A NEW STANDARD FOR MACHINE STRENGTH GRADING OF TIMBER – ASSESSMENT AND APPLICATION

Charlotte Bengtsson, Mikael Fonselius, Kjell Helge Solli & Jan Brundin
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A new standard for machine strength grading of timber – assessment and application

Abstract:  
A new standard “prEN 14081 Timber structures – Strength graded structural timber with rectangular cross section” is under development. This standard lays down the requirements for visual and machine graded structural timber and results in the possibility to CE-mark structural timber. Among other things the standard harmonises the procedures for calculation of strength grading machine settings in Europe. Within this project the methodology suggested in the new standard for deriving machine settings is evaluated. Further, documentation showing that spruce and pine raw material grown in the Nordic countries have similar properties have been produced.
Preface

This report describes the project “A new standard for machine strength grading of timber – assessment and application” funded by Nordtest (project no. 1616-02). The work has been carried out by:
Charlotte Bengtsson, SP Swedish National Testing and Research Institute (SP, project leader)
Mikael Fonselius, Technical Research Centre of Finland (VTT)
Jan Brundin, Swedish Institute for Wood Technology Research (Trätek)
Kjell Helge Solli, Norweigan Institute of Wood Technology (NTI)

The report consists of a short summary of the project carried out followed by two documents attached as appendices.

Borås November 2003

Charlotte Bengtsson
1 Introduction

1.1 Background

A new standard “prEN 14081 Timber structures – Strength graded structural timber with rectangular cross section” is under development. This standard lays down the requirements for visual and machine graded structural timber and results in the possibility to CE-mark structural timber. Among other things the standard harmonises the procedures for calculation of strength grading machine settings in Europe. The standard consists of four different parts:

- Part 1: General requirements
- Part 2: Machine Grading – Additional requirements for initial type testing
- Part 3: Machine Grading – Additional requirements for factory production control
- Part 4: Machine Grading – Grading machine settings for machine controlled systems

In part two the procedure for calculating settings for strength grading machines are described. Settings determined according to part two are presented in part four separately for different machine types as well as for different growth areas of the timber to be graded. Settings approved by CEN/TC124/WG2/TG2 are included in part four of the standard.

Machine strength graded timber is one important export product for the Nordic countries (Sweden, Finland and Norway). The volume of machine strength graded timber is increasing year after year. Presently, there are seven different machine types used in the Nordic countries. The calculation of settings for strength grading machines is an expensive and time consuming work. It is therefore of great importance for the Nordic industries producing strength graded timber that the coming standard EN 14081 works well for the Nordic conditions.

1.2 Aim of the project

The project has two main aims:

- To secure that the machine grading standard prEN 14081 is interpreted in the same way in the Nordic countries.
- Produce a documentation showing that spruce and pine raw material grown in the Nordic countries have similar properties (bending strength and modulus of elasticity).

It may seem obvious that a standard should be written in a clear way. This is however not the case for prEN 14081. A clear Nordic interpretation is therefore needed.

2 Realization of the project

2.1 Nordic raw material

In prEN 14081 it is stated that “settings shall be derived for the total growth area from which the timber will be graded within one or more countries”. Within the framework of this project the documentation given in Appendix 2 was produced.
This document was accepted by CEN/TC124/WG2/TG2. Settings listed in part four of the standard are now valid for the whole Nordic growth region.

2.2 Evaluation of the methodology in the standard
The procedure for calculating settings which is prescribed in prEN 14081 part 2 is unfortunately not tested and evaluated in a manner that is preferable for standards. In addition, the standard is written in a way that allows different interpretations.

Therefore, within this project a clear calculation procedure was suggested and presented in the CIB-paper in Appendix 1. This procedure is used in Sweden, Finland and Norway when calculating settings. The evaluation showed that the methodology has weaknesses when the raw material is “too good” or when low strength classes are wanted. Raw material from the Nordic countries is usually very good and this point leading to “good” settings for the Nordic countries has been questioned by representatives from other European countries.

It is also shown that the procedure is sensitive for the sampling of raw material. This is important input for improvement of the standard.

The procedure in prEN 14081 can result in different settings for the same strength class. This is an obvious consequence of the statistical method prescribed in prEN 14081. The industrial consequence of this fact needs to be analysed.

