An Orthotropic Single-Surface Plasticity Model for Spruce Wood Under Consideration of Knot Effects

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Overview

The analysis of layered wooden shells requires a suitable constitutive model for multi-axially loaded wood. This poster presents an orthotropic elasto-plastic model including knot effects for spruce wood suitable for the description of inelastic deformations both in-plane and transverse to the shell surface.A single-surface model with non-associative hardening/softening laws is used for the description of the failure mechanisms.The basis for the development of the presented constitutive material model are different experiments performed on the macroscopic level. Applicability of the model is verified by the finite element analysis of a layered cylindrical shell with one opening and stiffeners.

Literature: [1] Eberhardsteiner, J.: Mechanisches Verhalten von Fichtenholz - Experimentelle Bestimmung der biaxialen Festigkeitseigenschaften, Springer-Verlag, 2002.

[2] Mackenzie-Helnwein, P.; Müllner, H.W.; Eberhardsteiner, J.; Mang, H.A.: Analysis of Layered Wooden Shells using an Orthotropic Elasto-Plastic Model for Multiaxial Loading of Clear Spruce Wood, Computer Methods in Applied Mechanics and Engineering, in print.

Experimental Investigation

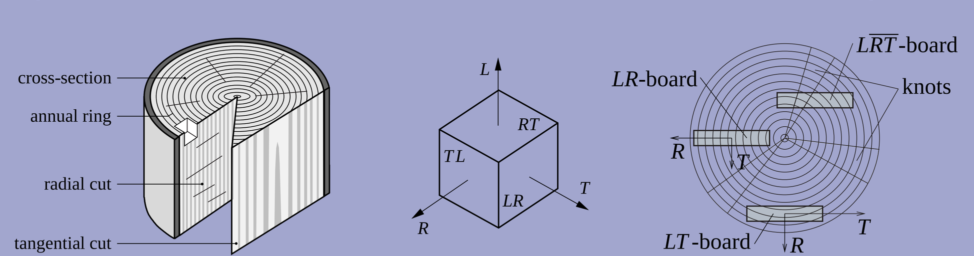
All tests are divided in three categories:

a) investigation of stress states with their principal directions being oblique to the principal material directions L (longitudinal) and R (radial), i.e. in the LR-plane (423 experiments, clear spruce wood).

b) additional experiments in the LT-plane (12 experiments, clear spruce wood).

c) specimens with selected knots, $L\overline{RT}$-plane (52 experiments).

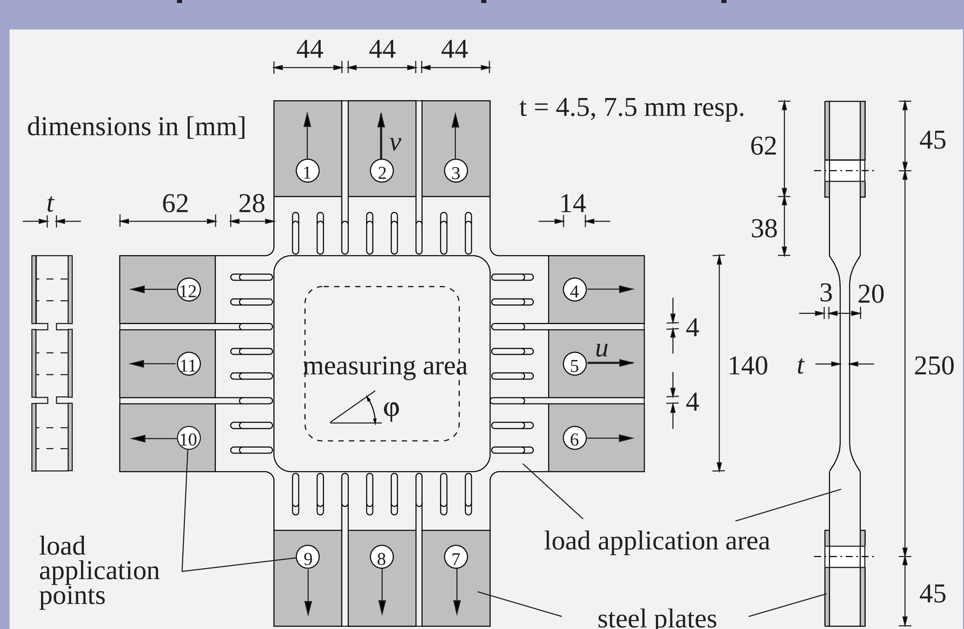
The notation $L\overline{RT}$ indicates that the fibre orientations of the specimens are mixed between the LR- and LT-plane.



