The influence of knot size and location on the yield of grading machines

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Abstract

The basis for the derivation of settings for a grading machine is a comparison between destructive test data and data recorded by the machine. If the knots are part of the strength predicting model, the model covers the length effect in timber as it predicts the relatively lower strength for longer boards. This paper discusses the influence of the location of the maximum knot value on the performance of the machine. The maximum knot value between the inner load points is used for model derivation in approval bending tests. In practise, these machines do not only consider knots in the centre part of the board, but over the full length. Therefore, the indicating properties during deriving settings and during grading in practise differ from each other. The grading machine detects the largest knot value independent of the position along the length of the board; by means of this value the strength class is predicted. The influence of these differences is discussed. Finally, the effect on yield is shown.

1 Introduction

The object of this investigation is to show the difference between indicating property during grading and indicating property during testing of the very same board. It is not always possible to test the section with the maximum knot value due to the test setup in the laboratory. In practise however, the strength class is determined during grading in sawmills based on the maximum knot value of the entire board. This causes an influence on the yield which is based on the method of derivation only.

Grading machines based on optical or X-ray scanners can use the knot value to predict the strength class. These machines are able to detect knots over the complete length. In contrast to other machine grading parameters such as eigenfrequency or density, the knot value differs over the length of boards.

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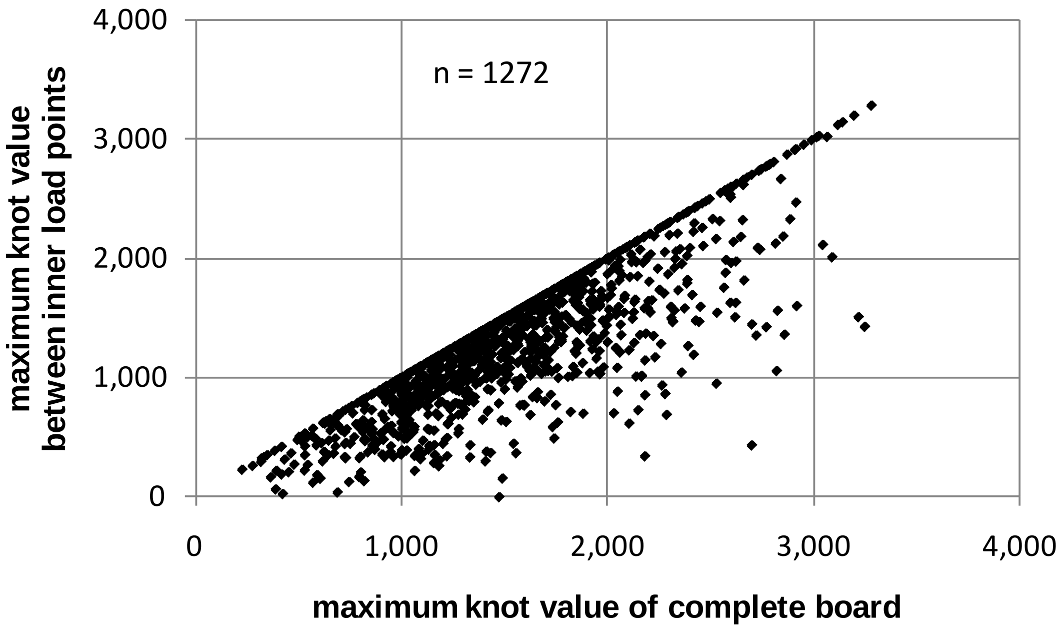

Figure 1: Maximum knot value of original board compared to the maximum knot value tested

Figure 1 shows the maximum knot value of the complete board (x-axis) against the maximum knot value between the inner load points in a four point bending test. The latter value is applied for deriving models and settings. Board length varied between four and five meters with different cross sections. The longer the original test board, the easier it becomes to locate the maximum knot value of the complete board inside the inner load points.

Knot values are determined by GoldenEye-702 based on an X-ray picture of the board and are evaluated according to a certain procedure, leading to numerical values in the range of 0 to about 3500.

The difference is caused by the test procedure given in prEN 384. According to prEN 384 a critical section shall be selected for each piece of timber (Figure 2). At this position the failure is expected to occur. This section can be selected by means of visual examination or any other information such as measurements from a strength grading machine. The regression model which is used to predict the strength is based on the maximum knot value located between the inner load points.

