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STRUCTURAL SYSTEMS FOR A 20-STORIED HYBRID BUILDING

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Abstract: Options for a tall hybrid building with timber structural systems are investigated as part of a desktop exercise. The proposed commercial building has a concrete podium at the ground level. There is a central core and structure along the perimeter leaving complete column-free space in between. The different structural systems include concrete and concrete-timber hybrid core in different combinations with frames, shear walls and braced frames. The building is located in region with high seismic risk and considerable wind load. Fire safety and vibration requirements are taken into considerations the design in addition to the structural and serviceability requirements. The results confirm the feasibility of wooden structural systems in tall hybrid buildings. Not surprisingly the design is mostly governed by drift under wind or seismic load. But the code requirements can be met with appropriate combinations of systems and materials. Structural member sizes have been determined and connection details for typical members have been detailed. Construction aspects have also been considered and an innovative practical construction scheme has been proposed.

1 INTRODUCTION

With increased confidence from earlier designs and widespread availability of suitable wood-based materials professionals are trying to push the limits of designing tall buildings with wood. Derived from practical realities, one of the recent trends is to use of materials such as concrete and steel in combination with wood to come up the most economical solution. The concept is investigated here through comparative designs of a virtual tall building with variations in structural systems such as those with concrete and timber shear walls, timber braces and post-tensioned timber frames.

2 BUILDING 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 1). 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 three lateral load resisting systems with shear walls, braces and post-tensioned frames. The details of the systems are presented in Table 1.

