JOURNAL OF STRUCTURAL MONITORING AND BUILT ENVIRONMENT
e-ISSN: 2773-5303

JSMBE

Vol. 5 No. 1 (2025) 88-95
https://publisher.uthm.edu.my/periodicals/index.php/rtcebe

Behaviour Of Cold-Formed Steel Built-Up Square Battened Columns Composed of Different Spacing of Chord and Battened Plate

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DOI: https://doi.org/10.30880/rtcebe.2025.05.01.010

Article Info

Received: 13 February 2025
Accepted: 23 June 2025
Available online: 30 June 2025

Keywords

Cold-formed steel, buckling behavior, battened, SHS column

Abstract

This study investigates square hollow sections (SHS) in built-up cold-formed steel (CFS) battened columns, aiming to assess structural performance and the impact of varied spacing configurations between chords and battened plates. Four configurations were tested under axial compression to evaluate differences in load-carrying capacity, deformation, and buckling behavior. Experimental results revealed that specimens with narrower chord and batten spacing exhibited higher stiffness and load capacity, while wider spacing led to earlier onset of buckling and greater lateral displacement. Notably, the configuration with 50 mm chords and 300 mm batten spacing achieved the highest ultimate load of approximately 590 kN, demonstrating superior axial performance. Load-strain and lateral displacement patterns confirmed that reduced spacing enhanced stability and delayed buckling failure. These findings provide actionable insights into optimizing the design of CFS battened columns for enhanced structural efficiency and reliability in engineering applications.

1. Introduction

Cold-formed steel (CFS) structures, valued for their efficiency and versatility, have seen increased use in construction. However, a crucial research gap exists in understanding the behavior of built-up square battened columns, especially concerning spacing configurations between chord and battened plate elements. Existing studies often provide general insights into CFS behavior yet lack a specific focus on square battened configurations and varied spacing. Previous studies, such as those by Chen et al. (2019) and Hancock et al. (2017), have addressed cold-formed steel behavior in general but do not specifically analyze the effects of different spacing arrangements in square battened columns. This study aims to fill these gaps by examining cold-formed steel built-up square battened columns, considering different spacing configurations. The primary goals include evaluating load-carrying capacity and investigating buckling behavior, aligning with standards such as Eurocode 3 (2005).

Additionally, the unique characteristics of CFS, produced through cold-working at room temperature, make it suitable for various structural applications. CFS exhibits different behaviors in terms of load-carrying capacity, deformation, and failure mechanisms due to its high strength-to-weight ratio, work-hardening, and strain-hardening properties (Shaikh et al., 2016). CFS, with both elastic and plastic characteristics, can withstand axial, flexural, and shear pressures. Different failure mechanisms, such as local buckling, flexural buckling, shear failure, and web crippling, are observed depending on stress circumstances and section shape (Schafer et al., 2010).

Comparatively, both hot-rolled steel and CFS are common construction materials, each with unique properties and uses. CFS, created by cold-forming thin steel sheets or strips at room temperature, offers design freedom, customization, and cost-effectiveness. In contrast, hot-rolled steel, produced by heating steel above its recrystallization temperature, excels in applications requiring wider spans, better load-carrying capabilities, and greater structural strength. The decision between CFS and hot-rolled steel depends on specific project needs. The design of built-up CFS battened columns involves configuring battens, horizontal plates fastened to the columns' sides. Engineers can enhance the column's strength, stiffness, and overall performance by adjusting batten configurations. Changes to batten size, spacing, and composition greatly impact load-carrying capacity and stiffness. Adjusting batten properties increases the column's total stability, ensuring it remains stable under various loading conditions (Shaikh et al., 2016).

The structural behavior of built-up CFS battened columns is influenced by the horizontal spacing between chords. Optimal column strength and minimized buckling occurrences require careful consideration of chord spacing, impacting resistance to twisting moments and lateral displacements. Architects and engineers must examine chord spacing during the design phase to balance stability, load-carrying capability, and overall structural efficiency.

