



Seismic Design with Wood:

Solutions for British
Columbia Schools

A CASE STUDY



SEISMIC DESIGN WITH WOOD: Solutions for British Columbia Schools

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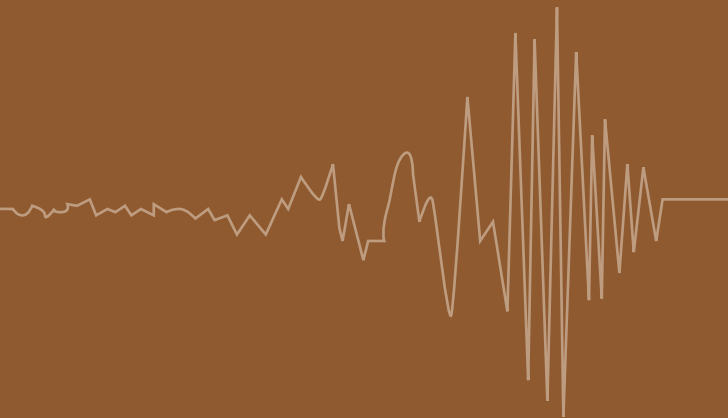
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bottom left: Cordova Bay Elementary School: photo credit: Iredale Group

bottom middle: Surrey Christian School Primary Wing:
photo credit: KMBR Architects Planners Inc.



“The catastrophic results from earthquakes in Japan and New Zealand have reiterated the importance of preparing for similar events here in B.C. Nothing is more important than the safety of students in this province, and this seismic upgrade project will provide current and future generations of students with secure buildings in which to work and study.”

*Hon. Don McRae, Minister of Education
Announcing funding for the seismic upgrade
of Wellington Secondary School
Friday, February 1, 2013*

1. Introduction: Earthquakes, Seismic Design and Public Safety

Although seismic events occur all over the world, the areas most susceptible to large earthquakes are those that lie along active fault lines. These fault lines are found at the boundaries of the Earth's tectonic plates, including the so-called 'Ring of Fire' (Figure 1.1) that encircles the Pacific Ocean. The Ring passes through British Columbia, as well as other active earthquake zones such as Japan, New Zealand, Chile, California and Alaska.

More sophisticated approaches to the seismic design of buildings have been developed as our understanding of earthquake behaviour has evolved. The experience gained from a succession of major earthquake events has confirmed that well-designed, ductile wood buildings performed well, especially from the standpoint of life safety.

2. British Columbia's Seismic Upgrade Program

With several major earthquakes having struck other countries on the Ring of Fire in the past two decades, there is a heightened awareness of the risk that British Columbia faces. Concern has grown throughout the province that many of its public buildings, including a significant number of its older schools, do not meet current safety requirements in terms of their seismic design. In fact, a survey commissioned by the provincial government and undertaken by the Association of Professional Engineers and Geoscientists of BC (APEGBC) in 2004 determined that 339 of the province's schools were at high risk of structural collapse in the event of a major earthquake, and hundreds more were at moderate risk.

In response to these findings, the province developed a phased seismic upgrade program to retrofit and/or replace the most vulnerable school buildings. To date, 224 schools in 37 school districts have been upgraded or replaced at a cost of almost \$1 billion, and work is scheduled or underway on the remaining 115 high risk schools.

