COLLEGE OF CREATIVE ARTS BUILDING, MASSEY UNIVERSITY, WELLINGTON

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SUMMARY

The College of Creative Arts building is about design integration: integrating the structural, services and functional elements of the building and expressing them as the architecture.

Athfield Architects won a design competition to create the new home for Massey University Wellington's College of Creative Arts. Their successful design uses timber as a warm, inviting and uniting element throughout the building. As a functional space, the different areas are open and flexible. The structural use of timber softens and modulates the volume.

By using innovative damage-control design, the college can rely on the structure to perform both seismically and architecturally over the years.

INTRODUCTION

The new College of Creative Arts building for Massey had to perform many functions for the university. For the greater campus, it was to unite the other faculties with the student heart of the campus two stories below. With a prominent position overlooking the Basin Reserve, and housing a design school, aesthetics were important both inside and out.

Athfield Architects' response to this was to house the "tough" functions, workshops and presentation spaces in a heavyweight plinth which retained the two-storey step in the landscape. The college's studios would be housed in a "floating" timber vessel above, and the whole would be linked through an integrated hallway/gallery space. The studio superstructure was conceived as a timber building embracing emerging technologies and their ambitions for the feel of the space.

Dunning Thornton provided high-level input to the competition entry. Once appointed, Athfields and Dunning Thornton pushed for the timber solution, as both could see the multi-disciplinary advantages. Dunning Thornton were confident in meeting the technical challenges after designing the Alan MacDiarmid building (PRESSS concrete) and through their assistance in the competition and peer review for the Nelson NMIT building. Massey embraced the team's vision and approved funding for the world's first post-tensioned LVL seismic-frame building.

STRUCTURAL FORM

The plinth structure comprises concrete floors and reinforced concrete blockwork walls. Retaining 8 metres of weathered rock and mixed-quality fill bank, the plinth is designed to withstand seismic loads significantly higher than the requirements to found the lightweight structure above. The total seismic force at the base of the plinth structure is 1300 tonnes, but 720 tonnes of this comes from the retained soil.

At areas of high stress, concrete walls replace blockwork, keeping the bank in check and permitting the broad double-height spaces that create the sculptural architectural forms. These were assisted by a number of structural steel beams, transferring the weight of the LVL structure out to the plinth's walls. Founding of the building was on rock at one end, and on the mixed-quality backfill of an old clay pit at the other. The plinth and upper level foundations were rigidly tied in order to solidly found the superstructure. However, the effect was to increase the seismic acceleration at the underside of the new timber building to seismic soil class C.

The superstructure is organised either side of a longitudinal corridor, with offices to the West and studio spaces to the East. A traditional academic two-bay grid of 6.5 and 9 metres was provided to enable this with a longitudinal spacing of 7.2 metres to suit office, studio and facade modules. With these longitudinal flows to the building, transverse walls or bracing would hamper the building's use, and so frames were the appropriate solution.

Longitudinally, closed areas around the toilet and fire escape stair were logical positions for shear walls. Given the durability and fire requirements of the external escape stair and the robustness required around a student toilet core, the team elected to use concrete shear walls.

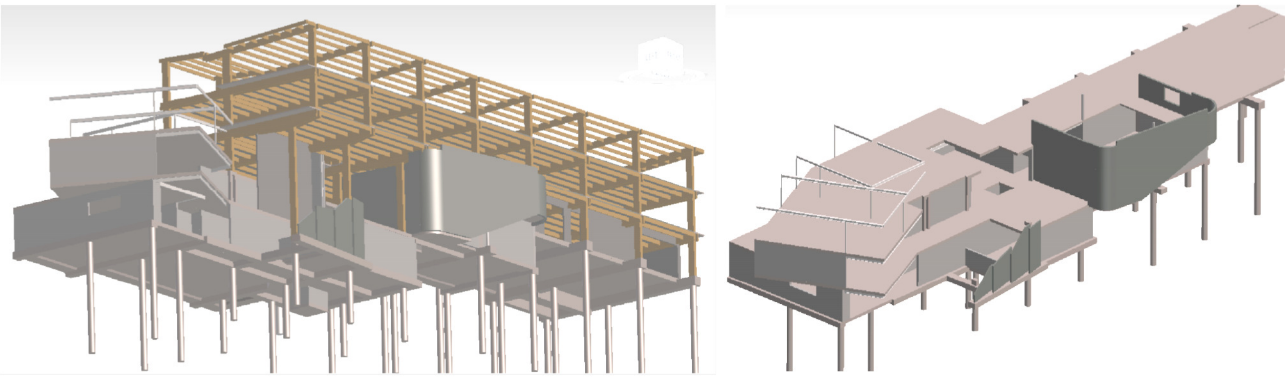

Figure 1. 3D of overall structure, sitting on the complex heavyweight plinth, with plinth shown again from above.

