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

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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. Experimental testing involves compression tests to evaluate load-bearing capacity and deformation under axial loading, with deflection measurements assessing overall stiffness and reactivity. Findings enhance understanding of structural behavior, shedding light on load-bearing capability, deflection behavior, and stability traits under diverse spacing conditions. The study evaluates existing design recommendations for square hollow sections, providing valuable insights for optimized CFS battened column design and construction, benefiting engineers and professionals in maximizing structural performance.

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. For instance, Chen et al. (2019) offers valuable insights but falls short in addressing the nuanced variations introduced by built-up square battened parameters. Similarly, Hancock et al. (2017) contribute to CFS understanding but do not explicitly focus on the complexities introduced by built-up square battened configurations and their varied spacing. 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 CFS column design is constructed on a foundation of square hollow section (SHS), steel plate, and rivets. Four sets of SHS were required to construct vertical members that were reinforced with steel plate and rivet together. The steel plate acts as a batten to make a CFS column more rigid once it has been constructed. The built-up CFS column has two battened spacings between each segment of 300 and 400 mm each, as well as two hollow spacings of 50 and 100 mm each. These spacing variations will have a variety of implications on buckling behaviour. It had a constant thickness of 3 mm and a length of 1500 mm. The detailed drawing of the built-up cold- formed steel column is shown in Fig. 1. Meanwhile, Table 1, in specimen's row indicates C as chords spacing and B as battened plate spacing, and the section properties was specified.

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

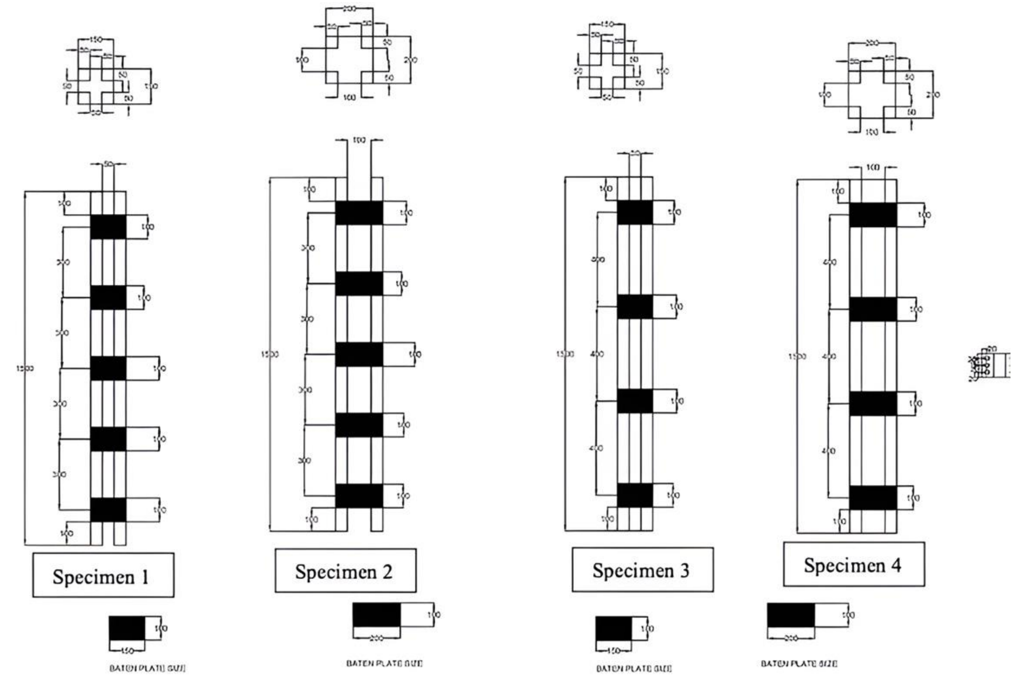

Fig. 1 Sketched diagram of the specimen's configuration.

2.1 Material preparation

To examine the behaviour of built-up cold-formed steel (CFS) battened columns, experimental procedures, must first prepare the material. First, the column was cut into 16 pieces to a height of 1500mm using cutter machine. The battened plate was cut into to size, 100mm x 150mm (36 pieces), 100mm x 200mm (36 pieces). Holes were made on the battened plate and SHS column using a drilling machine based on configurations in Fig. 2. Rivets were installed on the battened plate and column using hand riveter. The column was trimmed on top and bottom of the column for stability. Strain gauge was soldered to wire and was installed in the middle of the column. (Specimen 1 & 2 was installed 4 strain gages for each side and Specimen 3 & 4 was installed 2 strain gages at opposite side).

