Strength Grading of Structural Lumber by Portable Lumber Grading - effect of knots

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Abstract

Strength grading of structural lumber is not a new concept in Hungary. A special wooden dome structure - made from high strength lumber was constructed in 2000 at the campus of University of West Hungary, Sopron. The materials of the dome is Siberian Larch, strength grade is C40. The triangle truss structure covers 65 m^2 are by 0.7 m^3 structural wood. After 10 years of service, the dome structure is intact, demonstrates the benefits of graded lumber.

For grading the lumber of the dome structure, we measured the dynamic modulus of elasticity by longitudinal vibration. Density is measured by weighing the lumber. We have incorporated a parameter in the grading process determined by visual evaluation. It takes into account the effect of knots, and their concentration. This parameter is the Concentrated Knot Diameter Ratio: CKDR.

In 1986 Mr. Sobue in Japan introduced a method of calculation of the dynamic modulus of elasticity using Fast Fourier Transformation of the power spectrum in the vibrating specimen. The parameter measured was the natural frequency of the piece. Strong correlation coefficients were found for structural size specimens (Sobue 1986).

Due to the recent changes in wood structure design - moving from Hungarian design code MSz14081 to Euro Code 5 - we decided to verify the grading machine according to the EN 14025. The paper shows the partial results of the initial type testing of the Portable Lumber Grader (PLG) tool. 243 pieces of full size soft wood lumber has been and after the grading process the edge wise bending strength has been determined. The effect of knots are analysed carefully.

1 Materials and Methods

Mixed quality 5 by 10 cm cross-section, 2 m long softwood lumber, grown in the Western Carpathian region was tested. The number of specimens totalled is 243. The test material were mixture of *Picea*, *Pinus* and *Larix* species. Moisture content of the samples were not controlled, they were in air-dry condition. The moisture content was 16+/- 2 %.

The primary goal of our investigation was to perform the initial type testing of the– Portable Lumber Grader – tool (Divos 2002). Parallel with the initial type

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test we determined other strength predictor parameters like dynamic bending Modulus Of Elasticity (MOE), shear modulus, logarithmic decrement, and different knot parameters, like knot diameter ratio, knot area ratio and these parameters restricted to the edge of the lumber.

PLG measures the dynamic MOE of lumber using longitudinal vibration and density. The concentrated knot diameter ratio: CKDR is also involved in the grade decision process. Definition of CKDR is given later in this paper.

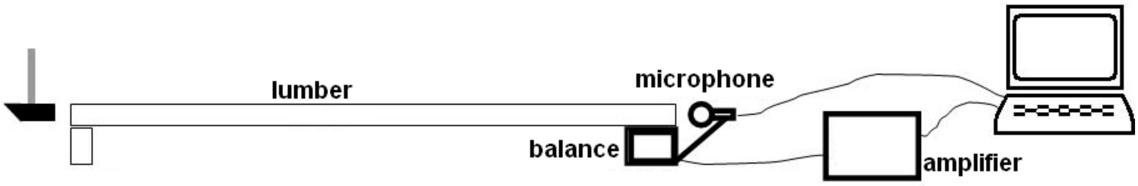

Figure 1. The setup of the Portable Lumber Grader

Most of the time, the moisture content of the lumber during the grading process is different from the moisture content in service condition. We define moisture difference using the following term: moisture difference = actual moisture content – future moisture content in service condition

The EN-338 norm is dealing with static MOE. The Portable Lumber Grader software determines the dynamic MOE first then applies a correction factor to predict the static MOE. The following term defines the measured MOE_{mea}:

$$MOE_{mea} = \frac{m}{l*w*h}(2lf)^2 0.87(1+u/50)+0.6$$

where *f*: frequency of the longitudinal vibration, mode number is 1.
u: moisture difference in %. If u > 18 than u=18.
l: length
w: width
h: height

The calculated MOE takes the effect of knots into account using the highest concentrated knot diameter ratio CKDR:

$$MOE = MOE_{mea} - 6.2CKDR$$

Before the destructive test, we have determined the following strength predictor parameters, because we wanted to improve the strength prediction capability of our grading tool:

- Knot Area Ratio (KAR), which requires a grader to visualise the knots going right through the cross-section. The KAR is the ratio of the cross - section that is taken up by knots, see figure 2. If two or more knots exist in any 15 cm long section, we are using the sum of the particular KAR values.

