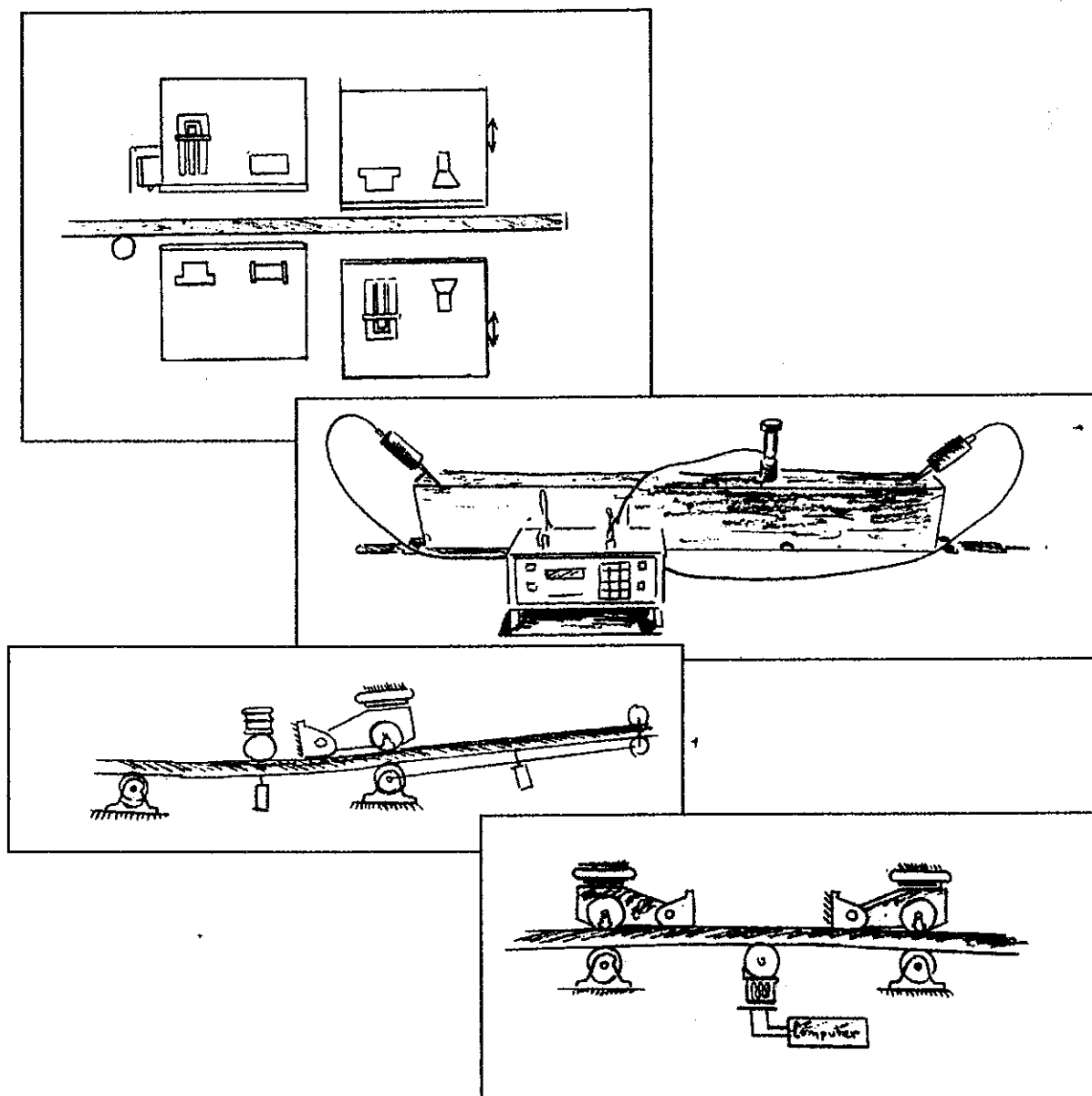


# Machine Strength Grading

## Comparison of Four Different Systems



Lars Boström

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## Abstract

### Machine strength grading - comparison of four different systems

The investigation presented in this report is part of a project concerning machine strength grading of timber. The report describes a comparison of four different machine grading systems. The grading machines used were Computermatic, Cook-Bolinder, Finnograder and Sylvatest. In addition, visual grading and measurement of knots were performed, but only some of the knot data is presented here.

Three dimensions, 45x120, 45x195 and 70x170 mm, of spruce timber (*Picea abies*) were examined. Two of these dimensions, 45x195 and 70x170 mm, were German timber, and the 45x120 mm timber was Swedish.

The investigation shows that the correlation between properties measured by the machines and the bending strength of the material varies slightly among the different systems. Cook-Bolinder and Computermatic, which are bending machines, have a coefficient of correlation around  $r^2 = 0.50-0.60$ , while  $r^2 = 0.35-0.50$  is the coefficient for Finnograder, which operates with microwave and gamma-radiation techniques, and  $r^2 = 0.20-0.50$  is the coefficient for Sylvatest, a field instrument based on ultrasonic pulse velocity measurements.

Grading yield and characteristic strength in the different grades used in Sweden have been compared. The results confirm that the currently used setting values can, and in some cases have to, be revised. The only machine with acceptable setting values is the Finnograder.

Key words: timber, machine strength grading, visual strength grading, bending strength, modulus of elasticity

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# Contents

<b>Abstract</b>	2
<b>Preface</b>	5
<b>Notations</b>	6
<b>1 Introduction</b>	7
<b>1.1 Background</b>	7
<b>1.2 Objective of the investigation</b>	8
<b>1.3 Scope</b>	8
<b>2 Description of the grading machines</b>	9
<b>2.1 General</b>	9
<b>2.2 Cook-Bolinder</b>	9
2.2.1 Construction of the machine - measurement principles	9
2.2.2 Setting of the machine	10
<b>2.3 Computermatic</b>	11
2.3.1 Construction of the machine - measurement principles	11
2.3.2 Setting of the machine	11
<b>2.4 Finnograder</b>	12
2.4.1 Measurement principles	12
2.4.2 Estimation of bending strength ( $f_m$ )	14
2.4.3 Setting values	14
<b>2.5 Sylvatest</b>	14
2.5.1 Measurement principles	14
2.5.2 Estimation of strength	15
2.5.3 Setting values	15
<b>2.6 Principles for deriving machine settings</b>	15
<b>3 Test material</b>	17
<b>3.1 Origin and quality</b>	17
<b>3.2 Handling and conditioning</b>	17
<b>4 Measurements</b>	18
<b>4.1 Machine strength grading</b>	18
4.1.1 Cook-Bolinder	18
4.1.2 Computermatic	18
4.1.3 Finnograder	19
4.1.4 Sylvatest	19

<b>4.2</b>	<b>Other measurements</b>	20
4.2.1	Bending strength	20
4.2.2	Static modulus of elasticity	20
4.2.3	Density	21
4.2.4	Moisture content	22
4.2.5	Knot measurements	22
<b>5</b>	<b>Results</b>	24
<b>5.1</b>	<b>General</b>	24
<b>5.2</b>	<b>Mechanical properties of the timber</b>	24
<b>5.3</b>	<b>Bending strength vs. edgewise modulus of elasticity</b>	24
<b>5.4</b>	<b>Edgewise modulus of elasticity vs. flatwise modulus of elasticity</b>	26
<b>5.5</b>	<b>Bending strength vs. flatwise modulus of elasticity</b>	27
<b>5.6</b>	<b>Bending strength vs. machine measurements</b>	29
5.6.1	Bending strength vs. Cook-Bolinder measurements	29
5.6.2	Bending strength vs. Computermatic measurements	30
5.6.3	Bending strength vs. Finnograder measurements	31
5.6.4	Bending strength vs. Sylvatest measurements	32
<b>5.7</b>	<b>Edgewise modulus of elasticity vs. machine measurements</b>	34
5.7.1	Edgewise modulus of elasticity vs. Cook-Bolinder measurements	34
5.7.2	Edgewise modulus of elasticity vs. Computermatic measurements	35
<b>5.8</b>	<b>Grading yield and characteristic strength</b>	36
5.8.1	Cook-Bolinder	37
5.8.2	Computermatic	37
5.8.3	Finnograder	38
5.8.4	Sylvatest	39
<b>5.9</b>	<b>Comparison between the different machines</b>	39
5.9.1	Correlation between bending strength and indicating property	39
5.9.2	Correlation between edgewise modulus of elasticity and indicating property	40
5.9.3	Grading yield	40
5.9.4	Characteristic bending strength	42
<b>5.10</b>	<b>Combined visual and machine strength grading</b>	43
5.10.1	Cook-Bolinder	44
5.10.2	Computermatic	44
<b>6</b>	<b>Conclusions</b>	46
	<b>References</b>	47
	<b>Appendix: Experimental results</b>	48

## **Preface**

The present investigation is part of a comprehensive research project concerning machine strength grading. The project is being carried out in cooperation between the Swedish Institute for Wood Technology Research (TRÄTEK) and the Swedish National Testing and Research Institute (SP).

The present investigation was planned by Jan Brundin at TRÄTEK and Carl-Johan Johansson and Lars Boström at SP.

The timber was machine graded at SP (Computermatic, Cook-Bolinder and Sylvatest) and at Limmareds Skogar (Finnograder). The machine grading and strength tests were mainly performed by Peter Dresen. Bertil Stenman, Thomas Claesson, Bertil Johansson, Kjell Pettersson and Mattias Magnusson were also involved in the grading and the testing.

Measurements of knots were carried out at SP by Kjell Sjöberg from TRÄTEK together with Bertil Stenman and Kjell Pettersson. Transformation of the knot projections into digital form, calculation of different knot measures and grading according to the ECE-rules and the Nordic T-rules were performed at the Technical University of Denmark under the supervision of Preben Hoffmeyer.

Carl-Gunnar Nyman, Limmareds Skogar, made the grading in the Finnograder possible and Limmareds Skogar also supplied the 45x120 mm timber, free of charge.

Borås in October 1994

Lars Boström

## Notations

All symbols are explained where they first appear. The following is a brief overview of some symbols.

bits	deflection measured by Computermatic (1 bits=0.1905 mm)
CRATIO	sum of knots on the face and the edges divided by $h + 2 \cdot t$
E	modulus of elasticity
$E_{\text{comp}}$	modulus of elasticity determined from Computermatic measurements
$E_{\text{cook}}$	modulus of elasticity determined from Cook-Bolinder measurements
$E_{\text{flatwise}}$	modulus of elasticity determined flatwise by a three-point bending test
$E_{\text{m}}$	modulus of elasticity determined edgewise by a four-point bending test (EN 408)
$E_{\text{machine}}$	modulus of elasticity determined by a grading machine
$E_{\text{sylva}}$	modulus of elasticity determined from Sylvatest measurements
$f_{\text{finno}}$	modulus of rupture estimated by Finnograder
$f_{\text{m}}$	static bending strength (EN 408)
G	shear modulus
h	depth of a cross-section (always the greater of the cross-section dimensions)
I	moment of inertia
I.P.	indicating property
$k_{\text{h}}$	correction factor for depth
L	length between support rollers
M	moment
m	mass
MKAR	area of the projection of all knots in the outer quarter of the width divided by $\frac{h \cdot t}{4}$
MOE	modulus of elasticity
MOR	modulus of rupture (bending strength)
NRATIO	knot size on the edge divided by t
P	force
t	thickness of a cross-section
TKAR	area of the projection of all knots in a cluster divided by $h \cdot t$
u	moisture content
V	volume
$\delta$	deflection
$\rho$	density
$\sigma$	stress

# 1 Introduction

## 1.1 Background

Machine strength grading was introduced in the Nordic countries and Great Britain in the 1970s. The first grading machine in Sweden was approved in 1974. Since then the number of machines has grown to 35 (November 1993). All of them, except one, are "bending" machines. There are four different types:

- Computermatic/Micromatic (31 machines)
- Cook-Bolinder (2 machine)
- Raute Timgrader (1 machine)
- Finnograder (1 machine)

The machines are basically unchanged since they were introduced on the market. No further development has been done, probably owing to the limited market. The amount of machine stress graded timber in Sweden is about 250,000 m<sup>3</sup>/year, see Table 1.1.

**Table 1.1** Amount of stress graded timber in Sweden 1989-1993 (m<sup>3</sup>).

Year	For export to England	For use in Sweden	Total amount
1989	165,683	123,207	288,890
1990	146,281	112,102	263,846
1991	128,852	116,994	245,846
1992	165,595	92,877	258,472
1993	203,977	65,781	269,758

At the beginning of the 1980s a completely new machine type, the Finnograder, was introduced [1]. It uses gamma radiation/absorption to determine the density of the wood, and microwave technique to detect knots. The machine was officially approved for grading in 1993.

During 1994, a European standard for machine strength grading of timber will be introduced [2]. This has given rise to an increased interest in machine strength grading, as it will enable a widening of the market for machine strength graded timber and, of course, for grading machines. The author knows of two new machines being developed at present. Both are basically bending machines, but naturally equipped with modern technology, such as laser to measure the thickness and the deflection of the timber.

In this context, the Swiss Sylvatest should also be mentioned [3]. It is not a fully developed grading machine, but rather a field instrument. It sends an ultrasonic pulse through the timber and measures the speed of the pulse.

## **1.2 Objective of the investigation**

With several different grading machines on the market, it is of great interest to potential buyers to be able to compare the machines. One very important factor is the yield of timber in each grade. Good grading economy requires high yields.

The yields depend on the ability of the machine to estimate the strength and the choice of setting values. The main objective of the present investigation was therefore to compare existing grading machines on equal terms, i.e. by using the same pieces of timber of different sizes in different types of grading machine.

Another important objective has been to obtain additional timber strength data to enable improved setting values for the grading machines, especially for thick timber.

## **1.3 Scope**

Four different stress grading machines have been examined: Computermatic, Cook-Bolinder, Finnograder and Sylvatest. The study also includes some discussion on the possibility of improving the bending type strength grading machines. For example it is of interest to know to what extent the accuracy could be improved by providing machines with knot-detecting devices.

## **2 Description of the grading machines**

### **2.1 General**

In a grading machine, one or several properties of the timber are measured. These properties are more or less well correlated with the strength of the timber. In the Computermatic machine only one property is measured, namely the deflection caused by the constant bending load acting on the timber as it passes through the machine. In the Finnograder, however, several properties are measured: the density, the slope of grain, and the size and location of knots.

In this chapter a detailed description is given of the properties measured in the machines and how these are used to estimate the strength of the timber. In the following, the term "indicating property" (I.P.) is used. In the standard proposal for machine strength grading, prEN519 [2], I.P. is defined as:

measurement or combination of measurements closely related to strength, from which the machine determines the grade of each increment of length of a piece of timber

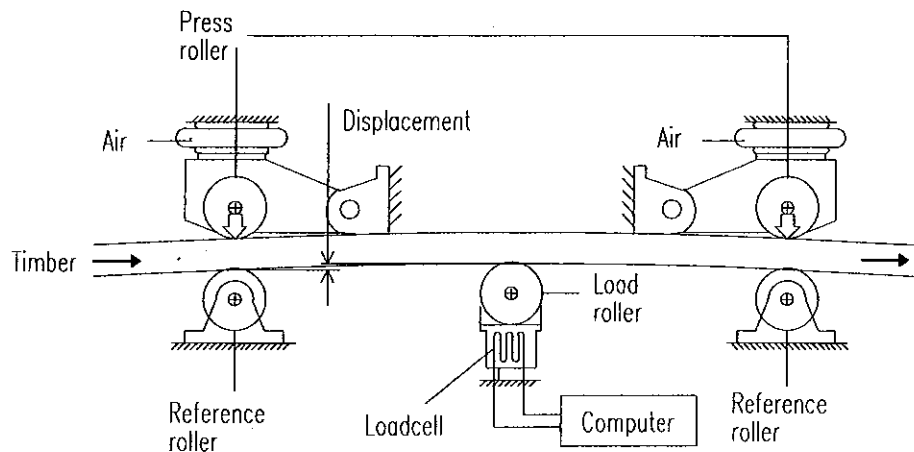
The following grading machines and non-destructive testing equipment were used in the project:

Computermatic MK PIVa	Production version and the most frequently used grading machine in Sweden
Cook-Bolinder SG-AF	Modified laboratory machine
Finnograder	Production version
Sylvatest	Non-destructive testing equipment

### **2.2 Cook-Bolinder**

#### **2.2.1 Construction of the machine - measurement principles**

The Cook-Bolinder machine measures the load required to give the timber a preset deflection. The machine consists of a cabinet in which there are two rollers (pinch rollers) at each of the infeed and outfeed end, that transport the timber through the machine. In the middle, between these, another roller with a load cell gives the timber a constant deflection. The distance between the support rollers is 900 mm. Normal grading speed is 60 - 100 m/min. The construction of the Cook-Bolinder machine is shown in Figure 2.1.



**Figure 2.1** Three-point bending test as performed in Cook-Bolinder.

The pre-set deflection used depends on the thickness of the timber, and the values are presented in the manual for the machine. Timber is seldom straight, rather more or less bow is present and has to be compensated for. The timber therefore has to be passed through the machine twice, and before the second passage the board has to be turned 180°. To obtain high speed in the grading, it is necessary to have two machines, one after the other. The indicating property is the mean of the two load values.

The bending stress ( $\sigma$ ) in the timber is not constant, but depends on the modulus of elasticity ( $E$ ), the deflection ( $\delta$ ) and the thickness ( $t$ ) of the timber.

$$\sigma = \frac{6 \cdot \delta \cdot E \cdot t}{L^2} \quad \text{Eq. 2.1}$$

The indicating property is measured every 100 mm in normal production machines, except for 480 mm at each end of the timber. In the machine used in this study, which is a slightly modified production machine, load values were recorded every 10 mm.

## 2.2.2 Setting of the machine

The preset deflection values used for the timber in this investigation are given in Table 2.1, and are also the values used for normal grading. According to Eq. 2.1, a deflection of  $\delta = 5.9$  mm for 45 mm thick timber corresponds to a bending stress of  $\sigma = 24$  MPa, if the modulus of elasticity in bending is  $E = 12\,000$  MPa. This is quite a high stress, which could possibly damage the timber. Therefore, in a normal production machine, the pinch roller pressure is adjusted so that the bending stress is maximized to  $\sigma = 15 - 20$  MPa. In the laboratory machine used in this project, a high pinch pressure was applied in order to obtain correct load data for the calculation of the modulus of elasticity along the timber.

In the common production machine, the load values along the timber are compared with limits for each grade. These load limit values are calculated as presented below. In Sweden, load limit values are given for a number of nominal cross-section dimensions. If the actual, measured dimensions deviate from the nominal, the preset deflection is adjusted.

**Table 2.1** Examples of preset deflections for Cook-Bolinder.

Timber thickness (mm)	Deflection (mm)
45	5.9
70	3.3

The load limit values for different grades and timber sizes can be calculated according to

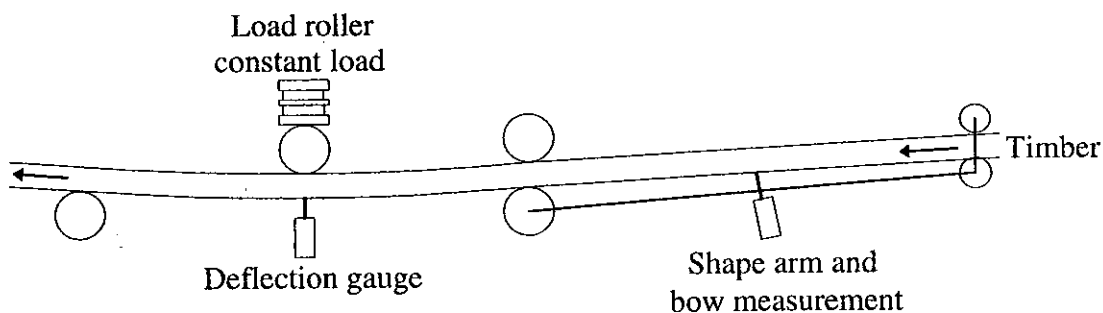
$$P_{lim} = 4.53 \cdot \delta \cdot h \cdot t^3 \cdot (E_{m,lim} - 840) \quad \text{Eq. 2.2}$$

where  $\delta$  is the pre-set deflection,  $h$  is the depth of the timber,  $t$  is the timber thickness and  $E_{m,lim}$  is the edgewise modulus of elasticity limit for a grade (in MPa). The background of this expression is described in section 2.6.

## 2.3 Computermatic

### 2.3.1 Construction of the machine - measurement principles

Computermatic applies a constant load to the timber and the resulting deflection is measured and recorded in binary form. Thus the deflection is the indicating property. In order to compensate for bow, the Computermatic has a "shape arm" mounted at the infeed side. The bow is measured with a transducer mounted on the shape arm, and the bow measurement is subtracted from the measured deflection at the loading point. The Computermatic machine has pinch rollers only at the infeed side. Normal grading speed is 60 - 100 m/min. The principle design is shown in Figure 2.2.



**Figure 2.2** Principle design of the Computermatic grading machine.

### 2.3.2 Setting of the machine

The force applied to the timber ( $P$ ) is chosen so that the bending stress in the timber is equal to  $\sigma = 13.8$  MPa (2000 psi).

$$P = \frac{2 \cdot \sigma \cdot h \cdot t^2}{3 \cdot L} \quad \text{Eq. 2.3}$$

where  $h$  is the depth of the timber,  $t$  is the thickness of the timber and  $L$  is the span between the support rollers (914 mm). In Table 2.2 the loads used in this investigation are shown.

**Table 2.2** Examples of pre-set loads for Computermatic.

Timber size (mm)	Load (kN)
45x120	2.41
45x195	3.57
70x170	11.87

The settings are calculated according to

$$\delta_{lim} = \frac{2.325 \cdot 10^6}{t \cdot (E_{m,lim} - 840)} \quad \text{Eq. 2.4}$$

where  $\delta_{lim}$  is the limit value of the deflection for the different grades,  $t$  is the thickness and  $E_{m,lim}$  is the edgewise modulus of elasticity for the specific grade. Note that Eq. 2.4 is valid only if the pre-set load is calculated according to Eq. 2.3.

