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Grading characteristics of structural Slovak spruce timber determined by ultrasonic and bending methods

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Abstract

The paper deals with evaluation of characteristics of structural Slovak spruce timber using an ultrasonic and a bending method. A destructive bending method was performed according to EN 408 and evaluated according EN 384. An ultrasonic device, Sylvatest-Duo, with build-in structural timber grading standards was used for measuring wave propagations velocity and gain of energy in wood.

Result analysis showed differences in strength-modulus relations between the methods. Objectives results provided by the bending method give more reliable and real characteristics of MOE_{stat}. Significant correlation between MOE_{stat} and MOR_{stat} (r~0,7) was confirmed. Moreover, another strong correlation between *MOR* and wood density enhance reliability of the ultrasonic method. Strength and dynamic modulus characteristics from the ultrasonic method correspond to characteristic values of spruce timber according to EN 338, which can be consider as a simple and approximate grading method for structural timber. A part of the results can be used for determination of characteristic values of the Slovak spruce timber.

1 Introduction

Utilization of wood in constructions has lots of advantages due to natural origin and unique properties. Unfortunately, using wood in building industry must take into account variability of properties used for grading purposes, namely strength, elasticity, and density.

Large dimensions of structural timber is used in wooden construction, therefore, one has to consider more factors related to strength properties of a construction element during utilization. Two methods are used for determination of strength and stiffness properties of wood: visual grading and machine grading. The machine grading is based on bending principle or other principles such as ultrasound, vibration, radiation, or combination of several indicating properties (Weidenhiller & Denzler 2009) related to stiffness or strength.

Determination of construction timber wood quality parameters is based according to EN 408. The most important characteristic are:

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- bending strength *MOR* (characteristic strength $f_{m,k}$)
- modulus of elasticity (E_{stat}, $E_{0,mean}$)
- density (ρ_0, ρ_{mean}).

According to Slovak national standard STN EN 338, both methods are valid. The standard gives a system of strength classes for designing of wooden elements (Table 1).

Table 1: Strength classes according to EN 338 and STN 49 1531. Requirements for characteristic values of strength in bending $f_{m,k}$, elastic modulus $E_{0,mean}$ and density ρ_{mean}.

Standard		Strength classes - characteristic values (Poplar wood and coniferous wood)									
EN 338	grade	C 14	C 16	C 18	C 22	C 24	C 27	C 30	C 35	C 40	C 50
	$f_{m,k}$ [MPa]	14	16	18	22	24	27	30	35	40	50
	$E_{0,mean}$ [MPa]	7 000	8 000	9 000	10 000	11 000	11 000	12 000	13 000	14 000	16 000
	ρ_{mean} [kg.m^{-3}]	350	370	380	410	420	450	460	480	500	550
STN 49 1531 (Slovak quality classes)		-	-	*SII*	*S I*	-	-	*S0*	-	-	-

1.1 Bending method

The most important grading parameter is modulus of elasticity MOE_{stat}. Reason is in proved high linear correlation between bending strength and modulus of elasticity. Higher modulus of elasticity or density, respectively, means higher strength. It is the basic for timber grading according to EN 338.

Nondestructive bending method is based on loading of wooden specimen in bending using a force lower than a proportional limit. A board is not damaged and relative deformation after unloading is close to zero. Devices for bending method are simple. A full-size element is either loaded by one force or by two forces. For determination of modulus of elasticity, either constant deflection (force is measured) or constant force (deflection is measured) is used.

1.2 Ultrasound method

Ultrasound timber grading method is nondestructive one. Evaluation of mechanical properties uses correlation between sound velocity in wood, dynamic modulus and density. Usually, there are use wave of frequency from 20 to 500 kHz. Based on velocity and attenuation of ultrasound and prior known correlations, mechanical properties of graded timber are evaluated.

Two piezoelectric sensors are placed on both ends of a measured board. Sound is transmitted from one sensor and received by the second one. Ultrasound velocity c can be calculated from the following equation

$$c = \sqrt{\frac{E_{dyn,\mathrm{design}}}{\rho_w}} \tag{1}$$

where $E_{dyn\ design}$ is dynamic modulus [MPa] and ρ_w wood density [kg.m^{-3}]. There is a significant linear relation between dynamic and *MOE* measured by destructive method (Divos & Tanaka 2005, Shan-Qing & Feng 2007). Another simple approach uses Sylvatest-Duo device when density of wood is unknown. A direct linear relationship of ultrasonic speed and *MOE* includes an aleatory model error, which covers also density effect (Sandoz et. al. 1994). Then measured velocity leads to output values of predicted modulus of elasticity (MOE_{sylv}), characteristic strength (MOR_{sylv}) and strength classes (*C*). Measuring can be done on standing trees, round wood, timber or in situ wooden members of a building.

