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TIMBER ENGINEERING - VSM196

LECTURE 10 –

JOINTS – OVERVIEW &
LATERALLY-LOADED CONNECTIONS

SPRING 2020

Topic

- Joints
- Overview
- laterally-loaded connections

- [DoTS: Chapter 4]

Content

- Overview of different joints
- Design ULS

- Design examples H1, H7

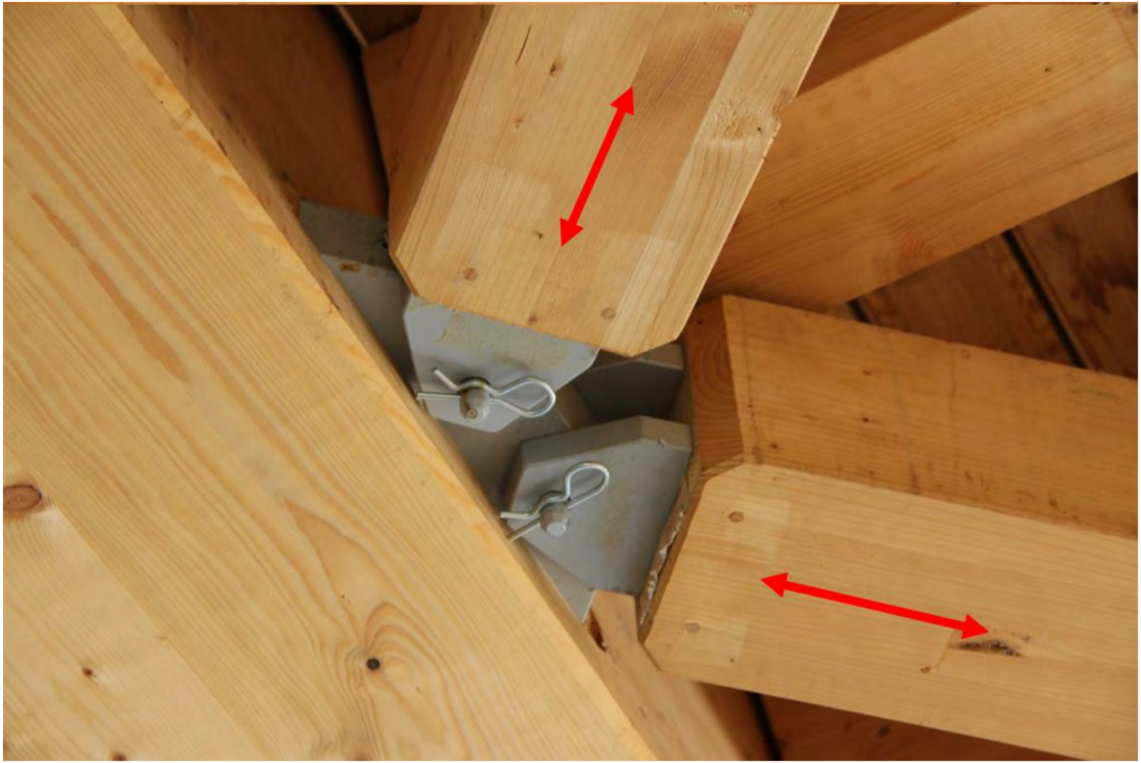
Intended Learning Outcomes of this lecture

- You understand different loading conditions of connections
- You can identify different demands on connections
- You can calculate the load-carrying capacity of dowel-type fasteners
- You can choose the adequate fasteners for connections in shear

Background

”...a structure is
an assembly of connections
separated by members.”
(McLain 1998)

Loading conditions on connections



Loading conditions on connections

- Axial forces

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Loading conditions on connections

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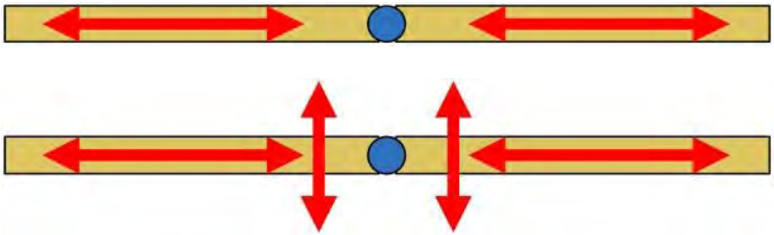
Loading conditions on connections

- Axial forces
- Shear forces



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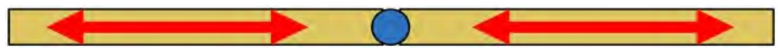
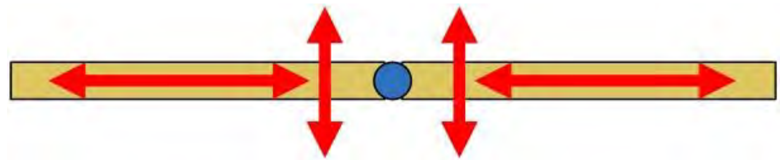
Loading conditions on connections

Loading conditions on connections

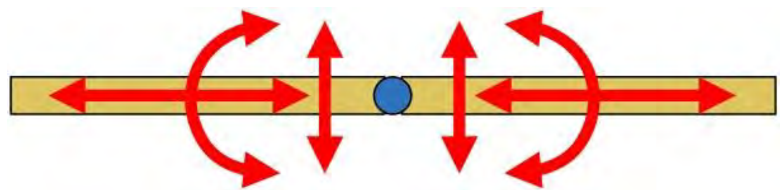
- Axial forces



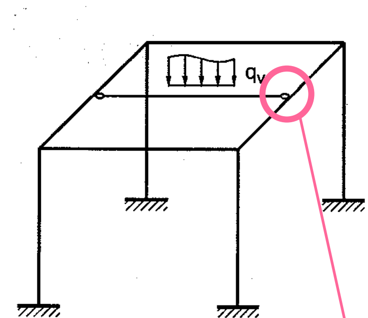
- Shear forces

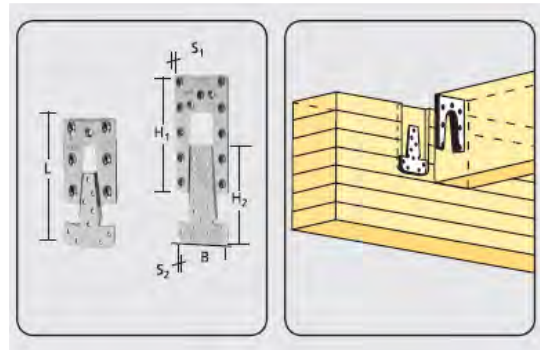


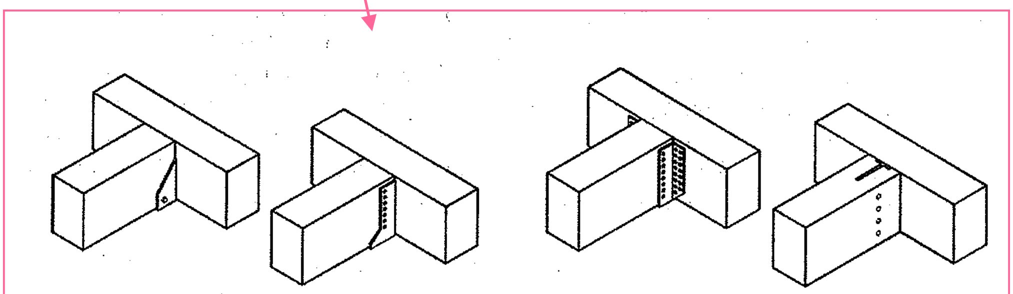
- Moments

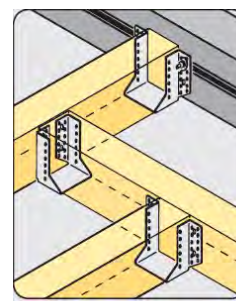


Hinged (pinned) connection between beams









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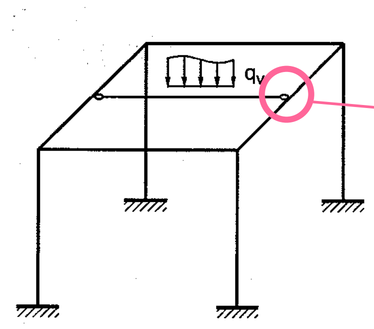
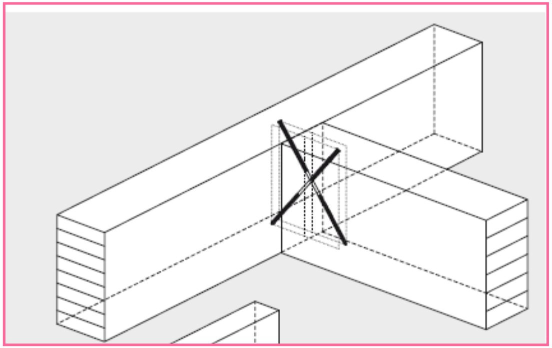
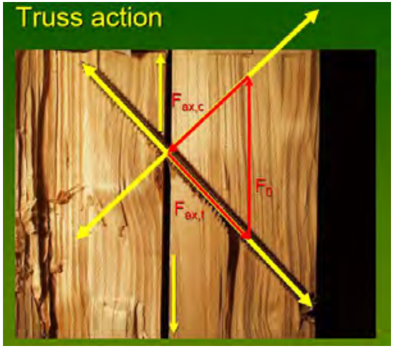
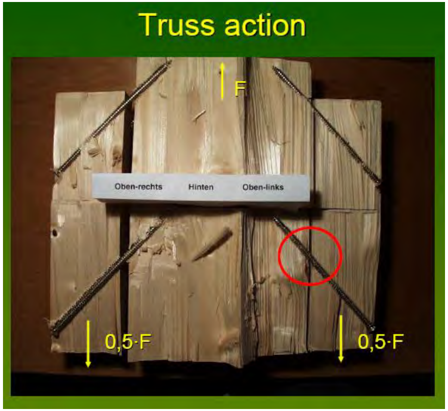
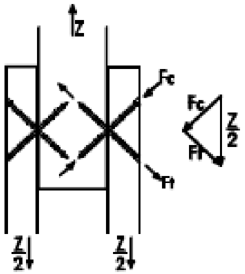
Hinged (pinned) connection between beams





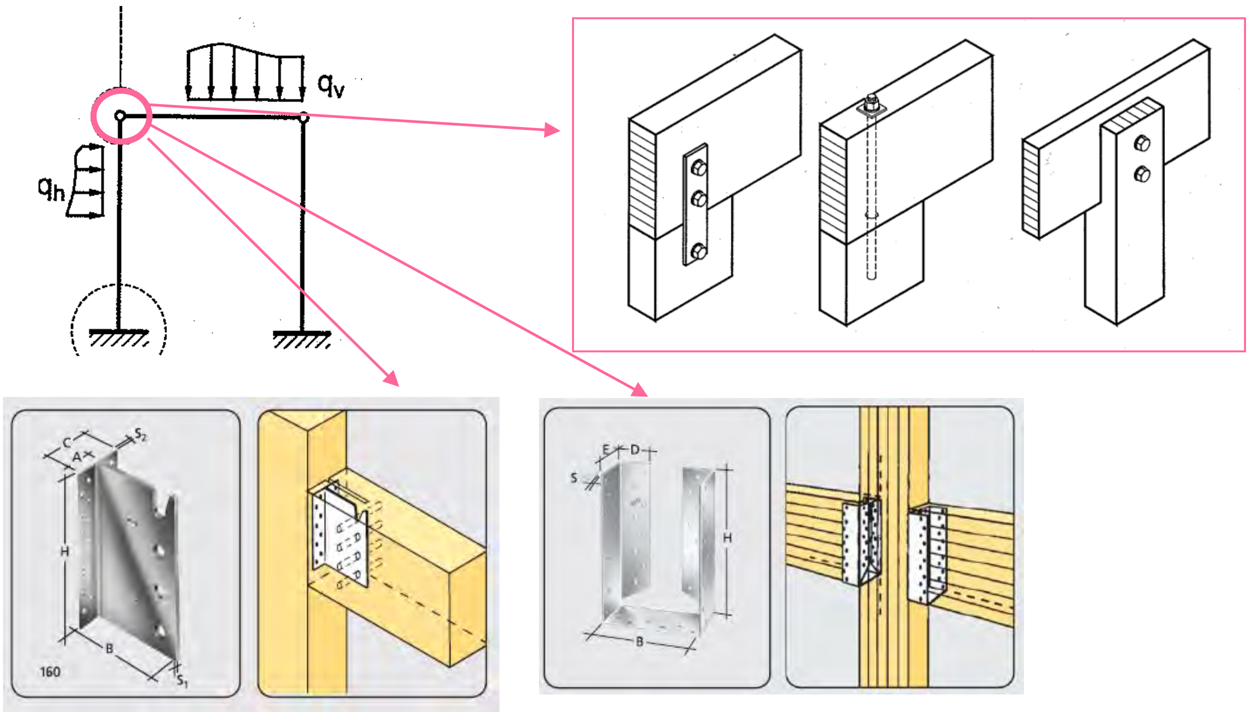




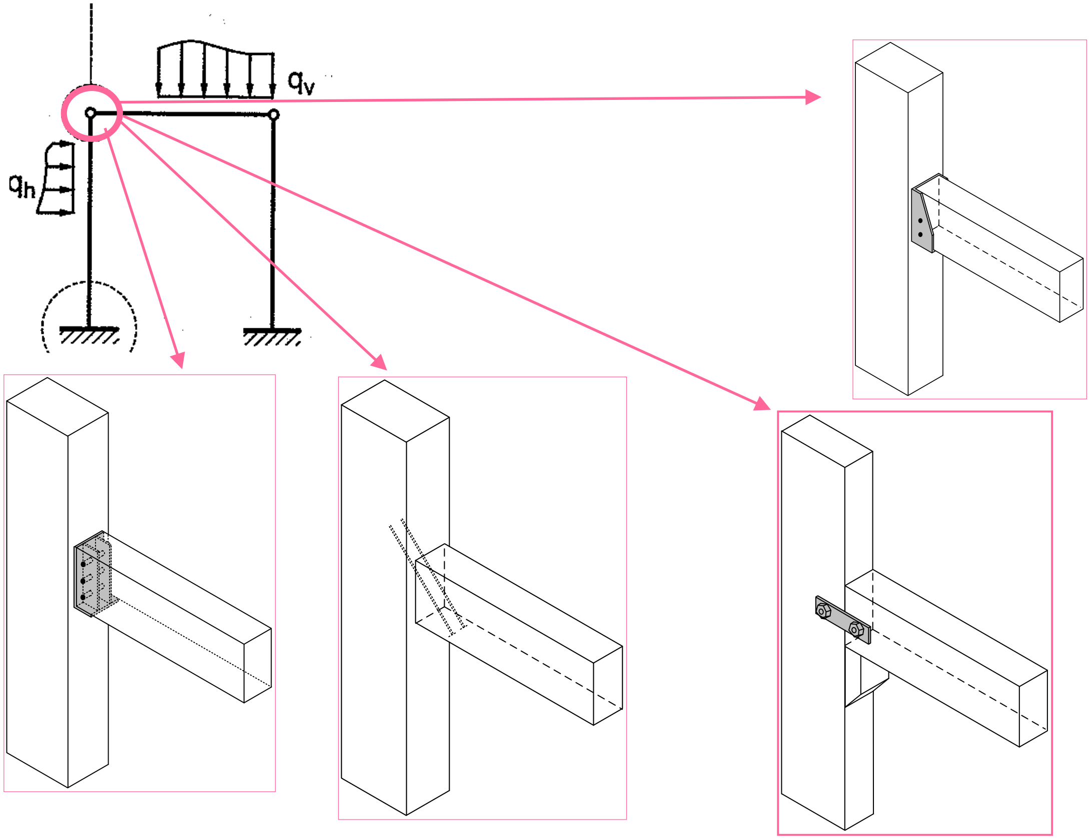


Source: H. J. Blaß

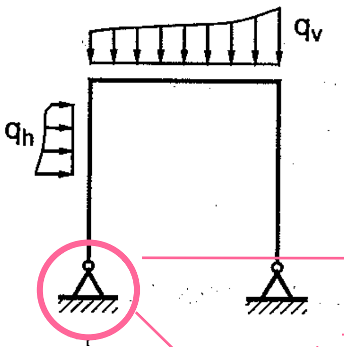
Hinged (pinned) connection between beams

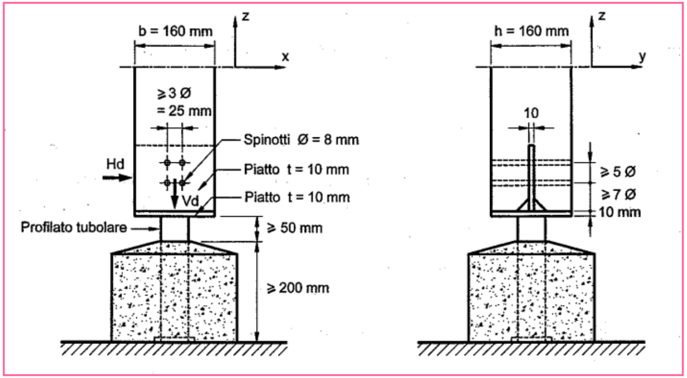


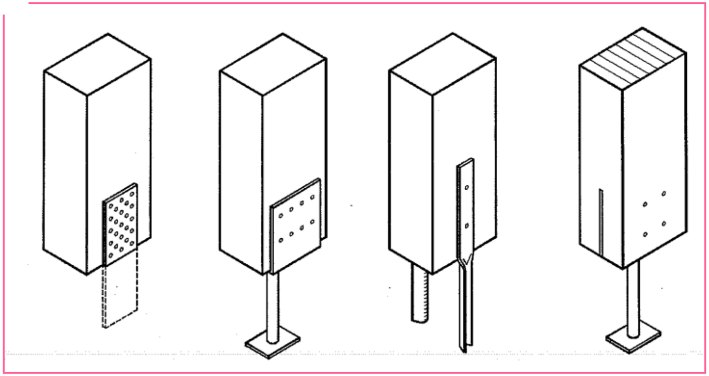
Hinged (pinned) connection between beams



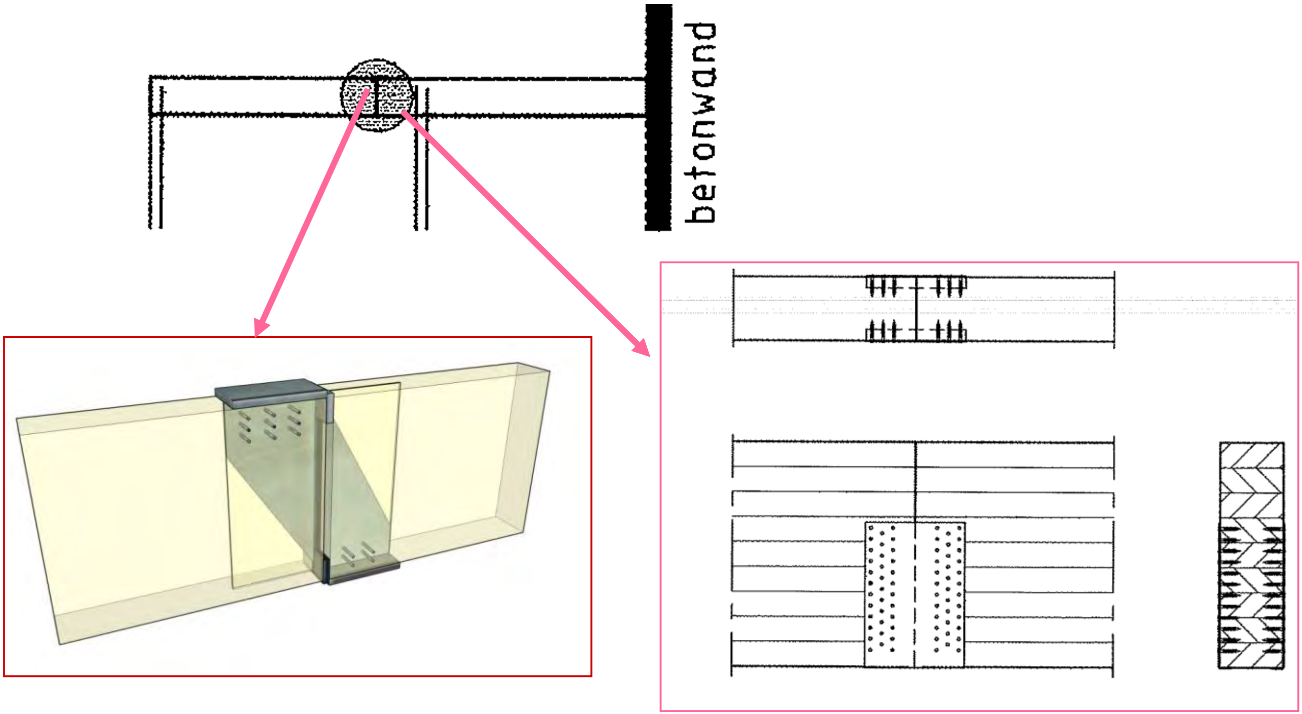
Hinged connection at the base of a column



