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Parametric Study of Cold Formed Steel Zee Sections

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ABSTRACT—Theuse of cold formed steel is increasing rapidly around the world due to many advances in construction and manufacturing technologies and relevant standards. However, the structural behavior of these thin walled steel structures is characterized by a range of buckling modes such as local, distortional and global buckling. In this context a parametric study on parameters (i.e. l/d, d/t) such as web depth, thickness, flange width and span are being made onto analyses Z Sections to arrive at design strength criterion in bending. ABAQUS and CUFSM are extensively used to perform Finite Element and Finite strip analysis of thin walled cold formed steel sections. The critical load values obtained from CUFSM are substituted in the DSM equations to arrive at the flexural capacity of the section. In ABAQUS loads are applied on the top flange of section where center of gravity is projected on to the top flange. The simply supported and fixed end conditions are considered. The results of ABAQUS simulation compared with the CUFSM found that the ABAQUS results are in good agreement with CUFSM. The ratio of design strength to yield strength is compared to find whether the section is economical and analyses to arrive at an optimum section has been performed.

KEYWORDS— Z sections, Cold formed steel, parametric study, buckling modes, Flexural capacity.

I. INTRODUCTION

Cold-formed thin-walled members are used in construction industry for many applications. The probably largest area of use is in conventional – mainly industrial – steel structures as secondary and tertiary load-bearing elements – purlins, sheeting – on a steel or reinforced concrete primary structure.There are two main ways of manufacturing Cold formed steel section, by rolling or press braking. These members are also called light gauge members. Cold formed steel sections are used in aerospace, aircraft & ship hull and in civil engineering building construction applications[1]. Some of the applications are railway coaches, various types of industrial equipment like storage racks, in industrial building, highway products and bridge super structures. Cold formed steel has made significant progress in Pre-engineered building construction due to its light weight, high strength to weight ratio and greater stiffness compared to normal steel, thus making it easier to deal with at construction sites. Advantages of Z section over other section are

- The "Z" shaped sections structural elements of steel can feature two flanges of different width also so that two elements with the same static height can overlap, fitting perfectly to each other.
- Due to antisymmetric geometry the moment of inertia on Z purlin's weak axis is much bigger than that of C purlin, Z purlin works much better from the integrity point of view.
- Z steel purlins can be overlapped continuously while C steel purlins cannot, therefore, it's better to use Z steel purlins instead of C purlins on metal buildings with continuous spans Z purlins are much stronger than C purlins due to its continuous or overlapping capability .[6]

The major structural aspect that governs the behaviour of cold formed steel sections is the buckling due to thiness of sections. Buckling occurs as local and distortional buckling before it can get into torsional and flexural-torsional modes. In this context a parametric study has been conducted on the Z sections that are commonly manufactured in Cold Formed Steel Industry. So as to arrive at the optimum cross-section profiles, the parameters that are considered for the study are the web depth, thickness, flange width and spans.

Following are the sizes of the sections that are considered for this study.

- Web depth = 200mm, 250mm
- Flange Width = 64mm,100mm
- Thickness = 1.75mm, 2mm, 2.25mm, 2.5mm.
- Span = 1m, 2m, 2.5m, 3m, 3.5m, 4m, 5m, 6m,7m & 8m .

II. METHODOLOGY

Numerical methods which are most commonly used for conducting buckling analysis are the finite strip method (FSM) and the finite element method (FEM). Using FEM could solve the nonlinear buckling/ultimate failure loads easily, however extracting the various buckling loads/modes for designing purpose would be challenging. Using FSM is easy and straightforward to get different buckling loads/modes. In order to understand both the elastic buckling and post-buckling failure performance, as well as to bridge the gap between research and design, both FSM and FEM are used in this study. The details of analytical methods used are enumerated below:

A. ABAQUS

The Finite Element Method (FEM) is a numerical technique to find approximate solutions of partial differential equations. It was originated from the need of solving complex elasticity and structural analysis problems in Civil, Mechanical and Aerospace engineering. In a structural simulation, FEM helps in producing stiffness and strength visualizations [2].Light gauge cold-formed steel compression members can be modelled and analysed under different types of boundary conditions. However, finite element analysis is playing an important role in engineering practice since it has some excellent features. It is relatively inexpensive and time efficient compared with physical experiments. In Abaqus, simulation for the cold formed steel Z section, 4-node shell element is used i.e S4R (4-node doubly curved general-purpose shell, reduced integration with hourglass control) [3].

