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Parametric Study of Cold Formed Steel Channel Sections for Optimum Design Strength

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Abstract— The last three decades have seen Light gauge cold-formed steel sections being used extensively in residential, industrial and commercial building as secondary load bearing members. In this context a parametric study on web depth, thickness, flange width and span are being made to analyse C 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. Loads are applied on the top flange of section at point where centre of gravity 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.

Keywords— Cold formed steel sections, parametric study, Finite Element Analysis, Finite Strip Analysis, Direct Strength Method and Flexural Capacity.

I. INTRODUCTION

Cold formed steel sections are being used extensively in the building industry particularly in industrial buildings as secondary members and as a part of roofing systems. The increased capability in the cold formed steel press and higher grades of steel has made it feasible to use cold formed steel C sections as main load bearing members in flexure and compression ie., to be placed as main and intermediate beams to support precast slab panels. The use of cold-formed steel sections leads to innovative designs for specific architectural purposes, efficient structural work, and is an economical design solution in various building applications. Furthermore, light gauge cold-formed steel sections have the following advantages:

- Ease of prefabrication and mass production.
- Uniform quality
- Low self-weight
- Economy in transportation and handling
- Fast and simple erection or installation
- Improved production of complex shapes

These advantages have led to cold-formed steel structures replacing conventional hot-rolled steel structures in many cases in the building construction industry. Development and usage of cold-formed steel structural members came to use in building construction in about the 1850s in the United States and Great Britain. However, they were not widely used in building structures until 1940 [1]. Today most developed countries increasingly use cold-formed steel framing systems for houses and other low-rise constructions. Pekoz (1999) [2] states that in the USA 500 homes were built in light gauge steel in 1992, 15,000 in 1993 and 75,000 in 1994. Further, it continued to increase. Having all the advantages of the CFS as structural members, therefore, cold formed steel materials have been increasingly used for many constructions.

Studies of cold formed steel have previously been reported that the structural members can be efficiently applied for many applications [3-5] where conventional hot-rolled members proved to be uneconomic solution. However, there are several disadvantages related to the thin section which causes the unique failure modes and deformation which those failure may not normally encounter within the conventional structural steel design. Therefore, design specifications and guidelines are essentially required to meet the strength design requirement for cold formed steel structural members. American Iron and Steel Institute Specification for cold-formed steel structural design rules was firstly introduced in the year 1946 by Prof. George Winter at Cornell University which followed by the British Steel Standard with modification provided by Prof. A.H. Chilver in 1961 and Australian Standard published design code for cold formed steel in the year of 1974. Eurocode have recommendation since 1987 with supplementary rules for cold formed steel members and sheeting specified in EN 1993-1-3 and the revision specified in the Eurocode-3 published in 2006. The cold formed steel has relatively high strength which the yield stress specified up to 550MPa [6].

The major structural aspect that governs the behaviour of cold formed steel sections is the buckling due to thinness 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 C 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 = 150mm, 175mm, 200mm, 225mm, 250mm, 275mm, 300mm & 350mm
- Flange Width = 80mm, 100mm, 125mm and 150mm
- Thickness = 1.5mm, 1.75mm, 2mm, 2.25mm, 2.5mm, 2.75mm, 3mm & 3.5mm
- Span = 1m, 1.5m, 2m, 2.5m, 3m, 3.5m, 4m, 5m, 6m & 7m

The buckling analysis has been carried out on CUFSM (Finite Strip Method Solver) and the critical loads obtained are substituted in the Direct Strength Method equations to arrive at the design strength of section. The same has also been carried out in ABAQUS (Finite Element Method Solver) and static analysis is carried out to arrive at the design capacities by comparing the buckling modes shapes.

