Scion Hub: A three storey seismically resilient timber diagrid.

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ABSTRACT

The new three storey Hub building at Scion's campus in Rotorua is an innovative approach to providing seismic resilience in timber. A demonstration project for Scion's work in the timber industry it utilises several forms of engineered timber, including an LVL diagrid to provide gravity support and bracing at the perimeter of the floorplates to provide 100% of the building's lateral resistance. This paper discusses the challenges of selecting the appropriate foundation system on a site at risk of liquefaction or geothermal deformations, how to make a rigid diagrid ductile for large earthquake forces or ground deformations, and the interesting forms of timber detailing employed. Design and testing of the energy dissipation and timber node components provided some challenges, with good learnings for future projects.

1   INTRODUCTION

Scion's new building began its life as a design competition for a new visitors' centre at the Rotorua campus. The winning architectural team of RTA Studio, with Irving Smith in association, won the competition, proposing that instead of a visitors' centre that Scion's administrative facilities were consolidated into a building that would speak to visitors about what they did.
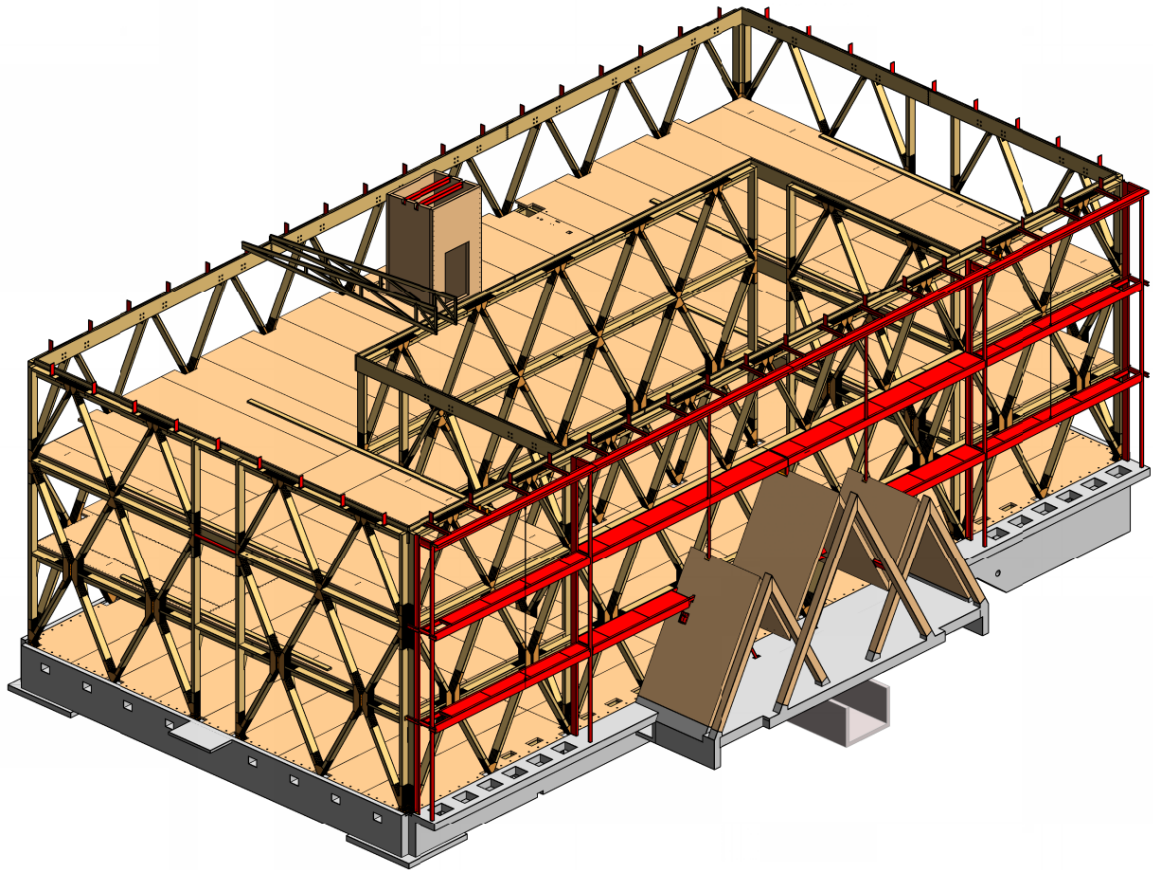

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Figure1: Architectural rendering courtesy RTA Studio, with 3D of structural arrangement from DT model.

