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EXPERIMENTAL CHARACTERIZATION OF DOWEL CONNECTIONS BEYOND THE ELASTIC DOMAIN

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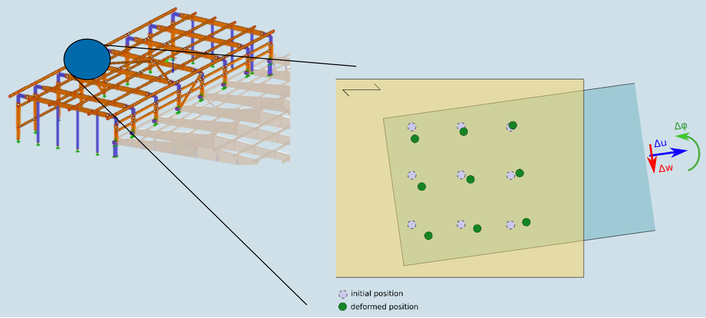
Motivation

In modern timber structures, dowel connections with steel fasteners inserted into pre-drilled holes are widely used. Under general load situations in dowel groups, **single dowels are loaded in arbitrary directions** with respect to the grain direction of wood, denoted as the load-to-grain angle (α). Due to the anisotropic material behavior of wood, the load-displacement characteristics of single dowels are changing with the load-to-grain angle. Moreover, due to local plastic deformations in the wood under steel dowels and due to plastic bending deformations of the steel dowel itself, single dowel connections show a **nonlinear mechanical behavior.**
In this study, an **integrative experimental framework** for single dowel connections is presented. This encompasses the study of single dowel connections loaded at different load-to-grain angles as well as the determination of mechanical properties of its individual components, namely the wood and the steel dowel.



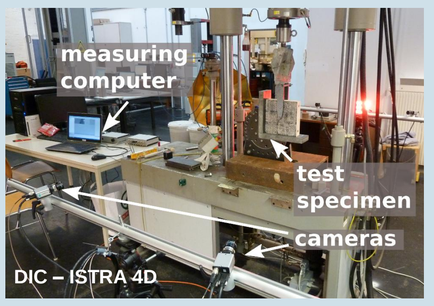
Materials & Methods

GENERAL PRINCIPLES

- Consistent determination of connection properties across the different scales of observation – wood, dowel, and connection
- Same materials throughout the test series – Laminated veneer lumber (LVL) and steel dowels of the same quality
- Materials with low variability – LVL and heat-treated steel dowels
- Testing up to large deformations with reinforced wood specimens

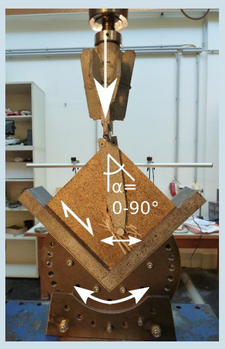
DEFORMATION MEASUREMENT TECHNIQUES

- Traditional technique – displacement transducers
- Non-contact deformation measurement systems based on digital image correlation (DIC)
  - 3D full field surface deformation measurement system (*ISTRA 4D*, Dantec Dynamics)
  - 3D point-tracking system (*Pontos*, Gom mbH)

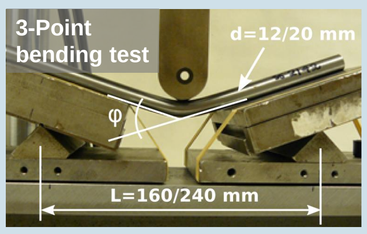


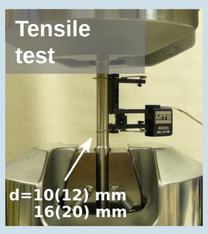
LAMINATED VENEER LUMBER (LVL)

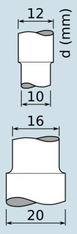
- Full-hole embedment tests acc. to EN 383 [1] [2]
- Dowel diameter d=12, 16, 20 mm
- Climatic conditions: 20 °C / 65 %RH
- Loading up to at least twice the dowel diameter, including two unloading cycles