This study constitutes a comprehensive exploration into the behavior of cold-formed steel (CFS) built-up square battened columns, with a dual focus encompassing the determination of load-carrying capacity and an investigation into buckling behavior. In the pursuit of assessing load-carrying capacity, the research will systematically vary parameters such as batten spacing, size, material properties, and attachment methods (Chen et al., 2019). This multifaceted analysis involves experimental testing and numerical simulations to discern the nuanced impacts of these parameters on the structural strength of the columns. Concurrently, the study will delve into the intricacies of buckling behavior, considering both local and global buckling phenomena (Hancock et al., 2017). Emphasis will be placed on understanding how different spacing configurations between chord and battened plate elements influence the initiation and progression of buckling. Integrating analytical methods, numerical simulations, and experimental testing, this research seeks to offer a comprehensive understanding of the structural performance of CFS built-up square battened columns. The insights derived aim to facilitate optimized design considerations and mitigate the risks associated with buckling in diverse construction scenarios (Eurocode 3, 2005).

2. Material and Method

The built-up cold-formed steel (CFS) column was constructed using square hollow sections (SHS), steel plates, and rivets. Table 1 shows the specification of built-up cold-formed steel column. Four SHS members were assembled as vertical components and reinforced with steel plates, which functioned as battens, to enhance the rigidity of the column. Two batten plate spacings—300 mm and 400 mm and two chord spacings 50 mm and 100 mm were implemented to examine their influence on buckling behavior. Each column specimen had a uniform thickness of 3 mm and a total height of 1500 mm. A detailed schematic of the column configuration is presented in Figure 1.

Table 1 *Specification of built-up cold-formed steel column*

Specimen	Parameter	Length (mm)	Thickness (mm)	Spacing Between Chords (mm)	Battened Plates Spacing (mm)
1	50C-300B	1500	3	50	300
2	100C-300B	1500	3	50	400
3	50C-400B	1500	3	100	300
4	100C-400B	1500	3	100	400

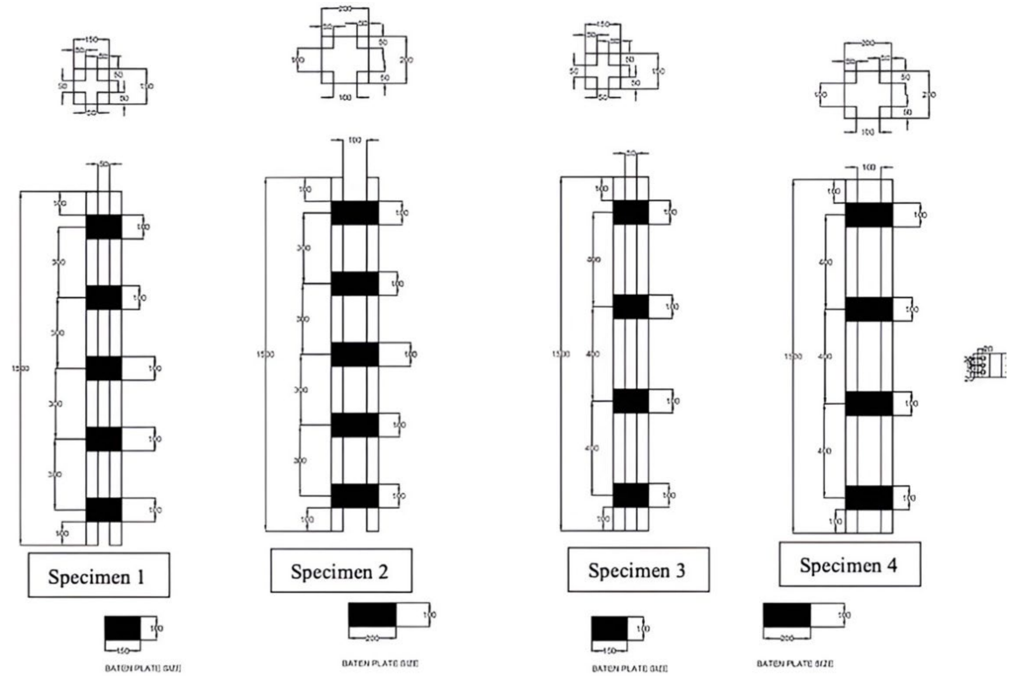

Fig. 1 *Sketched diagram of the specimen's configuration*

2.1 Material Preparation

To investigate the behavior of built-up cold-formed steel (CFS) battened columns, the materials were prepared following standardized experimental procedures. The SHS columns were cut into 16 pieces, each with a height of 1500 mm, using a cutting machine. Batten plates were fabricated in two sizes: 100 mm × 150 mm and 100 mm × 200 mm, with 36 pieces of each. Drilled holes were made in both the batten plates and SHS columns according to the configuration shown in Figure 1. Rivets were then used to assemble the batten plates onto the SHS columns using a hand riveter. The top and bottom ends of each column were trimmed to ensure uniformity and test stability.

