Improved design method for connections perpendicular-to-grain

Dennis Schoenmakers

André Jorissen
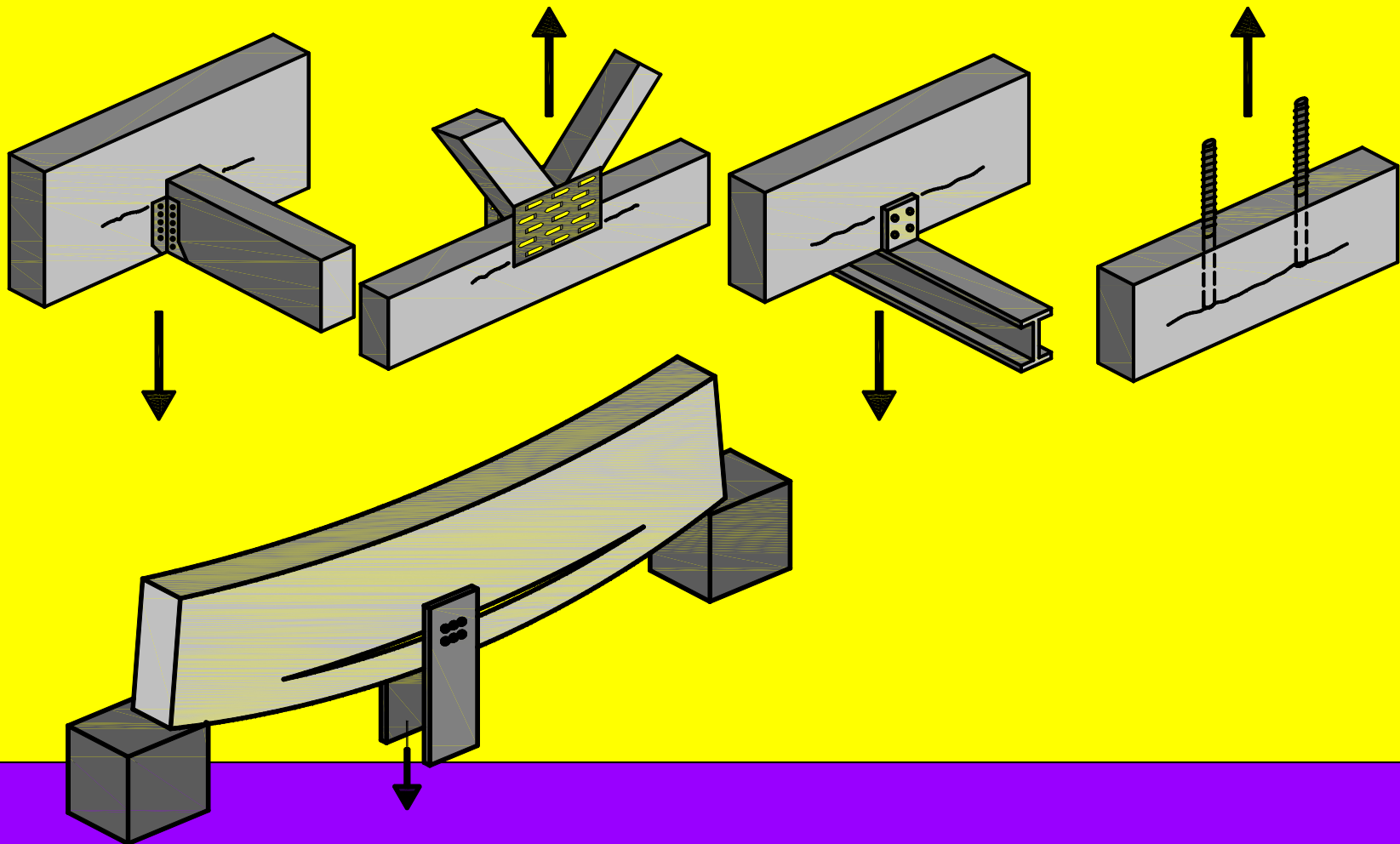
Ad Leijten

cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

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Eindhoven
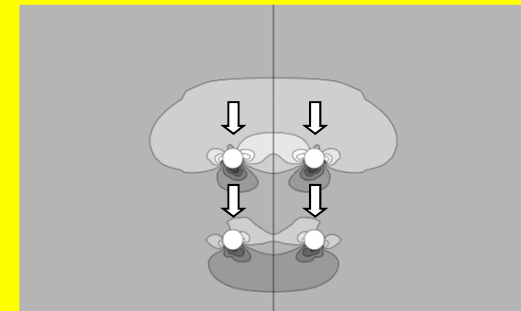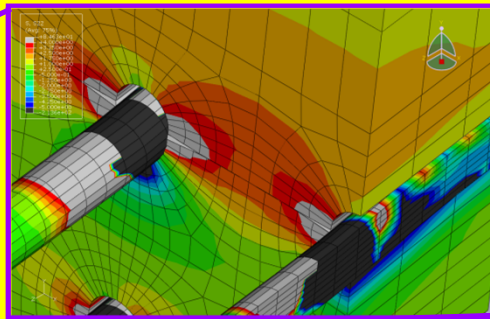University of Technology
Where innovation starts

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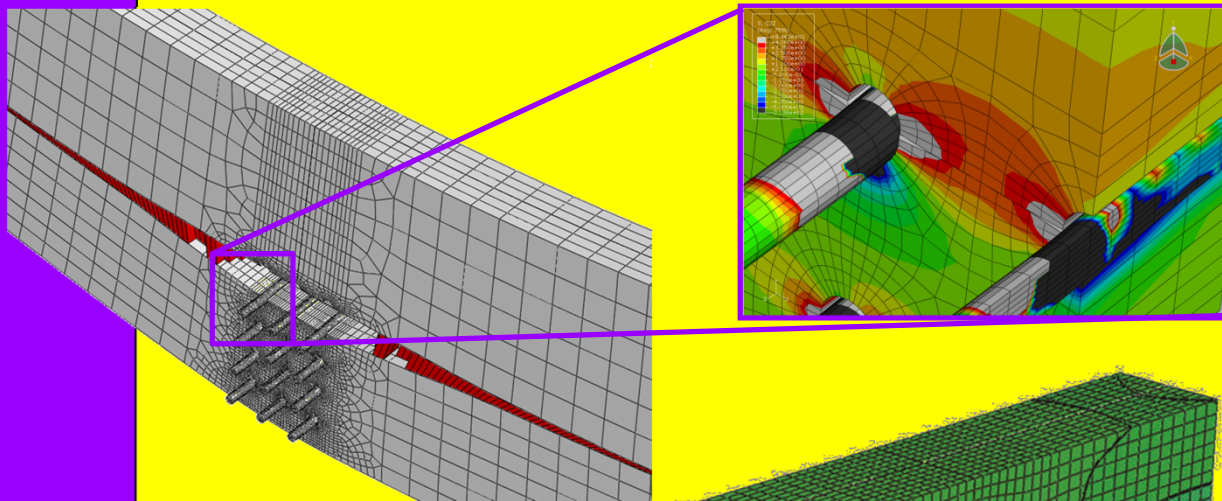# General / Introduction

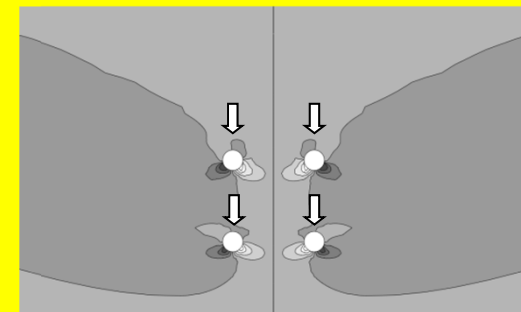➢ Critical situations in timber engineering design practice (joints)
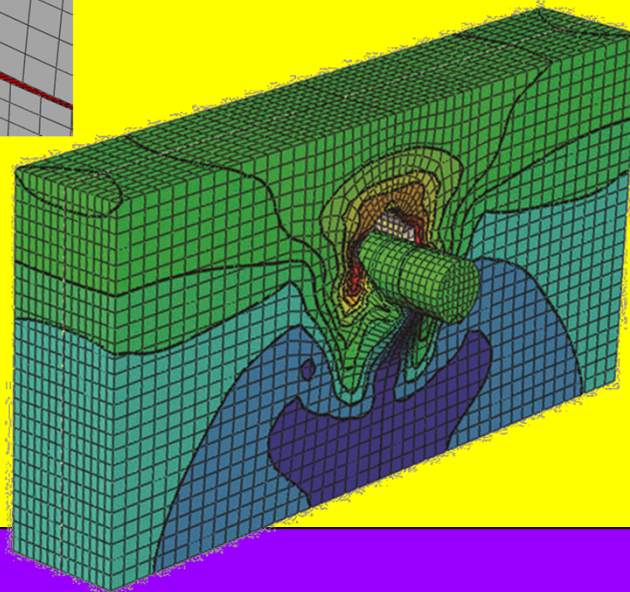
General / Introduction

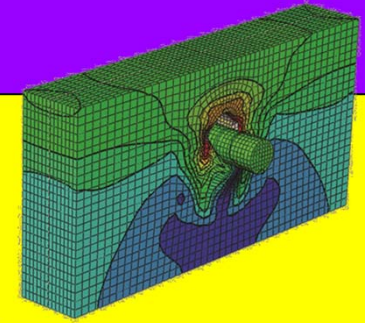➢   Associated fracture and failure mechanisms ←→ local stress state

