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Effect of stiffened element and edge stiffener in strength and behaviour of cold formed steel built-up beams

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Abstract. The aim of this study is to investigate the effect of stiffened element and edge stiffener in the behaviour and flexural strength of built-up cold-formed steel beams. An experimental and analytical analysis of CFS channel sections in four different geometries is conducted, including simple channel sections, a stiffened channel section with or without edge stiffeners. Nonlinear finite element models are developed using finite element analysis software package ANSYS. The FEA results are verified with the experimental results. Further, the finite element model is used for parametric studies by varying the depth, thickness, and the effect of stiffened element, edge stiffener and their interaction with compression flanges on stiffened built-up cold-formed steel beams with upright edge stiffeners. In addition, the flexural strength predicted by the finite element analysis is compared with the design flexural strength calculated by using the North American Iron and Steel Institute Specifications for cold-formed steel structures (AISI: S100-2007) and suitable suggestion is made.

Keywords: built-up beams; cold formed steel; beams; edge stiffener; finite element analysis

1. Introduction

The use of cold-formed steel members has increased appreciably in building construction during the last few decades. Cold-formed steel flexural members are commonly used in building construction either as the main structural elements such as beams, columns, frames etc., or as secondary structural elements such as roof purlins. The reasons for the increasing attractiveness of these products are high strength/weight ratio and suitability for a wide range of applications. The instabilities of cold-formed steel flexural members are combined local and distortional, lateral-torsional buckling and their interaction. Due to the easy fabrication process, met with the designer requirements, and low self weight, the applications of cold formed steel section is increasing in the construction industry (Anapayan *et al*. 2011). If the single section does not meet with the designer requirements, alternative is built-up sections. Though many works have been performed on the buckling behaviour of CFS beams, not much research has been done on thin walled built-up

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beams.

The section proposed in this study is similar to that the sections tested by Manikandan *et al.* (2014). However, Manikandan *et al.* (2014) only discussed the strength and buckling behaviour of the stiffened cold-formed steel channel section with and without edge stiffener. Hence, in this study, a detailed investigation of buckling behaviour of built-up cold-formed steel beam is carried out.

2. Review of literature

Initially, Desmond *et al.* (1981) was discussed the behaviour of simple edge stiffener. An experimental investigation of cold-formed hybrid beams consisting of higher strength steel flanges connected with low-strength steel webs subjected to dynamic loads was studied by Pan and Yu (2002). A series of new flexural tests focused on the local (Yu and Schafer 2003) and distortional (Yu and Schafer 2006) buckling failures of cold-formed steel Channel and Z section flexural members were reported by the author. Wang and Zhang (2009) presented a detailed study of a range of buckling modes (local and mixed local and distortional buckling) in a channel section with upright, inclined and complex edge stiffeners. The performance of a new shape of the CFS beam with curved flange is examined analytically and is compared with that of conventional shapes by Sabbagh *et al.* (2011). Anapayan *et al.* (2011) discussed the lateral distortional buckling test on a new hollow flange channel beam. Haidarali and Nethercot (2012) investigated the importance of edge and intermediate stiffeners in the cold-formed steel beams.

Huang and Young (2012) conducted a series of tests on lean duplex flexural members fabricated from cold-reduced high strength steel with nominal yield stress of 450 MPa. Kankanamge and Mahendran (2012) presented a study on the lateral-torsional behaviour cold-formed steel flexural members. They discussed the effect of lip size-to-flange width ratio on the behaviour of laterally restrained cold-formed steel beams. To address the limitation of inelastic behaviour in the design standards, experimental and numerical analysis of the cold-formed channel section with various types of edge stiffeners were performed by Maduliat *et al.* (2012). Distortional buckling of symmetric steel I-section beams with slender webs was tested by Naderian *et al.* (2014). Wang and Young (2014) investigate the structural behaviour and discuss the appropriateness of the current direct strength method in the design of cold-formed steel stiffened cross-sections subjected to bending. The failure modes of partially stiffened cold-formed sections in bending test were conducted by Maduliat *et al.* (2015) and gave the buckling coefficient for the partially stiffened sections. The bending behaviour of stiffened cold-formed steel built-up sections with edge stiffeners was discussed by Manikandan and Sukumar (2015).

