Analysis of Axial Behavior in Cold-Formed Steel-Plywood Composite Walls

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Abstract

The use of bricks as a wall material has significant drawbacks, including high weight and brittleness, making them vulnerable to damage, particularly under lateral loads like earthquakes. This study focuses on evaluating the axial performance of Cold-Formed Steel (CFS)-Plywood composite walls as an alternative to traditional brick walls. The study investigates the effects of bracing on axial compressive strength through laboratory testing of two composite wall specimens: one with bracing and one without. The results show that bracing significantly improves axial load capacity, with the braced specimen sustaining a maximum load of 69.666 kN, while the unbraced specimen withstood 64.413 kN. These findings highlight the potential of CFS-Plywood composite walls to serve as a lightweight, structurally sound alternative to brick walls, especially in multistory buildings subjected to axial loading.

Keywords: *Cold-Formed Steel, Plywood, Axial Compression, Composite Wall, Structural Stability*

I. Introduction

The increasing demand for lightweight yet durable construction materials has led to the development of composite wall systems that combine Cold-Formed Steel (CFS) and plywood. These materials offer excellent strength-to-weight ratios and environmental benefits, making them viable alternatives to conventional masonry, such as brick walls. However, one of the key challenges in applying these materials is ensuring structural stability, particularly under axial loads in multistory buildings, where such loads can be substantial.

Brick walls, while widely used, pose several disadvantages, including their high weight and brittleness. These characteristics make brick walls prone to failure under significant loads, especially when subjected to lateral forces such as those encountered during earthquakes. This vulnerability increases the risk of cracking or collapse, making brick walls less ideal in modern construction, where both safety and efficiency are paramount.

To address these challenges, CFS-Plywood composite walls offer a promising solution due to their lightweight nature, ease of assembly, and high load-bearing capacity. The integration of bracing in these composite systems has shown potential to further enhance axial performance by stabilizing the structure under high loads. Previous research has demonstrated that bracing significantly improves the mechanical properties of such systems, but more investigation is needed to quantify these benefits under axial loading conditions specifically.

This study aims to examine the role of bracing in enhancing the axial compressive strength of CFS-Plywood composite walls. The research will compare the performance of two wall specimens—one with bracing and one without—under controlled laboratory conditions to observe their respective behaviors under axial loads. The results are expected to contribute to the understanding of composite wall behavior and provide guidelines for safer, more efficient building designs.

II. Materials and Methods

This research aims to evaluate the axial behavior of composite walls made from Cold-Formed Steel (CFS) and plywood. Several key steps were taken, starting from material selection to final testing. The flowchart of the research process is illustrated in Fig. 1, which provides an overview of the methodology employed.