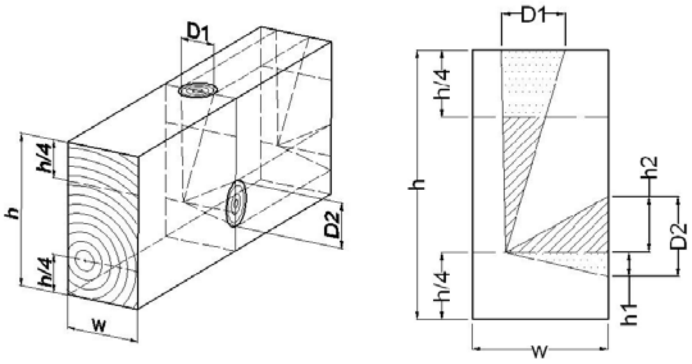

Figure 2. The definition of KAR parameter

- Knot Area Ratio at the edges. The edge zone is defined as ¼ height of the cross-section as indicated in figure 2. Knot Area Ratio at the edges is the ratio of the dotted cross-section relative to the half cross-section of the lumber.
- CKDR is the Concentrated Knot Diameter Ratio. The knot diameter is a distance between the two tangential lines parallel to arises (longitudinal direction) of a lumber surface in which the knot exists. If a knot diameter not less than 2.5 times as much as its smallest diameter, it shall be considered to have one half of its actual measured diameter. The knot diameter ratio (KDR) is a percentage of the diameter of a knot to the width of a lumber surface in which it exists. The concentrated KDR (CKDR) is the sum of KDR concerning the knots existing in any 15 cm length of a piece of the lumber. The highest - considering 4 faces - CKDR represents the piece of lumber. Figure 3 shows a case, where CKDR = (D1+D2+D3+D4)/(2h + 2w)

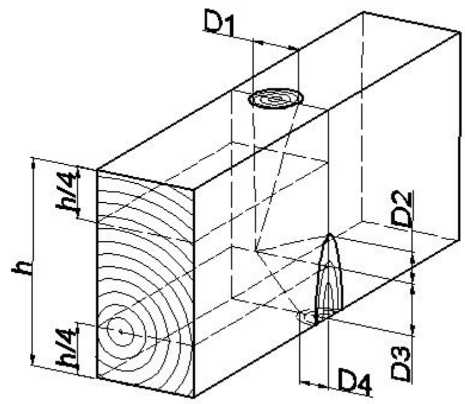

Figure 3. The parameters are used in CKDR definition

- CKDR edge is the same as CKDR but restricted to the edge zone. In case of figure 3, the CKDR edge is = (D1 + D3 + D4)/(h + 2W)
- Average annual ring width measured on the end of the lumber
- Maximum annual ring width
- Logarithmic decrement * 1000. The definition of the logarithmic decrement (LD) is: LD=β*T where “β” is the parameter of the exponential covering curve – see figure 4. “T” is the period of time, inverse of the

frequency. The LD is dimension less quantity. Usually the LD values are low numbers (0.01 – 0.04), depending on the material tested. For this reason we multiply LD by 1000. We measured LD in bending vibration, mode number 1, lumber was in edgewise position, rubber supports were at nodal point positions.

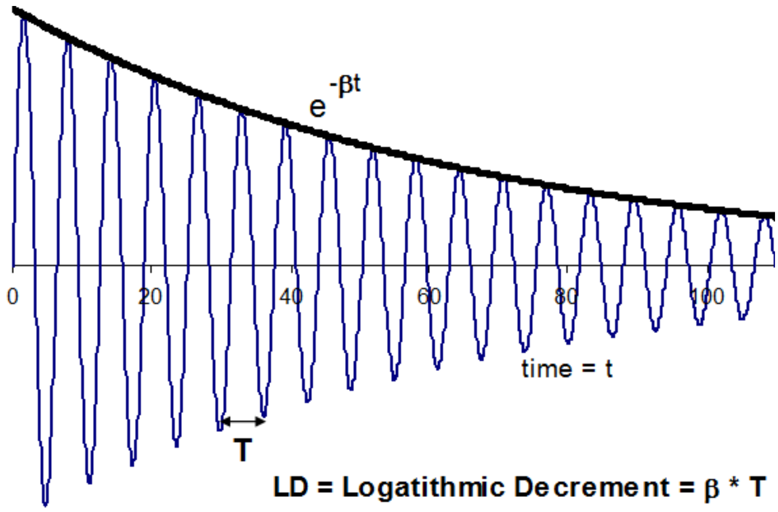

Figure 4. The definition of the logarithmic decrement, LD.

