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Modulus of elasticity tension/bending ratio of polish grown pine (*Pinus sylvestris L.*) and spruce (*Picea abies Karst.*) timber

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Abstract: *Modulus of elasticity tension/bending ratio of polish grown pine (Pinus sylvestris L.) and spruce (Picea abies Karst.)* timber. A representative sample of Pine and Spruce grown in Poland of three different sizes from two sawmills was measured by the grading machine "GoldenEye-706". Matched samples were tested in the laboratory in bending and tension according EN 408. The tension/bending ratio of modulus of elasticity is analyzed and compared with dynamic modulus of elasticity.

Keywords: modulus of elasticity, bending, tension, dynamic, grading

INTRODUCTION

The European standards for structural timber assume the same modulus of elasticity (MOE) for the three load types: bending, tension and compression [1].
In Europe the most commonly used strength classes are defined in EN 338 [8] ("C-classes" for softwoods and poplar, "D-classes" for hardwoods) and are assigned based on edgewise bending tests.

For timber where the tensile strength controls the design special strength classes are assigned based on tensile tests. Tensile strength classes ("L-classes" or "T-classes") are widely used for glued laminated timber (GLT), cross laminated timber (CLT) and flange material for I-beams.

Burger and Glos [1] established the relationship between modulus of elasticity in tension and bending. On 147 pieces of European spruce of sizes 50x120 mm^2 and 60x105 mm^2 the modulus of elasticity was measured on the same specimen for both testing modes (bending, tension). The average MOE in bending (measured with the local method) was 9% higher than compared to tension. This conclusion is verified in this study on Polish grown timber.

MATERIALS AND METHODS

Within the GRADEWOOD project [2], a representative sample of Pine (Pinus sylvestris L.) and Spruce (Picea abies Karst.) grown in Poland from two sawmills (Murów, Świętajno) was taken, consisting of three different cross-sections (38x100 mm^2, 50x150 mm^2, 44x200 mm^2) and a length of 4 meter (Table 1):

Tab. 1 Number of specimens divided by size, sawmill, species and testing mode

cross-section	sawmill	pine		spruce	
		bending	tension	bending	tension
38x100	Murów	35	35	73	37
	Świętajno	36	36	73	37
50x150	Murów	37	35	73	37
	Świętajno	37	37	73	34
44x200	Murów	35	37	68	37
	Świętajno	37	37	73	37

All specimens were graded with the grading machine "GoldenEye-706" [3] during one production run and all machine data was captured for future analysis. This grading machine combines the natural frequency measured by "ViSCAN" using a laser interferometer with density and knots (size and position) measurement by X-ray scanner. In a first step dynamic modulus of elasticity is calculated by formula (1) and in a second step then combined in a grading model with other parameters (knots, densities, board dimensions to consider size effects) to predict strength and static modulus of elasticity.

$$MOE_{dyn} = \rho \cdot (2 \cdot l \cdot f)^2 \qquad (1)$$

MOE_{dyn} - dynamic modulus of elasticity [N/mm^2],
ρ - density (measured by X-ray scanner) [kg/m^3],
l - length (measured by X-ray scanner) [mm],
f - frequency (measured by "ViSCAN") [Hz].

Dynamic MOE in the latest revision of EN 408 [10] was introduced as an alternative determination method of static global MOE "provided the correlation between measured dynamic modulus of elasticity and the global modulus of elasticity is well established and documented".

The total sample afterwards was divided randomly into two sub-samples of the same timber quality and analyzed in this study as "matched samples". In the laboratories of the Technical University of Munich (TUM), Germany (spruce bending/tension and pine tension) and the FCBA in Bordeaux, France (pine bending) several non-destructive measures (dynamic MOE, knot area ratio - KAR) were taken, before testing the timber according EN 408 [10] on the critical cross section as required by EN 384 [9]. The MOE in bending was measured in both laboratories simultaneously according the local (Clause 9) and global (Clause 10) method. The local MOE was measured by both laboratories at the neutral zone on both side faces. The global MOE was measured by FCBA in the centre of the tension edge on the narrow face and by TUM at the neutral axis on both side faces. Both methods are currently permitted by EN 408 and should provide equivalent results and indeed no significant differences between the laboratories were found in a round-robin test. The MOE in tension was measured over a length of 5 times the width by two transducers mounted on the narrow faces.

