CLTdesigner
A SOFTWARE TOOL FOR DESIGNING CROSS LAMINATED TIMBER (CLT) ELEMENTS

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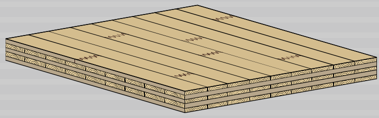
Indroduction

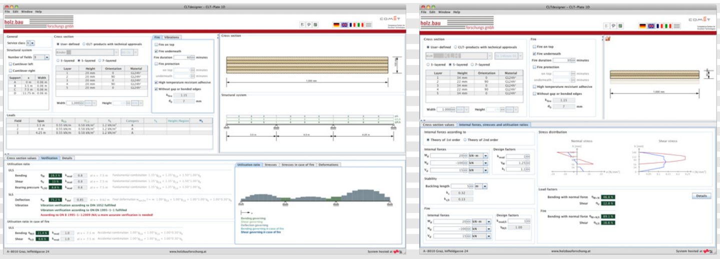


The application of cross laminated Timber (CLT), typically as two-dimensional elements like ceilings and walls, has been very common in modern timber engineering structures. CLT-elements represent multi-layer plate structures consisting of a sequence of alternating orthogonal orientated board layers. Usually build up symmetrically with respect to the plate mid-plane. The boards of each single layer are usually arranged side-by-side glued or unglued on the narrow face. CLT-elements are available 3- to 9-layered. Commonly 3- and 5-layered elements are used for walls, 5- and 7-layered ones for ceilings and 9-layered ones for special high-bearing purposes. The thickness of each layer lies in between 6 and 45 mm.

In order to provide save and reliable design guidelines numerous design concepts have been developed, but all these methods are very time-consuming in practice and due to approximations deviating from the exact mechanical solution.
For simplification of the design and for stimulating the application of CLT-elements a verification process, which is practicable adequate, traceable and easily capable by engineers and master carpenters in practice, was implemented into the software-tool CLTdesigner. This verification process is published in BSPhandbuch | Holz-Massivbauweise in Brettsperrholz (only available in German ISBN 978-3-85125-109-8).

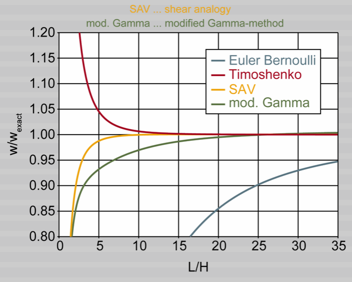
Modules

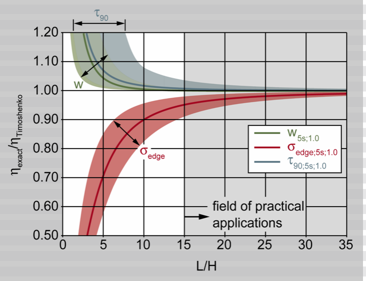
The software tool CLTdesigner is organised in modules. For the verification of CLT-plates under loads out of plane there are two modules implemented. The first module "ContinuousBeam" verifies CLT-plates according to EN 1995-1-1 and ON B 1995-1-1, as a continuous beam up to 7 spans with or without cantilevers. The CLT-plate can be subjected to self- and construction-weight, imposed load, snow and wind load. The ultimate limit state design (ULS) is provided in respect of bending and shear stresses as well as compression stresses perpendicular to grain for combinations of actions for persistent or transient and accidental (fire) design situations. The serviceability limit state design (SLS) is made in respect of deformations and vibrations. The second module "CSVerification" provides the cross-sectional verification of CLT-elements depending on given internal forces and moments as well as a stability verification tool based on the model column method.



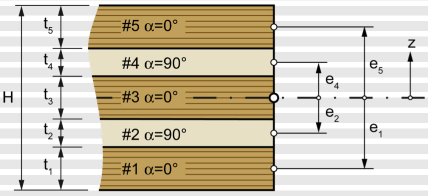
Principles of design verification and scope

Because of geometric relations within the CLT-element and geometric boundary conditions nowadays produced CLT-plates show a main load carrying direction. Therefore 1D-beam theory sufficiently represents the bearing behavior of CLT-plates for practical applications and is applied for calculating stresses and deformations. Nevertheless, compared to uni-axial layered products like glue laminated timber (GLT), due to low rolling shear modulus of cross layers, CLT-elements show remarkable deformations. Therefore shear deformation shall be taken into account in SLS-design. A comparison of the different design methods for cross-layered plates with an exact solution, reflects that all of them provide suitable solutions for practically relevant length to depth ratios L/H > 15. Beside that it is strongly recommended that the chosen method for the design of CLT-plates is congruent with the evaluation of strength and stiffness in testing procedures. The implemented method in the CLTdesigner is based on the Timoshenko beam theory.





