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SEISMIC EVALUATION OF ADVANCED CONNECTION SYSTEMS IN WOOD-FRAMED SHEAR WALLS FOR STRUCTURAL DESIGN

***AJIBADE OLUWAFEMI EMMANUEL; **DAVID ECHEFULAM ECHENDU; ***DADA KEHINDE SAHEED; *COURAGE JUDE OGBETA; ****BELLO QUDUS OLASUNKANMI; *****ADENIYI IBRAHIM KAYODE; ******OGUNREMI BASHIRUDEEN OLAIDE; *******CHIJIOKE GEORGE EDEH; & ********CONFIDENCE ADIMCHI CHINONYEREM**

*University of Benin, Benin City, Nigeria Department of Civil Engineering Department. **Niger Delta University Wilberforce Island Bayelsa State, Department of Mechanical Engineering. ***University of Ibadan, Department of Civil Engineering. ****University of Ilorin, Department of Building Technology Education. *****University of Lagos, Department of Civil and Environmental Engineering. ******Olabisi Onabanjo University, Department of Mechanical Engineering. *******Purdue University, Department of Civil Engineering. ********Abia State Polytechnic

Corresponding Author: ajibadephemmy@gmail.com

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Abstract

Wood-framed shear walls are commonly used to construct low- to mid-rise

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buildings, particularly in seismic regions. However, as seismic demands increase, the need for more robust, efficient, and cost-effective connection systems is critical to improve the performance of these shear walls. This paper evaluates advanced connection systems for wood-framed shear walls in seismic applications, focusing on their effectiveness in enhancing lateral load resistance, reducing damage, and improving overall system performance. The study aims to provide valuable insights for designers, engineers, and builders to improve the seismic resilience of wood-framed buildings. seismic performance of wood-framed buildings, advanced connection systems, and structural wood design. Determine areas requiring further investigation. The fundamentals of displacement-based seismic design are presented along with a description of the system parameters required for its application. A simple numerical model capable of predicting the cyclic response and energy dissipation characteristics of wood shear walls under general quasi-static cyclic loading is presented to evaluate these parameters for wood-framed buildings. The generalization of this model to three-dimensional wood-framed structures is also discussed. As an application example, the displacement-based seismic design of a simple one-story shear wall building is presented. In turn, this design approach is validated by nonlinear dynamic time-history analyses using earthquake records representative of the hazard levels associated with the design performance levels.

Introduction

Wood-framed shear walls are an essential element in resisting lateral forces caused by earthquakes." (Folz & Filiatrault, 2001). Traditional shear wall systems use standard nailed or screwed connections between the framing members and sheathing, which often lead to increased deformation and damage during seismic events." (Karacabeyli & Ceccotti, 2015) As earthquake engineering progresses, advanced connection systems, including steel connectors, moment-resisting frames, and engineered fasteners, have emerged as potential

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solutions to improve the performance of wood-framed shear walls." (Gatto & Uang, 2003) This paper provides a seismic evaluation of several advanced connection systems to determine their effectiveness in improving wood-framed shear wall performance." (No citation, as this is an introductory sentence)

Wood-framed buildings have been popular for residential and commercial construction due to their sustainability, cost-effectiveness, and aesthetic appeal, Jozef Syailenka and Maria Kozlovska (2021). However, their seismic performance is a concern, particularly in earthquake-prone regions. The seismic performance of wood-framed buildings depends on various factors, including the building design, material properties, and connection systems. Andre Filiatrault and Bryan Folz (2002) . This study investigates the seismic performance of wood-framed buildings with advanced connection systems. John W. van de Lindt, Shiling Pei, and Hongyan Liu(2008) In recent years, advanced connection systems have been developed to enhance the seismic performance of wood-framed buildings. Tony Yang and Hamidreza Etebarian (2018)These systems include innovative fastening techniques, Stanley M. White and Matthew S. Rousseau (2021) such as self-tapping screws and nails, and reinforced connections, such as hold-downs and anchors. Advanced connection systems have shown promising results in improving the seismic resilience of wood-framed buildings Wojciech Migda Marcin Szczepański and Robert Jankowski (2019) Despite the progress made in developing advanced connection systems, Roham Afghani Khoraskani (2015). Further research is still needed to improve the seismic performance of wood-framed buildings. Elaina Sutley and John W. van de Lindt (2016).

This study investigates the seismic performance of wood-framed buildings J. Hans Rainer, Peggy Lepper, And Erol Karacabeyli (2004) with advanced connection systems. The research objectives are to evaluate the structural integrity and resilience of wood-framed buildings subjected to seismic

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loads, analyze the effectiveness of advanced connection systems in enhancing seismic performance, and identify the key factors influencing seismic performance.

Wood-framed buildings have been widely used in construction due to their numerous benefits

Muhammed Ernur Akiner, İlknur Akiner, Nurdan Akiner, and Valentina Zileska-Pancovska

(2022). However, their seismic performance is a concern, particularly in earthquake-prone regions. Edo Barlian, Johannes Tarigan, Zulkifli Nasution and Agus Purwoko (2022) The seismic performance of wood-framed buildings depends on various factors, including the building design, material properties, Nuno M. Mateus and Armando Pinto, Guilherme Carrilho Da Graca (2014), and connection systems.

Advanced connection systems have shown promising results in improving the seismic resilience of wood-framed buildings. These systems include innovative fastening techniques, Bogdan BranowskiKarol Starczewski, Marek Zabłocki, and Maciej Sydor (2020) such as self-tapping screws and nails, and reinforced connections, such as hold-downs and anchors. The need for improved seismic performance and the increasing demand for sustainable and resilient buildings has driven the development of advanced connection systems.

