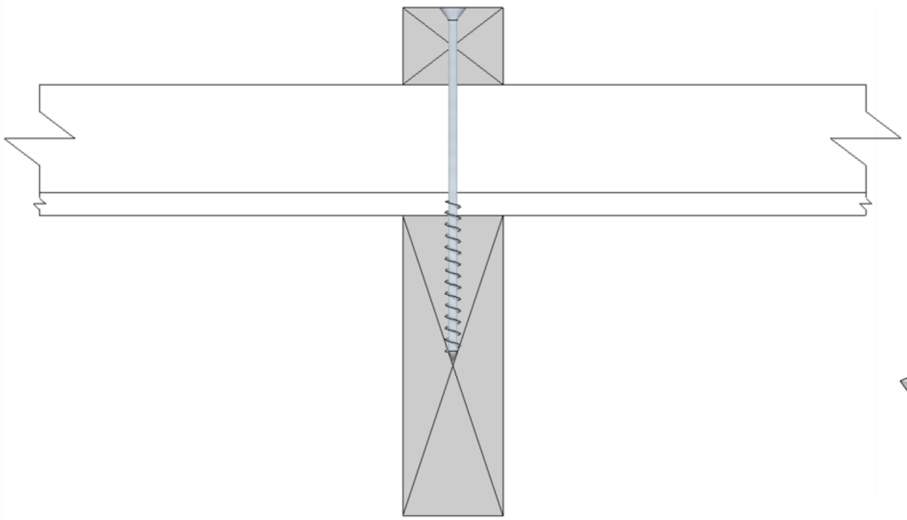
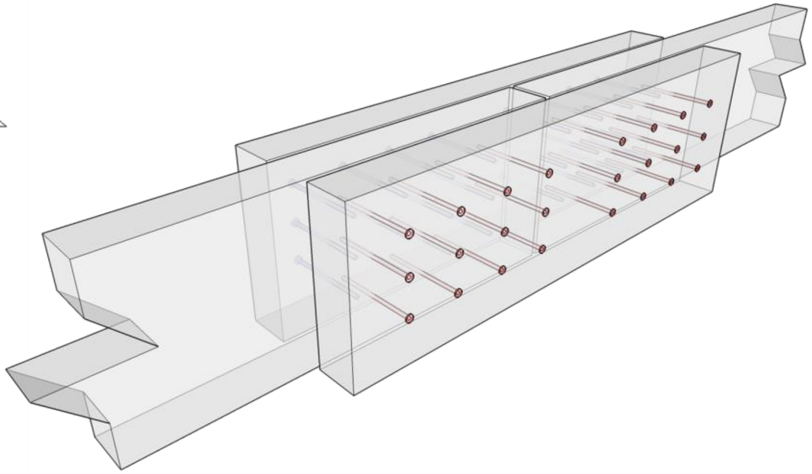
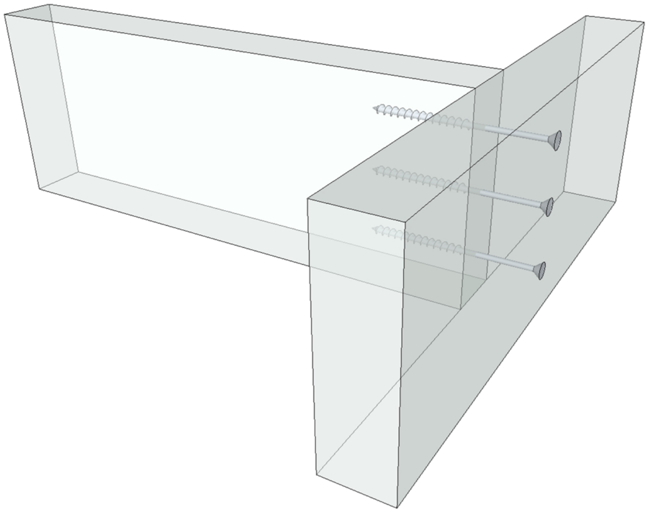
Edinburgh Napier
UNIVERSITY

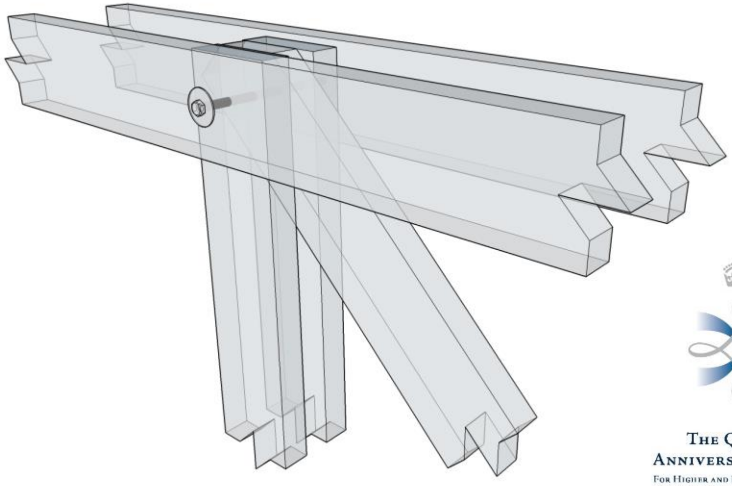
Timber connections

Andrew Livingstone
Centre for Offsite Construction + Innovative Structures
A.Livingstone@napier.ac.uk







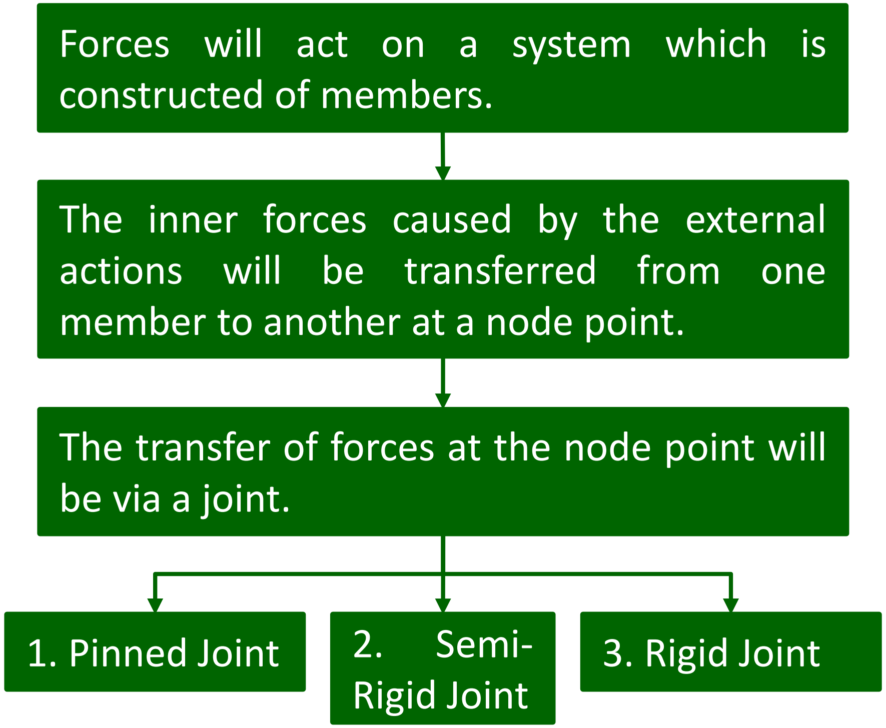


The Queen's
Anniversary Prizes
For Higher and Further Education
2015

Content

1) Introduction

It is commonly stated that "**a structure is a constructed assembly of joints separated by members**" (McLain ,1998) and in timber engineering the joint is generally the **critical factor** in the design of the structure. The **strength** of the **connectors** in the joint will normally dictate the strength of the structure; their stiffness will greatly influence its overall behaviour and member sizes will generally be determined by the numbers and physical characteristics of the connector rather than by the strength requirements of the member material.

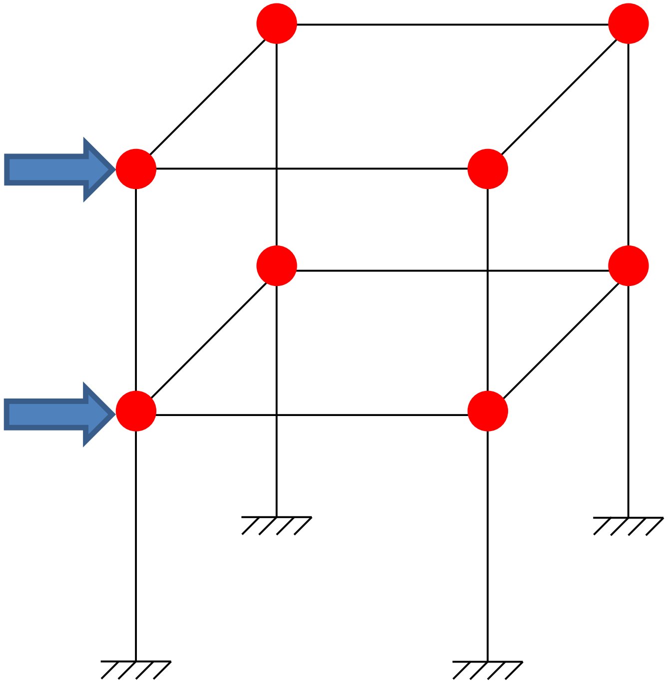


Forces will act on a system which is constructed of members.

The inner forces caused by the external actions will be transferred from one member to another at a node point.

The transfer of forces at the node point will be via a joint.

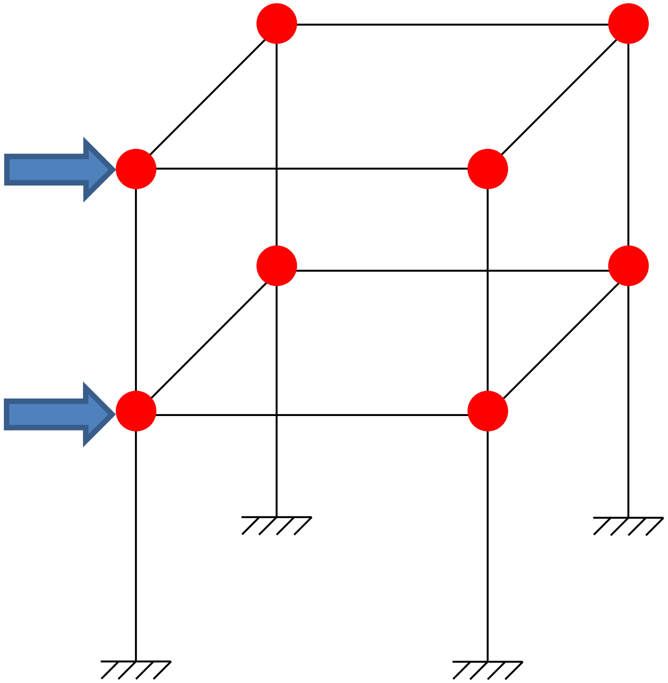
1. Pinned Joint
2. Semi-Rigid Joint
3. Rigid Joint



1. Joints are **crucial points** in many timber structures because they can determine the overall strength and performance.

2. The **length** of structural timber is generally **shorter** than the required spans and as a result splicing or composite structures (e.g. trusses) must be used.

3. Forces between members are most often **transferred** through **lap joints**, either by adhesives (glues) or by laterally loaded dowel-type fasteners (nails, bolts, screws, dowels or nail plates).