Timber concrete composite floors were chosen throughout the building for their appearance, their lightweight nature and for the exposed concrete mass providing both a thermal sink as the ceiling and a robust floor surface for the studio activities to occur on. These span longitudinally between the transverse LVL frames.

The roof comprises longitudinal timber rafters supporting a ply ceiling over which insulation and the metal roof were laid.

POST-TENSIONED FRAMES

The design challenges for the post-tensioned frames were seen to be:

- ongoing creep and sag issues under permanent loads (gravity and post-tensioning)
- flexibility of the structure giving large seismic and wind movements
- flexibility of the structure making the insertion of damping difficult at the joints
- dilation of the frames due to the rocking mechanism

These issues were addressed by the structural form of the frame as described below.

The main post-tensioning strands were deviated downward in the beam spans to balance out the dead load and half of the expected long-term live load in the building. Two deviator pins were used in the long 9 m spans, and a single pin in the 6.5 m span. These pins had to shape the post-tensioning cables without exceeding the minimum radii required by the strand manufacturers. A typical deviator is shown in Figure 2.

The strands were anchored off in bespoke-designed steel elements each end of the frame, which ensured that pressures on the beams were always in the positions intended. The cables could be left exposed in the building for fire, as the remaining timber structure was sufficiently strong to hold up the loads expected during fire evacuation.

Long-term shrinkage/axial deformation caused by the post-tensioning occurs primarily where elements are in perpendicular-to-grain bearing. This was designed out by using two beams passing each side of a single timber column. Although post-tensioned frames (concrete or LVL) had not been tested in this configuration before, it is a traditional method of timber construction to use "two and one" elements to form joints. Sections of beam (dubbed 'shear blocks') were glued to each side of the column to form the joint, and the main beams brought up to these on each side to form the rocking interface. The joint face was armoured with a 6 mm steel plate, which formed a hanger to carry the long-term gravity loads of the beam. The hanger was intumescent-coated and incorporated downward-sloping dowels such that it could perform its gravity load function during a fire.

Figure 3. Construction of shear blocks

The shear blocks glued on each side of the column were formed from a combination of ply and LVL to form the right mixture of grain running parallel to the beams and stability under the high shear flows imposed (Figure 3 and 4). The glued connection to the column utilised a plywood biscuit joint to increase the strength. The ply biscuits were cut at 45 degrees to the ply grain to increase their strength and robustness. The shear

