From Forest to Tower: Timber Building Systems in Seismic-Prone Areas

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Abstract

The construction sector is currently at a crossroads, facing the dual challenge of mitigating climate change through low-carbon materials and ensuring urban resilience against natural hazards. Mass timber has gained global momentum as a sustainable alternative to carbon-intensive materials. However, its application in seismically active regions requires a delicate balance between environmental benefits and structural reliability. This paper synthesizes the current state-of-the-art research at the intersection of timber engineering and seismic performance. The cross-Laminated Timber (CLT) building system was selected as an example highlighting the characteristics of the timber-based system under strong earthquakes. Furthermore, we update the current state of modeling strategies, emphasizing that nonlinear inelastic deformations are concentrated in mechanical connections (such as hold-downs and angle brackets), whereas CLT panels remain linear-elastic. This review also contextualizes mass timber engineering in Thailand, documenting the development of sustainable, high-strength CLT panels derived from local agricultural byproducts such as coconut wood and mixed-species configurations. Finally, this paper presents an ongoing research initiative dedicated to developing a novel Performance-Based Plastic Design (PBPD) methodology for CLT structures. Guided by a revised energy-balancing model that determines base shear strength requirements based on predefined yield mechanisms, structural weight, and target drift limits, this funded framework marks a critical paradigm shift toward establishing predictable seismic resilience and safety in modern mass timber buildings.

Keywords: Buildings, Cross-Laminated Timber, Earthquake, Low-carbon Material

1. Introduction

In the past 20 years, timber-based structures have become more popular in both residential and non-residential construction, even in countries that traditionally didn't use much wood in buildings. This shift is largely due to the introduction of efficient and eco-friendly engineered timber products such as Glue-Lam, cross-laminated timber (CLT), and Laminated Veneer Lumber (LVL), which are used in various parts of timber buildings.

Cross-laminated timber, for instance, has become one of the most widely used mass timber products in Europe for buildings. One of the key advantages of CLT is that it is not only high-strength but also environmentally friendly. The global production of CLT has been increasing rapidly, rising from 25,000 cubic meters in 1996 to 1.2 million cubic meters in 2020 in Europe alone [1]. This trend is also seen in countries such as the United States, Canada, Australia, New Zealand, and some Asian countries.

This paper reviews the latest research on cross-laminated timber (CLT) structures with respect to seismic response. The initial section of the paper provides an overview of the CLT panels and the seismic behavior of the CLT structural system. The second section focuses on modeling methodologies and predictive models for estimating the seismic demands of CLT structures. Lastly, the third section updates a part of the research activity on CLT structures in Thailand.

2. Cross-Laminated Timber (CLT) Panels

A Cross-Laminated Timber (CLT) panel is a two-dimensional mass timber manufactured by composing multiple layers of boards. These layers consist of adjacent boards that are rotated by 90 degrees relative to one another and glued together. The dimensions of CLT panels vary significantly, including thickness (t), width (b), and potentially unlimited length (l). This extended length is achievable by joining individual boards to create longer CLT boards. The number of layers is always odd and ranges from 3 to 9. Commonly used dimensions in construction practice.

CLT offers several advantages, including remarkable structural properties, thermal performance, and sustainability, making it a competitive alternative to conventional materials in medium- and high-rise construction. CLT panels exhibit a higher load-bearing capacity relative to most other construction materials in proportion to their own weight. This attribute enables the construction of high-rise buildings with relatively low mass. CLT panels can efficiently distribute loads both within their plane and perpendicular to it. CLT panels also offer substantial in-plane strength and stiffness. Thus, the material can serve as vertical shear walls, floor systems, and other structural elements in various contexts, such as bridges, sports arenas, and curved elements. CLT panels exhibit dimensional stability in response to moisture fluctuations, mitigating shrinkage and swelling tendencies. Moreover, CLT panels demonstrate excellent energy efficiency, represent an environmentally friendly construction material, and offer considerable flexibility in architectural design.

3. CLT Building Systems

Typically, CLT structures employ CLT panels for both vertical shear walls and horizontal floors. These panels are prefabricated off-site and assembled on-site using various metal connectors, including hold-downs, angle brackets, fasteners, and nails. In terms of configuration, shear walls can be divided into two primary groups: single (or monolithic) walls and segmented (or coupled) walls. The first has a high width-to-height ratio, with a width equal to the building's floor plan dimensions and a length corresponding to the inter-story height. The coupled walls are composed of narrow panels interconnected by vertical joints to maintain a lower width-to-height ratio.