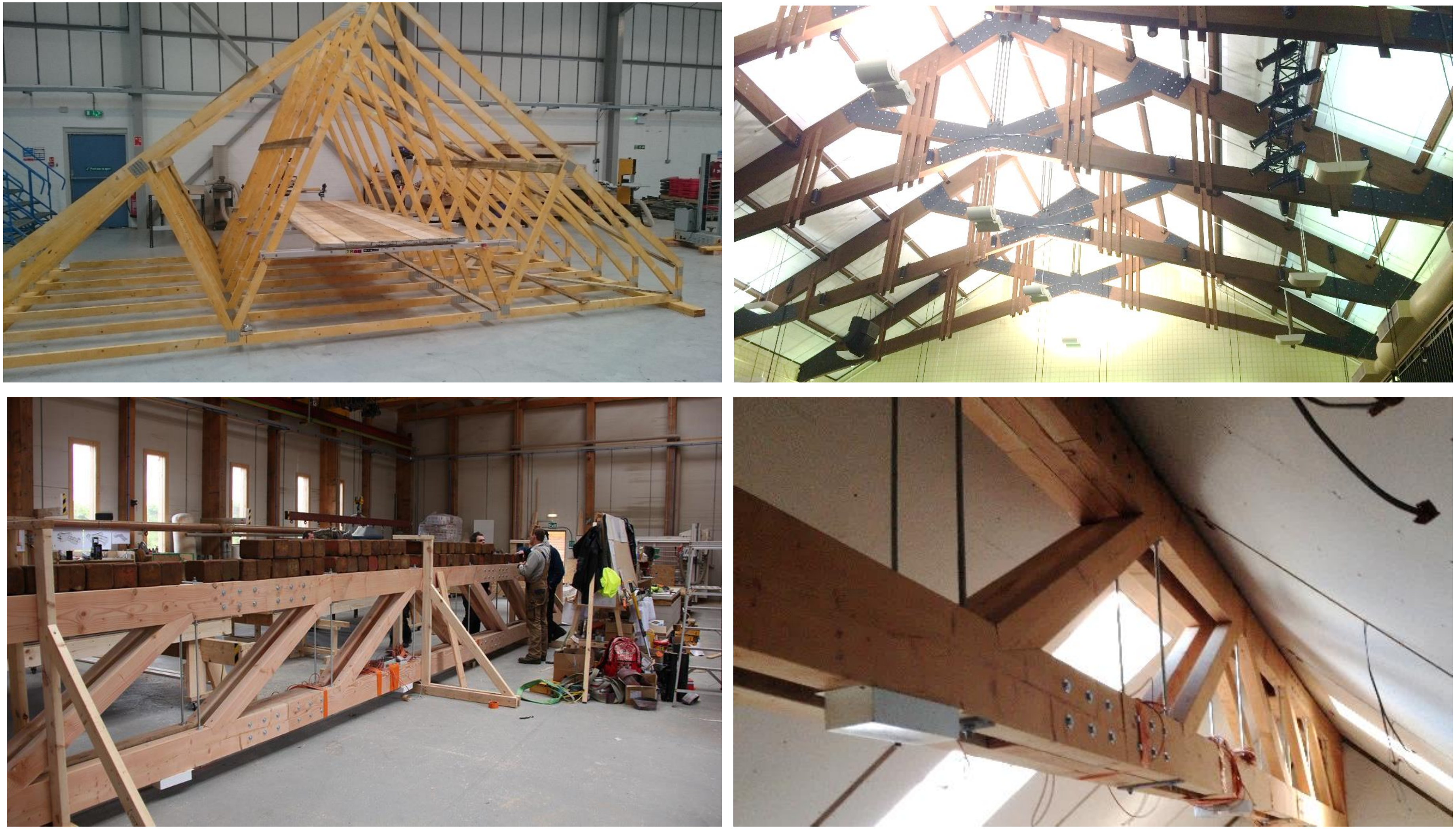


1.1 Examples of connections in systems

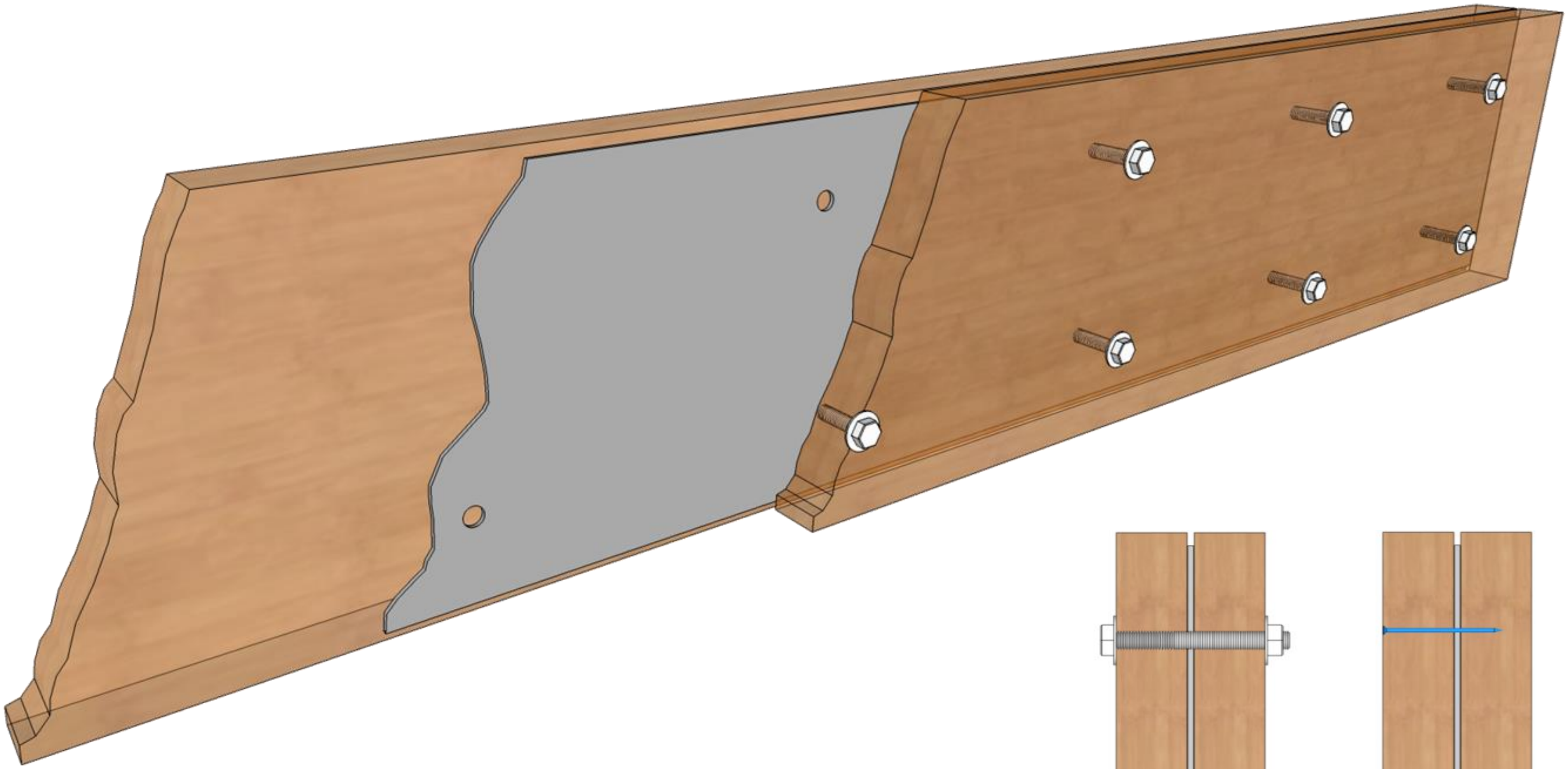
Top left	Post & beam system
Top right	Sibelius Hall, Lahti, Finland
Bottom	Scottish Parliament, Edinburgh, Scotland

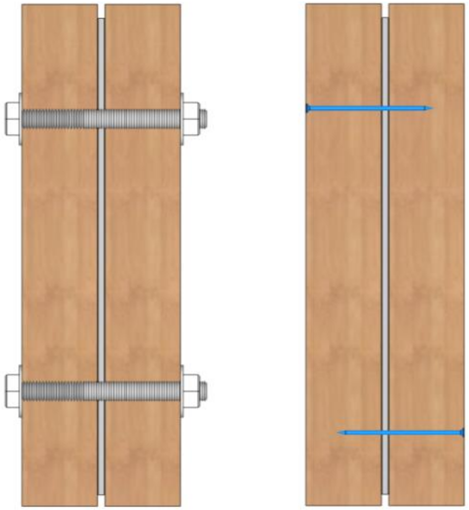
1.2 Increasing spans through connections

Examples of different truss systems where connections have been used to combine timber elements of different lengths to achieve longer spans.



1.2 Increasing spans through connections



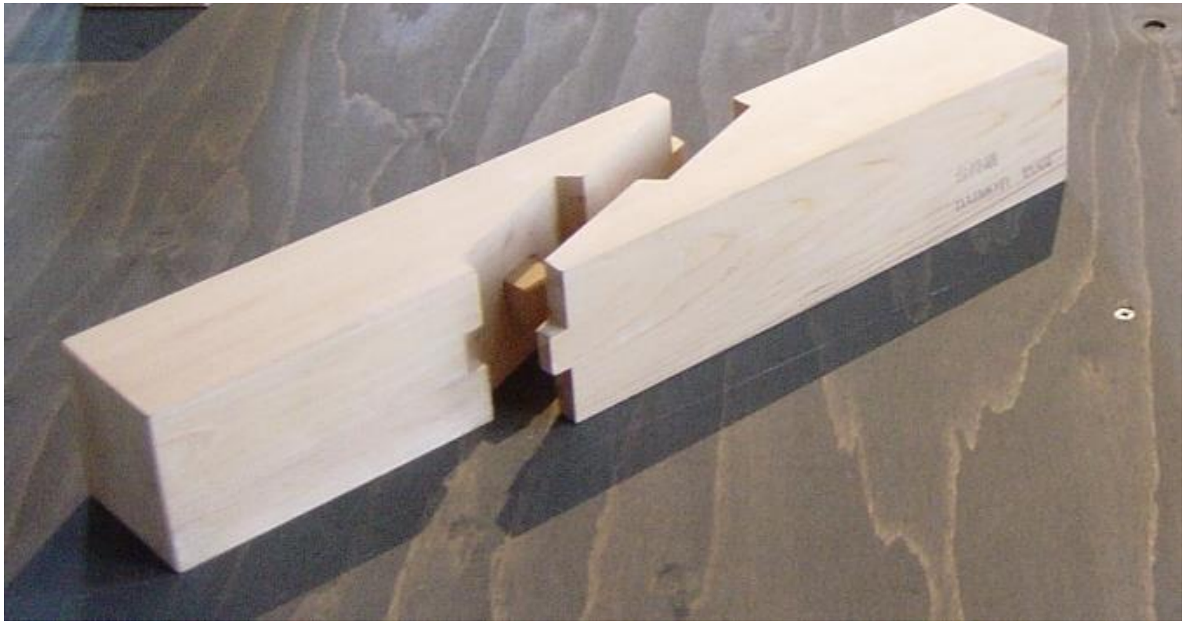


Bolted Flitch beam fabrication

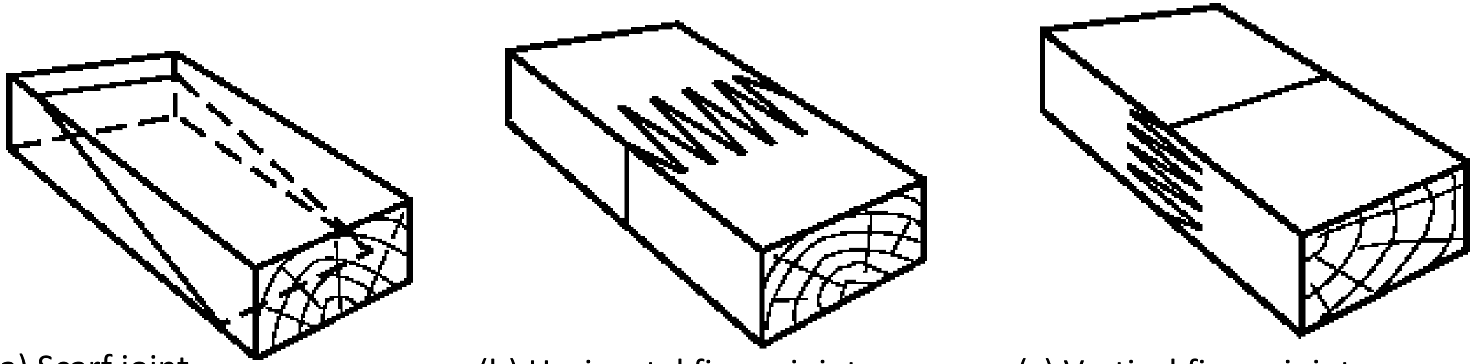
1.2 Increasing spans through connections

Bolted Flitch beam fabrication

1.3 Connection types



Traditional timber joint



(a) Scarf joint

(b) Horizontal finger joint

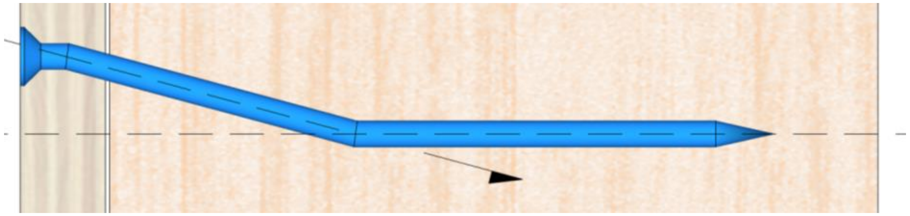
(c) Vertical finger joint

Glued joints

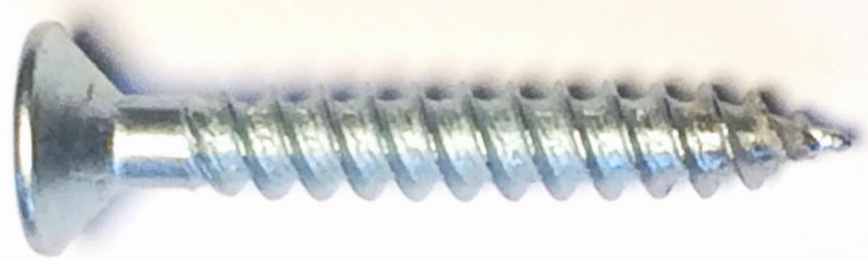
TRADA Wood information sheet 31

1.3 Connection types

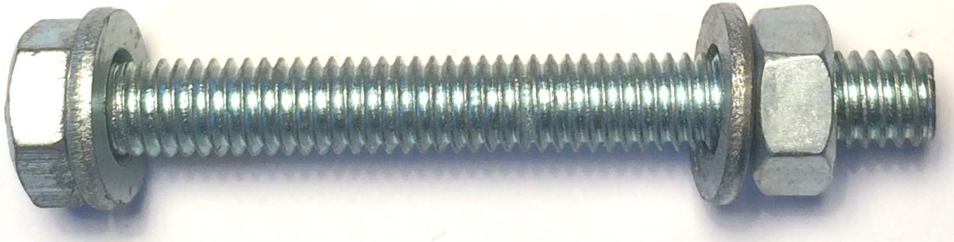
(a) Dowels



(b) Nail



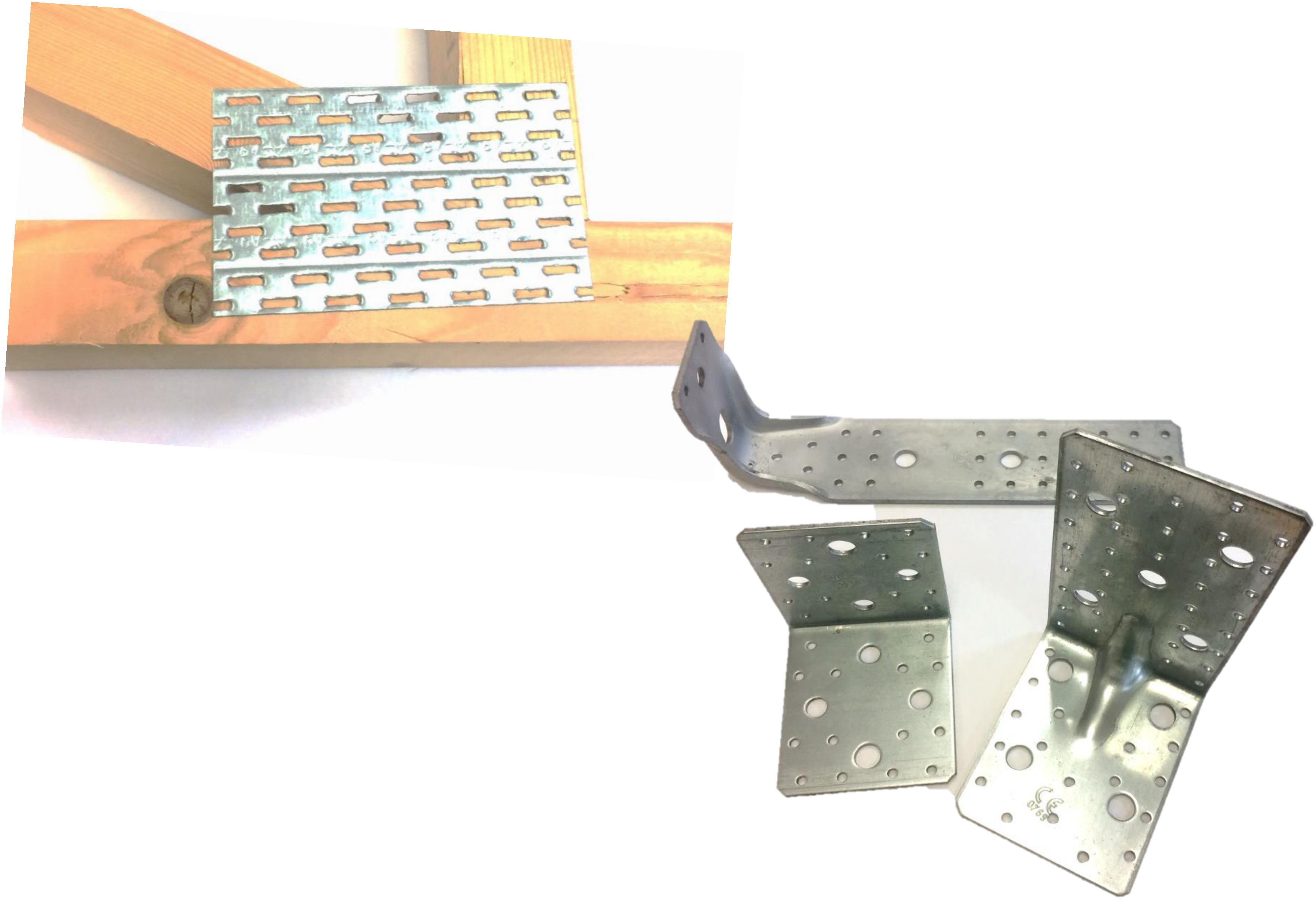
(c) A modern self-drilling wood screw



(b) Hexagonal head bolt

Dowel type connectors

1.3 Connection types

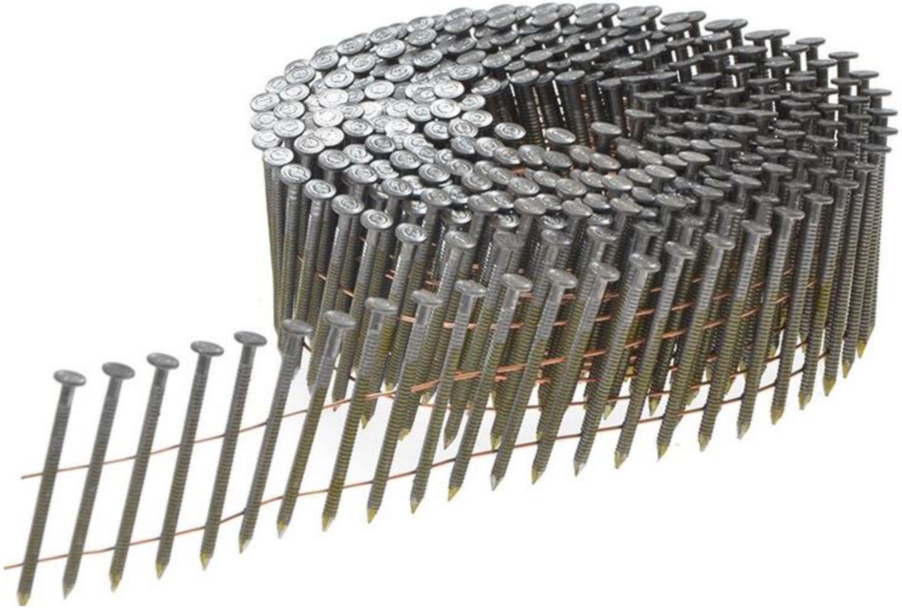


2) Nails, Screws, Bolts & Dowels

2.1 Nails

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 600N/mm²**. It is available in a standard range of diameters up to a maximum of 8mm and can be plain or treated against corrosion, for example, by galvanising.