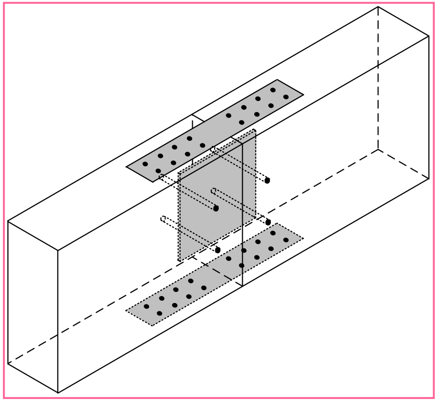


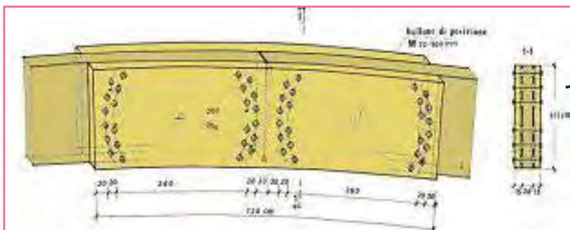


Gerber hinge

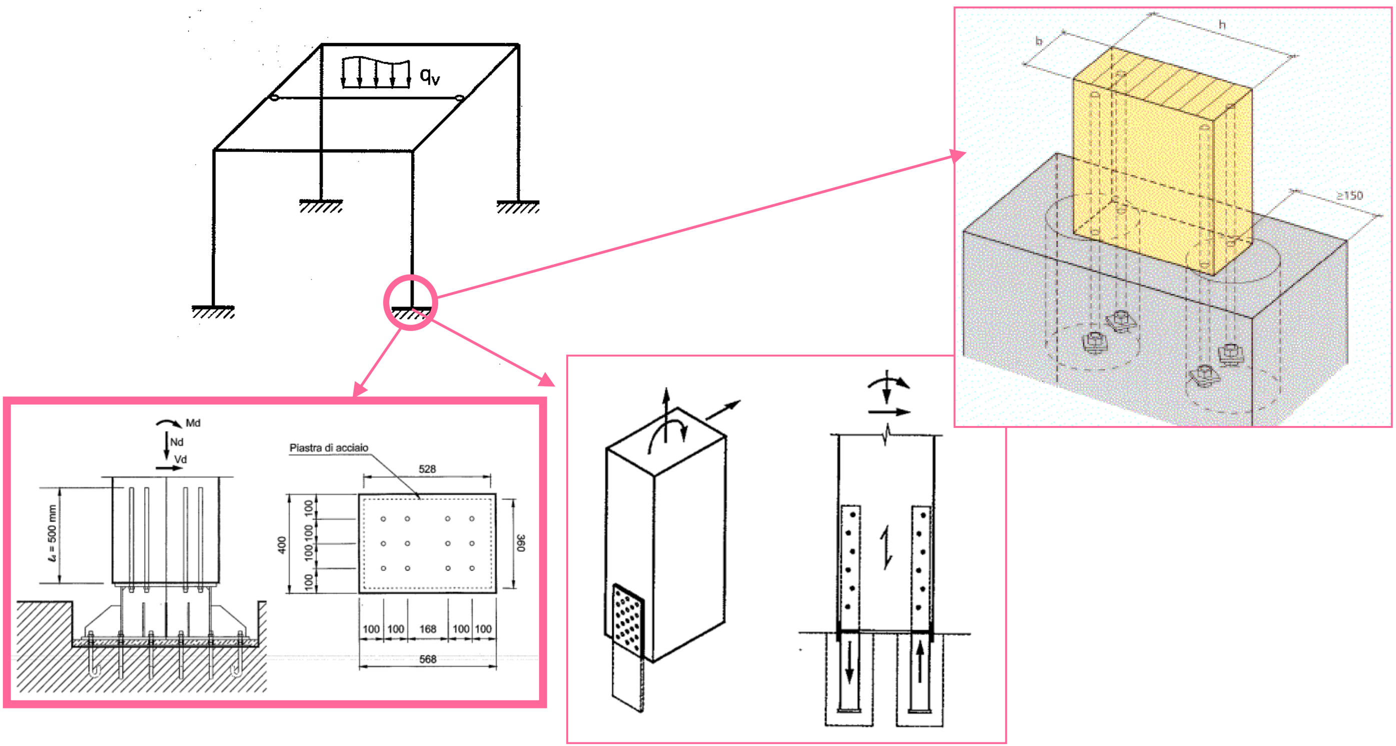


Moment resistant connection, beam-to-beam

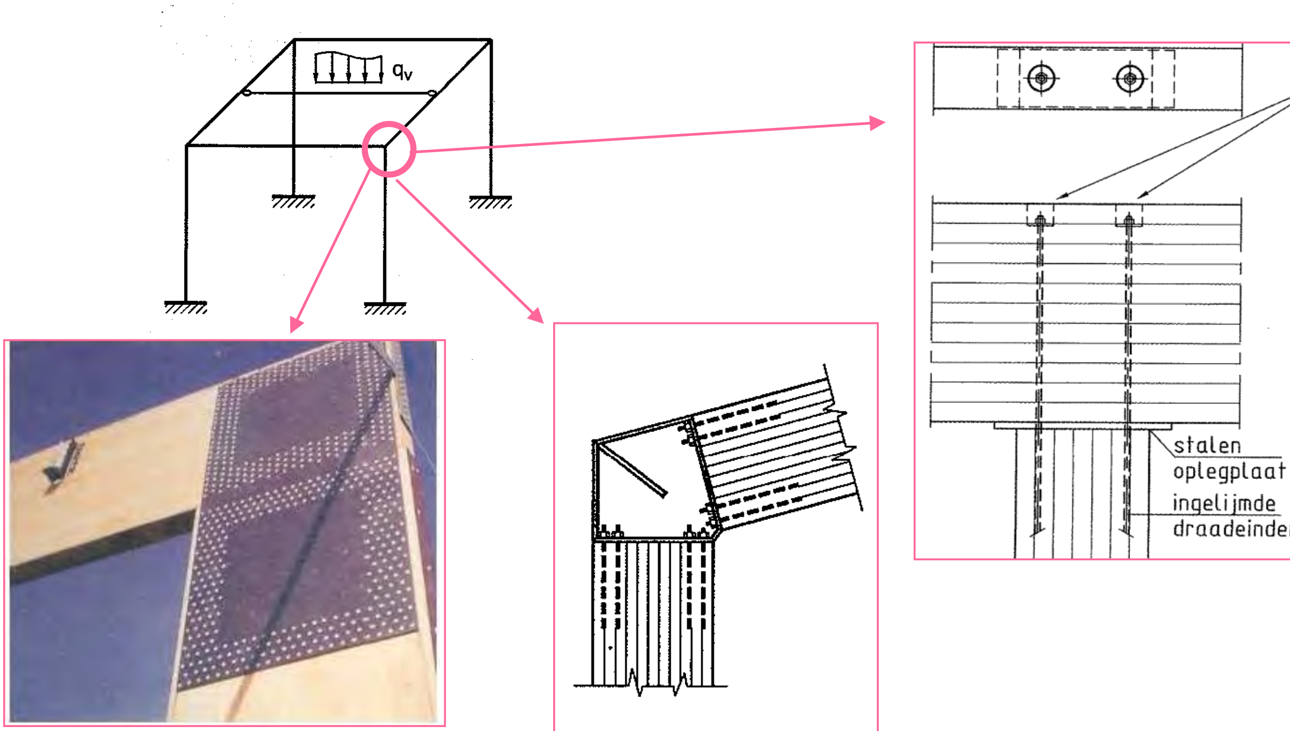




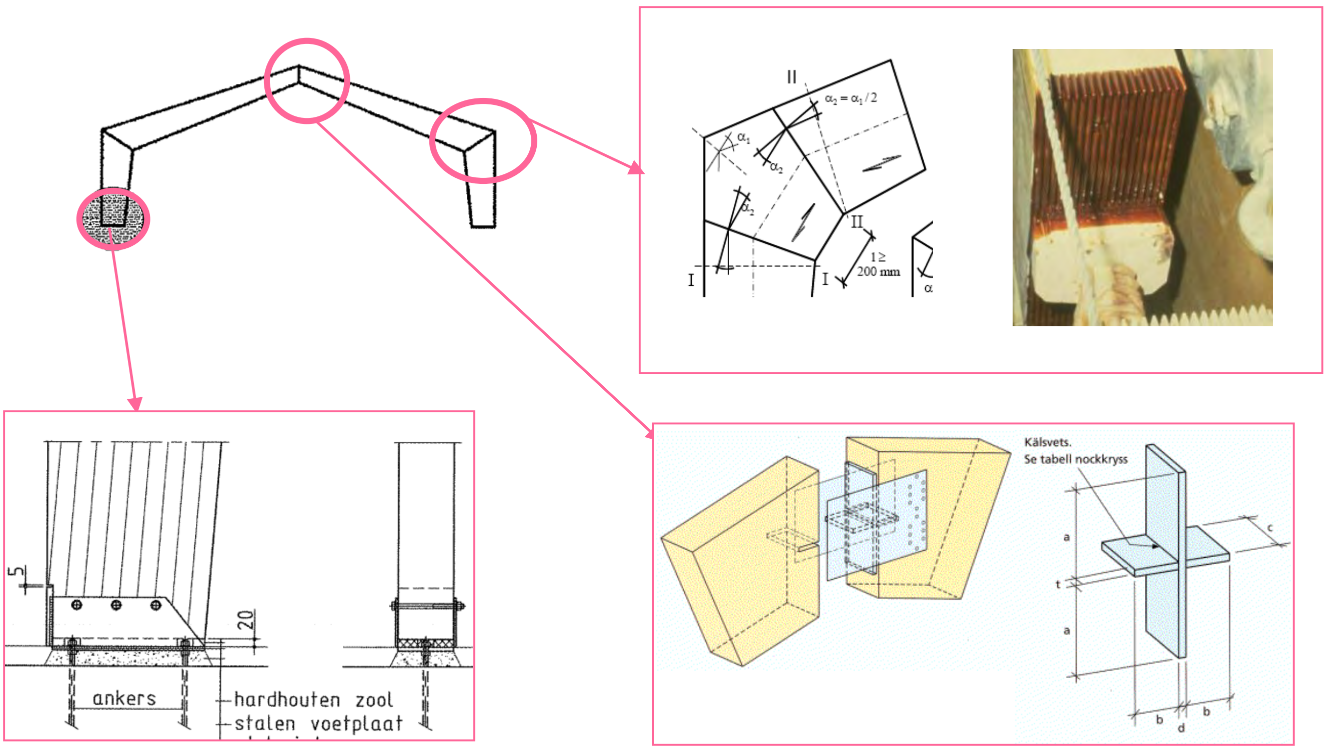
Moment resistant connection, at the base of a column



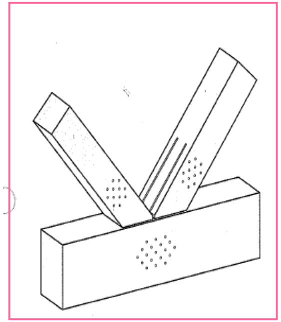
Moment resistant connection, beam-to-column

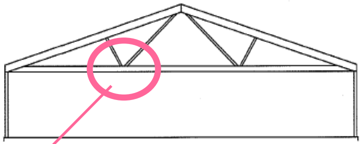


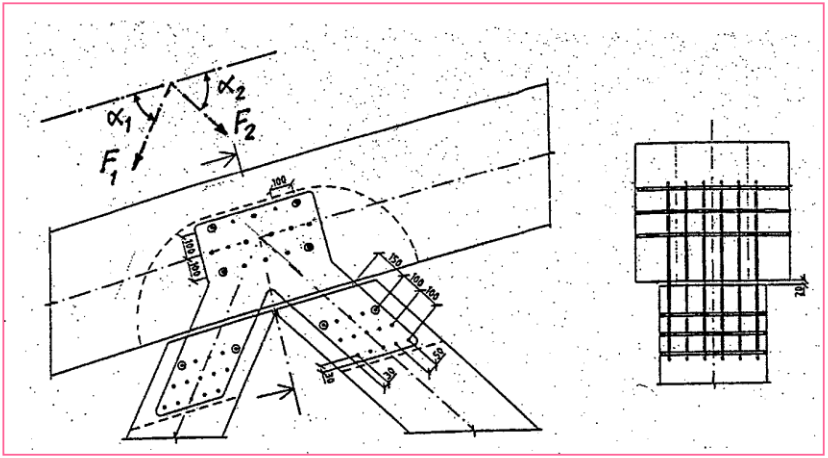
Connections in a three-hinge portal frame



Node in a truss

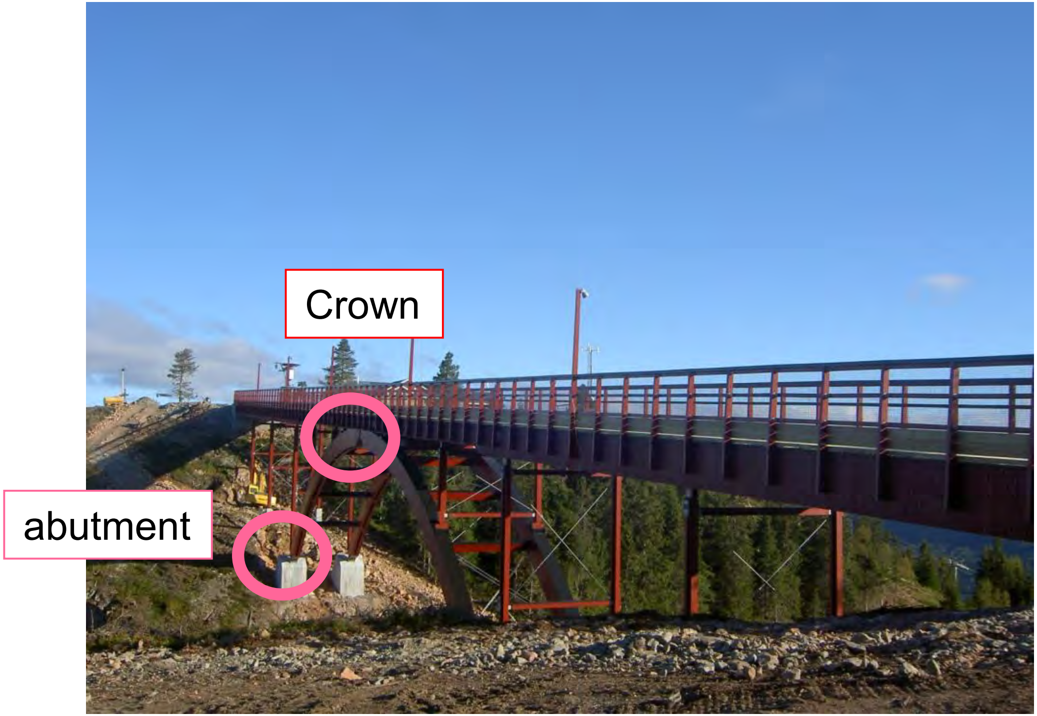






”Real hinges” (suitable for large structures)

- Bridge at Branäs, total length 130 m



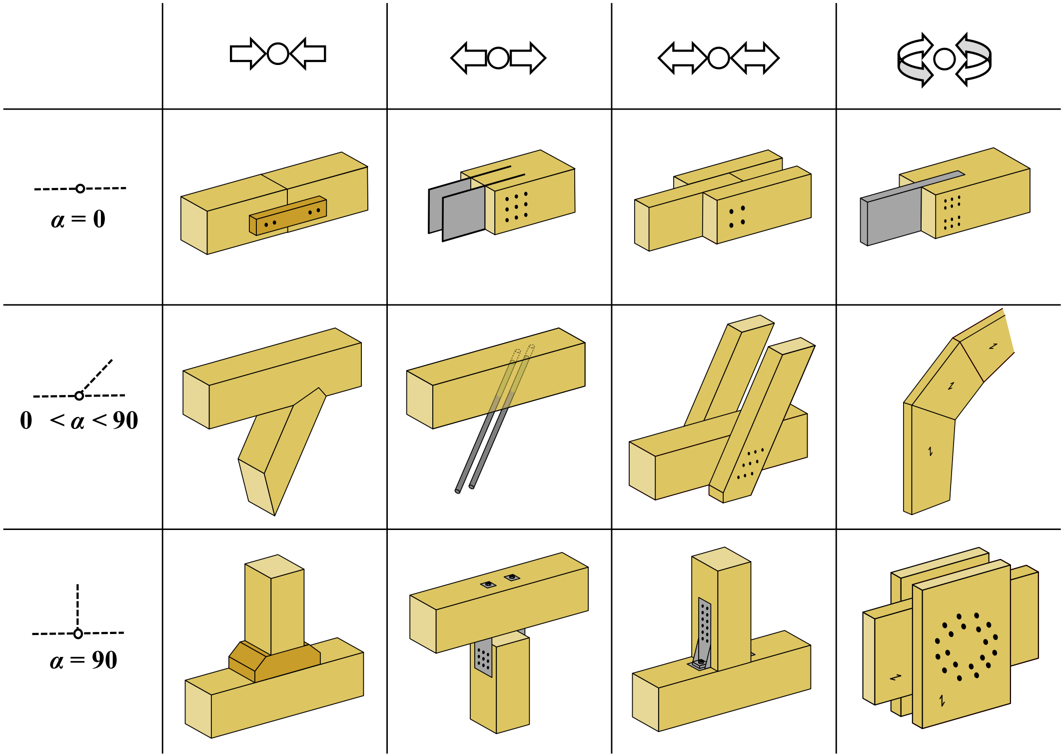
”Real hinges” (suitable for large structures)

- Bridge at Branäs, total length 130 m

Abutment

Crown

Loading conditions on connections



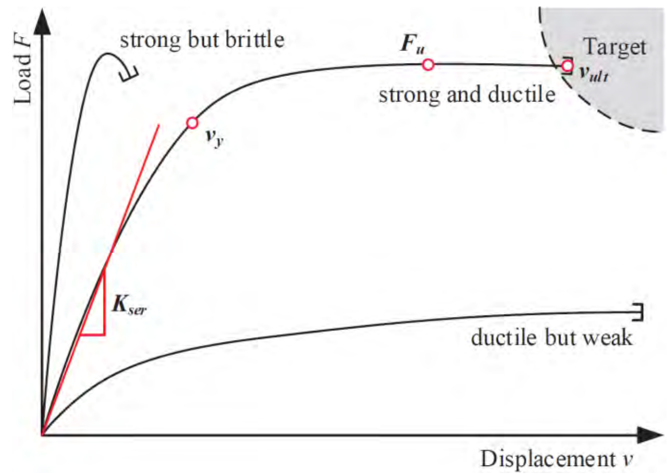
Requirements on connections

Basic requirements

- high load-carrying capacity
- high stiffness
- sufficient ductility
  and robustness

Additional requirements

- Durability and controlled quality
- Fire resistance
- Ease of manufacturing
- Simplicity of design
- Costs
- etc.



Source: adapted Haller, P. (1998)

Joints in general

Some remarks:

- Joints are the weak links in the structure, expensive to make and time consuming

- The simpler the joint and fewer the number of joints, the better is the structural behavior

- Keep it simple!!

