WOOD INNOVATION AND DESIGN CENTRE – LATERAL LOAD RESISTING SYSTEM

E. Karsh, Equilibrium Consulting Inc.

Email: ekarsh@eqcanada.com

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WIDC, TALL WOOD, GLULAM, CLT, LVL, PSL, HSK

ABSTRACT

This paper describes the structural system for the 29.5 metre high Wood Innovation and Design Centre in Prince George, British Columbia, with a particular focus on the CLT lateral load resisting system. The Wood Innovation and Design Centre is a provincially funded, 4,800 m^2, 6 + 2 storey academic and office project funded by the Province of British Columbia as a demonstration project to promote the use of mass timber in commercial applications. The project was granted a greater site specific maximum height allowance but was however required to undergo a stringent peer reviewed alternate solution permitting process.

The lateral load resistance for the building is provided by the CLT stair and elevator core, built of balloon framed panels as large as 10.5 metres long by 3 metres wide, as well as the CLT floor diaphragms. The core connections consist of self-tapping screws, off-the-shelf steel bracket connectors, custom plate and timber rivets as well as the HSK connection system for the wall hold downs and base shear connections.

1. INTRODUCTION

The Wood Innovation and Design Centre (WIDC) is a government sponsored academic and office demonstration project with the goal of inspiring institutions, private sector developers, and other architects and engineers to embrace wood panel and heavy timber construction in taller and larger buildings. At 29.5 metres, WIDC was the tallest modern “all-wood” building in the world at the time of completion in October, 2014.

The design team specifically elected not to use concrete above the ground floor slab, with the exception of a composite concrete topping at the mechanical penthouse used to isolate the mechanical equipment acoustically.

The form of the building is rational and restrained, allowing the beauty of wood to shine through. The building exterior is inspired by bark peeling away from the trunk of a tree: the bark on the north side is thick and protective from the wind and the cold, thinning away towards the south sunlight. The building is clad with a combination of natural and charred cedar panels. Wood charring is a centuries-old technique, borrowed from Japanese craftsmen, used to increase the wood’s resistance to fungus and decay as well as to increase its flame spread rating.

2. GENERAL DESCRIPTION

The Centre is an 8 storey structure, including the second floor mezzanine and penthouse levels, with a total area of approximately 4,800 square metres. The building houses the University of Northern British Columbia Master of Engineering in Integrated Wood Design program on the lower three floors, and the Emily Carr Design School on the upper four floors.

As a provincially funded demonstration project, the mandate for the Wood Design Innovation Centre was of course to expose as much of the structure and feature as many BC wood products as possible.

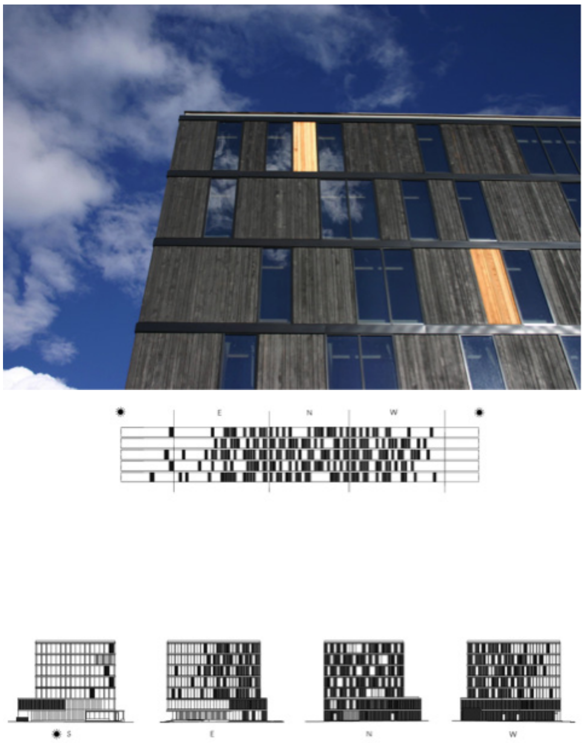

Figure 1: *Charred and natural cedar panel façade elevations with glazing increasing from north to south.*

Exposing the majority of the structure poses challenges beyond basic structural design requirements, including acoustic and fire resistance and the incorporation of services. Much thought was given in developing a structural concept that met those requirements in an architecturally interesting and practical manner.