Normal stress
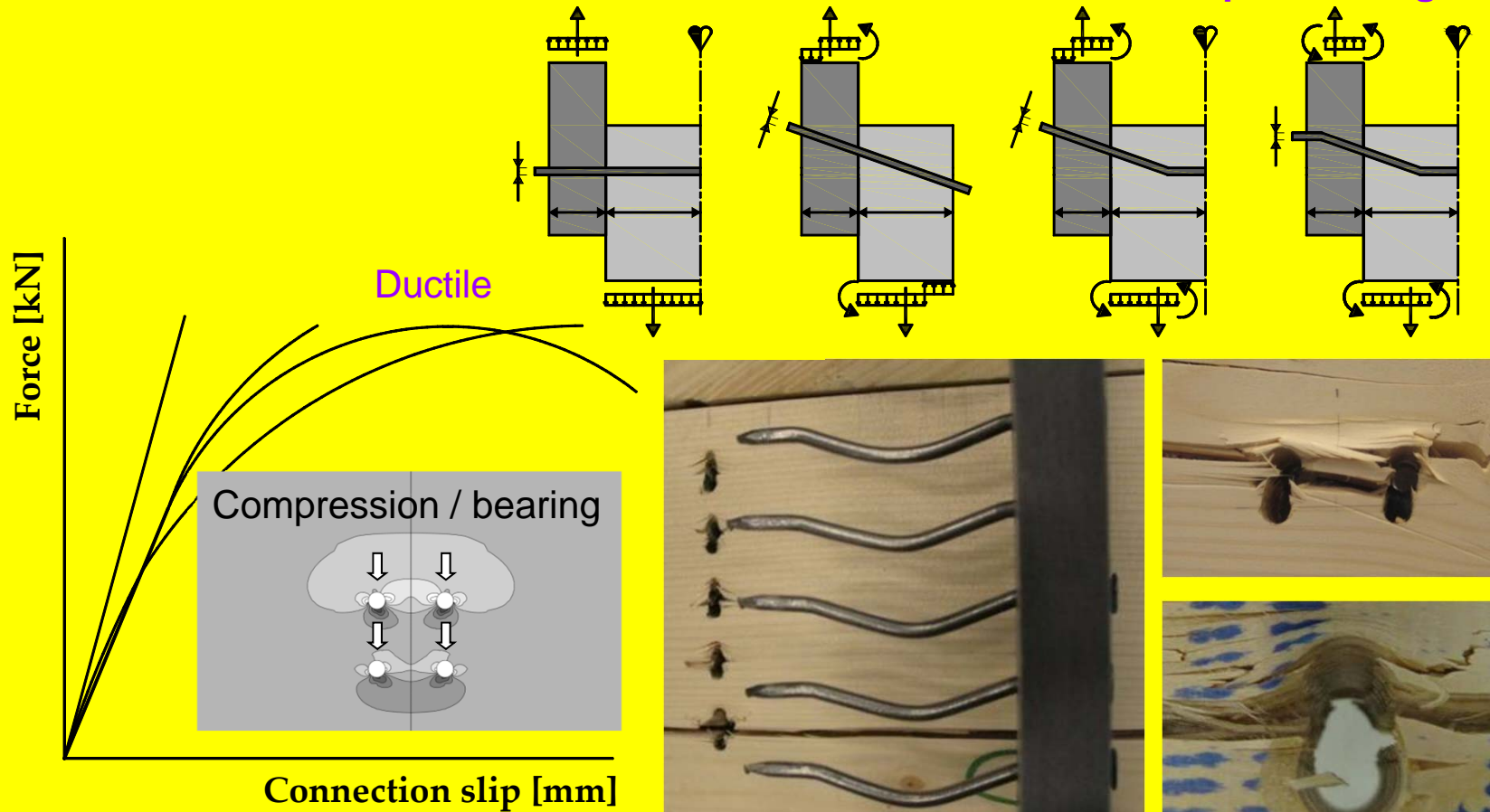
Shear stress

General / Introduction

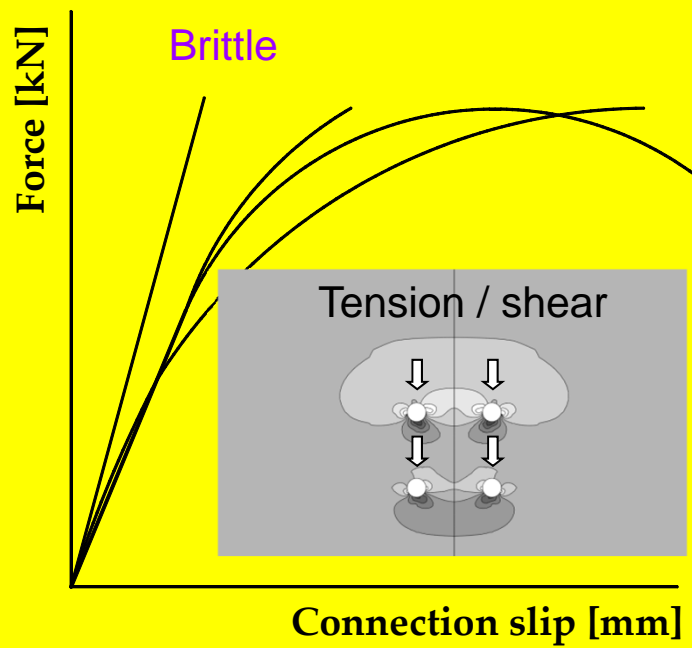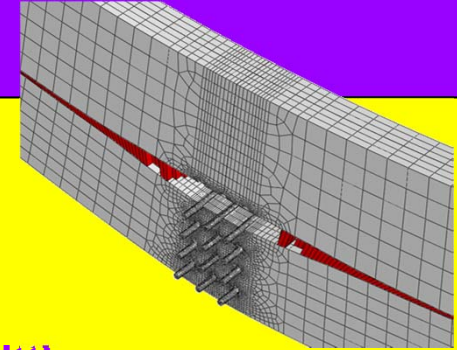➢ Associated fracture and failure mechanisms: **Embedment / plastic hinges**

Ductile

Force [kN]

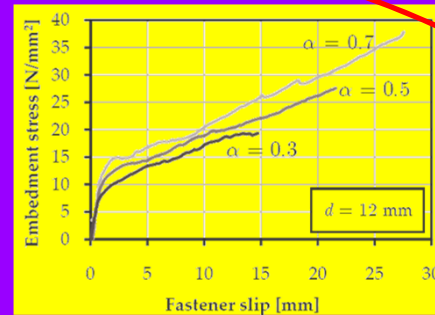Compression / bearing

Connection slip [mm]

General / Introduction

➢ Associated fracture and failure mechanisms: **Splitting**

Brittle

Tension / shear
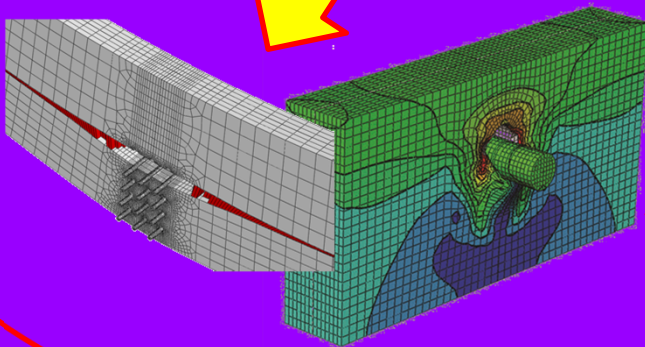
Force [kN]

Connection slip [mm]