Within the Abaqus model, there are two steps to deal with i.e, elastic buckling analysis and non-linear static analysis. Firstly, typical linear perturbation analysis is used to deal with the elastic buckling analysis. Several buckling modes can be obtained from the perturbation analysis .The particular buckling mode is to be identified and the eigen value is to be picked up. From this step, it provides essentially a critical elastic buckling load. Modified Riks Method which is relatively based on Newton- Raphson Method is used for non-linear static analysis. The elastic buckling load obtained from the first step is further used in the second step to get the flexural capacity of the section.

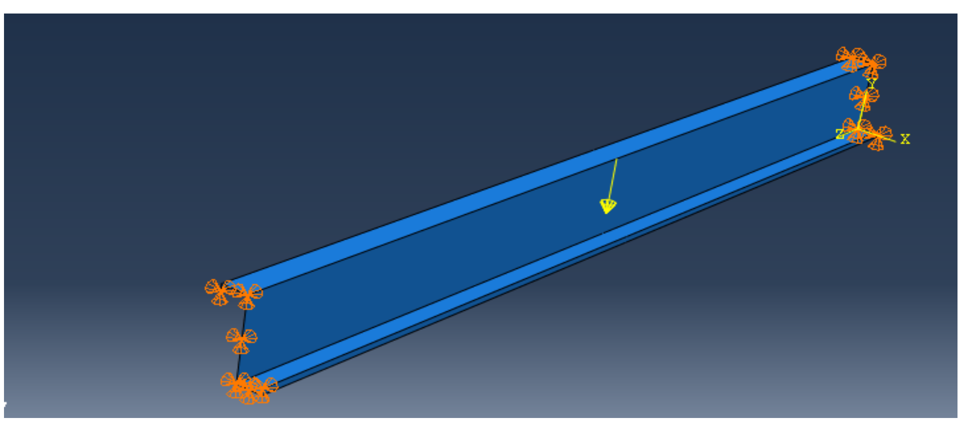

Fig. 1 Setting up of Boundary conditions and Loading

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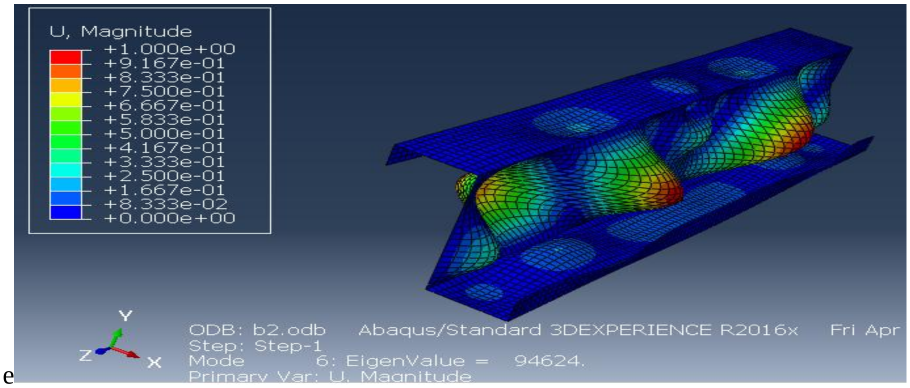