The building was delivered under a design-build contract with a schedule of only 16 months from beginning of design to occupancy. The project was given a site-specific height exceedance approval by the provincial government, but required a special alternate solution submission which included a fully engineered fire safety analysis and required that an independent shadow team peer review the architectural, structural and fire engineering design process and submissions.

The very aggressive design and construction schedule for the project could only be achieved by overlapping the design and construction activities. This was achieved by initiating the shop drawing process as soon as the member sizes and geometry were set. A "stick" model of the structure was generated and reviewed while site work and detailed connection design was under way, saving at least two months in the overall process.

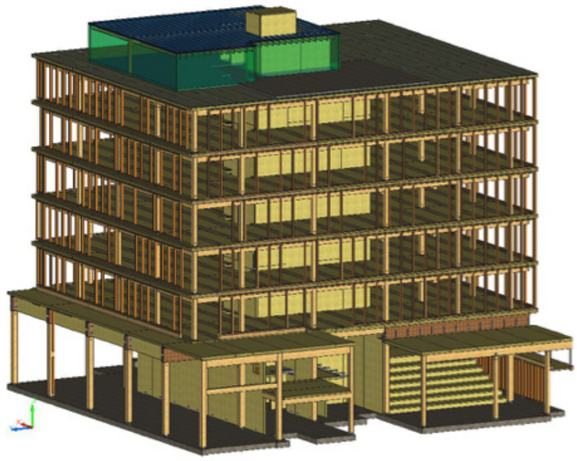

Figure 2: *Member-only or "stick" model of the building for early coordination and review.*

3. GRAVITY SYSTEM

The main gravity system consists of a glulam post and beam structure supporting Cross Laminated Timber (CLT) floor slabs. The beams frame into the column faces using pre-engineered aluminium dovetail connectors, or are pocketed through, allowing columns to bear on one another on end grain to make use of glulam's high longitudinal-to-grain bearing capacity and avoid cumulative shrinkage over the height of the building.

The CLT floor slabs are staggered and overlapped, creating a corrugated profile to allow for the incorporation and concealment of services in the floor cavities above and below. The upper and lower CLT slabs are connected together into a very robust corrugated composite element using the proprietary German connection system HSK. The roof structure consists of a single layer of CLT panels with a 600mm gap between the panels to provide service spaces. A 19mm plywood diaphragm bridges the gap and is held off of the CLT slab with 19mm strapping to create an air space. This air space prevents water from being trapped between the plywood and CLT in the occurrence of rainy weather, as both plywood and CLT are relatively airtight and could trap water for up to 6 months if not allowed to vent, almost certainly initiating mould or even rot.

Parallel Strand Lumber (PSL) was used for transfer beams over the lecture theatre and laboratory spaces for its high shear, bearing and bending capacity, as well as its low moisture content to avoid excessive differential shrinkage. Double PSL 175x1220mm were required over the lecture theatre. Given that PSL is manufactured to a maximum depth of 483mm, the

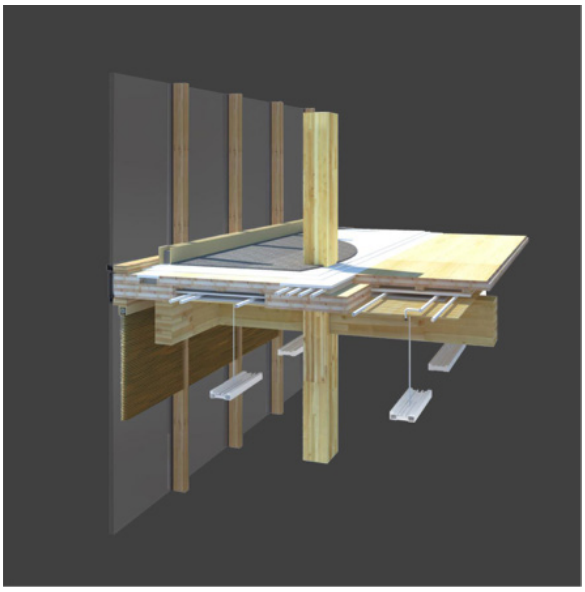

Figure 3: *Corrugated CLT composite floor system, showing the integration of services.*

transfer beams were achieved by block gluing smaller billets together, a process which has been used in BC for over two decades.

