DYNAMIC BEHAVIOR OF MODERN TIMBER STRUCTURES UNDER SEISMIC EXCITATION

Eknara Junda[1,*] and Watchara Chan-anan[1]
[1] *Nakhon Pathom Rajabhat University, Nakhon Pathom, Thailand*

*Corresponding author: eknara@webmail.npru.ac.th

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 significantly due to the introduction of efficient and eco-friendly engineered timber products like Glue-Lam, cross-laminated timber (CLT), and Laminated Veneer Lumber (LVL), which are used for various parts of timber buildings.

Cross-laminated timber, for instance, has become one of the most used mass timber products in Europe for buildings. One of the great things about CLT is that is not only high-strength but is also environmentally friendly. The global production of CLT has been rapidly increasing, going 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 like the United States, Canada, Australia, New Zealand, and some countries in Asia.

This paper reviews the latest research on cross-laminated timber (CLT) structures regarding the seismic response during earthquakes. The initial section of the paper overviews the CLT panes and the seismic behavior of the CLT structural system in general. The second section focuses on the modeling methodologies and predictive models to estimate 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 (as depicted in Figure 1).

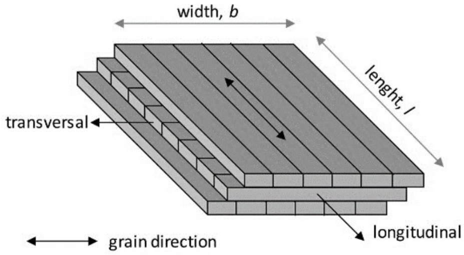

Figure 1. CLT panel [1].

The dimensions of CLT panels vary significantly, including thickness (t), width (b), and potentially unlimited length (l). This extended length is achievable because individual boards are joined together to create longer CLT boards. The number of layers is always an odd number and ranges from a minimum of three to a maximum of nine. Commonly used dimensions in construction practice.

There are several advantages of CLT like remarkable structural properties, thermal performance, and sustainability considerations enabling them to stand as competitive alternatives 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 allows for the construction of high-rise buildings with relatively lower mass. CLT panels can efficiently distribute loads 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 applications in various structural contexts such as bridges, sports arenas, and curved elements. CLT panels have dimensional stability in response to moisture fluctuations that can mitigate 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 system

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 comprised of narrow panels interconnected by vertical joints to maintain width-to-height ratios lower for such walls.

As regards the CLT building system, CLT buildings are often built utilizing the platform approach, in which the vertical continuity of the walls is stopped 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. Figure 2 illustrates the two different construction approaches whereas Figure 3 shows typical connections used for CLT buildings with platform approach.

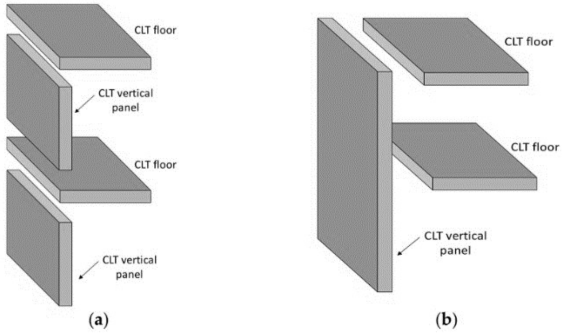

Figure 2. Construction approaches for CLT buildings [1].

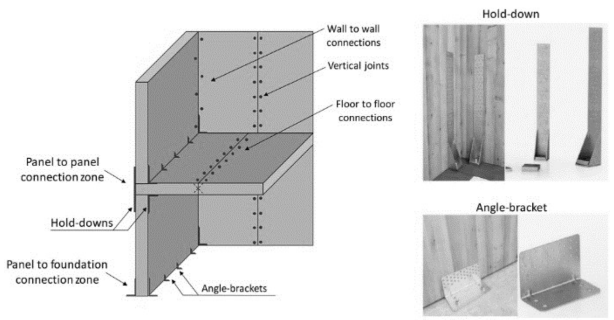

Figure 3. Typical metal connections [1].

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 4. 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.

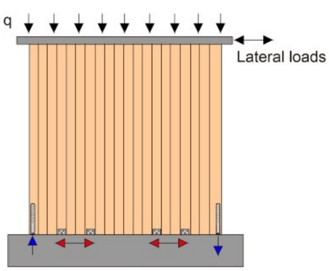

Figure 4. Seismic actions of the CLT shear wall.