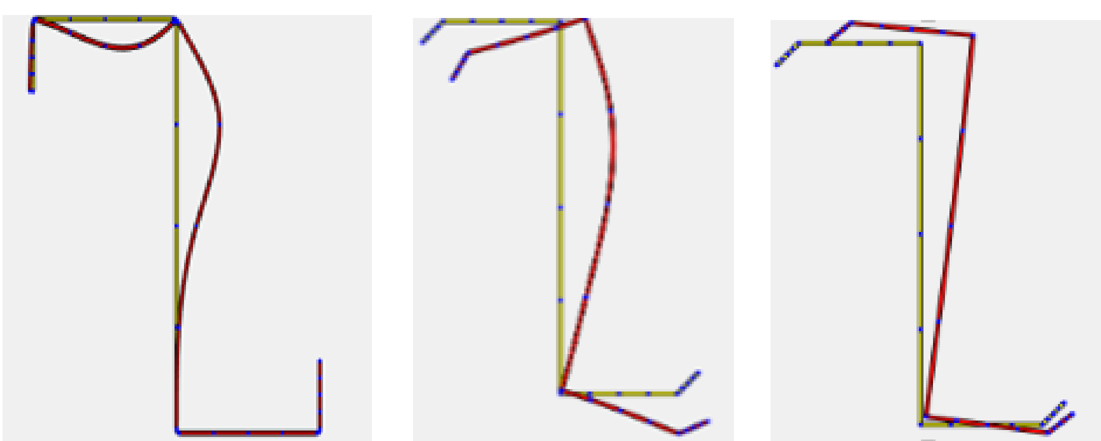
Fig. 2 Buckled Shape

B. CUFSM

CUFSM stands for Constrained and Unconstrained Finite StripMethod. The CUFSM computer programhas been developed by W. Schafer at John Hopkins University, Baltimore to investigate different modes of buckling in thin-walled structures. The analysis is based on the finite strip method, which subdivides the thin-walled sections into longitudinal strips. Any steel section can be analysed using CUFSM program and the appropriate length of a member can be obtained to suit the desired buckling mode. Following are the steps involved in modelling:

- Input the coordinates of each node on the cross-section
- Set material properties
- Specify the boundary conditions
- Define loads on the cross-section
- calculation and the post processing of results

The critical load values for different buckling modes are arrived at from the above analysis. They are further substituted into the Direct Strength Method equations to obtain the design strength. Fig. 3 shows the buckle shapes and the buckling curve obtained from CUFSM for Z section.



a. Local Buckling shape *b. Distortional Buckling shape* *c. Global Buckling shape*

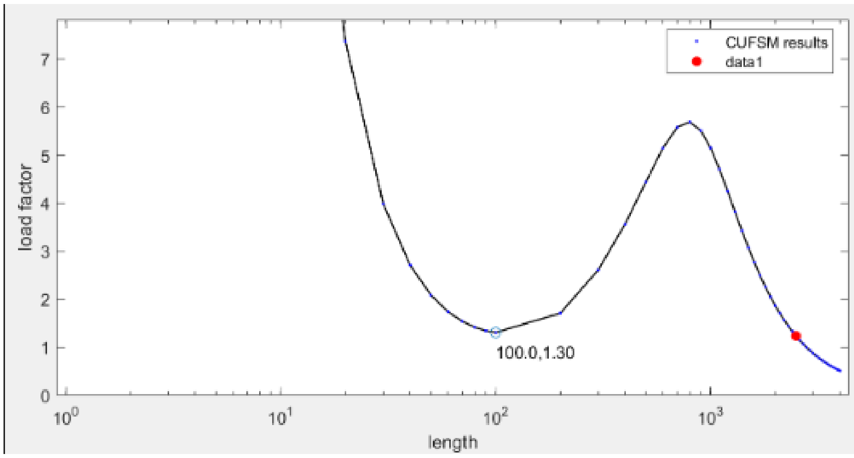


Fig. 3 Buckle shapes and the buckling curve of Z section obtained from CUFSM

C. Direct Strength Method

The Direct Strength Method is relatively new design method for CFS. This methodis used to determine the design load after obtaining load factors in elastic buckling in local, distortional, and global modes from CUFSM. After the determination of the load that causes first yieldfor entire cross-section, is then to be applied into equations in order to define strength prediction. Once the determination of elastic local, distortional, and global buckling loads is made then application of the method is straightforward [4].

