– For fasteners in double shear:

$$F_{v,Rk} = \min \begin{cases} f_{h,1,k} t_1 d & \text{(g)} \\ 0{,}5 f_{h,2,k} t_2 d & \text{(h)} \\ 1{,}05 \dfrac{f_{h,1,k} t_1 d}{2+\beta} \left[\sqrt{2\beta(1+\beta) + \dfrac{4\beta(2+\beta) M_{y,Rk}}{f_{h,1,k} d \; t_1^2}} - \beta \right] + \dfrac{F_{ax,Rk}}{4} & \text{(j)} \\ 1{,}15 \sqrt{\dfrac{2\beta}{1+\beta}} \sqrt{2 M_{y,Rk} f_{h,1,k} d} + \dfrac{F_{ax,Rk}}{4} & \text{(k)} \end{cases} \quad (8.7)$$

with

$$\beta = \frac{f_{h,2,k}}{f_{h,1,k}} \quad (8.8)$$

where:

$F_{v,Rk}$ is the characteristic load-carrying capacity per shear plane per fastener;

t_i is the timber or board thickness or penetration depth, with i either 1 or 2, see also 8.3 to 8.7 ;

$f_{h,i,k}$ is the characteristic embedment strength in timber member i;

d is the fastener diameter;

$M_{y,Rk}$ is the characteristic fastener yield moment;

β is the ratio between the embedment strength of the members;

$F_{ax,Rk}$ is the characteristic axial withdrawal capacity of the fastener, see (2).

NOTE: Plasticity of joints can be assured when relatively slender fasteners are used. In that case, failure modes (f) and (k) are governing.

(2) In the expressions (8.6) and (8.7), the first term on the right hand side is the load-carrying capacity according to the Johansen yield theory, whilst the second term $F_{ax,Rk}/4$ is the contribution from the rope effect. The contribution to the load-carrying capacity due to the rope effect should be limited to following percentages of the Johansen part:

– Round nails 15 %
– AC› Square and grooved nails 25 % ‹AC
– Other nails 50 %
– Screws 100%
– Bolts 25 %
– Dowels 0 %

If $F_{ax,Rk}$ is not known then the contribution from the rope effect should be taken as zero.

For single shear fasteners the characteristic withdrawal capacity, $F_{ax,Rk}$, is taken as the lower of the capacities in the two members. The different modes of failure are illustrated in Figure 8.2. For the withdrawal capacity, $F_{ax,Rk}$, of bolts the resistance provided by the washers may be taken into account, see 8.5.2(2).

(3) If no design rules are given below, the characteristic embedment strength $f_{h,k}$ should be determined according to EN 383 and EN 14358.

(4) If no design rules are given below, the characteristic yield moment $M_{y,Rk}$ should be determined according to EN 409 and EN 14358.

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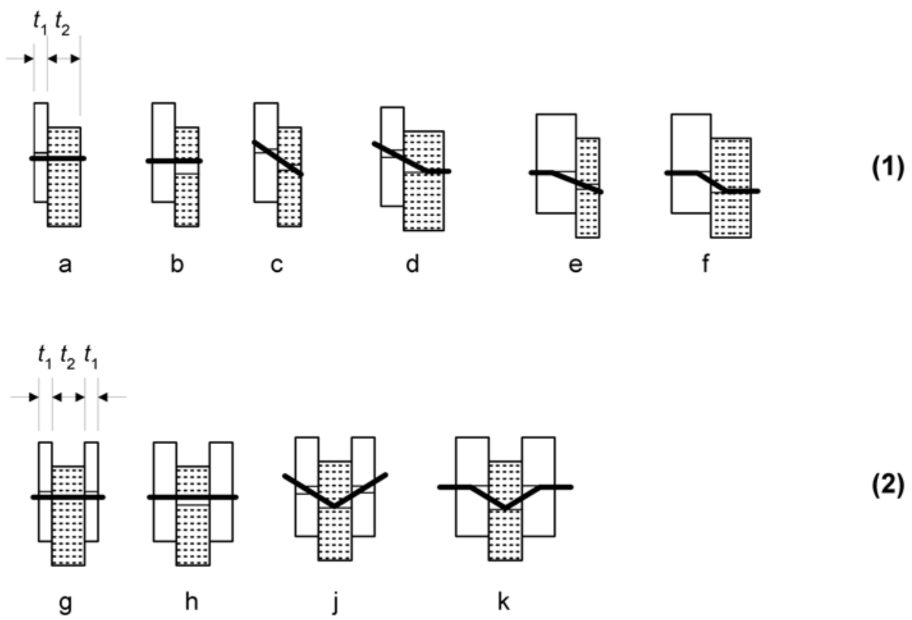

Key:
(1) Single shear
(2) Double shear

NOTE: The letters correspond to the references of the expressions (8.6) and (8.7)

Figure 8.2 – Failure modes for timber and panel connections.

