DOWELLED CONNECTIONS

TABLE OF CONTENTS

1 General ................................................................. 2
2 Material properties .................................................... 2
3 Loading ........................................................................... 4
4 Laterally loaded dowels ................................................... 4
  4.1 Timber-to-timber connections ..................................... 5
  4.2 Panel-to-timber connections ....................................... 5
  4.3 Steel-to-timber connections ........................................ 6
  4.4 Effective number of fasteners ..................................... 6
5 Multiple shear plane connections .................................... 7
6 Block shear failure .......................................................... 8
  6.1 Timber failure capacity of joint area ............................. 8
    6.1.1 Capacity of inner part lamellas ............................ 8
    6.1.2 Capacity of the edge part of lamellas ................... 9
  6.2 Connection forces at an angle to the grain ..................... 10
  6.3 Alternative dimensioning method .............................. 11
7 Steel plates ..................................................................... 12
  7.1 Tension strength ....................................................... 12
  7.2 Embedment strength ............................................... 12
  7.3 Block tearing .......................................................... 12
8 Fastener spacings and edge and end distances .................. 13
9 Allowed tolerances of dowelled connections ..................... 17
10 Bibliography .............................................................. 17
Endnotes ............................................................................. 17
1. GENERAL

The dowel diameter should be greater than 6 mm and less than 30 mm. Dowel holes $D$ in timber members should have a diameter of $0.95d \leq D \leq d$. If the end of the dowel is left inside the timber and the holes are not drilled through then the drill depth tolerance is $-0$ / $+5$ mm. The end of the dowel can be bevelled to make installation easier. The bevel is usually 2 mm. Allowed tolerances are shown in Table 6.

Dowel holes in steel plates should have a diameter no more than 1 mm or $1.1d$ (whichever is greater). Steel plates can be drilled with 2 mm bigger holes than the dowel if:

$$t_1 \text{ and } t_2 \geq 2 \cdot \sqrt[4]{\frac{M_y}{f_{h,k}}}$$

$$t_s \geq 4 \cdot \sqrt[4]{\frac{M_y}{f_{h,k}}}$$

where: the connection uses the thin steel plate ($t_t \leq 0.5d$) equations

$t_1$ and $t_2$ are the thicknesses of outer timber members

$t_s$ is the thickness of the inner member in double shear connection

$M_y$ is the characteristic fastener yield moment, equation (5)

$d$ is the fastener diameter, in mm

$f_{h,k}$ is the characteristic embedment strength in the timber member, equation (4)

Tie bolts should be used in dowelled connections. The amount of tie bolts should be at least one tenth of the amount of dowels in the connection. At least one tie bolt should be installed in the closest row to the end of the side member. Tie bolts may be used for lateral loads if they are unthreaded within the connection area and they have the same diameter and grade as the dowels.

After assembly the timber in the connection should not dry by over 5% of its weight.

In practice we recommend using 2 mm shorter dowels than the total thickness of the members in the connection. This shortening should be taken into account in the design.

2. MATERIAL PROPERTIES

The calculation method for steel dowels presented in this guide is valid only for dowels with diameter $d \leq 24$ mm and ultimate tensile strength $f_{u,k} \leq 800$ N/mm$^2$ (class 8.8). In addition, the timber thickness of side members $t_1$ and $t_2$ should be at least $4d$ and in dual or multi shear plane connections the timber thickness of inner members $t_s$ should be at least $5d$.

In this guide timber means solid timber, glued laminated timber, Kerto-S and Kerto-T. Due to its cross-veneers, Kerto-Q has better splitting resistance when compared to other timber when used in flatwise connections.

Wood-based panels should be CE-marked in accordance with EN 13986 (plywood, particleboard, OSB-board, medium fibreboard and hard fibreboard) or they should have a local type approval or statement/certificate from an institution approved by local building authorities that covers their use as load-bearing structures.
Table 1: Strength modification factors for service classes and load-duration classes $k_{mod}$ and partial factors $\gamma_M$ for material properties and resistances.\(^2\)

**STRENGTH MODIFICATION FACTORS FOR SERVICE CLASSES AND LOAD-DURATION CLASSES $k_{mod}$**

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>SERVICE CLASS</th>
<th>LOAD-DURATION CLASS</th>
<th>PERMANENT ACTION</th>
<th>LONG TERM ACTION</th>
<th>MEDIUM TERM ACTION</th>
<th>SHORT TERM ACTION</th>
<th>INSTANTANEOUS ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid timber, round timber, glued laminated timber, Kerto LVL plywood</td>
<td>1</td>
<td></td>
<td>0.60</td>
<td>0.70</td>
<td>0.80</td>
<td>0.90</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>0.60</td>
<td>0.70</td>
<td>0.80</td>
<td>0.90</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td>0.50</td>
<td>0.55</td>
<td>0.65</td>
<td>0.70</td>
<td>0.90</td>
</tr>
<tr>
<td>Particleboard EN 312-4* and -5, OSB/2*, Hard fibreboard</td>
<td>1</td>
<td></td>
<td>0.30</td>
<td>0.45</td>
<td>0.65</td>
<td>0.85</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>0.20</td>
<td>0.30</td>
<td>0.45</td>
<td>0.60</td>
<td>0.80</td>
</tr>
<tr>
<td>Particleboard EN 312-6* and -7, OSB/3, OSB/4</td>
<td>1</td>
<td></td>
<td>0.40</td>
<td>0.50</td>
<td>0.70</td>
<td>0.90</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>0.30</td>
<td>0.40</td>
<td>0.22</td>
<td>0.70</td>
<td>0.90</td>
</tr>
<tr>
<td>Medium fibreboard: MBH, LA*, MDF, HLS MDF, LA* and MDF, HLS</td>
<td>1</td>
<td></td>
<td>0.20</td>
<td>0.40</td>
<td>0.60</td>
<td>0.80</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.45</td>
<td>0.80</td>
<td></td>
</tr>
</tbody>
</table>

