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BUCKLING ANALYSIS OF COLD FORMED STEEL WITH COUPLED CHANNEL SECTIONS

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Abstract: The last few years have seen increasing usage of cold formed steel sections as load bearing members as opposed to secondary systems. In this context a study is being made to analyse Coupled Channel sections to arrive at design strength criterion in compression. The direct strength method of design for cold formed steel sections has been validated over the years through research and the same has been incorporated in the standard codes of practice in the countries like USA and Australia. ABAQUS and CUFSM has been extensively used to perform Finite Element analysis and Finite Strip method of thin walled cold formed steel sections and the results are compared to each other. Hence the analysis is being done on CUFSM and ABAQUS. The design strength curves will be arrived at using direct strength method. In this study, the behavior of Coupled Channel sections under the action of axial loads has been carried out. In ABAQUS, the loads are applied on both ends. The simply supported and clamped end conditions are considered.

***Index Terms* –** Coupled C sections, Cold formed steel, parametric study, buckling modes, Axial capacity.

Introduction

Cold-formed steel members are thin light, and efficient. However, this efficiency comes with complication: engineers must consider buckling of the thin walls of the cross-section in addition to global (e.g., flexural or lateral torsional) buckling of the member. Thin sheet steel products are extensively used in building industry, and range from purlins to roof sheeting and floor decking. Generally these are available for use as basic building elements for assembly at site or as prefabricated frames or panels. These thin steel sections are cold-formed, i.e. their manufacturing process involves forming steel sections in a cold state (i.e. without application of heat) from steel sheets of uniform thickness. Sometimes they are also called Light Gauge Steel Sections or Cold Rolled Steel Sections.

CFS sections are typically thin-walled with a thickness ranging from 0.4 mm to 6.5 mm. Much thicker material up to 8 mm can be formed if pre-galvanized material is not required for the particular application. The method of manufacturing is important as it differentiates these products from hot rolled steel sections. Normally, the yield strength of steel sheets used in cold-formed sections is at least 280 N/mm^2, although there is a trend to use steels of higher strengths, and sometimes as low as 230 N/mm^2. When individual component plates of cold-formed steel members are subjected to bending, they may buckle at stress lower than yield point due to high width to thickness ratios. It is well known that these plated elements will not necessary fail when their buckling stress is reached and that they often will continue to carry increasing loads due to large reserve post- buckling strength.

The properties of cold formed steel are altered by the forming process and residual stresses are significantly different from hot-rolled sections. Any design standard then must be particularly sensitive to these characteristic which are peculiar to cold formed steel. The characteristics of cold-formed steel are different from hot-rolled steel due to the fabrication 2 process. The yield stress of cold-formed steel is much higher than that of the conventional hot-rolled steel because the cold-forming process induces residual stresses which increase the yield stress. It is important for design standards to cater for these characteristics because they differentiate cold-formed steel from hot-rolled steel.

I. APPLICATIONS:

In building construction, cold-formed steel products are mainly used as structural members, diaphragms, and coverings for roofs, walls and floors. There are varieties of cold formed shapes available as structural members, which include open sections, closed sections, and built-up sections. Channel, Z-Couple Channel sections, I-sections, hat, and angle sections are open sections while box sections and pipes are closed sections. The built-up members are formed by connecting two or more cold formed steel members together, such as an I-section member built up by connecting two channel sections back-to-back. These structural shapes can be used in buildings as eave struts, purlins, girts, studs, headers, floor joists, braces, and other building components. Various shapes are also available for wall, floor, roof diaphragms and coverings.

II. OTHER APPLICATIONS:

i. Cold-formed steel shapes can be used for entire buildings and for complete roof, floor and wall systems.
ii. It can also be used as individual framing members such as studs, joists and truss members.
iii. It is used in agricultural machinery, storage racks, house hold appliances and electrical equipment’s etc.
iv. It is widely used in many industries such as automotive trucks, trailer and railway cars.
v. The light gauge steel members are specially used in aircrafts.
vi. It is also used in various types of buildings from large hangars to small Quonset huts.
vii. Corrugated and profiled sheets are widely used in steel concrete composite floor proof construction.
viii. It is used for variety of building products such as doors and windows.