Strain gauges were soldered to wires and installed at mid-height on the column specimens. Specimens 1 and 2 were instrumented with four strain gauges on each face, while Specimens 3 and 4 had two strain gauges mounted on opposing faces.

2.2 Column Test

The column test is a fundamental method for assessing material behavior under compressive loading. In this study, it was employed to evaluate the structural response of cold-formed steel (CFS) built-up square battened columns with varying chord and batten plate spacings. Axial compressive loads were applied incrementally until each specimen either failed or reached its deformation limit.

The test aimed to determine axial load capacity, buckling behavior, stiffness, and energy absorption—key parameters for evaluating overall structural performance and validating numerical simulation accuracy. A loading rate of ±20 kN per minute was maintained to ensure consistency and control across all specimens, allowing reliable observation of structural responses under varied configurations. The step-by-step testing procedures are illustrated in Figure 2.

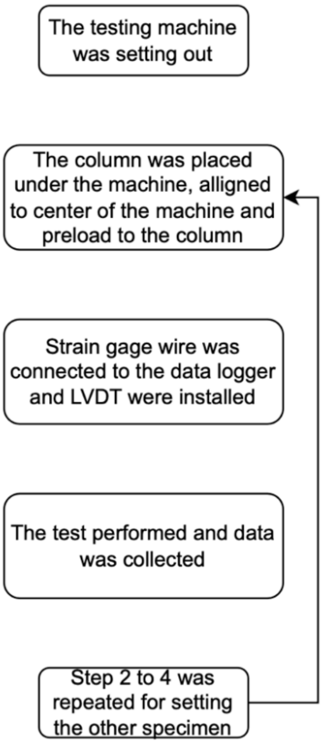

Fig. 2 *Procedures for column test*

2.2.1 Displacement Measurement

Displacement measurements were recorded using Linear Variable Differential Transformers (LVDTs), which provide critical data on structural response, stiffness, and overall column performance. Three LVDTs designated as LVDT A, LVDT C, and LVDT D were installed at specific locations on the specimen, as illustrated in Figure 3.

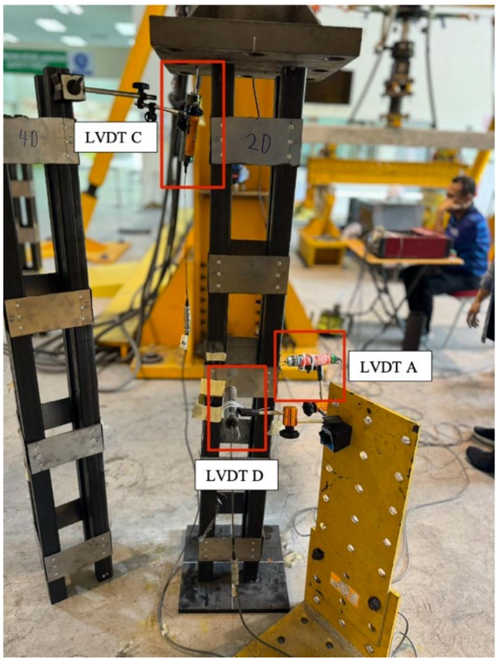

Fig. 3 *Locations of LVDT installed*

3. Analysis and Discussions

This chapter discusses a comprehensive experimental study on cold-formed steel built-up square battened columns. The study involved examining various factors, including batten plate dimensions, distance between columns, rivet joints, column size, and thickness. The specimens, numbered 1 through 4, were examined to understand their structural behavior under different scenarios. Deflection measurement was a key area of study, revealing how columns flex under applied stresses. The load-bearing capacity was also evaluated to determine the highest load each specimen could support before failure. A buckling study was conducted to examine column stability under different loading conditions, identifying critical spots for buckling, a mode of failure marked by abrupt lateral deformations. The data was presented in terms of load per minute to provide clarity and facilitate comparison of the structural behavior of the various specimens. The study aims to clarify how differences in parameters affect the behavior of cold-formed steel built-up square battened columns, providing guidance for future design considerations and optimizations. Table 2 shows the specimens configuration for testing.

Table 2 *Specimens configuration for testing*

Category	Specimen	Configurations
A	1	50mm chords, 300mm battened plate
	2	100mm chords, 300mm battened plate
B	3	50mm chords, 400mm battened plate
	4	100mm chords, 400mm battened plate

3.1 Axial Shortening

Axial shortening refers to the reduction in length of a structural element, such as a column, when subjected to compressive loads. This phenomenon is a key consideration in structural engineering, particularly in evaluating column behavior under vertical forces. When a compressive load is applied, the column undergoes axial shortening, which reflects its deformation and directly influences its stability and load-bearing performance.

