TKT4211: Timber Structures 1

Example C4:

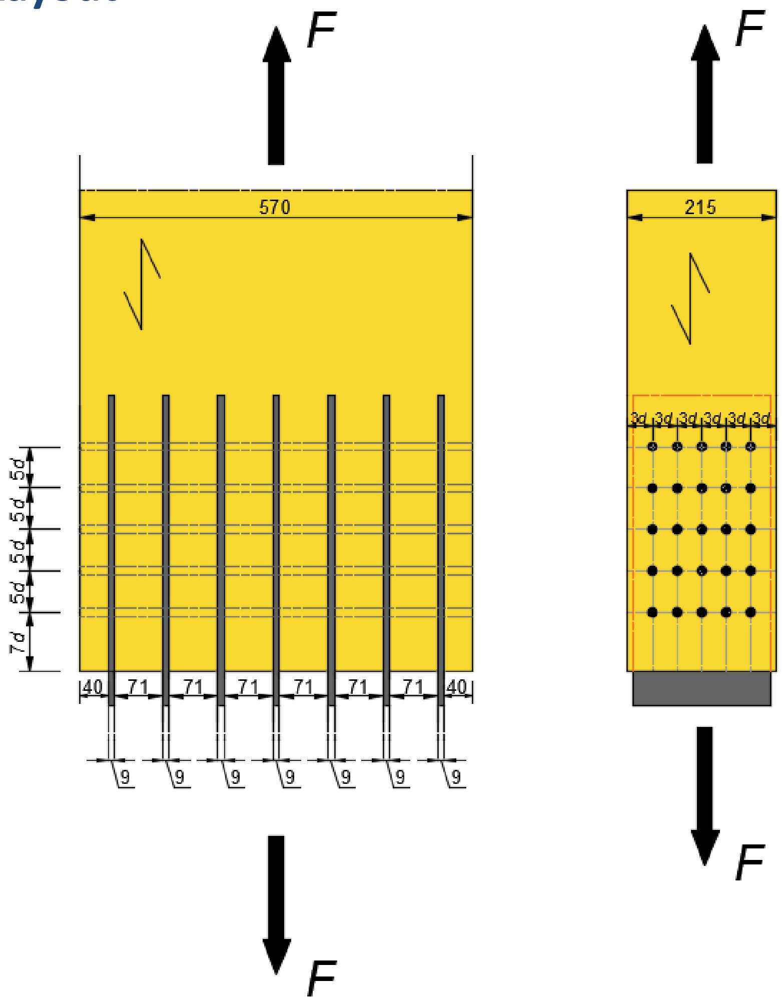
Connection with multiple slotted-in steel plates and dowels

Haris Stamatopoulos

Norwegian University of Science and Technology

Connection with multiple slotted-in steel plates and dowels

- Layout



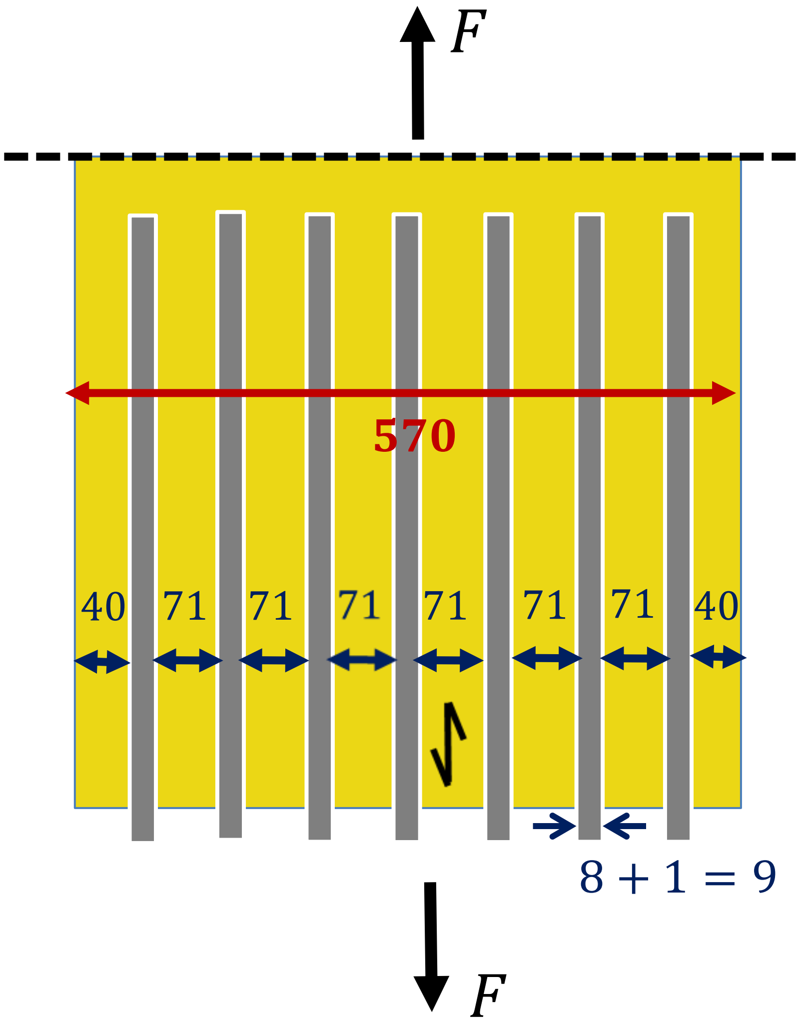
Similar example in practice

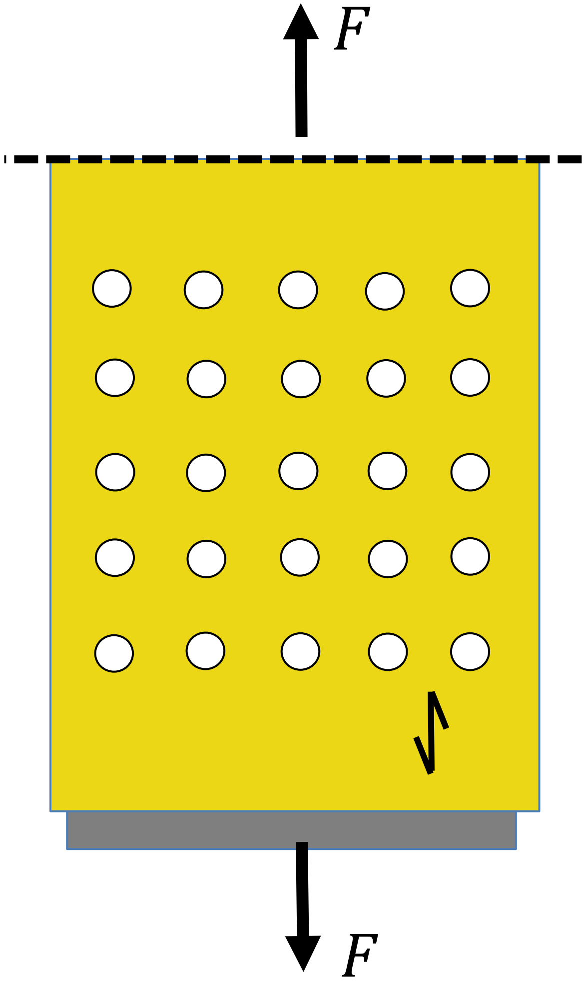
- 8mm-thick steel plates inserted in 9 mm slots
- Glulam GL32c
- 5x5 dowels, $d = 12\ \text{mm}$, $f_{\text{u,k}} = 400\ \text{N/mm}^2$

What is the maximum design value of the force F (i.e. F_{d}) in this connection?