Direct Strength Method is used to evaluate the elastic buckling capacities of local, distortional and global buckling modes for both compression and flexural CFS members. If elastic buckling value is high enough then full capacity will be developed. Then, the buckling failure modes will not occur before the yielding of the materials. However, the section flexural strength will not reduce due to local, distortional and global buckling effects. Therefore, yield moment (M_y) can be specified as the section flexural strength when the following conditions are satisfied:

Local buckling: $M_{crl} > 1.66M_y$

Distortional buckling: $M_{crd} > 2.21M_y$

Global buckling: $M_{cre} > 2.78M_y$

The nominal flexural strength, M_{nl}, for local buckling:

- For $\lambda_l \leq 0.776$, $M_{nl} = M_{ne}$
- For $\lambda_l \geq 0.776$, $M_{nl} = [1 - 0.15 \text{ X } (M_{crl}/M_{ne})^{0.4}] (M_{crl}/M_{ne})^{0.4} . M_{ne}$

Where $\lambda = (M_y/M_{crl})^{0.5}$

The nominal flexural strength, M_{nd}, for distortional buckling:

- For $\lambda_d \leq 0.673$, $M_{nd} = M_y$
- For $\lambda_d > 0.673$, $M_{nd} = [1 - 0.22 \text{ X } (M_{crd}/M_y)^{0.5}] (M_{crd}/M_y)^{0.5} . M_y$

Where $\lambda_d = (M_y/M_{crd})$

For nominal flexural strength, M_{ne}, for lateral-torsional buckling:

- For $M_{cre} < 0.56M_y$, $M_{ne} = M_{cre}$
- For $2.78M_y \geq M_{cre} \geq 0.56M_y$, $M_{ne} = (10/9)M_y[1-(10M_y/36M_{cre})]$
- For $M_{cre} > 2.78M_y$, $M_{ne} = M_y$

From the equations described above, at some point there will be related to the lowest load level at a particular mode. Therefore, the capacity for local buckling (M_{nl}), distortional buckling (M_{nd}) and global buckling (M_{ne}) moments can be determined. The buckling capacity can be sufficiently the smallest capacity for the design section:

$$\mathbf{M_n = Min\ (M_{nl}, M_{nd}, M_{ne}, M_y).}$$

For a Z section due to its anti-symmetry, the Center of Gravity (C.G) and Shear center coincides. So first local buckling occurs, then global buckling is followed after the local buckling. However Distortional mode is not a distint mode and never be a governing mode for Z section.

Comparison between the Finite Element Method and the Finite Strip Method[5]

FEM	FSM
Applicable to any type of geometry, boundary conditions or material variation. Extremely powerful and usable in nearly every case.	In static analysis it is used for structures with two opposite simply supported ends. In dynamic analysis it is used with all boundary conditions and with discrete supports
Implies a great number of equations and extremely big matrix. Can be very expensive and even impossible to use sometimes because of the demanding computing facilities	Usually has a much smaller quantity of Equations and matrix are also smaller. This leads to a much shorter computing time to find a solution with nearly the same accuracy
Large quantity of input data which can lead to mistakes.	Very small amount of input data due to theSmaller number of meshing.
Large quantity of output. Normallydisplacements of all the nodes are listed	Easier to specify only those nodes whichdisplacements and stresses are required
Difficult to program and a very bigComputational requirement.	Due to the reduction in the number ofdegrees of freedom, the computational requirements are smaller.

Analyses have been conducted for Z section for varying thickness and the design strength are presented. The exercise has been carried out for simply supported and clamped-clamped conditions. The critical buckling mode is local global for simple supported and global mode for clamped-clamped.

III) Results And Discussion:

The parametric study conducted on lipped Zee section to see the variation of strength with l/d, d/t and ratios has been summarised and presented in the form of figures.