8.2.3 Steel-to-timber connections

(1) The characteristic load-carrying capacity of a steel-to-timber connection depends on the thickness of the steel plates. Steel plates of thickness less than or equal to 0,5d are classified as thin plates and steel plates of thickness greater than or equal to d with the tolerance on hole diameters being less than 0,1d are classified as thick plates. The characteristic load-carrying capacity of connections with steel plate thickness between a thin and a thick plate should be calculated by linear interpolation between the limiting thin and thick plate values.

(2)P The strength of the steel plate shall be checked.

(3) The characteristic load-carrying capacity for nails, bolts, dowels and screws per shear plane per fastener should be taken as the minimum value found from the following expressions:

– For a thin steel plate in single shear:

$$F_{\mathrm{v,Rk}} = \min \begin{cases} 0{,}4\, f_{\mathrm{h,k}}\, t_1\, d & \text{(a)} \\ 1{,}15\sqrt{2 M_{\mathrm{y,Rk}}\, f_{\mathrm{h,k}}\, d} + \dfrac{F_{\mathrm{ax,Rk}}}{4} & \text{(b)} \end{cases} \qquad (8.9)$$

– For a thick steel plate in single shear:

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$$\text{A1} \; F_{v,Rk} = \min \begin{cases} f_{h,k}\, t_1\, d & \text{(c)} \\ f_{h,k}\, t_1\, d \left[\sqrt{2 + \dfrac{4 M_{y,Rk}}{f_{h,k}\, d\, t_1^2}} - 1 \right] + \dfrac{F_{ax,Rk}}{4} & \text{(d)} \; \text{A1} \\ 2{,}3 \sqrt{M_{y,Rk}\, f_{h,k}\, d} + \dfrac{F_{ax,Rk}}{4} & \text{(e)} \end{cases} \qquad (8.10)$$

– For a steel plate of any thickness as the central member of a double shear connection:

$$F_{v,Rk} = \min \begin{cases} f_{h,1,k}\, t_1\, d & \text{(f)} \\ f_{h,1,k}\, t_1\, d \left[\sqrt{2 + \dfrac{4 M_{y,Rk}}{f_{h,1,k}\, d\, t_1^2}} - 1 \right] + \dfrac{F_{ax,Rk}}{4} & \text{(g)} \\ 2{,}3 \sqrt{M_{y,Rk}\, f_{h,1,k}\, d} + \dfrac{F_{ax,Rk}}{4} & \text{(h)} \end{cases} \qquad (8.11)$$

– For thin steel plates as the outer members of a double shear connection:

$$F_{v,Rk} = \min \begin{cases} 0{,}5\, f_{h,2,k}\, t_2\, d & \text{(j)} \\ 1{,}15 \sqrt{2 M_{y,Rk}\, f_{h,2,k}\, d} + \dfrac{F_{ax,Rk}}{4} & \text{(k)} \end{cases} \qquad (8.12)$$

– For thick steel plates as the outer members of a double shear connection:

$$F_{v,Rk} = \min \begin{cases} 0{,}5\, f_{h,2,k}\, t_2\, d & \text{(l)} \\ 2{,}3 \sqrt{M_{y,Rk}\, f_{h,2,k}\, d} + \dfrac{F_{ax,Rk}}{4} & \text{(m)} \end{cases} \qquad (8.13)$$

where:

$F_{v,Rk}$ is the characteristic load-carrying capacity per shear plane per fastener;

$f_{h,k}$ is the characteristic embedment strength in the timber member;

t_1 is the smaller of the thickness of the timber side member or the penetration depth;

t_2 is the thickness of the timber middle member;

d is the fastener diameter;

$M_{y,Rk}$ is the characteristic fastener yield moment;

$F_{ax,Rk}$ is the characteristic withdrawal capacity of the fastener.