Partial factors $\gamma_M$ (EN 1995 recommended values and the Finnish NA values)

Fundamental combinations:
- Solid and Round timber in general
- Softwood structural timber, strength class ≥ C35
- Kerto LVL
- Glued laminated timber
- Plywood, OSB
- Particle- and fibreboards
- Connections
- Accidental combination

<table>
<thead>
<tr>
<th>MARKING</th>
<th>VALUE (EN 1993)</th>
<th>VALUE FI: NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{M0}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$\gamma_{M1}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$\gamma_{M2}$</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>$\gamma_{M3}$</td>
<td>1.25</td>
<td>1.25</td>
</tr>
<tr>
<td>$\gamma_{M3,ser}$</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>$\gamma_{M4}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$\gamma_{M5}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$\gamma_{M6,ser}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>$\gamma_{M7}$</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>$\gamma_{M8}$</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 2: In EN 1993-1-1, EN 1993-1-2 and EN 1993-1-8 the following partial factors are used according to EN 1993 recommended values and FI NA for structural members, cross sections and connections.

Steel plates need to be predrilled structural steel.

Dowelled connections can be done by through drilling the holes to timber members and pre-set steel plates. The design of this kind of connection is not covered in this guide.

Dowels and steel plates should, where necessary, either be inherently corrosion-resistant or be protected against corrosion.

Table 3: The minimum specifications for material protection against corrosion for fasteners. Electroplated zinc coating Fe/Zn classes are according to ISO 2081 and hot-dip coating Z classes according to EN 10346.\(^3\) Stainless steel according to EN 10088-1 (grades 1.4401, 1.4301 and 1.4310).\(^4\)

<table>
<thead>
<tr>
<th>FASTENER</th>
<th>SERVICE CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dowels</td>
<td>1</td>
</tr>
<tr>
<td>Steel plates up to 3 mm thickness</td>
<td>Fe/Zn 12c, Z275</td>
</tr>
<tr>
<td>Steel plates from 3 mm up to 5 mm in thickness</td>
<td>Fe/Zn 12c, Z275</td>
</tr>
<tr>
<td>Steel plates over 5 mm thickness</td>
<td>Fe/Zn 25c, Z350</td>
</tr>
</tbody>
</table>

\(^2\) Can only be used in service class 1

\(^3\) Stainless steel according to EN 10088-1 (grades 1.4401, 1.4301 and 1.4310)
3. LOADING

Dowels can be loaded only laterally. Reductions in cross section should be taken into account when analysing capacity of timber members.

In compressed Kerto-to-Kerto joints, 2/3 of the perpendicular compression force can be transferred directly through contact from member to member. If the contact surfaces have been CNC-machined, 3/4 of the perpendicular compression force can be transferred directly through contact from member to member. Splitting of the compressed side in sloped connections, such as ridge connections, should be prevented by shaping the end of the member or installing a hard fibreboard or steel plate with a height of about 3/4 of the total height of the connection.

4. LATERALLY LOADED DOWELS

When calculating the lateral load-capacity of the connection, the capacity of fasteners and block shear in the timber member should be checked. See Figure 1.

The design capacity of connection:

\[ R_d = \frac{k_{\text{mod}} \cdot R_k}{\gamma_M} \]  

where:  
- \( k_{\text{mod}} \) is the modification factor for duration of load and moisture content  
- \( \gamma_M \) is the partial factor for connection resistance

When connecting two different materials the smallest value of \( k_{\text{mod}} / \gamma_M \) should be used.

Figure 1: Laterally loaded connection
4.1 TIMBER-TO-TIMBER CONNECTIONS

The characteristic load-carrying capacity for a fastener per shear plane:

\[
R_k = \min \left\{ \frac{0.32 \cdot f_{h,k} \cdot t_u \cdot d}{1 + \frac{3 \cdot M_y}{f_{h,k} \cdot d \cdot t_u}}, \frac{1.6 \cdot \sqrt{M_y \cdot f_{h,k} \cdot d}}{t_u} \right\} \quad (2)^6
\]

where:

\[
t_u = \min \left( \frac{t_1 \cdot f_{h,1,k}}{f_{h,k}}, \frac{t_2 \cdot f_{h,2,k}}{f_{h,k}} \right) \quad (3)^7
\]

\[
f_{h,k} = \min \left( f_{h,1,k}, f_{h,2,k}, f_{h,3,k} \right) \quad (4)^8
\]

\[
t_1 \text{ and } t_2 \text{ are the timber thicknesses or penetration depths of outer member}
\]

\[
f_{h,1,k} \text{ and } f_{h,2,k} \text{ are the characteristic embedment strengths of outer timber members}
\]

\[
f_{h,3,k} \text{ is the characteristic embedment strength of inner timber member in a two shear plane connection}
\]

\[
d \text{ is the fastener diameter}
\]

