Nailed joints I

STEP lecture C4
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Objectives

To describe the different types of nail and present typical examples of their use. To present empirical equations for the prediction of embedding strength in timber and yield moment for nails. To introduce nail spacing requirements and to give an example of a timber-to-timber nailed joint design. To demonstrate the effects of pre-drilling and slip.

Prerequisites

C3 Joints with dowel-type fasteners - Theory

Summary

Various types of nail are described including smooth wire (round and square sections), annular ringed shank, helically threaded and square twisted nails. The advantages of the different forms are discussed.

The empirical equations for embedding strength and yield moments are quoted and a brief description of their origins and limitations presented.

The need to control spacing is described and EC5 recommendations are given. The advantages and disadvantages of pre-drilling are discussed. The importance of slip is stressed and an example of the design of a nailed timber-to-timber joint is presented.

Types of nail

Nails are the most commonly used fasteners in timber construction and are available in a variety of lengths, cross-sectional areas and surface treatments.

The most common type of nail is the smooth steel wire nail which has a circular cross-section and is cut from wire coil having a minimum tensile strength of 600 N/mm^2. It is available in a standard range of diameters up to a maximum of 8 *mm* and can be plain or treated against corrosion, for example, by galvanising. The head of the nail is most commonly forged into a flat circle of approximately twice the diameter of the shaft but some nails are available with smaller heads to enable these to be driven flush with the timber surface.

In some countries nails are produced with a square cross-section and these are used in the same applications as the smooth round nails described above.

The performance of a nail, both when under lateral load and under withdrawal loading, may be enhanced by modifying the surface of the nail. One approach is to deform the surface of a smooth round nail by cutting annular threading or helical threading onto the shank of the nail. Another takes nails with a square cross-section and twists them into a helical pattern. This process not only modifies the nail surface but also work hardens the steel thus raising the yield strength. Galvanising, chemical etching, coating with cement and coating with plastic are other ways in which the performance of a nail may be enhanced.

Nails may be driven by hand or by pneumatically operated portable machines. In the latter case cartridges of special nails, such as T-nails and nails with a segment of the head cut off, are used to enable them to be assembled in groups.

Pre-drilling

When nails are driven into dense timbers there is a danger that excessive splitting will occur. This can be combatted by blunting the pointed end of the nail so that it cuts through the timber fibres rather than separating them but a more reliable approach is to pre-drill the timber. In this latter case the nails are driven into pre-drilled holes normally having a diameter not greater than 80% of the nail diameter.

Pre-drilling produces three main advantages:

- the lateral load-carrying capacity of the nail is increased;
- the spacings between nails and the distances between the nails and the end and edge of the timber may be reduced thus producing more compact joints and
- less slip occurs in the joints.

On the other hand, pre-drilling is labour intensive and, therefore, expensive and the net cross-sectional area of the member is reduced. Consequently, it is normally only used when the characteristic density of the timber is 500 kg/m^3 or more.

Embedding strength

EC5 recommends the following values for the characteristic embedding strength for nails up to 8 *mm* in diameter driven into timber and they apply for all angles of load to grain direction.

Without predrilled holes

$$f_{h,k} = 0{,}082\,\rho_k d^{-0{,}3}\ N/mm^2 \qquad (1)$$

With predrilled holes

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

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

No increase in embedding strength is currently recommended for annular ringed shank nails, helically threaded nails and other nails with modified surfaces. This is due to a lack of embedment test data for these types of nails.

The equations for characteristic embedding strength have been determined by carrying out a large number of embedment tests covering a range of timber densities, timber species and nail diameters.

An illustration of the type of analysis that was used to produce Equations (1) and (2) is presented by Whale et al. (1989).

Yield moment

EC5 only presents guidance for the characteristic yield moment for common smooth steel wire nails made from a wire having a minimum tensile strength of 600 N/mm^2.

For round nails it proposes,

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

and for square nails,

$$M_{y,k} = 270 d^{2,6}\ Nmm \tag{4}$$

For round nails d is the diameter in mm and for square nails the side dimension in mm. Other types of nail would have to be tested in accordance with EN 409 "Determination of the yield moment for dowel type fasteners - Nails" to determine suitable values for $M_{y,k}$.