Connection with multiple slotted-in steel plates and dowels

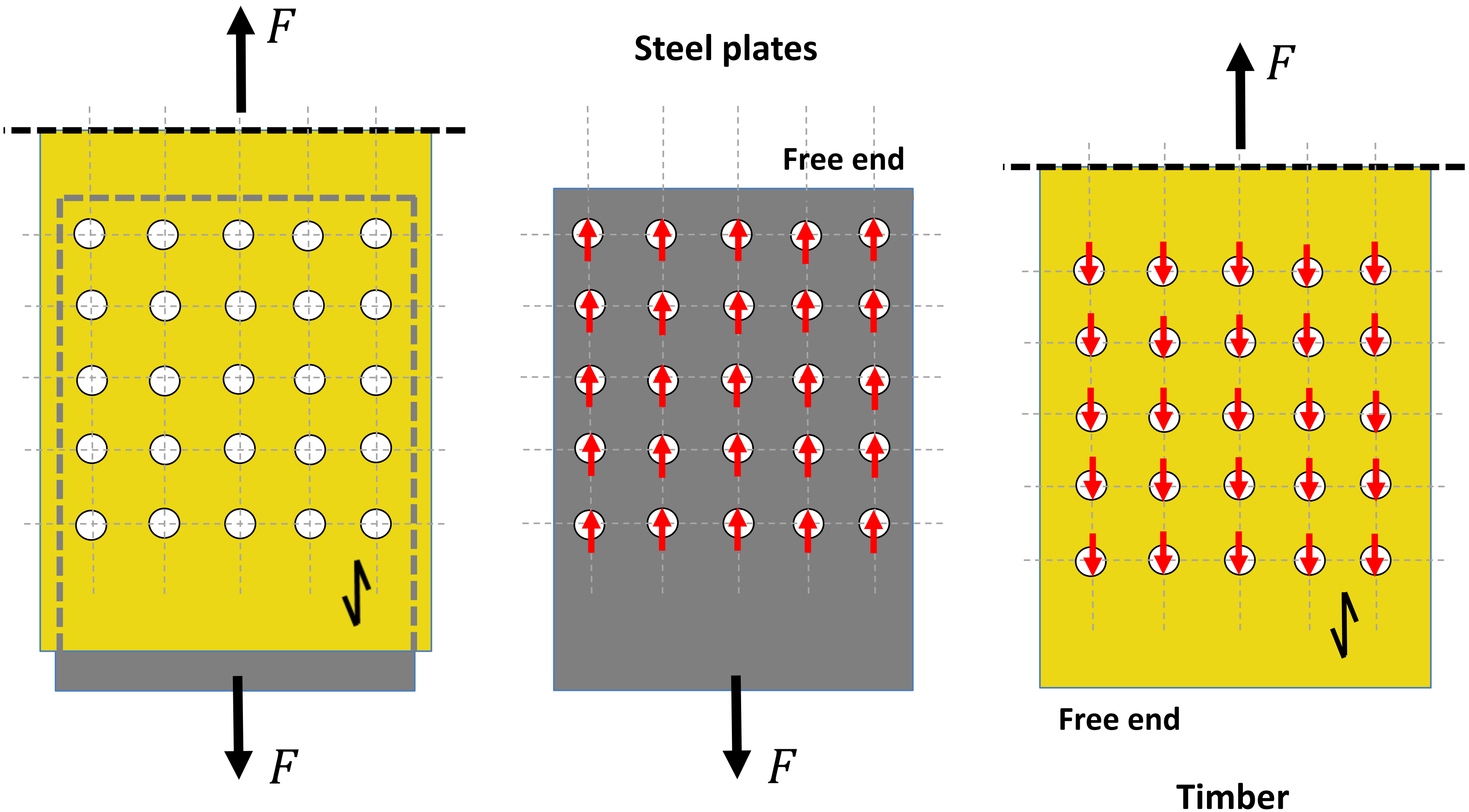
- Layout





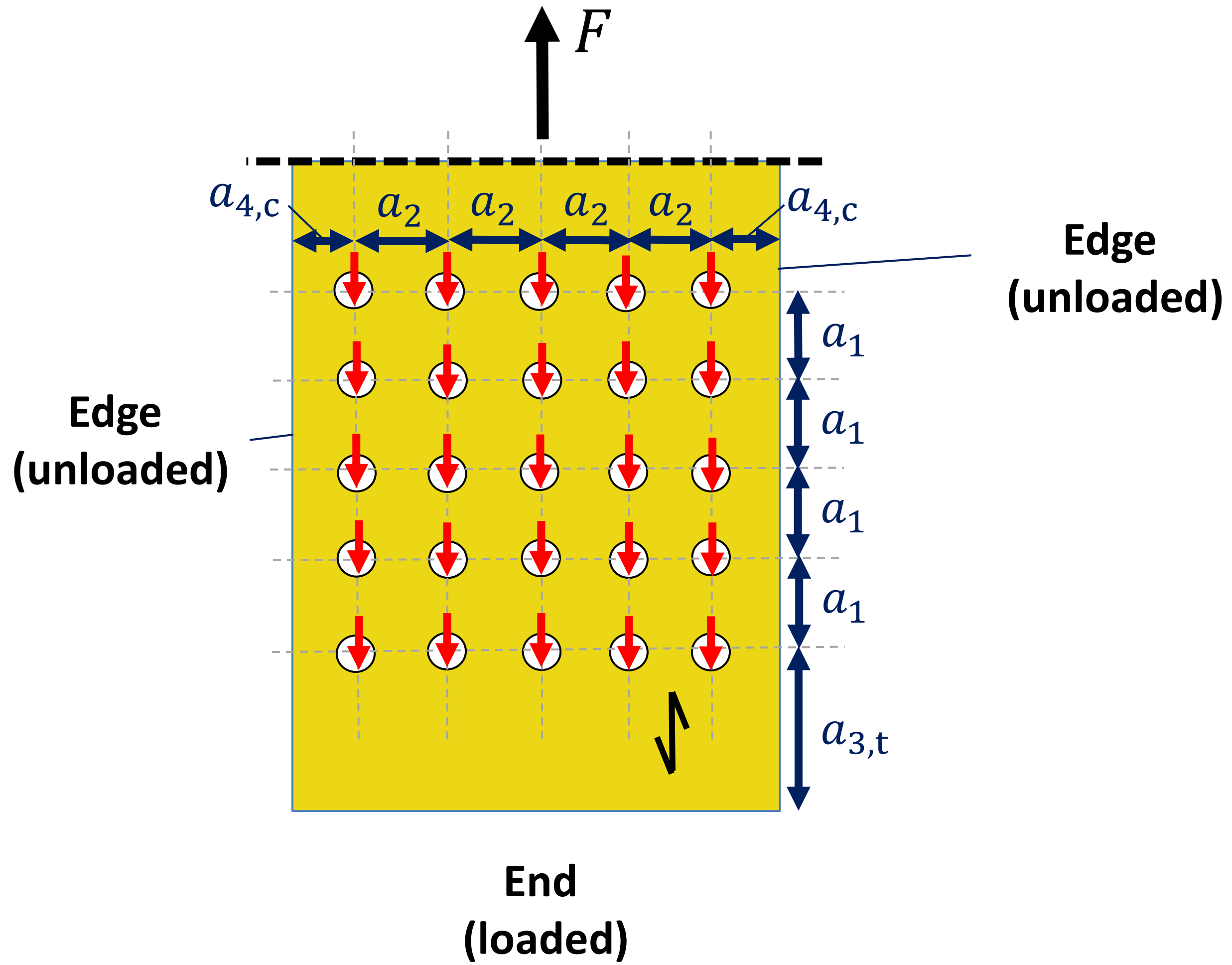
Connection with multiple slotted-in steel plates and dowels

- Free-body diagrams



Connection with multiple slotted-in steel plates and dowels

- Spacings, end and edge distances



Spacings, end and edge distances

- Dowels: EN1995-1-1, Table 8.5

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

Spacing and edge/end distances (see Figure 8.7)	Angle to grain	Minimum spacings and edge/end distances
a_1 (parallel to grain)	$0° \leq \alpha \leq 360°$	$(3+2\|\cos\alpha\|)d$
a_2 (perpendicular to grain)	$0° \leq \alpha \leq 360°$	$3\,d$
$a_{3,t}$ (loaded end)	$-90° \leq \alpha \leq 90°$	max ($7\,d$; 80 mm)
$a_{3,c}$ (unloaded end)	$90° \leq \alpha \leq 150°$ $150° \leq \alpha \leq 210°$ $210° \leq \alpha \leq 270°$	$a_{3,t}\,\|\sin\alpha\|$ max(3,5 d; 40 mm) $a_{3,t}\,\|\sin\alpha\|$
$a_{4,t}$ (loaded edge)	$0° \leq \alpha \leq 180°$	$\max((2+2\sin\alpha)d;3d)$
$a_{4,c}$ (unloaded edge)	$180° \leq \alpha \leq 360°$	$3\,d$