Research methodology

Design rules

➢ Research fields

Experimental
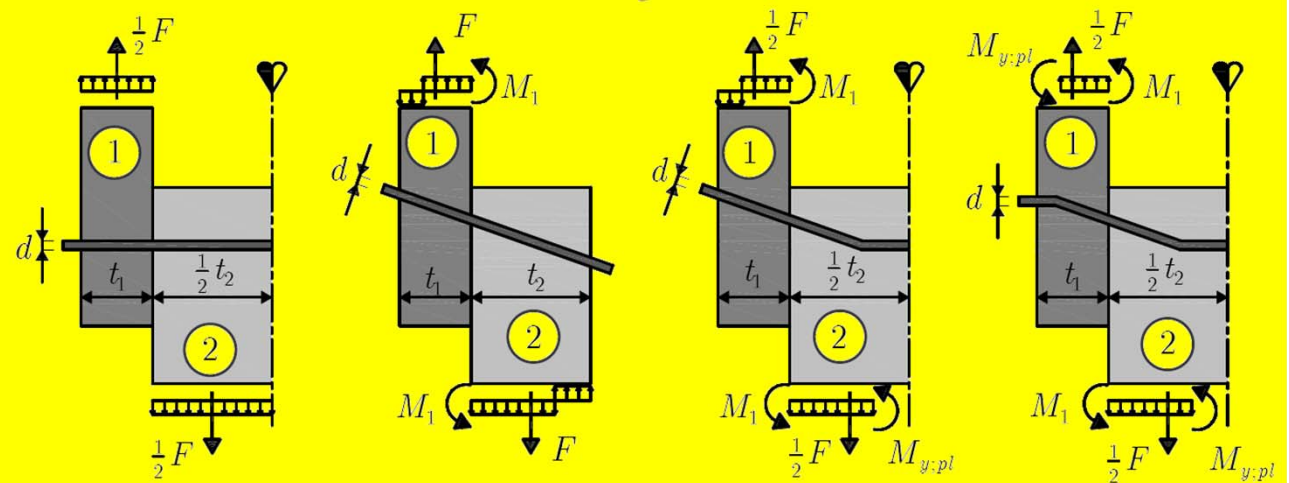

Numerical simulations

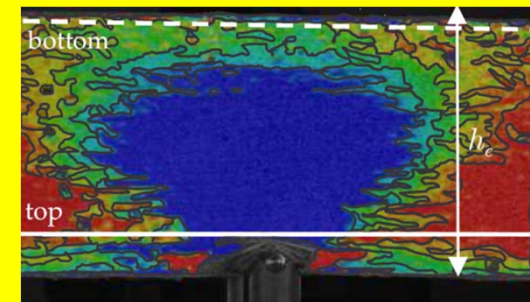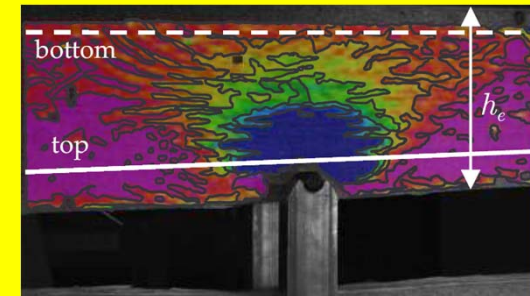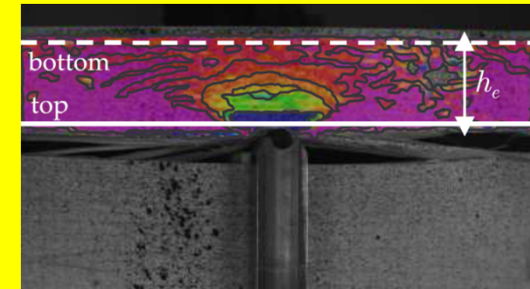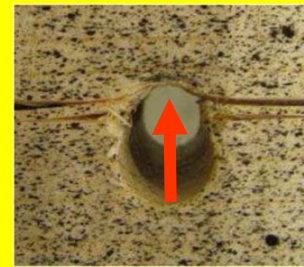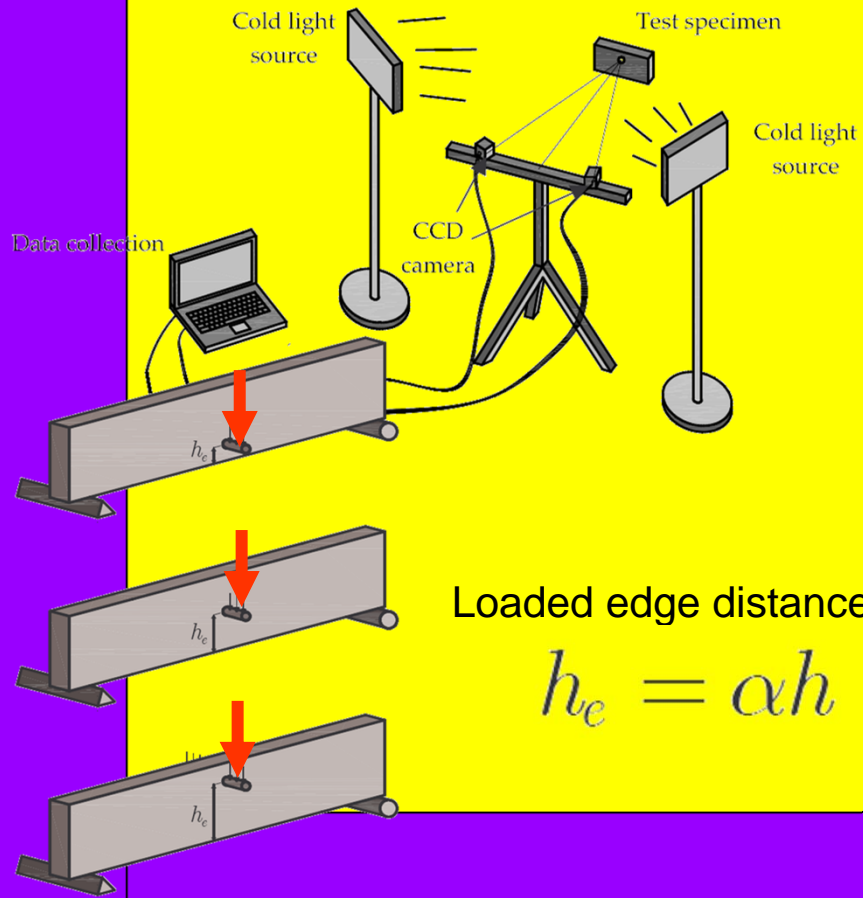$$F' = \frac{\partial}{\partial \lambda} F(\lambda, h_e)$$

Fysical models

Embedment (Bearing) failure perpendicular to the grain

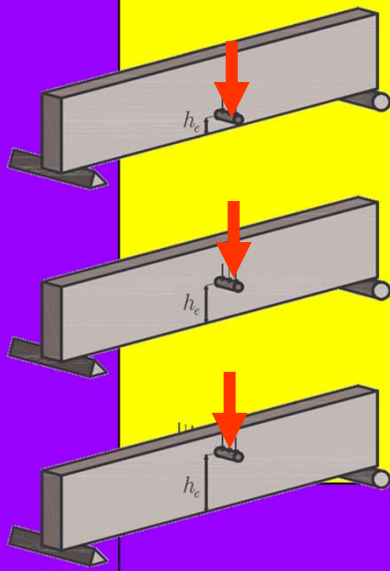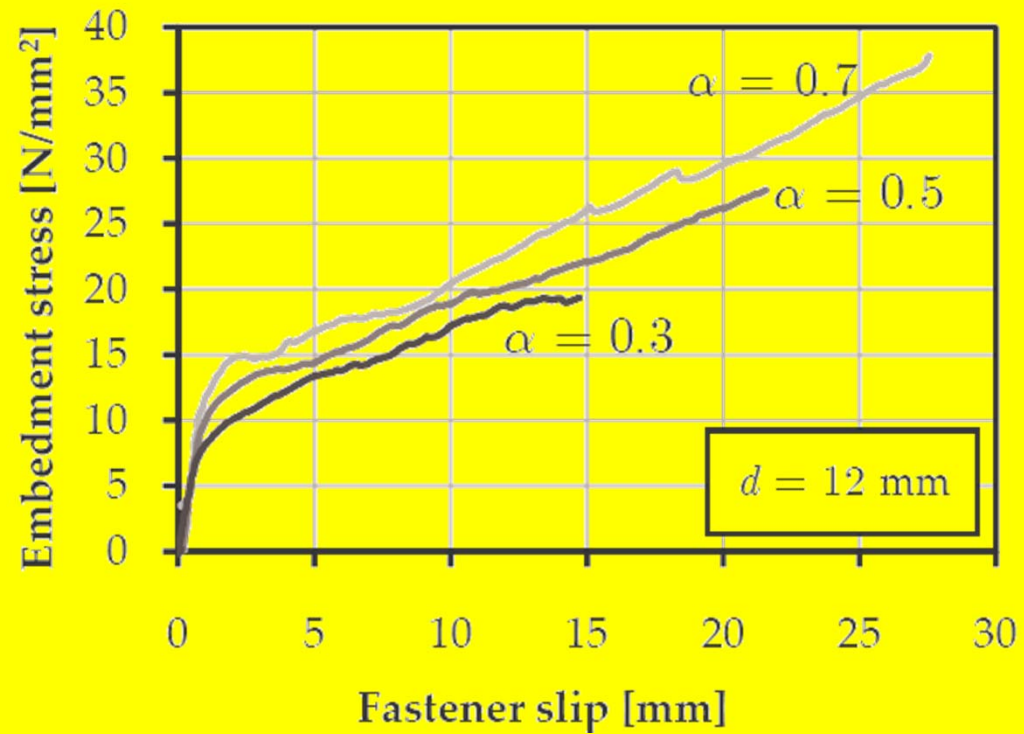# Embedment failure (bearing)
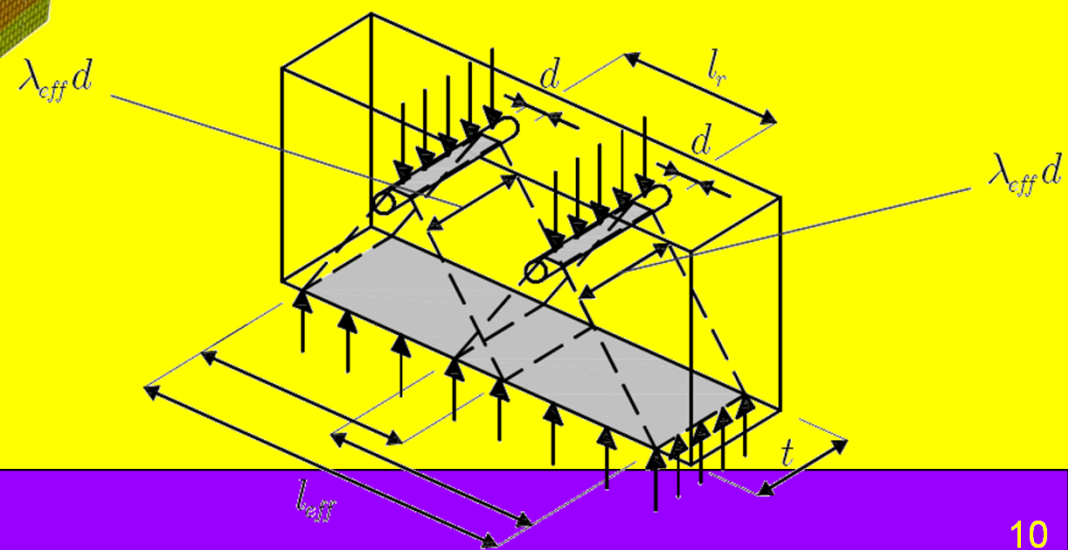
➢ Load-dispersion determined by experiments