The first edition of the European standards EN 338, EN 408 and EN 384 were all published the first time in year 1995. The strength classes were defined on edgewise bending tests measuring MOE by the local method, which was the only method given in the first edition of the test standard. The local method is free of the effect of shear deformations and local indentations on the supports. In the revision of EN 408 and EN 384 in the years 2003/2004 a 2nd possibility to establish MOE by measuring it according the global method was added and adjusting it to the local values by an empirical formula (2):

$$MOE_{local} = 1.3 \cdot E_{global} - 2690 \qquad (2)$$

Today the local MOE is still the standard reference, but it is allowed to determine it using one of the following two methods:

1) Direct measurement according the local method (Clause 9).
2) Indirect measurement according the global method (Clause 10) and adjustment to local values using the formula given in EN 384 (valid for all species).

In practice today most researchers prefer to use the indirect 2nd method, as this procedure in the laboratory is easier, quicker and not too sensitive with respect to measurements errors (larger deflections).
Both machine data and laboratory data were adjusted to reference moisture content of 12%.

RESULTS

Five MOE values are considered in the data analysis:
1) “dynamic”: Dynamic MOE (measured by the grading machine “GoldenEye-706”)
2) “local”: Static bending MOE measured according the local method (1st approach)
3) “global”: Static bending MOE measured according the global method
4) “bending”: Static bending MOE based on global MOE and adjusted to local MOE
5) “tension”: Static tension MOE

Mean MOE values are calculated separately for each species considering three different pooling approaches of the dataset:
1) All data (Poland)
2) Sawmill (Murów, Świętajno)
3) Cross section (38x100 mm^2, 50x150 mm^2, 44x200 mm^2)

Table 2 shows the mean values for the five different MOE methods:

Tab. 2 Modulus of elasticity: mean values

species	sample	mode	n	modulus of elasticity [N/mm^2]				
				dynamic	global	local	bending	tension
pine	Poland	bending	217	11992	11658	12499	12465	
		tension	217	12091				11591
	Murów	bending	107	12742	12364	13423	13383	
		tension	107	12888				12500
	Świętajno	bending	110	11263	10971	11599	11573	
		tension	110	11316				10706
	38x100	bending	71	11480	11396	11519	12125	
		tension	71	11923				11113
	50x150	bending	74	12764	12387	13325	13413	
		tension	72	12071				11682
	44x200	bending	72	11705	11167	12615	11827	
		tension	74	12273				11961
spruce	Poland	bending	433	11727	10841	11787	11403	
		tension	219	12199				11641
	Murów	bending	214	11174	10378	11264	10802	
		tension	111	11444				10713
	Świętajno	bending	219	12267	11293	12299	11991	
		tension	108	12974				12596
	38x100	bending	146	11262	10274	10639	10666	
		tension	74	11806				11102
	50x150	bending	146	11741	10789	12021	11336	
		tension	71	12079				11564
	44x200	bending	141	12194	11481	12734	12235	
		tension	74	12706				12256

Firstly, the ratios between mean MOE values are calculated:

1) dynamic bending / tension
2) static local / global
3) static bending / global
4) static local / tension
5) static global / tension
6) static bending / tension

The ratio for dynamic MOE between the bending and tension sub-sample is very close to 1 for pine, but significantly smaller than 1 for spruce. Therefore the random splitting of the total sample into two sub-samples was not perfect and this ratio is used to adjust the three ratios between the bending and tension sub-samples.

