Timber connections
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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.

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**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
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) Hexagonal head bolt

(c) A modern self-drilling wood screw

(b) Nail

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 $500\text{kg/m}^3$.

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

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

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

\[(t - t_2) > 4d\]
7.2 Embedment Strength test

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

$$f_{th} = \frac{F_{\text{max}}}{d \cdot t}$$  

(EN 383 eq. 2)

Where:

$F_{\text{max}}$ 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

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

Where:  
$\rho_k$ 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, $f_{h,2,k}$, to the characteristic embedment strength of member 1, $f_{h,1,k}$, is derived and written as:

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

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

\[
F_{ax.Rk} = \min \left\{ f_{ax,k} \cdot d \cdot t_{pen}, f_{head,k} \cdot d_h^2 \right\}
\]  

(EC5 eq. 8.23)

For smooth nails

\[
F_{ax.Rk} = \min \left\{ f_{ax,k} \cdot d \cdot t_{pen}, f_{ax,k} \cdot d \cdot t + f_{head,k} \cdot d_h^2 \right\}
\]  

(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 $12 \cdot d$

\[
f_{ax,k} = 20 \cdot 10^{-6} \cdot \rho_k^2 \quad \text{(EC5 eq. 8.25)}
\]

\[
f_{head,k} = 70 \cdot 10^{-6} \cdot \rho_k^2 \quad \text{(EC5 eq. 8.26)}
\]

Where:

$\rho_k$ 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 $t_{pen} < 12 \cdot d$ the withdrawal capacity multiplied by

\[
\frac{t_{pen}}{4 \cdot d - 2}
\]

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

when $t_{pen} < 8 \cdot d$ the withdrawal capacity multiplied by

\[
\frac{t_{pen}}{2 \cdot d - 3}
\]
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](image1.png)

![Failure mode b](image2.png)
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”.

\[ F_{v,Rk} \]

\[ N_d \]

Timber member

Dowel in single shear, fastener fully yields
7.5 Lateral load carrying capacity of metal dowel type fasteners to EC5

\[ F_{v,Rk} = \text{friction factor} + \text{johansen yield load} + \text{Rope effect} \]

Friction factor:

<table>
<thead>
<tr>
<th>Values used</th>
<th>failure modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% fastener partially yields</td>
<td>(d) (e) (j)</td>
</tr>
<tr>
<td>15% fastener fully yields</td>
<td>(f) (k)</td>
</tr>
</tbody>
</table>
7.5 Lateral load carrying capacity of metal dowel type fasteners to EC5

\[ F_{v,Rk} = \text{friction factor} + \text{johansen yield load} + \text{Rope effect} \]

\[ [1] = \text{friction factor} + \text{johansen yield load} \]

\[ \text{Limiting percentage (Lp)} = \begin{cases} 
15\% \text{ Round nails} \\
25\% \text{ Square nails} \\
50\% \text{ Other nails} \\
100\% \text{ Screws} \\
25\% \text{ Bolts} \\
0\% \text{ Dowels} 
\end{cases} \]

\[ \text{Rope effect} = \min \left( \frac{[1] + \frac{F_{ax,Rk}}{4}}{[1] + Lp\%} \right) \]

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

\[ F_{v,Rk} = \min \]

(a) \[ F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d \]

(b) \[ F_{v,Rk} = f_{h,2,k} \cdot t_2 \cdot d \]

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

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

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

(f) \[ F_{v,Rk} = 1.15 \frac{2\beta}{1 + \beta} \sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \frac{F_{ax,Rk}}{4} \]
7.5.1 Single shear - failure modes and associated equations

Failure mode a

\[ F_{v,Rk} = f_{h,3,k} \cdot t_1 \cdot d \]
7.5.1 Single shear - failure modes and associated equations

Failure mode b

\[ F_{v,Rk} = f_{h,2,k} \cdot t_2 \cdot d \]
7.5.1 Single shear - failure modes and associated equations

\[ F_{v,Rk} = \frac{f_{h,1,k} \cdot t_1 \cdot d}{1+\beta} \left[ \sqrt{\beta + 2\beta^2 \left(1+\frac{t_2}{t_1}\right) + \beta^3 \left(\frac{t_2}{t_1}\right)^2} - \beta \left(1+\frac{t_2}{t_1}\right) \right] + \frac{F_{ax,Rk}}{4} \]
7.5.1 Single shear - failure modes and associated equations

Failure mode d, fastener partially yields

\[ F_{v,Rk} = 1.05 \frac{f_{h,1,k} \cdot t_1 \cdot d}{2 + \beta} \left( \sqrt{2\beta(1+\beta) + \frac{4\beta(2+\beta)M_{y,Rk}}{f_{h,1,k} \cdot t_1^2 \cdot d}} - \beta \right) + \frac{F_{ax,Rk}}{4} \]
7.5.1 Single shear - failure modes and associated equations

Failure mode e, fastener partially yields

\[
F_{y,\text{Rk}} = 1.05 \frac{f_{h,1,k} \cdot t_2 \cdot d}{1+2\beta} \left[ \sqrt{2\beta^2 (1+\beta) + \frac{4\beta (1+2\beta) M_{y,\text{Rk}}}{f_{h,1,k} \cdot t_2^2 \cdot d}} - \beta \right] + \frac{F_{\text{ax,\text{Rk}}}}{4}
\]
7.5.1 Single shear - failure modes and associated equations

