NUMERICAL INVESTIGATION ON COLD FORMED PRESS BRAKING STEEL ZED SECTIONS UNDER AXIAL COMPRESSION

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Abstract - *This paper describes a buckling behavior of a series of innovative cold form press braking steel column sections .Buckling behavior was analyzed by both theoretical and Numerical analysis. For the optimization process of arbitrarily shaped thin walled member is done by CUFSM4.03 package. The steel channel and zed sections were considered with various profile and the dimensions were comprises as per the guidelines given in North American Specification (NAS). The parametric study was also carried out by varying the yield stresses and keeping the, thickness and length of the column as constant. The sections were made with cold formed steel sheets of thickness 2mm and 600mm in length. The yield stresses of steel sheets were varied as 250N/mm², 350N/mm² and 550N/mm² which are obtained from preliminary coupon test results. Theoretical analysis was done by Direct Strength Method, which was proposed by B.W.Schafter in 2004[9]. Numerical analysis is done by finite element modelling package ANSYS 12.1 with non-linear analysis on columns. This paper describes the failure modes of buckling in Cold Formed Steel sections and nominal load carried by the column under axial compression.*

Keywords: Cold formed steel, Zed/Zee Section, FEM, DSM, Buckling Mode.

1. INTRODUCTION

Cold formed steel (CFS) is the common term for products made by rolling or pressing steel semi-finished or finished goods at relatively low temperatures (cold working). Cold-formed steel goods are created by the working of steel billet, bar, or sheet using stamping, rolling (including roll forming), or presses to deform it into a usable product. Cold-worked steel products, such as cold-rolled steel (CRS) bar stock and sheet, are commonly used in all areas of manufacturing of durable goods, such as appliances or automobiles, but the phrase cold-formed steel is most prevalently used to describe construction materials. In the construction industry both structural and non-structural elements are created from thin gauges of sheet steel. These building materials encompass columns, beams, joists, studs, floor decking, built-up sections and other components. The strength of elements used for design is usually governed by buckling. The construction practices are more similar to timber framing using screws to assemble stud frames.

A main property of steel, which is used to describe its behaviour, is the stress–strain graph. The stress–strain graphs of cold-formed steel sheet mainly fall into two categories. They are sharp yielding and gradual yielding type illustrated below in Figure 1 and Figure 2, respectively.1.1

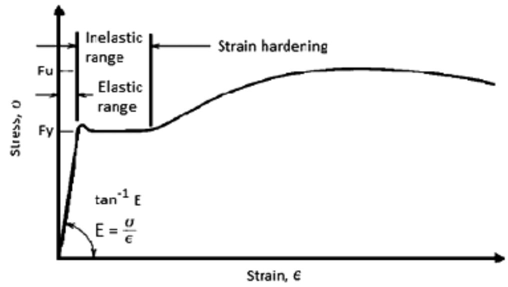

Figure -1 Sharp Yielding type

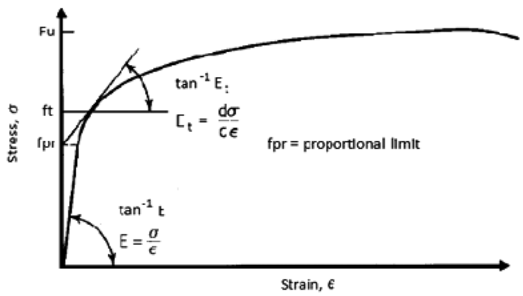

Figure -2 Gradual Yielding Type

1.1 Review Literature

A literature review or narrative review is a type of review article. A literature review is a scholarly paper, which includes the current knowledge including substantive findings, as well as theoretical and methodological contributions to a particular topic. Some of the literature reviews for our cold formed steel members are as follows,

André Dias Martins, et al (2017) proposed a topic on 'The direct strength design of cold-formed steel columns failing in local- distortional interactive modes.' They discuss proposals for the codification of efficient design approaches for cold-formed steel columns affected by local-distortional (L-D) interaction.