The test equipment consists of a biaxial servohydraulic testing apparatus for anisotropic materials and of a three-dimensional electronic Speckle Pattern Interferometer (ESPI) for the spatial deformation analysis of the measuring area of the plane specimen. Before testing, the samples were stored at 20 °C and 65 % relative humidity until an equilibrium moisture content of u =12 % was reached.

a) and b) Clear Spruce Wood

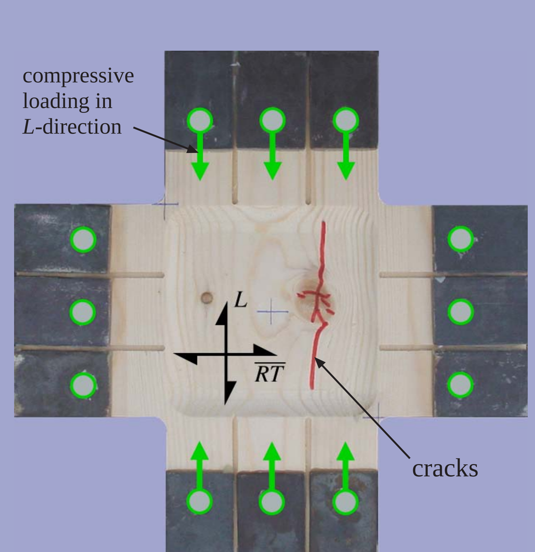
specimens for LR-plane and LT-plane



All experiments were performed under displacement control with different prescribed displacement rules depending on grain angle φ (measured to the horizontal axis) and biaxial load ratios κ = u : v.

c) Experiments with selected Knots

specimens for $L\overline{RT}$-plane



Knots are the commanding criterion of wood. This fact is inseparably combined with the fibre direction around the knots. These influences on the mechanical properties will be investigated within a separate test series.

Evaluation and Constitutive Modelling

Development of a Single-Surface Transversely Isotropic Elasto-Plastic Material Model Including Hardening and Softening Behaviour for the $L\overline{RT}$-System

Clear Spruce Wood

$$f(\sigma,p) = a_{LL}\sigma_L + a_{\overline{RT}\,\overline{RT}}\sigma_{\overline{RT}} + b_{LLLL}\sigma_L^2 + b_{\overline{RT}\,\overline{RT}\,\overline{RT}\,\overline{RT}}\sigma_{\overline{RT}}^2 +$$
$$+2b_{LL\overline{RT}\,\overline{RT}}\sigma_L\sigma_{\overline{RT}} + 4b_{L\overline{RT}L\overline{RT}}\tau_{L\overline{RT}}^2 +$$
$$+4b_{\overline{RT}\,\overline{RT}\,\overline{RT}\,\overline{RT}}\tau_{\overline{RT}\,\overline{RT}}^2 + 4b_{\overline{TRL}\,\overline{TRL}}\tau_{\overline{TRL}}^2 - 1 \quad = \quad 0$$