2.1 Nails

Nails may be driven by hand or by pneumatically operated portable machines. When nails are to be driven into dense timbers there is a danger that excessive splitting will occur. Methods of avoiding splitting are blunting the pointed end of the nail so that it cuts through the timber fibres rather than separating them or to pre-drill a hole in the timber less than 80% of the nail diameter. Pre-drilling is not normally carried out on timbers with a lower characteristic density of **500kg/m^3**.

Advantages of **pre-drilling**:

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

Disadvantages:

- Labour intensive and as a result expensive.
- Reduces the cross sectional area of the member.

2.2 Screws

Wood screws are especially suitable for steel-to-timber and panel to timber joints, but they can also be used for timber-to-timber joints. Such screwed joints are normally designed as single shear joints.

Screws are inserted by turning and this can be done either by hand or by power actuated tool depending on the situation.

The main advantage a screw has over a nail is its

additional withdrawal capacity.

2.3 Dowels

Dowels are circular **rods** of timber, steel, or **carbon-reinforced plastics** which have a minimum diameter of **6mm**.

Dowels are driven into identically or marginally undersized holes. These holes must either be drilled through all members in one operation or made using CNC machines.

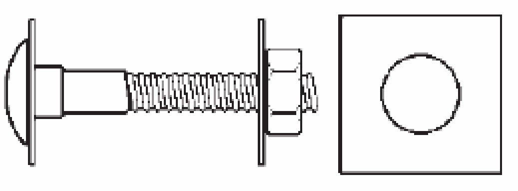
Joints with dowels are used in timber construction to transmit high forces. Dowels are an economic type of joint which is easy to produce.

2.4 Bolts

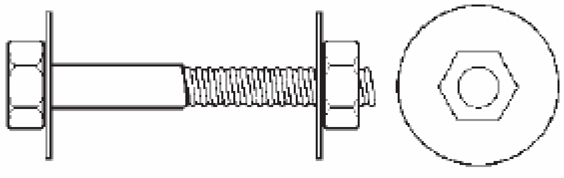
Bolts are dowel-type fasteners with heads and nuts. Bolts are normally ordinary machine bolts (M12 – M14 with a coarse head) with washers that have a side length of about 3d and thickness of 0.3d, where d is the bolt diameter.

Bolts will be placed through pre-drilled holes which are **1-2mm oversized** and the bolt and washer tightened on application such that the members of the connection fit closely together. If necessary bolts will be required to be re-tightened when the timber has reached equilibrium moisture content.

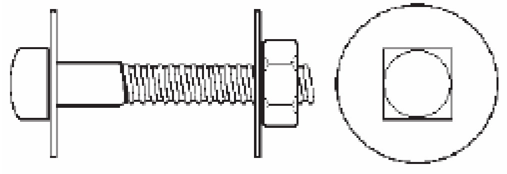
Another type of bolt is a lag screw which has a sharp end and coarse threads designed to penetrate and grip wood fibre.



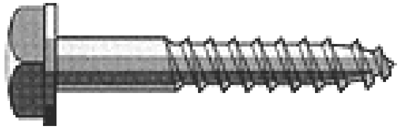
a) Carriage bolt



b) Hexagonal head bolt



c) Square head bolt



d) Lag screw

a, b & c TRADA Wood information Sheet 52   d Canadian wood council (www.cwc.ca)

3) Glued joints

Key advantages: of glued joints

- Structural glued joints are generally **stiffer**, require less timber and have a better **appearance** than mechanically fastened connections.
- They are **resistant** to corrosive atmospheres
- Joints made with thermosetting resins are **safer** in **fire** than mechanically fastened connections.

Key disadvantages are:

- stringent **quality control** is required
- unsuitable in conditions of **fluctuating moisture content** if dissimilar materials are involved or if there is a change in the angle of grain at their interfaces.
- unsuitable if there is a significant component of load perpendicular to the plane of adhesion.

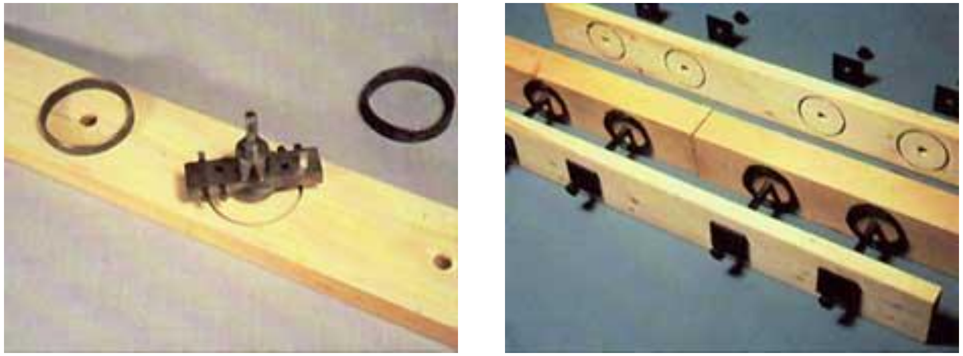
Adhesive	Application	Setting process and cure time	Advantages / Disadvantages
Thermo-Plastic			
Polyvinyl Acetate, Catalyzed Polyvinyl Acetate (PVA)	interior but some special formulations are waterproof	non-reactive, 40 minutes at room temperature	easy to work with
Hot Melts	Interior, high speed production lines	non-reactive, sets by cooling	grips on contact when hot
Thermo and Room Temperature Set			
Resorcinol formaldehyde (RF)	fully exterior, laminating, finger jointing, wood jointing	reactive, sets in 2 minutes with heat and 6 hours at room temperature	waterproof, high cost, marine-plywood
Phenol-resorcinol formaldehyde (PRF)			waterproof
Phenol formaldehyde (PF)	fully exterior, plywood, some particalboard		
Thermo-Set			
Melamine formaldehyde (MF)	semi-exterior and Interior, plywood, particleboard, formwork panels. (not often used alone in the UK)	reactive, sets with heat in 2 minutes and 30 minutes to 12 hours at room temperature	moisture resistant, low cost
Melamine urea formaldehyde (MUF)	semi-exterior and Interior, laminating, plywood, particleboard, finger jointing		
Urea formaldehyde (UF)	interior, plywood, particleboard, wood jointing, bent laminations	10 to 12 hours to cure. There are liquid catalysts that will allow the resin to cure in 20 minutes	easy to work, withsomewat gap filling, moisture resistant, foundry sand molds
Isocyanates and Polyurethanes (Most Polyurethane are thermo-set but thermoplastic are available)	isocyanates fully exterior, polyurethane semi-exterior and moist interior where temperature does not exceed 50°, laminating	reactive, one component sets with heat in 2 minutes, from to 2 to 60 minutes at room temperature for two-part resins	ability to set in high moisture conditions, suitable for multiple martials, 100% solid, good gap filling properties, low glue spread rate, expensive
Catalyst			
Epoxy resins	semi-exterior and Interior	reactive, hardens between 2 - 60 min gains full strength in 24 hours	structural repairs, suitable for multiple martials, timber end-jointing, waterproof, good gap filling properties
	(1) An elevated temperature is required to cure PF, MF and MUF adhesives. (2) PVA (polyvinyl acetate) adhesives should not be used for structural purposes, but in certain limited circumstances PVAc (cross linked PVA adhesives) may be acceptable.		

4) Timber connectors

Bolted joints can be strengthened by connectors in the joint surface.

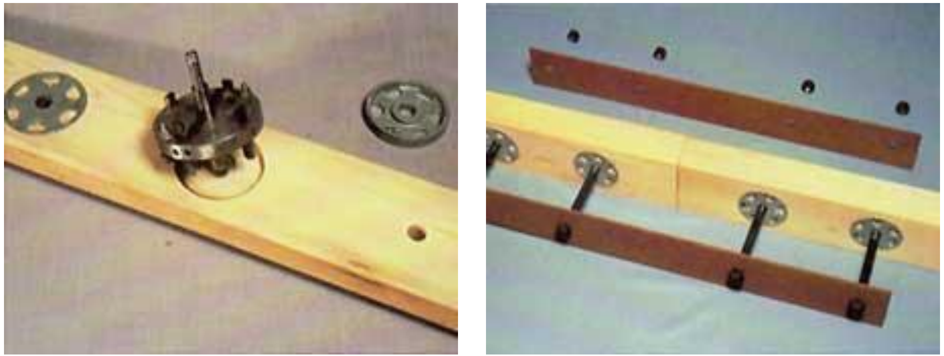
The following are defined as “Timber Connectors”:

1. **Split ring** connector joints
   - timber to timber only
   - Installed in pre-cut grooves
2. **Shear plate** connector joints
   - timber to timber or steel
   - Installed in pre-cut grooves
3. **Toothed-plate** connector joints
   - timber to timber or steel
   - Pressed into the timber



Dapping tool forming seat for split rings

Application of timber side plates



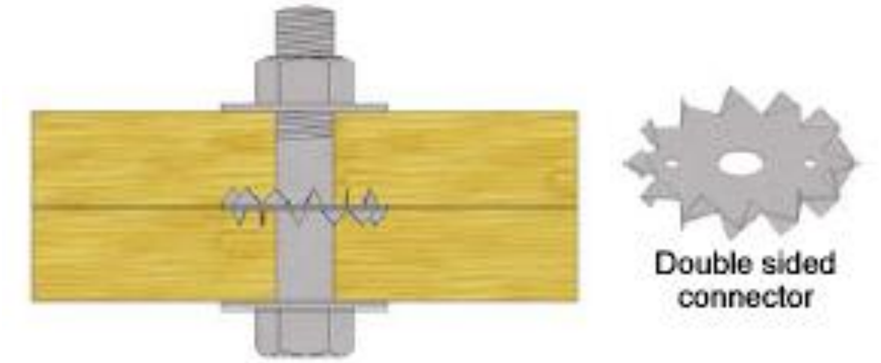
Dapping tool forming seat for shear plate

Application of steel side plates

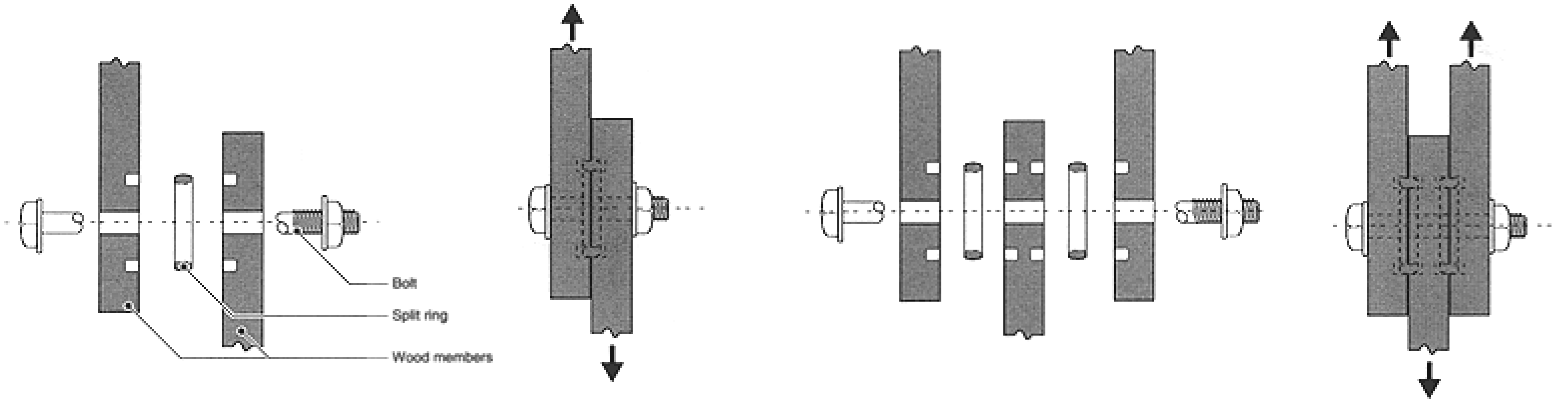
Fabrication of split ring and shear connector joints

Canadian wood council (www.cwc.ca)

Timber connectors are load transferring devices which rely on bolts or lag screws to restrain the joint assembly. They are more efficient structurally than bolts or lag screws used alone because they enlarge the wood area over which a load is distributed. Mainly used to transfer loads in heavy timber or glulam members as in roof trusses they are not usually protectively coated and need to be galvanized only if used with preservation treated wood or in wet service conditions. Specification and installation of the bolt is important as it clamps the joint together so that the connector acts effectively.

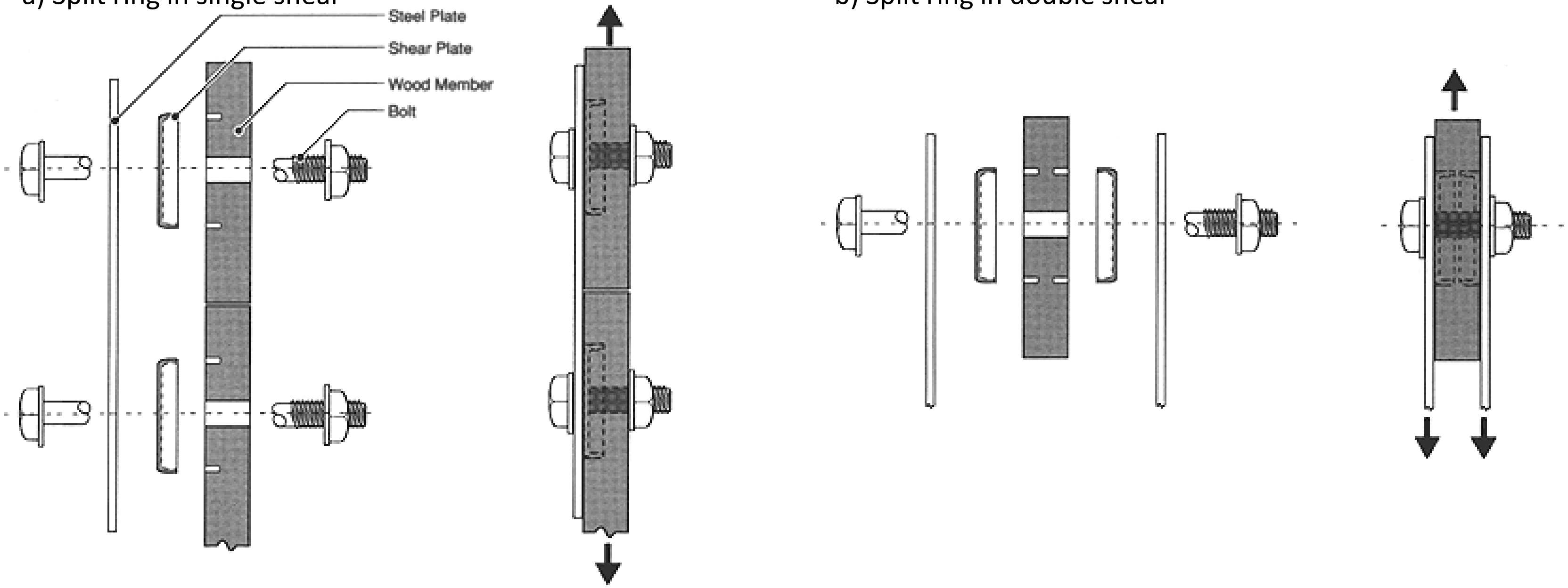


Toothed plate connector toothed plate connector (www.cullen-bp.co.uk)



a) Split ring in single shear

b) Split ring in double shear



c) One shear plate – bolts in single shear

d) Two shear plates – bolts in double shear

Split ring and shear plate connectors joints

Canadian wood council (www.cwc.ca)

5) Connection plates

Punched metal plate fasteners

A punched metal plate fastener is defined in prEN1075 “Timber Structures – Joints made of punched metal fasteners” as a fastener made of metal plate having integral projections punched out in one direction and bent perpendicular to the base of the plate, being used to join two or more pieces of timber of the same thickness in the same plane”.