NOTE 1: The different failure modes are illustrated in Figure 8.3

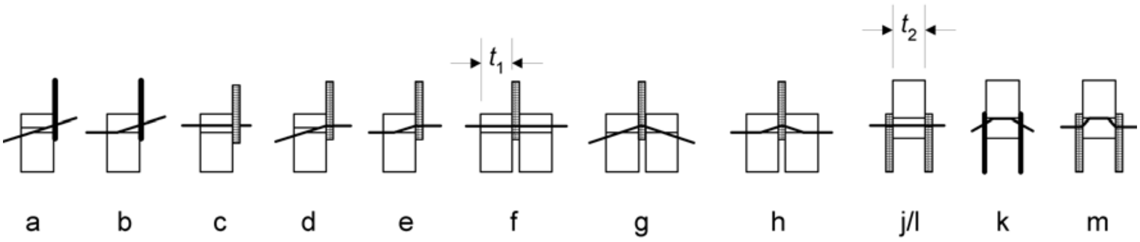

Figure 8.3 – Failure modes for steel-to-timber connections

(4) For the limitation of the rope effect $F_{ax,Rk}$ 8.2.2(2) applies.

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(5)P It shall be taken into account that the load-carrying capacity of steel-to-timber connections with a loaded end may be reduced by failure along the perimeter of the fastener group.

NOTE: A method of determining the strength of the fastener group is given in Annex A (informative).

8.3 Nailed connections

8.3.1 Laterally loaded nails

8.3.1.1 General

(1) The symbols for the thicknesses in single and double shear connections (see Figure 8.4) are defined as follows:
t_1 is:

the headside thickness in a single shear connection;

the minimum of the head side timber thickness and the pointside penetration in a double shear connection;
t_2 is:

the pointside penetration in a single shear connection;

the central member thickness in a double shear connection.

A1 (2) Timber should be pre-drilled when:
- the characteristic density of the timber is greater than 500 kg/m³;
- the diameter d of the nail exceeds 6 mm. A1

(3) For square and grooved nails, the nail diameter d should be taken as the side dimension.

(4) For smooth nails produced from wire with a minimum tensile strength of 600 N/mm², the following characteristic values for yield moment should be used:

AC $$M_{y,Rk} = \begin{cases} 0{,}3\, f_u\, d^{2{,}6} & \text{for round nails} \\ 0{,}45\, f_u\, d^{2{,}6} & \text{for square and grooved nails} \end{cases}$$ AC (8.14)

where:

$M_{y,Rk}$ is the characteristic value for the yield moment, in Nmm;

d is the nail diameter as defined in EN 14592, in mm;

f_u is the tensile strength of the wire, in N/mm².

(5) For nails with diameters up to 8 mm, the following characteristic embedment strengths in timber and LVL apply:
- without predrilled holes

$$f_{h,k} = 0{,}082\, \rho_k\, d^{-0{,}3} \quad \text{N/mm}^2 \qquad (8.15)$$

- with predrilled holes

$$f_{h,k} = 0{,}082\,(1 - 0{,}01\, d)\, \rho_k \quad \text{N/mm}^2 \qquad (8.16)$$

where:

ρ_k is the characteristic timber density, in kg/m³;

d is the nail diameter, in mm.

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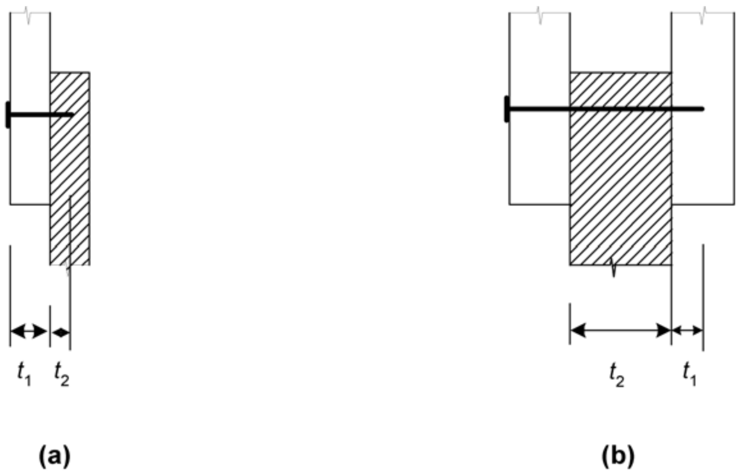

Figure 8.4 – Definitions of t_1 and t_2 (a) single shear connection, (b) double shear connection

(6) For nails with diameters greater than 8 mm the characteristic embedment strength values for bolts according to 8.5.1 apply.

