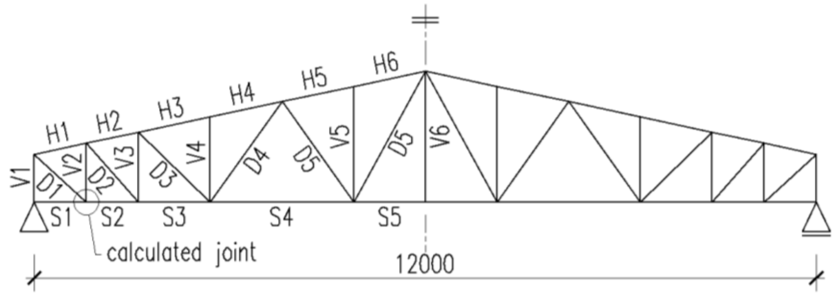
HOW TO DESIGN NAILED JOINT?

…worked examples for BO003 and BO006

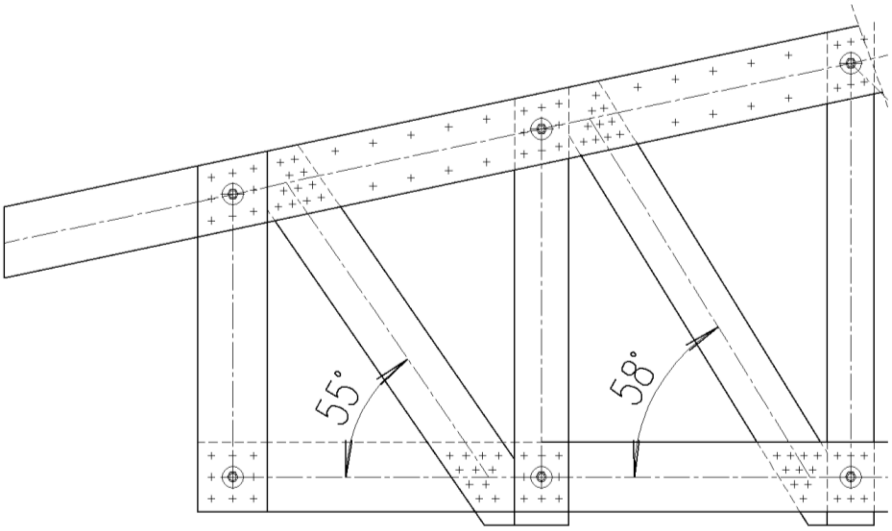
WORKED EXAMPLE 4: NAILED JOINT OF DIAGONAL AND BOTTOM CHORD OF TRUSS GIRDER

Make design and assessment of nailed joint of diagonal D1 and vertical V2 and bottom chord of truss girder. Calculation will be performed for load combination composed of permanent load and snow load. Members are made of solid timber C24. Joint is made of nails with diameter 4,5 mm with two shear planes. Service class no 2 is considered.

Axis scheme



Detail of calculated joint



Material

Solid timber C24 according to the EN 338

ρ_k = 350 kg/m^3 characteristic value of timber density

Predrilling

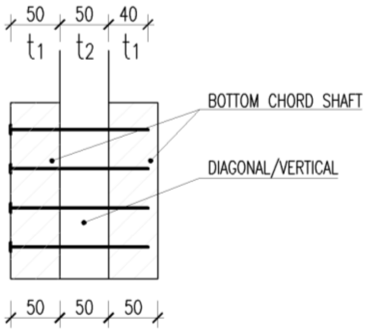
$d = 4{,}5\ \text{mm} \quad \leq \quad 6\ \text{mm}$ *=> it is not necessary to make predrilling*

$\rho_k = 350\ \text{kg/m}^3 \quad \leq \quad 500\ \text{kg/m}^3$ *=> it is not necessary to make predrilling*

$$t = 50\ \text{mm} \quad \geq \quad \max\begin{Bmatrix} 7 \cdot d \\ (13 \cdot d - 30) \cdot \dfrac{\rho_k}{400} \end{Bmatrix} = \max\begin{Bmatrix} 7 \cdot 4{,}5 \\ (13 \cdot 4{,}5 - 30) \cdot \dfrac{350}{400} \end{Bmatrix} = \max\begin{Bmatrix} 31{,}5 \\ 24{,}9 \end{Bmatrix} = 31{,}5\ \text{mm}$$

=> it is not necessary to make predrilling

=>No predrilling



Load carrying capacity per one fastener

Definition of thicknesses t_1 and t_2

$t_2 = 50\ \text{mm}$

$t_1 = \min\{50;40\} = 40\ \text{mm} \quad \geq \quad 8 \cdot d = 8 \cdot 4{,}5 = 36\ \text{mm}$ *=> it can be considered as double-shear joint*