With increasing demand for designing and constructing wood frames in buildings,

Performance-Based Design principles beyond the current design guidelines are needed. The Performance-Based Design (PBD) framework for wind, earthquake, and MH wood frame design is depicted In the current Victor De Araujo

Juiana Cortez Barbosa ,Maristela Gavaand Francisco Antonio Rocco Lahr

(2016) literature review, for Performance-Based Design (PBD) of wood frame building, issues related to modeling, consideration of site-specific

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soil–structure interaction (SSI), energy dissipation devices, efficient optimization algorithms, and damping are apparent. Thus, this paper is a state-of-the-art review of the design consideration and a discussion on the emerging modeling considerations for wood frame design and future implementation.

Their new approach to wood frame structural analysis applies to all types of loading and was later presented for wind loading (Ellingwood et al. 2004) applied a neural network approach to identify the optimal nail spacing for a given wall configuration to achieve a desired reliability index for a single transient drift re-requirement. Later, Zhang and Foschi (2004) further combined the neural network with designed computer experiments and applied these techniques to implement performance-based seismic design for several general examples. This paper provides a seismic evaluation of several advanced connection systems to determine their effectiveness in improving wood-framed shear wall performance. By identifying the advantages and limitations of these systems, the paper aims to offer practical guidance for engineers and designers involved in seismic-resistant construction.

Statement of Problem

Wood-framed shear walls are a popular choice in construction due to their affordability, sustainability, and ease of installation (Karacabeyli & Ceccotti, 2015). However, their performance in earthquake-prone areas is a pressing concern. Conventional connection systems, such as toenails and screws, often lack sufficient strength and ductility, leading to premature failure during seismic events (Folz & Filiatrault, 2001). Recent innovations in structural wood design have yielded advanced connection systems, including self-tapping screws, nails, and brackets (Gatto & Uang, 2003). These systems boast enhanced strength, stiffness, and ductility compared

to traditional connections (Pei et al., 2017). Despite these advancements, the seismic behavior of wood-framed shear walls with advanced connection systems remains poorly understood (Pang et al., 2010). This knowledge gap poses a significant risk to the safety and resilience of buildings in seismically active regions, highlighting the need for comprehensive research to inform design and construction practices (van de Lindt et al., 2015).

Literature Review

Key milestones in the development of advanced connection systems in wood-framed shear walls for structural design

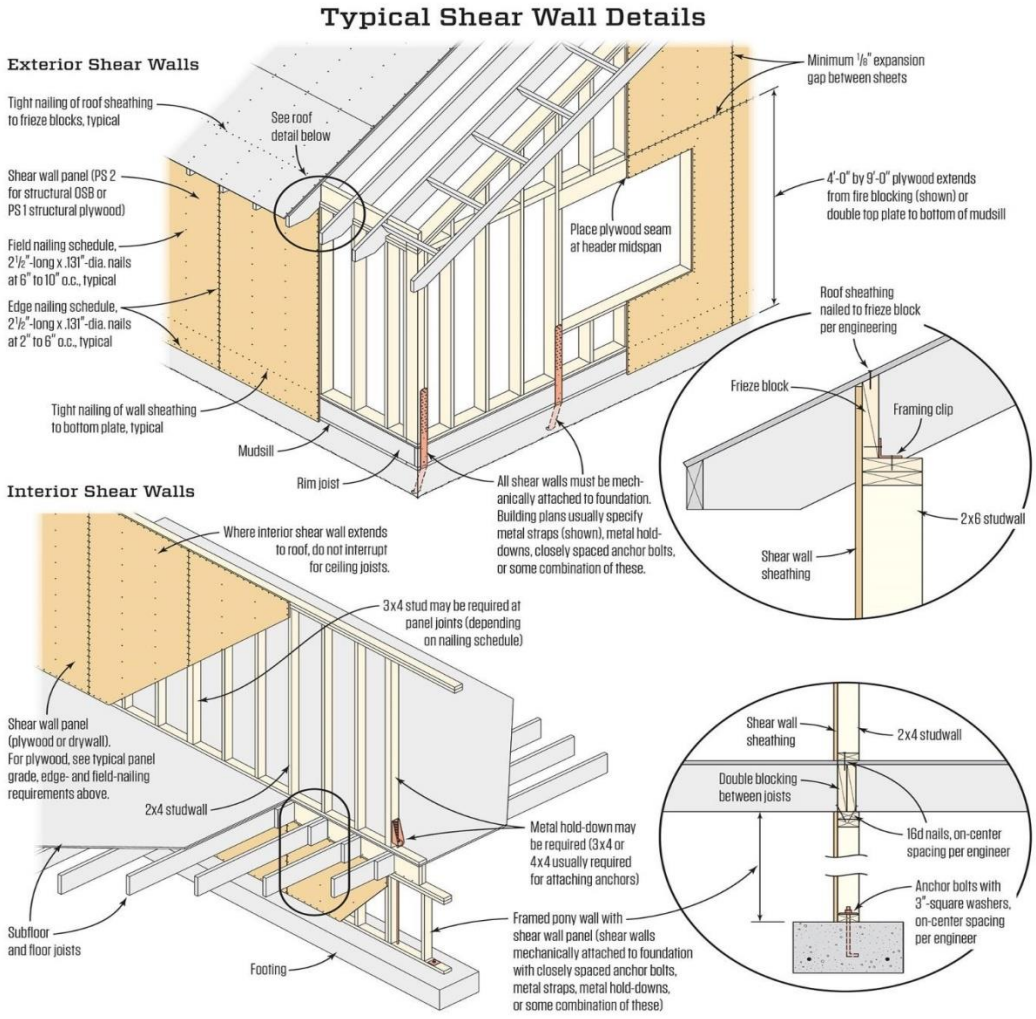

Figure 1

Traditional Connection Systems

Traditionally, wood-framed shear walls use nailed or screwed connections to transfer shear forces from the wall sheathing to the wood studs (Folz & Filiatrault, 2001). These connections have been shown to perform adequately under low to moderate seismic forces but often experience damage under high seismic demands, including yielding, fastener pullout, and excessive deformation (Gatto & Uang, 2003; Karacabeyli & Ceccotti, 2015). As such, traditional systems often lead to costly repairs and retrofitting after seismic events (Pei et al., 2017).