Quantifying axial shortening helps engineers assess a column's stiffness and resistance to failure. It is typically represented as a function of load to illustrate how the column responds at various compression levels. Figures 4 and 5 present the load versus axial shortening graphs for the tested specimens.

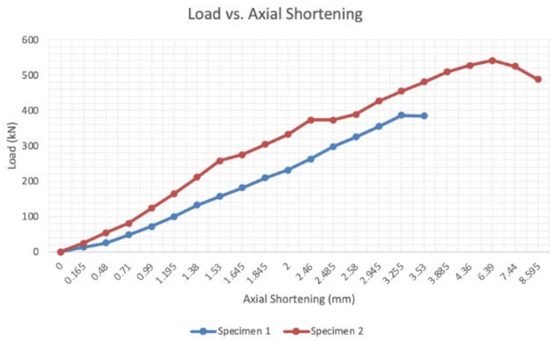

Fig. 4 *Load vs. axial shortening (specimen 1 & 2)*

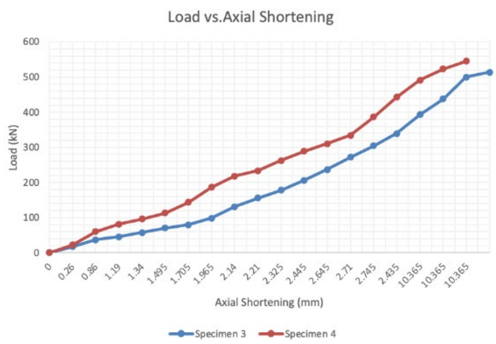

Fig. 5 *Load vs. axial shortening (specimen 3 & 4)*

3.2 Lateral Displacement

Lateral displacement, measured in the horizontal direction, indicates how much a structure deviates from its original position under external loads. It plays a critical role in evaluating structural stability, especially for cold-formed steel (CFS) built-up square battened columns. Monitoring lateral displacement is essential for assessing a column's resistance to lateral instability and verifying the safety and integrity of its design. Furthermore, the relationship between applied load and lateral displacement serves as an indicator of buckling behavior. Figures 6 and 7 present the corresponding load versus lateral displacement responses for all tested specimens.

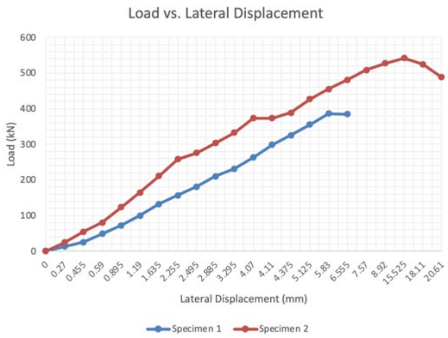

Fig. 6 *Load (kn) vs. lateral displacement (mm) (specimen 1 & 2)*

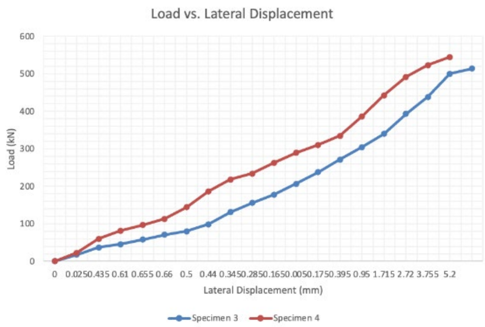

Fig. 7 *Load (kN) vs. lateral displacement (mm) (specimen 3 & 4)*

3.3 Load-Strain

Figure 8 illustrates the load–strain behavior of Specimens 1 and 2, providing insight into their deformation characteristics under axial compression. Specimen 2 demonstrates a higher ultimate load capacity and a more extended linear region, indicating greater stiffness and delayed yielding compared to Specimen 1. In contrast, Specimen 1 exhibits an early deviation from linearity and a less stable curve, suggesting earlier onset of plastic deformation and reduced structural resilience. The shape of the curves also reflects the influence of chord and batten spacing. The tighter spacing in Specimen 2 likely contributes to enhanced confinement and stress distribution, resulting in better axial performance. These findings align with the observed strain profiles and confirm that reduced spacing improves strain capacity and structural stability under compressive loads.

