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ASHBURTON DISTRICT COUNCIL CIVIC CENTRE: LEARNINGS ON TIMBER CONNECTIONS

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SUMMARY

This paper discusses the learnings from the structural engineering for the Ashburton District Council (ADC) Civic Centre with a focus on the timber connections which is easily the trickiest part 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.

INTRODUCTION

ADC Civic Centre is a 3-storey timber structure consisting Cross Laminated Timber (CLT) walls with post-tensioning 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 where architectural and fire requirements drove key connection design decisions.

With other building materials such as steel we have a clear understanding and examples of what connections should look like and how these connections influence design decisions such as section sizes and layout. Due to this experience engineers are comfortable delivering early design phase documentation before the connection design has been fully fleshed out.

With timber structures the connections drive section sizes and layout to a greater extent than other materials. With less built examples, less industry resources and more variability in timber materials and suppliers most engineers do not have the gut feel on what a timber connection needs to look like and what does not work. Design resources and codes are also more in flux, leading to a challenge in knowing what code, material values and manufacturing possibilities an engineer should be using in design.

PROJECT BACKGROUND & STRUCTURAL DESCRIPTION

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.

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.

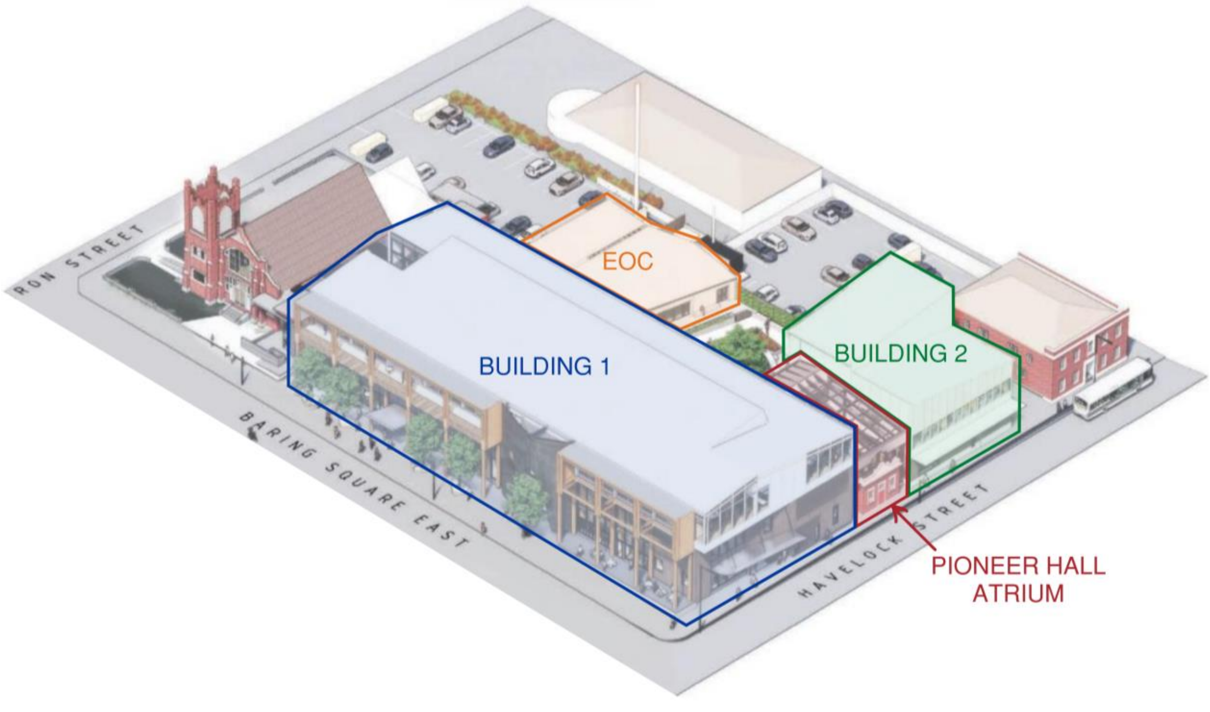

Figure 1. ADC Civic Centre buildings (background Athfield Architects Ltd.)

- 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.

