TKT4211: Timber Structures 1

Example C2:

Timber-to-timber connection with dowels and inclined members

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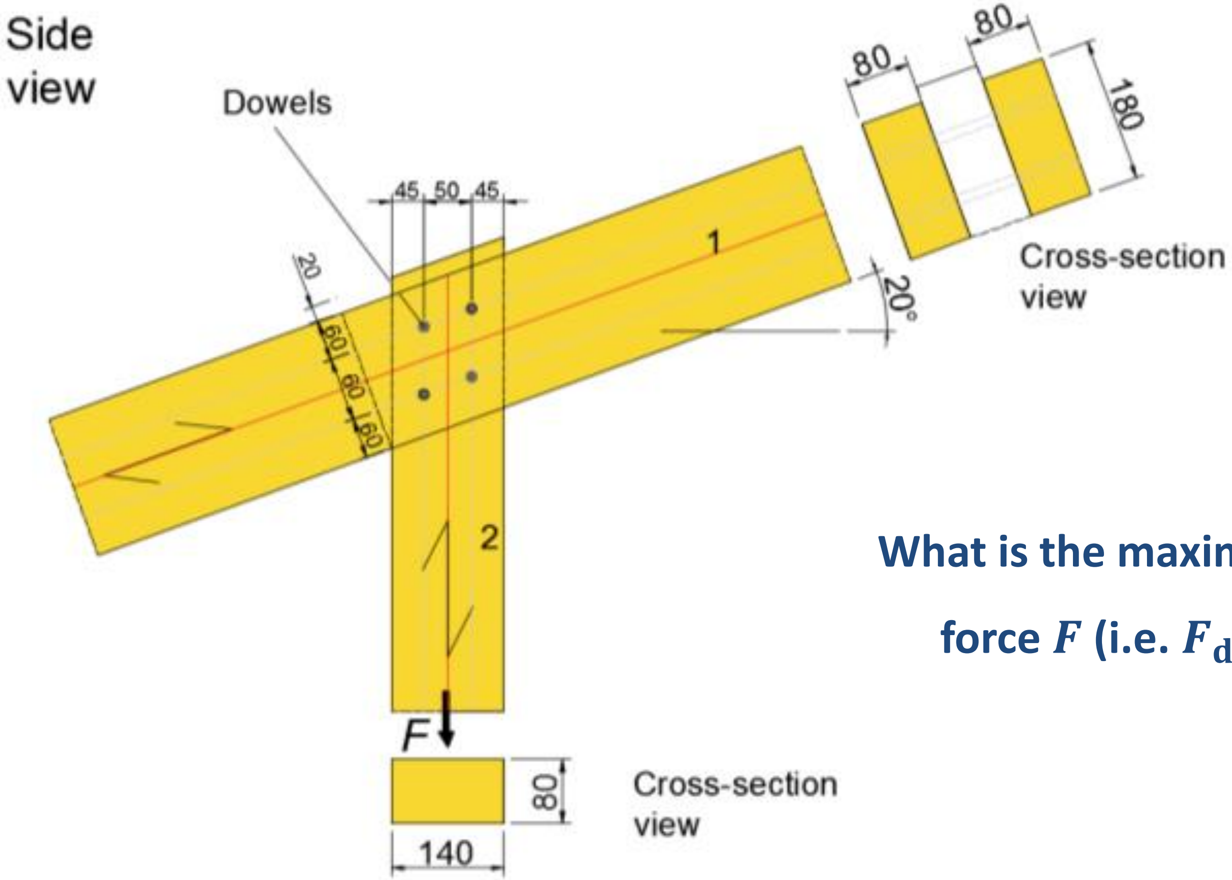
Timber-to-timber connection with dowels and inclined members

- Layout



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

- Timber C24
- Dowels: $d = 12$ mm, $f_{\mathrm{u,k}} = 360$ MPa
- Service class 2, short-term load

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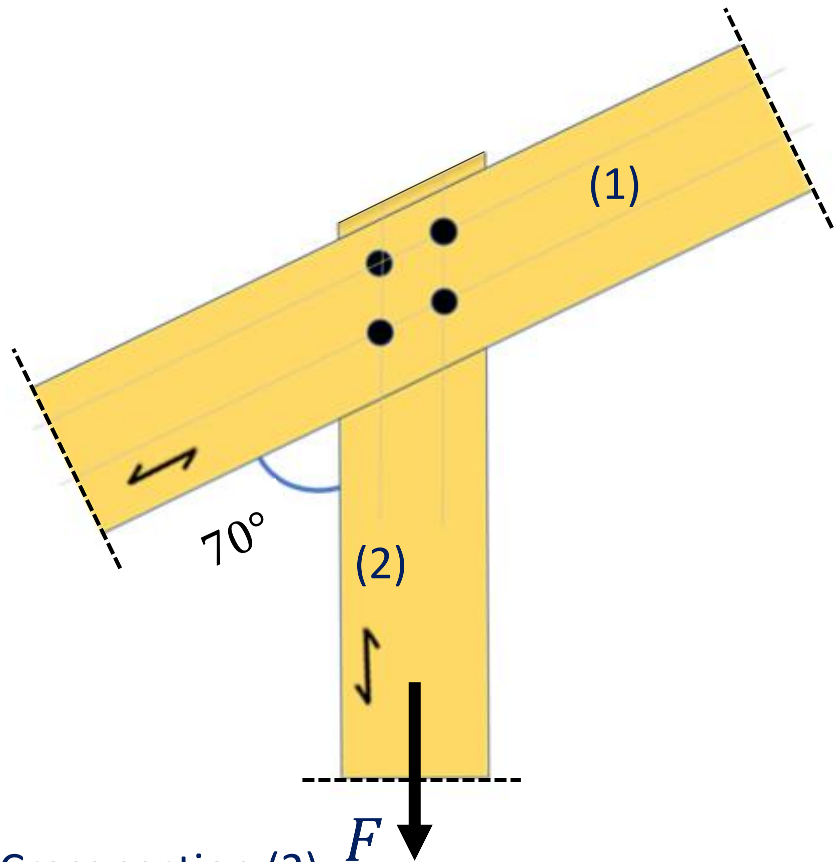
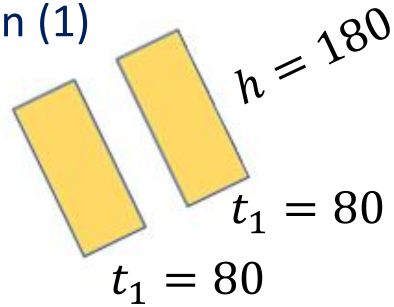
Timber-to-timber connection with dowels and inclined members

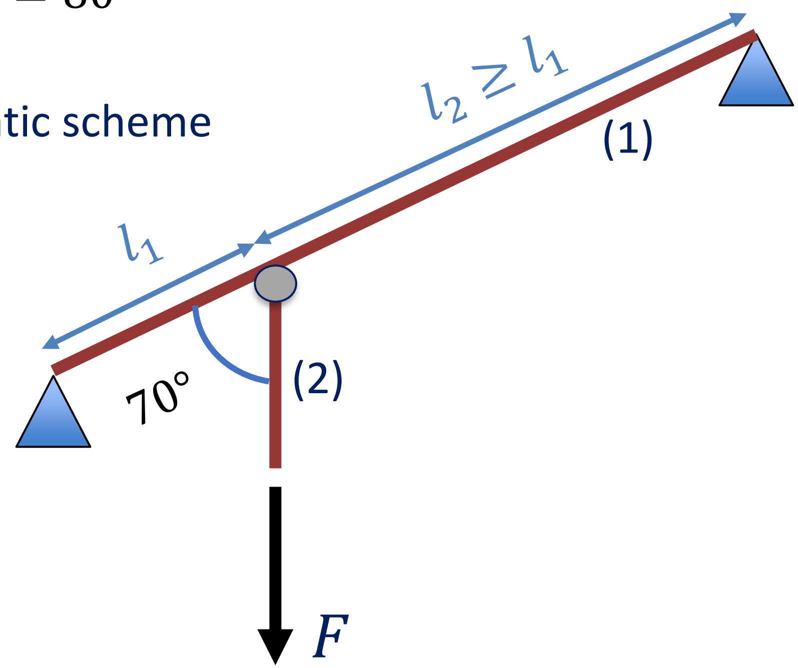
- Layout



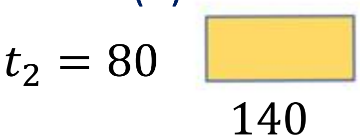
Cross section (1)



