Design of an adhesively bonded-in steel plate connection for Cross-Laminated Timber

A capacity-based design approach

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Timber construction has become more and more popular in the couple of last years. The development of engineered wood products such as Cross-Laminated Timber (CLT) has enabled the design of tall timber structures (twelve storeys or more). However, as timber buildings rise, new issues arise. Among them, the limitations of connections, since typical connections for CLT applications (angle and hold-down brackets associated with screws, self-tapping screws or nails) struggle with the intensity of shear and tensile loads to be transferred. Moreover, to bring ductility within the CLT structure, the connections must be designed to fail in a ductile way, according to capacity-based design recommendations.

This thesis focuses on an adhesively bonded connection for structural applications in CLT structures, which will be designed to fail in a ductile way. Triggering the ductile failure is challenging since the adhesively bonded connections usually fail in a brittle way. Moreover, there is no recommendation for the (capacity) design of adhesively bonded plates in the current version of the Eurocodes (European standards).

The connection studied in this work is made of a mild steel plate bonded in the CLT panel using a two component epoxy (*Xepox F* commercialized by Rothoblaas). Experimental campaigns on the connection are conducted to investigate the influence of several geometrical parameters on the connection behaviour, especially on its failure mode. Results from these campaigns guided the design of the proposed connection. Then, we focused on the development of numerical or analytical methods to evaluate the load-bearing capacities associated with the brittle failure mode and the ductile failure mode of the connection.

With proper surface preparation of the plate to prevent adhesion failure, the governing brittle failure mode of the bonded connection is the wooden failure of the CLT panel. Based on literature review, different approaches - from continuum mechanics or damage mechanics - to predict the load-bearing capacity of the brittle component of the connection were investigated and compared. We finally opted for a probabilistic approach based on the application of a Norris criterion combined with a Weibull distribution on the state of stresses obtained from a 3D finite element linear analysis.
To trigger the ductile failure, the steel plate cross-section can be reduced, for instance through perforations. To predict the load-bearing capacity of these perforated steel plates, we investigated numerical and analytical models.

Finally, once the ductile and the brittle failure modes were characterized, capacity design concepts were applied to ensure with an acceptable risk that the brittle failure of the adhesively bonded connection does not occur. Two design scenarios were investigated for the steel plate-to-CLT adhesively bonded connection: a fully bonded connection and a half-bonded/half-connected connection. The overstrength ratio to be applied on the connection to overdesign the brittle components was evaluated (depending on the ductile failure mode chosen). Due to concentrations of stresses, the provisions on strength degradation of the connection are not fulfilled when the ductile failure is located in the net cross-section of a perforated plate, as shown by cyclic tests. However, both these configurations exhibited satisfying performances regarding stiffness, load-bearing capacity and level of static ductility reached. In other words, the design proposed for this adhesively bonded-in steel plate connection ensures the ductile failure of the connection, and meets capacity-based design recommendations.