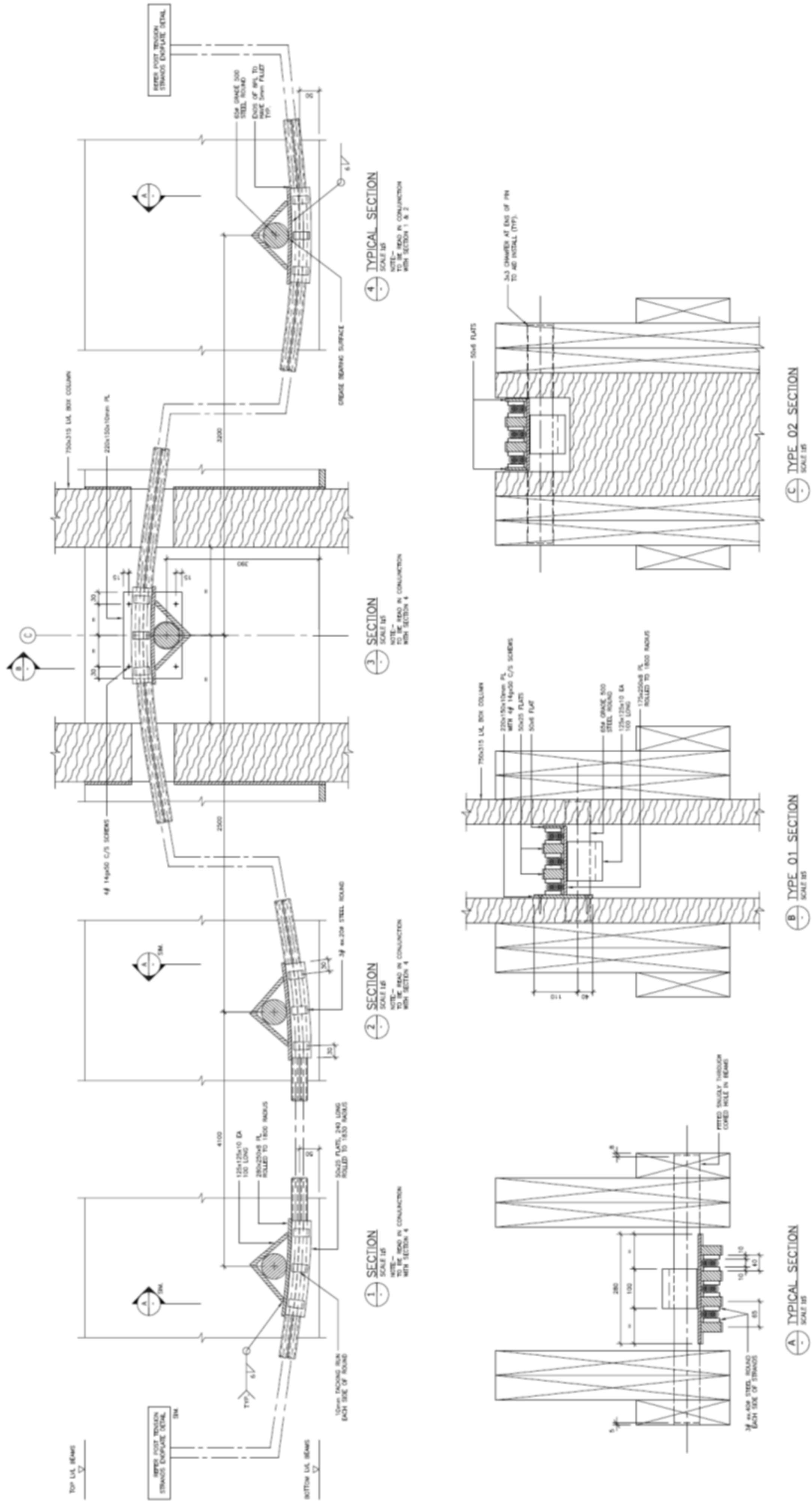

Figure 2. Typical deviator diagram.

