TKT4211: Timber Structures 1

# Example C5:

## Design of timber-to-timber (double shear) connection with bolts and bulldogs

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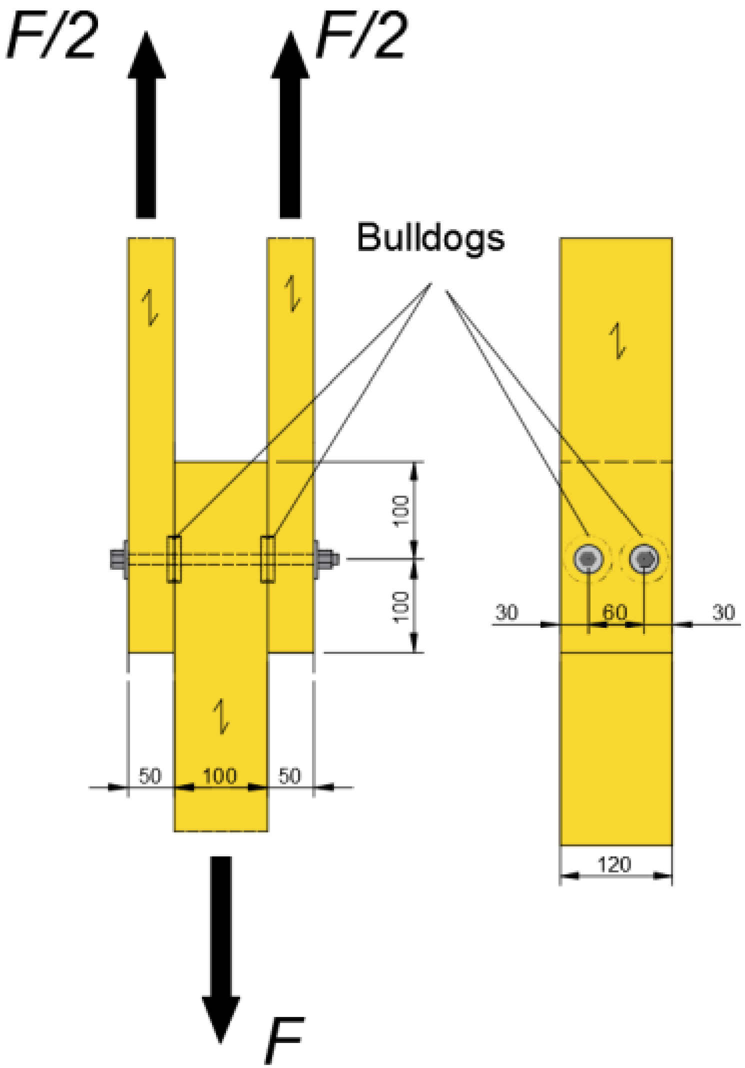
# Timber-to-timber (double shear) connection with bolts and bulldogs