Loaded edge distance

$$h_e = \alpha h$$

Embedment failure (bearing)
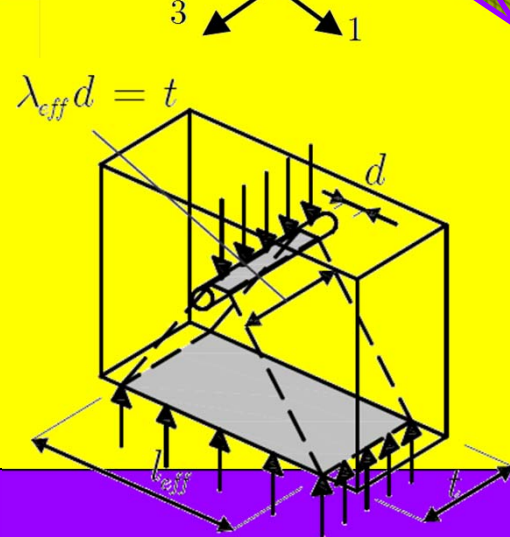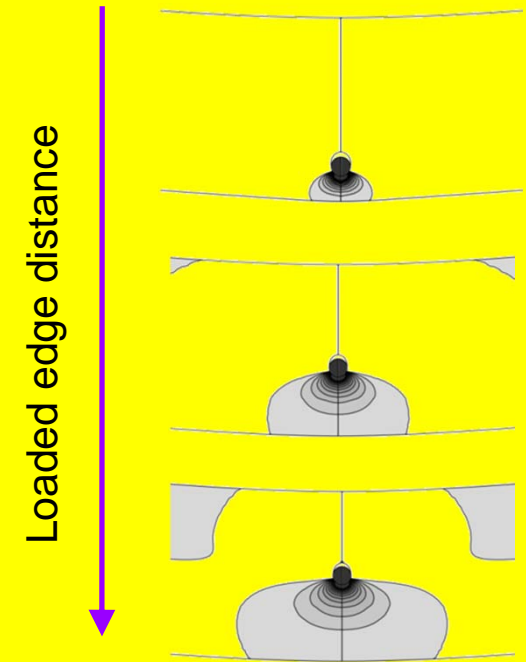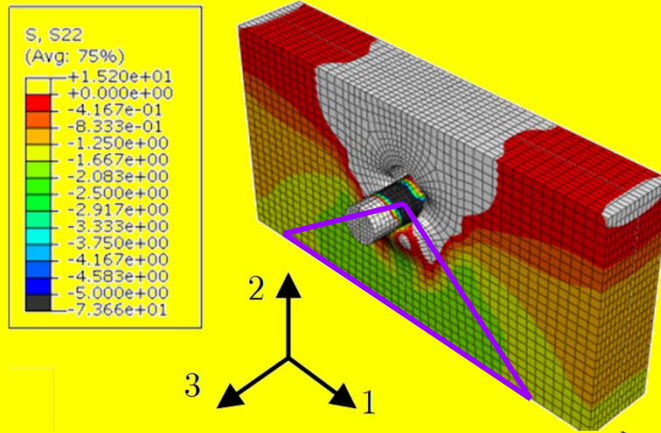
➢ Load-dispersion determined by experiments

Loaded edge distance

$$h_e = \alpha h$$

Embedment failure (bearing)

➢ Bearing strength = wood resistance

➢ Modeling load-dispersion effect

Loaded edge distance

$\lambda_{cff} d = t$

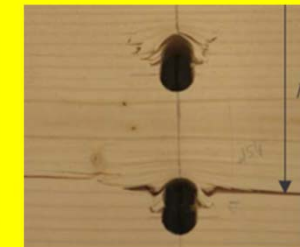$\lambda_{cff} d$
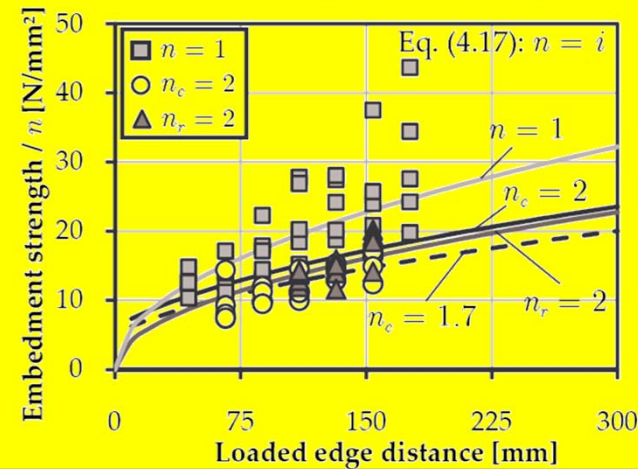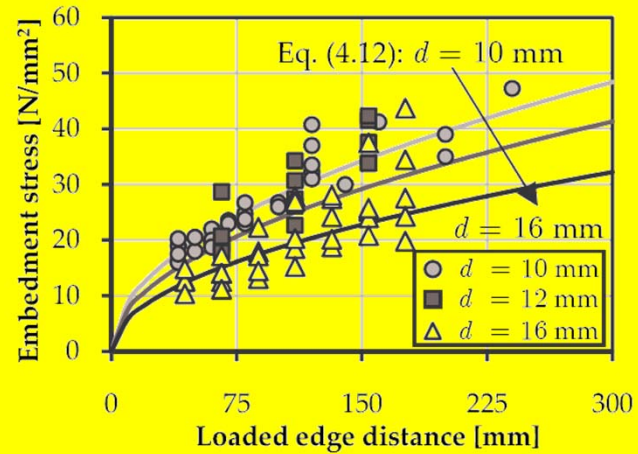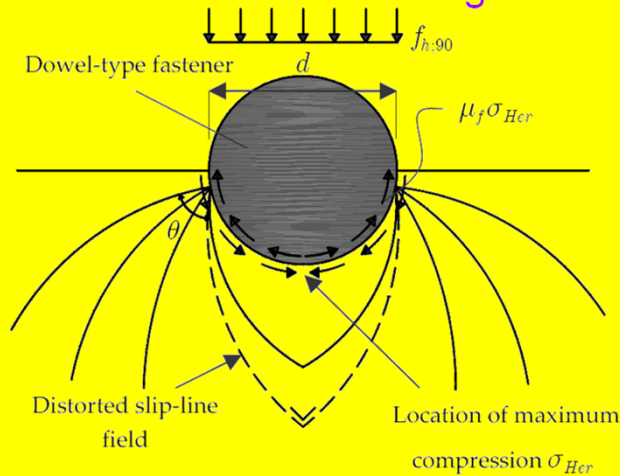
$\lambda_{cff} d$

Embedment failure (bearing)

➢ Model, based on plasticity, slip-line theory and contact mechanics

$$f_{h;90} = f_{c;90}\sqrt{\frac{3h_e}{d}}H_1$$

Material strength

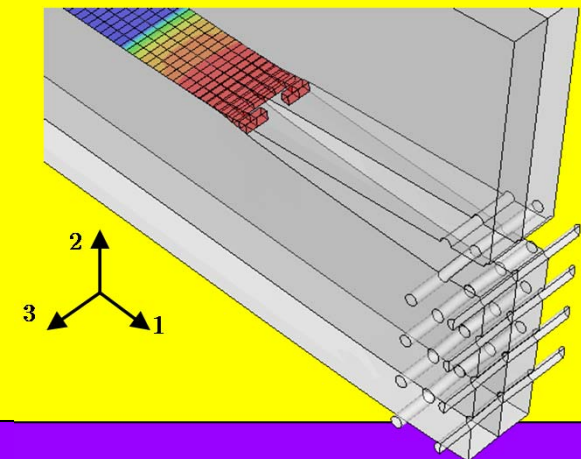**Specimen geometry**

Fastener diameter

Dowel-type fastener d $f_{h;90}$

$\mu_f \sigma_{Hcr}$

θ

Distorted slip-line field

Location of maximum compression σ_{Hcr}

Embedment stress [N/mm²]

Eq. (4.12): $d = 10$ mm

$d = 16$ mm

$d = 10$ mm
$d = 12$ mm
$d = 16$ mm

Loaded edge distance [mm]

Embedment strength / n [N/mm²]