Static scheme



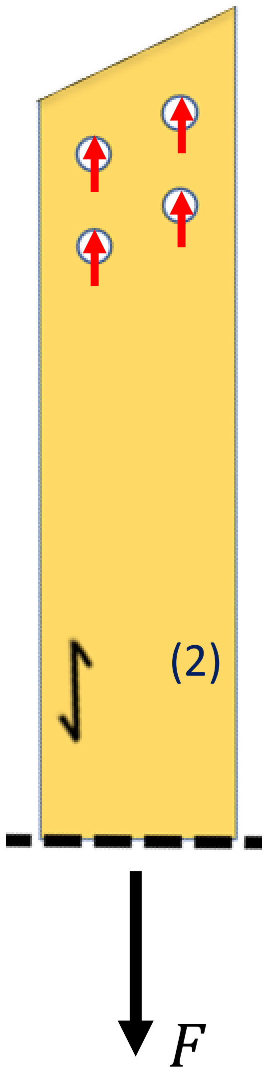
Cross section (2)



- SC2, short-term load: $k_{\text{mod}} = 0.90$ (Table 3.1, Solid Timber)
- Connections: $\gamma_{\text{M}} = 1.30$ (Table NA.2.3)

Timber-to-timber connection with dowels and inclined members

- Middle member: free body diagram

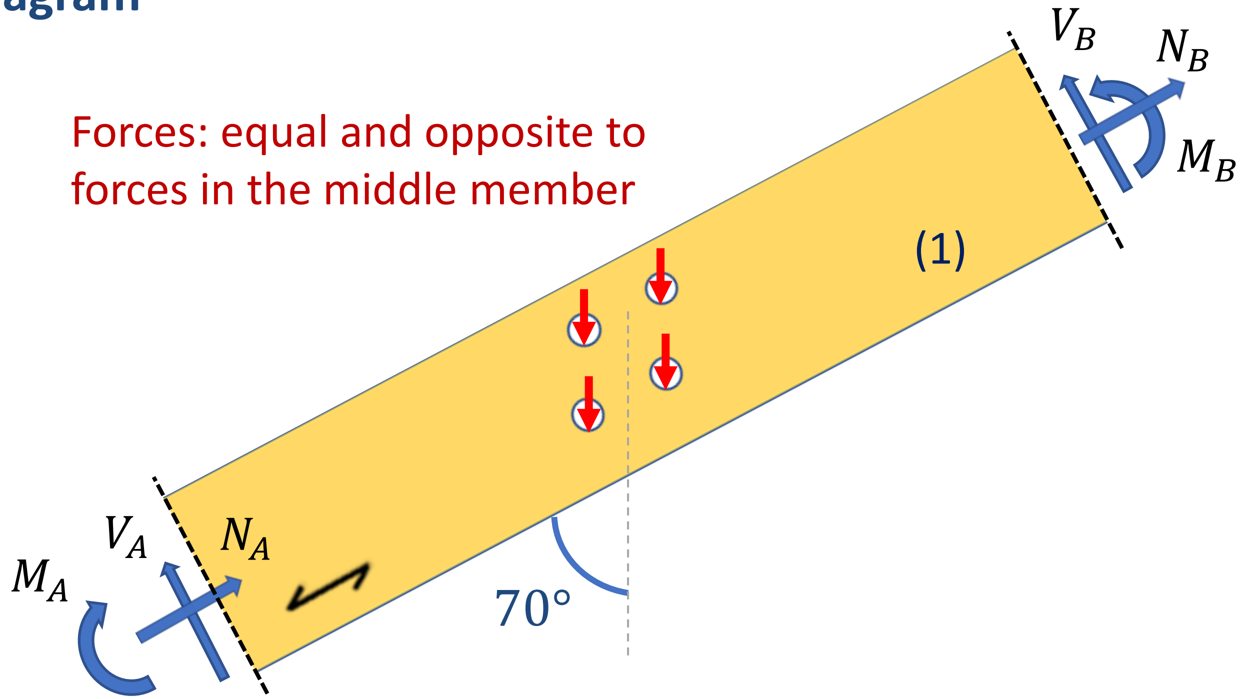


Middle member (2)

- Thickness: $t_2 = 80 \text{ mm}$ (Given by exercise)
- Timber C24 (EN338): $\rho_{\text{k},2} = 350 \text{ kg/m}^3$
- Eq.(8.32): $f_{\text{h},0,\text{k}} = 0.082 \cdot (1 - 0.01 \cdot 12) \cdot 350 = 25.3 \text{ N/mm}^2$
- Force-to-grain angle: $\alpha_2 = 0°$
- Eq.(8.31): $f_{\text{h},2,\text{k}} = f_{\text{h},0,\text{k}} = 25.3 \text{ N/mm}^2$

Timber-to-timber connection with dowels and inclined members

- Side members: free body diagram

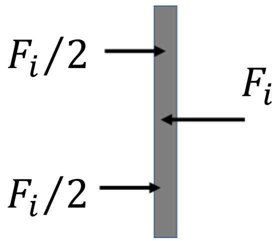


Side members (1)

- Thickness: $t_1 = 80 \text{ mm}$ (Given)
- Timber C24 (EN338): $\rho_{\mathrm{k},1} = 350 \text{ kg/m}^3$
- Force-to-grain angle: $\alpha_1 = 70°$
- Eq.(8.32): $f_{\mathrm{h,0,k}} = 0.082 \cdot (1 - 0.01 \cdot 12) \cdot 350 = 25.3 \text{ N/mm}^2$
- Eq.(8.33): $k_{90} = 1.35 + 0.015 \cdot 12 = 1.53$ (softwood)
- Eq.(8.31): $f_{\mathrm{h},\alpha,\mathrm{k}} = f_{\mathrm{h,1,k}} = \frac{25.3}{1.53 \cdot \sin^2(70°) + \cos^2(70°)} = 17.2 \text{ N/mm}^2$

Timber-to-timber connection with dowels and inclined members

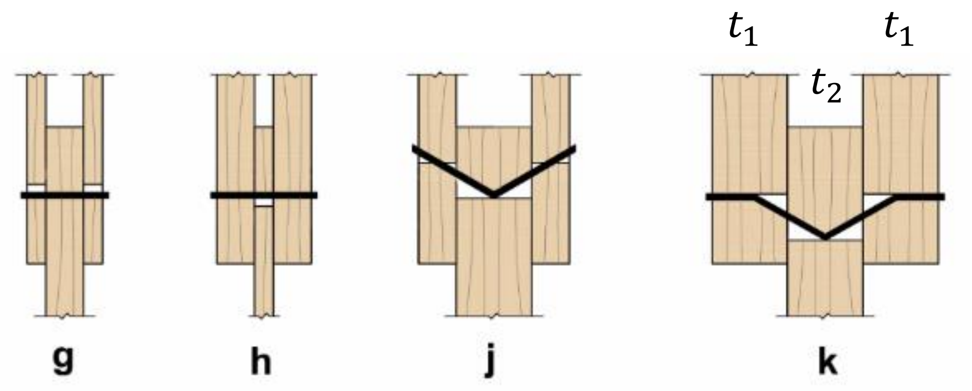
- Properties of dowels



- $d = 12\ \mathrm{mm}$
- $f_{\mathrm{u,k}} = 360\ \mathrm{N/mm^2}$
- $F_{\mathrm{ax,Rk}} = 0$ (dowels)
- Eq.(8.30): $M_{\mathrm{y,Rk}} = 0.30 \cdot 360 \cdot 12^{2.6} = 69070\ \mathrm{Nmm}$

Timber-to-timber connection with dowels and inclined members

- Load-carrying capacity



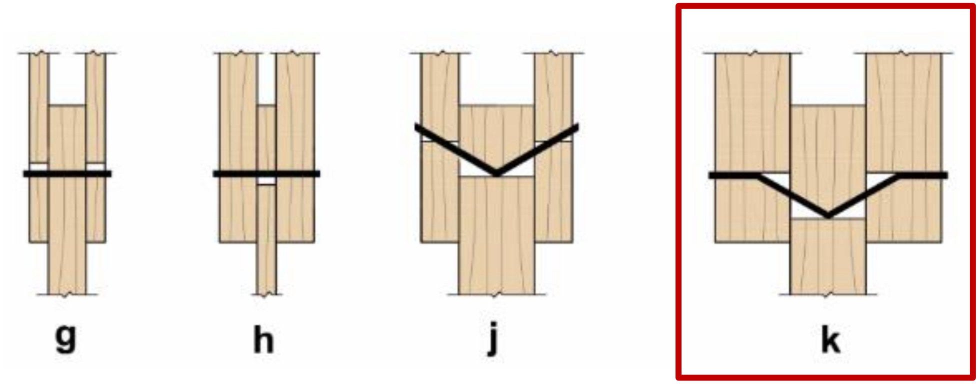
$$\beta = \frac{f_{h,2,k}}{f_{h,1,k}} = \frac{25.3}{17.2} = 1.47$$

EN 1995-1-1, **(eq.8.8)**

$$F_{v,Rk} = \min \begin{cases} f_{h,1,k} \cdot t_1 \cdot d & (g) \\ 0.5 \cdot f_{h,2,k} \cdot t_2 \cdot d & (h) \\ 1.05 \dfrac{f_{h,1,k} \cdot t_1 \cdot d}{2+\beta}\left[\sqrt{2\beta(1+\beta) + \dfrac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} \cdot d \cdot t_1^2}} - \beta\right] + \dfrac{F_{ax,Rk}}{4} & (j) \\ 1.15\sqrt{\dfrac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \dfrac{F_{ax,Rk}}{4} & (k) \end{cases}$$