- Density,
- Static MOE according to EN 408.
- MOE determined by PLG,
- Dynamic MOE, longitudinal vibration, mode no.: 1
- Dynamic MOE, longitudinal vibration, mode no.: 2
- Dynamic MOE, bending vibration, edgewise, mode no.: 1
- Dynamic MOE, bending vibration, edgewise, mode no.: 2
- Shear modulus: G, determined by torsional vibration

The definitions of the above dynamic MOE and shear modulus parameters are given in (Divos 1997 and 2005).

2 Results

243 pieces of lumber were tested by PLG. The grade decision parameters are the MOE calculated by the dynamic MOE measured in longitudinal vibration and density. Immediately after the grading process, the static MOE and bending strength was determined according to the EN 408, using universal testing machine. The strength grade determined by the PLG is called assigned grade. The optimum grade is determined by the measured bending strength – using size correction, the measured static MOE and density. The initial type testing requires at least 900 tests and here we present the partial results. Table 1 shows such a comparison between assigned and optimum grade, called as size matrix according to EN 14081. Unfortunately, the population at higher grade is low, because the low quality of the test material. We need to continue the initial type testing procedure with better quality material.

Table 1. The size matrix, R indicates rejected. No data means 0.

Optimum grade	Assigned grades												
	C50	C45	C40	C35	C30	C27	C24	C22	C20	C18	C16	C14	R
C50													
C45			1										
C40			1	5	4		1						
C35			**1**	1	3	2	1						
C30				**1**	6	3	2	1					
C27						1	2	3		2	2		
C24					**1**	**1**	2	1	1	1	1		
C22								8	1	2	7	4	
C20									1	3	1		
C18									**2**	1	12	7	3
C16											4	7	31
C14											**1**	6	40
R													51

The optimum grade equals or higher than the assigned grade, apart from 7 pieces, indicating a conservative grading process. It is good for safety, but unfortunate for the lumber manufacturer, because the down grading, results value loss. Downgrading is more serious at low grade and rejected samples. A slight modification of the grading algorithm will be necessary.

Additional strength predictor parameters were tested to develop a new lumber grading machine, that has even lower standard error of strength estimation. Table 2 shows the correlation coefficient between the above listed strength predictor parameters and the measured bending strength.

Table 2. The obtained correlation coefficient between the parameter listed and the measured bending strength.

Parameter	**Correlation coefficient**
KAR	-0.57
KAR, edge	**-.059**
CKDR	-0.51
CKDR, edge	-.054
Average annual ring width	-0.50
Maximum annual ring width	-0.48
Logarithmic decrement * 1000	**-0.72**
density	+0.50
static MOE	+0.84
MOE determined by PLG	+0.80
Dynamic MOE, longitudinal vibration, mode no.: 1	+0.79
Dynamic MOE, longitudinal vibration, mode no.: 2	+0.78
Dynamic MOE, bending vibration, edgewise, mode no.: 1	**+0.83**
Dynamic MOE, bending vibration, edgewise, mode no.: 2	+0.78
Shear modulus: G, determined by torsional vibration	+0.75
MOE, long1/G	+0.34

The MOE measured by bending vibration has higher correlation to bending strength, relative to the MOE measured by longitudinal vibration. For this reason the new tool will based on bending MOE. We also measured higher vibration modes, but these parameters were not independent from the MOE determined by basic vibration mode, so was not useful in grading tool development. The logarithmic decrement – measured in bending vibration is a statistically independent parameter from MOE. The KAR and the KARedge parameters also support the strength grading process. A multi parameter regression analysis provided the following strength predictor formula. The standard errors of the parameters are given in brackets:

$$\textit{strength} = 29.36 + 3.071 MOE_{bend1} - 0.5778 LD - 15.31 KAR - 10.64 KARedge$$

(5.30) (0.237) (0.1286) (4.54) (3.68)

Strength is given MPa, MOE in GPa. The standard error of strength estimation of the above strength predictor formula is 6.73 MPa, remarkably lower, than achieved by PLG. (8.0 MPa). Figure 5 shows the scatter of the actual and predicted strength.