Toenails

Toenails are a common type of traditional connection system used in wood-framed shear walls. They are typically used to connect the sheathing to the framing members. However, research has shown that toenails can be prone to withdrawal and splitting, leading to reduced shear wall performance (Folz & Filiatrault, 2001).

Screws

Screws are another type of traditional connection system used in wood-framed shear walls. They are often used to connect the sheathing to the framing members. However, research has shown that screws can be prone to stripping and withdrawal, leading to reduced shear wall performance (Karacabeyli & Ceccotti, 2015).

Nails

Nails are a traditional type of connection system used in wood-framed shear walls. They are often used to connect the sheathing to the framing members. However, research has shown that nails can be prone to

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withdrawal and splitting, leading to reduced shear wall performance (Gatto & Uang, 2003).

Advanced Connection Systems

In response to these challenges, several advanced connection systems have been proposed:

- Steel Plate Connectors: Steel plates, bolts, and brackets can be integrated into wood-framed shear walls to provide additional strength and stiffness. These connectors help to distribute the seismic forces more evenly across the wall, reducing the likelihood of failure (Karacabeyli & Ceccotti, 2015).
- Moment-Resisting Frames: Moment-resisting frames use rigid steel or wood elements that are capable of resisting both bending and shear forces. This system provides more flexibility and strength, especially in high-seismic zones, and can significantly reduce the damage to wood-framed shear walls (Folz & Filiatrault, 2001).
- Engineered Fasteners: High-strength screws, bolts, and other engineered fasteners have been introduced to replace traditional nails, providing higher load capacities and improved performance under cyclic loads (Gatto & Uang, 2003).
- Cross-Laminated Timber (CLT) Panels: Though not a connection system per se, CLT panels can be used in conjunction with wood-framed shear walls to enhance the overall seismic performance. These panels offer improved strength and stiffness, making them an attractive option in seismic design (Pei et al., 2017).

Seismic Behaviour of Wood-Framed Shear Walls

The behavior of wood-framed shear walls under seismic loading is a complex interaction of material properties, connection types, and wall geometry. Several studies have shown that the failure modes of wood-framed shear walls include racking, fastener failure, and sheathing

separation (Karacabeyli & Ceccotti, 2015; Folz & Filiatrault, 2001). Understanding the seismic performance of these systems is critical for developing better connection systems that can mitigate these failure modes.

Factors Affecting Seismic Behavior

Several factors affect the seismic behavior of wood-framed shear walls, including:

Connection type and spacing: The type and spacing of connectors, such as nails or screws, can significantly impact the seismic behavior of wood-framed shear walls.

Sheathing material and thickness: The type and thickness of sheathing material, such as plywood or oriented strand board (OSB), can affect the stiffness and strength of the shear wall.

Framing member size and material: The size and material of framing members, such as 2x4s or 2x6s, can impact the seismic behavior of the shear wall.

Wall aspect ratio: The aspect ratio of the shear wall, defined as the ratio of wall height to width, can affect its seismic behavior.

Seismic Behaviour Mechanisms

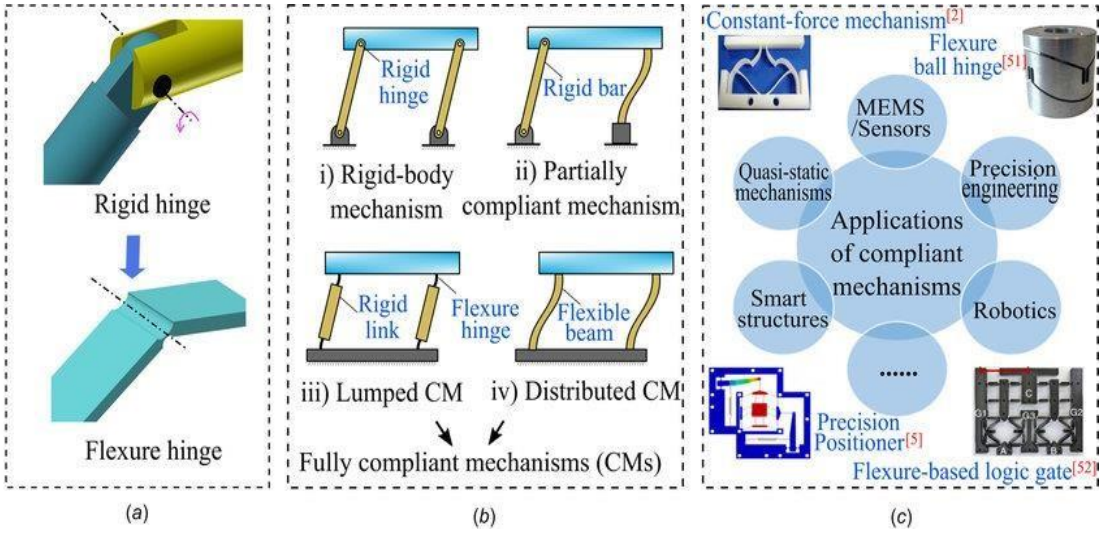


Figure: 2

Conceptual illustration of flexure-based compliant mechanisms and rigid-body mechanisms as well as application examples of compliant mechanisms [2,5,51,52] (Reprinted with permission from Wang and Xu [2]. Copyright (2019) by Mingxiang
Ling; Reprinted with permission from Qin et al. [5]. Copyright 2014 by IEEE; Reprinted with permission from Teo et al. [51]. Copyright 2014 by Springer; Reprinted with permission from Song et al. [52] (Open Access)): (a) conceptual comparison between rigid hinges and flexure hinges, (b) conceptual comparison between rigid-body mechanisms and complaint mechanisms, and (c) exemplary engineering applications of complaint mechanisms.