EN 1995-1-1, §8.2.2.(1), **(eq.8.7)**

Load-carrying capacity
- Force parallel to grain in side members



- **Timber-to-timber connections: Fasteners in double shear (eq.8.7)**

$$F_{\mathrm{v,Rk(g)}} = 17.2 \cdot 80 \cdot 12 = 16512\ \mathrm{N}$$

$$F_{\mathrm{v,Rk(h)}} = 0.5 \cdot 25.3 \cdot 80 \cdot 12 = 12144\ \mathrm{N}$$

$$F_{\mathrm{v,Rk(j)}} = 1.05 \cdot \frac{17.2 \cdot 80 \cdot 12}{2 + 1.47}\left[\sqrt{2 \cdot 1.47 \cdot (1 + 1.47) + \frac{4 \cdot 1.47 \cdot (2 + 1.47) \cdot 69070}{17.2 \cdot 12 \cdot 80^2}} - 1.47\right] + \frac{0}{4} = 7075\ \mathrm{N}$$

$$F_{\mathrm{v,Rk(k)}} = 1.15 \cdot \sqrt{\frac{2 \cdot 1.47}{1 + 1.47}} \cdot \sqrt{2 \cdot 69070 \cdot 17.2 \cdot 12} + \frac{0}{4} = \mathbf{6699\ N}$$

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

$$\mathrm{F}_{\mathrm{v,Rk}} = \min\left(F_{\mathrm{v,Rk(g)}}; F_{\mathrm{v,Rk(h)}}; F_{\mathrm{v,Rk(j)}}; F_{\mathrm{v,Rk(k)}}\right) = \mathbf{6699\ N}$$ [Failure mode (k)]

Load transfer
- Design check

- **Design load carrying capacity per shear plane per fastener:**

$$F_{\mathrm{v,Rd,i}} = \frac{k_{\mathrm{mod}}}{\gamma_{\mathrm{M}}} \cdot F_{\mathrm{v,R\kappa,i}} = \frac{0.9}{1.3} \cdot 6699 = 4638\ \mathrm{N}$$

EN 1995-1-1, §2.4.3(1), **eq.(2.17)**

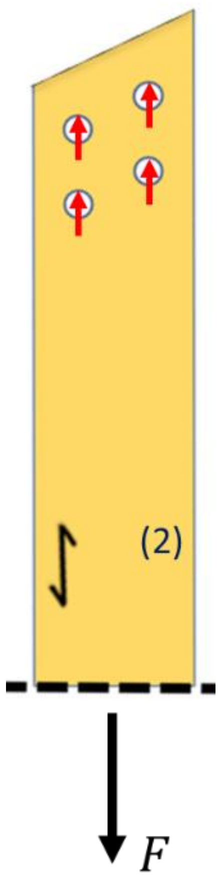
- **Load- per fastener per shear plane per fastener:**

$$F_{\mathrm{d,i}} = \frac{F_{\mathrm{d}}}{n_{\mathrm{shear\ planes}} \cdot n_{\mathrm{fasteners}}} = \frac{F_{\mathrm{d}}}{2 \cdot 4} = \frac{F_{\mathrm{d}}}{8}$$

- **Design check ($\boldsymbol{F_{\mathrm{d,i}} \leq F_{\mathrm{v,Rd,i}}}$):**

$$\frac{F_{\mathrm{d}}}{8} \leq 4638\ \mathrm{N} \quad \rightarrow \quad \boldsymbol{F_{\mathrm{d}} \leq 37.1\mathrm{kN}}$$

(load transfer)



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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)	$0° \leq \alpha \leq 360°$	$(3+2\ \lvert\cos\alpha\rvert)d$
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)	$90° \leq \alpha \leq 150°$ $150° \leq \alpha \leq 210°$ $210° \leq \alpha \leq 270°$	$a_{3,t}\ \lvert\sin\alpha\rvert$ max(3,5 d; 40 mm) $a_{3,t}\ \lvert\sin\alpha\rvert$
$a_{4,t}$ (loaded edge)	$0° \leq \alpha \leq 180°$	$\max((2+2\sin\alpha)d; 3d)$
$a_{4,c}$ (unloaded edge)	$180° \leq \alpha \leq 360°$	$3\ d$

Spacings, end and edge distances

- Middle member

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

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

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

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

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

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

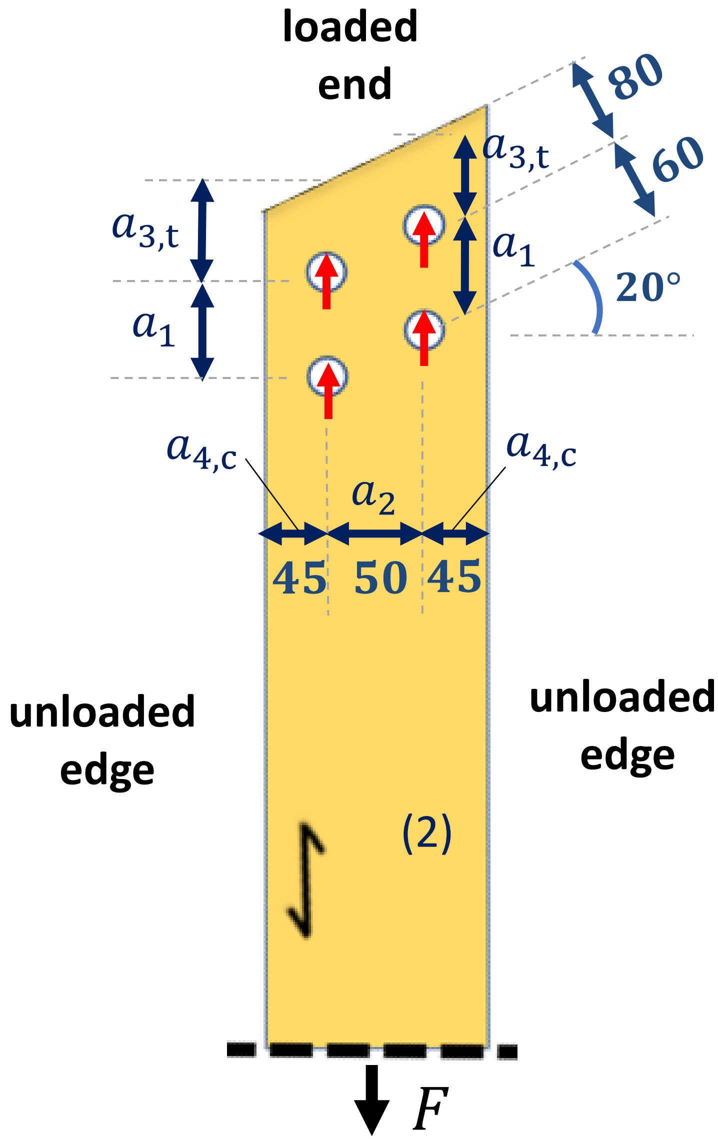
- **Actual distances and spacings (and check)**

$a_1 = 60/\cos 20° = 64 \text{ mm} > 60 \text{ mm}$ **(OK)**

$a_2 = 50 \text{ mm} > 36 \text{ mm}$ **(OK)**

$a_{3,\mathrm{t}} = 80/\cos 20° = 85\text{mm} > 84 \text{ mm}$ **(OK)**

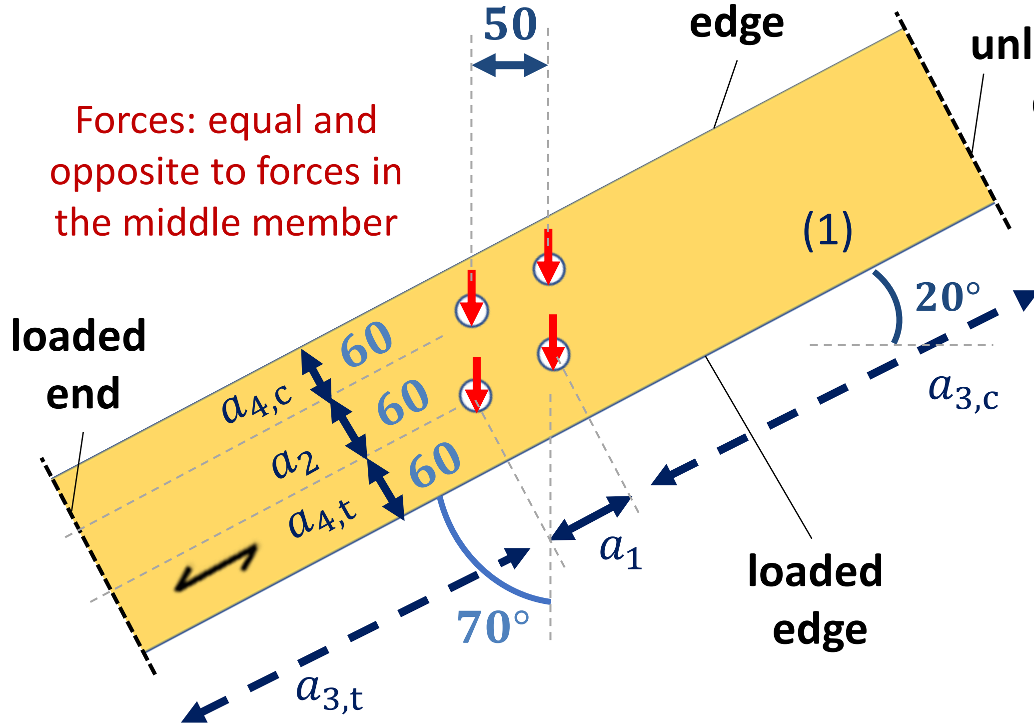
$a_{4,c} = 45 \text{ mm} > 36 \text{ mm}$ **(OK)**



