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## POST-TENSIONED TIMBER WALL-FRAME SYSTEM

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**Abstract:** For timber structures above mid-rise it is inefficient to use lightweight frames and shear wall systems. It is often necessary to add individual or groups of shear walls to complement the lateral load capacities of frame systems. Structural walls and frames with prefabricated members made of timber and connected with unbonded post-tensioning have recently been developed for buildings. Prefabricated post-tensioned timber members can be designed to have excellent lateral load resistance with the post-tensioning providing self-centering capacity. Numerical model of building structure has been developed to investigate the effects of interaction between the frames and shear walls under gravity and lateral load conditions. Combinations of different types and arrangements of frames and shear walls are investigated to compare their efficiencies. Based on the findings, recommendations on the optimum solutions as well as practical limits of this type of application are presented. The developments in the concept and understanding are expected to help in more efficient and thereby economic designs of tall wood building structures.

### 1 INTRODUCTION

Post-tensioned timber shear walls and frame systems have been studied and implemented in recent times. The current research looks into combining them for enhanced lateral load capacities. Initially numerical models of the two are developed separately and then combined to investigate the performance. A virtual tall building is also studied to explore feasibility of the concept in a practical structure.

### 2 NUMERICAL MODELLING

Numerical models were developed to replicate the systems and used to examine their behavior. The two major components were first modelled separately and then they were combined within a single numerical model.

#### 2.1 Wall Model

A simplified model was established in the Open System for Earthquake Engineering Simulation (OpenSees) finite element software (McKenna et al 2000) to simulate the global non-linear and inelastic behavior of the post-tensioned walls. It had been verified that the combination of lumped plasticity spring and elastic beam column element can ideally simulate the seismic response of post-tensioned member (Palermo et al 2005). The bilinear rotational spring was utilized to represent the behavior of post-tensioning response. The elastic Timoshenko beam, which takes the shear deformation into account, was used to model the response of walls, because the behavior of the wall is similar to thick beam (Figure 1). For the specimens with axial dissipaters, two truss elements with SAW material were applied to simulate

the hysteretic steel elements. The top of the truss element is connected with the rigid links, while the bottom was fixed directly to the base. For the coupled-wall specimens with UFPs, a truss element with calibrated Steel02 material was placed between two rigid links (Figure 2).

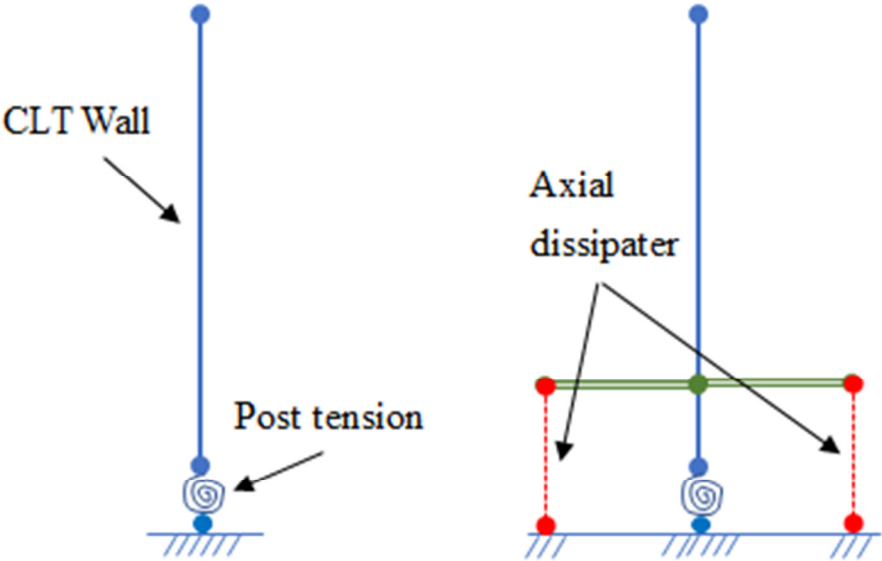


Figure 1: Model of single wall without (left) and with (right) energy dissipators

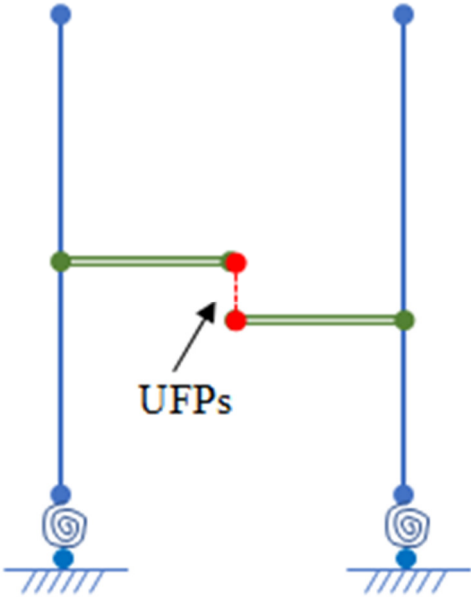


Figure 2: Model of coupled wall

**2.2 Frame Model**

The numerical model of the post-tensioned (PT) timber beam-column connection was also developed in OpenSees to understand the behaviour of the timber frame. The numerical model of the timber frame is