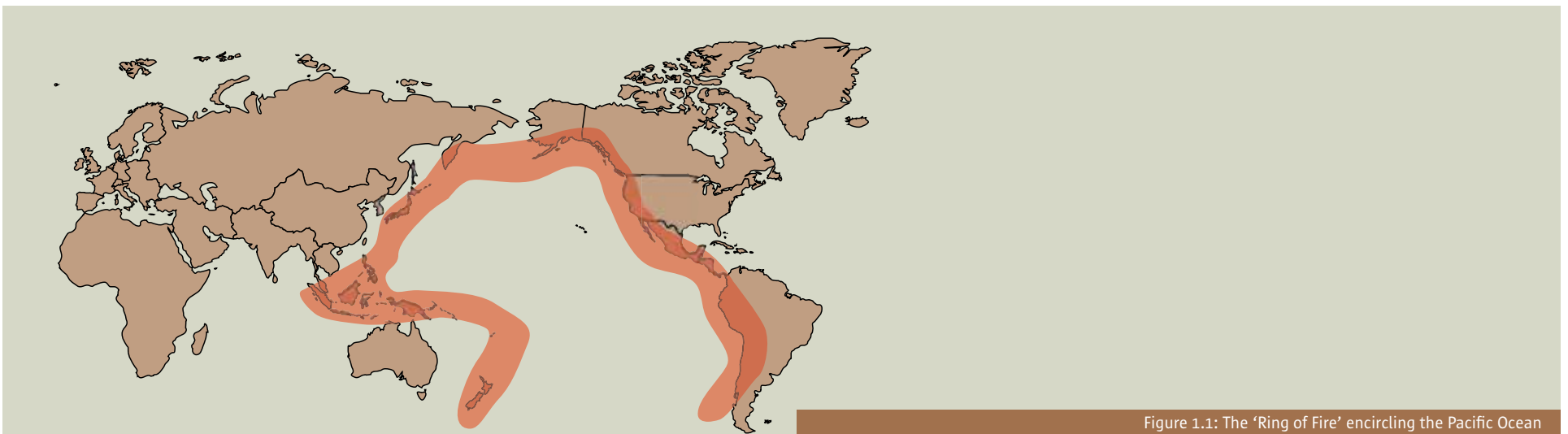


Figure 1.1: The 'Ring of Fire' encircling the Pacific Ocean

SEISMIC RISK RATINGS

Structural engineers calculate seismic risk ratings for buildings based on the perceived risk of damage from an earthquake. This calculation forms the basis for prioritizing remedial work. The current classification system used in British Columbia divides schools into high (H), medium (M) and low (L) risk categories. The high risk category is further divided into H1, H2 and H3 sub-categories and, for the purpose of this case study, only these three levels of risk will be discussed. The classification criteria for high risk structures are as follows (Figure 2.1):

High 1 (H1)	High 2 (H2)	High 3 (H3)
The most vulnerable structures; at highest risk of widespread damage or structural failure; not reparable after a seismic event. Both structural and non-structural seismic upgrades are required.	Vulnerable structures; at high risk of widespread damage or structural failure; likely not reparable after event. Both structural and non-structural seismic upgrades are required.	Isolated failure to building elements such as walls are expected; building likely not reparable after event. Both structural and non-structural seismic upgrades are required.

These classifications are applied not to schools as a whole, but to ‘blocks’ within each school. Blocks represent areas within a school that are of different construction types and have different structural characteristics. For example, gymnasiums will typically have a different structural system to classroom or administration blocks, and as a result may have a different risk rating.

SEISMIC FORCES

Seismic forces are initiated by the movement of tectonic plates and take the form of waves that travel either in the body of the Earth or at the surface. Body waves are further subdivided into primary (P) waves that behave like the repeated compression and release of a spring, and shake a building in the horizontal plane, and secondary (S) waves that are transverse in nature, and can also shake a building in the vertical plane. An important consideration in seismic design is that of ductility. In the case of major earthquake events, the energy dissipative components are designed to perform plastically, absorbing energy through deformation, permitting a certain level of damage to the structure but preventing the catastrophic collapse of the building. In typical wood buildings the main source of ductility is the connections.

Figure 2.1: Seismic Risk Ratings

3. Seismic Upgrading of Wellington Secondary School

Located in Nanaimo on the east coast of Vancouver Island, Wellington Secondary School is a two-storey, 10,750 m² structure with a capacity of 900 students from Grades 8 to 12. The school was built in several phases from 1969 to 2000. The plan is unusual and, at the time of the seismic assessment, consisted of a circular central block (Block F) with a small open courtyard at its centre, from which five other blocks radiated. These outer blocks (Blocks A, B, C, D and E) contained the classrooms, shops, a gymnasium and administrative spaces (Figure 3.1).

SEISMIC ASSESSMENT AND DESIGN APPROACH

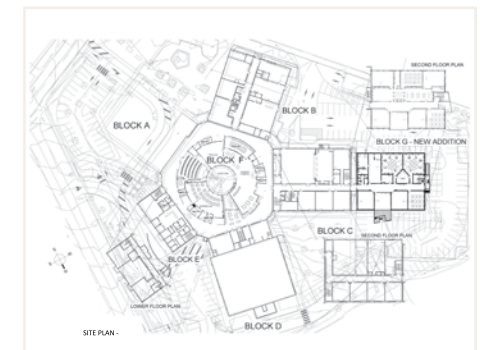
In 2012, structural engineers from Herold Engineering Limited prepared a seismic project investigation report (SPIR), which identified four of the blocks (all except Blocks C and D) as high risk (H1) and in need of seismic upgrading. The two seismic mitigation options considered were: comprehensive retrofit upgrades to bring all the existing structures up to current code standard; and, a partial retrofit upgrade, together with the demolition and replacement of the highest risk portions of the building (Blocks A and F). In the absence of other considerations, these two options were approximately equal in terms of cost.

