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 conviction

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

- Embedment tests according to EN 1381-2007 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

- 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

- ARAMIS (3D DIC-system)
- 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°
- εx: banding due to annual rings of plys
- Field of view reduced by splintering
- Note: Strains perp. to the grain; compression-blue, tension-red
- Changes depending on load stage
- Final assessment / validation by demolition of the test samples

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

- Failure mode 1 (NO plastic hinge)
- Loading in line with compression
- Loading inverse with compression

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 εyy
- Extension of the shear field by formation of a framework
- Corresponding bending strains from εz
- Indication for load redistribution due to crack formation: On the surface less compressive strains εz, due to plastic hinge inside

Two significant failure modes according to EC5:
- (1) Failure due to “notching” (EC 6.5)
- (2) Failure due to “connection of forces at an angle to the grain” (EC 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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