- **Minimum requirements (Table 8.5), $\alpha = 0°$**

$$a_1 \geq (3 + 2 \cdot |\cos 0°|) \cdot d = 5 \cdot d = 60 \text{ mm}$$

$$a_2 \geq 3 \cdot d = 36 \text{ mm}$$

$$a_{3,t} \geq \max(7 \cdot d, 80) = 7 \cdot d = 84 \text{ mm}$$

$$a_{4,c} \geq 3 \cdot d = 36 \text{ mm}$$

$a_{3,c}$ and $a_{4,t}$ are not relevant here

Connection with multiple slotted-in steel plates and dowels

- Spacings, end and edge distances

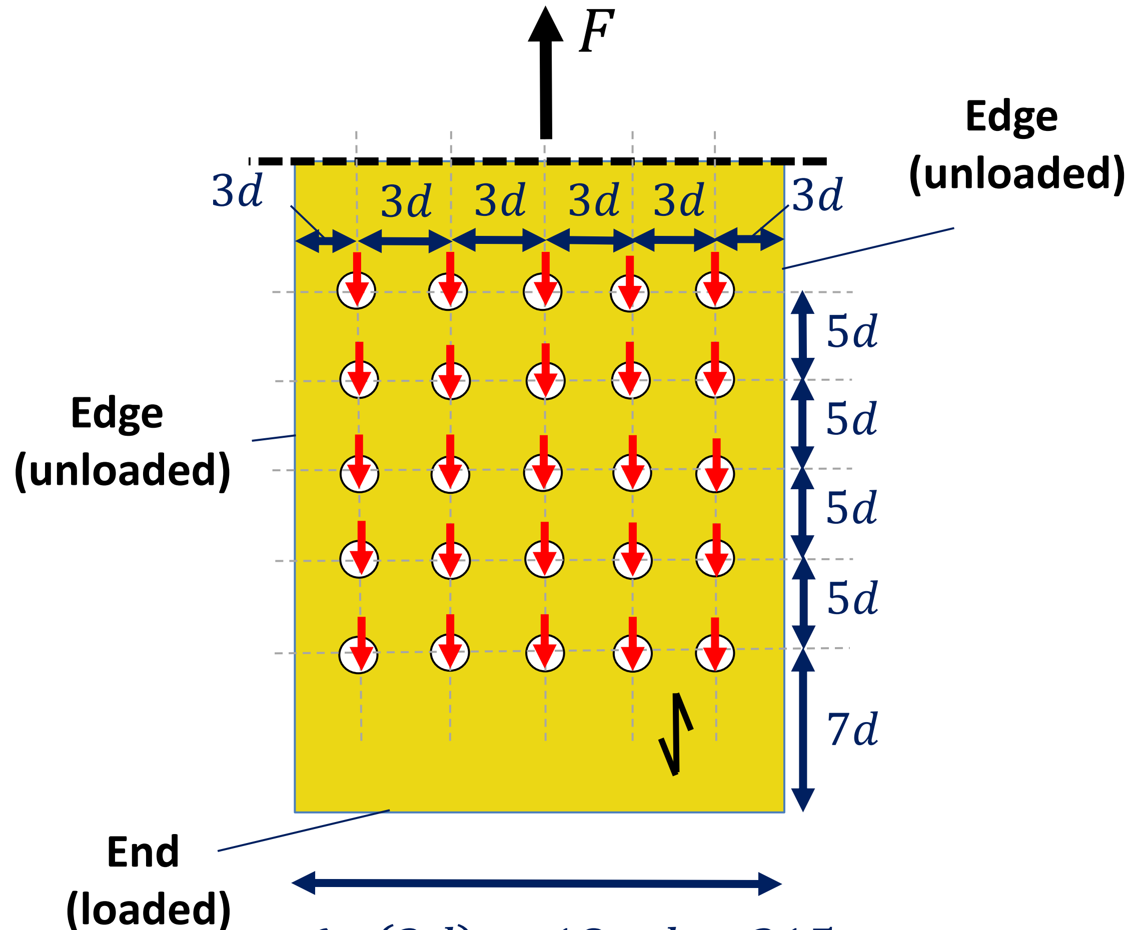
- **Use minimum spacings/distances**

$a_1 = 5 \cdot d = 60 \text{ mm}$

$a_2 = 3 \cdot d = 36 \text{ mm}$

$a_{3,\mathrm{t}} = 7 \cdot d = 84 \text{ mm}$

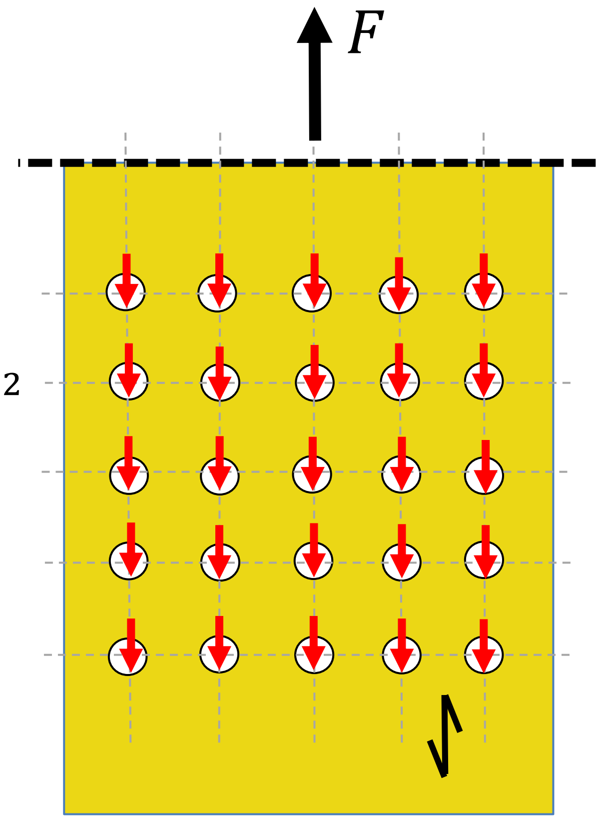
$a_{4,c} = 3 \cdot d = 36 \text{ mm}$



$6 \cdot (3d) = 18 \cdot d \approx 215 \text{ mm}$

Connection with multiple slotted-in steel plates and dowels

- Properties of timber and dowels



GL32c

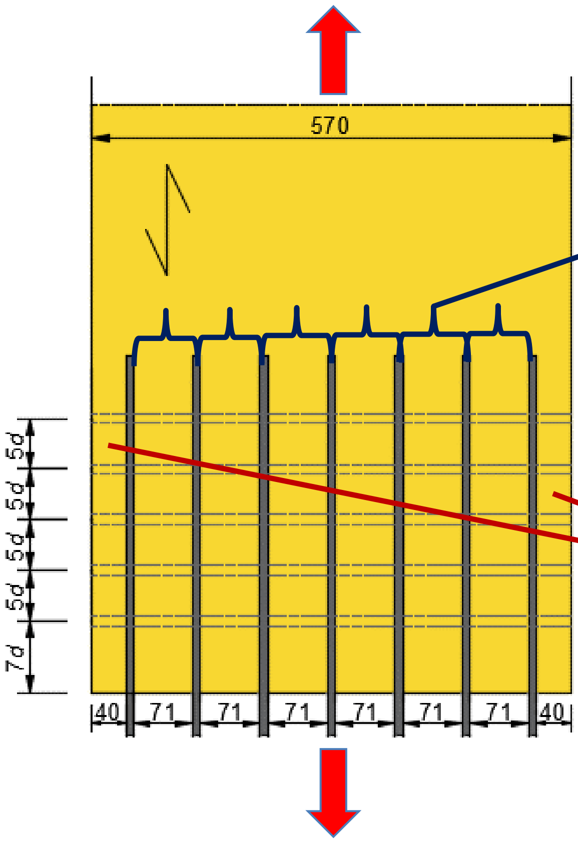
- EN14080: $\rho_{\mathrm{k}} = 400\ \mathrm{kg/m^3}$
- Force-to-grain angle: $\alpha = 0°$ (parallel to grain)
- Eq.(8.32): $f_{\mathrm{h,0,k}} = 0.082 \cdot (1 - 0.01 \cdot 12) \cdot 400 = 28.9\,\mathrm{N/mm^2}$
- Side members: $t_1 = 40\ \mathrm{mm}$
- Inner members: $t_2 = 71\ \mathrm{mm}$

Dowels

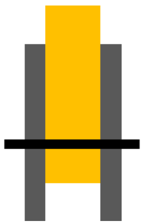
- $d = 12\ \mathrm{mm}$
- $f_{\mathrm{u,k}} = 400\,\mathrm{N/mm^2}$
- $F_{\mathrm{ax,Rk}} = 0$ (dowels)
- Eq.(8.30): $M_{\mathrm{y,Rk}} = 0.30 \cdot 400 \cdot 12^{2.6} = 76745\ \mathrm{Nmm}$

Load-carrying capacity

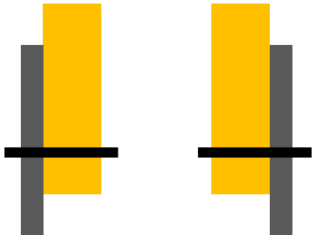
- Connections with multiple slotted-in steel plates: shear planes and members



Middle members: each member in ‘double shear’, steel-to timber with steel external members



Side members: each member in ‘single shear’, steel-to-timber

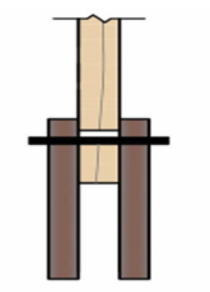


Load-carrying capacity

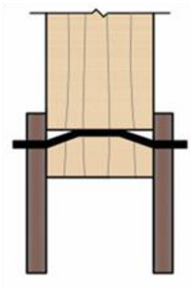
- Middle members: double shear steel-to-timber connections (timber in the middle)

thick steel plates
in fact medium thick, t = 0,66 * d

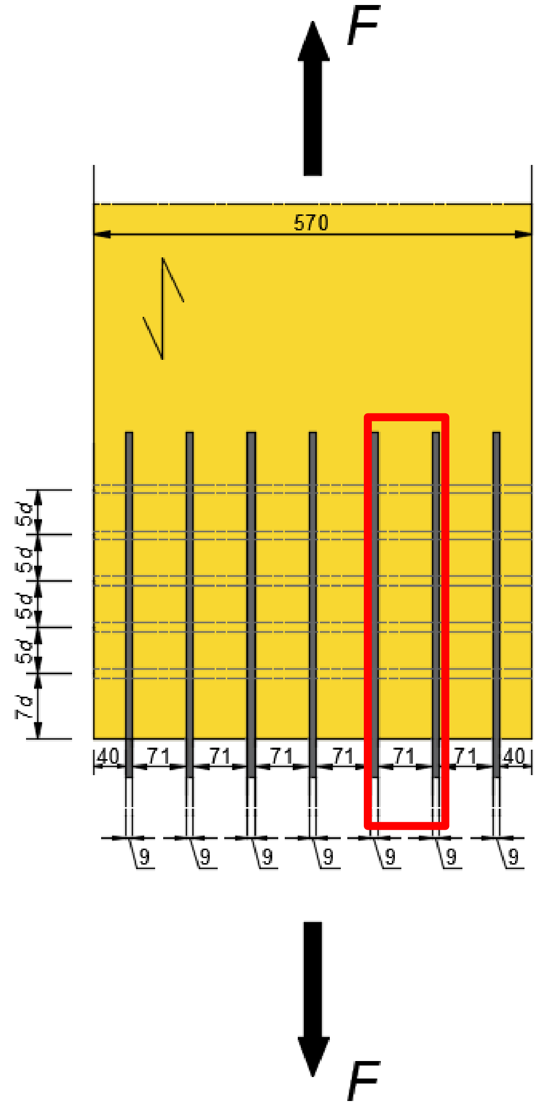
- **Assume: only modes (j/l) and (m) can occur**



j/l



m



$$F_{v,Rk} = \min\begin{cases} 0.5 \cdot f_{h,k} \cdot t_2 \cdot d & \text{(l)} \\ 2.3 \cdot \sqrt{M_{y,Rk} \cdot f_{h,k} \cdot d} + \dfrac{F_{ax,Rk}}{4} & \text{(m)} \end{cases}$$

EN 1995-1-1, §8.2.3.(3), **(eq.8.13)**

NTNU

Load-carrying capacity

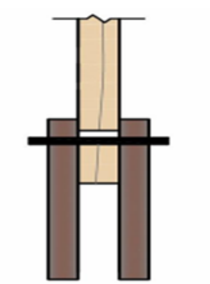
- Middle members: double shear steel-to-timber connections (timber in the middle)

- **Assume: only modes (j/l) and (m) can occur**

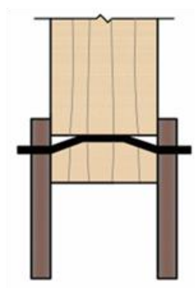
$$F_{\mathrm{v,Rk}}(\mathrm{j/l}) = 0.5 \cdot 28.9 \cdot 71 \cdot 12 = 12311\ \mathrm{N}$$

$$F_{\mathrm{v,Rk}}(\mathrm{m}) = 2.3 \cdot \sqrt{76745 \cdot 28.9 \cdot 12} + \frac{0}{4} = \mathbf{11865\ N}$$

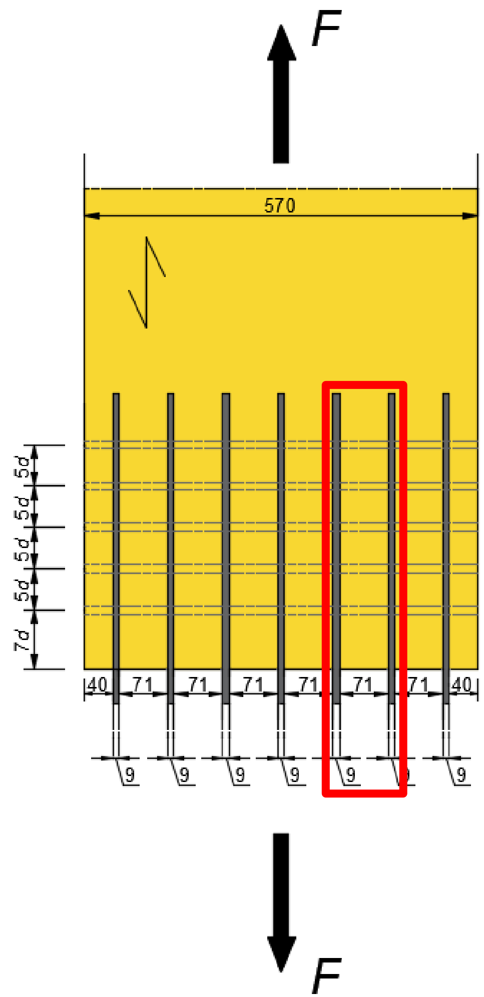
EN 1995-1-1, §8.2.3.(3), **(eq.8.13)**



j/l



m



- **Load carrying capacity per shear plane per fastener:**

$$\mathrm{F_{v,Rk}} = \min\left(F_{\mathrm{v,Rk(j/}l)}; F_{\mathrm{v,Rk(m)}}\right) = \mathbf{11865\ N}\ \text{[Failure mode (m)]}$$

