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3D-modeling of dowel-type timber connections

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Motivation

DOWEL-TYPE TIMBER CONNECTIONS

Dowel-type connections are commonly used in structural timber engineering. In the current code generation, e.g. EC5 [1], strength and stiffness design is partially derived from experiments, mechanic needs are not always satisfied. Simulations improve the predictability of connections and are easily adaptable to complex situations (e.g. variation of geometry and loading conditions, or in multi-dowel connections).
This work focuses on the adequate prediction of the loading behavior until reaching Serviceability Limit State (SLS). Up to the SLS, the plastic domain must not be reached. Plastic regions in the wooden part must therefore be limited, the steel dowels must not plastify.

LOADING BEHAVIOR

The loading behavior of dowel-type connections is typically separated into several stages:

- Consolidation: establishment of load transfer (compliant interface)
- Maximum stiffness: linear loading phase
- Decrease of stiffness: yielding of wood, plastic hinge(s) in dowel
- Maximum load: dependent on wood strength and friction
- Ductile loading plateau: influenced by friction, density and lateral reinforcement
- Failure: sudden load drop due to brittle cracking
- Un-/reloading: distinctively higher stiffness than first loading

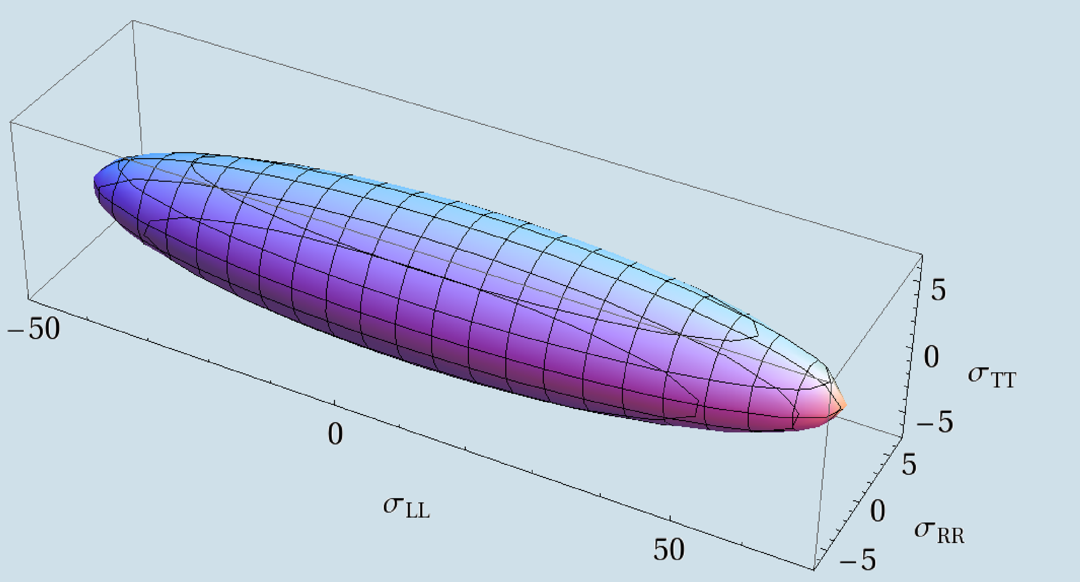
Methods – Simulations and Tests

FEM-SIMULATIONS

A single-surface orthotropic Tsai-Wu-criterion [2] is used in combination with an associated flow-rule to describe the elastic-plastic behavior. Calibration is carried out with one- and bi-axial strength values.

$$f(\sigma_{ij}) = a_{ij}\sigma_{ij} + b_{ijkl}\sigma_{ij}\sigma_{kl} - 1 \leq 0$$