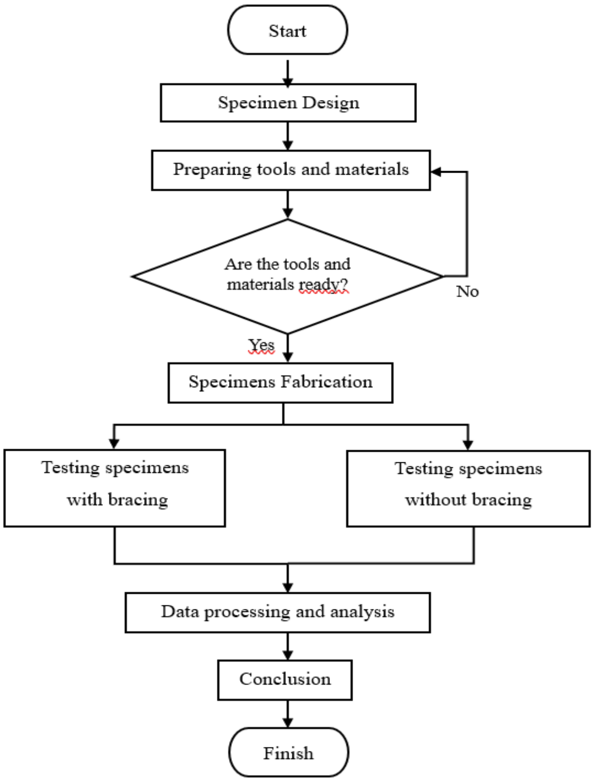

Figure 1 Mehtodologyy Employed

II.1 Materials

This study utilized a combination of Cold-Formed Steel (CFS) profiles and plywood panels to construct composite wall specimens. The selected CFS profiles were of type C75.35.35.0.75, recognized for their lightweight and high strength. These profiles were manufactured with a thickness of 0.75 mm, ensuring sufficient structural integrity while minimizing overall weight. According to Yu et al. (2000), the use of CFS provides excellent strength-to-weight ratios, making them ideal for modern construction applications (see Fig. 2 for the profile of the CFS).

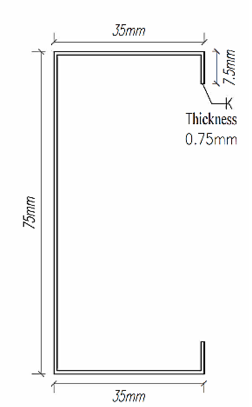

Figure 2 CFS profile

Plywood was chosen for its favorable mechanical properties, particularly its lightweight nature and durability. The plywood panels utilized in this research were sourced in standard sizes of 1220 mm x 2440 mm, with a thickness of 12 mm. This thickness was selected to balance structural strength and ease of handling, making it suitable for use in composite walls. Arriaga-Martitegui et al. (2008) highlight the effectiveness of plywood in providing additional stiffness and stability to composite structures (see Fig. 3 for the plywood panels used in this study)..

Figure 3 Plywood

II.2 Specimen preparation

The preparation of the specimens involved several critical steps to ensure consistency and reliability in testing. The initial design of the composite wall, including dimensions and configurations, is depicted in Fig. 4. This figure illustrates the initial design of the composite wall, showing the arrangement of the CFS and plywood panels.

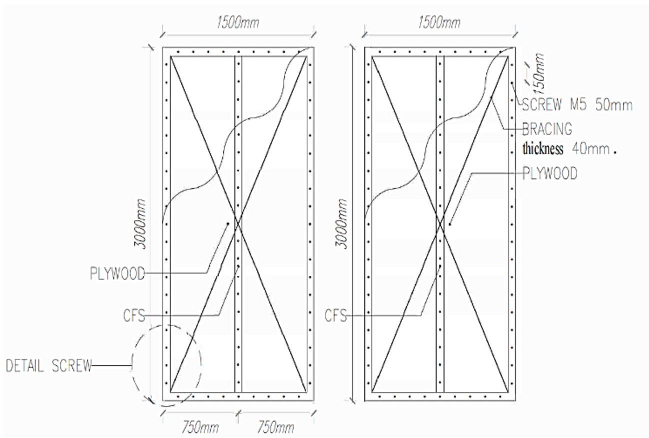

Figure 4 Design of Composite Walls

The plywood was attached to the steel flanges using self-drilling screws, with a spacing of 150 mm between screws. This assembly technique was essential for creating a stable bond between the plywood and the CFS, facilitating effective load transfer during testing. The detailing of the screws is illustrated in Fig. 5, highlighting their arrangement and explaining that the spacing was chosen to ensure a uniform load distribution, thereby reducing the risk of joint failure.

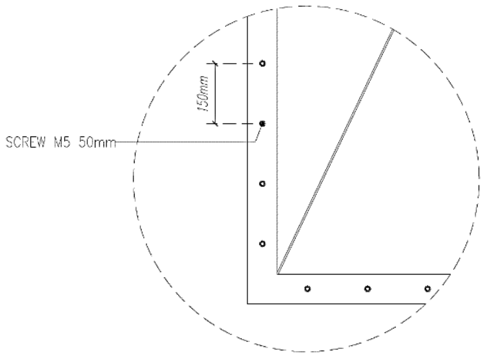

Figure 5 Detailing Screw

To enhance bonding, an epoxy adhesive was applied between the plywood sheets themselves. The curing process was facilitated using clamps to maintain proper alignment and pressure, ensuring that the composite structure achieved maximum strength. Once the adhesive had cured, each specimen was inspected for defects or irregularities, ensuring that they met the standards required for testing.Fig. 6 presents the design of the plywood utilized in the composite wall. The choice of this specific plywood type was based on its mechanical properties, which contribute to the overall performance of the composite structure. The dimensions and thickness of the plywood were selected to provide adequate strength and flexibility, which are crucial for the behavior of the composite wall under axial loads.

