

Importance of mass timber in lateral force-resisting systems

by

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Abstract

The use of mass timber is expanding in the construction industry, and its importance as a material of the future should not be overlooked. It is increasingly being used in the structures that humans occupy. In particular, it is being used in tall buildings. The following paper is not an all-inclusive investigation of mass timber. Rather, it isolates a highly technical aspect of incorporating mass timber, focusing specifically on lateral force-resisting systems in tall building applications. It highlights the importance of this topic, reviews relevant concepts of structural dynamics that underlie a more advanced discussion in this area, and then summarizes various research studies that have furthered the technical knowledge in this field. The most significant conclusion of this paper is that previous research has already demonstrated that mass timber is well-positioned to be a reliable lateral force-resisting system. With U-shaped flexural plates and coupled rocking walls, mass timber can perform as well or better than traditional materials, as it did by several key measures in studied scenarios. Further research should be pursued to address remaining concerns and fully appreciate all that mass timber can offer the construction industry.

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The Importance of Mass Timber in Tall Buildings

The study of mass timber in tall buildings is important for several reasons. Even though the application of this material in tall buildings emerged around 30 years ago, its adoption is proceeding at a rapid pace. Responsible engineers can and should be actively evaluating the inherent risks and opportunities associated with promising new materials, in particular, understanding a new material's capabilities and limitations in construction, as well as its impact on the environment. Mass timber is especially important vis-à-vis its applications and comparisons to alternative materials.

Expanding Utilization

According to the European Commission, in 2100, over 85% of the population will live in urban cities, with the urban population increasing from less than 1 billion in 1950 to 9 billion by 2100. (European Commission, 2020) The Council on Tall Buildings and Urban Habitat considers a building that is 14 or more stories, or greater than 165 feet high, to be a "tall building." In addition, they consider any building over 490 feet to be a skyscraper. As of April 2026, there are over 7,500 skyscrapers worldwide. (Skyscraper Center, 2026)

Many organizations, such as the International Building Code (IBC), recognize mass timber as a cost-efficient, environmentally friendly, and sustainable structural material, but engineers are still challenged to use wood as the main structural material in tall buildings. Due to recent changes in the IBC, per IBC 2021, mass timber buildings can potentially be 18 stories or 270 feet tall. (International Code Council, 2021) This is a significant change from the limits established previously in the IBC 2015, in which mass timber elements were permitted as part of Type IV Heavy Timber construction and restricted to a maximum of 6 stories or 85 feet tall. (International Code Council, 2015) These new mass timber regulations have been adopted, either in whole or in part, by 31 American states. (International Code Council, 2024)

Over the past decade, roughly 350 cross-laminated timber (CLT) mass timber buildings have been designed and constructed. (Jeong, G., 2024) For example, the Ascent Tower in Milwaukee, which opened in 2022, takes full advantage of the newly increased IBC 2021 mass timber building height limits. The Ascent Tower utilizes a system of glulam beams and columns that support one-way spanning CLT floors, while two reinforced concrete cores provide lateral stability. (Thornton Tomasetti, 2024) Soon, the Ascent Tower will be overshadowed by a new, taller, mass timber building, consisting of 55 floors by utilizing hybrid systems and engineered performance justifications. (Betts, 2024) New developments by inventive architects and engineers are continuously expanding and pushing the limits of mass timber construction.

Cross-Laminated Timber

Even though traditional wood-frame construction, using relatively small, standardized pieces of lumber, is limited to 6 stories high, attributes of mass timber buildings made from CLT allow for the design of even taller structures. CLT is a wood product made by gluing multiple layers of timber together at right angles, alternating the grain patterns as shown in Figure 1. CLT is much lighter than its primary alternatives, steel and concrete, making mass timber buildings lighter and also less stiff. However, due to its lightweight nature, exposing mass timber to lateral forces has the potential to introduce larger displacements that add risk. For this very reason, advanced discussions of technical concepts and well-designed research studies are imperative.

Figure 1. CLT Wood Product (Mallo, 2014)



(Pending Approval)

In recent years, large bodies of research on CLT's structural performance have been completed. As of 2024, The National Design Specification for Wood Construction has dedicated several chapters to CLT construction. (American Wood Council, 2024)

Comparisons to Alternatives

While the use of mass timber lateral force-resisting systems (LFRS) has been somewhat successful, the industry still relies on steel and concrete in the overall design of mass timber constructions. In North America, about 67% of tall mass timber buildings are considered hybrids, whereas approximately 52% are classified as such in Europe. (Safarik, D., 2022)

It is commonly known in the engineering and construction industries that as the height of a building increases, wind forces greatly increase along with building mass and base shear, and wind or seismic becomes the controlling design load in many scenarios. As stated previously, mass timber buildings are characterized as being lightweight and having low stiffness. These characteristics make them more susceptible to oscillations than other commonly used building materials. Large oscillations could cause deflections significant enough to be a structural hazard.

Skidmore, Owings & Merrill (SOM) is a construction engineering firm that has been developing methods to reduce the carbon impact of buildings. They published the Timber Tower Research Project Report in 2013, which primarily examined options for utilizing mass timber to reduce the embodied carbon footprint of buildings, by comparing mass timber to the benchmark of concrete. During their research, SOM identified three primary issues with a tall building; system strength, system stiffness, and net uplift due to lateral loads. (Skidmore, Owings & Merrill, 2013) The following discussion explores different options for using mass timber as a replacement for traditional materials in high lateral load applications.

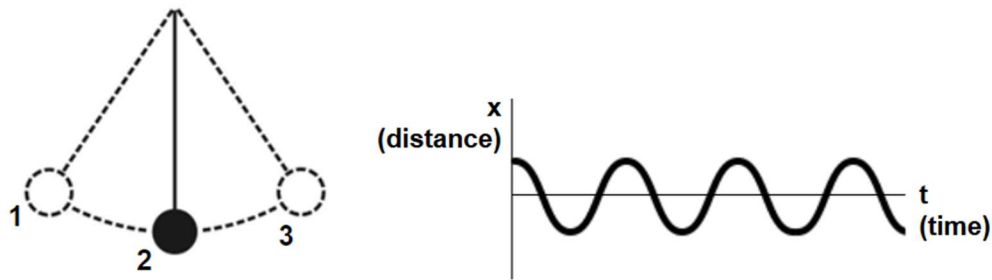
Structural Dynamics Concepts

Relevant structural dynamics concepts that underlie an advanced technical discussion of lateral force-resisting systems in high-rise mass timber buildings are briefly explained as follows.

Frequency

Frequency is the number of waves that pass a fixed point in a given amount of time, with the unit of measure being Hertz (Hz). The time it takes to complete one cycle of oscillation is called the period (T). Figure 2 depicts a basic pendulum system. This system is undamped, and when offset from its resting position, position 2, the pendulum oscillates. The motion of the pendulum is graphed in Figure 2 against time.

Figure 2. Basic Pendulum System



The frequency of a system can be determined using the following equations:

$$f_n = \frac{\omega_n}{2\pi}$$

$$\omega_n = \sqrt{\frac{k}{m}}$$

$$T_n = \frac{1}{f_n} = \frac{2\pi}{\omega_n}$$

Where f_n is the natural frequency (Hz), ω_n is the natural frequency (rad/s), k is the stiffness (N/m), m is the mass (kg), and T_n is the natural period (s).

Damping

Damping is the removal of energy from an oscillating system. The reduction in energy results in a decaying amplitude until the oscillation becomes negligible. The magnitude of damping is characterized by a damping factor, ζ .

$$\zeta = \frac{c}{c_{cr}} = \frac{c}{2m\omega_n}$$

Where c is a damping coefficient, c_{cr} is a critical damping coefficient, m is the mass of the system, and ω_n is the natural frequency of the system.