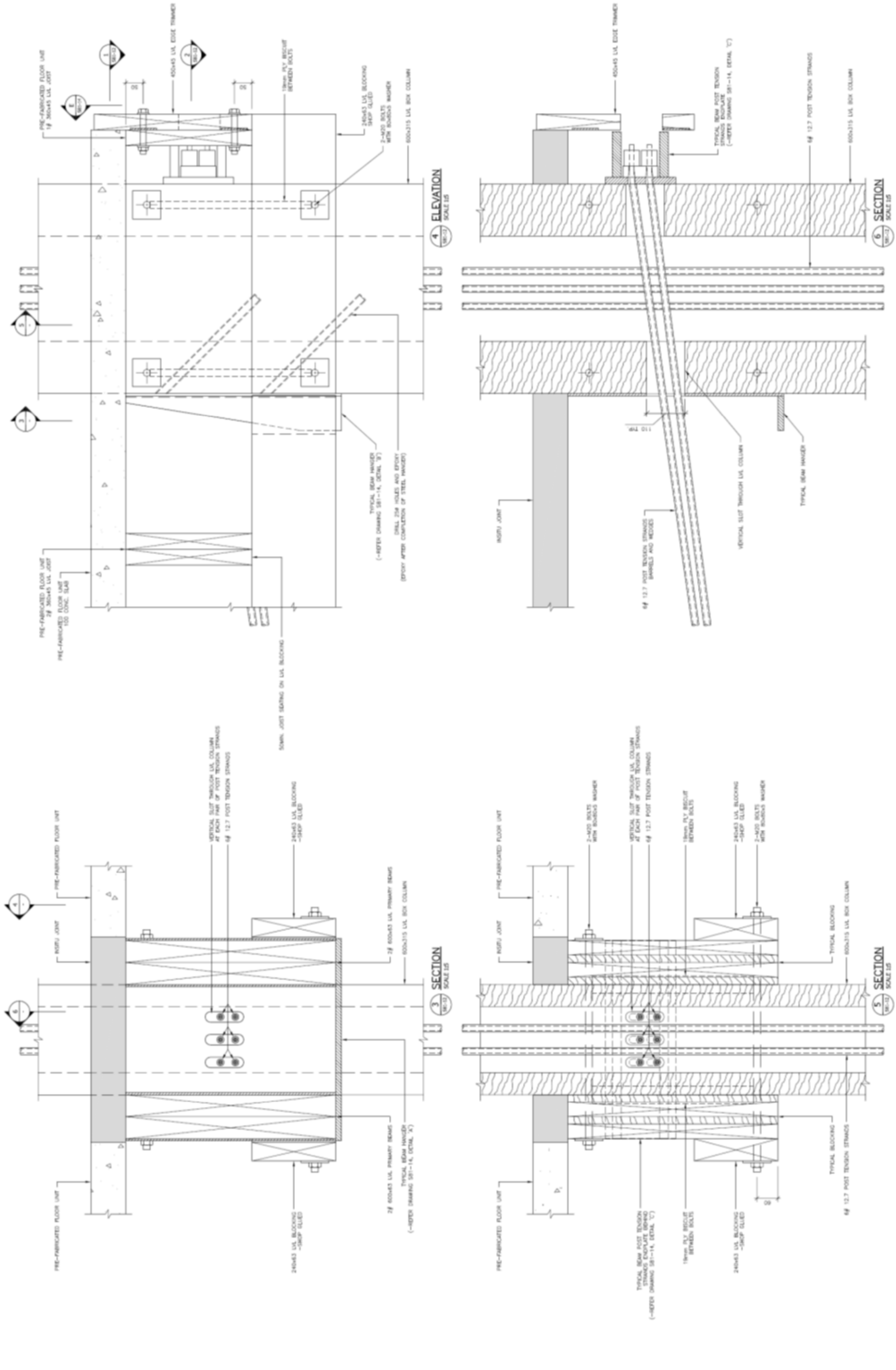

Figure 4. LVL frame steelwork - Post tension strand beam column details.

blocks could then be shop-glued and clamped to each side of the columns using four M20 high-tensile bolts.

The flexibility of the frame in service was the primary consideration in selecting the member sizes. Under serviceability limit state wind and earthquake loads the post-tensioned joints remain closed, and therefore movement results from the flexibility of the material alone. LVL 13 was selected for the primary elements to increase the flexural stiffness, however it is of note that even with the stiffer shear block arrangement used in this building, a significant proportion of the deflection comes from the shear deformation of the wood. Larger members were used for the central columns, as these are more effective structurally and they could be integrated architecturally with the central lightwell/service risers.

The floor beams were not governed by long-term deflections due to the deviated post-tensioning. However, their depth was critical to both short-term movements and for the vibration characteristics of the floor and frames together. A 3D model was built to test the dynamic properties of the combined structure during footfall in various locations (Figures 5 and 6).

Due to the high flexural and shear deflections, the idealised "gap opening" that occurs in LVL frames is far smaller than in PRESSS concrete frames. From our detailing of the Alan MacDiarmid building, we were also aware that detailing "full-scale" dampers that minimise slip before they take up load is expensive and difficult.

The building's damping is therefore derived by elasto-plastic hysteretic damping between the top of the concrete-walled presentation space (in the plinth) and the underside of the first floor (see Figure 7).

U-shaped flexural plates were used to provide reliable cyclic action over the large displacements required. By being initially stiff, and by selecting the appropriate force level, the effective damping achieved for the structure was able to be as high as 20% under ULS. As the damping occurs only at one floor, there are additional more lightly damped oscillations at level 2 and roof. Column stiffness was therefore especially important in controlling drift.

