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PRESTRESSED TIMBER STRUCTURES FOR MULTI-STORIED BUILDINGS: FROM THEORY TO PRACTICE

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ABSTRACT

A new generation of buildings have been designed in recent years with an innovative structural system developed in New Zealand over the last decade. Conventional post-tensioning is combined with timber structures made of engineered wood products to produce highly efficient systems suitable for supporting long floor spans. The moment connections are particularly useful in structures designed for seismic regions. The post-tensioning ensures self-centering in addition to ductility provided by additional energy dissipating elements within the connections. Extensive experimental and numerical studies have confirmed the expected performance of the systems and design procedures have been developed for practical applications. A summary of the evolution of the concept and developments are presented here. The concept has already been applied in design of a number of structures within and outside New Zealand. The applications are reviewed with discussion on the details implemented. The system has excellent prospect of emerging as a practical alternative for multi-storied timber buildings. Arrangements have been made recently to utilize the technology in North America and initiatives are currently underway for implementation in Canada.

Keywords: Prestressed Timber, Multi-storied Building, Seismic Design

1. INTRODUCTION

Around the middle of the last decade research initiated in New Zealand on application of post-tensioning in structural members made of engineered wood products. The moment capacities of connections are increased due to post-tensioning, the arrangement is self-centering at removal of load. In the “Hybrid” structures additional replaceable ductile elements are used for seismic loading which absorbs energy during seismic events but protects the structural members from serious damage (Figure 1). Engineered wood products have been found to be particularly suitable for this type of applications because of their superior strength characteristics compared to rough sawn timber and the concept has been applied to different engineered wood products such as Laminated Veneer Lumber (LVL), Glue Laminated Timber (Glulam) and Cross Laminated Timber (CLT). One of the common energy dissipating connection consisted of axially loaded deformed bars, encased in steel tubes to prevent buckling. A high level of deformation can be achieved by the ‘fuse’ with possibility of replacement after yielding.

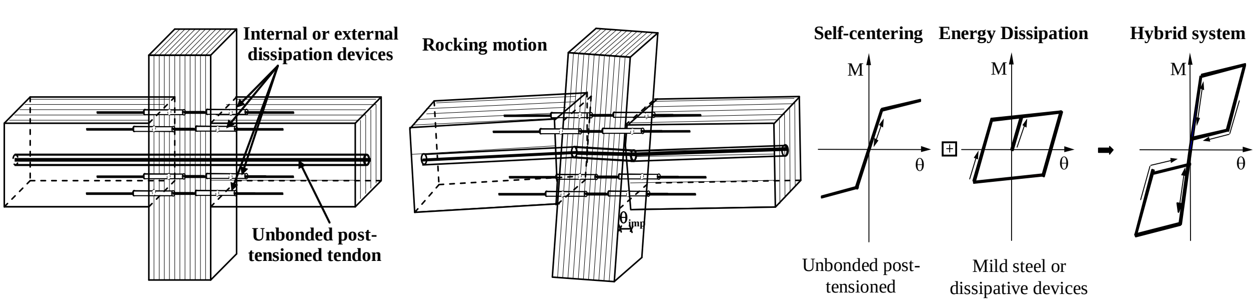

Figure 1: Application of Hybrid concept to LVL frame system and idealized flag-shape hysteresis loop

2. RESEARCH

As part of a comprehensive research investigation for the development of innovative seismic resisting systems for timber construction, a number of different hybrid solutions for frame and wall systems have been successfully tested for implementation in multi-storey LVL buildings at the University of Canterbury, Christchurch, New Zealand (Palermo et al. 2005, Necombe et al 2008). Initially beam to column, column-to-foundation or wall to foundation connections were tested with and without energy dissipation devices (Figure 2). The flag-shaped hysteresis plots of beam-column joint and wall specimens are shown in Figure 3. The research was extended (Iqbal et al 2007, 2010a, b) to shear walls coupled with energy dissipating elements and interior beam column joints which was followed up by tests on a two-storied building model (Figure 4).

The tests confirmed the behavior of the assemblies as well as feasibility of adopting the system in multi-storied building structures (Newcombe et al. 2010, Smith et al. 2008, 2011). The two-storied model suffered little damage and was re-used as a practical structure providing office space after some modifications. Design procedures were developed based on the research findings and design guidelines were published for practitioners (Expan 2013).

Figure 2: Exterior beam-column joint, wall-foundation, column-foundation test specimens (Palermo et al., 2005)