STEEL DOWEL



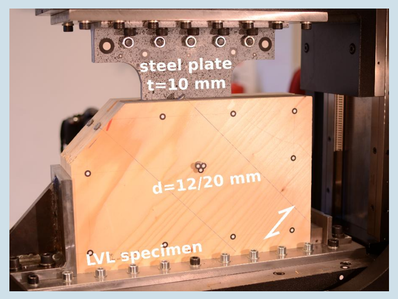




- Steel quality: commercial + heat-treated S235 [3]

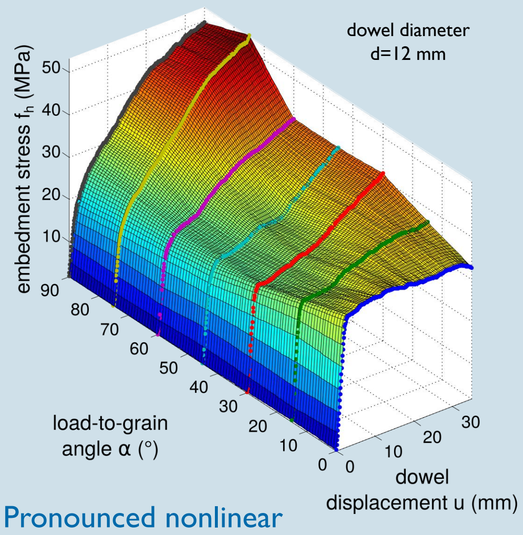
SINGLE DOWEL CONNECTION

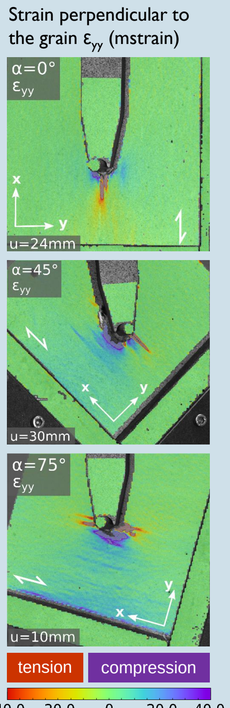
- Steel-to-LVL connection in double-shear
- α= 0, 45, 90°
- Climatic conditions: 20 °C / 65 %RH
- Loading up to at least twice the dowel diameter, including two unloading cycles



Results & Discussion

EMBEDMENT BEHAVIOR OF LVL

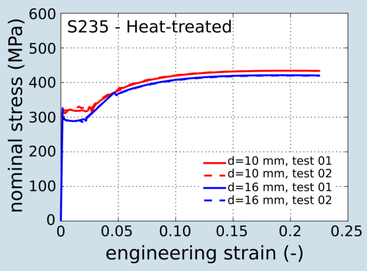


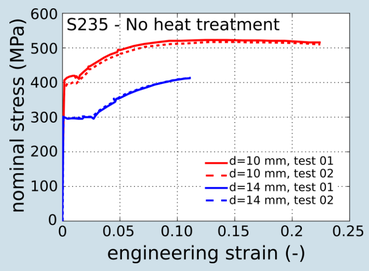


- Pronounced nonlinear load-displacement behavior
- Remarkable hardening for load-to-grain angles higher 45°
- Embedment stress depends on the dowel diameter
- Deviation of load and displacement direction