It should be noted that the Computermatic measures the deflection with a digital transducer with a resolution of 1 bits = 0.1905 mm (bits is the unit used by the manufacturer).

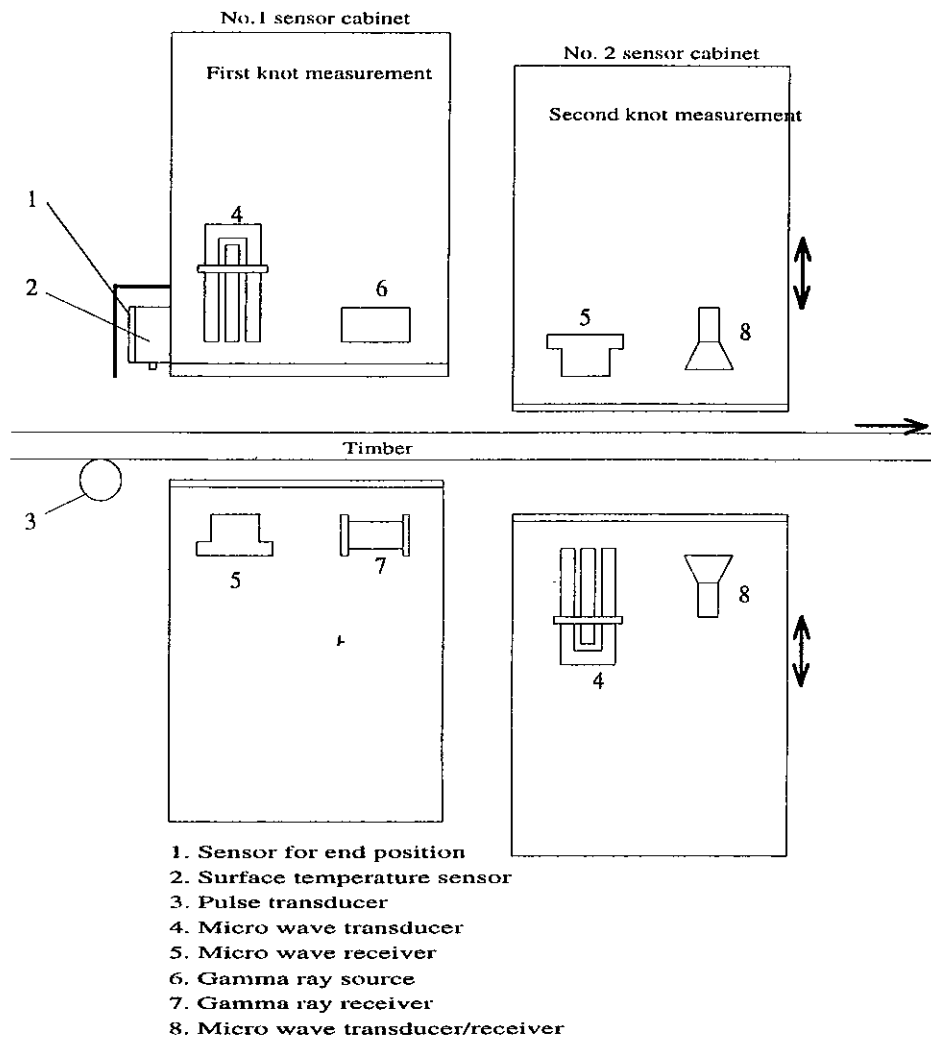
## 2.4 Finnograder

### 2.4.1 Measurement principles

Finnograder is a production machine that differs considerably from the previously described bending machines. All measurements are made with no contact with the timber. The machine measures the location and size of knots, the slope of grain, and the density. Furthermore, the machine measures the moisture content in order to adjust the density to correspond to a specified moisture content. The machine also measures the timber surface temperature, which is used to adjust the moisture content values.

The measurements are made for every 10 mm of the board. Normal production speed is 150-300 m/min.

One important advantage of the Finnograder, as compared with the bending machines, is that the whole piece of timber is graded. The measurements starts at about 50 mm from the leading end and stops at around 50 mm before the trailing end.



**Figure 2.3** Principle design of the Finnograder stress grading machine.

The density is obtained from the absorption of gamma-rays. This measurement gives the total mass of wood and water, and thus the amount of water (moisture content) has to be determined. The moisture content measurement is made by means of microwaves. However, the attenuation of microwaves is dependent on the temperature of the water, and therefore temperature has to be measured. The temperature is measured using infrared radiation from the surface.

Slope of grain is measured using polarized microwaves. The basis of the measurement is that the dielectric constant is bigger in the grain direction than in the direction perpendicular to the grain. Two different measurements of slope of grain are made. One represents the slope of grain of a knot-free portion, and is taken from a point of maximum attenuation. The second is a filtered value over 11 subsequent measurements.

The knot measurements are based on the change in the phase velocity of microwave radiation. The principle is that the dielectric constant of the knot is larger than that of the surrounding wood. Up to 15 detectors (for wide timber) are used over the width of the piece of timber. The readings are weighted (weight increasing towards the edges of the timber) and electrically summarized for both sides of the width.

## 2.4.2 Estimation of bending strength ( $f_m$ )

The strength of the timber is estimated from an empirically developed equation, Eq. 2.5. It should be noted that the estimated bending strength is the characteristic value.

$$f_m = (C_1 + C_2 \cdot \rho + C_3 \cdot \rho^2 + C_4 \cdot \rho^3) \cdot e^{-f(\rho, KVS, KVD, SFG, SFK, u)} \quad \text{Eq. 2.5}$$

where  $C_n$  are constants,  $\rho$  is density, KVS is sum of knots, KVD is the difference between knot values at both halves of the width, SFG is the slope of grain in knot-free areas, SFK is slope of grain at knots, and  $u$  is the moisture content.

## 2.4.3 Setting values

The Finnograder has quite recently been officially approved in Sweden, with the grade limits presented in Table 2.3 below.

**Table 2.3** Grade limits for Finnograder.

Strength class	Bending stress from Finnograder (MPa)
C30	$\geq 30$
C24	$\geq 24$
C18	$\geq 18$

## 2.5 Sylvatest

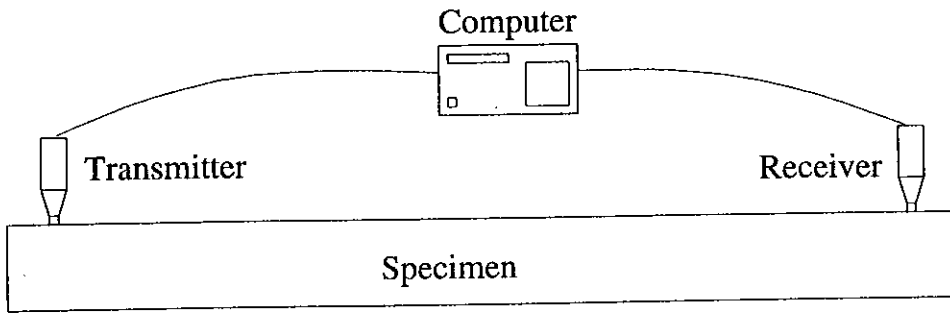
### 2.5.1 Measurement principles

Sylvatest in its present shape is not a production machine, but rather a field instrument. The principle of Sylvatest is that the speed of an ultrasonic wave is measured and then is correlated to the strength of the material, see Eq. 2.6.

$$E = \rho \cdot c^2 \quad \text{Eq. 2.6}$$

where  $c$  is the speed of the ultrasonic wave and  $\rho$  is the density of the material.

The device consists of one transmitter probe, one receiver probe, one probe for moisture content and temperature measurements and one box containing the computer to which the probes are connected, see Figure 2.4. Sylvatest measures the time it takes for an ultrasonic wave to travel from the transmitter to the receiver. By giving the computer the distance between transmitter and receiver, the speed of the ultrasonic wave can be computed.



**Figure 2.4** Principle of Sylvatest.

## 2.5.2 Estimation of strength

The computer in Sylvatest estimates the grade of the timber from the knowledge of species, ultrasonic wave speed, type of cross-section (round or rectangular), moisture content and temperature. The relationship between strength and speed of sound has been established by the manufacturer of Sylvatest and, for conifers, is

$$f_m = 0.039 \cdot c - 167 \quad \text{Eq. 2.7}$$

## 2.5.3 Setting values

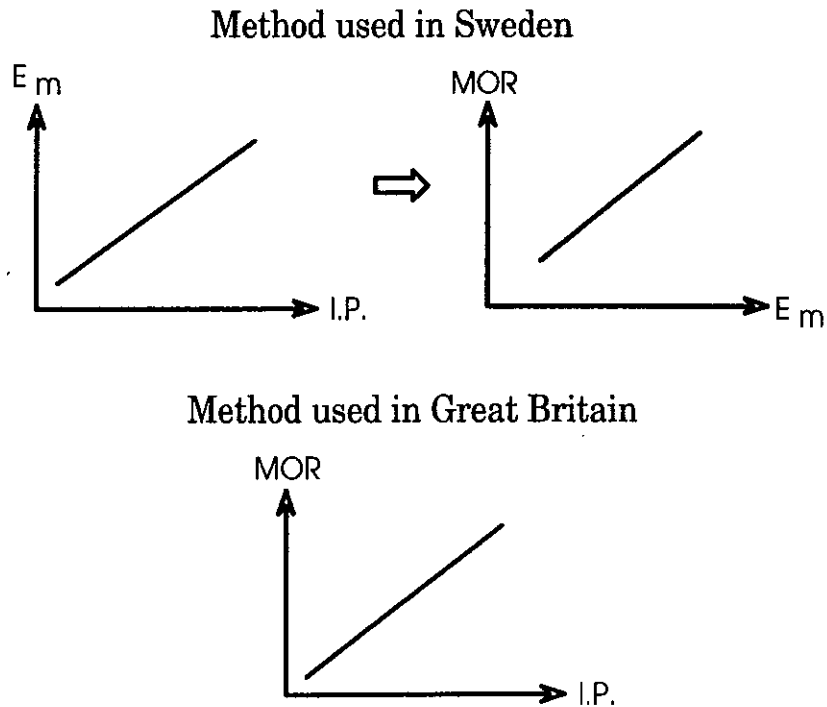
The setting values to be used for Swedish timber according to the manufacturer of Sylvatest are presented in Table 2.4

**Table 2.4** Setting values and some results for Sylvatest given by the manufacturer [4].

Strength class	Speed	mean $f_m$	5% fractile
C12	4750-5000	25	13
C18	5000-5250	34	19
C24	5250-5500	40	24
C30	>5500	54	36

## 2.6 Principles for deriving machine settings

When determining setting values for bending, two different methods can be distinguished between. In both methods, the strength of the material is estimated using some substitute parameter, for example the indicating property. The substitute parameter used can be the deflection measured as in a Computermatic machine, which is the method used in Great Britain [5], or it can be the edgewise modulus of elasticity ( $E_m$ ) as in the method used in Sweden [6]. These two methods represent two fundamentally different techniques for determining the setting values. The method used in Sweden relies on a predefined relation between edgewise modulus of elasticity ( $E_m$ ) and bending strength ( $f_m$ ), while the method used in Great Britain directly relates the indicating property to the bending strength ( $f_m$ ), see Figure 2.5.



**Figure 2.5** Different principles to establish a relation between indicating property (I.P.) and bending strength of the material ( $f_m$ ).

The advantage of the method used in Sweden is that less destructive testing is necessary to determine the setting values. The setting values of the grading machines are thus based on an established relation between  $E_m$  and the indicating property, and so destructive tests can be avoided to a large extent.

The setting values for bending machines in Sweden are based on results from an investigation carried out in the 1970's [6]. Two species, pine (*Pinus sylvestris*) and spruce (*Picea abies*), were included. For timber thicknesses from 34 mm up to 63 mm, the following values are valid for the different bending machines:

**Table 2.5**  $E_m$ -limits used in Sweden for the different grades.

Strength class	$E_m$ -limit (MPa)
C30	> 11580
C24	> 9250
C18	> 7610

The limit values for the I.P. can be derived from the following relation between  $E_m$  and the stiffness measured by the machine,  $E_{\text{machine}}$ :

$$E_m = 1.21 \cdot E_{\text{machine}} + 840 \text{ [MPa]} \quad \text{Eq. 2.8}$$

and

$$E_{\text{machine}} = \frac{P \cdot L^3}{48 \cdot \delta \cdot I} \quad \text{where } I = \frac{h \cdot t^3}{12} \quad \text{Eq. 2.9}$$

### 3 Test material

#### 3.1 Origin and quality

The material was spruce (*Picea abies*) from both Sweden and Germany. Two dimensions, 45x195 mm and 70x170 mm, were German timber from the Heidenheim/Ulm area in Bavaria. One dimension, 45x120 mm, was timber from Limmareds Skogar in southwestern Sweden. The number of specimens is shown in Table 3.1.

**Table 3.1** Number of specimens.

Dimension	Number of specimens
45x195	121
70x170	124
45x120	170

The length of the timber varied from 4 to 6 meters. The German timber had been graded in Germany with the aim of obtaining equal shares of the DIN 4074 grades S13, S10 and S8. The timber therefore has to be regarded as somewhat better than saw fallen quality.

The Swedish timber was of saw fallen quality.

#### 3.2 Handling and conditioning

The timber was kept under cover in the laboratory hall at SP. The moisture content was measured several times, and always before a grading was performed. The moisture content was between 10 and 15%. In the German timber the moisture content varied less and was between 11 and 13%, probably because it had been kept for a long time in the laboratory and thus had had a long conditioning time. The higher variation in the Swedish timber is likely to be an effect of it having arrived directly from the saw mill and being tested after only a short conditioning period.

## 4 Measurements

### 4.1 Machine strength grading

#### 4.1.1 Cook-Bolinder

The settings of the machine were in accordance with the manual, i.e. like in a production machine. The grading was performed at SP in a modified machine. The machine was run at a speed of 50 m/min in order to avoid dynamic effects such as vibrations and swinging of the timber. The load was measured every 10 mm along each piece of timber except for 450 mm at the leading and trailing ends. One machine was used, and so the timber was passed through the machine twice, and turned before the second run. In order to make a comparison between machines possible, the modulus of elasticity was determined as

$$E_{\text{cook}} = \frac{P \cdot 0.9^3}{4 \cdot \delta \cdot h \cdot t^3} \quad \text{Eq. 4.1}$$

where  $E_{\text{cook}}$  is the modulus of elasticity measured in the Cook-Bolinder machine,  $P$  is the measured load,  $\delta$  is the pre-set deflection,  $h$  is the timber depth and  $t$  is the thickness of the timber.

The measured modulus of elasticity was corrected to be valid for a moisture content of 12%, using the following empirical equation [7]:

$$E_{\text{cook},12\%} = \frac{E_{\text{cook}}}{1 + 0.0143 \cdot (12 - u)} \quad \text{Eq. 4.2}$$

The results presented always give the corrected values, unless otherwise noted.

#### 4.1.2 Computermatic

The settings of the machine were in accordance with the manual, i.e. like in a production machine. The grading was performed at SP in a normal production machine. The machine was run at a speed of 50 m/min in order to minimize the dynamic effects due to vibrations and swinging of the timber. The deflection was measured every 152 mm along each piece of timber except for 600 mm at the leading and trailing ends. In order to make a comparison between machines possible the modulus of elasticity was determined as:

$$E_{\text{comp}} = \frac{P \cdot 0.914^3}{4 \cdot 0.1905 \cdot \delta \cdot h \cdot t^3} \quad \text{Eq. 4.3}$$

where  $E_{\text{comp}}$  is the modulus of elasticity determined from the Computermatic measurement,  $P$  is the pre-set load,  $\delta$  is the measured deflection in bits (1 bits = 0.1905 mm),  $h$  is the timber depth and  $t$  is the thickness of the timber.

Modulus of elasticity was corrected to be valid for a moisture content of 12 %, according to the following empirically determined equation [7]:

$$E_{\text{comp},12\%} = \frac{E_{\text{comp}}}{1 + 0.0143 \cdot (12 - u)} \quad \text{Eq. 4.4}$$

The results presented always give the corrected values, unless otherwise noted.

### 4.1.3 Finnograder

The grading was performed at Limmareds Skogar AB in southern Sweden. The speed was 150 m/min, and all data measured by the machine were stored on a computer for later analysis.

### 4.1.4 Sylvatest

Normal Sylvatest equipment was used, and the tests were performed at SP. The distance between transducer and receiver was 4 m. Holes were drilled in order to attach the probes to the timber. The probes were mounted vertically, as shown in Figure 2.4, and they were mounted on one face of the timber. In order to determine the improvement of the measurement achieved by taking density into account, each plank was weighed and the dimensions were measured so that a mean density of the whole plank could be determined. A modulus of elasticity could then be determined as

$$E_{\text{sylva}} = c^2 \cdot \rho \quad \text{Eq. 4.5}$$

where  $c$ =speed of the ultrasonic wave  
 $\rho$ =mean density for the whole plank when tested

Note, however, that the Sylvatest, in its present form does not include the density when determining the grade of the timber.

The modulus of elasticity has been corrected to be valid for a moisture content of 12 %, according to the following empirically determined equation [7]:

$$E_{\text{sylva},12\%} = \frac{E_{\text{sylva}}}{1 + 0.0143 \cdot (12 - u)} \quad \text{Eq. 4.6}$$

The results presented always gives the corrected values, unless otherwise noted.

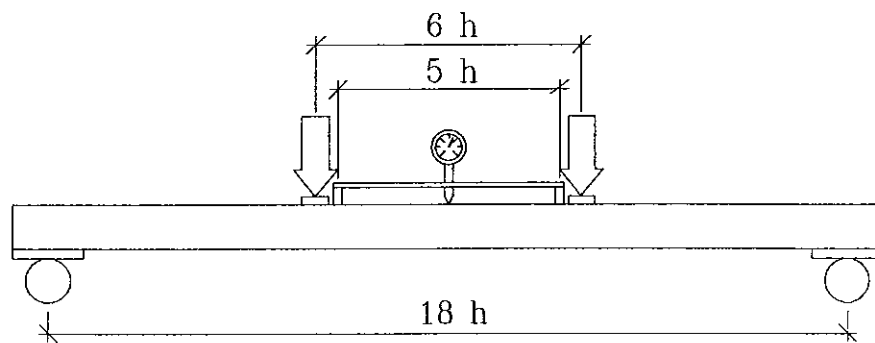
## 4.2 Other measurements

### 4.2.1 Bending strength

The weakest cross-section according to the Cook-Bolinder machine was located. The reason the Cook-Bolinder measurements were used for detection of the weakest cross-section was that this machine was considered to have the best resolution. It measures the stiffness every 10 mm.

It was not always possible to use the weakest point, because it was sometimes located too close to one of the ends of the timber, and therefore the second or third weakest point had to be used in order to enable this point to fall between the loads in the bending test.

The strength in bending was determined according to ISO 8375 - Timber Structures; Solid Timber in Structural Sizes; Determination of some Physical and Mechanical Properties [8], which in all essentials corresponds to EN 408 [9]. The testing arrangement is presented in Figure 4.1. The test is a four-point bending test, with loads applied at the third points of the span. The loading rate was adjusted to give failure within 3 to 7 minutes. The load was applied with a constant deformation rate.



**Figure 4.1** Testing arrangement for measurement of bending strength ( $f_m$ ) and edgewise modulus of elasticity ( $E_m$ ).

Bending strength has been corrected to be valid for a moisture content of 12 %, according to the following empirical equation [7]:

$$f_{m,12\%} = \frac{f_{m,\text{measured}}}{1 + 0.0295 \cdot (12 - u)} \quad \text{Eq. 4.7}$$

The results presented always give the corrected values, unless otherwise noted.

### 4.2.2 Static modulus of elasticity

Static modulus of elasticity was measured both edgewise and flatwise. The testing arrangement used for measuring the edgewise modulus of elasticity ( $E_m$ ) was the same as for measuring bending strength ( $f_m$ ), see Figure 4.1. A linear regression was made on the load-displacement data from a load corresponding to a bending stress of 4 MPa up to a load giving a bending stress equal to 14 MPa. The slope of the regression line ( $\Delta P/\Delta \delta$ ) obtained in this way was then used for the determination of  $E_m$  according to

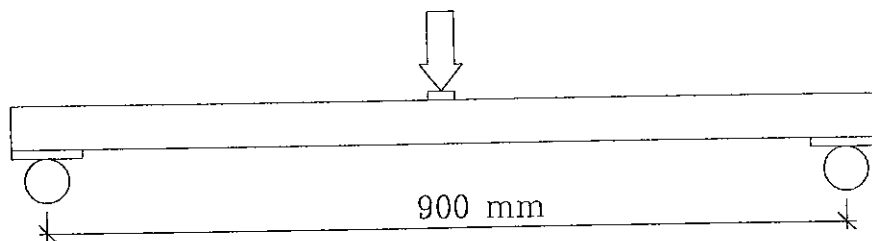
$$E_m = \frac{\Delta P}{\Delta \delta} \cdot \frac{L \cdot L_k^2}{48 \cdot I} \quad \text{Eq. 4.8}$$

where  $L=18 \cdot h$  and  $L_k=5 \cdot h$ .

The flatwise modulus of elasticity ( $E_{\text{flatwise}}$ ) was measured by means of a three-point bending test in order to simulate the bending in the grading machines, see Figure 4.2. The timber was loaded up to a measured bending stress of 15 MPa, with a loading rate so that the maximum load (giving a bending stress equal to 15 MPa) was reached within 1 to 2 minutes. The linear regression was determined in the same manner as for the edgewise bending test. The  $E_{\text{flatwise}}$  was then determined from:

$$E_{\text{flatwise}} = \frac{\Delta P}{\Delta \delta} \cdot \frac{L^3}{48 \cdot I} \quad \text{Eq. 4.9}$$

A problem with the three-point bending test was the unavoidable overhangs because of the short length between the supports. The reaction forces varied, depending on the location of the examined cross-section which could lead to errors in the measurements.



