Tatjana Kočetov Mišulić[1], Aleksandra Radujković*[1], Zdravko Popović[2], Ksenija Hiel[3]

Timber Strength Grading as Necessary Basis for Structural Design in ex-YU Region: Part 2

Ocjenjivanje drva prema čvrstoći kao nužna osnova za projektiranje konstrukcija na području bivše Jugoslavije: dio 2.

ORIGINAL SCIENTIFIC PAPER

Izvorni znanstveni rad

Received – prispjelo: 19. 4. 2023.

Accepted – prihvaćeno: 20. 9. 2023.

UDK: 674.032; 674.038; 674.06

https://doi.org/10.5552/drvind.2023.0106

ABSTRACT • *The aim of this paper is to contribute to the classification of structural timber in the ex-YU region into strength-class system through the application of experimentally obtained archive data in order to provide a realistic framework for most commonly used II grade (according to JUS) structural coniferous timber. The analysis of archive data was carried out on a sample of 150 specimens of structural size and based on the set of statistical requirements prescribed by EN standards, taking into account the change in disposition of loading in laboratory testing in the past and now. Statistical procedures prescribed by EN standards are given through calculation steps together with necessary adjustment factors that cover the size and number of specimens. The presented procedures given for structural-size specimens are also applicable to small clear specimens, so that a more comprehensive research and additional new examinations could be conducted with the available archive data simultaneously with the harmonization of the visual classification rules applied in the ex-YU region. The paper emphasises the direct dependence of the consistent application of the visual grading rules required by the relevant EN standard on strength-class system.*

KEYWORDS: *structural coniferous timber; visual grading; strength classes; statistical verification; European standards*

SAŽETAK • *Cilj ovog rada jest pridonijeti klasifikaciji konstrukcijskog drva na području bivše Jugoslavije u sustavu klasa čvrstoće primjenom eksperimentalno dobivenih arhivskih podataka kako bi se dobio realan okvir za najčešće upotrebljavano konstrukcijsko crnogorično drvo razreda II (prema JUS-u). Analiza arhivskih podataka provedena je na skupini od 150 uzoraka konstrukcijske veličine, i to na temelju skupa statističkih zahtjeva sadržanih u regulativi EU-a, pri čemu je uzeta u obzir promjena rasporeda opterećenja u laboratorijskim ispitivanjima u prošlosti i danas. Statistički postupci propisani EN normama dani su putem koraka izračuna, zajedno s potrebnim faktorima prilagodbe koji pokrivaju veličinu i broj uzoraka. Predstavljeni postupci dani za uzorke konstrukcijske veličine primjenjivi su i za male čiste uzorke, tako da bi se proširena kampanja s postojećim arhivskim podatcima i dodatnim novim ispitivanjima mogla provoditi istodobno s usklađivanjem pravila vizualne klasifikacije kon-*

* Corresponding author

[1] Authors are assistant professors at University of Novi Sad, Faculty of Technical Sciences, Department of Civil Engineering and Geodesy, Novi Sad, Serbia. https://orcid.org/0000-0003-3002-5885; https://orcid.org/0000-0003-4863-4486

[2] Author is full professor at University of Belgrade, Faculty of Forestry, Department of Wood Science and Technology Belgrade, Serbia. https://orcid.org/0000-0003-1557-4982

[3] Author is assistant professor at University of Novi Sad, Faculty of Agriculture, Department of Fruit Growing, Viticulture, Horticulture and Landscape Architecture, Novi Sad, Serbia. https://orcid.org/0009-0008-9793-7292

strukcijskog drva u bivšoj Jugoslaviji. U radu je naglašena izravna ovisnost dosljedne primjene pravila vizualnog ocjenjivanja kvalitete drva koja zahtijeva relevantna EN norma o sustavu klasa drva prema čvrstoći.

KLJUČNE RIJEČI: *konstrukcijsko crnogorično drvo; vizualno ocjenjivanje; klase čvrstoće; statistička verifikacija; europske norme*

1 INTRODUCTION
1. UVOD

The strength classification of solid timber is of key importance for the structural design and reflects on a range of modern products made of glued boards (e.g. glulam and cross-laminated timber) directly influencing their safety aspects.

In the first decade of the 21st century, countries from North and Central Europe (including Slovenia) carried out the "Gradewood" project: Grading of wood for engineering products (2007-2011), with the main goal to apply modern technologies and better practises in timber strength grading and integrate it to sawmilling process (machine grading). The results of the project significantly influenced some of the previously adopted EN standards (e.g. EN 1194:1999 with the lowest strength class GL24 withdrawn and replaced by EN 14080:2013 with the lowest strength class GL20). Within the project, the participating countries analysed commercially interesting growth areas in Europe, unifying the procedures and comparing the timber strength "quality".

However, most structural timber on EU market is still graded visually, so the optimisation of visual grading of timber in the ex-YU region and its strength classification is of greatest importance (Part 1).