The ratio between measured local and global bending MOE for pine is 1.07 (range: 1.01-1.11) and for spruce 1.09 (range: 1.04-1.11). The spruce value corresponds perfectly to the value found by Burger/Glos. They determined global MOE according DIN 52186 [7], which defines a third-point loading very similar to EN 408.

The ratio between the "predicted" local bending and global MOE for pine is 1.07 (range: 1.05-1.08) and for spruce 1.05 (range: 1.04-1.07).

The adjusted ratio between global bending and tension MOE for pine is 1.01 (range: 0.98-1.06) and for spruce 0.97 (range: 0.95-0.99). The global bending method provides values of similar magnitude as the tension method does.

The adjusted ratio between local bending and tension MOE for pine is 1.09 (range: 1.08-1.11) and for spruce 1.05 (range: 1.00-1.08). This analysis is comparable to Burger/Glos, as they determined the bending MOE directly by the local method described at this time already in prEN 408.

The adjusted ratio between calculated "predicted" local bending and tension MOE for pine is 1.08 (range: 1.08-1.13) and for spruce 1.02 (1.01-1.04). There is no difference between the direct and indirect method for pine, but for spruce the indirect method for bending MOE gives a lower MOE than the direct method.

Tab. 3 Modulus of elasticity: ratios between different methods

species	sample	bending/tension	local/global	bending/global	global/tension		local/tension		bending/tension	
		dynamic			direct	adj	direct	adj	direct	adj
pine	Poland	0.99	**1.07**	**1.07**	1.01	**1.01**	1.08	**1.09**	1.08	**1.08**
	Murów	0.99	1.09	1.08	0.99	1.00	1.07	1.09	1.07	1.08
	Świętajno	1.00	1.06	1.05	1.02	1.03	1.08	1.09	1.08	1.09
	38x100	0.96	1.01	1.06	1.03	1.06	1.04	1.08	1.09	1.13
	50x150	1.06	1.08	1.08	1.06	1.00	1.14	1.08	1.15	1.09
	44x200	0.95	1.13	1.06	0.93	0.98	1.05	1.11	0.99	1.04
spruce	Poland	0.96	**1.09**	**1.05**	0.93	**0.97**	1.01	**1.05**	0.98	**1.02**
	Murów	0.98	1.09	1.04	0.97	0.99	1.05	1.08	1.01	1.03
	Świętajno	0.95	1.09	1.06	0.90	0.95	0.98	1.03	0.95	1.01
	38x100	0.95	1.04	1.04	0.93	0.97	0.96	1.00	0.96	1.01
	50x150	0.97	1.11	1.05	0.93	0.96	1.04	1.07	0.98	1.01
	44x200	0.96	1.11	1.07	0.94	0.98	1.04	1.08	1.00	1.04

In a second step the ratios between the static methods and the dynamic method are calculated. Global bending and tension values are as expected [4] lower than dynamic values for two reasons: Dynamic MOE is measured on the full length specimen and static MOE on a portion including the weakest cross section. The global bending method includes shear effects which will result in lower values.

In this study, the ratio for the local bending MOE for pine is above 1 (direct method: 1.04, indirect method: 1.04), which is an unexpected result. For spruce the ratio is close to 1 (direct method: 1.01, indirect method: 0.97).

Tab. 4 Modulus of elasticity: ratios between dynamic and static methods

species	sample	global	local	bending	tension
pine	Poland	**0.93**	**1.04**	**1.04**	**0.96**
	Murów	0.92	1.05	1.05	0.97
	Świętajno	0.95	1.03	1.03	0.95
	38x100	0.99	1.00	1.06	0.93
	50x150	0.93	1.04	1.05	0.97
	44x200	0.89	1.08	1.01	0.97
spruce	Poland	**0.92**	**1.01**	**0.97**	**0.95**
	Murów	0.92	1.01	0.97	0.94
	Świętajno	0.92	1.00	0.98	0.97
	38x100	0.97	0.94	0.95	0.94
	50x150	0.90	1.02	0.97	0.96
	44x200	0.90	1.04	1.00	0.96

Differences between the direct (local) and indirect (bending) method could be explained by the empirical equation in EN 384. As shown in Figures 1 and 2, this equation fits on this particular dataset quite well for pine, but it does not for spruce. Even if the differences are quite small for the total sample with a mean MOE in the range of 11000 MPa to 12000 MPa, the differences become significant for graded timber. Timber of the lowest strength class will have in reality a higher local MOE as predicted by the empirical equation.