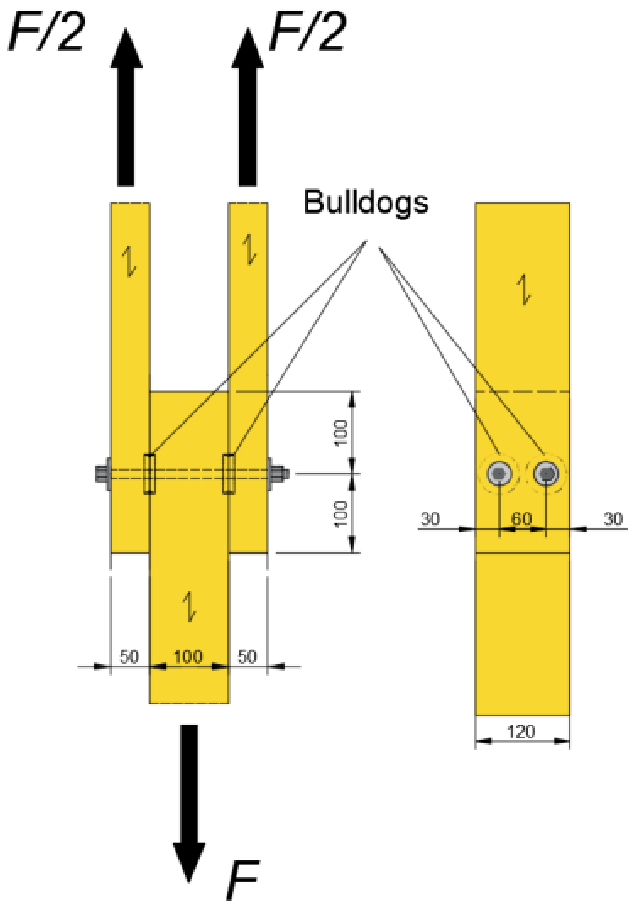
## - Layout



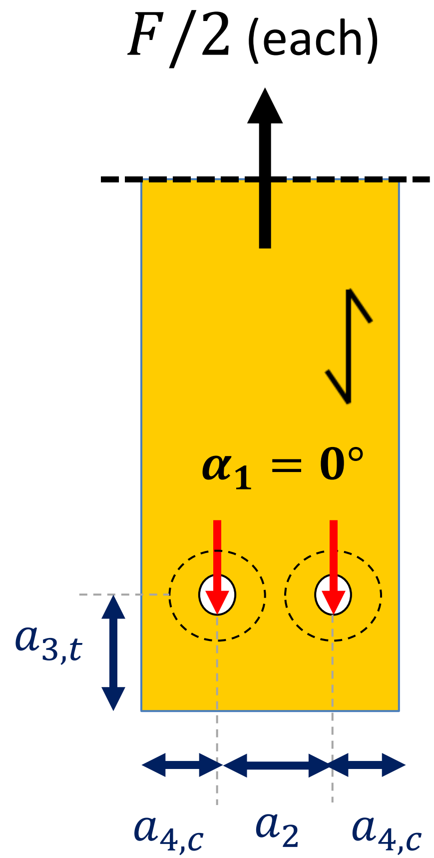

- Timber C30 (Both members)
- Service class 2, Short-term loading
- $k_{mod} = 0.9$
- Bolts: M10 – 8.8
- Bulldog: C1, EN912:
- Double-sided tooth-plate connector
- $d_c = 50$ mm, $h_c = 13$ mm, $t$ =1 mm

# Timber-to-timber (double shear) connection with bolts and bulldogs

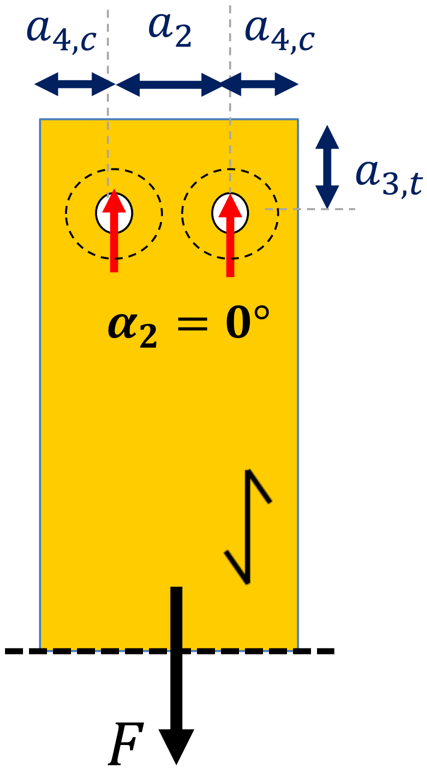
## - Free body diagrams




**Side members**




**Middle Member**

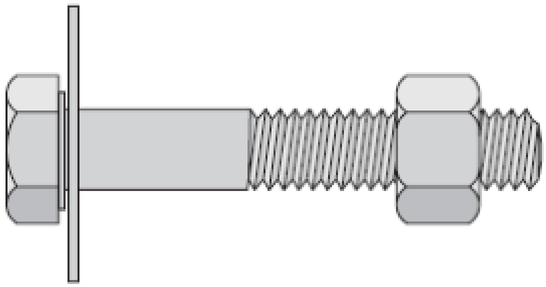


# Timber-to-timber (double shear) connection with bolts and bulldogs

## - Minimum spacings and distances: Bolts (Table 8.4)

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) | $0^\circ \le \alpha \le 360^\circ$ | $(4 + \lvert\cos\alpha\rvert)\, d$ |
| $a_2$ (perpendicular to grain) | $0^\circ \le \alpha \le 360^\circ$ | $4\, d$ |
| $a_{3,t}$ (loaded end) | $-90^\circ \le \alpha \le 90^\circ$ | max (7 $d$; 80 mm) |
| $a_{3,c}$ (unloaded end) | $90^\circ \le \alpha < 150^\circ$<br>$150^\circ \le \alpha < 210^\circ$<br>$210^\circ \le \alpha \le 270^\circ$ | $(1 + 6 \sin\alpha)\, d$<br>$4\, d$<br>$(1 + 6 \lvert\sin\alpha\rvert)\, d$ |
| $a_{4,t}$ (loaded edge) | $0^\circ \le \alpha \le 180^\circ$ | max [$(2 + 2 \sin\alpha)\, d$; $3d$] |
| $a_{4,c}$ (unloaded edge) | $180^\circ \le \alpha \le 360^\circ$ | $3\, d$ |



