Design of the Ashburton District Council Civic Centre: a steel designers' learnings from a timber building design

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ABSTRACT

This paper discusses the learnings from the structural engineering for the Ashburton District Council (ADC) Civic Centre. The building was initially steel but after consulting with the Ashburton community an alternative timber structural concept was selected. This revised approach led to a number of challenges in adapting a building originally conceived in steel, to timber.

ADC Civic Centre is a 3-storey timber structure consisting Cross Laminated Timber (CLT) walls with post-tensioning (Pres-Lam) and dissipators, Laminated Veneer Limber (LVL) gravity beams and columns, Potius flooring and a concrete topping slab. Key challenges included designing the structure to allow for movement expected in the rocking walls without sacrificing robustness in the connections. The drive to show off the timber led to exposed structure and services meaning architectural, services and fire requirements drove key design decisions.

As an industry we have had the opportunity to develop our earthquake design knowledge for steel and concrete buildings from learnings from the Christchurch Earthquakes and other events. Engineered timber structures are becoming more common, however there has not been as much practical application. Some approaches we use in steel design can be transferred, but in some areas the steel design thinking that most structural engineers are comfortable with needs to be turned on its head.

This paper shares the learnings from the design process and highlights some of the key features of timber design. It is expected to be of interest to structural engineers interested in the practical realities of the growing field of timber design.

1 PROJECT BACKGROUND

The Ashburton District Council Civic Centre project is a series of buildings located in Ashburton which will house the town's library, council offices and a civil defence facility. It is located at Baring Square, Ashburton.

The original concept design for the structure was a conventional steel building with initial architectural drivers related largely to maximising the amenity of the space to end users. Structurally, this meant to provide as much open space and flexibility as practical. It led to "stick and beam" type construction with a braced arrangement, reducing intrusion of the lateral load resisting system into the layouts and allowing for a loose fit arrangement that could be adapted both during design and during the building life.

The project then went to public consultation with various options provided to the community. The public consultation had the following outcomes:

- Clear direction that the public wanted a "do more" option, wanted higher levels of sustainability introduced into the design, and wanted the 'feel' of timber rather than concrete and steel.
- A study on where environmental sustainability features could be introduced.
- The adoption of a timber structural solution.

The design team then re-entered design to incorporate both the initial architectural drivers and the new drivers from community consultation of timber and sustainability. The design phase is now complete with the Contractors on site and a target project completion in late 2022.

The project architects are Athfield Architects. Beca are undertaking structural, building services, civil services and GHD are undertaking geotechnical. PTL were the structural peer reviewers.

2 STRUCTURAL DESCRIPTION

2.1 Building description

The ADC Civic Centre is predominantly timber construction including the primary gravity and lateral systems. Steel structure has been provided in locations where the loads, spans or geometry are prohibitive for timber structure. The development consists of four main structures indicated in Figure 1.

