Građevinski materijali i konstrukcije
Building Materials and Structures
journal homepage: www.dimk.rs

https://doi.org/10.5937/GRMK2300011P

Preliminary report

Behaviour of cold-formed steel built-up beams under flexural loading

Sangeetha Palanivelu*[1)]

[1)] *Associate Professor, Department of Civil Engineering, Sri Sivasubramaniya Nadar College of Engineering, Kalavakkam, Chennai, Tamilnadu, India*

Article history

Received: 28 June 2023
Received in revised form: 06 October 2023
Accepted: 23 October 2023
Available online: 09 November 2023

Keywords

CFS built-up beam,
flange plate,
channel section,
bolted connections,
ANSYS

ABSTRACT

Cold-Formed Steel (CFS) built-up beams are most commonly used as structural elements such as columns, beams, and trusses. They are also used to avoid buckling and increase member flexibility by providing flanges and side plates/batten plates. This study describes the flexure behaviour of the CFS built-up beam. Six CFS built-up beams were tested to failure with a Universal Testing Machine (UTM). CFS built-up beams of thickness 2 mm were developed using channel sections put back to back and close to close, as well as a lip and flange plate. The overall deflection and strain against the incremental load were discussed and compared with the control beam without a lip and flange plate. A back-to-back CFS built-up beam with lip a section could withstand 32% greater load under flexure than a back-to-back built-up beam without a lip. The Finite Element Analysis (FEA) was performed using the software ANSYS, and there was a high correlation between the experimental and analytical results.

1 Introduction

CFS built-up sections are extensively used in industrial buildings due to their high strength-to-weight ratio. The failure of structural elements is mainly due to buckling, which can be overcome by providing a flange plate or side plate. The presence of these plates increases the moment of inertia of the section and thus improves the flexibility of the member. The bolted built-up CFS beam with extended stiffener shows good flexural strength based on the location and spacing of the bolts[1]. The spacing of connectors has a less significant effect on the ultimate capacity of the CFS built-up beam made of three or four channel sections [2]. A design equation was proposed by the direct strength method specification for the CFS built-up hat section and also reported that, except thickness, all other dimensions of the built-up section significantly affect the strength and behaviour of beams [3]. The addition of intermediate web stifeners and edge stifeners improves the behaviour and strength of the CFS built-up channel section with a lip [4]. An extensive parametric study on the CFS built-up beam was carried out to examine the bending moment carrying capacity [5]. The effects of distortional buckling on a hollow flange channel beam are investigated, and the results of a finite element model are compared to the codal provisions for cold-formed steel constructions [6]. The flexural behaviour of CFS hollow beams with perforation was studied and reported that the rectangular hollow beams withstand 41 % more load than that square hollow beams [7]. The CFS channel column with circular, diamond, and elliptical holes along with and without lip was investigated to study the strength and buckling behaviour [8].

From the literature study, it was observed that more investigation on the strength and behaviour of the CFS built-up beams are found. However, the effect of the flange plate, web hat, and lip section on the CFS built-up beams was limited. Thus, this study was carried out for the innovative CFS built-up beams to examine the ultimate load-carrying capacity, moment-carrying capacity, and its behaviour under flexural loading.

2 Materials and Methods

Cold-formed steel of grade St 34-1079 (S355MC as per EN – 10027-1)was used to produce the CFS built-up beams in compliance with IS 811-1975[9] requirements. Cold-formed steel plate with a thickness of 2 mm was used to create channel sections with or without a 15 mm lip. Six different built-up beams were fabricated with various arrangements such as beam with or without flange plate (CF1, CF2, CF3, CF4, CF5 & CF6), beam with or without lip (CF3 & CF4), and beam with web hat (CF5) and box section (CF6). The flange plates are bolted to the built-up beam (CF1 to CF5) to behave as a single unit. The hexagonal bolt of size 12 mm diameter was used to connect the channels back-to-back. The mild steel bolt of 4 nos was utilised to connect the channel back to back to obtain the CFS built-up beam. The spacing between the bolt of 320 mm was maintained. The bolt hole of diameter 14 mm was drilled along the web of the channel for bolting. In specimens CF2, CF4 &CF6 the flange

* Corresponding author:
E-mail address: sangeethap@ssn.edu.in

plate has been welded using a semi-automatic arc welding process at four places to the length of 15 mm. The spacing between the weld maintained was 300 mm. The box section was obtained by welding the lip of the channel section (CF6) as mentioned in Table 1. The built-up beam measured 1000 mm in length was tested with the ends as simply supported condition. The coupon test [10] was used to investigate material parameters such as yield stress, ultimate stress, modulus of elasticity, and specimen elongation after fracture, which were determined to be 260 N/mm^2, 470 N/mm^2, and 2.02 x 10^5 N/mm^2 and 50 mm respectively and stress-strain behaviour was shown in Fig.1. The specimen details and its dimensions are shown in Table.1.