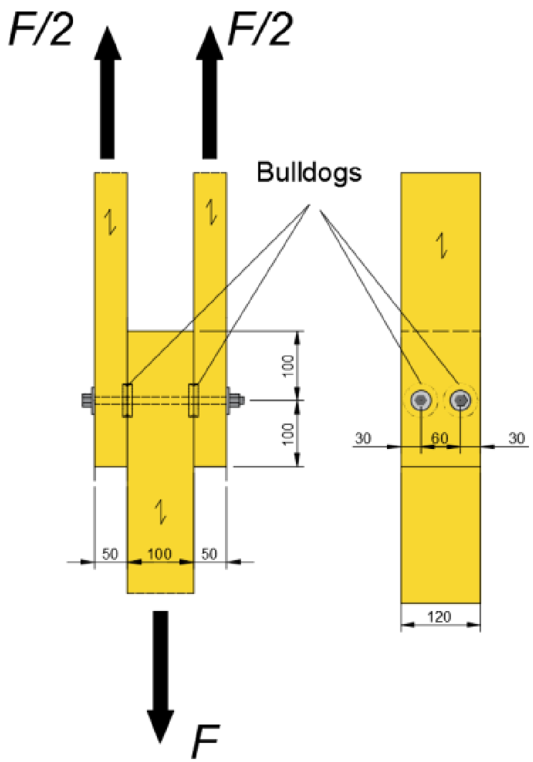
- **Both members ($\alpha_1 = \alpha_2 = 0°$)**

$a_1 = \mathrm{NA}$ **Not relevant**

$a_2 = 60 \text{ mm} \ge 4 \cdot d = 40 \text{ mm}$ **(OK)**

$a_{3,\mathrm{t}} = 100 \text{ mm} \ge \max(7 \cdot d, 80) = 80 \text{ mm}$ **(OK)**

$a_{4,\mathrm{c}} = 30 \text{ mm} \ge 3 \cdot d = 30 \text{ mm}$ **(OK)**





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# Timber-to-timber (double shear) connection with bolts and bulldogs

## - Minimum spacings and distances: Bulldogs (Table 8.8)

**Table 8.8 — Minimum spacings and edge and end distances for toothed-plate connector ty[pes] C1 to C9**

| Spacing and edge/end distances (see Figure 8.7) | Angle to grain | Minimum spacings and edge/end distances |
|---|---|---|
| $a_1$ (parallel to grain) | $0° \le \alpha \le 360°$ | $(1{,}2+0{,}3\,\lvert\cos\alpha\rvert)d_c$ |
| $a_2$ (perpendicular to grain) | $0° \le \alpha \le 360°$ | $1{,}2\,d_c$ |
| $a_{3,t}$ (loaded end) | $-90° \le \alpha \le 90°$ | $1{,}5\,d_c$ → $2{,}0\,d_c$ |
| $a_{3,c}$ (unloaded end) | $90° \le \alpha \le 150°$<br>$150° \le \alpha \le 210°$<br>$210° \le \alpha \le 270°$ | $(0{,}9+0{,}6\,\lvert\sin\alpha\rvert)d_c$<br>$1{,}2\,d_c$<br>$(0{,}9+0{,}6\,\lvert\sin\alpha\rvert)d_c$ |
| $a_{4,t}$ (loaded edge) | $0° \le \alpha \le 180°$ | $(0{,}6+0{,}2\,\lvert\sin\alpha\rvert)d_c$ |
| $a_{4,c}$ (unloaded edge) | $180° \le \alpha \le 360°$ | $0{,}6\,d_c$ |

- **Both members ($\alpha_1 = \alpha_2 = 0°$)**

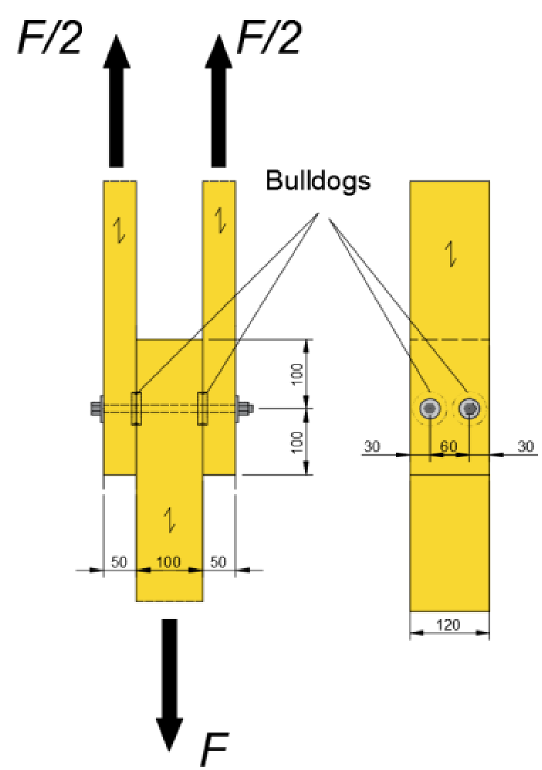
$a_1 = \text{NA}$ **Not relevant**

$a_2 = 60\ \text{mm} \ge 1.2 \cdot d_c = 1.2 \cdot 50 = 60\ \text{mm}$ **(OK)**

2.0 100 mm

$a_{3,\text{t}} = 100\ \text{mm} \ge 1.5 \cdot d_c = 1.5 \cdot 50 = 75\ \text{mm}$ **(OK)**