II. METHODOLOGY

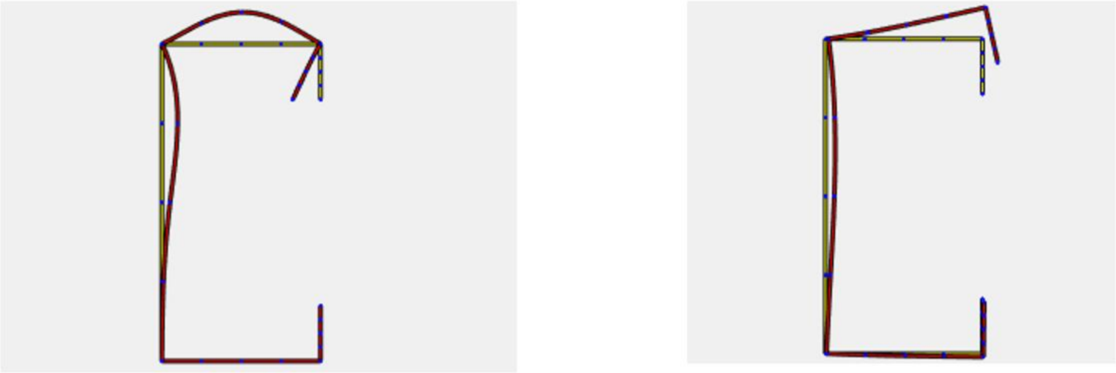
Two of the most commonly used numerical methods for conducting buckling analysis are the finite strip method (FSM) and the finite element method (FEM). Using FSM is easy and straightforward to get different buckling loads/modes. Using FEM could solve the nonlinear buckling/ultimate failure loads easily, 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. The details of analytical methods used are enumerated below:

A. CUFSM

The CUFSM computer program can be used 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 strength. Following are the steps involved in modelling

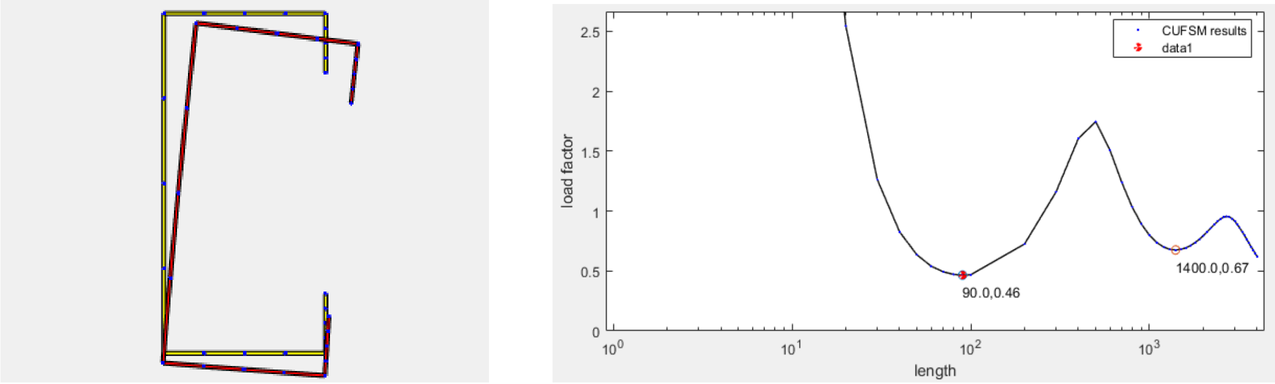
- Input the coordinates of each node on the cross-section
- Set material properties
- Specify the boundary conditions
- Input loads on the cross-section from cross section properties
- calculation and the post processing of results

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. 1 shows the buckle shapes and the buckling curve obtained from CUFSM for C section.



a. Local Buckling shape

b. Distortional Buckling shape



c. Global Buckling shape

d. Buckling Curve

Fig. 1 Buckle shapes and the buckling curve of C section obtained from CUFSM

B. *Direct Strength Method*

The Direct Strength Method is relatively new design method for CFS. This method is 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 yield for 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 $\lambda_d > 0.673$, $M_{nd} = [1- 0.22 X (M_{crd}/M_y)^{0.5}] (M_{crd}/M_y)^{0.5}. M_y$

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 they 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:

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

C. ABAQUS

The finite element analysis program (ABAQUS) is a very efficient tool to analyse the behaviour of steel structures. Light gauge cold-formed steel compression members can be modelled and analysed under different types of boundary conditions and temperature levels. However, the finite element method is not a new technique. It was first introduced in 1950 and there are many new improvements to its capacity. Today almost any type of problems can be analysed by using the finite element program ABAQUS although it is complex. 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 C section, 4-node shell element is used i.e S4R (4-node doubly curved general-purpose shell, reduced integration with hourglass control) [7].