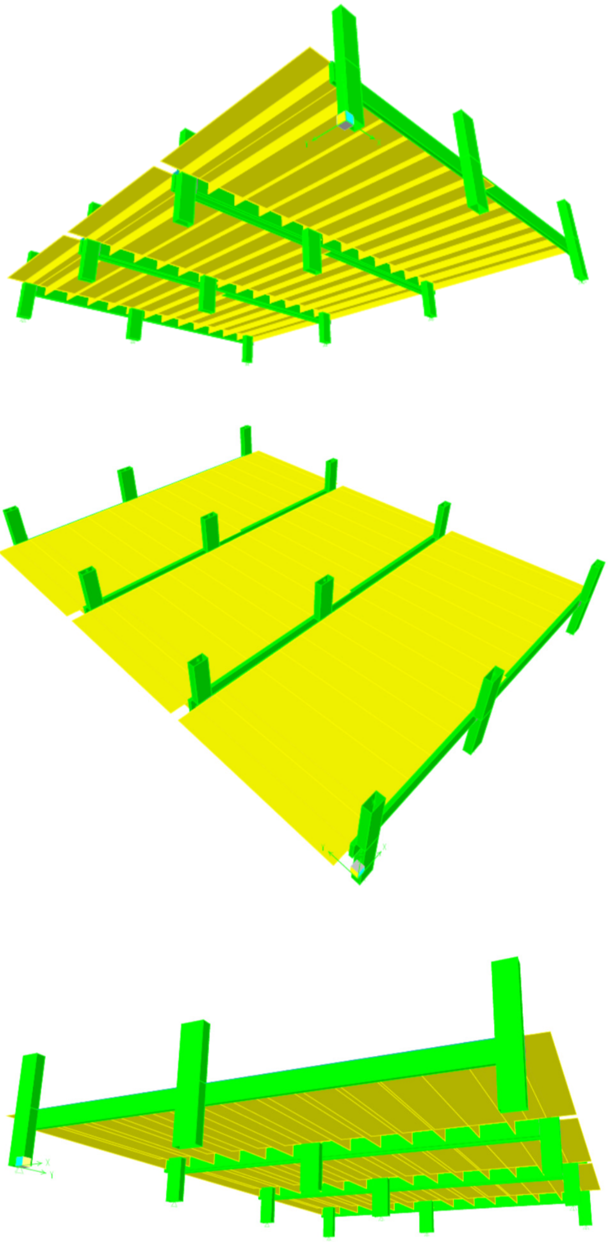

Figure 5. 3D model of floor units

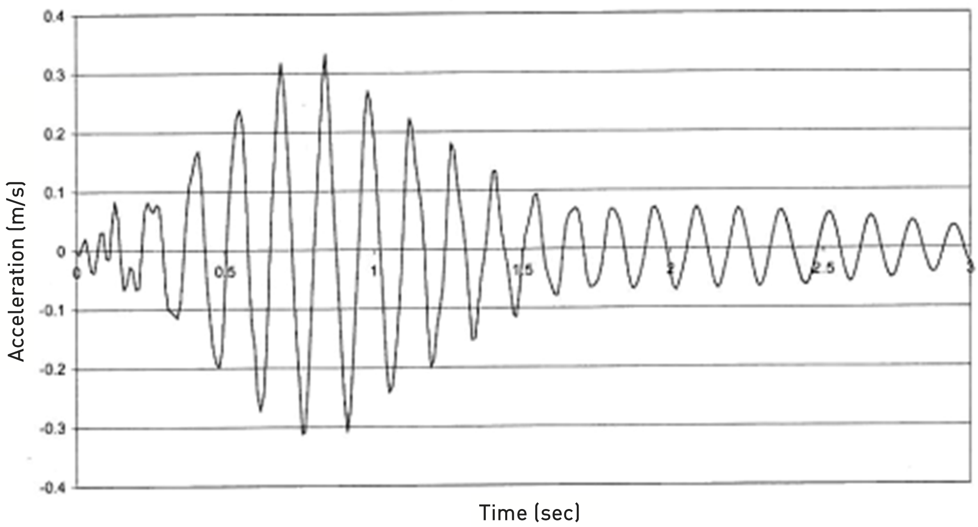

Figure 6. 1 kN pulse traversing across floor units at 6.67 Hz

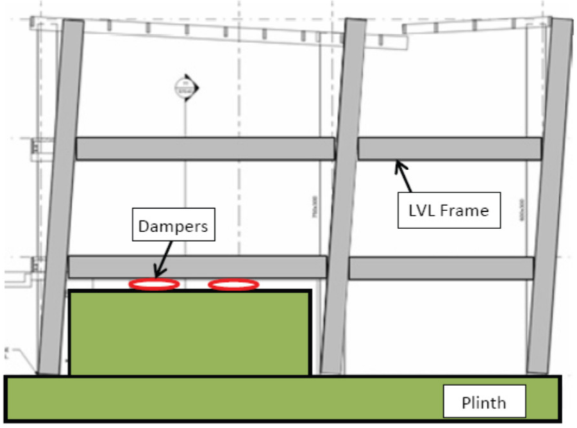

Figure 7. Representation of elasto-plastic hysteretic damping on building.