There are three types of damped systems: underdamped $\zeta < 1$, critically damped $\zeta = 1$, and overdamped $\zeta > 1$. An underdamped system will oscillate, but the amplitude of oscillation will decay over time. A critically damped system will return to an equilibrium position without oscillating. An overdamped system is similar to a critically damped system but returns to equilibrium at a slower rate.

Real structures have many different mechanisms that remove energy and act as dampers; internal material damping, engineered damping devices, even human occupants can act as dampers. The exact natural damping in a structure is hard to determine before the building is constructed.

Several commercial damping systems are routinely employed to minimize vibrations in tall structures. Common examples include tuned mass dampers, tuned liquid column dampers, and viscous fluid dampers. These systems can be modeled using established methods in finite-element structural analysis software, where damping parameters are determined from manufacturer specifications or laboratory testing. These commercial systems provide a well-documented means of reducing the dynamic response of tall buildings.

The first example of a commercial damping system in a high-rise building was utilized in 1969 at the World Trade Center towers. The system included large shock absorbers made of a flexible combination of metal, epoxy, and polyacrylic glue. (Hamburger, R., 2002) The shock absorbers were designed to bend with the wind pressure and then return to their original form. Over 10,000 were installed in each tower, located between the lower chords of the trusses and the gusset plates. They reduced the sway of the tower from 10 feet to approximately 12 inches on windy days (Hamburger, R., 2002).

Damping systems can be divided into two types, active systems and passive systems. An active system will change its properties based on the load at the time. This enables a real-time response and an instant adjustment to changing conditions. A passive system will have a constant response. An active system is more effective, however, it is also more costly, typically 2.5 to 4 times more than equivalent passive systems. The increased cost is typically justified in applications such as tall buildings, for the increased performance. (Sharma, R., 2026) A passive damping system can achieve an additional 3-4% of critical damping, while an active system can provide an additional 10% or more of critical damping. (Koutsoloukas, 2022)

Single Degree of Freedom (SDOF)

When a damped single degree of freedom (SDOF) system is put into motion by an external force, the damping of this system can be determined using the following equation:

$$\zeta = \frac{c}{2\sqrt{k * m}}$$

Where ζ is the viscous damping factor and c is the damping coefficient.

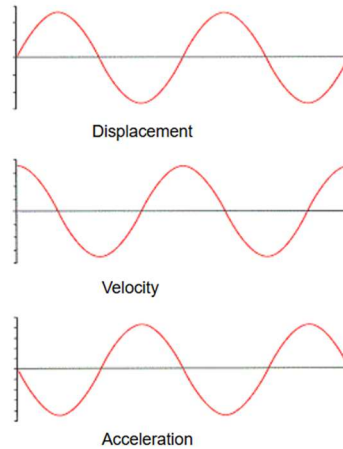
The equation of motion (EOM) of this system is:

$$m\ddot{u} + c\dot{u} + ku = p(t)$$

Where $\ddot{u}$ is the acceleration (m/s²), $\dot{u}$ is velocity (m/s), u is displacement (m), and $p(t)$ is a force dependent on time.

The velocity, $\dot{u}$, is the derivative of the displacement, u . The acceleration $\ddot{u}$, is the derivative of the velocity, $\dot{u}$. Therefore, the displacement, velocity, and acceleration, are all proportional, as shown in Figure 3, with the acceleration always in the direction towards the point of equilibrium.

Figure 3. Displacement, Velocity, and Acceleration of Pendulum

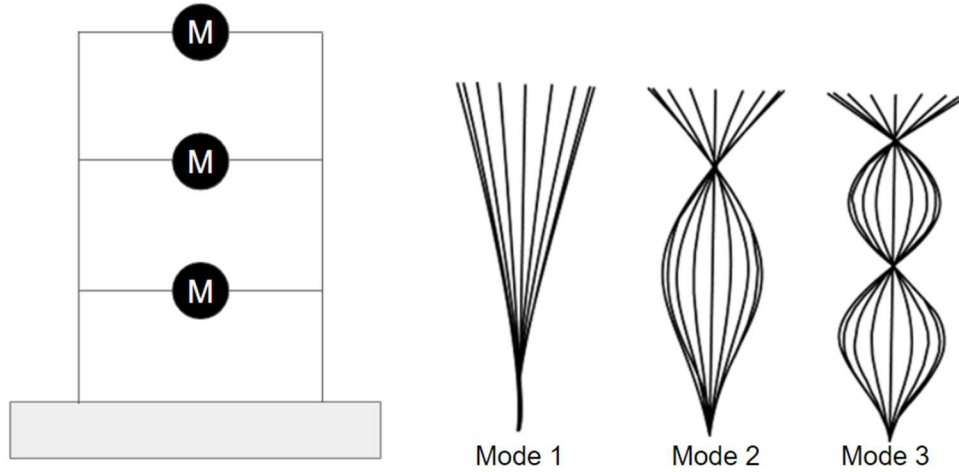


If a system is repeatedly acted upon by a force, for example, wind acting upon a building, it is important that the force and the structure have a different frequency. If the force and structure have the same frequency, known as resonance, this would cause amplified vibrations. Mismatched frequencies prevent small wind forces from causing disproportionately large and potentially damaging or uncomfortable motions. Wind doesn't have a single fixed frequency. Instead, wind is turbulent and contains a broad spectrum of frequencies. A building's own natural frequency is fixed by its mass, stiffness, and damping. Buildings are engineered so their single, or few, natural frequencies sit in low-energy parts of the wind spectrum, with added damping to quickly diminish any resonant motion that does occur.

Multiple Degree of Freedom System (MDOF)

A building is a multiple degree of freedom (MDOF) system, a system with many frequencies. A system that is vibrating with a natural frequency will have a natural mode and natural mode shape, which describes the shape of the system when responding to a force. Each frequency has a unique mode shape. An MDOF system is based on the same formulas as an SDOF system but uses matrices and vectors instead of scalars. The structure in Figure 4 is a three-story building with 3 degrees of freedom. This will result in 3 frequencies and 3 unique mode shapes as shown in Figure 4.

Figure 4. MDOF System and Mode Shapes



Frequencies are lower as the building gets taller. As height increases the structure becomes more flexible, the mass participating in the motion generally increases, and vibrations take longer to travel from the base to the top and back. This results in a longer period and therefore a lower frequency.

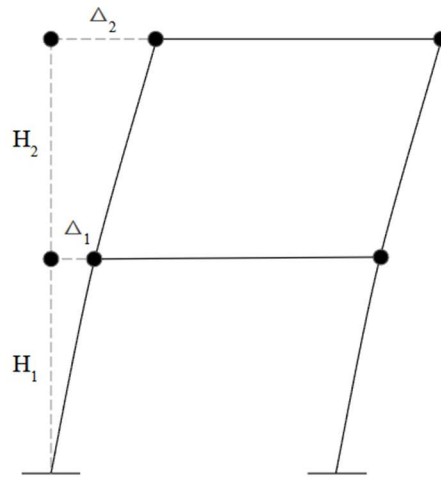
Story Drift

Story drift, as shown in Figure 5, is the lateral displacement of a floor relative to the floor below. The story drift ratio is the story drift divided by the story height.

$$\delta_2 = (\Delta_2 - \Delta_1)/H_2$$

Where δ is the story drift as a ratio, Δ_2 is deflection from 2nd floor to the base (m), Δ_1 is deflection from 1st floor to the base (m), H_2 is the 2nd story height (m), H_1 is the 1st story height.

