Influence of Built-up Cold-formed Steel Columns Battened for Long-span Portal Frame

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***Abstract*—Cold-formed steel structural systems are increasingly being used as primary or secondary structural elements in sustainable construction due to their lightweight, speed of construction, recyclability, and sustainability. However, the inherently low buckling resistance of thin-walled sections results in relatively low strength and ductility in cold-formed steel elements, which limits their performance in long-span portal frame structures, so they are generally used with column heights less than 4 m. This paper reports the results of a numerical investigation on the built-up cold-formed steel columns battened for long-span portal frames of 24 m. The built-up sections are formed by four identical lipped channels placed with batten plates. The result shows that built-up battened columns as an alternative to having structure columns taller rather than columns with conventional back-to-back built-up sections, especially when higher compression capacities are required.**

***Keywords*—cold-formed steel, buckling, battened column, compression, long-span portal frames**

I. Introduction

Cold-Formed Steel (CFS) built-up sections are widely used as compression members under axial compression to handle heavy loads and long spans when a single section is insufficient [1]. Built-up cold-formed steel members are typically joined together using a variety of techniques, such as bolted connections or screw fastening. These connections ensure the individual steel sections act together as a unified structural element, effectively distributing the loads and improving the overall strength and rigidity. The fastening operation with self-drilling screws can reduce labor time and eliminate the pre-drilling of holes in comparison to bolted connections.

In cold-formed steel construction, built-up columns are frequently used, especially for relatively slender columns because they offer enough flexural stiffness to resist buckling without increasing the cross-sectional area of the sections. When compared to singly symmetric sections in cold-formed steel structures, the doubly symmetric box-type closed section comprised of four-angle sections has significantly high torsional rigidity [2]. The ultimate compression capacity of battened columns is primarily influenced by the internal forces in the connecting parts, the general behavior of the built-up column, and the local buckling of the chord members. The deformations brought on by bending and shear stress have an impact on the behavior of the global buckling. The shear deformation in the battened columns is determined by the deformability of the batten plates.

Generally, portal frames from cold-formed steel are limited to spans of less than 15 m with column heights of less than 4 m [3–5], because cold-formed steel sections are vulnerable to local, distortional and overall buckling modes, as shown in Fig. 1. However, it is observed that no studies are reported on cold-formed steel built-up battened columns formed by four-lipped channels placed with batten plates as shown in Fig. 2.

Fig. 1. FE Model built-up BTB I-section column.

Fig. 2. FE model built-up battened column.

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The performance of built-up battened columns made of four-lipped channels with 6 m height will observe with long-span portal frame structures, compared with conventional built-up back-to-back channel sections by designing a long-span portal frame.

II. Literature Review

Most of the prior research on built-up section columns concentrated on I-sections, which are made up of two channels joined together with self-drilling screws. In experimental research on built-up I-section columns, T. A. Stone and R. A. LaBoube [6] discovered that the modified slenderness ratio technique was conservative in estimating the ultimate bearing capacity. Jia-Hui Zhang and Ben Young [7] tested a series of built-up I-section columns assembled from lipped sigma sections. The tests suggested that the direct strength method (DSM) can quite accurately predict the ultimate bearing capacity of the built-up column with back-to-back I sections.

K. Piyawat *et al*. [8] numerically studied the doubly symmetric welded built-up section and established a simple bearing capacity equation based on the three-dimensional surface fitting and experimental data correction. D. C. Fratamico *et al*. [9, 10] carried out experimental research on built-up I-section columns with a group of connectors at each end to investigate the effect of group fasteners on cross-section composite action.

K. Roy *et al*. [11–13] completed experimental and numerical research on a series of built-up I-section columns composed of lipped and unlipped channel sections, and evaluated design methods in the current code. T. Zhou *et al*. [14] established a new method for calculating the flexural buckling capacity of built-up I-section columns based on the energy method and the direct strength method.

A. Mangal Mahar *et al*. [15] proposed a compound slenderness (L/r) ratio considering the interaction effect of fastener spacing and overall slenderness (L/r) ratio for calculating the flexural buckling capacity of built-up back-to-back I-section columns. S. Selvaraj and M. Madhavan [16] investigated the local and global buckling behavior of built-up back-to-back I-section columns and modified the design curve according to the reliability and experiment analysis.

