LATERAL PERFORMANCE OF COLD-FORMED STEEL-PLYWOOD COMPOSITE WALLS

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Abstract

Traditional brick walls face notable limitations, particularly in their weight and vulnerability to lateral forces, which can lead to significant damage under seismic conditions. This study investigates Cold-Formed Steel (CFS) and plywood composite walls as an alternative solution, focusing on lateral load performance. Laboratory tests on CFS-plywood wall specimens, both with bracing and without bracing, allowed for a comparison of lateral load capacity, deflection, and crack development. The findings reveal that bracing improves lateral stability significantly, enabling the braced walls to support a peak load of 14.127 kN compared to 13.77 kN in unbraced walls. Additionally, bracing reduces deflection and distributes cracks more evenly, presenting CFS-plywood composite walls as a lightweight, resilient choice for earthquake-resistant structures.

Keywords: *Cold-Formed Steel, Plywood, Lateral Load, Composite Wall, Structural Resilience*

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I. INTRODUCTION

Brick is among the most widely used wall materials in construction, especially in residential buildings due to its affordability and accessibility. However, its weight and brittleness pose significant challenges, particularly in modern, earthquake-prone construction. The heavy load of brick walls increases the need for stronger foundations and larger support elements, which adds complexity and cost to building structures. Furthermore, brick's brittle nature makes it susceptible to cracking or even collapse when subjected to significant lateral forces, such as those generated by seismic events. Consequently, there is a need for alternative materials that provide structural stability while reducing weight and improving resilience to lateral forces.

In response to these challenges, recent advancements in construction materials have led to the development of Cold-Formed Steel (CFS)-Plywood composite walls as a viable alternative. CFS, a carbon steel formed at room temperature, offers high strength, ease of handling, and a much lighter weight compared to conventional masonry, making it suitable for structural applications. When paired with plywood, which contributes additional stiffness and stability, CFS-Plywood composite walls present a lightweight yet robust solution capable of withstanding lateral loads. Additionally, the use of bracing in these walls has demonstrated potential in further enhancing their stability, helping to prevent failure modes such as lateral buckling or twisting under load. This characteristic makes CFS-Plywood walls an attractive choice for multi-story buildings and structures that require resistance to lateral forces.

The potential of CFS-Plywood composite walls has been demonstrated in research exploring both their axial and lateral strength, suggesting promising results. However, studies specifically examining lateral performance with and without bracing remain limited. A focused examination of lateral behavior in CFS-Plywood walls is necessary to understand the extent to which bracing can enhance resilience against lateral forces, particularly in seismic-prone regions. As buildings increasingly aim for both structural efficiency and resistance to environmental stressors, CFS-Plywood composite walls could play a pivotal role in advancing lightweight construction that meets these demands.

This study, therefore, aims to assess the lateral load-bearing capacity and deformation characteristics of CFS-Plywood composite walls by comparing braced and unbraced configurations under controlled lateral loading conditions. By determining the maximum load capacities and analyzing deformation patterns in each configuration, this research seeks to provide practical insights into the viability of CFS-Plywood walls as a lightweight, resilient alternative to traditional brick walls. Ultimately, the findings are intended to support the design of seismic-resistant buildings, where reduced weight and enhanced lateral stability are critical for both safety and structural longevity

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II. MATERIALS AND METHODS

This study focuses on assessing the lateral performance of composite walls made from Cold-Formed Steel (CFS) and plywood. Key steps include material selection through to final testing, with an overview of the methodology illustrated in Fig. 1.