Table 1 Assignment of visual graded timber to strength classes according to prEN 1912:2022
Tablica 1. Razvrstavanje vizualno ocijenjenog drva u klase čvrstoće prema prEN 1912:2022

Country/ Standard *Zemlja/Norma*	**Source** *Izvor*	**Spruce and Fir (*Picea abies* and *Abies alba*)** *Smrekovina i jelovina (Picea abies i Abies alba)*
Slovenia SIST DIN 4074-1	Slovenia	S10 → C24 S7 → C18 S7 → C16 (fir)
Germany DIN 4074-1	CNE Europe	S13(K) → C30 S10(K) → C24 S7(K) → C18
Italy UNI 11035-1	Italy	S1 → C30 S2 → C24 S3 → C18
Nordic countries INSTA 142	NNE Europe	T3 → C30 T2 → C24 T1 → C18 T0 → C14
Balkan countries JUS	SEE Europe	I → ? II → ? III → ?

Table 1 presents the assignment of spruce and fir considered as species relevant for a group of countries in the Balkan region due to traditional visual grading methods (Germany) or by geographical origin (Italy) or by practical description of structural use of particular strength classes (Sweden). The official assignment is very useful for structural engineers because some provisional explanations could be found in the regional documents (e.g. JUS grade I is sometimes assigned to series of strength classes from C30 to C50, grade II as C24-C27, while grade III as C22). That kind of "assignment" overestimates the structural timber from ex-YU regional resources and such a declarative takeover of strength classes (especially from German regulations, due to previous standards) could mislead the designers because the main timber strength characteristics are highly influenced by geographical origin and climatic conditions and should be supported with satisfactory test data.

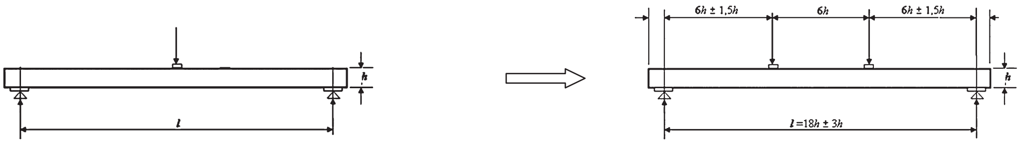
The aim of this paper is to emphasise the necessity to assign visual grades and species into strength classes of structural timber in the region. There, according to relevant EN standards, the "framework" for strength class assignment is given using statistic and quality analysis of visually graded spruce/fir II grade (JUS). The analysis also specifies potential problems that could occur in structural design due to inconsistency in visual grading in the regional practice and formal adoption of strength classes from other countries. Realistic strength "framework" is necessary in order to improve the competitiveness and share of timber material in construction sector due to the arising awareness of green building.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

In order to get the classification framework of locally available spruce/fir for structural purposes and to demonstrate the applicability of defined EN procedures, the analysis of one regional archive data sample is given in the following section. Test results are obtained by previously used procedures in visual grading and testing (JUS).

The test was conducted on the sample of 150 specimens of coniferous (spruce/fir, Bosnia and Herzegovina source) timber in reference moisture conditions as 3-point bending test on full-size visually graded timber (II quality grade, JUS) with dimensions 3.5 cm × 12 cm × 270 cm. Test pieces were taken directly from

Table 2 Review of procedure steps for MoR analysis through expressions given in EN codes
Tablica 2. Pregled koraka postupka za analizu *MoR*-a putem izraza danih u EN kodovima

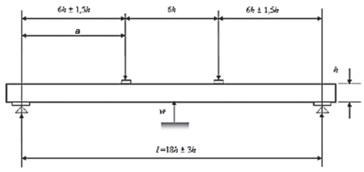
MoR	
Species, grade, dimensions *Vrsta, razred, dimenzije*	
Silver fir, Spruce / *obična jelovina, smrekovina* Coniferous timber II grade / *drvna građa od* četinjača *razreda II* 3.5/12/270 cm; *n* =150	
Measurement and conversion of MoR from 3 to 4 point test – EN 408 *Mjerenje i pretvorba MoR-a iz testa savijanja u 3 točke na test savijanja u 4 točke – EN 408*	
	
$f_{m,3P} = \frac{3Fl}{2bh^2}$	$f_{m,4P} = \frac{3Fa}{bh^2}$
Adjustment factors – EN 384 (size and test length effects) *Faktori prilagodbe – EN 384 (visina i efektivna duljina)*	
$h \neq 150\ \text{mm} \rightarrow k_h = \min \begin{cases} (150/h)^{0.2} \\ 1.3 \end{cases}$	$l \neq 18h \rightarrow k_l = (48h/l_{et})^{0.2},\ l_{et} = l + 5a_f$
$h = 120\text{mm} \rightarrow k_h = 1.0457$	$l = 270\text{cm},\ a_f = 0 \rightarrow k_l = 1.1636$
Characteristic values – EN 14358 *Karakteristične vrijednosti – EN 14358*	
$m_k = \exp(\bar{y} - k_s(n)s_y)$	$k_s(n) = (6.5n+6)/(3.7n-3)$
Characteristic values from subsamples – EN 384 *Karakteristične vrijednosti za poduzorke – EN 384*	
$f_k = \min\left(1.2f_{0.5,i,\min}; \sum_{i=1}^{ns} n_i f_{0.5,i} \Big/ n\right) \cdot k_n$	$f_{0.5,i} = m_{k,i}$; $k_n = 0.9$ for 3 subsamples