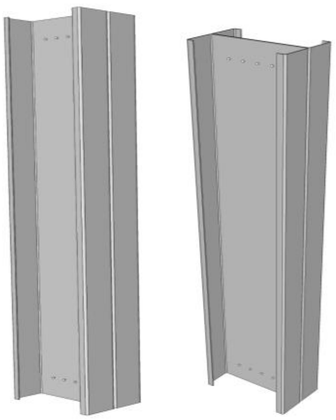

Fig. 3. Built-up back-to-back column.

The 3D drawing and arrangement of cold-formed steel built-up back-to-back column channel sections are shown in Fig. 3.

Research on axial capacity of built-up cold-formed steel lipped channels by J. Whittle and C. Ramseyer [17], concluded that decreasing the slenderness ratio increases the column's maximum load carrying capacity and increases the efficiency of column elements. Member capacity based on the unmodified slenderness ratio, fastener, and space between the battens were consistently conservative. Study on angle sections with battened plates, M. El Aghoury *et al*. [18] concluded that local buckling may occur in the thin angle leg or in the angle itself between the battened plates, and distorsional buckling may happen for battened columns which are composed of unstiffened four angles.

Ting T. and Lau H. [19] studied the cold-formed steel built-up back-to-back I-section columns experimentally and theoretically. The effective width concept-based design method has a better prediction than the direct strength method (DSM) when comparing experiment tests and theoretical results.

Georgieva I. *et al*. [20, 21] studied on cold-formed steel built-up members showed, however, that along with buckling, when clearances are provided to ensure ease of assembly and bolts are used to connect the section profiles, fastener flexibility also impacts the member's stability and strength. Flexibility due to the connection between the battens and member profile makes the development of a suitable design method for cold-formed steel built-up battened columns more complicated.

Anbarasu and Sukumar [22] studied the effect of stiffener members with spacers on intermediate-length columns. They also investigated numerically and theoretically the effect of spacing plates, fasteners, and the number of battens on built-up batten columns composed of lipped channel sections.

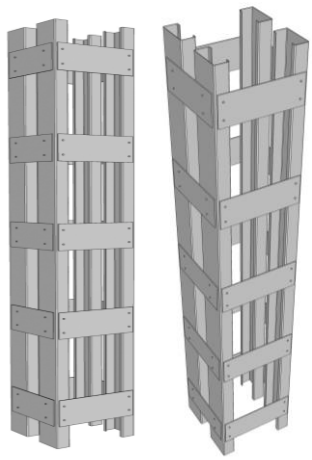

Fig. 4. Built-up battened column formed by four-lipped channels.

The batten arrangement provides increased rigidity and stability to the column. The battens act as stiffeners and distribute the load more uniformly across the column's height, reducing the risk of buckling or deformation under load. This enhanced stability allows for taller columns and higher design flexibility as shown in Fig. 4.

III. STRUCTURAL SYSTEM AND LAYOUT

The structural system of this study is with layout rectangular area of WxL plan dimensions, portal frame as shown in Fig. 5. The portal frame was designed based on the back-to-back cold-formed steel, with conventional back-to-back CFS columns and built-up battened CFS columns, all two models are shown in Figs. 6–7.

Span (W) Type : 24 m

Bay Length (L) : 30 m

Rafter pitch : 10°

Bay spacing : 6 m

Purlin distance : 1 m

Eaves height : 6 m

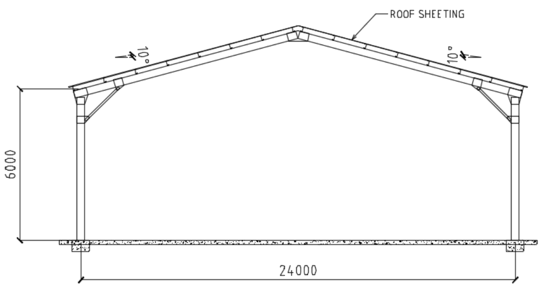

Fig. 5. Structure geometry.