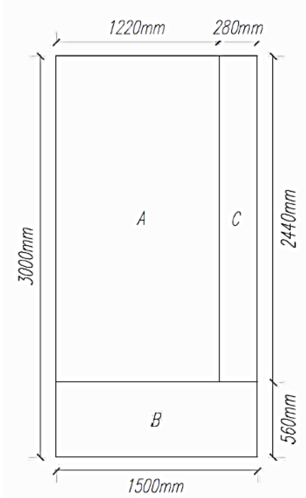

Figure 6 Plywood Desing

Additionally, the initial design of the CFS setup is shown in Fig. 7. The selection of this configuration was based on its structural benefits, including the ability to support significant axial loads while maintaining stability. The specific dimensions of the CFS frame were determined based on guidelines from industry standards, such as those provided by Xiauhua et al. (2021), ensuring that they met the required load-bearing criteria. Furthermore, the choice of bracing was made to enhance lateral stability and prevent buckling, which is critical for maintaining structural integrity. This bracing configuration was selected to improve load distribution, thereby increasing the overall performance of the composite wall system.

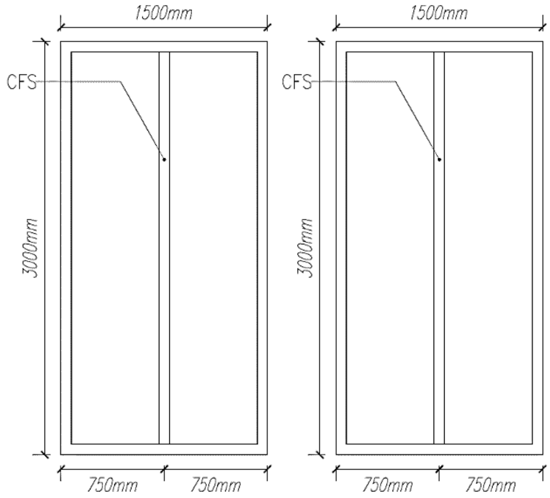

Figure 7 Cold-Formed Steel Design

II.3 Specimen Fabrication

The fabrication of the specimens was conducted in the Structural Laboratory of Universitas Islam Indonesia from March to July 2024. The process began with cutting the Cold-Formed Steel (CFS) profiles to the required lengths of 3000 mm for both vertical and horizontal members. Plywood panels, sourced in standard sizes of 1220 mm x 2440 mm, were also cut to the specified dimensions of 1500 mm x 3000 mm.The assembly involved placing the plywood panels on either side of the CFS joists, ensuring proper alignment before securing the components. The plywood was attached to the CFS flanges using M50 self-drilling screws, spaced 150 mm apart for uniform load distribution. All steps of the specimen fabrication are illustrated in Fig. 8.

Figure 8 Specimen Fabrication

After securing the plywood, epoxy adhesive was applied between the plywood sheets to enhance bonding strength; however, it is important to note that this adhesive was used solely for bonding the plywood panels together and not for connecting the plywood to the CFS. Clamps were utilized to hold the plywood panels in position during the curing process, ensuring that proper alignment and pressure were maintained until the adhesive reached its full strength.

Following the curing, each specimen underwent a thorough inspection for defects or irregularities as part of the quality control process. This inspection included checking for any misalignment, improper adhesion, or damage to the components. Specimens that met the quality standards were marked and prepared for the upcoming axial load testing phase.

To further enhance the structural performance, additional CFS members were installed at the center of the plywood panels to improve load distribution and overall stability of the composite wall. This reinforcement was crucial for minimizing the risk of buckling during tests. The grid system was then marked on the surface of the composite wall specimens, facilitating precise measurement of deformation during axial load tests.

These systematic steps ensured that the fabricated specimens were structurally sound and ready for testing, providing a solid foundation for evaluating their axial load performance.