- There is not a loaded edge (both are unloaded)
- There is not an unloaded end (far away)

Spacings, end and edge distances

- Side members



$a_{3,t}$ and $a_{3,c}$ are not relevant here (ends are far away)

- **Minimum requirements (Table 8.5), $\alpha = 70°$**

$a_1 \geq (3 + 2 \cdot |\cos 70°|) \cdot d = 44.2 \text{ mm}$

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

$a_{4,t} \geq \max[(2 + 2 \cdot \sin 70°) \cdot d, 3 \cdot d] = 46.5 \text{ mm}$

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

- **Actual distances and spacings (and check)**

$a_1 = 50/\cos 20° = 53 \text{ mm} > 44.2 \text{ mm}$ **(OK)**

$a_2 = 60 \text{ mm} > 36 \text{ mm}$ **(OK)**

$a_{4,t} = 60 \text{ mm} > 46.5 \text{ mm}$ **(OK)**

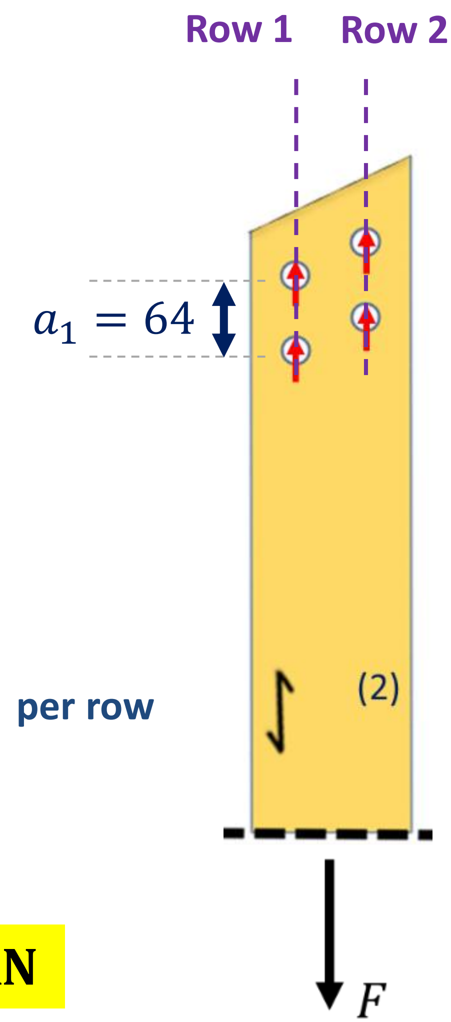
$a_{4,c} = 60 \text{ mm} > 36 \text{ mm}$ **(OK)**

Splitting: force components parallel to grain

- Middle member

- **Effective number of fasteners per row parallel to grain, Eq.(8.34)**
  - 2 fasteners in each row, i.e n=2

$$n_{\mathrm{ef}} = \min\left(n, n^{0.90} \cdot \sqrt[4]{\frac{a_1}{13 \cdot d}}\right) = \min\left(2, 2^{0.90} \cdot \sqrt[4]{\frac{64}{13 \cdot 12}}\right) = 1.49 \text{ fasteners per row}$$



- **Effective load-carrying capacity of each row, Eq.(8.1)**
  - Comment: for force applied parallel to grain in middle member the load-carrying capacity is $F_{\mathrm{v,Rk}(\alpha_2=0°)} = 6699$ N (per fastener per shear plane). Same as before.

$$F_{\mathrm{v,ef,Rk}} = \boldsymbol{n}_{\mathbf{ef}} \cdot F_{\mathrm{v,Rk}(\alpha_2=0°)} = 1.49 \cdot 6699 = 9982 \text{ N}$$

per shear plane

EN 1995-1-1, §8.1.2(4), **eq.(8.1)**

$$F_{\mathrm{v,ef,Rd}} = n_{\text{shear planes}} \cdot k_{\mathrm{mod}}/\gamma_{\mathrm{M}} \cdot F_{\mathrm{v,ef,Rk}} = 2 \cdot 0.9/1.3 \cdot 9982 = 13821 \text{ N}$$

per row

EN 1995-1-1, §2.4.3(1), **eq.(2.17)**

- **Design check, §8.1.2(5)**

$$F_{\mathrm{row,d}} = \frac{F_{\mathrm{d}}}{2 \text{ rows}} \leq F_{\mathrm{v,ef,Rd}} \text{ (per row)} = 13821 \text{ N} \quad \rightarrow \quad \boldsymbol{F_{\mathrm{d}} \leq 27.6 \text{ kN}}$$

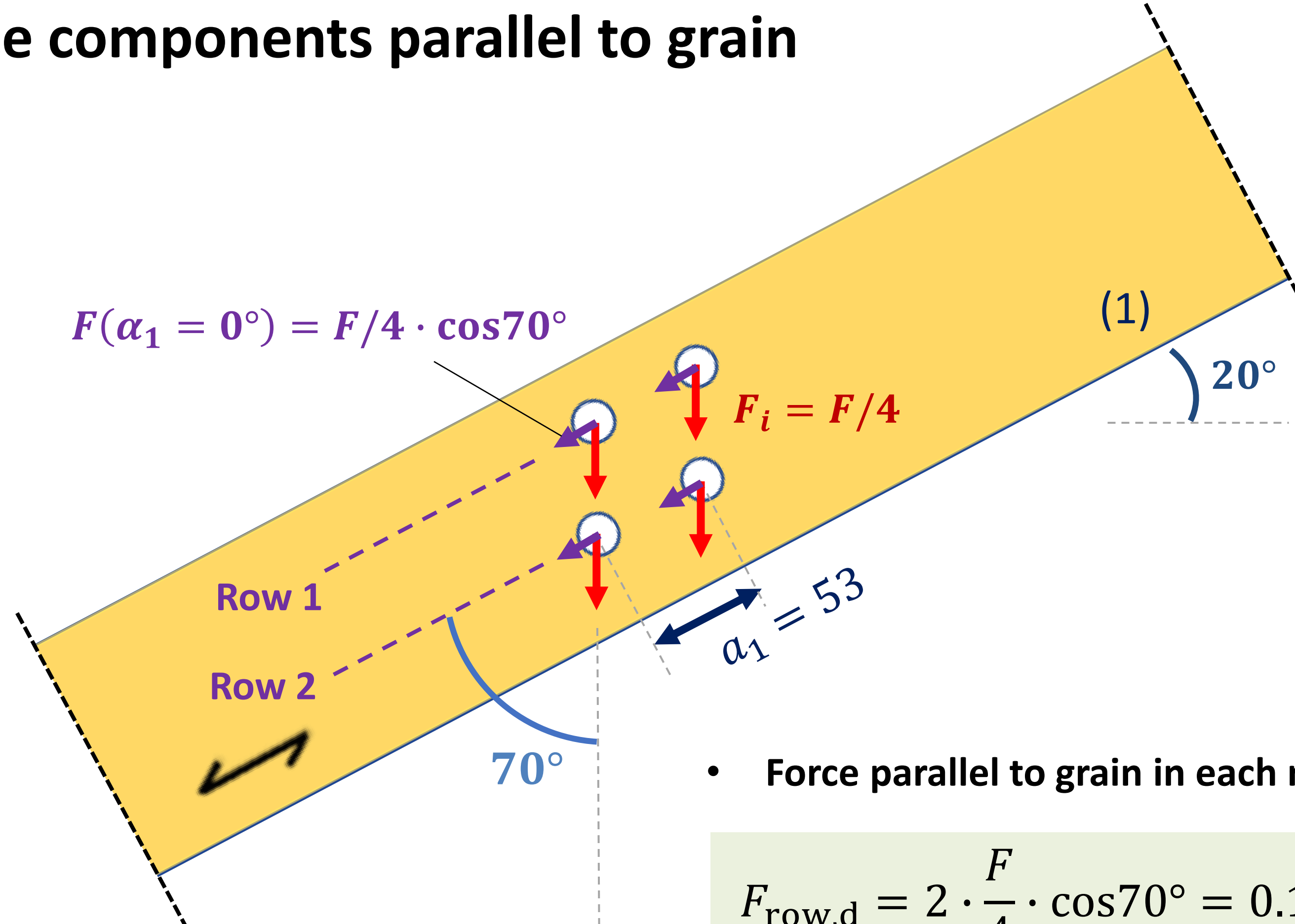
EN 1995-1-1, §**8.1.2(5)**

splitting for F parallel to grain (middle member)