The metal used is generally **galvanised** or stainless steel plate of thicknesses varying from **0.9mm to 2.5mm**.

The limiting strength of a punched metal plate is determined by one of two criteria:

1. Its anchorage (gripping) capacity in any of the jointed members.
2. Its net sectional steel capacity at any of the interfaces.

Dimension nailing plates

Dimensional nailing plates are made of light-gauge mild steel cut and folded to shape and pre-punched with holes for specified nails. The most common kinds are:

- Angle brackets
- Joist hangers
- Truss clips

6) Specification of connections

The specification of the fixing will depend on a range of factors:

-**Nature of the forces** being applied and their **magnitude**.
-**Practicality** and/or manufacturability
-**Aesthetics**
-**Environmental** conditions
-**Cost**

When specifying a connection it is important to consider how the whole system is to function and this will depend not only on the load-carrying capacity of the connection but also on the load-deformation characteristic of the connection.

Slip

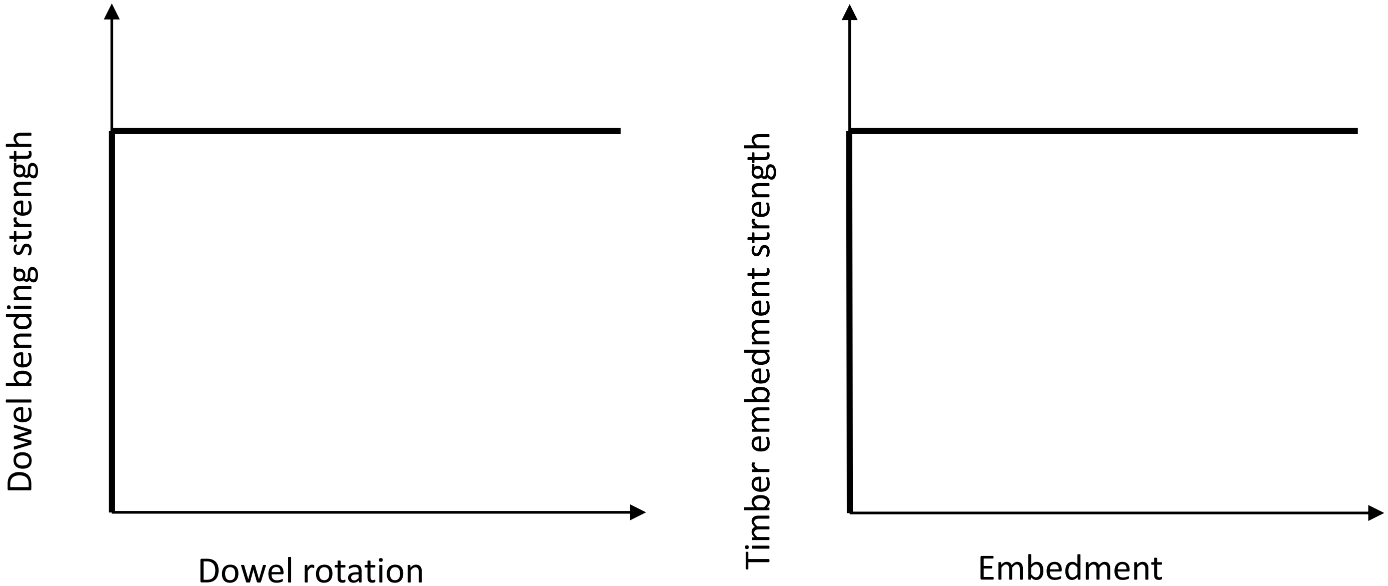
If the system being designed is statically indeterminate then the load deformation is influenced by the **deformation** of the members and slip in the joints. **Slip** in the joints is often the **largest contributor** and can therefore be an important criteria in specification.

Using nails, screws and bolts in combination

Also important in design is the concept of connections acting together. Nails, screws and bolts can be used together in a joint as they have similar ductile behaviour. However, because of the tolerance required in bolt holes to allow application they should not be considered to be acting together with other mechanical fasteners due to **initial slip**.

7) Eurocode design of dowel type fastener

Johansen (1949) first developed a **general theory** to predict the lateral load carrying capacity of dowel type fasteners which was based on the **assumption** that the connector and the timber (or wood based material) being connected will behave as essentially **rigid plastic materials** in accordance with the strength-displacement relationships.



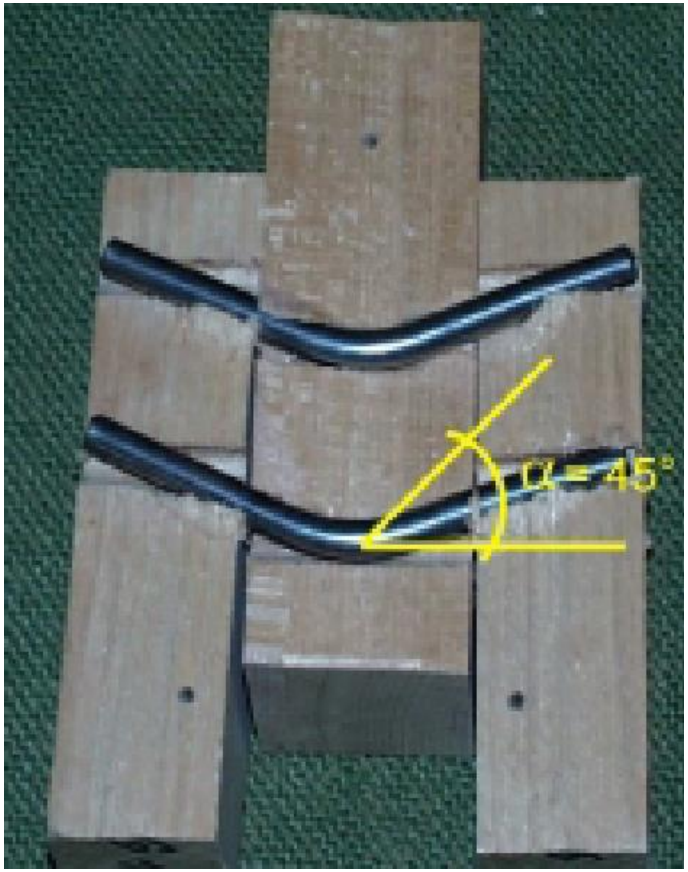
Strength/strain relationships used for dowel connections

The three main parameters which influence the load-carrying capacity behaviour of joints with dowel-type fasteners are:

1. The **bending capacity** of the dowel or yield moment.

2. The **embedding strength** of the timber or wood-based material.

3. The **withdrawal strength** of the dowel



Failure of lateral loaded dowel type connection Blass, H (2001)

7.1 Member notation

Member thickness, t_1 and t_2

In EC5 connections, the members are classified as member 1 and member 2.

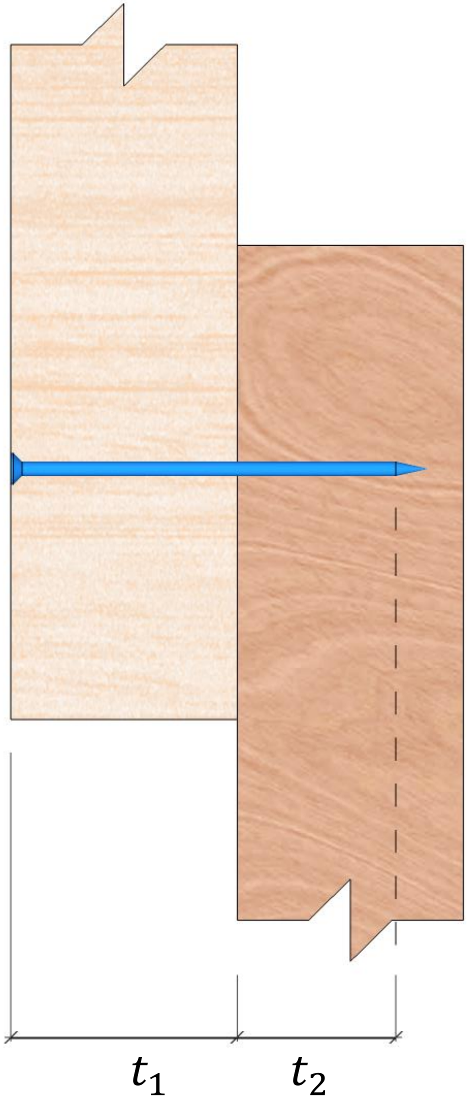
Single shear

For nails (all diameter):

t_1 is:
the nail headside member thickness;

t_2 is:
the nail pointside penetration;

where ‘nail headside material thickness’ is the thickness of the member containing the nail head and ‘nail pointside thickness’ is the distance that the pointed end of the nail penetrates into a member.



Nailed connection
Single shear

Member thickness, t_1 and t_2

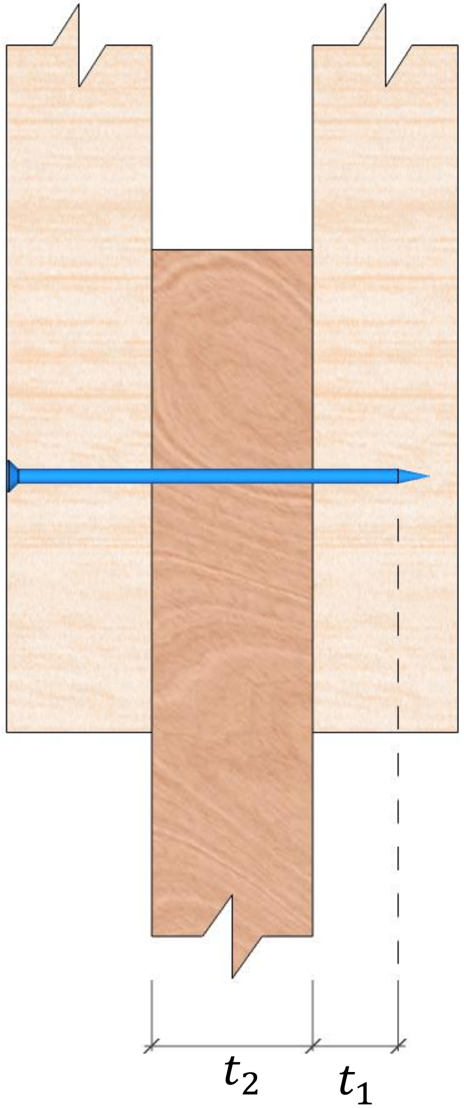
In EC5 connections, the members are classified as member 1 and member 2.

Double shear

For nails (all diameter):

t_1 is:
the minimum of the nail headside member thickness and the nail pointside penetration.

t_2 is:
the central member thickness for a connection.

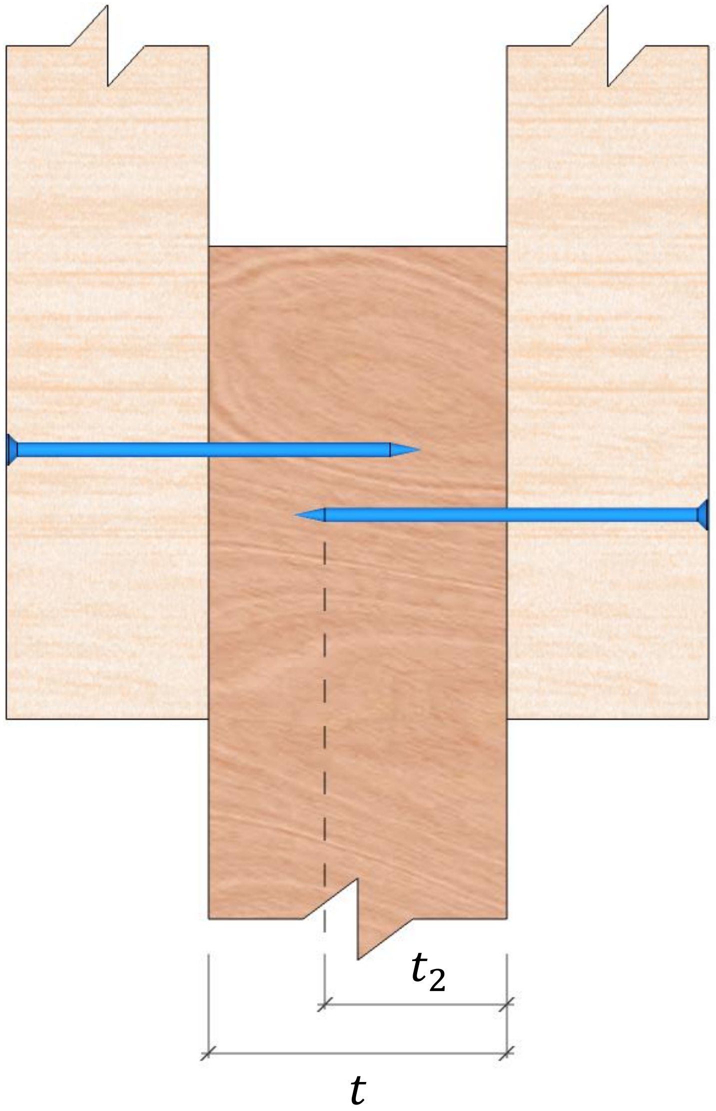


Nailed connection
Double shear

Note:

In a three-member connection, nails may overlap in the central member provided:

$$(t - t_2) > 4\,d$$



Overlapping nails

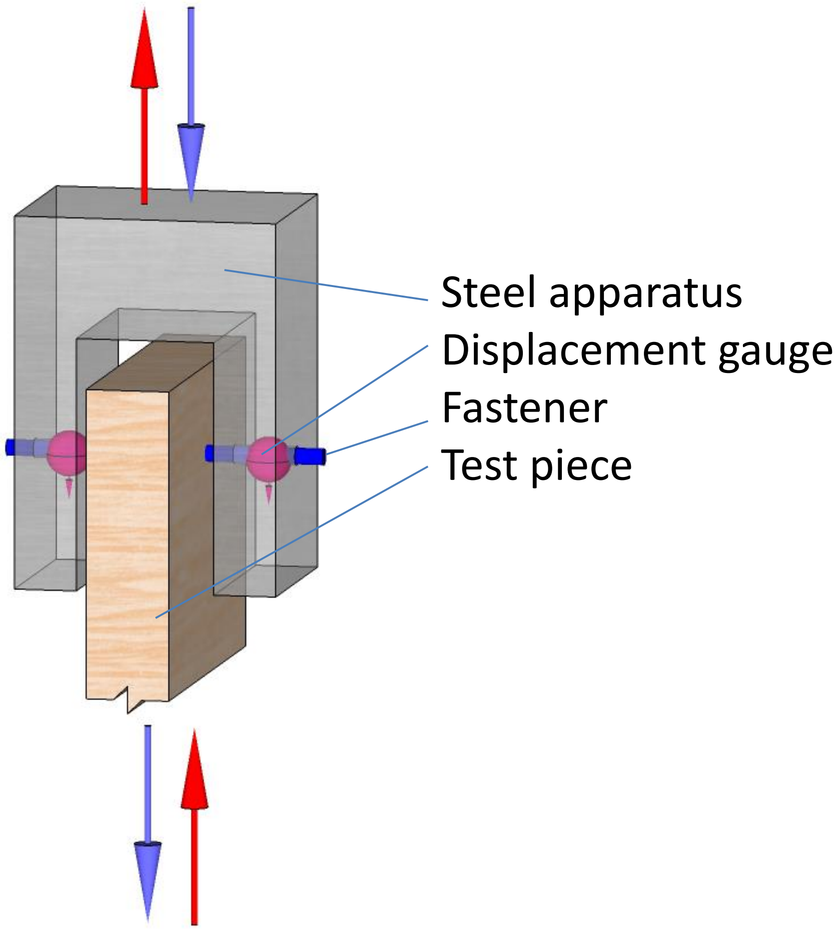
7.2 Embedment Strength test

The embedment strength of timber, or wood based product, f_h, is the average compressive strength at maximum load under the action of a stiff straight dowel:

$$f_h = \frac{F_{\max}}{d \cdot t} \qquad \text{(EN 383 eq. 2)}$$

Where:

F_{max}	is the embedment strength
d	is the Fastener diameter
t	is the thickness of timber



7.2 Embedment Strength

The following are the most important parameters when considering the embedding strength (Blass, H):

- **Density**: the embedding strength of softwood, hardwood and plywood increases linearly with density.
- Fastener and hole **diameter**, embedment strength decreases with increasing fastener diameter.
- **Angle** between load and grain direction: Is more critical for larger diameter dowels and is different for softwoods and hardwoods
- **Friction** & Adhesion: friction and adhesion between the dowel and timber increases embedment strength.
- **Moisture** content: like most strength and stiffness properties of timber, the embedding strength depends on the moisture content below the fibre saturation point.
- Reinforcement of the timber perpendicular to the grain: a glued-on wood based panel or a self-tapping screw orientated perpendicular to the grain prevents timber splitting and hence increases embedding strength and ductility.