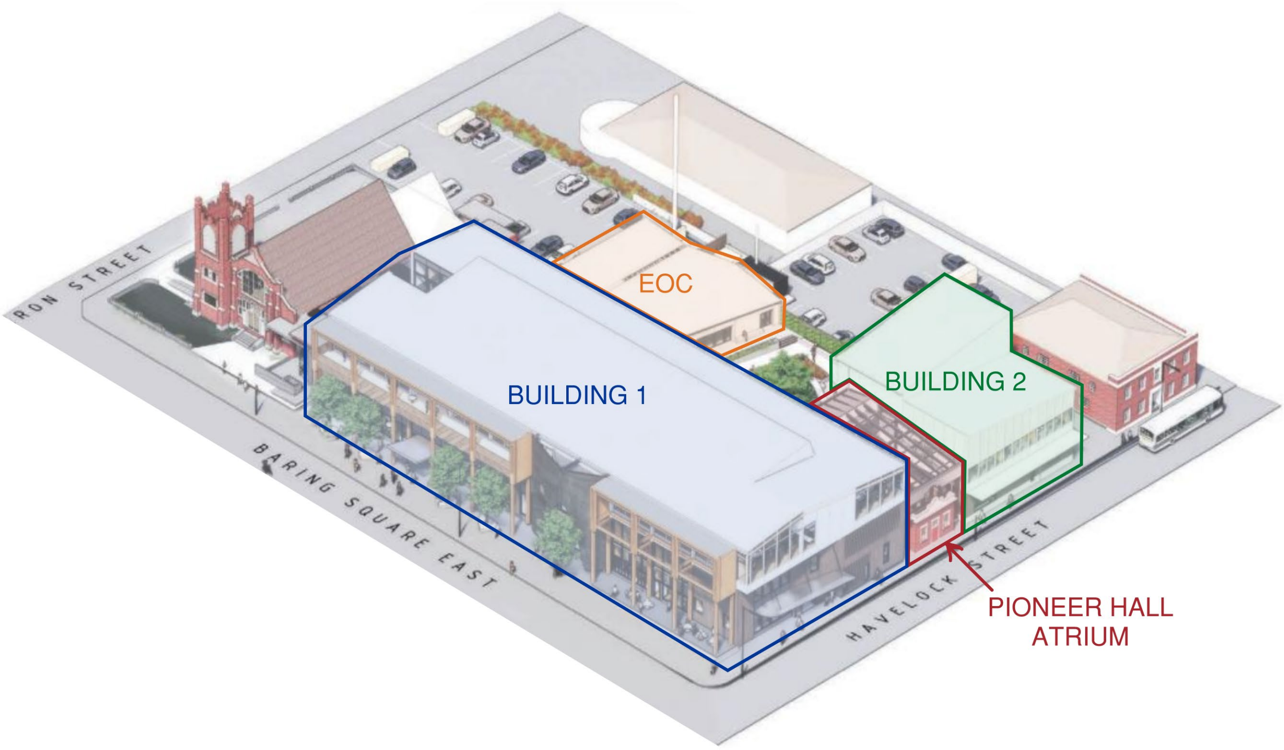

Figure 1: ADC Civic Centre buildings (background Athfield Architects Ltd.)

- Building 1, incorporating most of the new Ashburton Library and Council Chambers and office space for Ashburton District Council. Building 1 comprises 3 levels.
- Building 2, incorporating the remainder of the Ashburton Library. Building 2 comprises 3 levels.
- Pioneer Hall, an existing heritage-listed single storey building, which is to be strengthened and repurposed within the library space. Pioneer Hall will be within an atrium attached to Building 1.
- The EOC (Emergency Operations Centre), a single storey post-disaster and civil defence facility. The EOC is a single storey building across the courtyard from the other structures.

Separating the EOC from the main buildings allowed for the more complex multi-storey buildings to be designed to a lower IL3 importance level while the IL4 EOC was kept as a simple single storey timber framed construction with inherent resilience. This paper will focus on the design of Buildings 1 and 2 which incorporate the more complex engineered timber structure.

2.2 Primary gravity system – laminated veneer lumber (LVL)

Roof and floor loads are carried by the Potius panel system to primary LVL double beams and rafters. The primary beams carry the gravity loads to the LVL columns and CLT walls. The foundation system is foundation beams and pile caps on screw piles. Figure 2 shows a typical cross section through Building 1.