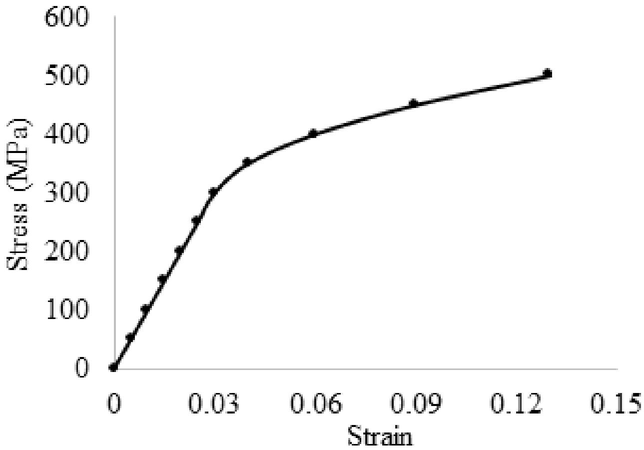
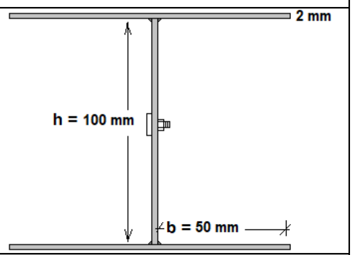
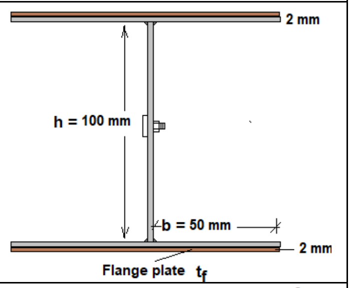
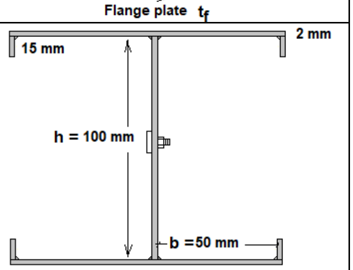
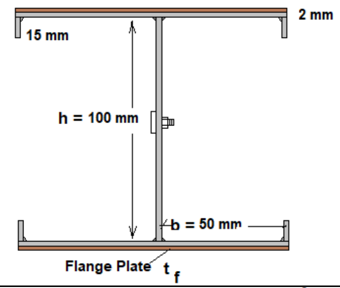
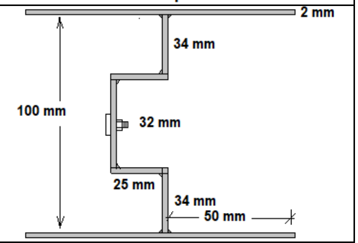
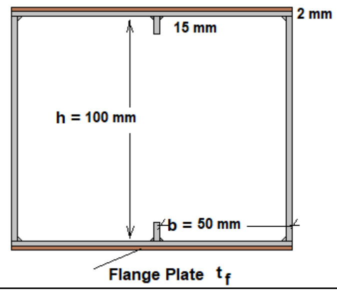


Figure 1. Stress - strain behaviour of the CFS material

Table 1. Description of the CFS built-up beams

Specimen ID	Specimen Description	Channel Dimension (mm)	Lip (mm)	Thickness of flange plate (mm)	Sectional view of the CFS beam
CF1	Channel section Back-to-back arrangemnet without flange plate	100 x 50 x 2	-	2	
CF2	Channel section Back-to-back arrangemnet with flange plate	100 x 50 x 2	-	2	
CF3	Channel section Back-to-back arrangemnet without flange plate	100 x 50 x 2	15	2	

CF4	Channel section Back-to-back arrangemnet with flange plate	100 x 50 x 2	15	2	
CF5	Channel section with hat arrangement in the web	100 x 50 x 2	-	2	
CF6	Closed channel section with flange plate	100 x 50 x 2	15	2	

2.1 Experimental study

The built-up beams are supported at the ends and tested for failure under flexure. The loads are applied using a 600 kN capacity Universal Testing Machine, all CFS built-up beams were tested until they failed under flexure. Hydraulic stroke control was used to apply the static stress at a rate of 0.5 mm/min [11]. Using a dial gauge with a count of 0.01 mm, the central vertical deflections were measured. Figure 2 illustrates where the dial gauge is located to measure the centre deflection. Using a 20 mm strain gauge pasted horizontally along the length of the beam to measure the strain in x- direction of the CFS built-up beam. The 5-channel strain indicator was used to measure the strain levels as shown in Figure 2. All of the built-up beams were tested until the maximum load was reached, and the deflection and strain were measured for a 2 kN load interval. Figure 2 shows the schematic test setup and experimental test setup. The tested specimens are shown in Figure 3. From Figure 3, it is observed that all the beam specimens show the local flange failure and overall torsional buckling of the CFS beam. The specimen with a flange plate was able to resist deformation, thus local bucking of the flange can be minimised (CF2).