The proposed building is a 3-storey 1800sqm facility that uses different engineered wood products in different ways to form the building's floors, stairs, lift shaft, partitions and primary bracing in both directions. The approach of displaying engineered wood in many uses was part of the architectural concept, with the structural bracing expressed as some form of diagrid around the building's perimeter.

2   INITIAL APPROACH

Our initial approach to the building was to use the abundant bracing to make an elastic wooden structure. This was an uneasy thing to do, not having any control over the seismic loads through energy absorption. The relatively lightweight structure was able to be braced with some additional factors for resilience, and at 3 storeys, foundations were relatively lightly loaded even for the 8m (small) commercial spans.

3   FOUNDATIONS

Due to project evolution, geotechnical investigations and design were in two phases. Initial investigations were for a greater campus-wide masterplan and had few results at the final site. What would usually be deemed good ground was found to be potentially subject to liquefaction, geothermal effects at depth and no prospective solid material to pile to within 20-25m. Further investigations were carried out using a more targeted combination of soil sampling and CPT testing, suitable for the pumaceous and semi-plastic soil layers. Whilst these suggested only limited liquefaction at some depth, some surface manifestation was possible and there were still questions regarding possible geothermal effects.

It was elected to found the building on deep concrete foundation walls which could spread the already light building loads over large areas and work with the relatively thick, dry (non-liquefiable) crust to spread differential settlements over larger distances.