Figure 5. Story Drift



Seismic loading codes impose limits on story drift as a percentage of the story height. The story drift ratio is a useful measurement that can be directly compared with the code requirements. Per ASCE 7-22, for a risk category I or II mass timber building, the allowable story drift is 2.0% of the story height. This allowance depends on building height or the number of floors.

The structural design concepts explained above form the foundation for the more advanced discussions of lateral force-resisting systems in high-rise mass timber buildings and are the underpinnings of the technical research that will be discussed next.

Existing Research

Several experiments have been conducted to determine the properties of mass timber where lateral force-resisting systems were employed. Research has focused on rocking walls with shaker tables to simulate loads experienced during seismic events. Uplift force, rocking walls, and shaker tables are explained below, and then highlights of research studies follow.

Uplift Force

During an earthquake, some columns in a building will be put under compression, while some columns will experience an uplift force and be put under tension. Timber is known to be elastic-plastic in compression and elastic-brittle in tension. Tensile failure in timber usually occurs where defects like knots exist. This is a disadvantage for natural-sawn lumber, as defects and knots are common, and the weakest point of a structural member governs the entire timber member. However, because mass timber is an engineered wood product, it significantly reduces the natural variability in strength, stiffness, and stability that is common in solid sawn timber. Mass timber reduces material defects through grading and laminations.

The parallel-to-grain direction is the strongest and stiffest for a mass timber member. CLT is typically designed with an odd number of layers and the outer layers oriented in the strongest direction for the intended use, for example, vertical for walls and spanning direction for floors. The alternating grain pattern improves stability, provides two-way bending and in-plane strength, and enhances resistance to splitting. In pure axial tension, engineers calculate effective net area using only the layers with grain parallel to the tension force. Cross layers contribute minimally and are typically neglected for conservative design. (WoodWorks, n.d.)

The tensile strength of softwoods, commonly pine or spruce, in the parallel-to-grain direction at 12% moisture content, is between 70 to 140 Megapascals (MPa). (Harte, A., 2001) In comparison, concrete typically has a tensile strength of 2 to 5 MPa. (Designing Buildings, 2022) It is possible that during an earthquake, mass timber columns that undergo uplift forces will have adequate tensile capacity, without the need for additional reinforcement, like rebar in concrete.

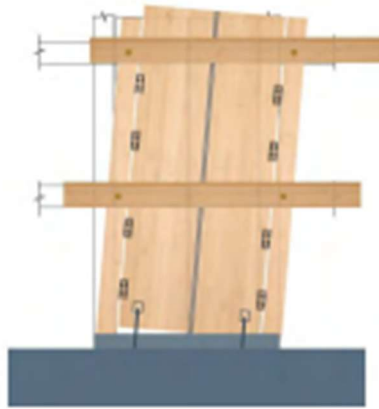
In 2022, a study at Graz University of Technology investigated tensile properties of CLT made from Norway spruce, with emphasis on tension out-of-plane (perpendicular-to-grain). Researchers tested board segments, glulam, and CLT varying the number of layers, layer orientation, and elements per layer. The cross-laminated structure of CLT resulted in 50–70% higher out-of-plane tensile properties compared to glulam, due to better stress distribution and a reinforcing effect from the crossed layers restricting transversal deformation. This study suggests regulating CLT out-of-plane tensile properties as ~30% higher than glulam for design purposes. It also discusses influencing factors like the number of layers and density matching. (Reinhard B., 2022)

Rocking Walls

Researchers have found a new lateral force-resisting system that utilizes mass timber, called a mass timber rocking wall, to be successful in providing needed stability during seismic testing. A rocking wall, as shown in Figure 6, acts as a basic pendulum system with damping. When a force pushes on the rocking wall, the wall will have a propensity to rock back and forth. Damping reduces oscillation amplitude over time. In most structures, oscillations decay rather than disappear immediately. While rocking walls can be used across a range of heights, they are primarily adopted in tall mass timber buildings, where increased lateral forces make their self-centering and low-damage performance particularly advantageous. They are less common in short buildings due to simpler, more economical, conventional CLT shear walls sufficing there. Rocking walls are frequently aligned along the building's outer edges or placed alongside stairwells and elevator shafts for practical reasons, like concealing the system or coordinating with egress requirements, while still providing effective lateral resistance. Notable efforts in

research and development have been invested in mass timber rocking walls to gain a better understanding of their behavior and limitations.

Figure 6. Basic Rocking Wall (Woodworks, 2023)



(Pending Approval)

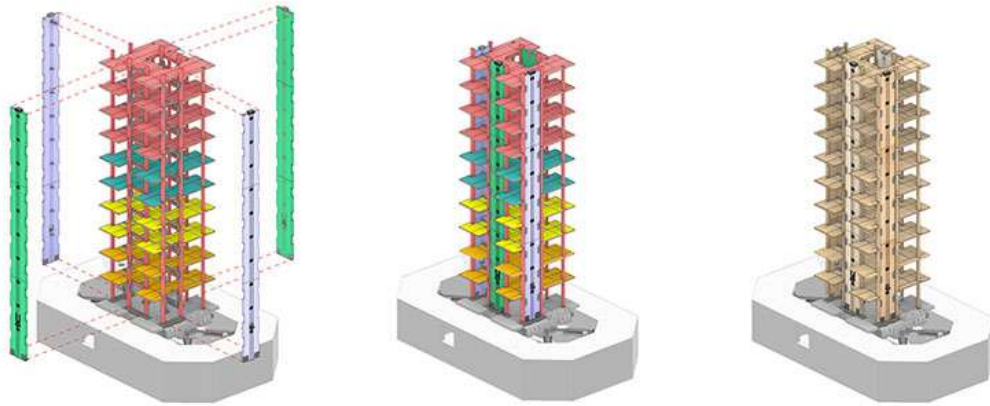
Use of Shaker Tables

One method of testing systems and materials against earthquakes is a shaker test on a shaker table. Shaker testing is often used in complex structures to test the structure's ability to withstand lateral forces. The structure is set into motion by shaking it. While the structure is shaking, the system's damping ability can be observed.

10-Story Test - University of California, San Diego

In 2023, the University of California San Diego tested a 10-story, 112-foot tall, fully mass timber building on the world's largest outdoor shaker table, which simulated seismic activity. The building's attributes allowed for the testing of a variety of timber floor options, cross-laminated timber, glue laminated timber, dowel laminated timber, and veneer laminated timber, as seen in Figure 7. These floor systems primarily resist gravitational loads. (Post, N., 2023)

Figure 7. 10-Story Test Setup (Woodworks, 2023)



(Pending Approval)

For resistance to lateral loads, the building had four mass timber rocking walls, one on each side. (Post, N., 2023)

The overarching goal of this project was to validate the capacity of mass timber as a viable material in the construction of buildings and its potential to replace steel and concrete. This is significant, as nearly every tall wood project currently built in the United States incorporates steel and concrete for its core. Researchers concluded that an all-timber lateral system with mass timber rocking walls can be incorporated into the construction of mass timber buildings and be successful in withstanding seismic events. (Post, N., 2023)

The rocking walls used in the 10-story test each had two high-strength threaded bars that ran the full height of the walls. These bars functioned to pre-compress the timber panels. At the bottom of the walls, the bars anchored into the foundation, and at the top of the wall, the rods attached to a steel assembly, which then transferred the loads from the rods into the timber wall panels. (Post, N., 2023)

Figure 8. Rocking Wall (Post, 2023)



(Pending Approval)

When experiencing lateral forces, the rocking walls will have a propensity to move back and forth. The heel end will lift off the ground, and the toe end will compress into the ground. The post-tension rods will help control the wall and bring it back to the center.