**Figure 4.2** Three-point bending test for measurements of  $E_{\text{flatwise}}$ .

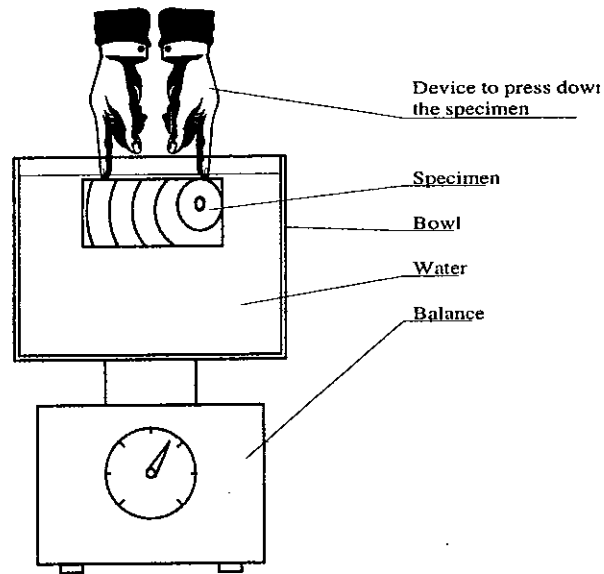
Modulus of elasticity has been corrected to be valid for a moisture content of 12 %, according to the following equation [7]:

$$E_{12\%} = \frac{E}{1 + 0.0143 \cdot (12 - u)} \quad \text{Eq. 4.10}$$

The results presented always give the corrected values, unless otherwise noted.

### 4.2.3 Density

Density specimens were cut close to the location of failure. Mass and volume were measured immediately after the bending test. Volume was measured by pressing the specimen into a bowl filled with water and measuring the increased weight of the bowl, see Figure 4.3. Thereafter the specimens were dried for 24 hours at 103°C and, finally, a second measurement of the mass was made. The density was calculated as the ratio weight of dry specimen to volume of the specimen with the same moisture content as when the static tests were made. The density was then recalculated to be valid for the volume at a moisture content  $u = 12 \%$ .



**Figure 4.3** Measurement of volume for density determination using Archimedes principle.

#### 4.2.4 Moisture content

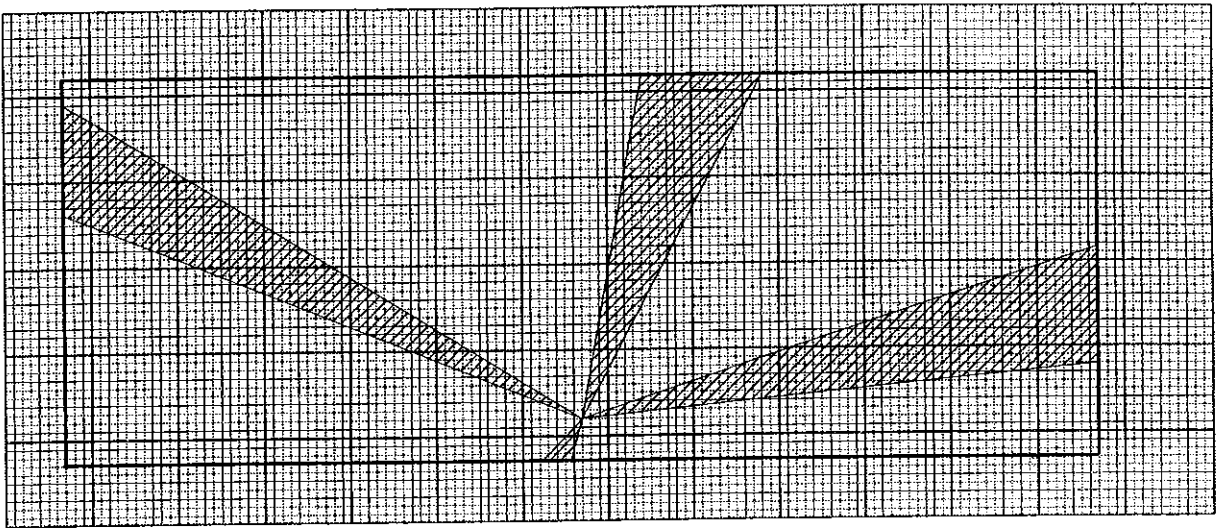
The results from the density measurements were used for determination of moisture content. The moisture content was calculated as

$$u = \frac{\text{mass water}}{\text{mass dry material}} \cdot 100 \% \quad \text{Eq. 4.11}$$

#### 4.2.5 Knot measurements

Knots were measured at one cross-section. The chosen cross-section was the one tested to failure. The following knot measures were calculated:

- CRATIO sum of knots on the face and the edges divided by  $h + 2 \cdot t$ , where  $h$  is the width of the board and  $t$  is the thickness
- NRATIO knot size on the edge divided by  $t$
- TKAR area of projection of all knots in a cluster divided by  $h \cdot t$
- MKAR area of projection of all knots in the outer quarter of the width divided by  $\frac{h \cdot t}{4}$



**Figure 4.4** Example of the recording of the knot projection.

## 5 Results

### 5.1 General

The next two sections are primarily aimed at describing the timber used to compare the grading machines. The relation between bending strength and edgewise modulus of elasticity is paid special attention, as it is an important basis for the determination of setting values for bending machines, at least as far as Sweden is concerned.

The rest of the chapter deals with the relations between bending strength and edgewise modulus of elasticity on the one hand, and different parameters measured with the machines on the other. Also included in this chapter are results from the knot measurement and a discussion of how the bending machines can be improved by including knot measures in the grading.

### 5.2 Mechanical properties of the timber

All three timber sizes have roughly the same edgewise modulus of elasticity. The bending strength, however, decreases with increasing depth of the timber. It is interesting to note that the difference in strength is greater than is indicated by the depth factor,  $k_h=(150/h)^{0.2}$ , in Eurocode 5. It seems that the exponent should be 0.4 rather than 0.2, see further next section.

Table 5.1 Mechanical properties of the tested timber.

Size	Bending strength $f_m$		Modulus of elasticity $E_m$		Density $\rho_{0,12}$		Moisture content $u$	
	Mean (MPa)	COV (%)	Mean (MPa)	COV (%)	Mean (kg/m <sup>3</sup> )	COV (%)	Mean (%)	COV (%)
45x120	49.2	24.7	13200	17.1	408	9.3	11.6	5.6
70x170	42.8	27.6	13400	19.8	388	9.9	10.4	5.6
45x195	40.7	35.7	13200	26.6	381	10.8	10.4	6.5

### 5.3 Bending strength vs. edgewise modulus of elasticity

By using linear regression analysis the following equations were found for the different sizes of timber:

Table 5.2 Relation between bending strength and edgewise modulus of elasticity.

Size	Regression equation	$r^2$	Std dev of regression
45x120 mm	$f_m = 0.00388 \cdot E_m - 1.9$	0.52	8.5
70x170 mm	$f_m = 0.00368 \cdot E_m - 6.4$	0.68	6.7
45x195 mm	$f_m = 0.00363 \cdot E_m - 7.2$	0.77	7.0

The 45x120 mm timber shows a relatively poor correlation. As presented in sections below, this is also the case for other relations. The reason for this is not clear, but one explanation

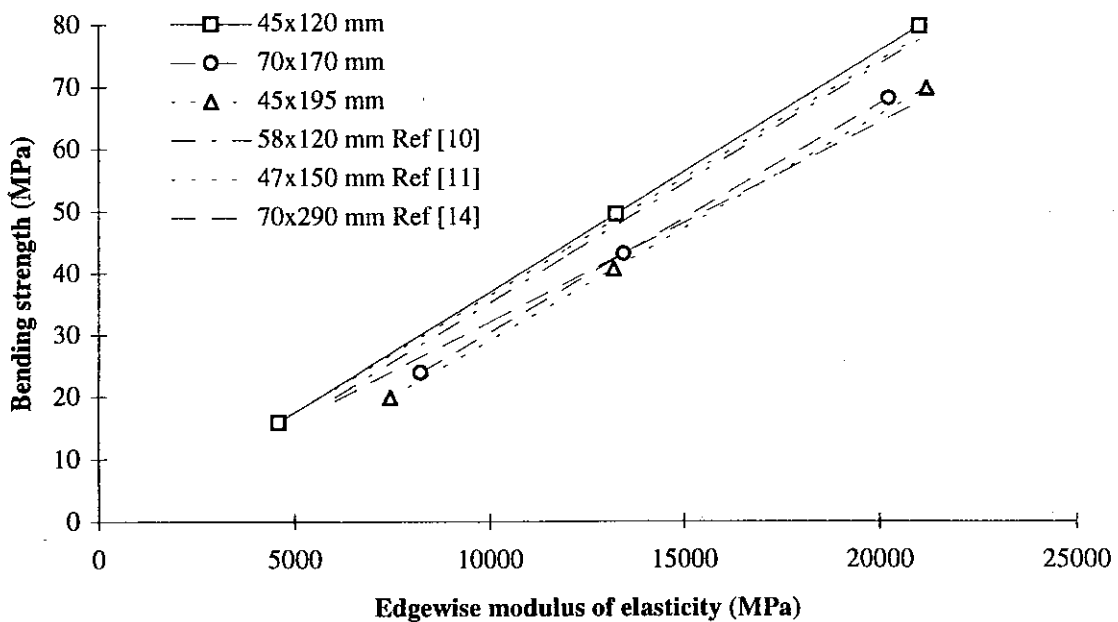
could be that the 45x120 mm timber had a considerable twist, much more pronounced than for the other dimensions.

The lines of regression are compared with results of earlier investigations [10, 11, 14] in Figure 5.1 (the line of regression used from [14] was made by drawing a line from origo through the point representing mean bending strength and mean modulus of elasticity, i.e. it is not a true line of regression). If the bending strength is corrected for depth according to Eurocode 5, the lines are brought closer to one another, but the 45x195 mm and 70x170 mm lines are still at some distance from the others, see Figure 5.2.

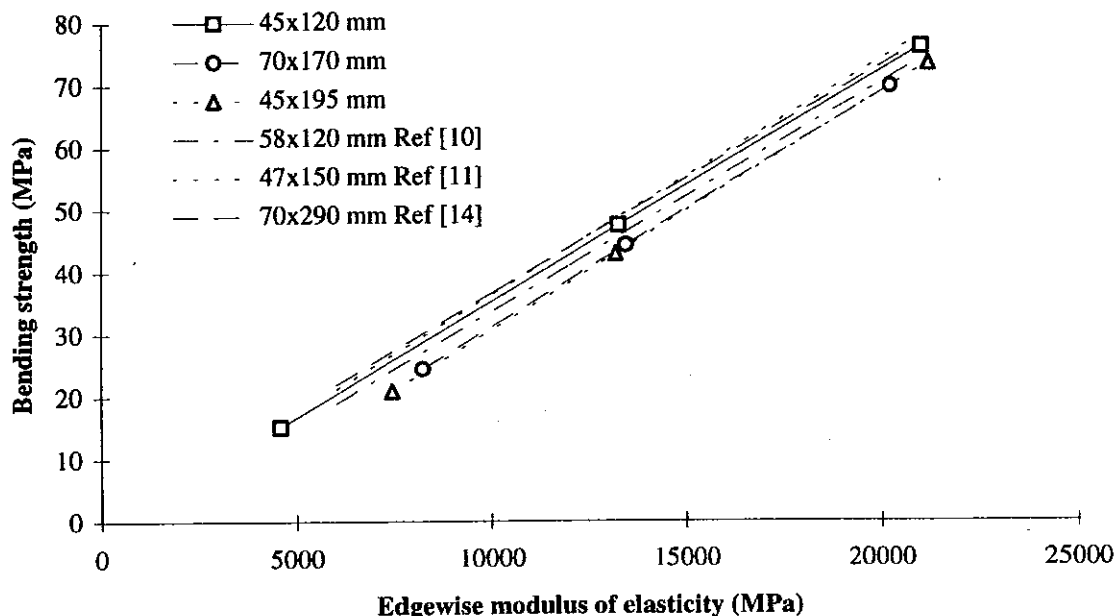
Judging from the results of the present investigation the volume effect is stronger than what is assumed in Eurocode 5. A non-linear regression analysis was performed, which resulted in the following expression:

$$f_m = 1.06 \cdot 10^{-3} \cdot \left(\frac{t}{50}\right)^{-0.03} \cdot \left(\frac{h}{150}\right)^{-0.38} \cdot E_m^{1.122} \quad \text{Eq. 5.1}$$

The multiple coefficient of correlation for the non-linear analysis was  $r^2=0.68$ . The effect of thickness appears to be minor, but the depth effect is much stronger than the factor given in Eurocode 5.



**Figure 5.1** Relations between  $f_m$  and  $E_m$ . The symbols on the lines represent minimum, mean and maximum edgewise modulus of elasticity.



**Figure 5.2** Relations between  $f_m$  and  $E_m$ . Results presented here are corrected for depth according to Eurocode 5. The symbols on the lines represent minimum, mean and maximum edgewise modulus of elasticity.

## 5.4 Edgewise modulus of elasticity vs. flatwise modulus of elasticity

A considerable difference is to be expected between the edgewise MOE measured with a four-point bending test and the flatwise MOE derived from a three-point bending test. The most important reasons for this are the following:

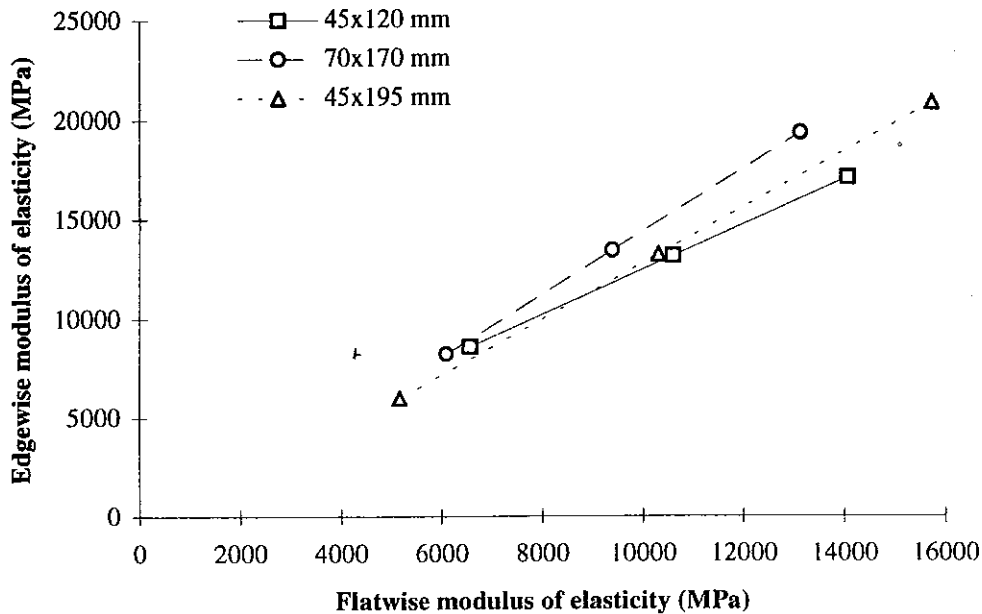
- The calculation of the flatwise MOE is based on the total deflection, which means that the shear deformations are included, see section 4.2.2.
- The MOE distribution over the timber cross-section is not uniform. A recent investigation [12] shows how the modulus of elasticity in the direction of the grain in a log increases from the pith and outwards.
- The effect of knots is also likely to be different in flatwise compared to edgewise bending.

In addition to the differences between edgewise and flatwise modulus of elasticity there were difficulties in measuring the flatwise modulus of elasticity. The span was only 900 mm, and thus large overhangs were inevitable. These overhangs could give rise to different reaction forces at the two supports which might lead to errors in the determination of the modulus of elasticity. Accordingly the flatwise modulus of elasticity presented here should be seen with caution.

Figure 5.3 shows lines of regression for the  $E_m - E_{\text{flatwise}}$  relations and Table 5.3 presents the regression data.

**Table 5.3** Relation between edgewise and flatwise modulus of elasticity.

Size	Regression equation	$r^2$	Std dev of regression
45x120 mm	$E_m = 1.13 \cdot E_{\text{flatwise}} + 1140$	0.56	1490
70x170 mm	$E_m = 1.57 \cdot E_{\text{flatwise}} - 1310$	0.82	1070
45x195 mm	$E_m = 1.42 \cdot E_{\text{flatwise}} - 1420$	0.86	1290



**Figure 5.3** Lines of regression for the  $E_m$ - $E_{\text{flatwise}}$  relation. The symbols on the lines represent minimum, mean and maximum value of the flatwise modulus of elasticity.

A non-linear regression analysis was performed and the following regression equation was obtained:

$$E_m = 0.829 \cdot \left(\frac{t}{50}\right)^{0.28} \cdot \left(\frac{h}{150}\right)^{0.08} \cdot E_{\text{flatwise}}^{1.048} \quad \text{Eq. 5.3}$$

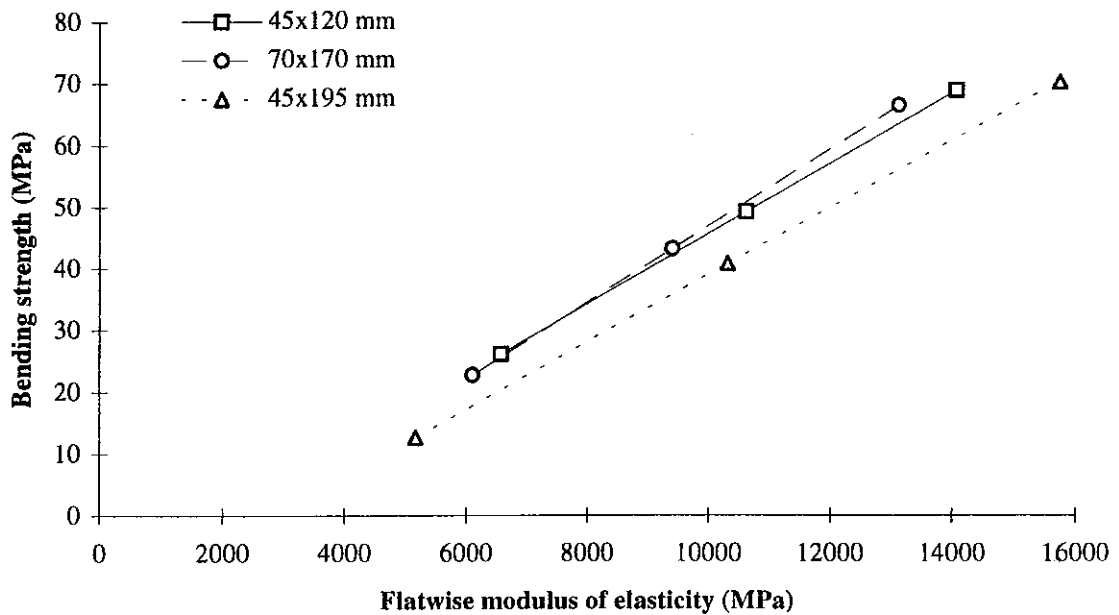
The multiple coefficient of correlation was  $r^2 = 0.76$ . The reason for the relatively low correlation could be that the 45x120 mm timber had a considerable twist. The analysis shows that while thickness affects the relation, the depth of the timber only does so to a small extent.

## 5.5 Bending strength vs. flatwise modulus of elasticity

The relation between the bending strength and the statically measured flatwise modulus of elasticity is useful for comparison with the relations obtained with the bending type grading machines. The relation is, of course, dependent both on depth and thickness of the timber, owing to factors discussed in section 5.4. The results of the linear regression analysis are shown in Table 5.4 and Figure 5.4.

**Table 5.4** Relation between bending strength and flatwise modulus of elasticity.

Size	Regression equation	$r^2$	Std dev of regression
45x120 mm	$f_m = 0.00571 \cdot E_{\text{flatwise}} - 11.4$	0.49	8.7
70x170 mm	$f_m = 0.00623 \cdot E_{\text{flatwise}} - 15.4$	0.62	7.3
45x195 mm	$f_m = 0.00546 \cdot E_{\text{flatwise}} - 15.6$	0.75	7.3



**Figure 5.4** Lines of regression for the  $f_m$ - $E_{\text{flatwise}}$  relation. The symbols on the lines represent minimum, mean and maximum value of the flatwise modulus of elasticity.

The following equation was obtained from a non-linear regression analysis:

$$f_m = 0.209 \cdot 10^{-3} \cdot \left(\frac{t}{50}\right)^{0.31} \cdot \left(\frac{h}{150}\right)^{-0.31} \cdot E_{\text{flatwise}}^{1.330} \quad \text{Eq. 5.4}$$

The multiple coefficient of correlation was  $r^2=0.65$ . The equation shows both a depth and a thickness dependency.

## 5.6 Bending strength vs. machine measurements

### 5.6.1 Bending strength vs. Cook-Bolinder measurements

Results from linear regression analysis are shown in Table 5.5 and Figure 5.5.

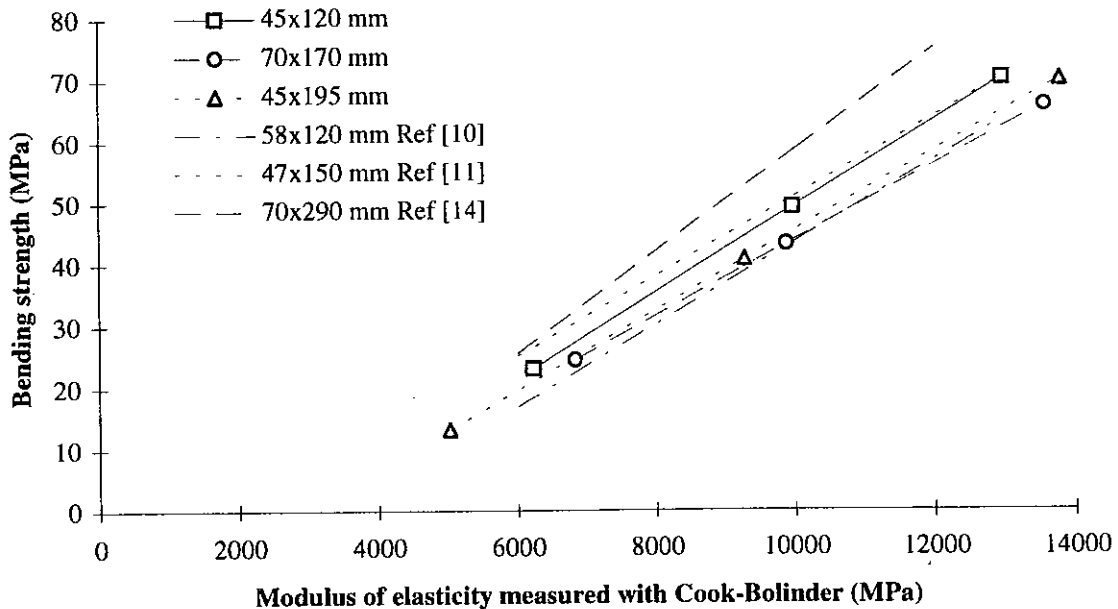
**Table 5.5** Relation between bending strength and modulus of elasticity measured with Cook-Bolinder.