<u>Primary gravity system – laminated veneer lumber (LVL)</u>

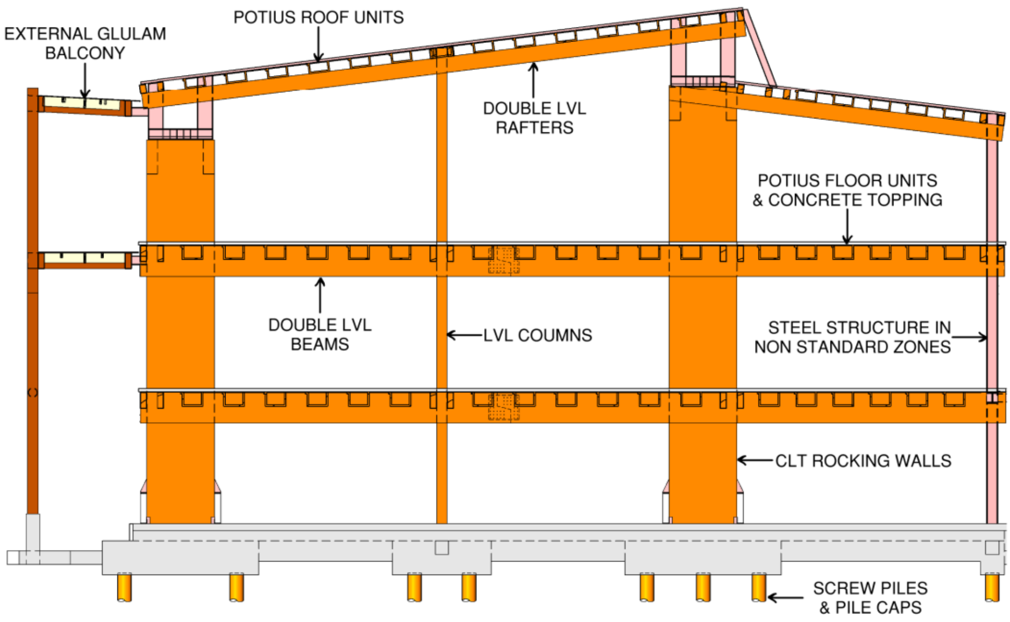

Figure 2. Typical Building 1 cross section

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.

<u>Lateral system – post-tensioned cross laminated timber (CLT) rocking walls</u>

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.

