
Comparative Numerical Study of Conventional and Low-Damage timber EBFs with Horizontal and Vertical Active Links

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ABSTRACT

An Eccentrically Braced Frames (EBFs) are among the most effective seismic lateral-force resisting systems, offering an optimal balance between stiffness, strength, and ductility. Their seismic performance largely depends on the behaviour of the link element, which is designed to yield and dissipate energy during earthquakes. However, when implemented in timber structures, conventional active link beams are prone to stiffness degradation, residual deformation, and permanent damage after severe seismic events, often requiring replacement or repair.

This study numerically investigates a low-damage alternative for timber EBFs by replacing the conventional yielding link beam with a frictional energy-dissipating device. Two modified EBF configurations are developed in ETABS, incorporating frictional links in both horizontal and vertical orientations. Their seismic behaviour is compared with that of a conventional timber EBF under identical loading conditions. Nonlinear pushover and time-history analyses are performed to evaluate key response parameters, including base shear, inter-storey drift, energy dissipation, and residual deformation.

The results demonstrate that the proposed timber EBFs equipped with frictional links exhibit stable and repeatable hysteretic behaviour with no permanent damage to the surrounding frame and negligible residual deformation. The horizontal and vertical frictional link configurations effectively decrease base shear demands while preventing stiffness degradation which demonstrates that frictional dampers can serve as a low-damage seismic solution for timber lateral-force-resisting systems.

Keywords: Low-damage solution, EBFs, Mass Timber structures

1 INTRODUCTION

1.1 Need for resilient and repairable structures

Despite the many advantages of mass timber, ensuring adequate seismic performance remains a challenge. Traditional seismic design has focused primarily on life safety and collapse prevention; however, recent earthquakes such as the 1995 Kobe, 2011 Christchurch, and 2016 Kaikōura events demonstrated that life safety alone is not sufficient. Even buildings that satisfied life-safety requirements experienced extensive damage, long recovery periods, and significant economic losses, with many structures rendered unserviceable or demolished due to severe structural and non-structural damage (Ceccotti et al., 2013) ; (Popovski & Gavric, 2016)).

These observations have shifted attention toward resilience-based seismic design, which focuses not only on life safety but also the ability of a structure to maintain functionality. Studies show that residual drifts above 0.5% are often uneconomical to repair, while drifts exceeding 0.2% may require major intervention before reoccupation (McCormick et al., 2008); FEMA P-58, 2012). As a result, modern design increasingly promotes low-damage systems that concentrate energy dissipation in replaceable or self-centring devices, protecting the primary structural elements ((Christopoulos et al., 2008) ; (Christopoulos et al., 2008)).

This transition toward resilience also supports sustainability goals. With the growing use of mass timber in multi-storey buildings, there is a clear opportunity to combine seismic resilience with low-carbon construction. Although timber offers environmental advantages, its seismic performance must be improved to meet resilience expectations. Developing low-damage systems for mass timber, particularly those using replaceable steel fuses or friction-based devices, is therefore essential for sustainable and repairable buildings in high-seismic regions such as New Zealand ((Hashemi et al., 2017); (Hashemi & Quenneville, 2020); (Lal et al., 2025))

1.2 Conventional mass timber structures: potential and observed behaviour in experimental tests

Mass timber construction includes engineered wood products such as glulam, LVL, CLT, and DLT, which are increasingly used as primary structural components. These systems offer favourable strength-to-weight ratios, high prefabrication potential, and reduced seismic mass compared to concrete and steel. In addition, their renewability and carbon storage capacity make them attractive for low-carbon construction (Abed et al., 2022).

From a seismic perspective, mass timber shows strong potential; however, the performance of conventional timber lateral systems is largely governed by connection behaviour rather than by the timber members themselves. In CLT walls and timber braced frames, energy dissipation mainly occurs through fastener yielding and local crushing of timber fibres in connections. Although this provides ductility, it also leads to stiffness degradation and residual deformations under cyclic loading. Full-scale experimental studies highlight both the strengths and limitations of these systems. The SOFIE shake-table tests on a seven-storey CLT building confirmed good global stability, but damage was concentrated in the connections. With increasing seismic intensity, this connection damage reducing lateral stiffness and complicating post-earthquake repair (Ceccotti et al., 2013).

Similar findings have been reported in other experimental studies on CLT wall systems with conventional connectors. (Popovski & Gavric, 2016)observed stable hysteretic behaviour with damping ratios of about 10–12%, mainly due to fastener yielding and panel rocking. (Yasumura et al., 2016) also showed that although lateral capacities often exceeded design demands, damage remained concentrated in the connections. Overall,

conventional mass timber walls and frames can satisfy life-safety requirements and provide sufficient ductility. However, because energy dissipation relies on connection damage, stiffness loss and residual drift remain major challenges for rapid post-earthquake recovery. In high-seismic regions, where aftershocks are expected and downtime costs are substantial, these limitations motivate the need for low-damage and replaceable mechanisms that facilitate functional recovery after seismic events.