Size	Regression equation	$r^2$	Std dev of regression
45x120 mm	$f_m = 0.00697 \cdot E_{\text{cook}} - 20.2$	0.51	8.5
70x170 mm	$f_m = 0.00613 \cdot E_{\text{cook}} - 17.3$	0.48	8.4
45x195 mm	$f_m = 0.00646 \cdot E_{\text{cook}} - 19.0$	0.73	7.6

Unlike the  $f_m$ - $E_{\text{flatwise}}$  relations presented in section 5.5, the line of regression for the 70x170 mm timber is under the other lines. The coefficient of correlation is also lower than for the other dimensions. The reason is not clear, but the following factors could affect the results:

- Indentations in the timber caused by the rollers
- Stiffness of the grading machine
- Extra moment due to pinch forces
- Measurement errors

A small study of the behaviour of the Cook-Bolinder machine was performed, but the results of that investigation could not explain the unexpected line of regression for the 70x170 mm timber. Measurement errors therefore cannot be ruled out.



**Figure 5.5** Relations between  $f_m$  and  $E_{\text{cook}}$ . The symbols on the lines represent minimum, mean and maximum modulus of elasticity measured with the Cook-Bolinder machine.

A comparison with results of earlier investigations [10, 11] shows that for timber with similar dimensions (45x120, 58x120 and 47x150 mm) there is also a considerable difference between the lines of regression.

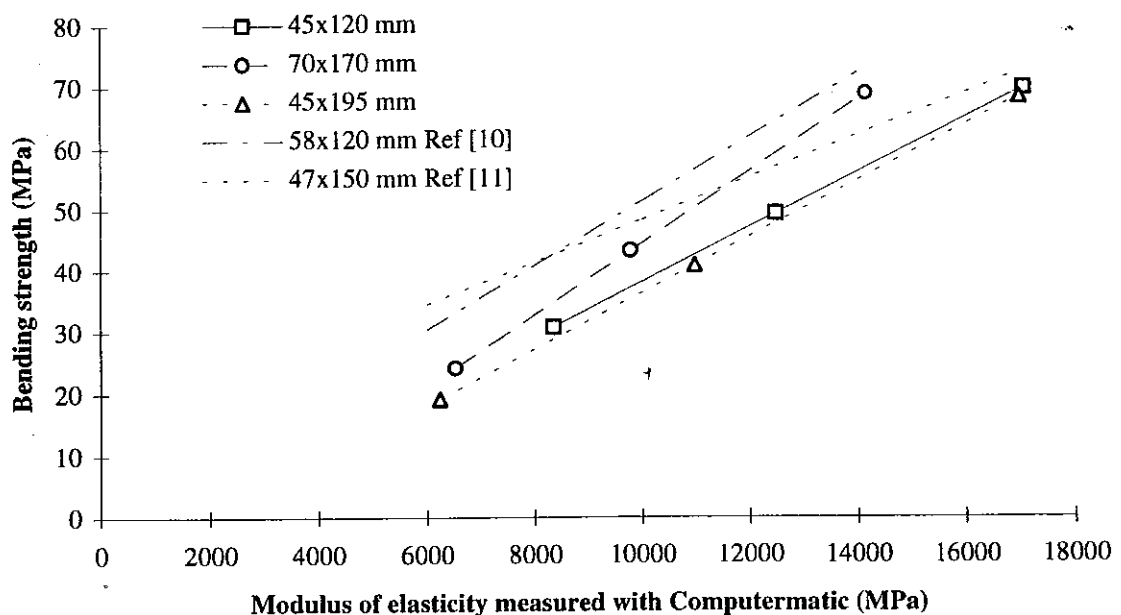
The diagram also includes a line of regression for large-size spruce [14], with the dimension 70x290 mm. The line of regression is above the other ones, as expected.

### 5.6.2 Bending strength vs. Computermatic measurements

The results of the linear regressions are presented in Table 5.6 and Figure 5.7. The equation for 70x170 mm timber differs significantly from the other two, as expected, owing to the larger thickness.

**Table 5.6** Relation between bending strength and modulus of elasticity measured with Computermatic.

Size	Regression equation	r <sup>2</sup>	Std dev of regression
45x120 mm	$f_m = 0.00447 \cdot E_{comp} - 6.6$	0.41	9.4
70x170 mm	$f_m = 0.00582 \cdot E_{comp} - 14.0$	0.60	7.4
45x195 mm	$f_m = 0.00458 \cdot E_{comp} - 9.5$	0.62	9.0



**Figure 5.7** Relations between  $f_m$  and  $E_{comp}$ . The symbols on the lines represent minimum, mean and maximum modulus of elasticity measured with Computermatic.

A non-linear regression analysis gave the following relation:

$$f_m = 505 \cdot 10^{-6} \cdot \left(\frac{t}{50}\right)^{0.43} \cdot \left(\frac{h}{150}\right)^{-0.07} \cdot E_{comp}^{1.221} \quad \text{Eq. 5.5}$$

The multiple coefficient of correlation was  $r^2 = 0.57$ . The thickness strongly influenced the bending strength, while the depth of the timber had almost no effect at all.

The lines of regression for timber with similar dimensions (45x120, 58x120 and 47x150 mm) are very different from one another. The slope is similar for the 45x120 mm and 58x120 mm [10] timber, while the slope is much lower for the 47x150 mm timber [11].

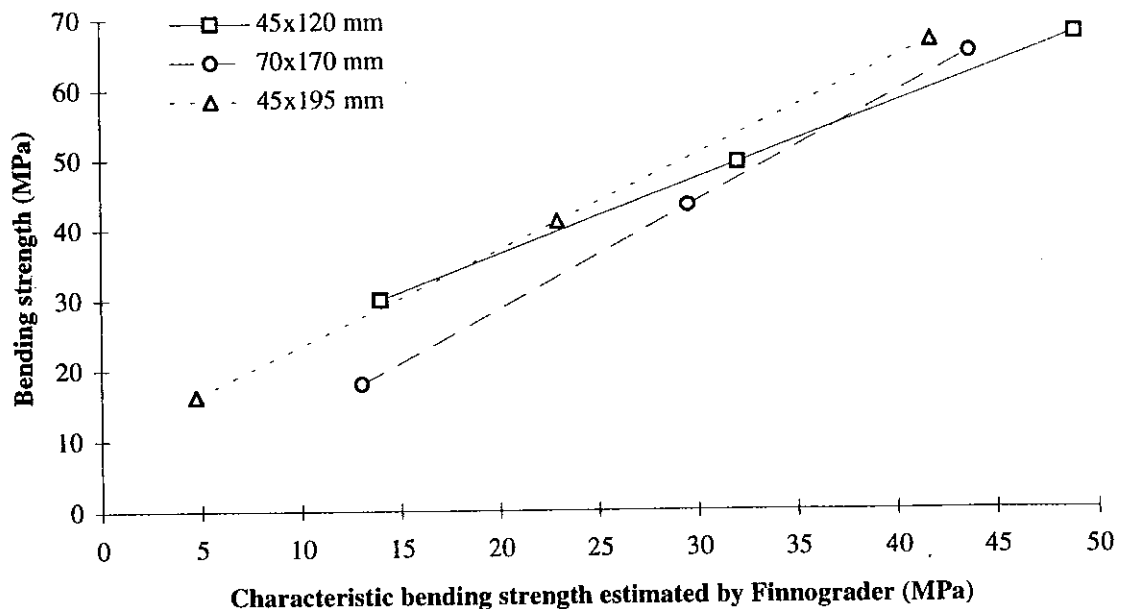
### 5.6.3 Bending strength vs. Finnograder measurements

In contrast to the bending machines, the Finnograder estimates the bending strength of the timber from several different measurements. In Table 5.7 and Figure 5.8 results from a linear regression analysis are presented. The correlation between static bending strength and indicating property from the Finnograder is lower than for the bending machines.

It should be noted that the Finnograder has a correction for size built into the algorithm used for estimation of strength. Furthermore, the strength estimated using the Finnograder is calculated so that it corresponds directly to the characteristic strength. Therefore, the strength values from the Finnograder are lower than the true bending strength values.

**Table 5.7** Relation between bending strength and characteristic bending strength estimated with Finnograder.

Size	Regression equation	$r^2$	Std dev of regression
45x120 mm	$f_m = 1.07 \cdot f_{finno} + 14.9$	0.34	9.9
70x170 mm	$f_m = 1.53 \cdot f_{finno} - 2.1$	0.38	9.3
45x195 mm	$f_m = 1.36 \cdot f_{finno} + 9.8$	0.55	9.7



**Figure 5.8** Relations between  $f_m$  and  $f_{finno}$ . The symbols on the lines represent minimum, mean and maximum characteristic bending strength estimated with Finnograder.

A non-linear regression analysis for the relation between bending strength and the strength estimated by Finnograder gave the following result:

$$f_m = 3.15 \cdot \left(\frac{t}{50}\right)^{-0.30} \cdot \left(\frac{h}{150}\right)^{0.12} \cdot f_{finno}^{0.790} \quad \text{Eq. 5.6}$$

The multiple coefficient of correlation was  $r^2 = 0.45$ . The expression indicates that the corrections made in the algorithm for timber dimensions are not enough. The thickness effect seems to be stronger than assumed.

### 5.6.4 Bending strength vs. Sylvatest measurements

The Sylvatest correlates the ultrasonic wave speed to the strength of the material. A better correlation is obtained if the density is also taken into consideration. Table 5.8 presents the regression results. Figure 5.9 displays the lines of regression between ultrasonic wave-speed (c) and bending strength. The correlation is poor compared with the other grading machines when only ultrasonic wave-speed is taken into account. However, if  $E_{sylv}$  is calculated by using the density as follows

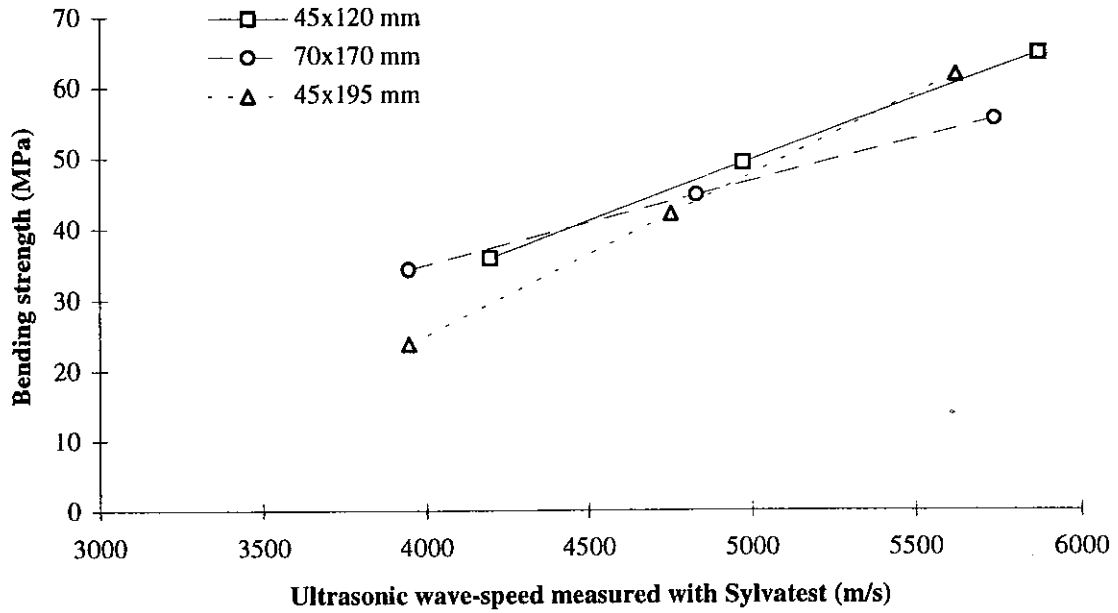
$$E_{sylv} = c^2 \cdot \rho \quad \text{Eq. 5.7}$$

the coefficient of correlation increases to the same level as for the Finnograder. The lines of regression where density has been considered are shown in Figure 5.10.

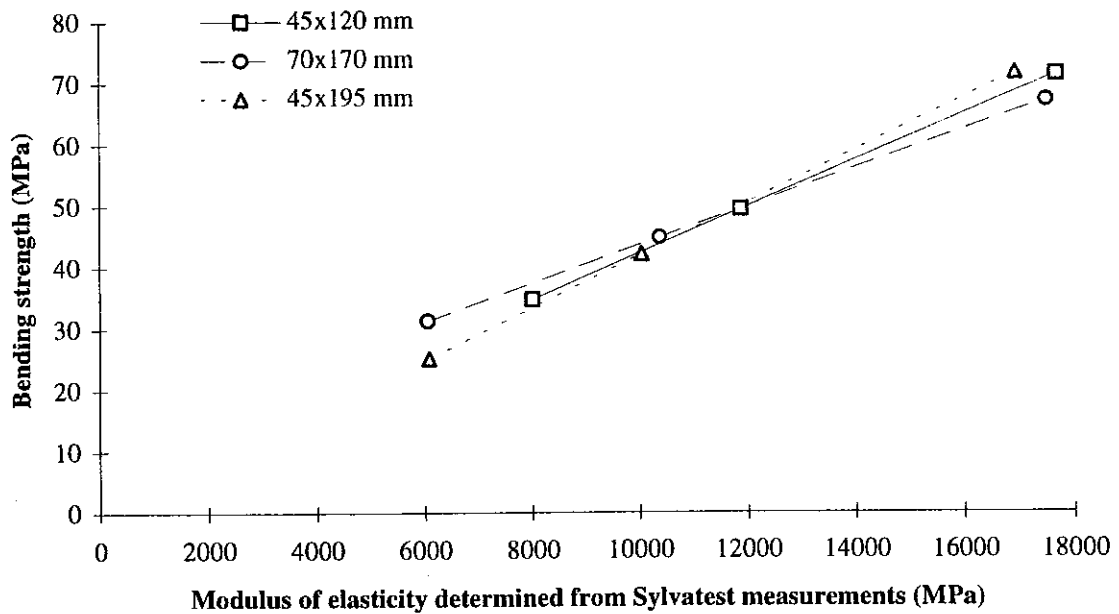
**Table 5.8** Relation between bending strength and measurements with Sylvatest.

Size	Regression equation	$r^2$	std dev of regression
<i>Strength vs. ultrasonic wave-speed</i>			
45x120	$f_m = 17.4 \cdot 10^{-3} \cdot c - 37.0$	0.20	10.8
70x170	$f_m = 11.9 \cdot 10^{-3} \cdot c - 12.8$	0.19	10.4
45x195	$f_m = 22.8 \cdot 10^{-3} \cdot c - 66.1$	0.50	10.1
<i>Strength vs. modulus of elasticity</i>			
45x120	$f_m = 3.78 \cdot 10^{-3} \cdot E_{sylv} + 4.5$	0.34	9.9
70x170	$f_m = 3.01 \cdot 10^{-3} \cdot E_{sylv} + 13.2$	0.33	9.4
45x195	$f_m = 4.28 \cdot 10^{-3} \cdot E_{sylv} - 0.8$	0.62	8.8

It should be pointed out that the Sylvatest measurements were made over a length of 4 m. If the ultrasonic wave-speed had been measured over a short length around the location of the failure, the correlation would have been greater, see for instance [14].



**Figure 5.9** Lines of regression between  $f_m$  and the ultrasonic wave-speed measured with Sylvatest. The symbols on the lines represent minimum, mean and maximum ultrasonic wave-speed.



**Figure 5.10** Lines of regression between  $f_m$  and  $E_{sylv}$ . The symbols on the lines represent minimum, mean and maximum modulus of elasticity determined with Sylvatest.

A non-linear regression analysis gave the following regression equations:

*Bending strength vs. ultrasonic wave-speed*

$$f_m = 3.93 \cdot 10^{-6} \cdot \left(\frac{t}{50}\right)^{-0.03} \cdot \left(\frac{h}{150}\right)^{-0.13} \cdot c^{1.916} \quad r^2 = 0.32 \quad \text{Eq. 5.8}$$

*Bending strength vs. modulus of elasticity from Eq. 5.7*

$$f_m = 11.0 \cdot 10^{-3} \cdot \left(\frac{t}{50}\right)^{0.02} \cdot \left(\frac{h}{150}\right)^{0.002} \cdot E_{\text{sylva}}^{0.896} \quad r^2 = 0.46 \quad \text{Eq. 5.9}$$

The Sylvatest measurements are not affected by the timber dimensions, as is the case with the other machines. The timber depth has a small influence when a regression is based on the wave speed, but if density is considered, the timber dimensions have no influence at all.

## 5.7 Edgewise modulus of elasticity vs. machine measurements

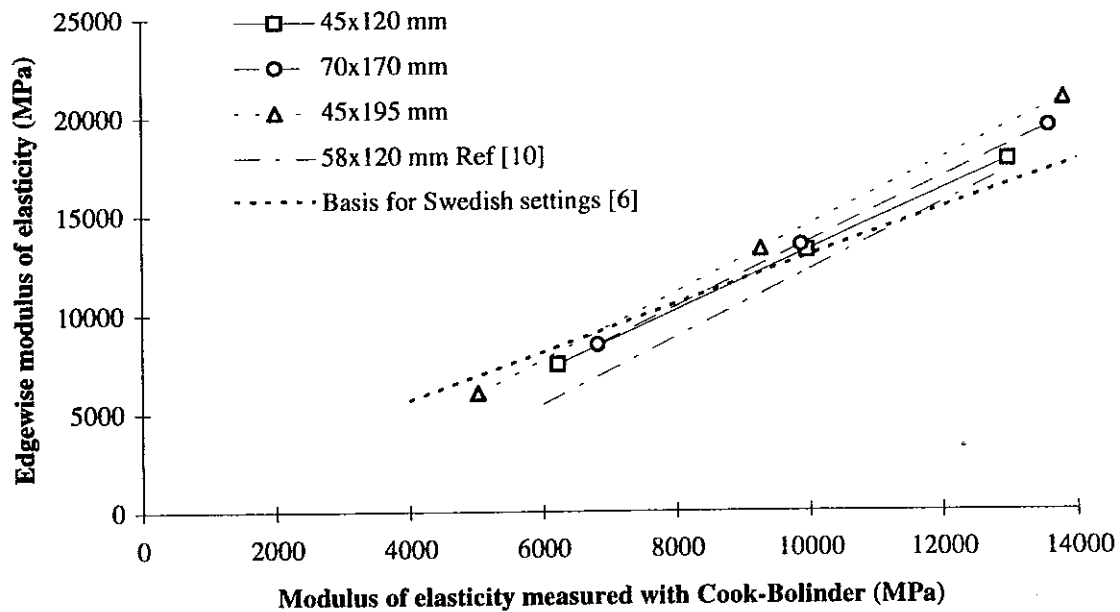
### 5.7.1 Edgewise modulus of elasticity vs. Cook-Bolinder measurements

Unlike the  $E_m$ - $E_{\text{flatwise}}$  relations in section 5.4, the  $E_m$ - $E_{\text{cook}}$  lines of regression are almost the same. The line of regression of the 70x170 mm timber is not above the others as would be expected. The reason for this is not clear, it could be a measurement error. The lines of regression for  $E_m$ - $E_{\text{cook}}$  are presented in Table 5.9 and Figure 5.11.

**Table 5.9** Relation between edgewise modulus of elasticity and modulus of elasticity measured with Cook-Bolinder.

Size	Regression equation	$r^2$	Std dev of regression
45x120 mm	$E_m = 1.57 \cdot E_{\text{cook}} - 2000$	0.71	1400
70x170 mm	$E_m = 1.63 \cdot E_{\text{cook}} - 2700$	0.71	1400
45x195 mm	$E_m = 1.70 \cdot E_{\text{cook}} - 2500$	0.87	1300

The line of regression from [6], which forms an important basis for the present setting values for the Swedish grading machines, corresponds relatively well with the lines obtained in the present study. But it does not correspond as well with the results presented in [10].



**Figure 5.11** Lines of regression for the  $E_m$ - $E_{cook}$  relation. The symbols on the lines represent minimum, mean and maximum modulus of elasticity measured with Cook-Bolinder.

### 5.7.2 Edgewise modulus of elasticity vs. Computermatic measurements

Lines of regression for the relation between  $E_m$  and  $E_{comp}$  are presented in Table 5.10 and Figure 5.12. A very good correlation is obtained for the 70x170 mm timber.