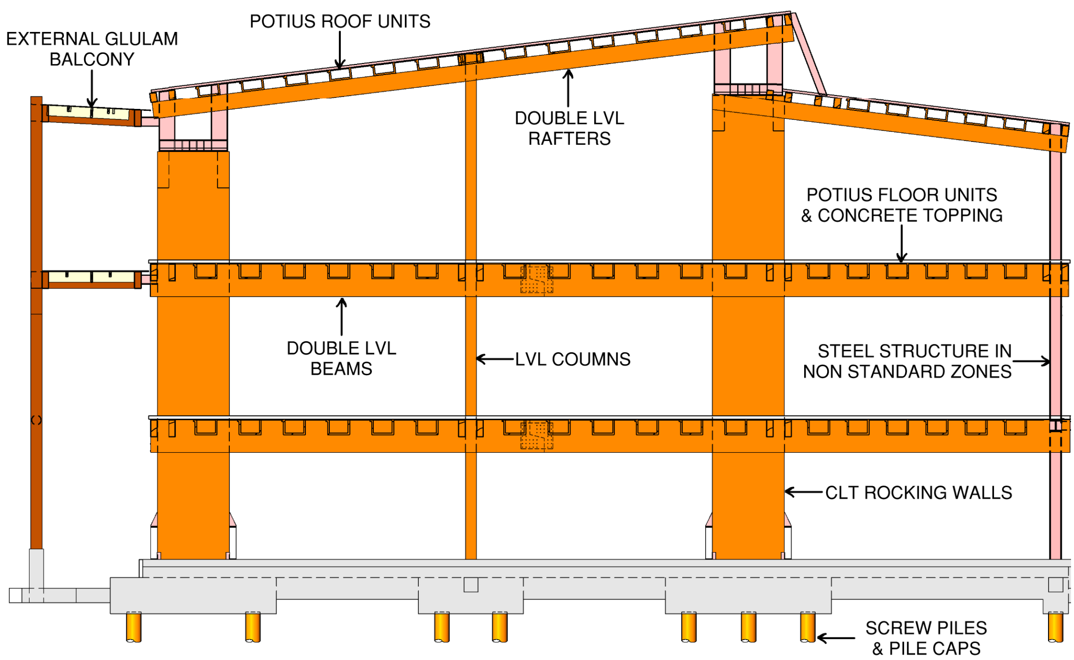

Figure 2: Typical Building 1 cross section

2.3 Lateral system – post-tensioned cross laminated timber (CLT) rocking walls

Lateral loads are transferred through a reinforced concrete diaphragm directly into CLT walls in both directions. A typical post-tensioned rocking CLT wall is as shown in Figure 3. Post-tensioning tendons are positioned through the middle and friction type dissipators are installed on the two sides of the bottom part of the wall. Each wall sits on a pile cap which distributes overturning loads to tension and compression screw piles.

Post-tensioned CLT rocking walls (Pres-Lam) have been developed over the last decade at the University of Canterbury and implemented on several projects, research is ongoing (Dekker 2012, Devereux 2011, Palermo 2005, Sarti 2017).