Regression models are derived on this dataset for timber grown in Poland:

pine: $MOE_{local} = 1.22 \cdot MOE_{global} - 1673$ $r^2=76\%$ n=217

spruce: $MOE_{local} = 1.18 \cdot MOE_{global} - 959$ $r^2=91\%$ n=433

all: $MOE_{local} = 1.19 \cdot MOE_{global} - 1189$ $r^2=80\%$ n=650

The relationship between global and local MOE is stronger for spruce than for pine.

For comparison, below are comparison ratios that were calculated based on a dataset of Polish-grown pine, which was tested in a previous study [5, 6]:

ratio local/global: **1.08**
ratio bending/global: 1.02
ratio global/dynamic: **0.86**
ratio local/dynamic: **0.93**
ratio bending/dynamic: 0.88

The ratio between dynamic and static methods on this dataset was significantly lower than in this study. This most probably can be explained by larger knots and overall lower timber quality.

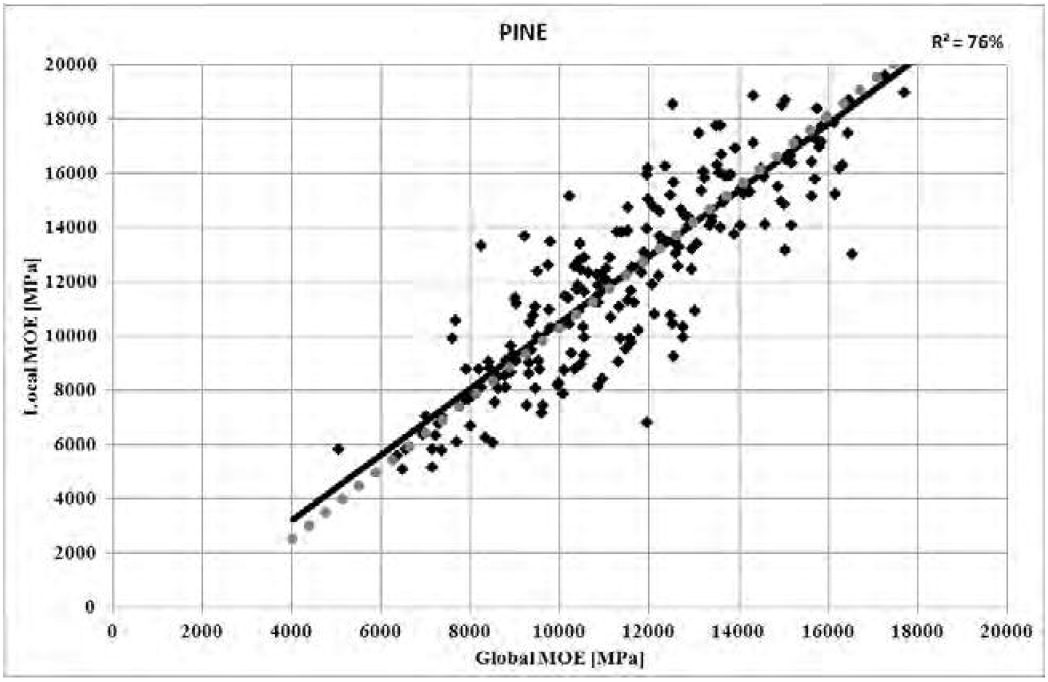

Fig. 1 Scatter plot of bending MOE for pine
solid line: linear regression on measured data, dotted line: formula of EN 384

