Nailed joints II

STEP lecture C5
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Objectives
To present an example of a laterally loaded, nailed panel-to-timber joint design.
To discuss the use of axially loaded nails.

Prerequisite
C4 Nailed joints I

Summary
The empirical equation for the embedding strength for plywood is given and the scope for the introduction of new panel products with the adoption of Johansen's theory is emphasised. An example of the design of a laterally loaded, nailed, panel-to-timber joint is presented.

The use of axially loaded nails is discussed and the factors to be considered are presented together with a design example.

Nailed panel-to-timber joints
Introduction
Johansen's equations are generally applicable for any combination of wood-based materials provided the appropriate material properties are known. Equations for the characteristic embedding strengths for some panels have been developed experimentally by carrying out a large number of embedment tests. For example, for plywood:

$$f_{h,k} = 0{,}11\rho_k \, d^{-0{,}3} \; N/mm^2 \qquad (1)$$

where ρ_k is the characteristic density in kg/m^3 and d the nail diameter in *mm*.

One of the main reasons for adopting Johansen's equations for joints in EC5 is that new materials, in particular panel products and new dowel-type fasteners, may easily be accommodated by developing the appropriate empirical equations for characteristic embedding strength and characteristic yield moment. Also Johansen type equations may be developed for any combination of materials using the approach described in STEP lecture C3.

Nail spacing
For panel-to-timber joints and for steel-to-timber joints closer spacings may be adopted than those recommended for timber-to-timber joints (see STEP lecture C4). This is because there is generally less tendency for the panel product to split on nailing and the nails are normally used in single shear so that they do not fully penetrate the solid timber member thus reducing the splitting tendency in that member. These effects have been confirmed by nailing tests.

EC5 recommends, for plywood-to-timber joints, that the nail spacings recommended for timber-to-timber joints may be reduced by multiplying the tabulated values by 0,85 but the minimum values in the plywood for an unloaded end or edge distance should be $3d$ and for a loaded end or edge distance $(3+4\sin\alpha)\,d$.

Similar modifications are suggested for steel-to-timber joints but the recommended multiplier is 0,7.

Design example. Plywood-to-timber tension splice joint
Specification

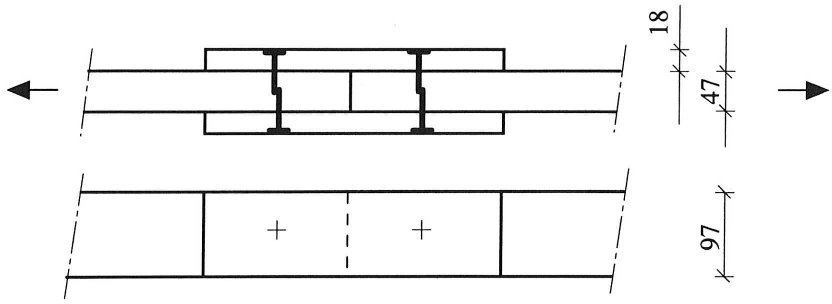

Figure 1 *Plywood-to-timber tension splice joint.*

Characteristic density of plywood = 640 kg/m^3
Minimum thickness of 18 *mm* nominal plywood = 17,1 *mm*
Timber not pre-drilled
Timber strength class C22, ρ_k = 340 kg/m^3
Smooth round nails 3,35 *mm* diameter 50 *mm* long
Design load (ultimate limit state) = 7200 *N*
Service class 2, load duration class medium term: k_{mod} = 0,80
G_k = 2000 *N* Q_k = 3000 *N*

Plywood $f_{h,k} = 0{,}11\rho_k\, d^{-0,3}\ N/mm^2$
$= 0{,}11 \cdot 640 \cdot 3{,}35^{-0,3} = 49{,}0\ N/mm^2$