Nail spacing

Nails must be spaced at suitable distances from each other, and from the ends and edges of pieces of timber, in order to avoid undue splitting. The various distances involved are shown in Figure 1.

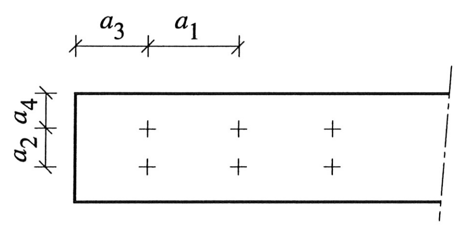

Figure 1 *Nail spacings and distances.*

a_1	*spacing parallel to the grain*
a_2	*spacing perpendicular to the grain*
a_3	*end distance*
a_4	*edge distance*

The end distance is said to be loaded when the load on the nail has a component towards the end of the timber. Otherwise it is referred to as an unloaded end distance. Loaded end distances need to be greater than unloaded ones.

In a similar way the edge distance may be loaded or unloaded.

The most suitable values for spacings and distances will vary from species to species depending principally upon the cleavage and shearing strength of the timber, the timber density and the nail diameter.

Pre-drilling reduces the splitting tendency considerably and hence allows much closer spacing of the nails as described earlier.

The spacings and distances recommended by EC5, and based on years of experience are presented in Table 1.

Distance	No Pre-drilling		Pre-drilled
	$\rho_k \leq 420\ kg/m^3$	$420 < \rho_k < 500\ kg/m^3$	
Spacing parallel	$d < 5$ mm: $10d$ $d \geq 5$ mm: $12d$	$15d$	$(4+3\,\lvert\cos\alpha\rvert)d$
Spacing perpendicular	$5d$	$5d$	$(3+\lvert\sin\alpha\rvert)d$
Loaded end	$(10+5\cos\alpha)d$	$(15+5\cos\alpha)d$	$(7+5\cos\alpha)d$
Unloaded end	$10d$	$15d$	$7d$
Loaded edge	$(5+5\sin\alpha)d$	$(7+5\sin\alpha)d$	$(3+4\sin\alpha)d$
Unloaded edge	$5d$	$7d$	$3d$

Table 1 *Spacings and distances for nails, d = nail diameter in mm, α = angle of force to grain direction.*

Nail slip

Nailed joints, in common with joints made with all other types of mechanical fastener, slip under load. This is illustrated in Figure 2 which shows a typical load-slip characteristic for a compression test on a three member nailed joint.

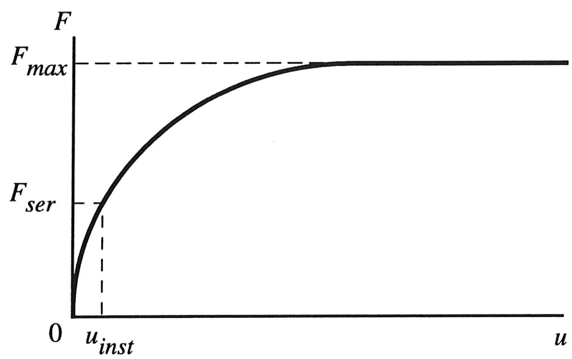

Figure 2 *Load-slip characteristic for a nailed joint. F_{max} is the maximum load, F_{ser} is the service load and u_{inst} the instantaneous slip.*

An estimate of the instantaneous slip that will occur when the service load is applied may be obtained from a knowledge of the instantaneous slip modulus K_{ser} determined from tests carried out in accordance with EN26891 "Timber structures. Joints made with mechanical fasteners. General principles for determination of strength and deformation characteristics," or from the following recommendations in EC5.

$$\text{For pre-drilled situations: } K_{ser} = \rho_k^{1,5}\frac{d}{20}\ N/mm \qquad (5)$$

$$\text{For no pre-drilling: } K_{ser} = \rho_k^{1,5}\frac{d^{0,8}}{25}\ N/mm \qquad (6)$$

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

Final slip measurements in nailed joints will be greater than the instantaneous values due to creep and may be estimated from:

$$u_{fin} = u_{inst}(1 + k_{def}) \qquad (7)$$

It is essential to allow for the slip in the joints when calculating the displacement of a nailed timber structure under service load. Normal elastic theories predict the displacement of structures from the elastic shortening or lengthening of the members in the case of trusses and from the assumption of no slip between the component parts in beams. Joint slip will add considerably to these effects and, therefore, produce much larger displacements.