Characteristic yield moment of nail made of wire with minimum tensile strength 600 MPa

$$M_{y,Rk} = 0{,}3 \cdot f_u \cdot d^{2{,}6} = 0{,}3 \cdot 600 \cdot 4{,}5^{2{,}6} = 8987\ \text{Nmm}$$

Characteristic embedding strength

$$f_{h,1,k} = f_{h,2,k} = 0{,}082 \cdot \rho_k \cdot d^{-0{,}3} = 0{,}082 \cdot 350 \cdot 4{,}5^{-0{,}3} = 18{,}3\ \text{N/mm}^2$$

Characteristic embedding strengths ratio

$$\beta = \frac{f_{h,2,k}}{f_{h,1,k}} = \frac{18{,}3}{18{,}3} = 1$$

Characterisitc load-carrying capacity of one nail per one shear plane should be taken as smallest valeu found from the following formulae for different failure modes

$$F_{v,Rk}(g) = f_{h,1,k} \cdot t_1 \cdot d = 18{,}3 \cdot 40 \cdot 4{,}5 = 3290\ \text{N} = 3{,}29\ \text{kN}$$

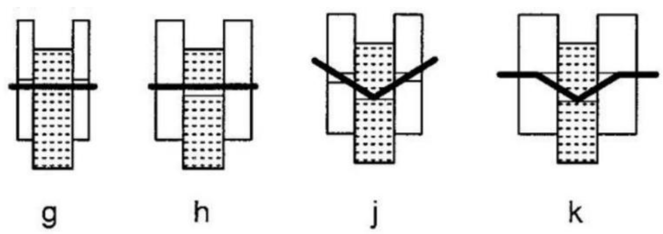
$$F_{v,Rk}(h) = 0{,}5 \cdot f_{h,2,k} \cdot t_2 \cdot d = 0{,}5 \cdot 18{,}3 \cdot 50 \cdot 4{,}5 = 2060\ \text{N} = 2{,}06\ \text{kN}$$

$$F_{v,Rk}(j) = 1{,}05 \cdot \frac{f_{h,1,k} \cdot t_1 \cdot d}{2+\beta} \cdot \left[\sqrt{2 \cdot \beta \cdot (1+\beta) + \frac{4 \cdot \beta \cdot (2+\beta) \cdot M_{y,Rk}}{f_{h,1,k} \cdot d \cdot t_1^2}}\right] =$$

$$= 1{,}05 \cdot \frac{18{,}3 \cdot 40 \cdot 4{,}5}{2+1} \cdot \left[\sqrt{2 \cdot 1 \cdot (1+1) + \frac{4 \cdot 1 \cdot (2+1) \cdot 8987}{18{,}3 \cdot 4{,}5 \cdot 40^2}}\right] = 1380\ \text{N} = 1{,}38\ \text{kN}$$

$$F_{v,Rk}(k) = 1{,}15 \cdot \sqrt{\frac{2 \cdot \beta}{1+\beta}} \cdot \sqrt{2 \cdot M_{y,Rk} \cdot f_{h,1,k} \cdot d} = 1{,}15 \cdot \sqrt{\frac{2 \cdot 1}{1+1}} \cdot \sqrt{2 \cdot 8987 \cdot 18{,}3 \cdot 4{,}5} = 1400\ \text{N} = 1{,}40\ \text{kN}$$

$$F_{v,Rk} = \min\{F_{v,Rk}(g); F_{v,Rk}(h); F_{v,Rk}(j); F_{v,Rk}(k)\} = \min\{3{,}29;\ 2{,}06; 1{,}38; 1{,}40\} = 1{,}38\ \text{kN}$$