This initial analysis was followed by a seismic project definition report (SPDR) prepared by Herold Engineering Limited and KMBR Architects Planners Inc. that re-evaluated the options in regard to their logistical, functional and programmatic implications for school operations during and after construction. Site constraints, the provision of temporary classroom accommodation, parking, site access and staging all had impacts on the cost and complexity of the project, and in combination, these considerations made the demolition and rebuild option the better choice.

AN EXPEDIENT AND ECONOMICAL SOLUTION

A comparative cost analysis concluded that the most economical way to provide the ‘swing space’ required to accommodate displaced students during a phased renovation project was to construct a new classroom block, then demolish Block A, the most expensive block to upgrade.

The preferred option included the seismic upgrade of Blocks B, D and E, the demolition and rebuilding of Block F and the demolition and replacement of Block A with a new classroom block (in another location and referred to as Block G) (Figure 3.2). With a strategic approach to phasing of the work, this option also provided the opportunity for some basic reorganization of the program to reflect contemporary approaches to teaching and learning.



Credit: KMBR Architects Planners Inc.

Wellington Secondary

Figure 3.1: Site plan - existing

Figure 3.2: Site plan - after renovation and addition



photo credit: Herold Engineering Ltd.

Figure 3.3: Wellington Secondary: dismantling of Block F

SEISMIC ANALYSIS OF BLOCK F

The original 1969 library structure (Block F) presented a considerable challenge to upgrade, and the analysis merits more detailed discussion. The roof structure consisted of radially arranged concrete T-beams resting on inner and outer concrete ring beams supported on concrete columns (Figure 3.3). These columns were supported in turn on concrete walls at basement level. The entire structure was heavy and, having been designed to a much less demanding seismic standard, did not have the required ductile connections between the elements nor adequate lateral restraint in the radial direction.

Generally, comparing two buildings with the same seismic-force-resisting system (SFRS) of equal height in the same geographic location and with the same soil conditions, a heavier building will attract more seismic force than a lighter building. The heavy weight of the Block F structure would have required a large number of custom steel brackets, substantial cross-bracing and enlarged foundations to transfer the required loads (significantly increased under current seismic codes) to the ground. The more desirable, and cost-neutral, alternative was to demolish the existing structure and replace it with a new lightweight building.

Wood was chosen for this new structure for reasons of economy, speed of construction and aesthetics (Figure 3.4). The wood solution met the constraints of a fast-track schedule and a tight budget, and at the same time introduced a warm look to the core of the school.

Demolition of Block A opened up an area adjacent to this core, that is now a new glazed entrance and the core itself has been transformed into a learning commons enlivened by a variety of activities.