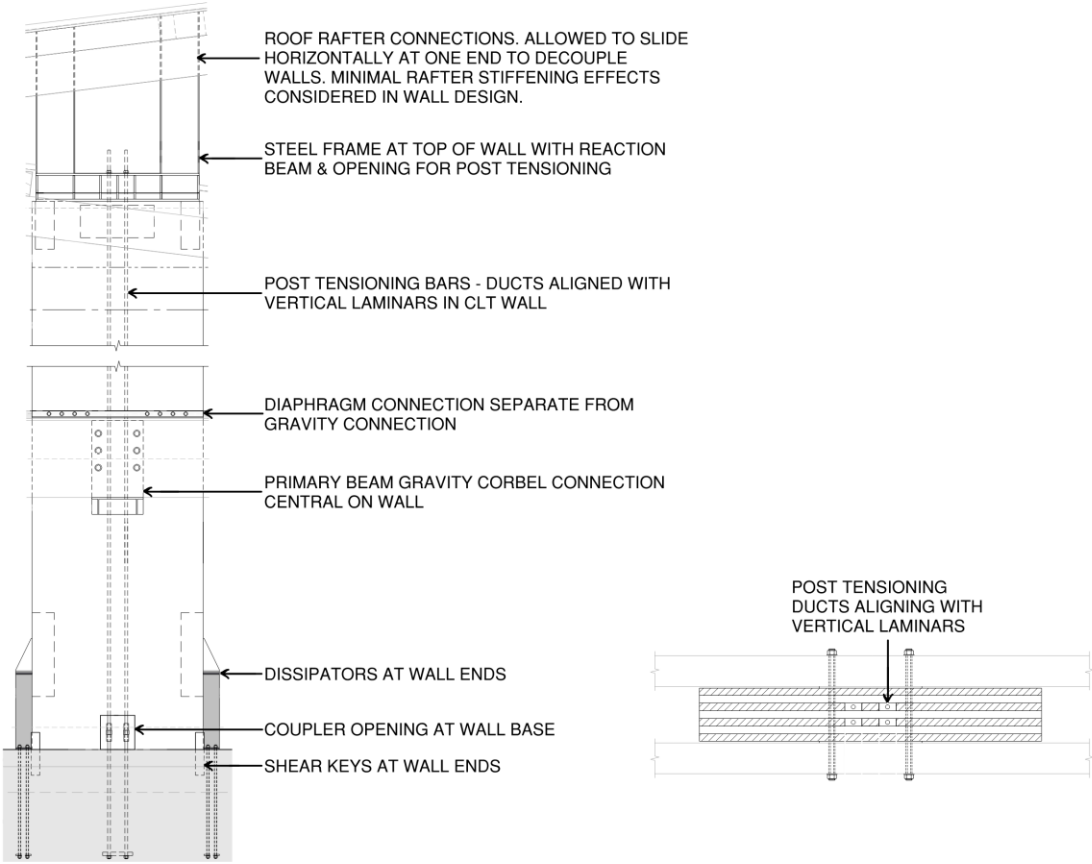

Figure 3. Key features of a typical CLT wall

PROJECT SPECIFIC CONNECTION EXAMPLES

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.

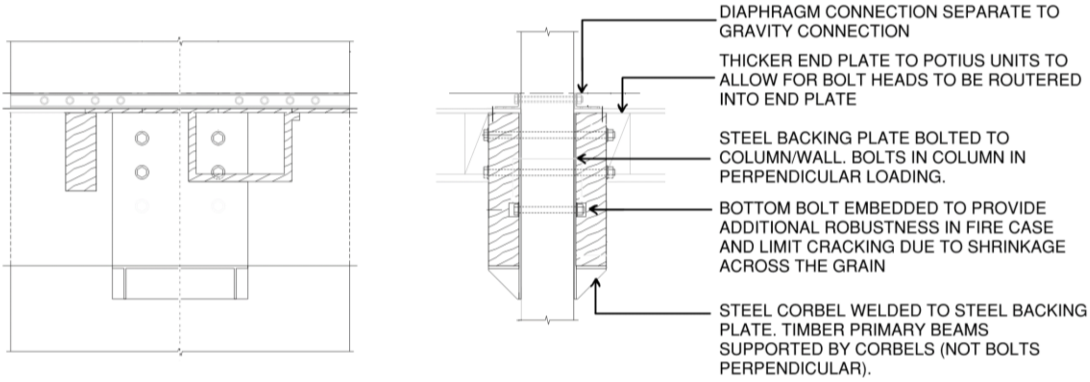

Figure 4. Primary beam to wall gravity and diaphragm connections

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 (sawn timber). During manufacture a space will be left for each post-tensioning cable between lamellas. Therefore, the layout of the post-tensioning cables was set by the CLT lamella locations. Figure 5 shows a duct sample fabricated by the supplier.

Figure 5. CLT duct sample

At the time of design lamellas from one supplier were typically 100mm x 45mm. During construction the supplier changed their available lamella widths due to a change in timber supply. During construction a redesign of the wall duct and fixing layouts was required to accommodate the available timber supply.

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.

TIMBER CONNECTION LEARNINGS

This is intended to be a summary of key learnings focusing on where timber connection design varies from design in other materials. This is not intended to be a design guide but hopes to point out some items which have a big impact on timber connection design.

For a paper with more detail on project background and on wider structural design learnings on this project such as section sizing, interactions with other materials and general coordination refer NZSEE conference paper “Design of the Ashburton District Council Civic Centre: a steel designers’ learnings from a timber building design” (Coulthard 2021).

Timber Design Codes

The New Zealand standards are currently in transition with no single standard covering everything that is required for design of a mass timber building. More so than other materials a designer needs to understand the timber material they are using, how they are using it and determine whether the current standard covers their specific case and is appropriate for use.

NZS3603:1993 is the current cited Timber Structures Standard in New Zealand. The engineered timber products and the way we use them has changed significantly since this standard was published, applying this code to engineered timber connections carrying high loads with large fixings or a great number of fixings may not be appropriate.

The Australian timber standard has been updated more recently in 2010 and their timber standard is AS1720.1:2010.

New Zealand is working to update our standard. There is a draft standard entitled DZ NZS/AS 1720.1. This draft standard is an adoption of the Australian standard with modifications to make it suitable for use in New Zealand. This standard is intended to supersede the current New Zealand standard NZS3603:1993.

The Australian AS1720.1:201 and draft New Zealand DZ NZS/AS 1720.1 standards incorporate connection design clauses present in the current New Zealand NZS3603:1993 standard. These existing clauses have been included in the new standards as a “simplified method” and limitations on where use of these clauses are appropriate are given. A “detailed method” is provided for connection design outside the scope of the simplified method.