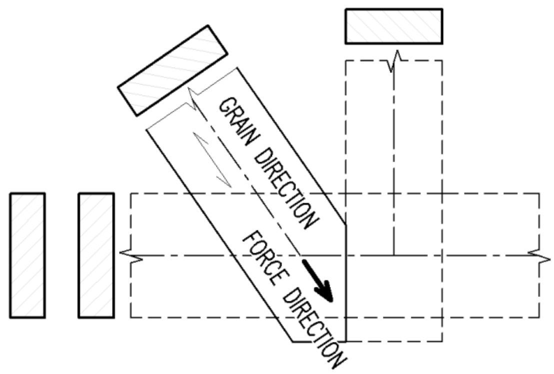


Design load-carrying capacity of one nail per one shear plane

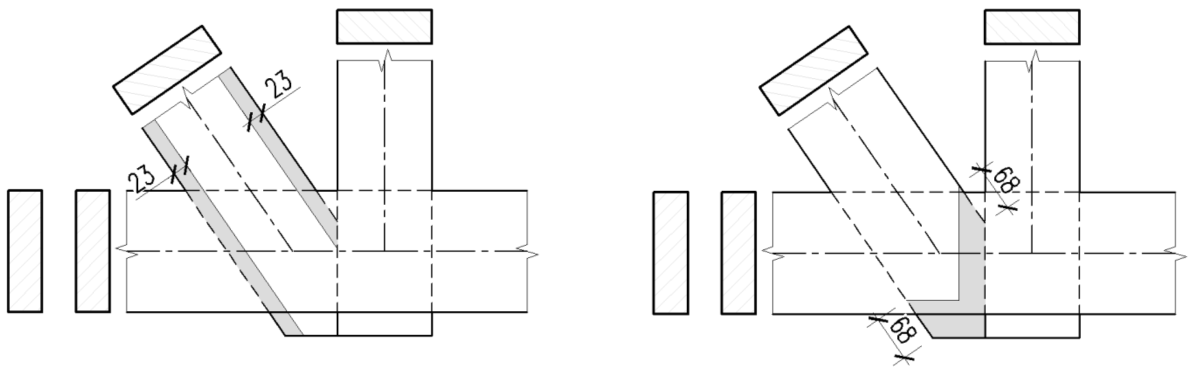
$$F_{v,Rd} = k_{mod} \cdot \frac{F_{v,Rk}}{\gamma_M} = 0{,}9 \cdot \frac{1{,}38}{1{,}3} = 0{,}96\ \text{kN}$$

Nails spacing and distances

Minimum values for diagonal (d): angle between diagonal grain direction and force direction δ=0°

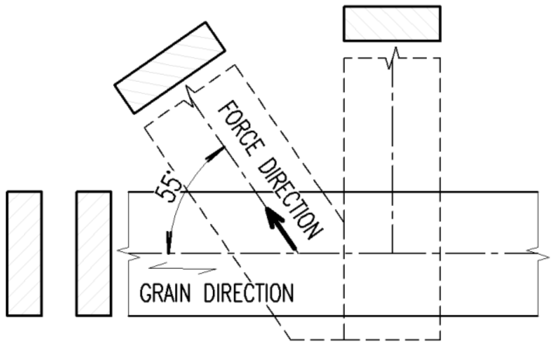


- distance from loaded end $a_{3,t}(\text{d}) \geq (10 + 5 \cdot \cos\delta) \cdot d = (10 + 5 \cdot \cos 0°) \cdot 4{,}5 = 68\ \text{mm}$
- distance from edges $a_{4,t}(\text{d}) = a_{4,c}(\text{d}) \geq 5 \cdot d = 5 \cdot 4{,}5 = 23\ \text{mm}$

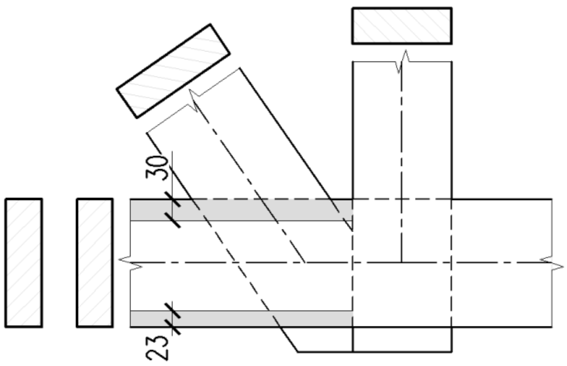


- spacing parallel to the grain $a_1(\text{d}) \geq (5 + 5 \cdot |\cos\delta|) \cdot d = (5 + 5 \cdot |\cos 0°|) \cdot 4{,}5 = 45\ \text{mm}$
- spacing perpendicular to the grain $a_2(\text{d}) \geq 5 \cdot d = 5 \cdot 4{,}5 = 23\ \text{mm}$

Minimum values for bottom chord (s): angle between chord grain direction and force direction δ=55°