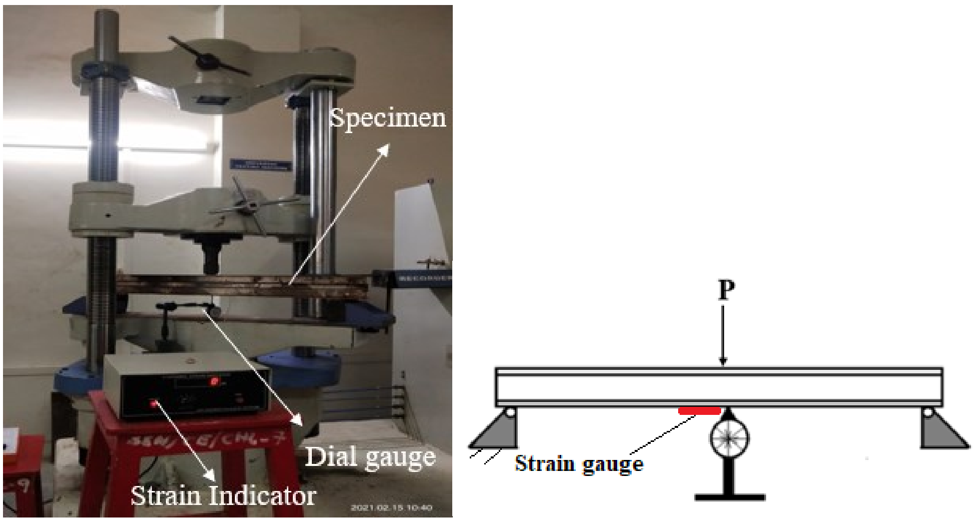


Figure 2. Expermental set-up

Figure 3. Tested CFS built-up beams

2.2 Numerical Study

All CFS built-up beams are modelled in AutoCADD and imported into the ANSYS programme. The CFS built-up beam was meshed using element SOLID 185 from the element collection of ANSYS. The simple support conditions in terms of displacement and rotation are simulated in the FEA at the ends of the beam. The translations along x, y and z were also constrained at the ends. The load was applied in increments as sub-steps using the Newton-Raphson method from the ANSYS library. The overall imperfection was taken as 1/1000 of the overall length of the column, including both the initial bending of the member and the initial eccentricity of the loading. For each incremental step of end-shortening, the total reaction at the end is obtained. Using, the 'UPGEOM' command in ANSYS, buckling mode was obtained. To validate the results, the material properties acquired from the experimental study were allocated to the built-up-beam models. At the mid-span of the CFS built-up beam, an axial load was applied. The mesh model of the CFS built-up beams is shown in Figure 4.

The deformed shape of the CFS built-up beams is shown in Figure 5. The local buckling of flange was observed for the beam CF1 and CF3 and it was compared based on the intensity of red colour patches. The CFS built-up beam CF2 and CF4 shows that the overall deflection of the beam is less for the CFS built-up beam. The local inward and outward buckling of the box built-up beam (CF6) and similar failure were noted in the tested specimen.