$a_{4,\text{c}} = 30\ \text{mm} \ge 0.6 \cdot d_c = 0.6 \cdot 50 = 30\ \text{mm}$ **(OK)**





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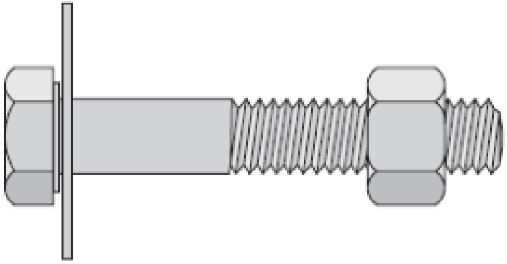
# Timber-to-timber (double shear) connection with bolts and bulldogs

## - Bolt properties



### Bolts

- $d = 10\ \mathrm{mm}$
- $f_{\mathrm{u,k}} = 800\ \mathrm{N/mm^2}$
- Eq.(8.30): $M_{\mathrm{y,Rk}} = 0.30 \cdot 800 \cdot 10^{2.6} = 95545\ \mathrm{Nmm}$

### Axial capacity

- We will neglect the rope effect in this Example

# Timber-to-timber (double shear) connection with bolts and bulldogs

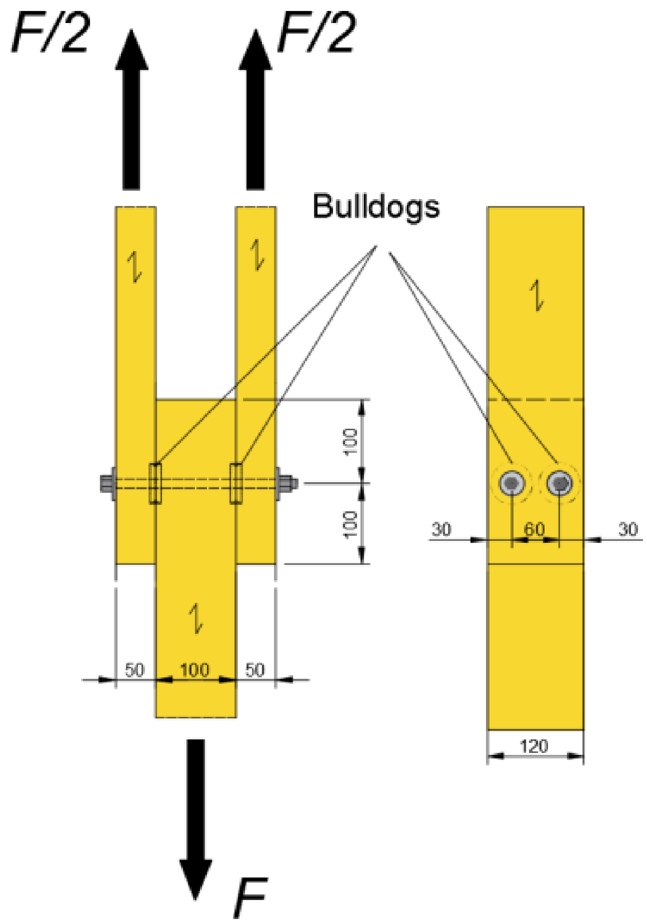
## - Member properties

### Side members (1)

- Thickness: $t_1 = 50$ mm (Given by exercise)
- Timber C30 (EN338): $\rho_{k,1} = 380\ \mathrm{kg/m^3}$
- Timber C30 (EN338): $\rho_{m,1} = 460\ \mathrm{kg/m^3}$
- Load-to-grain angle: $\alpha_1 = 0°$ (forces parallel to grain)
- Eq.(8.32)/Eq.(8.31):
- $f_{h,1,k} = f_{h,0,k} = 0.082 \cdot (1 - 0.01 \cdot 10) \cdot 380 = 28.0\ \mathrm{N/mm^2}$

### Middle member (2)

- Thickness: $t_2 = 100$ mm (Given by exercise)
- Timber C30 (EN338): $\rho_{k,2} = 380\ \mathrm{kg/m^3}$
- Timber C30 (EN338): $\rho_{m,2} = 460\ \mathrm{kg/m^3}$
- Load-to-grain angle: $\alpha_2 = 0°$ (forces parallel to grain)
- Eq.(8.32)/Eq.(8.31):
- $f_{h,2,k} = f_{h,0,k} = 0.082 \cdot (1 - 0.01 \cdot 10) \cdot 380 = 28.0\ \mathrm{N/mm^2}$