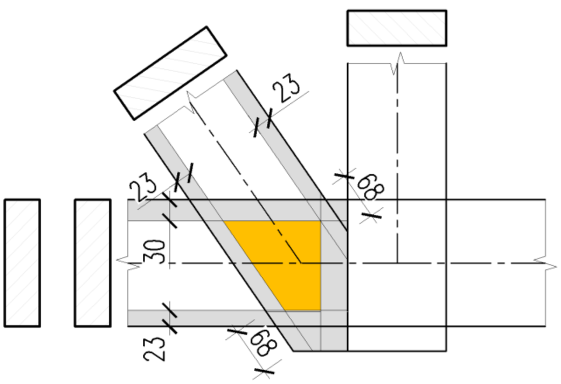


- distances from loaded edge $a_{4,t}(\mathrm{s}) \geq (5+2\cdot\sin\delta)\cdot d = (5+2\cdot\sin 50°)\cdot 4{,}5 = 30\ \mathrm{mm}$
- distance from unloaded edge $a_{4,c}(\mathrm{s}) \geq 5\cdot d = 5\cdot 4{,}5 = 23\ \mathrm{mm}$



- spacing parallel to the grain $a_1(\mathrm{s}) \geq (5+5\cdot|\cos\delta|)\cdot d = (5+5\cdot|\cos 50°|)\cdot 4{,}5 = 37\ \mathrm{mm}$
- spacing perpendicular to the grain $a_2(\mathrm{s}) \geq 5\cdot d = 5\cdot 4{,}5 = 23\ \mathrm{mm}$

Resulting area (orange) usable to nail spacing by minimum distances synthesis (grey)