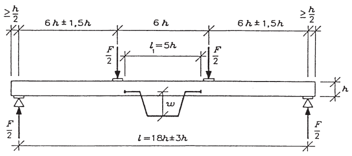
$f_{m,3P}$, $f_{m,4P}$ – bending strengths from 3 and 4 point tests / *čvrstoća na savijanje u 3 i 4 točke*
l – span in bending / *raspon pri savijanju*
F – loading force / *opterećenje*
a – distance between a loading position and nearest support in a bending test / *udaljenost između položaja opterećenja i najbližeg oslonca pri savijanju*
b, h – width and depth of cross section / *širina i visina presjeka*
k_h, k – adjusting factors for size and length / *faktori prilagodbe veličine i duljine*
l_{et} – effective length / *efektivna duljina*
a_f – distance between the inner load points / *udaljenost između unutarnjih točaka opterećenja*
m_k – 5 % value of variable *m / 5 %-tna vrijednost varijable m*
$\bar{y}$ – sample mean value / *srednja vrijednost uzorka*
s_y – standard deviation / *standardna devijacija*
$k_s(n)$ – factor used to calculate characteristic properties / *faktor koji se primjenjuje za izračun karakterističnih svojstava*
n – number of test values / *broj ispitnih vrijednosti*
f_k – 5% characteristic value of strength / *5 %-tna karakteristična vrijednost čvrstoće*
$f_{0.5,i,min}$ – lowest 5 % value of all subsamples / *najniža vrijednost od 5 % svih poduzoraka*
$f_{0.5,i}$ – lowest 5 % value for each subsample / *najniža vrijednost od 5 % za svaki poduzorak*
n_i – number of specimens in a subsample / *broj uzoraka u poduzorku*
n_s – number of subsamples / *broj poduzoraka*
k_n – factor to adjust for the number of subsamples / *faktor prilagodbe za broj poduzoraka*

production factory in order to define the real safety factor of built-in timber in low-rise wood frame buildings exported in the region. Tests were conducted until failure in edgewise position and were documented with descriptions about failure types of each specimen (e.g. zone and size of knots, slope of grains and failure in compression or tension zone, etc.). The same tests were used for the determination of bending strength (*MoR*) and bending stiffness (*MoE*), while density was determined separately.

The archive sample was considered as representative (in terms of the same origin from various areas and randomly chosen specimens) and with the possibility of division into subsamples in order to perform

Table 3 Review of procedure steps for *MoE* analysis trough expressions given in EN codes
Tablica 3. Pregled koraka postupka za analizu *MoE*-a uz pomoć izraza danih u EN kodovima

<table>
<tr><td colspan="2">MoE</td></tr>
<tr><td colspan="2">Species, grade, dimensions
Vrsta, razred, dimenzije</td></tr>
<tr><td colspan="2">Silver fir, Spruce / obična jelovina, smrekovina
Coniferous timber II grade / drvna građa od četinjača razreda II
3.5/12/270 cm; n = 150</td></tr>
<tr><td colspan="2">Measurement and conversion of MoE from 3 to 4 point test – EN 408
Mjerenje i pretvorba MoE-a iz testa savijanja u 3 točke na test savijanja u 4 točke – EN 408</td></tr>
<tr><td></td><td>$E_{m,g} = \dfrac{3al^2 - 4a^3}{2bh^3\left(2\dfrac{\Delta w}{\Delta F} - \dfrac{6a}{5Gbh}\right)}$

$E_{m,g} = \dfrac{l^3}{2bh^3\left(2\dfrac{\Delta w}{\Delta F} - \dfrac{3l}{5Gbh}\right)}$ for $a=l/2$</td></tr>
<tr><td colspan="2">Measurement of local MoE, EN 408
Mjerenje lokalnog MoE-a, EN 408</td></tr>
<tr><td></td><td>$E_{m,l} = \dfrac{3al_1^2\Delta F}{4bh^3\Delta w}$</td></tr>
<tr><td colspan="2">Modulus of elasticity parallel to grain, EN 384
Modul elastičnosti paralelno s vlakancima, EN 384</td></tr>
<tr><td>$E_0 = E_{m,g} \cdot 1.3 - 2690\ [\mathrm{MPa}]$</td><td>$E_0 = E_{m,l}$</td></tr>
<tr><td colspan="2">Characteristic mean value – EN 14358
Karakteristična srednja vrijednost – EN 14358</td></tr>
<tr><td colspan="2">$m_{mean} = \overline{y} - k_s(n)s_y \qquad k_s(n) = 0.78/n^{0.53}$</td></tr>
<tr><td colspan="2">Characteristic mean values from subsamples – EN 384
Karakteristične vrijednosti za poduzorke – EN 384</td></tr>
<tr><td colspan="2">$E_{0,mean} = \min\left(1.1\overline{E}_{i,min}; \sum_{i=1}^{ns} n_i\overline{E}_i \Big/ n\right)\cdot k_n/0.95 \qquad \overline{E}_i = m_{mean,i};\ k_n = 0.94$ for 3 subsamples</td></tr>
</table>

