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NOTE DE RECHERCHE

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POST-TENSIONED TIMBER WALL SYSTEM WITH SINGLE AND MULTIPLE ROCKING SEGMENTS

Abstract: High-rise timber buildings are gaining popularity around the world as a replacement for concrete and steel structures given that they are more environmentally friendly. Further research on lateral force resisting systems for timber buildings is required for them to become a reliable alternative to withstand high winds and strong earthquakes. One of the solutions is the Pre-Stressed Laminated (Press-Lam) system proposed for mass timber walls in New Zealand which was adapted from the PREcast Seismic Structural System (PRESSS) used for concrete and steel structures to resist earthquakes. So far, single rocking segment systems have been developed and analyzed assuming rigid connections between the panels, resulting in a dynamic amplification of the forces in the upper storeys and higher costs. The results of this research demonstrate through numerical modeling that this amplification can be reduced by introducing simple connections allowing a gap opening at the construction joints, which will lead to a more flexible structure and cost savings. This project was realized in collaboration with the University of Canterbury in New Zealand through an internship funded with the Queen Elizabeth Diamond Jubilee Scholarship.

Potential application and industrial benefits: With less seismic demand in the system, the cross section and post-tensioning areas of the upper panels can be reduced, which will result in material and cost savings. The connection design for construction joints can also be simplified, thus minimizing material and labor costs.

INTRODUCTION

In the past few years, the demand for high-rise timber buildings has been increasing due to their pleasing architectural look, environmental benefits, quick assembly and potentially high resistance to seismic loads. To provide earthquake resistance in timber buildings, the Pre-Stressed Laminated (Press-Lam) system was adapted from the PREcast Seismic Structural System (PRESSS)[1] at the University of Canterbury[2].

The Press-Lam system may consist of large walls made of laminated veneer lumber (LVL), cross-laminated timber (CLT) or glued laminated timber (glulam). This concept provides a combination of re-centering and energy dissipation during seismic events through panel rocking (Figure 1). Pre-stressed steel bars are positioned in the center of the wall and are designed to remain elastic during major seismic events, thus forcing the wall to return to its original position after the earthquake. Replaceable steel dissipaters are installed at both ends of the base of the wall and are designed to yield during the seismic event, thus providing energy dissipation for the system.

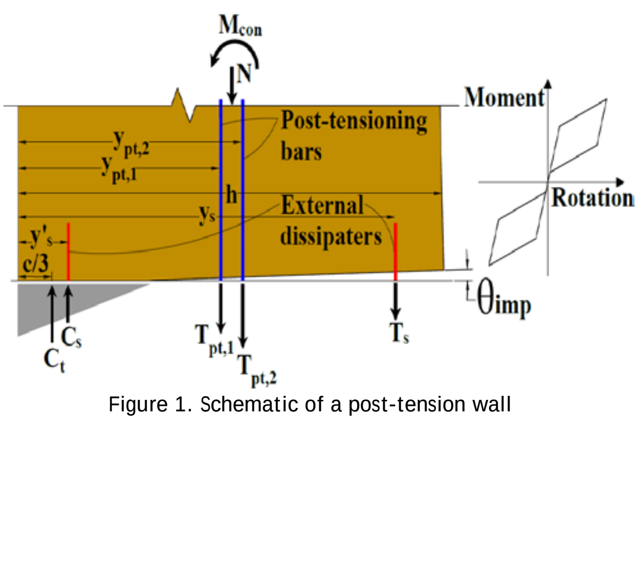

Figure 1. Schematic of a post-tension wall

The concept developed at the University of Canterbury uses a single LVL rocking segment that can be described as a continuous cantilever wall (Figure 2). This method requires the design of a perfectly rigid connection between the panels which produces a dynamic amplification in the upper storeys that is caused by the effects of higher modes of vibration. The objective of this project is to demonstrate through numerical modeling that these effects can be reduced by allowing gap openings between the panels using simple connections at the construction joints.

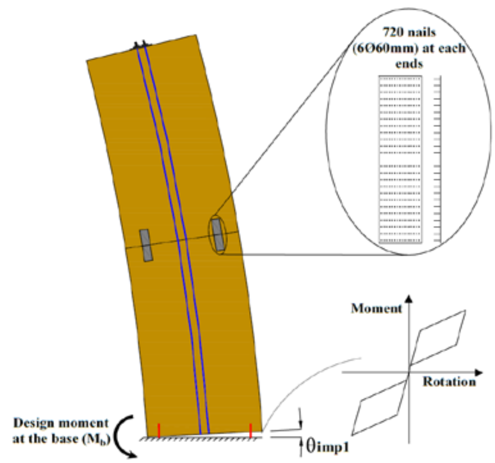

Figure 2. Single rocking segment

I. SINGLE ROCKING SEGMENT

To assess the behavior and seismic demand of a single rocking segment of the wall, multiple non-linear time history analyses (NLTHA) were carried out on several case study buildings having 3 to 9 storeys using numerical models developed with OpenSEES[3].

