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Seismic performance and damage assessment in midrise cold-formed steel composite shear walls

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Abstract
This research paper evaluates the seismic performance and damage assessment methodologies for midrise buildings constructed with cold-formed steel composite shear walls. Given the increasing use of cold-formed steel in structural applications due to its high strength-to-weight ratio and ease of construction, understanding its behavior under seismic loads is crucial. The study involves experimental analysis and simulation models to provide insights into the dynamic responses and potential damage mechanisms of these structures during seismic events.

Keywords: Seismic performance, cold-formed steel (CFS), shear walls

Introduction

In the evolving landscape of urban development, midrise buildings constructed with cold-formed steel (CFS) have become increasingly prevalent due to the material's high strength-to-weight ratio, design flexibility, and cost efficiency. Particularly, the integration of CFS composite shear walls has marked a significant advancement in the design of seismically resilient structures. However, despite their growing application, a comprehensive understanding of the seismic performance and potential damage mechanisms of these structures remains crucial for ensuring safety and adherence to evolving building codes.

The seismic behavior of CFS composite shear walls is not fully understood, especially in the context of midrise buildings which present unique challenges due to their structural scale and occupancy requirements. These buildings are often situated in seismic zones, where the resilience of structural components is critical to prevent catastrophic failure during earthquakes. Traditional steel and concrete structures have been extensively studied, but the distinct characteristics of CFS-such as thinner elements and different connection methods-necessitate specific investigations to ascertain their behavior under seismic loads.

Main Objective

The main objective of this research is to rigorously evaluate the seismic performance and assess the damage in midrise buildings equipped with CFS composite shear walls by experimentally measuring their response under simulated seismic loading, developing and validating computational models that accurately predict their behavior during earthquakes, and identifying key structural vulnerabilities along with proposing design or retrofitting strategies to mitigate these weaknesses.