R.S. Glauz (2017) proposed on topic 'Flexural-torsional buckling of general cold-formed steel columns with unequal unbraced lengths'. The design of cold-formed steel columns must consider flexural buckling, torsional buckling, and flexural- torsional buckling.

Tekcham Gishan Singh, et al (2017) explains the main concept of Structural performance of YSt–310 cold–formed tubular steel stub columns. A comprehensive experimental and numerical programme to investigate material characteristics and stub column member capacities of YSt 310 cold–formed SHS and RHS was conducted.

Helder D. Craveiro, et al (2016) did an Experimental analysis of built up closed cold formed steel columns with restrained thermal elongation under fire conditions. The investigation is that the interaction between the initial applied load and imposed level of restraint to thermal elongation may significantly influence the overall behaviour of cold formed steel columns under fire conditions.

Yan Lu, et al (2017) determines the Novel local buckling formulae for cold-formed C-section columns considering end condition effect. They derived a novel local buckling formula for cold-formed C-section column, which takes both the effects of cross-section plate element interactions and end conditions into account.

Jia-Hui Zhang, et al (2015) proposed the Numerical investigation and design of cold-formed steel built-up open section columns with longitudinal stiffeners. It recommends that the built-up open section columns with longitudinal stiffeners can be used as a prequalified section for column design in the current DSM.

C. Jiang et al (1998) investigated the Design of Thin-Walled Purlins for Distortional Buckling. It offers accurate approach to cladding restraint problems that can change the conventional lateral-torsional buckling mode of failure into one of distortional buckling which increases the stability of the purlin.

1.2 Scope of study

The scope of the study is to check for the effective performance of cold formed steel column sections that carry ultimate load with low buckling failure values and failure mode is predicted by carrying out various methods of analysis. CUFSM 4.03 (Constrained and Unconstrained Finite Strip Method) is used to calculate the buckling stress and buckling mode of arbitrarily shaped thin walled members. Numerical analysis is done by finite element modelling package ANSYS 12.1 (Analysis of Systems) with non-linear analysis on columns. Among the various sections with constant length and thickness and varying yield strength, the section and check which section profile that gives satisfactory results and showing effective performance is the efficient design approach of the columns. This is major parameter that the project concentrates by carrying out experiments and to compare the test results under compression.

2 PARAMETRIC STUDIES

By keeping the length and thickness of the members as constant, the yield strength of the members get varied.

From the above mentioned property of materials, varying cross sectional profile of Zed sections was derived.

Z1 – Plain Lipped Zed Section
Z2 – Plain lip stiffened Zed Section
Z3 – Plain lip stiffened Zed Section by inclined members
Z4 – Flange stiffened Zed Section
Z5 – Flange and Web stiffened Zed Section

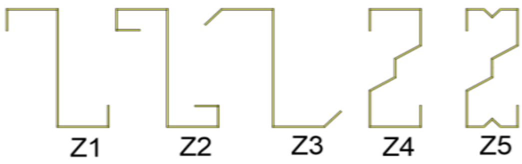

Figure -3 Cross sectional Profile of Specimen

Table -1: Parametric Study

Specifications	Data	Specifications	Data
Length	600mm	Poison's ratio	0.3
Thickness	2mm	Yield stress	250N/mm^2 350N/mm^2 550N/mm^2
Depth	160mm	Web stiffener angle	30^0
Width	65mm	Flange stiffener angle	45^0
Young's modulus	2.03 x 10^5 N/mm^2	Lip depth	30mm

2.1 Optimization of section

The column properties that fall within the geometrical limitation from DSM specifications of cold formed steel design as follows.

Table -2 Section Optimization

Parameter	Observed result	Status
76< h/t < 137	80	Satisfied
30< b/t < 56	32.5	Satisfied
0< d/t < 36	15	Satisfied
1.5 < h/b < 2.7	2.46	Satisfied

0 < d/b < 0.73	0.464	Satisfied
θ 50 deg	45^0 & 30^0	Satisfied

2.2 Theoretical Investigation

The methods used for the computation of buckling load and load factors are presented below.