II.4 Testing Apparatus

The testing of the composite wall specimens was conducted in the Structural Laboratory of Universitas Islam Indonesia, utilizing a comprehensive set of equipment designed to measure and analyze axial load performance. The primary apparatus included a robust steel portal frame, a hydraulic jack, a load cell, Linear Variable Displacement Transducers (LVDTs), and a data logger is illustrated in Fig. 9, which provides a detailed overview of the apparatus used during the testing.

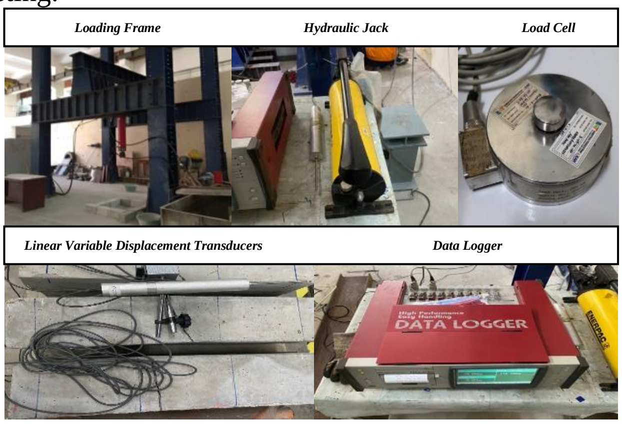

Figure 9 Tools Axial Loading Test

The steel portal frame, which supports loads up to 50 tons, provided essential stability for accurate load application. A hydraulic jack, also rated for 50 tons, was used to apply static axial loads incrementally, ensuring uniform and centralized loading to minimize eccentricity.

A load cell with a maximum capacity of 200 kN measured the axial loads on each specimen, providing critical real-time data for assessing load capacity. LVDTs, with a measurement range of ±100 mm and a precision of 0.01 mm to 0.1 mm, were installed on each specimen to monitor deformation under load, capturing precise displacements vital for analyzing the composite walls' behavior.

Data was continuously recorded using a TDS 630 data logger, which integrated with the load cell and LVDTs to provide a comprehensive dataset for analysis. The testing setup adhered to standardized axial loading procedures, and prior to loading, each specimen was weighed to establish baseline weights, essential for calculating load-to-weight ratios.

II.5 Testing Procedure

The testing procedure for the composite wall specimens was designed to thoroughly evaluate their axial load capacity and failure modes. Each specimen was securely positioned within the steel portal frame, ensuring proper alignment and anchorage for accurate load application. Before formal loading commenced, the specimens were weighed to determine their baseline weights, which are essential for calculating load-to-weight ratios during analysis. The hydraulic jack, rated for 50 tons, was calibrated to apply static axial loads incrementally to the specimens.

Axial loads were applied in a controlled manner, starting from a low load and increasing incrementally. Each increment was held for a designated period to allow the specimens to stabilize, during which time the load cell, with a maximum capacity of 200 kN, recorded the axial load applied to each specimen. Simultaneously, The layout for the installation of the LVDTs is depicted in Fig. 10 illustrates the layout for the installation of the LVDTs, showcasing both the side and front views. The side view provides insight into the precise positioning of the LVDTs along the height of the specimen, ensuring that they effectively capture vertical displacement. The front view further highlights how the LVDTs are arranged to monitor deformation across the width of the composite wall, enabling comprehensive measurement of any movement during the axial loading.

This careful arrangement was essential for capturing accurate displacement measurements during the loading process., capable of measuring displacements with high precision, monitored the deformation of the specimens. This real-time data was crucial for assessing the specimens' behavior under loading.

Throughout the testing process, careful observations were made to identify any signs of distress, such as cracking, excessive deformation, or buckling. The tests continued until clear indications of structural failure were observed, typically characterized by a plateau in load readings or significant deformations that exceeded acceptable limits.

