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THEORETICAL AND EXPERIMENTAL TENSION AND SHEAR CAPACITY OF NAIL PLATE CONNECTIONS

by

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BACKGROUND

The strength of nail plates with respect to the plate material has been studied at the Norwegian Institute of Wood Technology. This work served as a basis for a Nordic proposal for a design method and was presented by Norén 1981 in reference /1/.

In 1985 Bovim and Aasheim presented a paper /2/ where they made comparisons between measured and calculated values of plate strength. For all the tests a Gang Nail 18 plate was used. Their conclusion was that the design method presented gave a good prediction of the plate strength of nail plates.

During 1980-81 the Technical Research Centre of Finland (VTT) made an extensive investigation of one type of nail plate to achieve an approval using different shapes and sizes of the nail plate. The tests were carried out mainly by following the testing rules M.O.A.T. No 16:1979 of UEAtc. On the basis of the experience from these tests and the recommendations from RILEM/CIB 3TT published in 1982 and ISO 6891-1983 (E) a draft to a detailed testing method for nail plate joints was worked out in Finland. The method was presented 1985 in a paper /3/ by Kangas. In connection with this work a method to calculate design values /4/ was also presented. 15 complete series of different nail plates have so far been tested in Finland using this detailed testing method.

In 1990 Aasheim and Solli presented a translated version of the Norwegian design rules for nail plates /5/. It is expected that these rules will be included in the truss annexes in Eurocode no.5.

PURPOSE AND SCOPE

At the Swedish Institute for Wood Technology Research the design method given in /1/ has been used for several years in connection with the evaluation of results from testing of nail plate connections. Since it is possible to derive rather simple expressions for the tension and the shear capacity one purpose with this paper is to present these expressions and to explain where they are valid.

It has often been questioned if the proposed design method can be used for any nail plate. In order to elucidate this, the results from testing of 6 different nail plates are compared with the theory. All the tests have been carried out at the Technical Research Centre of Finland.

THEORY

Consider the nail plate connection given in Figure 1 where the nail plate is subjected to a force \( F_p \). The axes \( a \) and \( b \) denote the main directions of the plate. Normally the \( a \)-axis is chosen as the direction where the plate has its maximum tensile strength. The \( b \)-axis is perpendicular to the \( a \)-axis. The \( a \)-axis is positive pointing outwards from the cut line. The \( x \)-axis is parallel to the cut line.
The angle between the x-axis and the a-axis is denoted by $\alpha_{xa}$ and is in the range $0 \leq \alpha_{xa} \leq \pi$. The angle between the a-axis and the length direction of the plate force $F_p$ is denoted by $\alpha_{af}$ and is in the range $0 \leq \alpha_{af} \leq 2\pi$.

By denoting the length of the cut line in the nail plate by $f$, expressions for the widths $a_n$ and $b_n$ can be obtained to

$$a_n = \begin{cases} f \cos \alpha_{xa} & \text{for } 0 \leq \alpha_{xa} \leq \pi/2 \\ f \cos (\pi - \alpha_{xa}) & \text{for } \pi/2 \leq \alpha_{xa} \leq \pi \end{cases}$$  \hspace{1cm} (1)

$$b_n = \begin{cases} f \sin \alpha_{xa} & \text{for } 0 \leq \alpha_{xa} \leq \pi/2 \\ f \sin (\pi - \alpha_{xa}) & \text{for } \pi/2 \leq \alpha_{xa} \leq \pi \end{cases}$$  \hspace{1cm} (2)

The plate force $F_p$ can be divided into the components $F_a$ and $F_b$ along the a- and the b-axes giving

$$F_a = F_p \cos \alpha_{af}$$  \hspace{1cm} (3)

$$F_b = F_p \sin \alpha_{af}$$  \hspace{1cm} (4)

In the design method it is assumed that the strength of the nail plate is based on capacity values obtained from 6 different tests. In Figure 2 the different test specimens for determination of the capacity values are shown. All tests should be carried out without contact between the timber members. The following capacity values of the nail plate have to be determined