7.2 Embedment strength: Nails

For nailed panel-to-timber connections the embedment strengths are as defined by EC5

Characteristic embedment strength of nails

Timber based product	**Nail limitations**	**Characteristic embedment strength,** $f_{h,0,k}$ **(N/mm^2)**
LVL and timber	Nails with diameter up to 8mm in	$0.082\rho_k \cdot d^{-0.3}$ without predrilled holes & $0.082(1-0.01\cdot d)\rho_k$ with predrilled holes
Plywood	Head diameter of at least 2d	$0.11\rho_k \cdot d^{-0.3}$
Hardboard in accordance with EN 662-2		$30 \cdot d^{-0.3} \cdot t^{0.6}$
Particle board and OSB		$65 \cdot d^{-0.7} \cdot t^{0.1}$

Where: ρ_k is the characteristic density in kg/m^3

d is the diameter of the nail in mm

t is the panel thickness in mm.

7.2.1 Ratio of characteristic embedment strengths

To simplify the strength equations, the **ratio** of the characteristic embedment strength of member 2, $f_{\mathrm{h,2,k}}$, to the characteristic embedment strength of member 1, $f_{\mathrm{h,1,k}}$, is derived and written as:

$$\beta = \frac{f_{h,2,k}}{f_{h,1,k}} \quad EC5, equation \qquad (EC5\ eq. 8.8)$$

Where:

$f_{h,1.k}$	characteristic embedment strength of timber, in the headside member
$f_{h,2.k}$	characteristic embedment strength of timber, in the pointside member

7.3 The characteristic withdrawal capacity of nails

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

$$F_{ax.Rk} = min\begin{cases} f_{ax.k} \cdot d \cdot t_{pen} \\ f_{head.k} \cdot d_h^2 \end{cases} \qquad \text{(EC5 eq. 8.23)}$$

For smooth nails

$$F_{ax.Rk} = min\begin{cases} f_{ax.k} \cdot d \cdot t_{pen} \\ f_{ax.k} \cdot d \cdot t + f_{head.k} \cdot d_h^2 \end{cases} \qquad \text{(EC5 eq. 8.24)}$$

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, excluding the point length, in the point side member;
t	Is the thickness of the head side member;
d_h	Is the nail head diameter;

7.3 The characteristic withdrawal capacity of nails

Characteristic withdrawal strength $f_{ax.k}$ and $f_{head.k}$ should be **determined by test**, unless specified in the following.

For smooth nails with a pointside penetration of at least 12 · d

$$f_{ax.k} = 20 \cdot 10^{-6} \cdot \rho_k^2 \qquad \text{(EC5 eq. 8.25)}$$

$$f_{head.k} = 70 \cdot 10^{-6} \cdot \rho_k^2 \qquad \text{(EC5 eq. 8.26)}$$

Where:

ρ_k is the characteristic timber **density** in kg/m^3;

From EC5 8.3.2(7) reduction factors

For **smooth** nails, t_{pen} should be at least $8 \cdot d$

when $\boldsymbol{t_{pen}}$ **<** $\boldsymbol{12 \cdot d}$ the withdrawal capacity multiplied by $\dfrac{t_{pen}}{4 \cdot d - 2}$

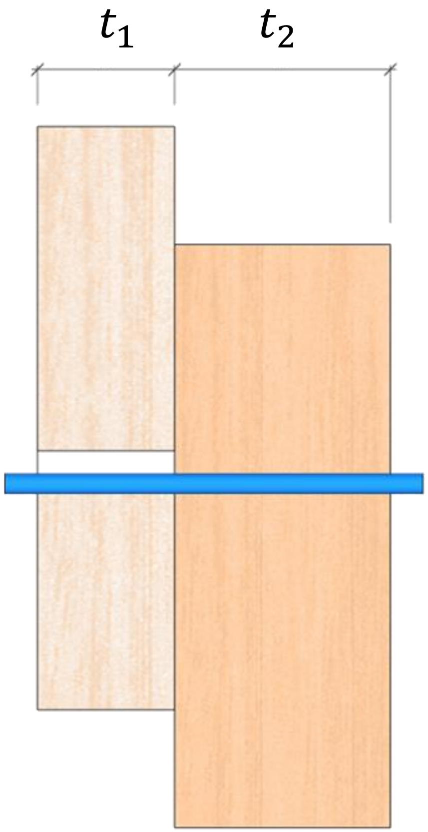
For **threaded** nails, t_{pen} should be at least $6 \cdot d$

when $\boldsymbol{t_{pen}}$ **<** $\boldsymbol{8 \cdot d}$ the withdrawal capacity multiplied by $\dfrac{t_{pen}}{2 \cdot d - 3}$

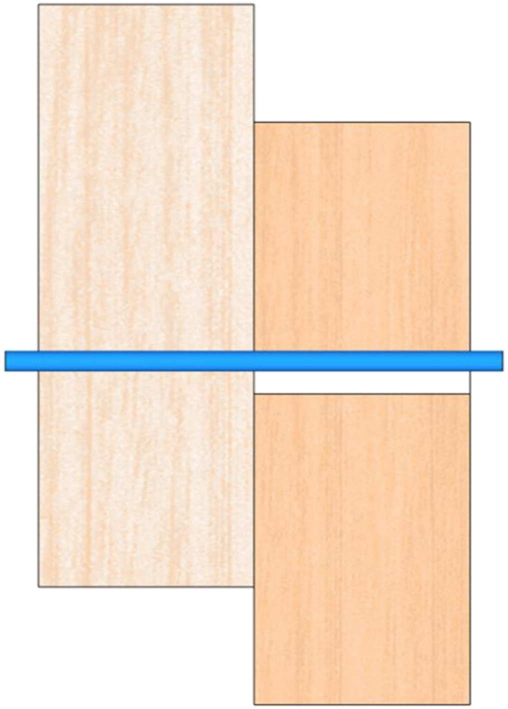
7.4 Friction effects

There are two types of friction effect that can arise in a connection:

1. One will develop if the members are in direct contact when assembled. This friction will be eliminated if there is no direct contact on assembly or if there is shrinkage of the timber or wood products in service and as a results is conservatively not considered in EC5.



Failure mode a

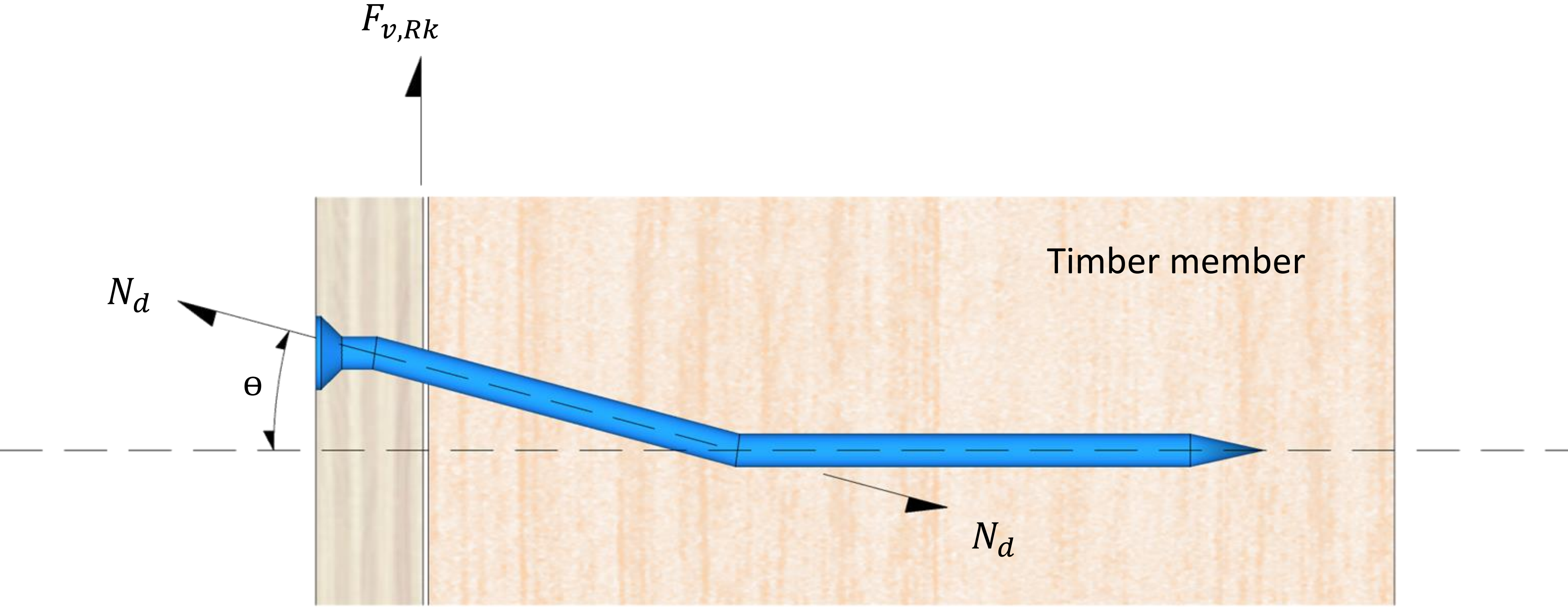


Failure mode b

7.4 Friction effects

The second condition:

2. The other will arise when the fasteners yield, pulling the members together as the fasteners deform. This type of friction will always arise in failure modes that include yielding of the fasteners and has been included for in the EC5 equations relating to such modes. This effect is termed the “rope effect”.



Dowel in single shear, fastener fully yields

7.5 Lateral load carrying capacity of metal dowel type fasteners to EC5

$$F_{v.Rk} = \boxed{friction\ factor \quad + \quad johansen\ yield\ load} + \quad Rope\ effect$$

Friction factor:

Values used		failure modes
5%	fastener partially yields	(d) (e) (j)
15%	fastener fully yields	(f) (k)

7.5 Lateral load carrying capacity of metal dowel type fasteners to EC5

$$F_{v.Rk} = friction\ factor \quad + \quad johansen\ yield\ load \quad + \boxed{Rope\ effect}$$

$$[1] = friction\ factor \quad + \quad johansen\ yield\ load$$

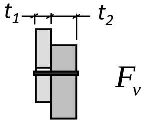
$$Limiting\ precentage\ (Lp) = \left\{ \begin{matrix} \text{15\% Round nails} \\ \text{25\% Square nails} \\ \text{50\% Other nails} \\ \text{100\% Screws} \\ \text{25\% Bolts} \\ \text{0\% Dowels} \end{matrix} \right\}$$

$$Rope\ effect \ = \min \begin{pmatrix} [1] \ + \dfrac{F_{ax.Rk}}{4} \\ \\ [1] + Lp\% \end{pmatrix}$$

Note : If the axial withdrawal capacity of the fastener is not known then the rope effect should be considered as zero.

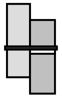
7.5.1 Single shear - failure modes and associated equations

$$F_{v.Rk} = \min$$



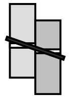
$$F_{v,Rk} = f_{h,1,k}\cdot t_1\cdot d$$

(a)



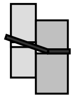
$$F_{v,Rk} = f_{h,2,k}\cdot t_2\cdot d$$

(b)



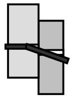
$$F_{v,Rk} = \frac{f_{h,1,k}\cdot t_1\cdot d}{1+\beta}\left[\sqrt{\beta+2\beta^2\left[1+\frac{t_2}{t_1}+\left(\frac{t_2}{t_1}\right)^2\right]+\beta^3\left(\frac{t_2}{t_1}\right)^2}-\beta\left(1+\frac{t_2}{t_1}\right)\right]+\frac{F_{ax,Rk}}{4}$$

(c)



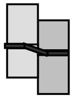
$$F_{v,Rk} = 1.05\frac{f_{h,1,k}\cdot t_1\cdot d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k}\cdot t_1^{\;2}\cdot d}}-\beta\right]+\frac{F_{ax,Rk}}{4}$$

(d)



$$F_{v,Rk} = 1.05\frac{f_{h,1,k}\cdot t_2\cdot d}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\frac{4\beta(1+2\beta)M_{y,Rk}}{f_{h,1,k}\cdot t_2^{\;2}\cdot d}}-\beta\right]+\frac{F_{ax,Rk}}{4}$$

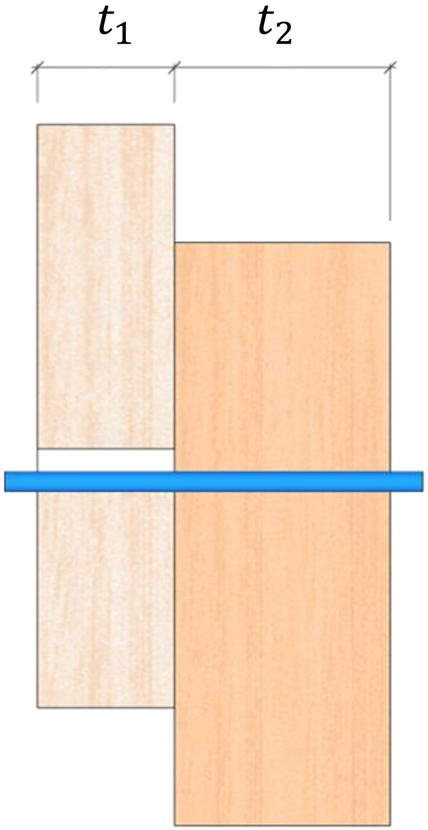
(e)



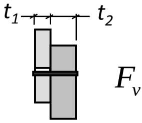
$$F_{v,Rk} = 1.15\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk}\cdot f_{h,1,k}\cdot d}+\frac{F_{ax,Rk}}{4}$$

(f)