**Table 5.10** Relation between edgewise modulus of elasticity and modulus of elasticity measured with Computermatic.

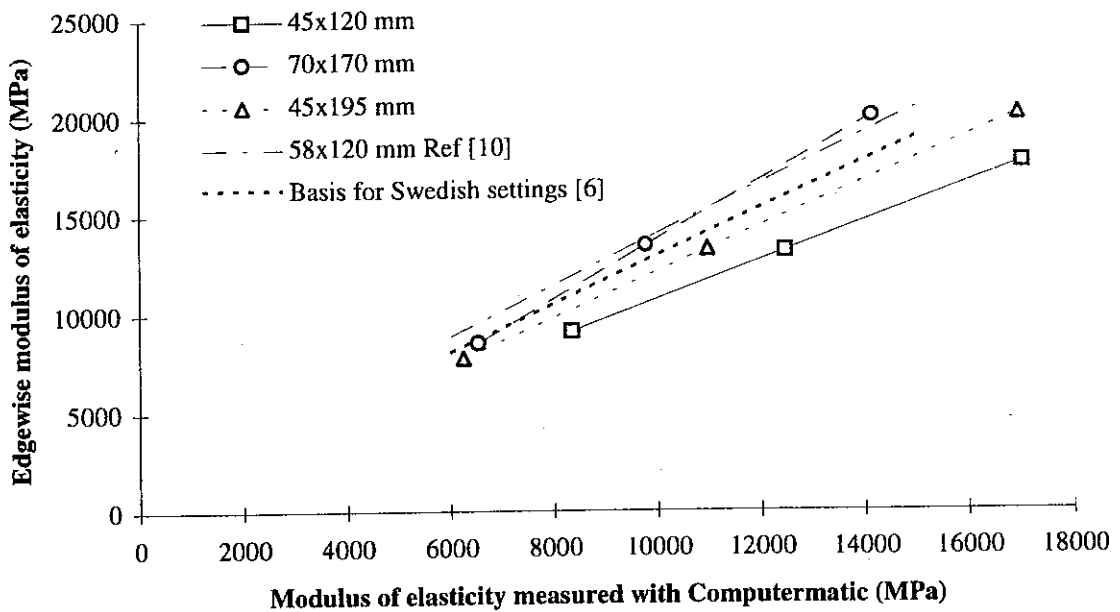
Size	Regression equation	$r^2$	Std dev of regression
45x120 mm	$E_m = 0.99 \cdot E_{comp} + 900$	0.57	1500
70x170 mm	$E_m = 1.60 \cdot E_{comp} - 1300$	0.84	1000
45x195 mm	$E_m = 1.15 \cdot E_{comp} + 600$	0.68	2000

The slope of the line of regression from [6] corresponds well with the present results and the results from [10]. However it is noteworthy that the 45x120 mm line of regression is so low. This might be explained by the considerable twist in that particular series. It is also striking that the line of regression for the 58x120 mm timber [10] is above the other lines. It should reasonably be slightly above the 45 mm timber line, but below the 70 mm timber line, owing to the shear deformations.

A non-linear regression analysis gave the following regression equation:

$$E_m = 1.34 \cdot \left(\frac{t}{50}\right)^{0.38} \cdot \left(\frac{h}{150}\right)^{0.27} \cdot E_{comp}^{0.985} \quad \text{Eq. 5.10}$$

The multiple coefficient of correlation was  $r^2 = 0.69$ . The analysis shows that there is strong dependency on thickness and some dependency on depth.



**Figure 5.12** Lines of regression for the  $E_m$ - $E_{comp}$  relation. The symbols on the lines represent minimum, mean and maximum modulus of elasticity measured with Computermatic.

## 5.8 Grading yield and characteristic strength

The grading yield presented is here based on the setting limits used in Sweden at present. The settings for the bending type machines were developed using a Computermatic machine. The stiffness limits found for Computermatic, for the different grades, were later applied to Cook-Bolinder machines. No limits for the Sylvatest have been approved in Sweden, and the values used were the ones presented by the manufacturer.

The characteristic strength,  $f_{m,k}$ , is the non-parametric 5th percentile value after multiplication by a depth factor, (Eq. 2.10). The depth factor was set according to the proposal in prEN 384 [13], which will be the European standard. The penalty for small sample sizes given in prEN 384 [13] has not been applied.

The required values for the machine grades are the characteristic strength properties given in the Swedish building code NR1 [15], see Table 5.11.

**Table 5.11** Required characteristic bending strength and edgewise modulus of elasticity for the different strength classes.

Strength class	$f_{m,k}$ (MPa)	$E_m$ (MPa)
C30	30	12000
C24	24	10500
C18	18	9000

The timber has also been graded in a single class (> C24), which means that all timber equal to, or better than, C24 has been sorted out. This is the most common grading in Sweden.

### 5.8.1 Cook-Bolinder

The results, presented in Table 5.12, indicate that the settings for strength class C30 are correct for the 45x120 mm and the 45x195 mm timber. For the C24 strength class the settings are correct for the 45x120 mm timber, while the characteristic bending strength not is acceptable for the 45x195 mm timber. As far as the 70x170 mm timber is concerned, no conclusions can be drawn as the measurements are likely to be erroneous, see section 5.6.1.

The yield is very high when grading C24 and better, and the characteristic bending strength values are correct. The characteristic bending strength is very high for the 45x120 mm timber, which can be explained in terms of the high strength of the material used. Only 1% of the material, i.e. 2 pieces of timber, were rejected from the C24 and better grading.

**Table 5.12** Grading yield and characteristic strength values for Cook-Bolinder. The values in brackets are uncertain because too few specimens were included in that grade.  $E_m$  is the mean edgewise modulus of elasticity for the actual grade. The last row represents grading in one strength class only, C24 and better.

Strength class	45x120 mm			70x170 mm			45x195 mm		
	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)
C30	83	31	13600	80	28	14200	57	30	15500
C24	16	24	10700	19	24	10500	33	20	10900
C18	1	(26)	(9100)	1	(28)	(9100)	8	(13)	(9000)
> C24	99	30	13200	99	26	13500	90	26	13800

In a recent study [14], large-size spruce timber was graded and the yield in the C30 strength class was only 23%. The characteristic bending strength was  $f_{m,k} = 38.2$  MPa, which is far too high. But the characteristic strength was correct in the strength classes C24 and C18,  $f_{m,k} = 25.0$  MPa and  $f_{m,k} = 19.2$  MPa, respectively.

### 5.8.2 Computermatic

The settings are incorrect for the 45x195 mm timber. The characteristic strength is too low for both the C30 and the C24 strength classes.

The 45x195 mm timber seems to be different from the other dimensions with respect to the characteristic strength, which is too low. The same could be found from the Cook-Bolinder grading, but with the difference that the characteristic strength was acceptable but the yield much lower than for the other dimensions. One explanation could be that the knottiness of the 45x195 mm timber differs from the other dimensions. In Table 5.14 some different knot measurements are presented.

**Table 5.13** Grading yield and characteristic strength values for Computermatic. The values in brackets are uncertain because too few specimens were included in that grade.  $E_m$  is the mean edgewise modulus of elasticity for the actual grade. The last row represents grading in one strength class only, C24 and better.

Strength class	45x120 mm			70x170 mm			45x195 mm		
	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)
C30	99	30	13200	71	33	14500	79	26	14200
C24	1	(26)	(9100)	26	24	10900	16	21	10100
C18	0	-	-	3	(25)	(9800)	5	(10)	(7900)
> C24	100	30	13100	98	26	13500	95	25	13500

TKAR, the total knot area ratio, is roughly the same for all dimensions, but the edge knot ratio, NRATIO, is much higher for the 45x195 mm timber. The knot measures also show a wider scatter for the 45x195 mm timber. One of the disadvantages of the bending machines is their low sensitivity to edge knots.

**Table 5.14** Knot measures for the timber studied.

Knot measure	45x120 mm		70x170 mm		45x195 mm	
	Mean	COV (%)	Mean	COV (%)	Mean	COV (%)
TKAR	0.205	48	0.216	45	0.222	58
NRATIO	0.323	70	0.286	61	0.378	74

### 5.8.3 Finnograder

The characteristic strength values obtained for the different grades are very close to the required values, except for the C30 strength class for the 45x195 mm, where the characteristic strength is too high. The results show a high yield in the highest grade for 45x120 mm and 70x170 mm timber, while the yield is low in the same grade for the 45x195 mm timber. One explanation for the low yield for the 45x195 mm timber is that the Finnograder weights the edge knots too heavily.

**Table 5.15** Grading yield and characteristic strength values for Finnograder. The values in brackets are uncertain because too few specimens were included in that grade.  $E_m$  is the mean edgewise modulus of elasticity for the actual grade.

Strength class	45x120 mm			70x170 mm			45x195 mm		
	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)
C30	73	33	13700	56	32	14700	25	41	17200
C24	18	26	12100	40	25	11900	25	24	13700
C18	7	(21)	(10400)	3	(23)	(10500)	26	20	12200
> C24	91	32	13400	96	25	13600	50	28	15500

## 5.8.4 Sylvatest

The yield is very low, and the characteristic strength is too high for the different grades, see Table 5.16. The conclusion is that the settings used are too conservative.

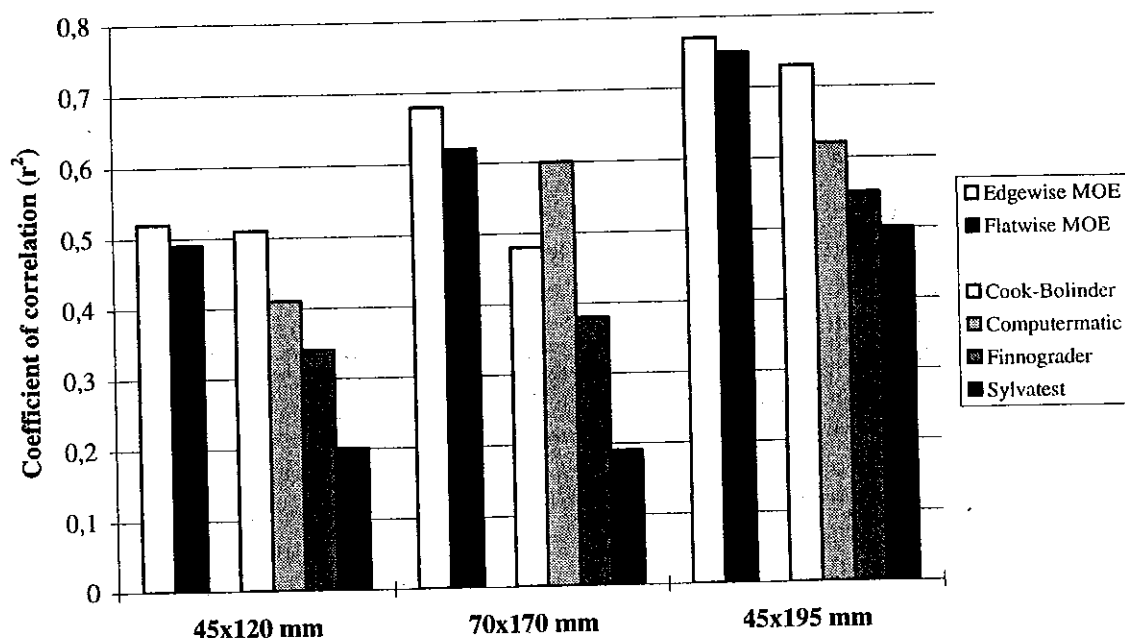
**Table 5.16** Grading yield and characteristic strength values for Sylvatest.  $E_m$  is the mean edgewise modulus of elasticity for the actual grade.

Strength class	45x120 mm			70x170 mm			45x195 mm		
	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)	Yield (%)	$f_{m,k}$ (MPa)	$E_m$ (MPa)
C30	6	(38)	(15400)	3	(63)	(19400)	6	(55)	(18400)
C24	7	(42)	(15400)	12	(35)	(15800)	10	(41)	(17200)
C18	35	36	13900	26	34	14600	12	(38)	(15800)
> C24	13	42	15400	15	35	16500	17	41	17700

## 5.9 Comparison between the different machines

### 5.9.1 Correlation between bending strength and indicating property

The most important property of a timber strength grading machine is its ability to predict the strength of the timber. This ability can be expressed using the coefficient of correlation between the indicating property measured by the machine and the bending strength. A machine giving a poor correlation to bending strength can never render a high yield in the high strength classes. In Figure 5.13 the coefficient of correlation,  $r^2$ , is shown for the examined grading machines, and for the different sizes of timber included in the study. The correlation varies between the different timber sizes, but it is clear that the bending type machines give the highest correlation.



**Figure 5.13** Correlation between indicating property and bending strength for the different machines.

## 5.9.2 Correlation between edgewise modulus of elasticity and indicating property

In Figure 5.14, the coefficients of correlation are presented for the two bending machines. The results indicate that the grading machines have a higher correlation to the bending strength than the flatwise static test. The reason for this may be the difficulties in carrying out the flatwise static tests because of the large overhangs, which were unavoidably.

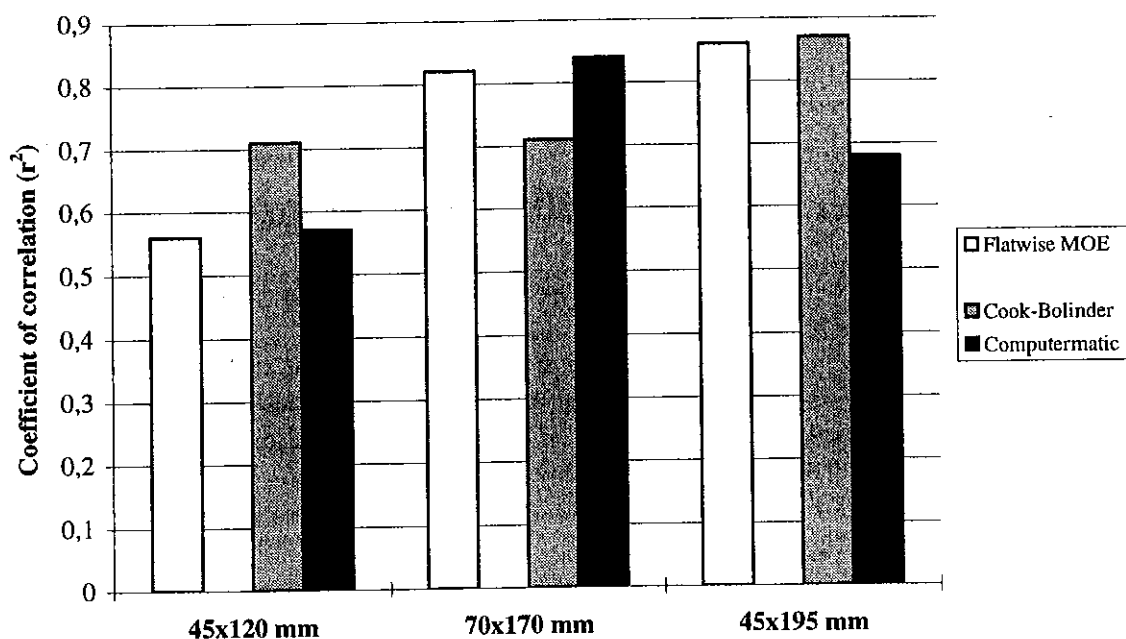


Figure 5.14 Correlation between indicating property and edgewise modulus of elasticity for the different machines.

## 5.9.3 Grading yield

In order to obtain the best possible yield, it is not only a high coefficient of correlation that is important, but also having correct setting values for the machines. In Figures 5.15 - 5.17 the yield is shown for the different machines. Note that the yield is only presented for the cases where the characteristic bending strength is equal to or above the required value.

The best yield is achieved in the bending type machines. The Computermatic gave the best yield for the 45x120 mm timber in the C30 strength class, but the characteristic strength was close to the limit for acceptability. The characteristic strength was 4% higher than required for the Cook-Bolinder and 9% for the Finnograder in the C30 strength class, and the yield from the Cook-Bolinder was 8% higher than from the Finnograder, which can be explained by the better correlation between bending strength and indicating property for the bending machines.

When comparing Computermatic and Finnograder, it can be noted that they both give about the same characteristic strength, but the yield is 15% higher for the Computermatic than the Finnograder.

The Computermatic overestimated the strength of the 45x195 mm timber both in the C30 and the C24 strength classes. The highest yield in the C30 class was obtained in the Cook-Bolinder, 30% more yield than from the Finnograder. For this dimension and the C30 strength class, the characteristic strength was close to the required value, while for Finnograder the characteristic strength was far too high,  $f_{m,k} = 41$  MPa.

The grade limits used in the Sylvatest must be revised in order to use the instrument for grading. Between 50 - 70% of the timber was rejects (below the C18 strength class) according to the Sylvatest readings.

When grading C24 and better, the best yield is obtained with the bending machines.

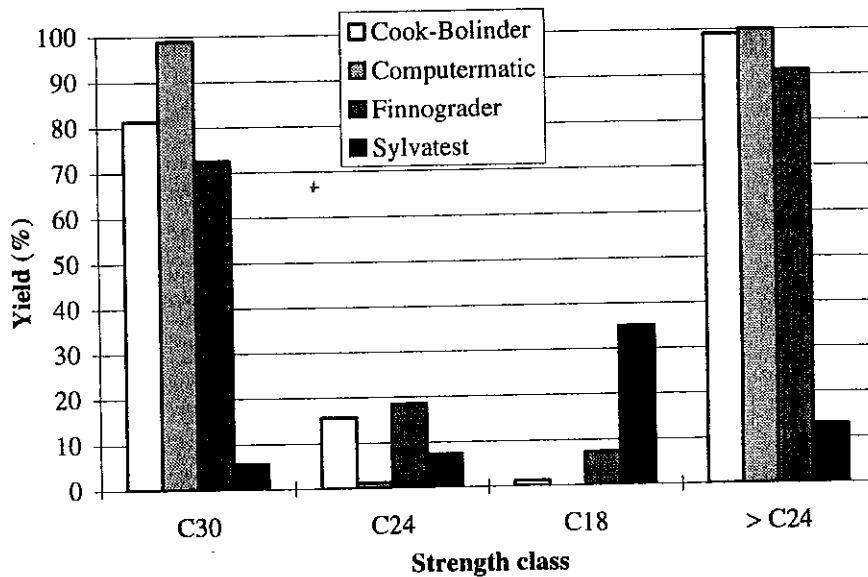


Figure 5.15 Grading yield for the 45x120 mm timber obtained with the different machines.

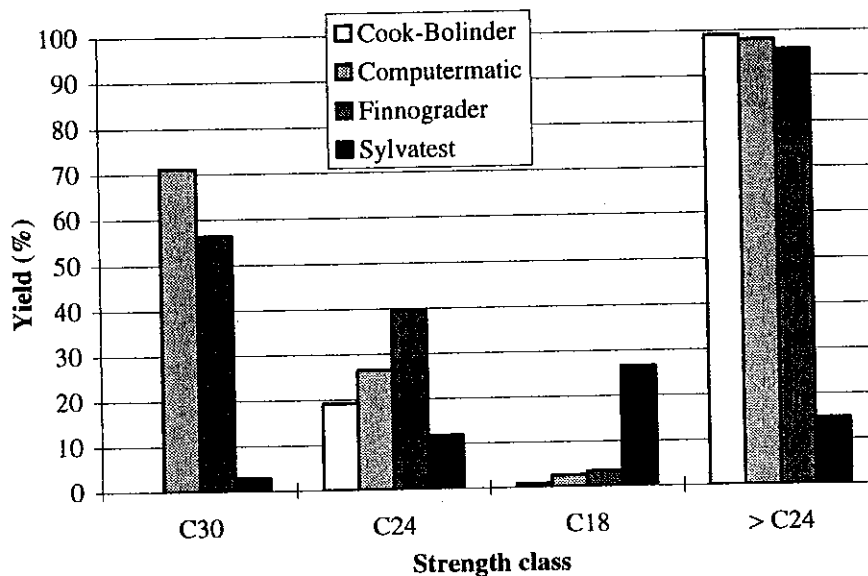
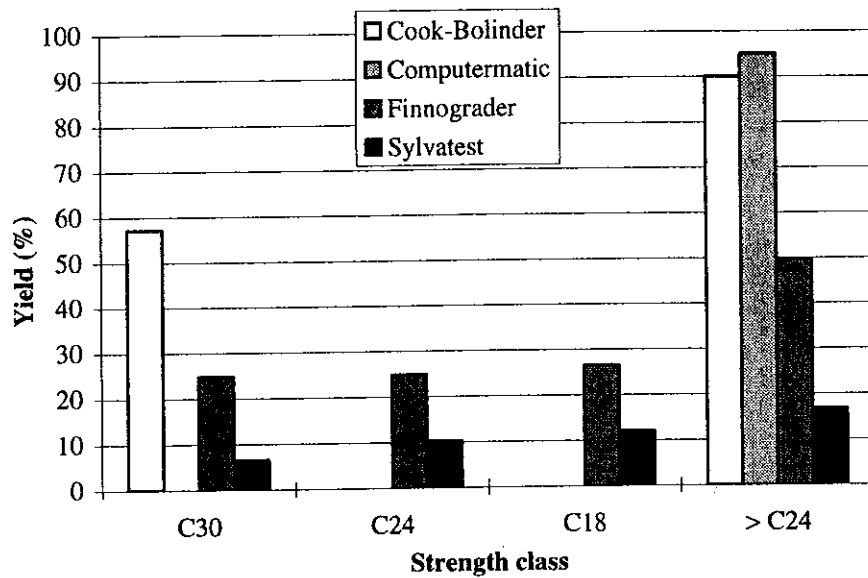


Figure 5.16 Grading yield for the 70x170 mm timber obtained with the different machines. The Cook-Bolinder values should be looked upon with caution, due to suspected measurement errors.



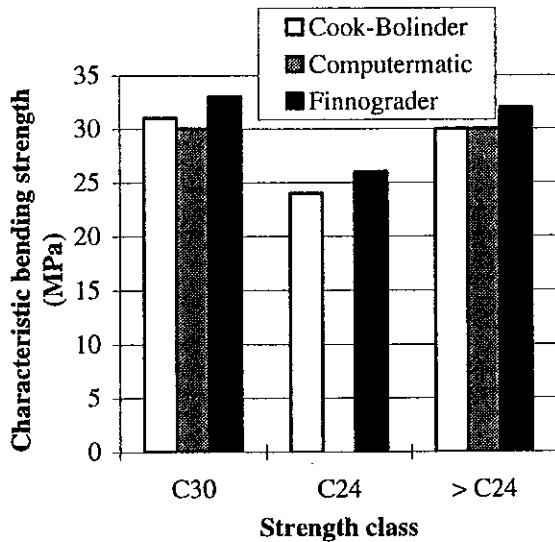
**Figure 5.17** Grading yield for the 45x195 mm timber obtained with the different machines.