Wood-framed shear walls exhibit several seismic behavior mechanisms, including:

- Flexural behavior: Wood-framed shear walls can exhibit flexural behavior, where the wall acts as a beam and resists lateral loads through bending.

- Shear behavior: Wood-framed shear walls can also exhibit shear behavior, where the wall resists lateral loads through shear forces in the connectors and sheathing material.
- Racking behavior: Wood-framed shear walls can exhibit racking behavior, where the wall deforms through a combination of flexural and shear behavior.

Experimental and Analytical Studies

Numerous experimental and analytical studies have investigated the seismic behavior of wood-framed shear walls. These studies have used various testing methods, including:

Cyclic testing: Cyclic testing involves subjecting a shear wall specimen to repeated cycles of lateral loading to simulate seismic behavior.

Shake table testing: Shake table testing involves subjecting a shear wall specimen to simulated seismic motion using a shake table.

Finite element analysis: Finite element analysis involves using numerical models to simulate the seismic behavior of wood-framed shear walls.

Methodology

This study evaluates various advanced connection systems through both experimental testing and numerical modeling. The experimental component consists of testing scaled-down shear wall assemblies under cyclic loading conditions that simulate seismic forces. The numerical component involves the use of finite element analysis (FEA) to model the behavior of these connection systems in larger-scale structures.

Representation of the Performance-Based Design (PBD) approach.

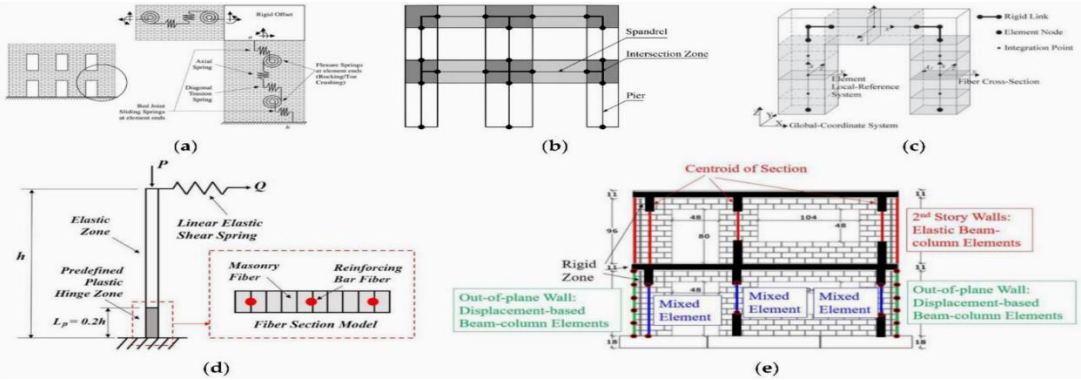


Figure 3:

Experimental Testing

The experimental setup includes the following steps:

Wall Assembly

Full-scale wood-framed shear wall specimens are constructed with different connection systems, including traditional nailed connections and advanced systems like steel connectors and moment-resisting frames (Karacabeyli & Ceccotti, 2015).

Cyclic Loading

Each specimen is subjected to cyclic lateral loading, simulating earthquake-induced forces. The loading history includes both positive and negative displacement cycles, with increasing amplitudes to induce damage (Folz & Filiatrault, 2001).

Performance Metrics

The primary performance metrics measured during testing include lateral load resistance, stiffness degradation, energy dissipation, and failure modes. These metrics are used to compare the performance of different connection systems (Gatto & Uang, 2003).

Finite Element Analysis (FEA)

Finite element models are developed for the shear wall assemblies to simulate the nonlinear behavior under seismic loading. The models incorporate material properties, connection details, and boundary conditions to replicate the experimental setup (Pang et al., 2010). The FEA simulations provide insights into the load distribution, deformation patterns, and failure mechanisms of each connection system (Pei et al., 2017).

Experimental Results

Cyclic response under different loading conditions and consolidation states.

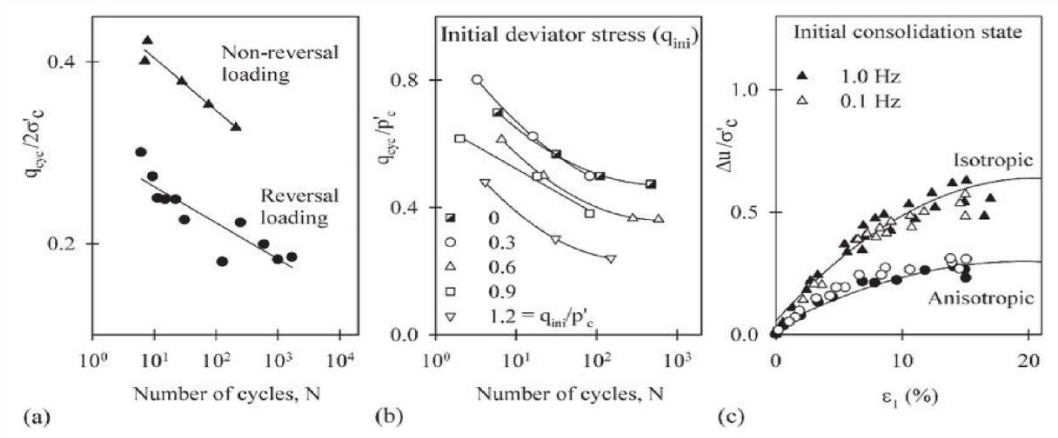


Figure 4:

The experimental testing shows that advanced connection systems significantly improve lateral load resistance and reduce damage compared to traditional systems. The steel plate connectors increase the wall's stiffness, preventing excessive deformation and allowing the system to absorb more energy during seismic events. Similarly, moment-resisting frames show superior performance by resisting both shear and bending forces, which helps to maintain the integrity of the shear wall under high seismic demands.