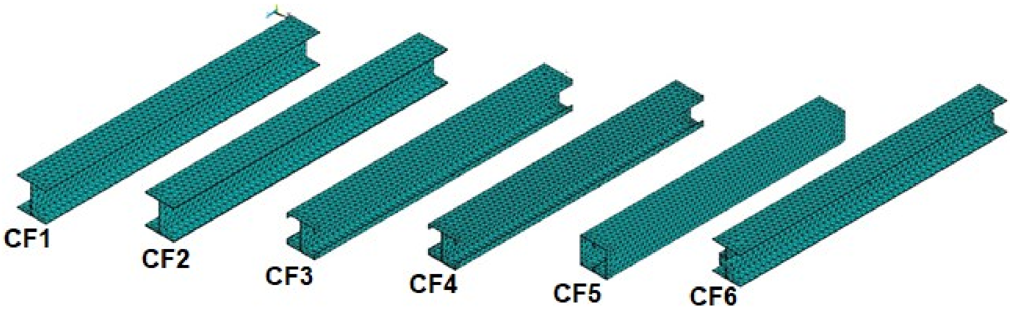


Figure 4. Mesh models of CFS built-up beams

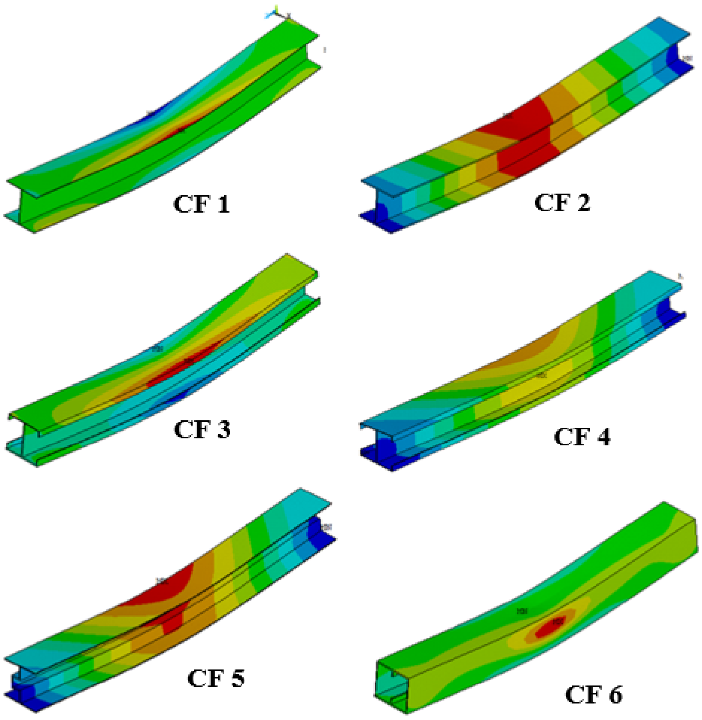


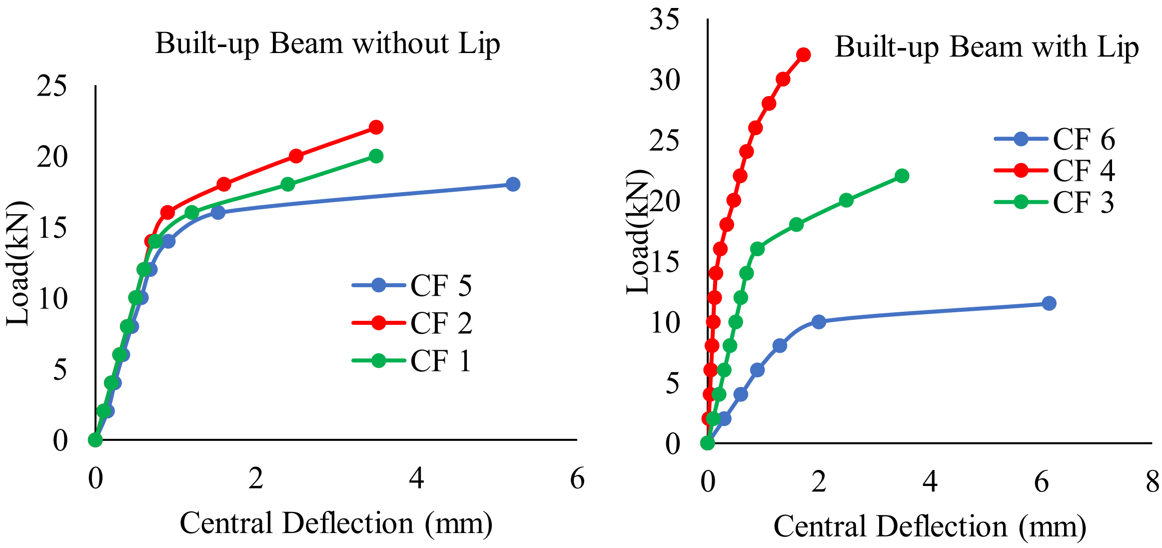
Figure 5. Deformed shape of the CFS built-up beams

3 Results and discussions

3.1 Effect of lip on the load-carrying capacity of the built-up beam

The Cold-formed steel built-up beams were tested for failure under one-point loading. The specimens were grouped as built-up beams without lip (CF 1, CF 2 & CF 5) and built-up beams with lip section (CF 3, CF 4 & CF 6). The behaviour between load carrying capacity and the central deflection is shown in Figures 6(a) & 6(b). From Figure 6(a), it was clear that the behaviour of the build-up beam without lip section(CF 1, CF 2 & CF 5) was uniform with the average load carrying capacity of 21 kN. The built-up beam CF 5 was able to resist the deflection up to 5.2 mm which was 33 % more than the CF 1 & CF 2(3.5 mm). The beam with that arrangement in the web avoids web torsional buckling and hence resisted more deflection under single point loading.