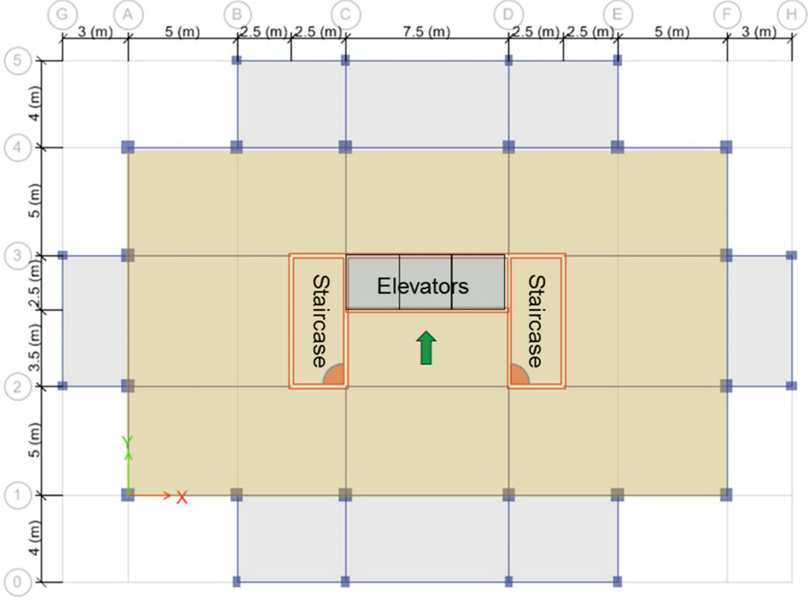


Figure 1: Building plan

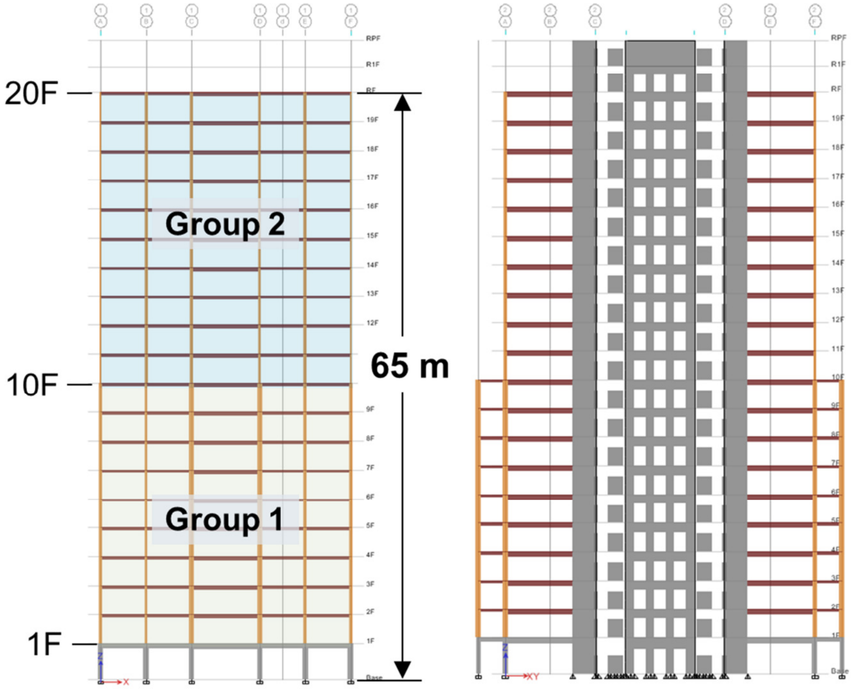


Figure 2: Side elevation (left) and section (right) of the building

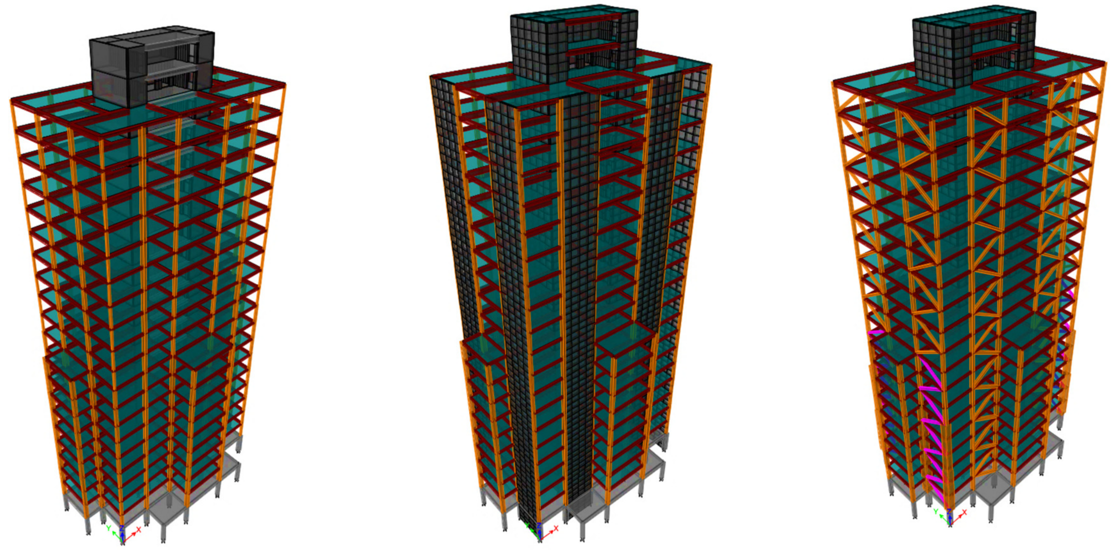
Table 1: Structural systems used

Designation	Core Details	Supplemental System
CC-TT	Concrete	N/A
CT-TT	Concrete elevator shaft + CLT stairwell	N/A
CT-SWSW	Concrete elevator shaft + CLT stairwell	Shear Wall
CT-BFBF	Concrete elevator shaft + CLT stairwell	Timber/Steel Braces
CT-PTPT	Concrete elevator shaft + CLT stairwell	Post-Tension Frame
CT-PTSW	Concrete elevator shaft + CLT stairwell	Post-Tension Frame (X) Shear Wall (Y)
CT-PTBF	Concrete elevator shaft + CLT stairwell	Post-Tension Frame (X) Timber /Steel Braces (Y)

3 NUMERICAL MODEL

3.1 Model Description

A three-dimensional numerical model of the complete building was developed in finite element software ETABS (Reference). Models of the structure with three structural systems: with reinforced concrete core, CLT core with exterior shear walls and CLT core with exterior braces are shown in Figure 3.



(a) RC core only

(b) CLT core with shear wall

(c) CLT core with braces

Figure 3: Structural system components

3.2 Material Properties

The strength of concrete used for the building was 35 MPa. The columns are D. Fir-L 16c-E, while the beams are Spruce-Lodge.-Pine 20f-E. For the shear walls Cross-Laminated Timber (CLT) graded in E1M5, 7-layer (315E) and 5-layer (245E) panels were chosen to be the shear panels in 1st group and 2nd group, respectively. The strength parameters of layers were input in ETABS as orthogonal material. And the shear wall sections were defined and modeled as a combination of directional layered shells.

Table 2: Material properties of Glulam for Beams and Columns

Member Properties	Columns and Braces (16c-E)	Beams (20f-E)
Modulus of elasticity, E	12400	10300
Bending moment, f_b	14.0	25.6
Longitudinal Shear, f_v	2.0	1.75
Compression parallel, f_c	30.2	25.2

4 ANALYSIS AND RESULTS

The building was analyzed for wind and seismic load separately in addition the dead, live and snow load. The effects of factored principal plus companion loads were determined in accordance with the load combinations of the NBCC 2015.