2.3 Calculation of settings
Calculation of settings are not included in this project. Financing of the concrete calculation work was found from other sources. At SP settings have been calculated for the Dynagrade strength grading machine and for the Computermatic machine. At VTT settings for the Raute Timgrader were derived and at NTI settings for the Cook Bolinder machine were calculated. The settings are presented in separate reports and published in part four of the prEN 14081 standard.

3 Results
The work within this project has resulted in the possibility to derive common settings for Nordic raw material.

The evaluation of the procedure in prEN 14081 (see Appendix 1) is a good basis for further work within the task group CEN/TC124/WG2/TG2. No other such evaluation of the present version of the standard is published.

Nordic sawmill industries grading timber have been continuously informed about the work within this project.

4 References
prEN 14081 Timber structures – Strength graded structural timber with rectangular cross section, part 1-4
Appendix 1

Settings for strength grading machines – evaluation of the procedure according to prEN 14081, part 2

Paper presented at CIB-W18 11-14/8 2003 in Estes Park, Colorado, USA.
1 Abstract
This paper presents experience gained during the application of the new standard prEN 14081-part 2. The standard contains a procedure for derivation of setting values for strength grading machines. The standard was applied for representative raw material from the Nordic countries (Sweden, Finland and Norway). Consequences when the raw material properties are better than those of the required grades and the importance of the choice of representative raw material data for derivation of settings are discussed. A “method for calculation” which would facilitate the use of the standard is suggested.

2 Background and introduction
A new standard “prEN 14081 Timber structures – Strength graded structural timber with rectangular cross section” is under development. This standard will harmonise the procedures for calculation of strength grading machine settings in Europe and results in the possibility to CE-mark structural timber. The standard consists of four different parts:
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In part two the procedure for calculating settings for strength grading machines are described. Settings determined according to part two are presented in part four separately for different machine types as well as for different growth areas of the timber to be graded. Settings approved by CEN/TC124/WG2/TG2 are included in part four of the standard.

The procedure for calculating the settings is denoted the “cost matrix method”. The method was presented by Rouger (1997). The present version of the standard (dated February 2003) deviates from earlier versions concerning the sampling procedure and the procedure when the characteristic values of the material to be graded are higher than those required for the actual grade.

The standard requires that settings are calculated separately for raw material from different countries which means that raw material from one origin must be graded with the same settings independent of where it is graded. Restricting the use of
settings to one country is a topic that has been discussed a lot. The Nordic countries (Sweden, Finland and Norway) have produced a document (Brundin et al. 2002) showing that raw material (spruce and pine) from these three countries has very similar relationships between modulus of elasticity and bending strength. As most grading machines measure stiffness it is appropriate to use this relationship as comparison. The variability within each country is as large as the variability between the countries. Hence, it was accepted by CEN/TC124/WG2/TG2 that Sweden, Finland and Norway can use the same settings.

2.1 Objectives of this paper
The objectives of this paper are to present experience gained during the application of the standard and to discuss some possible improvements. This paper does not present a full evaluation of the standard but it focuses on some experiences found when applying it for a representative raw material from the Nordic countries (Sweden, Finland and Norway). The methodology used is based on a common understanding of the method for calculation of settings achieved within a Nordic project (Nordtest project number 1616-02).

3 Analysis
3.1 Methodology
The methodology for calculating settings (interpreted from the standard) can briefly be described as follows (references given in this section correspond to clauses in prEN 14081 part 2):

1. Establish a database containing the test data (ID number, bending strength ($f_m$), modulus of elasticity ($E$), density and indicating property (IP) measured by the machine). $f_m$ shall be corrected to $h=150\,\text{mm}$ and $E$ and density to 12% moisture content according to EN 384. Number of specimens and sub-samples shall be arranged according to 6.2.1. The sub-samples shall consist of at least 100 specimens and contain material from one growth area or source of production. A minimum number of four sub-samples must be included and at least 900 specimens are required.

2. Optimum grading according to 6.2.4.3. The “1,12 factor” according to EN 384 shall not be applied for grades above C30 and the 95% factor shall be used on $E$. The optimum grading shall be carried out by maximising the number of specimens in the highest grades for which settings are required.

3. Establish a model relating strength to IP measured by the machine. In the analysis presented here a model of the following form was used:

$$f_{\text{mod},h=150} = k \cdot \left( \frac{h}{150} \right)^a \cdot \left( \frac{E}{150} \right)^b \cdot (\text{IP})^c$$

4. Leave out one sub-sample and determine settings for actual grade combination so that the required characteristic strength ($f_k$), $E$ and density are fulfilled. Repeat for all sub-samples.