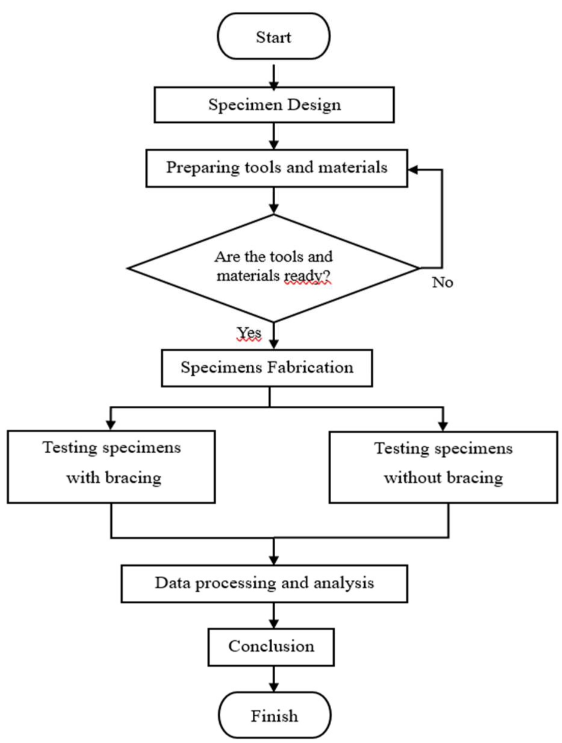

Figure 1 Mehtodologyy Employed

II.1 Materials

This research utilized a combination of CFS profiles and plywood panels to create composite wall specimens. The chosen CFS profile type is C75.35.35.0.75, recognized for its lightweight properties and high strength. Manufactured with a thickness of 0.75 mm, these profiles ensure structural integrity while keeping overall weight low. According to Yu et al. (2000), CFS offers excellent strength-to-weight ratios, making it ideal for modern construction applications (see Fig. 2 for the CFS profile).

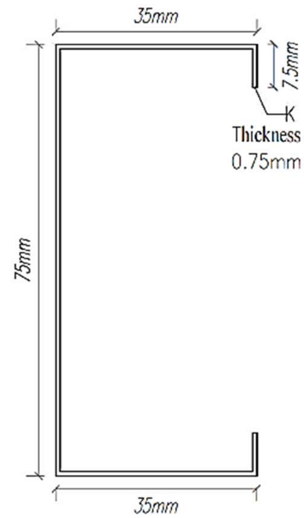

Figure 2 CFS profile

Plywood was selected for its favorable mechanical properties, particularly its lightweight nature and durability. Panels used in this study can see at Fig. 3 for the plywood panels, measured 1220 mm x 2440 mm with a thickness of 12 mm, chosen to balance structural strength with ease of handling, making it well-suited for composite walls. Arriaga-Martitegui et al. (2008) emphasize plywood's effectiveness in providing additional stiffness and stability to composite structures.

Figure 3 Plywood

II.2 Specimen preparation

The specimen preparation process included critical steps to ensure consistency and reliability in lateral testing. The initial design and configuration of the composite wall, detailing dimensions and material layout, are shown in Fig. 4. This figure presents the composite wall's structure, illustrating the placement of CFS and plywood panels.

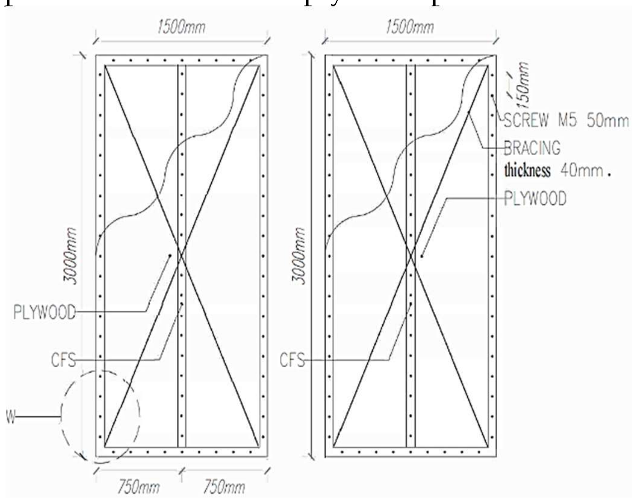

Figure 4 Design of Composite Walls

Each plywood panel was attached to the steel flanges with self-drilling screws, spaced 150 mm apart. This assembly technique ensured a stable connection between the plywood and CFS, allowing for efficient load transfer during testing. Fig. 5 details the screw arrangement and the 150 mm spacing, chosen to enable uniform load distribution and minimize the likelihood of joint failure.