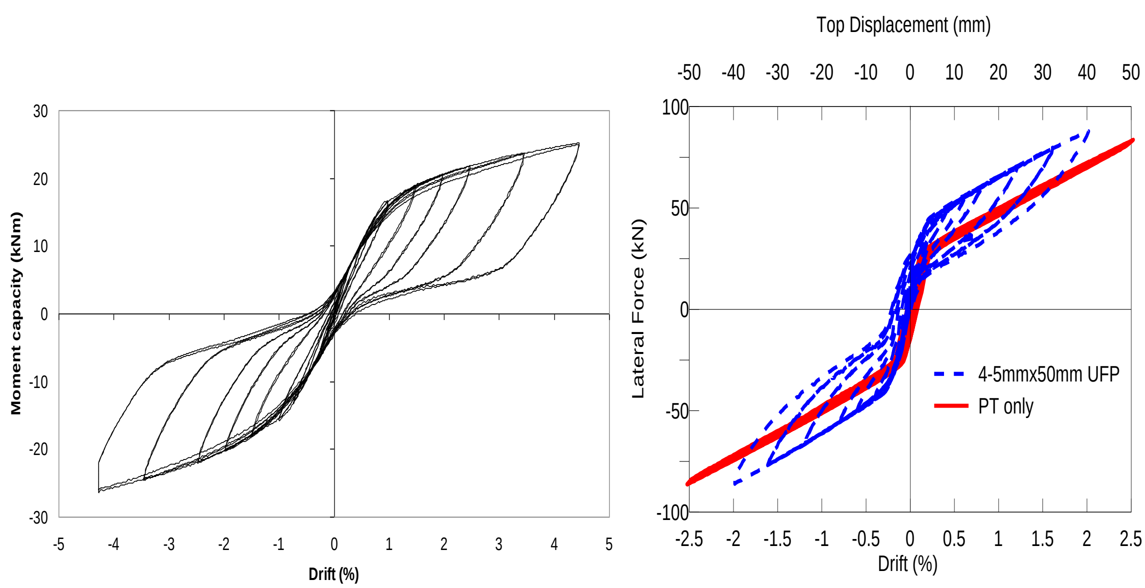

Figure 3: Hysteresis plots of beam-column joint (left) and coupled shear walls (right) test specimens


Figure 4: Coupled walls and two-storied building model

3. APPLICATIONS

The first building built with system (Devereux et al. 2011) is the Arts and Media Centre of Nelson-Marlborough Institute of Technology in New Zealand (Figure 5) with post-tensioned LVL shear wall panels and UFPs (Figure 6).


Figure 5: NMIT Arts and Media Centre during construction and after completion


Figure 6: NMIT structure and U-shaped flexural plates between walls

Figure 7: Carterton Events Centre during construction and after opening

The Carterton Events Centre (Figure 7) was a single-story building located in a high seismic region. The structure included LVL shear walls and timber trusses (Curtain et al. 2012, Dekker et al. 2012).

The post-tensioned structural system with wood (Figure 8) has been used in some variations. One of them is in a podium structure for College of Creative Arts (CoCA) of Massey University in Wellington, New Zealand (Cattanach et al 2012). The bottom two stories of the building are of concrete and the top three are made of wood. Innovative connection details were used in the column to overcome the weakness of LVL in perpendicular-to-the-grain direction; wood-concrete composite system (Yeoh 2011) was used for floors (Figure 9). In the Merritt Building in Christchurch (Figure 10) a series of portal frames were used (Stuff 2014) with energy dissipating elements between beams and columns (Figure 11).

Figure 8: College of Creative Arts during construction and completed

Figure 9: CoCA Building floor and post-tensioning anchorage

Figure 10: Merritt Building frames and completed building


Figure 11: Merritt Building beam-column connections

The Trimble Navigation building in Christchurch, New Zealand (Figure 12) is a prime example of application of the idea in different types of connections (Brown et al. 2014). The typical frames have post-tensioning with energy dissipating elements at the beam-column joints. The walls and columns have energy dissipaters connected to the foundation. The post-tensioned walls also have U-shaped Flexural Plates between them for additional energy dissipation. The beam-column joints have energy dissipating elements at the connections (Figure 13).


Figure 12: Trimble Building structure and completed building

Figure 13: Walls and Beam-Columns with energy dissipating connections in Trimble Building

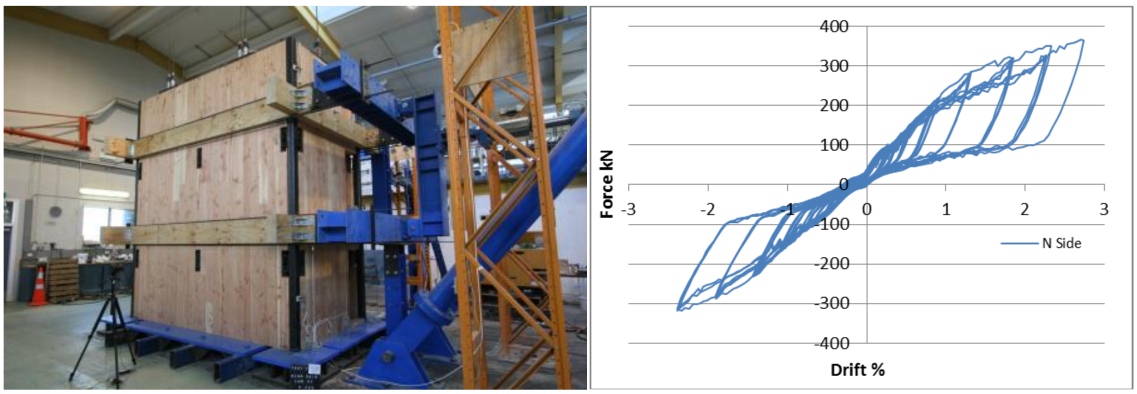

Figure 14: CLT shear wall test specimen and load-deflection plot

It should be mentioned that the post-tensioned concept is applicable not only to structures made of glulam or LVL but also to those with other types of engineered wood products. Utilizing information from latest research on CLT Hybrid structures the new Kaikoura District Council building in New Zealand (Figure 15) has been designed to be the first in the world with post-tensioned CLT structure (DesignBASE 2014, Xlam 2016). CLT shear walls have been used alongside LVL beams and columns and wooded floors. A number of other structures are currently at different stages of design or construction within New Zealand.