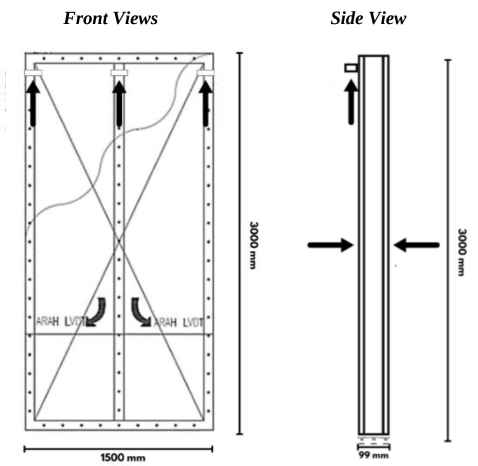

Figure 10 Layout LVDT

Fig. 11 shows the actual installation of the LVDTs on the specimens, demonstrating the meticulous placement necessary for effective data collection. This positioning was critical for ensuring that the LVDTs accurately captured the displacement, which is vital for analyzing the axial behavior of the composite walls.

Figure 11 Installation LVDT

Lastly, Fig. 12 provides an overview of the testing process, capturing the real-time response of the specimens to the applied loads. This figure highlights the monitoring procedures in place, which allowed for a comprehensive assessment of the specimens' performance under various loading conditions.

The collected data were vital for assessing the axial performance of the composite walls and understanding how various configurations influenced load capacity and structural stability. After testing, each specimen was inspected for damage and failure modes, providing valuable insights into their behavior under axial loads.

Figure 12 Axial Loading Test

III. Results and Discussions

This section presents the findings from the axial compression tests conducted on the composite wall specimens. The results highlight the influence of bracing on the axial load capacity, failure modes, and overall behavior of the specimens. The analysis includes load-displacement graphs, comparisons of failure patterns, and discussions regarding the implications of bracing on structural performance.

III. 1 Results of Axial Compression Testing

The axial compression tests were conducted to evaluate the strength of two composite wall specimens, specifically CFS-plywood, with and without bracing. From the curves, six graphs illustrate the results of the axial compression tests. These graphs indicate the positions of the vertical LVDTs installed on the specimens, both with and without bracing.

In Figure 13, the vertical load-displacement graph shows the relationship between the axial load (P) applied to the specimens and the axial displacement (Δ) measured by the vertical LVDT. For the unbraced specimen, the graph demonstrates elastic behavior during the initial loading phase, where the relationship between load and displacement is linear. However, after reaching approximately 60% of the maximum load, the graph begins to show deviations from linearity, indicating the occurrence of torsional buckling. This phenomenon aligns with the findings of Selvaraj and Madhavan (2019), who state that torsional buckling occurs due to uneven load distribution on structural elements, causing the elements to bend and twist simultaneously. At this point, the LVDTs installed on the left and right sides of the specimen began to show unstable displacements due to significant twisting in the structure. Consequently, the measurements recorded by the LVDTs on both sides became uncontrolled, leading to significant errors in displacement recording prior to structural failure.

The unbraced specimen was only able to withstand a maximum load of 64.413 kN with a displacement of 3.307 mm. This torsional buckling phenomenon occurred due to insufficient lateral stiffness in the unbraced specimen. Torsional buckling caused the specimen to experience deformation not only vertically but also laterally, as evidenced by the significant displacement recorded by the LVDTs. This resulted in the LVDT readings on the sides of the specimens being larger than expected under pure axial conditions. The load-displacement graph in Figure 13 shows a drastic decrease after reaching the peak load, indicating structural failure due to uncontrolled lateral and axial deformation occurring simultaneously.