shown in Figure 3. The column is pin connected to the ground and the end of beam is fixed connected using a roller. The reversed cyclic lateral displacement demand is applied at the top end of the column. The behaviour of timber connection with post tensioning in the beam can be simulated using a series of the zero-length rotational spring and elastic beam column elements. The post-tensioning behaviour is represented as a bi-linear elastic material. The model developed can appropriately capture the post tensioning response as well as the rocking mechanism implemented in the connection. It is also important to include the flexibility of joint panel into account using an elastic zero-length rotational spring at the beam-column connection. The remaining members are simulated using elastic beam column elements in the OpenSees model.

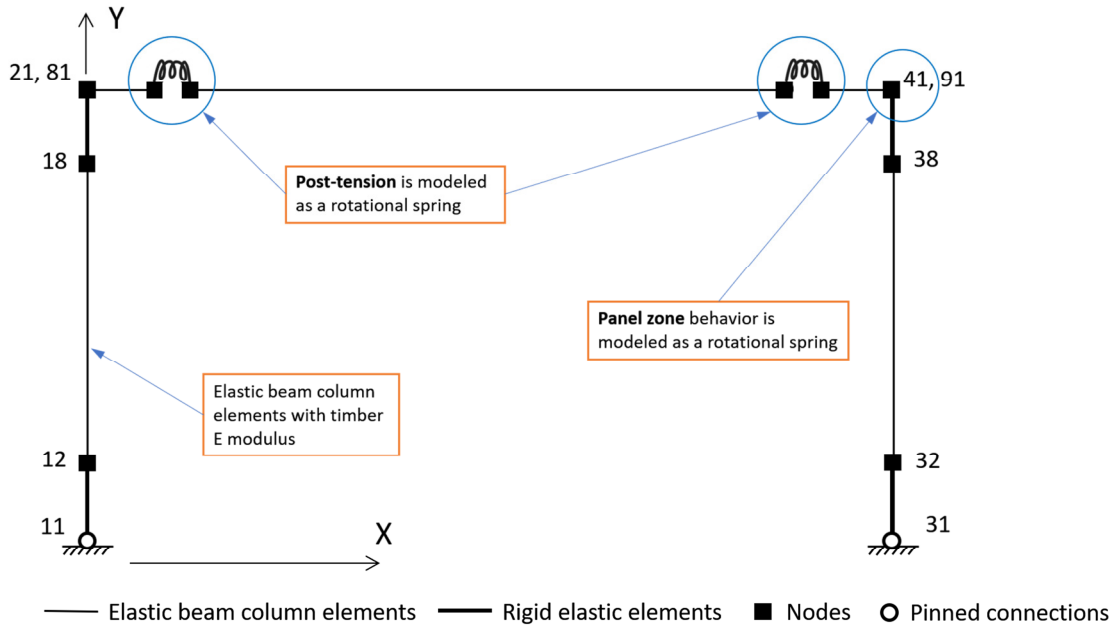


Figure 3: Model of coupled wall

### 2.3 Frame-Shear Wall Model

The two systems were implemented within a single model with multiple stories to observe performances and identify the interaction. The combined model (Figure 4) was detailed to allow compatibility as well as relative displacements between the two major components. This was done through careful restraints and release of degrees of freedom particularly at the wall-frame interfaces.

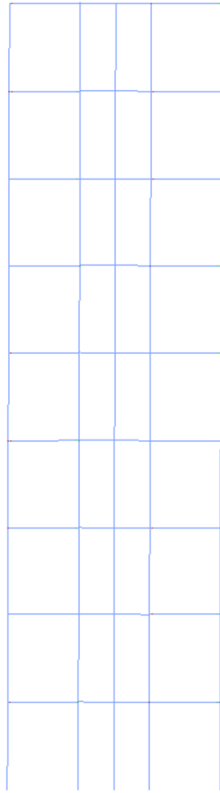


Figure 4: Frame-coupled wall combined model

### 3 ANALYSIS AND RESULTS

#### 3.1 Single Wall-Frame

The single wall frame model included a wall and a frame combined. The total base shear plotted against displacement at the top is presented in Figure 5. It is essentially elastic with complete re-centering ability.