Fig. 6. Model with back-to-back CFS channel sections.

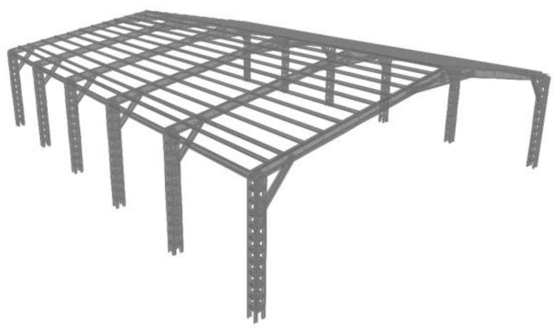

Fig. 7. Model with gapped built-up CFS channel sections.

IV. LOADING CALCULATION

The design loads applied to the building as part of the design optimisation are as follows:

Dead load (DL) : 0.15 kN/m^2

Live load (LL) : 0.60 kN/m^2

Wind pressure (q_s) : 1.00 kN/m^2

In accordance with BS 6399 (2002), the design wind pressures acting on each of the four sides of the building are obtained by multiplying q_s by a coefficient of pressure and other related factors. The external pressure coefficient C_{pe} and the internal pressure coefficient C_{pi} are combined to the coefficient of pressure on each side.

$$p = q_s(C_{pe} - C_{pi}) \quad (1)$$

where

C_{pe} is the external pressure coefficient

C_{pi} is the internal pressure coefficient

Wind load combinations are considered in the design process as provided in BS 6399 (2002). The following load combinations for ultimate limit design are checked against the portal frame design at the ultimate limit state (ULCs):

$$\text{ULC1}=1.4\text{DL}+1.6\text{LL} \quad (2)$$

$$\text{ULC2}=1.2\text{DL}+1.2\text{LL}+1.2\text{WL} \quad (3)$$

$$\text{ULC3}=1.4\text{DL}+1.4\text{WL} \quad (4)$$

$$\text{ULC4}=1.0\text{DL}+1.4\text{WL (for wind uplift)} \quad (5)$$

The Steel Construction Institute (SCI) recommended deflection limits from Table I are used to check the portal frame at its serviceability limit state for the following Serviceability Load Combinations (SLCs):

$$\text{SLC1}=1.0\text{LL} \quad (6)$$

$$\text{SLC2}=1.0\text{WL} \quad (7)$$

TABLE I. DEFLECTION LIMITS FOR PORTAL FRAMES

Deflection category	Reason for limit	Deflection limit
Lateral deflection at eaves	Damage to side cladding Damage to roof	$h_f/100$ $b_f/150$
Vertical deflection at apex	Ponding of water Visual acceptability	$\sqrt{b_f{}^2 + s_f{}^2}/125$ $L_f/240$

Notes : h_f is the column height; b_f is the frame spacing; s_f is the rafter length

TABLE II. PROPERTIES OF COLD-FORMED STEEL CHANNEL SECTION

CFS No.	Section	Thickness mm	Depth D mm	Width B mm	Lip L mm	Radius mm
1.	C150.15	1.5	152	64	20	5
2.	C150.19	1.9	152	64	20	5
3.	C200.15	1.5	203	76	25.5	5
4.	C200.19	1.9	203	76	25.5	5
5.	C250.19	1.9	254	76	25.5	6
6.	C250.24	2.4	254	76	25.5	6
7.	C300.19	1.9	300	95	30	6
8.	C300.24	2.4	300	95	30	6
9.	C300.30	3.0	300	95	30	6
10.	C400.24	2.4	400	125	30	6
11.	C400.30	3.0	400	125	30	6
12.	C400.40	4.0	400	125	30	6

TABLE III. COMPARISON WEIGHT OF PRIMARY FRAMES (KG/M²)