In the study, stiffened cold-formed steel built-up I section are considered and are formed by assembling stiffened cold-formed steel sections back to back using bolted connection with spacing of 150 mm (Fig. 1). Generally to avoid bearing failure, bearing plates and stiffeners are required at the support and loading points. Numerical investigations are carried out by using the finite element analysis software ANSYS. Initially, a detailed numerical analysis is carried out to investigate the effect of bearing plates, stiffeners and the effect of length variation in the strength and buckling behaviour of the stiffened cold-formed steel built-up beam. The study involved both experimental and numerical investigations. The results obtained from the finite element analysis (ANSYS) are compared with the experimental results. After validation of the finite element model, detailed parametric studies are carried out to investigate the effects of variations in depth, thickness, size of

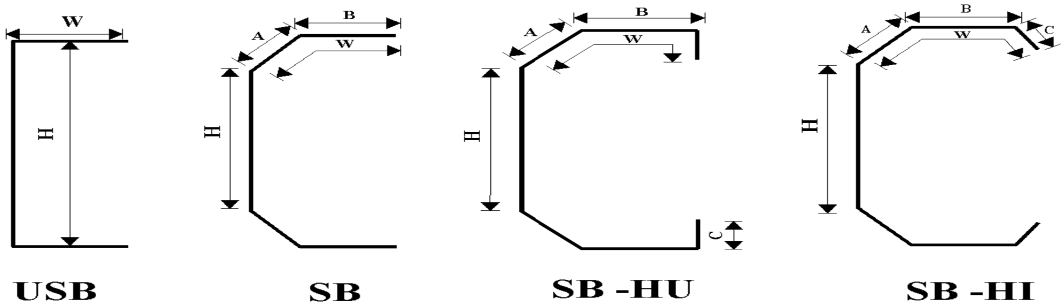


Fig. 1 Section Geometries

flange width, size of stiffened element and size of the lip on the flexural strength and behaviour of stiffened cold-formed steel built-up section with upright edge stiffener. Finally, the strength predicted by the finite element analysis is compared with the design strength calculated by using the North American Iron and Steel Institute Specification (AISI: S100-2007) for the cold-formed steel structures, and suitable recommendation are made.

3. Finite element analysis

In this study, an approximate, idealized centre line model with four-node shell-181 element is chosen with a mesh size of 10×10 mm by Manikandan *et al.* (2014, 2015). The cross-section is assumed to consist of plane elements with sharp corners. The effect of residual stresses on the strength and behaviour is considered to be negligible. Coupling option is used where ever the connection is necessary (Young and Ren 2006). All the sections are of thickness 2 mm with yield stress of 270 MPa and Young's modulus of 2.04 E5 MPa. All the specimens were analysed under simply supported end condition with two point loading. Initially, to obtain the buckling loads an eigenvalue elastic buckling analysis is performed and the flexural buckling mode obtained from elastic buckling analyses, is used to the geometric imperfection in the non-linear analysis. This was followed by a nonlinear buckling analysis is performed to predict the strength and the behaviour of the specimen. The first buckling mode shape is scaled by a factor L/1000 (Kankanamge and Mahendran 2012) to update the geometry of the finite element model to create the geometric imperfections for the nonlinear analysis. In order to account for the elasto-plastic behaviour; a simplified bilinear stress-strain curve was used, having a tangent modulus of 20000 N/mm^2.Details of finite element model are illustrated in Fig. 2.

3.1 Effect of bearing plate and stiffener on stiffened built-up open section

A finite element model (ANSYS) is developed to the effect of bearing plate and load bearing stiffener simulates the flexural strength and behaviour of the stiffened cold formed steel built-up open section (Fig. 3(b)). For all the cross-sections, the depth of the web (D) and thickness (t) of the section are taken as 170 mm and 2 mm respectively. All the beams had a length of 2300 mm. The chosen cross-sectional profiles are shown in Fig. 3(b). The details of the specimen are shown in Fig. 3. Table 1 shows the details of the selected cross-sections. Table 1 and Fig. 4 show the typical variations in flexural capacities on the stiffened cold formed built-up beams with the effect of the load bearing stiffener and bearing plate at the supports and loading points, obtained from the finite element analysis.