(7) In a three-member connection, nails may overlap in the central member provided (t - t_2) is greater than $4d$ (see Figure 8.5).

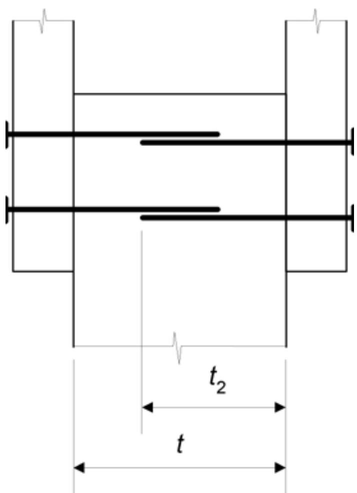

Figure 8.5 – Overlapping nails

(8) For one row of *n* nails parallel to the grain, unless the nails of that row are staggered perpendicular to grain by at least 1*d* (see figure 8.6), the load-carrying capacity parallel to the grain (see 8.1.2(4)) should be calculated using the effective number of fasteners n_{ef}, where:

$$n_{\mathrm{ef}} = n^{k_{\mathrm{ef}}} \tag{8.17}$$

where:

n_{ef} is the effective number of nails in the row;

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n is the number of nails in a row;

k_{ef} is given in Table 8.1.

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		

Key:
1 Nail
2 Grain direction

Figure 8.6 – Nails in a row parallel to grain staggered perpendicular to grain by *d*

(9) There should be at least two nails in a connection.

(10) Requirements for structural detailing and control of nailed connections are given in 10.4.2.

8.3.1.2 Nailed timber-to-timber connections

(1) For smooth nails the pointside penetration length should be at least $8d$.

(2) For nails other than smooth nails, as defined in EN 14592, the pointside penetration length should be at least $6d$.

[AC⟩ (3) Nails in end grain should not be considered capable of transmitting lateral forces. ⟨AC]

(4) As an alternative to 8.3.1.2(3), for nails in end grain the following rules apply:
- In secondary structures smooth nails may be used. The design values of the load-carrying capacity should be taken as 1/3 of the values for nails installed at right angles to the grain;
- Nails other than smooth nails, as defined in EN 14592, may be used in structures other than secondary structures. The design values of the load-carrying capacity should be taken as 1/3 of the values for smooth nails of equivalent diameter installed at right angles to the grain, provided that:
  - the nails are only laterally loaded;
  - there are at least three nails per connection;
  - the pointside penetration is at least $10d$;
  - the connection is not exposed to service class 3 conditions;
  - the prescribed spacings and edge distances given in Table 8.2 are satisfied.

Note 1: An example of a secondary structure is a fascia board nailed to rafters.

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Note 2: The recommended application rule is given in 8.3.1.2(3). The National choice may be specified in the National annex.

(5) Minimum spacings and edge and end distances are given in Table 8.2, where (see Figure 8.7):

a_1 is the spacing of nails within one row parallel to grain;

a_2 is the spacing of rows of nails perpendicular to grain;

$a_{3,c}$ is the distance between nail and unloaded end;

$a_{3,t}$ is the distance between nail and loaded end;

$a_{4,c}$ is the distance between nail and unloaded edge;

$a_{4,t}$ is the distance between nail and loaded edge;

α is the angle between the force and the grain direction.

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: $(5+5\|\cos\alpha\|)\,d$ $d \geq 5$ mm: $(5+7\|\cos\alpha\|)\,d$	$(7+8\|\cos\alpha\|)\,d$	$(4+\|\cos\alpha\|)\,d$
Spacing a_2 (perpendicular to grain)	$0^\circ \leq \alpha \leq 360^\circ$	$5d$	$7d$	$(3+\|\sin\alpha\|)\,d$
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)	$180^\circ \leq \alpha \leq 360^\circ$	$5d$	$7d$	$3d$

(6) Timber should be pre-drilled when the thickness of the timber members is smaller than

$$t = \max\begin{cases} 7d \\ (13d - 30)\dfrac{\rho_k}{400} \end{cases} \tag{8.18}$$

where:

t is the minimum thickness of timber member to avoid pre-drilling, in mm;

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ρ_k is the characteristic timber density in kg/m³;

d is the nail diameter, in mm.