#### 5.9.4 Characteristic bending strength

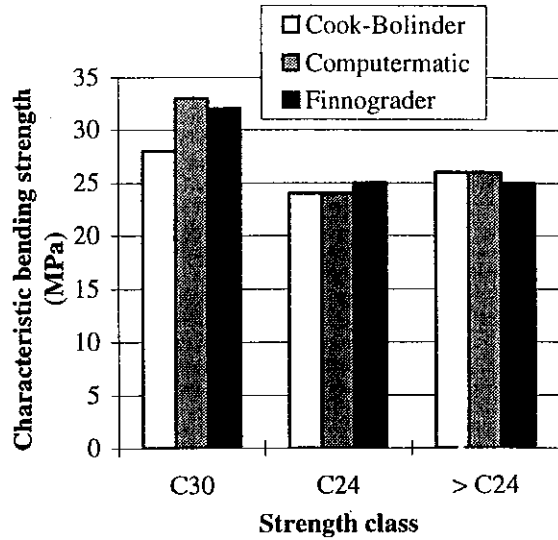
The characteristic bending strengths obtained for the different grades with the grading machines are presented in Figures 5.18 - 5.20. No values are presented for the Sylvatest because the limits used did not give enough pieces of timber in each respective grade to calculate a characteristic bending strength, see previous section. Values are only given for the cases which contained enough specimens to calculate the characteristic strength value.

The characteristic bending strength obtained with the different machines varies considerably. For the C30 strength class, the Cook-Bolinder gave a characteristic strength value for the 45x195 mm timber that was just below the limit. The Computermatic did not reach the requirements for the C30 class with the 45x195 mm timber, and was just below the required value for the 45x120 mm timber. For the Finnograder, the setting values can be considered correct for the C30 class except for the 45x195 mm timber, where the characteristic strength is over 40 MPa.

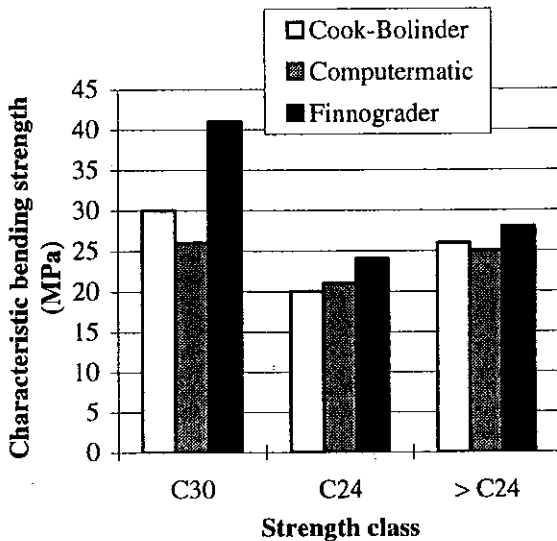
The characteristic bending strength is correct for the C24 strength class except for the bending machines when grading the 45x195 mm timber. Neither bending machine reached the required characteristic strength for that dimension.



**Figure 5.18** Characteristic bending strength for the 45x120 mm timber obtained with the different machines.



**Figure 5.19** Characteristic bending strength for the 70x170 mm timber obtained with the different machines. The Cook-Bolinder values should be looked upon with caution, due to suspected measurement errors.



**Figure 5.20** Characteristic bending strength for the 45x195 mm timber obtained with the different machines.

## 5.10 Combined visual and machine strength grading

The present section is devoted to the bending machines only, because the Finnograder already takes the knots into consideration, and on the Sylvatest, in its present shape as a field instrument, it would not be possible to attach a device for knot measurements.

When measuring the flatwise bending stiffness the effect of the knots is roughly the same whether it is in the middle of the face or at the edge. But when the timber is tested edgewise, it is well-known that failure is normally initiated at edge knots. Therefore it is of interest to study whether prediction of strength can be improved by also including different knot measures.

Edge knots are most interesting because it would be relatively simple to develop a technique for measuring these knots in the grading machines. It would be more expensive to measure all knots, i.e. also on the faces, because the number of sensors must be doubled.

### 5.10.1 Cook-Bolinder

Estimation of bending strength can be improved by including knot measurements, see Table 5.18. The best result is obtained by using the edge-knot measures NRATIO and MKAR, where NRATIO is a measure of the largest knot on the edges and MKAR is a measure of the size of the knots in the outer quarter of the width. For the 70x170 mm timber, the coefficient of correlation increased from  $r^2=0.48$  to  $r^2=0.65$  when the MKAR value was included. The effect was less drastic for the other dimensions, but a significantly increased correlation to bending strength was still found.

**Table 5.18** Relation ( $f_m = C_0 + C_1 \cdot E_{\text{cook}} + C_2 \cdot X$ ) between strength and machine and visual grading parameters. (X is the visual knot measure)

Dimension	X	C <sub>0</sub>	C <sub>1</sub>	C <sub>2</sub>	r <sup>2</sup>
45x120	-	0.00697	-20.2	-	0.51
45x120	CRATIO	0.00601	-5.1	-32.3	0.56
45x120	NRATIO	0.00647	-11.8	-10.6	0.55
45x120	MKAR	0.00645	-10.8	-14.8	0.55
45x120	TKAR	0.00614	-5.7	-30.2	0.56
70x170	-	0.00613	-17.3	-	0.48
70x170	CRATIO	0.00533	-2.9	-35.0	0.55
70x170	NRATIO	0.00541	-4.1	-21.6	0.58
70x170	MKAR	0.00504	2.9	-34.9	0.65
70x170	TKAR	0.00512	0.7	-37.2	0.57
45x195	-	0.00646	-19.0	-	0.72
45x195	CRATIO	0.00622	-14.7	-11.5	0.74
45x195	NRATIO	0.00622	-14.4	-6.4	0.75
45x195	MKAR	0.00611	-13.0	-8.7	0.75
45x195	TKAR	0.00613	-12.9	-13.9	0.75

### 5.10.2 Computermatic

For the Computermatic a significantly higher correlation to bending strength was also achieved by including knot measurements. As for the Cook-Bolinder, the best improvement was obtained for the 70x170 mm timber, where the coefficient of correlation increased from  $r^2=0.60$  up to  $r^2=0.73$  when the MKAR value was included.

The same type of investigation was made in [10], and the improvement found for 58x120 mm timber was an increased coefficient of correlation from  $r^2 = 0.70$  to  $r^2 = 0.75$  by including the NRATIO value.

**Table 5.19** Relation ( $f_m = C_0 + C_1 \cdot E_{comp} + C_2 \cdot X$ ) between strength and machine and visual grading parameters. (X is the visual knot measure)

Dimension	X	C <sub>0</sub>	C <sub>1</sub>	C <sub>2</sub>	r <sup>2</sup>
45x120	-	0.00447	-6.6	-	0.40
45x120	CRATIO	0.00372	9.8	-41.0	0.49
45x120	NRATIO	0.00413	2.1	-14.1	0.47
45x120	MKAR	0.00415	3.2	-20.0	0.48
45x120	TKAR	0.00385	8.8	-37.5	0.49
70x170	-	0.00582	-17.0	-	0.60
70x170	CRATIO	0.00532	-5.2	-18.6	0.62
70x170	NRATIO	0.00522	-2.2	-20.8	0.69
70x170	MKAR	0.00487	3.8	-30.9	0.73
70x170	TKAR	0.00506	-1.0	-25.5	0.64
45x195	-	0.00458	-9.5	-	0.62
45x195	CRATIO	0.00399	2.7	-30.6	0.66
45x195	NRATIO	0.00424	-1.1	-12.2	0.68
45x195	MKAR	0.00412	1.5	-18.6	0.70
45x195	TKAR	0.00410	2.5	-30.0	0.69

## 6 Conclusions

Four different timber strength grading machines were examined, Cook-Bolinder, Computermatic, Finnograder and Sylvatest. All machines except Sylvatest are production machines. Sylvatest is a field instrument and has for applications.

The conclusions drawn concerning the machines are:

- The best correlation between indicating property and bending strength was found for the bending machines, Cook-Bolinder and Computermatic. In general, Cook-Bolinder was also somewhat more accurate than Computermatic. In this context it should, however, be mentioned that the Finnograder is virtually insensitive to the grading speed. At grading speeds of around 90 m/minute (a normal speed for Cook-Bolinder and Computermatic) it is therefore likely that this machine is more accurate than both Cook-Bolinder and Computermatic. In the bending machines, vibrations and swinging of the timber increase with increasing speed, which almost always leads to an underestimation of the timber stiffness.
- The setting values used in the Computermatic for the C30 strength class give too high a characteristic strength for the 70x170 mm timber, while the characteristic strength only is 26 MP for the 45x195 mm timber, which is alarming. In the C24 strength class the Computermatic gives too low a characteristic strength for the 45x195 mm timber.
- When grading C24 and better, the yield is very high for both bending machines and good for the Finnograder as well. The characteristic strength is higher than required, which means that the setting values could be adjusted.
- The characteristic strength values obtained with the Finnograder are acceptable for both C30 and the C24 strength classes and also for all sizes of timber included in the study. It might be possible to adjust the setting values slightly to achieve a better yield.
- Sylvatest had a very limited strength predicting ability in its present form. The strength prediction is, however, improved by including the density.
- It has been shown that the correlation between bending strength and indicating property can be improved for the bending machines by including a measurement of the edge knots. This can be done, for example, using CCD or line cameras.

The following conclusions concerning the timber properties can also be drawn:

- The following non-linear relation was found between bending strength and edgewise modulus of elasticity:

$$f_m = 1.06 \cdot 10^{-3} \cdot \left(\frac{t}{50}\right)^{-0.03} \cdot \left(\frac{h}{150}\right)^{-0.38} \cdot E_m^{1.122}$$

The multiple coefficient of correlation was  $r^2=0.68$ , and it can be seen that there is a stronger depth effect than the 0.2 given in Eurocode 5.

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## Appendix: Experimental results

General					Static tests			Bending machines		Finnograder						Sylvatest		
Num	Dimen- sion	u	$\rho_{0,12}$	Mean ring width	MOR	Edge- wise MOE	Flat- wise MOE	MOE Cook- Bolin- der	MOE Com- puter- matic	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra- sonic wave speed	MOE Sylva- test
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa	m/s	MPa
X1	45x195	10	411	3,6	31,83	10686	7593	7463	7914	11	73	-4	33	103	373	14	4172	7006
X2	45x195	10	447	4,4	28,24	11883	10203	9425	10125	11	66	0	35	49	400	21	4384	8462
X3	45x195	10	457	2,7	37,87	15312	11251	10851	14174	11	62	-9	83	96	462	22	4983	11942
X4	45x195	10	436	2,9	51,85	14760	11023	10083	11887	11	53	0	24	82	392	20	4994	10582
X5	45x195	11	454	3,6	45,07	12958	8977	9007	10013	11	35	-14	33	61	441	31	4300	8282
X6	45x195	10	468	2	41,93	11498	10589	9953	11533	11	55	6	27	124	420	16	4643	9261
X7	45x195	10	390	3,6	43,44	12363	9501	8207	10380	11	42	-1	47	49	385	28	4226	7182
X8	45x195	11	441	2,4	50,61	15877	10915	10049	12964	11	62	-10	37	67	383	22	5172	11751
X9	45x195	10	480	1,7	55,06	16013	13017	11080	13385	12	36	9	36	73	432	31	4583	9453
X10	45x195	10	424	3,6	43,35	14328	10463	9468	11453	11	74	-11	36	80	400	18	4676	9524
X11	45x195	11	419	5	40,8	12040	9553	9157	11796	13	79	-1	47	54	387	17	4748	9912
X12	45x195	11	442	3,1	38,37	14088	10994	10416	10983	11	59	-23	32	68	392	22	5058	11065
X13	45x195	10	474	2,7	30,88	15456	9631	10626	11189	11	52	-8	53	69	447	27	4868	11030
X14	45x195	11	375	6,7	23,41	10422	8871	8227	9407	12	35	4	49	47	343	28		
X15	45x195	10	369	4,4	45,33	12269	9270	8477	10435	12	48	-11	28	49	343	25	4993	9444
X16	45x195	10	444	3,7	40,23	15416	9859	9454	12627	11	55	-18	44	51	411	27	5017	10890
X17	45x195	10	457	2,9	54,02	16920	11720	10491	14174	12	67	15	43	45	425	25	5077	11860
X19	45x195	10	488	1,4	65,54	18912	13801	11964	12371	11	35	-11	19	52	443	34	5361	13460
X20	45x195	11	413	2,9	45,17	15222	10873	10047	11980	11	45	7	33	56	381	27	4939	10186
X21	45x195	11	537	2,2	68,19	15824	11736	9997	12948	15	36	-6	9	33	468	39	4493	9920
X22	45x195	11	412	3,6	39,34	16011	10726	9509	11929	11	64	-1	21	49	401	22	3947	6527
X23	45x195	11	474	2,2	45,46	16880	13126	10092	14536	12	29	-8	21	21	446	39	5406	13913
X24	45x195	11	467	2,5	45,46	14526	10962	9778	12492	11	79	-15	31	49	438	22	5185	12772
X25	45x195	10	422	3,6	32,87	13977	10179	9135	9556	11	66	0	103	173	394	10	4279	7910
X26	45x195	10	456	2,5	41,08	15839	12220	10880	9276	11	39	-17	34	32	421	30	4880	10278
X27	45x195	10	467	2,3	52,51	16504	12226	10660	12945	11	47	4	47	40	423	30	5175	11736
X28	45x195	9	500	3,8	26,28	9526	7175	6674	7338	12	80	3	18	28	356	17	4782	8699
X29	45x195	10	357	5	29,37	9358	7335	6684	8776	13	60	-9	27	50	319	22	4684	7827
X30	45x195	11	369	2,9	28,56	10765	8146	7882	9133	12	81	-7	55	39	343	19	4495	7669
X31	45x195	10	397	2,1	49,39	15133	11014	9643	12856	11	44	1	43	16	381	29	4955	9856
X32	45x195	11	470	3,3	64,7	16499	12122	10907	12398	11	48	3	21	35	427	31	5152	12324
X33	45x195	11	463	2,3	47,89	15550	12123	10450	14299	11	62	12	15	27	427	27	5295	13317
X34	45x195	11	477	3,6	26,91	11371	8891	7727	8728	15	78	1	22	34	366	18	4900	9468
X36	45x195	10	406	2,5	25,12	9558	9438	8546	10139	11	91	5	30	35	370	17	4176	6946
X37	45x195	10	415	2,9	49,11	11893	10376	9140	11976	12	51	-14	37	54	400	27	5065	10908
X38	45x195	10	432	3,3	28,52	12883	8637	7510	8549	12	53	12	28	79	334	20	4483	7423
X39	45x195	10	371	4	39,19	10709	8244	7422	8660	12	64	-1	48	58	350	19	4676	8154
X40	45x195	11	402	2,7	37,59	10438	8113	7041	6608	12	47	-18	63	83	336	22	4546	7951
X41	45x195	11	433	2,3	32,83	14492	10560	9479	11258	11	51	-18	27	44	412	28	4503	8866
X42	45x195	10	484	2,5	57,99	16310	12443	11270	14334	12	42	-1	79	89	439	28	5272	12671
X43	45x195	10	392	2,5	41,84	11132	8996	8279	10168	12	73	-13	31	45	372	22	4369	7526
X44	45x195	10	435	2,2	30,69	11215	9783	9114	12750	11	56	-27	39	43	415	26	4267	7810
X45	45x195	10	396	3,5	39,67	11669	8401	7998	9977	12	46	-19	25	65	363	24	5066	9908
X46	45x195	10	393	4,4	22,67	10699	8886	7658	8982	12	70	-20	17	21	365	23	4477	8053
X47	45x195	10	485	3,6	32,58	8104	10278	9096	12142	11	80	-2	28	92	421	14	4957	11075
X48	45x195	10	503	2,9	39,76	14195	11164	10250	12608	12	63	3	21	114	451	17	4947	11926

General					Static tests			Bending machines		Finnograder						Sylvatest		
Num	Dimension	u	$\rho_{0,12}$	Mean ring width	MOR	Edge-wise MOE	Flat-wise MOE	MOE Cook-Bolinder	MOE Computer-matic	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra-sonic wave speed	MOE Sylva-test
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa	m/s	MPa
X49	45x195	10	418	2,7	50,15	15216	11413	10298	12091	10	46	-17	39	50	431	30		
X50	45x195	10	407	2,7	35,89	12679	9875	8741	10192	12	66	6	22	62	384	20	4825	9316
X51	45x195	10	448	3,1	26,54	11153	9587	9177	12681	11	84	-1	60	68	418	15	4518	8740
X52	45x195	10	469	2,3	18,51	7234	8344	7437	9048	12	56	20	31	73	376	22		
X53	45x195	10	474	3,1	26,35	11600	9026	7813	10408	11	80	-2	44	59	413	17	4071	7312
X54	45x195	10	389	4,4	10,02	4580	5513	5378	6245	11	62	-14	34	184	376	9	3947	6259
X55	45x195	13	378	5	23,76	10488	8165	7772	7898	13	38	-10	24	46	347	28	4442	7907
X56	45x195	10	479	3,1	19,55	9248	9590	8666	11189	12	56	32	29	120	438	18		
X57	45x195	11	397	4,5	25,26	11038	7532	7387	9850	12	62	0	20	19	366	17	4115	7278
X58	45x195	11	434	3,6	31,18	11448	9415	8696	12043	12	61	-3	35	71	413	16	4774	10203
X59	45x195	10	421	4	29,84	11096	8952	7894	6797	11	71	-1	16	136	390	11	4645	8924
X60	45x195	10	371	5	32,87	12104	8849	8302	9543	12	54	3	30	92	334	17	4894	8971
X61	45x195	10	413	2,2	33,91	9378	8116	7688	10266	12	64	28	26	262	372	6		
X62	45x195	10	444	2,9	27,11	10760	9975	8851	8882	11	41	13	21	139	393	17	4041	7134
X63	45x195	10	479	1,9	28,24	12765	10237	8938	8838	11	60	-5	67	63	433	24		
X64	45x195	10	338	6,2	24,27	8509	7572	6831	7511	13	80	6	35	99	323	13	4337	6913
X65	45x195	11	460	4,2	25,06	9596	8014	7274	9023	13	52	-20	27	224	424	11	4112	7493
X66	45x195	10	435	3,6	24,27	8999	7193	7129	7414	11	65	-23	64	137	406	14	4178	7390
X67	45x195	10	349	5,7	29,09	8642	6738	6419	6920	13	54	-24	36	81	311	20	4290	6721
X68	45x195	10	328	6,7	26,63	9210	7040	6785	7440	12	61	-10	67	79	327	20	3991	6080
X69	45x195	10	381	3,6	32,87	10798	9113	8760	10003	12	75	-9	30	78	363	17	4469	7673
X70	45x195	10	408	4,2	38,72	11366	7617	7159	8039	15	76	-8	30	104	382	17	4659	8979
X71	45x195	10	442	2,5	39,57	12577	9854	8983	11208	12	63	-23	30	72	369	21	4540	8582
X72	45x195	10	433	6,2	25,59	5892	5169	5023	7702	12	73	6	34	214	374	7	4672	8663
X73	45x195	10	454	3,6	40,71	8320	8237	7145	9389	12	84	-22	33	35	430	22	4421	9115
X74	45x195	11	391	2,7	40,7	10443	9098	8598	9493	12	57	14	17	28	365	26	4682	8929
X75	45x195	11	412	2,9	26,03	10784	8383	7625	7651	12	64	-17	61	96	405	19		
X76	45x195	10	480	5,5	30,41	11037	7773	6360	7647	13	60	3	65	309	408	5	4011	6881
X77	45x195	10	418	2,9	27,01	9213	7452	6766	8191	11	81	1	22	58	382	16		
X78	45x195	10	361	4,4	19,93	8774	7339	6551	8549								4762	8404
X79	45x195	10	386	5	13,03	6923	6495	5961	6891	12	81	3	18	33	323	16	4064	6136
X80	45x195	10	387	6	24,46	9386	7287	7048	8348	12	57	-5	16	102	335	16	4131	6418
X81	45x195	10	468	3,1	28,05	9840	8745	7669	10516	11	58	5	16	62	471	26	4365	8799
X82	45x195	10	430	2,9	14,54	5985	6412	5530	6830	12	46	11	23	249	389	8		
X83	45x195	10	472	2,1	52,89	13371	11317	9475	10266	11	32	-2	24	76	427	30	4642	9515
X84	45x195	11	595	1,4	64,02	17534	15745	13797	16976	14	36	-8	21	21	511	43	5498	16937
X85	45x195	10	368	1,7	29,09	11039	9458	8172	9866	11	57	16	33	33	359	25	4577	7947
X86	45x195	14	449	2,5	60,88	17811	13373	12141	13648	11	37	-12	45	30	426	34	4644	10112
X87	45x195	11	518	1,5	69,94	18692	15220	13267	16689	13	30	-7	42	71	482	38	5288	13901
X88	45x195	11	529	1,8	59,45	17692	14082	12156	12839	13	43	-17	38	39	489	35	5449	15186
X89	45x195	11	454	2,6	56,73	16508	12247	10657	15390	12	48	5	30	44	416	29	4848	10667
X90	45x195	10	439	2,5	46,37	17145	11128	9650	11237	12	36	-4	25	65	416	30	4587	9419
X91	45x195	10	451	3,6	48,83	15516	10250	9476	10209	11	75	-10	18	22	395	23	4603	9608
X92	45x195	10	405	4,5	27,86	11586	9247	8191	7893	11	56	-28	20	56	366	23		
X93	45x195	11	497	2,6	64,11	18931	14167	12440	15077	11	57	-3	18	18	487	31	5140	13182
X94	45x195	10	430	4,4	35,79	12273	9787	8886	11775	12	53	-25	18	41	395	27	4645	8999
X95	45x195	11	414	2,9	53,91	12104	9414	8473	10636	12	50	14	15	98	364	19	4786	8872
X96	45x195	10	438	2	55,16	16157	11667	10554	12681	11	54	11	22	55	441	28	4800	10411
X97	45x195	11	542	2	66,74	19799	14788	13252	15615	12	48	0	19	67	488	30	5120	14058
X98	45x195	10	450	2,7	37,02	13005	10349	8992	9154	12	70	-6	18	54	404	22	4206	7781