Stiffness of a layered cross section



○ centre of gravity of CLT cross section
○ centre of gravity of layer #i

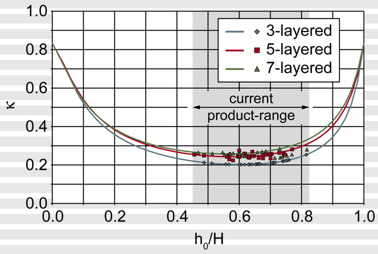
bending stiffness:

$$K_{clt} = \sum(J_i \cdot E_i) + \sum(A_i \cdot e_i^2 \cdot E_i)$$

shear stiffness: $S_{clt} = S_{ges} \cdot \kappa$

$$S_{ges} = \sum(G_i \cdot b_i \cdot t_i) = \sum(G_i \cdot A_i)$$

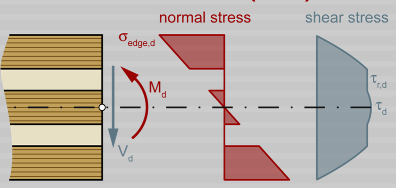
$$\kappa = \frac{1}{S_{ges} \cdot \frac{1}{K_{clt}^2} \cdot \int_h \frac{S^2(z,E(z))}{G(z) \cdot b(z)} dz}$$



When calculating stiffness values of a CLT cross section the orthotropic behaviour of timber in orthogonal layering have to be taken into account.

Due to the influence of the transversal shear flexible cross layers, the shear correction coefficient κ of a CLT-element is in the current product-range nearly constant and about 0.25 (compared to uni-axial 0.83).

Ultimate Limit States (ULS)



$$\sigma(z) = \frac{M_y}{K_{clt}} \cdot z \cdot E(z) \qquad \frac{\sigma_{edge,d}}{f_{m,clt,d}} \le 1.0$$

$$\tau(z_0) = \frac{V_z \cdot \int_{A_0} E(z) \cdot z \cdot dA}{K_{clt} \cdot b(z_0)}$$

$$\frac{\tau_d}{f_{v,clt,d}} \le 1.0 \text{ and } \frac{\tau_{r,d}}{f_{r,clt,d}} \le 1.0$$

Design values of strength for bending and shear

$$f_{m,clt,d} = k_l \cdot \frac{k_{mod} \cdot f_{m,glt,k}}{\gamma_M} \text{ with } k_l = \min\begin{cases}1.1\\ 1+0.025 \cdot n\end{cases} \text{ for } n>1$$

$$f_{v,clt,d} = f_{v,glt,d} = \frac{k_{mod} \cdot f_{v,glt,k}}{\gamma_M} \qquad f_{r,clt,d} = f_{r,glt,d}$$

Serviceability Limit States (SLS)

Deflections

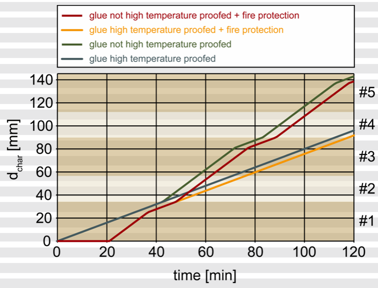
Due to low rolling shear modulus of cross layers the shear deformation shall be taken into account when calculating deflections at time t = 0. For long time effects the deformation factor k_{def} shall be considered. The proposed and implemented values are 0.85 for service class 1 and 1.10 for service class 2.

Vibrations

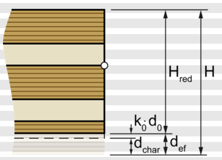
According to EN 1995-1-1 four criteria have to be verified for judging vibration behaviour of a CLT-plate: eigenfrequency, stiffness criterion (deflection caused by a concentrated static force of 1kN), vibration velocity and vibration acceleration. The damping factor, which is very important for this calculation, lies between 2.5% and 4.0% depending on the ceiling construction.

Structural fire design

The implemented structural fire design is based on the method of reduced cross section according to EN 1995-1-2. Therefore, the information about charring depth d_{char} over the time is decisive. The charring depth depends on the charring rate, the type of adhesive applied and on the availability of fire protection. The depth will also be reduced by $k_0 \cdot d_0$, which considers the zone of thermal modified material parameters.



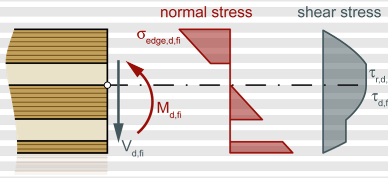
Reduced cross section



$$d_{ef} = d_{char} + k_0 \cdot d_0$$

$$\text{with } k_0 = \min\begin{cases}t/20\\ 1.0\end{cases}$$

$$d_0 = 7mm$$



$$f_{d,fi} = k_{mod,fi} \cdot \frac{f_{20}}{\gamma_{M,fi}} \text{ with } f_{20} = k_{fi} \cdot f_k$$

$$k_{mod,fi} = 1.0 \qquad \gamma_{M,fi} = 1.0 \qquad k_{fi} = 1.15$$

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