5. Determine the “production settings” as the average of the settings obtained under point 4. Check that the difference between the average and the most conservative sub-sample setting is less than 15%. Otherwise correct according to 6.2.4.4.
6. Grade the whole raw material by using the production settings determined under 5. These grades are called “assigned grades”.

7. Collect optimum grades and assigned grades in a “size matrix” according to 6.2.4.5. Example of a size matrix is shown in Table 1. Table 1. Example of a size matrix for the grade combination C35-C24-C18-reject.

<table>
<thead>
<tr>
<th>Optimum grade</th>
<th>Assigned grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C35</td>
</tr>
<tr>
<td>C35</td>
<td>554</td>
</tr>
<tr>
<td>C24</td>
<td>34</td>
</tr>
<tr>
<td>C18</td>
<td>1</td>
</tr>
<tr>
<td>Reject</td>
<td>0</td>
</tr>
</tbody>
</table>

8. Determine the elementary cost matrix according to 6.2.4.6. An example is shown in Table 2.
Table 2. Example of an elementary cost matrix.

<table>
<thead>
<tr>
<th>Optimum grade</th>
<th>Assigned grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C35</td>
</tr>
<tr>
<td>C35</td>
<td>0</td>
</tr>
<tr>
<td>C24</td>
<td>1,53</td>
</tr>
<tr>
<td>C18</td>
<td>3,15</td>
</tr>
<tr>
<td>Reject</td>
<td>5,418</td>
</tr>
</tbody>
</table>

9. Determine the “global cost matrix” as described in 6.2.4.6. Each value in the global cost matrix is obtained by multiplying the number in each cell of the size matrix by corresponding value in the elementary cost matrix and then dividing by the total number of pieces in the assigned grade. For example see Table 3.
Table 3. Example of a global cost matrix.

<table>
<thead>
<tr>
<th>Optimum grade</th>
<th>Assigned grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C35</td>
</tr>
<tr>
<td>C35</td>
<td>0</td>
</tr>
<tr>
<td>C24</td>
<td>(34*1,53)/589=0,088</td>
</tr>
<tr>
<td>C18</td>
<td>0,005</td>
</tr>
<tr>
<td>Reject</td>
<td>0</td>
</tr>
</tbody>
</table>

10. Check that none of the cells in the global cost matrix which indicate pieces wrongly upgraded contains a figure greater than 0.2 (the cells with bold text in Table 3), 6.2.4.7. Otherwise, correct the IP (point 5) for actual grades and repeat until the requirement is fulfilled.

11. Check that the characteristic values are fulfilled (fi, E and density) for the assigned grades, according to 6.2.4.8.
The above given interpretation of the standardised method was worked out by representatives for the Nordic countries. The standard would be considerably improved if such an interpretation was included in the standard.
3.2 Raw material used for the analysis
Test material from Norway Spruce (*Picea abies*) representing six different origins in Sweden, Finland and Norway, see Table 4, are used for the analysis presented in this paper. The material data are representative for spruce raw material from these countries. The whole material has a characteristic bending strength of 24,8 MPa, a mean modulus of elasticity of 12400 MPa and a characteristic density of 364 kg/m³.

Table 4. Spruce material used in this paper. The different sub-samples represent different locations in Sweden, Norway and Finland.

<table>
<thead>
<tr>
<th>Sub-sample No.</th>
<th>Dimensions</th>
<th>No. specimens</th>
<th>Mean bending strength [MPa]</th>
<th>Mean modulus of elasticity [MPa]</th>
<th>Mean density [kg/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34 x 95</td>
<td>395</td>
<td>43,0</td>
<td>11341</td>
<td>407</td>
</tr>
<tr>
<td></td>
<td>34 x 145</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 x 145</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 x 195</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70 x 220</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>40 x 145</td>
<td>97</td>
<td>50,1</td>
<td>12789</td>
<td>466</td>
</tr>
<tr>
<td>3</td>
<td>40 x 145</td>
<td>683</td>
<td>45,3</td>
<td>12804</td>
<td>447</td>
</tr>
<tr>
<td>4</td>
<td>40 x 145</td>
<td>100</td>
<td>43,5</td>
<td>11330</td>
<td>437</td>
</tr>
<tr>
<td>5</td>
<td>40 x 145</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 x 120</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>35 x 55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>35 x 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>58 x 120</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 x 145</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>2107</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 Results
To “speed up” the calculations according to the procedure described above a computer programme was developed. Our experience so far is that the procedure in prEN 14081, part two in general works well. However, during the forthcoming revision period the topics presented in this paper should seriously be analysed and discussed.