1.3 Low-Damage Solutions and Innovative Connection Systems for Mass Timber

The limitations of conventional timber systems have led to growing interest in low-damage seismic design. This approach concentrates inelastic behaviour in controlled, replaceable components called as structural fuses which protect primary structural members from permanent damage (Christopoulos et al., 2008); (Pall & Marsh, 1982). The main objective is to reduce residual deformations, lower repair costs, and enable rapid re-occupancy after earthquakes. For mass timber structures, this philosophy is particularly important, as damaged timber elements are difficult to repair or replace ((Hashemi et al., 2017); (Lal et al., 2025)).

Building on the low-damage design philosophy, several low-damage solutions have been developed for timber systems. Post-tensioned rocking walls use supplemental fuses or dampers to dissipate energy while allowing re-centring after shaking ((Kramer et al., 2016); (Blomgren et al., 2019)). Slip-friction joints and Resilient Slip Friction Joints (RSFJs) dissipate energy through controlled sliding, reducing reliance on fastener yielding and protecting timber components ((Hashemi et al., 2016); (Zarnani & Quenneville, 2015); (Hashemi & Quenneville, 2020)). Other approaches include sacrificial steel plates, perforated fuses, and timber buckling-restrained braces, all aimed at providing stable energy dissipation with improved reparability ((Wrzesniak et al., 2016); (Daneshvar et al., 2022); (Murphy et al., 2021); (Williamson et al., 2023); (Dong et al., 2021)). Collectively, these studies demonstrate that Low-damage systems help combine seismic resilience with sustainability, allowing timber buildings to maintain their environmental benefits while improving post-earthquake performance.

1.4 Friction Dampers as a Low-Damage Energy Dissipation Mechanism

Among low-damage solutions, friction dampers are considered one of the most effective and reliable options. They dissipate seismic energy through controlled sliding between steel surfaces, converting motion into heat without relying on plastic deformation of structural members (Pall & Marsh, 1982). Friction dampers typically show stable and repeatable hysteretic behaviour with little degradation under repeated loading. Unlike conventional yielding elements, they maintain consistent performance during multiple seismic events, which makes them suitable for regions where aftershocks are expected ((Tremblay et al., 2008); (Zhu et al., 2006)). For timber structures, friction dampers offer clear advantages by limiting damage in the fasteners, reduce residual drifts, and improve reparability after earthquakes. Their simplicity and replaceability make them attractive for low-damage seismic design in mass timber buildings (Hashemi & Lal, 2025).

1.5 Fundamentals of Eccentrically Braced Frames (EBFs)

Eccentrically Braced Frames (EBFs) are widely used in seismic design because they combine the stiffness of concentrically braced frames with the ductility of moment-resisting frames. In an EBF, inelastic deformation is intentionally concentrated in a short beam segment called the link, while the rest of the frame is designed to remain elastic ((Hjelmstad & Popov, 1983); (Kasai & Popov, 1986); (Popov & Engelhardt, 1988)). Links may yield in shear (short links) or flexure (long links), and shear-critical links are generally preferred due to their stable and uniform energy dissipation characteristics ((Azad & Topkaya, 2017)). Design codes define rotation limits and detailing requirements to ensure reliable cyclic behaviour, with allowable rotations of approximately

0.08 rad for shear links and 0.02–0.04 rad for flexural links ((Engelhardt & Popov, 1992); (Richards & Uang, 2006)).

Although EBFs have demonstrated strong seismic performance, conventional yielding links can still experience buckling, fracture, and permanent deformation under severe earthquakes, often requiring replacement (Richards & Uang, 2003). To improve reparability, replaceable link systems have been developed ((Stratan & Dubina, 2004); (Mansour et al., 2011); (Tan & Christopoulos, 2016); (Mortazavi et al.)). More recently, research has focused on self-centring and friction-based link mechanisms that reduce residual drift by avoiding permanent yielding ((Cheng et al., 2012); (Tong et al., 2019); (Lettieri et al., 2023)). When applied to mass timber structures, these low-damage concepts are particularly attractive due to the difficulties in repairing timber elements. Replacing conventional yielding links with friction-based devices therefore offers a promising way to maintain the stiffness and energy dissipation benefits of EBFs while improving resilience and sustainability in timber buildings.

2 METHODOLOGY

2.1 Building Description and Structural Layout

This study evaluates the seismic performance of a six-storey mass timber building equipped with EBFs through numerical modelling. The building represents a typical mid-rise office or institutional structure located in a high-seismic region. The model was developed in ETABS with a regular and symmetric layout to allow clear comparison between different EBF link configurations.

The building has a rectangular plan with five bays in the X-direction and four bays in the Y-direction, each with a uniform bay width of 6.4 m, resulting in overall plan dimensions of 32.0 m $\times$ 25.6 m. The first storey height is 3.5 m, while the upper storeys are 3.25 m high. All floors share identical geometry, and semi-rigid diaphragm behaviour is assumed. Elevator cores and stair openings are not explicitly modelled to maintain consistency and focus on global seismic response. Gravity loads are resisted by mass timber beams and columns, while the lateral system consists of perimeter timber EBFs. The structural layout and member geometry are kept identical for all configurations considered in this study (Figure 1).