Timber $f_{h,k} = 0{,}082\rho_k\, d^{-0,3}\ N/mm^2$
$= 0{,}082 \cdot 340 \cdot 3{,}35^{-0,3} = 19{,}4\ N/mm^2$

$$f_{h,d} = \frac{k_{mod} f_{h,k}}{\gamma_M}$$

Plywood $f_{h,d} = \dfrac{0{,}80 \cdot 49{,}0}{1{,}3} = 30{,}2\ N/mm^2$

Timber $f_{h,d} = \dfrac{0{,}80 \cdot 19{,}4}{1{,}3} = 11{,}9\ N/mm^2$

$$\beta = \frac{f_{h,d}\ \text{pointside}}{f_{h,d}\ \text{headside}} = \frac{f_{h,d}\ \text{timber}}{f_{h,d}\ \text{plywood}} = \frac{11{,}9}{30{,}2} = 0{,}39$$

$$M_{y,k} = 180\ d^{2,6}\ Nmm = 180 \cdot 3{,}35^{2,6} = 4172\ Nmm$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{4172}{1{,}1} = 3790\ Nmm$$

Nails in single shear
Check all equations for minimum value of R_d.

Mode 1b

$R_d \quad = f_{h,1,d}\, t_1\, d \qquad = 30{,}2 \cdot 17{,}1 \cdot 3{,}35 \qquad = 1730\ N$

t_2 = pointside penetration = nail length - headside thickness
= 50 - 17,1 = 32,9 *mm* > minimum = 8*d* = 26,8 *mm*

$R_d \quad = f_{h,1,d}\, t_2\, d\, \beta \qquad = 30{,}2 \cdot 32{,}9 \cdot 3{,}35 \cdot 0{,}39 \qquad = 1298\ N$

Mode 1a

$$R_d = \frac{f_{h,1,d} d t_1}{1+\beta}\left[\sqrt{\beta + 2\beta^2\left[1+\frac{t_2}{t_1}+\left(\frac{t_2}{t_1}\right)^2\right]+\beta^3\left(\frac{t_2}{t_1}\right)^2} - \beta\left(1+\frac{t_2}{t_1}\right)\right]$$

$$= \frac{30{,}2 \cdot 3{,}35 \cdot 17{,}1}{1{,}39}$$

$$\left[\sqrt{0{,}39 + 2 \cdot 0{,}39^2\left[1+\frac{32{,}9}{17{,}1}+\left(\frac{32{,}9}{17{,}1}\right)^2\right]+0{,}39^3\left(\frac{32{,}9}{17{,}1}\right)^2} - 0{,}39\left(1+\frac{32{,}9}{17{,}1}\right)\right]$$

$$= 597\ N$$

Mode 2a

$$R_d = 1{,}1\ \frac{f_{h,1,d} d t_1}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,d}}{f_{h,1,d} d t_1^2}} - \beta\right]$$

$$= 1{,}1\ \frac{30{,}2 \cdot 3{,}35 \cdot 17{,}1}{2{,}39}\left[\sqrt{2 \cdot 0{,}39 \cdot 1{,}39 + \frac{4 \cdot 0{,}39 \cdot 2{,}39 \cdot 3\ 790}{30{,}2 \cdot 3{,}35 \cdot 17{,}1^2}} - 0{,}39\right] = 684\ N$$

Mode 2b

$$R_d = 1{,}1\ \frac{f_{h,1,d} d t_2}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\frac{4\beta(1+2\beta)M_{y,d}}{f_{h,1,d} d t_2^2}} - \beta\right]$$

$$= 1{,}1\ \frac{30{,}2 \cdot 3{,}35 \cdot 32{,}9}{1+2 \cdot 0{,}39}\left[\sqrt{2 \cdot 0{,}39^2 \cdot 1{,}39 + \frac{4 \cdot 0{,}39 \cdot 1{,}78 \cdot 3790}{30{,}2 \cdot 3{,}35 \cdot 32{,}9^2}} - 0{,}39\right] = 680\ N$$

Mode 3

$$R_d = 1{,}1\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,d} f_{h,1,d} d} = 1{,}1\sqrt{\frac{2 \cdot 0{,}39}{1{,}39}}\sqrt{2 \cdot 3790 \cdot 30{,}2 \cdot 3{,}35} = 722\ N$$