$n = 1$
$n_c = 2$
$n_r = 2$

Eq. (4.17): $n = i$

$n = 1$
$n_c = 2$
$n_c = 1.7$
$n_r = 2$

Loaded edge distance [mm]
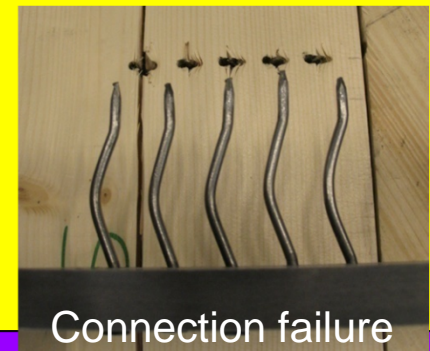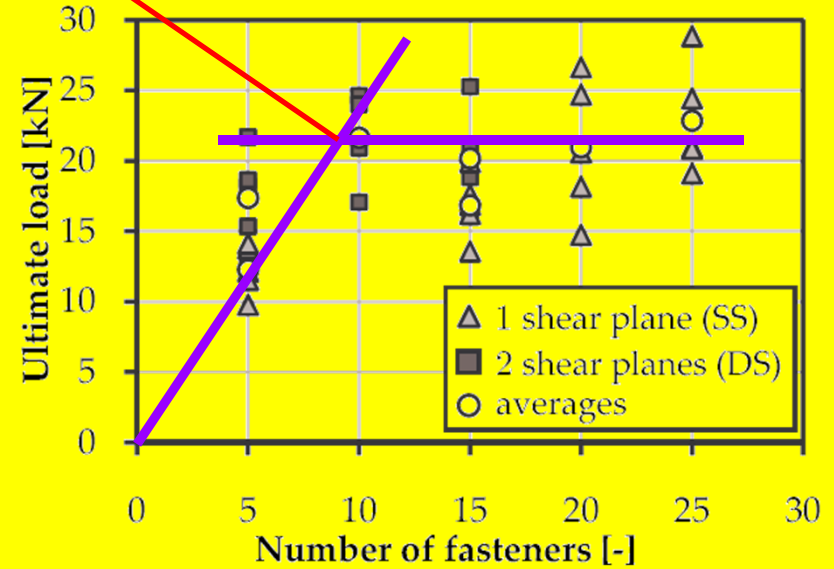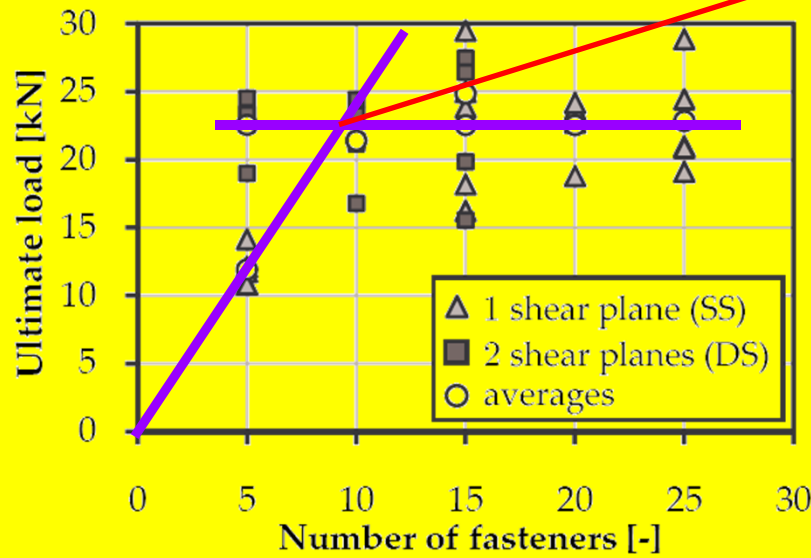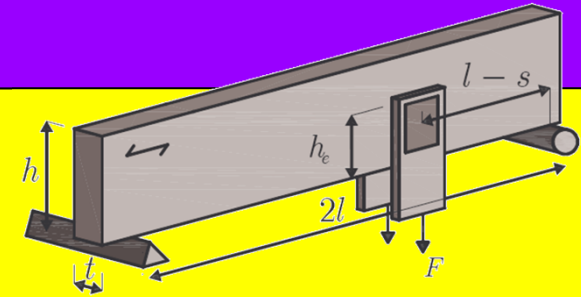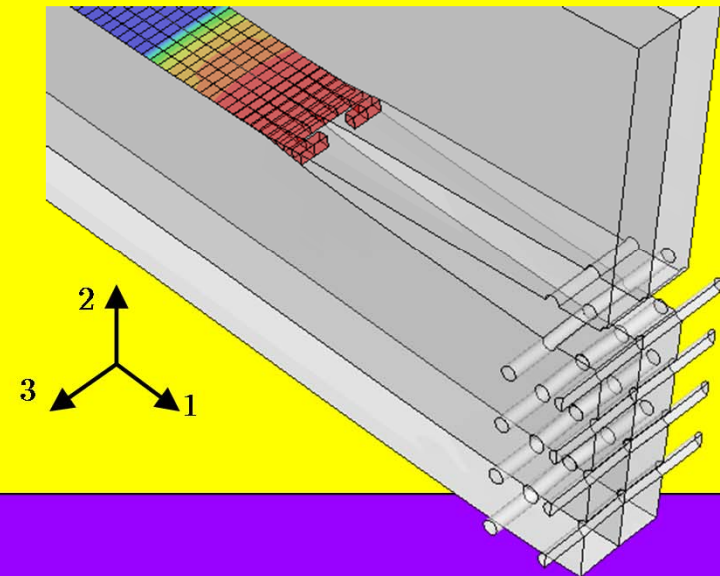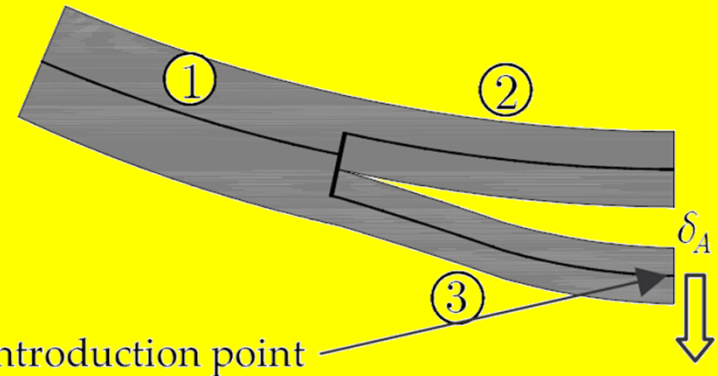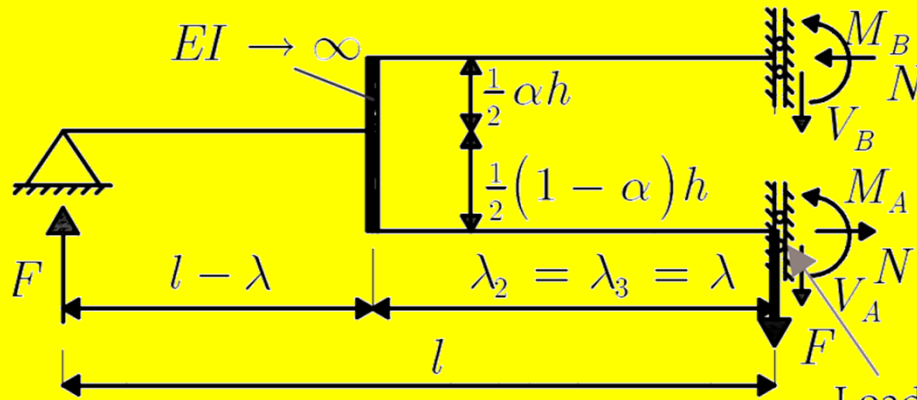
Splitting failure along the grain

Splitting failure

➢ Number of nails — Change in mechanism

Connection failure

Connection failure

Splitting failure

➤ Modeling the connection as a discrete location (single connection)
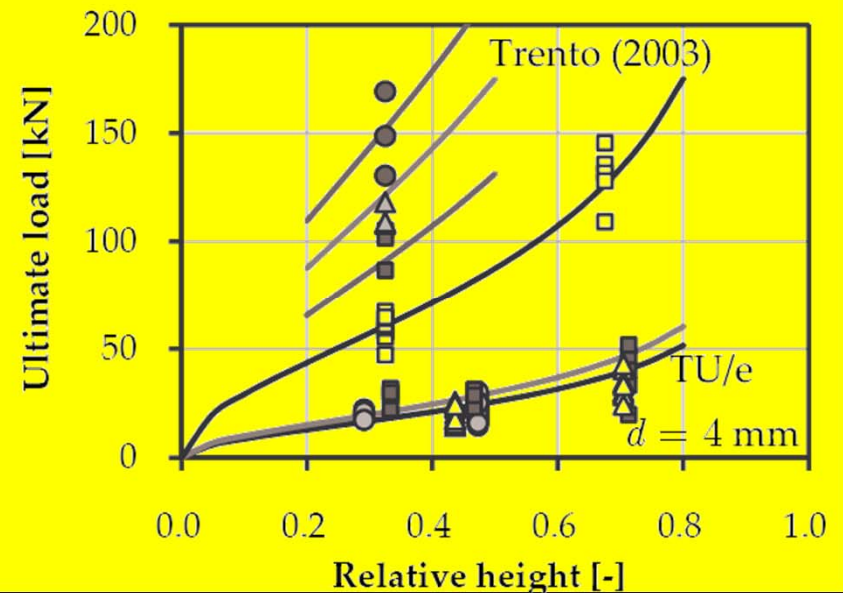

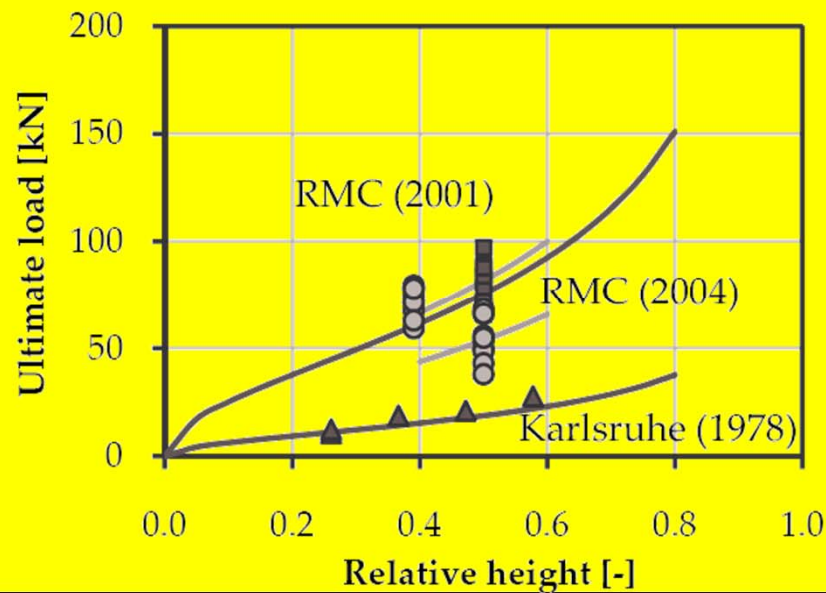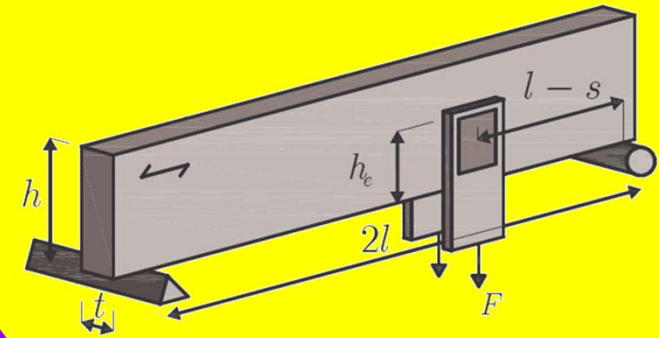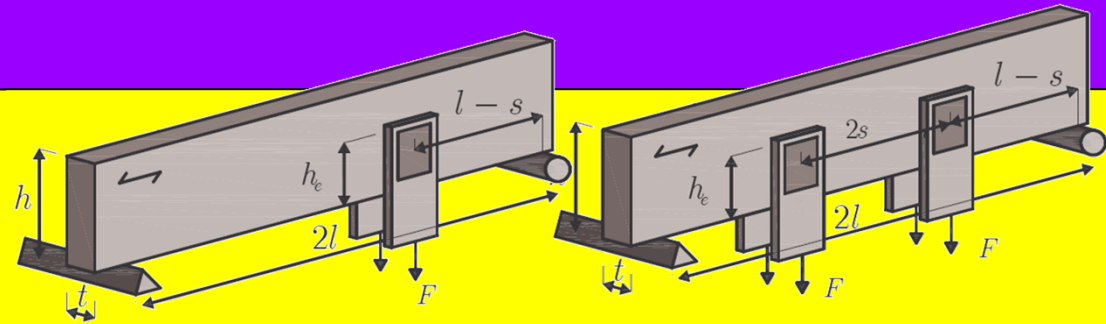
Load-introduction point

