COST E55 – Trondheim

On Ductility and Timber Structure Connections

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Maximum Resistance

- Failure takes place when max resistance is passed:

$$F = F_{max}$$
$$dF = 0$$

- For an axial loaded element:

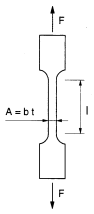
$$dF = \frac{\partial F}{\partial A}dA + \frac{\partial F}{\partial \sigma}d\sigma = 0$$

$$F = A\sigma = bt\sigma$$

- Max resistance is reached when:

"the increase of material resistance is offset by the change in geometry"

$$\frac{\partial \sigma}{\sigma} = -\frac{\partial A}{A}$$



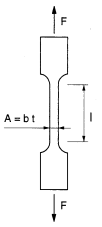
Maximum Resistance

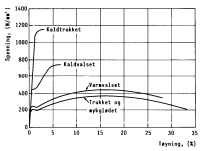
- Not solely a material property
- Geometry and geometry changes inevitable

- Max resistance and ductility are component properties
- For timber structure components:
  - Steel material properties and loaded components
  - Wooden material properties and loaded parts

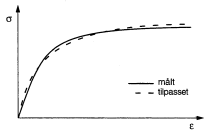
Steel properties

- Hot finished?
- Cold worked?



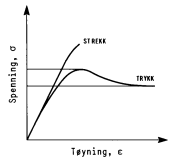


- Localized

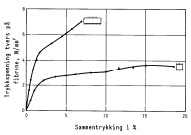


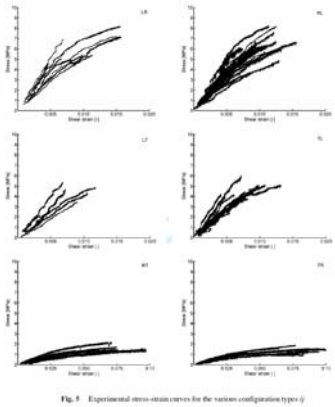
Ductility of wood?

- Fiber direction (0 or L)



- Normal direction (90 or T, R)





Wood Shear

(K. Dahl: Test results)

Evaluation of ductility

- Removal of elastic deformation:
  - Strain and curvature:

$$\varepsilon_p = \varepsilon - \varepsilon_e = \varepsilon - \frac{\sigma}{E}$$

$$\kappa_p = \kappa - \kappa_e = \kappa - \frac{M}{EI}$$

  - Deformation and rotation:

$$u_p = u - u_e = u - \frac{F}{AE}$$

$$\theta_p = \theta - \theta_e = \theta - \frac{M \cdot l}{EI}$$

Removal of elastic deformation

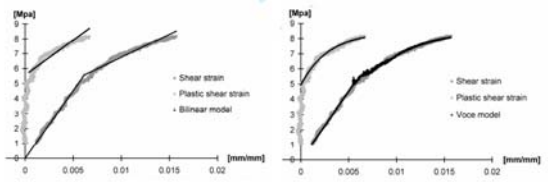


Fig. 8 Bilinear (left) and Voce shear adaptation of experimental stress-strain curve ($ij = LR$)

- (K. Dahl: Test results)

Ductility:

- A measure of ductility:

$$D_p = \frac{u_u - u_e}{u_e}$$

$u_u =$ ultimate deformation at F_{max}

$u_e =$ elastic deformation

- A purely elastic material has no ductility (brittle):

$$u_u = u_e \qquad D_p = 0$$

Ductility from shear test example:

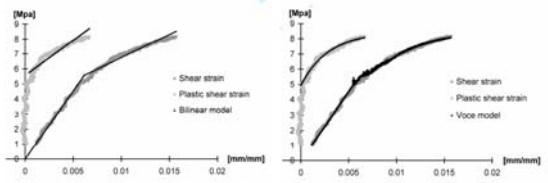


Fig. 8 Bilinear (left) and Voce shear adaptation of experimental stress-strain curve ($ij = LR$)

(K. Dahl: Test results)

$$D_p = \frac{u_u - u_e}{u_e} = \frac{0.07}{0.06} = 1.15$$

Ductility and Robustness

- Ductility of wooden structures can be achieved through:
  - Compression normal to grains
  - Compression locally around fasteners
  - Yielding of metallic fasteners
- The strength of wood is not ductility!
- Ductility may not be sufficient to achieve ROBUSTNESS
- Overstrength (may be) needed
- Working loads in the elastic domain

Proposal: Robustness Index

$$RI = \frac{F_{max}}{F_{ref}}(1 + r \cdot D_p)$$

- Where:

$F_{max} =$ maximum resistance

$F_{ref} =$ reference load

$r =$ weight parameter for ductility $(0..1)$

$D_p = \frac{u_u - u_e}{u_e}$

Parameters:

- Required Robustness Index $RI = \frac{F_{max}}{F_{ref}}(1 + r \cdot D_p) \geq 1.0..?$
- Overstrength: $\frac{F_{max}}{F_{ref}} \geq 1$
- Reference
  - load (external)? $F_{ref} = F_d$ or $= F_k$
  - or resistance? $F_{ref} = F_e = R_e$
- Ductility weight factor $r \geq \; > 0.? \;\; .. \;\; 1.?$
  - Calibration through probabilistic evaluation?

Robustness Index for shear test example:

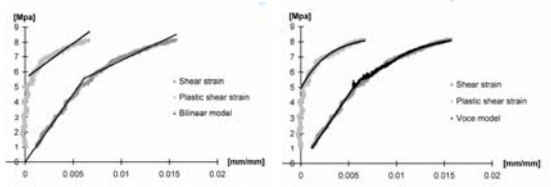


Fig. 8 Bilinear (left) and Voce shear adaptation of experimental stress-strain curve ($ij = LR$)

$D_p = \frac{u_u - u_e}{u_e} = \frac{0.07}{0.06} = 1.15$

$r := 0.5$

$F_{ref} := F_e = 5$

$RI = \frac{F_{max}}{F_{ref}}(1 + r \cdot D_p) = \frac{8}{5}(1 + 0.5 \cdot 1.15) = 2.5$