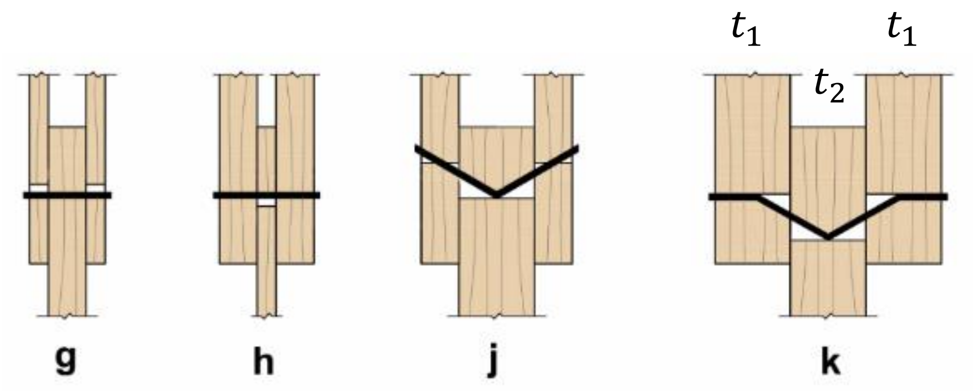



$$\beta = \frac{f_{h,2,k}}{f_{h,1,k}} = 1.0$$

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

# Load-carrying capacity: bolts

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




$\beta = 1$

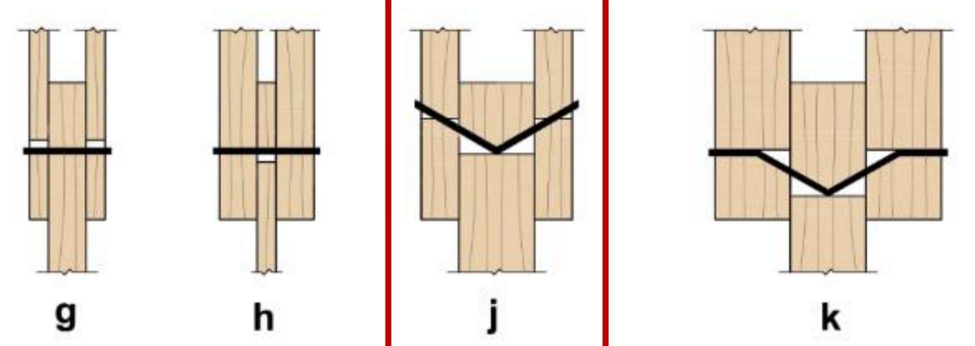
EN 1995-1-1, **(eq.8.8)**

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

EN 1995-1-1, §8.2.2.(1), **(eq.8.7)**

# Load-carrying capacity; bolts

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




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

- **Neglecting the rope effect**

$$F_{\mathrm{v,Rk(g)}} = 28 \cdot 50 \cdot 10 = 14000\ \mathrm{N}$$

$$F_{\mathrm{v,Rk(h)}} = 0.5 \cdot 28 \cdot 100 \cdot 10 = 14000\ \mathrm{N}$$

$$F_{\mathrm{v,Rk(j)}} = 1.05 \cdot \frac{28 \cdot 50 \cdot 10}{2+1}\left[\sqrt{2 \cdot 1 \cdot (1+1) + \frac{4 \cdot 1 \cdot (2+1) \cdot 95545}{28 \cdot 10 \cdot 50^2}} - 1\right] = 6734\ \mathrm{N}$$

$$F_{\mathrm{v,Rk(k)}} = 1.15 \cdot \sqrt{\frac{2 \cdot 1}{1+1}} \cdot \sqrt{2 \cdot 95545 \cdot 28 \cdot 10} = 8412\ \mathrm{N}$$

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

$\mathrm{F_{v,Rk}} = \min\left(F_{\mathrm{v,Rk(g)}}; F_{\mathrm{v,Rk(h)}}; F_{\mathrm{v,Rk(j)}}; F_{\mathrm{v,Rk(k)}}\right) = \mathbf{6734\ N}$ [Failure mode (j)]

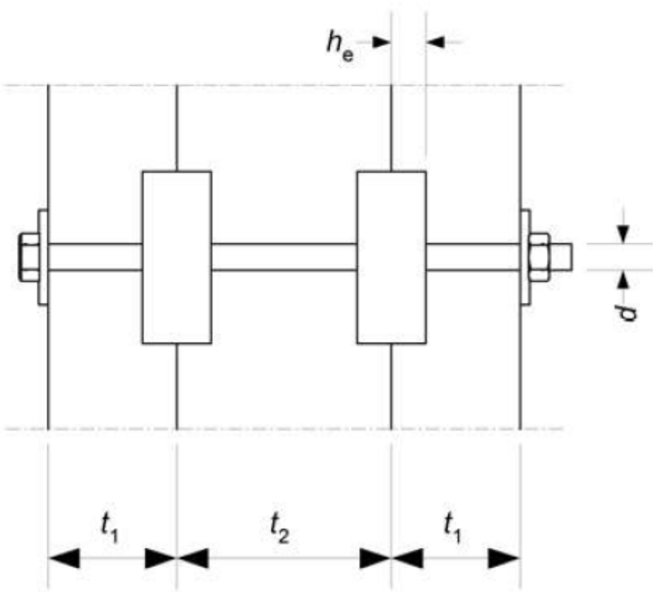
# Timber-to-timber (double shear) connection with bolts and bulldogs