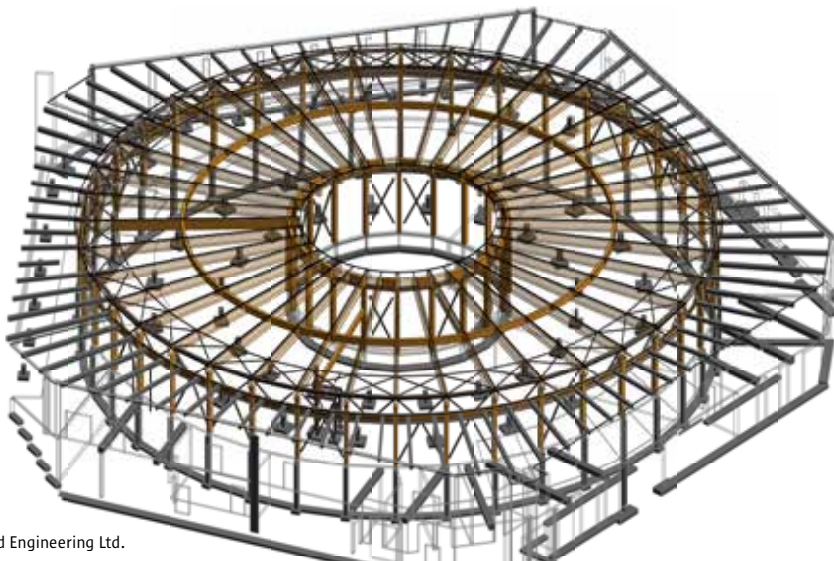
photo credit: ©2016 Artez Photo.com

Figure 3.4: Wellington Secondary: New structural members in Block F

DETAILED DESIGN

The seismic retrofit upgrading of Blocks B and E was carried out at the beginning of the project to fit with classroom and administrative scheduling. Both blocks had been constructed in 1987 with a combination of precast concrete panels, unreinforced (or partially reinforced) concrete masonry walls, and heavy timber roofs with glulam beams, tongue-and-groove decking and plywood sheathing. The seismic retrofit upgrading included additional reinforcement of the masonry walls, higher ductility connections between walls and roof, and the strengthening of the roof diaphragm with an additional layer of plywood.

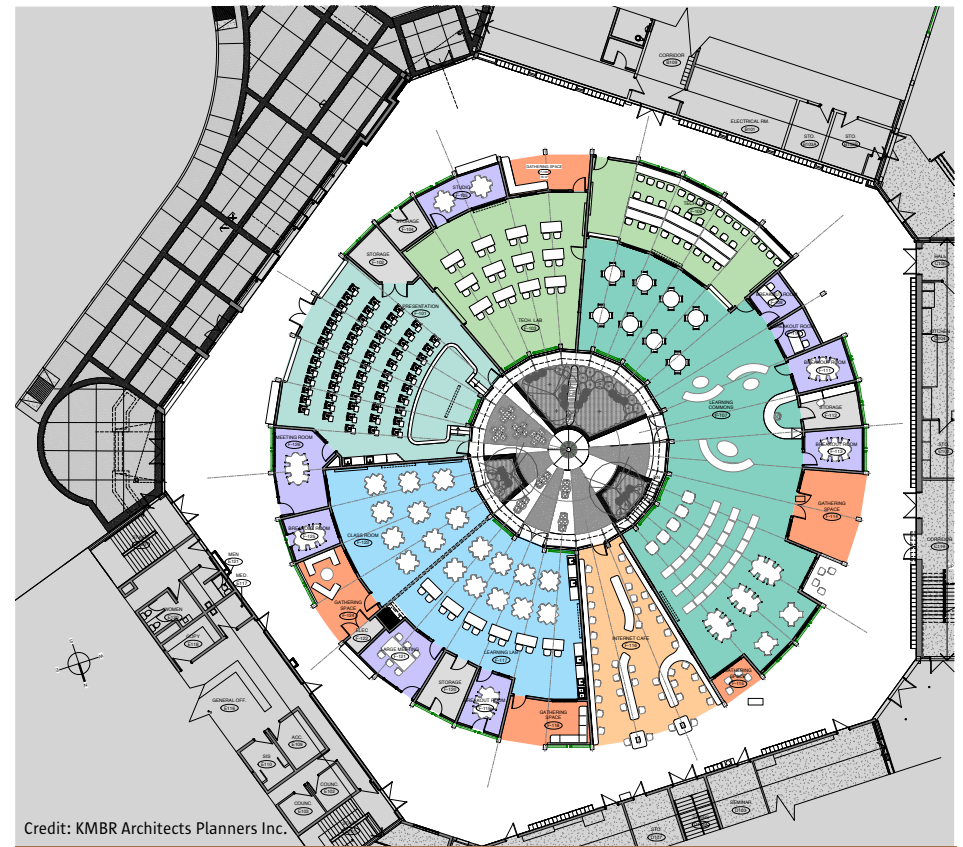
The structural engineers developed a retrofit system for Block F that made use of the existing foundations and replicated the geometry of the original (Figure 3.5). In plan, Block F is divided into two distinct but connected components. The 'main street' surrounds the central courtyard and forms a circle with an inner and outer ring of columns supporting a sloping roof. The inner ring of columns delineates the exterior glazed wall that encircles the courtyard, while the outer ring forms a colonnade that separates the main street from the rest of the school.



Credit: Herold Engineering Ltd.

Figure 3.5: Wellington Secondary: 3-D model of wood structure for new Block F

The main street is circular in plan, and the surrounding school is in the form of a pentagon, leaving an irregularly shaped zone between them (Figure 3.6). This zone was covered by an existing flat roof that was originally framed with solid timbers. The longest of these members had to be reinforced with laminated veneer lumber (LVL) beams so the roof could perform as an effective diaphragm between Block F and the surrounding blocks. The engineers also added a second layer of plywood sheathing in order to meet load transfer and drift requirements.