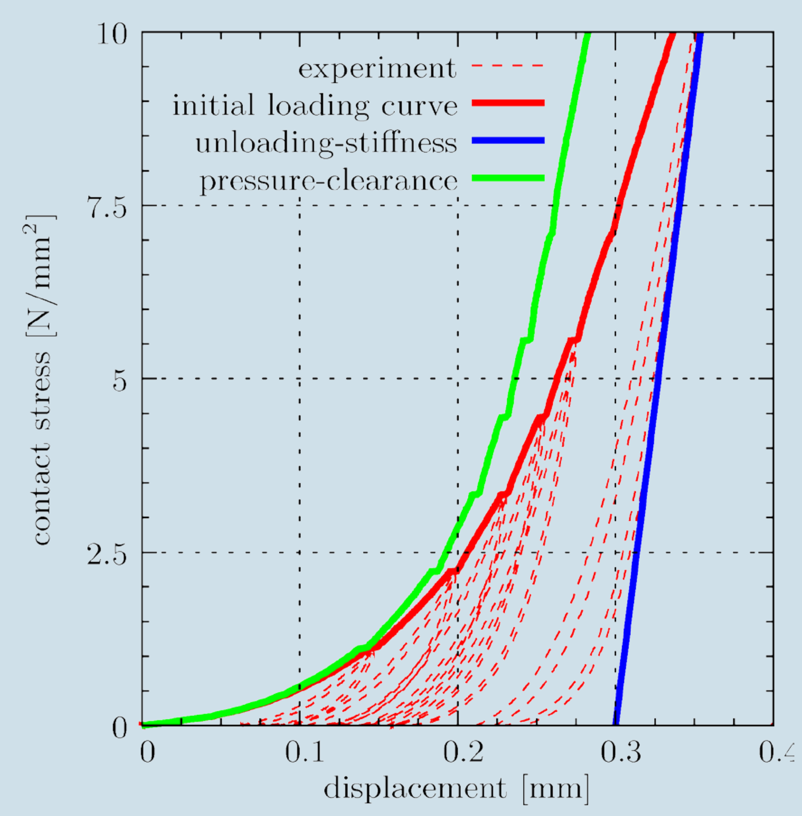
Formula for Tsai-Wu failure surface:
$f < 0$ … elastic domain
$f = 0$ … plastic domain



Ellipsoidal Tsai-Wu failure surface

Material behavior - UMAT

A non-linear pressure-clearance formulation is applied which includes non-recoverable displacements. Additionally, pressure dependent frictional behavior will be implemented.