- $P_{at}$ = tension capacity per unit width in the a-direction
- $P_{ac}$ = compression capacity per unit width in the a-direction
- $s_a$ = shear capacity per unit width in the a-direction
- $P_{bt}$ = tension capacity per unit width in the b-direction
- $P_{bc}$ = compression capacity per unit width in the b-direction
- $s_b$ = shear capacity per unit width in the b-direction

The strength of the nail plate should be verified by the condition

$$\left(\frac{F_a}{R_a}\right)^2 + \left(\frac{F_b}{R_b}\right)^2 = 1 \hspace{1cm} (5)$$

where $R_a$ and $R_b$ are the capacities of the nail plate in the a- and b-direction. The capacity values $R_a$ and $R_b$ are determined as maximum values according to the following expressions
Nail plate connection subjected to tensile force

First we will study the load case when a nail plate connection is subjected to a tensile force perpendicular to the cut line between the timber members. See Figure 3. The plate force \( F_p \) is in this case equal to the external force \( F \) acting on the connection. By denoting the angle between the \( a \)-axis and the length direction of the force \( F \) by \( \alpha \) we obtain the following relations between the angles \( \alpha \), \( \alpha_p \), and \( \alpha_{xa} \)

\[
\alpha_p = \alpha
\]

\[
\alpha_{xa} = \pi/2 - \alpha
\]

To be able to give analytical expressions for the capacities \( R_a \) and \( R_b \) we need to determine the angles for which the capacities change their equations. If we start with the capacity \( R_b \) we find the critical angle \( \alpha \) from Equation (8) by putting the expressions equal to each other.

\[
P_{bt} a_n = s_b \beta_n
\]

By inserting the Equations (1) and (2) into Equation (12) and replacing \( \alpha_{xa} \) with \( \alpha \) according to Equation (11) we find

\[
\alpha = \alpha_{pl} = \arctan \frac{s_b}{P_{bt}}
\]

In the same way it is possible to derive an expression for the critical angle for the capacity \( R_a \) from Equation (6). We obtain

\[
R_b = \max \left\{ \frac{P_{bt} a_n}{s_b \beta_n} \right\}
\]

for \( 0 \leq \alpha_p \leq \pi \)

(i.e. \( F_b \) tensile force)

\[
R_b = \max \left\{ \frac{P_{bc} a_n}{s_b \beta_n} \right\}
\]

for \( \pi \leq \alpha_p \leq 2\pi \)

(i.e. \( F_b \) compression force)
\[ \alpha_{p_2} = \arctan \frac{P_{at}}{s_a} \]  

Now we can calculate the tension capacity per unit width perpendicular to the cut line

\[ p = \frac{F}{l} \]  

By inserting the Equations (1)-(6), (8), (10) and (11) into Equation (15) we will obtain three different curves for the tension capacity when \( \alpha \) is within the interval \( 0 \leq \alpha \leq \pi/2 \).

\[
p = \sqrt{\frac{1}{\left( \frac{1}{P_{at}} \right)^2 + \left( \frac{\tan \alpha}{s_b} \right)^2}} \quad \text{for} \quad 0 \leq \alpha \leq \alpha_{p_1}
\]

\[
p = \sqrt{\frac{1}{\left( \frac{1}{P_{at}} \right)^2 + \left( \frac{1}{P_{bt}} \right)^2}} \quad \text{for} \quad \alpha_{p_1} \leq \alpha \leq \alpha_{p_2}
\]

\[
p = \sqrt{\left( \frac{1}{s_a \tan \alpha} \right)^2 + \left( \frac{1}{P_{bt}} \right)^2} \quad \text{for} \quad \alpha_{p_2} \leq \alpha \leq \pi/2
\]

The equations are graphically presented in Figure 4 for a Hydro Nail E nail plate. The equations are shown for all \( \alpha \)-values between 0 and \( \pi/2 \) even if they are only valid between certain limits. Equation (16) corresponds to the failure criterion that the tension capacity in the \( a \)-direction \( P_{at} \) and the shear capacity in the \( b \)-direction \( s_b \) is utilized. This failure criterion is valid for \( 0 \leq \alpha \leq \alpha_1 \). The theoretical failure criteria for the different curves can be seen from the top of Figure 4 where the capacities \( R_a \) and \( R_b \) are given for different \( \alpha \)-values.