Comment: if members are loaded with a force parallel to grain, this failure mode will always be more critical than load transfer, because $n_{\mathrm{ef}} \leq n$

Splitting: force components parallel to grain

- Side members



- **Force parallel to grain in each row**

$$F_{\text{row,d}} = 2 \cdot \frac{F}{4} \cdot \cos 70° = 0.171 \cdot F$$

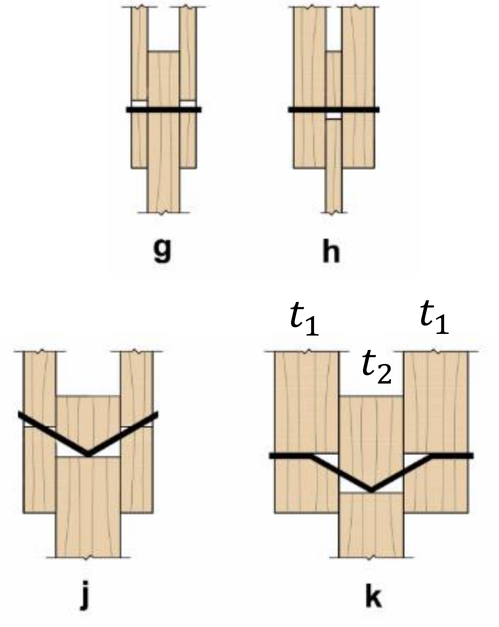
- **We need to find the load carrying capacity for force parallel to grain in the side members $F_{\mathbf{v,Rk}(\alpha_1=0°)}$, i.e. for $\alpha_1 = 0°$ (and therefore $\alpha_2 = 70°$)**

Timber-to-timber connection with dowels and inclined members

- Load-carrying capacity: force parallel to grain in side members

$$F_{v,Rk} = \min \begin{cases} f_{h,1,k} \cdot t_1 \cdot d & \text{(g)} \\ 0.5 \cdot f_{h,2,k} \cdot t_2 \cdot d & \text{(h)} \\ 1.05 \dfrac{f_{h,1,k} \cdot t_1 \cdot d}{2+\beta}\left[\sqrt{2\beta(1+\beta) + \dfrac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} \cdot d \cdot t_1^2}} - \beta\right] + \dfrac{F_{ax,Rk}}{4} & \text{(j)} \\ 1.15\sqrt{\dfrac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \dfrac{F_{ax,Rk}}{4} & \text{(k)} \end{cases}$$

EN 1995-1-1, §8.2.2.(1), **(eq.8.7)**



Side members (1)

- Force-to-grain angle: $\alpha_1 = 0°$, Eq.(8.32): $f_{h,0,k} = 25.3\ \mathrm{N/mm^2}$
- Eq.(8.31): $f_{h,1,k} = f_{h,0,k} = 25.3\ \mathrm{N/mm^2}$

$$\beta = \frac{f_{h,2,k}}{f_{h,1,k}} = \frac{17.2}{25.3} = 0.68$$

EN 1995-1-1, **(eq.8.8)**

Middle member (2)

- Eq.(8.32): $f_{h,0,k} = 25.3\ \mathrm{N/mm^2}$
- Force-to-grain angle: $\alpha_2 = 70°$, Eq.(8.33): $k_{90} = 1.35 + 0.015 \cdot 12 = 1.53$ (softwood)
- Eq.(8.31): $f_{h,\alpha,k} = f_{h,2,k} = \frac{25.3}{1.53 \cdot \sin^2(70°) + \cos^2(70°)} = 17.2\ \mathrm{N/mm^2}$

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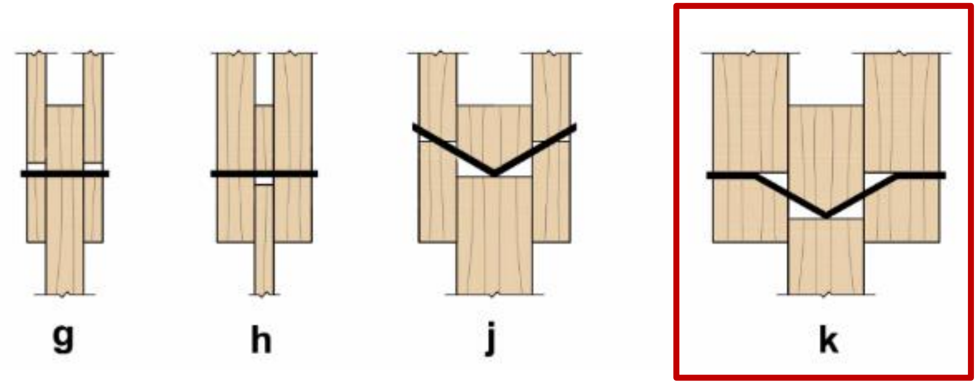
Load-carrying capacity

- Timber-to-timber connections: Fasteners in double shear



- **Timber-to-timber connections: Fasteners in double shear (eq.8.7)**

$$F_{v,Rk(g)} = 25.3 \cdot 80 \cdot 12 = 24288 \text{ N}$$

$$F_{v,Rk(h)} = 0.5 \cdot 17.2 \cdot 80 \cdot 12 = 8256\text{N}$$

$$F_{v,Rk(j)} = 1.05 \cdot \frac{25.3 \cdot 80 \cdot 12}{2 + 0.68}\left[\sqrt{2 \cdot 0.68 \cdot (1 + 0.68) + \frac{4 \cdot 0.68 \cdot (2 + 0.68) \cdot 69070}{25.3 \cdot 12 \cdot 80^2}} - 0.68\right] + \frac{0}{4} = 8706 \text{ N}$$

$$F_{v,Rk(k)} = 1.15 \cdot \sqrt{\frac{2 \cdot 0.68}{1 + 0.68}} \cdot \sqrt{2 \cdot 69070 \cdot 25.3 \cdot 12} + \frac{0}{4} = \mathbf{6700\ N}$$

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

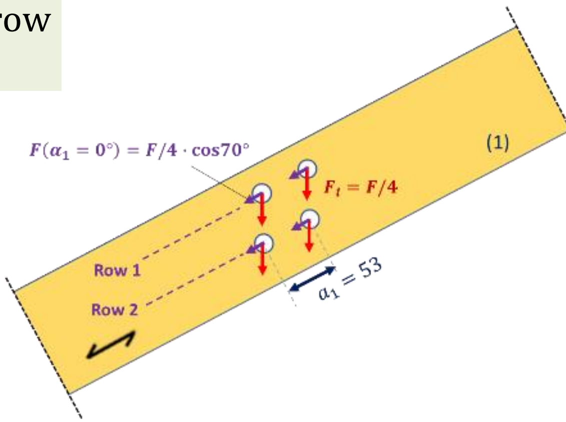
$$\mathrm{F}_{v,Rk} = \min\left(F_{v,Rk(g)}; F_{v,Rk(h)}; F_{v,Rk(j)}; F_{v,Rk(k)}\right) = \mathbf{6700N}$$ [Failure mode (k)]

Splitting: force components parallel to grain

- Side members

- **Effective number of fasteners per row parallel to grain, Eq.(8.34)**
  - 2 fasteners in each row, i.e $n = 2$

$$n_{\mathrm{ef}} = \min\left(n, n^{0.90} \cdot \sqrt[4]{\frac{a_1}{13 \cdot d}}\right) = \min\left(2, 2^{0.90} \cdot \sqrt[4]{\frac{53}{13 \cdot 12}}\right) = 1.42 \text{ fasteners per row}$$



- **Effective load-carrying capacity of each row, Eq.(8.1)**
  - Comment: for force applied parallel to grain in middle member the load-carrying capacity is $F_{\mathrm{v,Rk}(\alpha_1=0°)} = 6700\mathrm{N}$ (per fastener per shear plane).