2.2.1 Direct-Strength Method

Direct Strength, has been created that aims to alleviate the current complexity, ease calculation, and provide a more robust and flexible design procedure, and integrate with available, established, numerical methods."

Use of the Direct Strength Method requires (1) Determination of the elastic buckling behaviour of the member and (2) Using that information in a series of ultimate strength curves to predict the strength.
Design Equations:

1. Local buckling load:

$$1 - 0.15\left(\left(\frac{Pcrl}{Pne}\right)\right)^{0.4} x \left(\left(\frac{Pcrl}{Pne}\right)\right)^{0.4} P_{ne}$$

2. Distortional buckling load:

$$\left(1 - 0.25\left(\frac{Pcrd}{py}\right)^{0.6}\right) \mathrm{x} \left(\frac{Pcrd}{Py}\right)^{0.6} x\ Py$$

2.2.2 Indian Standard Method

India Specification: IS: 801, Indian standard codes of practice for use of cold-formed light gauge steel structural members in general building construction, Bureau of Indian Standards, New Delhi (1975). (Currently under revision) Building Code: see - model code National Building Code of India.

Design equations:

Basic design stress = $F_b = 0.6F_y$

$(W/t)_{lim}$ = $(1435/\sqrt{Fb})$

$(W/t)_{lim} < (W/t)$

(b/t) = $\frac{2120}{3.22\sqrt{Fb}} \mathrm{x}\ 1 - \frac{\left(\frac{465}{3.22}\right)}{\frac{WFb}{t}}$

Q = $\frac{effective\ area}{total\ area}$

C_c = $\sqrt{\left(\frac{2\pi^2 E}{FY}\right)}$

KL/r = slenderness ratio

$KL/r < C_c$

F_{al} = $\left(\frac{12}{23}\right)(Qfy) - \frac{3(Qfy)^2}{23\pi^2 E} \mathrm{x}\ (KL/r)^2$

Allowable load = F_{al} x area

2.2.3 Effective Width Method

Effective Width Method, for determining the nominal distortional buckling strength of typical cold-formed steel sections subjected to bending.

2.2.4 Allowable Strength Design

In this approach, the forces (bending moments, axial forces, shear forces) in structural members are computed by accepted methods of structural analysis for the specified working loads. These member forces or moments should not exceed the allowable values permitted by the applicable design specification. The allowable stress design method employs only one factor of safety for a limit state.

2.2.5 AISI Method

AISI's codes and standards work is conducted under the Construction Market Council of the Steel Market Development Institute (SMDI), a business unit of AISI, which oversees the industry's investment in advancing the competitive use of steel by meeting the demands of the marketplace.

2.3 CUFSM 4.01

The finite strip method is a technique of structural analysis used for bridge and tall structure design as well and in the design of construction components such as steel beams. The technique was first introduced in 1968 by B.W.Schafer and made this software package as open source software for the researchers and is less powerful and versatile than the finite element method but is more efficient in terms of computation power in some situations.

Table-3 (a) Section Properties

Section	Area (Inch²)	I_{xx} (Inch⁴)	I_{zz} (Inch⁴)
Z1-250-600	1.0602	6.5369	1.9071
Z1-350-600	1.0602	6.5369	1.9071
Z1-550-600	1.0602	6.5369	1.9071
Z2-250-600	1.2338	7.2372	2.544
Z2-350-600	1.2338	7.2372	2.544
Z2-550-600	1.2338	7.2372	2.544
Z3-250-600	1.0675	6.7393	2.3931
Z3-350-600	1.0675	6.7393	2.3931

Z3-550-600	1.0675	6.7393	2.3931
Z4-250-600	1.1729	6.6224	1.0541
Z4-350-600	1.1729	6.6224	1.0541
Z4-550-600	1.1729	6.6224	1.0541
Z5-250-600	1.2264	6.9171	1.0571
Z5-350-600	1.2264	6.9171	1.0571
Z5-550-600	1.2264	6.9171	1.0571

The section properties obtained from the CuFSM 4.01 package which will be useful for theoretical calculations, was mentioned in Table 3. The Graph represented in Figure 4 which shows the various buckling modes of failure regions (Local buckling,

Distortional buckling and Flexural or Global buckling) and also the load factor values for various column lengths. From the obtained results, it shows that the short columns subjected to crushing and the slender columns subjected to flexural buckling.