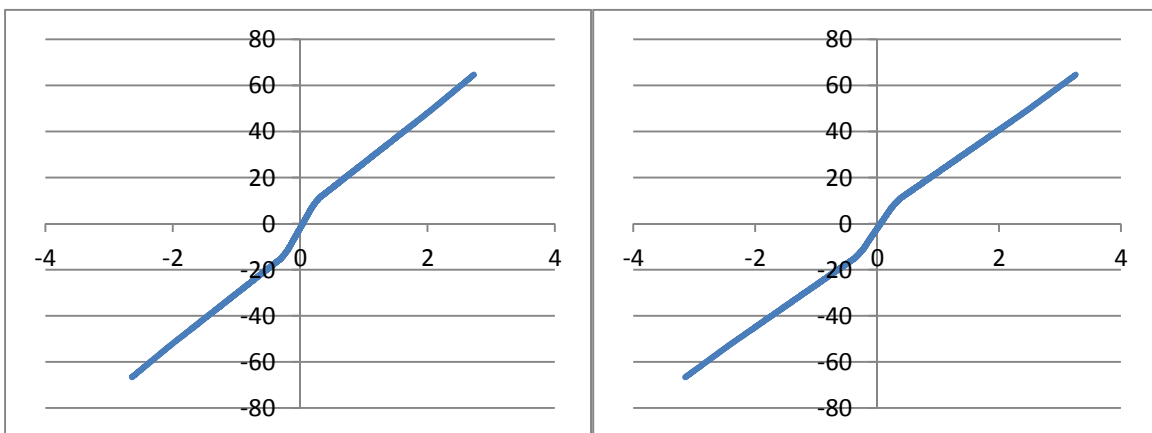


Figure 5: Force-Displacement at base (left) and top (right)

### 3.2 Coupled Wall-Frame

The coupled wall model consists of two frames, one at each side attached to the coupled walls. The base shear in the walls and frames against the top displacements are plotted in Figure 6.

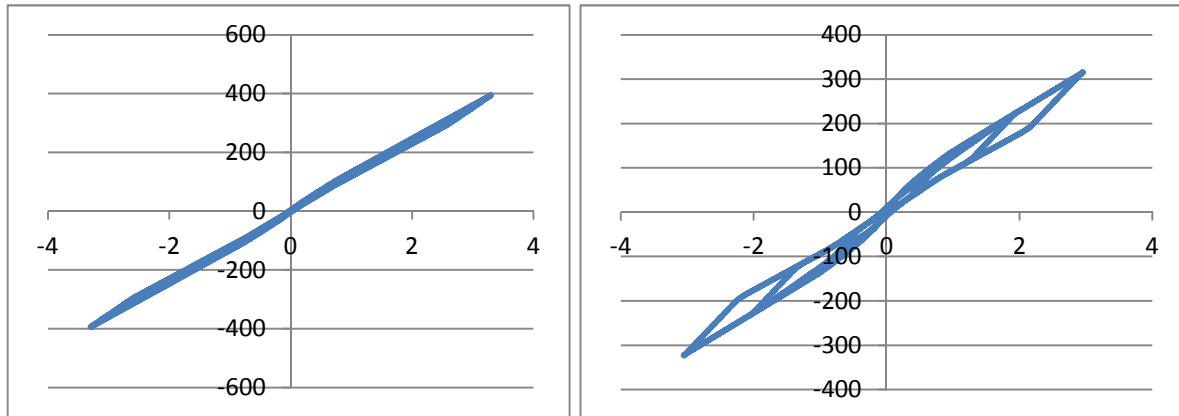


Figure 6: Force-Displacement in walls (left) and frame (right) at base

## 4 BUILDING EXAMPLE

A 20-story building model was analyzed to evaluate performance of the frame-shear wall systems. A number of structural systems were investigated to compare their performances under a series of gravity and lateral loads.

### 4.1 Description

The virtual building located in Vancouver, BC is meant for commercial/business occupancy. The 65-meter tall building is rectangular in plan with 440 sq. m floor area (Figure 7). The podium and bottom 10 stories have some extended floor areas (Figure 2). There is a central core housing staircases and elevators. Rest of the structural system is placed along the periphery, allowing completely column-free spaces in-between. There are two additional levels on top of the core for mechanical room and a water tank.

The building structure includes a concrete podium supporting the core and mass timber superstructure. The floor spans are mainly in 5 m and 6 m. The column sizes of the building are optimized into two groups for varying axial forces. Several different structural systems were used to investigate the feasibility and their relative merits. The gravity system of all the cases is Glulam beams and columns. The center core was divided into two parts: a concrete elevator shaft and two mass-timber stairwells. In addition there were lateral load resisting systems with post-tensioned frames. The details of the systems are presented in Table 1.