$$F_{\mathrm{v,ef,Rk}} = \boldsymbol{n}_{\mathbf{ef}} \cdot F_{\mathrm{v,Rk}(\alpha_1=0°)} = 1.42 \cdot 6700 = 9514 \text{ N}$$

per shear plane

EN 1995-1-1, §8.1.2(4), **eq.(8.1)**

$$F_{\mathrm{v,ef,Rd}} = n_{\text{shear planes}} \cdot k_{\mathrm{mod}}/\gamma_{\mathrm{M}} \cdot F_{\mathrm{v,ef,Rk}} = 2 \cdot 0.9/1.3 \cdot 9514 = 13173 \text{ N}$$

per row

EN 1995-1-1, §2.4.3(1), **eq.(2.17)**

- **Design check, §8.1.2(5)**

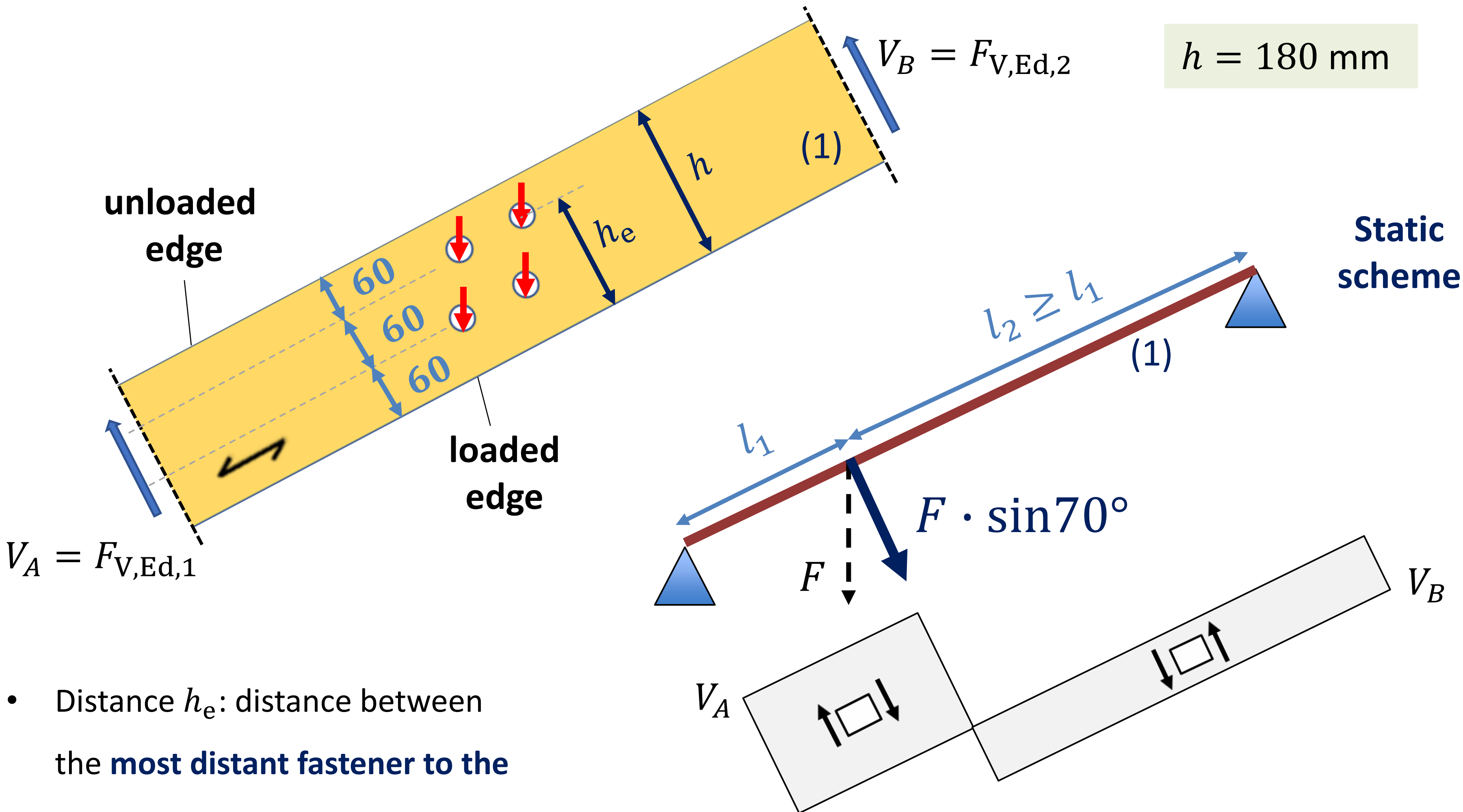
$$F_{\mathrm{row,d}} = 0.171 \cdot F \leq F_{\mathrm{v,ef,Rd}} \text{ (per row)} = 13173 \text{ N} \quad \rightarrow \quad \boldsymbol{F_{\mathrm{d}} \leq 77.0 \text{ kN}}$$

EN 1995-1-1, **§8.1.2(5)**

splitting for F parallel to grain (side members)

Splitting: force components perpendicular to grain

- Side members



- Distance h_e: distance between the **most distant fastener to the loaded edge.**

$h_e = 120$ mm

Splitting: force components perpendicular to grain

- Side members

- **Maximum design shear force:**

$$F_{\mathrm{v,Ed}} = \max(F_{\mathrm{v,Ed,1}}, F_{\mathrm{v,Ed,2}})$$

EN 1995-1-1, §8.1.4(2), **(eq.8.3)**

No info provided for the lengths l_1 and l_2.

Worst case scenario:

$$l_1 = 0 \; \rightarrow F_{\mathrm{V,Ed,1}} = F \cdot \sin 70°, F_{\mathrm{V,Ed,2}} = 0$$

$$F_{\mathrm{v,Ed}} = \max(F \cdot \sin 70°, 0) = F \cdot \sin 70°$$

- **Characteristic splitting capacity (softwood):**

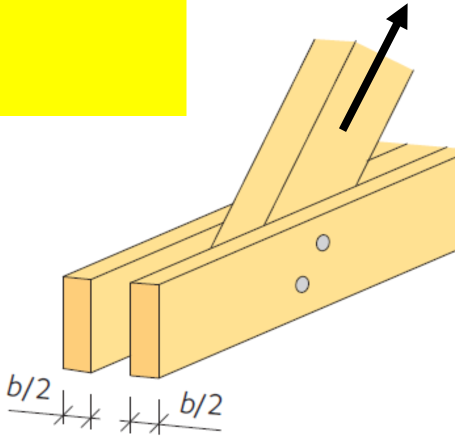
$$F_{90,\mathrm{Rk}} = 14 \cdot b \cdot w \cdot \sqrt{\frac{h_\mathrm{e}}{1 - \frac{h_\mathrm{e}}{h}}} = 14 \cdot 160 \cdot 1 \cdot \sqrt{\frac{120}{1 - 120/180}} = 42501 \text{ N}$$

EN 1995-1-1, §8.1.4(3), **(eq.8.4)**

$$w = 1$$

EN 1995-1-1, §8.1.4(3), **(eq.8.5)**

$$b = b/2 + b/2 = 80 + 80 = 160 \text{ mm}$$



EN 1995-1-1, Figure 8.1

Splitting: force components perpendicular to grain

- Side members

Limtreboka mener at en kan bruke gammaM til materialet, fordi det er en materialsjekke, og ikke en forbindelsessjekk. I dette tilfelle altså 1,25.

- **Design splitting capacity**:

$$F_{90,\mathrm{Rd}} = k_{\mathrm{mod}}/\gamma_{\mathrm{M}} \cdot F_{90,\mathrm{Rk}} = 0.9/1.3 \cdot 42501 = 29423\ \mathrm{N}$$

EN 1995-1-1, §2.4.3(1), **eq.(2.17)**

- **Design check (worst case scenario)**:

$$F_{\mathrm{v,Ed}} = \max(F_{\mathrm{v,Ed,1}}, F_{\mathrm{v,Ed,2}}) = F \cdot \sin 70° \leq F_{90,\mathrm{Rd}} = 29423\ \mathrm{N}$$

EN 1995-1-1, §8.1.4(2), **eqs.(8.2-8.3)**

$$\rightarrow \boldsymbol{F_{\mathrm{d}} \leq 31.3\ \mathrm{kN}}$$

splitting for F perpendicular to grain (side members)

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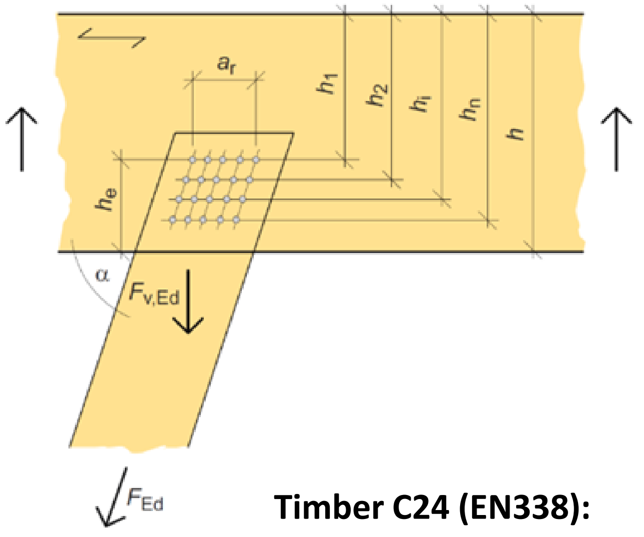
Splitting: force components perpendicular to grain

- Side members, alternative method (info)

Source: Limtreboka



$b = 160$ mm

$h = 180$ mm

$h_e = 120$ mm

$a_r = 53$ mm ($< h/2 = 90$ OK)

$t_{pen} = 80$ mm

$t_{ef} = \min\{b\,;\ 2 \cdot t_{pen};\ 12 \cdot d\} = 144$ mm

$k_s = \max\{1\,; 0.7 + 1.4 \cdot a_r/h\} = \max\{1\,; 0.7 + 1.4 \cdot 53/180\} = 1.11$