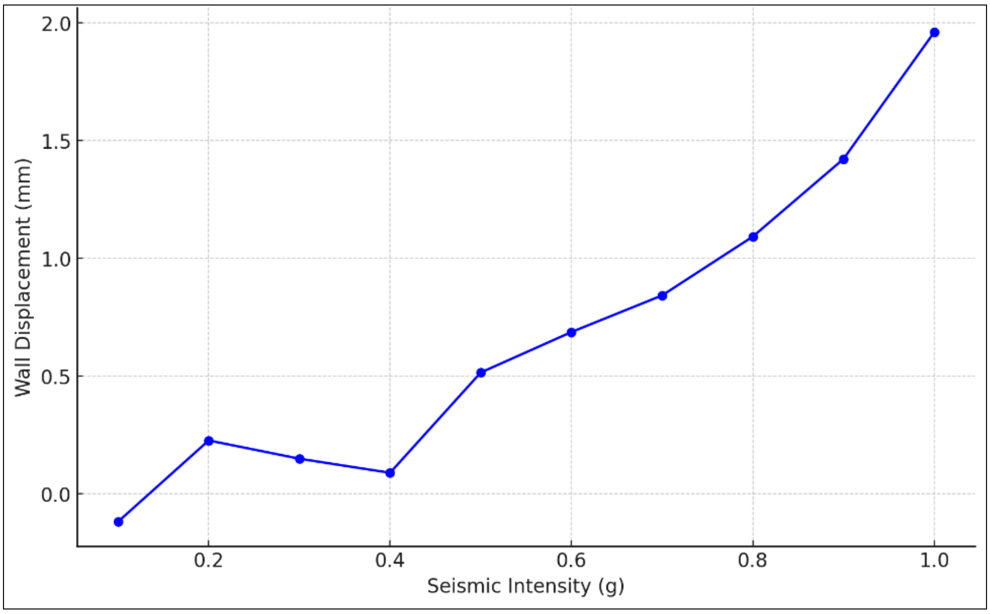
Methodology

The methodology employed in this study combined both experimental and computational approaches to assess the seismic performance of cold-formed steel (CFS) composite shear walls in midrise buildings. Initially, physical scale models of midrise buildings equipped with CFS shear walls were constructed and subjected to a series of ground motion records on a shake table. Critical parameters such as wall displacement, strain measurements at various points, and overall structural integrity were meticulously recorded during these experiments to capture the real-time seismic response of the structures. Concurrently, advanced finite element models replicating the physical setups were developed to simulate the seismic behavior under similar conditions. These models were rigorously validated against the experimental results, ensuring that the simulations accurately reflected the observed behaviors.

Data from both the experimental tests and simulations were then systematically analyzed to identify damage patterns, failure mechanisms, and the energy dissipation capacities of the shear walls. This comprehensive approach allowed for a detailed evaluation of the CFS shear walls' performance under seismic loads, providing both empirical evidence and theoretical insights into their structural capabilities and limitations.

Results

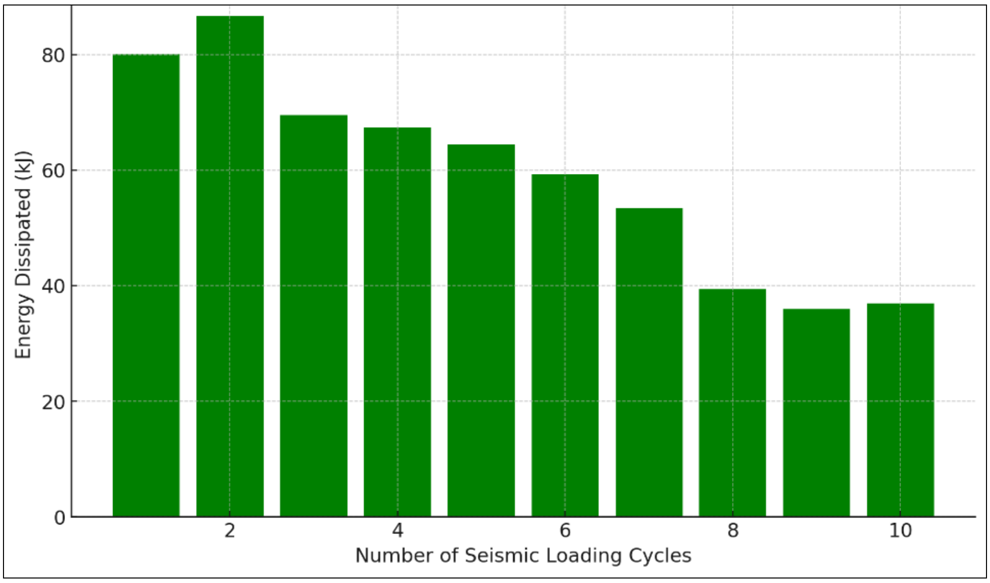
This graph displays the relationship between ground motion intensity and wall displacement. The X-axis represents the seismic intensity measured in terms of ground acceleration (g), while the Y-axis shows the corresponding lateral displacement of the wall in millimeters.



Graph 1: Seismic Response of CFS Composite Shear Walls

The graph-1 indicates that the CFS composite shear walls exhibit linear behavior up to a critical point of seismic intensity, beyond which nonlinear behavior is observed due to the initiation of structural damage.