**Nail plate connection subjected to shear force. No contact between timber members.**

We are now going to study the load case in Figure 5 where a nail plate connection subjected to a shear force along the cut line is shown. It is assumed that there is no contact between the timber members. This means that the entire shear force has to be transmitted merely by the nail plate i.e. \( F_0 \) is equal to \( F \). Depending on the value of the angle \( \alpha \) we obtain two cases. The first case is usually called tension shear and occurs when \( 0 \leq \alpha \leq \pi/2 \). With notations according to Figure 5 we obtain
\[ \alpha_{sp} = 2\pi - \alpha \]  
\[ \alpha_{xa} = \alpha \]  
(19)  
(20)

We want now to determine analytically the angles \( \alpha \) for which the capacities \( R_a \) and \( R_b \) obtain changed equations. For the capacity \( R_a \) the critical angle \( \alpha \) is obtained from Equation (6) by the relation

\[ p_a \cdot b_n = s_a \cdot a_n \]  
(21)

By inserting the Equations (1), (2) and (19) into Equation (21) we find

\[ \alpha_{s1} = \arctan \frac{s_a}{p_a} \]  
(22)

A corresponding calculation, for the capacity \( R_b \), based on Equation (9) will give

\[ \alpha_{s2} = \arctan \frac{p_bc}{s_b} \]  
(23)

It is now possible to calculate the shear capacity per unit width along the cut line.

\[ s = \frac{F}{t} \]  
(24)

By inserting the Equations (1)-(6), (9), (19) and (20) into Equation (24) we will get the following expressions for the shear capacity of the plate when \( 0 \leq \alpha \leq \pi/2 \).

\[ s = \frac{1}{\sqrt{\left(\frac{1}{s_a}\right)^2 + \left(\frac{\tan \alpha}{p_{bc}}\right)^2}} \]  
for \( 0 \leq \alpha \leq \alpha_{s1} \)  
(25)

\[ s = \frac{1}{\sqrt{\left(\frac{1}{p_a \tan \alpha}\right)^2 + \left(\frac{\tan \alpha}{p_{bc}}\right)^2}} \]  
for \( \alpha_{s1} \leq \alpha \leq \alpha_{s2} \)  
(26)

\[ s = \frac{1}{\sqrt{\left(\frac{1}{p_a \tan \alpha}\right)^2 + \left(\frac{1}{s_b}\right)^2}} \]  
for \( \alpha_{s2} \leq \alpha \leq \pi/2 \)  
(27)
So far we have only dealt with the load case tension shear. If the angle $\alpha$ is within the interval $\pi/2 < \alpha < \pi$ the nail plate is said to be in compression shear. By using the same fundamental equations as in the case of tension shear we obtain

\[ s = \frac{1}{\sqrt{\left(\frac{1}{P_{ac}\tan(180-\alpha)}\right)^2 + \left(\frac{1}{s_b}\right)^2}} \quad \text{for } \pi/2 < \alpha < \alpha_{s3} \tag{28} \]

\[ s = \frac{1}{\sqrt{\left(\frac{1}{P_{ac}\tan(180-\alpha)}\right)^2 + \left(\frac{\tan(180-\alpha)}{P_{bt}}\right)^2}} \quad \text{for } \alpha_{s3} < \alpha < \alpha_{s4} \tag{29} \]

\[ s = \frac{1}{\sqrt{\left(\frac{1}{s_3}\right)^2 + \left(\frac{\tan(180-\alpha)}{P_{bt}}\right)^2}} \quad \text{for } \alpha_{s4} < \alpha < \pi \tag{30} \]

where the angles $\alpha_{s3}$ and $\alpha_{s4}$ are given by

\[ \alpha_{s3} = \pi - \arctan \frac{P_{bt}}{s_b} \tag{31} \]

\[ \alpha_{s4} = \pi - \arctan \frac{s_3}{P_{ac}} \tag{32} \]

The Equations (25)-(27) and (28)-(30) are graphically presented in Figure 6 for the same nail plate as was previously mentioned. The different failure criteria can be seen in the top of Figure 6 where the capacities $R_a$ and $R_b$ are given as functions of the angle $\alpha$.