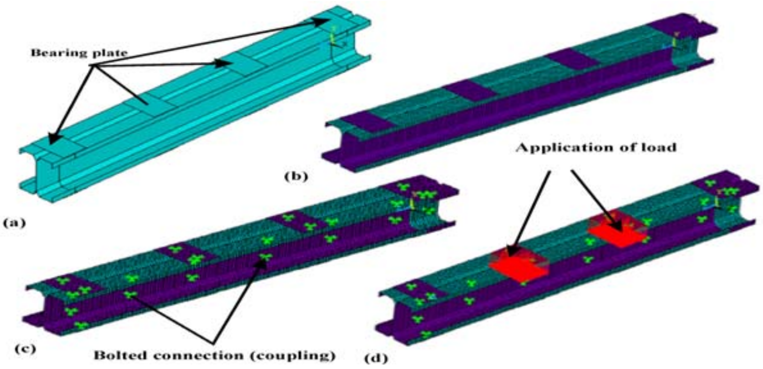


Fig. 2 Details of finite element model

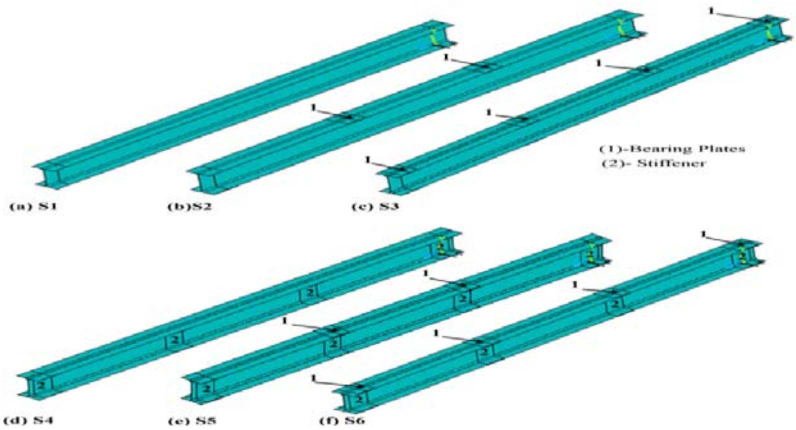


Fig. 3 Model of bearing plate and stiffener-cold-formed steel built-up open section

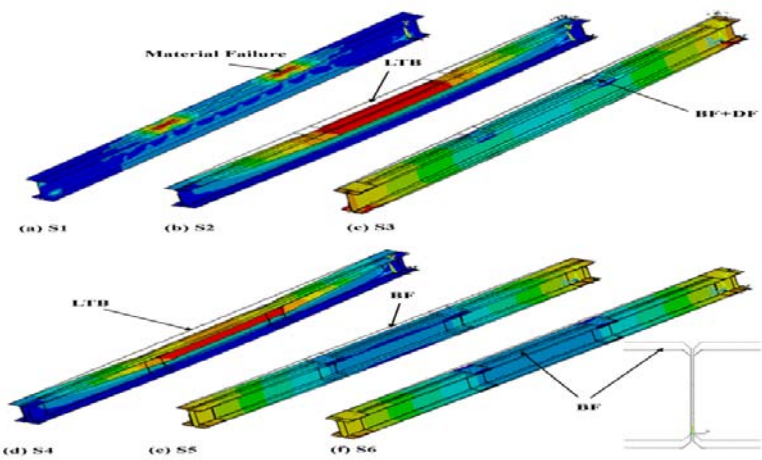


Fig. 4 Failure pattern on effect of bearing plate and stiffener at support and loading point

Specimens S1, S2, S3, S4, S5 and S6 have the same-cross sectional area. Specimen S1 (Fig. 4(a)) is filed by bearing failure while specimens S5 (Fig. 4(e)) and S6 (Fig. 4(f)) are failed by flexural bending i.e., The deflection is in the vertical plane, but specimens S2 (Fig. 4(b)) and S4 (Fig. 4(d)) fail by lateral torsional buckling. Similarly, specimen S3 (Fig. 4) is initially failed by bending and further application of the load causes distortional buckling of the flanges in the bending zone as shown in Fig. 4(e). The ultimate flexural strengths (M_{ANSYS}) are 3.09 kN.m in case of S1, 19.69 kN.m in case of S2, 24.62 kN.m in case of S3, 20.49 kN.m in case of S4, 22.28 kN.m in case of S5 and 26.99 kN.m in case of S6. The strength of the specimen S6 is more than that of all other beams (same cross-sectional area). From this study, it is found that, keeping the cross sectional area same, with the addition of the load bearing stiffener and bearing plates for the support and loading points (Fig. 4(f)), increases the flexural strength and improves the overall behaviour, performs well against the torsional buckling. Hence, all the beams are fabricated with the bearing plate at the supports and loading points.

3.2 Effect of length variation of stiffened cold-formed steel built-up open section

To study the effect of length variation on stiffened cold-formed steel built-up open section is chosen (Fig. 3(b)). The selected cross section profile and effect of length variation on stiffened cold-formed steel built-up open section as shown in Figs. 3(b) and 5 respectively. Similarly,

Table 1 Dimensions and comparison of load capacities - effect of bearing plate and stiffener

Specimen	Gross Area (sq.mm)	Section Dimensions (mm)					M_{ANSYS} (KN.m)	Failure Mode
		L	Flange Width-W		H	t		
			A	B				
S1	1120	2300	15	50	170	2	3.09	Bearing Failure
S2	1120	2300	15	50	170	2	19.69	LTB*
S3	1120	2300	15	50	170	2	24.62	BF+DB*
S4	1120	2300	15	50	170	2	20.49	LTB*
S5	1120	2300	15	50	170	2	22.28	BF*
S6	1120	2300	15	50	170	2	26.99	BF*