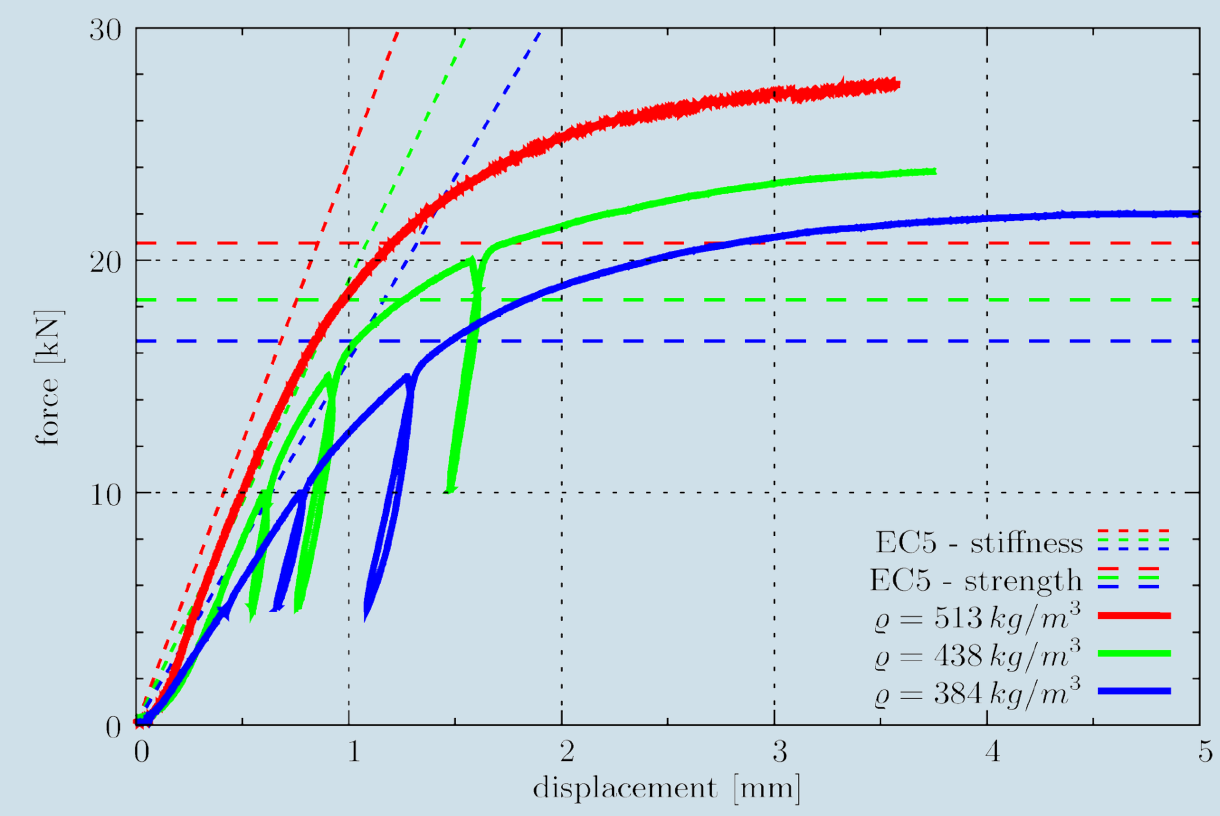


Results from experiments on contact and derived pressure-clearance curve

Interaction - UINTER

REFERENCE FOR THE SIMULATIONS

Tests on 66 single-dowel connections were performed. Geometry, density, and other parameters were varied. The output of the experiments provides insight into the loading behavior and failure modes which then leads to improved models for simulations.



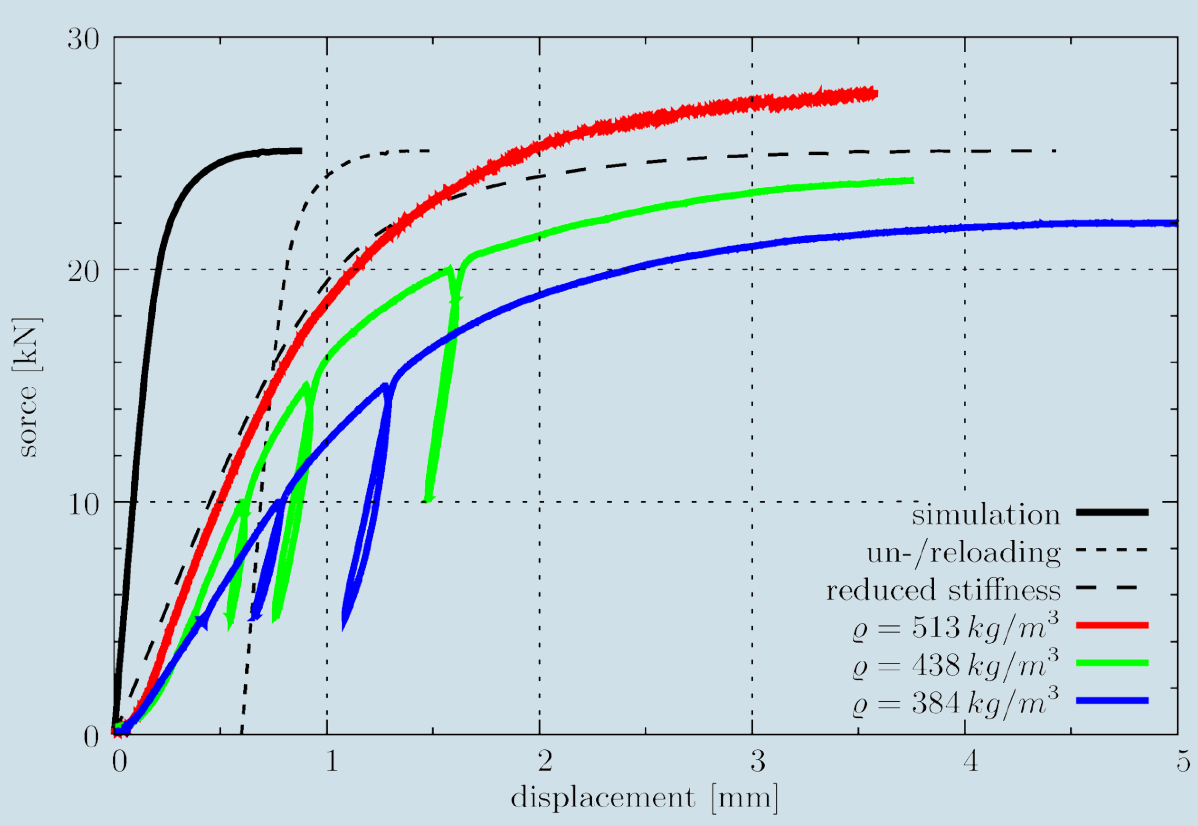
Load-displacement curves from experiments, compared to strength and stiffness design values according to EC5

Comparison with EC5

Results – Simulation of SLS for Dowel-Type Connections

COMPARSION WITH EXPERIMENTS

In the current model, stiffness is overestimated. Nevertheless, un- and reloading stiffness is well approximated by this loading curve. These differences underline the importance of proper contact behavior.
Knowledge of the stiffness properties in the SLS is essential for determining stress distribution in multi-dowel connections and to assess loading behavior in actual timber structures on a global level.