NTNU

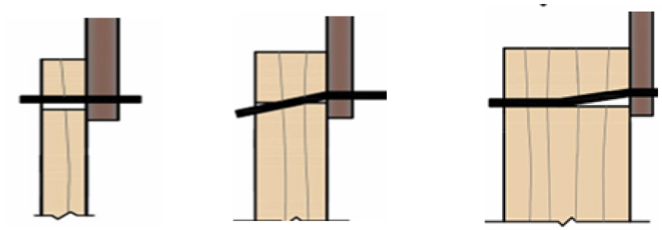
Load-carrying capacity

- Side members: single shear steel-to-timber connections

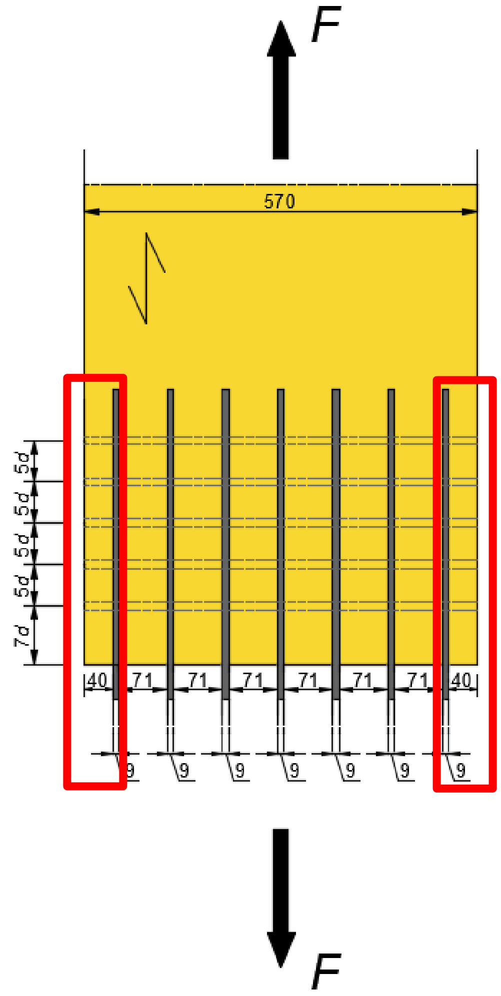
- **Assume: only modes (c), (d) and (e) can occur**

$$F_{\mathrm{v,Rk}} = \min \begin{cases} f_{\mathrm{h,k}} \cdot t_1 \cdot d & \text{(c)} \\ f_{\mathrm{h,k}} \cdot t_1 \cdot d \cdot \left[\sqrt{2 + \dfrac{4 \cdot M_{\mathrm{y,Rk}}}{f_{\mathrm{h,k}} \cdot d \cdot t_1^{\,2}}} - 1 \right] + \dfrac{F_{\mathrm{ax,Rk}}}{4} & \text{(d)} \\ 2.3 \cdot \sqrt{M_{\mathrm{y,Rk}} \cdot f_{\mathrm{h,k}} \cdot d} + \dfrac{F_{\mathrm{ax,Rk}}}{4} & \text{(e)} \end{cases}$$

EN 1995-1-1, §8.2.3.(3), **(eq.8.10)**



c d e



NTNU

Load-carrying capacity

- Side members: single shear steel-to-timber connections

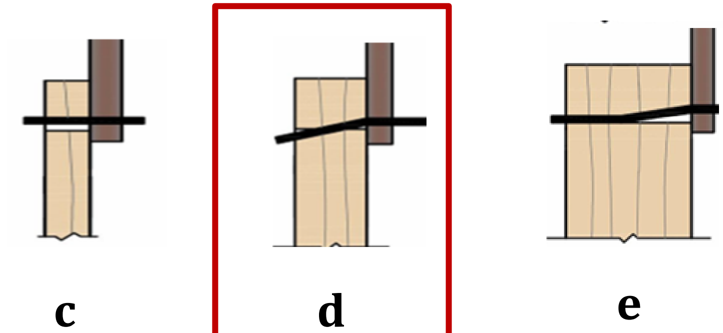
- **Assume: only modes (c), (d) and (e) can occur**

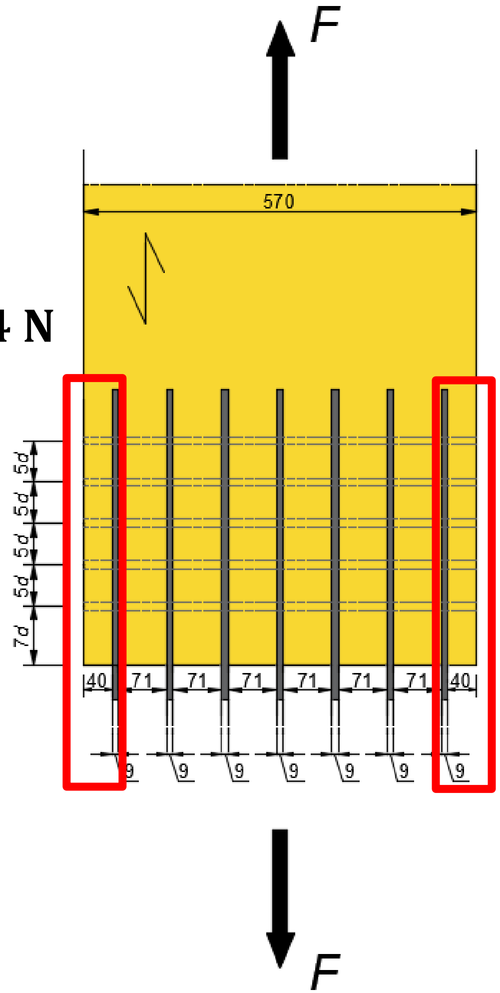
$$F_{v,Rk}(c) = 28.9 \cdot 40 \cdot 12 = 13872\ \mathrm{N}$$

$$F_{v,Rk}(d) = 28.9 \cdot 40 \cdot 12 \cdot \left[\sqrt{2 + \frac{4 \cdot 76745}{28.9 \cdot 12 \cdot 40^2}} - 1\right] + \frac{0}{4} = \mathbf{8294\ N}$$

$$F_{v,Rk}(e) = 2.3 \cdot \sqrt{76745 \cdot 28.9 \cdot 12} + \frac{0}{4} = 11866\ \mathrm{N}$$

EN 1995-1-1, §8.2.3.(3), **(eq.8.10)**





- **Load carrying capacity per shear plane per fastener:**

$$\mathrm{F}_{v,Rk} = \min\left(F_{v,Rk(c)}; F_{v,Rk(d)}; F_{v,Rk(e)}\right) = \mathbf{8294\ N}$$ [Failure mode (d)]

Load-carrying capacity

- Compatibility and total capacity per fastener

- **Compatibility**

- Failure modes: (m) + (d)
- (m) + (d) **are compatible** (EC5,§8.1.3.(2))
- Can be combined

- **Number of shear planes**

$n_{SP,\mathrm{tot}} = 14$ **total**

$n_{SP(\mathrm{m})} = n_{SP,\mathrm{tot}} - 2 = 14 - 2 = 12$ **middle members**

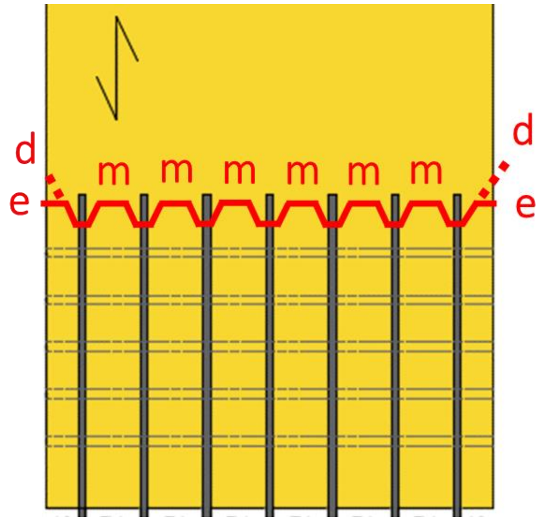
$n_{SP(\mathrm{d})} = 2$ **side members**

- **Load-carrying capacity per dowel (adding all shear planes):**

$$F_{\mathrm{v,Rk,i}} = n_{SP(\mathrm{m})} \cdot F_{\mathrm{v,Rk(m)}} + n_{SP(\mathrm{d/e})} \cdot F_{\mathrm{v,Rk(d/e)}}$$

$$\rightarrow F_{\mathrm{v,Rk,i}} = 12 \cdot 11865 + 2 \cdot 8294 = 158968\ \mathrm{N}$$

capacity for medium thick plate: 121,4 kN (76%)



Source: Blaβ

Load transfer

- Design check

- **Design load carrying capacity-per dowel:**

$$F_{v,Rd,i} = \frac{k_{mod}}{\gamma_M} \cdot F_{v,R\kappa,i} = \frac{k_{mod}}{\gamma_M} \cdot 158.9 \text{ kN}$$