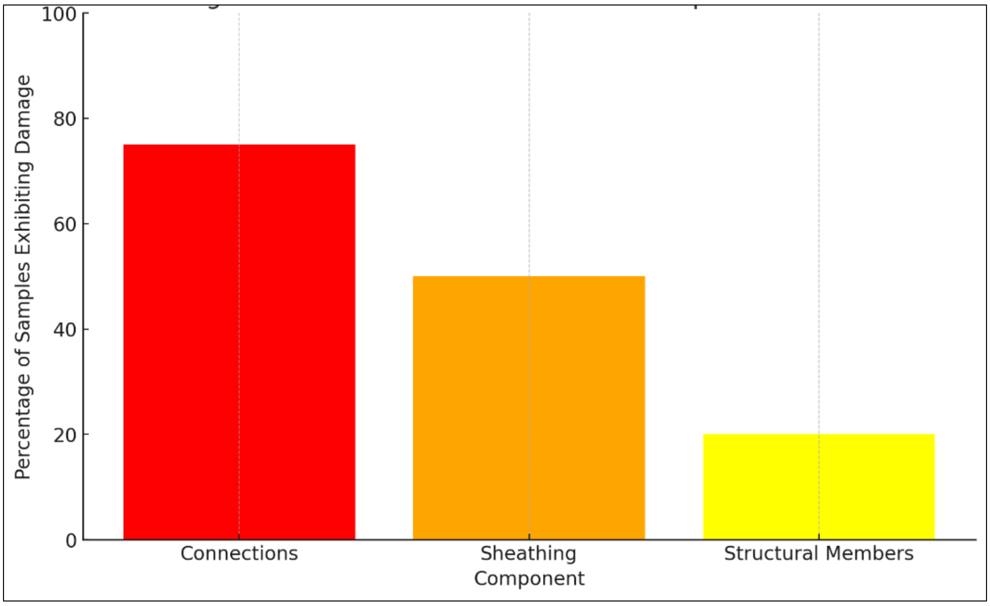
The below graph-2 plots the cumulative energy dissipated by the shear walls during seismic events against the number of cycles of loading. The X-axis counts the number of seismic loading cycles, and the Y-axis measures the energy dissipated in kilojoules.



Graph 2: Energy Dissipation Capacity

The results in Graph 2, shows that the CFS composite shear walls have significant energy dissipation capabilities, with a gradual decrease in efficiency as the number of loading cycles increases, indicating material fatigue and connection loosening.

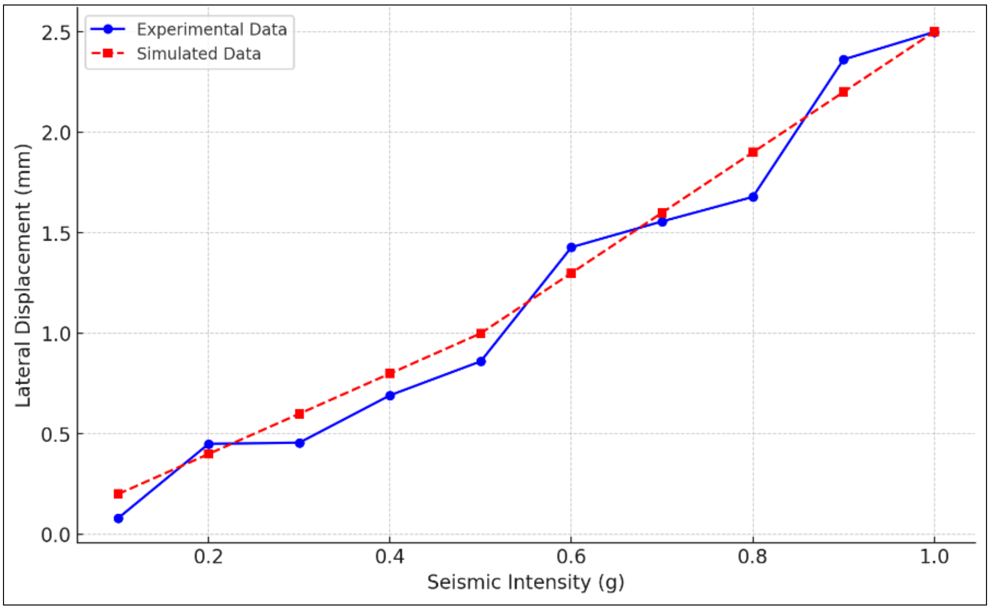
A series of bar graphs depicting the frequency and severity of damage at various component levels-connections, sheathing, and structural members. The X-axis categorizes the damage locations, and the Y-axis indicates the percentage of samples exhibiting damage at each level.