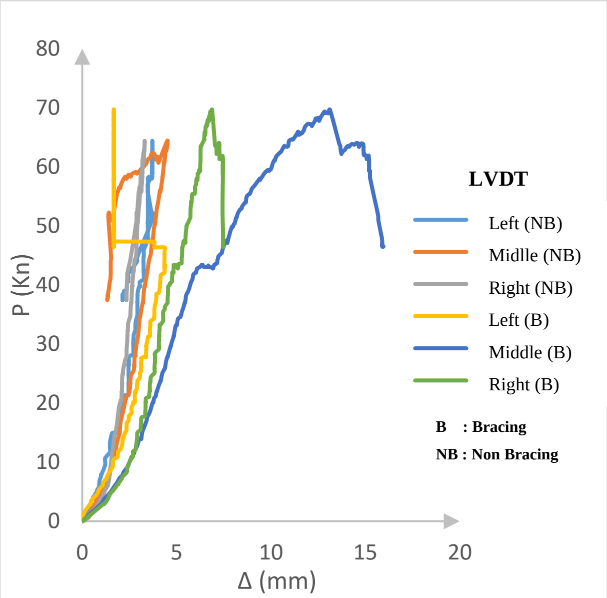

Figure 13 Lord – Displacment Curve Vertical

Conversely, in Figure 14, the vertical load-displacement graph for the braced specimen shows a more stable and linear relationship throughout the loading process. Bracing acts as a lateral stabilizing element that prevents twisting deformation, thereby allowing axial displacement to be better controlled. The braced specimen was able to withstand a maximum axial load of 69.666 kN with a measured displacement of 6.877 mm. Bracing helps distribute the load more evenly across the entire surface of the specimen, preventing torsional buckling and ensuring that axial displacement remains small until the point of failure is reached. After reaching its peak load, the graph shows a sharp decrease, indicating structural failure due to significant cracks in the plywood and local buckling in the cold-formed steel. However, this decrease occurred more slowly compared to the unbraced specimen, supporting the findings of Selvaraj and Madhavan (2019) and Chen and Zhang (2016), which indicate that the use of bracing increases structural stability and reduces the risk of failure due to lateral and local deformation.This section presents the findings from the axial compression tests conducted on the composite wall specimens. The results highlight the influence of bracing on the axial load capacity, failure modes, and overall behavior of the specimens. The analysis includes load-displacement graphs, comparisons of failure patterns, and discussions regarding the implications of bracing on structural performance.

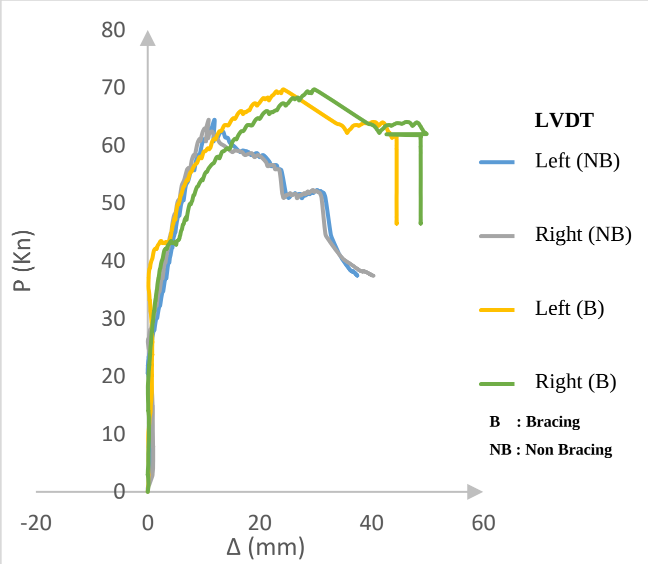

Figure 14 Lord-Displacement Curve Horizontal

III. 2 FAILURE MODES AND DEFORMATION PATTERNS

The failure modes observed during testing exhibited significant differences between the braced and unbraced specimens. Figure 15 illustrates the cracking pattern of the braced specimen, while Figure 16 depicts the cracking pattern of the unbraced specimen.

In Figure 15, the specimen with bracing displays a more orderly and localized cracking pattern. Cracks generally form around the joint areas where the axial forces are concentrated. This failure pattern occurs because bracing distributes forces more evenly, thereby reducing stress concentrations in specific areas. Cracks began to appear when the load reached approximately 60% of the tested maximum load, indicating the effectiveness of bracing in enhancing structural stability. During testing, the braced specimen was able to withstand a maximum load of 69.666 kN, with a measured displacement of 6.877 mm. This demonstrates that the structure remained within safe and stable limits, indicating that bracing not only serves to support loads but also slows down the progression of further damage.