$h_1 = 60$ mm

$h_2 = 120$ mm

$n = 2$ rows

$$k_r = \frac{n}{\sum_{i=1}^{n}(h_1/h_i)^2} = \frac{2}{(h_1/h_1)^2 + (h_1/h_2)^2} = 1.60$$

Timber C24 (EN338):

$f_{t,90,k} = 0.4\ \text{N/mm}^2 \qquad \gamma_M = 1.25$

$f_{t,90,d} = 0.4 \cdot 0.9/1.25 = 0.288\ \text{N/mm}^2$

Design capacity: $F_{90,Rd} = k_s \cdot k_r \cdot \left(6.5 + 18 \cdot (h_e/h)^2\right) \cdot (t_{ef} \cdot h)^{0.8} \cdot f_{t,90,d}$

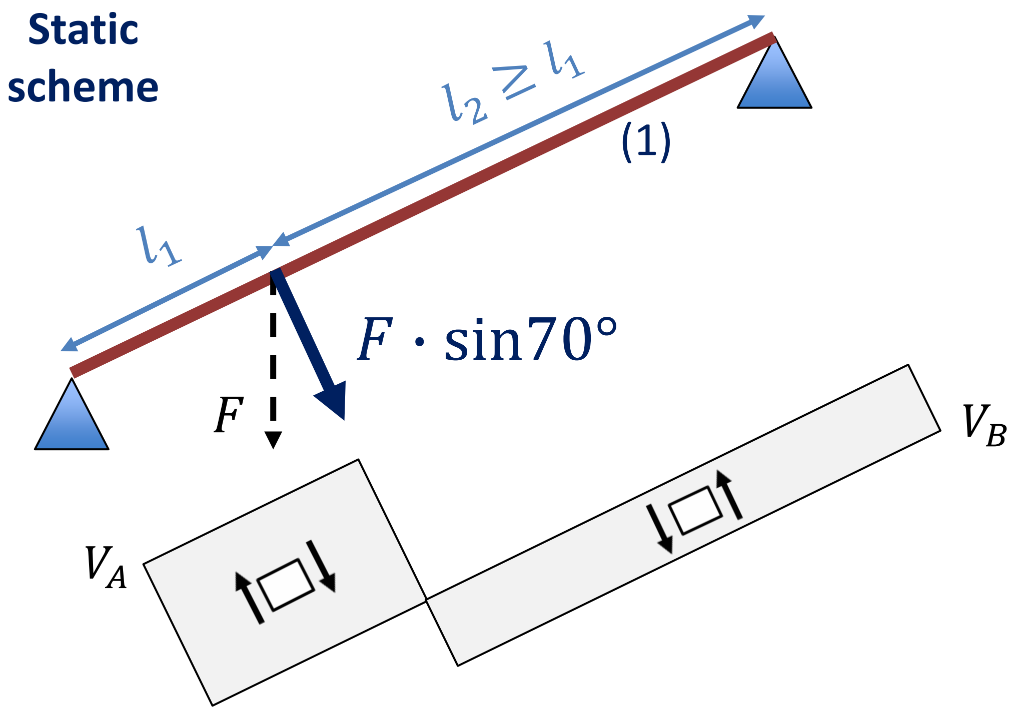
$F_{90,Rd} = 1.11 \cdot 1.60 \cdot \left(6.5 + 18 \cdot (120/180)^2\right) \cdot (144 \cdot 180)^{0.8} \cdot 0.288 = 25200$ N

$F_{v,Ed} = F \cdot \sin 70° \leq F_{90,Rd} = 25.2$ kN $\rightarrow$ $\boldsymbol{F_d \leq 26.8}$ **kN**

Note: here the capacity is not dependent on the value of shear (and therefore on the value of l_1)

Force components perpendicular to grain

- Shear capacity



Timber C24 (EN338):

$f_{v,k} = 4.0\ \mathrm{N/mm^2}$

$\gamma_M = 1.25$

$k_{cr} = 0.67$

$f_{v,d} = 4 \cdot 0.9/1.25 = 2.88\ \mathrm{N/mm^2}$

Shear capacity:

$$V_{max,d} = \frac{2}{3} \cdot k_{cr} \cdot b \cdot h \cdot f_{v,d} = \frac{2}{3} \cdot 0.67 \cdot (2 \cdot 80) \cdot 180 \cdot 2.88 = 37050\ \mathrm{N}$$

EN 1995-1-1 §6.1.7.(1) **eq.(6.13)**

No info provided for the lengths l_1 and l_2.

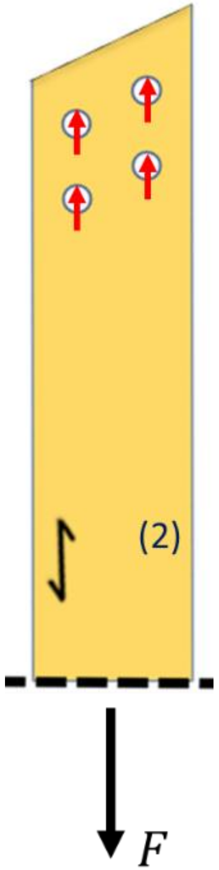
Worst case scenario: $l_1 = 0 \ \rightarrow F_{V,Ed,1} = F \cdot \sin 70° \leq 37050\ \mathrm{N}$ $\rightarrow$ $\boldsymbol{F_d \leq 39.4\ \mathrm{kN}}$

Shear (side members)

Splitting: force components perpendicular to grain

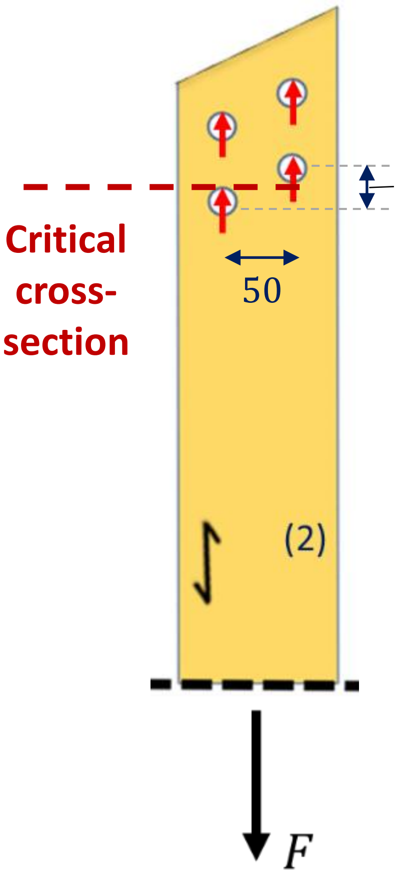
- Middle member

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



Net-section failure

- Middle member



(Table 8.5): $a_{1,\min} = 60\text{ mm}$

$50 \cdot \tan 20° = 18\text{ mm} \left(< \frac{a_{1,\min}}{2} = 30\text{ mm}\right)$

EN 1995-1-1 §5.2.(4), staggered fasteners: We should consider the fasteners in the same cross section

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

EN 1995-1-1, §6.1.2, **eq.(6.1)**

Assume small tolerance: $d \approx d_{hole}$

$$A_{net} = 80 \cdot (140 - 2 \cdot 12) = 9280\text{ mm}^2$$

Timber C24 (EN338):

$f_{t,0,k} = 14.5\text{ N/mm}^2$

$\gamma_M = 1.25$

$k_h = \min\left((150/140)^{0.2}, 1.3\right) = 1.01$

EN 1995-1-1 **eq.(3.1)**

$f_{t,0,d} = 14.5 \cdot 1.01 \cdot 0.9/1.25 = 10.5\text{ N/mm}^2$

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

$F \leq f_{t,0,d} \cdot A_{net} = 10.5 \cdot 9280 = 97440\text{ N}$ $\rightarrow$ $\boldsymbol{F_d \leq 97.4\text{ kN}}$

Tension parallel to grain (middle member)

Net-section failure

- Side members

Timber C24 (EN338):