The examples given are valid for a bending type grading machine, in this case a Computermatic. This machine measures the deflection of a piece of timber when a constant bending stress is applied.

4.1 Influence of quality of the raw material
As shown above the “typical” raw material from the Nordic countries fulfils the requirements for C24 without grading. If settings for C24 or below are wanted the usual “cost matrix” procedure can not be used. The standard prescribes two ways of dealing with this case:
6.2.4.9 a) “The setting shall be derived from the model for a strength value of 0.5 times the required strength for the grade”, or
6.2.4.9 b) “The setting shall be derived from the model for the worst indicating property value in the sample”.

“If there is one or more test specimens in the sample with a strength value lower than 0.5 times the required value of the critical strength property for the grade, then case a) shall be used, otherwise case b) shall be used.”

The consequences of these two cases are illustrated by examples below. For C18 the required strength is 16.1 MPa. Inserting 0.5 times this required strength (8.05 MPa, case a) in the model relating strength to indicating property results in unreasonable settings for the Computermatic grading machine. It is easily realised that this limit value is not realistic in the case of Computermatic when a bending stress of 13.8 MPa is applied when running the machine. The result is that settings 5-6 times less conservative than today will be accepted (this comparison is valid for C18 with a cross section of 50 x 150 mm). The allowed deflections to be measured by the Computermatic grading machine will be so high that they are not possible to measure.

Case b prescribes that the indicating property resulting in the lowest modelled strength within the sample should be used. For the data used in this paper the accepted deflection will be increased by 44% compared to the deflection accepted today in Sweden (for C18, 50 x 150 in cross section). This value may be reasonable but it is not pleasing to base the setting on one single IP-value within the sample. Additionally, in case b the rule will give exactly the same setting for C16, C18 and C24.

To achieve more reasonable settings when the material quality is too good or the grades to be graded are too modest the following procedure is suggested:

If the lowest grade to be graded is so low that the characteristic values of the grade determining properties for the total sample (excluding those pieces in any higher grade) exceed those required for the grade, the production setting for the grade shall be derived following the method below:

1) Determine the setting for the lowest possible single grade by using the cost matrix method
2) For this grade establish the relationship: setting/required strength
3) Use that relationship for determining the setting for the actual grade

Example, deriving setting for grading C24 as a single grade (this example is not valid for exactly the same raw material as used otherwise in this paper):

1) The lowest single grade to be graded is C27. The “setting” for that grade, here denoted $f_{mod}$ is 34.5.
2) Relationship setting/required strength: $34.5/(27/1.12)=1.43$.
3) Setting for C24=$(24/1.12)*1.43=30.6$

The Figure below illustrates case a in the standard and the new proposal given here. The values above C24 are calculated according to the cost matrix method.
It is obvious that the cost matrix method works well in the cases where the test material has properties corresponding to the properties of the required grade/grades. The main motivation for the proposal above is to use the mathematical model also for the lower strength classes and apply the same “level of safety” achieved by the cost matrix method also for lower grades. The mathematical model is based on several hundreds of test values and much more reliable than one single test value.

For the cases where the raw material is too good compared to the grades wanted a more conservative setting can be chosen. This is of course one option that is available, however it is not pleasing to have a standard permitting unreasonably liberal settings.

It may seem strange to grade good timber, as the Nordic one, to strength classes well below the strength of the timber itself. However, this is the need for many sawmills in the Nordic countries and is therefore an important topic to deal with.

4.2 “Upgrading” one case

The results when calculating settings for the combination C30-C24-C18-reject can be seen in Table 5. When the combination C30-C24-reject was chosen, the same settings were achieved, see Table 5. However, the requirement on the global cost matrix was not fulfilled, see Table 6. In the first case, both rejects and C18-pieces were wrongly upgraded to C24. In the second case only rejects are upgraded to C24, which is recognised more severe by the cost matrix method.

It is reasonable to think that the combination C30-C24-reject is derived directly from the combination C30-C24-C18-reject without a special calculation. The fact that the cost matrix is not fulfilled is then never discovered.
Table 5. Settings for two grade combinations.