Minimum value = 597 *N* Mode 1a failure

Number of nails $= \frac{7200}{597} = 12{,}06$ each side, say 12 each side

Check nail overlap in central member: 47 - 32,9 = 14,1 *mm* > 4*d* = 13,4 *mm*

Spacings
$\rho_k = 340\ kg/m^3$, no pre-drilling, $\alpha = 0°$

Spacing parallel	$= 0{,}85 \cdot 10d$	$= 28{,}5\ mm$
Spacing perpendicular	$= 0{,}85 \cdot 5d$	$= 14{,}2\ mm$
Loaded end distance	$= 0{,}85 \cdot 15d$	$= 42{,}7\ mm$
Unloaded edge distance	$= 0{,}85 \cdot 5d$	$= 14{,}2\ mm$

In plywood, unloaded edge not less than $3d$ $= 10{,}1\ mm$
loaded end not less than $7d$ $= 23{,}5\ mm$

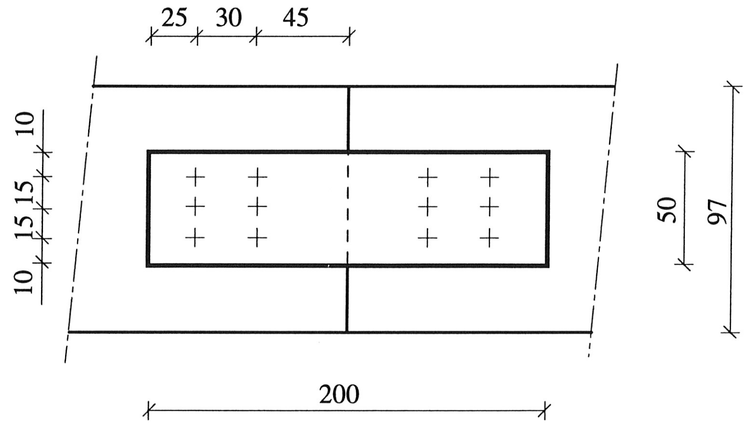

Figure 2 Acceptable nailing pattern.

No reduction in cross-sectional area is assumed

Slip

$$K_{ser} = \rho_k^{1,5} \frac{d^{0,8}}{25}$$

$$\rho_k = \sqrt{\rho_{k,1}\, \rho_{k,2}} = \sqrt{640 \cdot 340} = 466\ kg/m^3$$

$$K_{ser} = 466^{1,5} \cdot \frac{3{,}35^{0,8}}{25} = 1058\ N/mm$$

Design load per nail (serviceability limit state) $= \dfrac{5000}{12} = 417\ N$

Instantaneous slip per nail $= \dfrac{417}{1058} = 0{,}4\ mm$

Opening of joint $= 2 \cdot 0{,}4 = 0{,}8\ mm$

$$u_{fin} = \frac{2000}{12 \cdot 1058} \sqrt{(1+0{,}80)\,(1+1{,}0)} + \frac{3000}{12 \cdot 1058} \sqrt{(1+0{,}25)\,(1+0{,}30)} = 0{,}60\ mm$$

Final joint opening $= 1{,}20\ mm$

Axially-loaded nails

Smooth steel wire nails are relatively weak when loaded axially and, therefore, EC5 recommends that they should not be used for permanent and long-term axial loads. The best resistance is obtained when the nails are driven into side grain. Nails driven into end grain are normally assumed to have negligible axial load capacity. Changes in the moisture content of the timber will also reduce the axial load capacity of smooth nails.

Other factors which affect the resistance that nails can offer to axial withdrawal loads include the density of the timber into which the nail is driven and the surface condition of the nail. Consequently, cement-coated nails, annular and helically threaded nails and square twisted nails all perform better under axial loads than smooth nails. Another advantage of annular and helically threaded nails is that their resistance to withdrawal is little affected by changes in the moisture content of the timber (see EC5: 1-1 for further guidance).