2 Material and Methods

Experimental testing was performed on tested samples of structure dimensions (40x120x2200 mm) from spruce wood (Picea abies). Boards were conditioned to MC = 12%±1% at the temperature t = 20°C and relative humidity RH = 65%. Each of 49 boards was defined by dimension, moisture content and density using from gravimetric method.

Samples were tested using two methods: an ultrasound method (using Sylvatest Duo) and a destructive bending method according to EN 408 (giving bending strength f_m or MOR_{stat}, global modulus of elasticity MOE_{stat} and density ρ_w) and EN 384 (giving design characteristic strength $f_{m,k}$ characteristic modulus $E_{0,mean}$, characteristic density ρ_{05}),

Experimental testing in bending is shown in Figure 1a. Each board was symmetrically loaded at four point bending at the span of l_0 = 2160 mm (Figure 2). A sample was loaded until the failure. From force–deflection diagram, global modulus of elasticity (MOR_{stat}) and bending strength (f_m) were determined. A setup of an ultrasound method using Sylvatest Duo is shown in Figure 1b.

a) b)

Figure 1: Setup for testing full-size wooden elements a) bending method, b) ultrasound method in the longitudinal direction

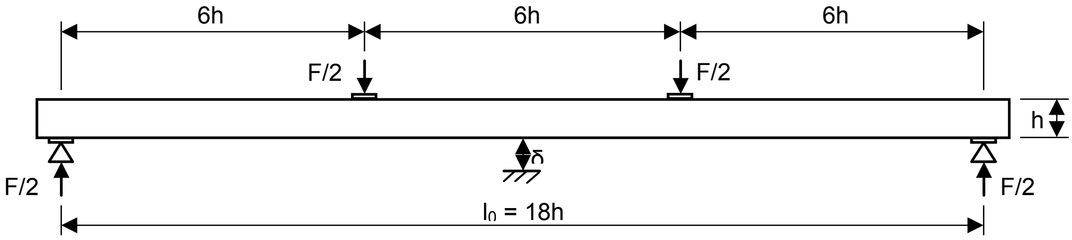

Figure 2: Experimental scheme for determination of global modulus of elasticity according to EN 408

3 Results and discussion

Some details of descriptive statistics are summarized in the Table 2. In calculation, requirements of standards EN 384 and EN 338 were accomplished.

Table 2: Descriptive statistic of density and basic outputs of bending and ultrasound methods

Basic mathematic-statistical characteristics	density	bending		ultrasound	
	ρ_w [kg.m^{-3}]	MOE_{stat} [MPa]	MOR_{stat} [MPa]	MOE_{sylv} [MPa]	MOR_{sylv} [MPa]
Number of samples	49	49	49	49	49
Arithmetic mean	404	11 541	47,6	14 899	42
Maximum value	687	16 997	71	17 835	53
Minimum value	330	8 330	32,7	9 177	31
Coefficient of variation, %	15,3	19	20	11	13,4

Ultrasound method counts with velocity as a property for identification of mechanical parameter. A linear dependency of modulus of elasticity on ultrasound velocity is illustrated in Figure 3. Although, the equation (1) proposes quadratic dependency on velocity, within a small range of velocity, such as this case, it can by simplified by linear equation. Interestingly the MOE_{sylv} gives almost the same slope as MOE_{stat}. Anyway, the ultrasound method overestimates MOE's values. This proves a well known fact that Slovak spruce timber is characterized by lower MOE compared to spruce timber coming from other parts of Europe. Therefore, it is important to adjust grading devices for spruce growing in Slovakia.

Density is also an important grading characteristic (Figure 4). EN 338 gives linear dependency between $\rho_{mean,338}$ and $E_{0,mean}$. Bending test according to EN 408 confirmed significant linearity of MOE_{stat} and ρ_w (r = 0,78). Since MOE_{sylv} is evaluated based on average density of a species, a linear relation with density of each individual wooden element has been found to be reduced. It is obvious that ultrasound method overestimate values of modulus at lower density. A calculated dynamic modulus $E_{dyn\ design}$ should by rather used instead, but unfortunately this requires information about density.