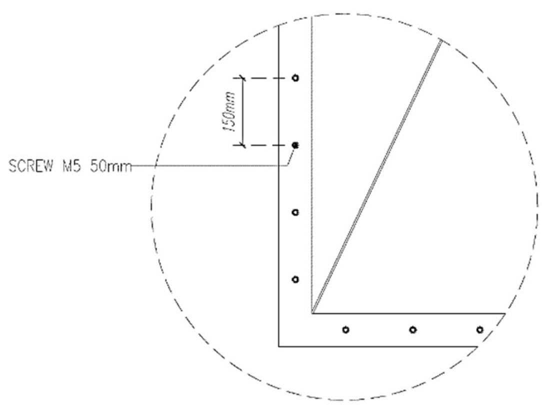

Figure 5 Detailing Screw

Epoxy adhesive was applied between the plywood sheets to enhance bonding strength. Clamps were used during the curing process to maintain alignment and pressure, ensuring the composite structure reached optimal strength. Following the adhesive curing, each specimen underwent an inspection to detect defects or irregularities, ensuring compliance with the testing standards. The specific plywood type used, as depicted in Fig. 6, was chosen for its mechanical properties that support the composite structure's overall stability under lateral forces. The selected dimensions and thickness provide both strength and flexibility, which are essential for the wall’s lateral performance.

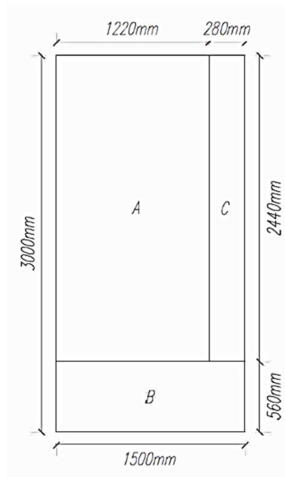

Figure 6 Plywood Desing

The initial CFS configuration is shown in Fig. 7. This setup was chosen for its structural benefits, especially its capacity to support significant lateral loads while maintaining stability. The CFS frame dimensions followed industry standards, such as those specified by Xiauhua et al. (2021), to meet load-bearing requirements. Additionally, bracing was incorporated to increase lateral stability and counteract buckling, critical for maintaining structural integrity. This bracing layout was designed to improve load distribution, enhancing the overall lateral load performance of the composite wall system.

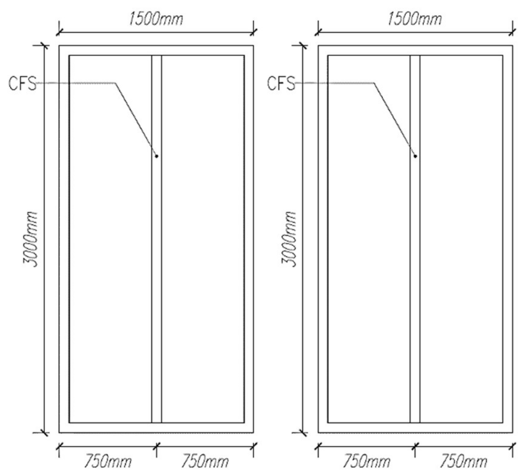

Figure 7 Cold-Formed Steel Design

II.3 Specimen Fabrication

The fabrication of specimens took place at the Structural Laboratory of Universitas Islam Indonesia from March to July 2024. The process began by cutting Cold-Formed Steel (CFS) profiles to a length of 3000 mm for both vertical and horizontal members. Plywood panels, provided in standard dimensions of 1220 mm x 2440 mm, were cut to 1500 mm x 3000 mm to fit the specifications. Assembly involved positioning plywood panels on either side of the CFS joists, ensuring proper alignment before securing with M50 self-drilling screws, spaced 150 mm apart to promote uniform load distribution. These fabrication steps are illustrated in Fig. 8.