The foundation for the building consists of a raft slab, which was preferred over standard strip and pad footings for this particular project due to cost and speed of construction, a significant consideration given the extremely tight timeline on this project.

4. DUCTILITY FACTORS FOR CLT

In Canada, the predicted elastic base shear is reduced (divided) by the product of two factors: R_d x R_o. The ductility factor, R_d, is a measure of the predicted ductility level of the lateral load resisting system, normally determined by convention or by FEMA procedure P695 in North America. The over strength factor, R_o, represents the estimated over strength of the lateral load resisting system, which is the difference between the code prescribed (calculated) capacity of the system and the load at which the system is expected to realistically begin to yield.

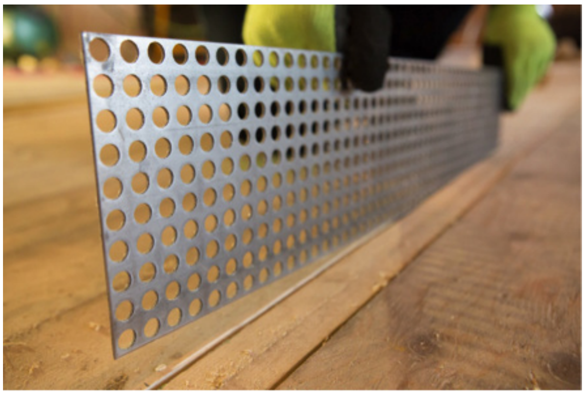

Figure 4: *HSK Connection of the corrugated CLT floor panels.*

In the case of Cross Laminate Timber, both in Canada and the US, the FEMA procedure is under way but has yet to be completed. In the meantime, conservative values for R_d and R_o are being used based on preliminary tests using single panel specimens anchored to the base using off-the-shelf proprietary hold down anchors and angle brackets.

It is widely agreed that more complex multi-storey, multi-panel shear wall systems, joined together using hundreds of self-tapping screws and anchored to the foundations using high-ductility connection systems will provide significantly more ductile systems than those tested in North America to date.

5. LOAD REQUIREMENTS

The project site in Prince George, British Columbia is located in a central region of the province where both wind and seismic loads are relatively low. The design climatic information for the project is included below.

Climatic Design Data (per BC Building Code 2010)

Roof Snow Load S = 2. 92 kPa

Hourly Wind Pressure: (1/10) = 0.29 kPa

Hourly Wind Pressure: (1/50) = 0.37 kPa

Average factored design wind pressure = 0.8 kPa

Seismic Design Data

5% damped spectral	Sa(0.2) = 0.130
accelerations	Sa(0.5) = 0.079
	Sa(1.0) = 0.040
	Sa(2.0) = 0.026
Peak ground acceleration	PGA = 0.070
Site Class (soil factor)	D
Ductility factor	R_d (CLT) = 2.0
Over strength factor	R_o (CLT) = 1.5

Both wind and seismic loads were considered in the design of the lateral load resisting system, as wind governed under certain conditions and seismic governed in others. Given the relatively low seismic demand for this site, the seismic design was carried out using a simple elastic response spectrum analysis using equivalent properties for CLT walls.

For comparative purposes, we have tabulated the service and design (factored) wind forces, as well as the design seismic base shear (based on $R_d x R_o$ = 3.0), and the prescribed elastic base shear, as a percentage of building weight.