<table>
<thead>
<tr>
<th>Combination</th>
<th>Settings $f_{\text{mod}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C 30</td>
</tr>
<tr>
<td>C 30 – C 24</td>
<td>40,2</td>
</tr>
<tr>
<td>C 30 – C 24 – C 18</td>
<td>40,2</td>
</tr>
</tbody>
</table>

Table 6. Global cost matrix for a) grade combination C30-C24-C18-reject, b) C30-C24-reject.

<table>
<thead>
<tr>
<th>Assigned grade</th>
<th>Optimum grade</th>
<th>C 30</th>
<th>C 24</th>
<th>C 18</th>
<th>Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>C30</td>
<td>0</td>
<td>0,22</td>
<td>0,576</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>C24</td>
<td>0,009</td>
<td>0</td>
<td>0,006</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>C18</td>
<td>0,096</td>
<td>0,173</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Reject</td>
<td>0,014</td>
<td>0,157</td>
<td>0,116</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assigned grade</th>
<th>Optimum grade</th>
<th>C 30</th>
<th>C 24</th>
<th>Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>C30</td>
<td>0</td>
<td>0,22</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>C24</td>
<td>0,009</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Reject</td>
<td>0,104</td>
<td>0,248</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

4.3 Influence of using different sub-samples

Using representative raw material is an absolutely crucial point for having correct and safe settings. In prEN 14081, part 2, it is prescribed that sub-samples shall be selected representing one growth area or source of production and that the minimum number of pieces in one sub-sample shall be 100. At least four sub-samples must be included and the total number of pieces must be at least 900. A test was made by using the raw material presented under point 3.2 in this paper. One sub-sample was left out and settings were calculated for the combination C30-reject. The results are presented in Table 7. It can be seen that the setting drops substantially when sub-sample 1 is left out. The difference between the least and most conservative setting for C30 is around 25%. Sub-sample 1 contains most of the dimensions and the material with the lowest density (for C30 the density is sometimes the governing parameter). The effects of location and the effects of timber size are not separated. In a coming version of the standard this must be cleared out.

Table 7. Settings for C30 when different sub-samples are included.

<table>
<thead>
<tr>
<th>Sub-samples included</th>
<th>Setting ($f_{\text{mod}}$) for C30</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-6</td>
<td>32,5</td>
</tr>
<tr>
<td>1, 3-6</td>
<td>39,5</td>
</tr>
<tr>
<td>1-2, 4-6</td>
<td>41,5</td>
</tr>
<tr>
<td>1-3, 5-6</td>
<td>39,0</td>
</tr>
<tr>
<td>1-4, 6</td>
<td>40,0</td>
</tr>
<tr>
<td>1-5</td>
<td>36,8</td>
</tr>
<tr>
<td>All (1-6)</td>
<td>38,2</td>
</tr>
</tbody>
</table>
4.4 Different settings for the same strength class

According to EN 338 a timber population may be assigned to a strength class if the following three criteria are fulfilled:

- The characteristic value of bending strength, \( f_{mk} \), is equal to or exceeds the corresponding value of that strength class.
- The mean value of modulus of elasticity, \( E \), is equal to or exceeds 95 % of the corresponding value of that strength class.
- The characteristic value of density is equal to or exceeds the corresponding value of that strength class.

For strength grading machines the settings are determined in such a way that these three criteria are fulfilled. Additionally, the requirement not to wrongly upgrade too many timber pieces is checked.

Hence, the requirements are given for \( f_{mk} \), \( E \) and density representing all the timber pieces in the same class. This means that the amount of timber pieces with a strength less than the required class strength can be increased by adding timber pieces with a strength above the class strength to the sample. (It may be wise in the forthcoming revision process to discuss an additional requirement to ensure that the weakest timber piece in each strength class is not too weak.)

Table 8 shows setting values for different grade combinations achieved by analysing the raw material presented in Table 4 (prEN 14081, part 2, version February 2003 was used). It can be seen that the settings for grading for example C24 on its own differs considerably from the setting for C24 when it is graded together with C30 and C18. Indeed the setting of 21,3 for C24 alone is considerably less restrictive than the setting of 34,0 for C24 but also less restrictive than the setting of 23,0 for C18!

Table 8. Settings for different grade combinations achieved when analysing the raw material presented in this paper.