The first test simulated a 6.7 magnitude earthquake, similar to the 1994 Northridge earthquake. The second test simulated a 7.7 magnitude earthquake, similar to the 1999 Taiwan earthquake. As expected, the building did not incur any damage during either test. This series of tests demonstrated that a tall mass timber lateral force-resisting system can withstand multiple high seismic events. (Post, N., 2023)

Story Drift Test - University of Canterbury

At the University of Canterbury, a cyclic test was performed. During this testing, beam-to-column connections, column-to-foundation connections, and wall-to-foundation connections were tested under lateral loading. The horizontal load was applied to the top of the tested

specimens, and a constant 120kN axial load was applied to simulate gravitational loads. The results demonstrate the beam-to-column response in terms of lateral force versus inter-story drift. Due to the compression strength perpendicular to the laminated veneer lumber (LVL) grain, the mass timber column was able to reach 2.75% story drift without damage, and no apparent stiffness degradation was observed. (Pampanin, M., et al., n.d.)

The IBC pulls its primary story drift requirements for seismic design directly from ASCE 7. Per ASCE 7-22, for risk category I and II, the story drift shall not exceed 0.020 times, or 2.0%, of the story height. (ASCE, 2022) A mass timber column capable of reaching 2.75% story drift with negligible damage demonstrates substantial deformation capacity beyond typical ASCE 7 prescriptive drift limits. This provides confidence in both serviceability and life-safety performance, even though the code drift limits serve as simplified proxies rather than absolute failure thresholds.

In all cases, researchers felt the tested systems could guarantee high levels of ductility, negligible residual deformations, and no significant damage to the structural elements. Furthermore, researchers proposed that after an earthquake, for buildings with these new structural systems, a significant reduction in repair and downtime costs can be expected as compared to the costs of traditional systems in similar circumstances. These results were very promising in support of being able to use mass timber lateral force-resisting systems in construction. (Pampanin, M., et al., n.d.)

U-Shaped Flexural Plates - University of Northern British Columbia

In 2016, researchers at the University of Northern British Columbia extended the research from the University of Canterbury, by introducing coupled mass timber walls, as shown in Figure 9, with U-shaped flexural plates (UFPs), as depicted in Figure 10. UFPs are an essential part of a timber rocking wall system. Experimental tests were conducted to study the force versus displacement behaviors for a single UFP and two UFPs installed in parallel. In their

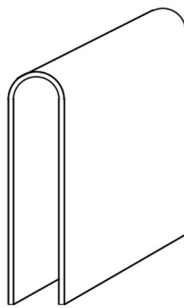
static and dynamic tests, LVL walls were connected with UFPs. The UFPs were tested at different sizes and different arrangements. A total of six LVL walls were tested, with and without UFPs. (Iqbal, A., et al., 2015)

Figure 9. Coupled LVL Walls (Iqbal et al., 2015)



(Pending Approval)

Figure 10. U-Shaped Flexural Plate



Using the results from the tests, numerical models were created: a lumped plasticity model and a multi-spring model. Both the numerical models and the test results demonstrated the feasibility of post-tensioned timber walls utilizing UFP dampers. The UFPs added significant

energy dissipation as well as excellent re-centering to the LVL walls. Different geometrical configurations performed well, highlighting the design flexibility of UFPs. Virtually no damage was observed in the structural members after many cycles of seismic loading, which indicates that a structure with this type of system will also have significant economic advantages in a post-earthquake scenario. During testing, it was noted that the behavior of UFPs in mass timber walls is very stable and predictable, despite UFPs being inexpensive to manufacture. (Iqbal, A., et al., 2015)

Rocking LVL Walls - University of Northern British Columbia

The University of Northern British Columbia conducted another project on coupled LVL rocking walls. A coupled wall, can reduce the amount of torque and resistance required by individual walls by distributing seismic energy throughout the height of the wall. Coupled walls have a greater lateral stiffness than the sum of their individual wall piers, which allows for a smaller footprint for the lateral force-resisting system. In this project, the LVL rocking wall was part of a 2-story all-timber building and subjected to seismic loading. (Iqbal, A., et al., 2016)

This research concluded that rocking LVL walls are sufficient in both strength and energy dissipation. Virtually no damage was observed in the structural members after several cycles of simulated seismic loading. The controlled rocking mechanism, combined with PT rods, prevented the development of a full traditional plastic hinge in the timber. Any compression at the toe did not lead to visible or performance-impairing damage. The primary damage was confined to the connections, which acted as energy dissipators. (Iqbal, A., et al., 2016)

Damping - Norwegian University of Science and Technology

The Norwegian University of Science and Technology conducted a study that focused on the evaluation of material damping in timber beam specimens. Damping evaluations were performed on 11 solid wood beams and 11 solid glulam beams. These evaluations included

testing the beams at different spans and different orientations. A total of 420 damping evaluations were performed. Only 14 evaluations were found to be inconsistent and were subsequently discarded. (Labonnote, N., 2013)

The research found that the damping ratio increases with a high number of modes, shorter spans, and an edgewise orientation. In particular, the damping ratio seems greatly dependent on the number of modes. This suggests that the more floors a mass timber column supports, the more damping that beam could potentially provide. (Labonnote, N., 2013)

Seismic Base Shear Comparison

In 2025, a Turkish research team compared the seismic performance of a 7-story mass timber building, utilizing CLT shear walls running from the foundation to the roof, and an identical 7-story reinforced concrete (RC) building, utilizing RC shear walls running from the foundation to the roof. This study evaluated the feasibility of using a mass-timber structural system as an alternative to conventional RC construction for buildings in Turkey, a high seismic region. (Mutlu, E., et al., 2025)

The RC building had a seismic mass of roughly 6680 kips, while the equivalent CLT building had a seismic mass of roughly 2436 kips, approximately 64% lighter. Due to the much lower mass and a longer fundamental period, placing it on a more favorable part of the response spectrum, the CLT building's base shear was approximately one-third that of the RC building in both directions. This directly results in lower demands on the lateral system and significantly smaller foundation forces. Researchers noted that although the CLT structure experienced larger lateral drifts, these remained within serviceable limits. Overall, researchers concluded from their results that mass-timber is a structurally viable and environmentally advantageous option for post-earthquake reconstruction of buildings. (Mutlu, E., et al., 2025)

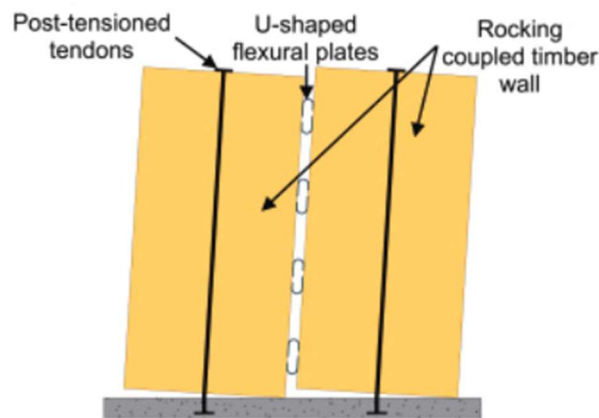
Structural Connections

Structural connections are critical to a system's performance. The following section highlights structural connections related to the rocking walls used in the mass timber applications being studied.

It is critical for a rocking wall to be able to return to its plumb position. The ability of a rocking wall to return to its plumb position, perfectly vertical, depends on its self-centering abilities.