Cutting Plywood ***Gluing Plywood*** ***Cutting CFS***
Installing CFS

Figure 8 Specimen Fabrication

After securing the plywood, an epoxy adhesive was applied between the plywood sheets solely to strengthen the bond between the layers—not for connecting plywood to CFS. Clamps held the plywood in place during the curing process to ensure alignment and sustained pressure until the adhesive fully cured. Each specimen was then inspected for any misalignment, insufficient adhesion, or other irregularities as part of quality control, and only specimens meeting the set standards were marked for the lateral load testing phase.

To improve load distribution and enhance stability under lateral loading, additional CFS members were positioned centrally on the plywood panels. This reinforcement helped reduce buckling risks during lateral load tests. A grid was marked on the surface of each specimen to enable precise deformation measurements throughout the lateral testing phase. These systematic steps ensured that each specimen was structurally sound and fully prepared for lateral load testing, providing a reliable basis for evaluating their performance under lateral forces.

II.4 Testing Apparatus

The lateral testing of composite wall specimens was conducted in the Structural Laboratory of Universitas Islam Indonesia, using a range of equipment designed to measure and analyze lateral load behavior. The main apparatus included a durable steel portal frame, a hydraulic jack, load cells, Linear Variable Displacement Transducers (LVDTs), and a data logger, as shown in Fig. 9, which provides a comprehensive view of the testing setup..

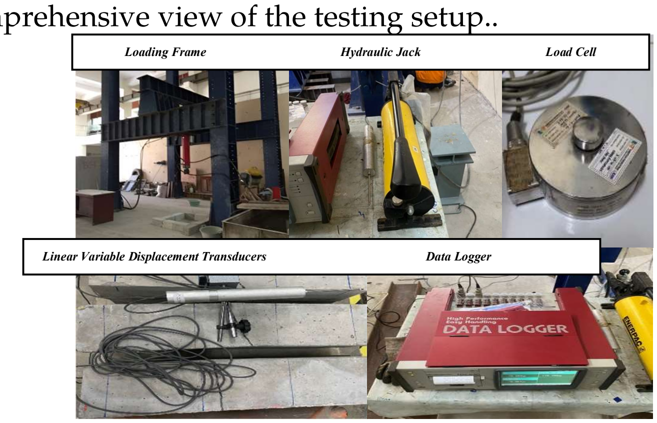

Figure 9 Tools Axial Loading Test

The steel portal frame, capable of supporting loads up to 50 tons, ensured stability for precise load application during the lateral tests. A hydraulic jack, also rated for 50 tons, applied static lateral loads incrementally, allowing for consistent and centered load application to reduce any potential eccentricity effects.

Load cells with a maximum capacity of 500 kN were used to measure the lateral loads on each specimen, delivering critical real-time data on load capacity. LVDTs, calibrated to measure displacements within a ±100 mm range with precision between 0.01 mm and 0.1 mm, were attached to each specimen to monitor deformation under lateral load, capturing the detailed displacements necessary for evaluating the walls' behavior.

Continuous data recording was managed by a TDS 630 data logger, which was synchronized with the load cells and LVDTs to compile a complete dataset for further analysis. The testing setup followed standardized procedures for lateral loading, and each specimen was weighed beforehand to determine baseline weights, which were critical for calculating load-to-weight ratios during the tests.

II.5 Testing Procedure

This testing procedure was established to assess the lateral load capacity of composite wall specimens and examine their failure characteristics under lateral stress. Each specimen was accurately positioned within the shear testing frame, ensuring correct alignment and support for consistent lateral load application. Prior to loading, the specimens were weighed to provide baseline values critical for load-to-weight ratio calculations during the analysis phase.

Lateral loads were applied in a gradual, stepwise manner, beginning at a low load and increasing incrementally. Each load stage was held for a set duration to stabilize the specimen, with the load cell (50 kN capacity) measuring the exact lateral force applied. LVDTs were strategically placed to measure lateral displacements across the height and width of each specimen. Fig. 10 illustrates the LVDT setup from both side and front views. The side view shows the LVDT positioning along the height of the specimen, which captures lateral displacement, while the front view reveals the arrangement across the wall’s width, enabling thorough deformation measurement under lateral load.