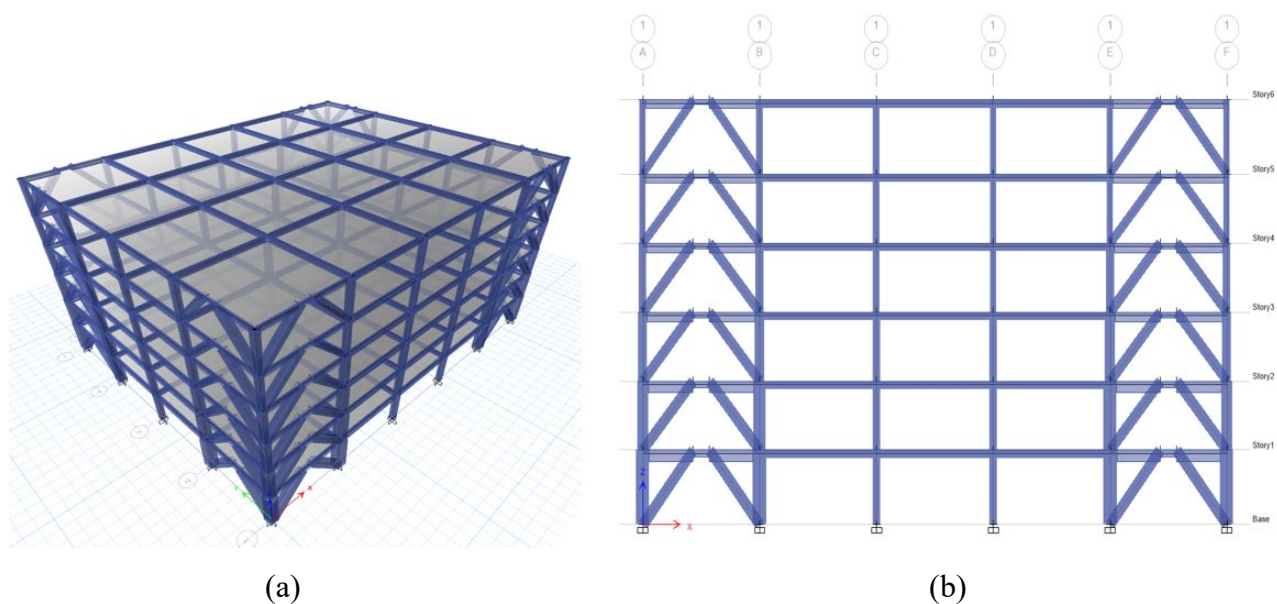


Figure 1. Six-storey mass timber archetype: (a) 3D view; (b) elevation view

Table 1. Gravity loads on respective levels of the buildings

Load	Type	Magnitude(kPa)
Dead	Dead	2.2
Floor Superimposed Dead, SD	Dead	2
Roof Superimposed Dead, SD	Dead	1
Unreduced Design Floor Live, Lo	Floor Live	3
Unreduced Design Roof Live, Lo	Roof Live	0.25

2.2 EBF Configurations Considered

Three EBF configurations are examined:

1. Conventional timber EBF with a yielding link,
2. Low-damage timber EBF with a horizontal frictional link, and
3. Low-damage timber EBF with a vertical frictional link.

In all cases, EBFs are symmetrically distributed along the building perimeter to ensure balanced stiffness and strength in both principal directions. The only difference between the three models is the type and orientation of the link element, allowing direct assessment of the influence of link behaviour on seismic response. The configurations and link orientations considered in this study are shown in Figure 2.

In the conventional configuration, the link is designed to yield in shear, consistent with standard EBF design practice. In the low-damage configurations, the yielding link is replaced by a friction-based energy dissipating device, intended to dissipate seismic energy through controlled sliding while preventing damage to the surrounding timber members.

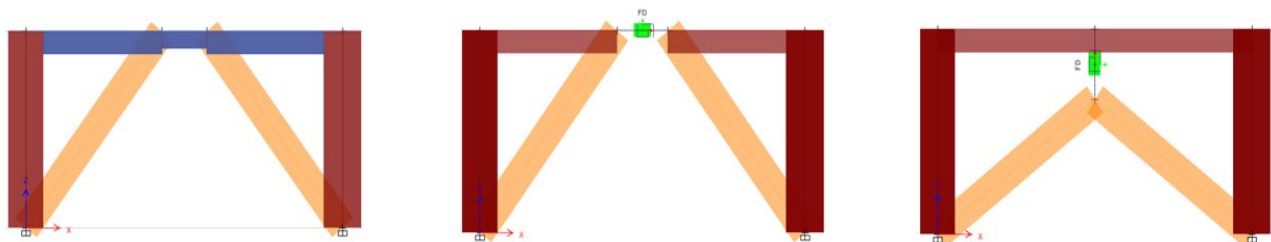


Figure 2. EBF configurations considered in this study: (a) conventional yielding link; (b) horizontal friction link; (c) vertical friction link

2.3 Numerical Modelling and Analysis Procedures

Numerical models of the six-storey mass timber building were developed in ETABS (Computers and Structures Inc., 2022) to evaluate the seismic performance of conventional and low-damage EBF systems. All members were modelled using frame elements. Timber beams, columns, and braces were assumed to remain elastic, while nonlinear behaviour was deliberately concentrated in the link region following capacity design principles. In the conventional configuration, nonlinear shear hinges were assigned to the link elements to represent yielding. In the low-damage models, frictional links were simulated using nonlinear link elements with the Plastic Wen hysteretic model to capture controlled sliding and stable energy dissipation.