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 performed for 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, essentially a critical elastic buckling load is obtained. 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.

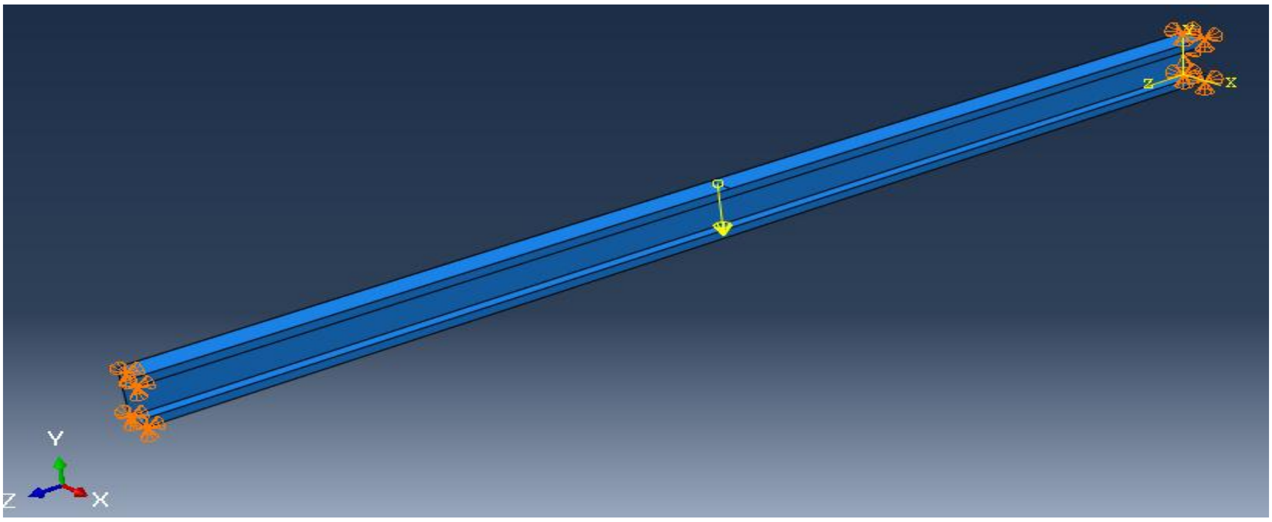


Fig. 2 Setting up of Boundary conditions and Loading

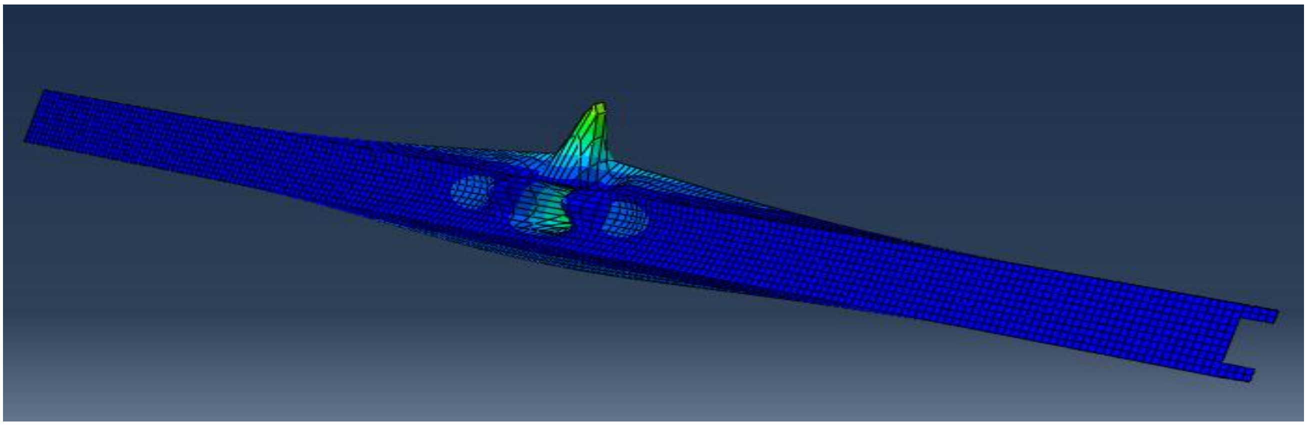


Fig. 3 Buckled Shape

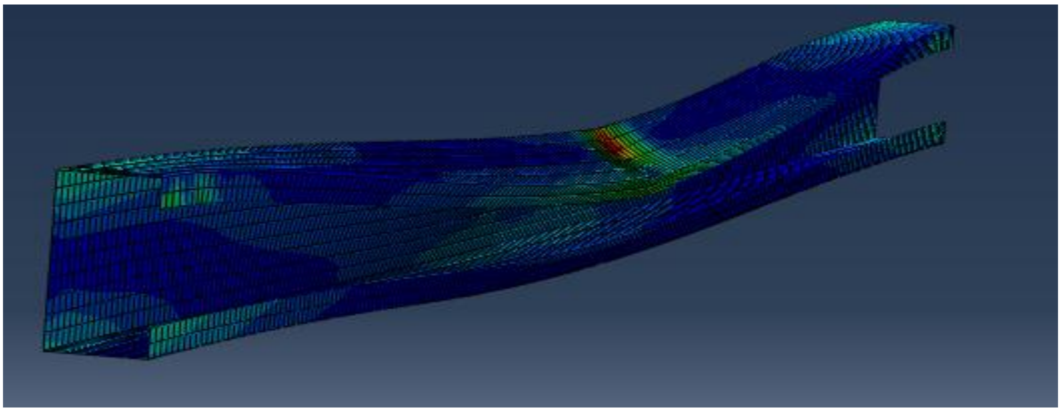


Fig. 4 Deflected shape after loading

III. RESULTS AND DISCUSSION

The results obtained from the CUFSM, direct strength method and ABAQUS are presented below for typical standard sections.

TABLE I
RESULTS OF CUFSM FOR LIPPED C SECTION

S.no	Dimension	Span(m)	t(mm)	My(kN.m)	Mcrl/My	Mcrd/My	Mcre/My	CUFSM Mn (kN.m)	ABAQUS Mn (kN.m)
1	LC	1	1.5	20.93	0.44	0.81	0.00	12.06	11.26
	200*100*35	2.5		20.93	0.44	0.70	0.00	10.45	9.51
		4		20.93	0.44	0.70	0.62	8.75	7.88
		1	2	27.91	0.77	0.99	0.00	19.51	17.36
		2.5		27.91	0.77	0.94	1.25	17.79	16.37
		4		27.91	0.77	0.94	0.65	14.40	13.10