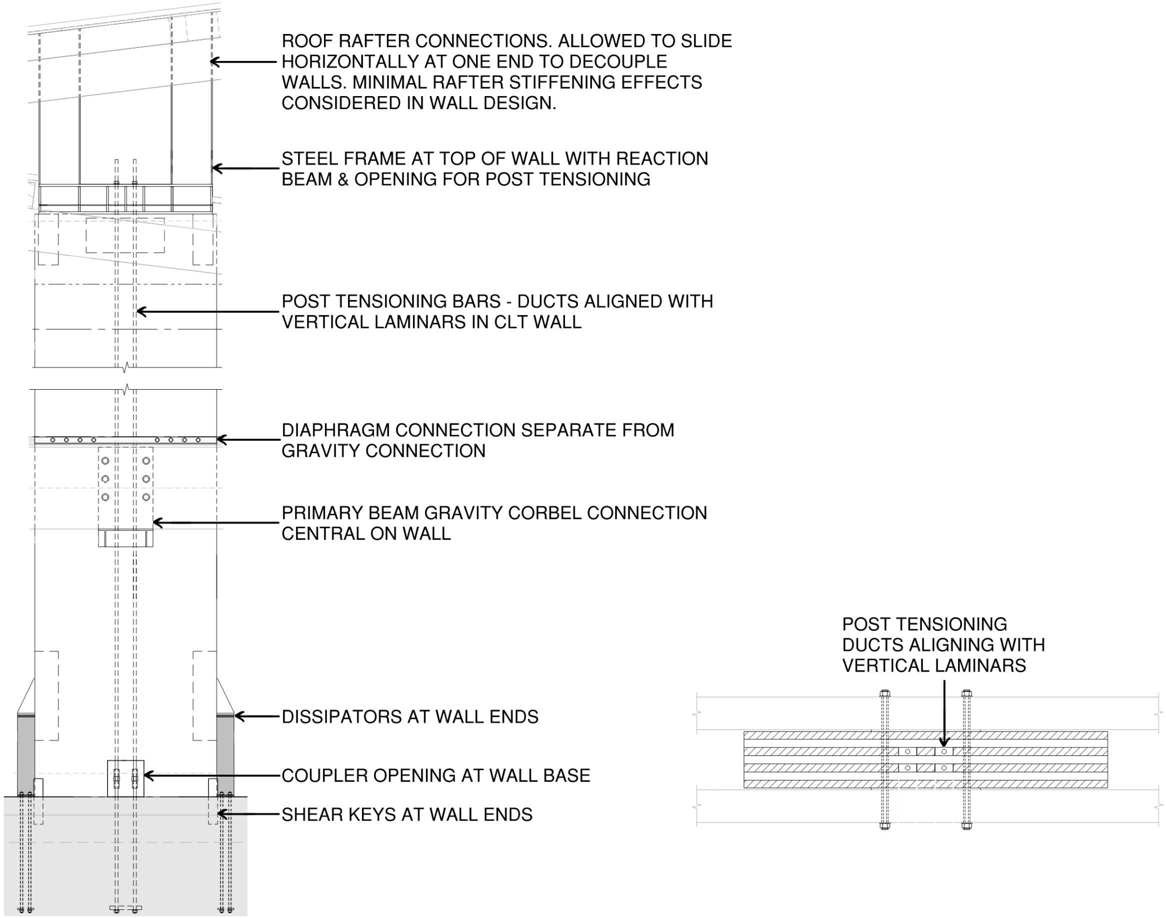

Figure 3: Key features of a typical CLT wall

2.3.1 Rocking wall design

Force-based seismic design is inappropriate to apply to rocking walls; instead, Direct Displacement-Based Design (DDBD) was used (Priestley, 2007). The building is relatively regular in plan, has evenly distributed walls and a rigid diaphragm; therefore, it was assumed that the demands would be evenly spread between the walls and the model was simplified to a two-dimensional representation for each direction. Three-dimensional issues, such as torsion and displacement compatibility, were investigated via a separate planar model following the wall design.

The wall dimensions were relatively fixed due to architectural constraints, so the design focussed around optimisation of damper and post-tensioning parameters to achieve an efficient and compliant design. Sectional analysis of the walls was undertaken using the Monolithic Beam Analogy method and the resulting backbones were combined and translated to a Single Degree of Freedom (SDOF) representation so that the building response could be plotted in acceleration-displacement ordinates to understand its performance (Newcombe 2008).

The lower limit of the post-tensioning force was governed by serviceability requirements, which is somewhat typical of timber rocking walls; however, this was complicated by the relatively short wall length that resulted in comparatively high wall stresses and resulted in a narrow range of allowable post-tensioning forces. We opted to select the lower end of that post-tensioning range, which allowed us to satisfy serviceability and long-term creep requirements at the expense of larger ULS and MCE displacement demand. We selected dampers that gave the system a relatively high area-based damping ratio that resulted in a corresponding reduction in displacement demand and allowed us to keep both ULS and MCE demands within acceptable limits.

2.3.2 CLT wall connection design

2.3.2.1.1 Floor to wall connections (gravity and diaphragm)

One of the major considerations with the rocking wall connections is the displacement incompatibility between the wall and the floor structure due to the rotation of the walls. Testing on these types of connections have been carried out at the University of Canterbury (Moroder 2014). Conclusions from this testing included that vertical displacement incompatibility does not appear to be a major issue, however rotational incompatibility is. An economic and reliable connection could be a group of bolts placed at the centre of the wall. For this project a low-damage approach was not a requirement and the focus was on providing economic and robust connections.

Gravity connections for the primary beams consist of 6 bolts central on the wall (either side of post-tensioning) supporting a steel corbel which in turn supports the beam. Four of the six bolts extend though the primary beams with oversized holes.

The diaphragm to wall connection was separated from the gravity connection. This is possible as the timber beams are not used as drag elements in the diaphragm. Loads are transferred directly from the concrete slab to the wall via an equal angle bolted to the wall and welded reinforcing. While this connection does not have slotted holes it is decoupled from the gravity system and the stiffness of the LVL beam.

Overall, these connections are not a true pin but minimise rotational stiffness and ensures gravity support can be maintained even with large wall rotations. The connections are shown in Figure 4.

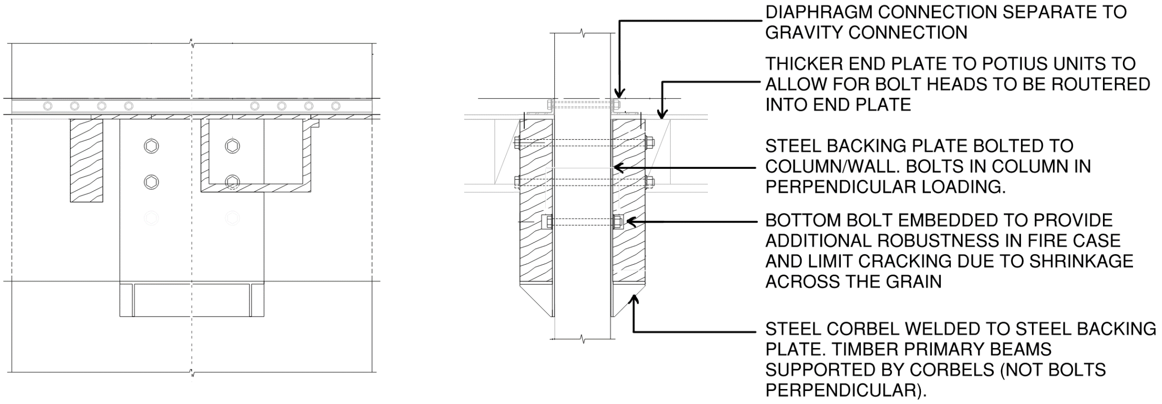

Figure 4: Primary beam to wall gravity and diaphragm connections

2.3.2.1.2 Post-tensioning connections

We worked with CLT suppliers to determine a construction methodology for the post-tensioning in the CLT walls. The CLT walls are formed out of lamellas, which are typically 100mm x 45mm. During manufacture a lamella will be removed and replaced with a cable duct for each post-tensioning cable. Therefore, the layout of the post-tensioning cables was set by the CLT lamella locations.