Credit: KMBR Architects Planners Inc.

Figure 3.6: Wellington Secondary: Floor plan of new Block F



photo credit: KMBR Architects Planners Inc.

Figure 3.7: Wellington Secondary: Interior view of drag rings for load transfer



photo credit: KMBR Architects Planners Inc.

Figure 3.8: Wellington Secondary: Roof top view of drag rings for load transfer



photo credit: ©2016 Artez Photo.com

Figure 3.9: Wellington Secondary: Radial post-and-beam structure of Block F

This upgraded roof connects to the outer ring of posts below the eave line of the central sloping roof. This results in a discontinuous section in which the roof diaphragms are not in the same plane, requiring that lateral loads be transferred into the vertical structure by a pair of ‘drag rings’ (Figures 3.7 and 3.8).

The outer ring of columns consists of 265mm x 380mm glulam posts, while those in the inner ring are 265mm x 342mm. The glulam beams that span between the two sets of posts are 265mm x 760mm deep (Figure 3.9).

In the vertical plane, lateral resistance is provided by a series of 16 steel cross-braced frames that tie into adjacent pairs of glulam columns in the outer ring. Because these braces form a circle in plan, they are able to resist lateral forces in whatever direction they may be applied (Figure 3.10). Architecturally, this solution eliminates the need for solid shear walls, enabling the core of the school to be transparent and the activities on one side of the courtyard to be seen from the other (Figures 3.11 and 3.12).

Throughout the timber structure of Block F, connections are designed to be relatively simple and economical – the majority being exposed steel plates and brackets. Steel brackets are also used to connect the bases of the glulam posts to the existing concrete basement walls (Figure 3.13). The entire wood structure is exposed and supports a profiled acoustic metal deck.



photo credit: ©2016 Artez Photo.com

Figure 3.10: Wellington Secondary: Cross-bracing around the perimeter of the courtyard provides lateral stability



Figure 3.11: Wellington Secondary: Exterior view of central courtyard



Figure 3.12: Wellington Secondary: Interior view toward central courtyard



Figure 3.13: Wellington Secondary: New glulam columns fitted with seismic cross-bracing



CONCLUSION

At Wellington Secondary, wood has shown itself to have many positive attributes when incorporated into a seismic mitigation strategy. Its light weight, versatility and economy have combined to bring this project to a successful resolution, on time and on budget. Wood has also contributed additional value, creating a warm and welcoming atmosphere, one that has transformed the identity of this aging school.



photo credit: ©2016 Artez Photo.com

Wellington Secondary: New interior with seismic upgrades

4. Seismic Upgrading of Cordova Bay Elementary School

Cordova Bay Elementary School is located in the District of Saanich, on the outskirts of Greater Victoria on the southern tip of Vancouver Island. The original school building was constructed in 1945 using light wood frame and, like Wellington Secondary, has undergone multiple renovations and additions since (Figure 4.1). It now has a capacity of 241 students from kindergarten to Grade 7.

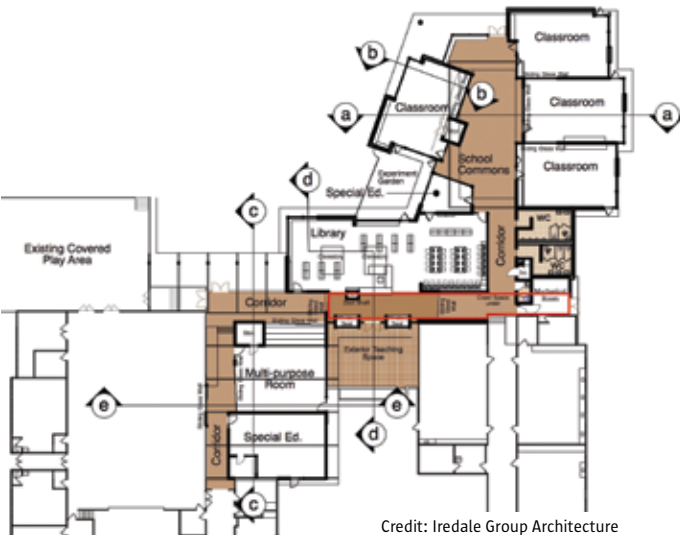
The multiple additional blocks, built between 1956 and 2005, are a combination of concrete, concrete block masonry, steel, and wood-frame construction. The seismic assessment carried out in 2004 resulted in most blocks being categorized as low or moderate risk.