		1	2.5	34.89	1.21	1.20	0.00	26.14	23.00
		2.5		34.89	1.21	1.20	1.41	25.03	21.78
		4		34.89	1.21	1.20	0.67	20.47	18.42
2	LC	1	1.5	27.87	0.41	0.74	0.00	15.71	14.61
	250*100*35	2.5		27.87	0.41	0.61	0.00	14.74	13.12
		4		27.87	0.41	0.61	0.62	11.43	10.29
		1	2	37.16	0.73	0.89	0.00	25.00	22.25
		2.5		37.16	0.73	0.83	1.34	23.42	21.31
		4		37.16	0.73	0.83	0.64	18.69	16.45
		1	2.5	46.45	1.13	1.07	0.00	33.46	30.11
		2.5		46.45	1.13	1.06	1.48	31.46	27.37
		4		46.45	1.13	1.06	0.65	26.67	24.54

Table 1 shows that the results obtained from CUFSM and ABAQUS has a variation of design strength of 9%-10%. The results given by ABAQUS depend on identifying the proper modes and its eigen value. The correspondence between CUFSM and ABAQUS changes with any shift in the mode selection, which will give a variation in the design strength particularly if it is a coupled mode.

The ratios of design strength to yield strength are given below. The ratio can be used as a guiding parameter while selecting a section for a particular span and loading.