This setup was essential for precise data collection, allowing for continuous real-time monitoring of the specimen's deformation under stress. The information gathered was crucial for understanding lateral response patterns and structural behavior.

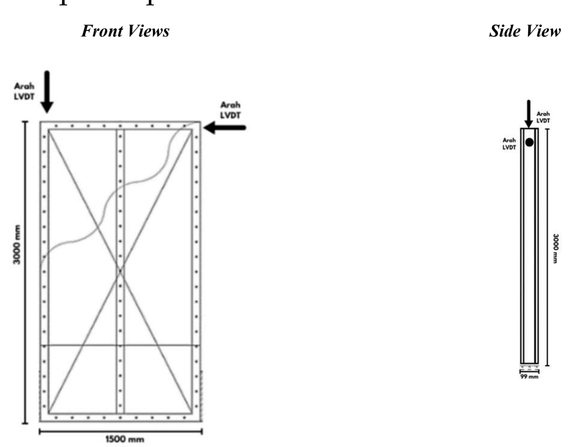

Figure 10 Layout LVDT

During the loading process, observations were carefully made to note any signs of material distress, such as cracks, significant deflection, or buckling. Testing continued until structural failure was apparent, typically indicated by a peak in load readings followed by large lateral displacements beyond acceptable thresholds. Fig. 11 demonstrates the LVDT installation on the specimens, highlighting the accurate placement necessary for effective data capture.

Figure 11 Installation LVDT

Finally, Fig. 13 offers an overall view of the testing setup and monitoring systems used to observe each specimen's response to lateral loading in real-time. This comprehensive configuration allowed a detailed assessment of the composite walls' lateral load performance and provided insight into how various configurations impacted load capacity and stability. After completing the tests, each specimen was inspected for visible damage and noted failure modes, providing essential data for evaluating lateral load resilience.

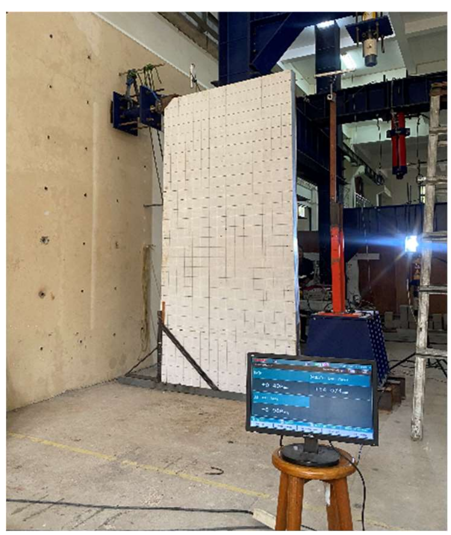

Figure 12 Axial Loading Test

III. RESULTS AND DISCUSSIONS

The results from the lateral load testing illustrate the differences in performance between braced and unbraced Cold-Formed Steel (CFS)-plywood composite wall specimens, focusing on their load-displacement behavior, failure modes, and the structural influence of bracing. These insights are essential for evaluating the lateral stability of CFS-plywood walls, especially in seismic-prone constructions.

III. 1 Results of Axial Compression Testing

The lateral load testing was performed on two distinct Cold-Formed Steel (CFS)-plywood composite wall specimens: one with bracing and the other without bracing. This testing utilized an actuator to apply lateral forces at the point of maximum strength. To ensure accurate results, the specimens were securely fixed a LVDT ase to prevent vertical lifting or detachment during testing. This setup ensured that the applied load remained linear, evenly distributed, and parallel to the target point. Data collection was carried out using Linear Variable Displacement Transducers (LVDTs) installed both vertically and horizontally on the specimens. The displacement data were recorded and analyzed using a data logger. Figures 13 and 14 illustrate the load-displacement curves for the vertical and horizontal components, respectively.