Nail plate connection subjected to shear force. Contact between timber members. No friction.

So far we have only dealt with nail plate connections assuming that the entire shear force is transmitted merely by the nail plates. We are now going to consider the case when there is contact between the timber members but no friction between them. To use contact between the timber members in the calculation model is advantageous when the nail plates are subjected to tension shear. The principle is shown for the nail plate connection in Figure 7. It is assumed that the shear force $F$ can be divided into one plate component $F_p$ parallel to the length direction of the plate and one component perpendicular to the cut line. It is possible to find more advantageous directions for the plate component $F_p$ but that will necessitate much more complicated equations. For ordinary nail plates it seems reasonable to use the
proposed assumption. To calculate the shear capacity of the nail plate connection we shall use the following values for the angles $a_F$ and $a_a$.

$$a_F = 0$$

$$a_a = \alpha$$

(33) (34)

The relation between the nail plate force $F_p$ and the shear force $F$ is

$$F = F_p \cos \alpha$$

(35)

By using the Equations (1)-(6) and (33)-(35) we can calculate the shear capacity per unit width of the nail plate connection to

$$s = \frac{F}{\ell} = p_{at} \sin \alpha \cos \alpha$$

(36)

The shear capacity $s$ as a function of the angle $\alpha$ is shown in Figure 8. As a comparison the curves assuming no contact between the timber members are shown with thin lines in the figure. Obviously there is a lot to gain by assuming contact in the connection.

Nail plate connection subjected to shear force. Contact between timber members. Friction included.

We now want to study the influence of friction forces between the timber members. In this case we assume that the shear force $F$ in Figure 9 is built up of three components namely one plate force $F_p$ parallel to length direction of the plate, one contact force $F_c$ perpendicular to the cut line and one friction force $\mu F_c$ parallel to the cut line. With one exception the same equations as in the case of no friction can be used. Thus Equation (35) has to be replaced by

$$F = F_p \cos \alpha + \mu F_c$$

(37)

where

$$F_c = F_p \sin \alpha$$

(38)

After deduction the shear capacity per unit width of the nail plate connection is obtained to

$$s = p_{at} \sin \alpha (\cos \alpha + \mu \sin \alpha)$$

(39)
The shear capacity $s$ is shown in Figure 10 as a function of the angle $\alpha$. The coefficient of friction $\mu$ has been given the value of 0.3. It should be pointed out that Equation (39) is also valid for angles $\alpha \geq \pi/2$ i.e. in compression shear. For $\alpha = \pi/2$ we obtain that the shear capacity per unit width of the nail plate connection is $\mu p_{cq}$ which should be compared with the shear capacity per unit width $s_b$ of the nail plate.

**TEST RESULTS. COMPARISON WITH THEORY.**

The tests reported in this paper have all been carried out at the Technical Research Centre of Finland. The selection of the material and the performance of the tests are in agreement with the procedure described in /3/. The specimens used in the tension and the shear tests are shown in Figure 11. The test specimen in shear deviates from what is specified in ISO 8969 but is preferred in Finland because it is simple to manufacture and easy to test. The experience in Finland is that the specimen seems to give reliable test values which are in good agreement with values determined according to the ISO standard. The load arrangement in shear is shown in Figure 11.

The results from testing 6 different nail plates are presented. The plates have been chosen for practical rather than scientific reasons. Some nail plate producers have kindly given us permission to publish their test results.