Rocking wall systems can have either pure rocking or controlled rocking behavior. In a pure rocking system, the structure relies on its weight to recenter the wall. In a controlled rocking system, recentering is achieved using post-tensioned (PT) rods. These systems can be equipped with steel plates and different energy dissipation devices, such as the U-shaped flexural plates (UFPs), as depicted in Figure 11. UFPs contain a steel component that will absorb damage, compressing and deforming to absorb excess force, and are particularly beneficial as these elements can easily be replaced should the need arise. (Froozanfar, M., et al., 2024)

Figure 11. Rocking Wall System with Post-Tensioned Rods (Froozanfar, M., et al., 2024)



(Pending Approval)

Post-Tension Rods

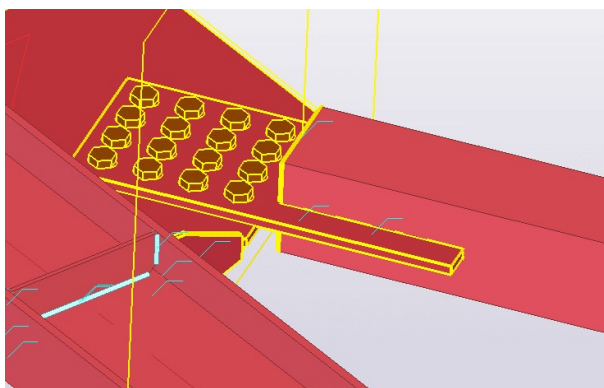
In mass timber buildings, post-tension rods, also known as post-tension tendons, are used to secure the walls to the foundation with tension, providing a recentering behavior. These PT rods are usually prestressed to half their ultimate strength, generating sufficient resistance against uplift while allowing adequate straining capacity to remain elastic during rocking. (Froozanfar, M., et al., 2024)

The PT rods are installed in ducts next to the rebar. The concrete foundation is then poured and hardened, and the rods are tensioned using hydraulic jacks that pull them tight, applying stress to the rods. (FMP Construction, 2024)

Steel Plates

The floor-to-rocking wall connection is also important. This connection is usually made with a steel plate that cantilevers into a rectangular steel pocket, as shown in Figure 12, lined with polytetrafluoroethylene, a plastic. The connection allows horizontal forces to transfer while not causing damage to the floor system. The wall panel can uplift and tilt freely about the steel plate while the floor remains connected to the wall and undamaged. (FMP Construction, 2024)

Figure 12. Steel Plate Connection (FMP Construction, 2024)

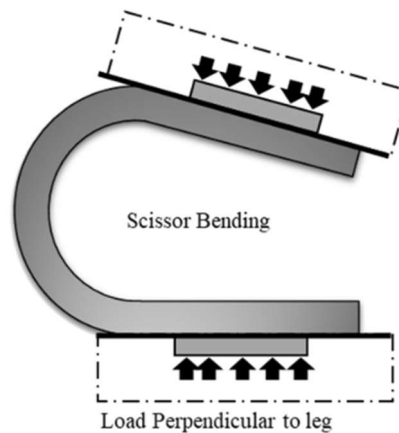


(Pending Approval)

Energy Dissipation Devices

Energy dissipation devices, such as UFPs or buckling-restrained braces, can attach the rocking wall to two columns, one on each side of the rocking wall. UFPs, as shown in Figure 13, are designed to bend as the wall tilts and prevent the rocking wall from bumping into the columns, while absorbing the seismic input energy during the rocking motion. (Busch, A., et al., 2021) These energy dissipation devices can be fastened to the mass timber wall and column. One leg of the U-shape is screwed to the edge of the wall and the other leg of the U-shape is screwed, bolted, or welded to the adjacent column depending on the column's material. (Mowafy A., et al., 2024)

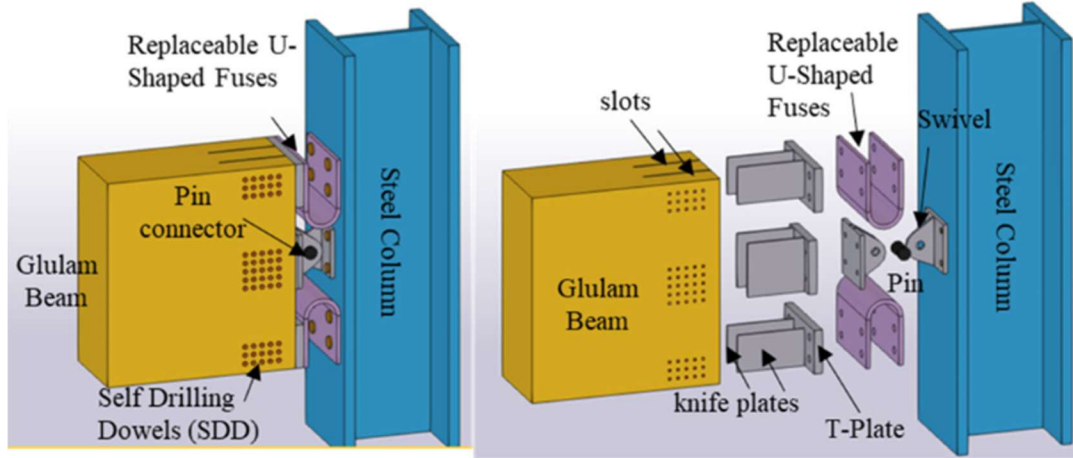
Figure 13. U-Shaped Flexural Plate Bending (Mowafy A., et al., 2024)



(Pending Approval)

This connection can be enhanced by combining UFPs with embedded knife plates. The embedded knife plates are designed to carry the yielding capacity of the fuse, which forces failure in the fuses, reducing the possibility of brittle failure in the wood. An example of this connection is shown in Figure 14. (Mowafy A., et al., 2024)

Figure 14. Example Connection Using Knife Plates (Mowafy A., et al., 2024)



(Pending Approval)

Structural connections such as those described above highlight not only their availability for incorporation into design, but also their contribution and criticality to realizing the benefits of rocking walls when used in mass timber applications.

Environmental Impact and Additional Benefits

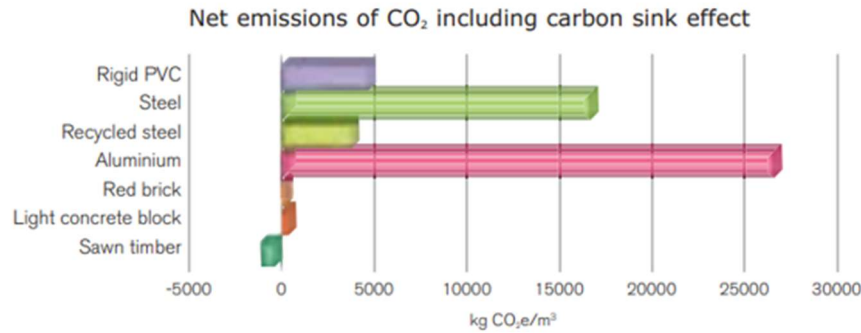
While mass timber is well-positioned to be a reliable lateral force-resisting system for its structural capacities, highlighting benefits related to CO₂ emissions, climate conditions, and fire safety is important. These, too, are considerations when selecting materials.

CO₂ Absorption

A discussion of mass timber's importance in any construction project would not be complete without addressing its environmental impact. Many sources identify mass timber's emission of CO₂ during fabrication as far less than the emissions for other more common materials. Life-cycle assessments from many studies break down the different stages, such as harvesting, fabrication, transport, and erection, plus the totals. The short answer in these studies: mass timber still comes out more positive overall, often reporting 15–50% or more in embodied carbon when compared to that of steel or concrete.