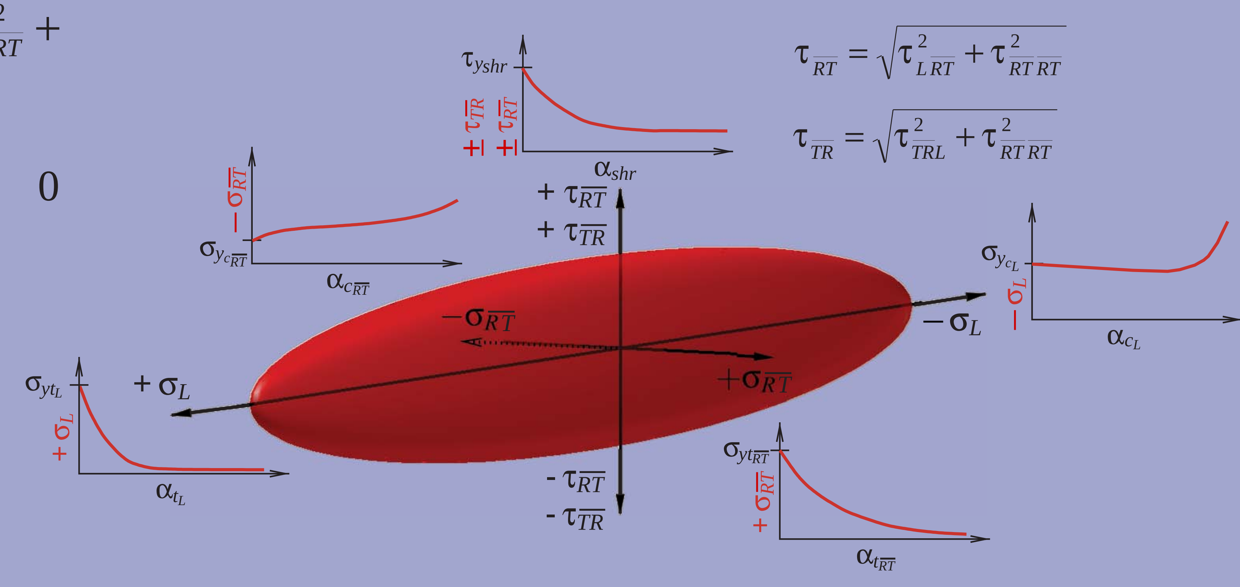
σ_L . . . stress in L-direction

$\sigma_{\overline{RT}}$ . . . stress in $\overline{RT}$-direction

$\tau_{L\overline{RT}}, \tau_{\overline{RT}\,\overline{RT}}, \tau_{\overline{TRL}}$ . . . shear stresses

$a_{LL}, a_{\overline{RT}\,\overline{RT}}, b_{LLLL}, b_{\overline{RT}\,\overline{RT}\,\overline{RT}\,\overline{RT}}, b_{LL\overline{RT}\,\overline{RT}}, b_{L\overline{RT}L\overline{RT}}, b_{\overline{TRL}\,\overline{TRL}}$ . . . Tsai-Wu material parameters