Overview



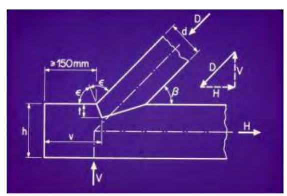












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Type of joints

Timber connections

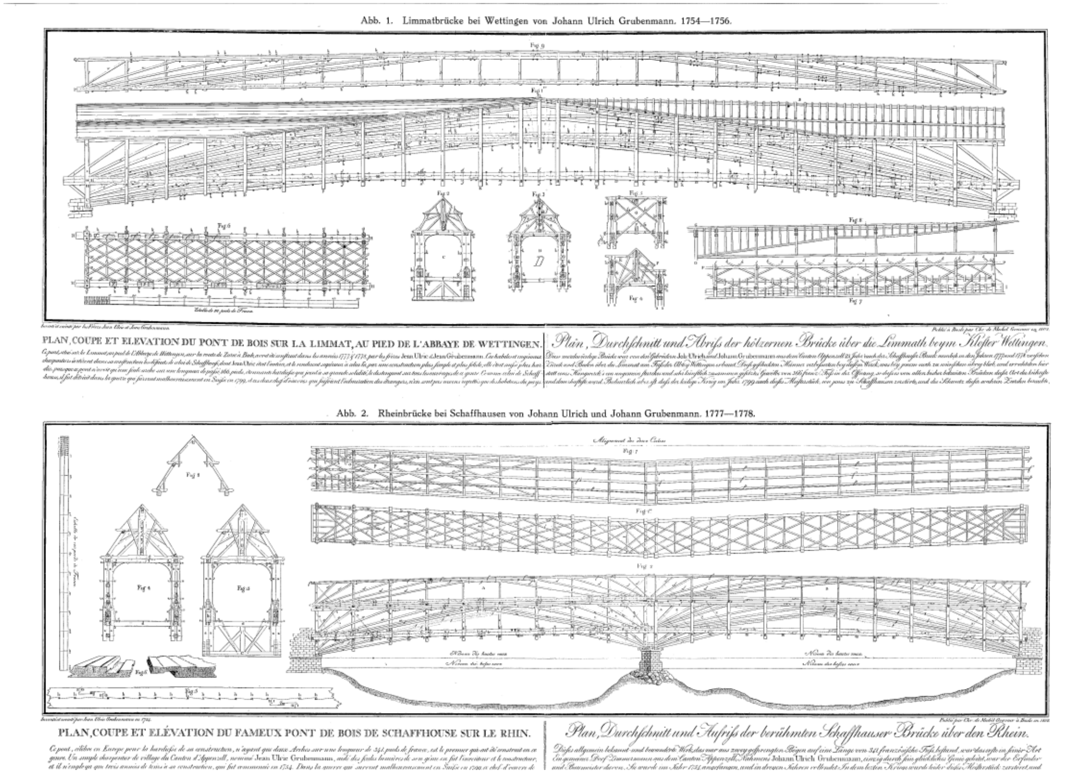
- Traditional or carpentry joints
- Modern timber connections

Connections with fasteners

- Dowel-type fasteners
- Ring, toothed plate and shear connection
- Punched metal plate

Glued connections

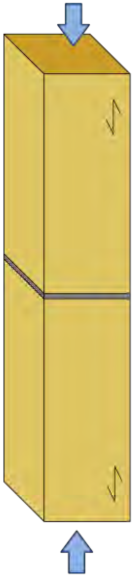
- Glued joint
- Glued-in rods



Carpentry connections

Compression joints

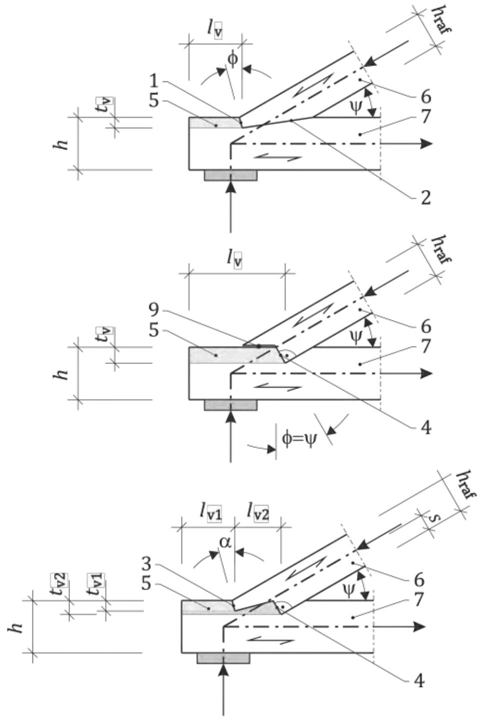
- Compression joints:
  - Butt joints (0°)
    ⇒ use Hardwood or metal interlayer!
  - Perpendicular to grain joints (90°)
    ⇒ use sufficient support area!
  - Step & carpentry joints (inclined)



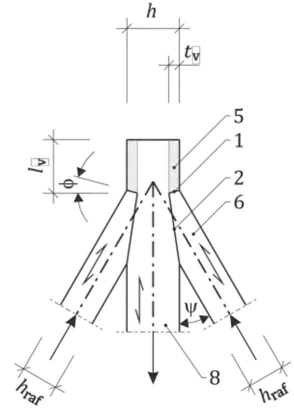
Carpentry connections

Layouts

- Single step joints



- Double step joints

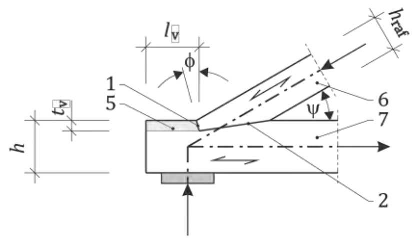


1 – Front surface
2 – Back surface
3 – Front surface, front notch
4 – Front surface, rear notch
5 – Toe
6 – Rafter
7 - Tie-beam
8 - King post
9 - Free gap
10 – Wedge cut-off (optional)

Carpentry connections

Geometry

- Single step joints



- The front surface angle ϕ should

$$\frac{\psi}{2} \leq \phi \leq \psi$$

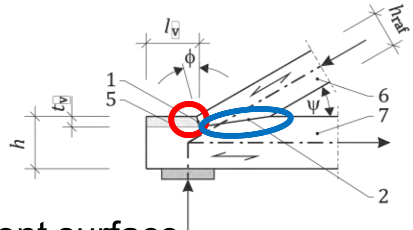
- end grain distance l_v ≥ 150mm
- Notch depth t_v

$$t_v \leq \begin{cases} h/4 & if \quad \psi < 50° \\ h/6 & if \quad \psi > 60° \end{cases}$$

Carpentry connections

Design

- Single step joints



1 – Front surface
2 – Back surface
5 – Toe
6 – Rafter
7 - Tie-beam

- Normal stress at the front surface

$$\sigma_{c,\alpha,d} \leq f_{c,\alpha,d}$$

$$\frac{N_{raf,Ed}\cos(\psi-\phi)cos\phi}{bt_v} \leq \frac{f_{c,0,d}}{\frac{f_{c,0,d}}{k_{c,90}f_{c,90,d}}\sin^2\phi+\cos^2\phi}$$

- Compression stress at the back surface

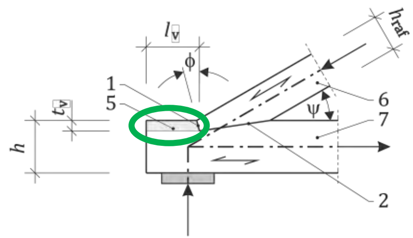
$$\sigma_{c,90,d} \leq k_{c,90}f_{c,90,d}$$

$$\frac{N_{raf,Ed}\,sin\psi}{b\left(\frac{h_{raf}}{sin\psi}-\frac{t_v}{tan\phi}\right)} \leq k_{c,90}f_{c,90,d}$$

Carpentry connections

Design

- Single step joints



1 – Front surface
2 – Back surface
5 – Toe
6 – Rafter
7 - Tie-beam

- Shear resistance parallel to grain

$$\sigma_{v,d} \leq f_{v,d}$$

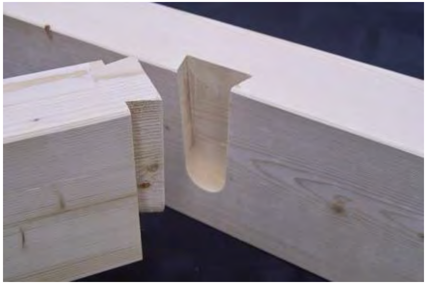
$$\frac{N_{raf,Ed}\cos\psi}{k_{red}bl_{v,ef}} \leq f_{v,d}$$

with $k_{red} = \begin{cases} 0{,}6 & \text{for sawn timber} \\ 0{,}8 & \text{for glulam} \end{cases}$

$$l_{v,ef} = l_v \leq 8t_v$$

Compression joints

- Compression joints:
  - Butt joints (0°)
    ⇒ use Hardwood or metal interlayer!
  - Perpendicular to grain joints (90°)
    ⇒ use sufficient support area!
  - Step & carpentry joints (inclined)
- Tension joints
  - Dovetail joints
  - Special joints



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Examples: Vasa Ship - 1628

Modern carpentry joints

- Tamedia Building, Zurich, Switzerland

Quelle: Blick.ch

Connections with metal fasteners

Dowel-type fasteners

- Nails
- Screws
- Dowels
- Bolts
- Nail plates

Dowel-type fasteners

- Nails
  - Brad (dyckert)
  - round nail
  - grooved wire nail (räfflad trådspik)
  - annular ring shanked nail (kamspik)
  - anchor nail (ankarspik)

Dowel-type fasteners

- Nails
    - Grooved wire nail
    - 2” 50mm
    - 3” 75 mm
    - 4” 100 mm
    - 5” 125 mm
    - 6” 150 mm

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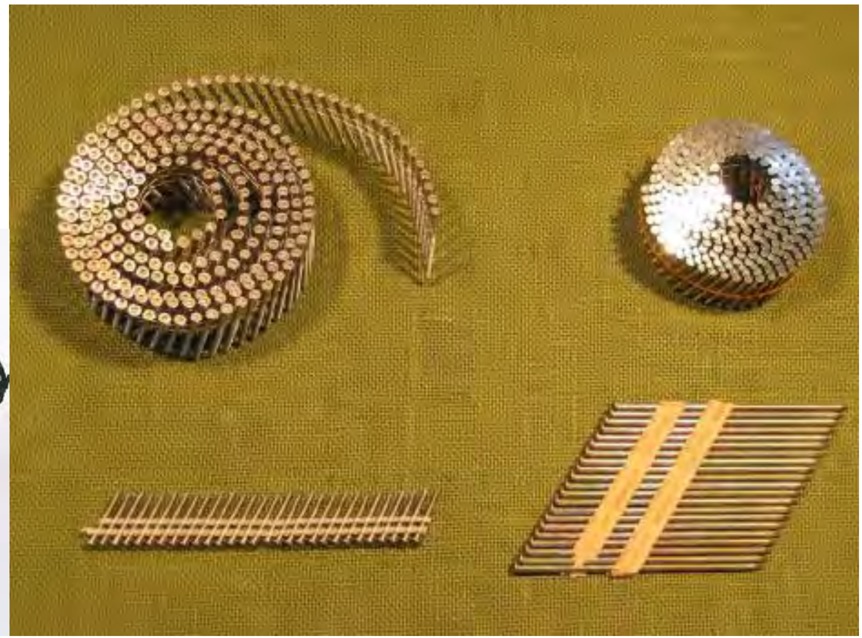
Marking of nails

- Grooved wire nail Length 150 mm
- Diameter 5,1 mm

Dowel-type fasteners

- Nails are often inserted by means of pneumatic nail-guns

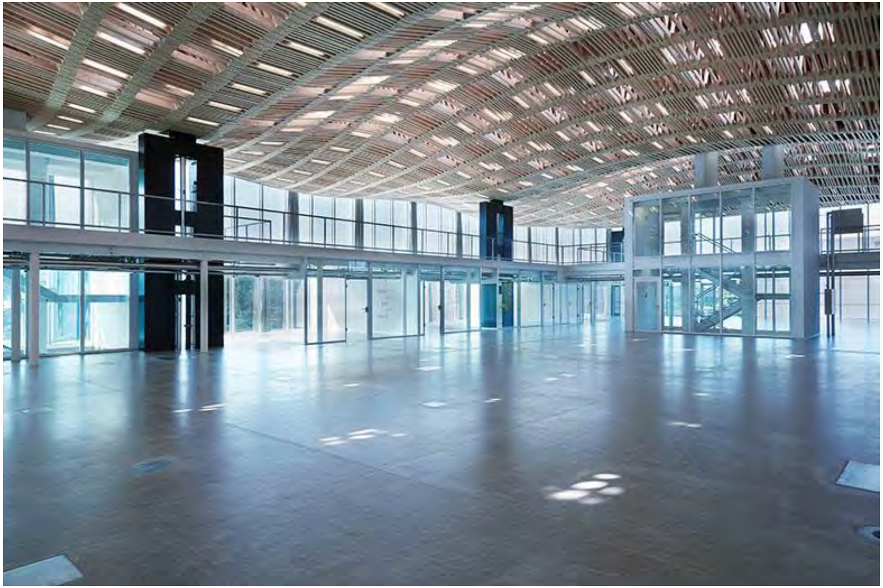


Dowel-type fasteners

- Nails
  - Examples of structures

Dowel-type fasteners

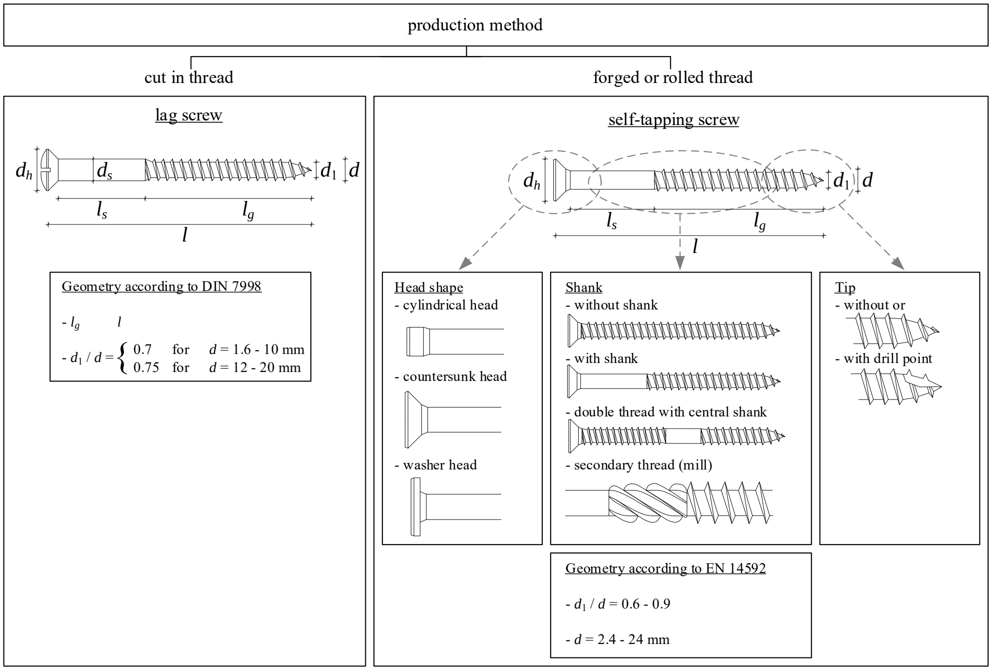
- Nails
    - Examples of structures



Source: Andrea Diglas / ITA/Arch-Tec-Lab AG

Dowel-type fasteners

- Screws



more about screws in lecture 11

Dowel-type fasteners

- Dowel

Source: H. J. Blaß

Dowel-type fasteners

- Dowels (sw. dymlingar)
  - Inserted in pre-drilled holes

Dowel-type fasteners

- Special dowels
- (d = 5-7mm, can perforate up to 3 plates, t =5mm)

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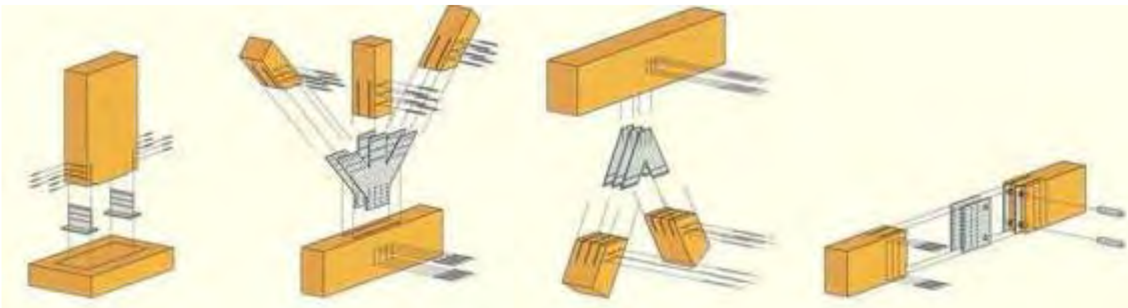
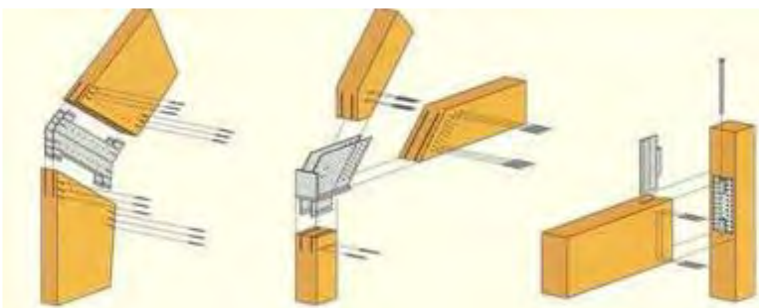
Some applications of self-drilling dowels





Dowel-type fasteners

- Bolt

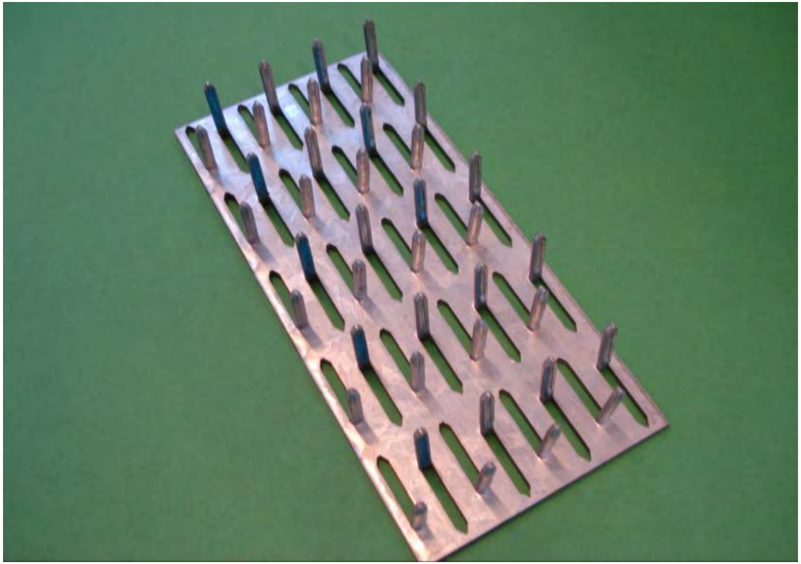
Source: H. J. Blaß

Dowel-type fasteners

- Threaded rod

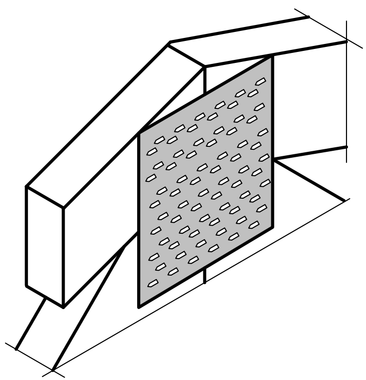
Source: H. J. Blaß

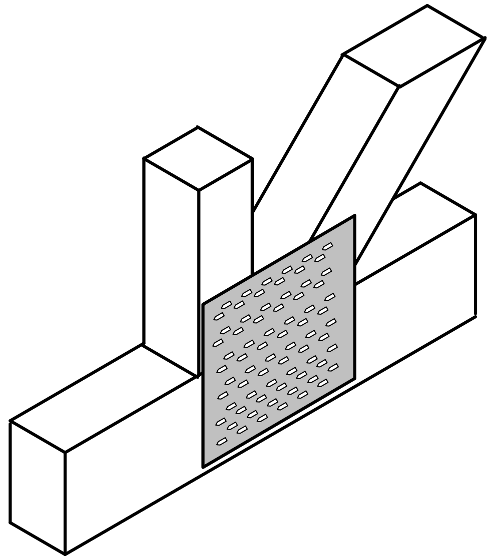
Nail plate



Nail plate

- Transfer load in shear at the surface of two members





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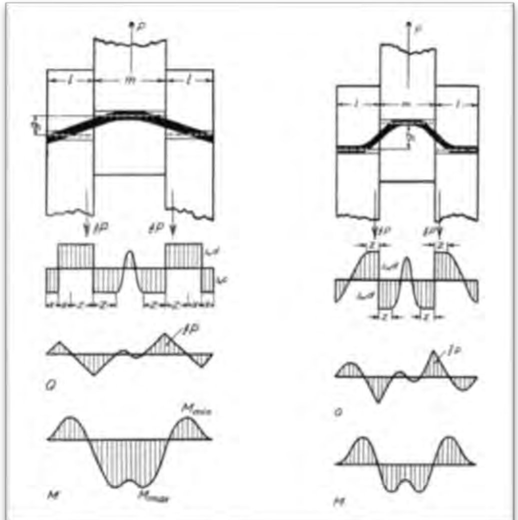
Assembly of nail plates