The characteristic value for the yield moment:

\[
M_y = 0.3 \cdot f_{u,k} \cdot d^2.6 \quad [\text{Nm}]
\]

where:

\[
f_{u,k} \text{ is the characteristic tensile strength, in N/mm}^2
\]

\[
d \text{ is the fastener diameter, in mm}
\]

The characteristic embedment strength, at an angle \( \alpha \) to the grain:

\[
f_{h,\alpha,k} = \frac{f_{h,0,k}}{k_{90} \cdot \sin^2 \alpha + \cos^2 \alpha} \quad [\text{N/mm}^2]
\]

where:

\[
f_{h,0,k} = \begin{cases} 0.082 \cdot (1 - 0.01d) \cdot \rho_k & \text{In general} \\ 37 \cdot k_Q \cdot (1 - 0.01d) & \text{for Kerto-}\text{-Q} \end{cases} \quad [\text{N/mm}^2] \quad (7)^{11}
\]

\[
k_Q = \begin{cases} 1 & \text{for flatwise connections} \\ 1 - \frac{2}{d} \leq 0.87 & \text{for edgewise connections} \end{cases} \quad [-] \quad (8)^{12}
\]

\[
f_{h,45,k} = f_{h,45,k} \quad \text{when } 45° \leq \alpha \leq 90°
\]

\[
\rho_k \text{ is the characteristic timber density, in kg/m}^3
\]

\[
d \text{ is the fastener diameter, in mm}
\]

\[
\alpha \text{ is the angle of the load to the grain}
\]

4.2 PANEL-TO-TIMBER CONNECTIONS

When the thickness of a wood based panel is larger than the limit set out in equation (10), then the characteristic loading capacity of panel-to-timber connections should be calculated with the equations for timber-to-timber connections.

\[
t_{\text{panel}} \geq \frac{80 \cdot d}{f_{h,\text{panel},k}} \quad [\text{mm}]
\]

where:

\[
f_{h,\text{panel},k} \text{ is the characteristic embedment strength of panel, in N/mm}^2
\]

\[
d \text{ is the fastener diameter, in mm}
\]

For plywood the following embedment strength should be used for all angles to face grain:

\[
f_{h,\text{panel},k} = 0.11 \cdot (1 - 0.01d) \cdot \rho_k \quad [\text{N/mm}^2]
\]

where:

\[
\rho_k \text{ is the characteristic density of plywood, in kg/m}^3
\]

\[
d \text{ is the fastener diameter, in mm}
\]

For particleboard and OSB the following embedment strength should be used for all loading directions:

\[
f_{h,k} = 50 \cdot d^{-0.6} \cdot t^{-0.2} \quad [\text{N/mm}^2]
\]

where:

\[
d \text{ is the fastener diameter, in mm}
\]

\[
t \text{ is the panel thickness, in mm}
\]
4.3 STEEL-TO-TIMBER CONNECTIONS

The capacity of steel plate should be checked according to EN 1993.

In compressed steel plate connections the buckling length of $0.8L_a$ can generally be used for outside plates, where $L_a$ is the distance between the first fasteners at opposite sides of the connection. The buckling does not need to be taken into account for steel plates installed inside a timber member if the expansion of timber members is prevented, for example, by using tie bolts and limiting the size of the slot for the steel plate to maximum of $1.25t_f$.

The drying shrinkage perpendicular to the grain direction should be taken into account with steel-to-timber connections.

It should also be taken into account that the load-carrying capacity of steel-to-timber connections with a loaded end may be reduced by failure along the perimeter of the fastener group. There are two types of loaded end failures: block shear and plug shear failure.

The characteristic load-carrying capacity for a thin steel plate, with $t_t \leq 0.5d$, in single shear:

$$R_k = \min \left\{ \frac{0.32 \cdot f_{h,k} \cdot t \cdot d}{1.6 \cdot \sqrt{M_y \cdot f_{h,k} \cdot d}} \right\}$$ (13)

The characteristic load-carrying capacity for a thick steel plate, with $t_t \geq d$, in single shear:

$$R_k = \min \left\{ \frac{0.8 \cdot f_{h,k} \cdot t \cdot d}{1.04 \cdot f_{h,k} \cdot d \cdot \left( 2 + \frac{4 \cdot M_y}{f_{h,k} \cdot d \cdot t^2} - 1 \right)} \right\}$$ (14)

where: $f_{h,k}$ is the characteristic embedment strength of the timber member, equation (4)
$t$ is the thickness of the timber member
$d$ is the fastener diameter
$M_y$ is the characteristic fastener yield moment, equation (5)

The characteristic load-carrying capacity of connections with steel plate thickness between a thin and thick plate, where $0.5d < t_t < d$, should be calculated by linear interpolation between equations (13) and (14).