As regards the CLT building system, CLT buildings are often constructed using the platform approach, in which the vertical continuity of the walls is interrupted at each story level by horizontal panels (floors). The vertical panels are either directly connected with a reinforced concrete foundation or on a horizontal wood floor or beam located between the base and the vertical panels at ground level. Alternatively, in low-rise structures, the balloon approach can be used. In this building system, the vertical walls remain continuous between stories, and the floors are linked on the inner side of the vertical walls using particular connecting components.

In seismic actions of CLT buildings, the structural response is notably complex due to the interaction between mechanical connections and CLT panels, as illustrated in Figure 1. Hold-down connectors are primarily designed to resist vertical uplift forces and the tension forces arising from overturning moments. Conversely, angle brackets are primarily designed for sliding movements because of seismic shear forces.

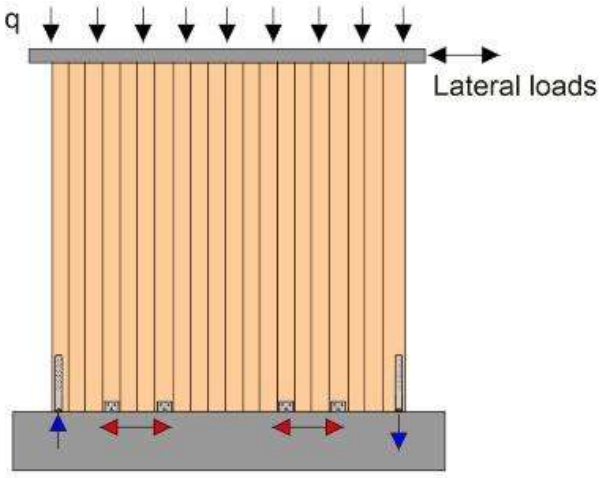


Figure 1 Seismic actions of the CLT shear wall.

4. Modeling Strategies and Predictive Models

Given that the nonlinear deformations in CLT walls subjected to lateral forces occur at their joints, the CLT panels themselves behave in a linear-elastic manner. Thus, an equivalent isotropic material model with linear-elastic properties is employed for the CLT panels [2]. In contrast, due to the nonlinear, large-deformation behavior, nonlinear-inelastic constitutive models are suitable for steel connectors, including angle brackets, hold-downs, and screws. The models for connectors should be able to capture the overall nonlinear responses, in terms of strength and deformation characteristics, as well as factors related to pinching strength and stiffness degradation. Moreover, the model should be calibrated against the experiment before being utilized in computational analysis. Figure 2 illustrates an example of the numerical model for CLT walls.

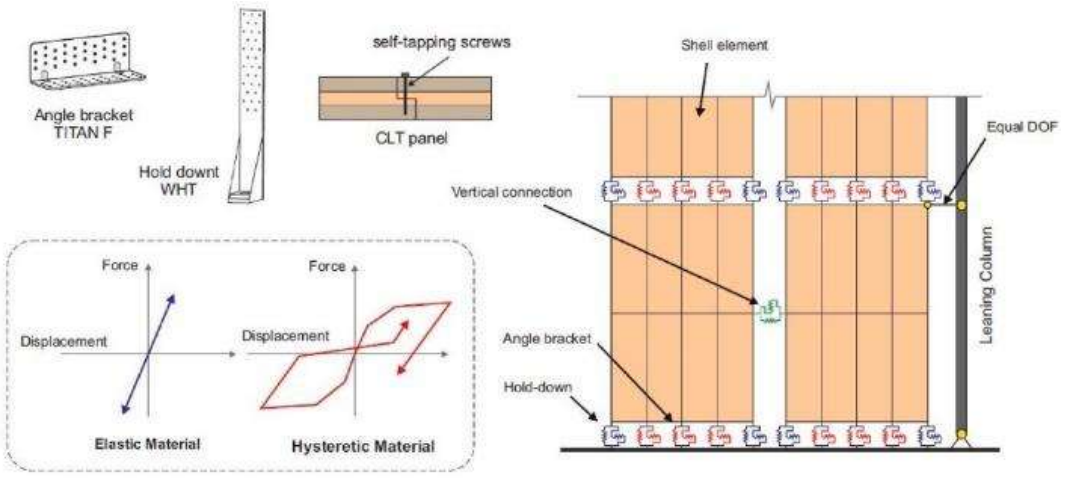


Figure 2 CLT Numerical model [2].

Despite their extensive use in construction practice, CLT panels are a relatively new construction material that has not yet been formally incorporated into national or international standards. Today, engineers and designers usually rely on non-codified guidelines in books, academic papers, or manuals published by research organizations or manufacturers that provide recommendations based on experimental and numerical data. In other words, there is a lack of research on the seismic response of CLT buildings worldwide. Useful documents are, for example, the experimental results from the SOFIE project [3] and Gavric, Igor et al. [4], the development of demand modification factors for CLT buildings [5-6]. Recently, Machine learning algorithms have been used to develop predictive models of demand drift in multi-story CLT buildings [2]. High accuracy is reported for this approach, with an R-squared of 0.95 when model estimates are compared to numerical results (based on nonlinear response history analysis, NRHA). The paper is also used to estimate seismic drift in CLT buildings.