7.5.1 Single shear - failure modes and associated equations



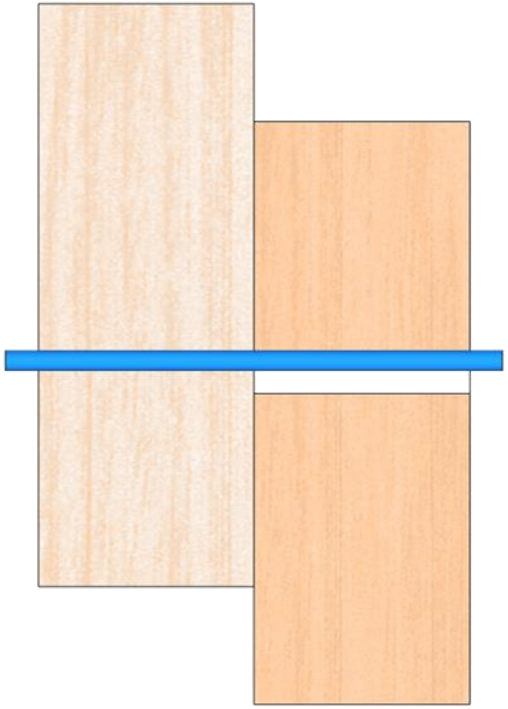
Failure mode a



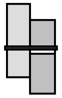
(a)

$$F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d$$

7.5.1 Single shear - failure modes and associated equations



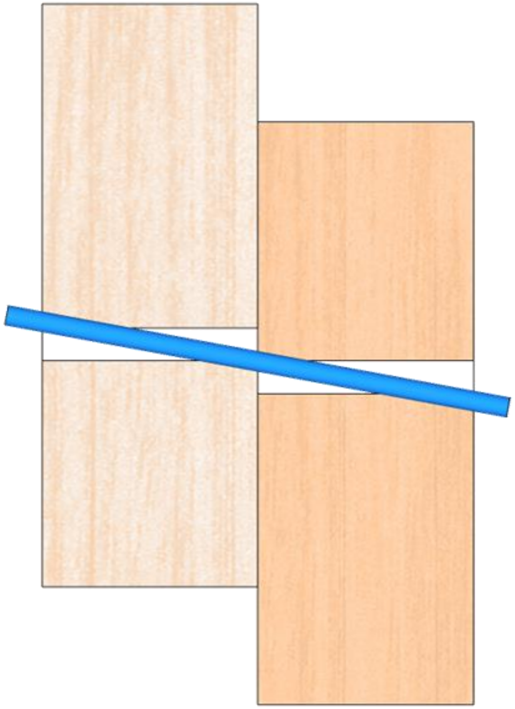
Failure mode b



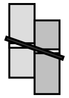
(b)

$$F_{v,Rk} = f_{h,2,k} \cdot t_2 \cdot d$$

7.5.1 Single shear - failure modes and associated equations



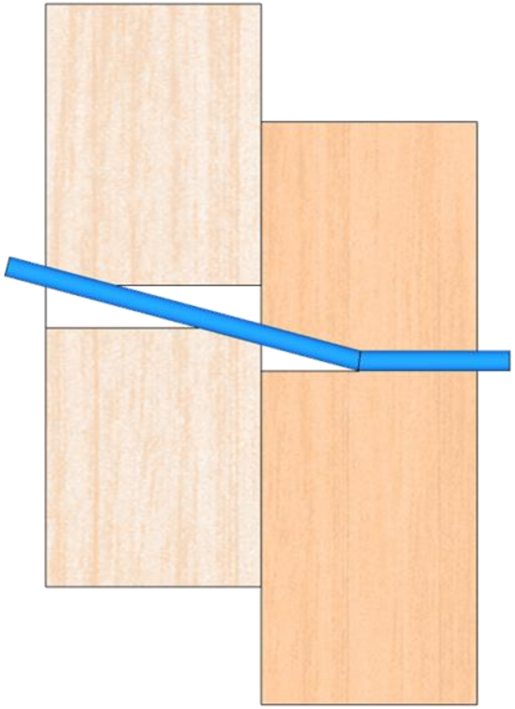
Failure mode c



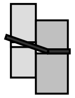
(c)

$$F_{v,Rk}=\frac{f_{h,1,k}\cdot t_1\cdot d}{1+\beta}\left[\sqrt{\beta+2\beta^2\left[1+\frac{t_2}{t_1}+\left(\frac{t_2}{t_1}\right)^2\right]+\beta^3\left(\frac{t_2}{t_1}\right)^2}-\beta\left(1+\frac{t_2}{t_1}\right)\right]+\frac{F_{ax,Rk}}{4}$$

7.5.1 Single shear - failure modes and associated equations



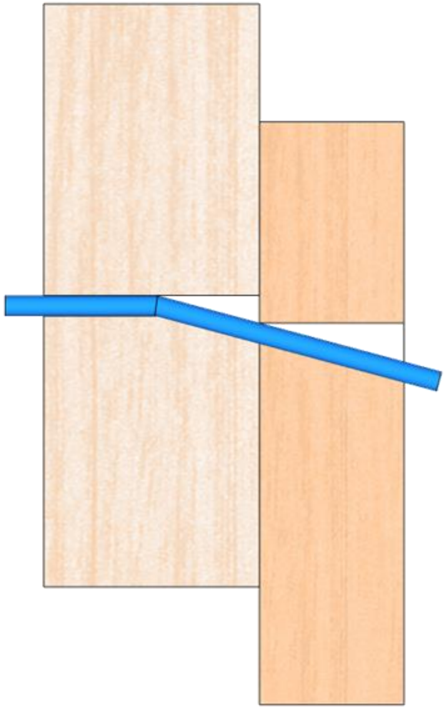
Failure mode d, fastener partially yields



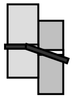
(d)

$$F_{v,Rk} = 1.05\frac{f_{h,1,k}\cdot t_1\cdot d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k}\cdot t_1^{2}\cdot d}}-\beta\right]+\frac{F_{ax,Rk}}{4}$$

7.5.1 Single shear - failure modes and associated equations



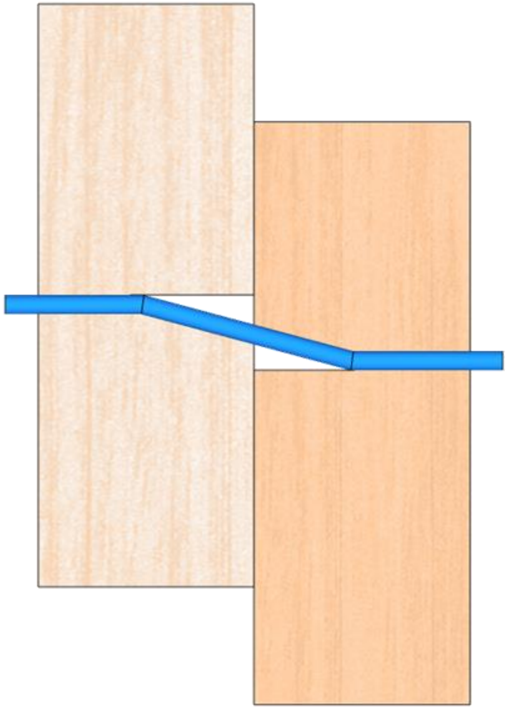
Failure mode e, fastener partially yields



(e)

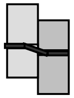
$$F_{v,Rk} = 1.05\frac{f_{h,1,k} \cdot t_2 \cdot d}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\frac{4\beta(1+2\beta)M_{y,Rk}}{f_{h,1,k} \cdot {t_2}^2 \cdot d}}-\beta\right]+\frac{F_{ax,Rk}}{4}$$

7.5.1 Single shear - failure modes and associated equations



Failure mode f,

fastener fully yields

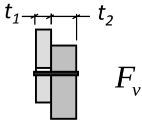


(f)

$$F_{v,Rk} = 1.15\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk}\cdot f_{h,1,k}\cdot d} + \frac{F_{ax,Rk}}{4}$$

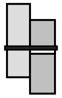
7.5.1 Single shear - failure modes and associated equations

$$F_{v.Rk} = \min$$



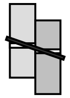
$$F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d$$

(a)



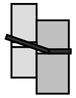
$$F_{v,Rk} = f_{h,2,k} \cdot t_2 \cdot d$$

(b)



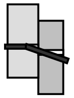
$$F_{v,Rk} = \frac{f_{h,1,k} \cdot t_1 \cdot d}{1+\beta}\left[\sqrt{\beta + 2\beta^2\left[1+\frac{t_2}{t_1}+\left(\frac{t_2}{t_1}\right)^2\right]+\beta^3\left(\frac{t_2}{t_1}\right)^2} - \beta\left(1+\frac{t_2}{t_1}\right)\right] + \frac{F_{ax,Rk}}{4}$$

(c)



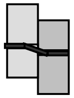
$$F_{v,Rk} = 1.05\frac{f_{h,1,k} \cdot t_1 \cdot d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} \cdot t_1^{\ 2} \cdot d}} - \beta\right] + \frac{F_{ax,Rk}}{4}$$

(d)



$$F_{v,Rk} = 1.05\frac{f_{h,1,k} \cdot t_2 \cdot d}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\frac{4\beta(1+2\beta)M_{y,Rk}}{f_{h,1,k} \cdot t_2^{\ 2} \cdot d}} - \beta\right] + \frac{F_{ax,Rk}}{4}$$

(e)

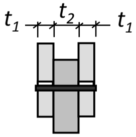


$$F_{v,Rk} = 1.15\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \frac{F_{ax,Rk}}{4}$$

(f)

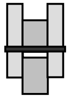
7.5.2 Double shear - failure modes and associated equations

$$F_{v.Rk} = \min \left\{ \right.$$



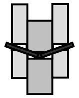
(g)

$$F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d$$



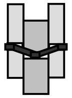
(h)

$$F_{v,Rk} = 0.5 \cdot f_{h,2,k} \cdot t_2 \cdot d$$



(j)

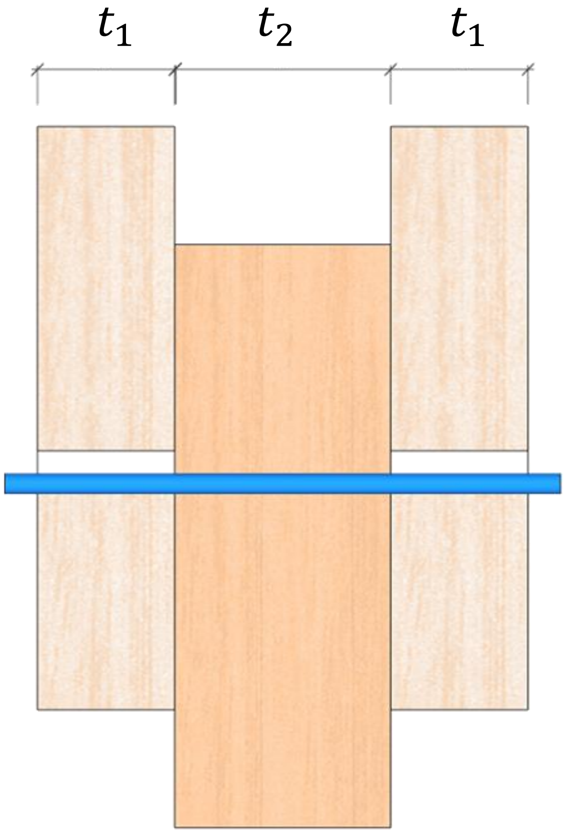
$$F_{v,Rk} = 1.05 \frac{f_{h,1,k} \cdot t_1 \cdot d}{2+\beta} \left[\sqrt{2\beta(1+\beta) + \frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} \cdot t_1^{2} \cdot d}} - \beta \right] + \frac{F_{ax,Rk}}{4}$$

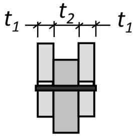


(k)

$$F_{v,Rk} = 1.15 \sqrt{\frac{2\beta}{1+\beta}} \sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \frac{F_{ax,Rk}}{4}$$

7.5.2 Double shear - failure modes and associated equations



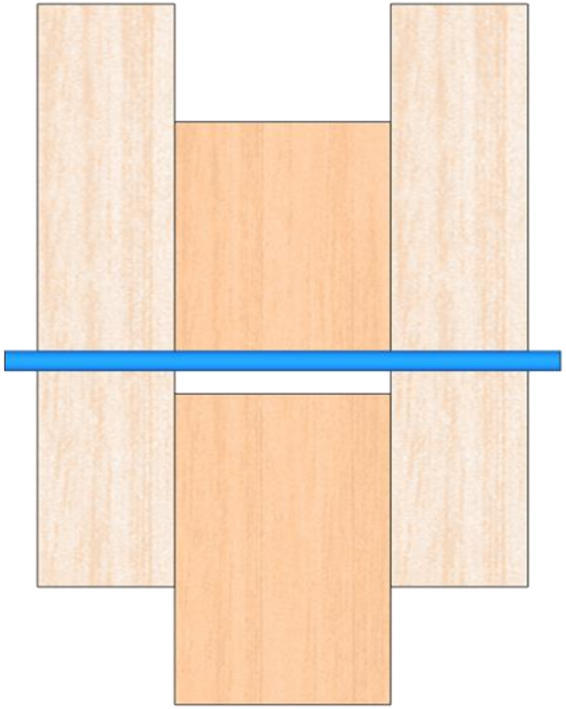


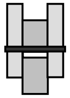
(g)

$$F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d$$

Failure mode g

7.5.2 Double shear - failure modes and associated equations



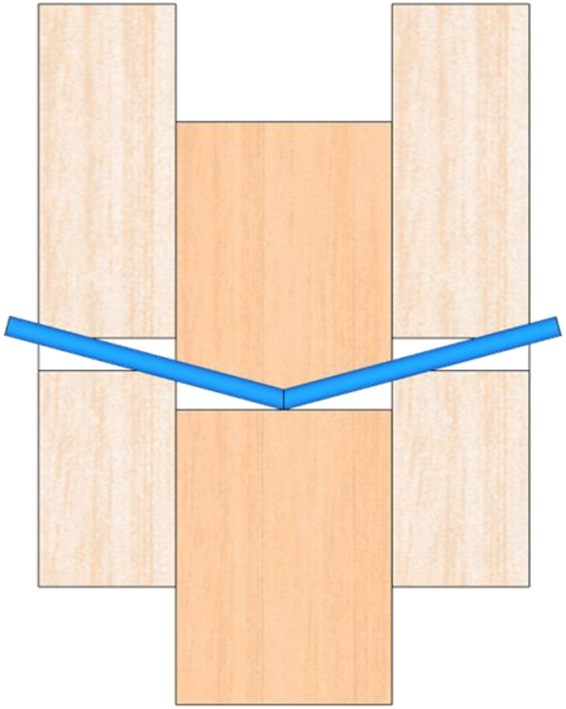


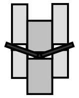
(h)

$$F_{v,Rk} = 0.5 \cdot f_{h,2,k} \cdot t_2 \cdot d$$

Failure mode h

7.5.2 Double shear - failure modes and associated equations



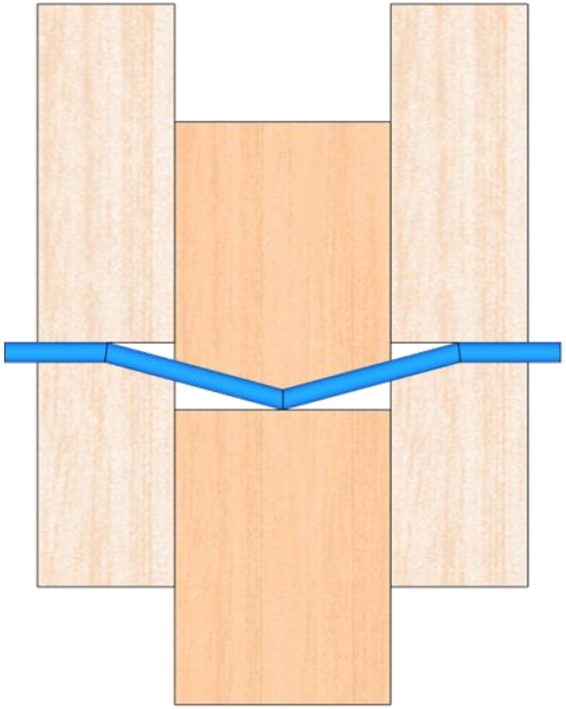


(j)

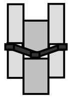
$$F_{v,Rk} = 1.05 \frac{f_{h,1,k} \cdot t_1 \cdot d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} \cdot t_1^{\,2} \cdot d}}-\beta\right]+\frac{F_{ax,Rk}}{4}$$

Failure mode j, fastener partially yields

7.5.2 Double shear - failure modes and associated equations



Failure mode k, fastener fully yields

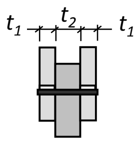


(k)

$$F_{v,Rk} = 1.15\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,Rk}\cdot f_{h,1,k}\cdot d}+\frac{F_{ax,Rk}}{4}$$

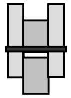
7.5.2 Double shear - failure modes and associated equations

$$F_{v.Rk} = \min$$



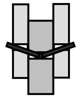
(g)

$$F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d$$



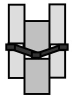
(h)

$$F_{v,Rk} = 0.5 \cdot f_{h,2,k} \cdot t_2 \cdot d$$



(j)

$$F_{v,Rk} = 1.05 \frac{f_{h,1,k} \cdot t_1 \cdot d}{2+\beta} \left[\sqrt{2\beta(1+\beta) + \frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} \cdot t_1^{\ 2} \cdot d}} - \beta \right] + \frac{F_{ax,Rk}}{4}$$



(k)

$$F_{v,Rk} = 1.15 \sqrt{\frac{2\beta}{1+\beta}} \sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \frac{F_{ax,Rk}}{4}$$

8) Other design considerations

8.1 Multiple connectors loaded laterally

- The total load carrying capacity of the joint will be the combined ultimate loads of the fasteners.