However, the 1965 addition, constructed with unreinforced concrete masonry exterior walls and a glulam and heavy timber roof, was designated H1, the highest risk category, and in urgent need of upgrading or replacement. Although the rehabilitation of existing buildings is the baseline for the provincial seismic upgrade program, at Cordova Bay this approach was not the most cost effective.



Credit: Iredale Group Architecture

Figure 4.1: Cordova Bay: Site plan



Credit: Iredale Group Architecture

Figure 4.2: Cordova Bay: Plan of new construction



Credit: StructureCraft Builders Inc.

Figure 4.4: Cordova Bay: 3-D model of wood structure



Photo credit: StructureCraft Builders Inc.

Figure 4.5: Cordova Bay: Installation of CLT wall panels

DESIGN APPROACH

With the block in question having an area of 2050 m², seven portable classrooms would have been required to accommodate students for the duration of the construction contract had the existing block been upgraded. Lease or purchase of these portables would have added significantly to the basic cost of construction.

Instead, the design team determined that the demolition and replacement of the existing building could be achieved in two phases, with the library and multipurpose spaces being used as temporary classrooms, eliminating the need for portables. Comparative cost analysis determined that this was a more economical option. In this scenario, the replacement building was approximately 1000 m², with the balance being repurposed from library space to classrooms after the new space was completed (Figure 4.2).

Having chosen to construct a replacement classroom block, it was proposed that the new structure be built with cross-laminated timber (CLT) wall and roof panels, light wood-frame construction for interior non-load-bearing partitions and cement board and galvanized aluminum cladding to match the 2005 addition (Figure 4.3).

CONSTRUCTION OF PHASE 1

Phase 1 of the project included the construction of four classrooms: the school commons, washroom block, corridor and the mechanical room. Phase 2 included the library, multi-purpose room, special education suite and corridor. A savings was achieved by utilizing nail-laminated timber (NLT) for the roof panels.

The result is that all of the load-bearing and shear walls are constructed from five-ply CLT, a few non-load-bearing walls are of light wood-frame construction, and the roof is NLT panels made from 2x8 material (Figures 4.4 and 4.5).



West Elevation

Credit: Iredale Group Architecture

Figure 4.3: Cordova Bay: Elevation of new construction

SEISMIC DESIGN

The CLT panels are set vertically, extending from the ground floor slab to the underside of the roof. Base connections are steel plates set into the concrete and recessed into rebates factory-milled into the CLT panels (Figure 4.6). The plates are secured using long, high-strength self-tapping screws, then covered with a wood plug so the connections are hidden and the CLT can be left exposed. The number of anchor plates used for each panel varies according to the lateral load they are required to resist. Some have one anchor plate; others have two.

The vertical edges of the panels are milled with a profile so when they are brought together, a lap joint is formed. This joint is then secured using pairs of similar self-tapping screws set at opposing angles to one another. Where an internal wall butts into an external wall, the panel edge is left flat rather than profiled, then the connection is made with a similar configuration of screws as that described previously. The use of a large number of small connections (rather than a smaller number of large connections) is the most efficient way to achieve the intended ductility and thus to dissipate energy.



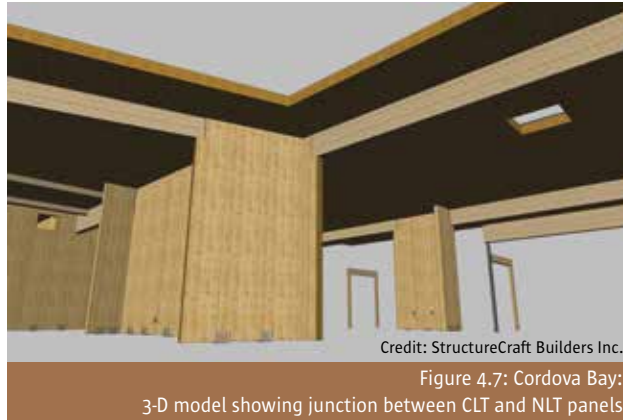
Figure 4.6: Cordova Bay: 3-D model showing base anchor detail



Photo credit: Iredale Group Architecture

Figure 4.8: Cordova Bay: Interior of lobby showing exposed CLT and NLT panels

The NLT panels bear directly on the CLT walls and are connected to them in a similar way (Figures 4.7 and 4.8). They arrive on site with a plywood diaphragm factory-installed over most of the panel, but held back from the edges. The panels are lifted into place by crane (Figure 4.9) at which point the diaphragm can be completed by installing a final row of plywood sheets that covers the joint between panels.