The punching patterns of the tested nail plates are shown in Annex A. The nominal values of the tooth length and the plate thickness are given in Table 1. For the nail plates Hydro Nail M and Hydro Nail PTN, Swedish structural steel of grade SIS 2122 was used. For the rest of the plates a Finnish structural steel Z36 was used. In Table 1 the required minimum values of the yield point and the tensile strength are presented. In connection with the manufacturing of the nail plates, strips of unpunched plate material were taken out and tested in tension. These tests showed that for the nail plates Hydro Nail M and Hydro Nail PTN the yield point was between 357 and 390 N/mm$^2$ and the tensile strength between 452 and 530 N/mm$^2$. For the other plates the yield point was between 395 and 445 N/mm$^2$ and the tensile strength between 530 and 575 N/mm$^2$. This means that the strength of all the tested plate material was rather high.

In Annex B the tension capacity $p$ and the shear capacity $s$ of all the tested nail plate connections are shown as functions of the angle $\alpha$. The test values in the annex represent mean values. The number of test specimens of each type have in most cases been 3 but in some cases 5. The nail plate dimensions are given as width times length. In connection with the shear tests four different shear capacities $s$ have been evaluated from the load-slip curves namely:

\[ s_{\text{con}} \] shear capacity when the initial gap of 2 mm is closed and contact between the timber members is obtained. This value is only given if there is a distinct change of slope in the load-slip curve (denoted $+$ in Annex B)
\[ S_{\text{ex}} \] extrapolated shear capacity up to a slip limit of 7.5 mm obtained from the initial curvature of the load-slip curve i.e. assuming no contact between the timber members (denoted \( \Delta \) in Annex B)

\[ S_{7.5} \] the maximum shear capacity up to a slip limit of 7.5 mm (denoted \( \xi \) in Annex B)

\[ S_{\text{max}} \] the maximum shear capacity up to a slip limit of 15 mm (denoted \( \zeta \) in Annex B)

All these \( s \)-values are shown in Annex B. In most cases however \( S_{7.5} \) is the only one present. As different shapes of each type of nail plate were tested, the shear capacity values had to be presented in two figures. The first figure contains shear capacities for plates of normal size and shape. The second figure contains results from testing of plates with low and high length-to-width ratios. Thus for the angle of 0 degrees the plate shape has been chosen in order to obtain anchorage failure. For \( \alpha = 30, 45, 60 \) and 150 degrees the behaviour of long and narrow plates have been studied. For \( \alpha = 45 \) and 150 degrees the capacity of very short and wide plates have been determined. The latter have been chosen mainly for theoretical reasons.

### Table 1 Nominal tooth length and plate thickness. Minimum yield point and tensile strength of the plate material.

<table>
<thead>
<tr>
<th>Nail plate</th>
<th>Nominal tooth length mm</th>
<th>Nominal plate thickness mm</th>
<th>Minimum yield point N/mm²</th>
<th>Minimum tensile strength N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro Nail E</td>
<td>14</td>
<td>1.25</td>
<td>360</td>
<td>480</td>
</tr>
<tr>
<td>Hydro Nail M</td>
<td>14</td>
<td>1.5</td>
<td>350</td>
<td>430</td>
</tr>
<tr>
<td>Hydro Nail PTN</td>
<td>8.5</td>
<td>1.0</td>
<td>350</td>
<td>430</td>
</tr>
<tr>
<td>FIX (PEIKKO)</td>
<td>13</td>
<td>1.3</td>
<td>360</td>
<td>480</td>
</tr>
<tr>
<td>TOP-83R</td>
<td>7 &amp; 12</td>
<td>1.3</td>
<td>360</td>
<td>480</td>
</tr>
<tr>
<td>TOP-91</td>
<td>14</td>
<td>1.3</td>
<td>360</td>
<td>480</td>
</tr>
</tbody>
</table>

The failure modes of all the tested nail plate connections are shown with capital letters in Annex B. The following notations are used:

- \( A \) = Anchorage failure, bending of the nails.
- \( B \) = Local buckling of the plate edge in shear test.
- \( D \) = Exceeding of the slip limit 15 mm. The increase of the load beyond the slip limit is not considered (D from deformation)
- \( S \) = Shear failure in the plate.
- \( T \) = Tension failure in the plate.