## - Toothed-plates (Bulldogs)

**Connectors, Type C1 (EN912):**

- $d_c = 50$ mm, $h_c = 13$ mm, $t$ =1 mm
- Tooth penetration: $h_e = (h_c - t)/2 = (13 - 1)/2 = 6 \text{ mm}$
- Check thickness of members (§8.10 and §8.9.2)

- $t_1 = 50 \text{ mm} \geq 2.25 \cdot h_e = 13.5 \text{ mm}$ **(OK)**
- $t_2 = 100 \text{ mm} \geq 3.75 \cdot h_e = 22.5 \text{ mm}$ **(OK)**



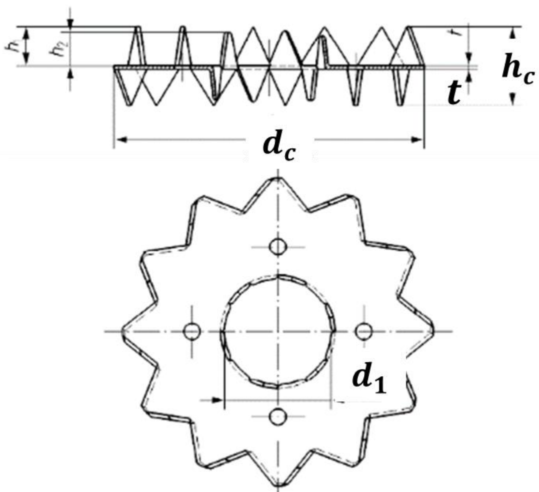




Figure C.1 — Connectors of type C1

# Timber-to-timber (double shear) connection with bolts and bulldogs

## - Toothed-plates (Bulldogs)

- **Connectors, Type C1 (EN912):**

$$k_1 = \min\begin{cases} 1 \\ t_1/(3\cdot h_e) \\ t_2/(5\cdot h_e) \end{cases} = \min\begin{cases} 1 \\ 50/(3\cdot 6) \\ 100/(5\cdot 6) \end{cases} = 1.0$$

EN 1995-1-1, §8.10.(4), **eq.(8.73)**

$$a_{3,t} = \max\begin{cases} 1.1\cdot d_c \\ 7\cdot d \\ 80\text{ mm} \end{cases} = \max\begin{cases} 1.1\cdot 50 \\ 7\cdot 10 \\ 80\text{ mm} \end{cases} = 80\text{ mm}$$

EN 1995-1-1, §8.10.(5), **eq.(8.75)**

$$k_3 = \min\begin{cases} 1.5 \\ \rho_k/350 \end{cases} = \min\begin{cases} 1.5 \\ 380/350 \end{cases} = 1.09$$

EN 1995-1-1, §8.10.(6), **eq.(8.78)**

$$k_2 = \min\begin{cases} 1 \\ a_{3,t}/(1.5\cdot d_c) \end{cases} = \min\begin{cases} 1 \\ 80/(1.5\cdot 50) \end{cases} = 1.0$$

EN 1995-1-1, §8.10.(5), **eq.(8.74)**

- **Capacity of per toothed plate connector:**

$$F_{v,Rk} = 18\cdot k_1\cdot k_2\cdot k_3\cdot {d_c}^{1.5} = 18\cdot 1\cdot 1\cdot 1.09\cdot 50^{1.5} = 6936\text{ N}$$

EN 1995-1-1, §8.10.(2), **eq.(8.72)**

# Timber-to-timber (double shear) connection with bolts and bulldogs

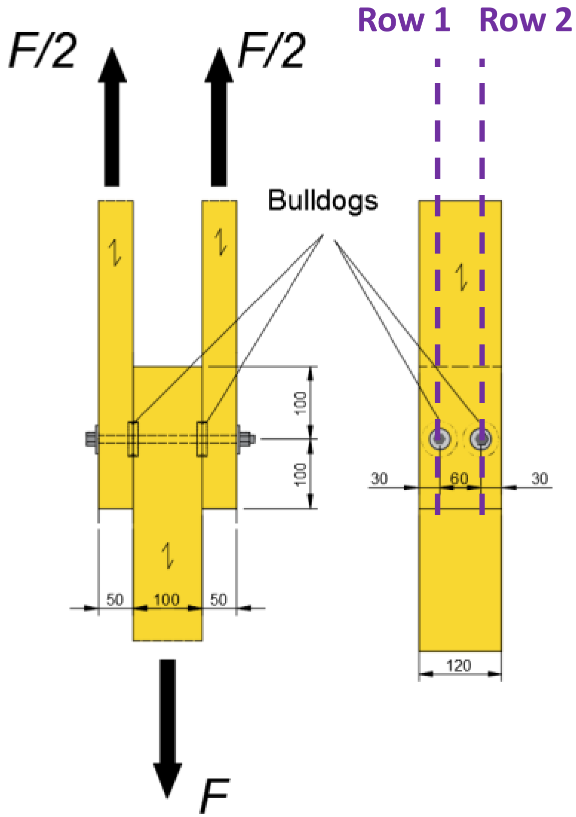
## - Load transfer/splitting for force components parallel to grain