Credit: StructureCraft Builders Inc.

Figure 4.7: Cordova Bay:
3-D model showing junction between CLT and NLT panels



Photo credit: StructureCraft Builders Inc.

Figure 4.9: Cordova Bay: Installation of NLT roof panels

ENVELOPE DESIGN AND SYSTEMS INTEGRATION

Where the NLT sits on top of an exterior wall, 600mm long sheets of foam insulation are factory-installed between all the laminations, to the full depth of the panel. At the same time, the top of the wall is wrapped with 'peel and stick' membrane. This combination of details ensures continuity of the building envelope air barrier.

Both the NLT and CLT panels had chases routed into them (as required) in the factory to accommodate conduit and piping for building services. Following installation, cover strips were used to conceal the service runs, creating a clean and uncluttered appearance for the exposed surfaces (Figures 4.10 and 4.11). This detail required a high degree of coordination between StructureCraft Builders Inc. and the members of the design team, for which a virtual 3-D model was essential.



Photo credit: StructureCraft Builders Inc.

Figure 4.10: Cordova Bay:
Service chase cut in NLT panel



Photo credit: StructureCraft Builders Inc.

Figure 4.11: Cordova Bay:
Service chase in NLT panel with cover strip installed

CONCLUSION

This project demonstrates that factory-produced CLT and NLT panels can be successfully combined to create economical and aesthetically pleasing buildings (Figure 4.12). It also confirms that simply detailed CLT panel systems can provide a cost competitive, code compliant solution for lateral design in high seismic zones such as British Columbia.

In addition, 3-D modelling, cooperation and coordination at the design and fabrication stages can greatly reduce or eliminate the problems that typically occur in site-built construction when conduits, ducts and pipes inadvertently occupy the same real estate.



Photo credit: Iredale Group Architecture

Figure 4.12: Cordova Bay: Exposed CLT and NLT panels bring visual warmth to the interior of the building



photo credit: KMBR Architects Planners Inc.

Figure 5.1: Surrey Christian School:
Exterior view showing stepped 1- and 2-storey cross-section



photo credit: KMBR Architects Planners Inc.

Figure 5.2: Surrey Christian School:
View of post-and-beam structure at the atrium

5. Seismic Design and Construction of Surrey Christian School Primary Wing

Located in the City of Surrey in the Lower Mainland of British Columbia, this new two-storey building includes 10 primary classrooms, a special education suite, two before-and-after-school daycare suites, and three kindergarten rooms.

The new primary wing is designed to share the core resource and recreational facilities of the existing Surrey Christian Middle School building nearby. The desire to connect at main floor level to the middle school meant that the new building, which is on a sloping site, was constructed on top of a new single level parking garage that is partially tucked into the hillside.

The classrooms are organized along a linear two-storey atrium that extends the full length of the building. On the lower level there are 10 classrooms, five on either side of the atrium. On the upper level, there are five classrooms along the north side of the atrium, while the south side opens onto a roof garden that serves as an outdoor learning space (Figure 5.1).

DESIGN AND CONSTRUCTION

To address the client's concerns for economy and speed, and at the same time deliver an attractive, high quality building, the design team proposed a simple engineered wood post, beam and panel structure that would lend itself to prefabrication. Exposing the wood structure wherever possible would also reduce the need for interior finishes and create a warm and supportive atmosphere for its young occupants.

The vertical structure consists of glulam posts at 2.7m centres along the length of the building. Each bay consists of four posts, two at the exterior walls and two at the atrium walls. The posts are one storey in height, with the sole exception of those on the south side of the atrium, which rise through two storeys (Figure 5.2). The glulam posts were factory-fitted with custom steel base plates attached using long, high-strength, self-tapping screws installed at opposing angles (Figure 5.3).



photo credit: KMBR Architects Planners Inc.

Figure 5.3: Surrey Christian School: Detail of typical column base

The main floor posts were bolted to the concrete slab of the parking structure, and braced longitudinally using light wood-frame infill panels. There are no longitudinal beams in the building. The posts were then ready to receive prefabricated floor and roof panels, 2.7m in width and spanning the full 8.5m depth of the classrooms (Figure 5.4). Each panel has two glulam edge beams connected with light wood-frame header panels at either end and bridged by a deck made up of nail-laminated 2x4 material (Figure 5.5).



photo credit: KMBR Architects Planners Inc.