Calculations of the tension capacity \( p \) and the shear capacity \( s \) of the tested nail plate connections have been carried out applying the theory described in this paper. Thus to determine the tension capacity \( p \) per unit width the Equations (16)-(17) have been used. The shear capacity \( s \) per unit width has been calculated under the
three different assumptions:

* No contact between timber members.
* Contact between timber members. No friction.
* Contact between timber members. Friction included ($\mu=0.3$).

In this case the Equations (25)-(30), (36) and (39) have been used. To be able to perform the calculations, values on the 6 fundamental plate capacities $p_{at}$, $p_{ac}$, $s_{a}$, $p_{bt}$, $p_{bc}$ and $s_{b}$ are needed. These values are given in Table 2 for each of the plates. The values represent mean values and comprise only the proper failure modes. Thus in the case of shear we have only accepted capacity values where there is no contact between the timber members. It must be pointed out that the capacity values in Table 2 are dependent on the steel quality and the thickness of the plate material used in the test specimens. No adjustment of the capacity values with respect to the nominal strength of the plate material and the nominal thickness of the plate has been undertaken. The values in Table 2 should therefore not be regarded as values which can be used for approving or comparing different plates.

Table 2 Plate capacity values obtained in the tests.

<table>
<thead>
<tr>
<th>Nail plate</th>
<th>$p_{at}$</th>
<th>$p_{ac}$</th>
<th>$s_{a}$</th>
<th>$p_{bt}$</th>
<th>$p_{bc}$</th>
<th>$s_{b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N/mm</td>
<td>N/mm</td>
<td>N/mm</td>
<td>N/mm</td>
<td>N/mm</td>
<td>N/mm</td>
</tr>
<tr>
<td>Hydro Nail E</td>
<td>394</td>
<td>185</td>
<td>109</td>
<td>120</td>
<td>75</td>
<td>98</td>
</tr>
<tr>
<td>Hydro Nail M</td>
<td>409</td>
<td>266</td>
<td>135</td>
<td>157</td>
<td>146</td>
<td>120</td>
</tr>
<tr>
<td>Hydro Nail PTN</td>
<td>262</td>
<td>112</td>
<td>115</td>
<td>155</td>
<td>122</td>
<td>81</td>
</tr>
<tr>
<td>FIX (PEIKKO)</td>
<td>414</td>
<td>194</td>
<td>140</td>
<td>228</td>
<td>141</td>
<td>107</td>
</tr>
<tr>
<td>TOP-83R</td>
<td>459</td>
<td>180</td>
<td>139</td>
<td>236</td>
<td>158</td>
<td>114</td>
</tr>
<tr>
<td>TOP-91</td>
<td>372</td>
<td>187</td>
<td>119</td>
<td>228</td>
<td>147</td>
<td>72</td>
</tr>
</tbody>
</table>

A comparison of the measured and the theoretical tension capacities $p$ in Annex B shows that the agreement is somewhat varying but mostly rather good for the investigated nail plates. There seems to be a tendency for the theory to underestimate the plate capacity when the angle $\alpha$ is 30 degrees. For the angle of 60 degrees the theory overestimates the plate capacity in four cases and underestimates it in one case.

It is more difficult to make an evaluation of the agreement between the measured and the theoretical capacities in shear than in the case of tension. That is a consequence of the more complicated conditions in shear, where it often is contact between the timber members. It must be pointed out that it is very important to make a distinction between the capacity of the nail plate and the capacity of the nail plate connection. Thus it is only when we talk about the capacity of the nail plate connection that contact and friction forces can occur.

If we compare the measured shear capacities with those obtained by the theory assuming no contact between the timber members (the
lower curve) we find that the test values mostly are above the theoretical curve. Due to local buckling of the plate edge (failure mode B) the test values sometimes are below the curve. This is often the case when $\alpha$ is equal to 30, 45, 135 and 150 degrees. In a few cases, anchorage failure (failure mode A) is the reason why the test values are below the theoretical curve. For those plate types where the local buckling mode occurs it might be possible in design to use reduced effective widths for some angles $\alpha$.