<table>
<thead>
<tr>
<th>Settings ( f_{mod} )</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C 40</td>
</tr>
<tr>
<td>C 24</td>
<td></td>
</tr>
<tr>
<td>C 27</td>
<td></td>
</tr>
<tr>
<td>C 30</td>
<td></td>
</tr>
<tr>
<td>C 35</td>
<td>50,0</td>
</tr>
<tr>
<td>C 27 – C 16</td>
<td></td>
</tr>
<tr>
<td>C 30 – C 18</td>
<td></td>
</tr>
<tr>
<td>C 30 – C 24 – C 18</td>
<td></td>
</tr>
<tr>
<td>C 35 – C 24 – C 18</td>
<td>50,0</td>
</tr>
<tr>
<td>C 40 – C 27</td>
<td>57,6</td>
</tr>
</tbody>
</table>

Although, it is in accordance with the European requirements it is confusing to have different settings for the same strength classes depending on the way the good material is handled. This may also be a problem for the quality control to be carried out, partly by the producer and partly by a third part body. If a producer uses the settings determined assuming saw falling material to be included in the class, it is of main importance for the quality control to ensure that nothing of that material has been creamed off before grading.
Although the three criteria presented above are also valid for visual grading it has in Europe been agreed to use some well defined national grading rules for assigning timber to the European strength classes. This means that the grading requirements are given for each individual timber piece instead of for a population of pieces. There are no possibilities to include low graded timber to a better class whatever high graded timber is included.

4.5 Use of the ”1,12-factor”

According to EN 384 the characteristic value of the strength, $f_k$, is given by

$$f_k = f_{05} \cdot k_s \cdot k_v$$

where $f_{05}$ is the 5th percentile of the strength taking into account the different samples, clause 5.4 of EN 384.

$k_s$ is a factor to adjust for the number of samples and their size.

$k_v$ is stated to be a factor taking into account the lower variability of $f_{05}$ values between samples for machine grades in comparison with visual grades. $k_v$ is equal to 1.12 for machine grades with $f_k$ equal to or less than 30 MPa. For all other machine grades and all visual grades $k_v$ is equal to 1.00.

A discussion related to the $k_v$ factor has been ongoing for several years and the factor included in the standard is a compromise that can not be defended statistically. At least not if the intention is to determine the characteristic value defined as the fifth percentile value for a certain confidence level on equal basis. For timber machine graded to strength classes above C30 the variability of $f_{05}$ values between samples is smaller than for machine grades to lower classes as well as smaller than for visual grades. Consequently, the $k_v$ factor of 1.12 should be used also for these high grades but it is not the conclusion written down in the standard.

If the raw material used in present paper is graded to C30 and reject by using $k_v = 1.12$ as prescribed by the standard, then 1782 of the 2107 pieces are assigned to C30. The non-parametric 5th percentile value for these 1782 pieces is 28.9 MPa while the mean modulus of elasticity is 12900 MPa and the density is 380 kg/m³ (the density was the governing factor). If the $k_v$ factor 1.00 instead of 1.12 is used then only 1293 of the 2107 pieces will be assigned to the class C30. The non-parametric 5th percentile value for these 1293 pieces is 30.1 MPa while the mean modulus of elasticity is 13400 MPa and the density is 387 kg/m³ (bending strength was the governing factor).

Lamellas to be used in the production of glued laminated timber can be either visually or machine graded. For machine graded lamellas the $k_v$ factor shall be taken as 1.00 for all classes, according to EN 1194.

5 Conclusions and recommendations

During the work in CEN/TC124/WG2/TG2 by formulating and applying the suggested procedure for calculating settings different interpretations and understandings have come up. A clear procedure with examples, as presented under section 3.1 in this paper, would improve the standard considerably and facilitate the use of the standard.
The procedure for derivation of settings when the raw material is too good or the wanted grades are too modest need to be revised. A suggestion is given in this paper.

In the paper it is illustrated that the raw material used when deriving the settings must be representative for the material to be graded in production. It is shown that by deleting one of the sub-samples used in the present analysis the setting for C30 can vary by around 25%.

Further, consequences by deriving combinations of settings from already existing ones are pointed out. It is also pointed out that the methodology can result in considerably different settings for the same strength class.