Figure 5.4: Surrey Christian School: Installation of NLT roof panels



photo credit: StructureCraft Builders Inc.
Figure 5.5: Surrey Christian School: Installation of NLT roof panels



photo credit: KMBR Architects Planners Inc.

Figure 5.6: Surrey Christian School: Primary roof panels installed in alternate bays leaving gaps for infill panels



photo credit: KMBR Architects Planners Inc.

Figure 5.7: Surrey Christian School: Detail of roof beam-to-column connection

These panels were installed in alternate bays along the length of the building (Figure 5.6), leaving the spaces between them to be filled with a second panel type that consisted only of 2x4 nail-laminated timbers (NLT). Because they were not stiffened by edge beams, these panels had to be lifted into place with great care, using spreader bars and multiple lifting points. The edge beams of the main panels rest directly on top of the posts and are connected to them with a similar detail to that used at the base (Figure 5.7).

Once all the main floor panels were installed, plywood sheathing was laid by the general contractor to create a horizontal diaphragm. The plywood was reclaimed from the formwork used for the parking garage. In the vertical plane, lateral stability is achieved by plywood-sheathed light wood-frame walls running north-south at either end of the building, and east-west along the length of the corridor between door openings. These shear walls were also prefabricated off site by StructureCraft Builders Inc. and installed using a crane (Figure 5.8). The lateral system was designed to resist all the required seismic loads, enabling the exterior walls of the classrooms to be fully glazed (Figure 5.9).

SYSTEMS INTEGRATION

The atrium roof is a little higher than the roof of the adjacent classrooms; setting the atrium roof beams on top of the classroom roof beams made it possible for ventilation ducts to enter the atrium wall at a high level, rather than penetrating the roof.

Within the building, systems integration was neatly achieved by concentrating mechanical ductwork in the central bay of each classroom and covering it with a suspended acoustic ceiling. This enabled the underside of the other floor and roof panels to be left exposed (Figure 5.10).

CONCLUSION

For this project, the use of factory prefabrication compensated in part for the additional time required to construct the parking garage. It was possible for the wood components to be prefabricated at the same time as the concrete was being poured on site. The installation of all the wood components took approximately one week. Prefabrication in wood was also compatible with the use of site-built light wood-frame construction for the interior partitions.

With the wood soffits of most roof panels and the glulam structure in the atrium being left exposed, the school has a warm and welcoming atmosphere that has exceeded the client's expectations and delighted students and teachers alike (Figure 5.11).



photo credit: StructureCraft Builders Inc.

Figure 5.8: Surrey Christian School: Installation of prefabricated light wood-frame shear walls



photo credit: KMBR Architects Planners Inc.

Figure 5.9: Surrey Christian School:

The placement of shear walls enables the exterior walls of the classrooms to be fully glazed



photo credit: KMBR Architects Planners Inc.

Figure 5.10: Surrey Christian School: A suspended ceiling conceals services in the central bay of each classroom, enabling the NLT panels on either side to remain exposed



photo credits KMBR Architects Planners Inc.

Figure 5.11: Surrey Christian School: Exposed wood structure in the atrium

6. Project Credits

WELLINGTON SECONDARY SCHOOL

Client: School District #68, Nanaimo Ladysmith
 Architect: KMBR Architects Planners Inc.
 Structural Engineer: Herold Engineering Limited
 Construction Manager: Unitech
 Engineered Wood Fabricator: Structurlam Products LP

CORDOVA BAY ELEMENTARY SCHOOL

Client: School District #63, Saanich
 Architect: Iredale Group Architecture
 Structural Engineer: Herold Engineering Limited
 Construction Manager: Durwest Construction Management Inc.
 Engineered Wood Fabricator (CLT):
 MERK Timber GmbH (Germany)
 Engineered Wood Fabricator (NLT):
 StructureCraft Builders Inc.
 Engineered Wood Installer: StructureCraft Builders Inc.

SURREY CHRISTIAN SCHOOL PRIMARY WING

Client: Surrey Christian School Society
 Architect: KMBR Architects Planners Inc.
 Structural Engineer: Fast + Epp
 Construction Manager: Companion Construction Inc.
 Engineered Wood Fabricator/Installer:
 StructureCraft Builders Inc.



photo credit: ©2016 Artez Photo.com

The circular central courtyard of Wellington Secondary

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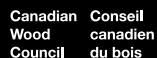
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