IV. RESEARCH METHODOLOGY:

In order to avoid tedious modelling and mesh procedure for each simulation, a second order elastic-plastic analysis is adopted to provide a simplified calculation method for bending members. Two of the most commonly used numerical methods for conducting buckling analysis are the finite strip method (FSM) and the finite element method (FEM). Using FSM is easy and straightforward to get different buckling loads/modes. Using FEM could solve the nonlinear buckling/ultimate failure loads easily, however extracting the various buckling loads/modes for designing purpose would be challenging. 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 thesis.

- FEM could solve the nonlinear buckling/ultimate failure loads easily, however extracting the various buckling loads/modes for designing purpose would be challenging.
- The Finite Strip Method (FSM) is used to investigate the elastic buckling behavior of CFS members using MATLAB platform and CUFSM was formulated.
- The design guidelines based on Direct Strength Method (DSM) are examined.

4.1 CUFSM SOFTWARE:

CUFSM has been developed by Benjamin W. Schafer at John Hopkins University, Baltimore based on finite strip method. CUFSM stands for Constrained and Unconstrained Finite Strip Method. The elastic buckling analysis of thin-walled cross-sections has long benefitted from the use of finite strip analysis. CUFSM helps to explore and better understanding of elastic buckling behaviour of thin-walled members and to accurately determine the elastic buckling stress of a thin-walled section of arbitrary cross-section. CUFSM calculates the buckling stress and buckling mode of arbitrarily shaped, simply supported, thin-walled members.

Conventional FSM provides a means to examine all the possible instabilities in a cold-formed steel member under longitudinal stresses (axial, bending or combinations thereof). CUFSM is an open source FSM program. The basic framework of the FSM stability solution will be familiar to anyone who has studied matrix structural analysis. New design methods such as the Direct Strength Method become highly efficient for the engineer when FSM stability solutions are employed.

Recently extensions to the conventional FSM solution have been explored namely the constrained finite strip method, or cFSM. A cFSM solution provides a means for

(1) Stability solutions to be focused only a given buckling mode (modal decomposition).

(2) A conventional FSM stability solution may be classified into the different fundamental buckling modes (modal identification).

Following are the steps involved in modelling:

- Give the coordinates of each node on the cross-section as input
- Material properties have to be set.
- Boundary conditions should be specified
- 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.

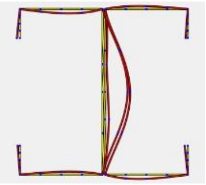

Figure-1 2D representation of the local buckling mode shape

4.2 FINITE ELEMENT MODELLING:

The finite element method is a numerical technique of solving differential equations describing a physical phenomenon. It is a convenient way to find displacements and stresses of structures at definite physical coordinates called nodes. The structure to be analysed is discretized into finite elements connected to each other at their nodes. Elements are defined and equations are formed to express nodal forces in terms of the unknown nodal displacements, based on known material constitutive laws. Forces and initial displacements are prescribed as initial conditions and boundary conditions. A global matrix system is assembled by summing up all individual element stiffness matrices and the global vector of unknown nodal displacement values is solved for using current numerical techniques.

The main objectives of the finite element study are to understand the compression behaviour and determine the ultimate load of CFS coupled channel sections, and identify the factors that affect the compressive strength. A parametric study was then carried out to investigate the influence of section depth, thickness on the ultimate load of CFS coupled channel sections.