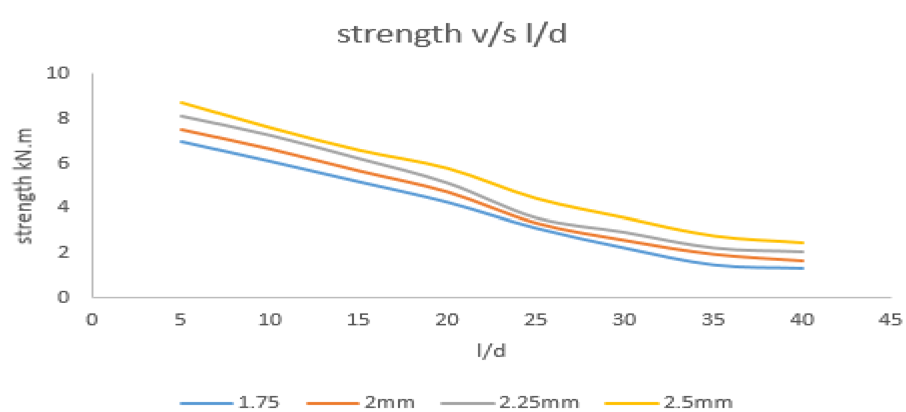


Fig.4 A graph of strength versus span/web depth for 250mm depth

The variation of strength with respect to l/d ratio specifies the critical ratio l/d beyond which the rate change of strength goes through a variation as shown in Fig. 4. The upper bound l//d ratio as observed from the above is taken as 25 and based on this ratio, the sections considered for the further analysis are 250X64X16 section.

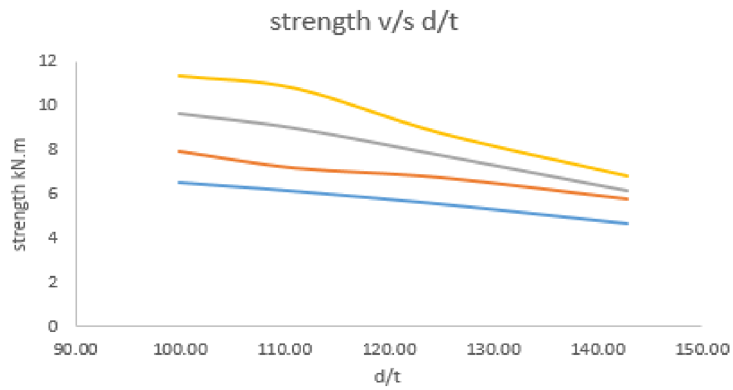


Fig. 5 A graph of strength versus web depth/thickness

Fig. 5 gives the variation of strength with respect to d/t values can be used to obtain a d/t value beyond which the strength for different spans will be approaching the same value. This can be the limiting d/t value for design purposes. The section considered is based on the l/d ratios and the sections that are supplied from Kirby building systems.The maximum for d/t can safely be taken as 110.

TABLE I
RESULTS OF CUFSM FOR LIPPED Z SECTION

S.no	Dimension	Span(m)	t(mm)	My(kN.m)	Mcrl/My	Mcre/My	CUFSMMn (kN.m)	ABAQUSMn (kN.m)
1	LZ	2.5	1.75	8.13	1.01	1.22	5.61	4.89
	200*64*16	3		8.13	1.01	0.86	5.14	4.57
		4		8.13	1.01	0.51	3.88	3.07
		2.5	2	9.29	1.30	1.23	6.99	6.01
		3		9.29	1.30	0.87	6.34	5.64
		4		9.29	1.30	0.51	4.25	3.86
		2.5	2.5	11.62	2.02	1.26	9.05	8.54
		3		11.62	2.02	0.89	8.01	7.56
		4		11.62	2.03	0.53	5.5	5.21
2	LZ	2.5	1.75	11.74	0.70	0.83	6.52	5.88
	250*64*16	3		11.74	0.70	0.78	6.38	6.02
		4		11.74	0.70	0.45	4.66	4.32
		2.5	2	13.42	0.85	0.84	7.97	7.64
		3		13.42	0.85	0.79	7.79	7.32
		4		13.42	0.85	0.46	5.51	5.01
		2.5	2.5	16.77	1.43	0.86	11.35	10.88
		3		16.77	1.43	0.78	10.78	10.02
		4		16.77	1.43	0.45	6.8	5.99

From table 1. The results given by ABAQUS depends on identify the proper mode and its Eigen value. Corresponding between CUFSM and ABAQUS changes with any shift in the mode selection with can sometimes be a coupled mode in ABAQUS.