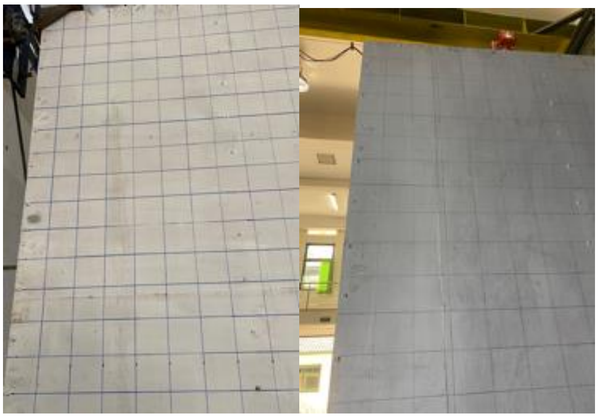

Figure 15Failure and Deformation Bracing

Conversely, in Figure 16, the unbraced specimen exhibited a more severe and widespread pattern of damage. Initial cracks appeared at the joint areas but quickly spread across the entire surface of the wall. In this specimen, damage began to occur earlier, at approximately 40% of the maximum load, reflecting a lack of lateral support. The rapid propagation of cracks was due to high stress concentrations at the joint points, where axial forces could not be effectively distributed without bracing. In this test, the unbraced specimen was only able to withstand a maximum load of 64.413 kN, with a measured displacement of 3.307 mm. This indicates that the specimen was more vulnerable to faster structural failure, signifying that without bracing, the composite wall could not effectively withstand the axial load.

Figure 16 Failure and Deformation Non Bracing

III. 3 Influence of Bracing on Axial Capacity

The results from the axial compression tests reveal a significant influence of bracing on the axial capacity of composite wall specimens. Bracing serves as a critical component in enhancing the structural performance of composite walls, particularly in terms of load-bearing capacity and stability under axial loads.

In the tests conducted, the braced specimen demonstrated a maximum load capacity of 69.666 kN, compared to only 64.413 kN for the unbraced specimen. This notable difference highlights the effectiveness of bracing in increasing the overall strength of the structure. The presence of bracing not only contributes to higher load capacities but also improves the overall behavior of the specimens during the loading process.

During the loading phase, the axial load applied to the braced specimen was distributed more evenly across its surface. This distribution is crucial because it minimizes stress concentrations at critical points, particularly around joints and connections, where forces are typically most intense. The bracing system effectively mitigates the risk of localized failures, which can be detrimental to the structural integrity of the composite wall.

As illustrated in the load-displacement graphs (Figures 13 and 14), the braced specimen exhibited a more stable and linear load-displacement relationship throughout the testing process. This behavior is indicative of the bracing's role in providing lateral support and enhancing the stiffness of the structure. In contrast, the unbraced specimen displayed significant deviations from linearity after a certain load threshold, suggesting instability and the onset of torsional buckling. The ability of the braced specimen to maintain a linear response under increasing loads demonstrates its enhanced resilience to deformation and failure.

Moreover, the displacement measurements reveal that the axial displacement of the braced specimen remained controlled, peaking at 6.877 mm, compared to the unbraced specimen's 3.307 mm. This control over displacement is vital for maintaining the structural integrity of the composite wall under axial loading conditions. The bracing effectively limits excessive deformations, ensuring that the structure can withstand greater loads without experiencing detrimental effects.

The bracing system also plays a pivotal role in distributing lateral forces that may arise during loading. This distribution is particularly important during dynamic loading scenarios, where wind or seismic forces can induce lateral movements. The presence of bracing enhances the overall stability of the composite wall, allowing it to resist both vertical and lateral forces more effectively.

These findings align with previous research conducted by Selvaraj and Madhavan (2019) and Chen and Zhang (2016), which emphasize the importance of bracing in improving structural stability and reducing the likelihood of failure due to lateral and local deformation. The results of this study contribute to a growing body of evidence that supports the inclusion of bracing in the design of composite walls to enhance their performance in real-world applications.

In summary, the incorporation of bracing significantly enhances the axial load capacity of composite wall specimens. By providing stability, reducing stress concentrations, and controlling displacement, bracing emerges as a vital design element that contributes to the overall resilience and effectiveness of composite wall structures.

III. 4 Contribution of the Research to the Literature

This research contributes significantly to the existing body of literature on the behavior of composite wall systems, particularly those constructed with Cold-Formed Steel (CFS) and plywood. The findings underscore the critical role of bracing in enhancing the axial load capacity and overall stability of composite walls, providing valuable insights for both academic researchers and industry practitioners.