Openings were provided at the base of the walls for cable couplers. Another higher opening was provided where the wall lengths exceeded available cable lengths. The process of post-tensioning requires access and space above the cables. Cut outs at the tops of the walls were provided to allow for initial post-tensioning and the ability to access again throughout the building's life.

Compressive forces in the CLT were critical where the force entering at the top of the wall is applied at the discreet post-tensioning location. A reaction beam is required to ensure local crushing does not occur under the post-tensioning. With the cut out provided to ensure safe tensioning and maintenance the required bearer width would not leave much width for the remaining 'columns' extending up to support the roof structure for the 2m long walls. Therefore a steel frame was provided at the tops of the 2m walls which also helped with complex roof and truss connections.

3 PROJECT LEARNINGS FOR TIMBER DESIGN

This is intended to be a summary of key learnings where approaching a timber design from a steel mindset might lead an engineer astray. As engineers we are taught that we should have a good idea of what the answer looks like before we start delving into the numbers. For steel design many of us are comfortable looking at a standard simply supported beam, cantilever, column or brace and knowing approximately what section and end connections should be appropriate for each situation.

When jumping into timber design that instinct has not been developed and is perhaps significantly off target due to previously working with very different materials. Without that gut feel it is a lot harder to form early concepts and to carry out self-verification throughout design. What an engineer might believe is a conservative assumption or not a critical element in preliminary design might turn out to have been incorrect as the details are worked through in the later detailed checks.

In order to produce commercially viable designs and keep improving our utilisation of timber products in major buildings. It is important to not only develop timber technologies and systems but to get the basics right and strengthen our understanding of what simple timber details should look like. A major contributing factor to the success of steel is the library of standard details and examples that have been developed.

3.1 Structural layout and sizing – getting the concept right

3.1.1 Structural system layout

For this project the adoption of a timber scheme necessitated a fundamental redesign of the building layout. This was driven by a number of key factors:

- Timber is significantly weaker than steel. It must therefore operate on a smaller grid, with larger elements, and more walls.
- Timber walls are relatively efficient, but timer braces are not. Considering the other project drivers we moved to a wall system.
- Timber construction works considerably better in cellular, box-like arrangements.