Figure 15 represents the Net CO₂ emissions of various materials during fabrication. Mass timber's net CO₂ emissions during fabrication are greater than those of sawn timber but substantially less than the CO₂ emissions of other materials. The net CO₂ emission for CLT during fabrication is believed to be 88 kg CO₂e/m³, whereas the comparable measure for concrete is 259 kg CO₂e/m³, and the comparable measure for rebar is 3,563 kg CO₂e/m³. (Oh, J., et al., 2022)

Figure 15. Net CO₂ Emissions During Fabrication (Singh, 2020)



(Pending Approval)

A 2020 research study from Aalto University highlights that wood stores carbon rather than emitting it. By definition, wood comes from trees, which absorb CO₂ from the atmosphere as they grow. Aalto's research concluded that if 80% of new buildings in Europe had structural components made of wood, this could remove 55 million metric tons of carbon dioxide per year, an estimate that is equivalent to 47% of the European cement industry's annual CO₂ emissions. Additionally, if for any reason a wooden building is no longer needed, it is easier to disassemble than a concrete building, and the wood can be reused or recycled, further extending its life cycle. (Amiri, A., et al., 2020)

As the use of mass timber in construction is experiencing rapid growth, this surge is in part driven by an elevated interest in eco-friendly building materials that have demonstrated performance capabilities, and mounting requirements to minimize emitted carbon in upcoming projects. There are a number of advantages from a commercial perspective. Incorporating mass timber is not only beneficial in meeting evolving building codes and carbon-related standards, it aligns with company-wide environmental commitments, and highlights developments as progressive and environmentally responsible.

The construction sector is pervasive in efforts to preserve the global environment, specifically, as it relates to CO₂ emissions. Its sheer size in this socio-political dilemma points to

its influence and prompts a search for alternatives. Cement manufacturing ranks amongst the largest sources of global anthropogenic CO₂ emissions, contributing approximately 8% of total CO₂ emissions worldwide. (Purton, M., 2024) As previously noted, the net CO₂ emission for CLT is reported to be 66 percent lower than that of concrete. (Oh, J., et al., 2022)

Climate Conditions During Construction

Think Wood claims that mass timber buildings are roughly 25% faster to construct than concrete buildings and require 90% less construction traffic. (Think Wood, 2025) Concrete projects involve frequent deliveries of ready-mix trucks for pours, aggregates, formwork materials, and waste removal, leading to high traffic in terms of vehicle congestion around the site. Mass timber's prefabricated nature of floors, walls, beams, and columns drastically reduces the number of truck deliveries and on-site vehicle movements. The time saved becomes especially crucial during tougher weather patterns.

Mass timber can be installed in a broad range of climate conditions. For example, on the outskirts of Sweden's capital, the construction of "Stockholm Wood City" is taking place. This city will be made entirely from timber and is set to provide 2,000 new homes by 2027. (Savage, M., 2025) In this colossal undertaking, construction staff have increased flexibility, maneuvering giant chunks of wood, working in sub-zero winter temperatures. Being able to work on a construction project year-round delivers economic advantages: fewer weather-related idle days reduces labor expenses, prefabrication reduces on-site labor needs, and there is less time spent managing winter-specific protections, which would be a necessity if using cast-in place concrete or field welding steel connections.

Fire Safety

Another crucial consideration for architects and engineers is fire safety. Mass timber has predictable charring rates when exposed to fire. This predictability is one of its advantages, allowing engineers to calculate residual cross-sections and maintain load-carrying capacity for a specified duration. Mass timber achieves fire resistance primarily through predictable section loss via controlled charring. It chars on the outside at around 600° F, creating a protective barrier that limits the spread of flames. (Breneman S., 2026)

Five separate tests of mass timber structures were conducted by the National Research Council of Canada in the summer of 2022. Experiments, such as the one shown in Figure 16, were conducted within a full-scale, two story, 3,595 square foot mass timber structure at the Canadian Explosives Research Laboratory in Ottawa. The findings demonstrated that in severe fire conditions, without sprinklers and exposed structural mass timber, the test structure remained stable after enduring five different fire tests of varying severity and duration, with an overall total of 19 hours of fire exposure. (Cameron, G., 2024)

Figure 16. Mass Timber Fire Safety Test (Cameron G., 2024)



(Pending Approval)

Discussion

Mass timber can serve as an effective lateral force-resisting system (LFRS). However, its behavior differs significantly from that of traditional steel and concrete systems. These differences influence system selection and require engineers to carefully evaluate project-specific requirements when choosing the most suitable solution.

Stiffness, Ductility, and Energy Dissipation

Mass timber LFRSs differ fundamentally from traditional steel and reinforced concrete systems in stiffness, ductility, and energy dissipation mechanisms.

Mass Timber LFRSs are generally less stiff than alternative steel or concrete systems. This is primarily due to a lower material modulus of elasticity. In a mass timber LFRS, CLT panels themselves have high in-plane stiffness, while the lower system stiffness is often governed by its rocking and uplift behavior. In contrast, steel systems have high stiffness with relatively low weight. In a steel system, moment frames and braced frames offer high lateral stiffness. Typically, reinforced concrete systems have the highest stiffness. This is especially relevant in shear walls. The high material modulus of concrete and its monolithic behavior results in the smallest drifts for a given load but also add significantly greater mass. Overall, mass timber's lower stiffness and lower mass often reduce seismic base shear although especially in tall buildings, its use requires additional elements within the system to control drifts.

The ductility in a mass timber LFRS comes almost entirely from engineered components. Rocking wall systems utilizing CLT and PT rods greatly increase ductility in the system because rocking can be a controlled kinematic mechanism rather than the result of a material in the system intrinsically yielding. Steel is a highly ductile material that yields and undergoes large plastic deformations before fracture. The ductility of reinforced concrete is engineered through proper rebar usage to allow controlled yielding and plastic deformations. It's important to

highlight that in a mass timber LFRS ductility is connection dependent. Ductility has the potential to be high in a mass timber LFRS with proper rocking wall design and connection selections.

Systems have different energy dissipation mechanisms. In a mass timber LFRS, energy dissipation is concentrated in added devices rather than in the timber members. In rocking wall systems, replaceable U-shaped flexural plates are used. These dissipate energy while post-tensioned (PT) rods provide self-centering. With steel, the energy dissipation mechanism is primarily through the yielding of steel elements. With reinforced concrete, the energy dissipation mechanism is primarily through the yielding of reinforcements and the crushing of concrete. Mass timber systems often achieve low-damage and resilient performance with minimal residual drift and replaceable energy-dissipating elements. This contrasts with traditional systems, where energy dissipation typically damages the primary structural members. Rocking mass timber walls can isolate damage to U-shaped flexural plates while the timber remains intact.

Mass timber rocking walls emphasize resilience and repairability, leveraging the material's light weight characteristics while shifting ductility and dissipation to engineered, replaceable components. Traditional steel and concrete systems rely more on material plasticity in the primary elements.

Fabrication and Low-Damage Performance

Mass timber rocking wall systems with vertical post-tensioning rods and replaceable energy-dissipating devices can be selected over braced frames or moment frames when the project emphasizes resilience, low-damage performance, and prefabrication speed.

Mass timber rocking wall systems may be chosen in high seismic zones where a project needs critical focus on resilience and recovery. Rocking walls are specifically designed to

achieve low-damage performance. They can experience high story drift and self-centering after an event. Energy dissipation is concentrated in replaceable components, such as U-shaped flexural plates, protecting the CLT panels from damage. This contrasts with braced frames and moment frames, where brace yielding can cause permanent deformations, damaging the primary structural members. Mass timber rocking systems can reduce post-earthquake repair costs and downtime.

Mass timber LFRSs may be selected when speed is important. Mass timber can offer fast, prefabricated construction with year-round erection capability. Large CLT panels arrive pre-cut with factory-installed connectors. Mass timber buildings are potentially 25% faster to construct than concrete buildings. (Think Wood, 2025) This provides schedule and cost advantages over braced frames and moment braces which can require extensive field bolting and welding. In addition, the lighter weight of mass timber reduces seismic inertial force base shear and allows engineers to utilize smaller foundation sizes. Steel and concrete buildings are typically heavier, generating larger base shear. Smaller base shear and overall gravity loads mean reduced overturning moments at the base and lower vertical loads. Smaller foundation elements can increase the speed of construction.