NORDIC STRUCTURES

Figure 3 shows the shapes of the shear and bending moment envelopes obtained with the NLTHA. Results are strongly marked by a dynamic amplification (ω) in the upper levels because of higher modes of vibration, which induce additional forces in the structure. To resist these higher forces, larger wall sections and stronger, perfectly rigid connections with thousands of fasteners are necessary, thus increasing the costs.

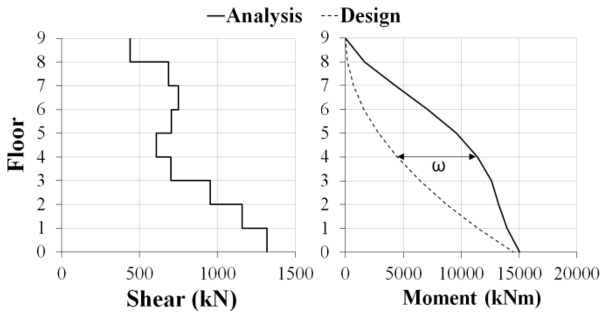

Figure 3. Single rocking segment NLTHA results

II. Multiple Rocking Segments

To reduce the dynamic amplification of bending moment demand presented above, gap openings can be allowed between the panels (Figure 4). This design will produce more flexibility and, hence, lower forces in the structure.

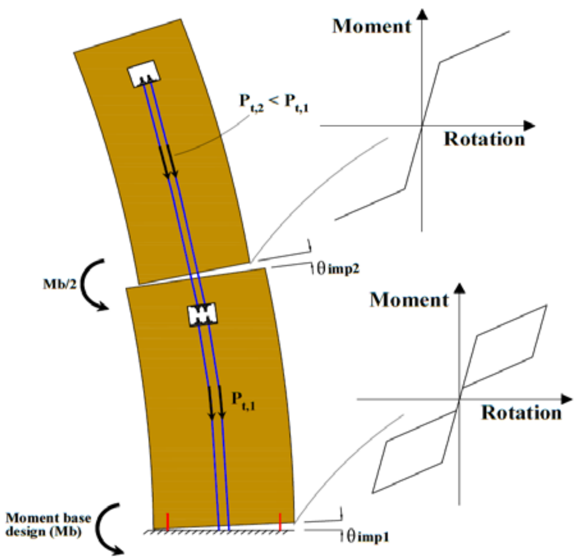

Figure 4. Multiple rocking segments

Because of the lower forces, it is possible to design the system with reduced wall cross section areas, post-tensioning bar areas and lower initial pre-stressing. One of the ways to increase the flexibility of the structure is to remove the dissipater elements between panels in the upper levels. Using this configuration, the design moment at the mid-height gap of the building can be taken as 50% of the design moment at the base, assuming a linear distribution of bending moment demand. The total deflection due to the gap opening, shear forces and bending moments need to be under permissible limits. The simplification of the connection between the panels, using only a steel plate and nuts instead of thousands of fasteners, results in material and labor cost savings.

The NLTHA calculations were also performed on multiple rocking segment systems in the same case study buildings so as to compare the forces induced in the structure during an earthquake. As expected, allowing gap openings along the height of the buildings significantly reduces the shear and bending moment dynamic amplification (Figure 5).

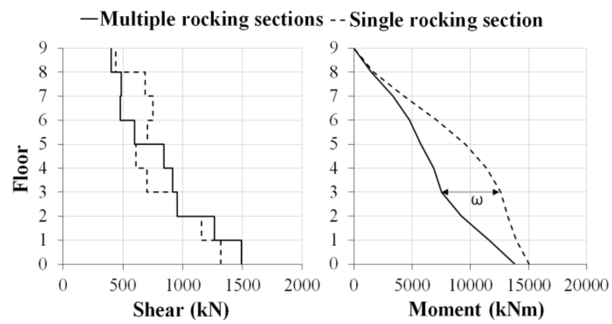

Figure 5. Multiple rocking segment NLTHA results

III. Conclusion

- Results show that allowing gap openings at every construction joint along the height of the structure will result in the reduction of the shear forces and bending moments up to 40%.

- Because of the lower forces, it is possible to design the system with reduced wall cross section areas, post-tensioning bar areas and lower initial pre-stressing which will result in material and cost savings.

- The construction joints can be simplified using steel plates and nuts instead of thousands of fasteners thus reducing material and labor costs.

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[1] Priestley M.1991. Overview of presss research program. PCI Journal 36(4): 50-57.
[2] Palermo A. et al. 2005. Seismic design of multi-storey buildings using laminated veneer lumber (lvl). New Zealand Society of Earthquake Engineering, Annual Conference.
[3] MecKenna F. Opensees. 2011. A framework for earthquake engineering simulation. Computing in Science and Engg 13(4): 58-66.

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