4   DIAGRID

4.1 VERSION I

The idea of making the diagrid ductile stemmed from our uneasiness regarding the potentially uncapped seismic loads, and our uneasiness regarding ground deformations. The diagrid's form meant its inherent stiffness would make it want to span across any differential ground deformations and would result in excessive member sizes and unworkable connections. If the diagrid could be split into sections that could be linked by ductile elements, they could allow the diagrid to conform to the ground deformations. This would allow us to limit the force exerted on the timber avoiding brittle failure. This could also be used to improve seismic resilience by providing seismic damping.
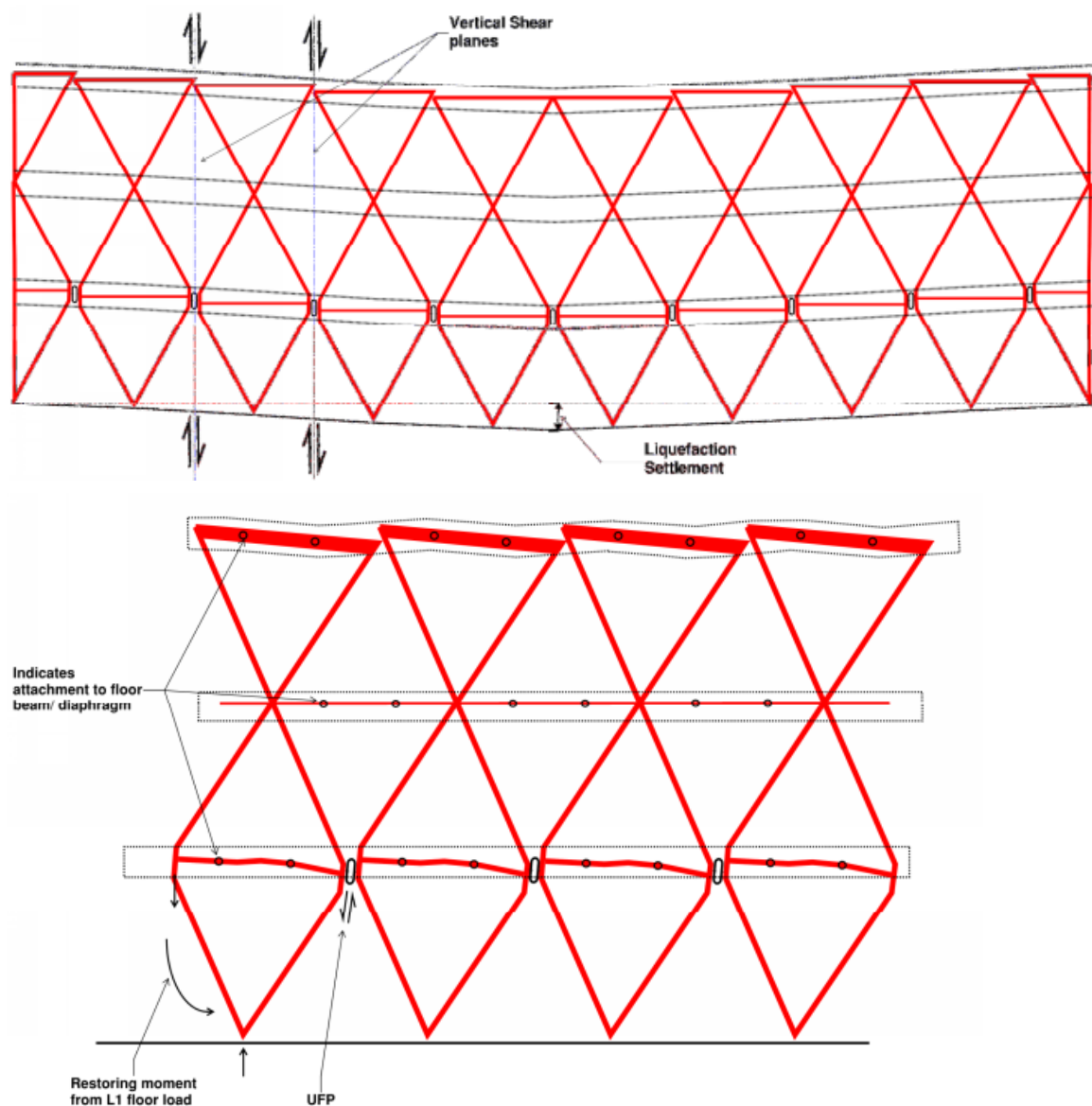

Figure 2: Diagrid deformations

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The selected diamonds were curtailed at the ends of each bracing line with a half-diamond which would provide hold-down for overturning (see below).
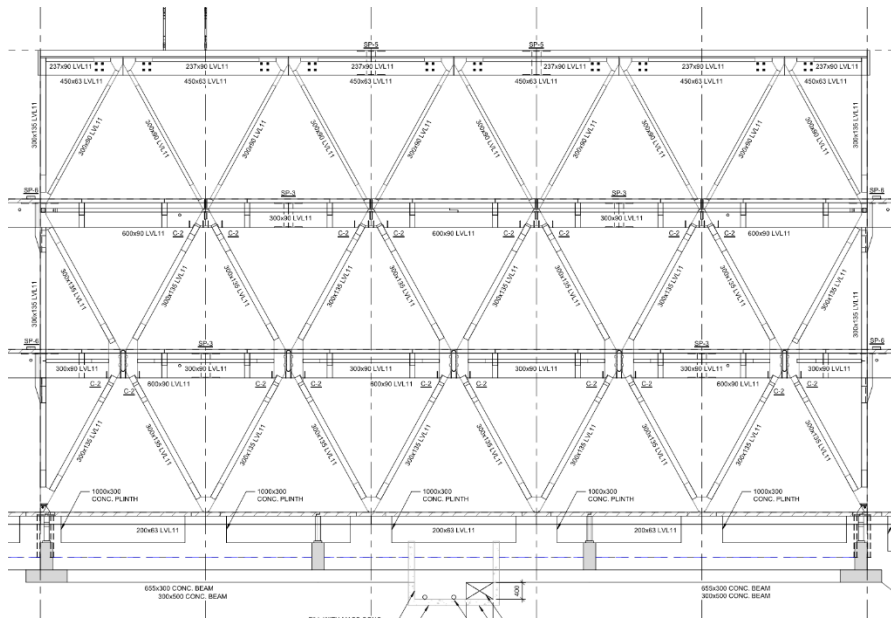