Analysis was carried out at both 2% and 5% damping to evaluate the sensitivity of the superstructure to these higher-mode oscillations.

It is interesting that for a complex seismic system, its primary member sizes can be completely derived from the static elastic analysis of the serviceability conditions.

A prototype was constructed of a central column-and-beam cruciform. This process allowed for proofing/ refinement of the manufacture, and for testing of the prototype at the University of Canterbury to calibrate the analysis, specifically the flexural and shear deformations of the members and the joint (see Figure 8).

Figure 8. Joint instrumentation and overall set-up at the University of Canterbury.

To accommodate the frame dilation inherent in beam-rocking systems, the diaphragm was rigidly connected to the 9 m span and left to run free over the 6.5m span. Corresponding soft packers were used at the columns to allow their movement.

TIMBER CONCRETE COMPOSITE (TCC) FLOORS

The design required a TCC floor that had the concrete exposed to the top surface and ceiling in order to achieve the thermal and architectural ambitions of the building. The major risk issue with TCC floors, other than vibration as described above, is the curvature induced by the differential shrinkage and creep between the concrete and the wood. The design intent for these floors was to pre-camber out that deflection. This was done by pre-bending the joists as shown below into the concrete mould before the concrete was cast. The concrete could then be cast to the curve of the joists and the system released once the initial set of the concrete had occurred (see Figure 9). A pre-camber of 25 mm was selected based on the following build-up.

IN THE YARD:

Dead load deflection from stacking after lifting from the mould	5mm	
70% of the shrinkage deflection	8mm	
50% of the long term creep deflection	2mm	
Subtotal		15mm

DURING CONSTRUCTION:

30% of the shrinkage deflection	4mm	
Partitions and fitout	2mm	
Remainder of the long term creep deflection	4mm	
Subtotal		10mm
Total		25mm