The deflection of a nailed timber truss due to slip in the joints can often exceed that due to the elastic axial movements in the members.

In nailed composite beam construction the simple theory of bending will not apply and stresses and deflections must be calculated allowing for the slip that will occur between, for example, the flanges and the web of a nailed I-beam. This incomplete interaction may be assessed using a procedure described in Annex B EC5:1-1.

Slip also affects the moment-rotation characteristics of joints such as nailed plywood gusset joints in some portal frame construction.

Design example. Nailed tension splice joint

Specification

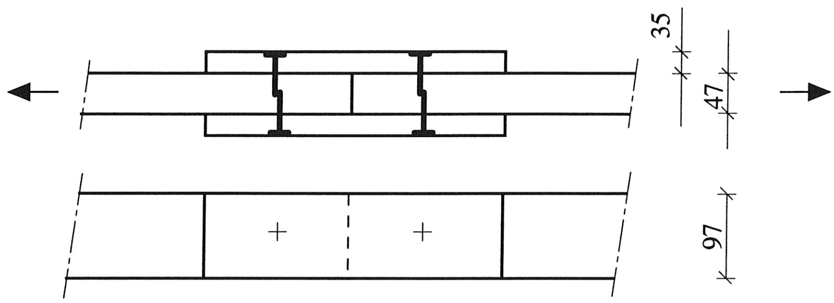

Figure 3 Tension splice joint.

Timber not pre-drilled Design load (ultimate limit state) = 3600 N
Strength class C16
Smooth round nails 3,35 mm diameter, 65 mm long
Service class 1, load duration class medium term: $k_{mod} = 0{,}8$
$G_k = 1000\ N$ $Q_k = 1500\ N$

$$f_{h,k} = 0{,}082\,\rho_k d^{-0{,}3}\ N/mm^2$$

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

$$f_{h,k} = 0{,}082 \cdot 310 \cdot 3{,}35^{-0{,}3} = 17{,}7\ N/mm^2$$

Assuming the same strength class for each component, $\beta = 1$

$$M_{y,k} = 180 d^{2{,}6} = 180 \cdot 3{,}35^{2{,}6} = 4170\ Nmm$$

$$f_{h,d} = \frac{k_{mod} f_{h,k}}{\gamma_M} = \frac{0{,}8 \cdot 17{,}7}{1{,}3} = 10{,}9\ N/mm^2$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{4170}{1{,}1} = 3790\ Nmm$$

Nails in single shear
(a) Manual approach

Check all equations for minimum value of R_d

Mode 1b

$$R_d = f_{h,1,d} t_1 d = 10{,}9 \cdot 35 \cdot 3{,}35 = 1278\,N$$

t_2 = pointside penetration

= nail length - headside timber thickness

= 65 - 35 = 30 *mm*

minimum = $8d$ = *26,8 mm* < *30 mm*

$$R_d = f_{h,1,d} t_2 d \beta = 10{,}9 \cdot 30 \cdot 3{,}35 \cdot 1{,}0 = 1095\,N$$

Mode 1a

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

$$= \frac{10{,}9 \cdot 3{,}35 \cdot 35}{2}\left[\sqrt{1 + 2\left[1 + \frac{30}{35} + \left(\frac{30}{35}\right)^2\right] + \left(\frac{30}{35}\right)^2} - 1\left(1 + \frac{30}{35}\right)\right] = 494\ N$$

Mode 2a

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

$$= 1{,}1\,\frac{10{,}9 \cdot 3{,}35 \cdot 35}{3}\left[\sqrt{4 + \frac{12 \cdot 3790}{10{,}9 \cdot 3{,}35 \cdot 35^2}} - 1\right] = 581\ N$$

Mode 2b

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

$$= 1{,}1\,\frac{10{,}9 \cdot 3{,}35 \cdot 30}{3}\left[\sqrt{4 + \frac{12 \cdot 3\ 790}{10{,}9 \cdot 3{,}35 \cdot 30^2}} - 1\right] = 530\ N$$

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Mode 3

$$R_d = 1{,}1 \sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,d}f_{h,1,d}d} = 1{,}1 \sqrt{2 \cdot 3\ 790 \cdot 10{,}9 \cdot 3{,}35} = 579\ N$$

Minimum value = 494 N Mode 1a failure

(b) Computer approach
The set of design equations can be written into a computer program with $f_{h,1,d}$, t_1, t_2, d, β and $M_{y,d}$ as input parameters.