From Figure 6(b), it was seen that the load-carrying capacity was more for the built-up beam with a lip section of 15 mm. In that, the beam CF 4 was found to be stiffer due to the presence of a flange plate of thickness 2 mm and also observed that the failure of the beam CF 4 was due to web torsional buckling. The built-up beam CF 6 was made by connecting two-lipped channel sections close-to-close, from Figure 6(b) it was observed that CF 6 was able to resist the deflection up to 6.15 mm (Max. central deflection = 1.85 mm as per theoretical calculation). The % decrease in the load-carrying capacity from CF 4 to CF 3 and from CF 4 to CF 6 is 45% and 48% respectively.



(a) (b)

Figure 6. Load-central curve for the built-up beam without a lip and with a lip section

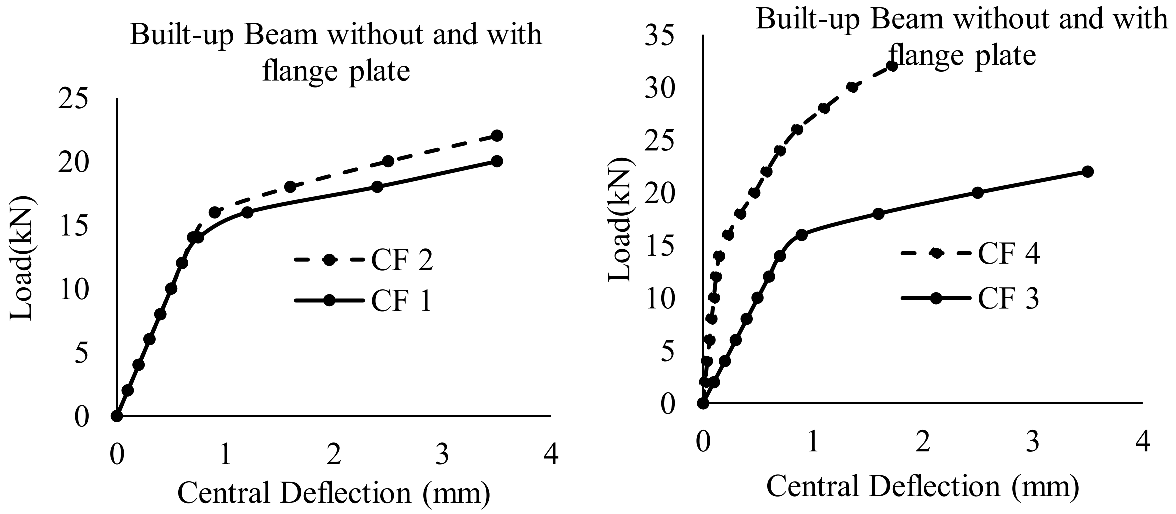
3.2 Effect of flange plate on the load-carrying capacity of the built-up beam

The built-up beams CF 1 and CF 2 are made with the channel section arranged back-to-back without a flange plate and with a flange plate (top and bottom) respectively. The behaviour of CF 1 and CF 2 without a lip section is shown in Figure 7(a). It was observed that from Figure 7(a), the load-deflection behaviour was linear until the load of 14.5 kN which is 18.5 % of the average load-carrying capacity of 22.25 kN (CF 1 & CF 2). Figure 7(b) shows that the load-deflection behaviour of the lipped built-up beam CF 3 and CF 4 with and without a flange plate respectively. The mode of failure of the CF 3 involves a rotation of the lip/flange components upon loading. The same was overcome by providing a flange plate of thickness 2 mm both at the top and bottom flange (CF 4) which increases the moment of inertia. The built-up beam CF 3 and CF 4 shows the linear behaviour up to the load of 16 kN.The strength of CF 4 was 1.5 times more than that of CF 3. Thus the use of a flange plate improves the strength and stiffness of the built- up beam.

Figure 8 shows the deflections observed from the experimental and numerical study. From the bar chart, it was observed that the numerical model is stiffer than the experimental one due to rigid body connections between the flange plates and channel sections.

3.3 Load-strain behaviour

The strain corresponding to the gradually applied load was recorded using a strain indicator and a graph was plotted between them. Figure 9. shows the load-strain plot of the built-up beams. CF 2 and CF 4 were able to resist the maximum strain in the range of 600-700 microstrain, this may be due to the presence of flange plates. Thus energy absorption capacity of CF 2 and CF 4 was also improved significantly. Whereas, the specimens CF 1, CF 3, CF 6 and CF 5 were able to resist microstrain values of 200, 50, 220 and 450 respectively.