In the case of tension shear ($0 \leq \alpha \leq 90$ degrees) we find that the test values often are much higher than what may be expected from the theoretical capacity of merely the nail plate. In the shear-failure mode (S) the test values almost always are above the upper curve i.e. the theoretical capacity assuming contact and friction. An other conclusion which can be drawn is that the shear capacity increases when the length-to-width ratio is increased and $\alpha$ is between 30 and 60 degrees. The capacity values for the plates with high length-to-width ratios are mostly higher than given by the theoretical curve assuming contact but no friction.

It is the authors' intention to extend the investigation to some other nail plate types which already have been tested. In particular plates with different punching patterns will be analysed.

CONCLUSIONS.

The proposed design code in /5/ is presented in a format easily applicable to results from standard tests. An evaluation of 6 different types of nail plates is made. The agreement between the measured and the theoretical capacity values in tension is somewhat varying but mostly rather good. The capacity values from the shear tests are often higher than the results from a theoretical calculation assuming no contact between the timber members. Special attention should be payed to the local buckling mode of the nail plate edge in the shear test. In the case of tension shear it might be possible to use a theory based on the assumption that there is contact but no friction between the timber members if the length-to-width ratio of the plate is high enough.

Even if only a limited number of nail plate connections have been investigated in this paper it can be stated that the theory is very useful for making reliable evaluations of test results.

REFERENCES


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FIXRON OY, Norokatu 5, 15170 Lahti, Finland

Top-Levy OY, Sepänkatu 9, 11710 Riihimäki, Finland

Nordisk Kartro AB, Box 124, 123 22 Farsta, Sweden
Figure 1  Nail plate subjected to a force $F_p$. Definition of angles and geometry.

Figure 2  Test specimens used for determination of capacity values.
Figure 3 Nail plate connection subjected to a tensile force $F$.

$$R_a = \begin{array}{c|c|c} \rho_{at} & b_n & s_a \frac{a_n}{a} \\ \hline s_b & b_n & \rho_{bt} \frac{a_n}{a} \end{array}$$

Figure 4 Theoretical tension capacity $p$ as a function of the angle $a$ for a nail plate connection.
Figure 5 Nail plate connection subjected to a shear force $F$. No contact between timber members.

$$\begin{align*}
R_a &= s_a a_n b_a b_n p_{ac} b_n s_a a_n \\
R_b &= p_{bc} a_n s_b b_n p_{bt} a_n
\end{align*}$$

Shear capacity $s$

Figure 6 Theoretical shear capacity $s$ as a function of the angle $\alpha$ for a nail plate connection. No contact between timber members.
Figure 7  Nail plate connection subjected to a shear force $F$. Contact between timber members. No friction.

Figure 8  Theoretical shear capacity $s$ as a function of the angle $\alpha$ for a nail plate connection. Contact between timber members. No friction.
Figure 9: Internal and external forces in a nail plate connection subjected to shear. Contact between timber members. Friction included.

Figure 10: Theoretical shear capacity \( s \) as a function of the angle \( \alpha \) for a nail plate connection. Contact between timber members. Friction included.
Figure 11  

a) Test specimen used in tension test.  
b) Test specimen used in shear test.  
c) Load arrangement in shear.
Figure A3 Hydro Nail PTN

Figure A4 FIX (PEIKKO)
ANNEX B

Figure B1

Figure B2
Figure B3

Shear capacity s, N/mm

Hydro Nail E 77x191

Figure B4

Tension capacity p, N/mm

Hydro Nail M
Figure B5

Shear capacity $s$, N/mm

Hydro Nail M 127x152

Figure B6

Shear capacity $s$, N/mm

Hydro Nail M 77x191
Figure B7

Tension capacity \( p, \text{ N/mm} \)

Shear capacity \( s, \text{ N/mm} \)

Figure B8
Figure B9

Shear capacity $s$, N/mm

Figure B10

Tension capacity $p$, N/mm
Shear capacity $s$, N/mm

Figure B11

Shear capacity $s$, N/mm

Figure B12
**Figure B13**

Tension capacity $p$, N/mm

**Figure B14**

Shear capacity $s$, N/mm
Shear capacity $s$, N/mm

Tension capacity $p$, N/mm

Figure B15

Figure B16
Figure B17

Figure B18