Failure mode f,
fastener fully yields

\[ F_{v,R_k} = 1.15 \sqrt{\frac{2\beta}{1+\beta}} \sqrt{2M_{y,R_k} \cdot f_{n,1,k} \cdot d} + \frac{F_{ax,R_k}}{4} \]
7.5.1 Single shear - failure modes and associated equations

\[
F_{v,Rk} = \min
\]

(a) \[F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d\]

(b) \[F_{v,Rk} = f_{h,2,k} \cdot t_2 \cdot d\]

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

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

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

(f) \[F_{v,Rk} = 1.15 \frac{2 \beta}{1 + \beta} \sqrt{2 M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \frac{F_{ax,Rk}}{4}\]
7.5.2 Double shear - failure modes and associated equations

\[
F_{v,Rk} = \min \begin{cases}
F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d \\
F_{v,Rk} = 0.5 \cdot f_{h,2,k} \cdot t_2 \cdot d \\
F_{v,Rk} = 1.05 \frac{f_{h,1,k} \cdot t_1 \cdot d}{2 + \beta} \left[ \sqrt{2 \beta (1 + \beta)} + \frac{4 \beta (2 + \beta) M_{y,Rk}}{f_{h,1,k} \cdot t_1^2 \cdot d} - \beta \right] + \frac{F_{ax,Rk}}{4} \\
F_{v,Rk} = 1.15 \sqrt{\frac{2 \beta}{1 + \beta}} \sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \frac{F_{ax,Rk}}{4}
\end{cases}
\]
7.5.2 Double shear - failure modes and associated equations

Failure mode g

\[ F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d \]
7.5.2 Double shear - failure modes and associated equations

```
F_{v, Rk} = 0.5 \cdot f_{h, 2, k} \cdot t_2 \cdot d
```
7.5.2 Double shear - failure modes and associated equations

Failure mode j, fastener partially yields

\[ F_{v,Rk} = 1.05 \frac{f_{h,1,k} \cdot t_1 \cdot d}{2 + \beta} \left[ \sqrt{2\beta(1 + \beta) + \frac{4\beta(2 + \beta)M_{y,Rk}}{f_{h,1,k} \cdot t_1^2 \cdot d}} - \beta \right] + \frac{F_{ax,Rk}}{4} \]
7.5.2 Double shear - failure modes and associated equations

Failure mode k, fastener fully yields

\[ F_{v,Rk} = 1.15 \sqrt{\frac{2\beta}{1+\beta}} \sqrt{2M_{y,Rk} \cdot f_{n,1,k} \cdot d + \frac{F_{ax,Rk}}{4}} \]
7.5.2 Double shear - failure modes and associated equations

\[ F_{v,Rk} = \min \]

\[ F_{v,Rk} = f_{h,1,k} \cdot t_1 \cdot d \]  (g)

\[ F_{v,Rk} = 0.5 \cdot f_{h,2,k} \cdot t_2 \cdot d \]  (h)

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

\[ F_{v,Rk} = 1.15 \frac{2\beta}{1 + \beta} \sqrt{2M_{y,Rk} \cdot f_{h,1,k} \cdot d} + \frac{F_{ax,Rk}}{4} \]  (k)
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 parallel 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)
8.2 Load Slip

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

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

Typical load slip curves (Racher, 2001)
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)

<table>
<thead>
<tr>
<th>Fastener type</th>
<th>$K_{ser}$ (N/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nails without predrilling</td>
<td></td>
</tr>
<tr>
<td>Small wood screws ($d \leq 6\text{mm}$) without predrilling</td>
<td>$\rho_m^{1.5}d^{0.8}/30$</td>
</tr>
<tr>
<td>Wood screws with predrilling</td>
<td></td>
</tr>
<tr>
<td>Bolts</td>
<td>$\rho_m^{1.5}d/23$</td>
</tr>
<tr>
<td>Dowels</td>
<td></td>
</tr>
<tr>
<td>Split ring and shear plate plate connectors</td>
<td>$\rho_md/2$</td>
</tr>
<tr>
<td>Toothed plate connectors</td>
<td>$\rho_md/2.67$</td>
</tr>
</tbody>
</table>

Notes:
- $\rho_m$ = 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 $\rho_{m} = \sqrt[6]{\rho_{m,1} \rho_{m,2}}$.
- For steel-to-timber or concrete-to-timber connections use $\rho_m$ 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°

"C16"
\[ \rho_k = 310 \, kg/m^3 \]

"C16+"
\[ \rho_k = 330 \, kg/m^3 \]

Fixings:
- M6 Grade 6.8 Bolt
- 3.1mm ringshank nail
\[ F_{v,Rk} = \min(F_{v,Rk.a}, F_{v,Rk.b}, F_{v,Rk.c}, F_{v,Rk.d}, F_{v,Rk.e}, F_{v,Rk.f}) \]
Characteristic lateral shear resistance $F_{v,Rk}$ can be calculated as:

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

The graph shows the relationship between the characteristic lateral shear resistance (kN) and the characteristic density (kg/m$^2$), with different lines representing different conditions. The fixings used are M6 Grade 6.8 Bolt.
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.