∗BF-Bending Failure; DB-Distortional Buckling; LTB-Lateral-Torsional Buckling

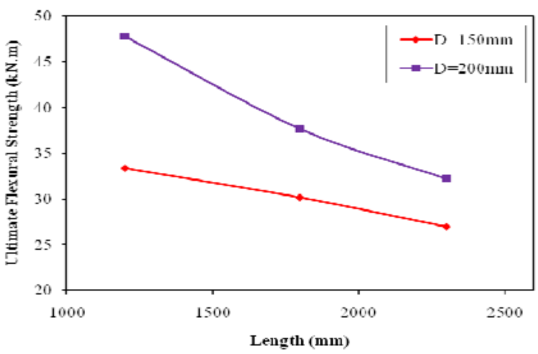


Fig. 5 Effect of length variation of stiffened cold-formed steel built-up open section

Table 2 Effect of length variation of stiffened cold-formed steel built-up open section

Specimen	Section Dimensions (mm)						Ultimate flexural strength M_{ANSYS} (KN.m)	Failure Mode
	L	Flange Width-W			H	t		
		A	B	C				
SB-1	1200	15	35	15	150	2	33.40	LTB*
SB-2	1800	15	35	15	150	2	30.16	BF*
SB-3	2300	15	35	15	150	2	26.99	BF*
SB-4	1200	15	35	15	200	2	47.82	LTB*
SB-5	1800	15	35	15	200	2	37.69	BF*
SB-6	2300	15	35	15	200	2	32.19	BF*

*BF-Bending Failure; LTB-Lateral-Torsional Buckling

selected cross section dimensions, effect of length variations in ultimate flexural strength (M_{ANSYS}) and corresponding failure modes obtained from the finite element analysis are presented in Table 2. The failure modes such as lateral torsional buckling and flexural bending are observed numerically and finally some of the specimens (SB-3 and SB-6) verified by experiments as summarized in Table 2. From this study, it is observed that the length of the member has a significant effect on behaviour and flexural strength of the stiffened cold-formed steel built-up open section. To ensure flexural bending on the stiffened cold-formed steel built-up with or without edge stiffener, the optimum length of the beam is 2000 mm.

4. Test setup

The experimental work is divided into two parts. In the first part, two beam sections, Unstiffened beam (USB) and Stiffened beam (SB) are tested to investigate their flexural strength and buckling behaviour.

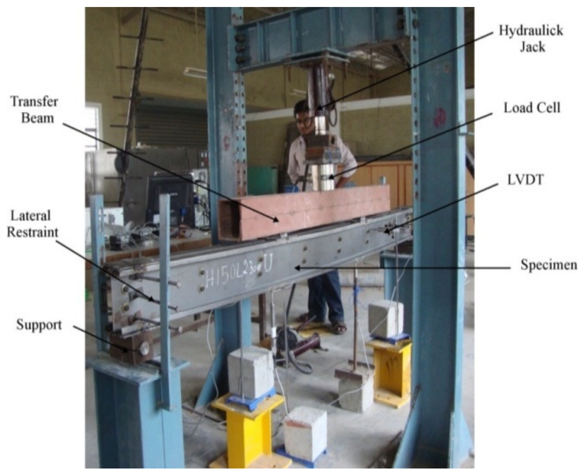
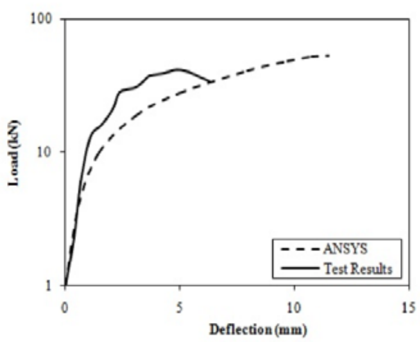


Fig. 6 Experimental set-up

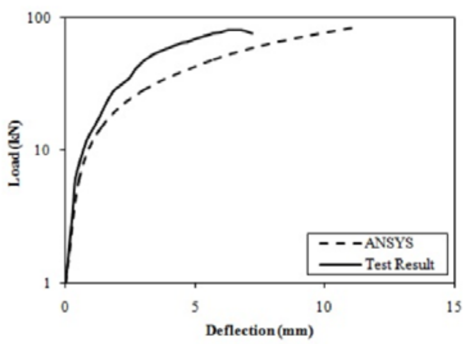
USB and SB series specimens are fabricated with web stiffeners at support and loading point. The second part of the study all the SB series specimen are tested again by adding edge stiffeners at the flanges (SB-HU and SB-HI) as shown in Fig. 1. All the beams are tested in a loading frame under simply supported end conditions subjected to two point loading. Applied load and deformation of the specimen are recorded using a data acquisition system. The details of experimental setup are illustrated in Fig. 6. Although North American Iron and Steel Institute specification for the cold-formed steel structures (AISI: S100-2007) does not establish limits for H/b ratios, Kankanamge and Mahendran (2012) gave the guidelines for selection of the H/b ratios of thin walled beams. All the sections are of thickness 2 mm with yield stress of 270 MPa and Young's modulus of 2.04 E5 MPa, a nominal web depth to flange width (H/b) ratios ranging from 2.35 to 3.8, a span of 2000 mm. The cross-section dimensions are fixed based on the North American Iron and Steel Institute specification for the cold-formed steel structures to eliminate the occurrence of local buckling. Table 3 shows the cross sectional dimensions and corresponding nomenclature defined in Fig. 1.