6 Acknowledgement

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7 References


EN 384 Structural timber – Determination of characteristic values of mechanical properties

EN 338 Structural timber – Strength classes

EN 1194 Glued laminated timber – Strength classes and determination of characteristic values

prEN 14081 Timber structures – Strength graded structural timber with rectangular cross section, part 1-4
Appendix 2

Nordic Spruce - A common growth area

Document accepted by CEN/TC124/WG2/TG2
Nordic Spruce - A common growth area

Jan Brundin
Charlotte Bengtsson
Mikael Fonselius
Kjell Solli

Introduction
It is well known that the goodness of grading machines of sawn timber depends on two fundamental issues. Firstly, the dependence between the material property or properties used by the machine to estimate the relevant characteristics (bending strength, modulus of elasticity and density) for determination of the strength class. Secondly, the ability of the machine to measure this material property or these material properties.
In traditional bending type machines the global modulus of elasticity in flatwise bending is measured and used to estimate the bending strength and local modulus of elasticity in edgewise bending. There are also machines in which the dynamic modulus of elasticity is used in stead of the static one. For these two machine types the correlation between the modulus of elasticity and bending strength is crucial.
The object of this report is to summarise the dependence between bending strength and local modulus of elasticity for Nordic spruce (Picea abies) grown at different regions in Finland, Norway and Sweden. Furthermore, Nordic pine (Pinus sylvestris) is compared to Nordic Spruce.

Nordic spruce
To avoid a discussion about the effect of size on bending strength only Nordic spruce (Picea abies) of which the thickness is between 40 and 50 mm and of which the width (depth) is between 140 and 150 mm is included. The bending strength was adjusted to the reference depth of 150 mm in accordance with EN 384. Furthermore, the modulus of elasticity was adjusted to the reference moisture content of 12 % in accordance with EN 384.
All specimens except the specimens in sample Fin-2, Fin-3 and Fin-4 were conditioned in a relative humidity of 65 % and a temperature of 20 °C before testing. The moisture content of these three Finnish samples was about 15 %. To counteract for this effect an additional adjustment equal to an increase of 7.5 % of the bending strength values were made for these three samples.
Table 1. Spruce from Finland, Norway and Sweden.

<table>
<thead>
<tr>
<th>Country Sample</th>
<th>Origin</th>
<th>No of specimens</th>
<th>Thickness mm</th>
<th>Width mm</th>
<th>Data source</th>
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<td>147</td>
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<tr>
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<td>Middle</td>
<td>194</td>
<td>42</td>
<td>147</td>
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<td>198</td>
<td>42</td>
<td>147</td>
<td>VTT 1995</td>
</tr>
<tr>
<td>Fin-E</td>
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<td>40</td>
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<td>148</td>
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<td>Nor-I</td>
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<td>40</td>
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<td>45</td>
<td>145</td>
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<td>South</td>
<td>112</td>
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<td>145</td>
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</table>

The basic data from Finland, Norway and Sweden is summarised in Table 1. The dependence between bending strength $f_m$ (N/mm$^2$) and modulus of elasticity $E$ (N/mm$^2$) for the 4 samples from Finland are:

- \( f_m = 0.00396E - 0.6 \quad R^2 = 0.62 \quad (1) \)
- \( f_m = 0.00400E - 2.9 \quad R^2 = 0.68 \quad (2) \)
- \( f_m = 0.00353E + 0.3 \quad R^2 = 0.57 \quad (3) \)
- \( f_m = 0.00454E - 10.1 \quad R^2 = 0.73 \quad (4) \)

Hence, the model for Finnish spruce can be expressed as:

- \( f_m = 0.00401E - 3.3 \quad (5) \)

In equation (5) the slope is given by the mean slope of equations (1) to (4). The constant is given in a similar way. Equation (5) is independent of the sample size in equations (1) to (4) and therefore gives a more realistic model for the combined Finnish spruce than a model based on pure regression analysis carried out for all single data.

The equations (1) to (5) are plotted in Figure 1. Finland is well represented by four samples from different growth regions. Based on these results the Southeast growth region seems to be somewhat different compared to the other ones. However, the difference is not remarkable and the slope of the regression lines varies less than 14% from the mean slope.
Figure 1. Dependence between bending strength and modulus of elasticity for Finnish, Norwegian and Swedish spruce.
Figure 2. Dependence between bending strength and modulus of elasticity for Nordic spruce.

The dependence between bending strength $f_m$ (N/mm$^2$) and modulus of elasticity $E$ (N/mm$^2$) for the 3 samples from Norway are:

- $f_m = 0.00445E - 6.6 \quad R^2 = 0.90 \quad (6)$
- $f_m = 0.00420E - 5.3 \quad R^2 = 0.72 \quad (7)$
- $f_m = 0.00425E - 4.3 \quad R^2 = 0.61 \quad (8)$

Hence, the model for Norwegian spruce can be expressed as:

$$f_m = 0.00430E - 5.4 \quad (9)$$

The equations (6) to (9) are plotted in Figure 1. Norway is represented by three samples mainly from the same growth region but sampled during different years. Based on these results there are no differences between the samples and the slope of the regression lines varies less than 4% from the mean slope.