$E_{m,l}$, $E_{m,g}$ – local and global modulus of elasticity in bending / *lokalni i globalni modul elastičnosti pri savijanju*
w – displacement / *pomak*
G – shear modulus / *modul smicanja*
l_1 – gauge length for determination of modulus of elasticity / *mjerna duljina za određivanje modula elastičnosti*
E_0 – modulus of elasticity parallel to grain / *modul elastičnosti paralelno s vlakancima*
m_{mean} – population mean value of variable m / *populacijska srednja vrijednost varijable m*
$E_{0,mean}$ – mean characteristic value of E_0 / *srednja karakteristična vrijednost* E_0
$\overline{E}_i$ – mean modulus of elasticity of one subsample / *srednji modul elastičnosti jednog poduzorka*
$\overline{E}_{i,min}$ – lowest $\overline{E}_i$ of all subsamples / *najmanji* $\overline{E}_i$ *od svih poduzoraka*

more detailed statistical analyses according to relevant EN standards. Statistical analysis was performed for three observed cases:

A) Whole number of specimens A (n = 150) – one sample;
B) Three randomly divided subsamples B1, B2, B3 (n = 50);
C) Two samples on the basis of recorded types of failure of each specimen and recorded excessive defects C1 (n = 88) and C2 (n = 62).

The conducted analyses were performed in order to consider the possibility of conversion of results from JUS to EN (case A), to estimate the statistical sensitivity of the obtained results in the sample-subsample relationship (cases A and B), and to evaluate the importance of visual classification on the final outcome of the strength classes assignment in the sample (case C).

The analysis of 3 referent timber properties (*MoR*, *MoE*, density) was performed according to EN 14358 with assumed lognormal and normal distributions for characteristic 5 % fractile or mean values, respectively. Goodness-to-fit tests (KS and $\chi 2$) confirmed that both proposed theoretical distributions are acceptable, so the parametric calculation was performed. All necessary descriptive parameters (mean/characteristic values, standard deviation and coefficient of variation) are given for each case study.

Compared to the 3-point bending test, there are no shear forces in the 4-point bending test in the area between the two loading pins. In order to convert the 3-point (JUS) to 4-point bending test (EN 408), as well as to normalise the size and lengths of specimens for *MoR*, adjustment factors from EN 384 were used. For *MoE* determination (EN 408), the conversion of measured global MoE to requested E_0 - modulus of elasticity parallel to the grains (i.e. local *MoE*) was conducted according to EN 384. The expressions given in Table 2 (*MoR*) and Table 3 (*MoE*) are used in order to harmonise archive data results with the testing procedures given in EN 408.

Density was determined on a parallel sample (2x30 specimens, dimensions 3.5 cm × 2.0 cm × 2.0 cm), taken from fir and spruce planks, from which the (combined) mean value was determined according to JUS. Density was determined as an auxiliary basic indicator of strength class(es) because this grading parameter was not considered fundamental in previous standards. Density was tested on small clear specimens, due to the confirmed fact that density is not influenced by the specimen size in softwood species (Krajnc *et al.,* 2019).

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Cases A, B, C were analysed considering 3 referent parameters (EN 338:2016) for the classification of timber: density, *MoR* and *MoE*, using expressions given in Tables 2 and 3.

Density as strength class (SC) indicator is adopted as the average value, determined from mean values from fir and spruce specimens. The moisture content of fir specimens was 11.5 % and of spruce 9.5 %, so the mean density of fir specimens adjusted to referent moisture content of 12 % was 416.6 kg/m^3 and for spruce 450.56 kg/m^3. As the archive data sample was of mixed species, the average value for further analysis was adopted as ρ=433.6 kg/m^3.