Figure 13 presents the vertical load-displacement behavior under lateral loading. For the unbraced specimen, the curve begins with a linear trend, reflecting elastic behavior at lower loads. This linearity persisted until approximately 60% of the maximum lateral load capacity, after which the curve began to deviate, indicating the onset of plastic deformation due to the applied lateral forces. At its peak load of 13.77 kN, the unbraced specimen exhibited a vertical displacement of 30.001 mm. Beyond this point, the curve declined sharply, reflecting structural failure. This failure was characterized by significant cracking in the plywood panels and localized buckling in the CFS frame near the screw connections. The absence of bracing resulted in uneven stress distribution, leading to rapid deformation and loss of structural integrity.

In contrast, the braced specimen displayed a more stable performance throughout the loading process. The load-displacement curve for the braced specimen remained linear over a larger range of applied forces, reflecting enhanced stiffness and a delay in the onset of plastic deformation. The braced specimen reached a peak lateral load of 14.127 kN, with a corresponding vertical displacement of 28.326 mm. The presence of bracing effectively mitigated excessive lateral deformation and improved load distribution across the structure. Unlike the unbraced specimen, the braced configuration demonstrated a slower reduction in stiffness after reaching the maximum load, which helped maintain structural stability longer and prevented premature failure. These results emphasize the role of bracing in enhancing the lateral load-bearing capacity and overall structural performance.

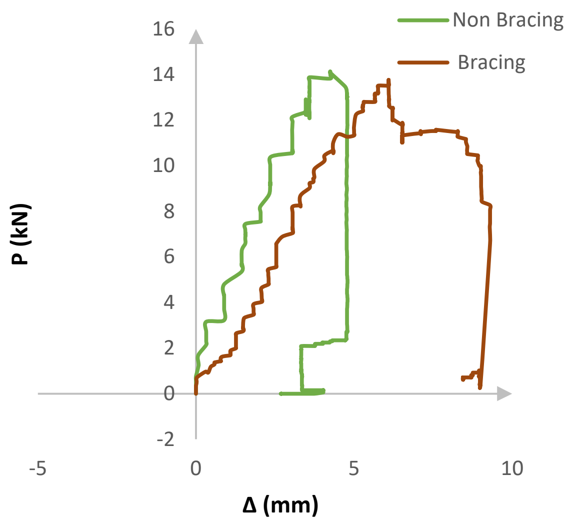

Figure 13 Load – Displacment Curve Vertical

The horizontal load-displacement behavior, as depicted in Figure 14, provides further insights into the lateral stability of the specimens. For the unbraced specimen, lateral displacement increased significantly as the load approached 60% of the maximum capacity. This behavior was attributed to uneven lateral force distribution, which caused localized stress concentrations at the screw connections. At the peak load of 13.77 kN, the unbraced specimen exhibited a horizontal displacement of 30.001 mm. The substantial lateral movement observed in this configuration underscores its limited ability to resist lateral forces, which resulted in premature structural failure and widespread cracking in the plywood panels.

On the other hand, the braced specimen demonstrated superior lateral stability. The horizontal displacement recorded for the braced configuration was significantly lower, even as the lateral load increased. At the peak load of 14.127 kN, the braced specimen exhibited a horizontal displacement of 28.326 mm. The bracing effectively reduced lateral movement by acting as a stabilizing element, which prevented uncontrolled displacement and distributed the applied forces more evenly across the structure. Although the displacement was slightly larger compared to the unbraced configuration, the braced specimen maintained structural integrity and avoided premature failure. These findings highlight the importance of bracing in mitigating lateral deformations and improving the overall performance of composite walls under lateral loading conditions.

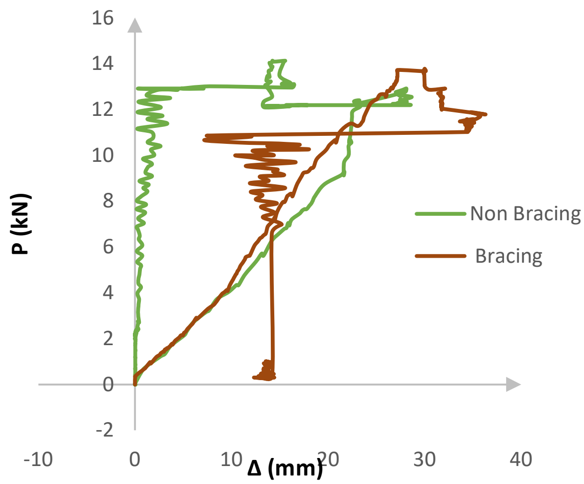

Figure 14 Load-Displacement Curve Horizontal

These results underscore the critical role of bracing in improving the lateral performance of CFS-plywood composite walls. By mitigating stress concentrations and stabilizing the structure, bracing enhances load-bearing capacity, reduces displacement, and delays the onset of failure, making it an essential consideration for earthquake-resistant designs.