Figure 3: Elevation of atria longitudinal diagrid

As with all timber structures, making them work is all about the connections. Our initial concept for the ductile node is shown below. This used very simple rectangular members and epoxy rod technology. This node was considered unsatisfactory in both achieving Scion's aim in maximising the use of wood within the building and with our concerns about achieving adequate stability in fire.
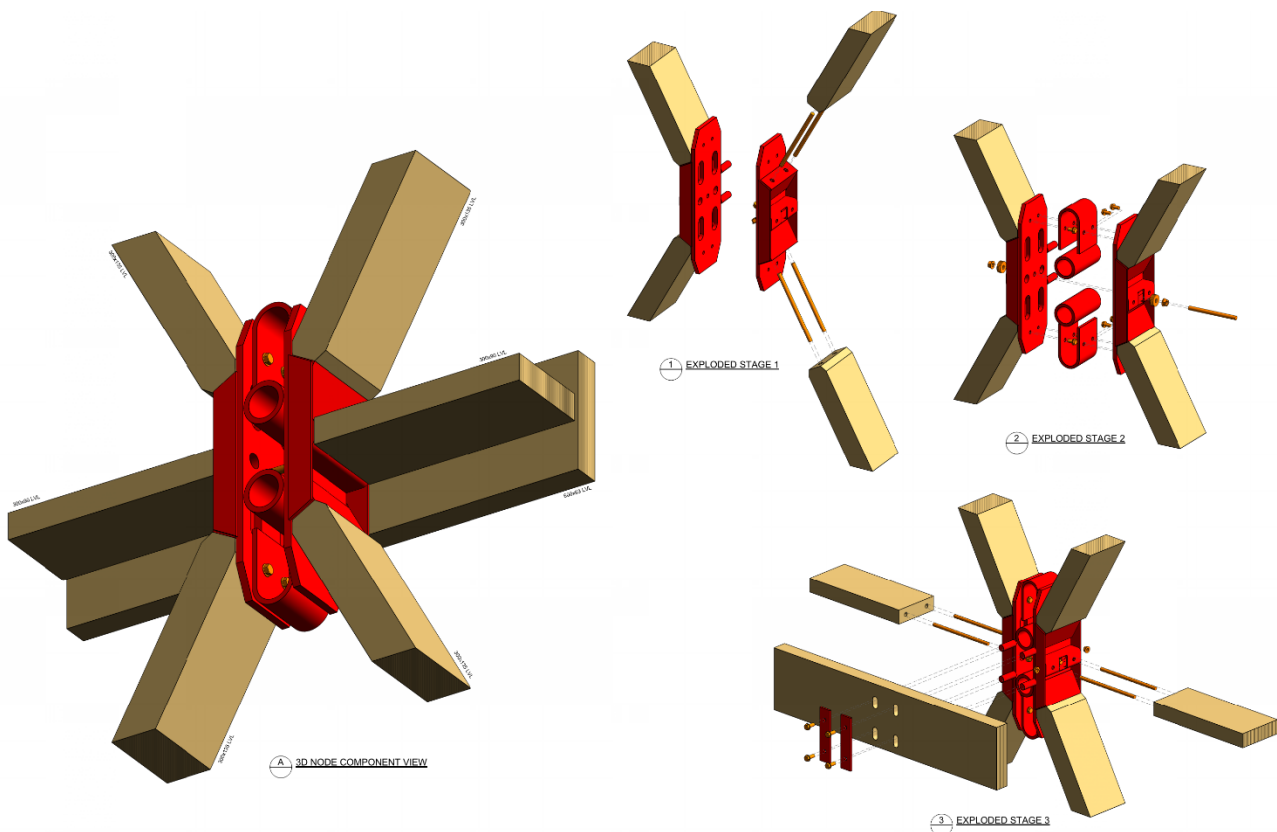

Figure 4: Steel node concept

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The roof half-diamonds were simpler to design. As we had already introduced the appropriate ductility into the structure, the roof could be more elastic for lateral loads, connecting the diamonds together with a simple beam on the inside which doubled to support the roof trusses allowed the shape to be like a multi-bay portal frame on top of the 2-storeyed diagrid structure below.