5. Result and discussion

Comparison load deflection curve and failure mode for some of the specimen between experiment and finite element analysis as shown in Fig. 8 and Fig. 9 respectively. Similar results are obtained for all the specimens and results are presented in Table 3. The failure modes such as combined local and distortional buckling, lateral torsional buckling is observed in the tests. Specimens USB-1 and SB-1 failed under flexure and flexural strength is 4.73 kN.m and 9.08 kN.m of the yield strength respectively. Specimens SB-HU1 and SB-HI1 having equal cross-sectional area, SB-HU1 failed by flexural bending while SB-HI1 failed by mixed local and distortional buckling. The flexural strength is 8.54 kN.m in the case of SB-HU1 and 7.78 kN.m in the case of SB-HI1.Similarly, specimens USB-2, SB-2, SB-HU2 and SB-HI2 having an equal cross-sectional area, in which USB-2, SB-2 and SB-HU2 failed by flexural bending and flexural strength are 9.11 kN.m, 10.35 kN.m and 9.37 kN.m respectively. But the specimen SB-HI2 is failed by combining local and distortional buckling. Specimens USB-3 (Fig. 8) and SB-3 failed by lateral-torsional buckling while specimen SB-HU3 failed by bending, but all the specimens have equal cross-sectional area.



(a)



(b)

Fig. 7 Load-Deflection curve (a) USB-2 (b) SB-2

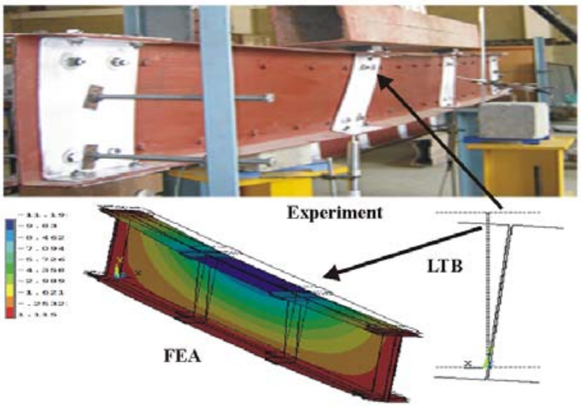


Fig. 8 Lateral torsional buckling failure of the specimen -USB-3

Table 3 Dimensions of the specimens and comparison of test results

Specimen ID	Section Dimensions (mm)				Flexural Strength (kN.m)		M_{EXP}/M_{ANSYS}	Failure Modes
	A	B	C	H	M_{EXP}	M_{ANSYS}		
USB-1	65		-	170	4.73	5.93	0.80	BF*
USB-2	65		-	220	6.72	9.11	0.74	BF*
USB-3	65		-	270	9.81	12.75	0.77	LTB*
SB-1	25	40	-	170	9.08	7.11	1.28	BF*
SB-2	25	40	-	220	9.41	10.35	0.91	BF*
SB-3	25	40	-	270	16.53	13.96	1.18	LTB*
SB-HU1	20	30	15	170	8.54	7.15	1.19	BF*
SB-HU2	20	30	15	220	9.37	10.04	0.93	BF*
SB-HU3	20	30	15	270	12.57	12.70	0.99	BF*
SB-HI1	20	30	15	170	7.78	6.79	1.15	L+DB*
SB-HI2	20	30	15	220	8.13	9.82	0.83	L+DB*
Mean							0.98	
Standard deviation							0.19	

*BF-Bending Failure; DB-Distortional Buckling; L-Local Buckling; LTB -Lateral-Torsional Buckling