There are tradeoffs associated with selecting mass timber for a shear wall. Some tradeoffs include potentially lower absolute stiffness than braced frames or moment frames, reliance on high-quality components and PT systems, and risk associated with limited full prescriptive codification in current ASCE 7 and IBC. Additionally, initial material costs may be higher.

Internal and External Energy Dissipation

Seismic energy dissipation in mass timber systems is achieved almost entirely through engineered connections and supplemental devices, not through plastic deformation of the timber members themselves. This is a significant fundamental difference between mass timber LFRS

and traditional steel or reinforced-concrete systems. Energy dissipation is provided by replaceable U-shaped flexural plates, which are made from steel. The movement forces the curved portion of the U to bend. Energy is resisted during the bending motion as the steel in the curved region yields in bending and undergoes large plastic strains without fracturing. Vertical PT rods run through the walls and provide a self-centering force. The PT rods pull the wall back to plumb. Notably, the timber wall itself contributes very little to the energy dissipation, allowing it to remain undamaged.

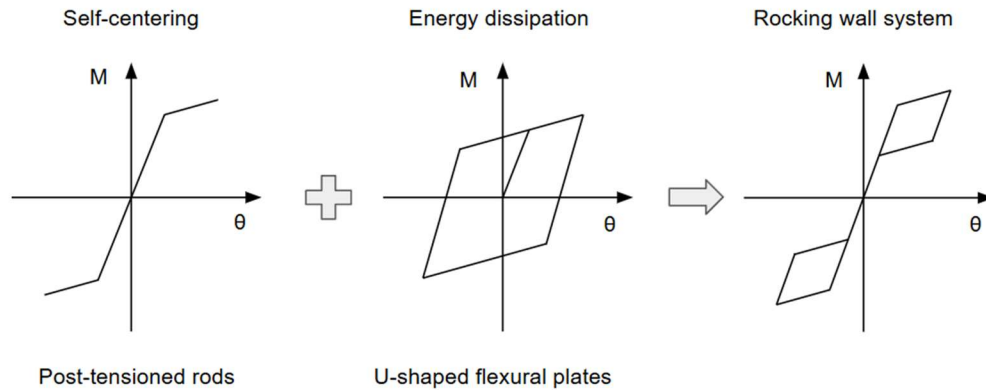
Influence of Uplift and Gap Opening

The uplift and gap opening at the base of a mass timber rocking wall fundamentally alter the system's seismic behavior compared to a conventional fixed-base shear wall. In a fixed-base wall, the base connection is rigid or semi-rigid with hold-downs and shear brackets, so lateral deformation is accommodated through shear and flexural distortion of the panel plus yielding in the connections and wood embedment. In contrast, rocking walls are designed to decompress and uplift at the heel once the overturning moment exceeds the initial PT compression. This controlled gap opening concentrates rotation at the base toe, with the PT bars elongating elastically to provide recentering.

Prior to decompression, the rocking wall exhibits an initial lateral stiffness comparable to that of an equivalent fixed-base wall. The initial PT force maintains full compression across the base, allowing the timber panel to engage its full axial, flexural, and shear stiffness. Once the decompression point is exceeded and gap opening begins at the heel, the effective stiffness drops significantly. The wall then behaves primarily in a rocking mode, with the rotational stiffness governed mainly by the axial stiffness of the PT rods rather than the flexural and shear stiffness of the timber wall itself.

When idealizing the lateral force–deformation response analytically or in numerical models, the appropriate choice is flag-shaped hysteresis as seen in Figure 17. This is the standard representation used in research and design for hybrid self-centering rocking systems.

Figure 17. Flag Shaped Hysteresis



The energy dissipators, UFPs, yield plastically, producing the horizontal portion of the flag-shaped hysteresis loop, while the PT rods stretch elastically. As the lateral force decreases during unloading, the PT rods begin to contract elastically. The yielded UFPs provide a much lower resisting force on the return path. The PT force at maximum drift is deliberately designed to be greater than the resisting force of the dissipators. This superposition of mechanisms produces the flag-shape hysteresis, enabling significant energy dissipation with minimal damage to the rocking wall and negligible residual drift.

Design of Connectors

In the mass timber rocking walls researched, traditional nailed or screwed hold-downs were generally not used. Instead, PT rods provide the primary clamping force, decompression

resistance, and self-centering restoring moment, while UFPs acted as “hold-down” elements by resisting uplift tension and providing energy dissipation. Connectors of this type are designed to engage during rocking and are replaceable post-event. (Iqbal, A., et al., 2015)

The lateral force–deformation response is idealized as flag-shaped hysteresis. Imbalance directly alters loop shape and performance. If PT forces are too large, with the tension too high, the system may have sufficient self-centering capabilities but inadequate energy dissipation. If PT forces are too small, with the tension too low, the system may have sufficient energy dissipation but inadequate self-centering.

A team of researchers working with the Wood Innovation Grant created prescriptive design procedures to aid in the design of mass timber rocking walls. (Busch, A., et al., 2021) These procedures are provided in the following paragraphs.

The maximum rotation of the rocking wall, $\theta_{maximum}$, can be represented by the following equation:

$$\theta_{maximum} = \frac{1.5 * C_1 * \delta_x - \delta_{xe,y}}{h_w}$$

Where C_1 is the inelastic displacement amplification factor taken in accordance with ASCE 41-14 Eq. 7.4.1.3.1, δ_x is the deflection at the top of the wall taken from a linear drift analysis, $\delta_{xe,y}$ is the deflection at the top of the wall when subjected to the floor forces that produce the base shear, and h_w is the height of the wall. (Busch, A., et al., 2021)

To ensure the PT rods provide a re-centering behavior the following equation was developed. This ensures that the rocking wall returns nearly to plumb after a seismic event:

$$\sum_{j=1}^n [(F_{pti,j} + F_{grav,j}) * \frac{l_{w,j}}{2}] \geq \sum_{j=1}^n [F_{edu,wh,j} * l_{w,j}]$$

Where $F_{pti,j}$ is force due to the elongation of the PT elements, $F_{grav,j}$ is the force due to the self-weight of the wall and any gravity loads, $l_{w,j}$ is the width of the wall panel, and $F_{edu,wh,j}$ is the force in the energy dissipation devices. (Busch, A., et al., 2021)

The moment capacity of the energy dissipation devices needs to be checked to ensure sufficient damping and adequate energy dissipation without making the flag-shaped response too narrow. This is represented in the following equation:

$$\sum_{j=1}^n M_{ed,rm,j} \geq \frac{1}{4} * \sum_{j=1}^n M_{n,rm,j}$$

Where $M_{ed,rm,j}$ is the overturning moment capacity contributed by the energy dissipation connectors, and $M_{n,rm,j}$ is the restoring moment from the PT rods and gravity. $\frac{1}{4}$ was determined to be the minimum ratio preventing the PT force from dominating too much, which would potentially result in larger drifts. (Busch, A., et al., 2021)

LVL and CLT Behavior

In coupled rocking wall systems, two or more vertical wall segments rock at the base while being linked horizontally by coupling elements. These coupling elements transfer forces, add stiffness, and often provide energy dissipation. The walls themselves can be made of Laminated Veneer Lumber (LVL) or Cross-Laminated Timber (CLT).

LVL consists of veneers laminated with grain predominantly parallel to the member length. This gives LVL exceptionally high in-plane bending and axial stiffness, as well as high compressive strength parallel to grain. In rocking walls, LVL panels behave more like a homogeneous element with minimal contribution from perpendicular-to-grain properties. The overall lateral stiffness of an LVL rocking system is generally higher compared to CLT due to the material's uniformity.