Seismic performance was evaluated using Nonlinear Static Pushover (NSP) analysis and verified through Nonlinear Time History Analysis (NLTHA). The building was assumed to be located on Soil Class D and classified as Importance Level 2, with a 1/500 ultimate limit state exceedance probability and a near-fault factor of 1.0. Drift limits of 1.5% for ULS and 0.33% for SLS were adopted, with a structural performance factor of $S_p = 0.7$. All models were analysed using identical loading and analysis procedures to ensure consistent comparison.

2.4 Selection of ground motion records and scaling

To evaluate the seismic performance of the proposed timber EBF systems, nine earthquake ground motion records (18 horizontal components) were selected for Nonlinear Time History Analysis (NLTHA). The records represent seismic hazard conditions relevant to New Zealand and reflect strong ground motions expected in high-seismic regions. All records were scaled according to NZS 1170.5 to match the target ultimate limit state design spectrum. Direct integration time-history analyses were performed to capture dynamic response and record-to-record variability. Seismic performance was compared across all configurations using key response parameters, including base shear, inter-storey drift, residual drift, and floor acceleration. Details of the selected ground motions are provided in Table 2.

Table 2. Selected ground motion records for NLTH.

Event	Country	Year	M	Fault Mechanism
ChiChi-TCU051	Taiwan	1999	7.6	Reverse Oblique
Christchurch-CBGS	New Zealand	2011	6.2	Reverse Oblique
Christchurch-Riccarto	New Zealand	2011	6.2	Reverse Oblique
Darfield	New Zealand	2010	7.1	Strike-Slip
Duzce	Turkey	1999	7.2	Strike-Slip
Imperialvalley Elcentro	USA	1940	6.9	Strike-Slip
Imperialvalley06	USA	1979	6.5	Strike Slip
Kaikoura	New Zealand	2016	7.8	Thrust & Strike-Slip
Kocaeli	Turkey	1999	7.6	Strike-Slip

3 RESULTS AND DISCUSSION

3.1 Nonlinear static push-over analysis (hysteresis damping)

Nonlinear Static Pushover (NSP) analysis was performed to evaluate the lateral force–displacement response of the proposed timber EBF systems. Hysteretic damping was calculated using the area-based method following Jacobsen’s approach (Chan et al., 2021). The initial elastic response transitions to inelastic behavior at the yield point, indicating plastic deformation. As shown in Figure 3, Both systems exhibit a clear force plateau after the onset of sliding, indicating controlled energy dissipation through friction

The vertical configuration achieved a hysteretic damping ratio (ξ_{hyst}) of 49.3%, while the horizontal configuration showed 48.6%, with both systems reaching a similar maximum shear capacity of approximately 3,200 kN.

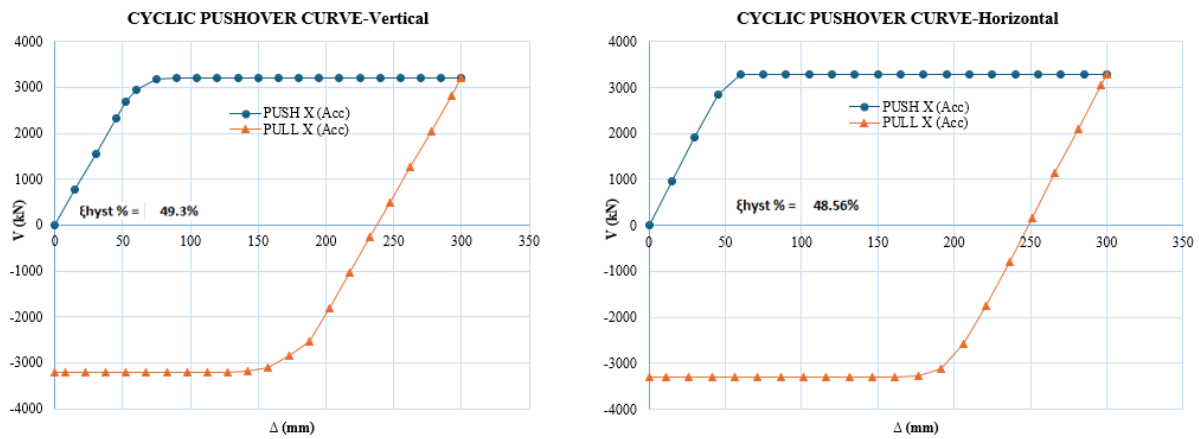


Figure 3. Cyclic pushover curves for horizontal and vertical friction link configurations