From this study, it is observed that the stiffened cold-formed steel built-up section with upright edge stiffener exhibit a higher capacity than the all other sections and also improves the behaviour and performed well against local buckling.The section property calculations for such members are performed using a simplified linear method (Wang and Zhang 2009). The upright and inclined edge stiffener have equal length of c, but the moment of inertias about its own centroidal axis parallel to the flange are $I_{XX\ (SB\text{-}HU)}=0.083c^3\ t$ and $I_{XX\ (SB\text{-}HI)}=0.042c^3t$; $I_{XX(SB\text{-}HU)}>I_{XX(SB\text{-}HI)}$. The comparison between the flexural strength obtained from the experiments and finite element analysis (M_{EXP} and M_{ANSYS}) for the stiffened cold-formed steel built-up open sections with or without edge stiffener are listed in Table 3. The mean and standard deviation of M_{EXP}/M_{ANSYS} are 0.98 and 0.19 respectively. It is shown that the flexural strength obtained from the finite element analysis (M_{ANSYS}) is in good agreement with the experimental results (M_{EXP}). Therefore, it is concluded that the finite element analysis can be used a high level of confidence in predicting the load capacity of the flexural member. The results of the FE analysis are compared with the experimental results of all specimens. The failure modes shown in FE analysis are in conformity with that of the test.

6. Parametric studies on built-up beam with upright edge stiffener

From the results, it is observed that the upright edge stiffener provided in the flange of all the SB specimens improved their overall behaviour and reduced the local buckling within the bending zone. Therefore, detailed parametric studies are carried out to investigate the effects of change in cross-section geometries on the stiffened cold-formed steel built-up section with upright (SB-HU) edge stiffeners. The verified finite element model is then used for an extensive parametric study to investigate the influence of the depth and thickness, the effect of stiffened element, edge stiffener and their interaction with compression flanges on the stiffened cold-formed steel built-up beams with upright edge stiffener. The thickness (t) is varied from 1.6 mm to 3 mm and depth of the section (D) is varied from 150 mm to 300 mm while keeping the flange width (b) as 35 mm, the size of stiffened element (a) and size of the lips (c) are taken as 15 mm. All the beams have a length of 2000 mm. The normalized ratios of the flexural strength to yield strength (M_{ANSYS}/M_y) of the beam are influenced by various parameters and are graphically represented in the following subsections.

The verified finite element model is then used for an extensive parametric study to investigate the influence of the depth and thickness, the effect of stiffened element, edge stiffener and their interaction with compression flanges on the stiffened cold-formed steel built-up beams with upright edge stiffener. The cross-sectional dimensions and comparisons of flexural strength (M_{AISI}/M_{ANSYS}) are shown in Table 4. The specimens are labelled according to their size of upright edge stiffener, flange width and depth of the sections from U1-U28 as shown in Table 4. Table 4 and Fig. 9 to Fig. 11 show the typical variations in flexural capacities on the stiffened cold-formed steel built-up beams with upright edge stiffener.

6.1 Effect of section depth and thickness variation of section with upright edge stiffener

The thickness (t) is varied from 1.6 mm to 3 mm and depth of the section (h) is varied from 150 mm to 300 mm while keeping the flange width (b) as 35 mm, the size of stiffened element (a) and size of the lips (c) is taken as 15 mm. All the beams have a length of 2000 mm. The normalized ratios of the flexural strength to yield strength (M_{AISI}/M_Y) of the beam are influenced by various parameters and are graphically represented in the following subsections.

The effect of the sectional depth and thickness on the M_{ANSYS}/M_y ratio is illustrated in Fig. 9 for four depths of the sections (150, 200, 250 and 300 mm) and three thicknesses of the sections (1.6 mm, 2 mm and 3 mm). It is observed that, the M_{ANSYS}/M_y ratio increases with an increase in the thickness of the section (t) and M_{ANSYS}/M_y ratio is reduced by increasing the height-to-thickness (h/t) ratio. Fig. 9 shows the flexural strength of the section increases with an increase in thickness of the section. The parametric study has shown that the flexural strength as well as the behaviour of a stiffened cold-formed steel built-up section with upright edge stiffener are significantly affected by the height-to-thickness (h/t) ratio.

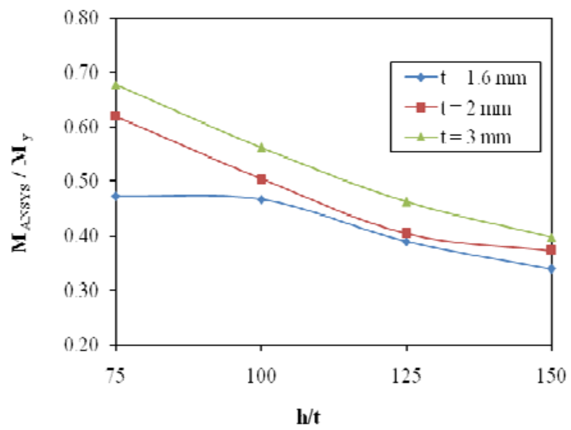


Fig. 9 Effect of section depth and thickness variation

6.2 Effect of flange width, size of stiffened element and lip size of section with upright edge stiffener

Flange width of the section (b), size of stiffened element (a) and size of the upright stiffener (c) is changed. Sixteen stiffened built-up beams with upright edge stiffeners are analysed using the developed finite element model. For all the cross-sections, the depth and thickness of the section are taken as 200 mm and 2 mm respectively. A total of 16 combinations between a/t and c/t are considered, a/t varies from 5 to 12.5 while b/t lies within the range of 17.5 to 32.5 and c/t varies from 5 to 10 while b/t lies within a range of 17.5 to 25. Table 4 shows the details of the selected cross-sections and comparisons of results.