	% of Building Weight
Service Wind	3.0%
Factored Wind	4.5%
Design Base Shear	3.0%
Elastic Base Shear	9.0%

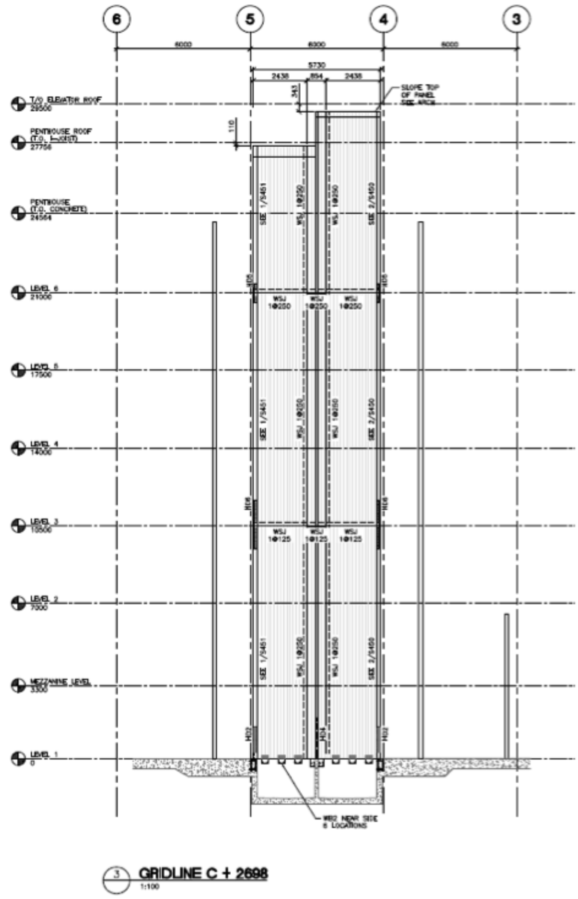

Figure 5: *Elevation of Typical CLT shear wall.*

It is of note that the factored design wind force exceeds the design (reduced) seismic base shear based on $R_d x R_o$ of 3.0. On the other hand, the elastic seismic load is twice as high as the factored wind load. In other words, the wind load governs for an equivalent $R_d x R_o$ greater than 2.0, and the seismic design loads govern for $R_d x R_o$ values smaller than 2.0. This means that in our case, there was no advantage in designing the building for $R_d x R_o$ greater than 2.0 as wind would have governed anyway.

6. LATERAL LOAD RESISTING SYSTEM

The lateral resistance for the Wood Design and Innovation Centre is provided by the stair and elevator core, which are entirely built of CLT from the raft foundation slab to the penthouse roof.

The raft slab is typically 400mm thick, and is thickened to 600 mm underneath the core and around the perimeter of the building for additional boundary condition stiffness and frost protection purposes.

Most of the shaft walls consist of 169mm thick, 5 layer spruce CLT wall panels, except for the 239mm thick,

Figure 6: *CLT core installation in progress.*

7 ply CLT wall adjacent to the main lobby stair, which has a greater unsupported length. Where CLT walls are left exposed, the exposed lamination consisted of Douglas Fir MSR lumber (lam stock) to achieve a better finished appearance.

The shaft walls are balloon framed (vertically continuous) over 3 storeys with up to 3 metre wide x10.5 metre tall panels, connected together vertically and then spliced horizontally at the 3^{rd} and 6^{th} floors in order to achieve the 29.5 metre core height.

Vertical walls joints are half-lapped and connected with self-tapping screws over the full height of the core. Horizontal joints at the 3rd and 6th floors are also half-lapped and connected with self-tapping screws to resist horizontal shears, and connected each end of the wall with hold downs consisting of 6mm steel plates and timber rivets to resist uplift forces.

Figure 7: *Typical hold down with the reduced section plate and HSK connectors.*

The base of the core is anchored to the raft foundation for shear using custom bent plates with ring nails and epoxied concrete anchors in locations with light loads, and base plates with the HSK perforated plate and adhesive system by TiComTec in more heavily loaded locations. Uplift forces are resisted by steel plates anchored to the CLT using the same HSK perforated plate and adhesive system by TiComTec, and field welded to embeds cast into the raft slab. These steel plates have a reduced-area section which is designed to allow the steel to yield in a ductile manner before the HSK fails.

The shear walls were designed to remain elastic under the factored wind load, and meet the code required maximum wind load drift limit of height/400. For loads beyond that level, the walls were designed to provide the required ductility through yielding of the vertical joints first, and then the hold downs at a slightly higher load, providing a degree of ductility much superior to the required R_dR_o of 2.0.