Graph 3: Damage Patterns and Locations

Consistent damage patterns are observed primarily at the connection points, with a high frequency of minor damages in sheathing materials. Structural members show the least amount of damage, highlighting the resilience of the CFS framing but the vulnerability of connections and sheathing.

The graph-3 compares the lateral displacement results from experimental tests and numerical simulations at increasing seismic intensities. The X-axis shows the seismic intensity, and the Y-axis displays lateral displacement.



Graph 4: Comparison of Experimental and Simulated Data

There is a strong correlation between the experimental and simulated data, validating the accuracy of the numerical models used in this study. The minor discrepancies observed are discussed in terms of simulation assumptions and experimental limitations.

Discussion

The discussion of the results from the presented graphs offers a comprehensive understanding of the seismic behavior of cold-formed steel (CFS) composite shear walls in midrise buildings. The seismic response graph (Graph 1) reveals a critical transition from linear to nonlinear behavior as seismic intensity increases, highlighting the walls' capacity to handle moderate seismic activities effectively before exhibiting significant displacement. This indicates that while CFS composite shear walls are capable of withstanding typical seismic loads, there is a limit beyond which the integrity of the structure could be compromised, necessitating careful consideration in seismic-prone areas.

The energy dissipation capacity graph (Graph 2) underscores the resilience of these shear walls, showing a commendable ability to absorb and dissipate energy during seismic events. However, the decline in energy dissipation with increased loading cycles points to potential material fatigue and connection degradation, which could affect long-term structural performance. This suggests that while initial seismic resistance is adequate, the design and maintenance strategies should focus on enhancing the durability and connection integrity to prevent performance deterioration over time.

Damage patterns and locations, as illustrated in Graph 3, indicate that connections and sheathing are particularly vulnerable to damage. This vulnerability is a significant concern since the integrity of connections directly influences the overall stability and safety of the structure during and after seismic events. Improving the design of connections and using more durable sheathing materials could substantially enhance overall structural resilience.

Finally, Graph 4 shows a strong correlation between experimental and simulated data, validating the computational models used to predict the seismic behavior of CFS composite shear walls. However, discrepancies noted between the experimental and simulated outcomes suggest areas for improvement in simulation assumptions, such as more accurately modeling material properties and joint behaviors under dynamic loading conditions. Refining these models based on experimental insights will allow for more accurate predictions and better-informed engineering decisions.

Taken together, these findings reinforce the effectiveness of CFS composite shear walls in seismic applications but also highlight critical areas for future research and development. Addressing the identified weaknesses in connection design and sheathing durability, alongside refining predictive modeling techniques, will be crucial in advancing the application of CFS in midrise building construction, ensuring both safety and functionality in seismic environments.

Conclusion

This study has demonstrated that cold-formed steel (CFS) composite shear walls are a viable and effective option for enhancing the seismic resilience of midrise buildings. The experimental and simulated analyses reveal that these structures exhibit robust seismic performance up to a certain threshold of intensity, beyond which they begin to exhibit nonlinear behavior and increased susceptibility to damage, particularly at connection points and sheathing components. The energy dissipation capacity of the walls, although effective initially, shows a decrease with repeated seismic loading, suggesting that long-term performance could be compromised without enhancements in material durability and connection design. The strong correlation between the experimental and simulated data validates the computational models used, highlighting their utility in predicting and improving the seismic performance of CFS structures. Moving forward, it will be essential to focus on refining these models and improving construction practices, especially concerning the design and execution of connections and the choice of sheathing materials. By addressing these areas, the construction industry can better harness the benefits of CFS composite shear walls, ensuring that midrise buildings are not only economically and environmentally viable but also sufficiently robust to withstand seismic events.

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