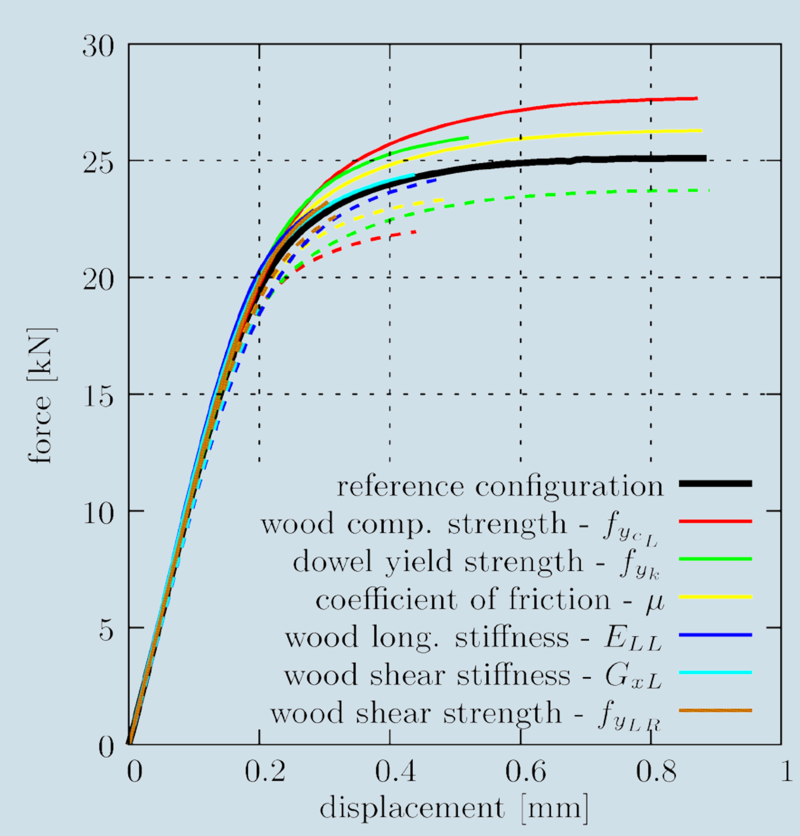


Loading curves for various experiments in comparison to simulation results for connections of intermediate width forming a single plastic hinge in the dowel

Determination of SLS

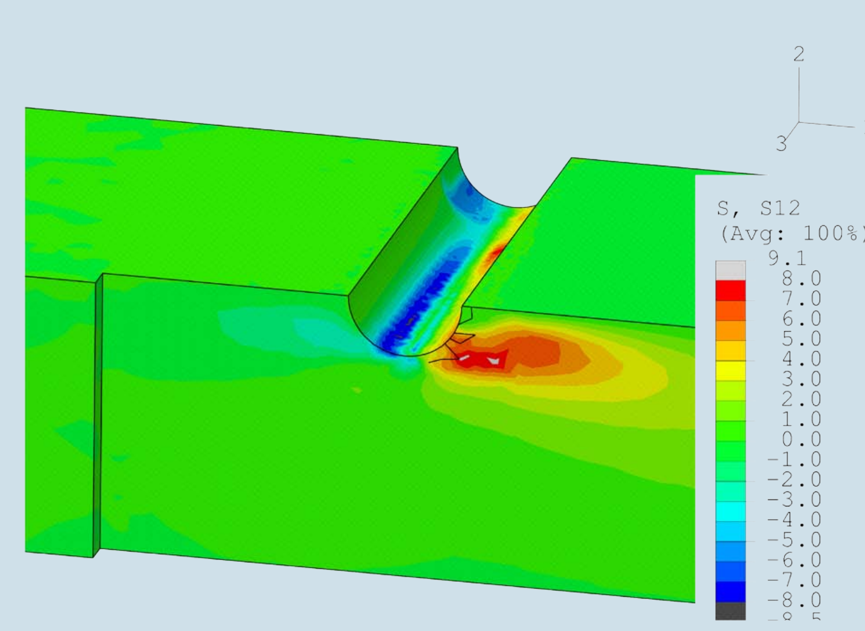
OUTCOME

Simulations allow for parametric studies, the need of experiments will be reduced. Furthermore, they allow insight into the actual, highly complex, 3D-stress/strain distribution. High-loaded zones, which are prone to brittle failure modes, can be determined.



Variation of parameters by +/- 20% compared to reference configuration

Parametric Studies



Typical shear-stress-distribution

Insight

References:
[1] EN 1995-1-1:2006: Design of Timber Structures - Common rules and rules for buildings
[2] S.W. Tsai, E.M. Wu, Journal of Composite Materials, 58-80, 1971

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