Table 1: Structural systems used

Designation	Core Details	Supplemental System
CT-PTPT	Concrete elevator shaft + CLT stairwell	Post-Tensioned Frame
CT-PTSW	Concrete elevator shaft + CLT stairwell	Post-Tensioned Frame+ Shear Wall

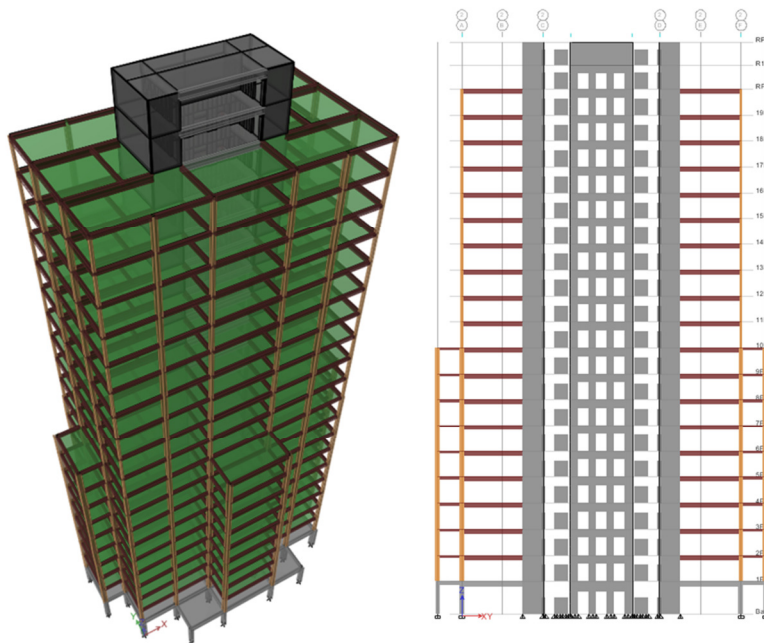


Figure 7: 3-D view (left) and section (right) of building

#### 4.2 Modelling and Results

The post-tensioning can be simulated as rotational springs at the end of the beams, which is so called “lumped plasticity approach”. Additionally, an elastic rotational spring is also applied at the position of column panel joint simulating the flexibility of the timber columns. A single equivalent rotational stiffness for post-tensioning was applied within the model.

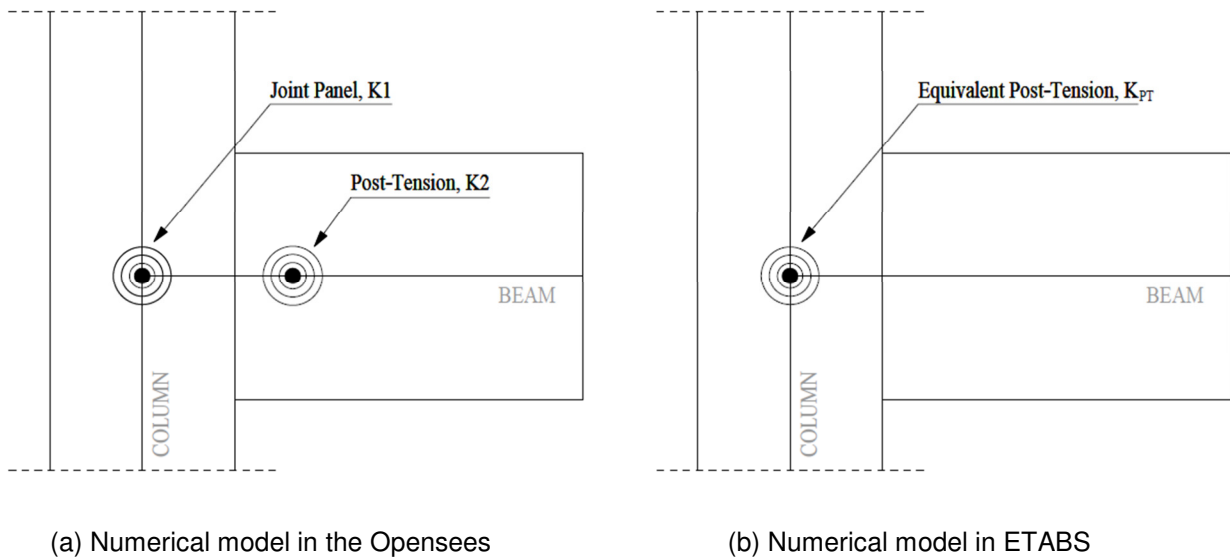


Figure 7: The numerical modeling method of post-tensioning effect

The model was analyzed for gravity and lateral load combinations. Seismic base shear values for two structural systems are presented in Table 2.

Table 2: Seismic base shear

Structural System	Long Direction (kN)	Short Direction (kN)
<b>CT-PTPT</b>	13638.9	12311.3
<b>CT-PTSW</b>	13688.5	9900.9

## References

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