4.2 VERSION II

Version II aimed at using the minimum steel necessary while still achieving the ductile deformations shown in the figures above. The UFPs were connected in using only a single flat plate with shear keys to transmit the loads to timber. The noding forces were to be taken by a multi-layered joint made from cross-banded LVL orientated appropriately to feed the forces from the diagonal members back into the horizontal ties and into the UFPs. Critical force cases are shown in the diagrams below. The joints' design is governed by rolling shear in the cross-banded LVL. The force of the grain in one direction can only transmit through the layers of the material by rolling the perpendicular layers of grain across their axis. To provide sufficient strength without a visually intrusive size, we used LVL 16, which had slightly higher rolling-shear capacities as it is a more dense material.
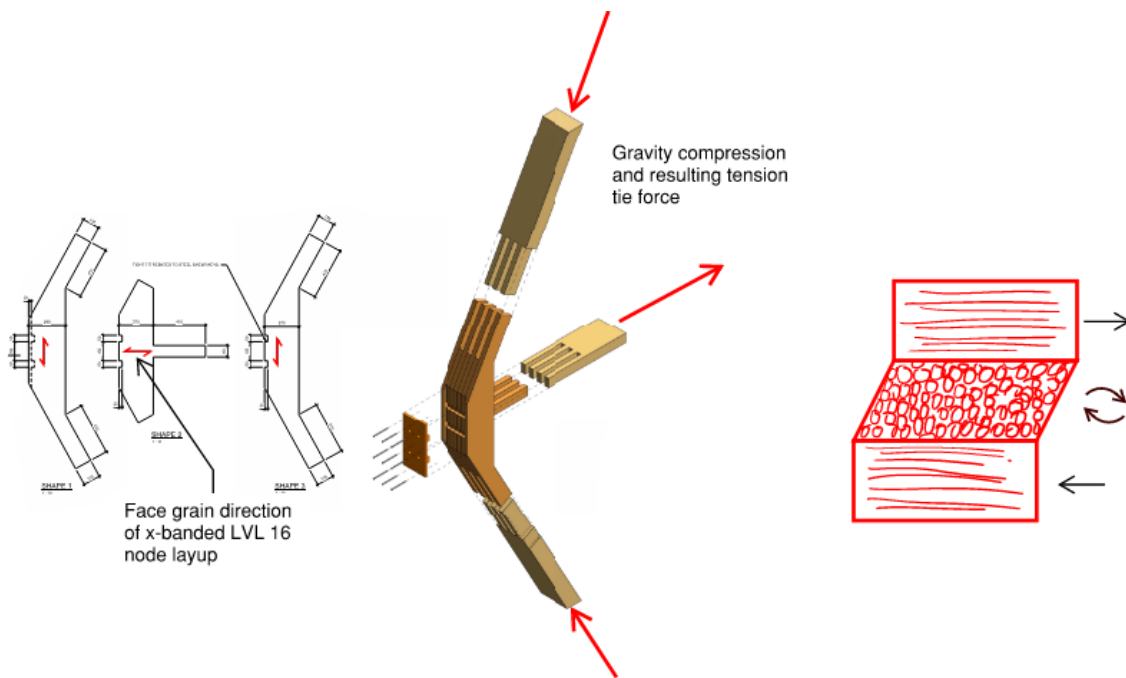

Figure 5: Exploded Schematic of typical diagrid node layup, gravity forces, and rolling shear