The effects of accidental torsional moments due to $(\pm 0.10D_n)F_n$ at each level were assigned in ETABS with the eccentric ratio of 0.1 at both directions, based on the Clause 4.1.8.12 (4). On the other hand, according to 4.1.8.12 (8), the base shear obtained from spectrum analysis should be at least as large as 80% of the base shear calculated from static analysis procedure. For the inter-story drift limitation under seismic load, according to 4.1.8.13 (3), the value should be below 2.5% for a building with importance factor, $I_E = 1.0$.

The data of linear spectrum of Vancouver was referred to NBCC 2015 Division B, Appendix C, Table C-3. The wind load in ETABS was defined by its built-in program with NBCC 2015. The inter-story drifts from the linear dynamic analysis and from the serviceability wind load combination in x and y direction are illustrated in Figure 4. The results suggest that inter-story drifts of the structure remain under the limit for both wind and seismic loads for the concrete or hybrid core when used with lateral force resisting system.

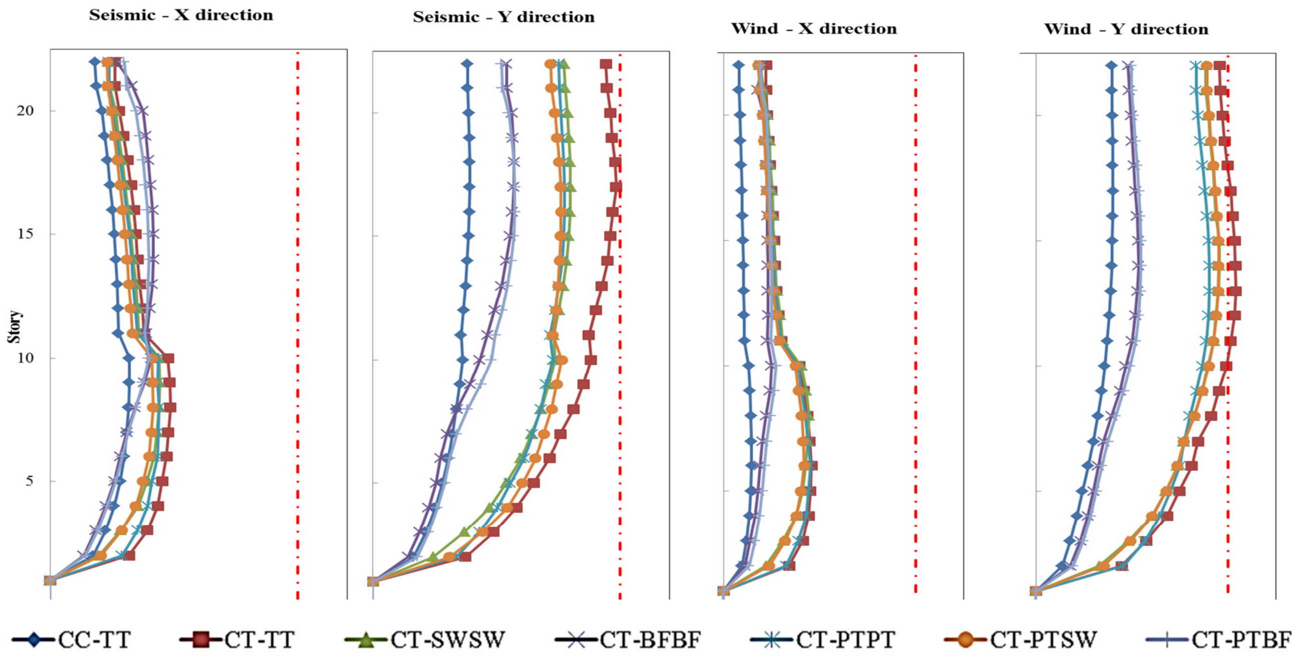


Figure 4: The inter-story drifts under seismic load

5 CONCLUSION

The analysis showed that it is possible to design a 20-story building with mass timber in combination with concrete and steel to satisfy the requirements in National Building Code of Canada under both wind and seismic loads. Six different structural systems and their combinations were compared. The results illustrate that case CT-SWSW and CT-PTSW can meet the drift requirements and the DCR of shear forces in CLT panels can be accepted; hence, these are the two practical and economical scenarios.

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