Table-3 (b) Section Properties

Section	X_{cg}	Z_{cg}	Local	Distortion
Z1-250-600	-0.000018	3.1103	1.2935	2.3752
Z1-350-600	-0.000018	3.1103	0.9240	1.6967
Z1-550-600	-0.000018	3.1103	0.5879	1.0796
Z2-250-600	0	3.1103	1.3453	3.4968
Z2-350-600	0	3.1103	0.9610	2.4979
Z2-550-600	0	3.1103	0.6115	1.5895
Z3-250-600	0	3.1103	1.2869	1.5543
Z3-350-600	0	3.1103	0.9193	1.1103
Z3-550-600	0	3.1103	0.5849	0.7065
Z4-250-600	1.2401	3.1103	3.6563	1.9319
Z4-350-600	1.2401	3.1103	2.6119	1.38
Z4-550-600	1.2401	3.1103	1.662	0.87814
Z5-250-600	1.2402	3.1103	4.5457	1.9417
Z5-350-600	1.2402	3.1103	3.2472	1.387

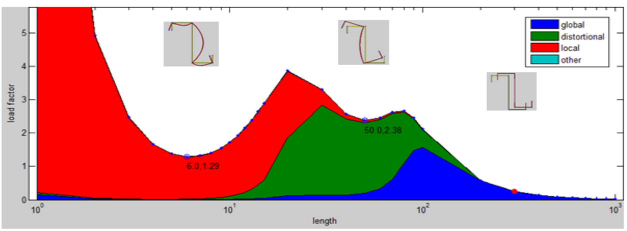

Figure -4 Buckling curve

2.4 Numerical Investigation

Numerical investigation on cold formed press braking steel zed members are done by finite element method technique which is commercially available in the name as ANSYS 12.0. ANSYS is numerical method for solving problems of engineering and mathematical physics. Typical problems areas of interest include structural analysis, heat transfer, fluid flow, Mass transport, and electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problem for partial differential equation the finite element method formulation of the problem results in a system of algebraic equation.

2.4.1 Type of Element

In this study, there are two types of Elements were used in finite element package of ANSYS 12.0 are, (1) 4 node 181 Shell elements, (2) Structural Mass 21 element. Shell 181 element is used for cold formed steel sections where as they are having 3 Translational and 3 Rotational degree of freedom. Mass 21 element is used for the creation of CG node where the axial load is applied. Typical DOF of Shell and Mass elements are shown in Figure 5 and Figure 6. The model creation through these elements was shown in Figure 7.

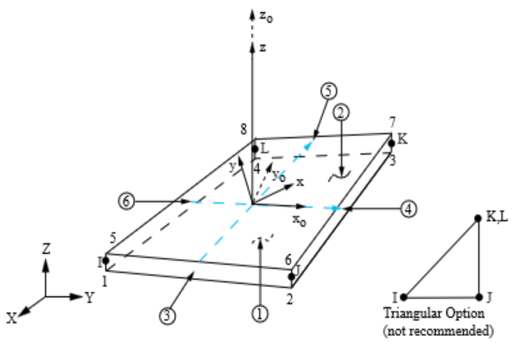

Figure -5 Shell 181 Elements

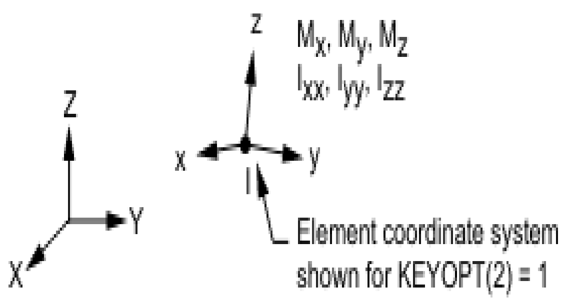

Figure -6 Structural Mass 21 Elements

2.4.2 Types of mesh

There are two types of meshing pattern adopted in ANSYS package. The meshing can be done either by free mesh