2.2 Column Test

The column test is a crucial method for assessing the behavior of materials under compressive forces. It is particularly useful for analyzing the behavior of cold-formed steel built-up square battened columns with varied chords and battened plates spacing. The test involves applying axial compressive loads to specimens, gradually increasing the force until the specimen fails or exceeds a certain deformation limit. The primary objective is to determine the column's axial load capacity, buckling behavior, stiffness, and energy absorption capacity, which are essential for evaluating structural performance and confirming the precision of numerical simulations used in design calculations. Load rate of ±20 kN per minute was applied to the columns, a controlled environment was created in which the structural response to different loading circumstances could be observed. The procedures for column test were explained in Fig. 2.

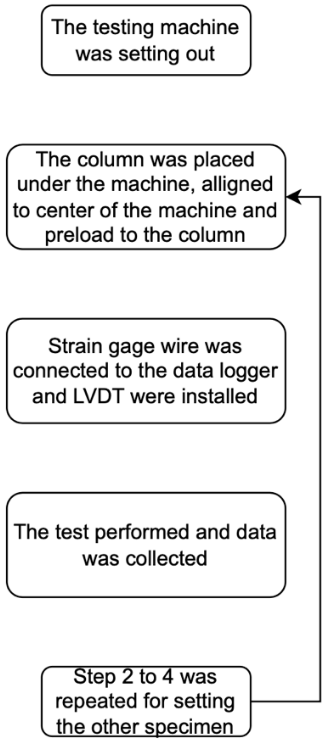

Fig. 2 Procedures for column test.

2.2.1 Displacement Measurement

Displacement measurements were measured using LVDT (Linear Variable Differential Transformer) which can provide crucial information on the structural response, stiffness, and overall effectiveness of the columns. There are 3 LVDT installed which is LVDT A, LVDT C, and LVDT D and the locations is shown in Fig. 3.

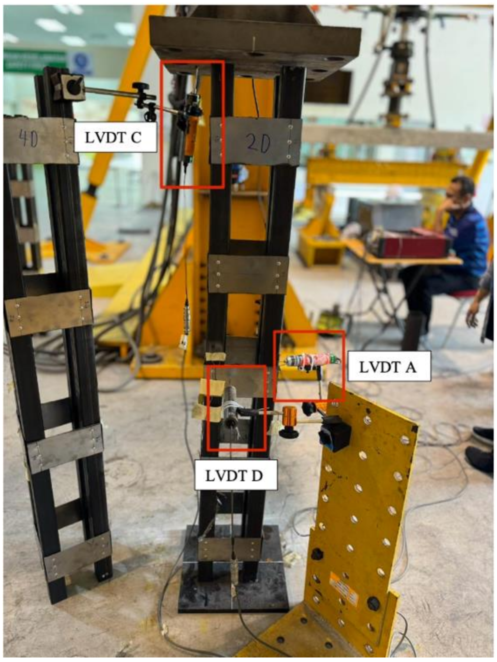

Fig. 3 Locations of LVDT installed

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 the length of a structural element, such as a column, when subjected to compressive loads. This phenomenon is a critical consideration in structural engineering, particularly when assessing the behavior of columns under vertical forces. When a load is applied to a column, it experiences compression, leading to the axial shortening of the structural element. This reduction in length is often measured and analyzed to understand the column's response to compressive loads. It becomes particularly crucial when evaluating the load-bearing capacity of the column, as axial shortening directly influences the structural stability and overall performance. Engineers commonly represent axial shortening in terms of the load-bearing capacity, using graphical representations to depict how the column deforms under varying compressive loads. Fig. 4 and 5 depicts the graph of load vs. axial shortening.

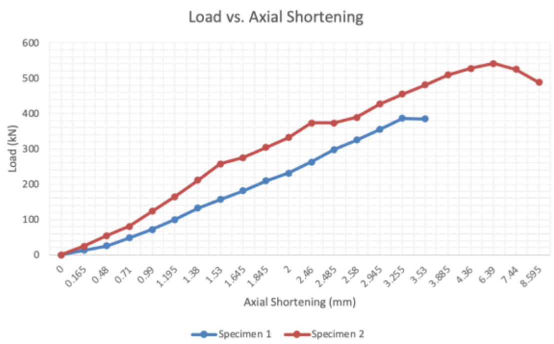

Fig. 4 Load vs. Axial Shortening (Specimen 1 & 2)