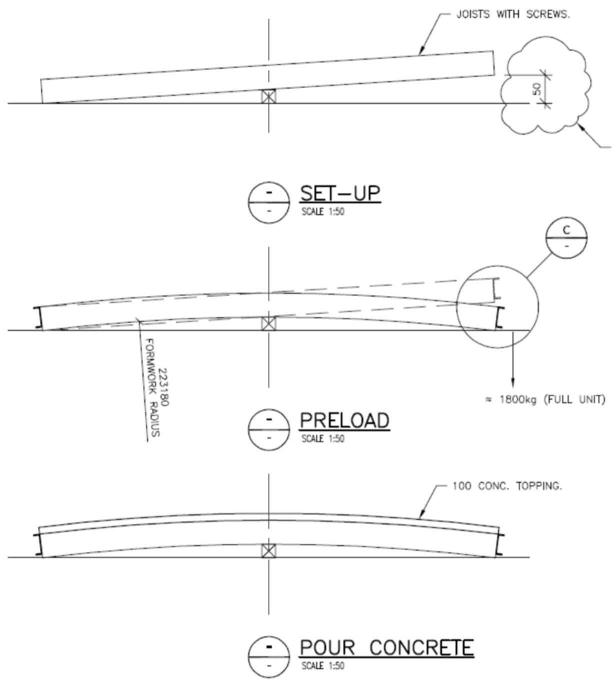

Figure 9. Pre-fabrication sequence

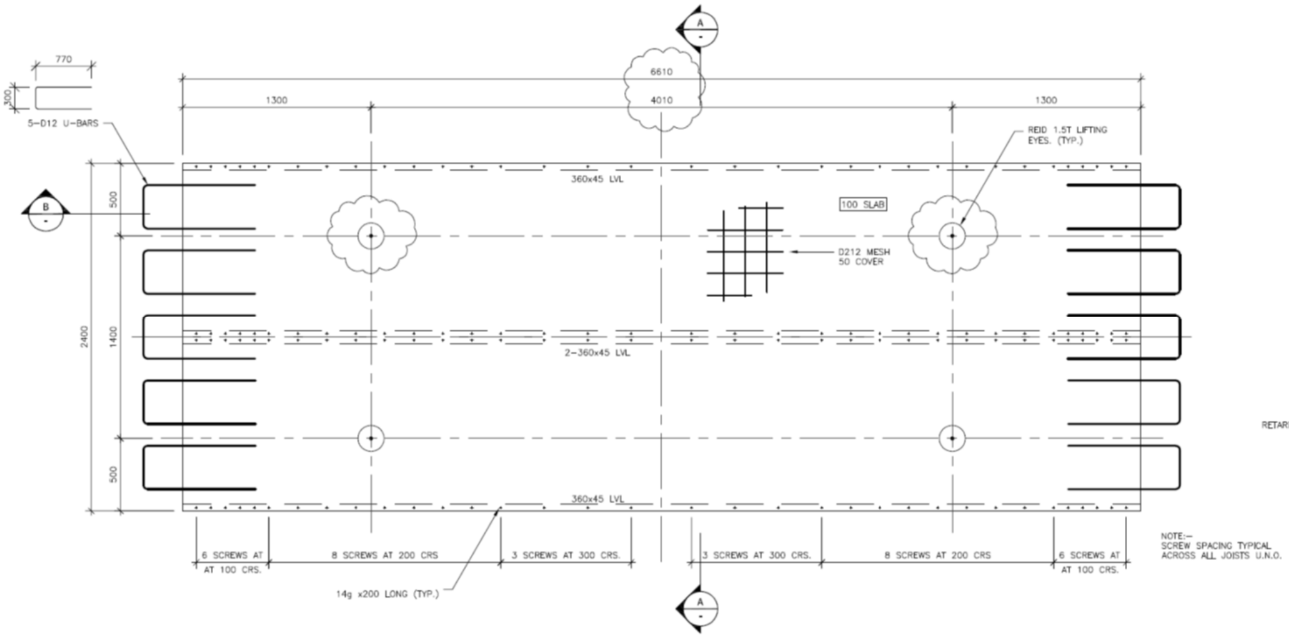

Figure 10. Typical floor unit plan (Scale 1:20)

As there are several variables in this make-up, and with the structure so exposed, it was essential that our predictions were perfect. Two prototype floor modules were cast, cured and monitored for six months before the main production began. As it happened, our predictions of the movements were correct. However, the prototypes gave significant confidence to the client and contractor, and more sleep to the consultants.

Connection between the concrete and the timber was via diagonally driven 14-gauge type 17 screws. These were grouped according to the shear flow as shown in Figure 10. Several other options were considered, however these gave the greatest strength for the cost. There were some concerns regarding the quality of the screw material, but in general the capacity was governed by pull-out from the LVL. It was heartening that when one floor unit was dropped during construction, the LVL joist split below the level of the screws rather than at the interface with the concrete.

The units are connected at the base of each outside joist. Whilst this provides some diaphragm action, further analysis showed that the vierendeel action of the floor planks acting with the *in situ* strips over the beams was a stiffer and potentially stronger mechanism (see Figure 11). However the connection between the joists forms a back-up mechanism for the diaphragm and ensures the single 45 mm joists remain connected as a double 90 mm joist in the fire condition.