The characteristic load-carrying capacity for a steel plate of any thickness as the central member of a double shear connection should be calculated with equation (14) where $t$ is the smaller thickness of the timber side member.

The characteristic load-carrying capacity for steel plates as the outer member of double shear connection:

$$R_k = \min \left\{ \begin{array}{ll}
0.4 \cdot f_{h,k} \cdot t \cdot d & \text{for } t_t \leq 0.5d \\
1.6 \cdot \sqrt{M_y \cdot f_{h,k} \cdot d} & \text{for } t_t \geq d \\
2.4 \cdot \sqrt{M_y \cdot f_{h,k} \cdot d} & \text{for } 0.5d < t_t < d 
\end{array} \right\}$$ (15)

4.4 EFFECTIVE NUMBER OF FASTENERS

For one row of $n$ fasteners parallel to the grain direction, the load-carrying capacity parallel to the grain should be calculated using the effective number of fasteners $n_{ef}$:

$$n_{ef} = \min \left\{ \begin{array}{l}
n_t \\
0.9 \sqrt{\frac{a \cdot t}{50 \cdot d^2}}
\end{array} \right\}$$ (16)

where: $n_t$ is the number of fasteners in the row $i$
$d$ is the fastener diameter
$a$ is the spacing of fasteners in the direction of the grain
$M_y$ is the characteristic fastener yield moment, equation (5)
$t_t$ is the end distance of fasteners
$M_y$ is the characteristic fastener yield moment, equation (5)

$t_1$ and $t_2$ are the thicknesses of outer timber members, these should be discarded if the outer member is not timber

$t_i$ is the thickness of the inner member of double shear connection or the smallest thickness of an inner member of a multiple shear connection

$t_t$ is the thickness of the central member of a double shear connection.

The drying shrinkage perpendicular to the grain direction should be taken into account with steel-to-timber connections.

It should also be taken into account that the load-carrying capacity of steel-to-timber connections with a loaded end may be reduced by failure along the perimeter of the fastener group. There are two types of loaded end failures: block shear and plug shear failure.

The characteristic load-carrying capacity for a thin steel plate, with $t_t \leq 0.5d$, in single shear:

$$R_k = \min \left\{ \frac{0.32 \cdot f_{h,k} \cdot t \cdot d}{1.6 \cdot \sqrt{M_y \cdot f_{h,k} \cdot d}} \right\}$$ (13)

The characteristic load-carrying capacity for a thick steel plate, with $t_t \geq d$, in single shear:

$$R_k = \min \left\{ \frac{0.8 \cdot f_{h,k} \cdot t \cdot d}{1.04 \cdot f_{h,k} \cdot d \cdot \left( 2 + \frac{4 \cdot M_y}{f_{h,k} \cdot d \cdot t^2} - 1 \right)} \right\}$$ (14)

where: $f_{h,k}$ is the characteristic embedment strength of the timber member, equation (4)
$t$ is the thickness of the timber member
$d$ is the fastener diameter
$M_y$ is the characteristic fastener yield moment, equation (5)
5. MULTIPLE SHEAR PLANE CONNECTIONS

In multiple shear plane connections the resistance of each shear plane should be determined by assuming that each shear plane is part of a series of three-member connections. The total capacity of multiple shear connections is obtained by multiplying the smallest per shear capacity by the number of shear planes, see Figure 2.

\[
R_{v,d} = 2R_{1,d} \\
R_{v,d} = 4 \min\{R_{1,d}; R_{2,d}\} \\
R_{v,d} = 6 \min\{R_{1,d}; R_{2,d}; R_{3,d}\}
\]

Figure 2: Calculating the connection capacity of a multiple shear plane steel plate connection. \(R_{1,d}\) is the capacity per shear of a two shear plane timber-steel-timber (\(t_u\)-steel-\(t_u\)) connection, \(R_{2,d}\) is the capacity per shear of a two shear plane steel-timber-steel (\(t_u\)-\(t_s\)-\(t_u\)) connection and \(R_{3,d}\) represents the capacity per shear of a two shear plane timber-steel-timber (\(t_s\)-steel-\(t_s\)) connection.\(^{24}\)
6. BLOCK SHEAR FAILURE

6.1 TIMBER FAILURE CAPACITY OF JOINT AREA

The effective number of fasteners is taken into account in the following equations. This method can be used for Kerto-S, Kerto-Q, Kerto-T used flatwise and glued laminated timber.

To take into account the possibility of splitting or shear or tension failure of the joint caused by the force component parallel to grain $F_{0,Ed}$ the following expression should be satisfied:

$$ F_{0,Ed} \leq F_{0,Rd} = \frac{k_{mod}}{\gamma_M} F_{0,Rk} $$

(19)

The characteristic timber failure capacity of the joint area:

where: $F_{0,Rk} = \sum_{i=1}^{m} F_{i,0,Rk}$

(20)

where $F_{i,0,Rk}$ is the timber failure capacity for lamella $i$ of the timber member calculated according to equation (21) and $m$ is the number of joint lamellas in the timber member.