III. 2 Failure Modes and Deformation Patterns

Distinct differences in failure modes and deformation patterns were observed between the braced and unbraced specimens during lateral load testing, providing critical insights into the structural benefits of bracing. Figures 15 and 16 illustrate these differences in cracking patterns and overall deformation behavior.

In the braced specimen (Figure 15), cracks were localized around the connections between the plywood panels and the CFS frame, particularly near the screws. These cracks remained limited to specific areas, indicating that the bracing successfully distributed the stresses throughout the structure. The plywood showed minor cracking near the load application points, while the CFS frame exhibited no signs of buckling or twisting. This controlled cracking pattern reflects the ability of bracing to prevent excessive stress concentrations and maintain the structural integrity of the composite wall. As a result, the braced specimen maintained its functionality until it reached its peak load.

Figure 15Failure and Deformation Bracing

Conversely, the unbraced specimen (Figure 16) exhibited a more widespread and severe cracking pattern. Initial cracks appeared near the corners of the plywood panels; areas that experienced the highest stress due to the absence of lateral support. These cracks quickly propagated across the plywood, resulting in large-scale structural failure. The CFS frame in the unbraced specimen experienced significant buckling, with multiple sections undergoing pronounced lateral displacement. This behavior further compromised the structural integrity of the wall, highlighting the critical role of bracing in mitigating such failures

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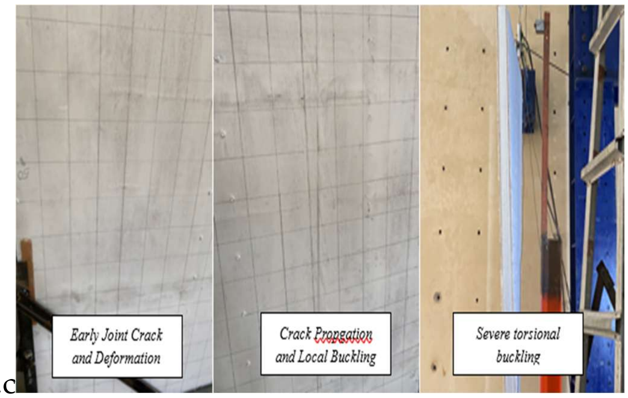

Figure 16 Failure and Deformation Non-Bracing

The observed failure modes provide valuable insights into the mechanisms of lateral instability in composite walls. The controlled cracking and reduced deformation in the braced specimen emphasize the importance of incorporating bracing in the design of earthquake-resistant structures.

III. 3 INFLUENCE BRACING ON LATERAL CAPACITY

The results from the lateral load tests demonstrate the significant impact of bracing on the lateral capacity and overall stability of Cold-Formed Steel (CFS)-plywood composite walls. Bracing serves as a critical component in improving the structural behavior of these systems, particularly in their ability to resist lateral forces and maintain stability under deformation.

In the tests conducted, the braced specimen demonstrated a maximum lateral load capacity of 14.127 kN, compared to 13.77 kN for the unbraced specimen. Although the difference in peak load capacity appears modest, the braced specimen showed superior performance in terms of displacement control, stiffness retention, and delayed failure. These results underscore the effectiveness of bracing in enhancing the overall load-bearing strength of composite walls and in improving the structural behavior under lateral loading conditions.

The bracing system played a key role in redistributing lateral forces more evenly across the composite wall. This uniform force distribution reduces stress concentrations at critical points such as joints and screw connections, which are typically more susceptible to localized failures. The unbraced specimen, by contrast, experienced higher stress concentrations, resulting in earlier cracking and significant displacement after 60% of the maximum load was applied. This difference highlights the role of bracing in controlling stress distribution and improving the wall's resistance to lateral forces.