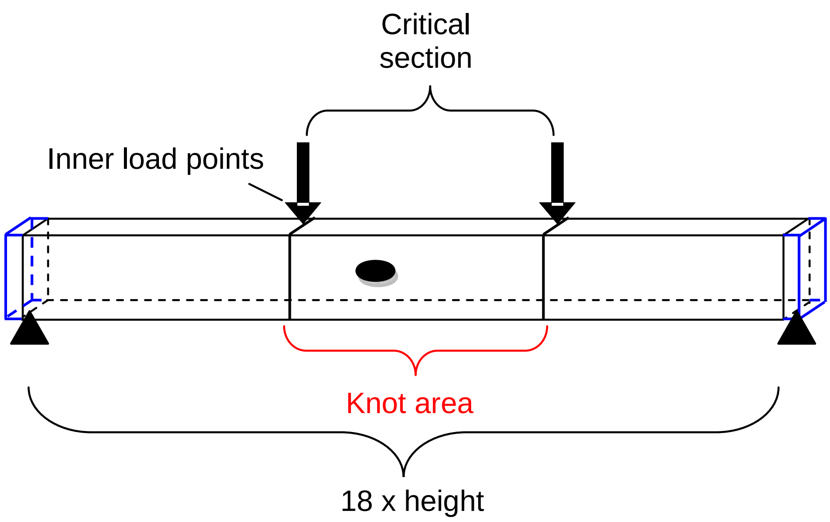

Figure 2: Knot area between the inner load points at bending test

The scatter plot in Figure 1 depicts in general, that in some cases the maximum knot value is not tested for deriving the model and settings. One third of the data points (n = 425) align perfectly with the bisecting line in Figure 1. For the remaining specimens a smaller knot value located in the test range is used.

Consequently, if the knot value is part of a mathematical strength grading model, the indicating properties during deriving settings differ from the indicating properties calculated during the grading process. The very same board is treated differently. The indicating property is either equal or lower in practise. In contrast to machines that determine weak locations such as knots, there are grading machines that determine properties such as density or eigenfrequency. These properties are not related to any weak locations in the board and are generally mean values covering the full board length. These parameters are scarcely influenced by different assessments between sawmill grading and laboratory testing.

2 Material and method

2.1 Material

The analysis is based on Norway spruce (*Picea abies*) from Central Europe. The specimens comprised 15 cross-sections (thickness 20 to 165 mm, width 64 to 281 mm), in total 1272 specimens. The models and settings were calculated according to European standards (prEN 14081, prEN 384, and prEN 408); the three grade determining properties (strength, modulus of elasticity, and density) are considered. The machine data were recorded by GoldenEye-706.

Table 1 shows the mean value and the coefficient of variation (cov) of the bending strength f_m, the local modulus of elasticity E_m and the density ρ_{12}.

Table 1: Description of sample

n	f_m		E_m		ρ_{12}	
	mean N/mm²	cov %	mean N/mm²	cov %	mean kg/m³	cov %
1272	39.0	31.5	11300	25.6	438	11.3

2.2 Method

2.2.1 Knot values during laboratory testing

Based on these specimens two different models are calculated. These two models could be applied in practise as well. The first model (model 1) simulates a grading machine which is capable to detect the eigenfrequency and the density; the outcome of this is an indicating property (IP_1) based on the dynamic modulus of elasticity (MOE).

The second machine is also able to detect and calculate the dynamic modulus of elasticity. Additionally, this kind of machine is able to detect knots. Therefore, the knot information is used in the second model to predict the strength more accurately (IP_2).

$$Model\ 1: \quad IP_1 = a + b \times MOE \qquad \text{Equation 1}$$

$$Model\ 2: \quad IP_2 = c + d \times MOE + e \times knot \qquad \text{Equation 2}$$

The indicating property (IP_i) is calculated from MOE (dynamic modulus of elasticity in N/mm²) and knot (biggest knot related to the cross-section). Model 2 considers the maximum knot value measured in the range between the inner load points. According to the current method, this knot value is used to develop the model as well as to derive settings. By means of 1272 specimens of Norway spruce the regression coefficients (a, b, c, d, and e) are calculated. The knot value is multiplied by a negative factor, i.e. the larger the knot, the lower the corresponding indicating property (IP_2).

2.2.2 Knot values during grading

During grading in practise the length of the entire board needs to be considered since the cross section with the lowest strength is governing strength class assignment. Software calculates the maximum knot value. This value is plugged in the developed model, the indicating property is generated.

3 Results

It is obvious, that the coefficient of determination (r^2) between the bending strength and the indicating property of model 2 is higher than that of model 1. The additional parameter leads to an increased r^2-value of about five percent. In machine grading the correlation between indicating property and bending strength plays an important role, if different models are compared.