A correction for the ultrasound method is suggested. It can by either correction of MOE_{sylv} or rather determination of static modulus using linear relationship between $E_{dyn\ design}$ and MOE_{stat} (Figure 5).

Figure 6 compares strength properties of both methods with characteristic values according to EN 338. Objective destructive bending method is more reliable. Significant linear correlation (r=0.7) has been confirmed. Characteristic strength values for a tested set of samples (lower 5 percentile) were calculated. The slope of this characteristic strength is not similar to the $f_{m,k,338}$. For given samples, $f_{m,k,bending}$ has lower values of modulus of elasticity compared to ultrasound modulus and EN 338 standard ($f_{m,k,338}$). It also means that the Slovak timber did not perform well in terms of modulus of elasticity and it has to be graded to the lower strength classes despite of high strength values.

4 Conclusions

Characteristics of structural Slovak spruce timber were measured using an ultrasonic method (Sulvatest-Duo) and a destructive bending method according to EN 408 and EN 384.

Result analysis showed differences in bending strength and modulus of elasticity between the methods. Objectives results provided by the bending method give reliable and real characteristics of MOE. High correlation between MOE and MOR (r~0.7) was confirmed. Moreover, another strong correlation between MOR and density enhance reliability of the ultrasonic method.

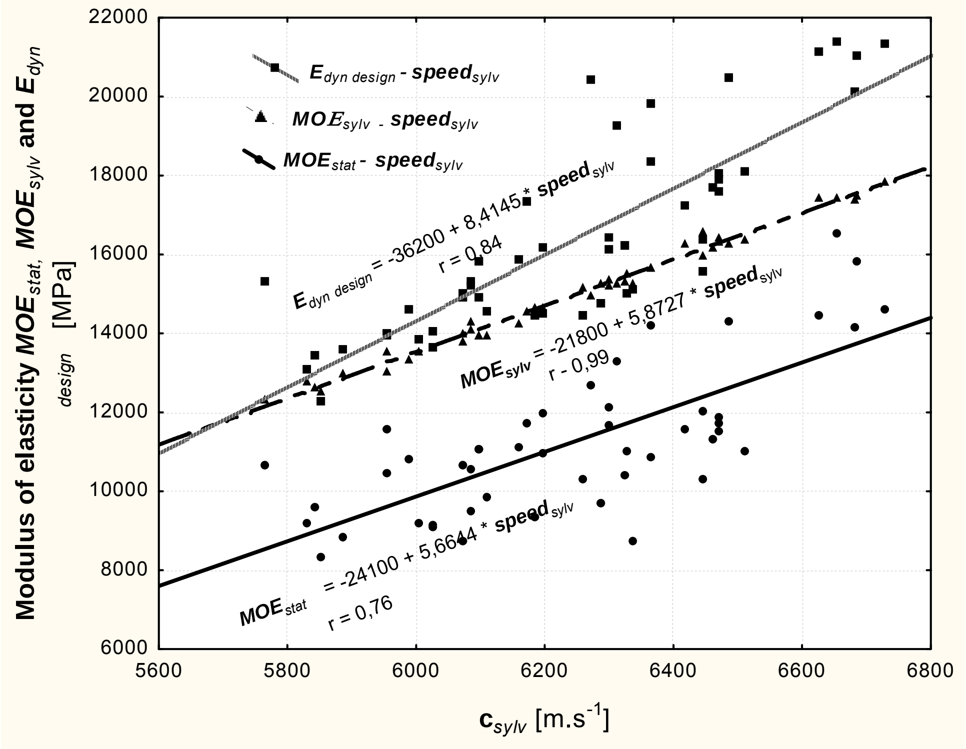

Figure 3: Modulus of elasticity MOE_{stat}, MOE_{sylv} and $E_{dyn\ design}$ related to ultrasonic $speed_{sylv}$.

