Finite Element Analysis Loads P_{FEA} (kN)
RC-1.0-500-P	47.44
RC-1.13-500-P	53.39
RC-1.45-500-P	82.65
RC-2.0-500-P	120.88

Table 4. Finite Element Analysis Loads

observed that the column with less thickness predominantly failed by local buckling, the increase in thickness increases the local buckling strength of the rack columns.

7. Result and Discussions

The FE analysis results are validated by comparing it with the experimental results of these four specimens. A comparison between the test results and FEA results of shown in Table 5.

From Table 5, generally it is shown that the ultimate loads obtained from the FEA closely predicted the experimental ultimate loads. The mean and standard deviation of the FEA ultimate loads are 0.9614 and 0.0332 respectively.

The reliability of the FEA Model is illustrated below with the obtained results of RC-1.0-500-P Specimen as shown in Figures 6(a) and (b).

Figure 6 (a) shows the buckling of column test specimen RC-1.0-500-P The specimen failed in combined load and distortional buckling modes. Figure 6 (b) shows the deformed shape of the specimen predicted by the FEA. The deformed shape obtained from the FEA, closely simulated the experimental buckling modes. The resemblances of Figure 6 (a) and Figure 6 (b) demonstrate the reliability of the FEA predictions.

Load versus axial shortening curves predicated by the FEA are compared for RC-1.0-500-P shown in Figure 7.

Conclusions and Recommendations

This paper has presented the details of 4 compression tests conducted to investigate the buckling behaviour and capacities of cold-formed steel rack columns under axial compression, and the corresponding finite element analyses to determine their ultimate loads. Developments of Finite element models are discussed and the corresponding failure modes, ultimate loads and load vs axial shortening behavior are compared. It is found that, the FE models are able to predict the buckling behaviour and ultimate strength of intermediate length rack columns. The further experimental and numerical research is needed to improve the accuracy of design predictions for local and distortional buckling strength of cold formed steel rack columns of low yield stress steel.

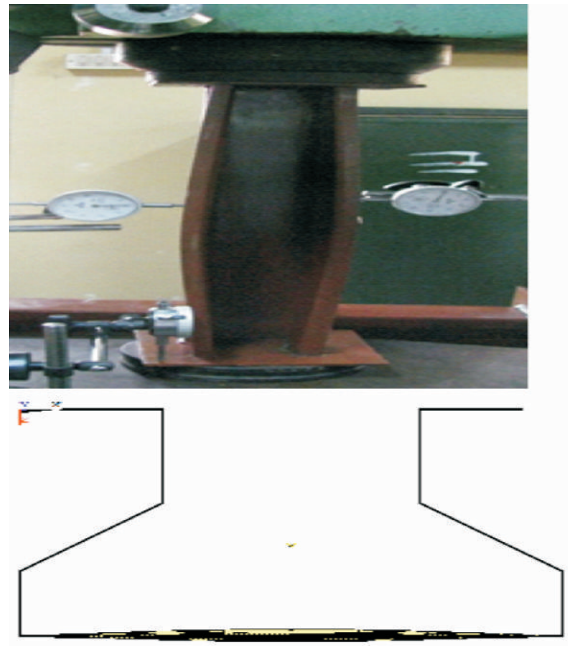

Figure 6 (a) Experimental Result for RC-2.0-500-P

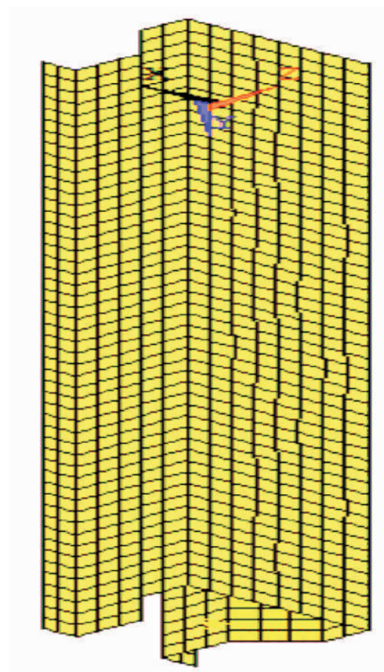

Figure 6 (b) FEA Result for RC-2.0-500-P

Specimen ID	Experimental Load P_{Exp}	FEA Load P_{FEA}	P_{Exp}/P_{FEA}
RC-1.0-500-P	47.5	47.44	1.00
RC-1.13-500-P	50	53.39	0.94
RC-1.45-500-P	77	82.65	0.93
RC-2.0-500-P	118	120.88	0.98
		Mean	0.96
		Standard deviation	0.033

Table 5. Comparison of Experimental and FEA Results

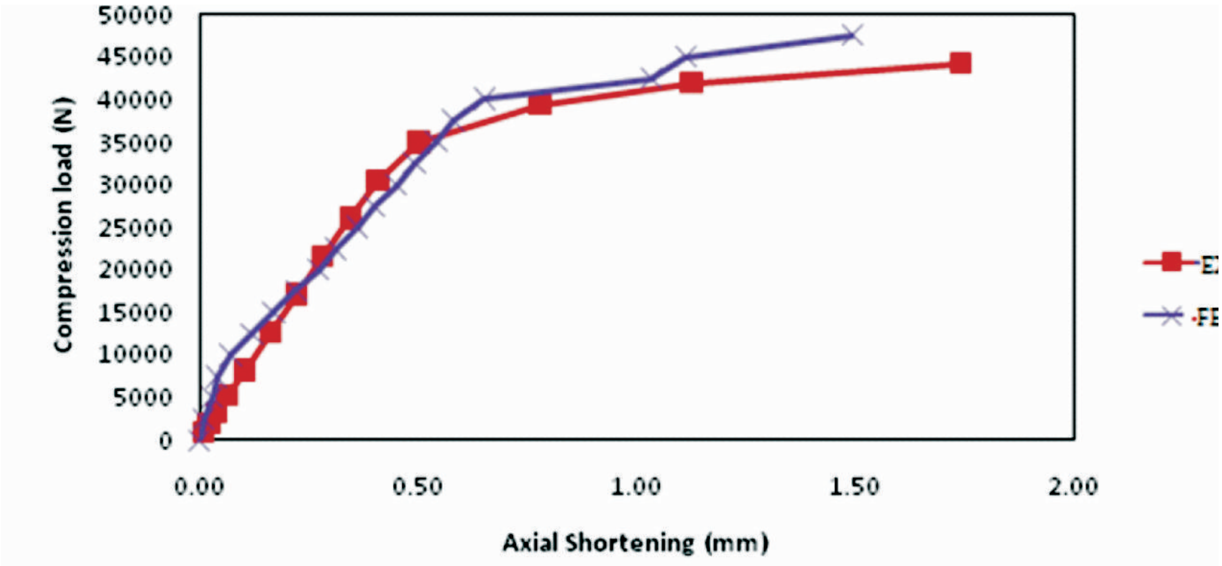

Figure 7. Comparison Load vs Axial Shortening Curve for RC-1.0-500-P

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