TABLE 2

Mn/My RATIOS FOR LIPPED C SECTION

S.no	Dimension	Span(m)	t(mm)	My(kN.m)	Mn(kN.m)	Mn/My
1	LC	1	1.5	20.93	12.06	0.58
	200*100*35	2.5		20.93	10.45	0.50
		4		20.93	8.75	0.42
		1	2	27.91	19.51	0.70
		2.5		27.91	17.79	0.64
		4		27.91	14.40	0.52
		1	2.5	34.89	26.14	0.75
		2.5		34.89	25.03	0.72
		4		34.89	20.47	0.59
2	LC	1	1.5	27.87	15.71	0.56
	250*100*35	2.5		27.87	14.74	0.53
		4		27.87	11.43	0.41
		1	2	37.16	25.00	0.67
		2.5		37.16	23.42	0.63
		4		37.16	18.69	0.50
		1	2.5	46.45	33.46	0.72
		2.5		46.45	31.46	0.68
		4		46.45	0.65	0.57

Similar analysis has been conducted on sections with different sizes. The results have been presented in the form of parametric studies by considering l/d, d/t and d/b ratio as the parameter.

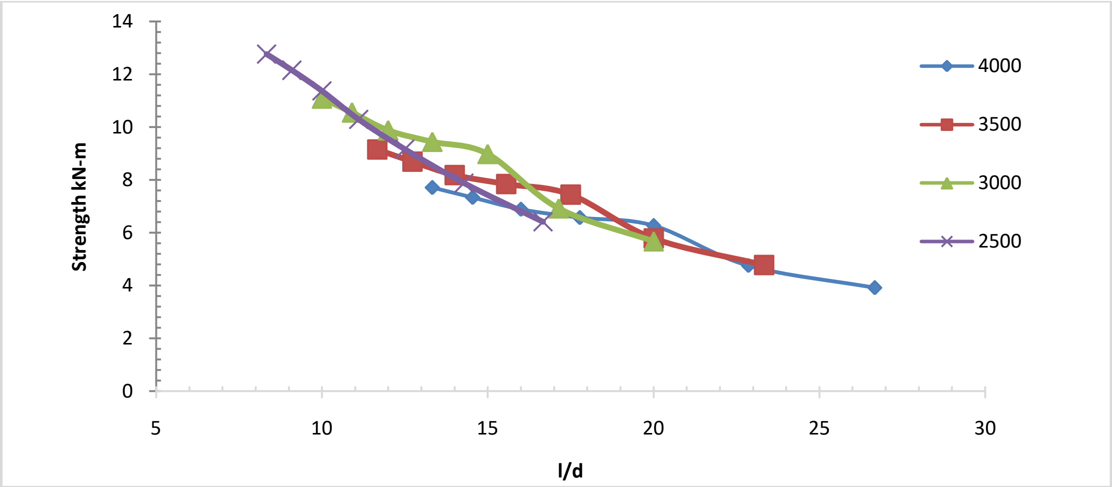


Fig.4 Variation of strength with span/web depth

The variation of strength with respect to l/d ratio shows the strength approaching a constant value beyond the l/d ratio between 15-20. By taking a maximum l/d value of 20, the section for further analysis has been considered as 200X100X35.