3.2 Nonlinear Time History Analysis (NLTHA)

Nonlinear Time History Analysis (NLTHA) was conducted to evaluate the seismic performance of the six-storey mass timber building equipped with conventional and low-damage EBF systems. All structural configurations were subjected to the selected ground motion records scaled to the design-level seismic intensity, as described in the previous section. A Rayleigh damping model was adopted, with a 2% inherent damping ratio assigned to the first mode and the mode contributing approximately 90% of the total mass participation. Key seismic response parameters, including base shear, inter-storey drift were extracted from the analyses. The reported responses are based on the mean values obtained from nine ground motion records, consistent with recommendations for response history analysis to capture record-to-record variability. Although the New Zealand seismic design standard NZS 1170.5 permits the use of a minimum of three records, a larger set was employed in this study to improve the reliability of the comparative assessment of the different EBF link configurations.

3.3 Base Shear

Figures 4 and 5 present the peak base shear demands obtained from NLTH analyses in the X- and Y-directions, respectively. In both directions, the conventional EBF system consistently develops the highest base shear across all ground motion records. In the X-direction, peak values for the conventional configuration range approximately between 5,400 kN and 6,500 kN, significantly exceeding the mean DBD base shear level ($\sim 4,200$ kN). A similar trend is observed in the Y-direction, where conventional base shear reaches values up to approximately 6,400 kN. In contrast, the friction-based systems show substantially reduced force demands. The horizontal friction link generally produces base shear values close to 4,000–4,800 kN, while the vertical configuration results in slightly lower demands, typically between 3,200–4,500 kN depending on the record. For most ground motions, both friction configurations remain close to the DBD target level. Overall, the friction-based EBF systems reduce base shear demand by approximately 20–35% compared to the conventional configuration. The vertical link shows marginally lower force demand than the horizontal link in several records; however, the difference between the two low-damage configurations remains relatively small.

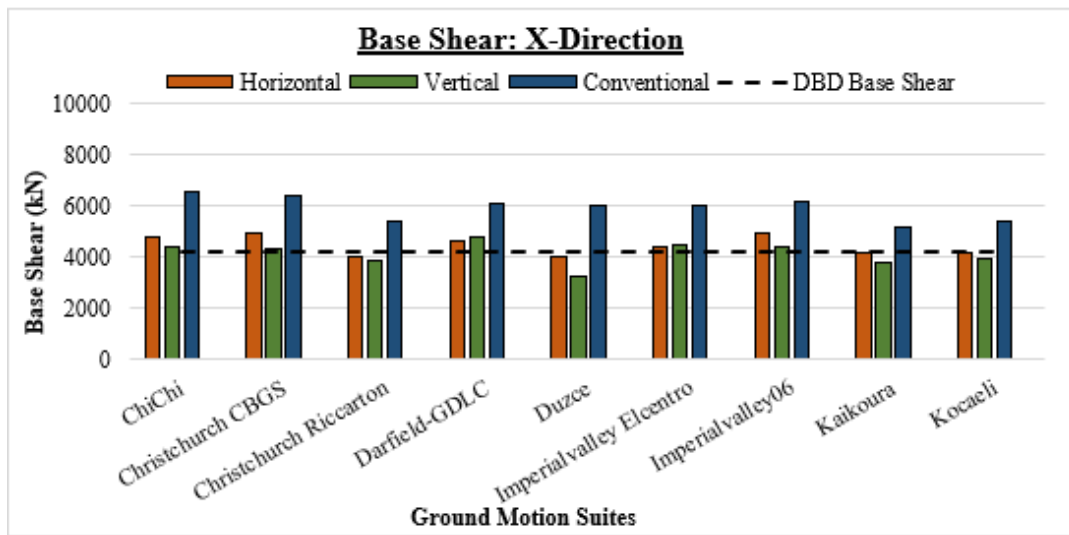


Figure 4. Peak base shear response in the X-direction from NLTH analysis for conventional and friction-based EBF systems