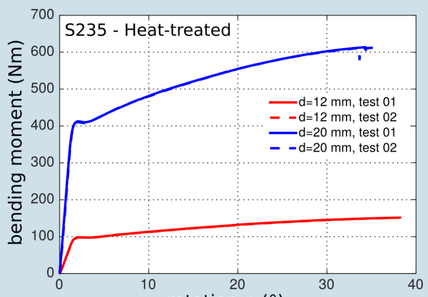
STEEL DOWEL MATERIAL PROPERTIES

Tensile tests



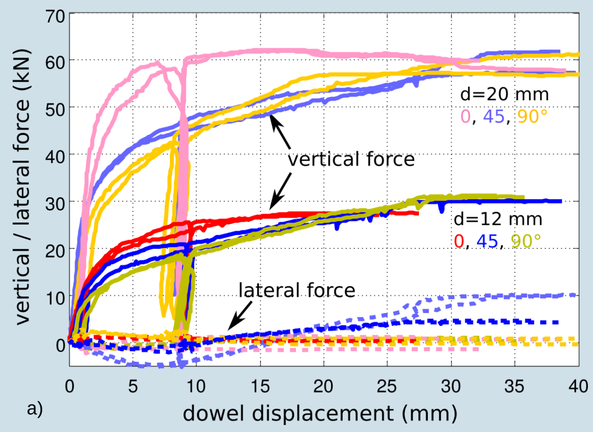


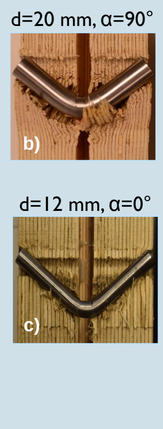
3-Point bending tests



- Pronounced influence of the steel quality on the plastic yield moment (uniform material properties for heat-treated dowels)

CONNECTION PROPERTIES





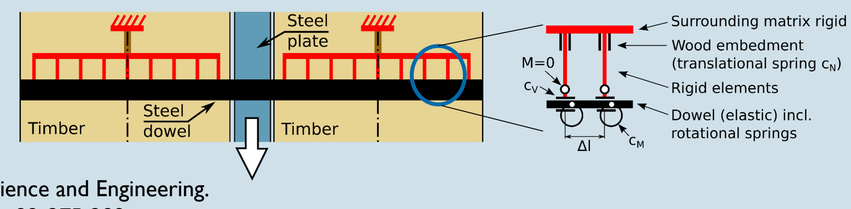
- Nonlinear load-displacement behavior depending on the load-to-grain angle (a)
- One plastic hinge in the center of the connection (b, c)
- Lateral force of up to 15-20 % of the vertical loading for load-to-grain angle of 45°
- Results are in line with the phenomena detected in embedment tests

CONCLUSIONS

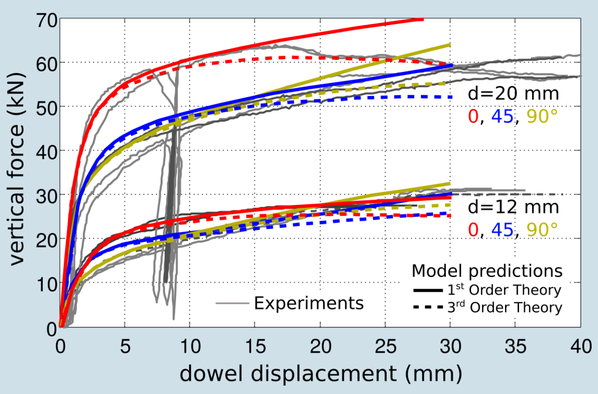
- Embedment and single dowel connection tests showed a remarkable influence of the orthotropic material behavior of timber on the load-displacement behavior of steel dowels
- The steel quality has been found to have a considerable influence on the moment-rotation behavior of the dowel
- The established dataset represents a valuable source for the development of numerical models for dowel connections

ENGINEERING MODELING APPROACH FOR SINGLE DOWEL CONNECTIONS

- Beam on nonlinear elastic foundation model [4]
- Prediction of single dowel load-displacement relationships for arbitrary layouts and loadings



VALIDATION SINGLE DOWEL BEHAVIOR



References:
[1] Schweigler et al., 2014, ICEM 16.
[2] EN 383, 2007, Austrian Standards Institute
[3] Bader et al., 2015, Wood Material Science and Engineering.
[4] Hochreiner et al., 2013, Bauingenieur, 88, 275-289.

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