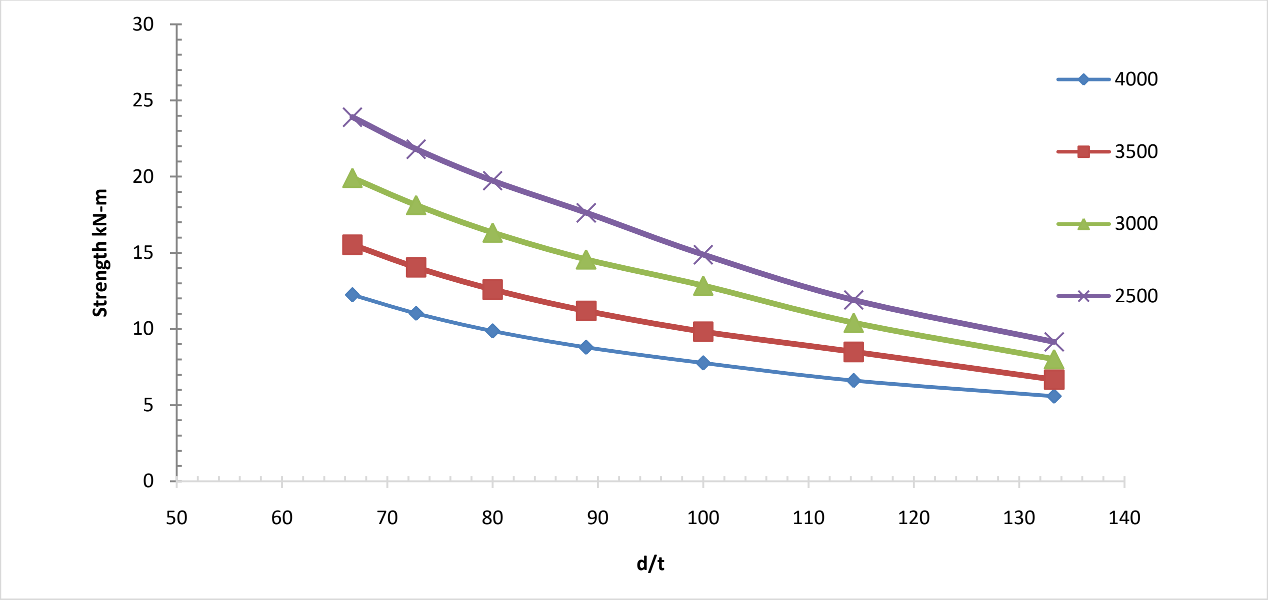


Fig. 5 Variation of strength with web depth/thickness

Fig. 5 gives the variation of strength with respect to d/t values. It is observed that beyond a certain value of'd/t' the strength for all spans is approaching the same value. From the Fig. 5 the optimum d/t limiting value can be 100.

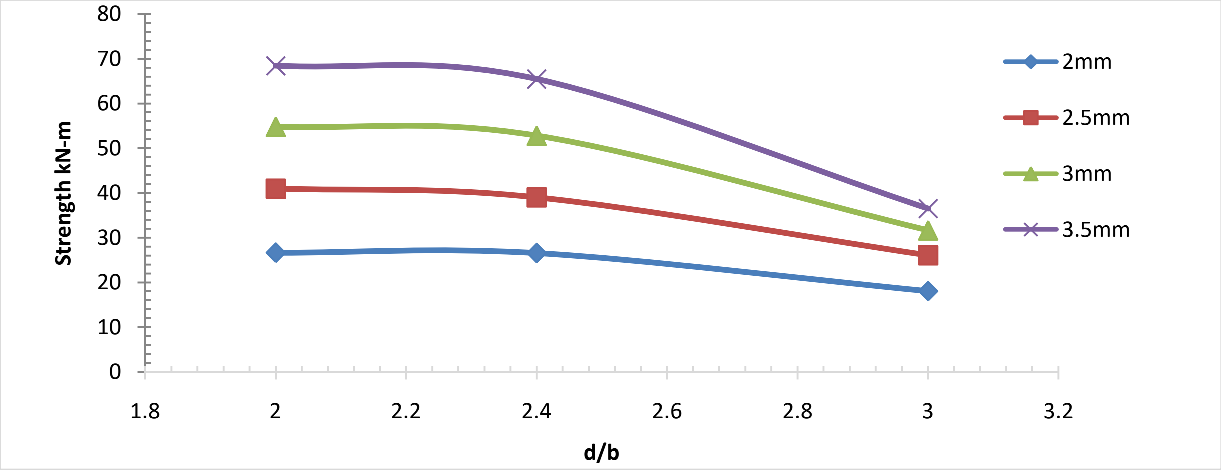


Fig.6 Variation of strength with web depth/flange width

Fig. 6 specifies the critical d/b ratio with a span of 4m, which shows a similar pattern over different thicknesses. A limiting d/b ratio can be obtained from these plots resulting in a lower bound and upper bound for this ratio for different spans. For different sections and for different spans, similar pattern is observed.

IV. CONCLUSIONS

The parametric studies conducted give upper bounds for l/d, d/t and d/b ratios. These form the basis for arriving at limiting values and bounds on these ratios in the design specifications as a basis for design using Direct Strength Method. These values can also be considered as bounds in any optimization routine for cross section profiles. The results of ABAQUS are in good agreement with CUFSM. The ratios of M_n/M_y value may be used for fixing a limiting ratio while selecting the section for a particular span.

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