Splitting failure

➤ Model (Fracture Mechanics)

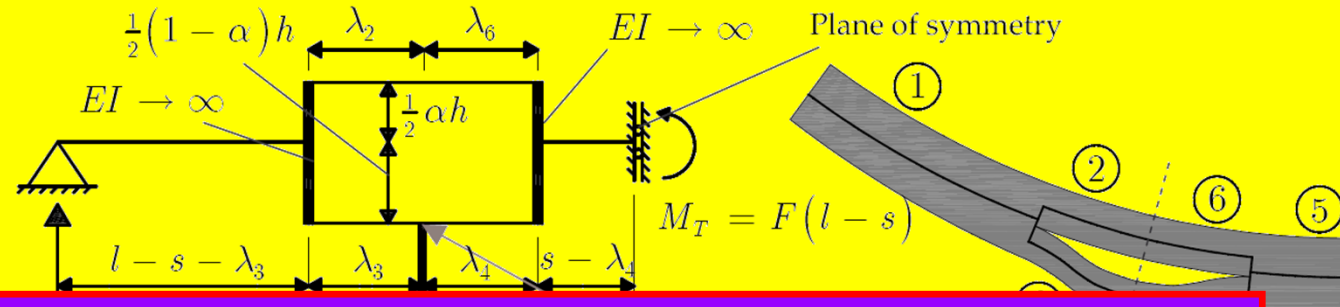$$F_{ult} = 2F_{crit} = 2t \sqrt{\dfrac{G \mathcal{G}_c h \alpha}{\dfrac{3}{5}(1-\alpha)}}$$

Specimen geometry

Material strength

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Splitting failure

- Modeling two connections, spaced symmetrically (Fracture Mechanics)

?? Factor 2 ??

$$\tfrac{1}{2}(1-\alpha)h \quad \lambda_2 \quad \lambda_6 \qquad EI \to \infty \qquad \text{Plane of symmetry}$$

$EI \to \infty$

$\tfrac{1}{2}\alpha h$

$M_T = F(l-s)$

$l - s - \lambda_3 \quad \lambda_3 \quad \lambda_4 \quad s - \lambda_1$

Experimental / Numerical / Mathematical: 145%

Mid span

Support

Connection location

Damage initiation

$\lambda_3 \approx 60\,\text{mm}$

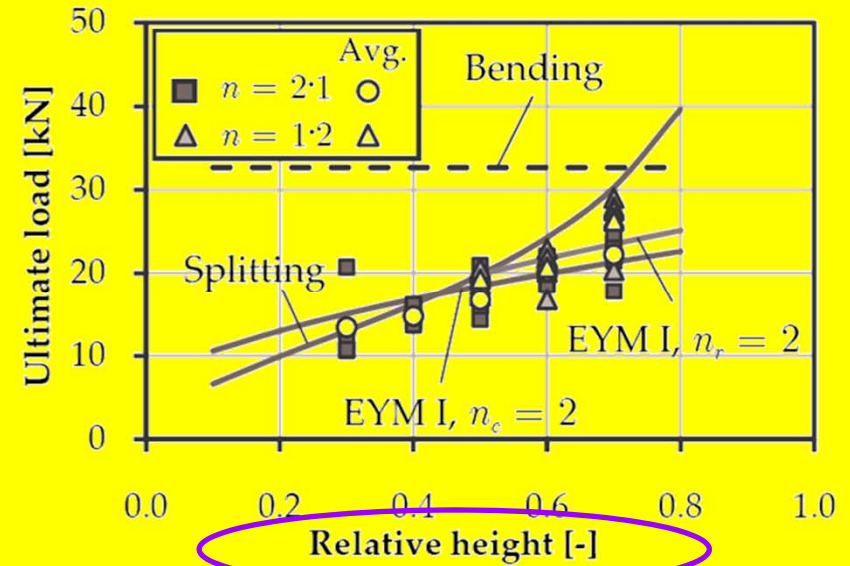Damage initiation
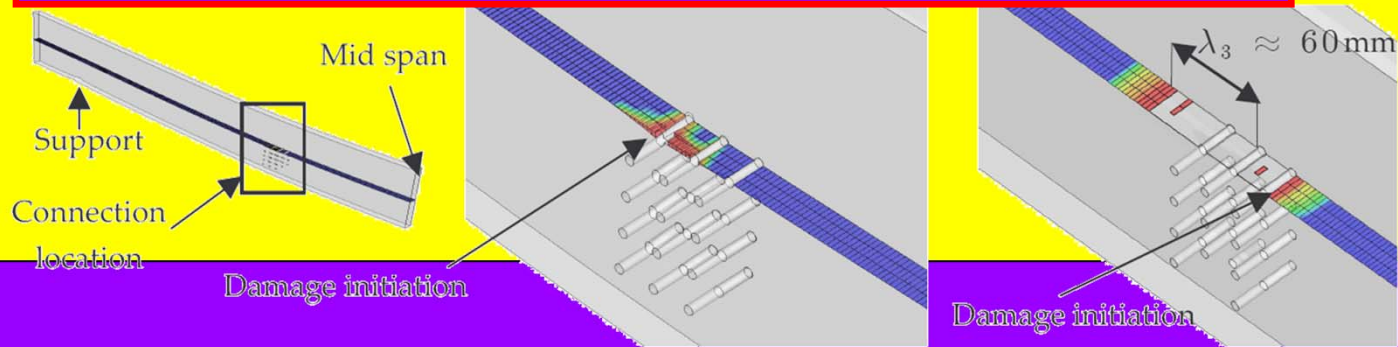
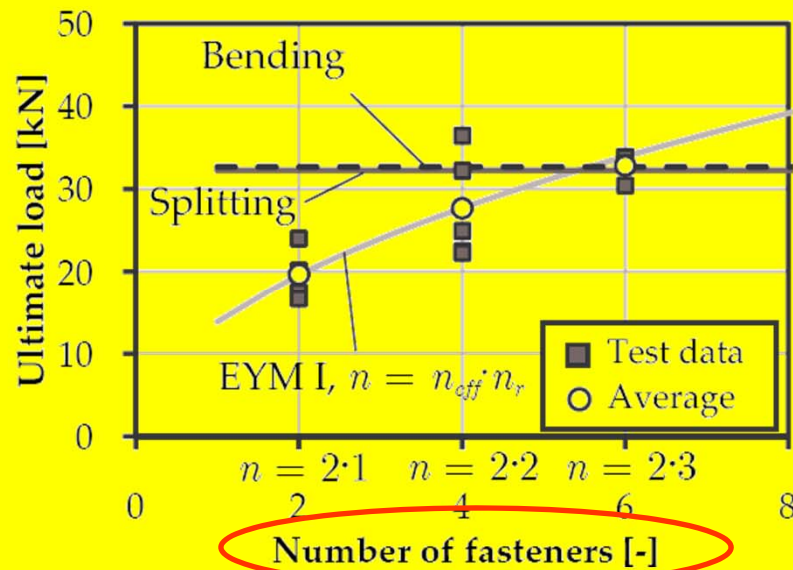**Governing is fracture (splitting) or bearing**

Governing fracture or failure mechanism
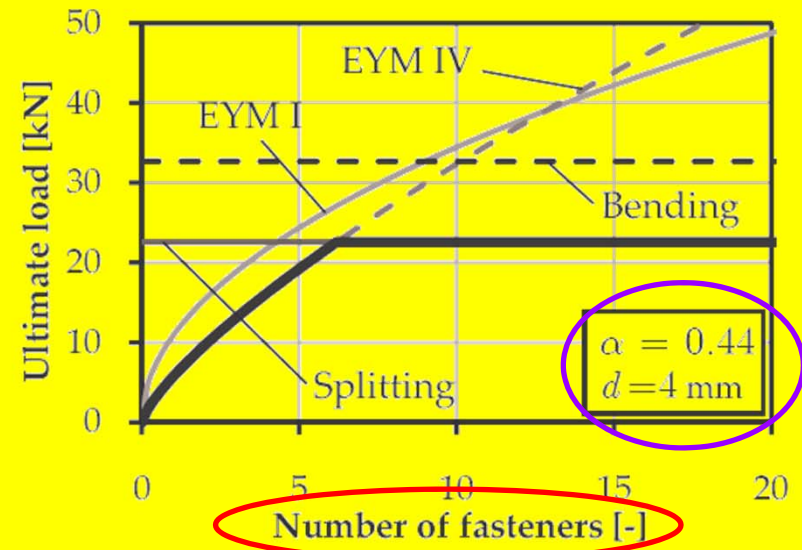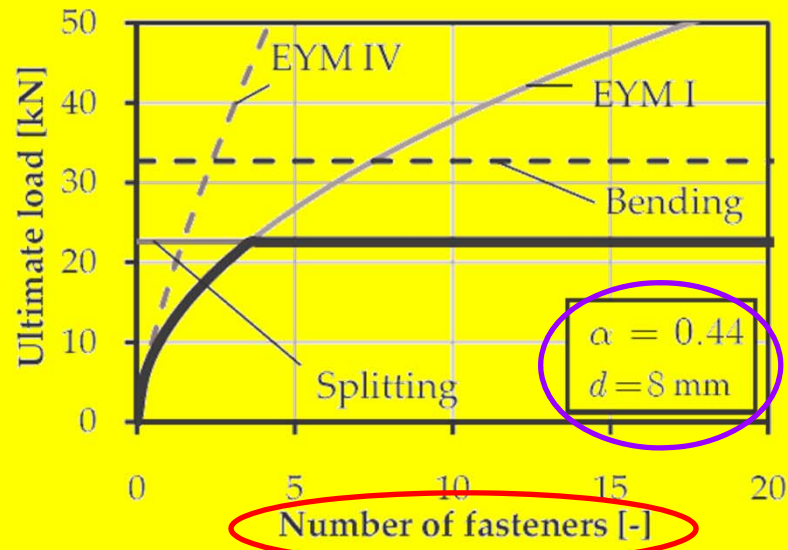
➢ Equations:

$$F_{ult} = 2n_{eff} = f_{c;90} \sqrt{\frac{3h_c t}{nd \ \lambda_{eff} d}} d^{-0.37} d \ \lambda_{eff} d$$

$$F_{ult} = 2t \sqrt{\frac{G G_c h_c}{\frac{3}{5}\left(1 - \frac{h_c}{h}\right)}}$$