Roof trusses

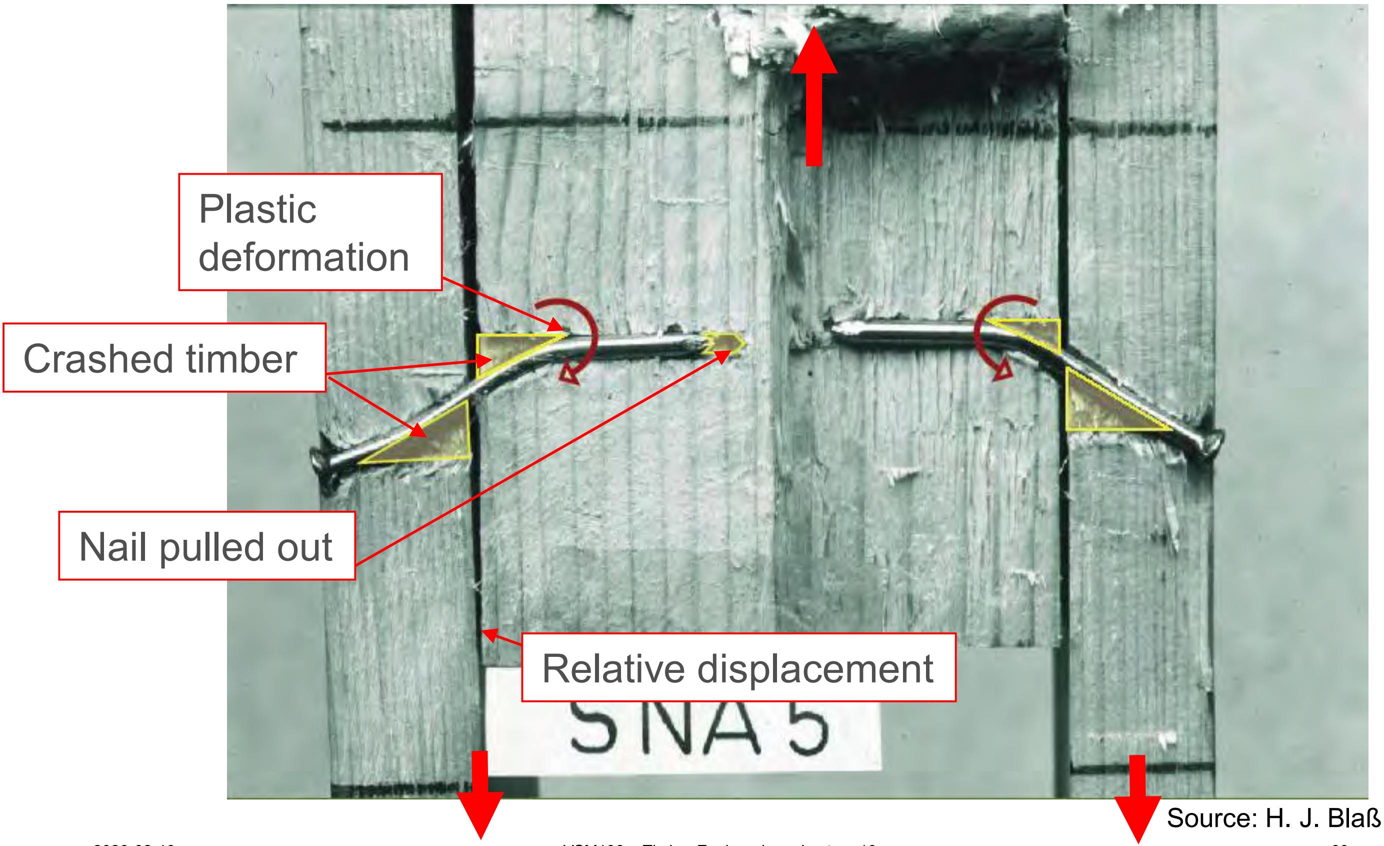
Source: Derome.se

Floor trusses



Load-carrying capacity of dowel-type fasteners

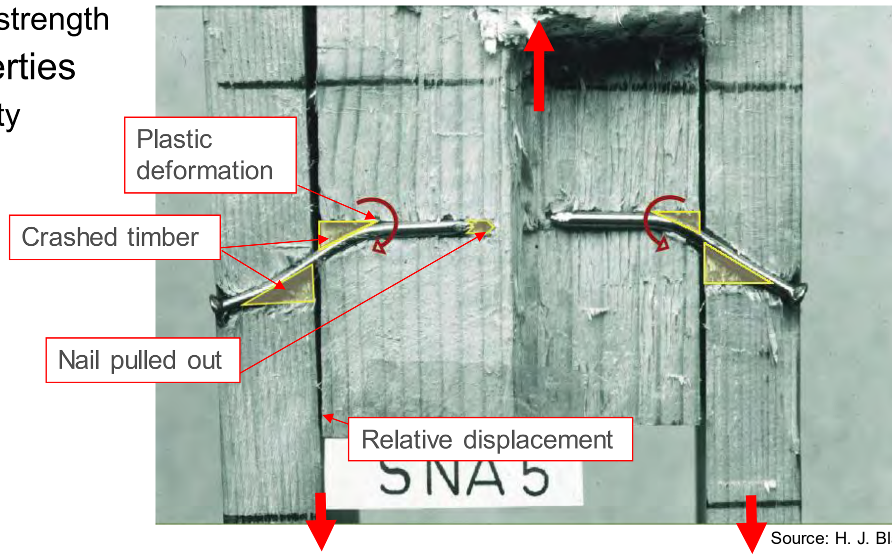
Some preliminary observations



Source: H. J. Blaß

Load-carrying capacity

- To calculate the load-carrying capacity of connections with dowel-type fasteners one needs:
    - Joint geometry
    - Material properties
        - Fastener yield moment
        - Embedding strength
    - Fastener properties
        - Axial capacity



Source: H. J. Blaß

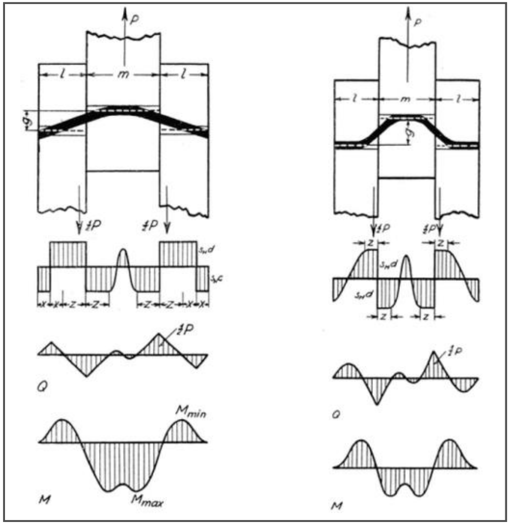
Parameters influencing the load-carrying behavior

- The bending capacity of the dowel (mainly depends on d and f_y)
- Embedding capacity of the timber (primarily depends upon ρ)
- The withdrawal capacity of the fastener
  (threaded connectors or connectors with washer and screw head/nut provide higher capacity than smooth fasteners)

Theory for dowel-type fasteners

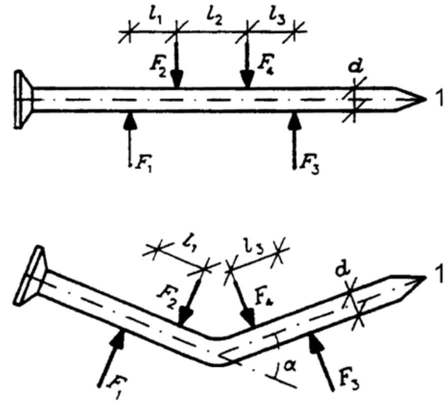
Johansen's yield theory

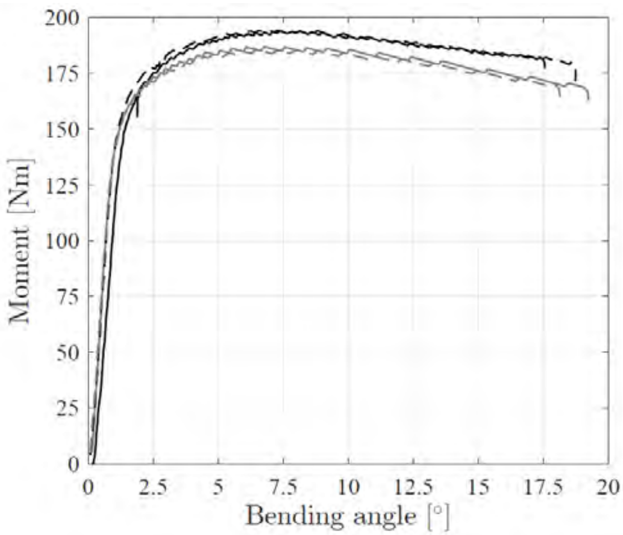
- Assumptions
  - Rigid-plastic behavior of the fastener in bending
  - Rigid-plastic behavior of the timber in embedding

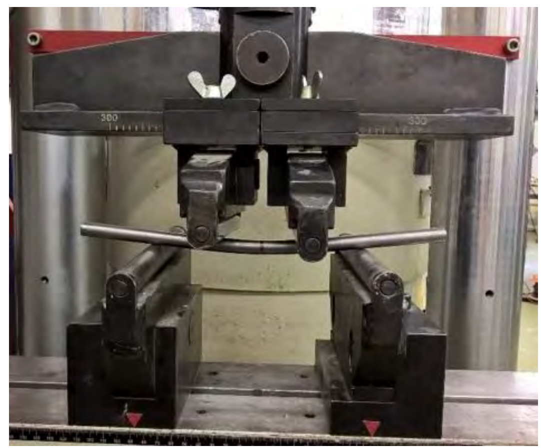


Source: Johansen 1949

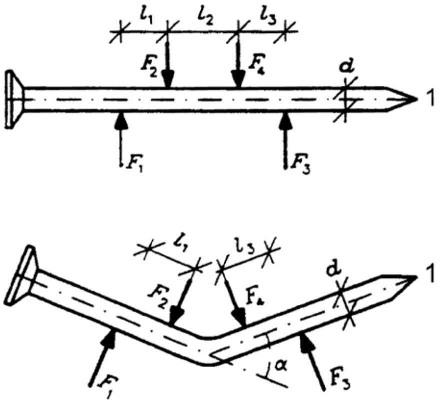
Behaviour of the fastener

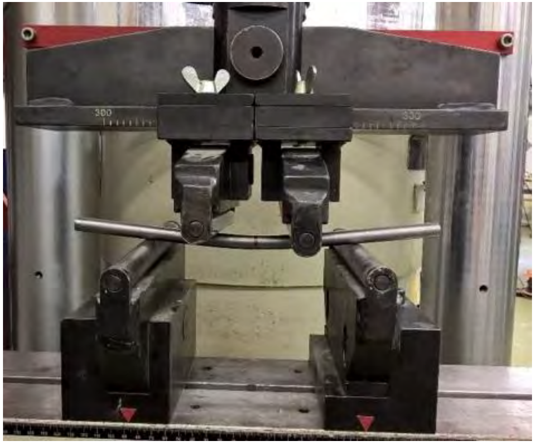




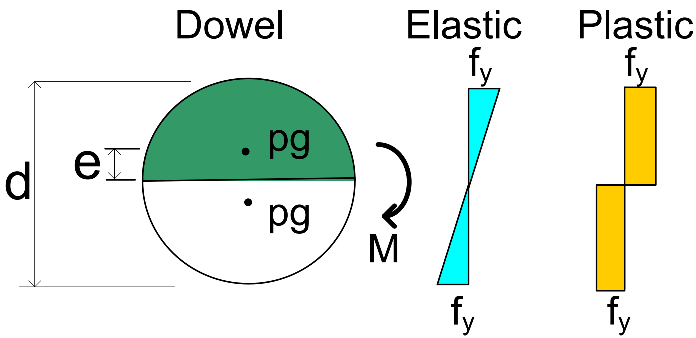


Behaviour of the fastener (Johansen)





Bending capacity



- For a half circle:

$$e = \frac{2 \cdot d}{3 \cdot \pi} \qquad A = \frac{\pi \cdot d^2}{8}$$

- Two limit cases for the yield moment

$$M_{el} = f_y \cdot W = f_y \cdot \frac{\pi \cdot d^3}{32}$$

$$M_{pl} = f_y \cdot Z = f_y \cdot (A \cdot 2 \cdot e) = f_y \cdot \left(\cdot \frac{\pi \cdot d^2}{8} 2 \cdot \frac{2 \cdot d}{3 \cdot \pi} \right) = f_y \cdot \frac{d^3}{6}$$

Plastic bending capacity

A full yielding of the cross section requires:

- Large strains → large bending angle (up to 45°)
- However, in general, when the connection fails, the bending angle is considerably less than 45°. Therefore, the following formula applies:

$$M_{pl} = 0{,}3 \cdot f_u \cdot d^{2{,}6} \text{ (Nmm)}$$

$M_{y,Rk}$	[Nmm]
d	[mm]
f_u	[N/mm^2]

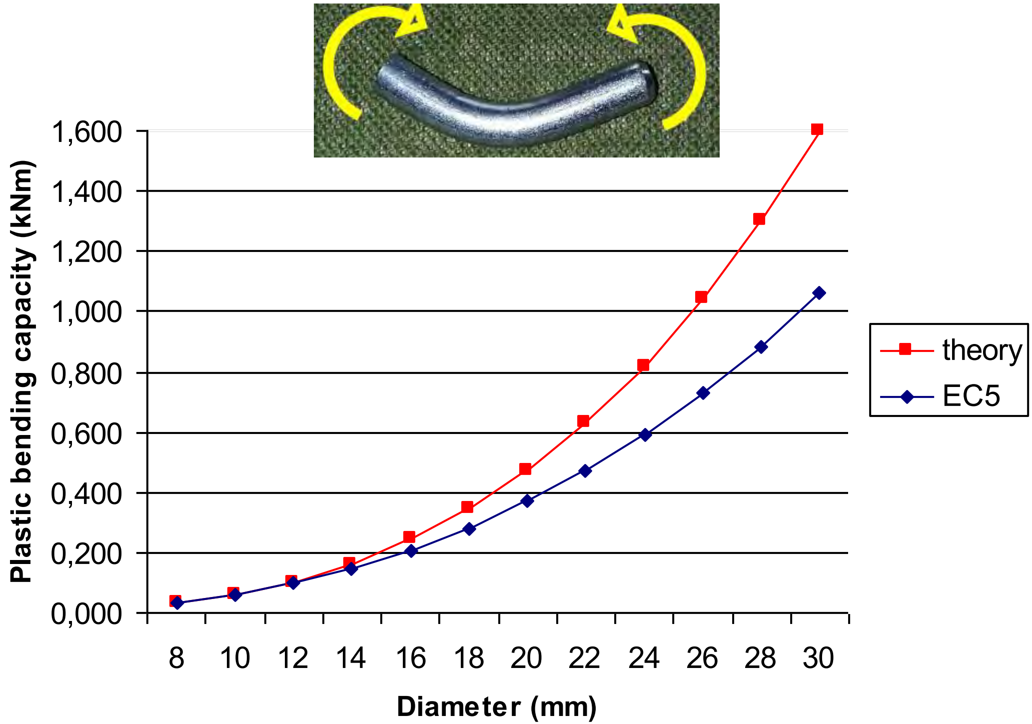
- Definition in Eurocode 5
  - Smooth nails from wire with f_u >600 N/mm²

$$M_{y,Rk} = \begin{cases} 0{,}3 f_u d^{2{,}6} & \text{for round nails} \\ 0{,}45 f_u d^{2{,}6} & \text{for square nails} \end{cases}$$

EC5, Eq. 8.14

  - Dowels, bolts $M_{y,Rk} = 0{,}3 f_{u,k} d^{2{,}6}$ EC5, Eq. 8.30
  - Staples $M_{y,Rk} = 240 d^{2{,}6}$ EC5, Eq. 8.29

Plastic bending capacity



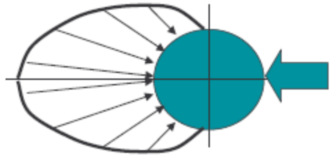
- Assumption: f_y = 355 N/mm^2, f_u = 510 N/mm^2

Brittle failure must be avoided!

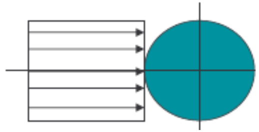
- High strength steels (e.g. 8.8 or 10.9) have a more brittle behaviour than mild steels (e.g. S235, S275 or S355)

Behavior of the timber

- “real” stress distribution



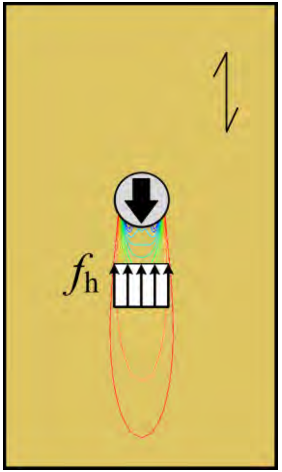
- “assumed” stress distribution

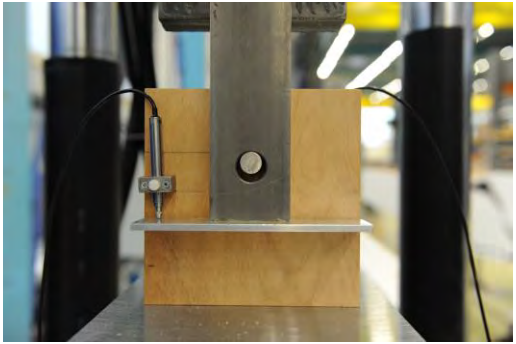


- Embedding strength

$$f_h = \frac{F_u}{d \cdot t}$$

- Is influenced mainly by:
  - d diameter of the fastener
  - ρ density of the wood
  - α direction of the grain





Compression test acc. to EN 383

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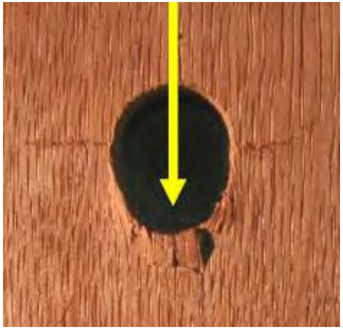
Behavior of the timber

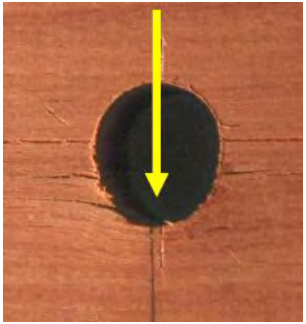
The embedding strength is affected by:

- Direction of the load

// grain



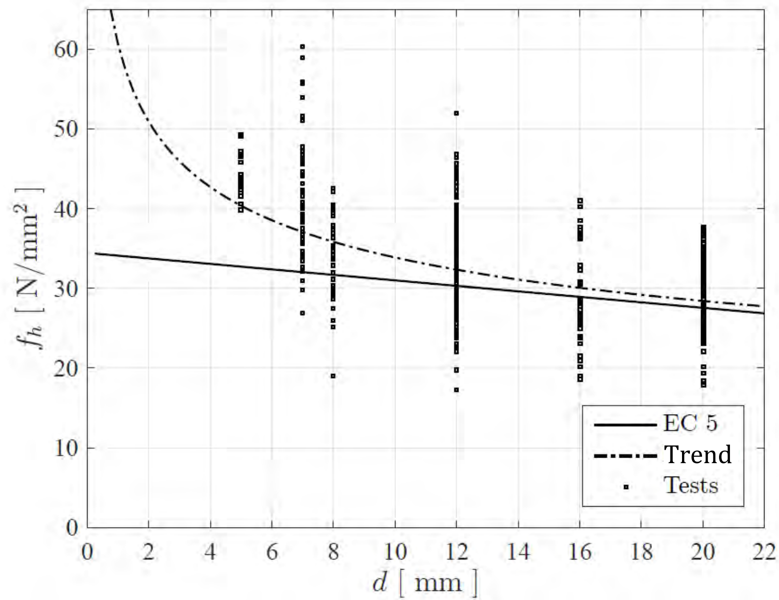
⊥ grain



Behavior of the timber

The embedding strength is affected by:

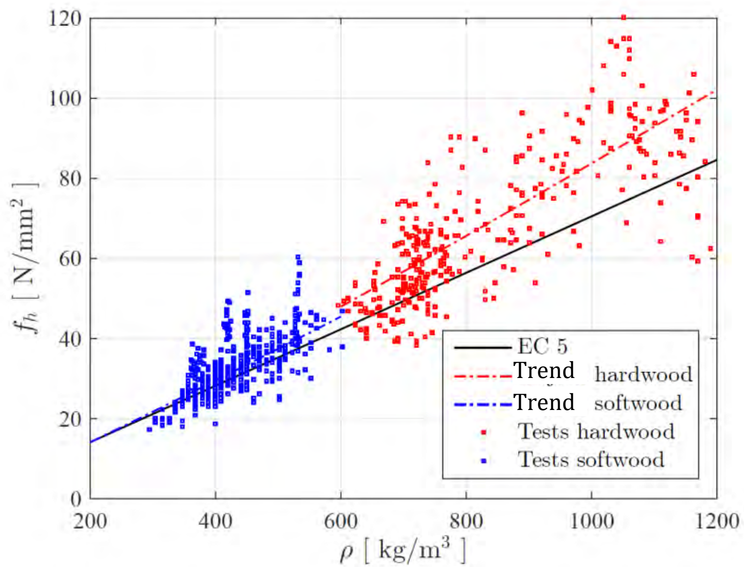
- Diameter of the fastener



Behavior of the timber

The embedding strength is affected by:

- Density of timber



- The higher the density of the wood, the higher embedding strength

Behavior of the timber

- Characteristic embedment strength of timber materials in Eurocode
- Nails:
- for timber and LVL (nails up to 8 mm)
  - $f_{h,k} = 0{,}082\rho_k d^{-0{,}3}$ [N/mm²] Without predrilled holes Eq. 8.15
  - $f_{h,k} = 0{,}082(1 - 0{,}01d)\rho_k$ [N/mm²] With predrilled holes Eq. 8.16
- for plywood
  - $f_{h,k} = 0{,}11\rho_k d^{-0{,}3}$ [N/mm²] Eq. 8.20
- for hardboard
  - $f_{h,k} = 30d^{-0{,}3}t^{0{,}6}$ [N/mm²] Eq. 8.21
- for particleboard
  - $f_{h,k} = 65d^{-0{,}7}t^{0{,}1}$ [N/mm²] Eq. 8.22

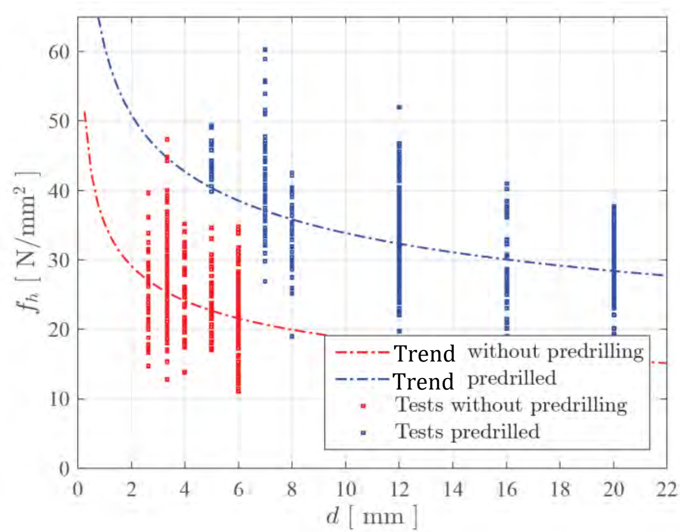
Behavior of the timber

- The embedding strength is also affected by pre-drilling
- Nails:
  - $f_{h,k} = 0{,}082\rho_k d^{-0{,}3}$ [N/mm²] Without predrilled holes Eq. 8.15
  - $f_{h,k} = 0{,}082(1 - 0{,}01d)\rho_k$ [N/mm²] With predrilled holes Eq. 8.16

EC5. Eq. 8-15, 8-16

Behavior of the timber

- The embedding strength is also affected by pre-drilling
- Nails:
  - $f_{h,k} = 0{,}082\rho_k d^{-0{,}3}$ [N/mm²] Without predrilled holes Eq. 8.15
  - $f_{h,k} = 0{,}082(1 - 0{,}01d)\rho_k$ [N/mm²] With predrilled holes Eq. 8.16



EC5. Eq. 8-15, 8-16

Johansen theory - timber to timber joint

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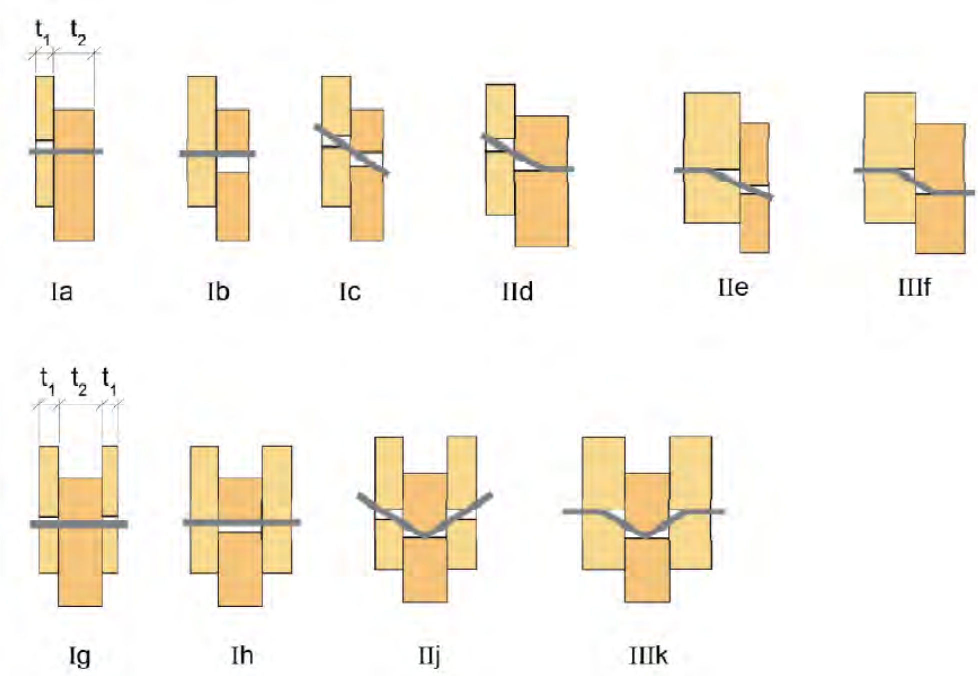
Possible failure modes of dowel-type fasteners



1 shear plane

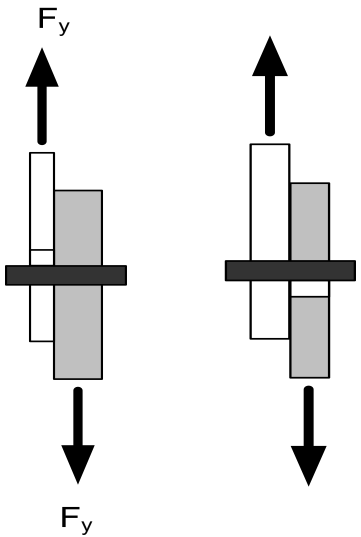
2 shear planes

Failure modes a & b

- Failure in timber, either in the first or the second piece

$$F = f_{h1} \cdot t_1 \cdot d$$

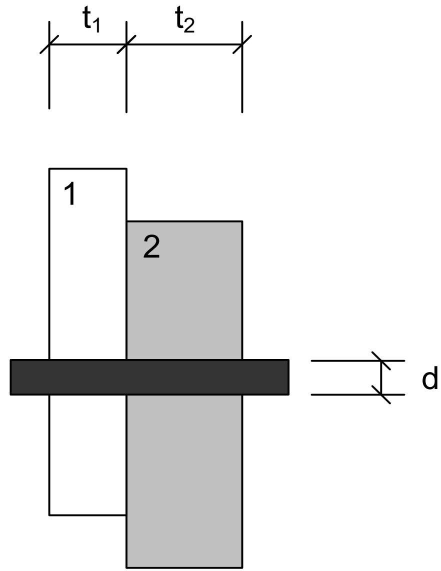
$$F = f_{h2} \cdot t_2 \cdot d$$



Definition

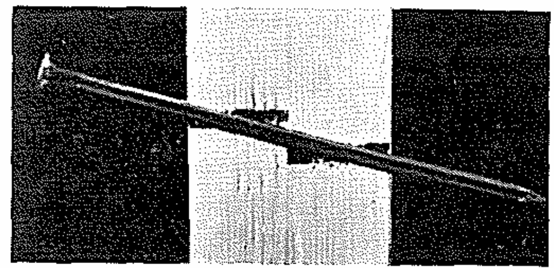
- f_{h1} (f_{h2}) - Embedment strength in timber 1 (timber 2)

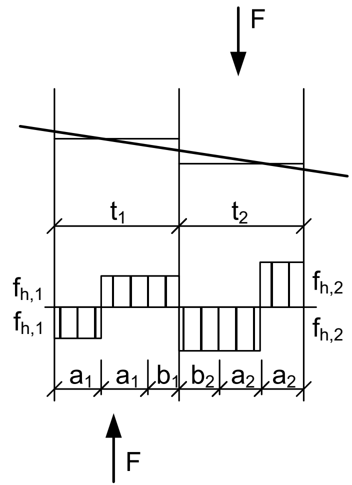
$$\beta = \frac{f_{h2}}{f_{h1}}$$



Failure mode c

- The dowel is stiff and change the angle in relation to timber.
- Embedding failure in one or both pieces of timber





Failure mode c - derivation

- Embedding failure:

$$F_{v,R} = f_{h1} d b_1 = f_{h2} d b_2 = \beta f_{h1} d b_2$$

$$b_1 = \beta b_2$$

- Equilibrium at the interfaces gives

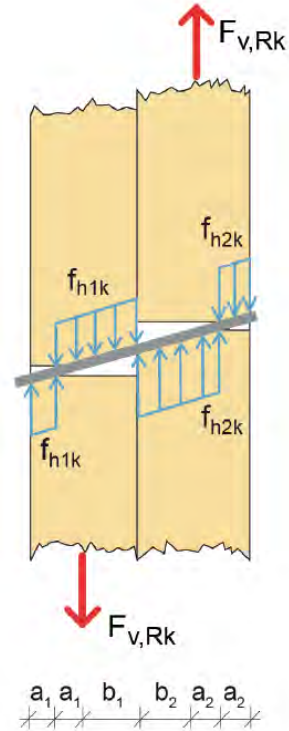
$$M_{left} = f_{h1} d \left(\frac{b_1^2}{2} + a_1 \left(b_1 + \frac{a_1}{2} \right) - a_1 \left(b_1 + \frac{3a_1}{2} \right) \right) = \cdots$$

$$\ldots = f_{h1} d \left(\frac{b_1}{2} - a_1^2 \right)$$

$$M_{right} = f_{h2} d \left(a_2^2 - \frac{b_2^2}{2} \right) = \beta f_{h1} d \left(a_2^2 - \frac{b_2^2}{2} \right)$$

- Equalling and replacing $b_2 = b_1/\beta$ leads to:

$$\frac{b_1^2}{2} \frac{1+\beta}{\beta} = \beta a_2^2 + a_1^2$$



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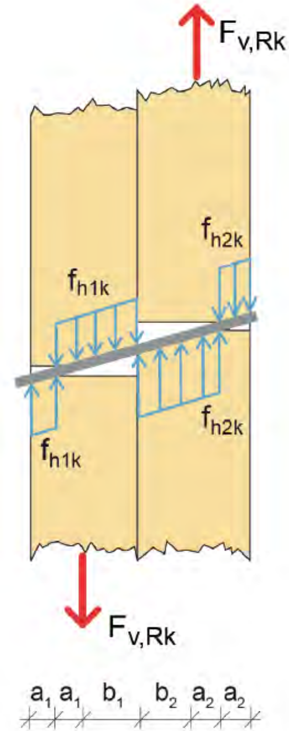
Failure mode c - derivation

- Equalling and replacing $b_2 = b_1/\beta$ leads to:

$$\frac{b_1^2}{2}\frac{1+\beta}{\beta} = \beta a_2^2 + a_1^2$$

- Expressing $a_1 = (t_1 - b_1)/2$ and $a_2 = (t_2 - b_2)/2$ and substituting a second order equation remains:

$$b_1^2\left(\frac{1+\beta}{\beta}\right) + 2b_1(t_1 + t_2) - (t_1^2 + \beta t_2^2) = 0$$



- The solution for b_1 is entered in the expression for $F_{v,R}$

$$F_{v,R} = f_{h1}db_1 = \frac{f_{h1}dt_1}{1+\beta}\left(\sqrt{\beta + 2\beta^2\left(1 + \frac{t_2}{t_1} + \left(\frac{t_2}{t_1}\right)^2\right) + \beta^3\left(\frac{t_2}{t_1}\right)^2} - \beta\left(1 + \frac{t_2}{t_1}\right)\right)$$

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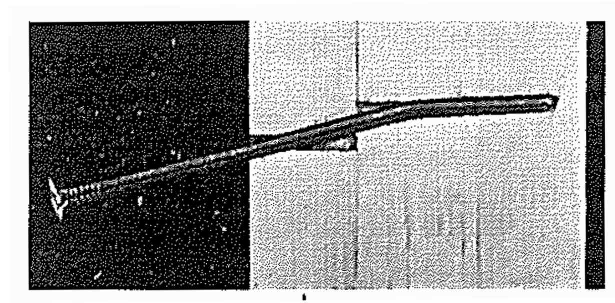
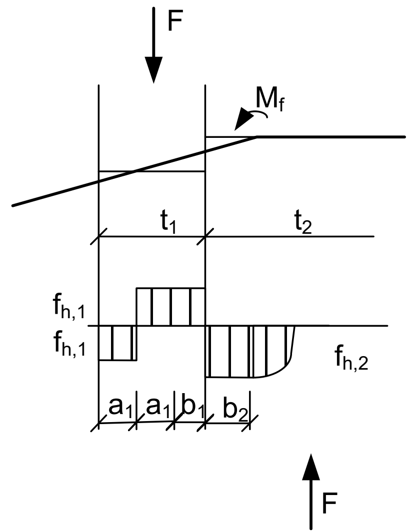
Failure modes d & e

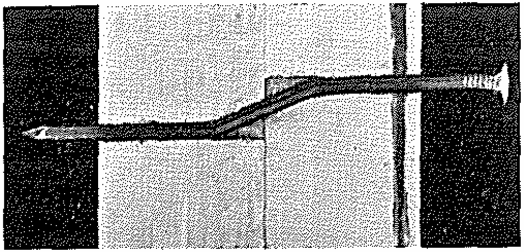
- One plastic hinge occurs

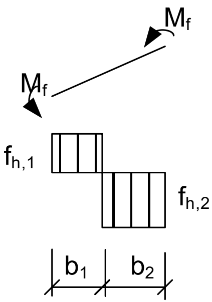


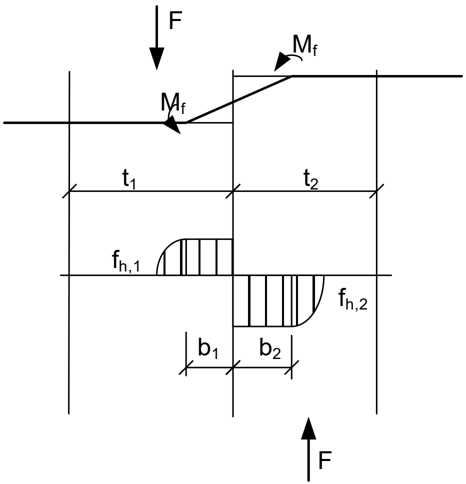


Failure mode e

- Two plastic hinges occur in both timber pieces



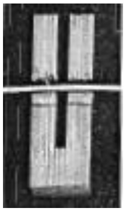




From brittle to plastic failure

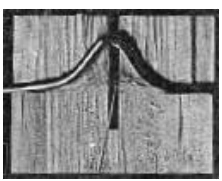
- Example of a connection

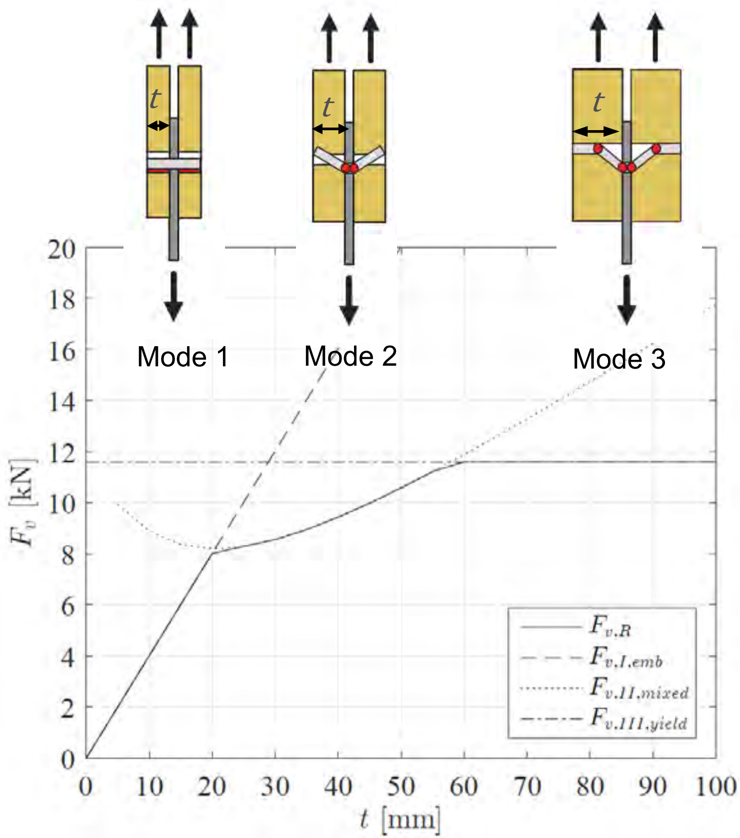
I



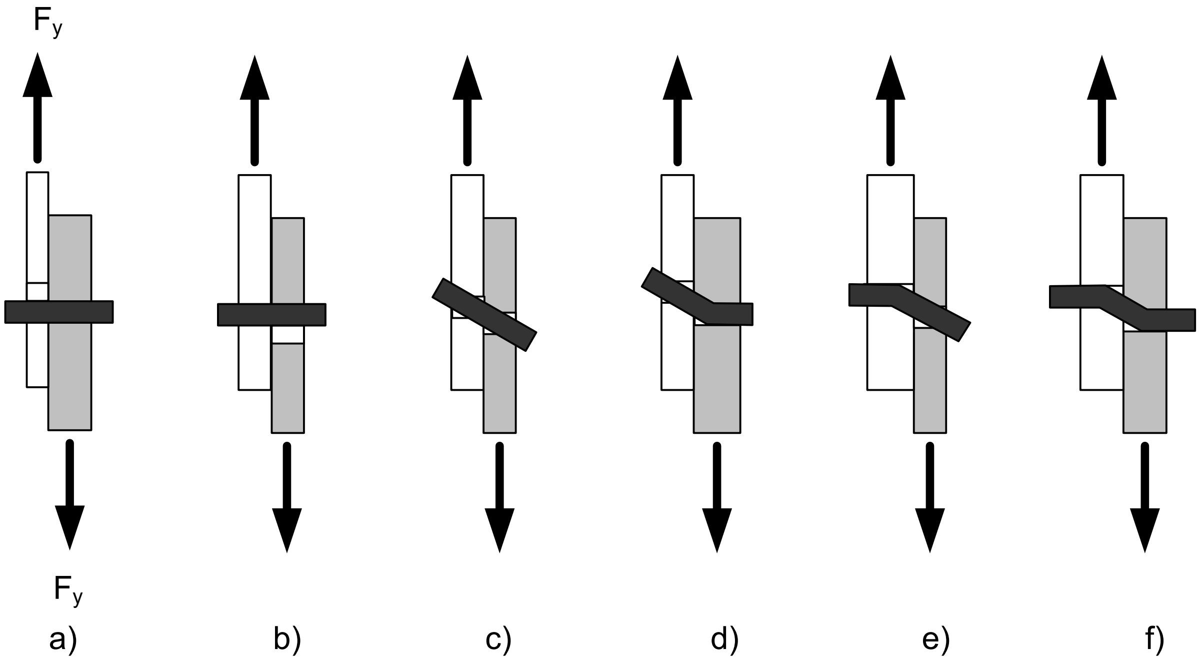
II

III

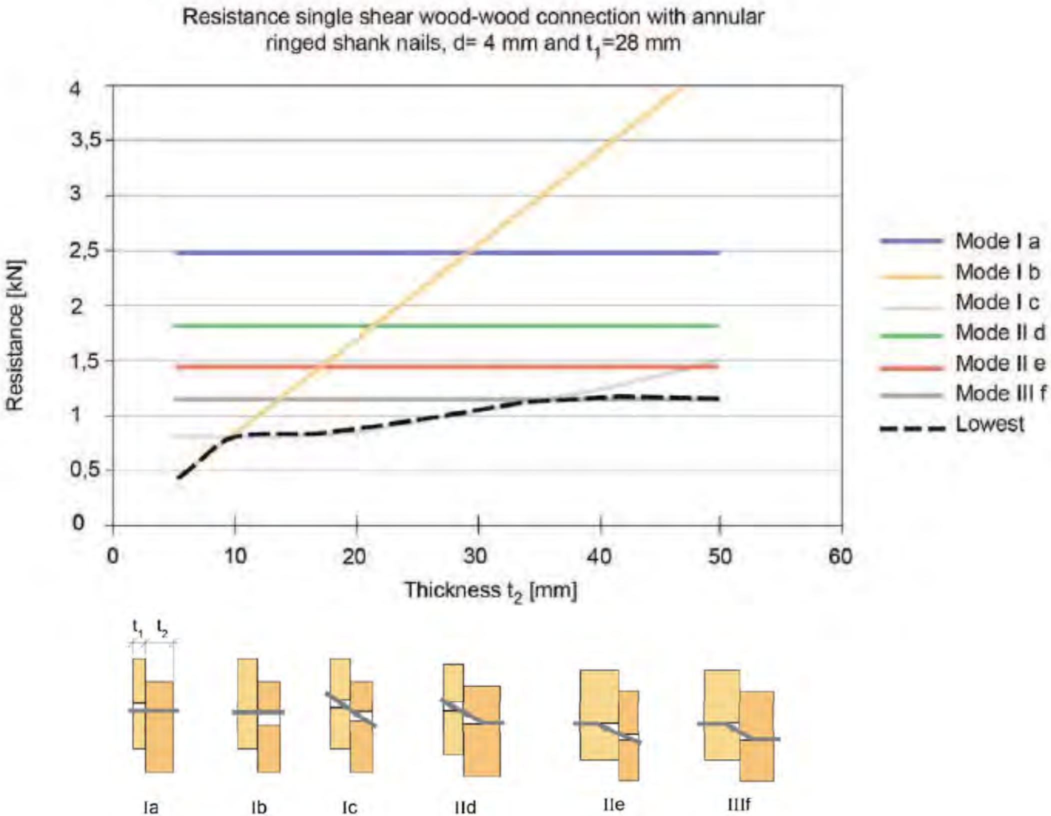




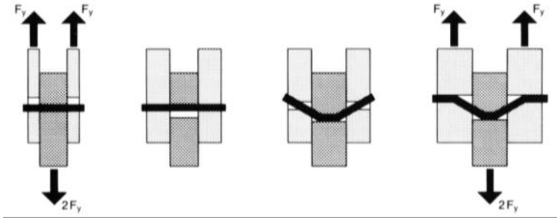
Johansen's equations for one shear plane