The Eurocode is another useful resource for various situations not covered by New Zealand and Australian Standards. The Eurocode is useful to understand, particularly when using specialist fixings which have been designed and tested to Eurocode requirements. It is important to note that the Eurocode is designed to suit timber properties of materials common in Europe. Timber grown in New Zealand typically has different properties such as density which can have a large impact on connection design.

One portion of the new timber standard which has progressed out of draft, AS/NZS 1720.4:2019 Timber Structures Part 4: Fire resistance of timber elements. This code is current but not yet cited. As connection fire requirements are a key aspect of timber design every engineer entering timber design should read and understand the implications of this short 24 page standard prior to beginning any connection design. Details of this standards requirements are discussed later in this paper.

Timber Materials

I watched a webinar series through Wood Solutions by Dr Jon Shanks and Prof. Geoff Boughton (2020) which among other topics talked about the basics of timber material. One item that has stuck with me is timber is like a bundle of straws. That bundle of straws was used to explain a lot of timber behaviour and is now what I use to visualise timber behaviour.

The bundle of straws summarises the key timber behaviour which is the difference between properties of timber parallel to the grain and perpendicular to the grain. Timber is stronger parallel to the grain, similar to how the straws can resist forces to the ends well. Timber perpendicular to the grain is much weaker and will compress similar to if you squeeze the straws in the middle. Figure 6 is a visualisation of loads parallel and perpendicular to timber grains.

This has large impacts on both timber section and connection design. Connections parallel are much stronger, but with connections a group of fixings in a single line parallel has a reduction in strength.

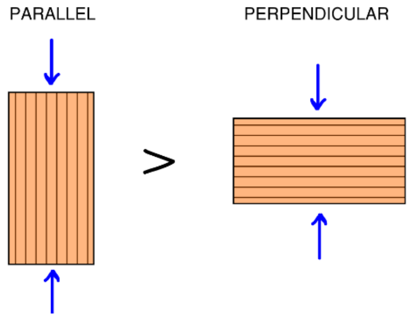

Figure 6. Timber is much stronger parallel to the grain than perpendicular

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. Timber should ideally not be used for significant compression perpendicular to the grain.

Another important timber property is that it creeps. This is incorporated into design through long term factors. The capacity of a timber element or connection can be reduced to 60% if the loading is permanent. If displacements are critical to the connection, for example post tensioning then this shortening needs to be included in the design.

<u>Engineered Timber Products</u>

Taking the key ideas that timber is a natural variable material and that its properties are very directional a range of mass timber products have been developed to best utilise the material. On this project we used four different products. Below I summarise in very simple terms some key factors of the different products and how they affect timber connection design:

- **Sawn Timber.** Sawn timber has been utilised for simple timber framing in this project.
- **Laminated Veneer Lumber (LVL).** LVL involves peeling thin wood veneers and gluing them together with the grains aligned. LVL has a clear parallel and perpendicular direction. As it is made up of many thinner layers the element properties are more uniform which allows higher factors to be used in design. LVL is more vulnerable to moisture so is only suitable for internal applications. LVL has been utilised for the internal gravity structure in this project.
- **Glulam or Glue Laminated Timber**. Glulam involves gluing together sawn timber. This product has a clear parallel and perpendicular direction, but as larger chunks of timber are utilised than in LVL more of the behaviour of sawn timber remains, so connection design incorporates similar factors to sawn timber. Glulam has been utilised for all external gravity structure in this project.
- **Cross Laminated Timber (CLT)**. CLT involves gluing together layers of sawn timber which alternate directions. Typically, the outer layers are parallel and a higher grade timber. CLT has good properties in both directions but sacrifices strength in each direction to do so. This means simple connection design equations do not apply as a bolt through CLT is neither parallel or perpendicular. CLT has been utilised for the post tensioned walls and stairs in this project.

Every connection in this building has a completely different design depending on what materials are being connected and what direction the load is relative to the grain for each element. The design is also different for each load combination.

Further, the design with these materials will vary based on the specific material properties and layups of each element. Throughout design various suppliers were included in the process, providing comments on the availability of materials, manufacturing capabilities and other factors. Construction on this project begun this year. On all engineered timber products, we have been asked to make changes to the specified timber products such as changing lamella sizes in the CLT mentioned above and reducing maximum LVL lengths.

Engineered timber is a moving target with huge variations between materials, between suppliers and over time. Understanding how these factors affect your connection design and what is a small change in construction and what undermines the entire connection philosophy is important.