LVL is highly anisotropic. Strength and stiffness are excellent in the parallel to grain direction, along the wall height in a vertical panel, but very low perpendicular to grain. CLT is less anisotropic overall due to the cross-layered construction. In rocking wall systems, the wall panel itself primarily experiences combined axial and bending stresses. Most deformation and energy dissipation come from the connections. LVL is very strong axially but has low perpendicular-to-grain properties. A properly oriented LVL rocking wall will have the panel installed with the parallel-to-grain direction vertical. To achieve the same moment-rotation behavior as an LVL wall, CLT panels typically need to be 20% wider. (Pilon, S., et al., 2019)

In coupled rocking designs, both LVL and CLT materials use similar connection strategies. They utilize PT for recentering and steel energy dissipators, although CLT might need slightly larger elements to achieve equivalent energy dissipation and flag-shaped hysteresis because of its lower panel stiffness. Full-scale tests have been performed on both materials, showing a ductile, low-damage response when capacity design is followed. (Iqbal, A., et al., 2016; Post, N., 2023) CLT systems emphasize rocking dominated by connections, while LVL systems can engage more panel flexural contribution.

Rocking Wall Elements - Summary of Key Characteristics

Table 1 summarizes key characteristics of rocking wall elements. This comparison highlights the performance differences, providing a clear reference for understanding their strengths in lateral force-resisting.

Table 1. Summary of Key Characteristics

	CLT Rocking Walls	LVL Rocking Walls	Coupled Walls	U-shaped Flexural Plates	PT Rods
Primary Mechanism	Cross-layers reduce in-plane stiffness.	High parallel-to-grain stiffness.	Coupled rocking of multiple walls, relative movement between walls activates coupling devices.	Flexural yielding in the steel, acts as a ductile fuse.	Elastic axial elongation of high-strength steel rods provides clamping force and restoring moment through recentering.
Stiffness	Moderate initial stiffness, lower effective in-plane flexural/shear stiffness due to transverse layers.	High initial stiffness, excellent parallel-to-grain modulus and strength.	Higher effective system stiffness than single rocking walls due to coupling.	Moderate stiffness improvement. Depends on geometry, thickness, width, and bend radius.	High axial stiffness, contributes to pre-uplift system stiffness and provides post-uplift restoring stiffness.
Peak Drift	Moderate drift due to rocking accommodating large rotations with low damage to timber.	Higher drift than CLT due to consistent parallel-to-grain direction.	Comparable or slightly lower peak drifts than single rocking walls.	Enables larger system peak drifts.	Enables larger system peak drifts.
Residual Drift	Low, however, can be costly to replace. Proper use of components is recommended.	Low, however, can be costly to replace. Proper use of components is recommended.	Low, coupling helps distribute demands evenly.	Low residual drift, can easily and affordably be replaced.	Excellent self-centering capability, primary driver of low residual drift.

Table 1. Summary of Key Characteristics Continued

	CLT Rocking Walls	LVL Rocking Walls	Coupled Walls	U-shaped Flexural Plates	PT Rods
Energy Dissipation	Low without dissipators.	Low without dissipators.	Increases possible dissipation, allows for dissipators to be placed between walls.	Excellent dissipation.	Negligible dissipation.
Damage Location	Crushing at base toe.	Crushing at base toe.	Crushing at base toe.	Concentrated in steel, easily replaced, timber stays protected.	Minimal to none in the rods themselves, any damage is at anchoring.
Construct-ability	Large, prefabricated panels reduce on-site labor.	Precise factory-finished elements, straightforward erection.	More challenging, coordination of multiple walls and coupling devices increases complexity.	Lightweight steel components, simple bolted or welded attachment.	Lightweight steel components, specialized equipment and sequencing after wall erection.
Code Adoption	Fewer prescriptive rules, growing acceptance with testing data.	Established design guidelines.	Coupled systems often require project-specific validation, growing acceptance with testing data.	Well-accepted, manufacturer data and test reports ease approval.	Well-established in design codes.
Best Use	Projects prioritizing prefabrication, large panel sizes, and balanced two-way action.	High-efficiency, narrower walls in tall buildings.	Tall mass timber buildings needing enhanced damping and stiffness while maintaining low-damage self-centering.	Supplemental dissipator in rocking or coupled systems. Ideal for stable hysteresis and post-event replaceability.	Providing reliable self-centering, essential component for low residual drift.

Recommendations for Future Research

Mass timber is still an emerging technology. As more research effort is invested in this area, the integration of mass timber lateral force-resisting systems will likely be adopted more widely. While many strong research contributions have shown promising results, more investigation is needed.

One area for further research is moisture. The influence of moisture content on mass timber damping has not been studied in these specific tall building applications. The moisture content of timber structures has seasonal variation. Further investigations should assess the extent to which moisture content has any significant influence on damping qualities. Similarly, investigations should assess the extent to which the density of mass timber has an influence in specific tall building applications.

Another area for further research is occupancy. Damping associated with a human occupant was found to have a greater effect on floor performance. Modal analysis of vibration response signals showed that normal floor resonance associated with jumping at a sub-harmonic of the floor's natural frequency was almost completely damped by the passive, seated people. (Brownjohn, J., 2001) This strategy is another way to possibly increase damping, and therefore, further research on its application in mass timber structures could potentially identify an otherwise missed opportunity.

The transmission of vibrations from one mass timber structure to a neighboring mass timber structure is important to understand for the comfort of people in adjacent properties. Vibrations propagating through the soil can either amplify or attenuate the seismic response of adjacent buildings. This phenomenon is known as structure-soil-structure interaction (SSSI). Transmission of vibrations for full-scale side-by-side mass timber structures has not yet been investigated. Further research is recommended in this area as well.

As code provisions continue to increase the maximum allowable height of mass timber buildings, it is important that experimental studies evaluate the performance of these taller structures. In particular, testing tall buildings, systems exceeding 14 stories, is needed to accurately represent real-world applications and capture the dynamic behavior, higher-mode effects, and overall response of mass timber lateral force-resisting systems in tall buildings.

Finally, the possible uses of timber elements in concrete and steel buildings deserve targeted exploration. For example, using CLT to replace composite metal deck slabs in steel-framed buildings could be an insightful and useful area of study. More investigation into hybrid structures, specifically using timber elements in concrete and steel buildings, should be pursued.

Conclusions

Mass timber represents a transformative material in the evolution of tall building design. As demonstrated throughout this report, its adoption is accelerating due to favorable code revisions, proven environmental advantages, and expanding real-world applications. While mass timber structures are inherently lighter and less stiff than traditional alternatives, potentially leading to larger displacements under lateral loads, targeted innovations in lateral force-resisting systems effectively mitigate these challenges.

Structural dynamics fundamentals provide the theoretical foundation for understanding mass timber's capabilities. Existing research, encompassing shaker table tests, drift evaluations, and specialized component studies, collectively demonstrates that mass timber can deliver robust, low-damage performance. Systems incorporating post-tensioned rods for self-centering, steel plates or UFPs for energy dissipation, and other rocking mechanisms have shown comparable or superior metrics, such as controlled drift, minimal residual deformation, and effective energy dissipation, relative to conventional steel and concrete LFRS in tested scenarios.

Beyond lateral resilience, mass timber offers additional benefits, including carbon sequestration, improved construction, and enhanced fire performance. These attributes position mass timber not merely as a sustainable substitute but as a material capable of advancing resilient, low-carbon urban development amid growing global urbanization and climate imperatives.

Further research should be pursued to address remaining concerns and more fully appreciate all that mass timber can offer in the construction of tall buildings. With mass timber, the limits of design and construction have the potential to be pushed even further.

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