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 as linear-elastic behavior. Thus, an equivalent isotropic material model characterized by linear elastic properties is acceptably employed for the CLT panels [2]. In contrast, due to the nonlinear large deformation, nonlinear-inelastic materials are suitable for the steel connectors, including angle brackets, hold-downs, and screws. The materials 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 5 illustrates an example of the numerical model for CLT walls.

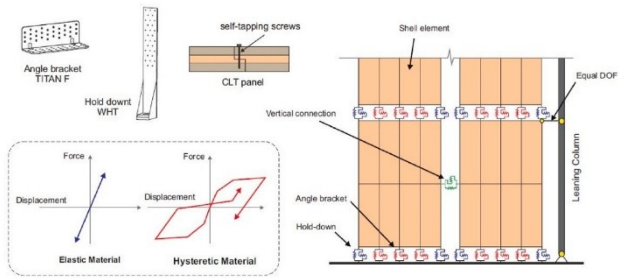

Figure 5. CLT Numerical model [2].

Despite their extensive utilization in construction practice, it is important to note that CLT panels are a 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 found in books, academic papers, or manuals published by research organizations or manufacturers that make 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 result 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 for the drift demand in multi-story CLT buildings [2]. High accuracy is reported from this approach with an R-squared of 0.95 when the model estimates are compared to numerical results (based on nonlinear response history analysis, NRHA) The paper is also employed for the estimation of the seismic drift in CLT buildings.

5. A part of research activities on CLT structures in Thailand

Research regarding CLT structures is relatively new in Thailand compared to traditional building materials like 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]. Figure 6 shows the specimen of a coconut CLT panel developed in the research group. The result showed that the average compressive strength of the coconut CLT panel was around twice, compared to general softwood CLT products. Therefore, the developed CLT can be efficiently used in both exterior and interior walls in buildings.

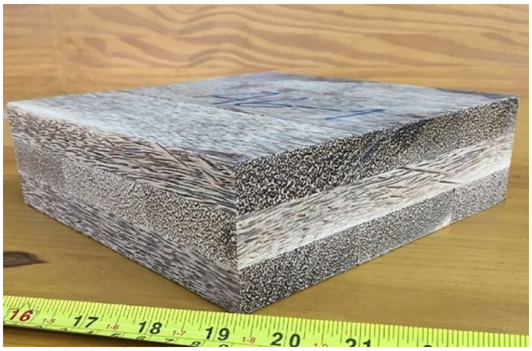

Figure 5. Coconut CLT panel specimen [7].

In 2022, Srivaro, Suthon et al. developed a mix of species in the CLT panel made of rubberwood and coconut wood [8]. The findings suggest that using the mixed species techniques proposed is capable of enhancing the mechanical characteristics of coconut wood cross-laminated timber (CLT) and reducing the material cost of rubberwood CLT while maintaining structural performance.

6. CONCLUSIONS

This paper provides a comprehensive examination of current research pertaining to the seismic response of structures constructed using cross-laminated timber (CLT) when subjected to earthquakes. The initial section of the paper offers an overview of CLT panels and the seismic performance characteristics of CLT structural systems. The subsequent section concentrates on modeling approaches and predictive models employed to assess the seismic behavior and demands imposed on CLT structures. Finally, the third section provides updated insights into ongoing research activities related to CLT structures in Thailand.

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8. AUTHOR BIOGRAPHIES

Eknara Junda is currently an assistant professor at Program of Civil Engineering, Faculty of Science & Technology, Nakhon Pathom Rajabhat University. He is also a research graduate at Department of Civil and Environmental Engineering, Faculty of Engineering, Imperial College London, UK. His research interests include sustainable construction materials, timber structures, nonlinear structural response analysis, statistical modeling, AI application in Civil Engineering, disaster risk reduction, and computational and simulation methods.

Watchara Chan-anan obtained Ph.D. in Civil Engineering (Structure) from king mongkut's university of technology thonburi, Thailand. He is an assistant professor at Program of Civil Engineering, Faculty of Science & Technology, Nakhon Pathom Rajabhat University. His research interests include performance-based seismic design, computational and simulation engineering, and nonlinear structural response analysis.