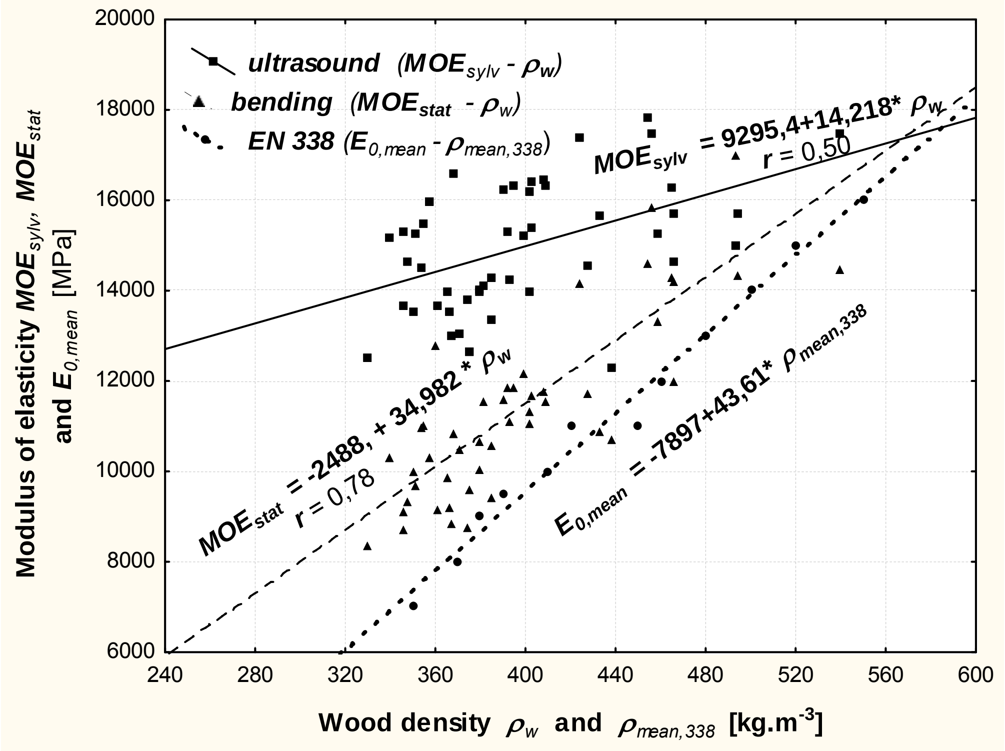

Figure 4: Modulus of elasticity, MOE_{sylv}, MOE_{stat} and $E_{0,mean}$ related to measured density ρ_w and $\rho_{mean,338}$.

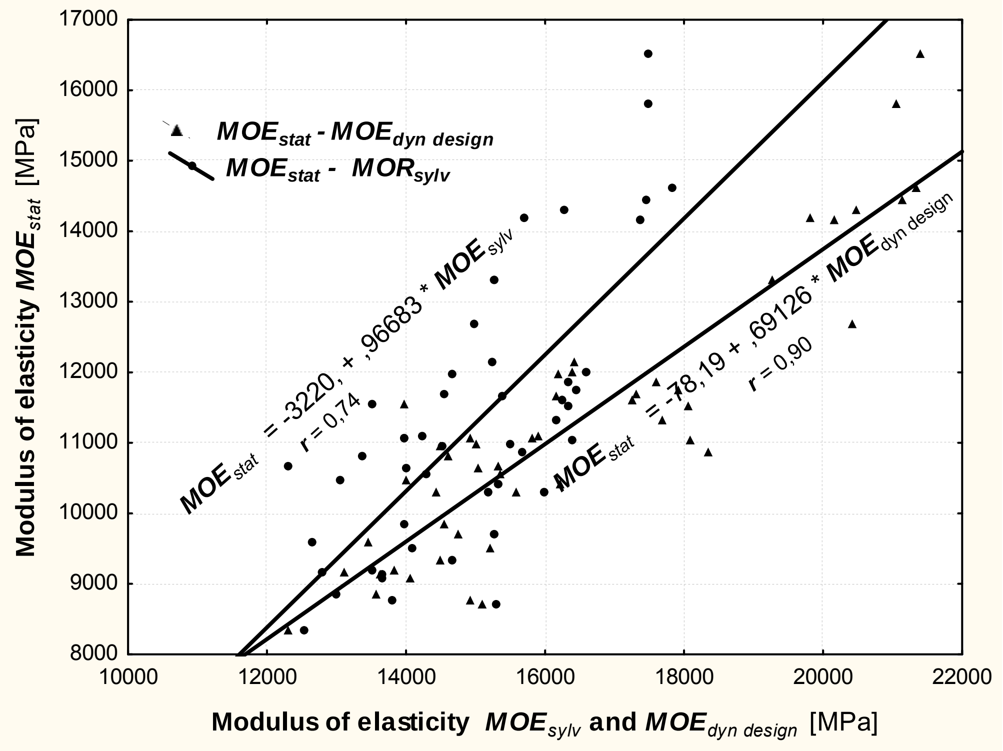

Figure 5: Modulus of elasticity *MOE*$_{stat}$ related to modulus of elasticity *MOE*$_{sylv}$ and *MOE*$_{dyn\ design}$.