(7) Timber of species especially sensitive to splitting should be pre-drilled when the thickness of the timber members is smaller than

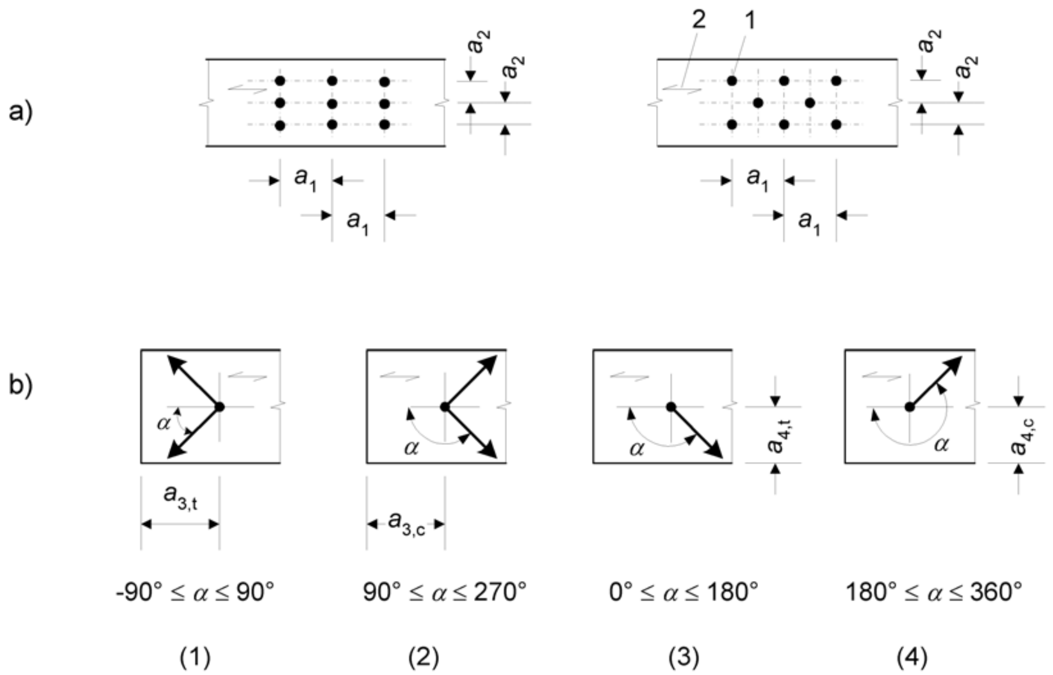
$$t = \max \begin{cases} 14d \\ (13d - 30)\dfrac{\rho_k}{200} \end{cases} \tag{8.19}$$

Expression (8.19) may be replaced by expression (8.18) for edge distances given by:

$a_4 \geq 10\ d$ for $\rho_k \leq 420$ kg/m^3

$a_4 \geq 14\ d$ for 420 kg/m$^3 \leq \rho_k \leq 500$ kg/ m^3.

Note: Examples of species sensitive to splitting are fir (abies alba), Douglas fir (pseudotsuga menziesii) and spruce (picea abies). It is recommended to apply 8.3.1.2(7) for species fir (abies alba) and Douglas fir (pseudotsuga menziesii). The National choice may be specified in the National annex.



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

Figure 8.7 – Spacings and end and edge distances
(a) Spacing parallel to grain in a row and perpendicular to grain between rows, (b) Edge and end distances

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8.3.1.3 Nailed panel-to-timber connections

(1) Minimum nail spacings for all nailed panel-to-timber connections are those given in Table 8.2, multiplied by a factor of 0,85. The end/edge distances for nails remain unchanged unless otherwise stated below.

(2) Minimum edge and end distances in plywood members should be taken as 3*d* for an unloaded edge (or end) and (3 + 4 sin α)*d* for a loaded edge (or end), where α is the angle between the direction of the load and the loaded edge (or end).