(a) (b)

Figure 7. Load-deflection behaviour of the built-up beam with a flange plate

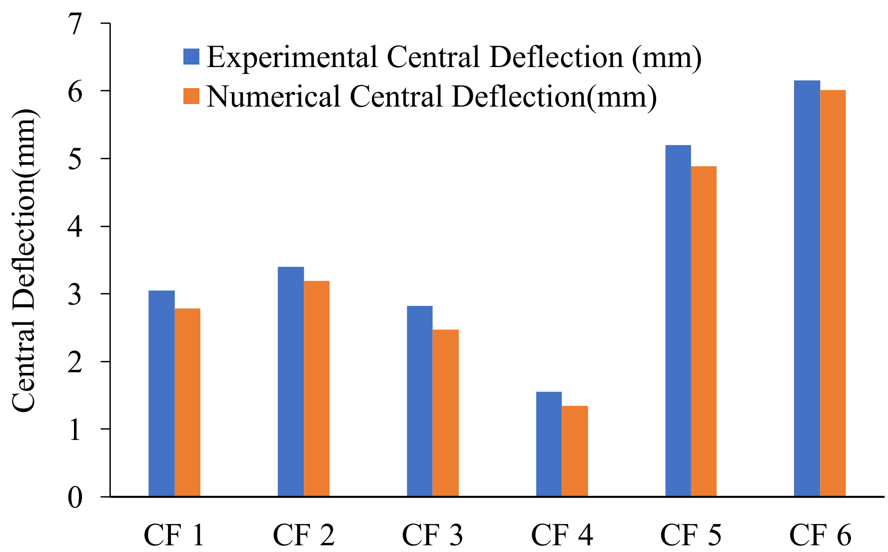


Figure 8. Bar chart comparison of the maximum central deflection

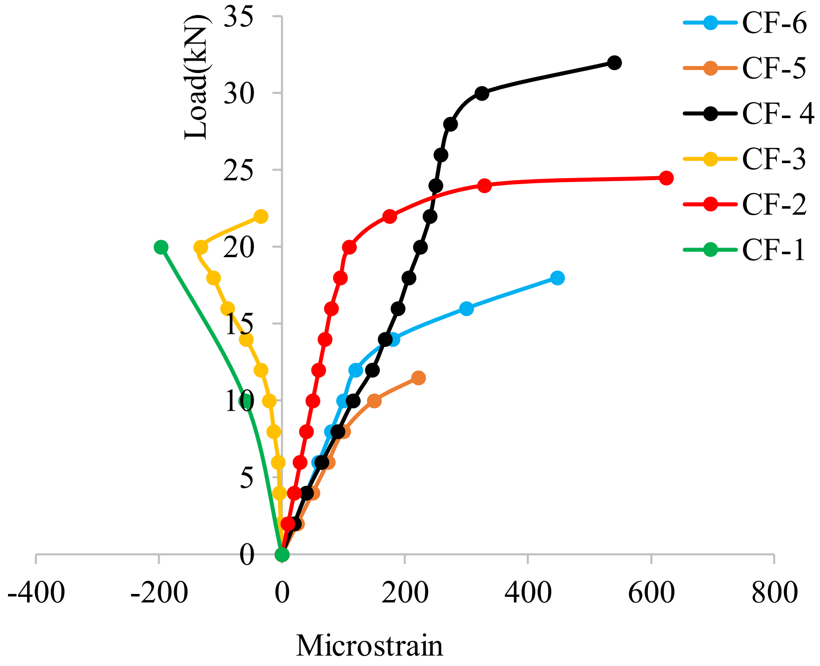


Figure 9. Load- strain behaviour of CFS built-up beams

3.4 Theoretical Investigation

The nominal flexural strength (M_{DSM}) for CFS structures, according to the DSM [12], is the minimum of lateral-torsional buckling (M_{ne}), local buckling (M_{nl}), and distortional buckling (M_{nd}), as shown below.

The lateral-torsional buckling strength (M_{ne}) is

For $M_{cre} < 0.56\ M_y$; $M_{ne} = M_{cre}$

For $2.78\ M_y > M_{cre} > 0.056 M_y$; $M_{ne} = \frac{10}{9} My\left(1 - \frac{10My}{36\ Mcre}\right)$

Where , M_{cre} - Critical Moment Capacity
M_y - Yield moment capacity
M_{nl} - Lateral-Torsional Buckling coefficients

Table 2. compares the results of the FEA model to the theoretical outcome. According to Table 2, the Direct Stiffness Method is conservative in calculating the flexural strength of CFS beams. The calculated mean and standard deviation for the ratio of M_{FEA} and M_{DSM} are 0.91 and 0.03 respectively. The percentage difference between the flexural strength of M_{FEA} and M_{DSM} is less than 10 %. The linear regression analysis is made between M_{DSM} and M_{FEA} of the CFS built-up beams and it is shown in Figure 10. M_{DSM} and M_{FEA} have a relationship of M_{FEA} = 0.901 M_{DSM} with a regression coefficient of 0.901. Thus, the flexural strength of CFS built-up beams could be determined using FEA models, and a satisfactory correlation between numerical and theoretical studies was attained.