Timber failure capacity for the lamella $i$ should be takes as:

$$ F_{i,0,Rk} = F_{ip,Rk} + F_{ep,Rk} $$

(21)

6.1.1 CAPACITY OF INNER PART LAMELLAS

The capacity of inner part lamellas:

$$ F_{ip,Rk} = \begin{cases} \min \left( A_{ip} \cdot f_{h,0,k} \cdot F_{v,k} \right) & \text{in tension joints} \\ \min \left( A_{ip} \cdot f_{h,0,k} \cdot F_{v,k} \right) & \text{in compression joints} \end{cases} $$

(22)

where: $f_{h,0,k}$ is the embedment strength of timber parallel to grain

$$ A_{ip} = (n - n_1) \cdot d \cdot t_i $$

(23)

$$ F_{v,k} = F_{v,k} + (n_2 - 1) \cdot d \cdot t_{ef,j} \cdot f_{h,0,k} $$

(24)

$$ F_{v,k} = \begin{cases} F_{v,k} \left( 1 - 0.3 \cdot \frac{F_{ip}}{F_{v,k}} \right) & \text{, when } F_{ip} \leq F_{v,k} \\ F_{v,k} \left( 1 - 0.3 \cdot \frac{F_{v,k}}{F_{ip}} \right) & \text{, when } F_{ip} > F_{v,k} \end{cases} $$

(25)

$$ F_{ip} = \begin{cases} 1.7 \cdot n_1^{0.1} \cdot A_{ip} \cdot f_{h,0,k} & \text{for Kerto-LVL} \\ 2.0 \cdot n_1^{0.1} \cdot A_{ip} \cdot f_{h,0,k} & \text{for glued laminated timber} \end{cases} $$

(26)

$$ F_{v,k} = k_v \cdot n_1^{0.1} \cdot A_{v,ip} \cdot f_{v,k} $$

(27)

$n$ is the number of fasteners

$n_1$ is the mean number of fasteners in the rows parallel to grain $(n_1=n/n_2)$

$d$ is the fastener diameter

$t_i$ is the lamella thickness ≤ penetration of the fastener

$n_2$ is the maximum number of fasteners in the fastener rows perpendicular to grain

$f_{t,0,k}$ is the tension strength of the timber member

<table>
<thead>
<tr>
<th>$f_{t,0,k}$</th>
<th>4.1 N/mm²</th>
<th>for flatwise Kerto-S connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{t,0,edge,k}$</td>
<td>4.5 N/mm²</td>
<td>for edgewise Kerto-S connections</td>
</tr>
<tr>
<td>$f_{t,0,flat,k}$</td>
<td>2.3 N/mm²</td>
<td>for flatwise Kerto-Q connections</td>
</tr>
<tr>
<td>$f_{t,0,edge,k}$</td>
<td>2.4 N/mm²</td>
<td>for edgewise Kerto-Q connections</td>
</tr>
<tr>
<td>$f_{t,0,flat,k}$</td>
<td>1.3 N/mm²</td>
<td>for flatwise Kerto-T connections</td>
</tr>
</tbody>
</table>

$f_{v,0,k}$ is the shear strength of the timber member

$$ f_{v,0,k} = \begin{cases} 0.68 \cdot d \cdot \sqrt{\frac{f_y}{f_{h,0,k}}} \leq t_i & \text{for side lamellas} \\ 1.63 \cdot d \cdot \sqrt{\frac{f_y}{f_{h,0,k}}} \leq t_i & \text{for middle lamellas} \end{cases} $$

(29)

$$ A_{ip} = (n_2 - 1) \cdot (a_2 - d) \cdot t_i $$

(30)

$$ A_{ip} = 2 \cdot (n_2 - 1) \cdot (a_1 + a_3) \cdot t_{ef,j} $$

(31)

$f_y$ is the yield strength of the fastener

$a_1$ is the fastener spacing parallel to the grain

$a_2$ is the fastener spacing perpendicular to the grain

$a_3$ is the fastener end distance
6.1.2 CAPACITY OF THE EDGE PART OF LAMELLAS

The capacity of the edge part of lamellas:

$$F_{s,ip} = \begin{cases} 
\min(A_{s,ip} \cdot f_{k,0,0} ; F_{s,k} ; F_{v,k}) & \text{in tension joints} \\
\min(A_{s,ip} ; F_{s,k}) & \text{in compression joints} 
\end{cases}$$  \(32\)

where:

$$A_{s,ip} = n_1 \cdot d \cdot t_i$$  \(33\)

$$F_{s,k} = F_{v,k} + d \cdot t_{ef,i} \cdot f_{k,0,0}$$  \(34\)

$$F_{v,k} = \begin{cases} 
F_{s,k} \cdot \left(1 - 0.3 \frac{F_{s,k}}{F_{v,k}} \right) & \text{when } F_{s,k} \leq F_{v,k} \\
F_{v,k} \cdot \left(1 - 0.3 \frac{F_{v,k}}{F_{s,k}} \right) & \text{when } F_{v,k} < F_{s,k} 
\end{cases}$$  \(35\)

and $F_{v,k}$ is calculated according to equations (25) - (27) with substitutions from equation (36):

$$A_{t,ip} = k_{t,ip} \cdot A_{s,ip} \text{ and } A_{v,ip} = A_{v,ip}$$  \(36\)

where:

$$k_{t,ip} = \frac{2a_4 - d}{t_i}$$  \(37\)