Designed nail spacing

Area limitations

$a_{3,t}(\mathrm{d}) = 71{,}6\ \mathrm{mm} \geq 68\ \mathrm{mm}$

$a_4(\mathrm{d}) = 27{,}5\ \mathrm{mm} \geq 23\ \mathrm{mm}$

$a_{4,t}(\mathrm{s}) = 35\ \mathrm{mm} \geq 30\ \mathrm{mm}$

$a_{4,c}(\mathrm{s}) = 34\ \mathrm{mm} \geq 23\ \mathrm{mm}$

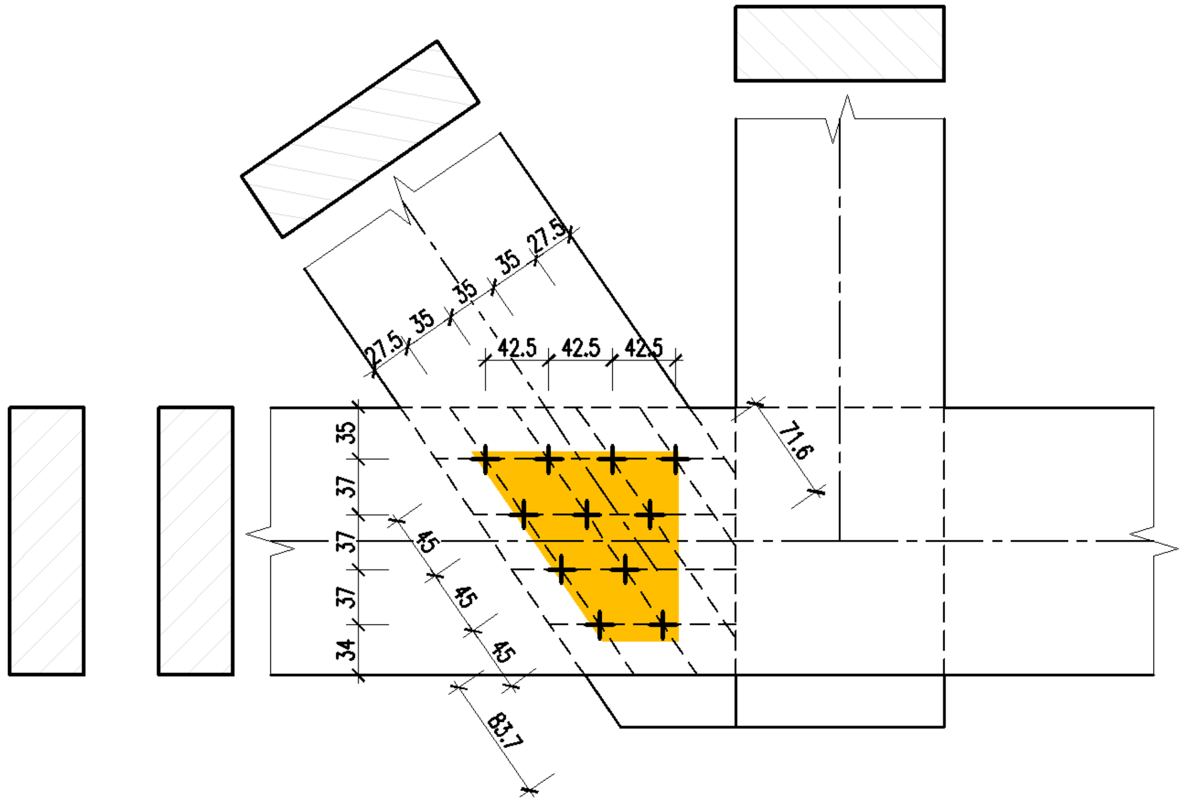
Nails spacing

$a_1(\mathrm{d}) = 45\ \mathrm{mm} \geq 45\ \mathrm{mm}$

$a_2(\mathrm{d}) = 35\ \mathrm{mm} \geq 23\ \mathrm{mm}$

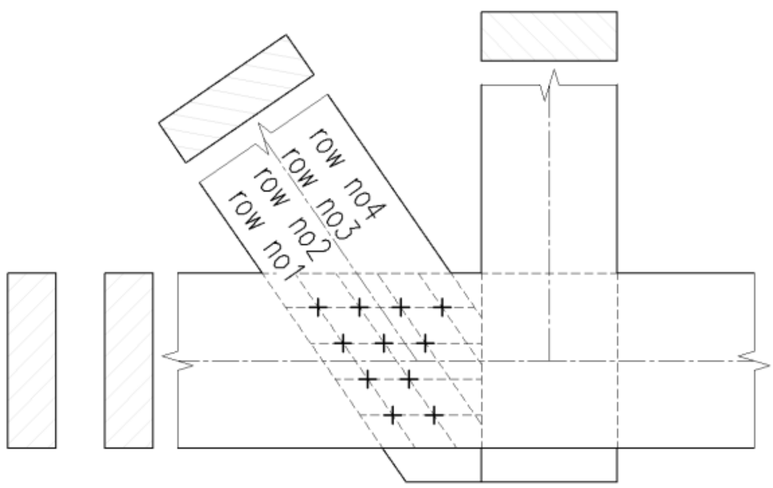
$a_1(\mathrm{s}) = 42{,}5\ \mathrm{mm} \geq 37\ \mathrm{mm}$

$a_2(\mathrm{s}) = 37\ \mathrm{mm} \geq 23\ \mathrm{mm}$



Load carrying capacity of whole joint

Load carrying capacity of whole joint is a sum of load-carrying capacity of all rows with effective number of nails.



Row no 1

Reduction factor depending on nail diameter d and spacing a_1 ratio

$$a_1 = 45\text{ mm} = 10 \cdot d \quad \Rightarrow \quad k_{\text{ef}} = 0{,}85$$

Effective number on nails in the row

$$n_{\text{ef},1} = n_1^{k_{\text{ef}}} = 4^{0{,}85} = 3{,}25$$

Load-carrying capacity of the rows per two shear planes

$$F_{\text{v,ef,Rd},1} = n_s \cdot n_{\text{ef},1} \cdot F_{\text{v,Rd}} = 2 \cdot 3{,}25 \cdot 0{,}96 = 6{,}24\text{ kN}$$

Row no 2

$$a_1 = 45\text{ mm} = 10 \cdot d \quad \Rightarrow \quad k_{\text{ef}} = 0{,}85$$

$$n_{\text{ef},2} = n_2^{k_{\text{ef}}} = 4^{0{,}85} = 3{,}25$$

$$F_{\text{v,ef,Rd},2} = n_s \cdot n_{\text{ef},2} \cdot F_{\text{v,Rd}} = 2 \cdot 3{,}25 \cdot 0{,}96 = 6{,}24\text{ kN}$$

Row no 3

$$a_1 = 45\text{ mm} = 10 \cdot d \quad \Rightarrow \quad k_{\text{ef}} = 0{,}85$$

$$n_{\text{ef},3} = n_3^{k_{\text{ef}}} = 2^{0{,}85} = 1{,}8$$

$$F_{\text{v,ef,Rd},3} = n_s \cdot n_{\text{ef},3} \cdot F_{\text{v,Rd}} = 2 \cdot 1{,}8 \cdot 0{,}96 = 3{,}46\text{ kN}$$

Row no 4

$$F_{\text{v,ef,Rd},4} = n_s \cdot n_{\text{ef},4} \cdot F_{\text{v,Rd}} = 2 \cdot 1 \cdot 0{,}96 = 1{,}92\text{ kN}$$

All the rows together = whole joint

$$F_{\text{v,ef,Rd}} = \Sigma F_{\text{v,ef,Rd},i} = 6{,}24 + 6{,}24 + 3{,}46 + 1{,}92 = 17{,}86\text{ kN}$$

$$\frac{N_{\text{Ed}}}{F_{\text{v,ef,Rd}}} = \frac{16{,}24}{17{,}86} = 0{,}91 \quad \leq \quad 1{,}0$$

=> condition is satisfied

Joining of vertical V2 will be done the same way