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In-plane shear loading of CLT and experimental tests of CLT beams

Verification of load-bearing capacity of CLT at in-plane shear involves consideration of three failure modes: I) gross shear failure, II) net shear failure and III) shear failure in the crossing areas between flatwise bonded laminations. Several design approaches are present in contemporary design handbooks and predicted capacities differ considerably between them. A model for prediction of design relevant stresses acting in the crossing areas (failure mode III) has been developed.

Experimental (shear/bending) tests of CLT at beam loading conditions have been carried out at ZAG (Slovenia), see Fig. 1. The studied parameters were the individual lamination width and the cross-section lay-up in terms of the thickness of the individual longitudinal layers. In general, similar load vs. displacement responses were found for all tests: after an initial linear response, a gradual stiffness decrease was found before reaching final failure.

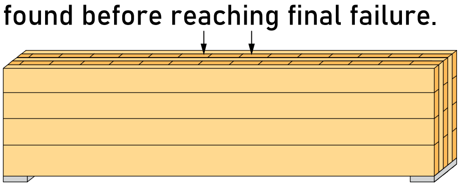


Fig. 1: CLT beam test setup

The decreasing stiffness is related to damage in the crossing areas, which gives significant relative sliding between adjacent laminations (Fig. 2). The results will serve as a valuable data base for development of reliable design approaches for beam loading conditions and regarding evaluation of models for analysis and failure criteria.

Fig. 2: Shear failure in crossing areas

CLT connections with self-tapping screws – brittle failure modes

The orthogonally layered structure in CLT gives many advantageous properties relating to reinforcing effects with respect to perpendicular to grain tension and shear. For connections, the reinforcement effect may partly limit the risk of brittle failure modes in connections, related to cracking of the timber laminations. Avoiding brittle failures is an important safety aspect of timber engineering. Prediction of capacity with respect to brittle failure is however in general a difficult task. For CLT, with varying fibre orientation, the situation is even more complex.

To further study the brittle failure modes in CLT connections, tests of high-capacity connections using laterally loaded self-tapping screws were performed. A pull-pull test configuration was used (Fig. 3) and the study comprised several design parameters; lay-up, width, orientation and screw length.

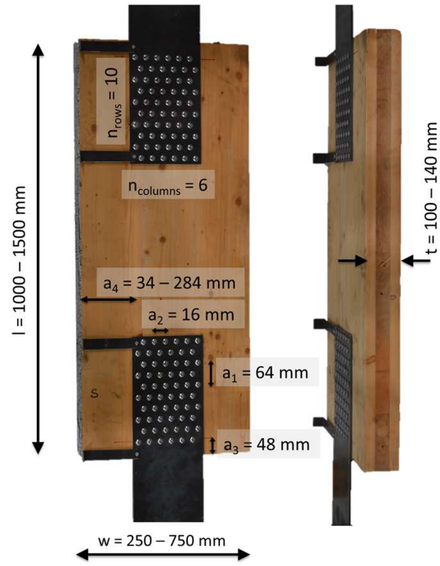


Fig. 3: Pull-pull test setup

The failure modes were all classified as brittle, involving different types of plug shear failure (as shown in Fig. 4), step shear failure, and net tension failure. For specimens with loading parallel to the grain of the external laminations, brittle failure typically occurred after the yielding of the fasteners had already started. The overall ductility was however low, and these types of connections are hence not appropriate for use in seismic areas, where higher local ductility would be desirable.

Fig. 4:

Plug shear failure of CLT connection

Computational modelling of wood and CLT

Multisurface failure criterion for clear-wood

The closer investigation of CLT components with locally high loads or occurring stress peaks is a numerically challenging task. Standard algorithms in commercial finite element software are usually not able to represent the different behaviour of wood under longitudinal or perpendicular-to-grain compression. Therefore, we developed a numerically robust so-called user material subroutine (UMAT) for the FE software Abaqus, which was not only made available to all project partners but is also available online together with a short documentation (https://gitlab.imws.tuwien.ac.at/e202-02/multisurface-plasticity).

Accurate 3D digital models of CLT plates

Especially for materials with a complex micro- and macro-structure, like wood, crack initiation and propagation are subject to multiple interlinked effects. Detailed simulations (Fig. 5), where knots and fibre deviations are also modelled, are used to obtain effective material properties (stiffness, strength, fracture energies,…), which can then be used on the wood product level (GLT, CLT,…) and which in this way can consider local weak spots in stochastic simulation models.

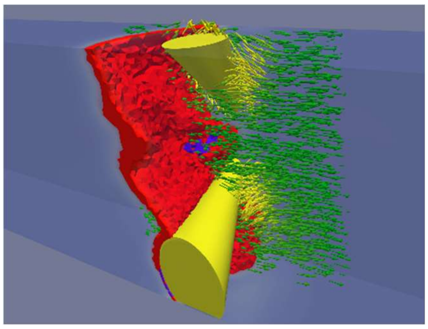


Fig. 5: Failure mode within knot group

3D simulation of common structural CLT-based details

The simulation of CLT-based structural details enables insights into the mechanical processes beyond the information gained by experiments. One example would be the punching behaviour of continuous two-way CLT flat slabs with and without load distribution plates (Fig. 6), where the entire failure behaviour is modelled and compared to experimental results. The validated model can then easily be extended to other plate dimensions, boundary conditions, plate structures, etc.

Another numerical study concerns a form-fitting CLT wall-slab connection (Fig. 7), which was developed at TU Munich. Here, the aim is to determine the rotational stiffness of the connection as a function of the prestressing of the vertical walls.

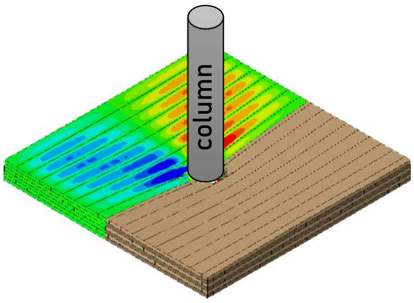


Fig. 6: CLT slab punching behaviour

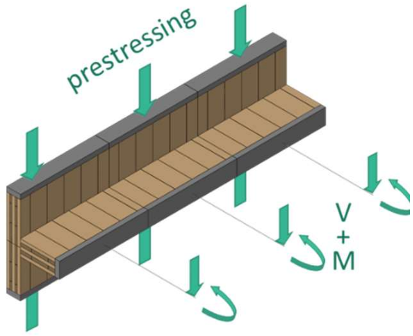


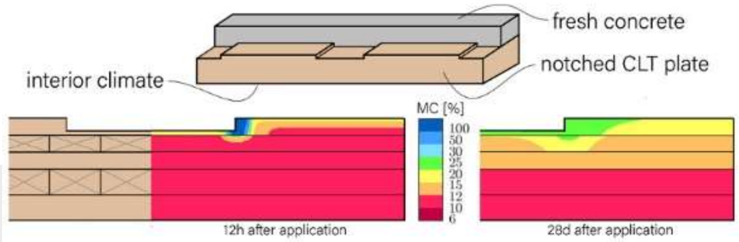
Fig. 7: Innovative CLT wall-slab connection

The resulting rotational stiffness can then be used in simplified models in engineering software.

Since the exact influence of moisture in timber constructions is often not known or difficult to determine experimentally, we implemented an advanced moisture transport model for wood, e.g., to investigate the influence of the application of fresh concrete on notched and unsealed CLT plates (Fig. 8).

Fig. 8:

Moisture field in TCC plates



AUTHORS:

B. Azinović, T. Pazlar, H. Danielsson, E. Serrano, J. Füssl, M. Lukacevic and J.M. Cabrero.