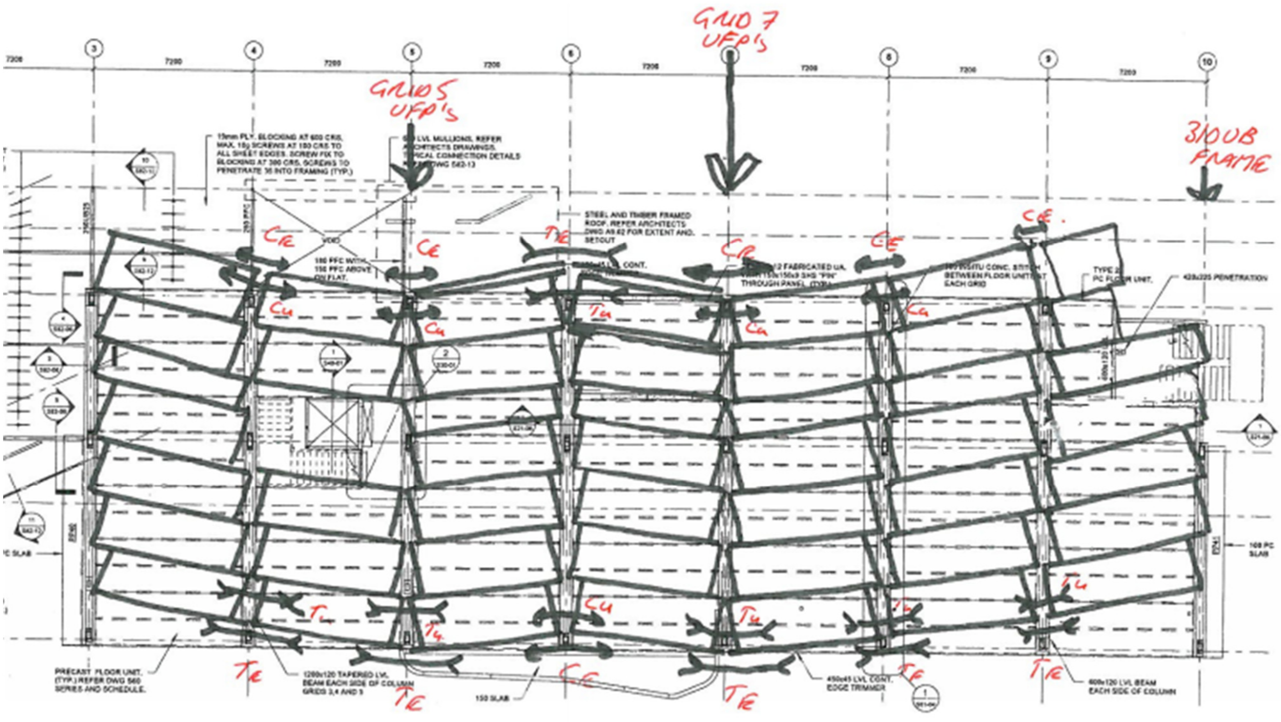

Figure 11. Vierendeel action of floor units.

Testing carried out at BRANZ by James O'Neil *et al* from the University of Canterbury (not specific to this project) during the construction illustrated the importance of the method of connection, as any movement would allow fire to split the two joists and devour each independently. By using fully threaded screws, this connection was held tight even as the outer char layers were lost.

PROCUREMENT OF FRAME AND FLOORS

Both frame and floors were pre-tendered based on P&G and margin and a schedule of rates in a quality-based assessment. The successful tenderers were to build the prototype of each before being awarded the full contract for the project. By working closely with the specialist sub-contractors in the production of the prototypes, we were able to make refinements to the methodology. The most significant of these was solving the method of sealing between the concrete form and the joists during the pouring of the TCC floors. The sub-contractor came up with the idea of using a sheathed post-tensioning strand in the gap stressed down to seal it. This was then successfully stripped away as the unit was lifted and prevented almost all grout loss. Dunning Thornton thank Hunter Laminates and Concrete Structures Ltd for their input during this phase.

ROOF

Although lightweight, the appearance of the roof was to be similar to the concrete floors below, albeit with a cross-fall to allow drainage. The roof was set out on the same module as the floors below, with joists/rafters at 1.2 m centres spanning between the main frames. The supported plywood on top of these rafters was the exposed final finish to the building. It was therefore always intended that the roof would be prefabricated in some form to protect this exposed plywood from the weather during construction.

Although initially designed to be panellised in 2.4 m x 7.2 m panels like the floors below, an option to prefabricate full bays of roof was also suggested. The contractors, Arrow International, embraced the second option and created an at-grade prefabrication area on a spare site not far from the building. In this way, large (9 m x 7.2 m) modules were built with structure, insulation and cladding. These were built in pairs so that the connection/mating of the structural and roofing elements was always correct. Panels were transferred to the building by the use of two road cranes. Once this process was perfected, Arrow believed that up to four panels could have been placed and secured in one day.

CONCLUSION

The design of the Massey College of Creative Arts building was an extreme technically challenging undertaking – moment-resisting frames are not a 'natural' structural form for timber. However, by addressing the technical challenges by innovating in geometry and the method of constructing systems, the risks of such a new venture were minimised and the building completed very successfully.

Although the building was designed before the series of earthquakes in Christchurch, Massey were extremely pleased that their design embraced the emerging damage-control design principals. Design of the LVL-frame system, however, required extreme attention to detail and the consideration of several options for each arrangement before an economic, easy to build and aesthetically pleasing form was arrived at.

The building is extremely successful in using the structure as architecture and unifying the building into a warm, robust, flexible environment for the students. It is hoped that the details produced here are the first step towards new ways of finding structure and architecture using timber components commercially.

ACKNOWLEDGMENTS

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