Portal Frame Span 24 m	Member	Section	Weight kg	Cost IDR
Back-to-back CFS Column				
	Column	2-C400.40	506.313	15,189 K
	Rafter	2-C400.30	791.114	23,733 K
	Eaves Strut	2-C250.19	31	930 K
	Apex Strut	2-C250.19	38.7	1,161 K
	Total		1367.127	41,014 K
Built-up battened CFS Column				
	Column	4-C150.24	273.837	8,215 K
	Rafter	2-C400.30	79.114	23,733 K
	Eaves Strut	2-C250.19	31	930 K
	Apex Strut	2-C250.19	38	1,161 K
	Batten Plate		77,017.7	2,,311 K
	Total		1211.668	36,350 K

V. RESULT AND DISCUSSION

Batten columns are formed vertically by joining multiple cold-formed steel sections using battens plates. This construction technique significantly enhances the load-carrying capacity of the column.

From Table III and Figs. 8–9 is observed that steel consumption is more in portal frames using conventional built-up back-to-back column sections 2-C400.40 as compared to portal frames using built-up battened column sections 4-C150.24, the nominal dimensions of the sections are presented in Table II. The weight is more in the portal frame which uses conventional built-up back-to-back column sections. Table IV shows the details of portal frame deflection under SCI deflection at the eaves and apex.

TABLE IV. DEFLECTION (MM)

Portal Frame Span 24m	Member	Section	Calculated Deflection mm		Deflection Limits mm	
			Eaves	Apex	Eaves	Apex
CFS with BTB Column	Column Rafter	2-C400.40 2-C400.30	12.25	72.90	40	108.66
CFS with Battened Column	Column Rafter	4-C150.24 2-C400.30	14.89	88.39	40	108.66

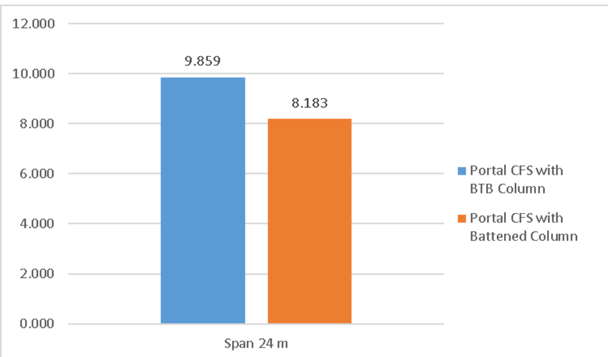

Fig. 8. Comparison of weight of primary frames (kg/m²).

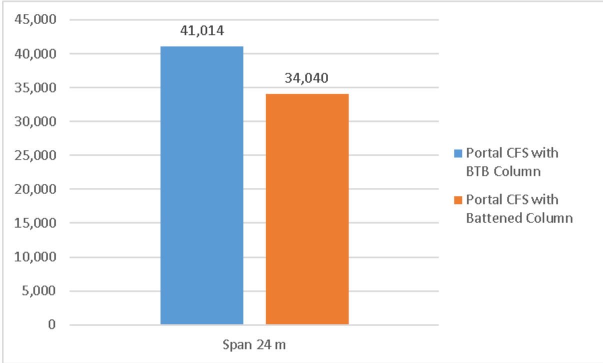

Fig. 9. Comparison of cost of primary frames.

VI. CONCLUSION

In terms of weight ratio and sustainability, this paper has highlighted several possible benefits of cold-formed steel built-up battened columns over conventional built-up back-to-back columns.

Long-span portal frames with cold-formed steel built-up battened column channel sections are shown to be economic, rather than conventional built-up back-to-back channel sections.

As shown in Fig. 8 and summarized in Table III, the weight of portal frame 24 m span with built-up battened columns is 155.459 kg reduced from than portal frame with conventional built-up back-to-back columns. Total weight of portal frames with built-up battened columns is reduced by 11.37% than portal frames with built-up back-to-back columns.

The results presented in this paper can be used by future researchers and this particular type of built-up battened column sections to be used in long-span portal frames as an alternative to conventional built-up back-to-back column sections without any gap, especially when larger beam span and higher compression capacity is required.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. JS performed Material preparation, FE model, and analysis, and wrote the first draft of the manuscript; all authors commented on previous versions of the manuscript; all authors had approved the final version.

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