Fig. 10 demonstrates the relationship between the normalized ratio a/t and the normalized ratio of the flexural strength to the yield strength of the beam (M_{ANSYS}/M_y) for different values of b/t. Obviously, the size of the stiffened element has a significant effect on the flexural strength of the stiffened cold-formed steel built-up section with upright edge stiffener. It is observed that the M_{ANSYS}/M_y ratio increases with an increase in the a/t ratio. Fig. 10 shows that M_{ANSYS}/M_y ratio is

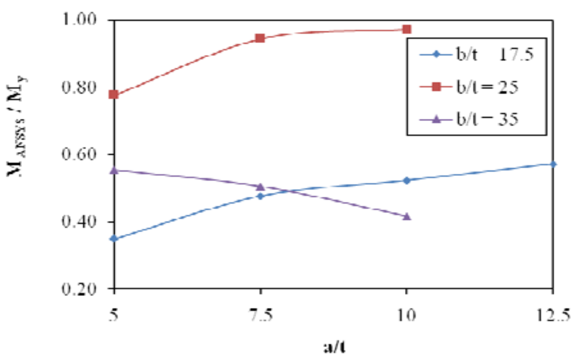


Fig. 10 Effect of variation in size of stiffened element

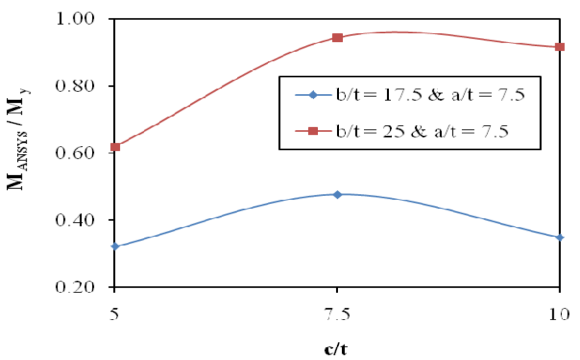


Fig. 11 Effect of variation in flange width

reduced by increasing the flange width-to-thickness ratio (b/t). Fig. 11 demonstrates the effect of size of upright edge stiffener for an a/t ratio of 7.5. It is observed that the flexural strength of the beam increases with increase in lip size-to-thickness ratio (c/t) up to a certain limit beyond which flexural strength is reduced. The parametric study has shown that the flexural strength as well as the behaviour of the stiffened cold-formed steel built-up section with upright edge stiffener is significantly affected by the size of stiffened element and upright edge stiffener.

Table 4 Comparison of results with FEA and AISI specifications

ID	Section Dimensions (mm)					Flexural Strength (kN.m)		$\frac{M_{AISI}}{M_{ANSYS}}$	Failure Mode
	A	B	C	H	t	M_{ANSYS}	M_{AISI}		
U1	15	35	15	150	1.6	4.31	5.00	1.16	BF*
U2	15	35	15	200	1.6	6.13	6.61	1.08	BF*
U3	15	35	15	250	1.6	6.90	8.14	1.18	BF*
U4	15	35	15	300	1.6	7.76	8.96	1.15	BF*
U5	15	35	15	150	2	7.05	7.15	1.01	BF*
U6	15	35	15	200	2	8.28	10.28	1.24	BF*
U7	15	35	15	250	2	11.50	13.68	1.19	BF*
U8	15	35	15	300	2	15.21	15.33	1.01	BF*
U9	15	35	15	150	3	11.50	9.41	0.82	BF*
U10	15	35	15	200	3	13.80	13.72	0.99	BF*
U11	15	35	15	250	3	15.33	18.43	1.20	BF*
U12	15	35	15	300	3	16.98	21.30	1.25	BF*
U13	10	35	15	200	2	7.28	8.11	1.11	BF*
U14	15	35	15	200	2	10.04	9.64	0.96	BF*
U15	20	35	15	200	2	11.12	11.19	1.01	BF*
U16	25	35	15	200	2	12.27	12.76	1.04	BF*
U17	10	50	15	200	2	18.88	18.43	0.98	LTB*
U18	15	50	15	200	2	23.23	20.55	0.88	LTB*
U19	20	50	15	200	2	24.23	22.72	0.94	LTB*
U20	10	65	15	200	2	15.33	17.68	1.15	DB*
U21	15	65	15	200	2	14.18	15.86	1.12	LB*
U22	20	65	15	200	2	11.88	14.62	1.23	LB*
U23	15	35	10	200	2	6.13	6.72	1.10	BF*
U24	15	35	15	200	2	9.37	9.64	1.03	BF*
U25	15	35	20	200	2	8.05	10.11	1.26	BF*
U26	15	50	10	200	2	13.99	14.22	1.02	LTB*
U27	15	50	15	200	2	23.23	20.55	0.88	LTB*
U28	15	50	20	200	2	24.33	21.12	0.87	LTB*
				Mean				1.07	
				Standard Deviation				0.13	