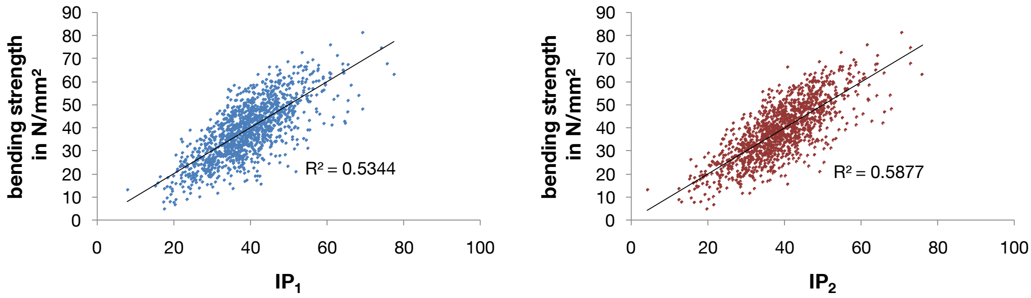

Figure 3: Bending strength versus indicating property for different grading models

The higher coefficient of determination results in higher yields for the wood industry. As it is shown in Table 2, in each strength class the more complicated model (IP_2) achieves higher yield. The difference between the two models falls to a minimum at strength class C 18 (0.1 %). The yields reach a peak at C 30; yield of model 1 exceeds yield of model 2 by 7.9 %. At C 18 and C 24 the additional information of the knot value seems to be of lower importance than at higher strength classes. Table 2 compares the yields which are given in reports for an approval; it must be reemphasized, that for model 2 the maximum knot value between the inner load points is considered only.

Table 2: Yields in different strength classes (EN 338)

	$model_1$ [%]	$model_2$ [%]	$(model_2 - model_1) / model_1$
C 18	99.4	99.5	0.00
C 24	95.0	95.8	0.01
C 30	64.7	72.6	0.12
C 35	13.3	19.7	0.48
C 40	4.2	6.8	0.62

For grading results of the complete board, model 2 is further discussed since model 2 includes the knot parameter. The results for model 1 do not change. The very same boards (n=1272) are graded again. In real life grading, the machine detects the knots over the entire length. During deriving settings the maximum knot value between the inner load points are used. Figure 4 shows the effect on the indicating property of each board caused by different assessment of the maximum knot value between testing and grading.

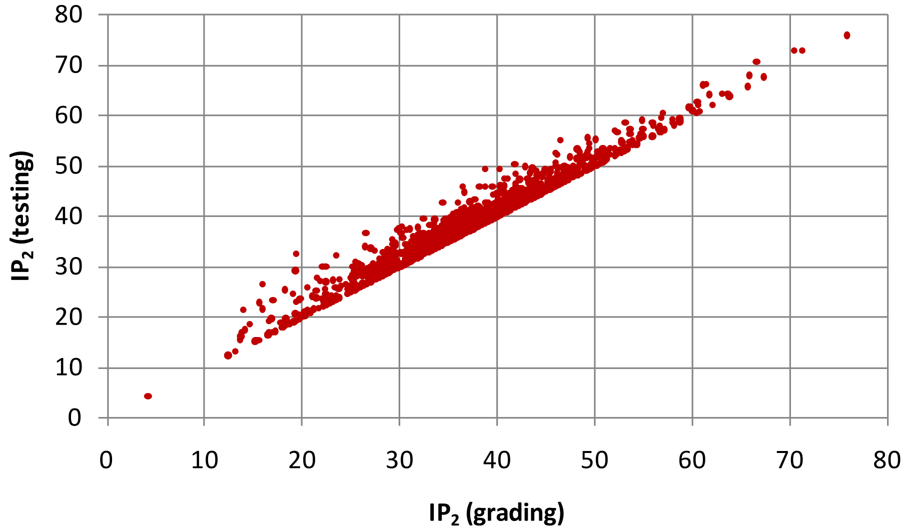

Figure 4: Indicating properties of model 2 during testing and grading

The scatter in Figure 1 affects the scatter in Figure 4. As it is known from Figure 1, approximately one third of the boards (n = 425) have same IP-values during laboratory testing and sawmill grading. All these points are located on the bisecting line. The remaining boards are systematically assigned to lower indicating properties during grading. The maximum knot value of the entire board is at least the maximum value used when deriving settings (see Figure 1). With increasing knot value the indicating property IP_2 of model 2 decreases, because the knot value is multiplied by a negative factor (the sign of the regression coefficient e is negative). As a result, the indicating property of the entire board is equal to or less than the indicating property used for deriving settings (Figure 4).

Figure 5 shows the impact on yield for different strength classes, models, and settings. As a reference, the yields of the machine type based on model 1 are mentioned. There is of course no difference between grading and testing when using model 1. The blue and the dark red columns of Figure 5 repeat the yields given in Table 2. The light red column on the right hand side illustrates the yield of the very same board, when they are graded in practise.