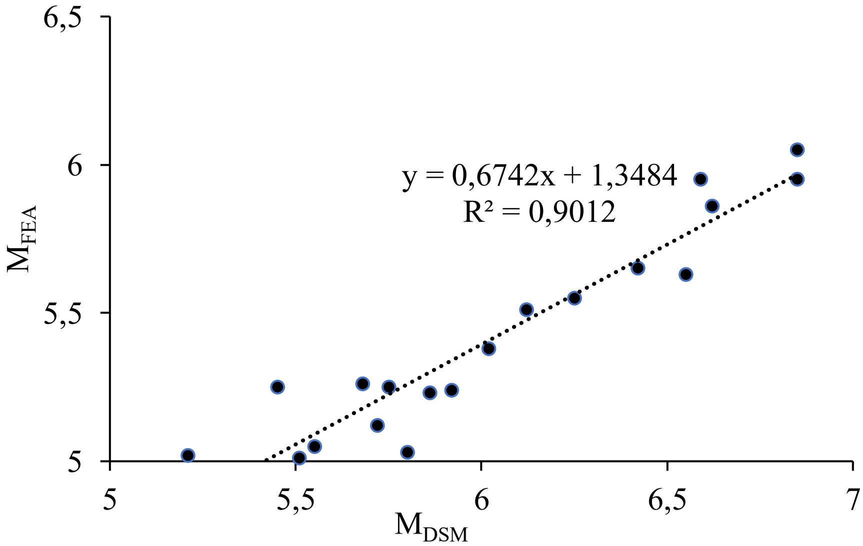


Figure 10. Variations of M_{DSM} and M_{FEA}

Table 2. Comparison between the results of FEA model and theoretical outcome

Specimen	Section dimension (mm)						M_{FEA} (kN.m)	M_{DSM} (kN.m)	M_{FEA}/M_{DSM}	Failure Mode
	h	b	D/S	t	t_f	L				
CF1 -L800 -H100	100	50	6.85	2	0	800	5.95	6.25	0.87	L
CF1 -L1000 -H100	100	50	6.62	2	0	1000	5.86	6.12	0.89	L + LT
CF1 -L1200 -H100	100	50	6.42	2	0	1200	5.65	6.01	0.88	L + LT
CF1 -L1400 H100	100	50	6.12	2	0	1400	5.51	5.99	0.90	L + LT
CF2 -L800 - H100	100	50	6.02	2	2	800	5.38	5.89	0.89	LT
CF2 -L1000 -H100	100	50	5.92	2	2	1000	5.24	5.72	0.89	F + LT
CF2 -L1200 -H100	100	50	5.72	2	2	1200	5.12	5.53	0.90	F + LT
CF2 -L1400 -H100	100	50	5.51	2	2	1400	5.01	5.24	0.91	F + LT
CF3 -L800 -H100	100	50	6.85	2	0	800	6.05	6.42	0.88	L
CF3 -L1000 -H100	100	50	6.59	2	0	1000	5.95	6.21	0.90	L + LT
CF3 -L1200 -H100	100	50	5.86	2	0	1200	5.23	5.54	0.89	L + LT
CF3 -L1400 -H100	100	50	5.13	2	0	1400	4.96	5.01	0.97	F + LT
CF4 -L800 -H100	100	50	6.55	2	2	800	5.63	6.31	0.86	LT
CF4 -L1000 -H100	100	50	6.25	2	2	1000	5.55	6.10	0.89	F + LT
CF4 -L1200 -H100	100	50	5.80	2	2	1200	5.03	5.62	0.87	F + LT
CF4 -L1400 -H100	100	50	5.01	2	2	1400	4.55	4.95	0.91	F + LT
CF5 -L800 -H100	100	50	5.75	2	0	800	5.25	5.42	0.91	F + LT
CF5 -L1000 -H100	100	50	5.55	2	0	1000	5.05	5.35	0.91	F + LT
CF5 -L1200 -H100	100	50	5.25	2	0	1200	4.95	5.02	0.94	F + LT
CF5 -L1400 -H100	100	50	5.01	2	0	1400	4.45	4.89	0.89	F + LT
CF6 -L800 -H100	100	50	5.45	2	2	800	5.25	5.35	0.96	L + F
CF6 -L1000 -H100	100	50	5.68	2	2	1000	5.26	5.46	0.93	L + F
CF6 -L1200 -H100	100	50	5.21	2	2	1200	5.02	5.12	0.96	L + F
CF6 -L1400 -H100	100	50	5.02	2	2	1400	4.95	5.00	0.99	L + F
								Mean	**0.91**	
							Standard Deviation		**0.03**	

4 Conclusions

Six distinct specimens were tested for the flexural behaviour of cold-formed steel built-up beams. Single-point loading was applied to all specimens at the centre of the CFS built-up beam. The flexural test was performed under UTM of capacity 600kN. The maximum central deflection at the centre of the beam was recorded and load-strain behaviour was studied and compared for all the test specimens. All of the specimens were further evaluated using the ANSYS Finite Element Analysis programme. The following results were drawn from the experimental, numerical, and theoretical research.