Case A is presented in Table 4 trough probability distribution functions of fitted lognormal distribution for *MoR* and fitted normal distribution for *MoE*, together with histograms of archive data for *MoR* and recalculated test data as local *MoE*. Necessary descriptive statistics and final characteristic values (adjusted and converted) are as follows: 5 % fractil for *MoR* and mean value for *MoE*. Analysis results in Case A show that the obtained characteristic value of *MoR* is 15.16 MPa, while the mean *MoE* is 10.8 GPa. Coefficients of variation (CoV) are significantly higher both for *MoR* (*CoV* =43 %) and *MoE* (*CoV*=24 %) than assumed in JCSS report (CoV_{MoR}= 25 %, CoV_{MoE}=13 %) for the determination of other mechanical properties (EN 384:2016). The higher CoV is expected for visually graded structural timber and was reported by many authors (Ridley-Ellis *et al.,* 2022; Kupniewska *et al.*, 2020; Stapel and van de Kuilen, 2014; Ranta-Maunus *et al.,* 2011; Ranta-Maunus, 2009).

Case B is analysed in Table 5, by giving the relevant statistical parameters for each subsample and taking into account the adjusting factor for the number of subsamples in characteristic value calculation. As subsamples are chosen randomly, respecting that the minimal required number of specimens (n>40) has to be satisfied, the *CoVs* are even higher comparing to case A. The analysis in case B indicates smaller 5 % *MoR* value (13.43 MPa) and slightly smaller value for *MoE* (10.6 GPa), compared to case A.

Case C is analysed in Table 6, where the additional visual selection of two (sub) samples was made according to the recorded "desirable" failure type in compressed/tension zone C1 (good lot - GL) and failure type due to excessive defects, and number and position of knots and/or high slope of grains C2 (low tail - LT). Relevant statistical parameters and characteristic values are given for two independent additionally graded sets of specimens. Coefficients of variation for *MoR* (CoV_{C1} =26 %, and CoV_{C2} =34 %) and *MoE* (CoV_{C1} =21 % and CoV_{C2}=22 %) show values for C1 close to those suggested by JCSS. Also, it indicates that the division of the total sample into C1 and C2 was with a reason because of insufficient quality of primary visual classification. C1 sample shows higher characteristic bending strength and stiffness properties compared to the basic sample A and remaining C2.

All analyses are summarised in Table 7 in order to get the "framework" of strength classes according to EN 338 and observed sample of II grade. The mean density value of sample(s) refers to strength class C27 (ρ_{mean}=430 kg/m^3) and is not a determining parameter for SC assignment in analysed cases - the relevant property is always the value that leads to the lowest SC based on worst characteristic criterion.

Case A shows that conversion of results regarding test arrangements and specimens size, as well as transition from previously commonly measured global modulus of elasticity to local, could be easily performed by calculation. *MoR* results indicate that SC of the observed sample is C14 ($f_{m,k}$ =14 N/mm^2, $E_{m,0,mean}$=7 kN/mm^2), while the stiffness found in tests is higher than the assigned SC value. Case B shows that statistical analyses through subsample is stricter and requires more data (min 5 subsamples with min 200 specimens in total) or better (consistent) visual grading. In Case B, the classification framework is not possible to eval-

Table 4 *MoR* / *MoE* results – CASE A
Tablica 4. Rezultati *MoR* / *MoE* – SLUČAJ A

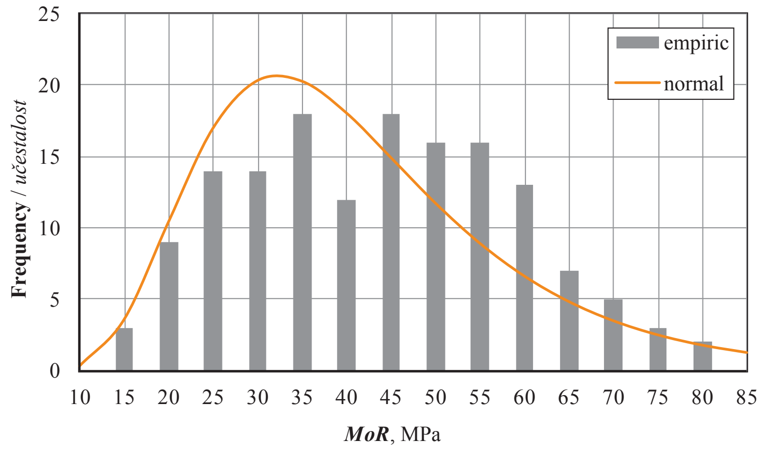
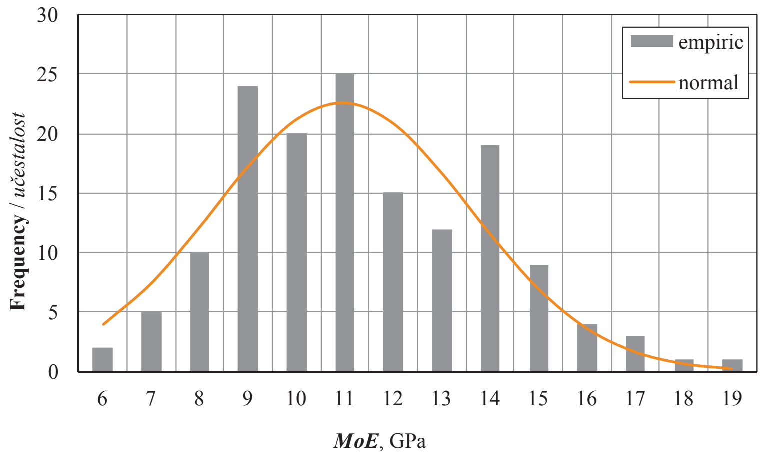
<table>
<tr><th>MoR, MPa</th><th colspan="2">Lognormal distribution
Lognormalna distribucija</th></tr>
<tr><td rowspan="7">
</td><td>All data</td><td>A (n=150)</td></tr>
<tr><td>$\bar{y}$</td><td>41.62</td></tr>
<tr><td>s_y</td><td>17.84</td></tr>
<tr><td>CoV</td><td>0.43</td></tr>
<tr><td>$f_{m,k}$</td><td>15.16</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><th>MoE, GPa</th><th colspan="2">Normal distribution
Normalna distribucija</th></tr>
<tr><td rowspan="7">
</td><td>All data</td><td>A (n=150)</td></tr>
<tr><td>$\bar{y}$</td><td>10.94</td></tr>
<tr><td>s_y</td><td>2.64</td></tr>
<tr><td>CoV</td><td>0.24</td></tr>
<tr><td>E_0</td><td>10.8</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