$f_{\mathrm{m,k}} = 24\ \mathrm{N/mm^2}$

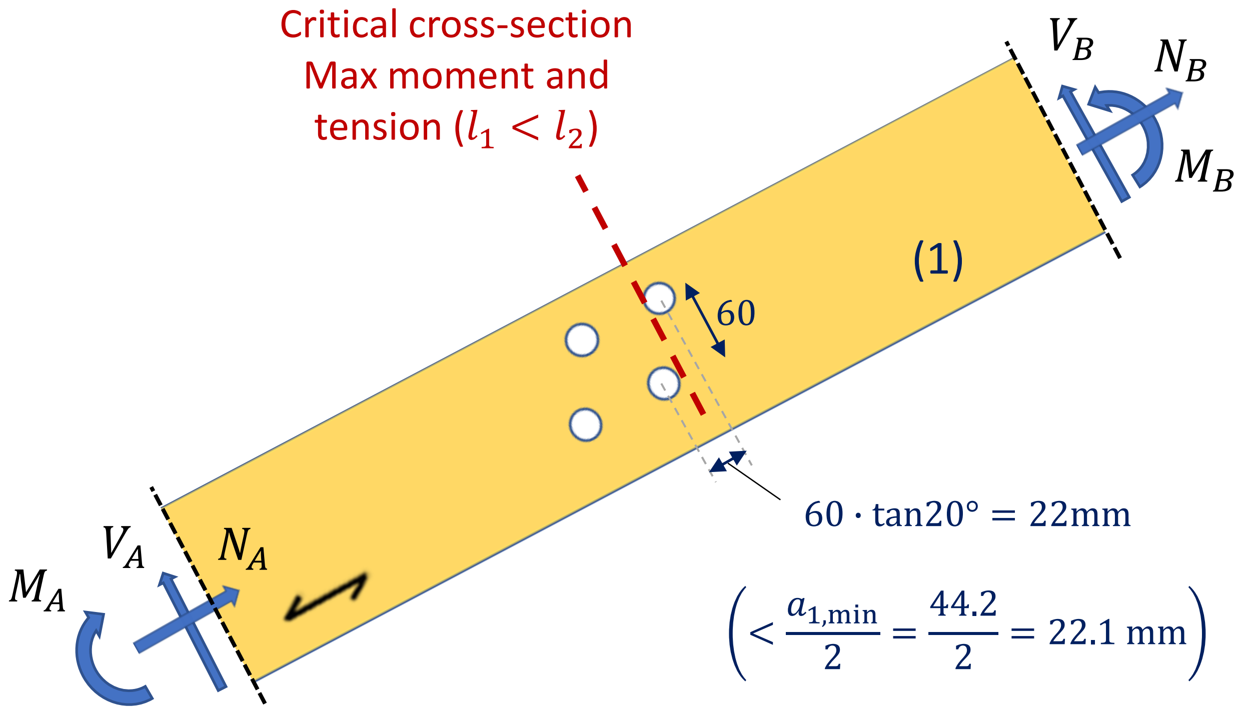
$f_{\mathrm{t,0,k}} = 14.5\ \mathrm{N/mm^2}$

$h > 150\ \mathrm{mm} \rightarrow k_{\mathrm{h}} = 1.0$

EN 1995-1-1 **eq.(3.1)**

$f_{\mathrm{c,0,k}} = 21.0\ \mathrm{N/mm^2}$

$\gamma_{\mathrm{M}} = 1.25$



$f_{\mathrm{m,d}} = 24 \cdot 0.9/1.25 = 17.3\ \mathrm{N/mm^2}$

$f_{\mathrm{t,0,d}} = 14.5 \cdot 0.9/1.25 = 10.44\ \mathrm{N/mm^2}\ (< f_{c,0,\mathrm{d}})$

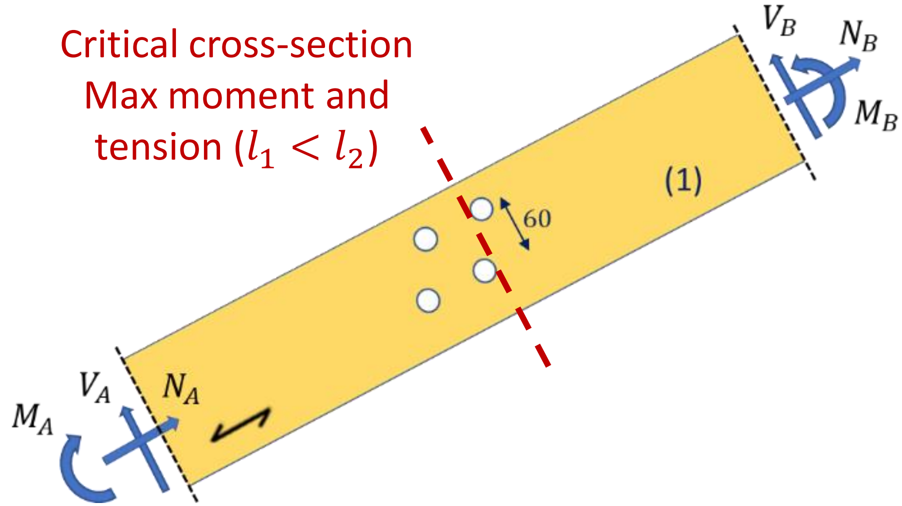
EN 1995-1-1 (**eq.2.14)**

EN 1995-1-1 §5.2.(4), staggered fasteners: We should consider the fasteners in the same cross section

Comment: The check for tension and moment is critical (on the right) because the moment is higher ($l_1 < l_2$) and the tensile strength is smaller than the compressive.

Net-section failure

- Side members



Combined side members

$$A_{\text{gross}} = 2 \cdot 80 \cdot 180 = 28800 \text{ mm}^2$$

$$A_{\text{net}} = 2 \cdot 80 \cdot (180 - 2 \cdot 12) = 24960 \text{ mm}^2$$

$$\frac{A_{\text{gross}}}{A_{\text{net}}} = \frac{28800}{24960} = 1.154$$

$$I_{\text{gross}} = \frac{b \cdot h^3}{12} = \frac{2 \cdot 80 \cdot 180^3}{12} = 7.78 \cdot 10^7 \text{mm}^4$$

$$I_{\text{net}} = I_{\text{gross}} - 2 \cdot \left(\frac{b \cdot d^3}{12} + {y_i}^2 \cdot b \cdot d\right) = 7.78 \cdot 10^7 - 2 \cdot \left(\frac{2 \cdot 80 \cdot 12^3}{12} + 30^2 \cdot 2 \cdot 80 \cdot 12\right) = 7.43 \cdot 10^7 \text{ mm}^4$$

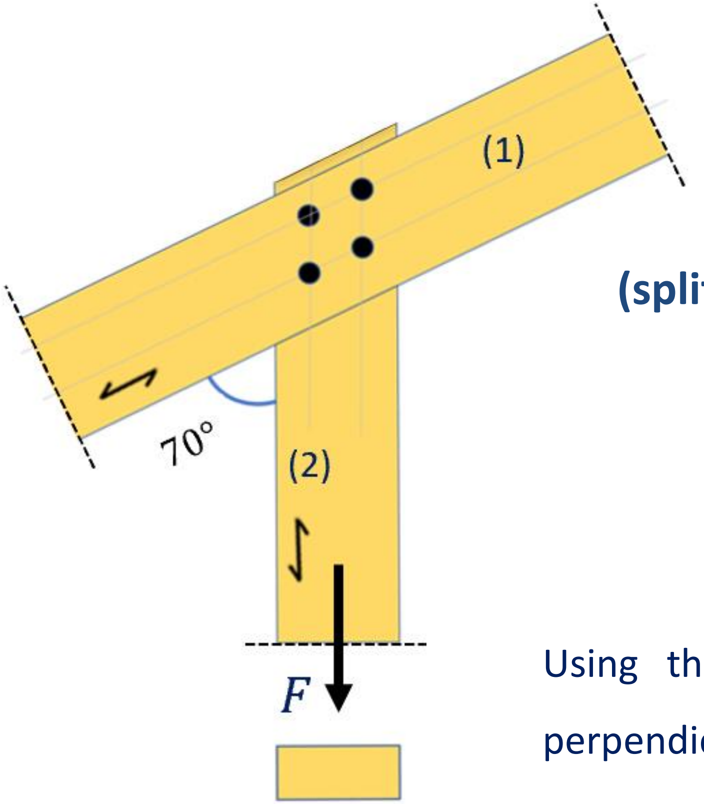
$$\frac{W_{\text{gross}}}{W_{\text{net}}} = \frac{I_{\text{gross}}/(h/2)}{I_{\text{net}}/(h/2)} = \frac{I_{\text{gross}}}{I_{\text{net}}} = \frac{7.78 \cdot 10^7}{7.43 \cdot 10^7} = 1.047$$

Comment: The lengths l_1, l_2 are not given and we cannot determine the value of moment and perform the net-section design check here. Compared to the gross cross-section, the axial stresses and the bending stresses will be **15.4%** and **4.7%** higher respectively due to the presence of holes.

Timber-to-timber connection with dowels and inclined members

- Summary

$$F_\mathrm{d} \leq \min(37.1\ \mathrm{kN}, \mathbf{27.6\ kN}, 77.0\ \mathrm{kN}, 31.3\ \mathrm{kN}^*, 39.4\ \mathrm{kN}, 97.4\ \mathrm{kN})$$



$$\boldsymbol{F_\mathrm{d} \leq 27.6\ \mathrm{kN}}$$

(splitting for F parallel to grain in middle member is critical)

Using the method by EN1995 for splitting for force components perpendicular to grain we got a maximum value of $31.3\ \mathrm{kN}$, assuming conservatively $l_1 = 0$. Using the alternative method, we got a maximum value of $\mathbf{26.8\ kN}$ (i.e. smaller that 27.6 kN and therefore critical)