TSAI-WU yield surface and evolution laws

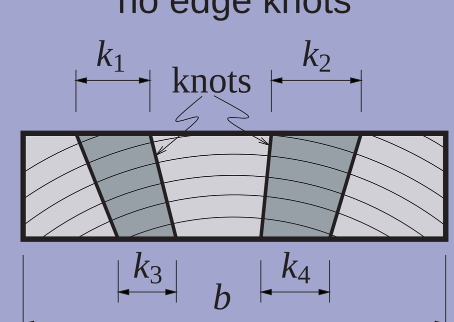


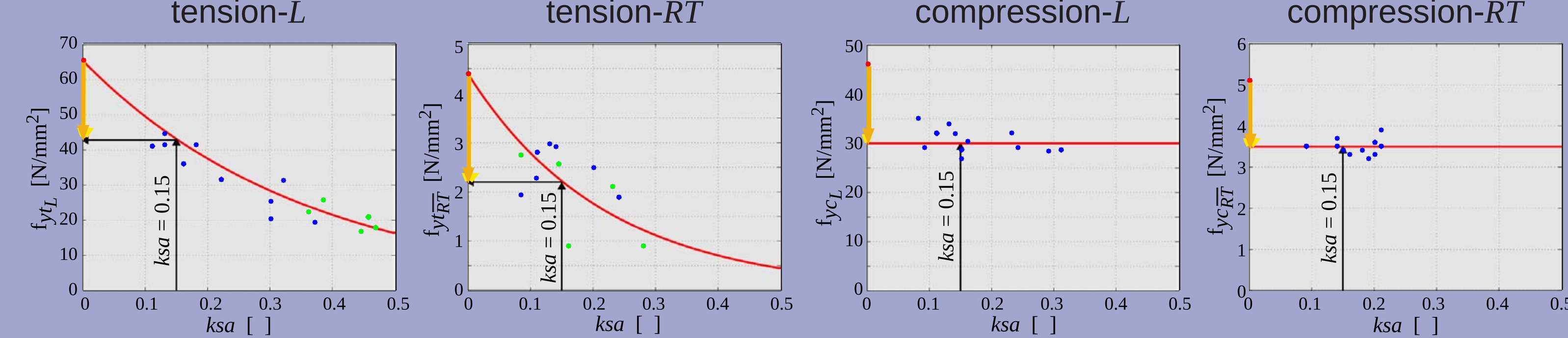
Including Knot Effects

by shrinking of the TSAI-WU yield surface

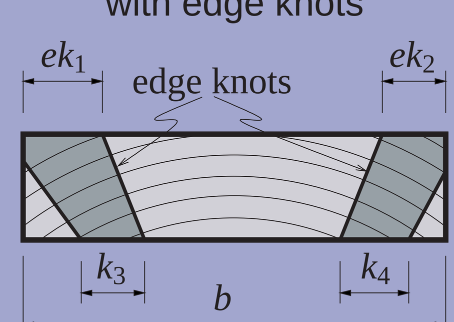
cross section of a board

no edge knots





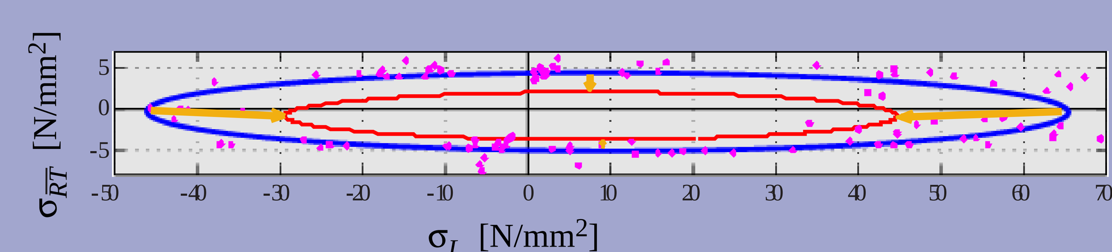
with edge knots



knot factor:

$$ksa = \frac{\sum_{i=1}^{m} k_i + s \cdot \sum_{j=1}^{n} ek_j}{2b}$$

S . . . increase factor for edge knots



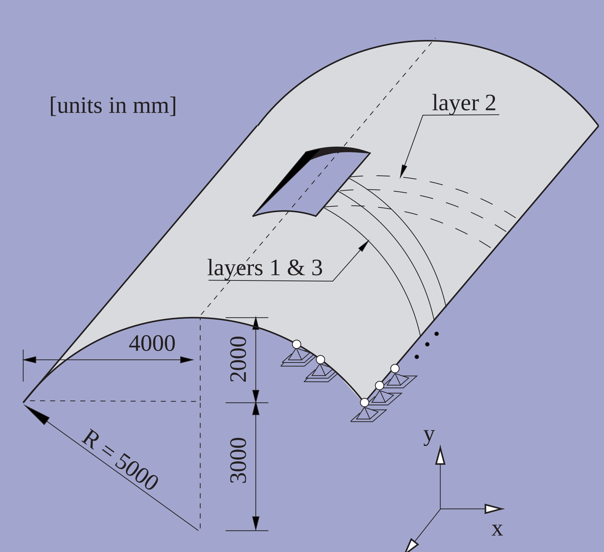
section of the TSAI-WU yield surface in the $\sigma_L\sigma_{\overline{RT}}$-plane