(3) For nails with a head diameter of at least 2*d*, the characteristic embedment strengths are as follows:

– for plywood:

$$f_{\text{h,k}} = 0{,}11\,\rho_{\text{k}}\,d^{-0{,}3} \tag{8.20}$$

where:

$f_{\text{h,k}}$ is the characteristic embedment strength, in N/mm^2;

ρ_{k} is the characteristic plywood density in kg/m^3;

d is the nail diameter, in mm;

– for hardboard in accordance with EN 622-2:

$$f_{\text{h,k}} = 30\,d^{-0{,}3}\,t^{0{,}6} \tag{8.21}$$

where:

$f_{\text{h,k}}$ is the characteristic embedment strength, in N/mm^2;

d is the nail diameter, in mm;

t is the panel thickness, in mm.

– for particleboard and OSB:

$$f_{\text{h,k}} = 65\,d^{-0{,}7}\,t^{0{,}1} \tag{8.22}$$

where:

$f_{\text{h,k}}$ is the characteristic embedment strength, in N/mm^2;

d is the nail diameter, in mm;

t is the panel thickness, in mm.

8.3.1.4 Nailed steel-to-timber connections

(1) The minimum edge and end distances for nails given in Table 8.2 apply. Minimum nail spacings are those given in Table 8.2, multiplied by a factor of 0,7.

8.3.2 Axially loaded nails

A1 (1)P Nails used to resist permanent or long-term axial loading shall be threaded.

NOTE: The following definition of threaded nails is given in EN 14592: Nail that has its shank profiled or deformed over a part of its length of minimum 4,5 d (4,5 times the nominal diameter) and that has a characteristic withdrawal parameter $f_{\text{ax,k}}$ greater than or equal to 6 N/mm^2 when measured on timber with a characteristic density of 350 kg/m^3 when conditioned to constant mass at 20 °C and 65 % relative humidity. A1

(2) For threaded nails, only the threaded part should be considered capable of transmitting axial load.

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(3) Nails in end grain should be considered incapable of transmitting axial load.

(4) The characteristic withdrawal capacity of nails, $F_{ax,Rk}$, for nailing perpendicular to the grain (Figure 8.8 (a) and for slant nailing (Figure 8.8 (b)), should be taken as the smaller of the values found from the following expressions:

– For nails other than smooth nails, as defined in EN 14592:

$$F_{ax,Rk} = \begin{cases} f_{ax,k}\, d\, t_{pen} & \text{(a)} \\ f_{head,k}\, d_h^2 & \text{(b)} \end{cases} \tag{8.23}$$

– For smooth nails:

$$F_{ax,Rk} = \begin{cases} f_{ax,k}\, d\, t_{pen} & \text{(a)} \\ f_{ax,k}\, d\, t + f_{head,k}\, d_h^2 & \text{(b)} \end{cases} \tag{8.24}$$

where:

$f_{ax,k}$ is the characteristic pointside withdrawal strength;

$f_{head,k}$ is the characteristic headside pull-through strength;

d is the nail diameter according to 8.3.1.1;

t_{pen} is the pointside penetration length or the length of the threaded part in the pointside member;

t is the thickness of the headside member;

d_h is the nail head diameter.

(5) The characteristic strengths $f_{ax,k}$ and $f_{head,k}$ should be determined by tests in accordance with EN 1382, EN 1383 and EN 14358 unless specified in the following.

(6) For smooth nails with a pointside penetration of at least 12d, the characteristic values of the withdrawal and pull-through strengths should be found from the following expressions:

$$f_{ax,k} = 20 \times 10^{-6}\, \rho_k^2 \tag{8.25}$$

$$f_{head,k} = 70 \times 10^{-6}\, \rho_k^2 \tag{8.26}$$

where:

ρ_k is the characteristic timber density in kg/m³;

(7) For smooth nails, the pointside penetration t_{pen} should be at least 8d. For nails with a pointside penetration smaller than 12d the withdrawal capacity should be multiplied by ($t_{pen}/4d - 2$). For threaded nails, the pointside penetration should be at least 6d. For nails with a pointside penetration smaller than 8d the withdrawal capacity should be multiplied by ($t_{pen}/2d - 3$).

(8) For structural timber which is installed at or near fibre saturation point, and which is likely to dry out under load, the values of $f_{ax,k}$ and $f_{head,k}$ should be multiplied by 2/3.

(9) The spacings, end and edge distances for laterally loaded nails apply to axially loaded nails.

[A1) (10) For slant nailing the distance to the loaded end should be at least 10d (see Figure 8.8(b)). There should be at least two slant nails in a connection. (A1]

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