$$A_{s,ip} = 2 \cdot \left((n_1 - 1) \cdot a_1 + a_3\right) \cdot t_{ef,i}$$  \(38\)

$$k_{s,ip} = \frac{1}{1 + \frac{A_{s,ip}}{A_{v,ip}}}$$  \(39\)

and:

$$a_i$$ is the fastener edge distance

The splitting capacities:

$$F_{s,k} = \frac{14n_i^{0.9}}{s_{hole}} \cdot t_{ef,i} \cdot (a_3 - 0.5d) \cdot f_{t,90,k}$$  \(40\)

$$F_{se,k} = \frac{14n_i^{0.9}}{s_{end}} \cdot t_{ef,i} \cdot (a_3 - 0.5d) \cdot f_{t,90,k}$$  \(41\)

where: $f_{t,90,k}$ is the tension strength of timber member

<table>
<thead>
<tr>
<th>Strength</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8 N/mm²</td>
<td>for flatwise Kerto-S connections</td>
<td></td>
</tr>
<tr>
<td>0.4 N/mm²</td>
<td>for edgewise Kerto-S connections</td>
<td></td>
</tr>
<tr>
<td>6.0 N/mm²</td>
<td>for flatwise Kerto-Q connections</td>
<td></td>
</tr>
<tr>
<td>0.4 N/mm²</td>
<td>for edgewise Kerto-Q connections</td>
<td></td>
</tr>
<tr>
<td>0.5 N/mm²</td>
<td>for flatwise Kerto-T connections</td>
<td></td>
</tr>
</tbody>
</table>

$$s_{hole} = \max \left\{ 1, \frac{0.65 a_3}{a_4} \right\}$$  \(42\)

$$s_{end} = \frac{2.7}{\cosh \left( \frac{a_3}{a_4} - 1.4 \right)}$$  \(43\)
6.2 CONNECTION FORCES AT AN ANGLE TO THE GRAIN

When a force in a connection acts at an angle to the grain, see Figure 5, the possibility of splitting caused by the tension force component, \( (F_{Ed} \cdot \sin \alpha) \), perpendicular to grain, shall be taken into account.

For solid timber, glued laminated timber, Kerto-S, Kerto-T and Kerto-Q edgewise, the following expressions shall be satisfied:

\[
F_{v,Ed} \leq F_{90,d}
\]  
\[(44)^{52}\]

where: \( F_{90,d} \) is the design splitting capacity

\[
F_{v,Ed} = \max\left(F_{v,Ed1}; F_{v,Ed2}\right)
\]  
\[(45)^{53}\]

\( F_{v,Ed1} \) and \( F_{v,Ed2} \) are the design shear forces on either side of the connection caused by the connection force component \( (F_{Ed} \cdot \sin \alpha) \) perpendicular to the grain

For softwood, the characteristic splitting capacity:

\[
F_{90,k} = 14 \cdot b \cdot \frac{h_e}{\sqrt{1 - \frac{h_e}{h}}}
\]  
\[(46)^{55}\]

where: 
- \( h_e \) is the loaded edge distance to the centre of the most distant fastener, in mm, see Figure 5
- \( h \) is the timber member height, in mm
- \( b \) is the member thickness, but not more than the penetration depth, in mm

The equation (46) does not need to be checked for flatwise Kerto-Q connections since Kerto-Q when used flatwise is not sensitive to splitting caused by connection forces at an angle to the grain due to the cross-veneers.
6.3 ALTERNATIVE DIMENSIONING METHOD

Timber failure capacity of the joint area can be calculated by the method shown in RIL 205-1-2009 in section 8.2.4S Lohkeamismurto. When using this method, the connection area for splitting and row shear is taken into account by using the effective number of fastener \( n_{ef} \), see equation (16). This method cannot be used for edgewise Kerto connections.

When connection force components are parallel to the grain, the timber failure should be checked at tension loaded member ends. There are two types of timber failure modes: block shear and plug shear. The block and plug shear capacities do not require checking for connections where all the fasteners are in a single row parallel to the grain \( (n_2 = 1) \).

For Steel-to-timber connections with Kerto-Q both block shear and plug shear capacity should be checked.

For dowelled connections, where the amount of fasteners in a row parallel to grain is not more than four and the dowel spacing perpendicular to the grain \( a_2 \geq 4d \), the block shear capacity does not need to be checked.

For dowelled timber-to-timber connection the plug shear capacity does not require checking.

