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imws

ASSESSMENT OF EMBEDMENT AND PLUG-TENSION-SHEAR FAILURE OF DOWEL GROUPS BY DIC MEASUREMENTS

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MOTIVATION

Focus of interest:

- ❑ Load carrying behavior of dowel groups subjected to bending ± normal force
  - ➢ Knowledge about elastic limit, nonlinearities and collapse load
- ❑ Global system response and history of crack formation
  - ➢ Indications for necessities of subsequent numerical modeling
- ❑ Background for overcoming of limits within the traditional design of EC5
  - ➢ Visualization of failure mechanisms for sake of convincement

Measurement tasks:

- ❑ Relative displacements (incl. relative rotation) of the steel plate to the LVL-beam
- ❑ Failure mode according to EC5 and bending angle of the single dowels
- ❑ Identification of local strains and extensions induced by dowel groups
- ❑ Visualisation of load redistributions due to crack formations by strain fields
- ❑ Data base for coupling of the global system response to the sequence of crack formation and internal load redistribution among the dowels

TEST SETUP AND GLOBAL SYSTEM RESPONSE

Single dowel

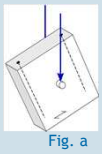


Fig. a

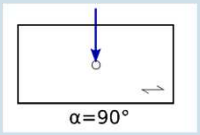


Fig. b

- ❑ Embedment tests according to EN 383:2007 with extensions
- ❑ LVL (Kerto-S), 45 mm for M12 resp. 51 mm for M16
- ❑ Test samples were prevented from premature splitting by reinforcements (Fig. a)

Dowel group

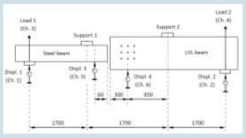


Fig. c

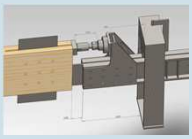


Fig. d

- ❑ Rectangular and circular arrangement of dowels
- ❑ Four point bending test (=M) acc. to Fig. c
  Inverse support conditions to reduce global displacements in the field of view (DIC)
- ❑ Additional eccentricity (=M+N) acc. to Fig. d
- ❑ Some test samples were prevented from premature splitting by reinforcements

Setup of measurements

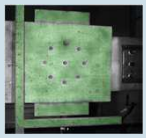
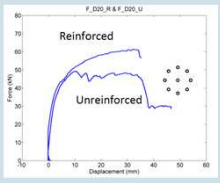


Fig. e


Fig. f

- ❑ ARAMIS (3D DIC-system)
  - 2-cam system (4 megapixels)
  - ➢ Displacement and strain field (Fig. e)
- ❑ PONTOS (3D point-measurement system)
  - Distinct markers (dots see Fig. f)
  - ➢ Movement of the dowel heads
- ❑ Some LVDTs for redundancy purpose

Global system response



Typical load displacement curves:

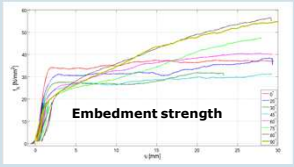
- ❑ M12: Smooth slip curve every time
- ❑ M20: Significant drop of stiffness in case of unreinforced test samples

Note: Limitation of the rotation due to restrictions of the test setup

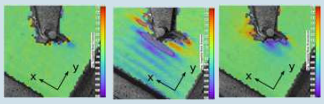
DIC RESULTS

Embedment behavior of a single dowel


- ❑ Load in line with displacement
  Later on deviation along the fiber



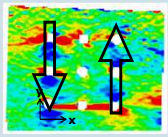
- ❑ Hardening for α =60°÷90°

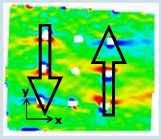


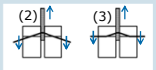
- ❑ ε_y: banding due to annual rings of plys
- ❑ Field of view reduced by splintering

Identification of the type of failure modes (1÷3)

- ❑ Failure mode 1 (NO plastic hinge)
- ❑ Failure mode 2-3 (1÷2 plastic hinges)
- ❑ Loading in line with compression
- ❑ Loading inverse with compression

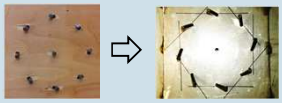

dowel M20


dowel M12

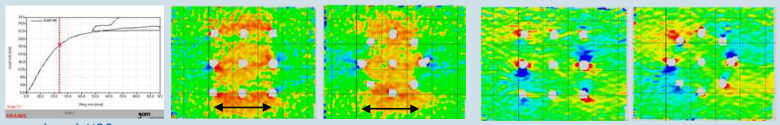


Note: Strains perp. to the grain; compression=blue, tension=red

- ❑ Changes depending on load stage
- ❑ Final assessment / validation by demolition of the test samples

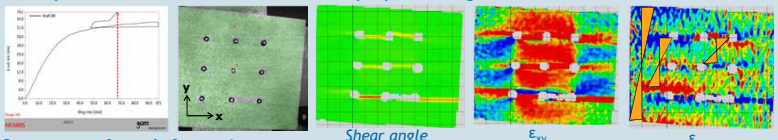


Experimental results essential for the design acc. to EC5



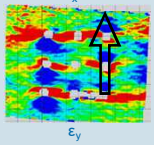
Superposition of global shear strains induced by the dowel group

- ❑ Similar extension for both rectangular and circular dowel groups
- ❑ Only interaction of local tensile stress perp. to the grain and shear stress



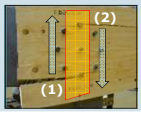
Sequence of crack formation

- ❑ *Shear angle* as perfect indication for crack formation additional to ε_{xy}
  Extension of the shear field by formation of a framework
- ❑ Corresponding bending strains from ε_x
- ❑ Indication for load redistribution due to crack formation : On the surface less compressive strains ε_y due to plastic hinge inside →



Two significant failure modes according to EC5:

(1) Failure due to "notching" (EC5 6.5)
(2) Failure due to "connection of forces at an angle to the grain" (EC5 8.1.4)



LESSONS LEARNED

Structural assessment:

- ❑ DIC measurements are a powerful tool for monitoring crack formation
  Surface identification of plastic hinge formation in the interior
- ❑ Reinforcement by full threaded screws ensure plastic behavior of dowels groups
- ❑ Large plastic displacements are possible and should be included in the design process for sake of competitiveness of timber structures
- ❑ Underestimation of load carrying capabilities perpendicular to the grain

Future projects:

- ❑ Additional embedment tests with extended specifications (different wood species, elevated temperature, creep, growth irregularities e.g. knots)
- ❑ Validation of numerical model for plastic behavior of dowel groups to be implemented in commercial structural analysis software
- ❑ Specification of design rules for block failure in case of moment loading
- ❑ Optimization of strategies for the reinforcement of dowel groups

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