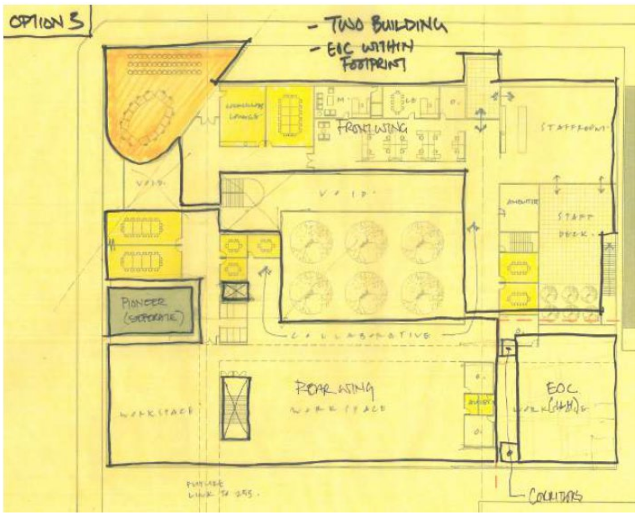

Figure 5: An initial conventional steel concept

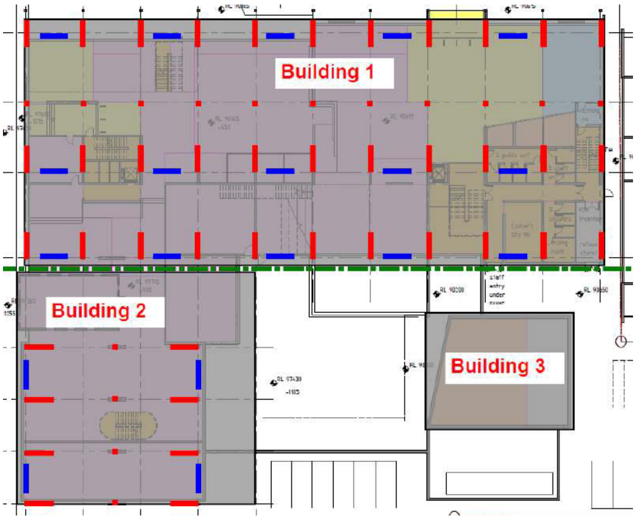

Figure 6: The initial timber concept layout

The initial structural layout concepts for the conventional steel option focused more on spaces and building seperation as shown in one example in Figure 5. This was allowed due to the lower intrusion of the steel stability system into the spaces. After the project's change in direction the initial timber layout concept shown in Figure 6 we provided had a greater focus on a repeated module of columns and walls which was critical in getting the wider design team on board with the new strucutral drivers. It was important that the architectural team understand and accepted these layout limitations.

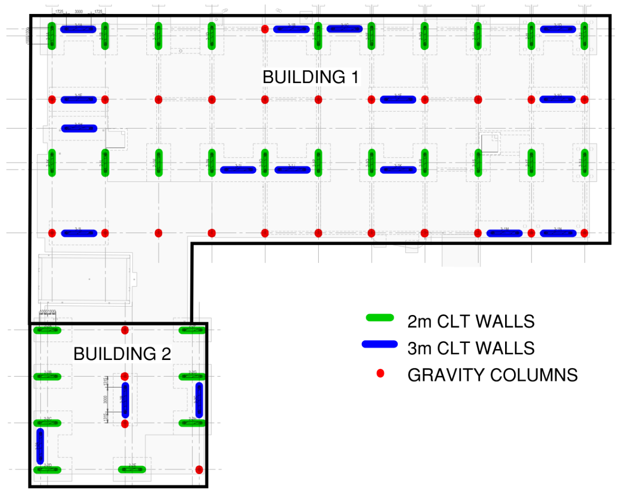

Figure 7: The final structural layout

The final layout shown in Figure 7 maintained the consistent grid in the transverse direction, though reduced the number of walls from the initial conecpt. In the longitudinal direction where longer 3m walls were utilised, the walls were distributed to compromise with the architectural layout requirements. This was developed by giving a structural requirement that an even distribution of walls was achieved by ensuring a quarter of the walls were in each in each quadrant of Building 1 and the walls were distributed across the grid lines. The architectural team then placed walls in locations that suited the library layout. This fairly even distribution allowed the 2D wall analysis model discussed in section 2.3.1.

3.1.2 Structural section sizing

A key item in structural timber sizing is understanding the timber product and making sure the correct supplier data and design factors are used. Most importantly timber is an anisotropic material strong parallel to the grain and quite weak perpendicular to the grain. Different engineered timber products use the stronger parallel qualities by layering the timber grain in specific ways which has a large impact on how the elements are designed. Overall, timber requires much larger structural sizing than steel and even more so if elements are resisting loads in their weaker directions.

It is important to adjust expectations of the material. The primary beams in this project are pairs of 900mm x 180mm LVL11. In a conventional steel building a 530UB92 would give the same calculated long term strength and deflection performance. The illustration in Figure 8 shows how the structural area is approximately doubled for the same performance.

As shown in Figure 3, CLT rocking walls in this project are 2000mm long by 310mm wide with a cut out at the base to allow for coupling of the post-tensioning bars. For rocking wall design the long term compression strength of these walls were the critical factor driving post-tensioning levels. When considering the long term compression strength for these walls the following factors needed to be considered:

- Strength reduction factor and long term k1 factor (0.8 x 0.6 = 48%) or the additional recommendation that long-term compression loads should not exceed 40% of total capacity (40%).
- Only the vertical lamellas contribute to the compression strength of the wall. For these walls four of seven laminars were vertical (56% of wall thickness vertical).
- The 400mm wide opening at the base of the wall removes a portion of the compression zone (80% of total wall length remains)

These factors combine to give a long-term compression capacity of only 18% of the unfactored compression capacity of the wall cross section. For the 2m walls this is approximately equivalent to the compression capacity of a 250UC steel column. While a steel column and a CLT wall perform two very different structural purposes this comparison helped understand and communicate the limitations on the level of allowable post-tensioning. As discussed in section 2.3, limit on the post-tensioning drove the lateral design of the walls.