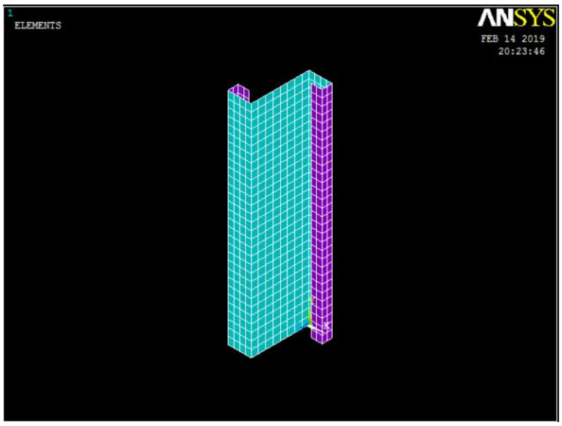

Figure -7 Element Creation

or mapped mesh which is shown in Figure 8. In this study, the elements size after meshing is kept constant as 20mm and Mapped meshing pattern is adopted throughout the project.

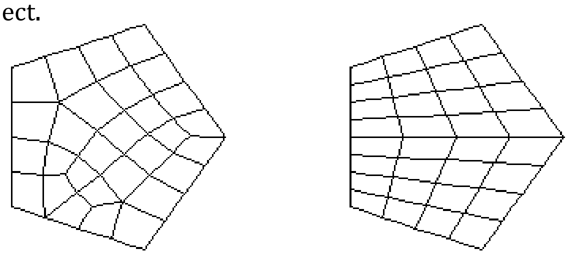

Figure -8 Free and Mapped Mesh

2.4.3 Boundary Condition

The fixed end condition in cold formed steel sections were given in software package as input parameters by arresting the displacement and rotational degrees at bottom, and except displacement degrees in axial direction, remaining are arrested. Boundary conditions adopted in this study was mentioned in Table 4. The generated model in ANSYS 12.0 after meshing was shown in Figure 9.

Table -4 Boundary Conditions

Boundary condition	Element	Constraints
Fixed end support	Top face	$U_X, U_Z,$ rot$_x$ rot$_y$ rot$_z$
	Bottom face	U_X, U_y $U_Z,$ rot$_x$ rot$_y$ rot$_z$

These analyses can easily be inappropriate. Care should be taken to specify appropriate model and solution parameters. Understanding the problem, the role played by these parameters and a planned and logical approach will do much to ensure successful solution. Material nonlinearity involves the nonlinear behavior of a material based on a current deformation, deformation history, rate of deformation, temperature, pressure, and so on. Examples of nonlinear material models are large strain (visco) elastic-plasticity and hyper elasticity (rubber and plastic materials).

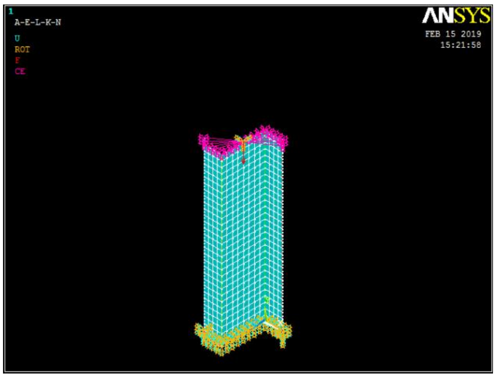

Figure -9 Model Generation

2.4.4 Nonlinear Analysis

A nonlinear analysis is an analysis where a nonlinear relation holds between applied forces and displacements. Nonlinear effects can originate from geometrical nonlinearity's (i.e. large deformations), material nonlinearity's (i.e. elasto-plastic material), and contact. These effects result in a stiffness matrix which is not constant during the load application. This is opposed to the linear static analysis, where the stiffness matrix remained constant. As a result, a different solving strategy is required for the nonlinear analysis and therefore a different solver.

After nonlinear analysis of Cold formed steel Zed column sections, the various buckling modes of failure were described in Figure 10.