EN 1995-1-1, §2.4.3(1), **eq.(2.17)**

- **Design load carrying capacity-entire connection:**

$$n_{fasteners} = 25 \text{ dowels}$$

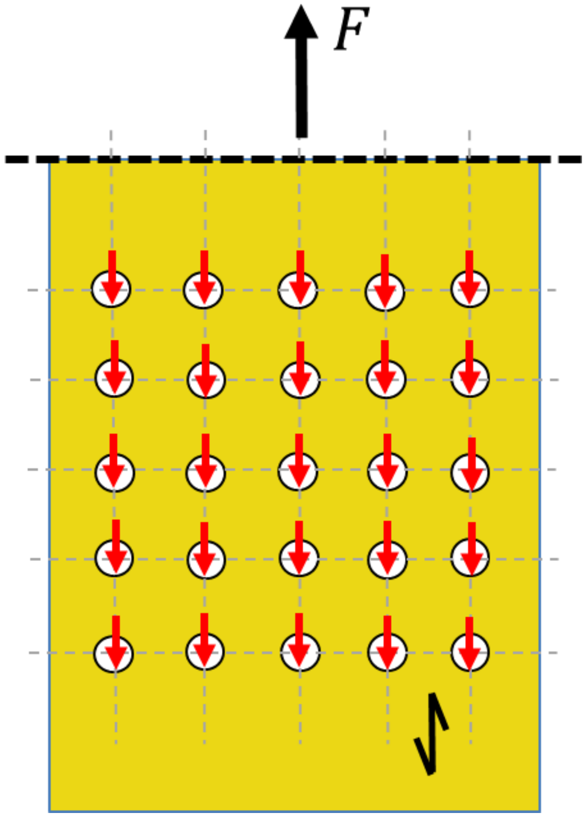
$$F_{v,Rd} = n_{fasteners} \cdot \frac{k_{mod}}{\gamma_M} \cdot F_{v,R\kappa,i} = 25 \cdot \frac{k_{mod}}{\gamma_M} \cdot 158.9 \text{ kN}$$

$$\rightarrow F_{v,Rd} = \frac{k_{mod}}{\gamma_M} \cdot 3975 \text{ kN}$$

- **Load transfer check:**

$$\boldsymbol{F_d \leq F_{v,Rd} = \frac{k_{mod}}{\gamma_M} \cdot 3975 \text{ kN}}$$

$$\boldsymbol{\gamma_M = 1.30}$$



Source: Blaβ

Splitting: force components parallel to grain

- Design check

- **Effective number of fasteners per row parallel to grain, Eq.(8.34)**
  - 5 fasteners in each row, i.e n =5

$$n_{\mathrm{ef}} = \min\left(n, n^{0.90} \cdot \sqrt[4]{\frac{a_1}{13 \cdot d}}\right) = \min\left(5, 5^{0.90} \cdot \sqrt[4]{\frac{5 \cdot 12}{13 \cdot 12}}\right) = 3.35$$

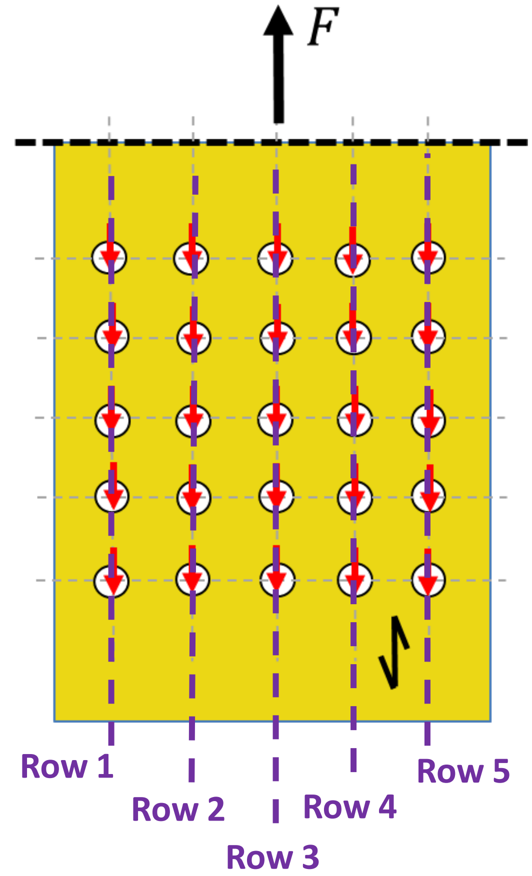
- **Effective load-carrying capacity of each row, Eq.(8.1)**
  - Comment: The force is applied parallel to grain $F_{\mathrm{v,Rk}(\alpha=0°)} = 158.9\ \mathrm{kN}$. Same as before.

$$F_{\mathrm{v,ef,Rk}} = \boldsymbol{n}_{\mathbf{ef}} \cdot F_{\mathrm{v,Rk}(\alpha=0°)} = 3.35 \cdot 158.9\ \mathrm{kN} = 532.9\ \mathrm{kN}$$ **per row**

EN 1995-1-1, §8.1.2(4), **eq.(8.1)**

$$F_{\mathrm{v,ef,Rd}} = k_{\mathrm{mod}}/\gamma_{\mathrm{M}} \cdot F_{\mathrm{v,ef,Rk}} = k_{\mathrm{mod}}/\gamma_{\mathrm{M}} \cdot 532.9\ \mathrm{kN}$$ **per row**

EN 1995-1-1, §2.4.3(1), **eq.(2.17)**



Source: SJÖDIN

- **Design check, §8.1.2(5)**

$$F_{\mathrm{row,d}} = \frac{F_{\mathrm{d}}}{5\ \mathrm{rows}} \le F_{\mathrm{v,ef,Rd}}\ (\mathrm{per\ row}) = k_{\mathrm{mod}}/\gamma_{\mathrm{M}} \cdot 532.9\ \mathrm{kN} \rightarrow \boldsymbol{F_{\mathrm{d}} \le \frac{k_{\mathrm{mod}}}{\gamma_{\mathrm{M}}} \cdot 2664\ \mathrm{kN}}$$

EN 1995-1-1, §**8.1.2(5)**

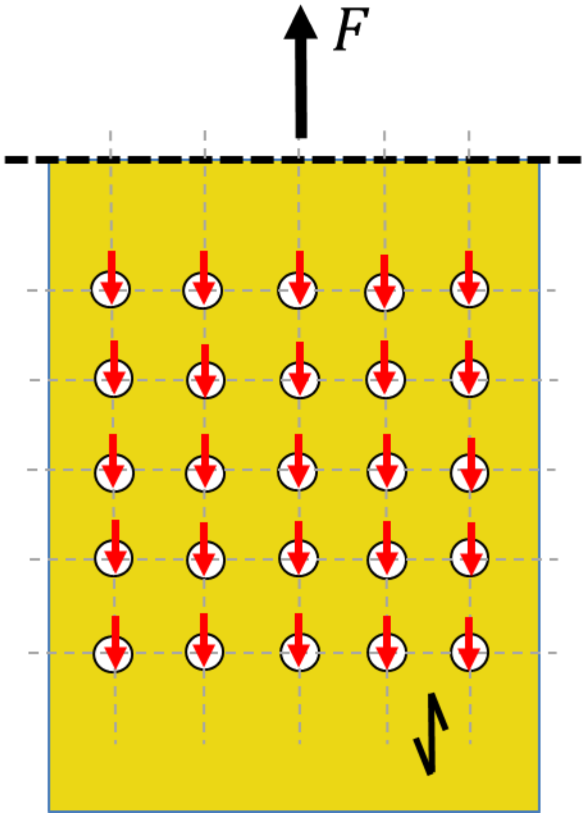
$$\boldsymbol{\gamma_{\mathrm{M}} = 1.30}$$

NTNU

Splitting: force components perpendicular to grain

- Not relevant

- Splitting perpendicular to grain is not relevant because there are no force components perpendicular to grain (i.e. no shear: $\boldsymbol{F}_{\mathbf{V,Ed}} = \mathbf{0}$)

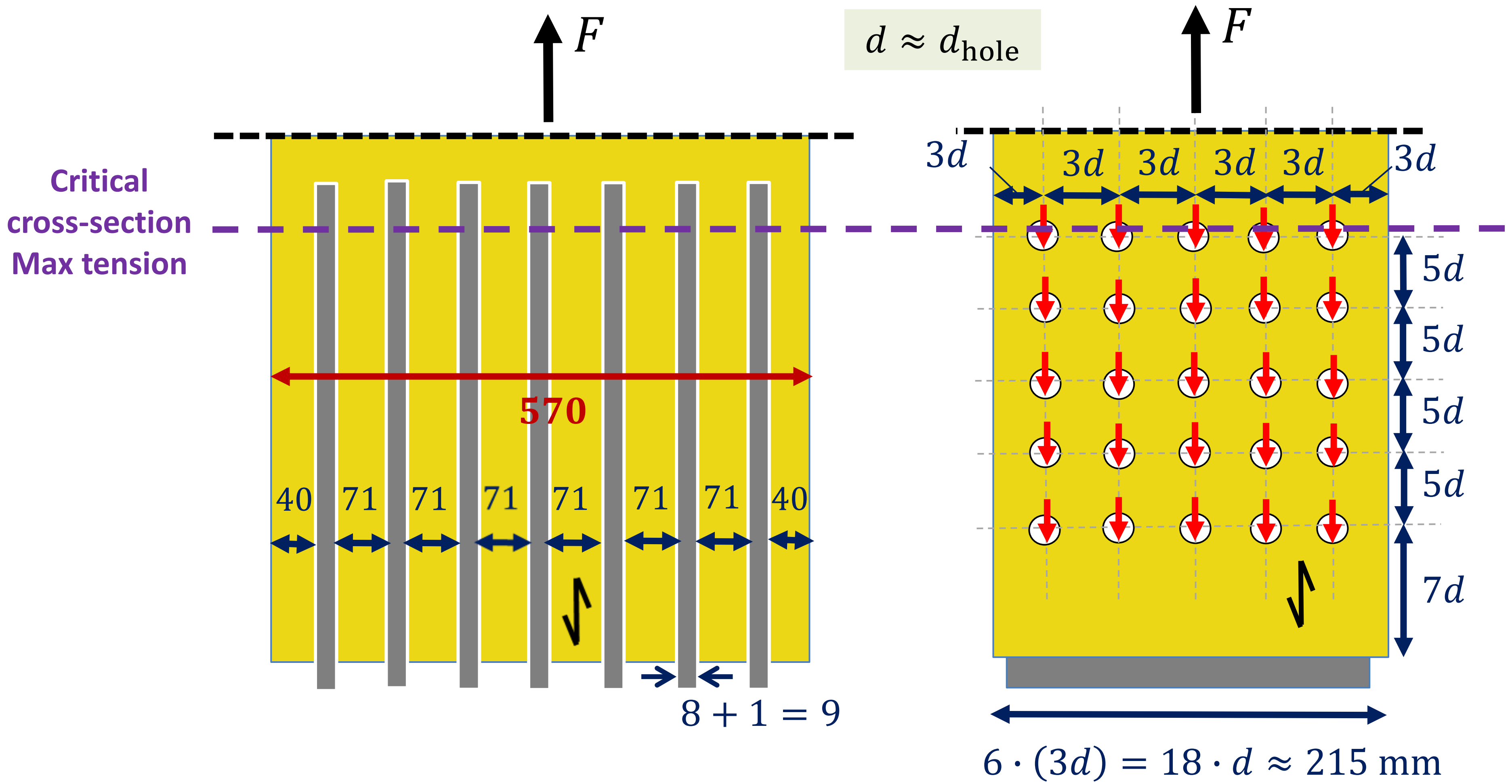


Net-section failure

- Net area

Assume small tolerance:

$d \approx d_{\text{hole}}$



$$A_{\text{net}} = (570 - 7 \cdot 9) \cdot (215 - 5 \cdot 12) = 78585 \text{ mm}^2$$

Net-section failure

- Design check

$$\sigma_{t,0,d} = \frac{F}{A_{net}} \leq f_{t,0,d}$$

EN 1995-1-1, §6.1.2, **eq.(6.1)**

Glulam GL32c (EN14080):

$$f_{t,0,k} = 19.5\ \mathrm{N/mm^2}$$

$$\gamma_M = 1.15$$

$$k_h = \min\left((600/570)^{0.1}, 1.1\right) \approx 1.0$$

full section width for kh

EN 1995-1-1 **eq.(3.2)**

$$f_{t,0,d} = 19.5 \cdot k_{mod}/\gamma_M\ \ (\mathrm{N/mm^2})$$

EN 1995-1-1 (**eq.2.14)**

$$F_d \leq f_{t,0,d} \cdot A_{net} = k_{mod}/\gamma_M \cdot 19.5 \cdot 78585\ (\mathrm{N})$$

$$\rightarrow \boldsymbol{F_d \leq \frac{k_{mod}}{\gamma_M} \cdot 1532\ \mathrm{kN}}$$

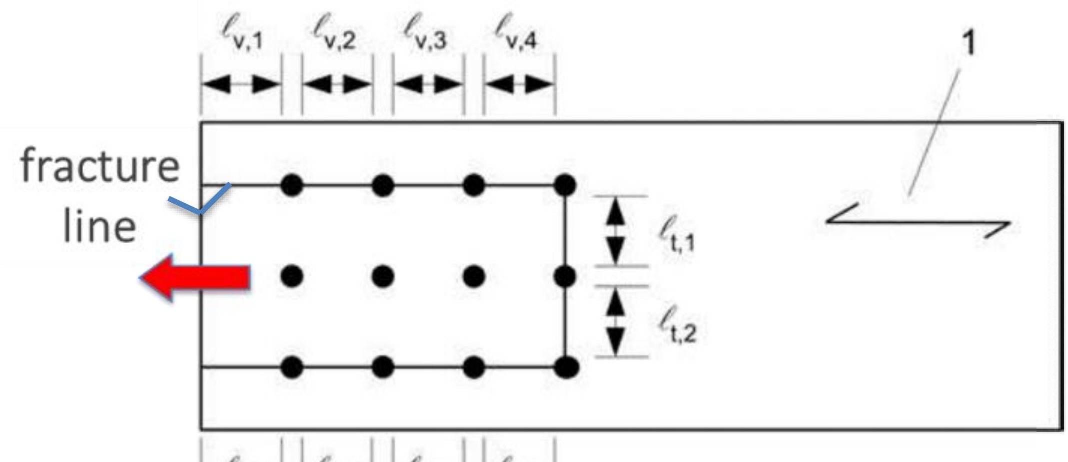
=1198 kN

$$\boldsymbol{\gamma_M = 1.15}$$

Source: VTT

Block shear

- EN1995-1-1, 8.2.3(5), Annex A



EN 1995-1-1, Figure A.1

Source: Antti Hanhijärvi & Ari Kevarinmäki

- **8.2.3(5)**
  - Steel-to-timber connections with a loaded end should be checked for block shear

Block shear

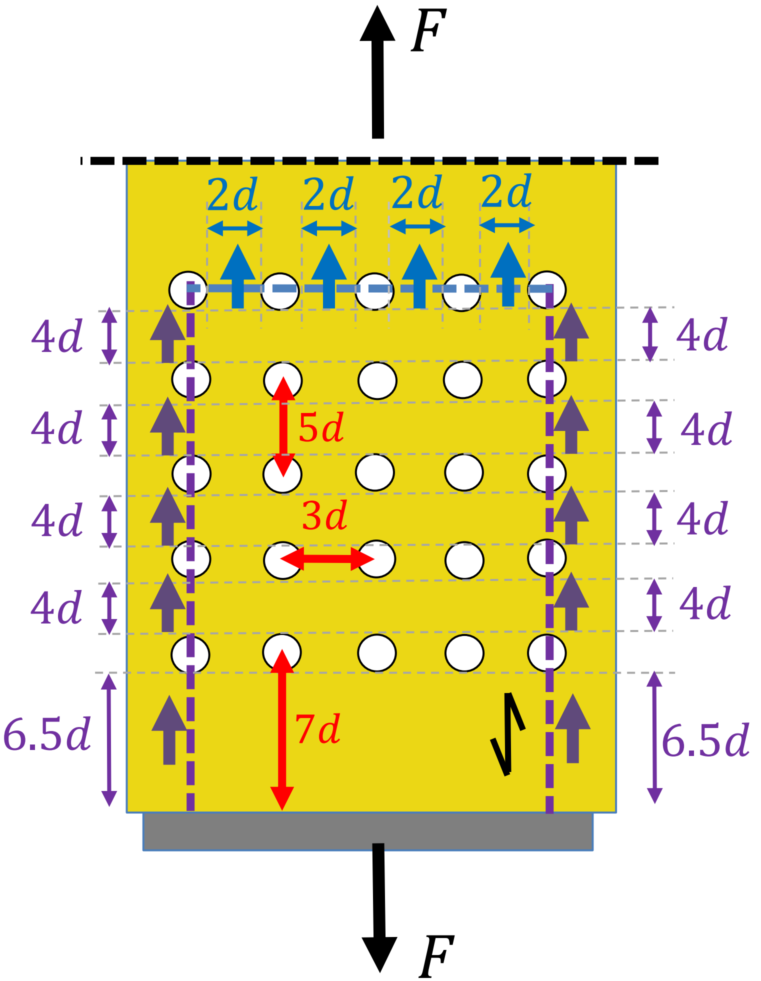
- EN1995-1-1, 8.2.3(5), Annex A

- **Net distances**

$$l_{\mathrm{t,i}} = l_{\mathrm{t,1}} = l_{\mathrm{t,2}} = l_{\mathrm{t,3}} = l_{\mathrm{t,4}} = 2 \cdot d$$

$$l_{\mathrm{v,i}} = 4 \cdot d \text{ (between fasteners)}$$

$$l_{\mathrm{v,i}} = 6.5 \cdot d \text{ (between fasteners and end)}$$



$$L_{\mathrm{net,t}} = \sum_i l_{\mathrm{t,i}} = 4 \cdot (2 \cdot d) = 8 \cdot d = 96 \text{ mm}$$

EN 1995-1-1, §A(1), **eq.(A.5)**

$$L_{\mathrm{net,v}} = \sum_i l_{\mathrm{v,i}} = 8 \cdot (4 \cdot d) + 2 \cdot (6.5 \cdot d) = 45 \cdot d = 540 \text{ mm}$$

EN 1995-1-1, §A(1), **eq.(A.4)**

Block shear

- EN1995-1-1, 8.2.3(5), Annex A, Tension

- **Total thickness (tension)**

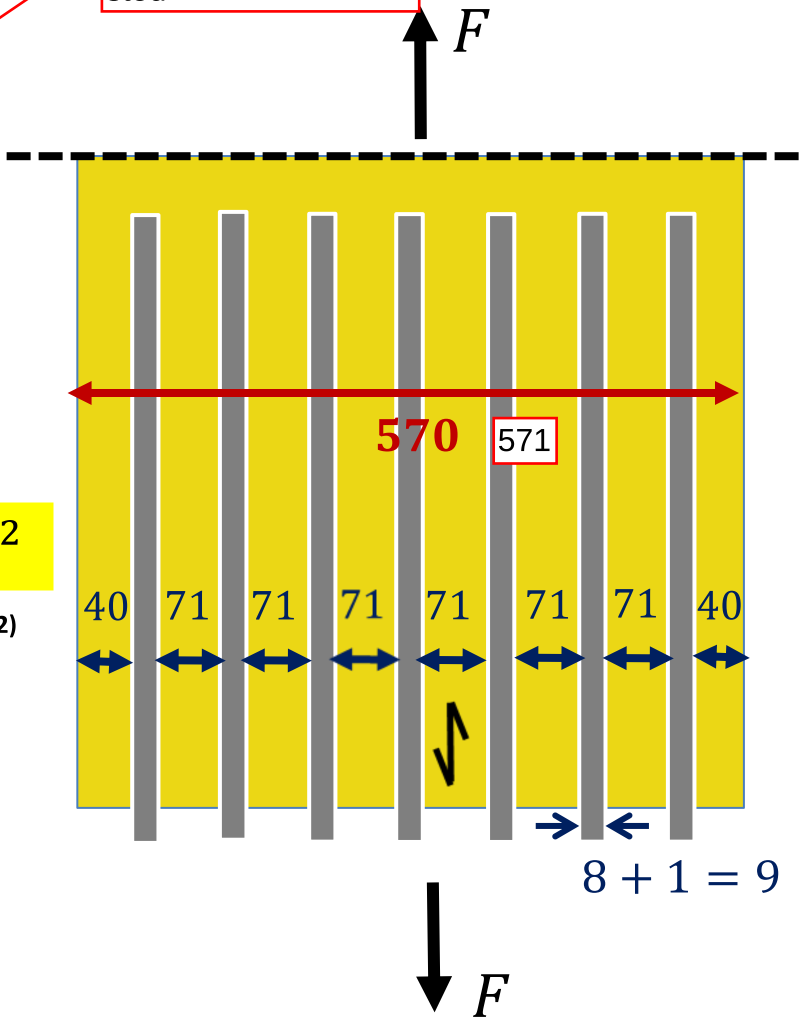
$$t_{\text{net,t}} = 570 - 7 \cdot 9 = 507 \text{ mm}$$

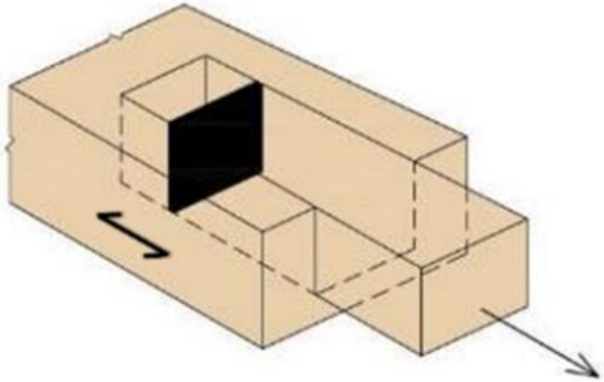
det mangler 1mm et sted

- **Total area (tension)**

$$A_{\text{net,t}} = L_{\text{net,t}} \cdot t_{\text{net,t}} = 96 \cdot 507 = 48672 \text{ mm}^2$$