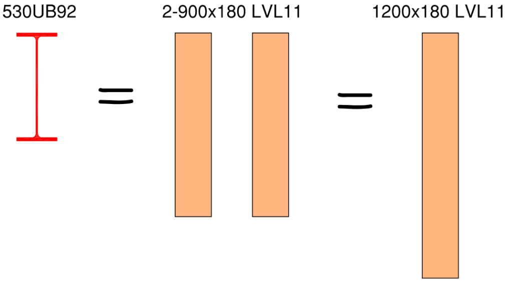

Figure 8: Steel to LVL simply supported beam equivalents

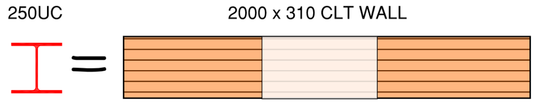

Figure 9: Steel to CLT compression equivalents

Key learnings from structural timber sizing:

- For simply supported beams expect timber to require double the structural area than the equivalent steel beam for the same floor weights.
- For timber in compression ensure the 'active' parallel portion of the section is loaded below 40%.
- For timber acting in its perpendicular orientation expect it to be a weak (similar to a steel plate out of plane). Consider another load path or some strengthening of the element if the loads are significant.
- Despite sizes being larger than for steel – expect connection geometry to still be critical in section sizing. Determine the critical connections and work outwards from there.

3.2 Connections – the trickiest part of timber design

As with section sizing, understanding the specific timber product, its anisotropic properties and the factors contributing to the connection strength is critical. Timber connection design is very complex, however some key items to consider in connection design are:

- Timber construction benefits from more smaller connections. An irregular structural layout funnelling large loads through individual connections may not be feasible. Checks on key connections should be carried out as part of developing a timber concept.
- Smaller bolts work better with timber, if you are reaching for a larger bolt then it might be worth considering a different connection.
- Timber is strong parallel to the grain but very weak perpendicular. As a rule of thumb, don't attempt to carry significant loads through a fixing perpendicular to the grain – bolts perpendicular to the grain should be limited to secondary beams or secondary actions.
- Direct bearing is excellent – utilise corbels where possible.
- Your fire approach will define your connection design – this should be decided right at the beginning of the project and will need input from the project fire engineer. See section 3.4.
- Proprietary connections are useful and easily specified. However, they have a risk of having stated capacities for the same fixing changing between technical publication issues. In this project we experienced documented capacities of a proprietary connection halving in the course of detailed design due to a new issue of technical information. We recommend specifying capacity requirements of all proprietary fixings on the structural documentation.

3.3 Mixing materials – concrete toppings come with pros and cons

While timber is weaker than other materials it also is a lot lighter, meaning a switch from a conventional steel and concrete structure to timber reduces the demands on the structure and makes the weaker timber structure more feasible and reduces foundation requirements.

A concrete floor topping was selected for this project to meet diaphragm, fire, acoustic and vibration requirements. The significant weight of the concrete floors means the timber structural elements are effectively pushed to carry a concrete building weight. This removed one of the major benefits of timber construction.

This added building weight had flow on effect on all timber sizing and connections. Harder to define are other factors such as how the moisture in the concrete topping affects the timber it comes in contact with, how the concrete topping shrinkage affects the structure and composite action between the timber and concrete.

Wet concrete topping is to be poured directly on timber elements and cured. Concrete slabs in all construction types shrink as part of the curing process. This can lead to cracking of the slab and increased deflections of the supporting beams. In timber construction this carries an increased risk due to a couple of factors. In the short term, during curing the dry timber can absorb moisture from the curing concrete – increasing concrete shrinkage and also increasing the moisture content in the timber. In the long term timber has a creeping effect, meaning it compresses over timer under applied loads. For this project risks of shrinkage, cracking and deflections from concrete curing were be reduced by designing the beams to be non-composite, using a low shrinkage design concrete and providing a delayed pour strip cutting the building in half to reduce the continuous slab length.

3.4 Timber connections in fire – a challenge for timber construction

Timber connections in fire have become a key issue in timber building design. AS/NZS 1720.4:2019 Timber structures Part 4: Fire resistance of timber elements (which is not yet cited) requires protection of metal connectors in joints by one of the following methods:

- Embedding.
- Fire-resistant protective insulation covering to a limiting temperature.
- Fire resistance testing.

The key item here is the insulation covering is required to prevent the temperature under the insulation from exceeding 300°C for dowel like fasteners. There is not an intumescent coating rated to 300°C available on the market which makes this clause difficult to meet. Overall, this code drives the preferred method for fire resistance of timber connections to be embedment, with entirely concealed steel ensuring a layer of timber at least as thick as the calculated char depth is provided to all steel elements. The authors highlight that these requirements as particularly onerous. We consider it will raise the cost of timber buildings and may impact their adoption.