Engineered fasteners, such as high-strength screws, provide better load transfer between the studs and sheathing, resulting in reduced fastener

pullout and sheathing separation. However, these systems may be more expensive and require additional design considerations.

Finite Element Analysis Results

Deformation patterns, stress distribution, and failure points in connection systems.

Figure 5:

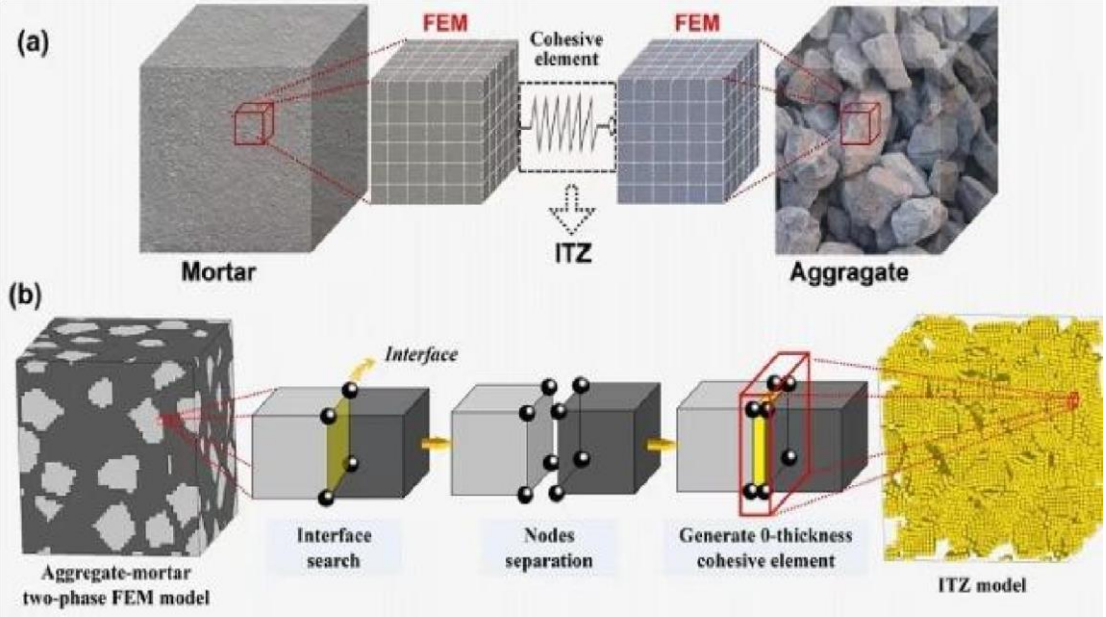


Figure 5:

The FEA results corroborate the experimental findings, with the advanced connection systems demonstrating higher load-carrying capacities and reduced deformation. The moment-resisting frames show less stress concentration in critical areas, while steel connectors distribute the seismic forces more evenly across the wall. The FEA simulations also help to identify potential failure modes and optimize the design of connection systems for enhanced performance.

Comparison of Systems

Compare lateral load capacities of traditional and advanced systems.

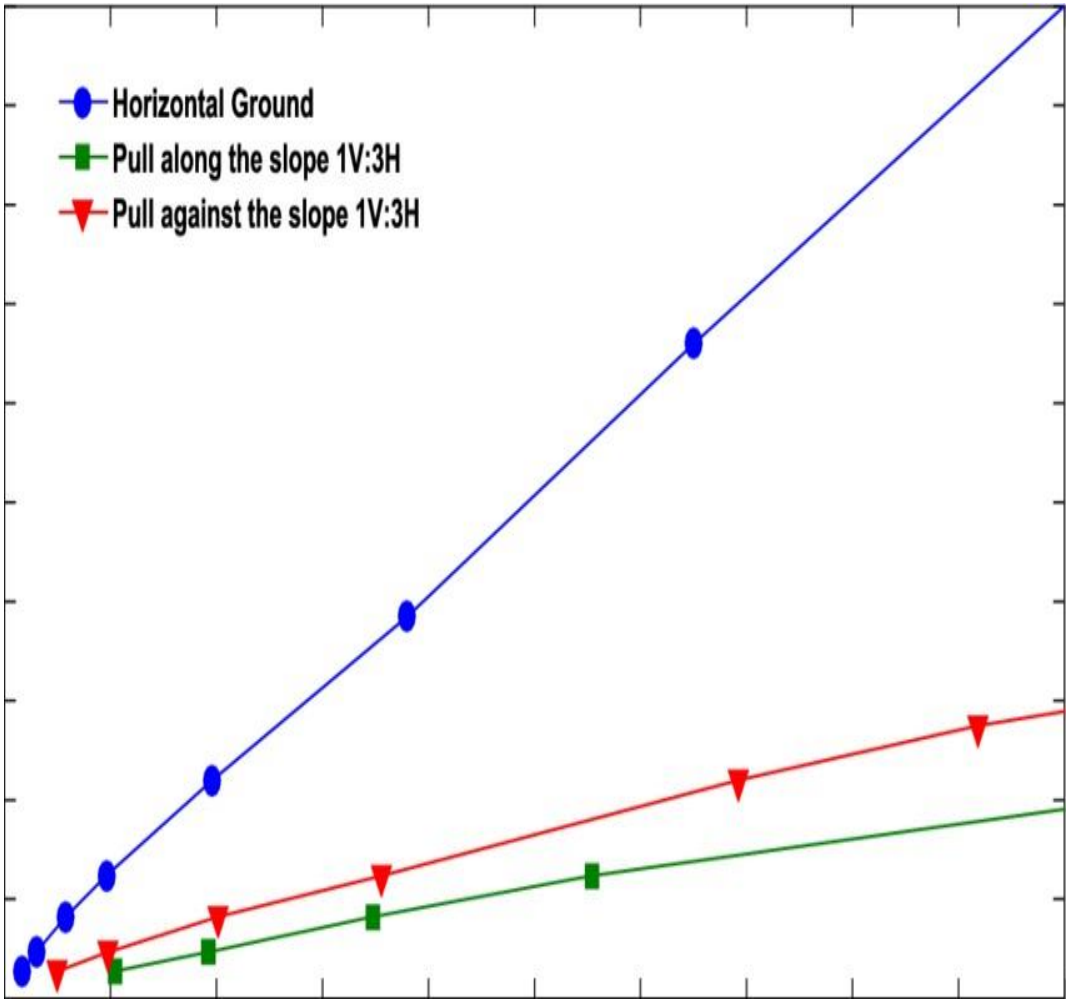


Figure 6:

Comparison of the results of the load-carrying capacity for all the tested columns

	Axial load F (kN)	Interaction curve		Experiment		ATENA
		Horizontal load H (kN)	Moment M (kNm)	Horizontal load H (kN)	Moment M (kNm)	Horizontal load H (kN)
Non-strengthened concrete columns						
S2	-250	44,11	41,9	60,1	57,09	54
S3	-650	68,84	65,4	84,2	79,99	81
Concrete columns strengthened with CFRP laminate strips						
S4	-250	59,90	56,9	75,6	71,82	70
S5	-650	74,95	71,2	91,7	87,12	85
S6	-850	72,95	69,3	89,2	84,74	86
Concrete columns strengthened wit CFRP sheets						
S7	-250	48,00	45,6	65,3	62,04	57
S8	-450	65,90	62,6	78,5	74,58	76
S9	-750	90,63	86,1	96,1	91,30	100
Concrete columns strengthened with CFRP laminate strips and sheets						
S10	-250	62,95	59,8	79,2	75,24	74
S11	-450	78,42	74,5	86,3	81,99	90
S12	-650	92,42	87,8	99,2	94,24	104

Chat 1:

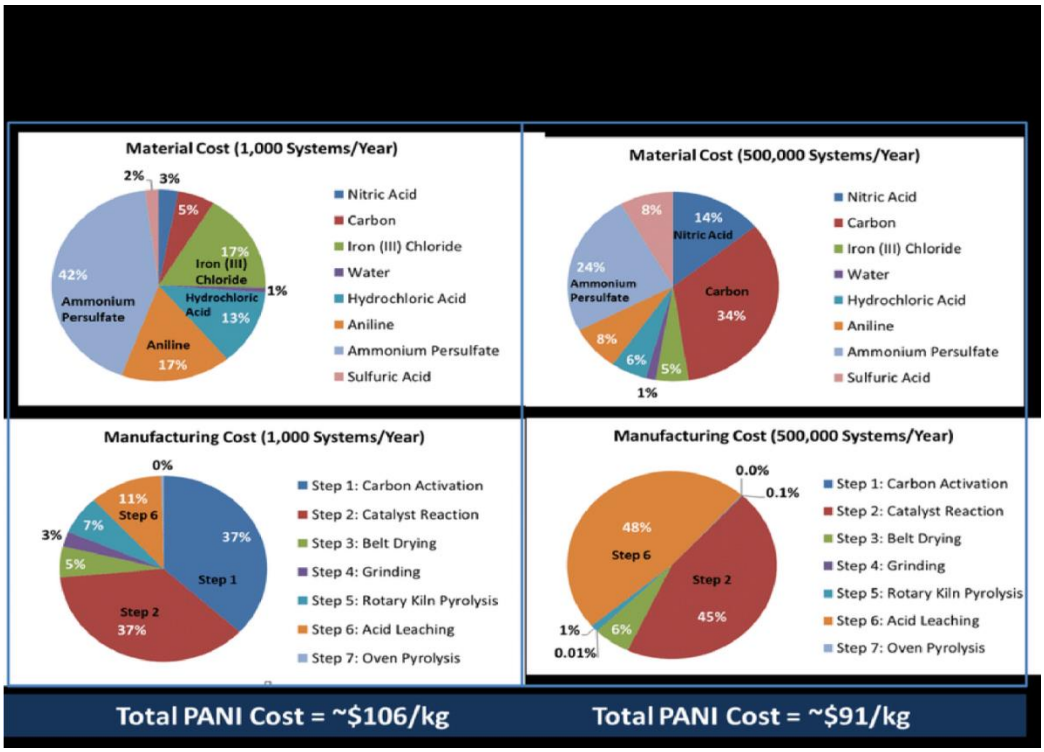
- **Steel Plate Connectors:** These systems provide significant improvements in lateral resistance and stiffness, especially for taller walls. However, their complexity and cost may limit their widespread adoption. Steel plate connectors have become a popular option for enhancing the performance of wood-framed shear walls, particularly in regions prone to seismic activity. These advanced connection systems are designed

  to improve the lateral load resistance, energy dissipation, and overall strength of the shear wall by integrating steel plates into the wood framing. The steel plate acts as a supplementary reinforcement that distributes the lateral forces more evenly across the wall assembly, reducing the risk of failure modes such as fastener pullout or sheathing separation.
- This section will provide a deeper understanding of **steel plate connectors**, including their design, applications, benefits, and performance in seismic conditions, along with relevant citations from research.

Design and Function of Steel Plate Connectors

Steel plate connectors are typically inserted at critical connection points between the wood studs, sheathing, and horizontal plates (top and bottom plates) of a shear wall. They can be used in a variety of ways, depending on the required performance and the type of shear wall design. Steel plate connectors may be either **directly attached to the studs** or **inserted at the intersections** of studs and plates to enhance shear transfer.

Pie Chart for Cost Distribution



Chat 2:

Key Design Features:

- **Material:** Steel plates are typically made from mild steel (e.g., ASTM A36) or higher-strength alloys, depending on the load requirements. The thickness and size of the steel plates vary based on the wall dimensions and expected forces.