*BF-Bending Failure; DB-Distortional Buckling; LB-Local Buckling; LTB -Lateral-Torsional Buckling

7. Comparisons of numerical results with code predictions

The flexural strength obtained from the finite element analysis (M_{ANSYS}) compare with design strength (M_{AISI}) calculated by using the North American Iron and Steel Institute Specifications for the cold-formed steel structures (AISI: S100-2007) as shown in Table 4. The mean and standard deviation of the M_{AISI}/M_{ANSYS} are 1.07 and 0.13 respectively. It shows that AISI specifications over-predict the flexural strength of the stiffened cold-formed steel built-up section with upright edge stiffener, a new modification factor is proposed. Fig. 12 shows the regression analysis result between M_{ANSYS} and M_{AISI}. From this analysis, it is found that the relationship between M_D=0.975 M_{AISI} with R^2=0.90, thus confirming the fact that the moment capacities predicted by finite element analysis are equal to 90.00 % of the nominal moment capacity calculated according to AISI specifications. On the basis, it is proposed that a modification factor of 0.975 is to be applied to the flexural strength of stiffened cold-formed steel built-up section with edge stiffened flanges, in AISI Specifications. The proposed modification results are verified through the results available from the literature (Yu and Schafer 2003, Manikandan and Sukumar 2015) and results are presented in Table 5. From these results it is observed that the design results reasonably predict the test results with a mean and standard deviation of M_{Design}/M_{EXP} is 1.04 and 0.08 respectively.

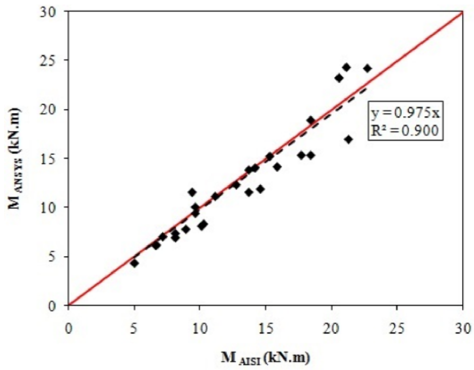


Fig. 12 Comparison of results with FEA and AISI specifications

Table 5 Verification of proposed formula

Specimen ID as per Literature	Experimental M_{EXP} (kN.m)	Design strength M_{Design}(kN.m)	$\frac{M_{Design}}{M_{EXP}}$
12C068-9E5W[17]	11.80	12.11	1.03
8C054-1E8W[17]	6.30	6.33	1.01
11.5Z092-1E2W[17]	39.80	39.20	0.98
12C068-3E4W[17]	15.50	17.57	1.13
USB-C1	31.70	30.13	0.95
SB-C1	9.09	10.74	1.18
SB-C3	4.87	5.02	1.03
	Mean		1.04
	Standard Deviation		0.08

8. Conclusions

This paper has presented the flexural strength and behaviour of stiffened cold-formed steel built-up section with edge stiffeners. The strength and failure mode predicted from the finite element analysis is correlate with the test results. The developed finite element models are used to perform a parametric study to investigate the influence of the depth and thickness, the effect of stiffened element, edge stiffener and their interaction with compression flanges on the stiffened cold-formed steel built-up beams with upright edge stiffener.

The subsequent conclusions are drawn from the present investigation:

• The parametric study has shown that the flexural strength as well as the behaviour of a stiffened cold-formed built-up section with upright edge stiffener was significantly affected by the height-to-thickness ratio

• This study proved that the provisions of stiffened element at the flange/web junction and edge stiffeners at the flanges are increasing the flexural strength and improves the behaviour

• The flexural strength and buckling behaviour of the stiffened beam with upright edge stiffener was significantly affected by the size of stiffened element and size of upright edge stiffener.

• For stiffened cold-formed steel section with or without edge stiffeners, the flexural capacity predicted by the North American Iron and Steel Institute Specifications for the cold-formed steel structures (AISI: S100-2007) are overestimated, an appropriate modification factor in the design is proposed in this paper

This investigation has shown that the provision of stiffened element at flange/web junction and the upright edge stiffeners improve the behaviour and increase the flexural strength of the section.

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