Table 5 *MoR* / *MoE* results – CASE B
Tablica 5. Rezultati *MoR* / *MoE* – SLUČAJ B

Lognormal distribution / *Lognormalna distribucija*				**Normal distribution** / *Normalna distribucija*			
***MoR*, MPa**	B1 (*n*=50)	B2 (*n*=50)	B3 (*n*=50)	***MoE*, GPa**	B1 (*n*=50)	B2 (*n*=50)	B3 (*n*=50)
$\bar{y}$	42.69	40.52	41.81	$\bar{y}$	10.72	10.52	11.58
s_y	21.00	16.71	16.12	s_y	2.58	2.54	2.73
CoV	0.49	0.41	0.39	*CoV*	0.241	0.242	0.236
$f_{m,k,i}$	13.52	14.98	16.29	$E_{0,i}$	10.47	10.26	11.31
$f_{m,k}$	13.43			E_0	10.57=10.6		

Table 6 *MoR* / *MoE* results – CASE C
Tablica 6. Rezultati *MoR* / *MoE*– SLUČAJ C

Lognormal distribution / *Lognormalna distribucija*			**Normal distribution / *Normalna distribucija***		
***MoR*, MPa**	C1 (GL) (*n*=88)	C2 (LT) (*n*=62)	***MoE*, GPa**	C1 (GL) (*n*=88)	C2 (LT) (*n*=62)
$\bar{y}$	50.51	28.51	$\bar{y}$	11.96	9.49
s_y	12.94	9.72	s_y	2.54	2.05
CoV	0.26	0.34	*CoV*	0.212	0.216
$f_{m,k,}$	25.60	12.18	E_0	11.78	9.31

Table 7 Summary of strength class "framework" in analysed cases
Tablica 7. Sažetak „okvira" razreda čvrstoće u analiziranim slučajevima

Spruce/fir (II) *Smrekovina/jelovina (II)*	**Relevant parameters** *Relevantni parametri*	**Cases** / *Studije slučaja*			
		A	B	C1 (GL)	C2 (LT)
MoR	$f_{m,k}$, N/mm^2	15.16	13.43	25.60	12.18
	EN 338	C14	-	C24	-
MoE	$E_{m,0,mean}$, kN/mm^2	10.8	10.6	11.8	9.3
	EN 338	C22	C22	C27	C18
Density / *gustoća*	ρ_{mean}, kg/m^3	433.6			
	EN 338	C27			
Strength class / *klasa čvrstoće*	EN 338	C14	-	C24	-

uate due to *MoR*, while *MoE* still remains high. Case C indicates that the analysed timber C1 could be classified as C24 ($f_{m,k}$ =24 N/mm^2, $E_{m,0,mean}$=11 kN/mm^2), while the remaining part of the basic sample C2 stays unclassified.

The linear regression model, Figure 1a, as a convenient method for the presentation of the interdependence of mechanical properties, was applied on the test results of the whole sample.

The coefficient of determination between *MoE* and *MoR* is R^2=0.415, which is consistent with other similar studies (Steiger and Arnold, 2009; Ranta Manus *et al.,* 2009/2011; Kupniewska *et al.,* 2020; Moore *et al.,* 2009). Although moderate and lower compared to small-size tests, the *MoE-MoR* correlation is found satisfactory and comparable for full-size tests (Krajnc *et al.,* 2019), so the structural size specimens could be used in the evaluation of the relative quality of timber.