General					Static tests			Bending machines		Finnograder							Sylvatest	
Num	Dimension	u	$\rho_{0,12}$	Mean ring width	MOR	Edge-wise MOE	Flat-wise MOE	MOE Cook-Bollinder	MOE Computer-matic	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra-sonic wave speed	MOE Sylva-test
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa	m/s	MPa
X99	45x195	10	462	2,9	59,78	17447	12349	10973	13438	11	52	-11	15	77	433	24	5212	12648
X100	45x195	10	412	2,2	44,58	14819	10445	9484	9958	11	44	3	43	53	392	27	5470	12768
X102	45x195	10	523	1,8	73,76	19574	14784	12975	15333	13	29	-2	39	49	483	42	5623	15502
X103	45x195	10	494	2,2	57,8	19205	14991	12970	16697	12	34	-2	19	23	473	40	5533	15172
X104	45x195	10	460	2,9	37,68	12651	10532	8931	10000	11	49	-12	42	102	415	20	4840	10205
X105	45x195	10	460	2	55,16	17582	12969	11548	14828	12	30	-8	21	56	452	37	5514	14094
X106	45x195	10	451	3,8	30,69	12882	11100	9631	10837	11	43	-23	54	52	434	30	4359	8438
X107	45x195	11	475	2,3	60,23	17698	13570	11609	13468	12	43	-3	16	32	440	33	5590	14581
X108	45x195	11	531	1,5	64,6	21010	14665	13059	14612	12	40	12	41	60	492	36	4777	11971
X109	45x195	11	432	1,9	35,75	14146	10897	9564	10141	11	60	-8	35	32	414	27	4589	9033
X110	45x195	10	505	1,6	41,37	14295	11209	9922	11055	12	46	-17	14	24	472	34	5405	14235
X111	45x195	11	451	2,5	55,76	18366	13351	11408	13948	11	51	-5	27	42	428	30	4755	10382
X112	45x195	10	529	1,2	72,82	19378	14959	13045	13155	13	31	-7	27	60	500	41	5588	15933
X113	45x195	11	514	2,5	57,99	19353	13491	11708	11585	12	44	0	60	102	492	27	5427	15407
X114	45x195	10	527	2,9	63,09	18662	13911	12982	14236	11	38	-4	59	69	490	35	5258	13624
X115	45x195	11	418	4	49,06	11289	9484	7981	8865	13	55	-5	22	24	392	27	4211	7525
X116	45x195	10	437	3,3	52,32	15584	11461	10308	13946	11	75	0	45	32	418	21	5145	11577
X117	45x195	10	448	2,5	34,85	12985	10225	8719	10166	12	58	-8	25	22	406	28	4261	7874
X118	45x195	13	519	2,3	60,79	18567	14679	12952	15988	13	42	-7	18	68	456	31	5522	14849
X119	45x195	10	417	2,1	44,96	15076	11151	9776	11502	11	55	-11	33	77	398	22	4555	8783
X120	45x195	10	442	3,1	28,14	13275	10246	9460	11102	11	52	-6	14	33	411	29	4744	9586
X121	45x195	10	536	1,2	66,68	17085	14164	12081	12318	13	36	7	23	37	480	40	5523	15549
YL3	70x170	11	526	3,1	65,96	17437	12292	10507	12268	12	69	-12	46	55	510	37	4901	12747
YL4	70x170	10	430	2,7	50,81	11854	8667	9517	8955	12	62	11	63	49	432	33	4587	8879
YL5	70x170	10	435	5	48,45	12304	8763	9275	8845	13	39	0	75	121	371	32	5108	9930
YL6	70x170	11	443	2,5	46,82	13021	9730	8540	9988	13	55	-24	28	56	389	29	5442	11987
YL7	70x170	11	448	2,6	42,84	14276	10316	9665	10424	12	60	-13	47	75	432	33	4724	10115
YL8	70x170	11	545	1,9	65,86	19962	11321	10587	13930	12	43	4	27	48	514	45	5741	17503
YL9	70x170	11	491	2,9	71,01	18251	11247	10678	11281	12	62	-6	54	49	446	34	4327	8860
YL10	70x170	10	452	2,9	51,47	15424	10214	10312	10538	11	51	1	40	101	425	34	4588	9109
YL11	70x170	10	449	2,4	57,8	14960	10720	9976	11043	12	61	-12	60	79	419	32	5155	11391
YL12	70x170	11	448	2,5	53,33	14658	10020	10260	10717	12	54	-12	33	41	419	33	5316	12582
YL13	70x170	11	522	2	62,95	20225	13107	12494	12775	11	45	-14	38	44	514	41	5536	16214
YL14	70x170	10	477	2,3	34,94	15041	9462	9599	9532	11	46	-8	22	31	433	36	5269	11575
YL15	70x170	10	424	2,4	39,29	15840	9837	9864	9960	12	55	-5	48	53	424	34	5249	11596
YL16	70x170	10	448	4	44,48	13969	9820	9601	9434	12	47	2	54	68	407	32	4703	9604
YL17	70x170	11	422	2,9	43,03	14815	10241	10340	9970	11	42	-19	21	21	418	33	5144	11370
YL18	70x170	11	477	2,9	63,43	17260	11441	10758	11502	11	53	6	38	37	467	38	4075	8228
YL19	70x170	11	391	4,4	39,44	11763	7645	8572	7543	12	45	-22	35	42	375	30	3994	6443
YL20	70x170	11	396	3,6	39,25	10623	7847	8816	8280	12	42	0	22	45	361	31	4823	8819
YL21	70x170	10	381	5	32,02	11161	8100	8119	8356	13	77	7	33	48	355	26	4447	7597
YL22	70x170	10	410	2,7	45,52	11344	8876	8260	8793	12	72	17	63	61	393	28	4424	8183
YL23	70x170	10	446	2,5	45,33	13899	9564	10613	10287	11	58	-4	56	67	436	34	5047	11135
YL24	70x170	11	435	1,9	53,43	13714	9877	8985	10101	12	61	-16	22	55	405	31	5307	12060
YL25	70x170	11	472	2,7	46,05	14285	10462	11201	10387	12	58	-13	31	48	457	35	5205	13142
YL26	70x170	10	397	2,5	29,94	11423	8040	9081	8264	11	50	13	45	38	389	31	5019	9990
YL27	70x170	11	414	3,3	52,85	15210	9693	9939	10056	12	56	-10	20	20	426	33	4802	10103
YL28	70x170	11	492	1,8	30,31	15776	11031	10878	11946	11	41	2	29	35	484	42	4947	12231
YL29	70x170	11	527	1,9	71,79	18143	12142	11878	12498	11	70	-9	68	56	510	37	5526	15351
YL30	70x170	10	459	2,7	39,19	12045	9563	9488	9150	12	57	5	77	153	442	32	5207	10589

General					Static tests			Bending machines		Finnograder						Sylvatest		
Num	Dimen- sion	u	$\rho_{0,12}$	Mean ring width	MOR	Edge- wise MOE	Flat- wise MOE	MOE Cook- Boln- der MPa	MOE Com- puter- matic MPa	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra- sonic wave speed m/s	MOE Sylva- test MPa
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa		
YL31	70x170	10	404	2,9	53,17	13175	9330	9765	9366	12	58	-25	16	29	370	28	4645	9396
YL32	70x170	10	448	2,7	42,88	14149	10101	13321	9819	12	58	-23	74	21	416	30	4379	8246
YL33	70x170	11	437	2,7	62,27	16004	10491	10655	11185	11	60	-1	21	66	444	34	4363	9380
YL34	70x170	11	497	2,1	49,93	16372	11249	11787	12012	11	52	-22	48	47	483	35	4486	10071
YL35	70x170	11	499	1,4	56,83	16592	11458	11888	11804	11	44	5	37	70	493	42	4441	8932
YL36	70x170	11	440	2,9	41,58	12930	8775	9816	9360	13	57	-20	81	115	421	31	4075	7857
YL37	70x170	10	448	3,2	26,16	12224	8429	9250	8373	12	86	0	20	64	450	29		
YL38	70x170	10	483	2,2	47,03	13403	10137	10656	10279	12	69	-5	61	86	467	34		
YL39	70x170	11	439	5	36,23	11266	8023	8762	8220	14	77	19	94	63	450	30		
YL40	70x170	11	547	4,5	32,93	12251	10299	11286	10717	13	74	-16	24	106	494	34		
YL41	70x170	11	555	5	39,15	11607	8928	9804	9002	13	74	-13	75	150	414	28		
YS1	70x170	10	455	2,5	52,13	15330	9759	10526	10004	11	81	-7	73	68	456	31	5251	12581
YS2	70x170	10	470	1,9	49,11	16438	10768	11276	11173	11	68	3	21	45	436	32	5181	11979
YS3	70x170	10	422	2,4	51,57	13598	9513	9896	9816	11	60	-29	74	103	387	28	5135	10744
YS4	70x170	10	462	2,1	58,56	15747	11543	11761	11525	10	56	-8	31	43	462	36	5380	13424
YS5	70x170	10	433	2,5	40,52	15619	10111	10503	10048	11	61	-15	28	46	437	33	5203	11750
YS6	70x170	10	397	2,6	53,64	15103	10366	10587	10492	11	73	-2	66	74	390	28	5278	11840
YS7	70x170	10	440	2	48,64	14345	9677	10158	10310	11	63	-5	39	69	441	33	5047	11469
YS8	70x170	10	467	1,5	51,19	16380	11464	12311	12487	11	80	5	72	137	459	31	5021	11701
YS9	70x170	10	475	1,9	56,19	16852	11467	11599	12025	10	56	-10	64	76	515	41	5090	12305
YS10	70x170	11	531	2,1	73,83	18506	12888	13581	14157	11	50	-10	52	82	509	41	5016	12862
YS11	70x170	9	398	2,5	37,4	12796	9041	9608	8583	10	68	-6	34	68	390	29	5173	10234
YS12	70x170	11	479	1,8	65,28	19403	12155	12524	13573	10	45	-8	17	32	477	40	5437	14353
YS13	70x170	10	451	3,1	59,97	14385	10202	10808	10707	12	44	0	51	106	428	36	4454	8878
YS14	70x170	10	404	1,9	39,01	12226	8581	9216	9189	11	59	-18	13	70	373	29	4979	9403
YS15	70x170	10	454	2,8	61,2	16357	11530	11786	11743	11	61	-3	71	92	454	34	5193	12720
YS16	70x170	10	459		33,81	9084	7933	8262	8346	12	52	-24	99	118	425	31	4373	8099
YS17	70x170	10	362	3,3	32,49	9477	7727	8149	7794	11	90	0	78	66	355	23	3967	6060
YS18	70x170	10	379	3	41,84	11116	7889	8369	8603	11	74	-14	32	55	375	27	4766	8564
YS19	70x170	10	490	2,5	44,01	16361	12183	12221	12597	11	58	3	57	67	479	37	5307	13726
YS20	70x170	10	455	1,4	41,46	13738	8561	9665	8923	11	68	-6	45	90	387	29	4926	9753
YS21	70x170	10	451	2,1	36,46	12077	7302	9058	8702	10	81	0	29	80	450	30	4100	7403
YS22	70x170	10	378	3,7	36,55	12736	8333	8989	8382	11	79	-3	48	128	378	26	3947	6153
YS23	70x170	10	464	2,4	51,57	15090	10123	10351	10506	11	69	-13	67	163	451	29	5157	12134
YS24	70x170	10	384	2,9	28,99	10763	7590	8782	8011	11	82	-3	67	146	375	24	4632	8200
YS25	70x170	10	386	2,6	24,74	9247	8089	8059	7896	11	84	-16	87	44	400	27		
YS26	70x170	10	439	2,5	39,57	9903	8194	9709	8664	11	54	19	49	33	440	33	4671	9568
YS27	70x170	11	514	4,2	25,55	9693	7390	9032	8597	12	84	-16	86	242	440	20		
YS28	70x170	10	401	2,8	36,64	11097	8709	9356	9073	12	67	-13	58	87	377	28	4949	9502
YS29	70x170	10	441	3,2	44,67	13758	8738	9710	9312	11	83	3	40	84	422	28	4916	10564
YS30	70x170	10	459	3,3	35,61	12723	8397	9503	8941	11	79	-3	33	134	439	29	4968	10537
YS31	70x170	10	421	2,8	41,93	12879	8893	9850	9326	11	74	-3	22	65	419	29	4967	10384
YS32	70x170	10	453	3,3	42,5	13519	9193	10157	9746	10	75	-7	71	117	448	32	4955	11288
YS33	70x170	10	420	1,9	28,9	9074	7096	7235	6531	11	60	-5	61	61	396	30		
YS34	70x170	10	405	4,5	23,08	10380	7286	8173	7619	12	60	-16	131	260	392	21	4892	9412
YS35	70x170	10	448	2,6	51,85	14320	10431	10857	10552	12	70	0	34	57	443	32	5028	11192
YS36	70x170	10	423	2,9	33,53	13752	9227	9923	9312	11	77	0	59	81	420	29	4461	8437
YS37	70x170	10	442	2,5	35,89	14397	10207	10312	10745	11	79	-6	18	56	420	29	4544	9029
YS38	70x170	11	418	2,7	43,81	14135	9526	10566	9883	11	75	-10	31	98	407	29	4879	10211
YS39	70x170	10	456	3,8	48,36	14724	9984	10794	9919	10	69	-12	64	93	427	31	4925	10851

General					Static tests			Bending machines		Finnograder						Sylvatest		
Num	Dimension	u	$\rho_{0,12}$	Mean ring width	MOR	Edge-wise MOE	Flat-wise MOE	MOE Cook-Bolinder	MOE Computer-matic	u	KVS	KVD	SFG	SKF	$\rho$	MOR	Ultra-sonic wave speed	MOE Sylva-test
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa	m/s	MPa
YS40	70x170	10	417	4,2	39,01	13209	8501	9476	8382	12	80	-18	89	159	418	26	4323	7958
YS41	70x170	10	468	2	45,62	15182	10419	11022	10792	12	59	-27	57	74	453	31	5054	11815
YS42	70x170	11	546	2	53,23	19712	13143	13137	13397	10	52	-14	40	35	530	42	5461	15673
YS43	70x170	10	451	2,3	48,26	16828	10936	11324	11494	11	49	10	24	56	457	37	4695	10081
YS44	70x170	11	453	2,8	59,16	15417	9986	10993	10781	11	60	-6	84	91	451	35	5193	12166
YS45	70x170	10	363	3,5	24,27	10465	8095	8325	8418	12	69	9	21	37	365	27	4747	8599
YS46	70x170	11	464	2,3	63,53	15288	10879	11289	11214	12	78	-10	43	71	437	30	5368	13107
YS47	70x170	11	438	4	49,93	14144	9840	10755	10013	11	66	2	17	46	439	32	4884	11005
YS48	70x170	11	424	4,3	30,7	10869	7413	8682	8018	11	92	-17	26	53	409	26	4362	8707
YS49	70x170	11	480	2,8	34,1	12580	10010	10935	10472	11	51	18	86	97	455	35	5021	12041
YS50	70x170	10	472	3,3	32,21	12119	9116	9936	9649	11	77	-11	76	123	449	31	4152	7840
YS51	70x170	10	410	2,5	54,12	16232	10813	10544	11221	11	61	-1	17	64	420	32	5376	11840
YS52	70x170	10	452	4,1	25,22	10719	8216	8950	8627	12	77	-11	82	144	429	29	4273	7697
YS53	70x170	10	469	1,8	49,87	14862	11091	11335	11375	11	53	16	55	54	464	35	5242	12616
YS54	70x170	11	435	2,9	47,99	12161	9181	9426	10252	12	76	-17	26	99	408	28	4532	8842
YS55	70x170	10	392	3,1	27,77	9453	7148	7718	7320	12	69	-3	50	87	390	28		
YS56	70x170	10	479	2,5	38,16	11367	8261	8396	8382	11	87	-11	28	61	405	27	4846	9985
YS57	70x170	11	395	3,1	28,27	9148	6110	6825	6955	12	82	6	83	84	358	25	4169	6668
YS58	70x170	11	494	3,5	33,51	13709	8610	10157	9700	12	66	-18	133	98	451	33	4254	8851
YS59	70x170	10	421	2,5	48,83	13528	9785	10176	9802	11	66	-16	66	112	420	31	5056	11104
YS60	70x170	10	413	2,7	35,42	11218	8984	9167	9230	12	72	4	34	44	405	29	4197	7447
YS63	70x170	10	501	4	31,64	11474	7095	7610	7719	12	82	-2	59	99	385	26		
YS64	70x170	10	400	3,2	30,6	9810	7220	8361	7416	11	93	-14	19	30	377	25	4793	8978
YS65	70x170	11	429	2,5	36,43	11278	8890	9095	9241	11	80	-17	35	67	423	29	4476	8744
YS66	70x170	11	487	2,6	36,62	12262	8079	8825	8159	12	71	-34	143	375	432	14	4184	7904
YS67	70x170	11	434	2,4	48,67	14184	9367	9176	10252	12	90	-10	39	104	402	27	5195	11596
YS68	70x170	11	472	3,2	27,39	12152	9314	8908	9700	11	87	-3	15	56	451	29	4254	8532
YS69	70x170	11	426	3,1	38,37	12087	8517	9006	9121	11	83	-3	35	45	420	28		
YS70	70x170	11	492	4,2	41,67	14428	8812	10259	10906	11	85	0	83	69	481	31		
YS71	70x170	11	458	3	27,01	10089	8837	9186	9161	12	83	-12	79	98	409	28		
YS72	70x170	13	428	2,8	33,07	11727	8846	8981	8822	13	58	-18	22	175	420	29		
YS73	70x170	11	450	2,6	44,1	12295	8904	9566	9360	12	104	-4	32	79	405	23	4971	10743
YS74	70x170	11	448	2,4	51,39	14802	9053	9919	10162	11	71	-8	47	119	431	31	5088	11715
YS75	70x170	11	561	2,4	43,33	12624	9557	9828	9954	12	59	14	30	44	419	32		
YS76	70x170	10	451	3,8	34,19	12423	8733	8982	9455	11	87	-4	45	67	411	26	5027	10791
YS77	70x170	11	434	3,1	44,3	13946	9921	10094	10341	13	89	0	43	55	424	27		
YS78	70x170	10	435	3,3	25,31	9017	6198	7157	6633	12	84	-2	64	110	406	27		
YS79	70x170	10	415	5	23,89	8227	7055	7391	7072	12	88	-9	87	136	394	26	3955	6303
YS80	70x170	11	464	2,5	32,45	12309	8676	10290	9443	12	80	-12	49	98	441	29	4866	10997
YS81	70x170	11	461	3,1	25,06	10597	8050	8884	8697	12	83	-8	20	24	424	29	4809	10457
YS82	70x170	11	379	4,2	39,15	11182	6496	7635	6877	12	85	-5	37	129	364	25	4772	9010
ZL1	45x120	12	460	3,3	57	14343	11469	11238	12973	15	37	-2	18	81	443	31	5166	12877
ZL2	45x120	11	538	1,8	51,97	13438	11300	10816	13090	14	42	-3	41	70	491	34	5054	12816
ZL3	45x120	11	455	1,9	36,91	11534	10255	9362	11191	13	46	-5	17	16	441	32	5103	11360
ZL4	45x120	11	493	2,3	51,49	14035	8097	9794	11792	14	38	4	39	34	427	33	4980	10958
ZL5	45x120	11	455	2,5	31,28	8889	7549	8038	10401	13	58	0	32	35	450	28	4829	10947
ZL6	45x120	12	477	1	57	13084	10646	10483	13355	14	40	-12	32	49	466	35	4947	11960
ZL7	45x120	12	615	2,2	56	13650	11196	10512	14189	15	37	-2	32	51	565	47	4639	12767
ZL8	45x120	12	498	2,4	57,9	13198	10104	9409	13355	14	39	-5	31	35	480	38	4748	11387
ZL9	45x120	11	476	2,5	60,03	13322	10227	9248	12435	15	34	-4	18	30	413	34	5143	12132