for clear spruce wood

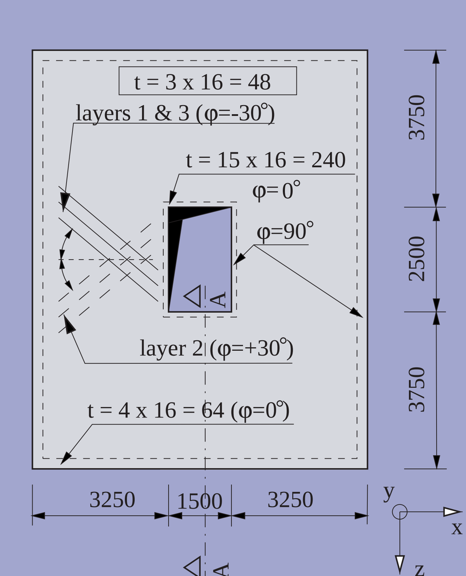
including a knot factor of ksa = 0.15

Numerical Example: FE-Simulation of a Cylindrical Shell

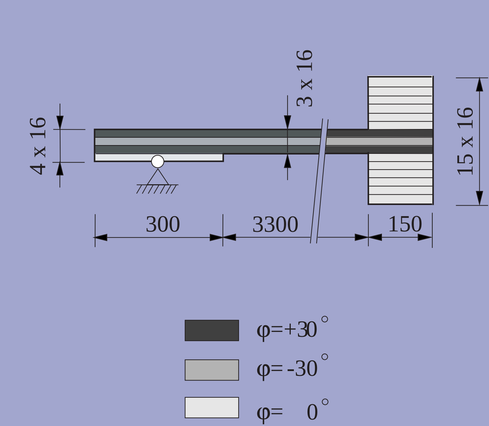
axonometric projection



horizontal projection

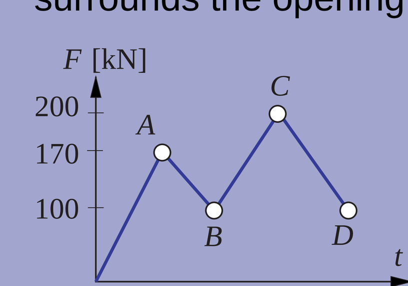


cross section A-A



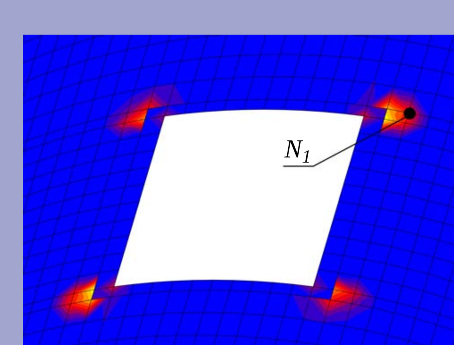
loading

- dead load:
  ρ = 0.45 g/cm^3
  is equivalent to
  g = 0.216 kN/m^2
- live load F up to 200 kN, distributed along the stiffening beam which surrounds the opening

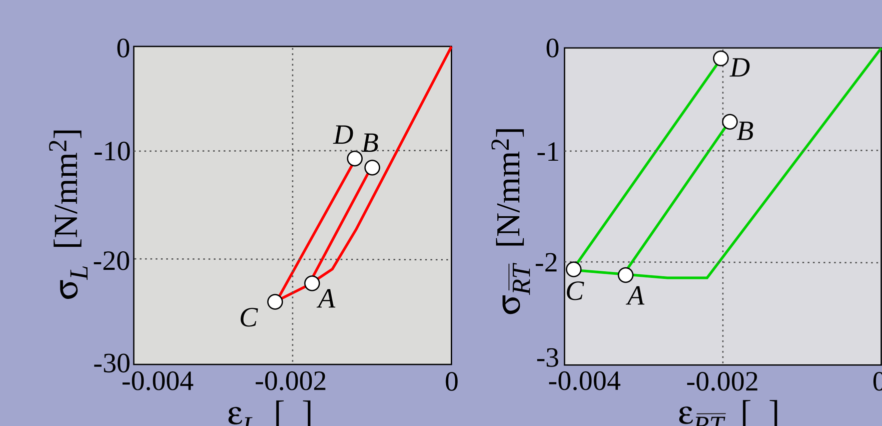


used material parameter set

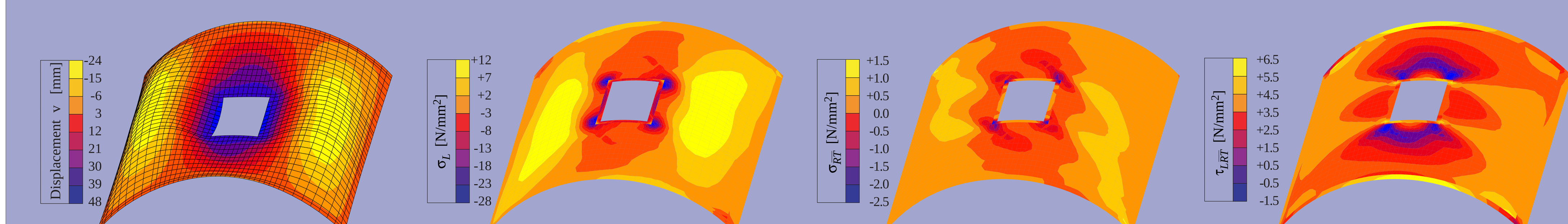
E_L = 13000 N/mm^2		σ_{yt_L} = 44.4 N/mm^2	
$E_{\overline{RT}}$ = 560 N/mm^2		σ_{yc_L} = –30.0 N/mm^2	
$\nu_{L\overline{RT}}$ = 0.50		$\sigma_{yt_{\overline{RT}}}$ = 2.2 N/mm^2	
$G_{L\overline{RT}}$ = 516 N/mm^2		σ_{yc_R} = –3.6 N/mm^2	
$G_{\overline{RT}\,\overline{RT}}$ = 203 N/mm^2		$\tau_{y_{\overline{RT}}}$ = 4.6 N/mm^2	
$G_{\overline{RT}L}$ = 516 N/mm^2		$\tau_{y_{\overline{TR}}}$ = 4.6 N/mm^2	



zones of plastic deformation



stress-strain diagrams for the characteristic node N_1



vertical displacements and deformed configuration (scaling factor = 15)

stress σ_L in the top layer (= outer surface)

stress $\sigma_{\overline{RT}}$ in the top layer (= outer surface)

shear stress $\tau_{L\overline{RT}}$ in the middle layer (= layer 2)