(c) Möller chart approach
If Möller charts are available, in this case for $\beta = 1$, then the mode of failure may be identified quickly and only one equation needs to be used.

In this example $t_2 = 35\ mm$ and $t_1 = 30\ mm$ since t_2 has to be the larger dimension for the Möller chart.

$$\frac{t_2}{t_1} = \frac{35}{30} = 1{,}17$$

$$\frac{t_1}{\sqrt{\frac{M_{y,d}}{f_{h,d}d}}} = \frac{30}{\sqrt{\frac{3790}{10{,}9 \cdot 3{,}35}}} = 2{,}94$$

From Figure 11 in STEP Lecture C3 the failure mode is identified as mode 1a.

$$\text{Number of nails} = \frac{\text{Design load}}{\text{Design resistance per nail}} = \frac{3600}{494} = 7{,}3 \text{ each side}$$

Adopt eight nails each side for symmetry as shown in Figure 4.

The nails will overlap in the centre member and this is permitted by EC5 provided that the thickness of the central member less the pointside penetration is greater than $4d$.
In this example 47 - 30 = 17 mm and $4d = 4 \cdot 3{,}35 = 13{,}4\ mm$
17 mm > 13,4 mm acceptable

Spacings
$\rho_k = 310\ kg/m^3$. No pre-drilling. $\alpha = 0°$

From Table 1:

Spacing parallel	= 10d	= 33,5 mm
Spacing perpendicular	= 5d	= 16,8 mm
Loaded end distance	= 15d	= 50,3 mm
Unloaded edge distance	= 5d	= 16,8 mm

An acceptable arrangement is shown in Figure 4.

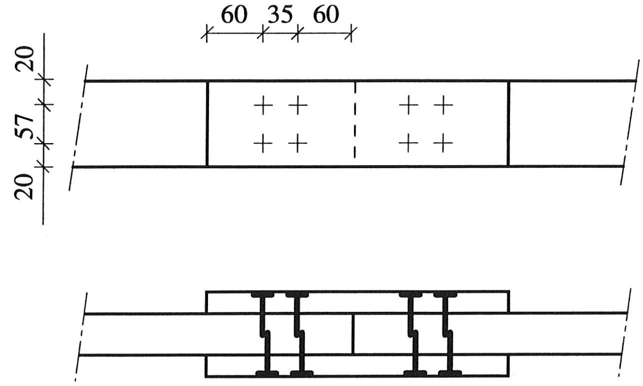

Figure 4 Acceptable nailing pattern.

Total length of each splice plate = 2 (60+35+60) = 310 *mm*

No reduction in the cross-sectional area of each member is assumed since the nail diameter is not greater than 6 *mm* and the nails are driven without pre-drilling.

Slip

For no pre-drilling

$$K_{ser} = \rho_k^{1,5} \frac{d^{0,8}}{25} N/mm = 310^{1,5} \frac{3{,}35^{0,8}}{25} = 574\ N/mm$$

Design load (serviceability limit state) = 2500 *N*

$$\text{load per nail} = \frac{2500}{8} = 312{,}5\ N$$

$$\text{instanteous slip per nail} = \frac{312{,}5}{574} = 0{,}54\ mm$$

All nails are assumed to slip by the same amount and so each central member will move 0,54 *mm* relative to the cover plates so that the abutting faces of the central members will draw apart by 2 · 0,54 *mm* = 1,08 *mm*.

$$u_{fin} = \frac{1000}{8 \cdot 574}(1 + 0{,}60) + \frac{1500}{8 \cdot 574}(1 + 0{,}25) = 0{,}76\ mm$$

Final joint opening = 2 · 0,76 = 1,52 *mm*

Reference

Whale, L.R.J., Smith, I. and Hilson, B.O. (1989). Characteristic properties of nailed and bolted joints under short term lateral load. Part 4 - The influence of testing mode and fastener diameter upon embedment test data. J. Inst. Wood Sci. 11(5): 156-161.