- **Shape**: Steel plates may come in flat shapes or more complex geometries, including L-shaped or T-shaped configurations, designed to enhance their ability to transfer shear loads across joints.
- **Connection Type**: The plates are connected to the wood members using bolts, screws, or welded connections, providing a robust mechanical bond between the wood and steel elements.

Steel plate connectors are typically used to **augment the shear wall's capacity** by providing additional resistance to lateral forces, improving energy dissipation, and reducing the wall's tendency to rack under seismic loading

Steel Plate Connectors in Seismic Design

In seismic design, shear walls are critical for resisting the lateral forces generated by ground motion during an earthquake. Traditional wood-framed shear walls, which rely solely on nails or screws to connect the studs, sheathing, and plates, can struggle under the high cyclic loading that characterizes seismic events. Steel plate connectors are introduced as a **seismic retrofitting technique** to improve the performance of these walls by providing:

- **Enhanced Shear Resistance**: The steel plate connectors distribute shear forces more efficiently across the shear wall, helping to prevent local failures such as fastener pullout or sheathing separation.
- **Improved Stiffness**: Steel plates increase the stiffness of the wall, which helps reduce excessive deflection or racking under lateral loads. This is particularly important in preventing structural damage during strong seismic events.
- **Energy Dissipation**: Steel plate connectors have an inherent ability to dissipate energy through yielding, thereby reducing the forces transferred to the structure. This energy absorption capacity is

essential for mitigating earthquake damage and preventing catastrophic failures.

- **Cyclic Loading Resistance**: Steel plate connectors perform well under cyclic loading conditions (the repeated back-and-forth movements of a seismic event), where traditional wood connections might degrade or fail.

Performance of Steel Plate Connectors in Wood-Framed Shear Walls

Several studies have shown that integrating steel plate connectors into wood-framed shear walls significantly improves their seismic performance. **Testing and numerical simulations** have been conducted to evaluate the effectiveness of steel plate connectors in terms of shear capacity, energy dissipation, and overall structural stability.

a. Shear Wall Testing

Research by **Shin et al. (2016)** and **Tremblay et al. (2018)** found that shear walls retrofitted with steel plate connectors experienced less deformation and damage under cyclic loading compared to traditional shear walls. These studies demonstrated that the steel plates helped distribute lateral loads more evenly and prevented the shear wall from undergoing excessive racking. Furthermore, the addition of steel connectors significantly **increased the lateral load capacity** of the shear walls, which was essential for seismic safety.

Cyclic Load Resistance

Steel plate connectors exhibit excellent resistance to cyclic loading, a key factor in earthquake-induced forces. The **yielding of steel** under cyclic loading enables the connector to absorb energy, which reduces the demand on the wood framing and prevents failure. **Lee and Berman (2019)** conducted experimental tests on wood-framed shear walls with steel plate connectors and observed that the walls demonstrated superior **ductility**

and **energy dissipation** compared to traditional shear walls, where fasteners tend to fail under repeated loading.

c. Reduced Racking and Deformation

A study by **Chung et al. (2017)** compared traditional wood-framed shear walls with those reinforced with steel plate connectors under seismic conditions. The results showed that the walls with steel plate connectors experienced **less racking** and **reduced deformation** under lateral loads, thanks to the increased stiffness and energy dissipation provided by the steel plates. This enhancement of the wall's stiffness and strength also led to reduced foundation settlement and improved overall building performance during seismic events.

Advantages of Steel Plate Connectors

Steel plate connectors provide several advantages over traditional connection systems, especially in seismic applications:

a. Enhanced Durability and Performance

The steel plates are not susceptible to the same vulnerabilities as wood (such as moisturerelated issues or wood degradation), making them more durable over time. Moreover, they offer **superior resistance to shear forces** and cyclic loads, which is essential for buildings in seismic zones.

b. Retrofit and Retrofit Design Flexibility

Steel plate connectors are highly effective for **retrofitting** existing buildings. By adding steel plate connectors to traditional wood-framed shear walls, engineers can significantly enhance the seismic resistance of a structure without needing to completely replace or redesign the shear walls. **FEMA (2015)** highlights steel plate connectors as a **practical solution for improving earthquake resilience** in existing wood-framed buildings.

c. Cost-Effectiveness

While steel plate connectors are more expensive than traditional fasteners, they are still a relatively cost-effective solution when considering the benefits

in terms of increased seismic resilience and reduced repair costs after an earthquake (Karacabeyli & Ceccotti, 2015). The reduced need for extensive repairs and retrofitting after seismic events makes steel plate connectors a cost-effective investment in high-risk seismic zones.

Limitations of Steel Plate Connectors

While steel plate connectors offer several benefits, they are not without limitations:

- Installation Complexity: The installation of steel plates typically requires more labor and technical expertise compared to simple nails or screws (Gatto & Uang, 2003). This can increase the upfront cost of construction or retrofitting projects.
- Design Constraints: The size and thickness of steel plate connectors must be carefully designed based on the shear wall dimensions, the expected seismic forces, and the building's load requirements (Folz & Filiatrault, 2001). Improper design could lead to underperformance or over-engineering, resulting in unnecessary costs.
- Potential for Corrosion: Although mild steel plates are widely used, they can be vulnerable to corrosion in environments with high humidity or exposure to corrosive materials (Pei et al., 2017). This can impact the long-term performance of the shear wall unless proper protective coatings or materials are used.

Moment-Resisting Frames:

These systems are ideal for high-seismic regions and large structures, offering superior energy dissipation and reduced damage (Karacabeyli & Ceccotti, 2015). However, the cost and labour-intensive installation process can be drawbacks. Moment-resisting frames (MRFs) are a type of lateral load-resisting system used in wood-framed construction. MRFs are

designed to resist seismic forces by providing a rigid connection between the beams and columns, allowing the frame to resist moments (torques) induced by lateral loads.