The dependence between bending strength $f_m$ (N/mm$^2$) and modulus of elasticity $E$ (N/mm$^2$) for the 4 samples from Sweden are:

- $f_m = 0.00510E - 14.0 \quad R^2 = 0.74 \quad (10)$
- $f_m = 0.00370E + 0.6 \quad R^2 = 0.50 \quad (11)$
- $f_m = 0.00430E - 5.2 \quad R^2 = 0.54 \quad (12)$
- $f_m = 0.00430E - 8.4 \quad R^2 = 0.62 \quad (13)$
Hence, the model for Swedish spruce can be expressed as:

\[ f_m = 0.00435E - 6.8 \]  

(14)

The equations (10) to (14) are plotted in Figure 1. Sweden is well represented by four samples from at least three different growth regions. Based on these results the unknown growth region seems to be somewhat different compared to the other ones. However, the difference is not remarkable and the slope of the regression lines varies less than 18 % from the mean slope.

To compare spruce from Finland, Norway and Sweden to each other the equations (5), (9) and (14) are plotted in Figure 2. Based on these results there are no differences between the three countries. The slope of the regression lines varies between 0.00401 and 0.00435 and the difference is less than 5 % from the mean slope.

**Nordic pine**

The basic Nordic pine (Pinus sylvestris) data is summarised in Table 2. This data is not as extensive as the data for spruce but pine and spruce can be compared. As for spruce the bending strength was adjusted to the reference depth of 150 mm in accordance with EN 384. Furthermore, the modulus of elasticity was adjusted to the reference moisture content of 12 % in accordance with EN 384. Since the moisture content of the sample Fin-11 was about 13.5 % the bending strength values of this sample were increased by 3.75%.

The dependence between bending strength \( f_m \) (N/mm²) and modulus of elasticity \( E \) (N/mm²) for the sample from Finland is:

\[ f_m = 0.00440E - 6.2 \quad R^2 = 0.67 \]  

(15)

To compare pine and spruce from Finland equations (15) and (5) are plotted in Figure 3. Based on these results there are no remarkable differences between the species. The slopes of the regression lines are 0.00401 and 0.00440.

<table>
<thead>
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<th>Thickness mm</th>
<th>Width mm</th>
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<td>40</td>
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<td>Swe-11</td>
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</tr>
<tr>
<td>Swe-13</td>
<td>Unknown</td>
<td>199</td>
<td>45</td>
<td>140</td>
<td>SP</td>
</tr>
</tbody>
</table>
Figure 3. Dependence between bending strength and modulus of elasticity for pine and spruce from Finland (above) and Sweden (below).

The dependence between bending strength $f_m$ (N/mm$^2$) and modulus of elasticity $E$ (N/mm$^2$) for the 3 samples from Sweden are:

$$f_m = 0.00390 E - 3.5 \quad R^2 = 0.59 \quad (16)$$
$$f_m = 0.00350 E + 2.6 \quad R^2 = 0.53 \quad (17)$$
$$f_m = 0.00530 E - 16.7 \quad R^2 = 0.72 \quad (18)$$

Hence, the model for Swedish pine can be expressed as:

$$f_m = 0.00423 E - 5.9 \quad (19)$$

To compare pine and spruce from Sweden equations (19) and (14) are plotted in Figure 4. Based on these results there are no differences between the species. The slopes of the regression lines are 0.00423 and 0.00435.
Conclusions
The dependence between bending strength and modulus of elasticity of spruce (Picea abies) as well as of pine (Pinus sylvestris) grown in Finland, Norway and Sweden has been summarised. Based on about 1500 and 500 test results available for spruce and pine, respectively, the conclusions are:

- The differences between bending strength and modulus of elasticity of spruce (Picea abies) grown in Finland, Norway and Sweden is considerably smaller than the differences within a country.
- Hence, it is reasonable to use Finland, Norway and Sweden as a common growth area when settings are determined for grading machines which uses the modulus of elasticity to estimate the bending strength.
- Setting based on modulus of elasticity and derived for spruce (Picea abies) may be used also for pine (Pinus sylvestris). However, if more optimal settings are needed they shall be derived in accordance with the relevant European standards.

Literature
Foslie M. Moen K. (1968) Strength properties of Norwegian spruce (Picea abies Karst), Part 1. NTI.
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