The building's floors are supported on corbels on the inside face of the diagrid. The floor's edge-beam can span between every second corbel as the diagrid diamonds rock over, as shown in the illustration above. This also provides a restoring force to the lateral displacements. The corbels were notched into the diagrid to minimise their size by using end-grain bearing in the timber. The top face of the corbel was armoured with nylon to provide some protection during the slight hammering action that would occur during rocking and to minimise any friction causing unnecessary overstrength actions as the diagrid moved backwards and forwards.
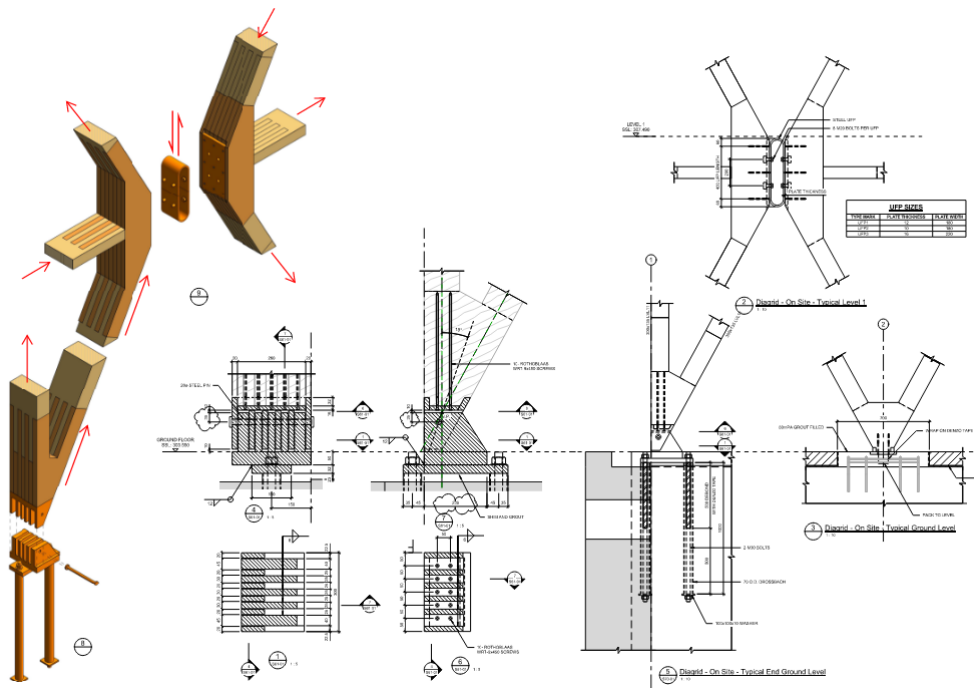
Figure 6: Exploded Schematic of typical diagrid UFP connection and end hold-down, and seismic forces.

Hold-down at the diagrid ends was done using a steel hinge joint by using multiple layers of steel. Being at the floor level of the lowest floor of the building and being relatively oversized for capacity, its fire exposure was not of concern.. Adjustment for foundation tolerance was achieved by having moveable threaded rod connections at each end of a line of diagrid and only a shear-key type connection at the intermediate points, that was grouted once the structure was erected to lock in the tolerance.

5   DIAPHRAGMS

The distribution of diaphragm forces, if by purely by tributary area, would have resulted in very heavy diagrids around the atria and very little demand around the perimeter. However, because the diagrid system is now ductile, we could allow the atria diagrids to have a smaller force capacity, and so be of the same proportions as the perimeter diagrid.
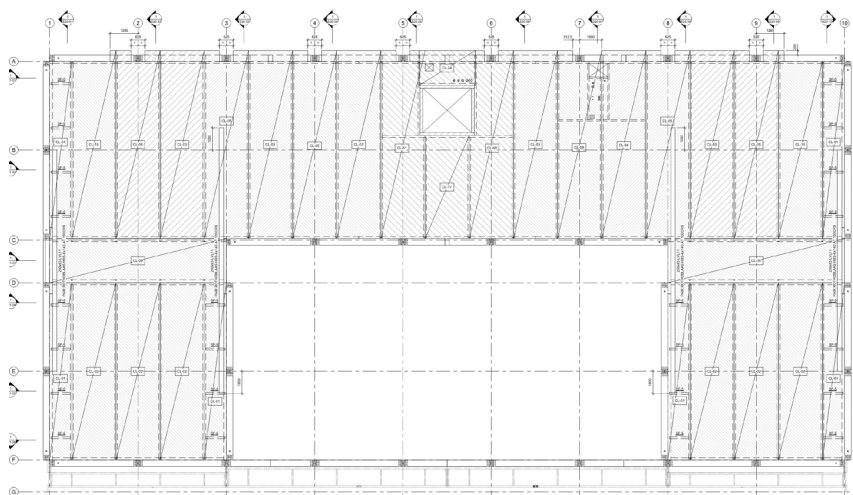