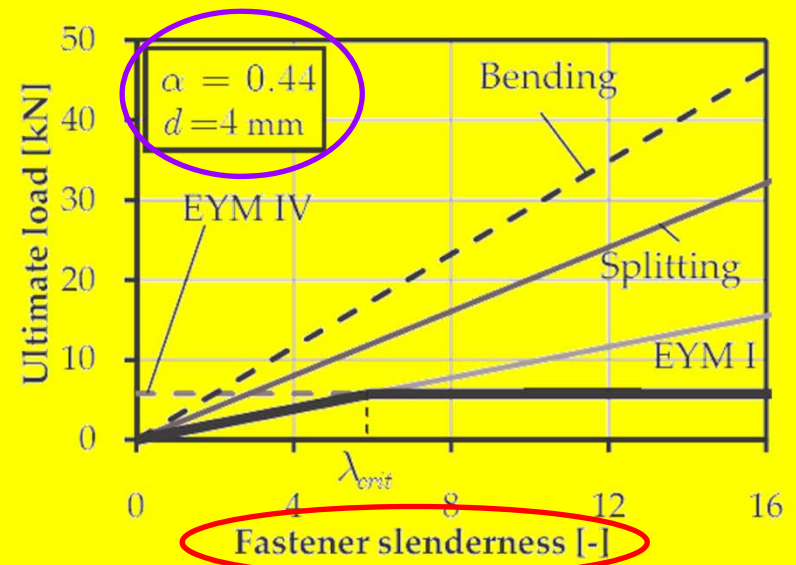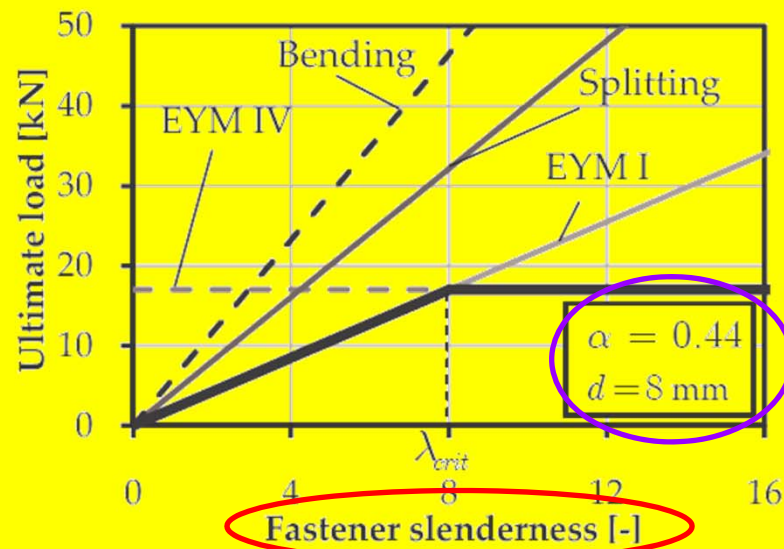➢ Governed by number of fasteners and loaded edge distance (~rel. height)

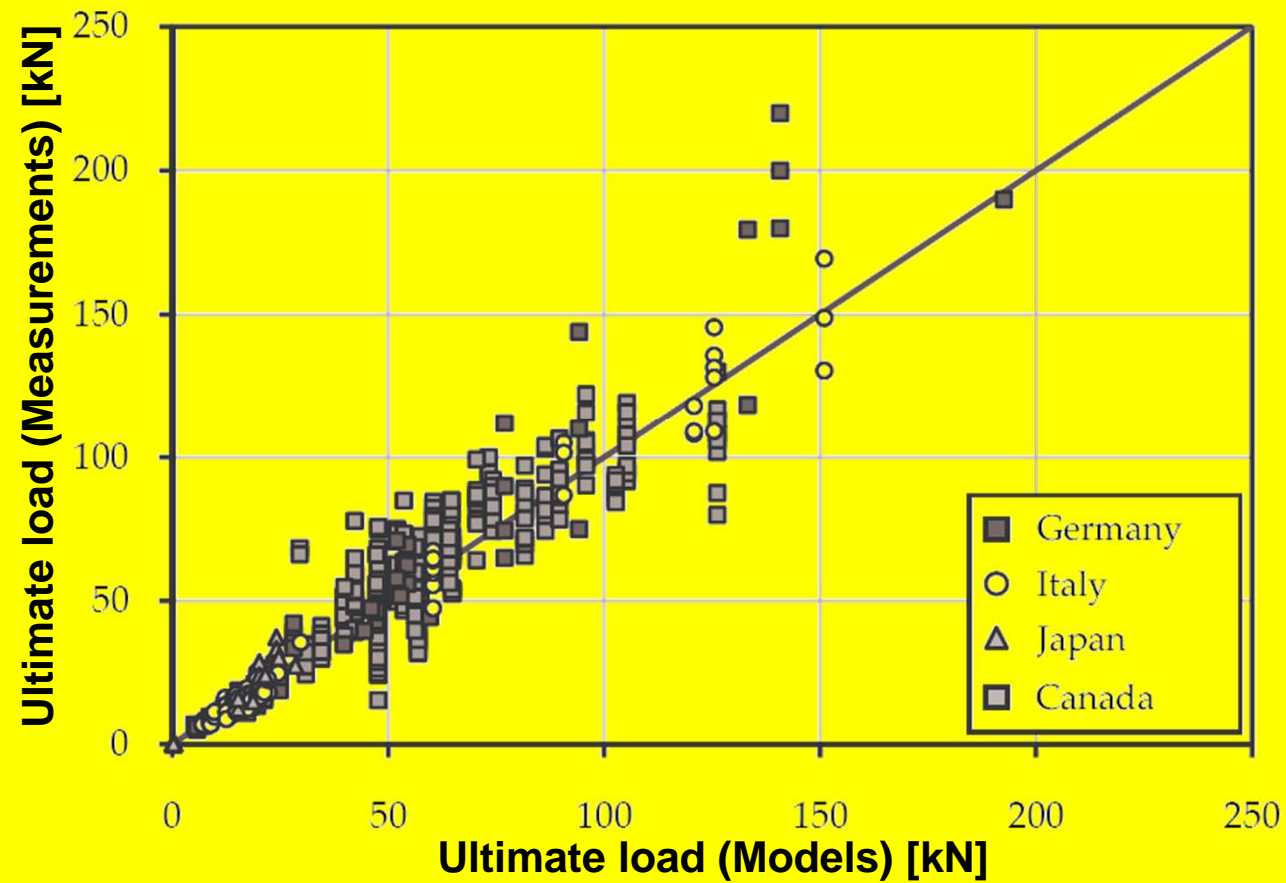# Governing fracture or failure mechanism

➢ Other examples:

Governing fracture or failure mechanism
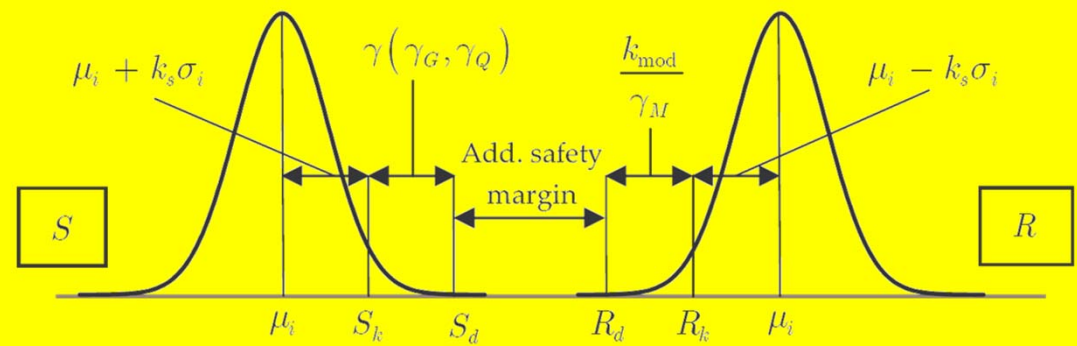
➢ Other examples (Single fastener connection):
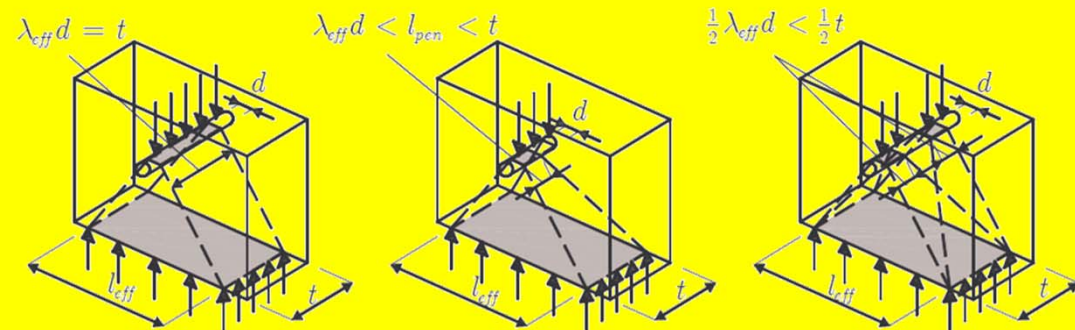
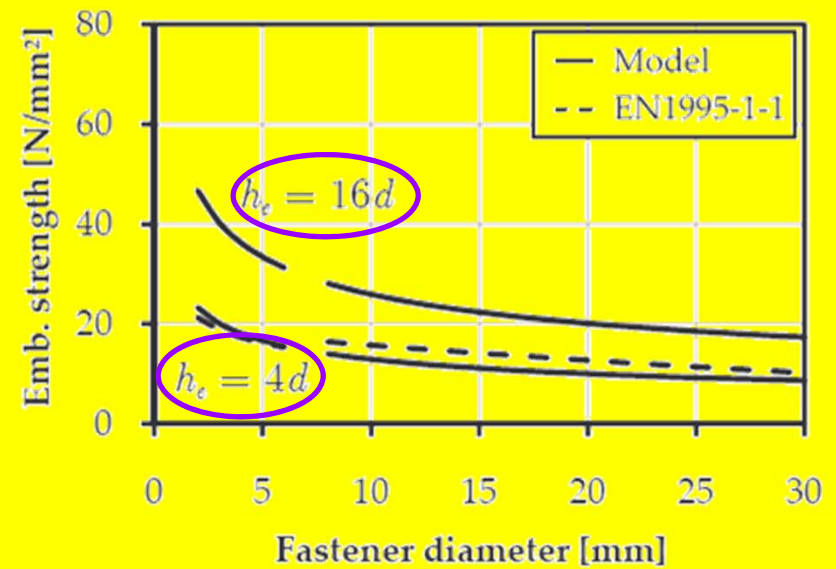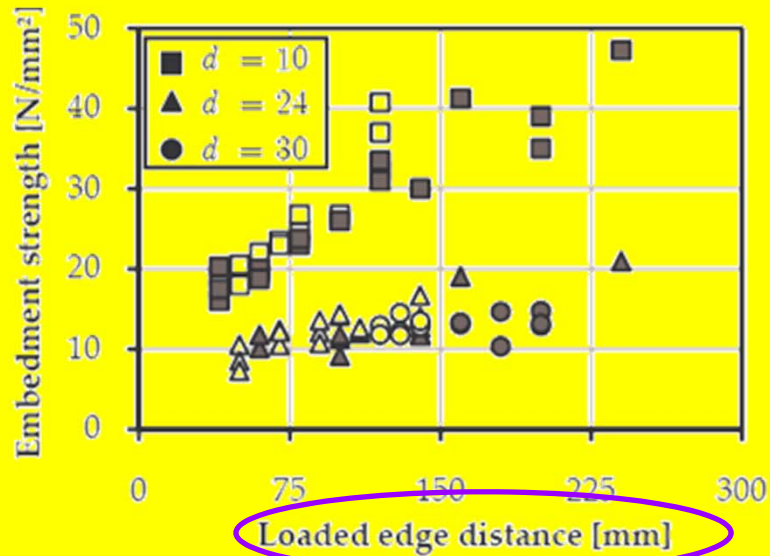# Governing fracture or failure mechanism
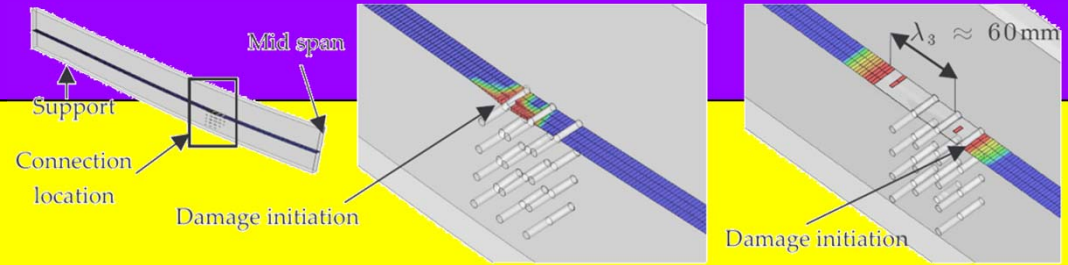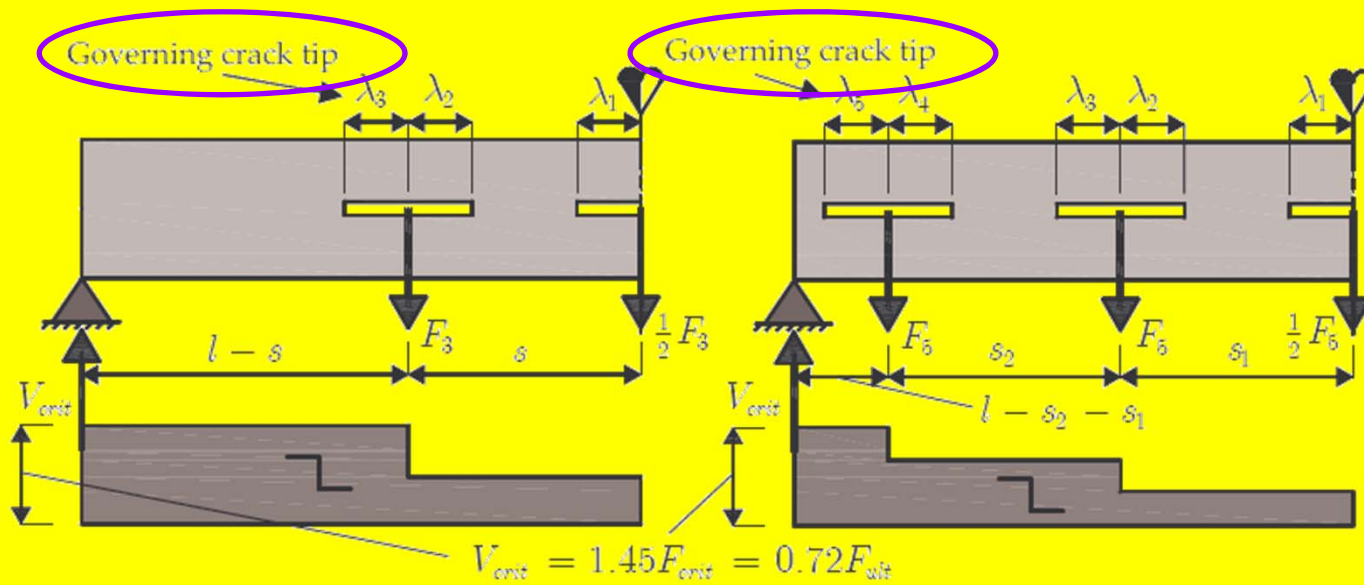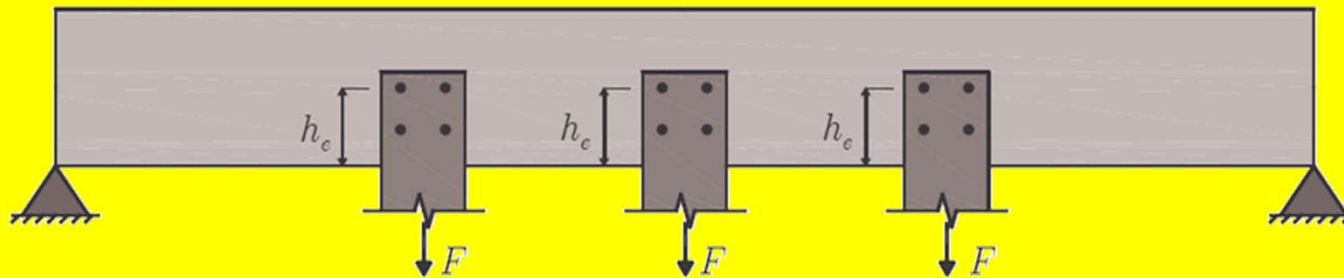
➢   Experiments from literature (more than 1000)

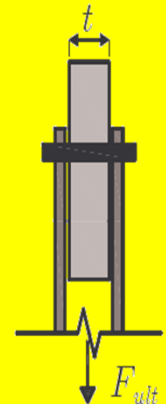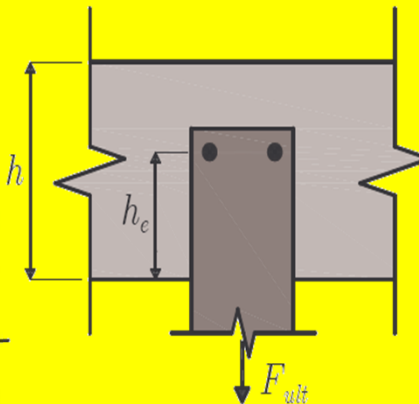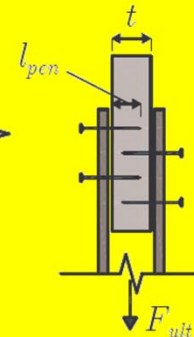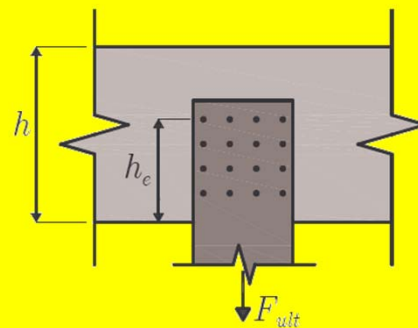# Design rules

Design rules

➤ Embedment strength per fastener

Design rules

➢ Splitting capacity of multiple connections

$$V_{crit} = 1.45 F_{crit} = 0.72 F_{ult}$$

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Design rules

➤ Practical examples
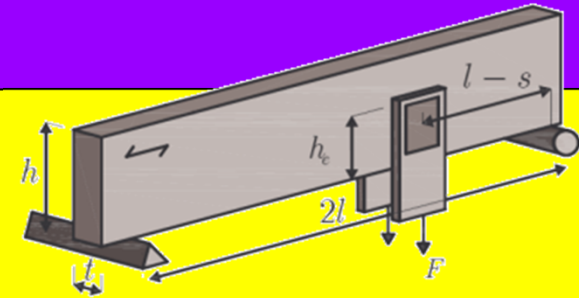
	Eurocode 5	Eurocode 5
Connection strength:	$F_{ult} = 20.0$ kN	$F_{ult} = 35.5$ kN
Splitting strength:	$F_{ult} = 14.1$ kN	$F_{ult} = 118.5$ kN

	This research		This research	
Connection strength:	$F_{ult} = 13.4$ kN	**67 %**	$F_{ult} = 40.5$ kN	**114 %**
Splitting strength:	$F_{ult} = 12.9$ kN	**91 %**	$F_{ult} = 118.5$ kN	**100 %**

Eurocode 5 unsafe (9 %)   **14 % increase**

Thank you for your attention

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