Following are the steps involved in modelling:

- Material properties
- Elements and finite element meshes
- Boundary condition and loading
- Buckle analysis (eigen value analysis)

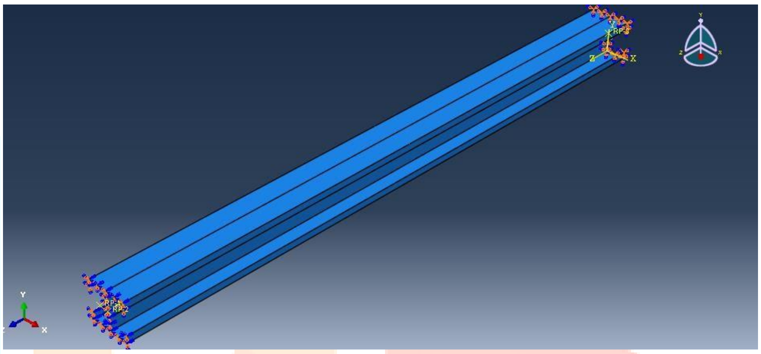

Fig-2 loading and boundary conditions

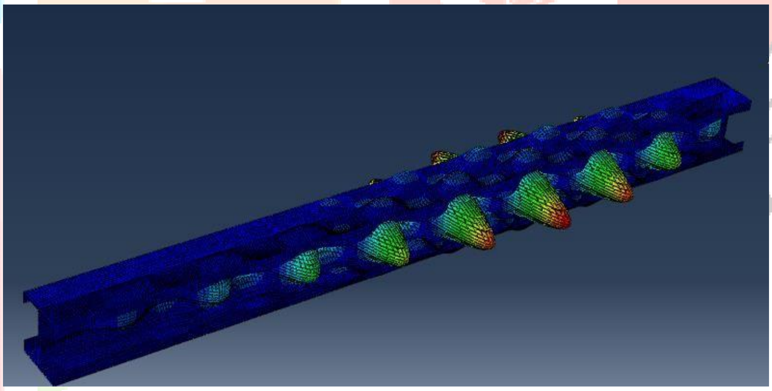

Fig-3 Eigen value from FEM analysis

FEM for buckling requires two type of analysis. The first is known as Eigen value analysis that executes the buckling modes and loads. Such an analysis is a linear elastic analysis performed using the procedure available in the ABAQUS library with the live load applied within the step. The buckling analysis provides the factor by which the live load must be multiplied to reach the buckling load. For practical purposes, only the lowest buckling mode predicted from the Eigen value analysis is used. The second is called load displacement non-linear analysis and follows the Eigen value prediction. It is necessary to consider whether the post buckling response is stable or unstable. But for present thesis only the first i.e., the buckling analysis only linear elastic analysis (Eigen value) procedure has been considered.

4.3 DIRECT STRENGTH METHOD:

This is a design methodology that has been adopted by the North American Cold-Formed Steel Specification as an alternative method to the traditional effective width design approach. The DSM does not depend on effective width, nor require iteration for the determination of member design strength. Instead the analysis have to determine the load after elastic buckling in local, distortional, and global buckling. From the determination dealing with the load that causes first yield are then to be applied into equations in order to define strength prediction (directly).

Load (Py) can be specified as the section compressive strength when the following conditions are satisfied:

- Local buckling: Pcrl> 1.66Py
- Distortional buckling: Pcrd> 2.21Py
- Global buckling: Pcre> 2.78Py

A. What are Mcr and Pcr?

They are the elastic buckling moment and the elastic buckling load. They are inputs in the Direct Strength Method. For typical open thin-walled shapes, such as cold formed steel Cees, Zees or hats, three critical loads/moments exist

- Pcrl/Mcrl: Elastic critical local buckling load/moment 18
- Pcrd/Mcrd: Elastic critical distortional buckling load/moment
- Pcre/Mcre: Elastic critical Euler buckling load/moment
- Py/My: Ultimate load/moment Multiple modes (e.g. flexural, torsional, and flexural-torsional may exist for global buckling).

4.4 Comparison between the Finite Element Method and the Finite Strip Method:

FEM: Applicable to any type of geometry, boundary conditions or material variation. Extremely powerful and usable in nearly every case. 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. Large quantity of input data which can lead to mistakes. Large quantity of output. Normally displacements of all the nodes are listed. Difficult to program and a very big Computational requirement.

FSM: 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. 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. Very small amount of input data due to the smaller number of meshing. Easier to specify only those nodes which displacements and stresses are required. Due to the reduction in the number of degrees of freedom, the computational requirements are smaller.