Johansen's equations for one shear plane



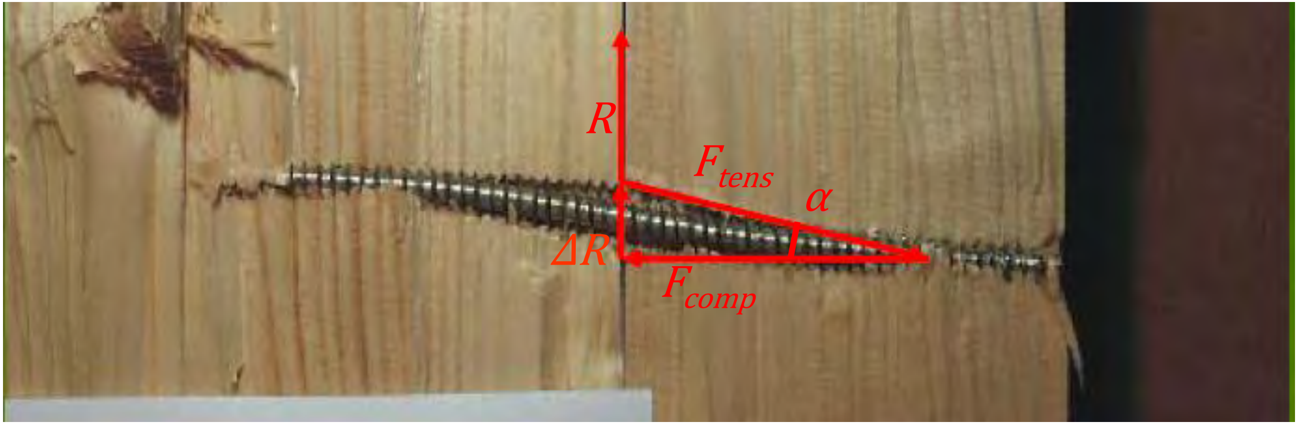
Johansen's equations for two shear planes



$$F_{\mathrm{v,Rk}} = \min \begin{cases} f_{\mathrm{h,1,k}} t_1 d & \text{(g)} \\ 0{,}5 f_{\mathrm{h,2,k}} t_2 d & \text{(h)} \\ 1{,}05 \dfrac{f_{\mathrm{h,1,k}} t_1 d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\dfrac{4\beta(2+\beta)M_{\mathrm{y,Rk}}}{f_{\mathrm{h,1,k}} d \quad t_1^2}}-\beta\right]+\dfrac{F_{\mathrm{ax,Rk}}}{4} & \text{(j)} \\ 1{,}15\sqrt{\dfrac{2\beta}{1+\beta}}\sqrt{2M_{\mathrm{y,Rk}} f_{\mathrm{h,1,k}} d}+\dfrac{F_{\mathrm{ax,Rk}}}{4} & \text{(k)} \end{cases}$$

What is this term??

Rope effect



- R is the resistance calculated according to "classic Johansen´s theory"
- In the inclined part of the fastener, tensile forces F_{tens} develop due to the angle of rotation α. This give rise to a component ‖ the joint line (ΔR)
- Moreover, the compression force F_{tens} also increases the strength of the connection, due to the friction between the timber parts

$$(\Delta R)_{Tot} = \Delta R + \mu \cdot F_{comp}$$

Rope effect

- $\frac{F_{ax,Rk}}{4}$ is the characteristic axial withdrawal capacity of the fastener divided by 4

- It is the contribution from the rope effect should be limited to the following % of the Johansen part

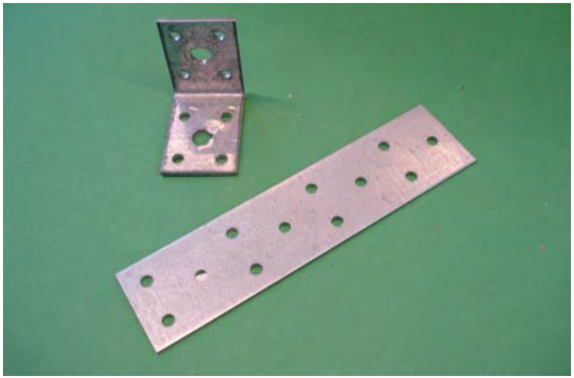
Round nails	15 %
Square nails	25 %
Other nails	50 %
Screws	100%
Bolts	25 %
Dowels	0 %

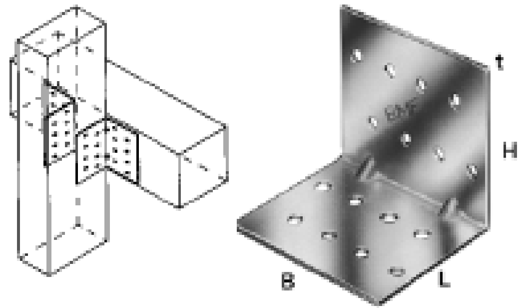
- Be very careful with the increase in strength due to the “rope effect”, especially for nails. The reason is that there are not many test results showing the long term behaviour of such connections

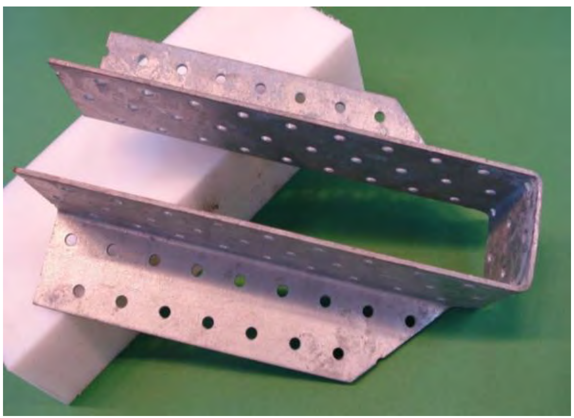
See 4.6.2 in the book

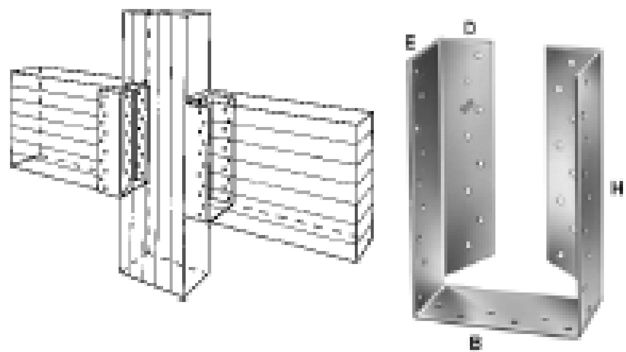
Steel to timber connections

Nailing metals and plates



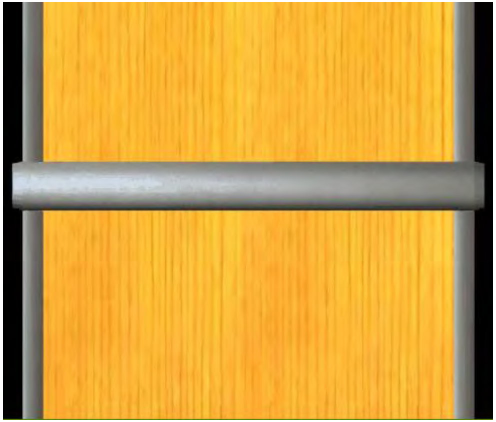




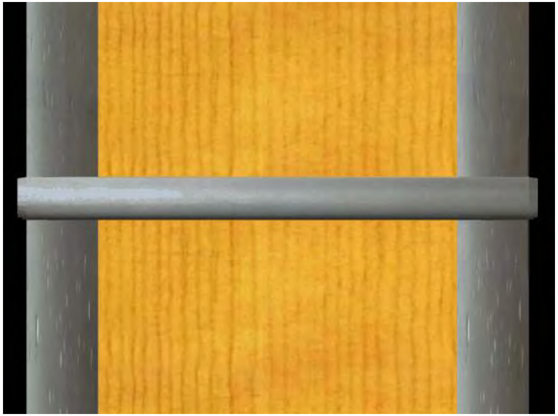


Steel to timber connections

- Steel plates acts as a simple support

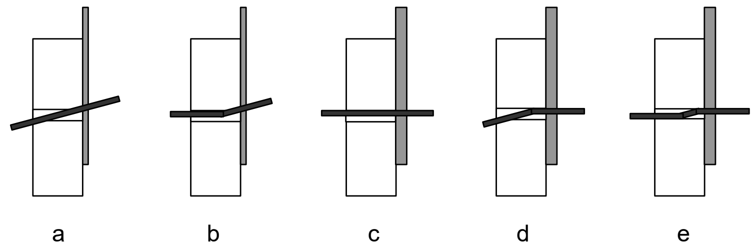


- Steel plates provide a clamped support



$$\begin{cases} t \leq 0.5d \Rightarrow thin\,plate \\ t > d \Rightarrow thick\,plate \end{cases}$$

Steel to timber connections - one shear plane



- Thin plates

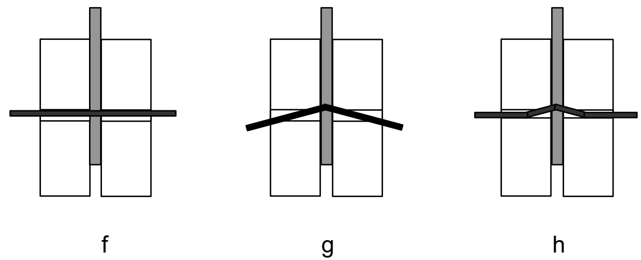
$$F_{v,Rk} = \min \begin{cases} 0{,}4\, f_{h,k} t_1 d & \text{(a)} \\ 1{,}15 \cdot \sqrt{2M_{y,Rk} f_{h,k} d} + \dfrac{F_{ax,Rk}}{4} & \text{(b)} \end{cases}$$

- Thick plates

$$F_{v,Rk} = \min \begin{cases} f_{h,'k} t_1 d & \text{(c)} \\ f_{h,k} t_1 d \left[\sqrt{2 + \dfrac{4M_{y,Rk}}{f_{h,k} d t_1^{\,2}}} - 1 \right] + \dfrac{F_{ax,Rk}}{4} & \text{(d)} \\ 2{,}3 \cdot \sqrt{M_{y,Rk} f_{h,k} d} + \dfrac{F_{ax,Rk}}{4} & \text{(e)} \end{cases}$$

Eq. 8-9 to 8-13

Steel to timber connections - slotted-in plate

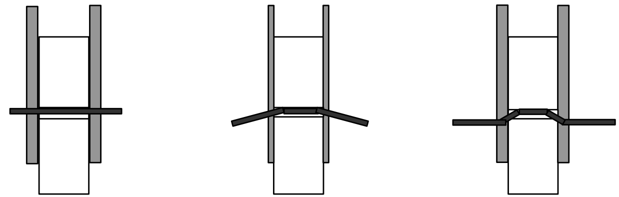


- Thin and thick plates

$$F_{v,Rk} = \min \begin{cases} f_{h,'k} t_1 d & \text{(f)} \\ f_{h,1,k} t_1 d \left[\sqrt{2 + \dfrac{4M_{y,Rk}}{f_{h,1,k} d t_1^{\,2}}} - 1 \right] + \dfrac{F_{ax,Rk}}{4} & \text{(g)} \\ 2{,}3 \cdot \sqrt{M_{y,Rk} f_{h,1,k} d} + \dfrac{F_{ax,Rk}}{4} & \text{(h)} \end{cases}$$

Eq. 8-9 to 8-13

Steel to timber connections - two shear plane



- Thin plates

$$F_{v,Rk} = \min \begin{cases} 0{,}5\, f_{h,2,k} t_2 d & \text{(j)} \\ 1{,}15 \cdot \sqrt{2M_{y,Rk}\, f_{h,2,k} d} + \dfrac{F_{ax,Rk}}{4} & \text{(k)} \end{cases}$$

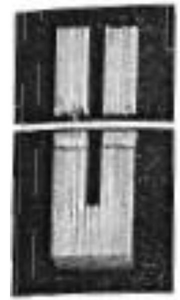
- Thick plates

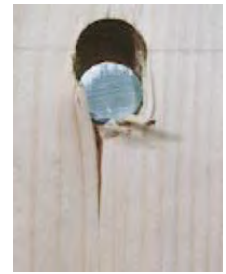
$$F_{v,Rk} = \min \begin{cases} 0{,}5\, f_{h,2,k} t_2 d & \text{(l)} \\ 2{,}3 \cdot \sqrt{2M_{y,Rk}\, f_{h,2,k} d} + \dfrac{F_{ax,Rk}}{4} & \text{(m)} \end{cases}$$

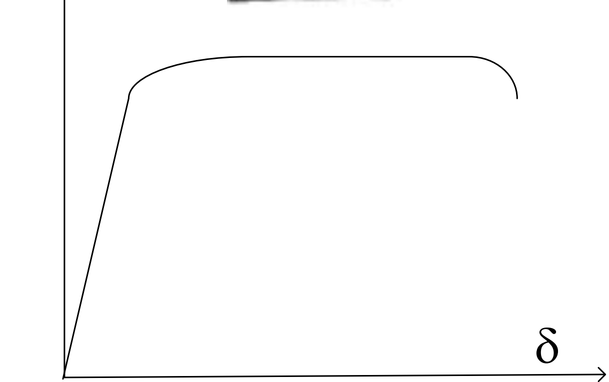
Eq. 8-9 to 8-13

Connection with only one dowel

- The failure occurs when the embedding strength of the timber is reached. If there is only one dowel in line, this failure occurs after rather large plastic deformations

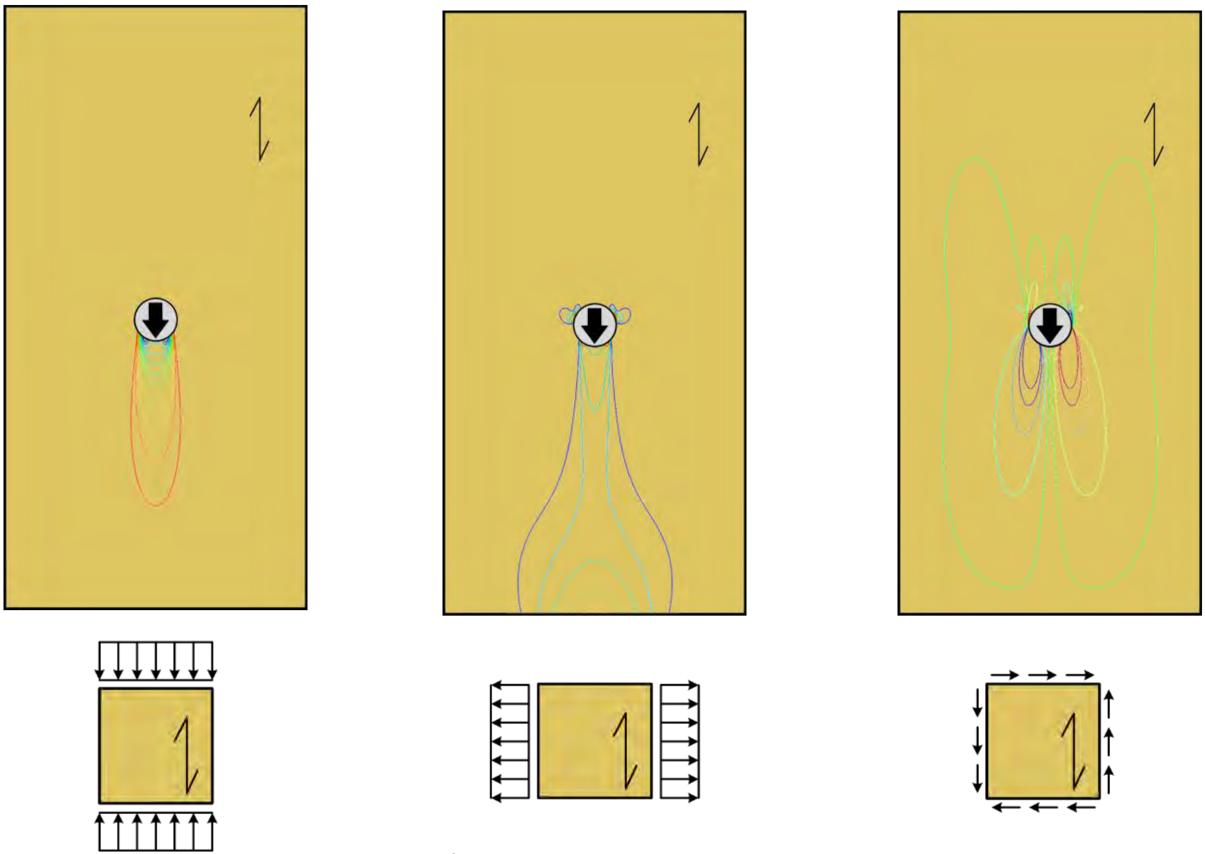




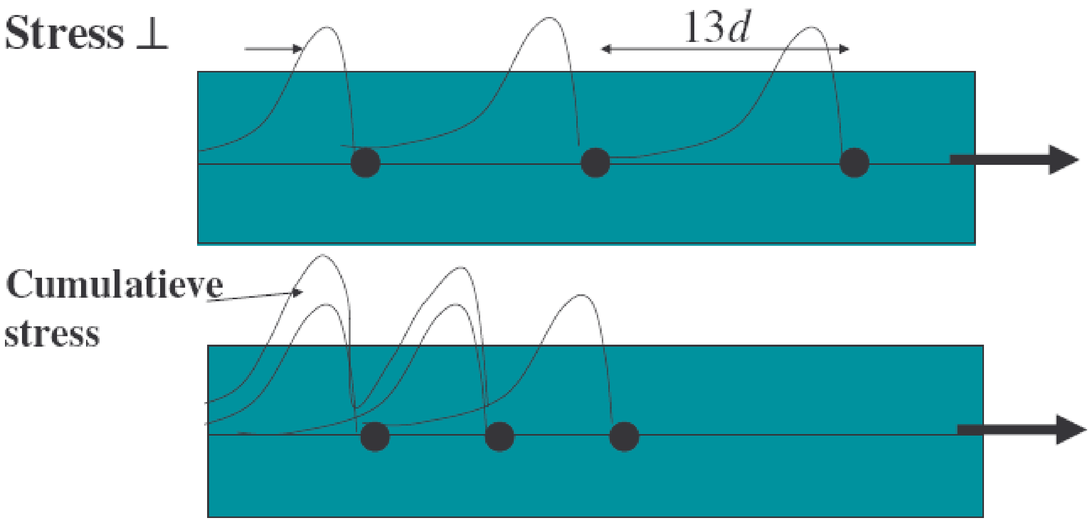


But, usually there are several fasteners on a joint, How does it work?