With the high demands on the connections and connection types utilised in this project in many cases embedding the bolts would have led to less robust connections for their long term loadings. As we did not want to sacrifice everyday strength for the fire case we looked into how we could make exposed connections work.

For this project, all exposed primary beam connections incorporate steel corbels to provide direct bearing for both long term and fire load cases and all bolted connections are through bolts with oversized washers or plates on both sides. The oversized washers and corbels ensure the connections aren't as vulnerable as simple dowel connection. All exposed steel including the corbels and washers are to have a 400°C/60 minute intumescent paint provided. Based on input from an intumescent paint supplier this coating, exposed to the design fire case for this which has a 50 minute period, the actual temperature of the steel will be less.

3.5 Communicating timber expectations to the stakeholders

3.5.1 Serviceability performance expectations

As timber is a natural material it is an intrinsically variable material, shrinking, expanding and warping over time and change in environment. Through design we worked to reduce or mitigate the issues that can arise with timber. However, we must expect a timber building to behave differently to a similar building of steel or concrete construction. It is important to understand and communicate to the stakeholders the different serviceability performance of a timber building to ensure fitout design and construction is carried out in a way that suits the building and mitigates the serviceability risks.

In construction the timber elements are required to be dry so that the initial shrinkage and warping has already occurred. If moisture is reintroduced to the elements then warping, shrinkage and delamination of LVL elements could occur. Control of the moisture content of the timber throughout construction is important. Mitigation requirements include protection of elements in storage, reducing time exposed on site and providing protection to elements once in place.

We expect movements to occur over a period of time after construction due to the timber creep effect. This means further movement can occur after the internal fit out has been put in place. Allowance for this movement should be considered in the fitout and construction. Measures could include allowance for initial movements to occur before building deflection critical fit out elements such as operable walls and providing floor coverings that can handle the movements such as carpet rather than a hard tile.

Footfall induced floor vibration can be an issue in timber buildings and we anticipate that footfall induced vibration will be higher in this building than in a comparable steel or concrete building. As more timber buildings are constructed we can increase our understanding of this for future designs.

3.5.2 Design team coordination

Due to the drivers to have a timber building, there was a desire to put the timber on display. The timber, connections, services would all be exposed leading to increased coordination requirements for the design team. Key items were:

- Larger timber sections and less ability to provide penetrations for services meant certain items needed to be set out early. The Potius panel system was set out early as the services will run in between the units and will only penetrate the floor slab in between units.
- Exposed timber leads to surface spread of fire requirements – this resulted in much of the exposed undersides of Potius panels to require an intumescent paint coating.
- Exposed connections were needed to be coordinated architecturally.

3.5.3 Quantity surveying / costs

Just as we as an industry are still relatively inexperienced at designing and coordinating large timber projects, the New Zealand cost consultancy industry is still relatively inexperienced at costing those timber projects. However, we are aware that a lot of the cost in timber projects is in the following places:

- Complex connections.
- Timber sections not matching standard timber manufacturing sizes leading to offcuts (paying for the offcuts).
- Additional costs to fabricate engineered timber elements outside local manufacturers capability.

Therefore, a priority in early stages of timber design should be to communicate with manufacturers to determine how best to utilise their product, what are their standard sizes, and determine any details that add huge manufacturing costs and getting the typical connection details designed and provided to the Quantity Surveyor.

4 CONCLUSIONS

Timber is a fantastic product with many advantages over other building materials, particularly from a sustainability perspective. With the global sustainability drivers we want to see more uptake of the material in major structures in the future. It has its challenges, mainly due to its novelty and industry lack of experience in using the product.

As an industry we have had the opportunity to develop our design knowledge for steel buildings from learnings from many projects, the Christchurch Earthquakes and other events. A major contributing factor to the success of these types of projects has been the development of standard details, products, specifications, design tools and solutions built through experience. This shared industry knowledge allows consistency in the design, cost and coordination of these projects where the design team has understanding of the key drivers.

In this paper we have summarised some of the key learnings from the ADC Civic Centre project, from a perspective of an engineer who is familiar with designing with the resources available for conventional steel buildings. Designing with timber, particularly in earthquake design which leads to utilisation of elements for different load cases, requires a shift in approach and a questioning of key assumptions.

In order to produce commercially viable designs and keep improving our utilisation of timber products in major buildings. It is important to not only develop and test complex timber technologies and systems but to get the basics right and strengthen our understanding of what works for timber. While designing with timber is a challenge now, with more experience we can make timber a competitive product for commercial designs.

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