V. RESULTS AND DISCUSSION

The geometries of the lipped coupled channel sections are discussed below. Numerical simulation of different coupled channel sections by using connection between each channel has been carried out and also by varying different parameters such as thickness of sections, span of sections, and by varying web depths. Therefore coupled channel sections chosen for the present study are from the standard sections available that is **web depth of 200mm and 250mm, flange width of 80mm and 100mm, a lip size of 35mm and thickness of 1.75mm, 2mm and 2.5mm**. The connection is placed between the two channels of the web at one-third and two third distances from origin.

i. Coupled C-section(Simple-Simple)

- Web Depths – 200mm, 250mm
- Flange Width – 80mm, 100mm
- Lip length – 35mm
- Thickness –1.75mm, 2mm, 2.5mm
- Spans – 3m, 4m, 5m
- End conditions – simply supported condition

Table 1 Results of CUFSM and ABAQUS of Coupled C-section for spacing 3mm

Span(mm)	**Thickness(mm)**	**LOAD(KN)**					
		200*80*35		**200*100*35**		**250*100*35**	
		CUFSM	**ABAQUS**	**CUFSM**	**ABAQUS**	**CUFSM**	**ABAQUS**
3000	1.75	821.92	146.66	883.94	183.6	1000.19	190.85
4000		821.92	138.38	883.94	149.79	1000.19	173.96
5000		821.92	110.32	883.94	123.66	1000.19	145.97
3000	2	948.45	213.05	1010.22	223.6	1143.08	240.72
4000		948.45	177.01	1010.22	187.22	1143.08	205.98
5000		948.45	141.63	1010.22	159.33	1143.08	192.56
3000	2.5	1185.56	293.33	1232.77	345.6	1428.8	376.66
4000		1185.56	266.54	1232.77	292.89	1428.8	334.78
5000		1185.56	200.93	1232.77	248.91	1428.8	303.22

Table 2 Results of CUFSM and ABAQUS of Coupled C-section for spacing 5mm

Span(mm)	**Thickness(mm)**	**LOAD(KN)**					
		200*80*35		**200*100*35**		**250*100*35**	
		CUFSM	**ABAQUS**	**CUFSM**	**ABAQUS**	**CUFSM**	**ABAQUS**
3000	1.75	822.004	166.83	884.22	186.35	932.6	191.31
4000		822.004	145.36	884.22	149.2	932.6	157.8
5000		822.004	117	884.22	128.3	932.6	144.4
3000	2	941.429	215	1010.53	229.36	1143.3	242.56
4000		941.429	187.5	1010.53	195.05	1143.3	210.11
5000		941.429	147.18	1010.53	160.95	1143.3	195.02
3000	2.5	1174.5	328.49	1263.81	353.47	1429.17	367.57
4000		1174.5	282.24	1263.81	297.35	1429.17	328.41
5000		1174.5	206.69	1263.81	249.13	1429.17	269.45

Table 3 Results of CUFSM and ABAQUS of Coupled C-section for spacing 10mm

Span(mm)	**Thickness(mm)**	**LOAD(KN)**					
		200*80*35		**200*100*35**		**250*100*35**	
		CUFSM	**ABAQUS**	**CUFSM**	**ABAQUS**	**CUFSM**	**ABAQUS**
3000	1.75	823.499	170.81	885.519	188.41	1001.462	228.57
4000		823.499	145.29	885.519	154.96	1001.462	164.25
5000		823.499	118.45	885.519	141.61	1001.462	148.89
3000	2	942.914	222.74	1012.22	231.56	1144.529	244.5
4000		942.914	189.21	1012.22	208.98	1144.529	214.56
5000		942.914	150.19	1012.22	169.14	1144.529	198.59
3000	2.5	1176.42	341.75	1265.02	343.56	1430.61	373.54
4000		1176.42	280.02	1265.02	302.14	1430.61	334.78
5000		1176.42	214.15	1265.02	262.33	1430.61	294.99

ii. Coupled C-section (Clamped-Clamped)

- Web Depths – 200mm, 250mm
- Flange Width – 80mm, 100mm
- Lip length – 35mm
- Thickness –1.75mm, 2mm, 2.5mm
- Spans – 3m, 4m, 5m
- End conditions – clamped support condition