5. A Part of Research Activities on CLT Structures in Thailand

Research on CLT structures is relatively new in Thailand compared to traditional building materials such as steel and concrete. In 2021, CLT panels made of coconut wood were developed, and fundamental material properties of the material were reported by Srivaro, Suthon et al [7]. The results showed that the average compressive strength of the coconut CLT panel was approximately twice that of general softwood CLT products. Therefore, the developed CLT can be used efficiently in both exterior and interior walls of buildings. In 2022, Srivaro, Suthon et al. developed a mixed-species CLT panel composed of rubberwood and coconut wood [8]. The findings suggest that using the proposed mixed-species techniques can enhance the mechanical properties of coconut wood cross-laminated timber (CLT) and reduce the material cost of rubberwood CLT while maintaining structural performance.

In 2025, our research group was awarded a research grant by the National Research Council of Thailand (NRCT) to advance mass timber engineering in Thailand. This project is about developing a novel performance-based plastic design (PBPD) methodology tailored for Cross-Laminated Timber (CLT) structures

to ensure predictable performance and safety under seismic loading. Moving away from conventional elastic design, this new method systematically aligns structural components with a predefined plastic yield mechanism. The cornerstone of the proposed framework is a revised energy-balancing model that equates the elastic and plastic energy components required to drive the CLT structure to its target drift to those of an equivalent elastic system. By establishing a proper lateral force distribution along the height of the structure, the model enables engineers to solve the energy equations and determine the precise base shear strength as a function of structural weight and the normalized design pseudo-acceleration, as shown in Figure 3. Ultimately, this research transforms CLT seismic design into a rational, displacement-and-energy-based mechanism, significantly enhancing the structural resilience of modern mass timber buildings.

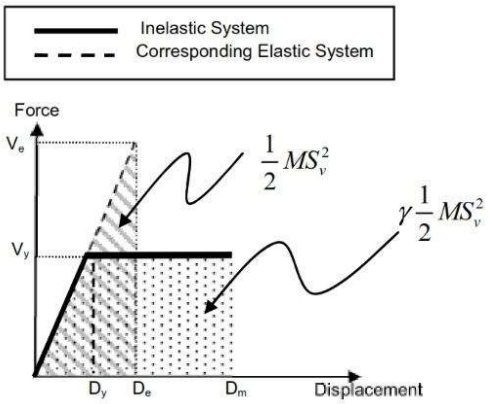


Figure 3 Equivalent elastic system used in the proposed PBPD framework.

6. Conclusion

This paper synthesizes global advancements, structural complexities, modeling strategies, and recent localized research on Cross-Laminated Timber (CLT) systems under seismic loading. The following key conclusions can be drawn:

1. Material and Systemic Efficiency: CLT has established itself as a premier global mass timber product due to its exceptional high-strength-to-weight ratio, dimensional stability, and environmental sustainability. When implemented in residential and non-residential mid- to high-rise buildings—predominantly through the platform construction approach—CLT panels serve as efficient vertical shear walls and horizontal floor systems, providing excellent in-plane load distribution.

2. Seismic Performance and Modeling Demands: Under seismic actions, the structural response of CLT buildings is highly complex and dominated by the interaction between mechanical connections and the timber panels. Because CLT panels behave in a linear-elastic manner, nonlinear inelastic deformation, pinching behavior, and stiffness degradation are primarily concentrated in localized metal connectors (such as hold-downs and angle brackets).

3. Emergence of Mass Timber Research in Thailand: CLT research in Thailand has transitioned from fundamental material exploration to sophisticated structural engineering frameworks. Initial local

breakthroughs established the viability of using agricultural byproducts to produce pure coconut-wood and mixed-species (rubberwood-coconut) CLT panels that exhibit up to twice the compressive strength of traditional softwood alternatives while remaining cost-effective.

4. Moving forward from material optimization, localized structural research has culminated in a major milestone. The ongoing transformation of the domestic seismic design paradigm from conventional elastic analysis to an advanced Performance-Based Plastic Design (PBPD) framework for CLT structures. By utilizing a revised energy-balancing model that calibrates required base shear strengths as functions of target drift, ductility, and structural weight, this methodology establishes a rational, energy-based approach that will significantly enhance the structural resilience and safety of mass timber structures in seismic zones.

7. Acknowledgment

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