- **Total (effective) load-carrying capacity of the connection**

$$F_{\mathrm{v,ef,Rk,tot}} = \{n_{\mathrm{ef}} \cdot F_{\mathrm{v,Rk}}\}_{\mathrm{BOLTS}} + \{n \cdot F_{\mathrm{v,Rk}}\}_{\mathrm{BULLDOGS}}$$

EN 1995-1-1, §8.10(1), Porteous and Kermani

$n_{\mathrm{ef}} = 1.0$ **One fastener per row parallel to grain, i.e. $n = 1$**




- **Per shear plane and fastener**

$$F_{\mathrm{v,ef,Rk,tot}} = \{1 \cdot 6734\}_{\mathrm{BOLTS}} + \{1 \cdot 6936\}_{\mathrm{BULLDOGS}} = 13670\ \mathrm{N}$$

$$F_{\mathrm{v,ef,Rd,tot}} = \frac{k_{\mathrm{mod}}}{\gamma_{\mathrm{M}}} \cdot F_{\mathrm{v,Rk}} = \frac{0.9}{1.3} \cdot 13670\ \mathrm{N} = 9464\ \mathrm{N}$$

- **Design check: Capacity of entire connection**

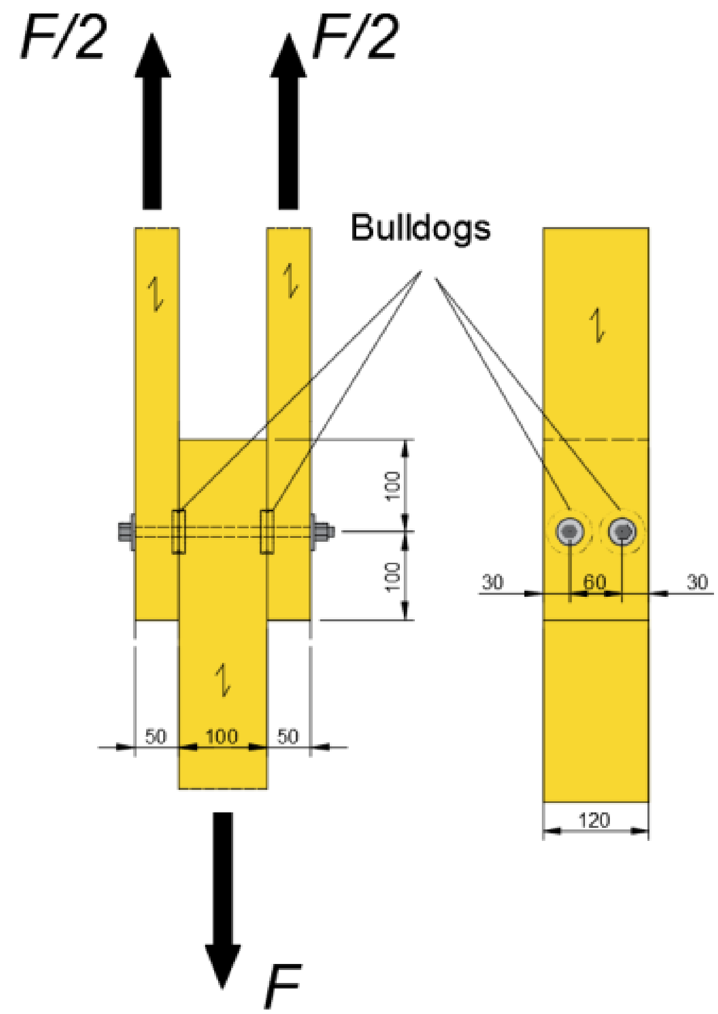
- **We have a toothed plate in all shear planes and fasteners**

$$\frac{F}{n_{\text{shear planes}} \cdot n_{\text{fasteners}}} = \frac{F}{2 \cdot 2} \leq F_{\mathrm{v,ef,Rd,tot}} = 9464\ \mathrm{N} \quad \rightarrow \quad \boldsymbol{F_{\mathrm{d}} \leq 37.9\ \mathrm{kN}}$$