Variations of composite systems have also been in other structures. The St Elmo court building in Christchurch (Stuff 2012) uses concrete columns with wooden floor and beam systems (Figure 16) whereas in Tait Communications building, also in Christchurch (Figure 17), wooden frames have been used in parallel to steel braced frames and wooden frames at the interior (Aurocon Group 2015).

Figure 15: CLT Shear walls within wooden structure of Kaikoura District Council Building

Figure 16: St Elmo Court structure and completed building

Figure 17: Tait Communications complex structure during construction

4. APPLICATIONS OUTSIDE NEW ZEALAND

Since the first application in the NMIT building the concept has been applied in a number of others have been structures in Europe and North America. Following up on the work done on gravity frames (Figure 18) in New Zealand (van Beerschoten 2012), researchers at the Swiss Federal Institute of Technology (ETH) at Zurich decided to design and construct the House of Natural Resources (Figure 19) within their campus as a research facility for sustainable construction (ETH 2015, Frangi 2014).

Two more structures are currently at planning and design phase in North America. The proposed Cathedral Hill 2 in Ottawa (Figure 19) is a 14-storied commercial-cum-residential building to be built entirely with Glulam and CLT. The shear walls made of CLT will be post-tensioned and will also include energy dissipating connections (Douglas Consultants 2015). In addition to meeting the serviceability criteria such as acoustics and vibration, because of its height the building has to be designed for adequate fire safety and deformations over short and long periods. Prefabrication and fast erection features have to be considered as they are more important in this case from commercial point of view.

One of the winners of the US Tall Wood Building Competition is the Framework Project (Figure 19), a 12-storied building planned in Portland, Oregon (USDA 2015). The building will use CLT as the primary material, with ductile connection details.

FPInnovations has recently signed an agreement with the New Zealand researchers to utilize the technology in North America (FPInnovations 2015, Stuff 2015). That is expected to facilitate adoption of the technology in many other structures in North America and initiatives to achieve that are already underway.

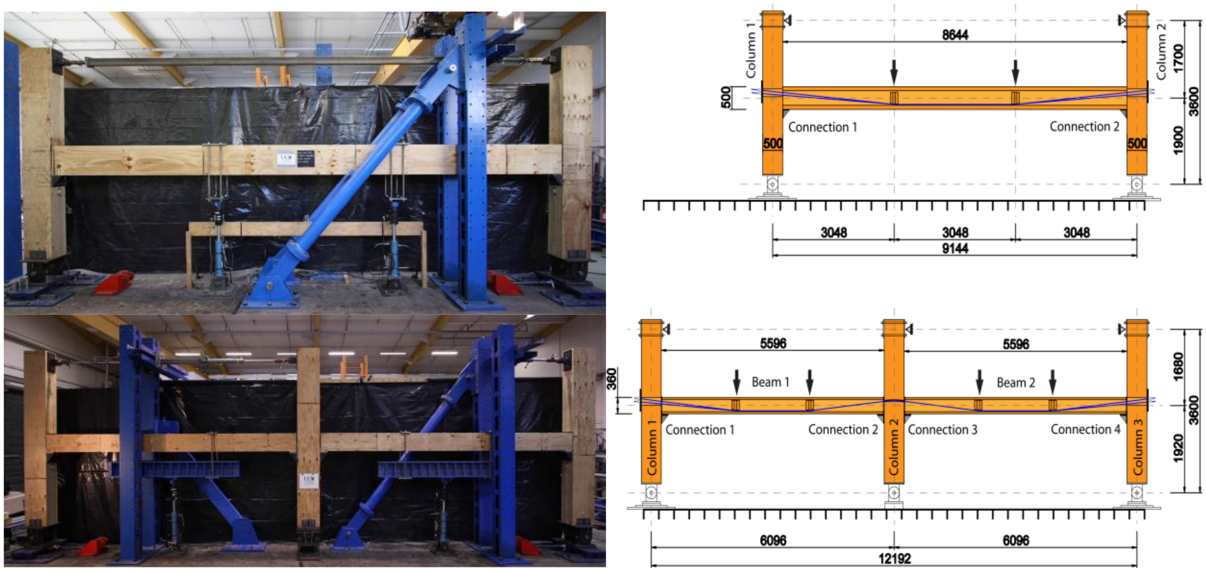

Figure 18: Gravity frame test structures and details including draped tendon layouts


Figure 19: ETH House of Natural Resources building frame and completed building


Figure 20: Cathedral Hill2 (left) and Framework Portland (right)

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