Table 4 Results of CUFSM and ABAQUS of Coupled C-section for spacing 3mm

Span(mm)	**Thickness(mm)**	**LOAD(KN)**					
		200*80*35		**200*100*35**		**250*100*35**	
		CUFSM	**ABAQUS**	**CUFSM**	**ABAQUS**	**CUFSM**	**ABAQUS**
3000	1.75	821.92	250.14	883.94	266.85	1000.19	268.89
4000		821.92	243.22	883.94	246.46	1000.19	270.3
5000		821.92	230.62	883.94	232.69	1000.19	251.133
3000	2	948.45	259.31	1010.22	331.41	1143.08	351.15
4000		948.45	250.31	1010.22	314.25	1143.08	341.53
5000		948.45	245.5	1010.22	293.61	1143.08	318.33
3000	2.5	1185.56	382.95	1232.77	496.43	1428.8	525.47
4000		1185.56	329.56	1232.77	461.61	1428.8	507.33
5000		1185.56	313.49	1232.77	439.09	1428.8	466.47

Table 5 Results of CUFSM and ABAQUS of Coupled C-section for spacing 5mm

Span(mm)	**Thickness(mm)**	**LOAD(KN)**					
		200*80*35		**200*100*35**		**250*100*35**	
		CUFSM	**ABAQUS**	**CUFSM**	**ABAQUS**	**CUFSM**	**ABAQUS**
3000	1.75	823.49	254.15	884.22	249.34	932.6	268.405
4000		823.49	245.16	884.22	244.66	932.6	272.11
5000		823.49	231.17	884.22	234.48	932.6	253.35
3000	2	941.42	332.96	1010.53	324.92	1143.3	351.15
4000		941.42	319.20	1010.53	311.67	1143.3	344.93
5000		941.42	299.29	1010.53	306.18	1143.3	322.83
3000	2.5	1174.5	495.6	1263.81	496.29	1429.17	538.83
4000		1174.5	473.73	1263.81	466.35	1429.17	512.04
5000		1174.5	449.56	1263.81	457.53	1429.17	483.82

Table 6 Results of CUFSM and ABAQUS of Coupled C-section for spacing 10mm

Span(mm)	**Thickness(mm)**	**LOAD(KN)**					
		200*80*35		**200*100*35**		**250*100*35**	
		CUFSM	**ABAQUS**	**CUFSM**	**ABAQUS**	**CUFSM**	**ABAQUS**
3000	1.75	823.49	258.91	885.51	269.68	1001.46	285.45
4000		823.49	248.53	885.51	263.87	1001.46	284.22
5000		823.49	235.65	885.51	254.32	1001.46	265.32
3000	2	942.91	364.23	1012.22	368.76	1144.52	371.07
4000		942.91	326.151	1012.22	330.831	1144.52	362.39
5000		942.91	308.65	1012.22	321.102	1144.52	322.83
3000	2.5	1176.42	500.65	1265.02	521.69	1430.61	539.35
4000		1176.42	493.31	1265.02	497.1	1430.61	513.83
5000		1176.42	452.36	1265.02	470.1	1430.61	485.54

From above represented tables for three different sections varying in spans and thicknesses following observations are made

- For simply-simply boundary condition the axial capacity of the sections obtained from ABAQUS and axial capacity from CUFSM varying with 10.3%- 11.5%
- For clamped-clamped boundary condition the axial capacity of the sections obtained from ABAQUS and axial capacity from CUFSM varying with 11.9%- 12.3

VI. CONCLUSION:

- Results obtained from FEM analysis and FSM has anaverage variation of design strength of 10.5%-12.5%.
- As spacing increases for built-up sections there is an increase of 10% -12%.
- For flange width of 80mm distortion becomes critical for spacing of 10mm and strength is not increasing from that of 5mm spacing.
- From Direct Strength Method the sections governing Local-Global modes.
- In average of about 56% increase in strength is observed for clamped end condition when compared to simply supported end condition.

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