# Timber-to-timber (double shear) connection with bolts and bulldogs

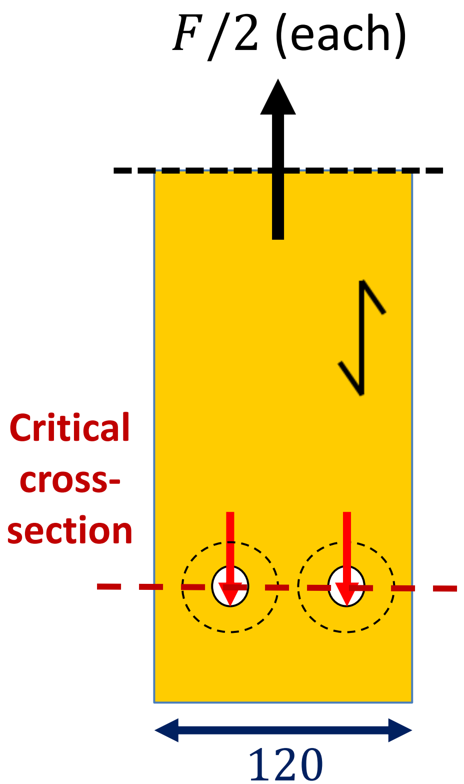
## - Splitting for force components perpendicular to grain

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



# Timber-to-timber (double shear) connection with bolts and bulldogs

## - Net cross-section check: side members




**Assume:**

$d_{\mathrm{hole}} = d + 1 = 11$ mm

**Timber C30 (EN338):**

$f_{\mathrm{t,0,k}} = 19\ \mathrm{N/mm^2}$  $\gamma_{\mathrm{M}} = 1.25$

$k_{\mathrm{h}} = \min\left((150/120)^{0.2}, 1.3\right) = 1.045$

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

$$f_{\mathrm{t,0,d}} = f_{\mathrm{t,0,k}} \cdot k_{\mathrm{h}} \cdot k_{\mathrm{mod}}/\gamma_{\mathrm{M}} = 19 \cdot 1.045 \cdot 0.9/1.25 = 14.3\ \mathrm{N/mm^2}$$

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

$$A_{\mathrm{net}} = 50 \cdot (120 - 2 \cdot 11) = 4900\ \mathrm{mm^2}$$

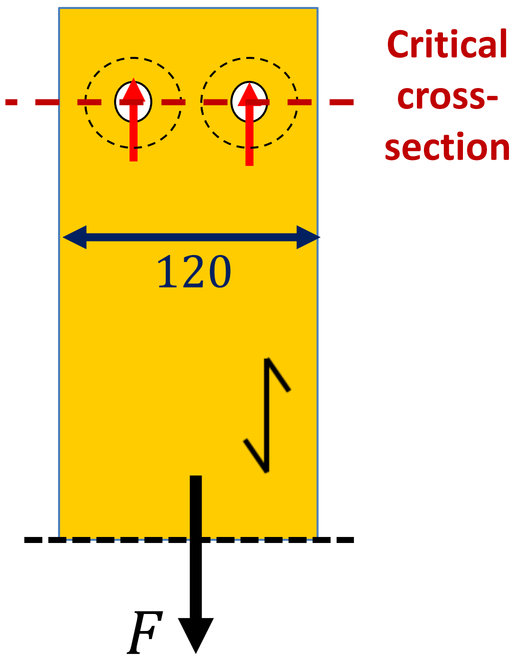
$$\frac{\sigma_{\mathrm{t,0,d}}}{f_{\mathrm{t,0,d}}} \le 1.0 \rightarrow \frac{F}{2} \le A_{\mathrm{net}} \cdot f_{\mathrm{t,0,d}} = 4900 \cdot 14.3 \rightarrow \boldsymbol{F_{\mathrm{d}} \le 140\ \mathrm{kN}}$$

EN 1995-1-1, §6.1.2, **eq.(6.1)**

$\boldsymbol{F_{\mathrm{t,0,d}} = 140\ \mathrm{kN} > F_{\mathrm{v,Rd}} = 37.9\ \mathrm{kN}} \rightarrow$ **Net section failure is not critical**

# Timber-to-timber (double shear) connection with bolts and bulldogs

## - Net cross-section check: middle member




**Timber C30 (EN338):**

$f_{t,0,k} = 19\ \mathrm{N/mm^2}$ $\gamma_M = 1.25$

$k_h = \min\left((150/120)^{0.2}, 1.3\right) = 1.045$

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

$f_{t,0,d} = f_{t,0,k} \cdot k_h \cdot k_{mod}/\gamma_M = 19 \cdot 1.045 \cdot 0.9/1.25 = 14.3\ \mathrm{N/mm^2}$

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

$A_{net} = 100 \cdot (120 - 2 \cdot 11) = 9800\ \mathrm{mm^2}$

$\frac{\sigma_{t,0,d}}{f_{t,0,d}} \leq 1.0 \rightarrow F \leq A_{net} \cdot f_{t,0,d} = 9800 \cdot 14.3$ $\rightarrow$ $\boldsymbol{F_d \leq 140\ \mathrm{kN}}$

EN 1995-1-1, §6.1.2, **eq.(6.1)**

**Assume:**

$d_{hole} = d + 1 = 11$ mm

$\boldsymbol{F_{t,0,d} = 140\ \mathrm{kN} > F_{v,Rd} = 37.9\ \mathrm{kN}}$ → **Net section failure is not critical**