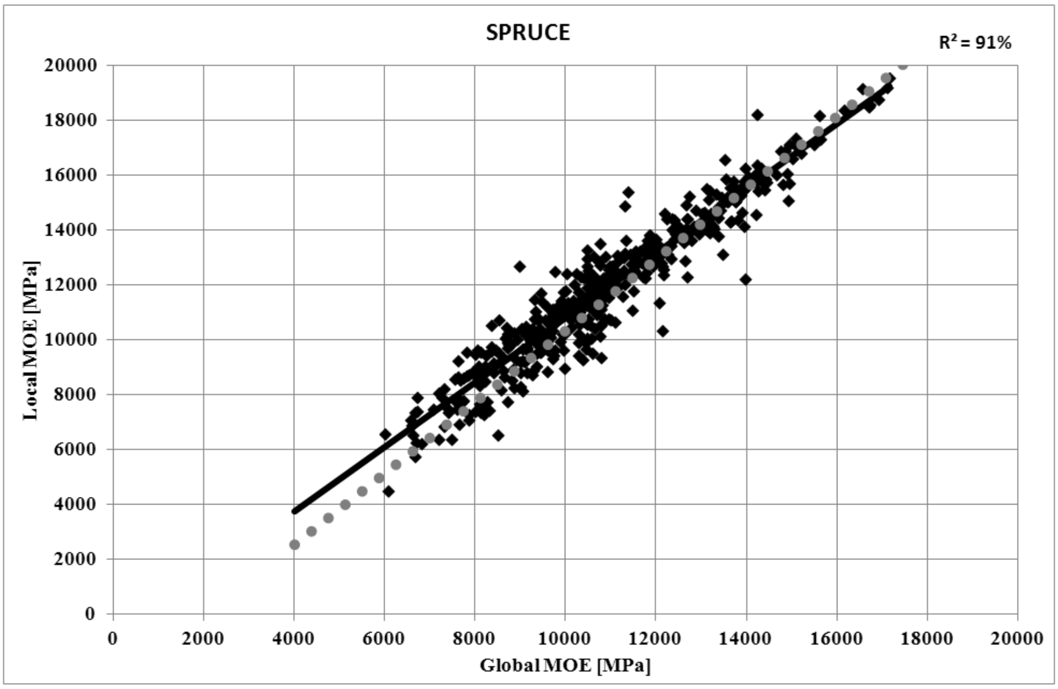

Fig. 2 Scatter plot of bending MOE for spruce
solid line: linear regression on measured data, dotted line: formula of EN 384

CONCLUSIONS

There is not a unique MOE value, but depends strongly on the load type and measurement method. Local MOE in bending is higher than MOE in tension, while global MOE is about the same level. Currently European standards currently neglect those differences. The empirical equation between global and local bending MOE may have an influence on the bending/tension ratio, if the indirect method is used to measure bending MOE. The result of this study should be verified in a next step on the full GRADEWOOD dataset containing more than 6000 specimens.

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Streszczenie: *Moduł sprężystości przy rozciąganiu i zginaniu polskiej tarcicy sosnowej i świerkowej.* W referacie zaprezentowano wyniki badań modułu sprężystości przy zginaniu i przy rozciąganiu polskiej tarcicy sosnowej świerkowej. Tarcicę o 3 różnych przekrojach poprzecznych, pochodzącą z dwóch tartaków, zbadano przy użyciu urządzenia do wytrzymałościowego sortowania tarcicy GoldenEye-706. Następnie dla tej tarcicy określono, zgodnie z EN408, moduł sprężystości przy zginaniu i przy rozciąganiu. Przeanalizowano związek pomiędzy modułem sprężystości przy zginaniu i przy rozciąganiu oraz porównano statyczny moduł sprężystości przy zginaniu z dynamicznym modułem sprężystości przy zginaniu.

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