Stresses in the timber



Several connectors in a row (|| grain): effect of the spacing



"Wedge effect"

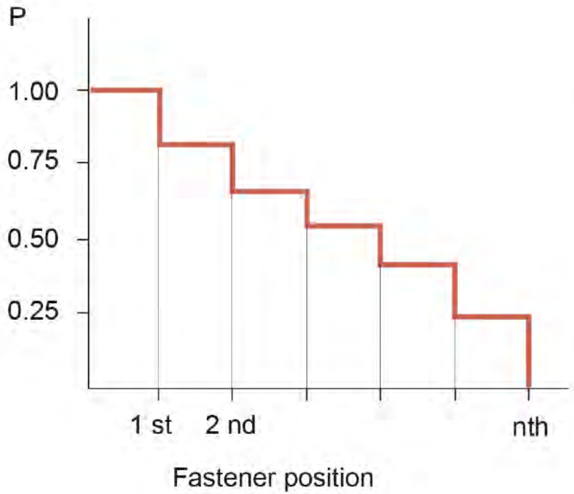
Group effect

- Fasteners are usually used in groups
- The load distribution is not uniform due to
  - Variation of timber strength
  - Hole size
  - Misalignment
  - Uneven load transfer

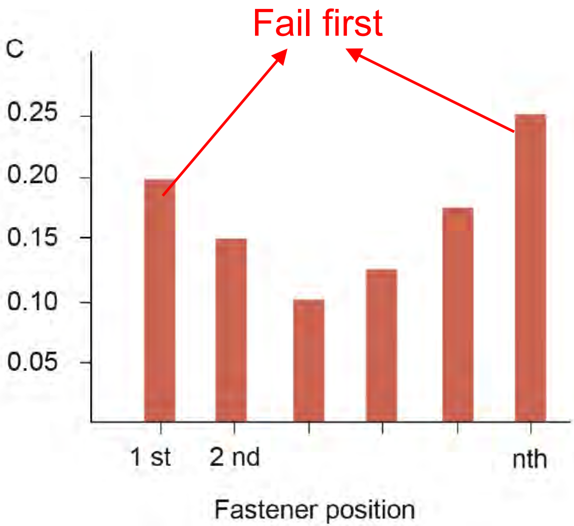
- The first and the last fastener in a row usually take the highest load and the joint usually fails at these locations

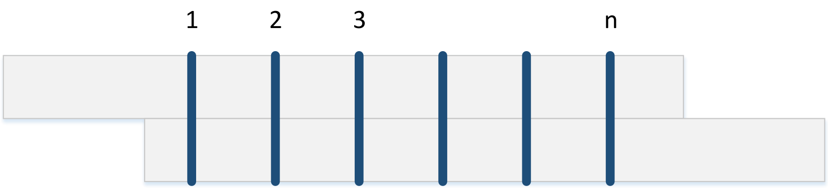
Group effect

- Force distribution in member



- Force distribution in fasteners





Cramer (1968)

Group effect

- Eurocode treats the group effect as following, EC5 8.3.3.1(8)

- $n_{ef} = n^{k_{ef}}$ nails and staples Eq. 8.17

Table 8.1 – Values of k_{ef}

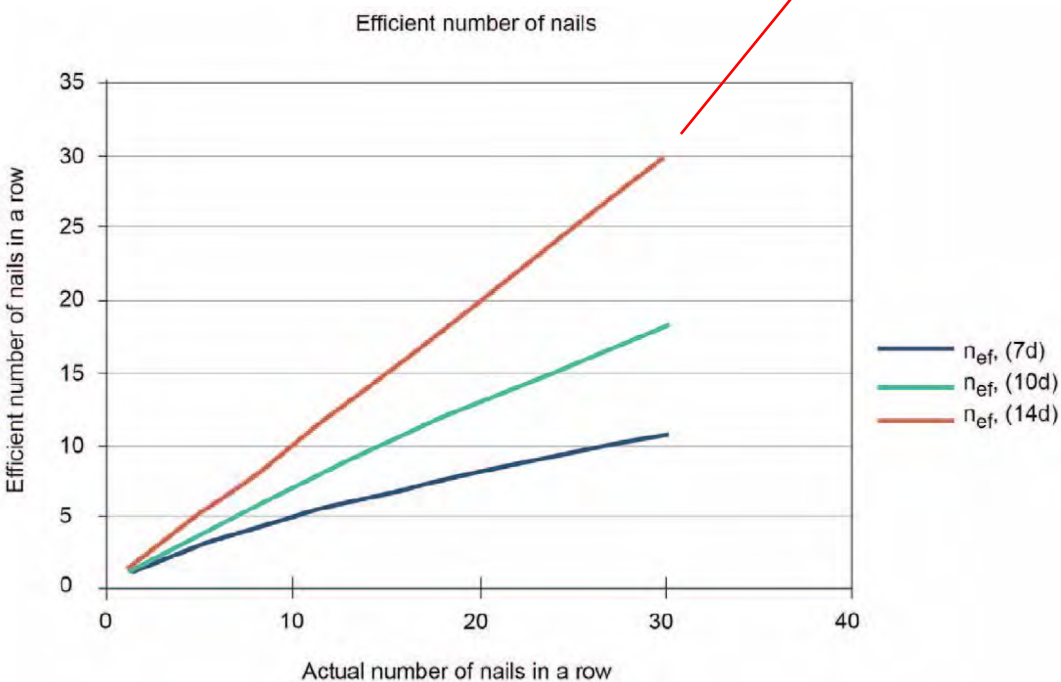
Spacing[a]	k_{ef}	
	Not predrilled	Predrilled
$a_1 \geq 14d$	1,0	1,0
$a_1 = 10d$	0,85	0,85
$a_1 = 7d$	0,7	0,7
$a_1 = 4d$	-	0,5
[a] For intermediate spacings, linear interpolation of k_{ef} is permitted		

- $n_{ef} = \min \begin{cases} n \\ n^{0,9} \sqrt[4]{\dfrac{a_1}{13d}} \end{cases}$ bolts and screws Eq. 8.34

Group effect

- Example for nails

No group effect



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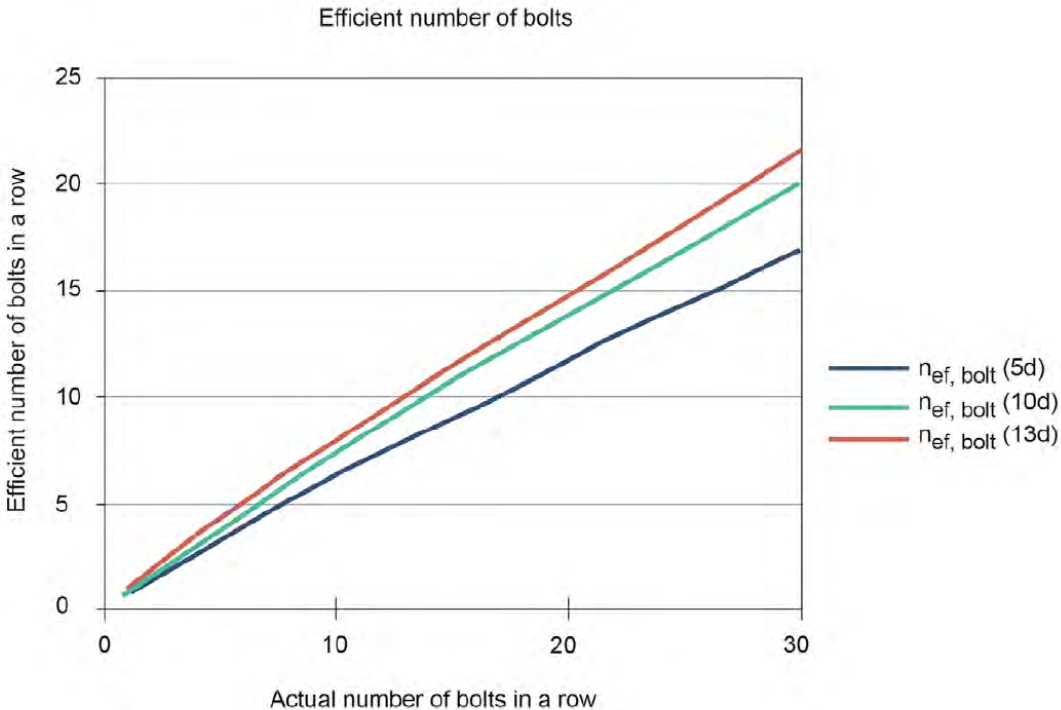
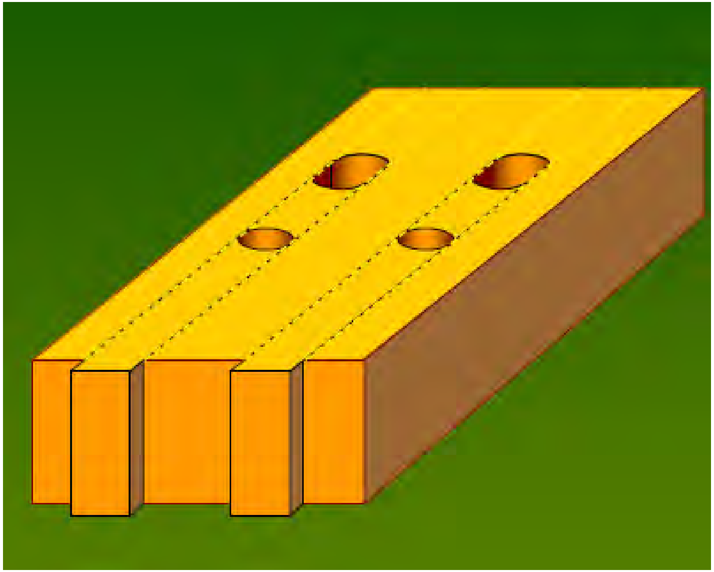
Group effect

- Example for bolts



Plug-shear



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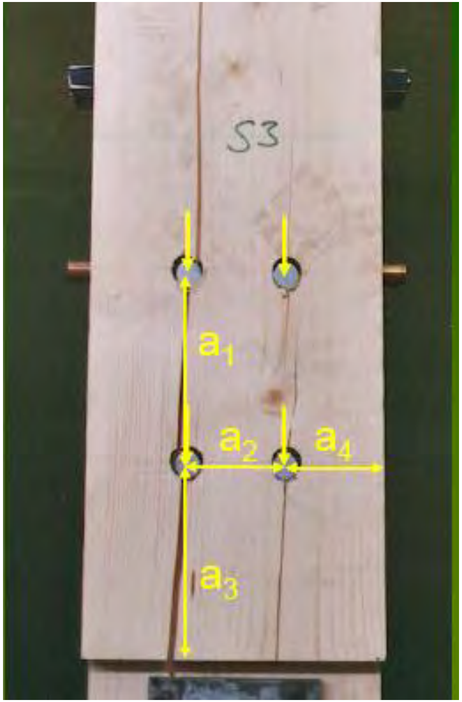
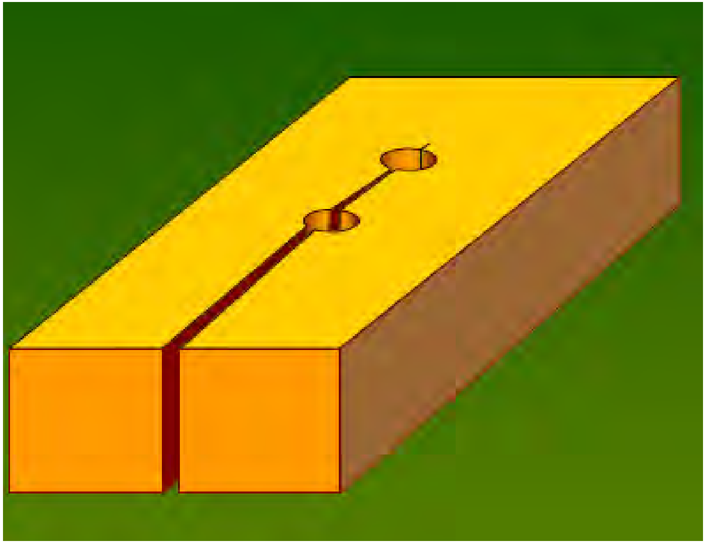
Splitting

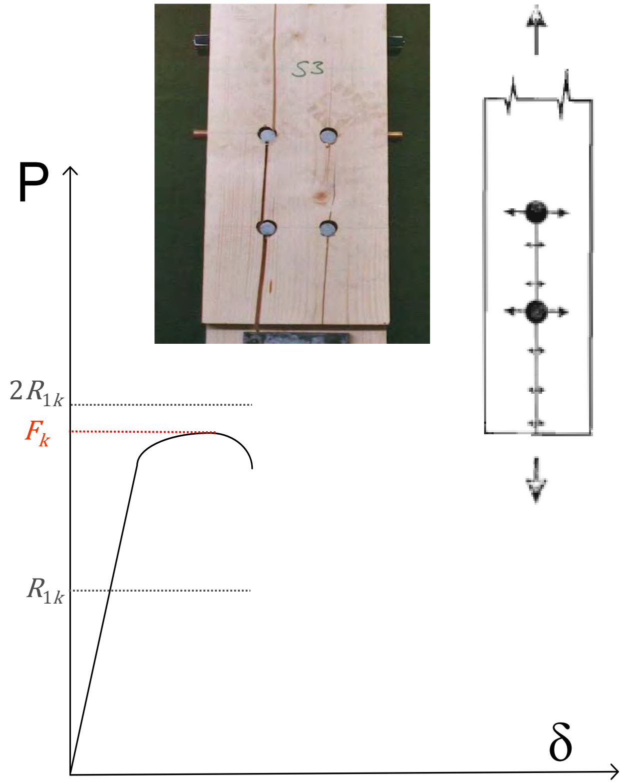




Connection with more than one dowel in line

- If there are more than one dowel in line, the failure occurs by splitting of the timber or by shear plug.
  However, the ductility may be increased by increasing the slenderness of the dowel

$$F_k < 2\ R_{1k}$$



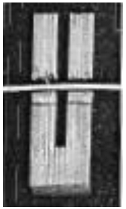
How can we reduce the group effect?

- Use larger distances between connector and larger end distance
- Use slender connectors (slender connectors have a reduced “wedge effect” if compared to stocky connectors)
- Reinforce the connection

From brittle to plastic failure

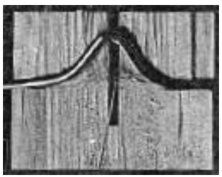
- Choose sufficient timber thickness!

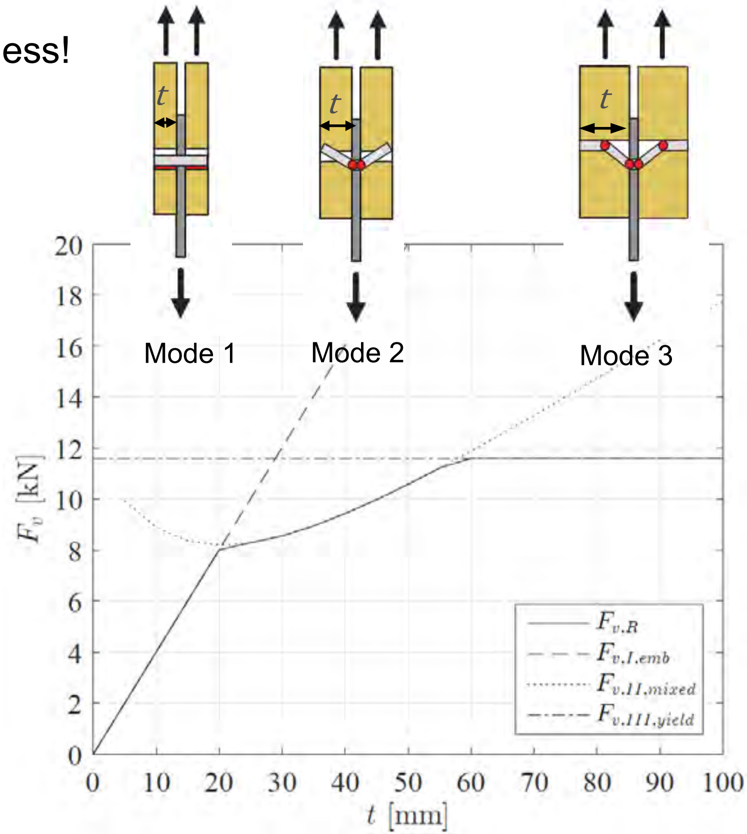
I



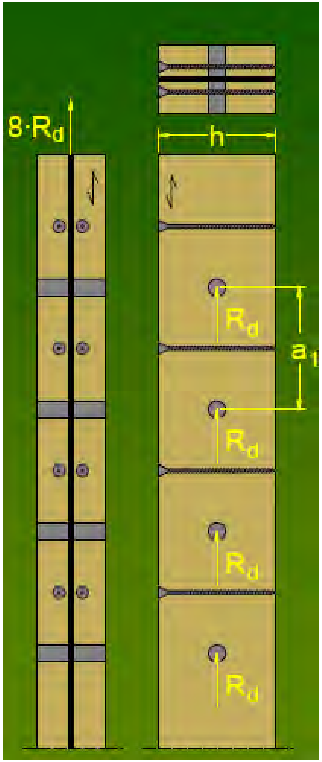
II

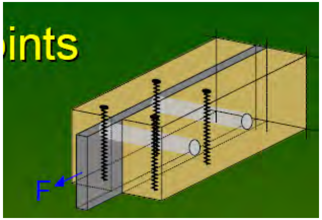
III

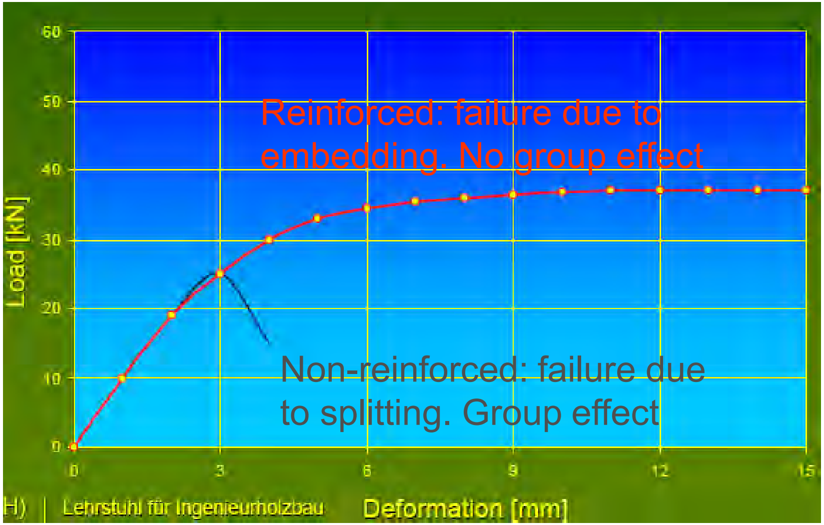




Reinforcement of the connection







Source: H.J. Blaß

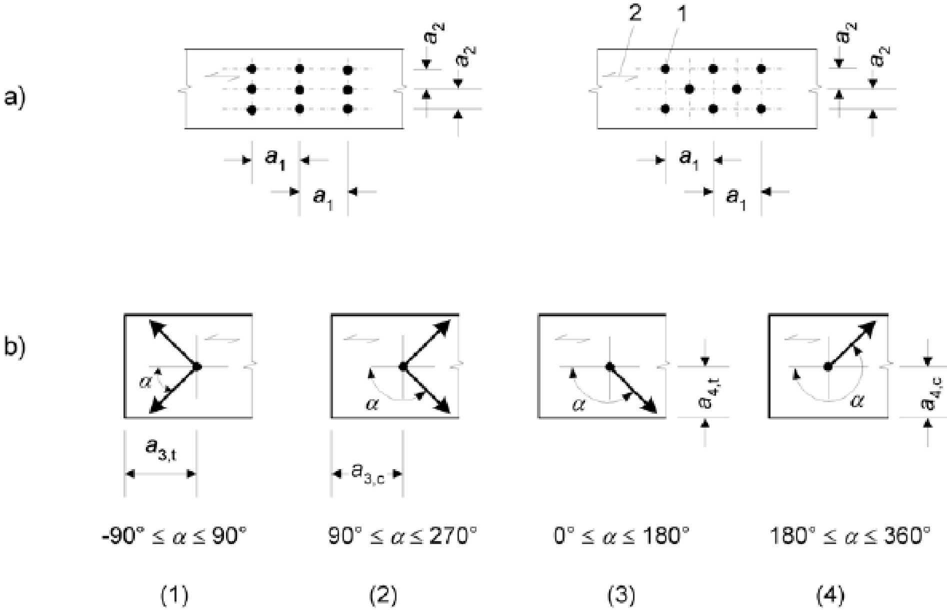
Spacings and distances

- Nails

Table 8.2 – Minimum spacings and edge and end distances for nails

Spacing or distance (see Figure 8.7)	Angle α	Minimum spacing or end/edge distance		
		without predrilled holes		with predrilled holes
		$\rho_k \leq 420$ kg/m^3	420 kg/m^3 $< \rho_k \leq 500$ kg/m^3	
Spacing a_1 (parallel to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$d < 5$ mm: $(5+5\lvert\cos\alpha\rvert)\, d$ $d \geq 5$ mm: $(5+7\lvert\cos\alpha\rvert)\, d$	$(7+8\lvert\cos\alpha\rvert)\, d$	$(4+\lvert\cos\alpha\rvert)\, d$
Spacing a_2 (perpendicular to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$5d$	$7d$	$(3+\lvert\sin\alpha\rvert)\, d$
Distance $a_{3,t}$ (loaded end)	$-90^\circ \leq \alpha \leq 90^\circ$	$(10+5\cos\alpha)\, d$	$(15+5\cos\alpha)\, d$	$(7+5\cos\alpha)\, d$
Distance $a_{3,c}$ (unloaded end)	$90^\circ \leq \alpha \leq 270^\circ$	$10d$	$15d$	$7d$
Distance $a_{4,t}$ (loaded edge)	$0^\circ \leq \alpha \leq 180^\circ$	$d < 5$ mm: $(5+2\sin\alpha)\, d$ $d \geq 5$ mm: $(5+5\sin\alpha)\, d$	$d < 5$ mm: $(7+2\sin\alpha)\, d$ $d \geq 5$ mm: $(7+5\sin\alpha)\, d$	$d < 5$ mm: $(3+2\sin\alpha)\, d$ $d \geq 5$ mm: $(3+4\sin\alpha)\, d$
Distance $a_{4,c}$ (unloaded edge)	$180^\circ \leq \alpha \leq 360^\circ$	$5d$	$7d$	$3d$