Figure 7: Plan on Diaphragm. Front wall diagrid (bottom) is stabilised by the external walkway in the double façade acting as a horizontal beam.

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Because forces are being redistributed, diaphragm loads were consequentially higher. This required, not unsurprisingly, closer centred fixings in the U-shaped ends of the floor, which could be relatively easily accommodated in the CLT. However, these ends would tend to prise off the main rectangular section of floor. Stiffening cords were introduced on top of the CLT to provide moment capacity around the U-bend: these simple ties were possible as the building has a raised "batten and cradle" floor which provides electrical distribution, acoustic absorption and vibration damping to the floor structure.

The roof, being a simple rectangle, uses a simple plywood ceiling diaphragm.

6   STAIRS

In keeping with the structurally expressed wood theme, the stairs are cantilevered "scissor stairs" into the atria. These could not easily interface with the diagrid, including its movements, and so each stair was gravity founded on a separate post and then tied back to the floors, as shown in the diagram below. This allows movement of the building in both directions. The stair structure is hybrid of CLT, steel and LVL, again to maximize the use of timber where possible.
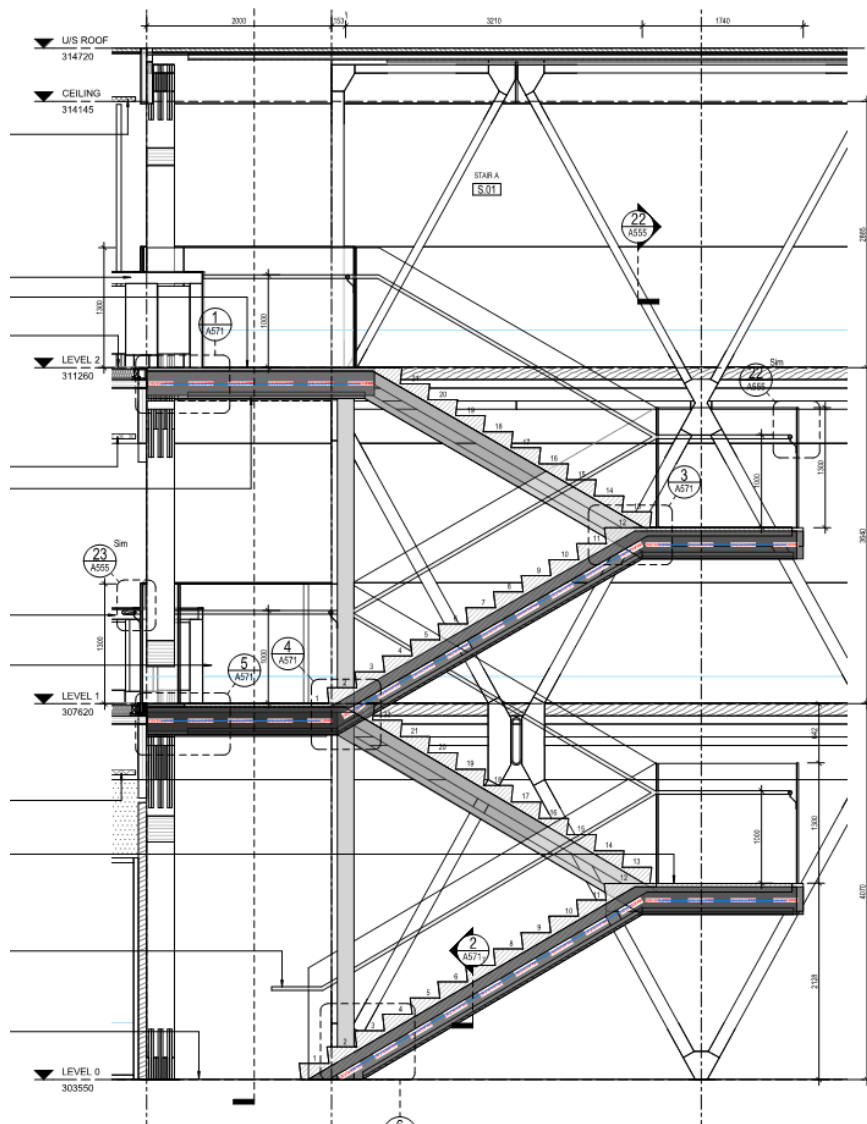