Figure 1b) represents the EN 338 basic strength class values for $f_{m,k}$ and $E_{m,0,mean}$, following the experimental data values from the analysed cases and assigned SC values. From the diagram, it is obvious that *MoE-MoR* test points lay below the EN 338 line, so that strength is the limiting factor. Higher MoE obtained from tests than assigned strength class values in EN 338 could be considered as additional hidden safety. Due to geographical position of the region and on the basis of "Gradewood" project results (Ranta Manus *et al.,* 2011), stiffness and density were expected to be relatively higher in Southern Europe, which was confirmed by the results from Italy (Nocetti *et al.,* 2013; Negro *et al.,* 2013). The structural timber of similar mixed species is habitual in civil engineering practice. The research findings (Steiger and Arnold, 2009) show that the differences among species are less pronounced in structural size timber than in small clear specimens, which also contributes to a realistic result.

4 CONCLUSIONS
4. ZAKLJUČAK

Based on the consideration of EN standards, JUS visual grading rules and analysed cases, the following conclusions were made:

Overall, the analysed test results show that bending strength is the limiting property for SC classification of regional timber, while stiffness provides an additional safety factor.

Evaluation of II grade structural fir/spruce timber (Case A) points out that all data corresponds to C14, which is generally acceptable for the intended use in low-rise wood frame buildings (for wall studs with deformation requirements that are not too stringent).

Recommended analysis through subsamples (Case B) requires more specimens in factory production control.

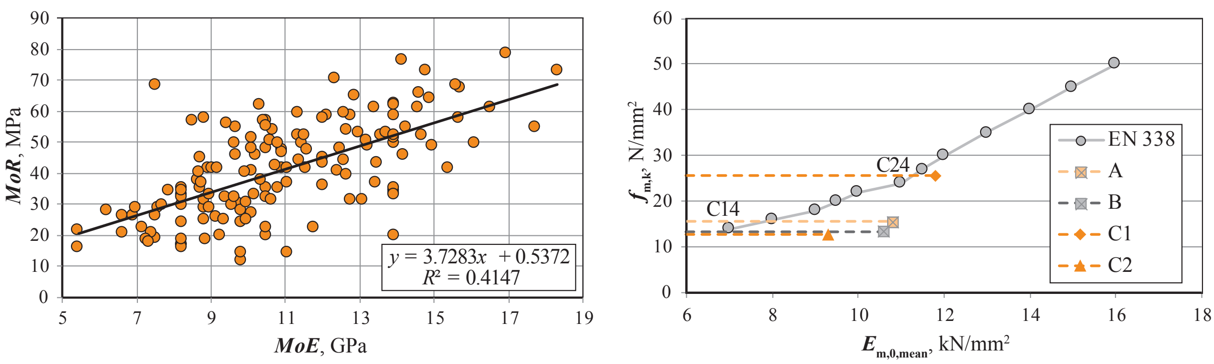


Figure 1 a) *MoE-MoR* linear regression, b) *MoR*/*MoE*: analysed cases vs EN 338 SC
Slika 1. a) Linearna regresija *MoE-MoR*, b) *MoE*/*MoE*: analizirani slučajevi u odnosu prema klasama EN 338

By additional visual grading (Case C1) of the basic sample, the strength class C24 was achieved, which is generally expected in EU countries for II grade (S10) coniferous timber, considered as high strength class for load-bearing purposes.

The rough estimation of mean strength values (case C), with the application of the global safety factor (n=4 for bending) according to the concept of allowable stress design, indicates that the whole sample of II grade (S10) is obtained by mixing the grade I (S13) and grade III (S7), which also highlights the need for stricter visual grading in limit state design concept.

High coefficients of variation in the analysed cases for class determining parameter - bending strength, also indicate the need for more consistent visual grading assessment, because the other strength parameters in a particular strength class are established on the basis of recommended *CoV*=0.25. Also, in the case of high(er) *CoV*s, the conversion of other mechanical properties (EN 384) could not be considered valid and reliable. That could lead to incorrect assessment (even overestimation) of the other strength properties (especially perpendicular to the grains), which could be a very sensitive problem in design calculations.

Regional coniferous timber is obviously in the range of C14 to C24 for normal structural use and it will be very helpful to introduce one SC in between, as well as to define the final structural purpose of each class. This would lead to additional benefits in the ex-YU timber trade (Part 1).

Considering the need of conversion of regional construction timber classification into EN SC system, it has been confirmed that the conversion of archive test results on structural size specimens with different loading arrangement directly leads to realistic SC of timber. The necessary additional data can also be obtained through the analysis of archive test data on small clear specimens that are widely available in the ex-YU region. In that case, the correlation of mechanical properties, determined on small and structural size specimens, should be taken into account.

Acknowledgements – Zahvala

This research has been supported by the Ministry of Science, Technological Development and Innovation through project No. 451-03-47/2023-01/200156 “Innovative scientific and artistic research from the FTS domain”.