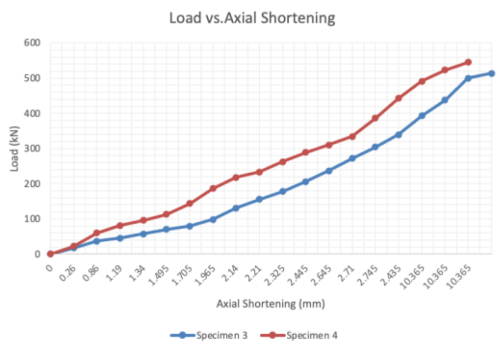

Fig. 5 Load vs. Axial Shortening (Specimen 3 & 4)

3.2 Lateral Displacement

Measured horizontally, lateral displacement shows how the structure moves from its initial position when subjected to outside forces. It is very important for checking how stable a building is because it shows how it reacts to loads and helps check the safety and integrity of cold-formed steel built-up square battened columns. In the meantime, from the graph of load vs. lateral displacement, also can be considered as buckling behavior. As for that, Fig. 6 and 7 shows the Load vs. Lateral Displacement graph.

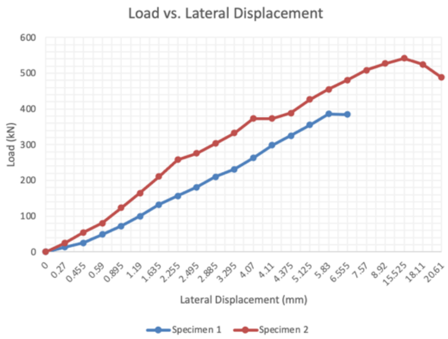

Fig. 6 Load (kN) vs. Lateral Displacement (mm) (Specimen 1 & 2)

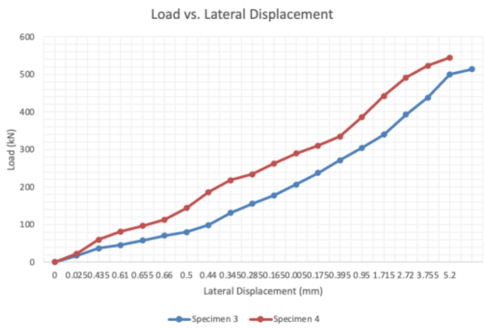

Fig. 7 Load (kN) vs. Lateral Displacement (mm) (Specimen 3 & 4)

3.3 Load-Strain

A load-strain graph, sometimes referred to as a stress-strain curve, shows how a material will behave mechanically when loads are applied. It illustrates the connection between the material's deformation (strain) and the applied force(load) as shown in Fig. 8 and Fig. 9. This graph, which displays a material's yield strength, ultimate strength, elastic and plastic deformation regions, and other mechanical parameters, is crucial for comprehending how a material reacts to external forces.

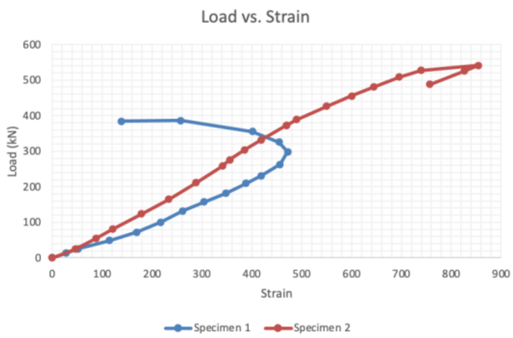

Fig. 8 Load (kN) vs. Strain (ε) (Specimen 1 & 2)

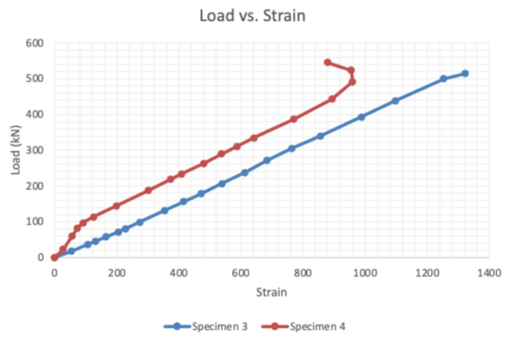

Fig. 9 Load (kN) vs. Strain (ε) (Specimen 3 & 4)

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.

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Conflict of Interest

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

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Yazid and Jamaluddin;* ***data collection:*** *Yazid;* ***analysis and interpretation of results:*** *Yazid and Jamaluddin;* ***draft manuscript preparation:*** *Yazid and Jamaluddin. All authors reviewed the results and approved the final version of the manuscript.*

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