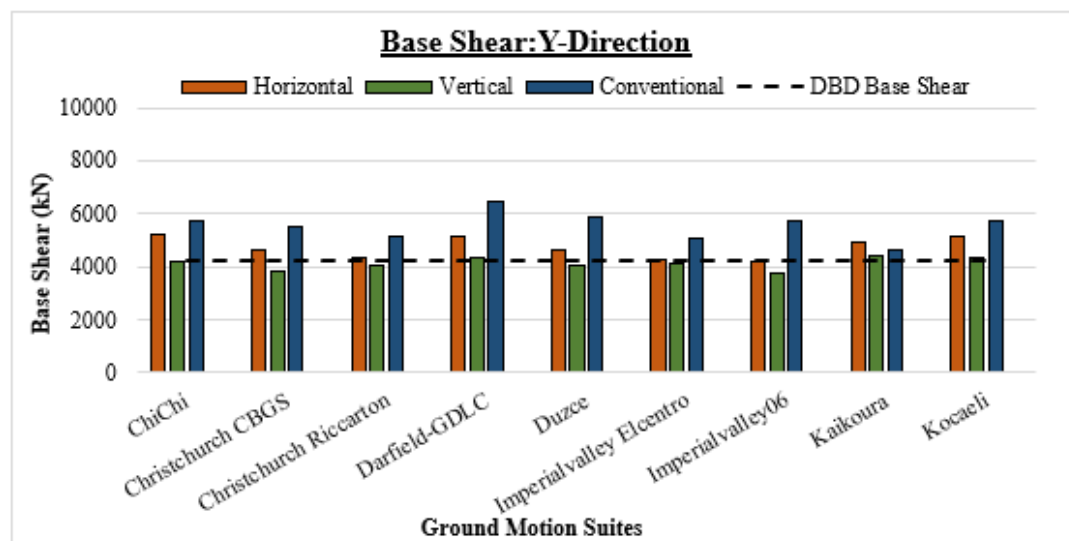


Figure 5. Peak base shear response in the Y-direction from NLTH analysis for conventional and friction-based EBF systems

3.4 Inter-story drift

Figures 6 and 7 show the peak inter-storey drift values obtained from NLTH analyses for each ground motion in the X- and Y-directions. In the X-direction, the conventional EBF consistently produces the lowest drift across all records, generally remaining below about 1.3%. The friction-based systems show higher drift demands. The horizontal link usually ranges between about 0.7% and 1.5%, while the vertical link produces slightly larger values, reaching close to 1.9% in some cases.

A similar pattern is observed in the Y-direction. The conventional system again shows the smallest drift response for most records. The horizontal configuration remains slightly lower than the vertical link in most cases. Overall, the friction-based systems increase drift compared to the conventional EBF, but most values remain close to the design drift limit shown in the figures. The conventional system remains the stiffest configuration, while the vertical friction link generally produces the highest drift demands.

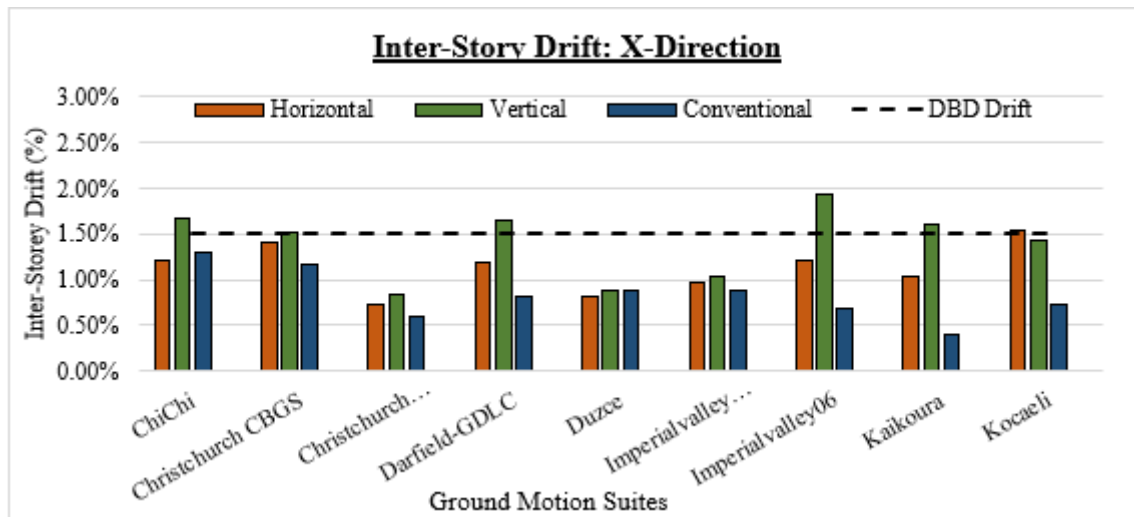


Figure 6. Peak inter-storey drift profile in the X-direction for conventional and friction-based EBF systems