3. RESULTS AND DISCUSSIONS

The obtained results for allowable buckling load from theoretical analysis (Direct Strength Method) and Numerical Investigation (ANSYS12.0) are mentioned in Table 5. Typical buckling modes observed in the numerical analysis were shown in Figure 10. The load vs deflection curve obtained in ANSYS are mentioned in Figure 11. The comparison of results shows that the numerical and theoretical result matches closes to each other.

Table -5 Comparison of Theoretical and Numerical Results

Section ID	Theoretical Analysis (DSM)	Numerical Results (FEA)	P_{FEA} / $P_{Theoritical.}$
Z1-250	153.476	154	1.00
Z1-350	190.429	197	1.03
Z1-550	251.238	249	0.99
Z2-250	181.793	184	1.01
Z2-350	226.107	231	1.02
Z2-550	299.614	303	1.01
Z3-250	151.262	151	1.00
Z3-350	188.342	192	1.02

Z3-550	245.102	254	1.04
Z4-250	176.611	171	0.97
Z4-350	223.858	228	1.02
Z4-550	295.948	295	1.00
Z5-250	184.896	181	0.98
Z5-350	234.469	236	1.01
Z5-550	310.107	318	1.03
		Mean	1.01

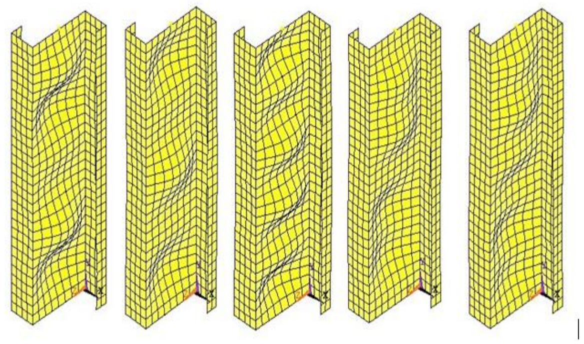

Figure 10 Typical Failure modes of Buckling

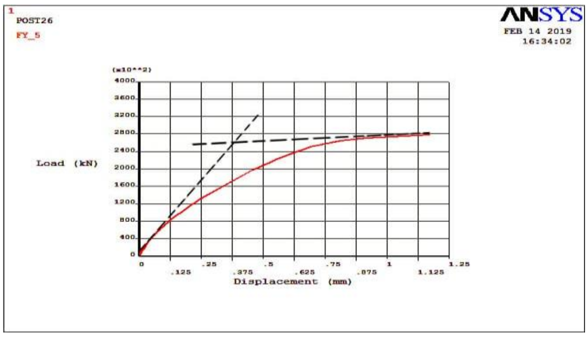

Figure -11 Load vs Deflection Curve

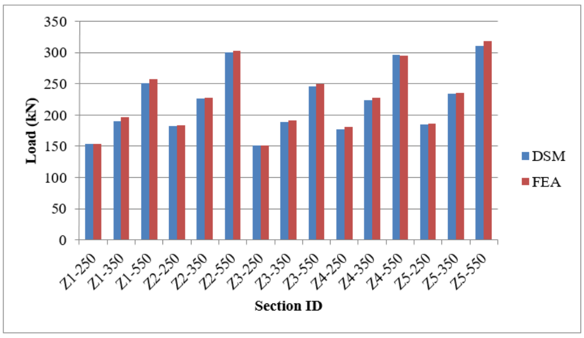

Figure -12 Comparisons of Theoretical and Numerical Results

4. CONCLUSIONS

Based on the investigations made on the fixed ended cold formed press braking steel zed column members under axial compression, the following are the conclusions were made.

- Results of theoretical and numerical analysis are closer to each other.
- The increase in yield strength of steel sections will results in increase in allowable buckling load on the columns.
- The sections provided with stiffeners are failed due to distortional buckling whereas the plain zed sections are failed due to local buckling. For the given height, occurrence of global buckling is not possible.
- Ultimate load carrying capacity is inversely proportional to slenderness ratio (L/r ratio).

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BIOGRAPHIES

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