- However, this would only be the case if all the respective single fasteners reached their ultimate loads at the same time as the whole connection failed.

- In fact the ultimate load carrying capacity of the connection is smaller than the sum of the single fastener ultimate loads and this is know as “group effect”.

$$F_{v.ef.Rk} = n_{ef}\, F_{v.Rk}$$

n_{ef}	is the effective number of fasteners in line parallel to the grain.
$F_{v.Rk}$	is the characteristic load-carrying capacity of each fastener parrellel to the grain.

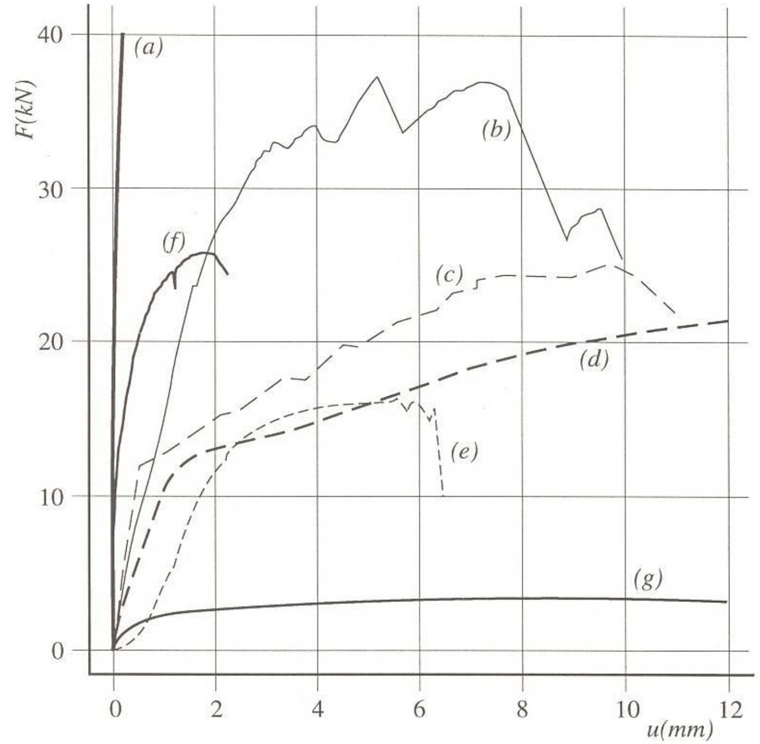
8.2 Load Slip

- The design procedure has to combine the **global analysis** of the structural timberwork and the **local analysis** of the connections.

- The key problem lies in **joint behaviour** that affects the distribution of the forces and the deformation of the structure.

- It can be determined from test results for the chosen joints in accordance with EN26891 "Joints made with mechanical fasteners – General principles for the determination of strength and deformation characteristics".

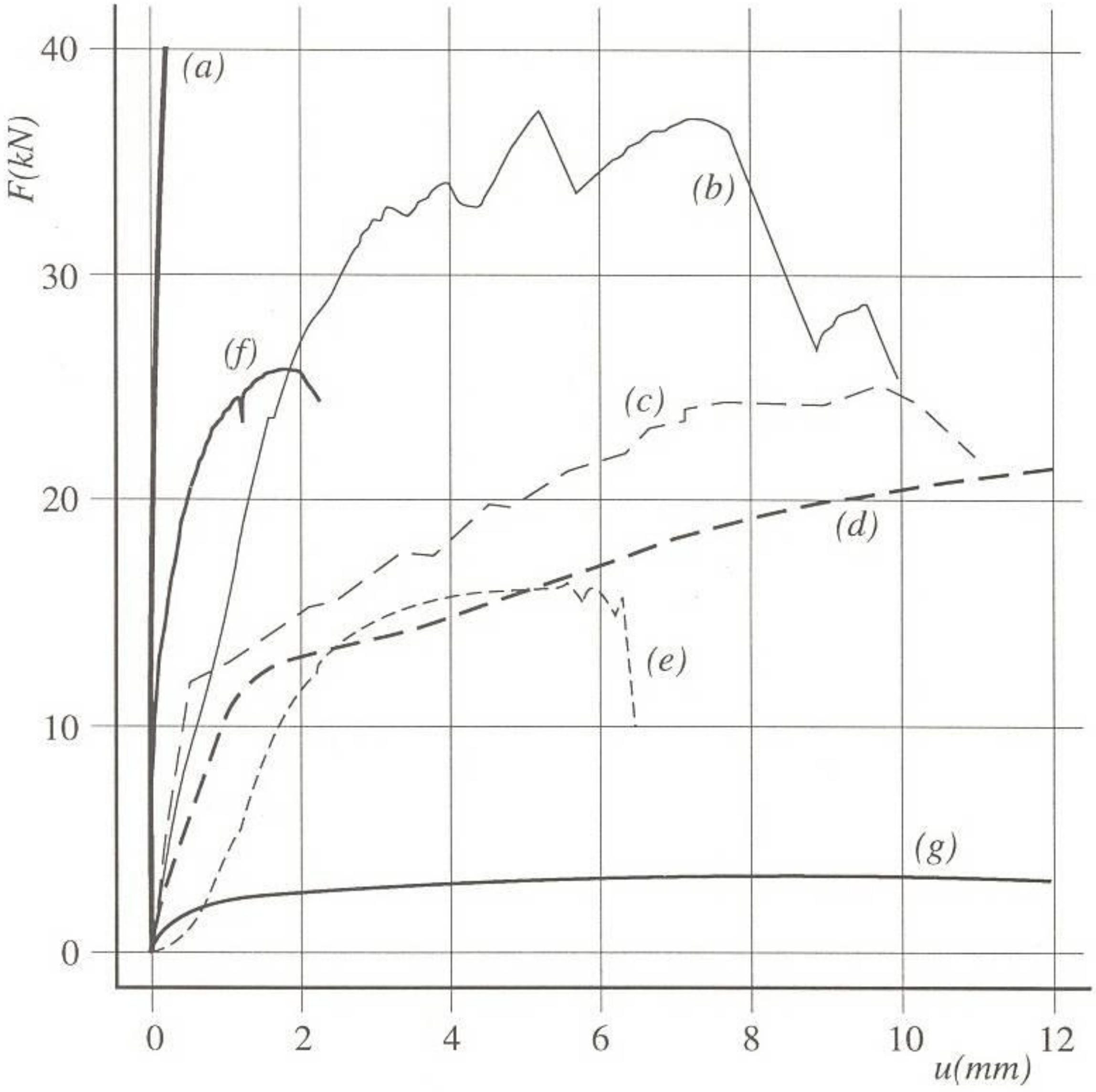
- Otherwise the joint properties from the behaviour of single fastener (Racher, 2001)



Experimental load-slip curves for joints in tension parallel to the grain: (a) glued joints (12,5 10^3 mm^2), (b) split-ring (100 mm), (c) double sided toothed-plate (62 mm) (Hirashima, 1990), (d) dowel (14 mm), (e) bolt (14 mm), (f) punched plate (10^4 mm^2), (g) nail (4,4 mm).

Typical load slip curves (Racher, 2001)

8.2 Load Slip



Typical load slip curves (Racher, 2001)

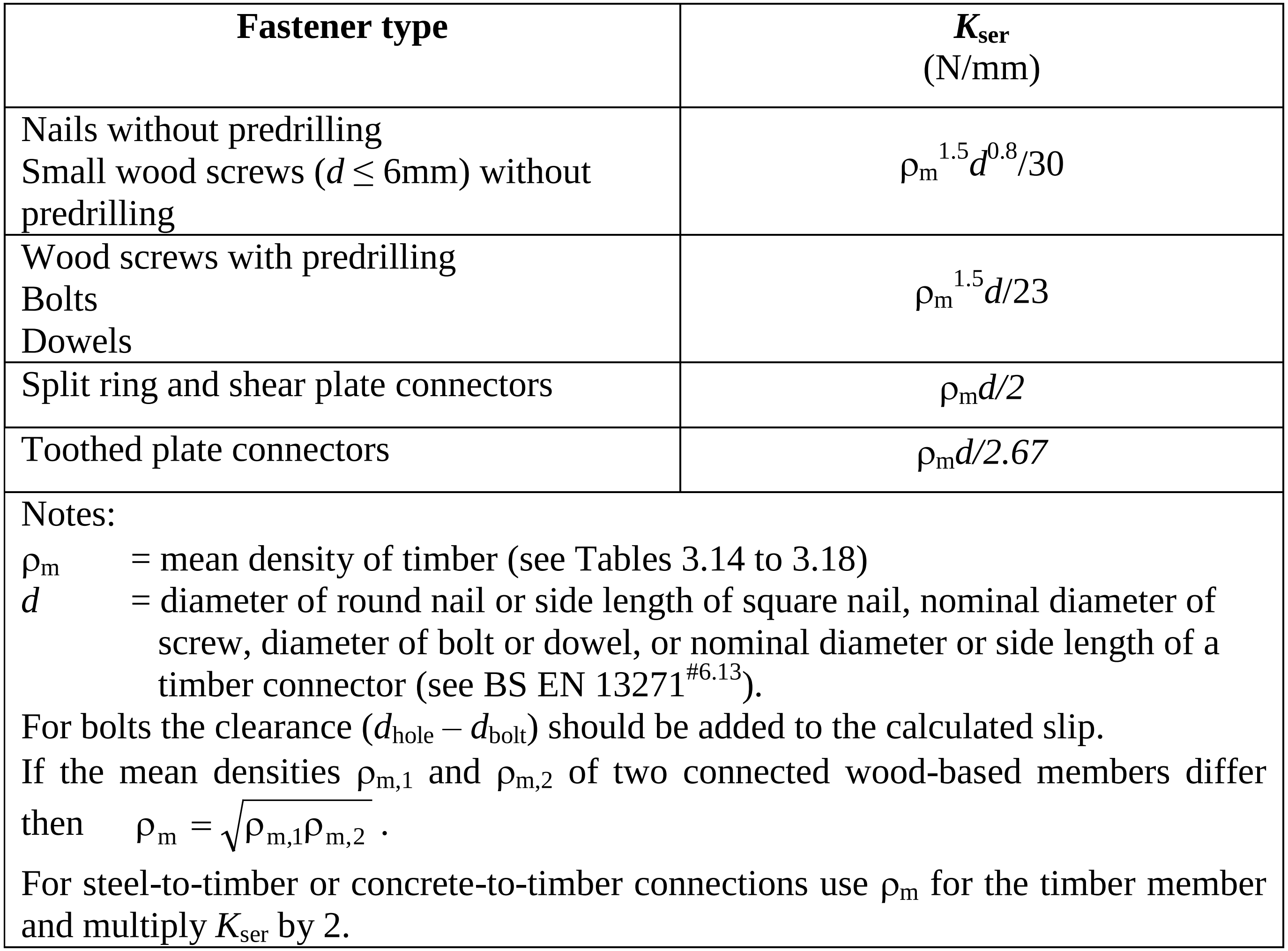
Experimental load-slip curves for joints in tension parallel to the grain:

(a) glued joints (12.5 10^3 mm^2)
(b) split-ring (100 mm)
(c) double sided toothed-plate (62mm)
(d) dowel (14mm)
(e) bolt (14mm)
(f) punched plate (10^4 mm^2)
(g) nail (4.4 mm)

8.2 Load Slip

In accordance with EC5 load slip is a function of the **mean density** of timber and the diameter of the fixing, Table 3 :

Values of K_{ser} for fasteners in timber-to-timber and wood-based panel-to-timber connections (IStructE, 2007)



Fastener type	$\boldsymbol{K_{ser}}$ (N/mm)
Nails without predrilling Small wood screws ($d \leq$ 6mm) without predrilling	$\rho_m^{1.5} d^{0.8}/30$
Wood screws with predrilling Bolts Dowels	$\rho_m^{1.5} d/23$
Split ring and shear plate connectors	$\rho_m d/2$
Toothed plate connectors	$\rho_m d/2.67$

Notes:

ρ_m = mean density of timber (see Tables 3.14 to 3.18)

d = diameter of round nail or side length of square nail, nominal diameter of screw, diameter of bolt or dowel, or nominal diameter or side length of a timber connector (see BS EN 13271#6.13).

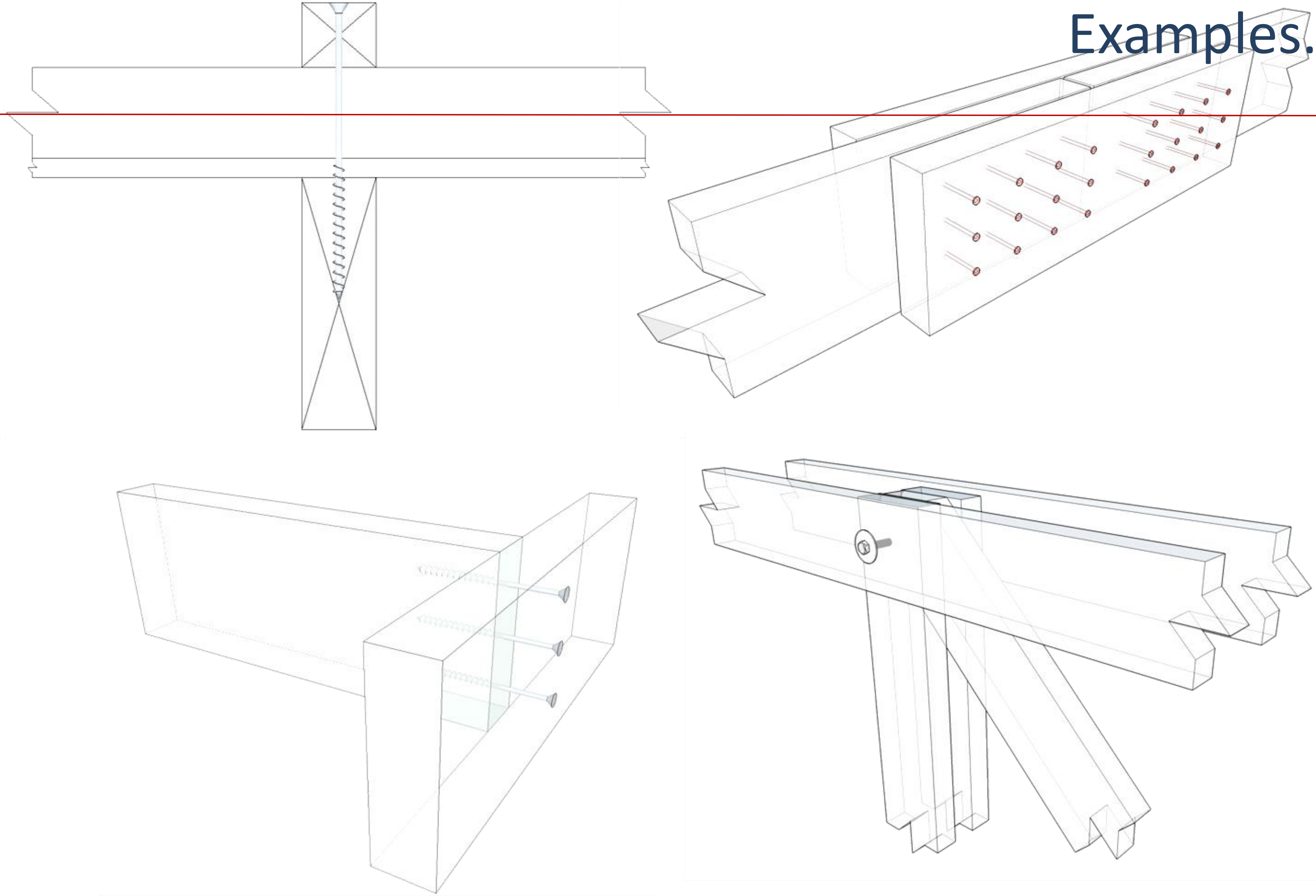
For bolts the clearance ($d_{hole} - d_{bolt}$) should be added to the calculated slip.