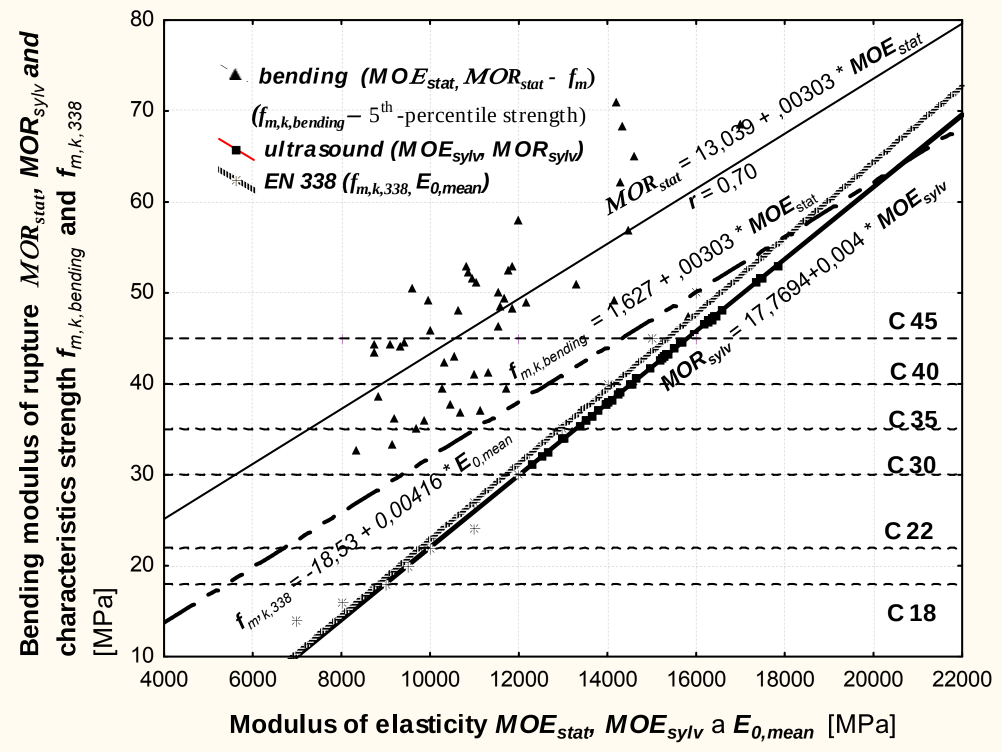

Figure 6: Bending strength depending on the modulus of elasticity of spruce wood from bending and ultrasound method and the characteristics value according to EN 338.

An ultrasound method overestimated MOE values at low density and underestimate bending strength at high density of spruce wood. Measured density could enhance ultrasound method. Results proves a well known fact that in general, Slovak spruce timber is characterized by lower MOE compared to spruce timber coming from other parts of Europe. Therefore, it is important to adjust grading devices for spruce coming from Slovakia. Correction relations of MOE values for Sylvates Duo were proposed.

A part of the results will be used for determination of characteristic values of the Slovak spruce timber.

5 Acknowledgment

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7 Used symbols

Symbol	Unit	Description
c	[m.s^{-1}]	velocity of stress wave
c_{sylv}	[m.s^{-1}]	velocity of stress wave given by SYLVATES DUO
ρ_w	[kg.m^{-3}]	wood density at moisture content "w"
ρ_{mean}	[kg.m^{-3}]	average density to EN 338
MOE_{stat}	[MPa]	modulus of elasticity in bending according to EN 408
MOE_{sylv}	[MPa]	modulus of elasticity in bending given by SYLVATES DUO
$E_{dyn\ design}$	[MPa]	dynamic modulus, calculated by the equation $E_{dyn} = c^2.\rho_w$
$E_{0,mean}$	[MPa]	average elasticity modulus parallel to the grain according to EN 338
MOR_{stat}	[MPa]	bending strength according to EN 408
MOR_{sylv}	[MPa]	bending strength given by SYLVATEST DUO
$f_{m,k\ ,bending}$	[MPa]	lower 5th percentile of bending strength according to EN 408
$f_{m,k\ ,\ 338}$	[MPa]	characteristic bending strength according to EN 338