Layouts

Making timber projects and timber connections work is primarily about getting the building approach that suits timber. At concept stage we have the opportunity to influence this and get the design team on board. With steel we tend to funnel large loads through specifically designed connections into discrete lateral resisting systems. Timber isn't as suitable for this concentration of load. With timber we need to operate on smaller and more consistent grids.

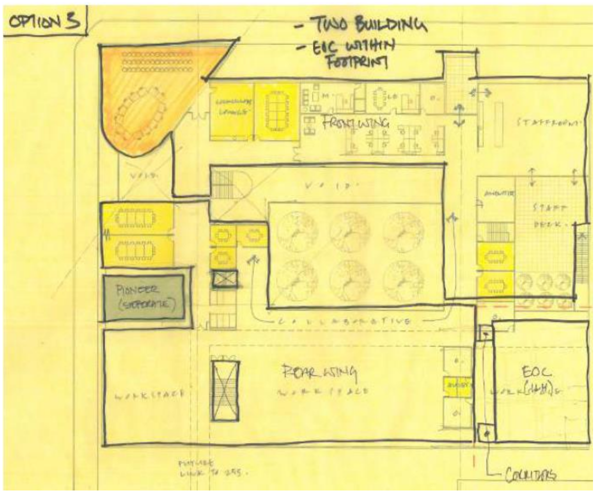

Figure 7. An initial conventional steel concept

Figure 8. The initial timber concept layout

For this project we had both steel and timber concepts. The initial structural layout concepts for the conventional steel option focused more on spaces and building seperation as shown in one example in Figure 7. This was allowed due to the lower intrusion of a steel stability system into the spaces. After the project's change in direction the initial timber layout concept shown in Figure 8 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.

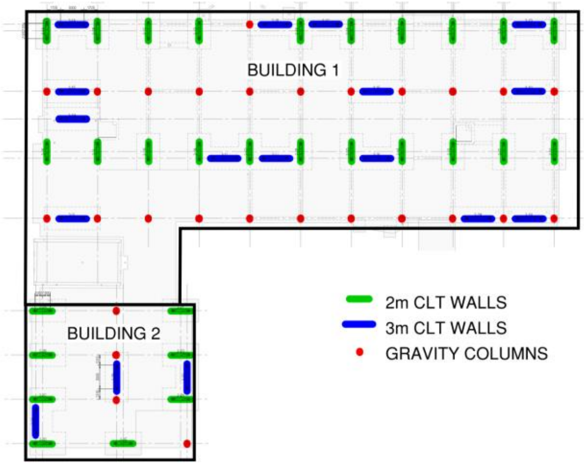

Figure 9. The final structural layout

The final layout shown in Figure 9 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.

While the sizes provided on this project worked, we should have pushed for more size in the vertical structure (wall length and columns). We thought we were generous with the sizing – but in reality the sizing was just enough and led to more complex connections. A particular example was fitting the bolts and their required spacings into 315mm wide columns. Don't underestimate the timber sizing, connection layouts often define section sizes so need to be developed early and inform structural concepts.

Another item that wasn't captured fully at concept stage was splices and cantilevers. In order to get larger spans and cantilevers in steel buildings we rely on the ability to provide continuous members and back spans through welding. With timber we are limited to lengths of timber that can be fabricated and transported in New Zealand. Providing splice connections with good long term properties and stiffness is tricky in timber. Cantilevers are quite achievable in the direction of the primary beams. However, providing even a small cantilever perpendicular to the primary beams is challenging if your primary and secondary beams are in the same structural depth. The floor cantilevers project east and west of building 1, which led to complex cantilever connections involving steel straps and timber blocking to transfer the tension and compression components of the cantilever through the primary beams (perpendicular to the grain).

Timber connections in fire – a challenge for timber construction

Timber connections in fire have become a key issue in timber building design. As discussed above 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 investigated 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.

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. A lot of the cost in timber projects is in the complex connections and fabrication capabilities of local manufacturers.

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.

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.

In this paper I have summarised some of the key learnings from the ADC Civic Centre project on timber connections. 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.

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.

As an industry and as individual engineers getting up to speed with timber design and keeping up to date with what is possible within the New Zealand timber fabrication industry is a challenge. A key first step to get our industry up to speed is getting an up to date timber code and getting timber suppliers to give clear information on their capabilities. The more we design timber buildings, share our experience with each other and work together as an industry the more successful timber will become.

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