If the mean densities $\rho_{m,1}$ and $\rho_{m,2}$ of two connected wood-based members differ then $\rho_m = \sqrt{\rho_{m,1}\rho_{m,2}}$.

For steel-to-timber or concrete-to-timber connections use ρ_m for the timber member and multiply K_{ser} by 2.

9) Connection calculations examples

Examples...

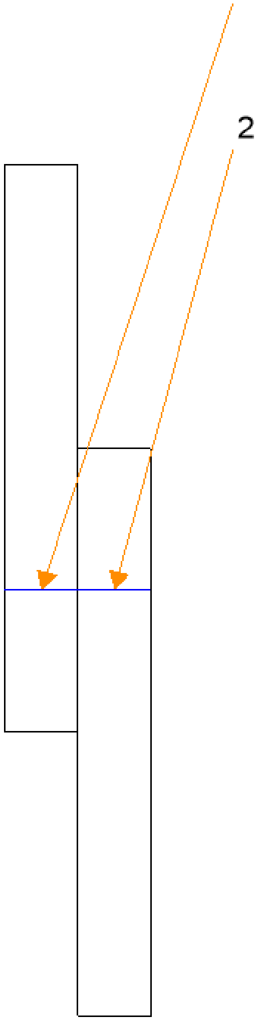


10) Comparing C16+ vs C16 timber connections

Member

1, 145 × 45 mm, C30, Rotated 0°

2, 145 × 45 mm, C30, Rotated 180°



Plan

“C16”

$\rho_k = 310\ kg/m^3$

vs

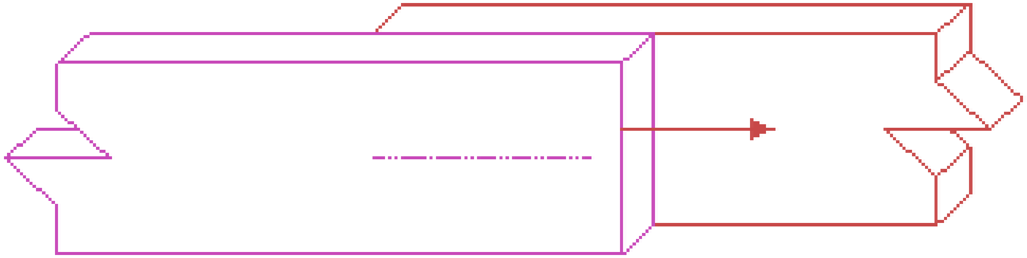
“C16+”

$\underline{\rho_k = 330\ kg/m^3}$

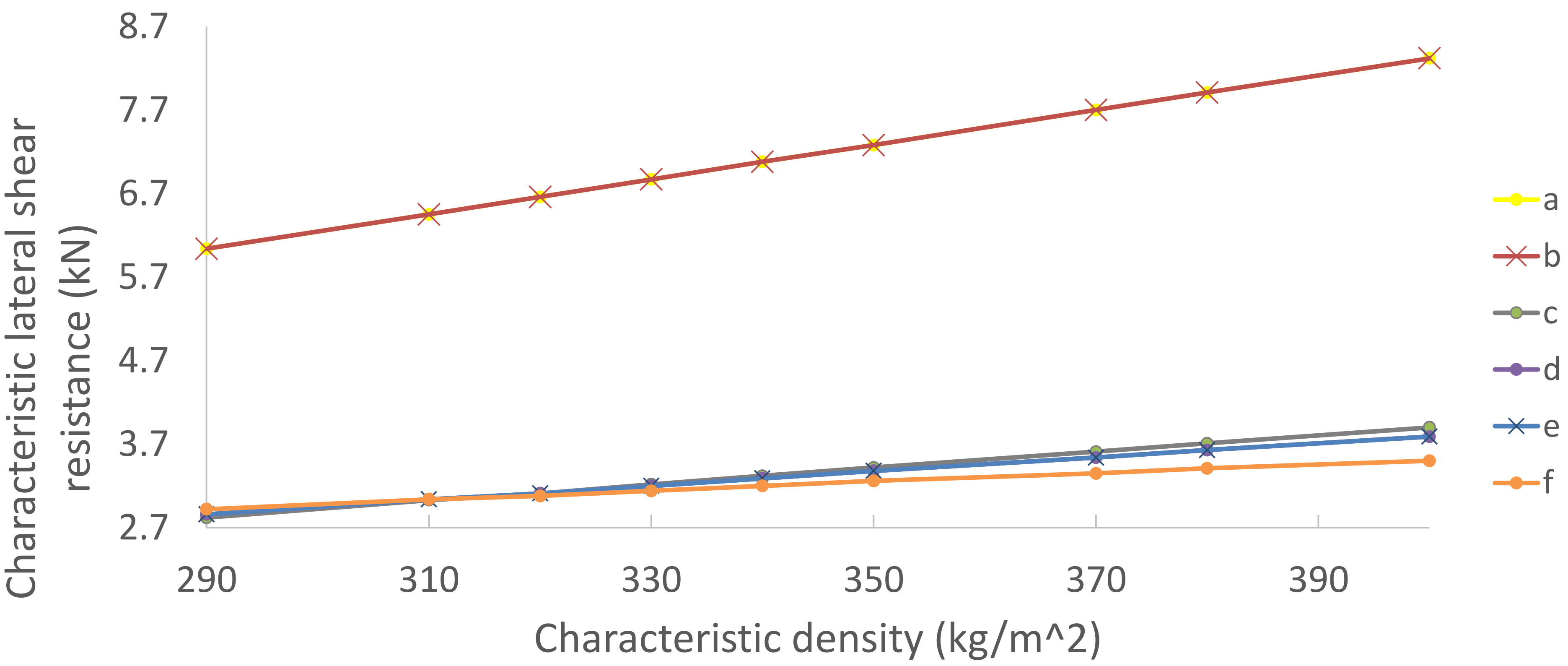
Fixings:

M6 Grade 6.8 Bolt

3.1mm ringshank nail

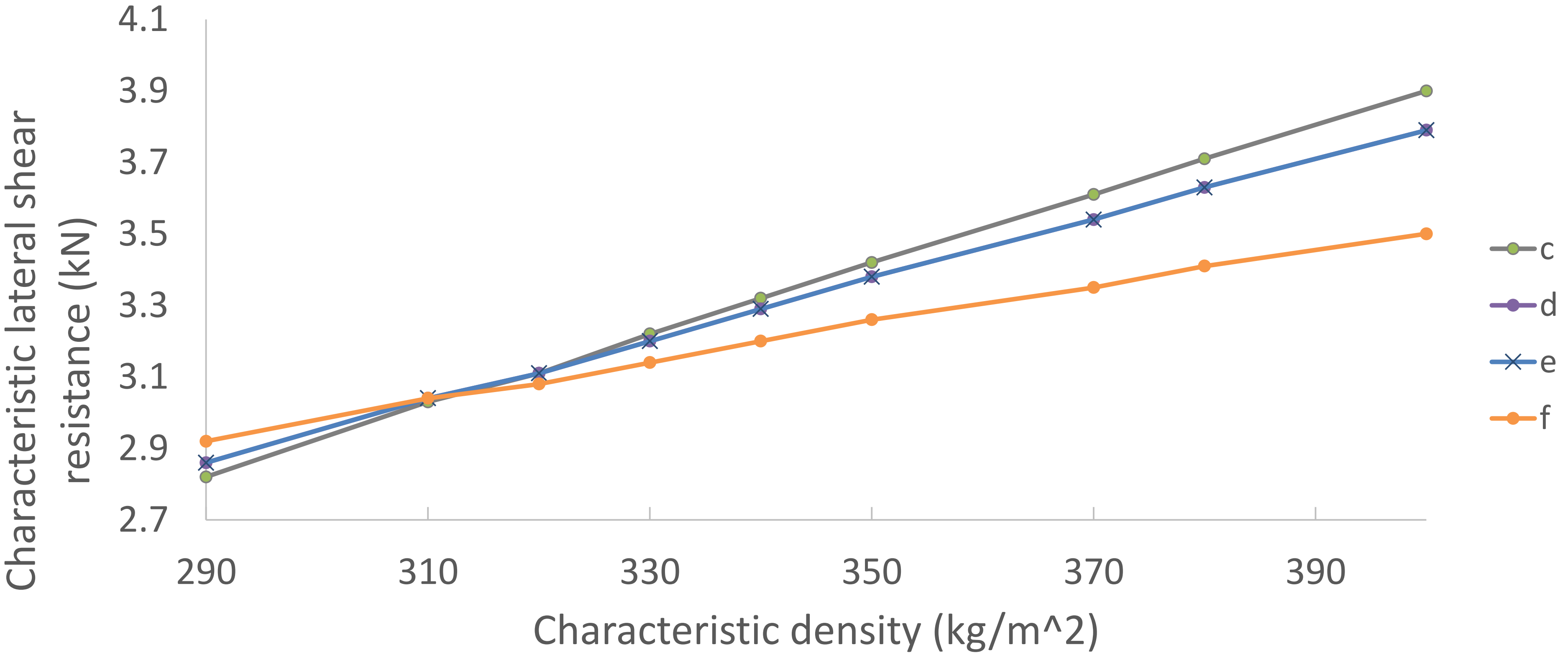


$$F_{v.Rk} = \min(F_{v.Rk.a}, F_{v.Rk.b}, F_{v.Rk.c}, F_{v.Rk.d}, F_{v.Rk.e}, F_{v.Rk.f})$$



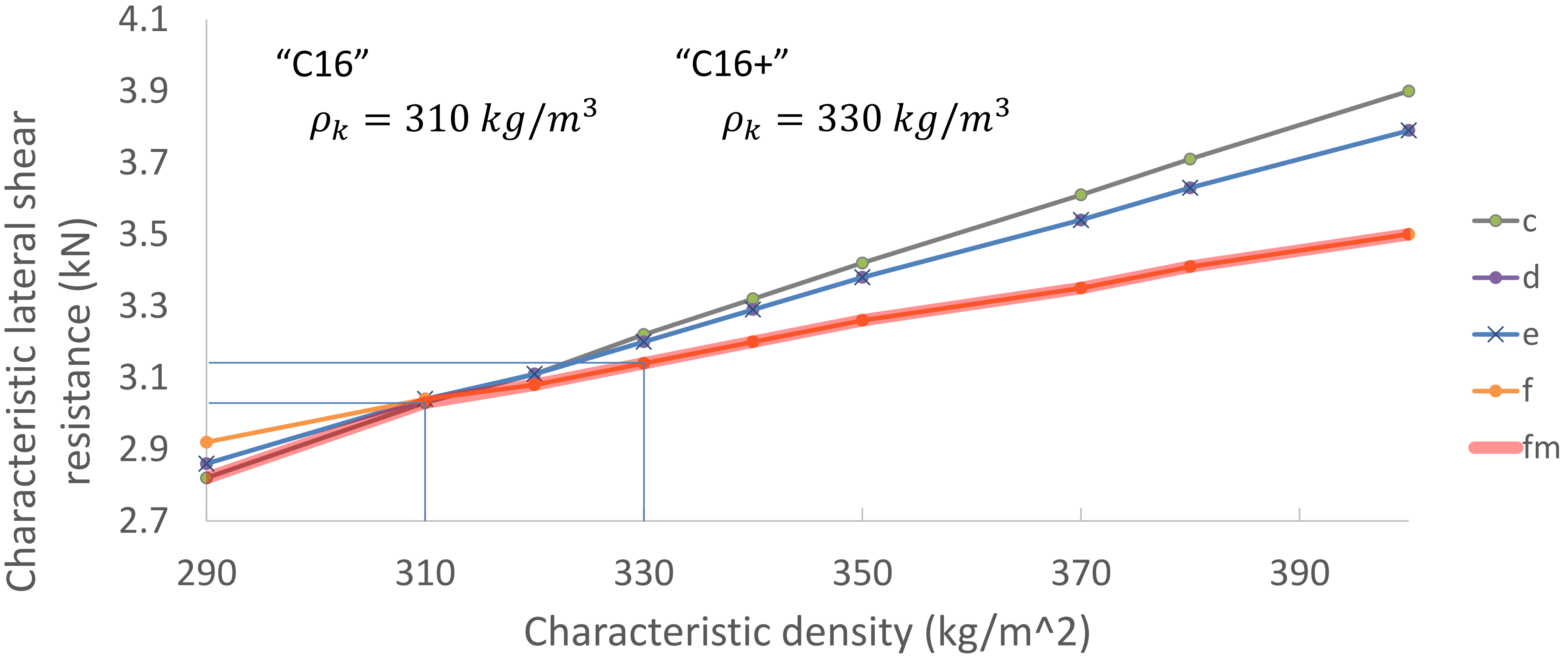
Fixings: M6 Grade 6.8 Bolt

$$F_{v.Rk} = \min(\cancel{F_{v.Rk.a}}, \cancel{F_{v.Rk.b}}, F_{v.Rk.c}, F_{v.Rk.d}, F_{v.Rk.e}, F_{v.Rk.f})$$



Fixings: M6 Grade 6.8 Bolt

$$F_{v.Rk} = \min(F_{v.Rk.a}, F_{v.Rk.b}, F_{v.Rk.c}, F_{v.Rk.d}, F_{v.Rk.e}, F_{v.Rk.f})$$



Fixings: M6 Grade 6.8 Bolt

Uplift of 3.6% to 4% Depending on the diameter of the fixing.

11) Summary

11 Summary

1. The strength and stiffness of the connectors in a system are critical when considering the overall strength and serviceability criteria of a structure.

2. The specification of connection details can be based on test results or approved design standards

3. The specification of the fixing will depend on a range of factors; nature of the forces being applied and their magnitude, practicality and/or manufacturability, aesthetics, environmental conditions and cost

4. The design of dowel type connections to Eurocode 5 is based on theories developed by Johansen.
   - The bending capacity of the dowel or yield moment.
   - The embedding strength of the timber or wood-based material.
   - The withdrawal strength of the dowel

Edinburgh Napier
UNIVERSITY

Institute
for
Sustainable
Construction

The Queen's
Anniversary Prizes
For Higher and Further Education
2015

Centre for
Offsite Construction +
Innovative Structures