5 REFERENCES
5. LITERATURA

1. Burawska-Kupniewska, I.; Krzosek, S.; Mańkowski, P.; Grześkiewicz, M., 2020: Quality and Bending Properties of Scots Pine (*Pinus Sylvestris* L.) Sawn Timber. *Forests, 11:* 1200: 1-12. https://doi.org/10.3390/f11111200
2. Krajnc, L.; Farrelly, N.; Harte, A., 2019: Relationships between wood properties of small clear specimens and structural – sized boards in three softwood species. Holzforschung, 73 (11): 987-996. https://doi.org/10.1515/hf-2019-0039
3. Moore, J.; Mochan, S.; Brüchert, F.; Hapca, A.; Ridley-Ellis, D.; Gardiner, B.; Lee, S., 2009: Effects of genetics on the wood properties of Sitka spruce growing in the UK: bending strength and stiffness of structural timber. *Forestry,* 82 (5): 491-501. https://doi.org/10.1093/forestry/cpp018
4. Negro, F.; Cremonini, C.; Zanuttini, R., 2013: CE Marking of structural timber: the European standardization framework and its effects on Italian manufacturers. Drvna industrija, 64 (1): 55-62. https://doi.org/10.5552/drind.2013.1214
5. Nocetti, M.; Brancheriau, L.; Bacher, M.; Brunetti, M.; Crivellaro, A., 2013: Relationship between local and global modulus of elasticity in bending and its consequence on structural timber grading. European Journal of Wood and Wood Products, 71: 297-308. https://doi.org/10.1007/s00107-013-0682-7
6. Ranta-Maunus, A., 2009: Strength of European timber. Part 1: Analysis of growth areas based on existing test results. VTT Publications, 706: 1-174. ISBN 978-951-38-7337-0
7. Ranta-Maunus, A.; Denzler, J. K.; Stapel, P., 2011: Strength of European timber. Part 2: Properties of spruce and pine tested in Gradewood project. VTT Working Papers, 179: 1-115. ISBN 978-951-38-7521-3
8. Ridley-Ellis, D.; Stapel, P.; Bano, V., 2016: Strength grading of sawn timber in Europe: an explanation for engineers and researchers. European Journal of Wood and Wood Products, 74: 291-306. https://doi.org/10.1007/s00107-016-1034-1
9. Ridley-Ellis, D.; Gil-Moreno, D.; Harte, A., 2022: Strength grading of timber in the UK and Ireland in 2021. International Wood Products Journal, 13 (2): 127-136. https://doi.org/10.1080/20426445.2022.2050549
10. Stapel, P.; van de Kuilen, J. W., 2014: Efficiency of visual strength grading of timber with respect to origin, species, cross section, and grading rules: a critical evaluation of the common standards. Holzforschung, 68 (2): 203-216. https://doi.org/10.1515/hf-2013-0042
11. Steiger, R.; Arnold, M., 2009: Strength grading of Norway spruce structural timber: revisiting property relationships used in EN 338 classification system. Wood Science and Technology, 43: 259-278. https://doi.org/10.1007/s00226-008-0221-6
12. *** DIN 4074-1:2012 Strength grading of wood. Part 1: Coniferous sawn timber. German National Standard.
13. ***EN 14080:2013 Timber structures – Glued laminated timber and glues solid timber – Requirements. European Committee for Standardization, Brussels.
14. ***EN 14081-1:2016 Timber structures – Strength graded structural timber with rectangular cross section. Part 1: General requirements. European Committee for Standardization, Brussels.
15. ***EN 14358:2016 Timber structures – Calculation and verification of characteristic values. European Committee for Standardization, Brussels.
16. ***EN 1995-1-1:2004 Eurocode 5: Design of timber structures. Part 1-1: General – Common rules and rules for buildings. European Committee for Standardization, Brussels.
17. ***EN 338:2016 Structural timber – Strength classes. European Committee for Standardization, Brussels.

18. ***EN 384:2016 Structural timber – Determination of characteristic values of mechanical properties and density. European Committee for Standardization, Brussels.
19. ***EN 408:2012 Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties. European Committee for Standardization, Brussels.
20. ***prEN 1912:2022 Structural timber – Strength classes – Assignment of visual grades and species. European Committee for Standardization, Brussels.
21. ***JCSS, 2006: Probabilistic model code. Part 3.5: Timber. Joint Committee on Structural Safety, 16 p.
22. ***Sweedish wood: https://www.swedishwood.com/wood-facts/about-wood/wood-grades (Accessed Jan 27, 2023).
23. ***Zbirka jugoslovenskih pravilnika i standarda za gradjevinske konstrukcije, 1995. Knjiga 4: Drvene konstrukcije. Beograd, 687 p.

Corresponding address:

Assist. Prof. ALEKSANDRA RADUJKOVIĆ
University of Novi Sad, Faculty of Technical Sciences, Department of Civil Engineering and Geodesy,
Dr Sime Miloševića 12, 2100 Novi Sad, SERBIA, e-mail: leksa@uns.ac.rs