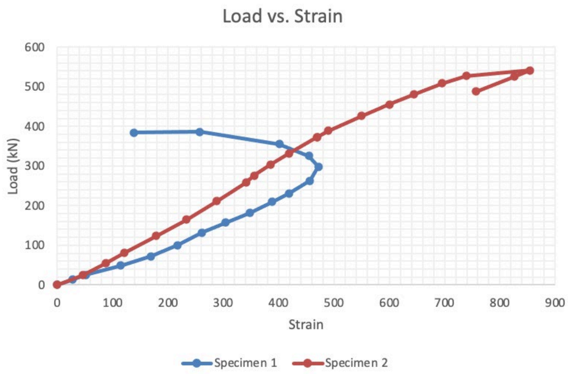

Fig. 8 *Load (kn) vs. strain (ε) (specimen 1 & 2)*

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Figure 9 displays the load–strain responses of Specimen 3 and Specimen 4, highlighting the influence of batten and chord spacing on structural performance. Specimen 4, with wider chord and batten spacing, achieved a notably higher ultimate load compared to Specimen 3. This indicates that increased spacing in Specimen 4 may have allowed for better distribution of stresses and delayed the onset of buckling or localized strain concentration. On the other hand, Specimen 3 exhibited a lower peak load and a steeper initial slope, followed by early strain escalation, suggesting more rapid material yielding or reduced axial stiffness. The contrast in curve profiles supports the conclusion that structural stiffness and ductility are sensitive to the chosen spacing configuration.

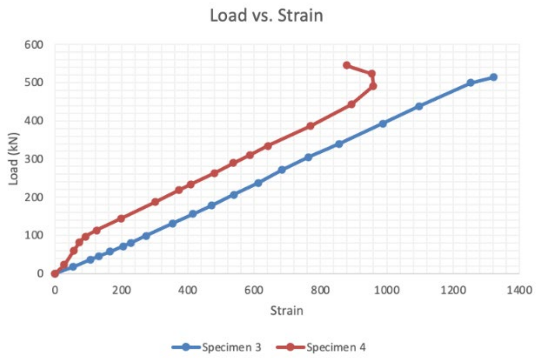

Fig. 9 *Load (kn) vs. strain (ε) (specimen 3 & 4)*

Overall, the results demonstrate that even subtle changes in geometry significantly affect strain development and load-bearing behavior.

3.4 Load-Strain

The LVDT data analysis of four specimens (Specimen 1, Specimen 2, Specimen 3, and Specimen 4) in reveals valuable insights into their failure modes, specifically focusing on buckling behavior. Specimen 1 exhibits pronounced buckling with a maximum negative vertical displacement of -14.025mm as the load increases. Similarly, Specimen 2 displays an increased lateral displacement reaching -20.61mm, indicating the onset of buckling. Specimen 3 shows a progressive flexural buckling mechanism with a maximum vertical displacement of -3.14mm. In contrast, Specimen 4 experiences a steady rise in vertical displacement, reaching a maximum of 10.365mm, highlighting buckling development under the applied load. Overall, all four specimens undergo buckling, emphasizing the significance of LVDT data in identifying and understanding specific failure modes associated with buckling in cold-formed steel columns, which may not be visible to the naked eye.

4. Conclusion

This This research provides valuable insights into the load-carrying capacity and buckling behavior of cold-formed steel (CFS) built-up square battened columns, revealing the influence of parameters such as chord spacing and battened plate spacing on structural performance. The investigation systematically addresses determining the load-carrying capacity and buckling behavior objectives, exploring different batten designs, column sizes, and spacings, highlighting the flexibility of the batten arrangement as a critical factor. The research fully accomplishes the second objective, providing crucial insights into buckling behavior under various loading scenarios, advancing design techniques for dependable steel structures. Comparing experimental data with theoretical predictions emphasizes the need for further research to refine design methodologies, stressing the significance of considering diverse material attributes and environmental factors in future studies. The conclusions advocate for incorporating dynamic loading conditions and practical implementations in real-world projects, recommending standardized processes and collaboration with standards organizations to establish design guidelines. Overall, this research significantly contributes to understanding cold-formed steel built-up square battened columns, facilitating safer and more effective construction practices in structural engineering, with provided recommendations serving as a roadmap for future research endeavors.

Acknowledgement

I would like to express my sincere appreciation to my supervisor, Prof. Madya Ir. Dr. Norwati Binti Jamaluddin for the support given throughout the duration for this research. Appreciation also goes to everyone involved directly or indirectly towards the compilation of this thesis.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

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