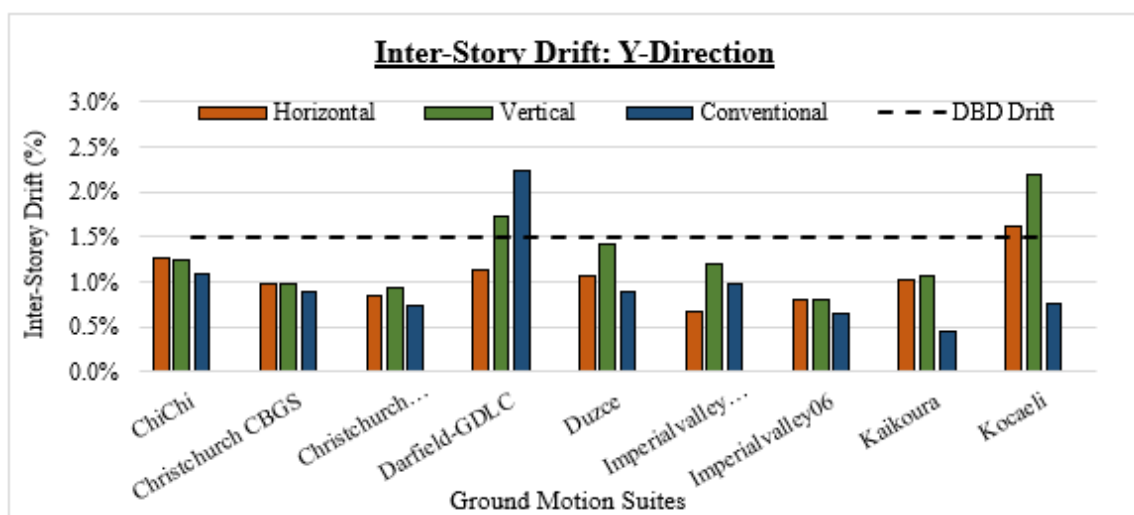


Figure 7. Peak inter-storey drift profile in the Y-direction for conventional and friction-based EBF systems.

4 CONCLUSION

This study presented a comparative numerical investigation of conventional and friction-based timber EBF systems for a six-storey mass timber building. Two low-damage configurations, using horizontal and vertical friction links, were compared with a conventional shear-yielding link system through NSP and NLTH analyses. The NSP results showed stable and repeatable hysteretic behaviour for both friction configurations, with damping values of about 49%. A clear force plateau was observed, confirming that energy dissipation occurs through controlled sliding rather than material yielding. The NLTH analyses further showed that the friction-based systems significantly reduced base shear compared to the conventional EBF. In both directions, the proposed low-damage system maintained force levels close to the design base shear, while the conventional system consistently attracted higher demands. The vertical friction link produced slightly lower base shear than the horizontal configuration. In terms of inter-storey drift, the conventional EBF showed the lowest drift response due to its higher stiffness. The friction-based systems resulted in higher drift, especially for the vertical link, but in most cases the values stayed near the design limit.

Overall, the findings demonstrate that replacing conventional yielding links with friction-based devices can provide an effective low-damage solution for timber EBF systems. The proposed configurations reduce seismic

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force demand, offer stable energy dissipation, and improve post-earthquake reparability while preserving the environmental advantages of mass timber construction.

5 ACKNOWLEDGEMENT

The Authors would like to thank Natural Hazards Commission Toka Tū Ake, WIDE Trust and Te Hiranga Rū QuakeCoRE for their support of this research. The Te Hiranga Rū QuakeCoRE publication number is 1149.

6 REFERENCES

- Abed, J., Rayburg, S., Rodwell, J., & Neave, M. (2022). A Review of the Performance and Benefits of Mass Timber as an Alternative to Concrete and Steel for Improving the Sustainability of Structures. *Sustainability*, 14(9), 5570.
- Azad, S. K., & Topkaya, C. (2017). A review of research on steel eccentrically braced frames. *Journal of Constructional Steel Research*, 128, 53–73.
- Blomgren, H.-E., Pei, S., Jin, Z., Powers, J., Dolan, J. D., Van De Lindt, J. W., Barbosa, A. R., & Huang, D. (2019). Full-scale shake table testing of cross-laminated timber rocking shear walls with replaceable components. *Journal of Structural Engineering*, 145(10), 04019115.
- Ceccotti, A., Sandhaas, C., Okabe, M., Yasumura, M., Minowa, C., & Kawai, N. (2013). SOFIE project–3D shaking table test on a seven - storey full - scale cross - laminated timber building. *Earthquake engineering & structural dynamics*, 42(13), 2003–2021.
- Cheng, C., Hsu, C., & Lin, K. (2012). Seismic behavior of self-centering designed eccentrically braced frames. *The 15th world conference on earthquake engineering*.
- Christopoulos, C., Tremblay, R., Kim, H.-J., & Lacerte, M. (2008). Self-centering energy dissipative bracing system for the seismic resistance of structures: development and validation. *Journal of Structural Engineering*, 134(1), 96–107.
- Daneshvar, H., Niederwestberg, J., Dickof, C., Jackson, R., & Chui, Y. H. (2022). Perforated steel structural fuses in mass timber lateral load resisting systems. *Engineering Structures*, 257, 114097.
- Dong, W., Li, M., He, M., & Li, Z. (2021). Experimental testing and analytical modeling of glulam moment connections with self-drilling dowels. *Journal of Structural Engineering*, 147(5), 04021047.
- Engelhardt, M. D., & Popov, E. P. (1992). Experimental performance of long links in eccentrically braced frames. *Journal of Structural Engineering*, 118(11), 3067–3088.
- Hashemi, A., & Lal, R. (2025). Seismic performance evaluation of mass timber buildings equipped with resilient and conventional friction devices. *Resilient Cities and Structures*, 4(2), 103–115.
- Hashemi, A., Masoudnia, R., & Quenneville, P. (2016). A numerical study of coupled timber walls with slip friction damping devices. *Construction and Building Materials*, 121, 373–385.
- Hashemi, A., & Quenneville, P. (2020). Large-scale testing of low damage rocking Cross Laminated Timber (CLT) wall panels with friction dampers. *Engineering Structures*, 206, 110166.
- Hashemi, A., Zarnani, P., Masoudnia, R., & Quenneville, P. (2017). Seismic resistant rocking coupled walls with innovative Resilient Slip Friction (RSF) joints. *Journal of Constructional Steel Research*, 129, 215–226.
- Hjelmstad, K. D., & Popov, E. P. (1983). Cyclic behavior and design of link beams. *Journal of Structural Engineering*, 109(10), 2387–2403.
- Kasai, K., & Popov, E. P. (1986). General behavior of WF steel shear link beams. *Journal of Structural Engineering*, 112(2), 362–382.
- Kramer, A., Barbosa, A. R., & Sinha, A. (2016). Performance of steel energy dissipators connected to cross-laminated timber wall panels subjected to tension and cyclic loading. *Journal of Structural Engineering*, 142(4), E4015013.
- Lal, R., Hashemi, A., & Quenneville, P. (2025). An innovative connection system for platform-type mass timber buildings. *Resilient Cities and Structures*, 4(2), 14–29.