The characteristic block shear capacity of timber member:

\[
F_{bt,k} = L_{net,t} \cdot t_1 \cdot k_{ht} \cdot f_{t,0,k}
\]

(47)

where \( f_{t,0,k} \) is the tension strength of timber member without the size effect

\[
k_{ht} = \begin{cases} 
1.50, & \text{for solid wood and glued laminated timber} \\
1.25, & \text{for Kerto-LVL}
\end{cases}
\]

(48)

\[
L_{net,t} = (n_2 - 1) \cdot (a_2 - D)
\]

(49)

\( n_2 \) is the number of rows perpendicular to the grain
\( a_2 \) is the fastener spacing perpendicular to the grain
\( D \) is the hole diameter
\( t_1 \) is the thickness of the timber member \( (t_1 \leq 2t_{ef}) \)

The characteristic block shear capacity of Kerto-Q member:

\[
F_{bt,k} = \max \left( \frac{L_{net,t} \cdot t_1 \cdot f_{t,0,k} + 0.7 \cdot L_{net,v} \cdot t_1 \cdot f_{v,k}}{D} \right)
\]

(50)

where:
\( f_{v,k} \) is the edgewise shear strength \( (f_{v,0,edge,k} = 4.5 \text{ N/mm}^2) \)

\[
L_{net,v} = 2 \cdot (a_3 + (n_1 - 1) \cdot (a_1 - D))
\]

(51)

\( a_3 \) is the fasteners end distance
\( a_1 \) is the fastener spacing parallel to the grain
\( n_1 \) is the amount of rows parallel to the grain

The characteristic plug shear capacity of a Kerto member:

\[
F_{ps,k} = L_{net,J} \cdot t_{ef} \cdot f_{t,0,k} + (a_3 + (n_1 - 1) \cdot a_1) \cdot f_{v,0,k}
\]

(52)

where:

\[
L_{net,J} = (n_2 - 1) \cdot (a_2 - D)
\]

(53)

\[
t_{ef} = \frac{R_k}{d \cdot f_{t,0,k}}
\]

(54)

\( f_{t,0,k} \) is the shear strength of the timber member

\[f_{t,0,flat,k}\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>flatwise Kerto-S connections</td>
<td>2.3 N/mm²</td>
</tr>
<tr>
<td>flatwise Kerto-Q connections</td>
<td>1.3 N/mm²</td>
</tr>
<tr>
<td>flatwise Kerto-T connections</td>
<td>1.3 N/mm²</td>
</tr>
</tbody>
</table>

\( R_k \) is the characteristic load-carrying capacity per shear plane per fastener

\( f_{t,0,k} \) is the characteristic embedment strength

---

**Figure 6:** a) Block shear b) Plug shear
7. STEEL PLATES

7.1 TENSION STRENGTH

\[
\frac{N_{Ed}}{N_{t,Rd}} \leq 1,0
\]  

(55)

where:  
\(N_{Ed}\) is the tension force design value

\[
N_{t,Rd} = \min \left\{ \frac{N_{pl,Rd}}{N_{u,Rd}} \right\}
\]  

(56)

the design tension capacity for gross area:

\[
N_{pl,Rd} = \frac{A \cdot f_y}{\gamma_{M0}}
\]  

(57)

the design tension capacity for net area

\[
N_{u,Rd} = \frac{0.9 \cdot A_{net} \cdot f_u}{\gamma_{M2}}
\]  

(58)

\(A\) is the gross area of cross-section  
\(A_{net}\) is the net area of cross-section  
\(f_u\) is the ultimate tensile strength  
\(f_y\) is the yield tensile strength  
\(\gamma_{M0}\) and \(\gamma_{M2}\) are the partial factors

7.2 EMBEDMENT STRENGTH

The design embedment strength for a single fastener:

\[
F_{b,Rd} = k_1 \cdot a_b \cdot f_u \cdot d \cdot t
\]  

(59)

where:  
\(a_b = \min \left( \alpha_d; \frac{f_{ub}}{f_u}; 1.0 \right) \)  

(60)

parallel to force:

- for plate’s end fasteners  
\(\alpha_d = \frac{e_1}{3d_0}\)

- others  
\(\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}\)

7.3 BLOCK TEARING

The block tearing design capacity of a steel plate when a symmetrical fastener group has a centric force:

\[
V_{eff,3,Rd} = \frac{f_u \cdot A_{nt}}{\gamma_{M2}} + \frac{f_y \cdot A_{nv} \cdot \sqrt{3}}{\gamma_{M0}}
\]  

(61)

where:  
\(A_{nt}\) is the tension stressed net area of cross-section  
\(A_{nv}\) is the shear stressed net area of cross-section  
\(f_u\) is the ultimate tensile strength  
\(f_y\) is the yield tensile strength  
\(\gamma_{M0}\) and \(\gamma_{M2}\) are the partial factors
8. FASTENER SPACINGS AND EDGE AND END DISTANCES
Figure 7: Minimum spacings and end and edge distances
The fastener spacing parallel to the grain $a_1$ and perpendicular to the grain $a_2$: 

- $a_3,1$ in loaded end
- $a_3,0$ in unloaded end

$\alpha$ is the angle between a force and the grain direction.