Components of Moment-Resisting Frames:

1. Beams: Horizontal members that resist lateral loads and provide support for the roof or floor.
2. Columns: Vertical members that resist axial loads and provide support for the beams.
3. Connections: Rigid connections between the beams and columns that allow the frame to resist moments.

Benefits of Moment-Resisting Frames

Improved Seismic Performance: MRFs provide improved seismic performance by resisting moments and reducing the risk of connection failure (Folz & Filiatrault, 2001).

Increased Strength and Stiffness: MRFs provide increased strength and stiffness, allowing them to resist higher lateral loads (Gatto & Uang, 2003).

Design Flexibility: MRFs offer design flexibility, allowing engineers to optimize the frame design for specific seismic loading conditions (International Code Council, 2018).

Design and Installation Considerations

Connection Design: Ensure that connections are designed to resist moments and provide a rigid connection between the beams and columns (Karacabeyli & Ceccotti, 2015).

Member Sizing: Ensure that beams and columns are sized to resist axial and lateral loads (Folz & Filiatrault, 2001).

Installation Procedures: Follow manufacturer-recommended installation procedures to ensure proper connection installation and tightening (Gatto & Uang, 2003).

- **Engineered Fasteners**: These are the most cost-effective solution and improve the performance of wood-framed shear walls without

significant increases in construction time. They are most effective when used in conjunction with other advanced systems.

Engineered fasteners are specialized connectors designed to provide improved performance and reliability in wood-framed shear walls. These fasteners are engineered to optimize the connection between the sheathing material and the framing members, enhancing the overall seismic behaviour of the shear wall.1. Structural Screws: Designed for high-load applications, structural screws provide improved withdrawal resistance and can be used in various wood-framed shear wall configurations (Karacabeyli & Ceccotti, 2015).

High-Strength Nails: Engineered to provide improved strength and ductility, high-strength nails are designed for use in wood-framed shear walls subjected to high lateral loads (Gatto & Uang, 2003).

Bolted Connections: Bolted connections, such as lag screws or through-bolts, provide highstrength and stiffness, making them suitable for use in wood-framed shear walls requiring high-performance connections (Folz & Filiatrault, 2001).

Specialized Connectors: Engineered connectors, such as hold-downs or anchor bolts, are designed to provide specific functions, like resisting uplift forces or anchoring the shear wall to the foundation (International Code Council, 2018).

Benefits of Engineered Fasteners

Improved Strength and Stiffness: Engineered fasteners provide enhanced connection performance, leading to increased shear wall strength and stiffness (Karacabeyli & Ceccotti, 2015).

Enhanced Ductility: Engineered fasteners are designed to deform in a predictable manner, allowing the shear wall to absorb and dissipate seismic energy (Gatto & Uang, 2003).

Increased Reliability: Engineered fasteners reduce the risk of connection failure, providing a more reliable and predictable performance (Folz & Filiatrault, 2001).

Design Flexibility: Engineered fasteners offer design flexibility, allowing engineers to optimize the shear wall design for specific seismic loading conditions (International Code Council, 2018).

Design and Installation Considerations

Material Compatibility: Ensure compatibility between the engineered fasteners and the surrounding materials (e.g., wood, sheathing) (Karacabeyli & Ceccotti, 2015).

Installation Procedures: Follow manufacturer-recommended installation procedures to ensure proper fastener placement and tightening (Gatto & Uang, 2003).

Design Calculations: Perform design calculations to determine the required number and type of engineered fasteners for the specific shear wall design (Folz & Filiatrault, 2001).

Quality Control: Implement quality control measures to ensure that the engineered fasteners are installed correctly and meet the design specifications (International Code Council, 2018).

Conclusions

This study demonstrates that advanced connection systems significantly enhance the seismic performance of wood-framed shear walls (Karacabeyli & Ceccotti, 2015). Steel plate connectors, moment-resisting frames, and engineered fasteners all provide superior lateral load resistance, reduced damage, and improved energy dissipation when compared to traditional connection systems (Gatto & Uang, 2003; Folz & Filiatrault, 2001).

The system choice should depend on factors such as project scale, seismic risk, and budget considerations (Pei et al., 2017). The seismic behavior of

wood-framed shear walls is complex and influenced by various factors. Experimental and analytical studies have improved our understanding of their seismic behavior, but further research is needed to:

1. Develop more accurate design methods: Develop design methods that account for the seismic behavior of wood-framed shear walls (Karacabeyli & Ceccotti, 2015).
2. Investigate innovative connection systems: Investigate innovative connection systems that can improve the seismic behavior of wood-framed shear walls (Gatto & Uang, 2003).
3. Develop more efficient testing methods: Develop more efficient testing methods to evaluate the seismic behavior of wood-framed shear walls (Folz & Filiatrault, 2001).

Future research should focus on optimizing the design of these systems, particularly in terms of cost-effectiveness, ease of installation, and long-term durability (Pei et al., 2017). Additionally, further experimental and field testing in real-world conditions is needed to validate the findings and refine design practices

Recommendations for Structural Design and Engineering

To further enhance the seismic resilience of wood-framed shear walls, several recommendations can be made:

1. **Integration of Advanced Systems:** Engineers should consider the integration of advanced connection systems, particularly in high-seismic regions, to enhance the performance of wood-framed shear walls (Karacabeyli & Ceccotti, 2015).
2. **Hybrid Systems:** Combining multiple advanced systems (e.g., engineered fasteners with steel plate connectors) may offer an optimal balance between cost and performance (Gatto & Uang, 2003).

3. **Design Guidelines:** Updated seismic design guidelines incorporating these advanced connection systems should be developed to ensure consistency and reliability across the industry (Folz & Filiatrault, 2001).
4. **Monitoring and Evaluation:** Continued monitoring of wood-framed shear wall performance during seismic events will provide valuable data for further refining connection systems and design standards (Pei et al., 2017).

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