- Lettieri, A., de la Peña, A., Freddi, F., & Latour, M. (2023). Damage-free self-centring links for eccentrically braced frames: development and numerical study. *Journal of Constructional Steel Research*, 201, 107727.
- Mansour, N., Christopoulos, C., & Tremblay, R. (2011). Experimental validation of replaceable shear links for eccentrically braced steel frames. *Journal of Structural Engineering*, 137(10), 1141–1152.
- McCormick, J., Aburano, H., Ikenaga, M., & Nakashima, M. (2008). Permissible residual deformation levels for building structures considering both safety and human elements. *Proceedings of the 14th world conference on earthquake engineering*.
- Mortazavi, P., Kwon, O.-S., & Christopoulos, C. EXPERIMENTAL BENCHMARK HYBRID SIMULATIONS ON STEEL EBFS DESIGNED WITH NOVEL CAST STEEL REPLACEABLE MODULAR YIELDING LINKS UNDER SEISMIC EXCITATIONS.
- Murphy, C., Pantelides, C. P., Blomgren, H.-E., & Rammer, D. (2021). Development of timber buckling restrained brace for mass timber-braced frames. *Journal of Structural Engineering*, 147(5), 04021050.
- Pall, A. S., & Marsh, C. (1982). Response of friction damped braced frames. *Journal of the Structural Division*, 108(6), 1313–1323.
- Popov, E. P., & Engelhardt, M. D. (1988). Seismic eccentrically braced frames. *Journal of Constructional Steel Research*, 10, 321–354.
- Popovski, M., & Gavric, I. (2016). Performance of a 2-story CLT house subjected to lateral loads. *Journal of Structural Engineering*, 142(4), E4015006.
- Richards, P., & Uang, C.-M. (2003). Development of testing protocol for short links in eccentrically braced frames. *Department of Structural Engineering, University of California, San Diego*.
- Richards, P. W., & Uang, C.-M. (2006). Testing protocol for short links in eccentrically braced frames. *Journal of Structural Engineering*, 132(8), 1183–1191.
- Stratan, A., & Dubina, D. (2004). Bolted links for eccentrically braced steel frames. *connections in steel structures V*, 223–332.
- Tan, K. G., & Christopoulos, C. (2016). Development of replaceable cast steel links for eccentrically braced frames. *Journal of Structural Engineering*, 142(10), 04016079.
- Tong, L., Zhang, Y., Zhou, X., Keivan, A., & Li, R. (2019). Experimental and analytical investigation of D-type self-centering steel eccentrically braced frames with replaceable hysteretic damping devices. *Journal of Structural Engineering*, 145(1), 04018229.
- Tremblay, R., Lacerte, M., & Christopoulos, C. (2008). Seismic response of multistory buildings with self-centering energy dissipative steel braces. *Journal of Structural Engineering*, 134(1), 108–120.
- Williamson, E., Pantelides, C. P., Blomgren, H.-E., & Rammer, D. (2023). Design and cyclic experiments of a mass timber frame with a timber buckling restrained brace. *Journal of Structural Engineering*, 149(10), 04023131.
- Wrzesniak, D., Rodgers, G. W., Fragiocomo, M., & Chase, J. G. (2016). Experimental testing of damage-resistant rocking glulam walls with lead extrusion dampers. *Construction and Building Materials*, 102, 1145–1153.
- Yasumura, M., Kobayashi, K., Okabe, M., Miyake, T., & Matsumoto, K. (2016). Full-scale tests and numerical analysis of low-rise CLT structures under lateral loading. *Journal of Structural Engineering*, 142(4), E4015007.
- Zarnani, P., & Quenneville, P. (2015). A resilient slip friction joint. Patent No. WO2016185432A1, NZ IP Office.
- Zhu, S., Zhang, Y., & Lu, L.-W. (2006). Seismic analysis of steel framed buildings with self-centering friction damping braces. *4th International conference on earthquake engineering, Taipei (Taiwan)*,