TABLE 2

RESULTS OF CUFSM FOR LIPPED Z SECTION OF FLANGE WIDTH = 64mm, LIP = 16mm, THICKNESS = 2.5mm and SPAN = 4m

	Simple-simple					Clamped-clamped			
Web Depth(mm)	My(kN.m)	Mcrl/My	Mcre/My	Mn(kN.m)	Mode	Mcrl/My	Mcre/My	Mn(kN.m)	Mode
200	11.62	6.5	0.67	6.50	lg	2.98	2.05	10.03	g
250	16.77	8.8	0.65	9.83	lg	1.85	1.84	14.24	g

TABLE 3
Mn/My RATIOS FOR LIPPED Z SECTION

S.no	Dimension	Span(m)	t(mm)	My(kN.m)	Mn(kN.m)	Mn/My
1	LZ	2.5	1.75	8.13	5.61	0.69
	200*64*16	3		8.13	5.14	0.63
		4		8.13	3.88	0.48
		2.5	2	9.29	6.99	0.75
		3		9.29	6.34	0.68
		4		9.29	5.05	0.54
		2.5	2.5	11.62	9.05	0.78
		3		11.62	8.01	0.69
		4		11.62	6.5	0.56
2	LZ	2.5	1.75	11.74	6.52	0.56
	250*64*16	3		11.74	6.38	0.54
		4		11.74	5.66	0.49
		2.5	2	13.42	7.97	0.59
		3		13.42	7.79	0.58
		4		13.42	6.81	0.51
		2.5	2.5	16.77	11.35	0.68
		3		16.77	10.78	0.64
		4		16.77	8.8	0.51

From table 3 For spans of 2.5m,3m,3.5mm and the section with thickness of 2mm and 2.5mm for web depth of 200mm and 250mm are to be considered as base section for design of purlins, as the ratio of design strength to capacity at yield stress for these sections is greater than 0.5.

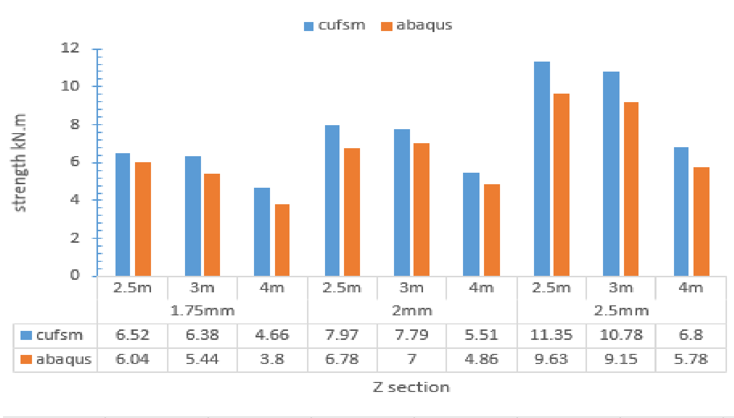


Fig.6 Comparison of Design Strengths for the section 250X64X16 for spans 2.5m,3m, 4m and thickness1.75mm,2mm, 2.5mm.

III. CONCLUSIONS

1) Results obtained from FEM analysis and FSM has a variation of design strength of 10%-15% with abaqus being conservative results.
2) With the increase in web depth of 50mm, about 30.88% of increase in strength is observed.
3) The increase is observed as 22% and 72%for 2mm and 2.5 mm thickness respectively for in case of 250mm depth section when compared to 1.75mm thickness.
4) The variation of strength with respect to l/d ratio specifies the critical ratio l/d beyond which the strength varies drastically giving lower values. The upper bound l//d ratio as observed from the above is taken as 25.
5) The variation of strength with respect to d/t values can be used to obtain a d/t value beyond which the strength for different spans will be approaching the same value. This can be the limiting d/t value for design purposes. The section considered is based on the l/d ratios. The upper bound for d/t can safely be taken as 110.
6) For the spans of 2.5m,3m,3.5mm and sections with thickness of 2mm and 2.5mm for web depth of 200mm and 250mm are to be considered as base section for design of purlins the ratio of design strength to capacity at yield stress for these sections is greater than 0.5.
7) The critical buckling mode in local global for simply supported condition and global mode for clamped-clamped condition.

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