$-90^\circ \leq \alpha \leq 90^\circ$ Loaded end
$90^\circ \leq \alpha \leq 270^\circ$ Unloaded end
$0^\circ \leq \alpha \leq 180^\circ$ Loaded edge
$180^\circ \leq \alpha \leq 360^\circ$ Unloaded edge

Figure 8: Fastener spacings and edge and end distances.
Table 4: Dowel minimum spacings and edge and end minimum distances

<table>
<thead>
<tr>
<th>SPACING AND EDGE-END DISTANCE, SEE FIGURE 8</th>
<th>ANGLE</th>
<th>SOLID TIMBER AND GLUED LAMINATED TIMBER</th>
<th>KERTO-S, KERTO-T AND EDGewise KERTO-Q</th>
<th>FLATWISE KERTO-Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_1$</td>
<td>$0° \leq \alpha \leq 360°$</td>
<td>$(3+2</td>
<td>\cos\alpha</td>
<td>)d$</td>
</tr>
<tr>
<td>$a_2$</td>
<td>$0° \leq \alpha \leq 360°$</td>
<td>$3d^{(a)}$</td>
<td>$3d^{(a)}$</td>
<td>$3d^{(a)}$</td>
</tr>
<tr>
<td>$a_{3a}$</td>
<td>$-90° \leq \alpha \leq 90°$</td>
<td>$\max(7dt,80\text{ mm})$</td>
<td>$\max(7dt,105\text{ mm})^{(b)}$</td>
<td>$\max(4dt,60\text{ mm})^{(c)}$</td>
</tr>
<tr>
<td>$a_{3c}$</td>
<td>$90° \leq \alpha \leq 150°$</td>
<td>$3d$</td>
<td>$3d$</td>
<td>$(3+</td>
</tr>
<tr>
<td>$a_{3d}$</td>
<td>$150° \leq \alpha \leq 210°$</td>
<td>$\alpha_{3d} \cdot</td>
<td>\sin\alpha</td>
<td>$</td>
</tr>
<tr>
<td>$a_{3e}$</td>
<td>$210° \leq \alpha \leq 270°$</td>
<td>$3d$</td>
<td>$3d$</td>
<td>$(3+</td>
</tr>
<tr>
<td>$a_{3f}$</td>
<td>$270° \leq \alpha \leq 330°$</td>
<td>$\alpha_{3f} \cdot</td>
<td>\sin\alpha</td>
<td>$</td>
</tr>
<tr>
<td>$a_{3g}$</td>
<td>$330° \leq \alpha \leq 360°$</td>
<td>$\alpha_{3g} \cdot</td>
<td>\sin\alpha</td>
<td>$</td>
</tr>
</tbody>
</table>

(a) Block shear should also be checked in timber connections if $a_2 < 4d$.
(b) For dowels with diameter $d < 15\text{ mm}$, the minimum end distance may be further reduced to $7d$, if the embedment strength $f_{h,0,k}$ is reduced by factor $a_3/(105\text{ mm})$.
(c) For dowels with diameter $d < 15\text{ mm}$, the minimum end distance may be further reduced to $4d$, if the embedment strength $f_{h,0,k}$ is reduced by factor $a_{3d}/(60\text{ mm})$.
(d) The minimum spacing may be further reduced to $5d$ if the embedment strength $f_{h,0,k}$ is reduced by factor $\sqrt{a_3/(4+3|\cos\alpha|d)}$.

Table 5: For dowelled moment resisting multi shear Kerto-to-Kerto flatwise connections with circular patterns of fasteners, the following minimum values of distances and spacings may be used:

<table>
<thead>
<tr>
<th>SPACING AND EDGE-END DISTANCES</th>
<th>KERTO-S TO KERTO-Q a)</th>
<th>KERTO-S TO KERTO-S</th>
<th>KERTO-Q TO KERTO-Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>End distance</td>
<td>$6d$ in Kerto-S</td>
<td>$7d$</td>
<td>$4d$</td>
</tr>
<tr>
<td></td>
<td>$4d$ in Kerto-Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edge distance</td>
<td>$4d$ in Kerto-S</td>
<td>$4d$</td>
<td>$3d$</td>
</tr>
<tr>
<td></td>
<td>$3d$ in Kerto-Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spacing on a circular</td>
<td>$5d$</td>
<td>$6d$</td>
<td>$4d$</td>
</tr>
<tr>
<td>Spacing between circulars b)</td>
<td>$5d$</td>
<td>$5d$</td>
<td>$4d$</td>
</tr>
</tbody>
</table>

(a) When Kerto-Q is used as outer member
(b) Between radius of the circulars

Figure 9: For dowelled moment resisting multi shear Kerto-to-Kerto flatwise connections with circular patterns of fasteners
9. ALLOWED TOLERANCES OF DOWELLED CONNECTIONS

Table 6: Allowed tolerances of dowel connections - allowed deviations from designed position, unless structural design otherwise states

<table>
<thead>
<tr>
<th>Dowel connection</th>
<th>diameter</th>
<th>length</th>
<th>±0 / ±0.1 mm</th>
<th>±2 mm</th>
<th>±0.05 d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dowel location</td>
<td>simultaneous drilling</td>
<td>±3 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hole location</td>
<td>separate drilling</td>
<td>±1 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smooth length of dowel in wood lamella</td>
<td>- max(2 mm; 0.05 t)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gap in joint</td>
<td>grooved or battened members</td>
<td>≤ min(3 mm; 0.25 f_p)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a) Drilling through all the parts without stopping or using a predrilled part as a template.
b) Prerequisite that the metal plates have 1 mm bigger holes than the dowel diameter.
c) t is the design length of the smooth part of the fastener in the lamella.
d) Gap between the timber and steel plate surface in steel-to-timber connections where f_p is the thickness of the steel plate.
e) In each shear plane of the connection in every member.

10. BIBLIOGRAPHY

3 VTT CERTIFICATE NO 184/03. Revised 24 March, 2009.