EN 1995-1-1, §A(1), **eq.(A.2)**

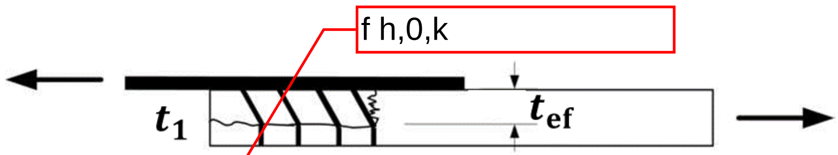


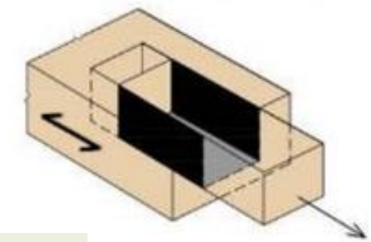


Block shear

- EN1995-1-1, 8.2.3(5), Annex A, Shear

- **Side members: assuming 3-sided failure (method according to EN1995-1-1)**





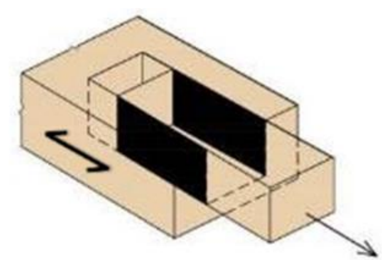
$$t_{ef(d)} = t_1 \cdot \left[\sqrt{2 + \frac{4 \cdot M_{y,Rk}}{f_{h,k} \cdot d \cdot {t_1}^2}} - 1\right] = 40 \cdot \left[\sqrt{2 + \frac{4 \cdot 76745}{28.9 \cdot 12 \cdot 40^2}} - 1\right] = 24\ \mathrm{mm/side}$$

EN 1995-1-1, §A(1), **eq.(A.7)**

$$A_{net,v} = \frac{L_{net,v}}{2} \cdot \left(L_{net,t} + 2 \cdot t_{ef}\right) = \frac{540}{2} \cdot (96 + 2 \cdot 24) = 38880\ \mathrm{mm}^2/\mathrm{side}$$

EN 1995-1-1, §A(1), **eq.(A.3)**

- **Side members: assuming 2-sided failure**



$$A_{net,v} = L_{net,v} \cdot t_1 = 540 \cdot 40 = 21600\ \mathrm{mm}^2/\mathrm{side}$$

We choose conservatively $A_{net,v} = 21600\ \mathrm{mm}^2$ for each side member

Block shear

- EN1995-1-1, 8.2.3(5), Annex A, Shear

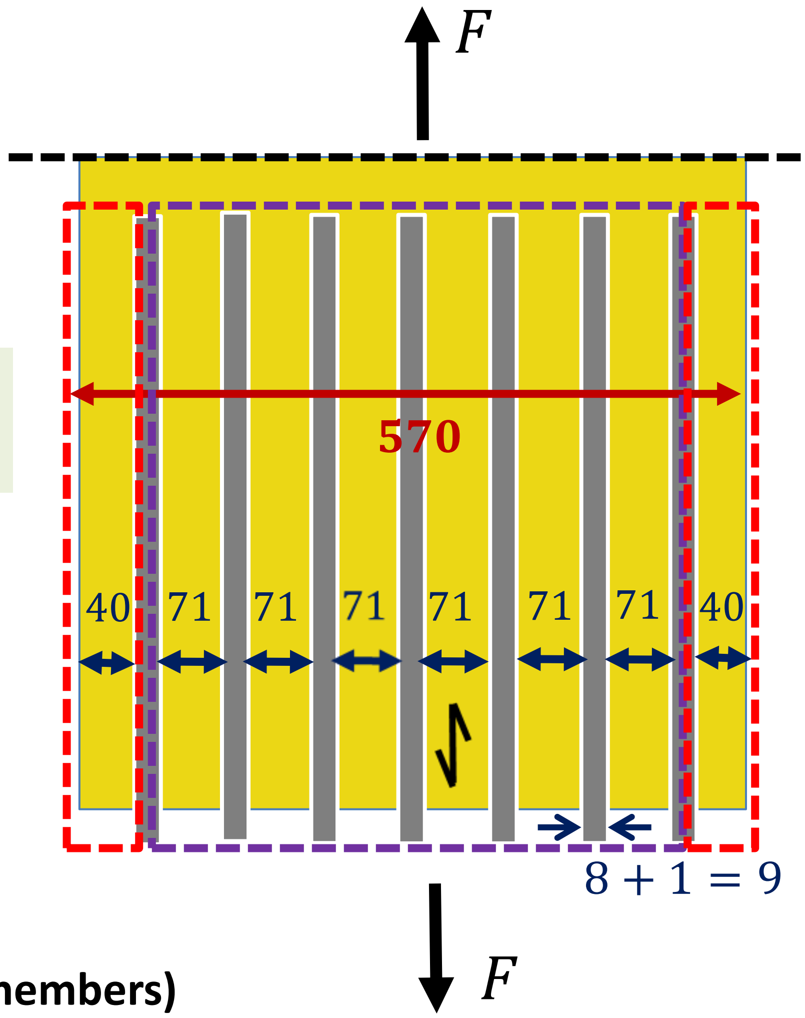
- **Total area (shear), middle members:**
  - **Failure mode (m), Eq.(A.3)**

$$A_{\text{net,v}} = L_{\text{net,v}} \cdot \sum t_{\text{i}} = 540 \cdot (6 \cdot 71) = 230040 \text{ mm}^2$$

EN 1995-1-1, §A(1), **eq.(A.3)**

- **Total area (shear), side members members:**
  - **See previous slide**

$$A_{\text{net,v}} = 2\text{sides} \cdot 21600 \text{ mm}^2/\text{side} = 43200 \text{ mm}^2$$



- **Total area (shear), entire member (middle + side members)**

$$A_{\text{net,v}} = 230040 + 43200 = 273240 \text{ mm}^2$$

Block shear
- Design check

- **Glulam GL32c (EN14080):**

$f_{t,0,k} = 19.5\ \mathrm{N/mm^2}$ $\quad$ $f_{v,k} = 3.5\ \mathrm{N/mm^2}$

- **Characteristic capacity**

$$F_{bs,Rk} = \mathbf{max}\begin{Bmatrix} 1.5 \cdot A_{net,t} \cdot f_{t,0,k} \\ 0.7 \cdot A_{net,v} \cdot f_{v,k} \end{Bmatrix} = \mathbf{max}\begin{Bmatrix} 1.5 \cdot 48672 \cdot 19.5\ \mathrm{N} \\ 0.7 \cdot 273240 \cdot 3.5\ \mathrm{N} \end{Bmatrix} = \mathbf{max}\begin{Bmatrix} 1423\ \mathrm{kN} \\ 669\ \mathrm{kN} \end{Bmatrix} = 1423\ \mathrm{kN}$$

EN 1995-1-1, §A (1), **eq.(A.1)**

- **Design capacity and design check**

$$F_{bs,Rd} = \frac{k_{mod}}{\gamma_M} \cdot F_{bs,Rk}$$

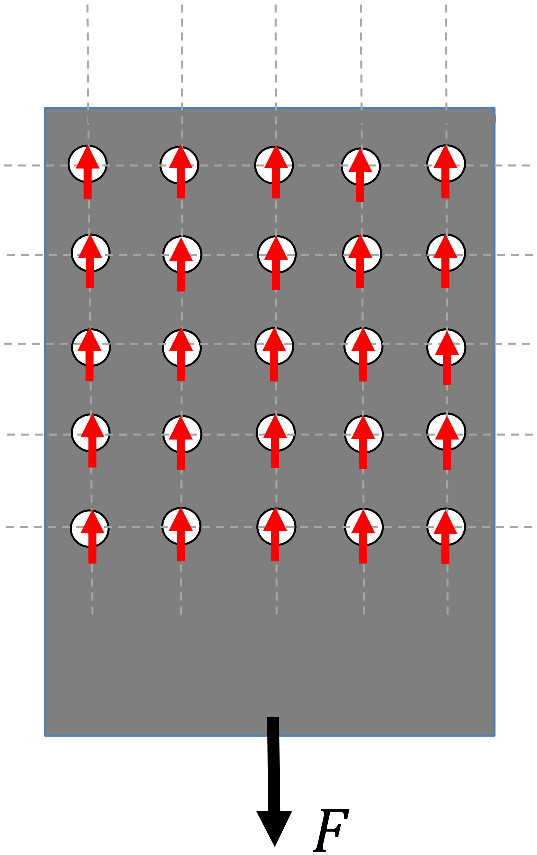
EN 1995-1-1, §2.4.3(1), **eq.(2.17)**

$$\rightarrow \quad \boldsymbol{F_d \leq \frac{k_{mod}}{\gamma_M} \cdot 1423\ \mathrm{kN}}$$

$$\boldsymbol{\gamma_M = 1.30}$$

Source: Antti Hanhijärvi & Ari Kevarinmäki

Steel plates
- Design checks (EN1993)



NS-EN 1993-1-8, tabell 3.3

Table 3.3: Minimum and maximum spacing, end and edge distances

Distances and spacings, see Figure 3.1	Minimum	Maximum[1) 2) 3)]		
		Structures made from steels conforming to EN 10025 except steels conforming to EN 10025-5		Structures made from steels conforming to EN 10025-5
		Steel exposed to the weather or other corrosive influences	Steel not exposed to the weather or other corrosive influences	Steel used unprotected
End distance e_1	$1{,}2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Edge distance e_2	$1{,}2d_0$	$4t + 40$ mm		The larger of $8t$ or 125 mm
Distance e_3 in slotted holes	$1{,}5d_0$ [4)]			
Distance e_4 in slotted holes	$1{,}5d_0$ [4)]			
Spacing p_1	$2{,}2d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm
Spacing $p_{1,0}$		The smaller of $14t$ or 200 mm		
Spacing $p_{1,i}$		The smaller of $28t$ or 400 mm		
Spacing p_2 [5)]	$2{,}4d_0$	The smaller of $14t$ or 200 mm	The smaller of $14t$ or 200 mm	The smaller of $14t_{min}$ or 175 mm

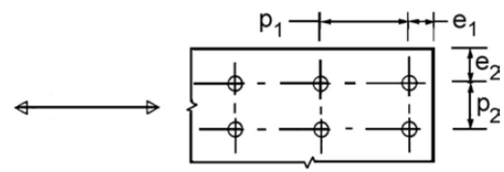
1) Maximum values for spacings, edge and end distances are unlimited, except in the following cases:
- for compression members in order to avoid local buckling and to prevent corrosion in exposed members and;
- for exposed tension members to prevent corrosion.