- Flange plates are used in cold-formed steel built-up beams to increase their flexural capacity. By adding stiffeners to the top and bottom flanges of the beam, the section's resistance to bending moments is enhanced.
- Flange plates also contribute to the overall stability of the cold-formed steel beam. They reduce the potential for lateral-torsional buckling and help maintain the beam's integrity when subjected to bending loads.
- The back-to-back cold-formed steel channel section with a lip section was able to resist 32 % more load under flexure as compared to a back-to-back built-up beam without a lip.
- The cold-formed steel beam with that section inside was found to resist less load due to a weaker axis along the hat portion of the back-to-back beam section.
- The load-strain behaviour of CF-5 (Cold-formed channel closed section) was found to resist more load and strain.
- From the analytical results, the percentage difference between the experimental and analytical central deflection is within 10 %. This shows good correlation between the experimental and analytical models was obtained.
- The built-up beam CF 2 and CF 4 were able to resist the maximum strain in the range of 600 – 700 microstrain, this may be due to the presence of flange plates. Thus energy absorption capacity of CF 2 and CF 4 was also improved significantly.
- The DSM is conservative in predicting the flexural strength of CFS built-up beams. The calculated mean and standard deviation for the ratio of M_{FEA} and M_{DSM} is 0.91 and 0.03 respectively. The percentage difference between the flexural strength of M_{FEA} and M_{DSM} is less than 10 %. Thus, the flexural strength of CFS built-up beams could be determined using FEA models, and a satisfactory correlation between numerical and theoretical studies was attained.

List of symbols

Mcre	Critical Moment Capacity
My	Yield moment capacity
Mnl	Lateral-Torsional Buckling coefficients
$M_{c,Rd}$	Cross-section design bending moment of resistance
M_{FEA}	Finite element moment resistance
M_{DSM}	Direct Design Method moment resistance

Abbreviations

CFS	Cold-Formed Steel
UTM	Universal Testing Machine
ANSYS	Finite element software
DSM	Direct Design Method

References

[1] Fadhluhartini Muftah, Mohd Syahrul Hisyam Mohd Sani, Mohd Mawardi Mohd Kamal(2019) ,Flexural Strength Behavior of Bolted Built Up Cold Formed Steel Beam with Outstand and Extended Stiffener, International Journal of Steel Structures 19(3):719–732

[2] Meza, F.J., Becque, J. and Hajirasouliha, I. (2020), Experimental study of cold-formed steel built-up beams, Journal of Structural Engineering, 146 (7). 04020126.

[3] Manikandan.P, Ezhilan.A, (2019), Investigation on cold formed steel built up new innovative hat shaped closed section under bending, International Journal of Advanced Structural Engineering 11:1–8.

[4] Manikandan.P, Thulasi.M, (2019) ,Investigation on cold formed steel lipped channel built up I beam with intermediate web stiffener, International Journal of Advanced Structural Engineering 11:97–107.

[5] Mohamed Ghannam (2019), Bending Moment Capacity of Cold Formed Steel Built Up Beams, International Journal of Steel Structures 19(2):660–671

[6] R. Senthilkumar, T. S. Sunil, P. Jayabalan,(2019) ,Buckling Behaviour of Hollow Flange Channel Beam Sections in Bending, International Journal of Steel Structures 19(5):1454–1464.

[7] Sangeetha P, Revathi S.M, Sudhakar V, Swarnavarshini D & Sweatha S(2021), Behaviour of cold-formed steel hollow beam with perforation under flexural loading, Materials Today: Proceedings, 38: 3103-3109.

[8] Sangeetha P, Dhinagaran M, Gobinaath A S, Saravana Kumar A S & Jeevan Raj A D(2022),Performance Assessment of the Perforated CFS Unlipped and Lipped Channel Section Under Compression, Lecture Notes in Civil Engineering 179:265 – 277.

[9] IS 801: 1975, Code of Practice for Use of Cold Formed Light Gauge Steel Structural Members In General Building Construction

[10] IS 1608: 2005, Indian standard code of practice for Metallic Materials: Tensile testing at ambient temperature.

[11] Davison, B., & Owens, G. W. (Eds.). (2011) Steel designers' manual. New York: Wiley.

[12] AISI S100: 2007, Specification for the design of cold-formed steel structural members: American Iron and Steel Institute.