General					Static tests			Bending machines		Finnograder							Sylvatest	
Num	Dimen- sion	u	$\rho_{0,12}$	Mean ring width	MOR	Edge- wise MOE	Flat- wise MOE	MOE Cook- Bolinder MPa	MOE Com- puter- matic MPa	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra- sonic wave speed m/s	MOE Sylva- test MPa
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa		
ZL10	45x120	11	456	2,4	28,46	13226	8561	8962	10175	13	32	6	50	87	433	31	4819	10401
ZL11	45x120	12	503	0,7	75,8	19138	12618	12342	14647	15	32	1	23	24	468	40	5168	13621
ZL12	45x120	11	487	2	44,49	13117	10353	10124	12018	14	40	0	19	43	476	37	4362	9396
ZL13	45x120	11	449	1,9	47,21	11197	9280	8820	10992	15	45	-9	36	60	432	30	5023	11349
ZL14	45x120	11	524	1,7	42,74	13257	10076	9992	12435	14	44	-4	44	47	483	35	5111	12640
ZL15	45x120	11	474	3,2	39,73	11977	9000	9391	12099	15	42	2	19	46	435	32	4998	11508
ZL16	45x120	12	533	1,7	75,3	17538	13543	12539	14708	16	33	-3	18	24	502	43	5346	15099
ZL17	45x120	12	516	2,5	42,4	11571	10826	10191	12898	14	45	-10	40	79	504	33	4841	12334
ZL18	45x120	12	468	2,6	56,2	14480	11168	10600	13759	14	39	-3	19	49	435	33	5221	12637
ZL19	45x120	11	417	2,3	54,79	12797	10569	9812	11402	15	42	6	37	42	410	31	4418	8613
ZL20	45x120	11	448	3,3	29,82	10451	9461	8987	13475	14	47	8	37	68	452	30	4945	11370
ZL21	45x120	11	464	2,6	53,04	12530	10091	9503	11672	15	34	-2	27	26	444	37	5093	11348
ZL22	45x120	11	525	2,5	55,47	14477	10931	10049	11191	14	36	3	35	32	451	36	4869	11342
ZL23	45x120	11	468	2,2	46,05	11454	9167	9456	11033	14	47	5	19	19	454	33	4714	10330
ZL24	45x120	11	423	2,2	42,94	13361	10541	9879	11928	13	38	-14	45	67	429	31	5064	11437
ZL25	45x120	11	403	2,3	53,72	13347	10194	9840	11771	14	36	-2	26	46	421	33	5132	11389
ZL26	45x120	11	444	1,1	57,99	14148	11631	10684	12695	13	39	-1	18	19	437	34	4910	10415
ZL27	45x120	12	431	2,8	64,4	14364	10251	9670	11949	14	38	-1	23	48	401	31	4910	10914
ZL28	45x120	12	418	3,6	64,6	13604	10463	9716	10515	14	41	0	28	31	395	30	4904	10887
ZL29	45x120	12	484	1,1	58,3	16806	11141	12453	13988	14	42	1	17	23	518	40	5335	14986
ZL30	45x120	11	423	2,9	49,64	12297	8039	8617	9461	14	31	0	19	79	412	31	4960	10638
ZL31	45x120	12	476	2,1	65,4	14149	11975	10936	13988	14	33	-8	14	32	459	39	5423	13930
ZL32	45x120	12	511	3,3	30,9	10486	9529	8610	10982	14	51	2	53	62	455	28	4759	11232
ZL33	45x120	12	443	3,1	38,3	11659	10123	9496	11351	14	53	0	29	41	435	28	5018	11611
ZL34	45x120	11	447	3,2	26,03	9724	7184	6255	8346	13	40	-14	28	56	383	28	4789	8990
ZL35	45x120	12	435	2,2	46,6	14043	10319	9505	11478	14	39	4	14	29	428	33	5016	11306
ZL36	45x120	12	431	2,6	47,4	12202	9680	9467	11351	15	35	3	28	27	411	34	4991	11163
ZL37	45x120	12	451	2,9	31,6	11051	9033	8969	10183	14	48	-1	23	30	451	31	4720	10682
ZL38	45x120	11	443	2,9	33,61	11648	10851	10001	11938	13	42	-5	21	22	438	33	5122	12027
ZL39	45x120	11	452	3,6	45,75	11872	11336	9657	10668	13	39	-7	44	53	433	33	5095	11613
ZL40	45x120	12	519	2,8	63,1	12422	11734	11093	13759	15	48	2	45	62	486	32	5282	14219
ZL41	45x120	11	439	2,1	53,91	13291	9926	10031	11692	13	34	0	23	54	397	31	5003	11035
ZL42	45x120	11	478	2	58,97	16354	12653	11742	15218	13	38	0	18	19	466	37	5350	13363
ZL43	45x120	11	514	1,9	56,93	13492	11817	10489	13396	13	38	-7	18	32	498	40	4640	10728
ZL44	45x120	12	446	2,2	51,9	12889	10333	9640	11401	14	39	0	29	59	437	32	5111	11902
ZL45	45x120	10	459	3,4	48,07	12229	9515	9695	9958	14	36	-11	30	76	437	31	4541	9466
ZL46	45x120	12	513	3,1	70,8	21190	11206	11892	16040	15	31	-10	23	21	470	40	5114	14235
ZL47	45x120	12	535	1,7	44,9	13050	11452	11119	14343	15	44	-3	29	52	540	40	4746	12474
ZL48	45x120	11	455	2,5	41,97	12371	10845	9849	12790	13	49	1	20	39	432	30	5293	12865
ZL49	45x120	11	501	1,4	57,61	11023	12102	10656	12694	14	24	1	55	116	469	34	5108	12836
ZL50	45x120	11	491	2	32,64	15715	11733	10545	13001	14	43	-19	61	85	508	32	4966	11837
ZL51	45x120	12	535	1,1	54,2	17692	11142	12016	15763	14	45	5	23	27	520	39	5286	15285
ZL52	45x120	12	513	3	69,6	12086	10195	9276	10658	14	40	-1	21	56	479	35	4331	9113
ZL53	45x120	11	430	1,8	49,64	10777	9391	8452	10252	12	31	3	72	78	435	32	4665	9606
ZL54	45x120	12	515	1,3	58,6	15415	11232	12052	15657	15	44	-2	26	33	501	37	5173	14481
ZL55	45x120	12	503	2,6	72,5	17881	10759	11906	14647	14	23	-1	26	26	467	44	5432	14212
ZL56	45x120	12	504	3,3	44,1	11216	9496	9235	13355	14	41	1	30	46	490	37	5029	12928
ZL57	45x120	12	544	2,5	52,6	13270	10058	9496	11949	14	31	-3	23	113	481	32	4875	11663
ZL58	45x120	12	480	2,3	48,3	13639	10264	10010	12887	14	40	1	33	48	486	37	5016	12110
ZL59	45x120	12	526	2	60,2	17105	11864	11188	14733	14	25	-1	28	33	510	48	5107	12768

General					Static tests			Bending machines		Finnograder						Sylvatest		
Num	Dimen- sion	u	$\rho_{0,12}$	Mean ring width	MOR	Edge- wise MOE	Flat- wise MOE	MOE Cook- Bolin- der	MOE Com- puter- matic	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra- sonic wave speed m/s	MOE Sylva- test MPa
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa		
ZL60	45x120	12	562	1,4	58,2	14173	12876	11764	14945	15	28	-1	82	46	514	45	5072	14030
ZL61	45x120	12	443	2,5	42,6	10810	8712	8445	10480	14	42	2	68	69	429	30	4458	8718
ZL62	45x120	11	477	2,2	36,53	14132	10044	10439	13189	14	35	-2	69	96	490	34	5194	12751
ZL63	45x120	11	419	2,7	47,21	12822	9862	8976	9391	14	34	6	27	70	410	31	5096	10970
ZL64	45x120	12	417	2,6	42,9	10398	9842	9269	10533	14	55	2	12	24	414	27	5064	11271
ZL65	45x120	12	448	2,6	46	10110	9769	8301	11266	15	42	-17	18	44	400	30	4784	9592
ZL66	45x120	11	464	2,1	33,71	10951	8772	9359	11546	13	42	-10	71	125	408	22	5173	11617
ZL67	45x120	12	515	2,1	47,8	13548	12597	11035	12973	15	34	-12	17	25	483	40	5126	13374
ZL68	45x120	11	441	2,9	43,03	12007	9104	8674	11402	14	42	-1	34	33	428	32	4932	10745
ZL69	45x120	11	423	2,9	42,26	11769	9601	9528	10846	14	33	-9	34	81	409	30	4792	9788
ZL70	45x120	11	405	3,6	32,54	8435	6580	6225	8849	14	31	-5	39	62	412	33	4406	8048
ZL71	45x120	11	424	2,2	39,34	10681	9432	8963	11335	14	40	0	15	51	434	32	5189	11567
ZL72	45x120	11	431	2,6	51,19	11584	9744	9223	10992	12	38	6	29	58	427	31	5034	11141
ZL73	45x120	11	461	3,6	33,03	9967	8151	7700	10941	15	35	-2	60	169	433	22	4818	10584
ZL74	45x120	12	484	2,6	38,5	12981	11562	10729	13060	14	43	0	65	63	489	34	5101	13021
ZL75	45x120	11	473	2,9	36,23	11661	10067	9240	11182	15	48	-2	52	96	455	26	4850	11149
ZL76	45x120	12	532	3	58,1	15804	11555	10707	12602	16	39	-5	37	65	535	41	4322	10644
ZL77	45x120	15	473	3,3	68	19265	14083	12981	17056	15	36	-3	39	126	522	34	5204	16047
ZL78	45x120	12	436	2	42,8	13927	10549	9890	12220	13	39	-3	13	17	451	36	5293	12469
ZL79	45x120	12	447	2,6	44,3	13708	11426	9554	12613	13	38	-2	22	24	448	35	5207	11990
ZL80	45x120	12	631	2,1	43,6	12763	12331	11558	15135	14	54	7	13	86	523	29	5005	14180
ZL81	45x120	12	480	2,7	55,4	14414	11281	10079	12865	12	41	1	32	18	494	38	4913	12051
ZL82	45x120	11	441	2,9	49,15	11159	10122	9743	11201	13	43	1	33	56	467	33	4920	10949
ZL83	45x120	11	436	3,3	25,35	7449	7679	7085	10264	14	51	0	64	50	429	28	4330	8011
ZL84	45x120	12	526	1,8	56,7	15001	11659	11268	13287	14	31	-4	17	23	520	46	4927	12791
ZL85	45x120	12	452	2,4	55,6	13877	10910	9944	11623	15	41	0	29	30	428	33	5092	12056
ZL86	45x120	14	447	2,2	61,41	15260	11726	10142	13839	14	34	-5	43	16	427	35	5534	14069
ZL87	45x120	11	406	2,6	34,29	10133	7194	7731	8953	13	35	-1	94	109	407	25	4892	10038
ZL88	45x120	12	434	2,7	42,7	12750	10363	9482	11266	14	44	-2	16	27	437	32	5137	11802
ZL89	45x120	12	496	2,3	69,4	16275	13933	12110	15135	12	26	-1	31	17	518	49	5797	16499
ZL90	45x120	12	454	2,8	57,1	14353	10802	10687	12613	15	38	0	42	47	446	35	5238	12553
ZL91	45x120	12	522	2	36,9	13741	11821	10794	13343	15	26	-6	17	36	494	46	5015	12630
ZL92	45x120	11	456	4	25,26	9645	7793	7677	9195	15	46	11	70	163	433	20		
ZL93	45x120	12	479	2,6	55,9	13371	11377	10385	13668	14	25	-1	19	30	438	40	5080	12060
ZL94	45x120	12	465	2,2	51,8	13873	10998	10318	12518	15	44	-9	36	59	444	32	5357	13552
ZL95	45x120	11	417	2,4	38,37	14392	11233	10128	11840	14	42	3	19	51	424	30	5709	14203
ZL96	45x120	11	475	2,7	31,18	12166	9045	9425	11267	15	29	-3	52	91	465	36	4999	11734
ZL97	45x120	12	559	1,5	66,5	17186	13505	12278	16095	13	32	-2	16	22	535	48	5238	13982
ZL98	45x120	11	476	1,9	44,49	11623	10868	9779	13344	13	41	-7	32	58	476	34	5037	12284
ZL99	45x120	12	431	2,3	53,4	14484	10971	9981	11869	14	34	-1	38	40	418	34	4927	11116
ZL100	45x120	12	498	2	63,6	15956	12779	11375	14343	14	43	7	21	46	501	38	5675	16394
ZL101	45x120	11	428	3	39,93	13471	9276	9202	10764	13	43	-7	32	50	432	32	4975	10848
ZL102	45x120	14	472	2,2	47,71	12678	9695	8812	11390	14	50	3	57	59	443	28	4794	11115
ZS1	45x120	12	595	1,7	55,2	16018	12206	11557	14428	15	43	2	69	103	551	35	4322	11061
ZS2	45x120	11	476	2,5	43,91	10833	10165	9525	11165	14	52	14	21	109	454	23	4912	11646
ZS3	45x120	11	447	2,9	46,73	12052	9022	9286	12259	12	38	-9	101	117	440	24	4754	9818
ZS4	45x120	13	426	2,8	41,01	11554	9705	9199	11634	14	44	-2	31	104	434	24	4976	11957
ZS5	45x120	12	438	2,9	40,1	11654	9085	8768	11488	13	54	0	29	68	431	24	4920	10972

General					Static tests			Bending machines		Finnograder							Sylvatest	
Num	Dimension	u	$\rho_{0,12}$	Mean ring width	MOR	Edge-wise MOE	Flat-wise MOE	MOE Cook-Bolinder	MOE Computer-matic	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra-sonic wave speed	MOE Sylva-test
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa	m/s	MPa
ZS6	45x120	11	440	4	36,82	12360	9205	9065	11692	12	43	-3	28	49	391	28	5076	11293
ZS7	45x120	11	428	3,6	37,59	11276	9203	8617	11575	13	41	2	29	76	413	26	4346	8420
ZS8	45x120	12	412	2,7	45,5	11479	9389	8389	9460	11	38	3	30	32	407	32	4923	10018
ZS9	45x120	12	522	3,8	51,8	13228	11724	10542	12613	14	44	-4	34	52	486	34	5539	15418
ZS10	45x120	12	503	1,4	78,5	19269	13561	12333	14983	14	35	10	22	83	493	36	5182	13834
ZS11	45x120	11	461	2,2	62,66	13041	10785	9954	12525	13	51	0	19	56	481	30	4993	11831
ZS12	45x120	12	498	1,9	55,5	15270	12885	11232	13204								5037	12818
ZS13	45x120	12	440	2,5	45,2	12091	10600	9396	11555	13	41	-3	20	61	437	30	5076	11905
ZS14	45x120	12	481	1,9	73,8	14435	11909	11035	14189	14	36	-8	42	18	458	37	5141	12623
ZS15	45x120	12	474	3,8	45,4	12118	10080	9281	11163	11	34	0	35	84	464	30	4833	10867
ZS16	45x120	11	477	4	40,02	10676	10808	9947	12414	14	41	2	77	98	465	29	4727	10745
ZS17	45x120	12	513	1,7	59,2	13191	11037	10078	13166	12	38	-6	23	57	473	35	4795	11485
ZS18	45x120	12	554	1,3	68,3	15437	12015	10904	14549	13	35	7	24	31	472	39	4940	13049
ZS19	45x120	11	617	1,7	60,23	15852	12544	10429	13464	14	46	0	58	100	459	26	5700	16888
ZS20	45x120	12	436	1,2	63,3	13613	10687	9540	11859	14	41	6	16	18	428	33	5606	13877
ZS21	45x120	11	485	2,5	39,83	11033	10321	9589	11307	12	48	11	41	130	492	20	4649	11455
ZS22	45x120	12	530	2,5	44,9	14634	10751	10057	13137	14	48	0	60	112	494	27	4808	11862
ZS23	45x120	12	508	1,9	60,5	13488	11265	10736	13748	11	33	1	46	118	512	28	4937	12188
ZS24	45x120	12			69	12695	12028	10757	14585	12	41	8	34	27	522	41	4950	12519
ZS25	45x120	12	429	2,3	32,6	13519	9661	9411	11469	13	41	11	39	40	450	34	4986	10734
ZS26	45x120	11	480	1,7	47,79	14665	10990	10594	12621	12	34	-6	52	68	485	36	5082	12538
ZS27	45x120	12	556	2,1	60,6	13668	11242	10025	13210	12	45	7	18	28	499	38	5222	13310
ZS28	45x120	12	490	1,5	58,7	15569	12962	11614	15461	10	45	3	47	52	498	34	5368	14512
ZS29	45x120	12	475	3,3	43,5	12755	11244	10091	10963	13	43	-3	64	92	455	27	4820	11179
ZS30	45x120	12	496	2,3	43,9	16201	12245	11366	13989	14	41	3	20	42	468	36	5147	13531
ZS31	45x120	12	500	2,2	53,8	16154	12870	10756	15110	11	37	-6	28	42	489	39	5019	12328
ZS32	45x120	12	473	2	39,4	10642	9292	9188	11154	11	43	1	23	43	458	33	4887	11364
ZS33	45x120	12	472	1,4	63		11651	10794	14922	13	34	3	42	31	508	43	5068	13082
ZS34	45x120	12	522	1,2	57,5	15054	12595	11221	14586	14	37	-2	32	35	509	42	5874	17300
ZS35	45x120	12	525	1	72	13530	12888	11433	13577	13	42	-8	32	31	512	40	5112	13445
ZS36	45x120	12	552	2,3	65,9	16985	12891	12475	15976	11	34	-6	32	85	574	40	5083	14298
ZS37	45x120	12	475	1,9	65,6	15318	12257	11006	13759	12	38	-1	27	64	454	32	5046	12405
ZS38	45x120	12	425	2,5	55,7	12363	10776	9763	10918	10	41	5	17	37	438	33	5200	11402
ZS39	45x120	13	533	2,2	73,15	14654	13398	11953	15458	15	46	3	15	17	482	35	5486	15639
ZS40	45x120	12	554	1,8	52,7	16815	12767	11782	14321	12	40	1	50	105	502	28		
ZS41	45x120	11	465	2	28,95	12196	8793	9321	11392								4750	10781
ZS42	45x120	12	488	3,6	42,2	10517	7900	7609	10649	16	43	10	130	168	436	23	4656	9781
ZS43	45x120	12	501	1,9	69,7	16440	13363	11848	16216	15	42	0	39	35	486	36	5856	17689
ZS44	45x120	12	549	1,9	35,8	14377	13675	11867	14635	13	41	-3	25	59	514	37	5079	13956
ZS45	45x120	11	462	3,6	44,49	14203	10241	9372	11169	15	37	-4	30	116	448	28	4687	10238
ZS46	45x120	12	460	1,9	56,7	14247	11859	10658	12613	14	27	1	73	83	454	36	5061	12295
ZS47	45x120	12	526	1,9	39	10756	10350	9206	12007	13	55	-4	49	100	493	23	4806	12073
ZS48	45x120	12	491	2	68,7	15542	10895	10736	13748	12	45	-4	42	40	466	33	5111	12761
ZS49	45x120	11	571	2,1	48,38	14736	11061	11443	14429	14	51	4	24	41	505	34	4993	12738
ZS50	45x120	11	497	2,8	40,41	12055	8997	8482	13577	13	35	-13	38	140	486	25	4689	10937
ZS51	45x120	11	461	4	45,85	10709	9348	8408	10794	12	41	1	33	65	407	27	4661	9739
ZS52	45x120	12	539	2,2	56,4	12216	11905	10542	13759	15	41	-2	25	40	513	40	4507	11153
ZS53	45x120	11	488	2,7	21,27	10234	9076	8918	10157	13	50	-3	44	138	475	20	4199	8547
ZS54	45x120	11	461	3,1	35,46	12150	10348	9008	12008	13	55	-1	35	141	447	16	4973	10822
ZS55	45x120	11	432	3	34,87	10799	8292	8231	10900	14	51	9	57	82	460	27	4453	9372

General					Static tests			Bending machines		Finnograder						Sylvatest		
Num	Dimension	u	$\rho_{0,12}$	Mean ring width	MOR	Edge-wise MOE	Flat-wise MOE	MOE Cook-Bolinder	MOE Computermatic	u	KVS	KVD	SFG	SFK	$\rho$	MOR	Ultra-sonic speed	MOE Sylva-test
	mm	%	kg/m <sup>3</sup>	mm	MPa	MPa	MPa	MPa	MPa	%					kg/m <sup>3</sup>	MPa	m/s	MPa
ZS56	45x120	11	515	1,9	46,82	12628	11551	9713	14084	14	29	-7	39	34	487	43	4836	11675
ZS57	45x120	11	407	2,3	46,24	12638	11495	9392	11025	13	28	-4	103	137	403	24	4603	8545
ZS58	45x120	10	399	2,9	45,81	10763	8660	8329	9810	12	33	-7	33	143	404	18	4896	9503
ZS59	45x120	11	486	2,1	67,03	17664	11568	10708	13989	12	30	-4	85	135	474	27	5640	15207
ZS60	45x120	11	424	3,6	32,45	11746	9136	8320	10755	13	46	9	36	88	409	24	4789	9797
ZS61	45x120	11	463	2,2	65,57	17386	12669	11556	14285	11	27	-5	32	51	417	35	5414	13107
ZS62	45x120	11	500	1,9	49,15	13938	11837	10413	13155	15	31	-8	41	109	480	33	4972	11960
ZS63	45x120	11	454	3,3	40,41	13109	10003	9040	11771	12	43	2	56	60	390	26	4873	10723
ZS64	45x120	11	488	2,3	29,53	11471	9093	8604	13029	12	45	1	104	108	475	26	4198	8740
ZS65	45x120	11	422	4	31,09	8917	8589	8217	10410	11	53	4	34	80	446	22	4699	9626
ZS66	45x120	11	547	2,4	57,22	12156	10711	10104	13200	13	16	-2	56	194	508	23	4750	11290
ZS67	45x120	11	497	2,2	38,57	10372	9084	8882	12102	14	54	5	20	34	445	29	4394	9378
ZS68	45x120	12	440	2,7	38,4	10092	8500	7551	9188	11	40	-6	52	128	426	19	4436	8235
ZS69	45x120	11	399	4,4	24,19	9793	7391	7712	9602	11	35	-14	66	110	427	22	4598	8551
ZS70	45x120	12	504	1,8	43	11855	10926	10210	13377	13	46	-5	32	38	462	33	4886	11818
ZS71	45x120	12	500	2,5	57,7	12179	11483	10816	13090	15	30	-7	35	132	462	29	4358	9255
ZS72	45x120	12	515	1,4	59,4	16209	11619	11485	15067	11	23	-2	32	85	507	39	5003	12792
ZS73	45x120	11	421	3,3	39,25	10892	9153	8361	10410	12	30	-9	41	175	407	15	4673	9228
ZS74	45x120	11	520	1	59,65	15312	11625	11157	13977	11	42	15	16	63	541	36	4963	13276
ZS75	45x120	12	498	3,3	44,1	10766	9858	8809	11176	14	38	9	29	22	489	14	4747	11375
ZS76	45x120	11	489	2,2	52,85	14380	11472	10542	13885	11	48	-1	37	69	473	27	5013	12124
ZS77	45x120	11	450	1,8	41,67	12492	9283	9358	12442	12	39	6	32	57	407	30	5006	10992
ZS78	45x120	11	573	1,3	45,37	11780	12303	11057	15751	11	45	2	34	82	562	33	5078	14117

**Explanations to the table:**

**General**

Num Specimen number  
Dimension Nominal dimension of specimen (mm)  
u Moisture content directly after bending strength test (%)  
 $\rho_{0,12}$  Density, dry weight and volume at u=12% (kg/m<sup>3</sup>)  
Mean ring width Mean annual ring width at tested cross-section (mm)

**Static tests**

MOR Bending strength (MPa)  
Edgewise MOE Edgewise modulus of elasticity (MPa)  
Flatwise MOE Flatwise modulus of elasticity (MPa)

**Bending machines**

MOE Cook-Bolinder Modulus of elasticity determined from Cook-Bolinder test (MPa)  
MOE Computermatic Modulus of elasticity determined from Computermatic test (MPa)

**Finnograder**

u	Moisture content determined by Finnograder (%)
KVS	Sum of knots
KVD	Difference between knot values at the both halves of the width
SFG	Slope of grain in knotfree areas
SFK	Slope of grain at knots
$\rho$	Density ( $\text{kg/m}^3$ )
MOR	Characteristic bending strength determined by Finnograder (MPa)

**Sylvatest**

Ultrasonic wave-speed	Speed of an ultrasonic pulse (m/s)
MOE Sylvatest	Modulus of elasticity determined from Sylvatest measurement

**Note:** The bending strength values have not been corrected for depth. All modulus of elasticities give in the appendix have been corrected for moisture content and are valid for  $u=12\%$ .