Spacings and distances



Key:
(1) Loaded end
(2) Unloaded end
(3) Loaded edge
(4) Unloaded edge
1 Fastener
2 Grain direction

Spacings and distances

- Staples

Table 8.3 – Minimum spacings and edge and end distances for staples

Spacing and edge/end distances (see Figure 8.7)	Angle	Minimum spacing or edge/end distance
a_1 (parallel to grain) for $\theta \geq 30°$ for $\theta < 30°$	$0^{\circ} \leq \alpha \leq 360^{\circ}$	$(10 + 5\|\cos \alpha\|)\,d$ $(15 + 5\|\cos \alpha\|)\,d$
a_2 (perpendicular to grain)	$0^{\circ} \leq \alpha \leq 360^{0^{\circ}}$	$15\,d$
$a_{3,t}$ (loaded end)	$-90^{\circ} \leq \alpha \leq 90^{\circ}$	$(15 + 5\|\cos \alpha\|)\,d$
$a_{3,c}$ (unloaded end)	$90^{\circ} \leq \alpha \leq 270^{\circ}$	$15\,d$
$a_{4,t}$ (loaded edge)	$0^{\circ} \leq \alpha \leq 180^{\circ}$	$(15 + 5\|\sin \alpha\|)\,d$
$a_{4,c}$ (unloaded edge)	$180^{\circ} \leq \alpha \leq 360^{\circ}$	$10\,d$

Spacings and distances

- Bolts

Table 8.4 – Minimum values of spacing and edge and end distances for bolts

Spacing and end/edge distances (see Figure 8.7)	Angle	Minimum spacing or distance
a_1 (parallel to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$(4 + \lvert\cos\alpha\rvert)\,d$
a_2 (perpendicular to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$4\,d$
$a_{3,t}$ (loaded end)	$-90^\circ \leq \alpha \leq 90^\circ$	max ($7\,d$; 80 mm)
$a_{3,c}$ (unloaded end)	$90^\circ \leq \alpha < 150^\circ$ $150^\circ \leq \alpha < 210^\circ$ $210^\circ \leq \alpha \leq 270^\circ$	max $[(1 + 6\sin\alpha)\,d;\ 4d]$ $4\,d$ max $[(1 + 6\sin\alpha)\,d;\ 4d]$
$a_{4,t}$ (loaded edge)	$0^\circ \leq \alpha \leq 180^\circ$	max $[(2 + 2\sin\alpha)\,d;\ 3d]$
$a_{4,c}$ (unloaded edge)	$180^\circ \leq \alpha \leq 360^\circ$	$3\,d$

Spacings and distances

- Dowels

Table 8.5 – Minimum spacings and edge and end distances for dowels

Spacing and edge/end distances (see Figure 8.7)	**Angle**	**Minimum spacing or edge/end distance**
a_1 (parallel to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$(3 + 2\lvert\cos\alpha\rvert)\,d$
a_2 (perpendicular to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$3\,d$
$a_{3,t}$ (loaded end)	$-90^\circ \leq \alpha \leq 90^{0^\circ}$	max (7 d; 80 mm)
$a_{3,c}$ (unloaded end)	$90^{0^\circ} \leq \alpha < 150^\circ$ $150^\circ \leq \alpha < 210^\circ$ $210^\circ \leq \alpha \leq 270^\circ$	$\max(a_{3,t}\lvert\sin\alpha\rvert)\,d;\,3d)$ $3\,d$ $\max(a_{3,t}\lvert\sin\alpha\rvert)\,d;\,3d)$
$a_{4,t}$ (loaded edge)	$0^\circ \leq \alpha \leq 180^\circ$	$\max([2 + 2\sin\alpha)\,d;\,3d)$
$a_{4,c}$ (unloaded edge)	$180^\circ \leq \alpha \leq 360^\circ$	$3\,d$

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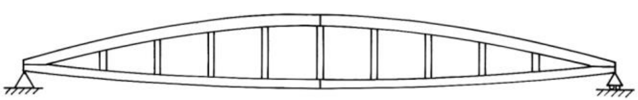
Denmark, Ballerup arena- 2001



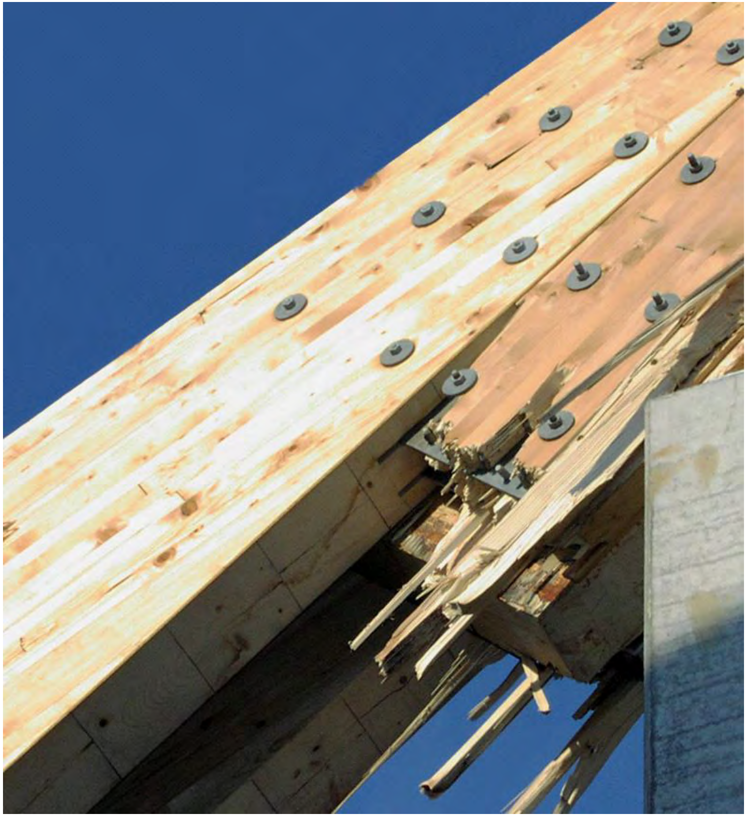
- Wooden trusses, span 72m

Denmark, Ballerup arena- 2001

- Collapse in Jan 2003

Denmark, Ballerup arena- 2001

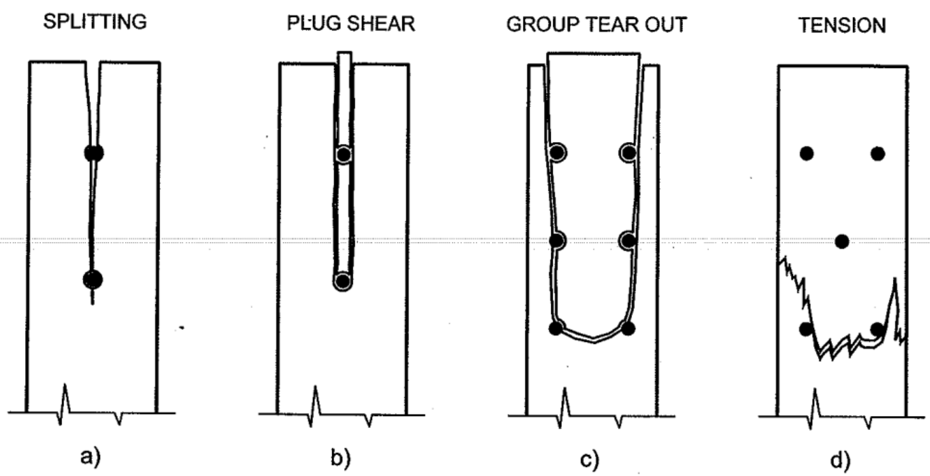
- Collapse in Jan 2003



Timber failure

The timber failure modes are not contemplated in the Johansen´s theory!!

- In particular:
  - Failure type a) and b): is avoided by using adequate distances
  - Failure type c) and d) need to be checked separately



Shear connectors

Shear connectors

- Mechanism

Shear connectors

- Punched metal plates
- Split rings
- Shear plates
- Toothed plates

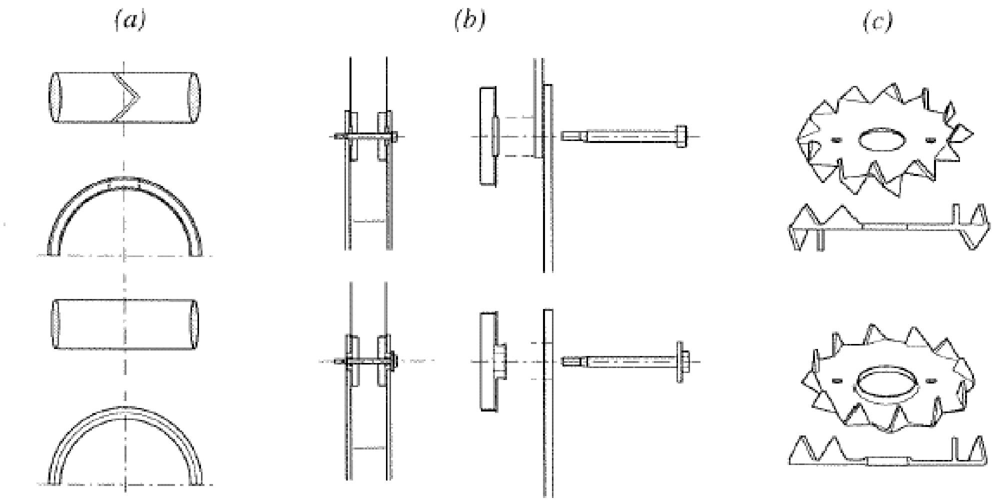
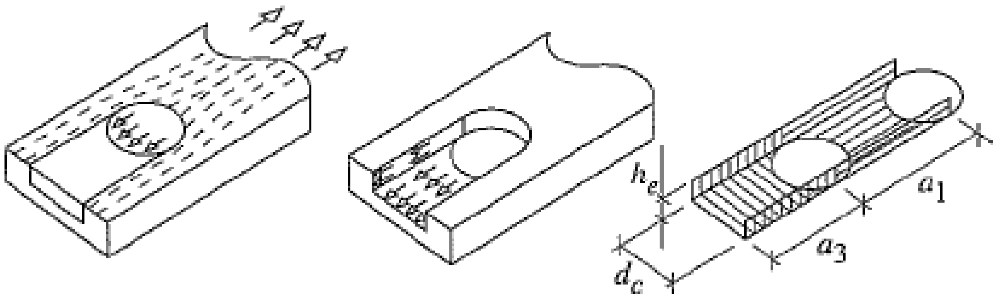


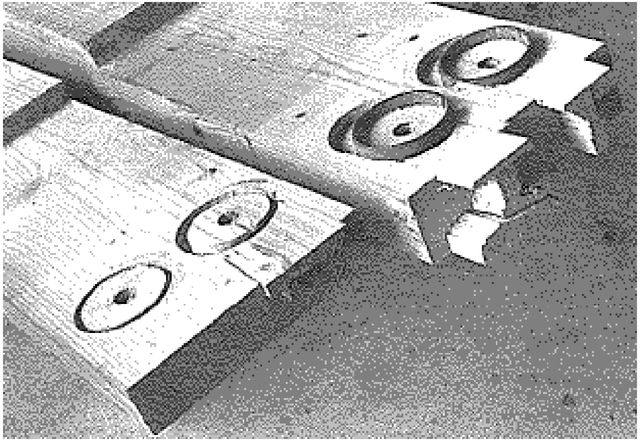
Figure 2 *Usual timber connectors: (a) split-rings, (b) shear-plates, (c) single and double sided toothed-plates.*

Ring connector and shear failure



Stresses in a ring connector joint and corresponding shear areas.

- $R_c = \min \begin{cases} f_v A_s \\ f_h d_c h_c \end{cases}$



Liseberg - Balder

- Double-sided toothed plate
- Multiple joint with shear plates and in combination with bolt

Liseberg - Balder

Liseberg - Balder

Glued joints

Glued joints

Properties

- Transfer force in shear
- Stiff
- Do not interact statically with ”mechanical joints”
- Carry the whole load until failure
- Requirements on MC i.e. 12% and temperature above freezing
- Glued joints in load-bearing structures are made in a factory

Glued joints

Advantages:

- High stiffness and high strength
- Very automated process
- Very economic for applications such as: finger joints, glulam, etc

Disadvantages:

- Very sensitive to unskilled manufacture
- Requires manufacture control
- Should not be performed on-site
- Brittle failure
- Very sensitive to shrinkage and swelling of the wood

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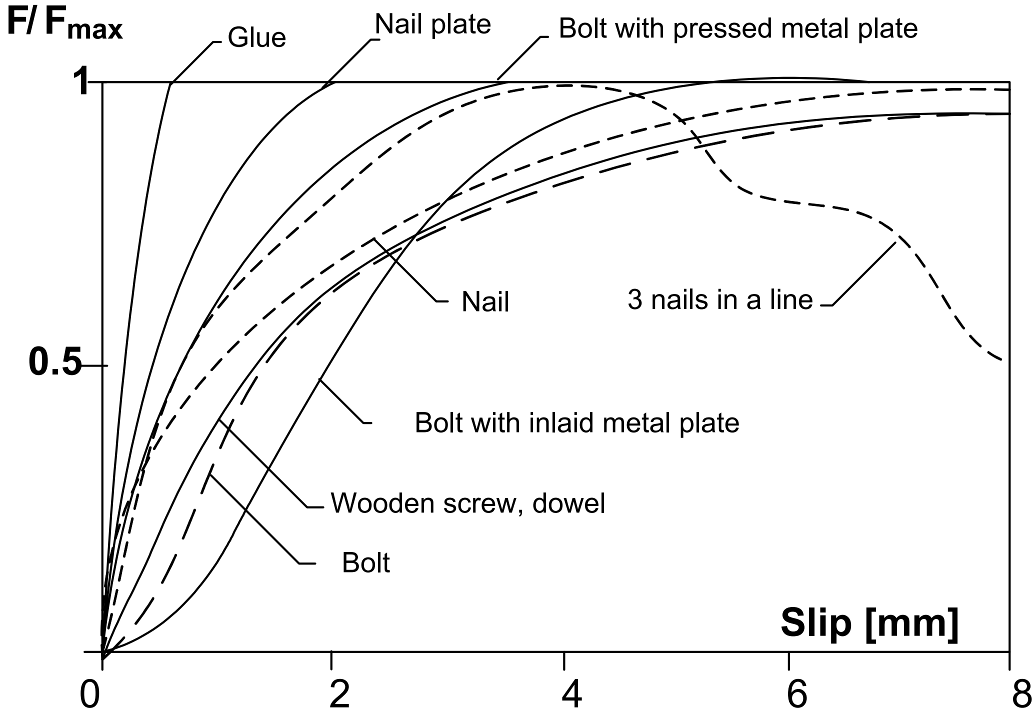
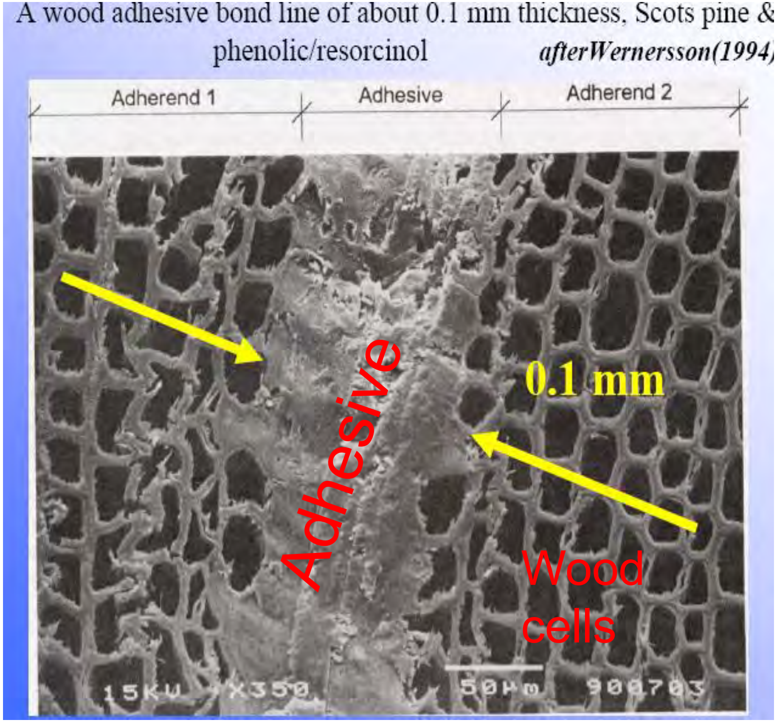
Behavior of connections: typical load-slip curves



Bond between members

What is the adhesive for?

- Fills the voids between wooden members
- Produces adhesive bonds to each members



After S. Aicher

Stiffness of adhesive

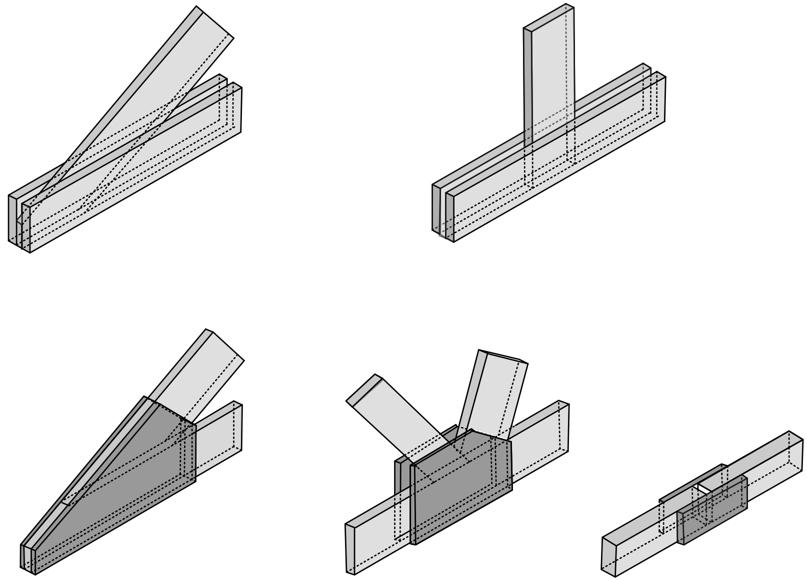
- The stiffness of the joint depends upon the thickness of the bond line. For common adhesives

Thickness (mm)	Shear modulus (MPa)
0,1	1300-1800
0,4	700-850
0,8	600

Types of adhesives

- Phenol-resorcinol-formaldehyde (PRF)
  - Curing: room temperature or at elevated temperature (high-frequency curing, for faster curing);
  - Properties: dark, thickness up to 2 mm (“gapfilling”)
  - Use: glulam, finger joints, overlap joints, nail and screw-gluing, etc
- Melamine-Urea-formaldehyde (MUF)
  - Curing: room temperature or at elevated temperature (high-frequency curing, for faster curing);
  - Properties: light, thickness about 0,1mm
  - Use: glulam, finger joints
- Polyuretheans (PUR)
  - Curing: room temperature
  - Properties: Ductile behaviour, lower shear strength than PRF and MUF
  - Use: finger joints, glued-in rods, etc
- Epoxy resins (EP)
  - Curing: room temperature
  - Properties: Ductile or brittle behaviour, depending on the type
  - Use: glued-in rods, metal-to-wood connections, repairing of wood

Some applications of glued joints

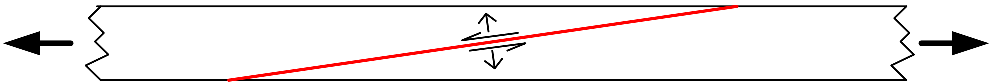


- Transfer load in shear at the surface of two members
- Normally plywood or Kerto-Q plates are nail-glued to the truss members

Some applications of glued joints

After S. Aicher

Scarf joints



- From the purely technical point of view, it is the jointing method delivering the highest strength
- (It is the forerunner of the finger joint)
- Still today, it can be used for some specific application, for example for jointing two large glulam elements

- Uneconomic due to high loss of timber
- Expensive cramping arrangement (but could be probably performed by means of screw-gluing, by means gapfilling adhesives)

Examples H1 and H7

AVANCEZ

1829

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