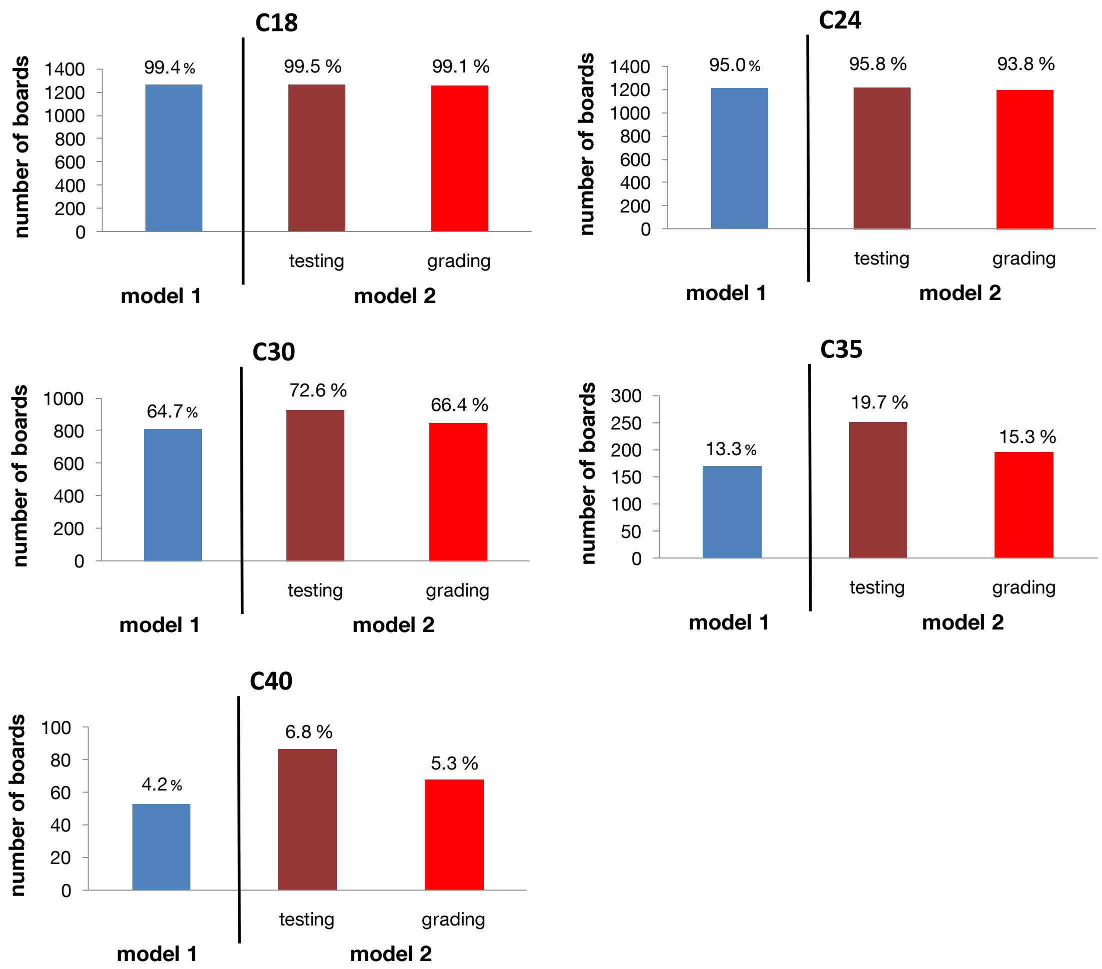

Figure 5: Yields separated for model 1 and model 2

The difference between grading yield and testing yield increases for higher strength classes, because even a small knot has a considerable influence in the case of almost defect free timber. Across all five strength classes considered the yield of the very same boards during grading is lower than during testing, if model 2 is used (dark and light red columns on the right side). The difference of yield ranges between 0.4 % for C 18 and 6.2 % for C 30. Looking at C 18 and C 24, in practise the yield of the more complicated model 2 ranks even below the yield of model 1 (blue column on the left side).

4 Conclusions

When deriving settings for bending members the maximum knot value between the loading points is used. In many cases, the knot value that is tested is smaller than the knot value of the entire board, because it is not possible to place the maximum knot value between the loading points. If the knot value is used in praxis it has almost no effect on the yield in low strength classes, because these boards have generally a low quality over the full length of the boards. In high strength classes the yields increase, when the complex model including the knot parameter is used. Such a machine covers automatically the length effect in timber as it predicts the relatively lower strength for longer boards (Isaksson and Thelandersson 1995). The indicating property differs between the derivation of settings and the practice for one and the same board. This is the case, if the knot value is included in the model, but the maximum knot value cannot be placed between the load points. Hence, the yields in practise differ from those calculated during the derivation of settings. Grading machines that are able to detect local weaknesses (for example knots) perform better than grading machines that determine only average board parameters. In principle, grading machines that detect local weaknesses are also able to correctly grade correctly also longer boards than used in the approval testing. However, this higher performance is not considered when machines are approved according to the European standard EN 14081.

The effect also depends on:

- the model used
- the species
- the original length of the boards tested
- the width of the boards tested at bending tests

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