Figures 15 and 16 illustrate this behavior. In the vertical load-displacement graph (Figure 15), the braced specimen exhibited a more linear relationship throughout the loading process. The linearity of the curve reflects the structure's ability to maintain consistent stiffness and resist deformation, a behavior facilitated by the bracing system. In contrast, the unbraced specimen exhibited significant deviations from linearity after a certain load threshold, indicating instability and the onset of torsional buckling. The braced specimen's ability to maintain a stable response under increasing loads demonstrates its enhanced resilience to deformation and failure.

Furthermore, displacement measurements revealed that the axial displacement of the braced specimen remained controlled, peaking at 28.326 mm, compared to 30.001 mm for the unbraced specimen. While these differences in displacement may seem minor, they are critical in maintaining the structural integrity of the composite wall. The bracing effectively limits excessive lateral deformation, ensuring that the wall can withstand greater loads without experiencing detrimental effects.

In summary, bracing significantly enhances the lateral capacity of composite wall systems by improving load distribution, reducing displacement, and preventing premature failure. The findings emphasize the importance of bracing in ensuring that cfs-plywood composite walls can perform effectively under lateral loading conditions, making it an essential design element in structural applications, particularly in areas prone to seismic activity.

III. 4 CONTRIBUTIONS OF THE RESEARCH TO THE LITERATURE

This research makes a significant contribution to the field of composite wall systems, particularly those made with Cold-Formed Steel (CFS) and plywood. The findings demonstrate that bracing plays an integral role in improving the lateral load capacity and overall stability of these composite walls, offering valuable insights for both researchers and practitioners.

While previous studies have explored the benefits of bracing, this research specifically focuses on its application in CFS-plywood composite walls under lateral loading conditions. The results confirm that incorporating bracing leads to higher load capacities, more controlled deformation, and better stability, thereby reducing the likelihood of failure under dynamic forces. These findings support and expand upon earlier studies by Selvaraj and Madhavan (2019) and Chen and Zhang (2016), which emphasized the importance of bracing in enhancing structural resilience.

By addressing the performance of CFS-plywood composite walls under lateral loads, this research fills a gap in the literature, providing empirical evidence that supports the inclusion of bracing in their design. The documented differences in performance between braced and unbraced specimens highlight the critical need to consider bracing in the design and construction of composite wall systems, ensuring that these structures can perform safely and efficiently in real-world applications.

III. 5 DESIGN AND CONSTRUCTION IMPLICATION

The findings of this study have important implications for the design and construction of CFS-plywood composite walls. Given the demonstrated effectiveness of bracing in enhancing lateral load capacity and stability, it is essential for engineers and architects to prioritize its integration into design practices.

The enhanced performance observed in braced specimens underscores the importance of incorporating bracing techniques to improve load-bearing capacity and control displacement. This is particularly crucial in regions exposed to seismic or wind forces. Design standards and guidelines should be updated to reflect these findings, ensuring that engineers are equipped with the knowledge to optimize structural stability and performance.

Moreover, understanding the interaction between CFS and plywood when combined with bracing will help optimize material selection, reduce construction costs, and enhance the overall structural integrity. The research opens the door for future studies on innovative bracing configurations and materials that can further improve the performance of composite wall systems under various loading conditions, contributing to the advancement of structural engineering.

Finally, the practical implications of this research emphasize the need for implementing effective bracing techniques in real-world construction projects. The findings serve as a reference for industry professionals, promoting the construction of safer and more resilient structures.

IV. CONCLUSIONS

This research highlights the impact of bracing on the axial load capacity and overall stability of CFS-plywood composite walls, revealing that the incorporation of bracing significantly enhances structural performance under axial loads. Bracing improves load-bearing capabilities and controls deformation, thereby reducing the risk of structural failure. Future studies could explore innovative bracing configurations and materials to further optimize 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, contributing to the development of safer and more resilient structures in various engineering contexts...

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