Previous studies have indicated that bracing can effectively improve the structural performance of various systems, yet this research specifically highlights the distinct advantages of using bracing in CFS-plywood composite walls. The results demonstrate that incorporating bracing leads to higher load capacities and more controlled deformation behavior, confirming and expanding upon the findings of earlier investigations, such as those conducted by Selvaraj and Madhavan (2019) and Chen and Zhang (2016). These studies established a foundation for understanding how bracing contributes to the stability of structural systems under load.

Furthermore, this research addresses the knowledge gap regarding the specific performance of CFS-plywood composite walls under axial loading conditions. The detailed analysis of the load-displacement behavior, along with the observed failure modes, provides empirical evidence supporting the effectiveness of bracing as a design strategy. By documenting the differences in performance between braced and unbraced specimens, this study emphasizes the necessity of considering bracing in the design and construction of composite wall systems.

The implications of this research extend beyond academic inquiry, offering practical guidance for engineers and architects involved in the design of composite structures. By illustrating the benefits of bracing, this study encourages the adoption of bracing techniques in real-world applications, thereby promoting safer and more efficient structural designs.

In summary, the contributions of this research to the literature are twofold: it reinforces the existing understanding of the importance of bracing in structural systems while also providing specific insights into the performance of CFS-plywood composite walls. These findings pave the way for future research that can explore innovative bracing techniques and materials, ultimately advancing the field of structural engineering.

III. 5 Design and Construction Implication

The findings from this research carry significant implications for the design and construction of composite wall systems, particularly those utilizing Cold-Formed Steel (CFS) and plywood. Given the demonstrated effectiveness of bracing in enhancing the axial load capacity and overall stability of these systems, it is essential for engineers and architects to incorporate bracing into their designs.

First, the enhanced structural performance observed in braced specimens indicates that designers should prioritize the integration of bracing techniques to improve load-bearing capacities and control displacement. This practice is crucial for ensuring the safety and durability of structures, particularly in regions susceptible to lateral forces, such as wind and seismic activities. Previous studies, such as those by Selvaraj and Madhavan (2019) and Chen and Zhang (2016), have established the positive effects of bracing on structural stability, reinforcing the necessity for its inclusion in composite wall designs.

Moreover, the findings suggest that current design standards and guidelines should be updated to reflect these insights. Incorporating recommendations for bracing in composite wall design can help engineers make informed decisions, ultimately leading to more resilient structural systems.

Additionally, the research elucidates the interaction between CFS and plywood in composite wall systems, indicating that understanding the mechanical properties and behaviors of these materials when combined with bracing can optimize material selection and construction practices. This optimization can result in efficient use of materials, reduced construction costs, and enhanced structural integrity, as noted by Arriaga-Martitegui et al. (2008), who highlighted the advantages of plywood in providing additional stiffness and stability to composite structures.

Furthermore, the study opens avenues for future research into innovative bracing solutions. Future investigations could explore various bracing materials and configurations, as well as their effects on the performance of composite walls under different loading conditions. This exploration could contribute to the development of advanced design methodologies, as indicated by Chen and Zhang (2016), who called for further studies on the benefits of bracing in enhancing the resilience of structures.

Finally, the practical implications of this research extend to real-world applications. Construction projects utilizing composite wall systems should prioritize the implementation of effective bracing techniques to ensure structural safety and performance. The evidence provided by this research can serve as a reference point for industry professionals seeking to enhance the resilience of their structures.

IV. Conclusions

This research has demonstrated the significant impact of bracing on the axial load capacity and overall stability of CFS-plywood composite walls, revealing that the incorporation of bracing enhances structural performance under axial loads. The findings indicate that bracing not only improves load-bearing capabilities but also controls deformation, thereby minimizing the risk of structural failure. Future studies could explore innovative bracing configurations and materials to further enhance the performance of composite wall systems. Additionally, the practical application of these findings underscores the importance of implementing effective bracing techniques in real-world construction projects, ultimately contributing to the development of safer and more resilient structures in various engineering contexts.

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