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Fire performance of mass timber joints

Designers need to show that heavy timber buildings maintain their stability during and after a fire. A joint research project has initial findings on the fire performance of mass timber construction joints to help.

TIMBER IS INCREASING in popularity as the primary structural material for multi-storey buildings. Key drivers for choosing it include:

- poor soils, where lighter structures reduce foundation requirements
- adding floors, where a lighter material reduces the load from additions to an existing structure
- prefabrication for faster construction of the primary structure
- meeting sustainability and green building objectives.

Timber's increased use has been enabled by engineered wood products such as laminated veneer lumber (LVL), glulam and cross-laminated timber (CLT), which have overcome some of the limitations of sawn lumber. These products have more consistent material properties, greater strengths, larger element dimensions and the opportunity for extensive prefabrication.

Structural performance in fire

A significant challenge in the design of heavy timber buildings is demonstrating that structural stability is maintained during and after a fire, as required by Building Code clause C6.

Timber is fundamentally different to other common construction materials because the material itself burns and reduces the load-bearing cross-section of the elements. The strength of timber is reduced at relatively low temperatures - at 100°C, compressive strength reduces by 75%, shear strength by 60% and tensile strength by 35%.

Experiments on the behaviour of large cross-section timber beams and columns in fire have shown that, when exposed to the ISO 834 standard fire, a thermal field is established - an insulating char layer forms on the exposed surfaces as the wood burns.

Low thermal conductivity and moisture present in the timber result in slow heat transfer beyond the char layer. During the heating phase of a fire, the inner core of timber elements remains close to ambient temperature and strength.

The reduced cross-section method (RCSM), which is the basis of timber element design for fire performance in building codes worldwide including AS/NZS 1720.4:2019 *Timber structures - Part 4: Fire resistance of timber elements,* predicts the structural capacity of the element from this strong core.

Connections can be the hot point

Connections are often the most highly stressed parts of timber buildings and must be carefully detailed for strength, stiffness, constructability, ductility and efficiency. Connections between timber elements use steel plates and fasteners such as bolts, dowels and screws to transfer the loads between timber elements.

These steel components interrupt the otherwise expected thermal field and conduct heat into the core of timber elements. In these cases, the RCSM should not be directly applied because the actual thermal field at and near the connections is different to the thermal field considered in this method.

To design connections where the steel components may get hot and disrupt the thermal field, the performance of timber connections in fire must be understood and new design methods developed.

Research into connections performance

A collaborative research project between the University of Canterbury and BRANZ is under way to investigate the performance of unprotected heavy timber beam-column connections in fire.

LVL beam-column subassemblies were exposed to fire in seven experiments:

- Two investigated the performance of post-tensioned connections under moment loads.
- Three examined partially exposed brackets and internal corbel connections under shear loads.
- Two researched connection performance and thermal fields in decay phases of real fires.

The timber beams and columns were fabricated with thermocouples laid in the laminations to measure temperatures in the wood near and remote from the connection. Additional thermocouples were installed at the beam-column interface.

Beam-column subassemblies were placed in a custom-built cabinet to achieve realistic exposure to the surfaces (see Figure 1) and the furnace was heated to the ISO 834 standard fire (see Figure 2).

In the loaded experiments, the beam was loaded with a realistic design moment or shear load at the connection and an axial load was applied to the column. In the decay phase tests, the same stiffened steel bracket connection was heated to the standard fire time-temperature curve for 30 minutes and then cooled at two controlled rates.

Figure 1: Beam-column subassembly in cabinet.

Three key preliminary findings

These experiments have illustrated that connections in timber buildings are critical design components and, in fire, will typically fail before the timber elements themselves. There are three key preliminary findings.

Charring results in deformations that can impair connection performance

As the timber begins to char, deformations occur to maintain load-carrying capacity and steel deflects as the elastic modulus decreases at high temperatures. The rate of these deformations increases as the fire exposure continues.

These deformations change the nature of the loading on the connection – for example, by introducing a horizontal component. Increased charring was observed where exposed steel was in contact with the timber and where gaps were formed as the joint deformed.

Connection performance and failure mechanisms are different to those at ambient temperatures

The connection mechanics in fire are different compared with ambient conditions as wood is burned, allowing slip and slack to develop in the connections. In addition, the elastic modulus and strength of steel decreases. Failure mechanisms such as bending of steel brackets, thread stripping and screw buckling can occur, which result in earlier failure.

These outcomes cannot be predicted by simply extrapolating ambient mechanics.

The thermal wave continues to propagate through the member during the decay phase

In the decay phase experiments, it was observed the maximum temperature in the middle of the timber section did not occur until 3 hours after fire exposure ended. The hot steel components also continued to conduct heat into the wood around the connection for several hours, leading to greater localised charring around them.

As the strength of wood decreases with temperature, the connection strength will decrease as the thermal wave propagates through the member.

Designing timber connections

Designing timber connections for satisfactory performance in fire is a primary consideration in the design of timber buildings. Predicting the response of these connections over the full duration of a fire is complex because:

- there is a disrupted thermal field from steel components
- there are deformations from charring
- there is interaction between different components as they heat up and lose strength and stiffness at different rates.

Fire resistance of connections in heavy timber buildings needs to be carefully detailed to ensure that connections and the full structure will perform adequately over the full duration of the fire.