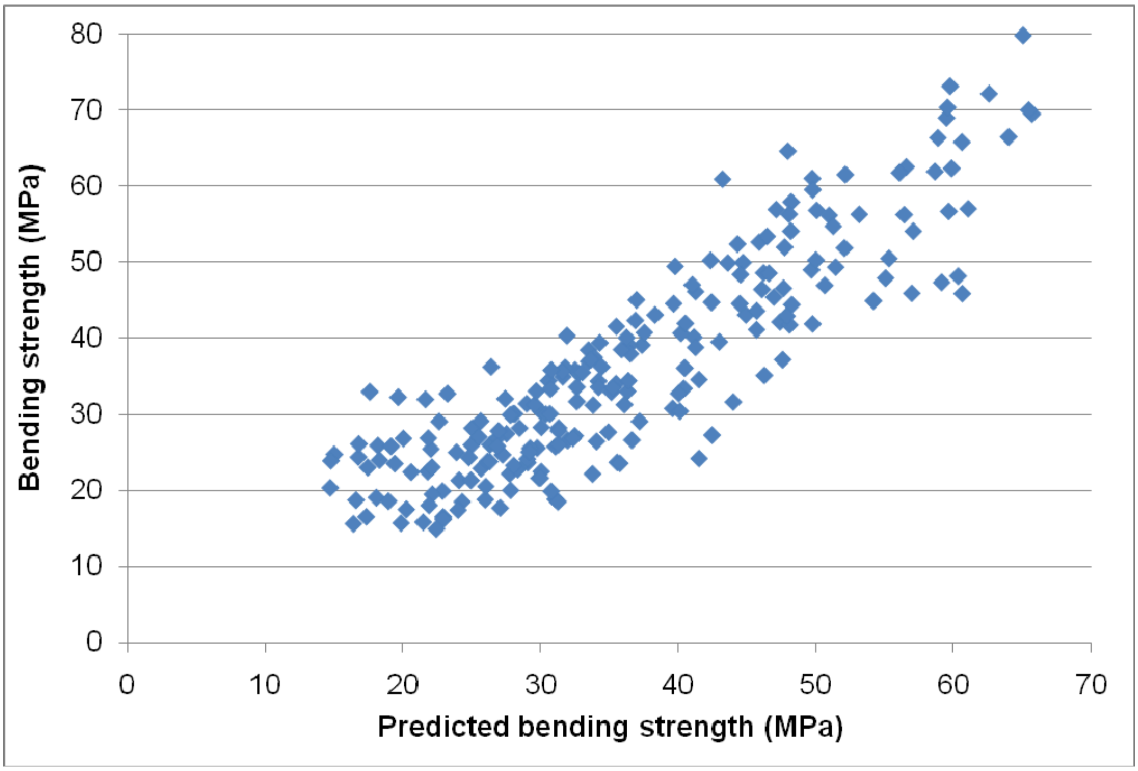

Figure 5. The link between the strength and the strength predictor

3 Conclusions

We are at the beginning of the initial type testing of Portable Lumber Grading tool. Instead of the strength, the static MOE is the dominant in optimum grade determination parameter. The size matrix is rather "sharp", most of the samples are in the main axle, indicating reliable grading by PLG tool. The initial type testing process is not finished yet, but the result are excellent. Slight modification of the grading algorithm will be necessary to avoid downgrading at low grades. We need to restart the initial type testing procedure. The standard error of strength estimation by PLG is 8.0 MPa.

The additional test shows, that the strength prediction of the grading process can be improved by changing the predictor parameters. Using dynamic bending MOE, logarithmic decrement, knot area ratio and knot area ratio restricted to the edge zone provides 6.73 MPa standard error of strength estimation. Unfortunately grading by bending vibration is much slower, comparing to the longitudinal vibration because the frequency of bending vibration is much lower.

Literature

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