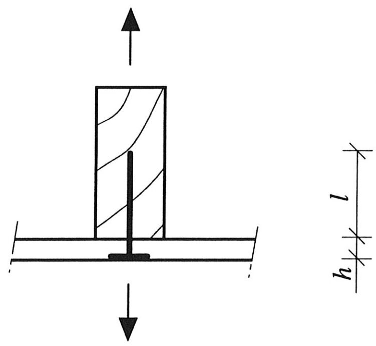

Figure 3 Perpendicular nailing.

There are two ways in which the nailed joint shown in Figure 3 is likely to fail (ignoring tensile failure of the nail itself):

(a) withdrawal of the nail from the member receiving the point, and
(b) the nail head being pulled through the sheet material.

Empirical equations for resistance have been developed for a number of combinations. For smooth nails the resistance is given by the lower of the following values:

For pointside withdrawal $R_d = f_{1,d}\, d\, \ell$ (2)

For head pull-through $R_d = f_{1,d}\, d\, h + f_{2,d}\, d^2$ (3)

Where d is the nail diameter, *mm*
h is the thickness of headside timber, *mm*
ℓ is the pointside penetration, *mm*
$f_{1,d}$ is the design strength for member receiving point
$f_{2,d}$ is the design strength for headside member

EC5 suggests the following equations for characteristic strengths:

$f_{1,k} = (18 \cdot 10^{-6})\, \rho_k^2\ N/mm^2$ (4)

and

$f_{2,k} = (300 \cdot 10^{-6})\, \rho_k^2\ N/mm^2$ (5)

where ρ_k is in kg/m^3.

When the head diameter of a smooth nail is at least twice the diameter of the nail shank then it may be assumed that the head pull-through mode of failure cannot occur.

The pointside penetration, ℓ, should not be less than $12d$.

Design example. Axially loaded nails

Specification

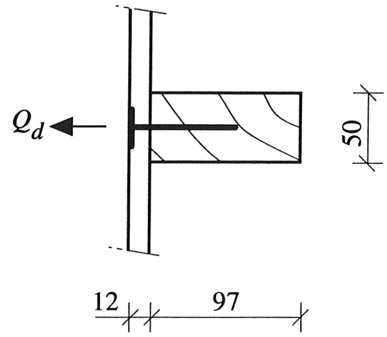

Figure 4 *Axially loaded nail.*

Figure 4 shows 12 *mm* thick plywood cladding nailed to timber studs acted upon by a wind generated suction force Q_d.

Q_d = 750 *N* per metre of height
Characteristic density of plywood = 550 kg/m^3
Timber strength class C16, not pre-drilled
Smooth round nails 3,00 *mm* diameter, 50 *mm* long
Service class 3
Find the necessary spacing for the nails.

For strength class C16, $\rho_k = 310\ kg/m^3$

$f_{1,k} = 18 \cdot 10^{-6} \cdot 310^2 = 1{,}73\ N/mm^2$

$f_{2,k} = 300 \cdot 10^{-6} \cdot 550^2 = 90{,}75\ N/mm^2$

For service class 3 and short-term load duration

$k_{mod} = 0{,}7$

$$f_{1,d} = 0{,}7 \cdot \frac{1{,}73}{1{,}3} = 0{,}93\ N/mm^2$$

$$f_{2,d} = 0{,}7 \cdot \frac{90{,}75}{1{,}3} = 48{,}8\ N/mm^2$$

Pointside withdrawal resistance

$f_{1,d} d \ell = 0{,}93 \cdot 3{,}00 \cdot (50 - 12) = 106\ N$

For head pull-through (assuming head diameter < $2d$)

$R_d = f_{1,d}\, d\, h + f_{2,d}\, d^2 = 0{,}93 \cdot 3{,}00 \cdot 12{,}00 + 48{,}8 \cdot 3{,}00^2 = 473\ N$

Pointside withdrawal critical

$$\textbf{Nail spacing required} = \frac{106}{750} \cdot 1000 = 141\ mm$$

Provide 3,00 x 50 *mm* nails at 140 *mm* centres.