2) The local buckling resistance of the plate in compression between the fasteners should be calculated according to EN 1993-1-1 using $0{,}6\,p_1$ as buckling length. Local buckling between the fasteners need not to be checked if p_1/t is smaller than $9\,\varepsilon$. The edge distance should not exceed the local buckling requirements for an outstand element in the compression members, see EN 1993-1-1. The end distance is not affected by this requirement.

3) t is the thickness of the thinner outer connected part.

4) The dimensional limits for slotted holes are given in 1.2.7 Reference Standards: Group 7.

5) For staggered rows of fasteners a minimum line spacing of $p_2 = 1{,}2d_0$ may be used, provided that the minimum distance, L, between any two fasteners is greater or equal than $2{,}4d_0$, see Figure 3.1b).



- **Tension:** $$N_{\mathrm{t,Rd}} = \min\left(\frac{f_{\mathrm{y}} \cdot A}{\gamma_{\mathrm{M0}}}, \frac{0.9 \cdot f_{\mathrm{u}} \cdot A_{\mathrm{net}}}{\gamma_{\mathrm{M2}}}\right)$$

EN 1993-1-1, §6.2.3, **Eqs.(6.5-6.7)**

Steel plates should also be checked according to EN1993. Skipped here

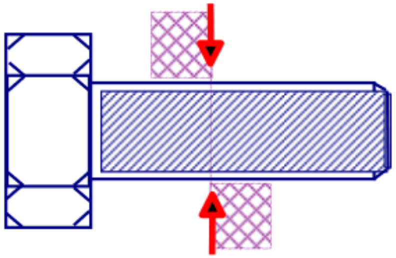
NTNU

Dowels

- Shear and bearing resistance

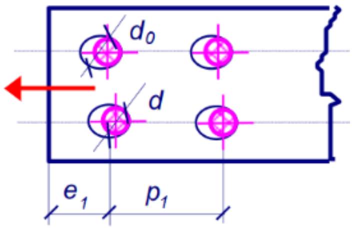
- **Shear resistance**

$$F_{V,Rd} = \frac{a_v \cdot f_{u,b} \cdot A}{\gamma_{M2}}$$



- **Bearing resistance**

$$F_{b,Rd} = \frac{k_1 \cdot a_b \cdot f_u \cdot d \cdot t}{\gamma_{M2}}$$



Dowels should be checked for shear and bearing according to EN1993. Skipped here.

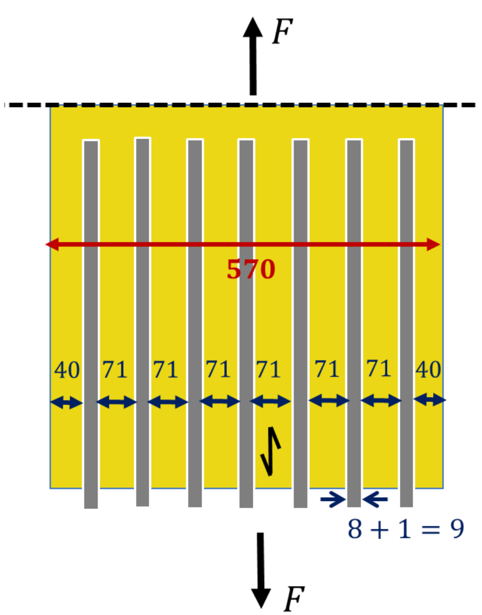
Connection with multiple slotted-in steel plates and dowels

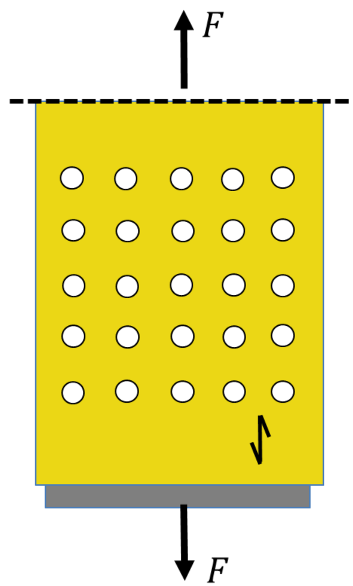
- Summary: capacity

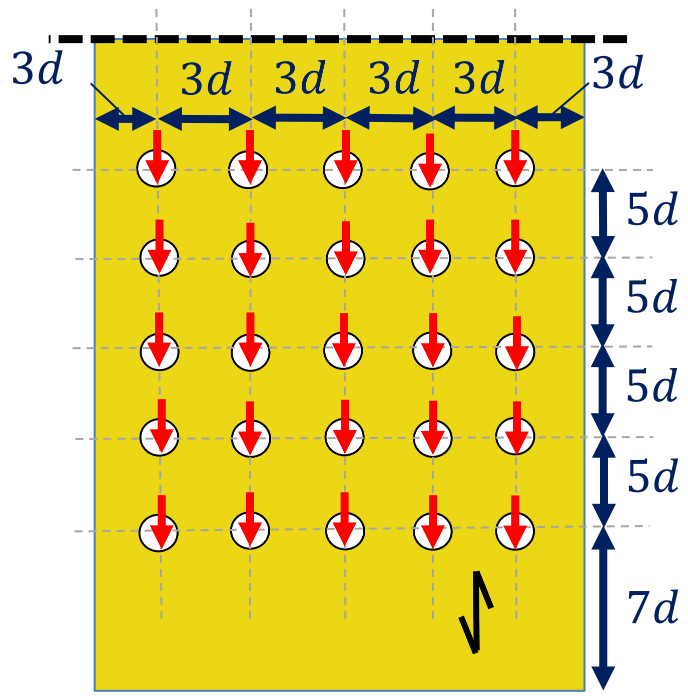
$$F_{\mathrm{d}} \leq \min\left\{\frac{k_{\mathrm{mod}}}{\gamma_{\mathrm{M}}=1.3}\cdot 3975\ \mathrm{kN}, \frac{k_{\mathrm{mod}}}{\gamma_{\mathrm{M}}=1.3}\cdot 2664\ \mathrm{kN}, \frac{k_{\mathrm{mod}}}{\gamma_{\mathrm{M}}=1.15}\cdot 1532\ \mathrm{kN}, \frac{\boldsymbol{k}_{\mathbf{mod}}}{\boldsymbol{\gamma}_{\mathbf{M}}=\mathbf{1.3}}\cdot \mathbf{1423\ kN}\right\}$$

$$\boldsymbol{F}_{\mathbf{d}} \leq \frac{\boldsymbol{k}_{\mathbf{mod}}}{\boldsymbol{\gamma}_{\mathbf{M}}=\mathbf{1.3}}\cdot \mathbf{1423\ kN}$$

(block shear is critical)



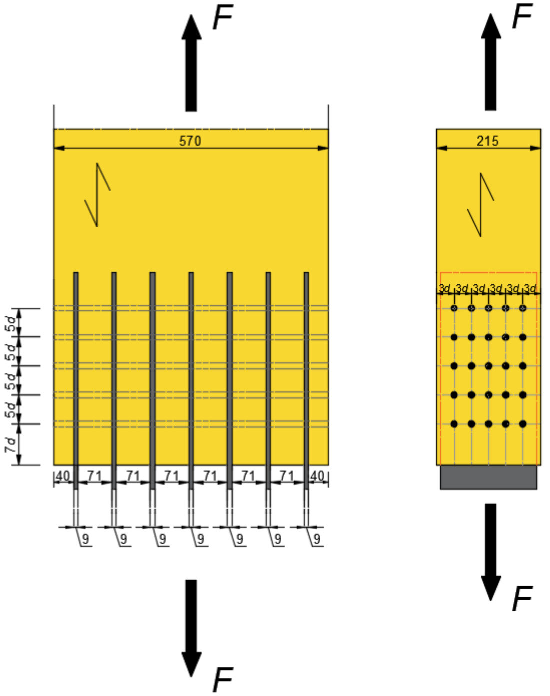




Connection with multiple slotted-in steel plates and dowels

- Stiffness (assume member length end-to-end = 5m, connections on both ends)

Table 7.1 – stiffness based on timber member per shear plane per fastener	$K_{\text{ser}} = \frac{{\rho_{\text{m}}}^{1.5} \cdot d}{23} = \frac{440^{1.5} \cdot 12}{23} = 4815 \text{ N/mm}$
§7.1.(3) – steel-to-timber connection (per shear plane per fastener)	$K_{\text{ser}} = 2 \cdot 4815 = 9630 \text{ N/mm}$
Entire connection	$K_{\text{ser}} = \left(\begin{matrix} 25 \\ dowels \end{matrix}\right) \cdot \left(\begin{matrix} 14\ shear \\ planes \end{matrix}\right) \cdot 9630 = 3.4 \cdot 10^6 \text{ N/mm}$
§2.2.2.(2) - Slip modulus for the ULS	$K_{\text{u}} = \frac{2}{3} \cdot 3.4 \cdot 10^6 = 2.25 \cdot 10^6 \text{N/mm}$
Member stiffness	$K_L = \frac{A \cdot E}{L} = \frac{570 \cdot 215 \cdot 13500}{4600} = 3.6 \cdot 10^5 \text{N/mm}$
System stiffness (Ultimate limit state)	$K_{\text{system,u}} = \frac{K_{\text{c}} \cdot K_{\text{L}}}{K_{\text{c}} + 2K_{\text{L}}} = 2.72 \cdot 10^5 \text{N/mm}$ $\frac{K_{\text{system,u}}}{(A \cdot E/L)} = \frac{K_{\text{system,u}}}{(215 \cdot 570 \cdot 13500/5000)} \approx 82\%$
System stiffness (Serviceability)	$K_{\text{system,ser}} = \frac{K_{\text{c}} \cdot K_{\text{L}}}{K_{\text{c}} + 2K_{\text{L}}} = 2.97 \cdot 10^5 \text{N/mm}$ $\frac{K_{\text{system,ser}}}{(A \cdot E/L)} = \frac{K_{\text{system,ser}}}{(215 \cdot 570 \cdot 13500/5000)} \approx 90\%$



$$L = 5 \text{ m}$$

Center-to-center length

$$L' = 5000 - 2 \cdot 204 \approx 4600 \text{ mm}$$