The diaphragms are provided by the corrugated CLT slabs, which are connected together with a combination of self-tapping screws and the HSK system. The diaphragm CLT panels are connected to the post and beam frames using self-tapping screws, and to the shear walls with 89x241mm laminated strand lumber (LSL) ledgers, which are in turn fastened to the face of the shear walls panels using a combination of horizontal and 45 degree self-tapping screws.

Figure 8: *Floor to ledger connection at the core.*

7. OTHER STRUCTURAL ELEMENTS

Other structural elements of note include the 80x228mm Brisco Fineline (LVL) window mullions, to which the glazing system is directly mounted. Laminated veneer lumber was chosen for the support of the glazing system due to its low post manufacturing moisture content and dimensional stability.

The main entrance canopy and lobby feature stair are also built of Brisco LVL slabs, adding to the pallet of BC sourced timber material used in the building. Yellow Cedar glulam posts were used for the exterior colonnade supporting the exterior edge of the main entrance canopy.

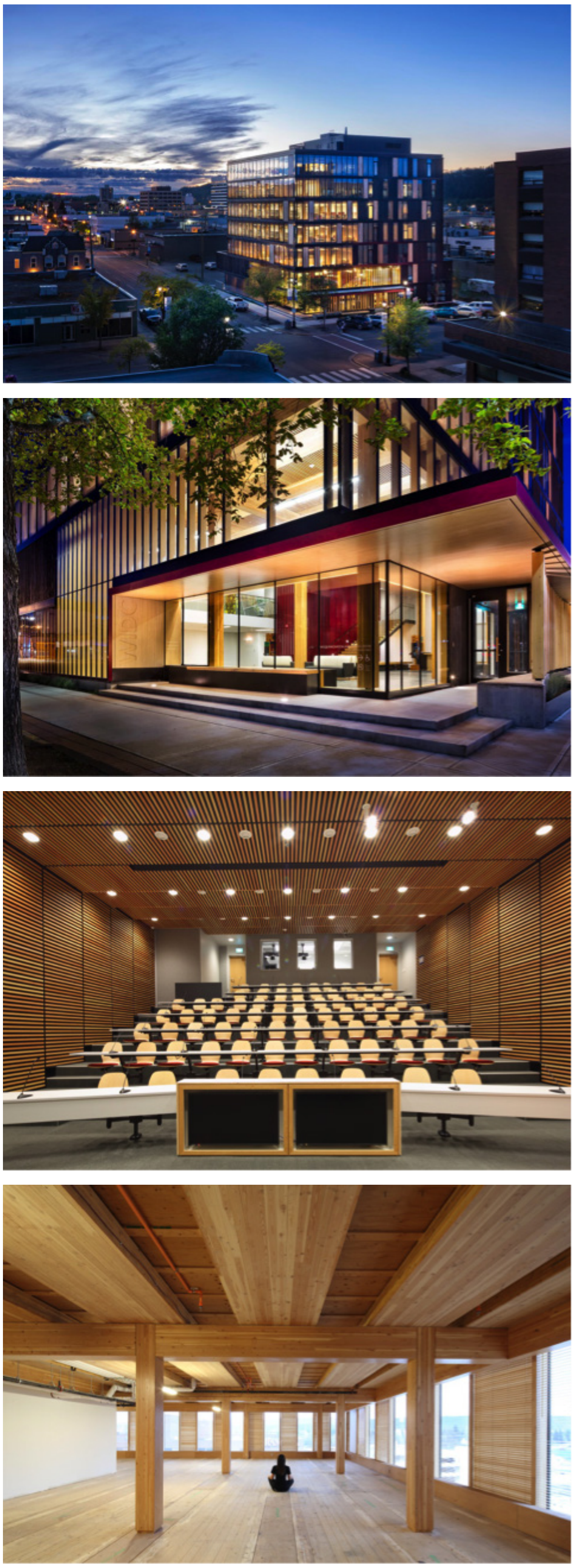

Figure 9: *Completed project. From top to bottom: Overall view, lecture theatre, main entrance, and shell only (pre-tenanted) top floor with exposed roof structure.*