Figure 8: Stair section courtesy RTA Studio

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7   TESTING

While all aspects above are theoretically derivable by calculation, we believed there were uncertainty risks in the layup of the nodes and the plastic performance of the UFPs. Test jigs for two types of node (one typical, one base hold-down) were designed so that Scion's own lab with somewhat modest testing equipment could be used.

Images of the timber node test set-up are shown below. While the nodes performed satisfactorily up to overstrength loads, continued loading showed an interesting failure mechanism not in the nodes themselves but in the member connection to the test equipment. Because of the direction the diagrid members were pinned to the jig, shear in the non cross-banded members had to flow from one layer of the LVL to the next. Of course the forces found the weakest layer, the lower-bound properties, rather than being able to average through the layers if the shear forces had flowed the other way as is normally the case for typical LVL use situations. This highlights is an important consideration for future designs that use complex layering as this one.

Figure 9: Testing setup

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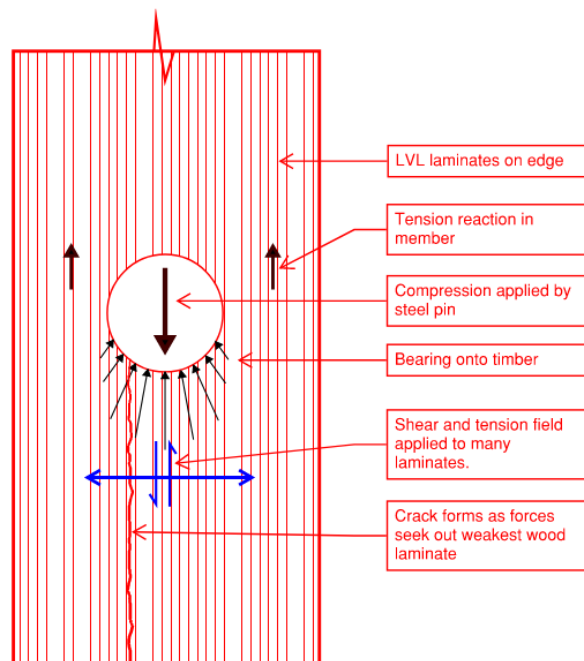
Figure 10: LVL test failure from laminate weakness selection

The UFP design complied easily with the tabulated values in the PRESSS handbook, which reports on the 1970s testing. The first tested UFPs failed very prematurely compared with the reported values. We suspect firstly that the UFPs were cut across the grain of the steel plate they were fabricated from rather than along, which encouraged the brittle tearing evident below. We also suspect that the values in the PRESSS handbook graph are not applicable to these thicknesses of plate and that they were concluded from very small-scale tests. We believe all UFP installations should be tested before construction to ensure appropriate strength grade and ductility is achieved.

An adjustment to the thickness and width of UFPs resulted in acceptable performance

8   PEER REVIEW

As the structure is obviously innovative in many ways, a peer review was arranged during the design process with Ruamoko Consulting Engineers Christchurch. Our thanks go to Ruamoko for a positive and constructive process. It is always refreshing when someone else approaches the engineering of your design in a different way and questions your assumptions. It is also heartening when you come to similar conclusions.

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