

**MOR and MOE of Serbian Spruce (Picea omorika Pančić/Purkyně) Wood from Natural Stands**

Modul loma i modul elastičnosti drva omorike (Picea omorika Pančić/Purkyně) iz prirodnih sastojina

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**ABSTRACT** • The paper presents the results of testing the bending stress of Serbian spruce wood from natural stands. In testing the samples, in addition to the modulus of rupture, the bending stress at the proportionality limit, the ratio between the stress at the proportionality limit and the modulus of rupture as well as the modulus of elasticity of wood were determined. The study included nine trees from natural stands, and a total of 261 samples were tested. Regression analysis determined the dependences of these mechanical properties on the annual ring width, the proportion of late wood and wood density, as well as the dependence of the modulus of elasticity on the modulus of rupture.

**Keywords:** Picea omorika; modulus of rupture; modulus of elasticity; natural stands

**SAŽETAK** • U radu su prikazani rezultati ispitivanja naprezanja pri savijanju drva Pančićeve omorike podrijetlom iz prirodnih sastojina. Osim modula loma, pri ispitivanju uzoraka utvrđeni su i savojno naprezanje u točki proporcionalnosti, odnos čvrstoće na savijanje u točki proporcionalnosti i modula loma, kao i modul elastičnosti drva. Istraživanje je obuhvatilo devet stabala iz prirodnih sastojina, a ispitani su ukupno 261 uzorak. Regresijskom analizom utvrđeni odnosi navedenih mehaničkih svojstava i širine goda, kao i odnos modula elastičnosti i modula loma.

**Ključne riječi:** Picea omorika; modul loma; modul elastičnosti; prirodne sastojine

**1 INTRODUCTION**

**1. UVOD**

Serbian spruce (Picea omorika Pančić/Purkyně) is naturally distributed in Bosnia and Herzegovina and Serbia in the area around the middle and lower reaches of the Drina River. It is found on steep, rocky cliffs, mostly on limestone, rarely serpentine, at altitudes of 300 to 1700 m (Vidaković and Franjić, 2004).

Serbian spruce is interesting from many aspects, both to the science and profession, and to the general public. A large number of scientific and professional papers deal with various issues related to Serbian

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spruce, ranging from its distribution, the configuration of the terrain as well as the habitat where it occurs (Fukarek, 1935, 1950; Ćolić, 1953, 1957) to the latest genetic research (Aleksić and Geburek, 2010, 2014; Mataruga et al., 2020). However, it is very difficult to find information in the literature concerning the mechanical properties of Serbian spruce wood, especially the wood originating from natural stands. Lukeć-Simonović (1970) investigated in more detail the mechanical properties of Serbian spruce from its natural stands in western Serbia, while no such research has been done in Bosnia and Herzegovina.

Modulus of rupture (MOR) and modulus of elasticity (MOE) are among the most important parameters for determining the wood quality, especially for the usage of wood in construction (Bodig and Jayne, 1982). The modulus of elasticity, as a measure of stiffness, can be used to estimate strength because there is a positive correlation between stiffness and strength (Panshin and de Zeeuw, 1980). Popović (1990) states that the ratio between the bending stress at the proportionality limit and the modulus of rupture is a very important fact in the practical application of wood, where, if this ratio is known, the use of loads exceeding these values and leading to permanent deformation or fracture can be prevented.

Knowledge of the stress at the proportionality limit, maximum stress and their ratio, as well as the knowledge of the effect of certain factors on the specified bending characteristics has both scientific and practical significance. These factors are very important for designing the bending tools and for determination of the stress that products can be exposed to during use (Svoboda et al., 2017).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

The material for the research comes from three localities of the natural stands of Serbian spruce managed by the FE Panos - Višegrad. These are Gostilja (GO), Stolac 1 (S1) and Stolac 2 (S2). Location GO is at 1130 m above sea level, and S1 at 1200 m above sea level, while the total area of this stand is 25.8 ha. S2 at 960 m above sea level, while the total area of the stands is 29.5 ha.

According to Mataruga et al. (2011), Serbian spruce has been listed as an endangered plant species ranging from its distribution, the configuration of the terrain as well as the habitat where it occurs (Fu-

| Location | Number of trees | Diameter at breast height, cm | Tree height, m | Trunk length, m |
|---|---|---|---|---|
| GO | 112 | 29.13 | 28.2 | 18.5 |
| S1 | 131 | 30.00 | 28.4 | 24.4 |
| S2 | 128 | 30.97 | 25.8 | 20.7 |
| Average value | 124 | 30.03 | 25.4 | 21.2 |

Table 1 Average values of characteristics of Serbian spruce trees
Tablica 1. Prosječne vrijednosti svojstava stabala Pančićeve omorike
samples. Samples were placed so that they were on one radial side and the distance between the supports was 280 mm. The loading speed was set to 10 mm/min. Load-deflection graphs were obtained by testing and they were used to obtain the values of bending stress at the proportionality limit, \( \text{MOR} \) and \( \text{MOE} \). The calculation formulas for \( \text{MOR} \) (Eq. 2) and bending stress at the proportionality limit (Eq. 3) are:

\[
\sigma_r = \frac{3 \cdot F_{\text{max}} \cdot l}{2 \cdot b \cdot h^2} \quad \text{(MPa)}
\]

\[
\sigma_{s0} = \frac{3 \cdot F_{s0} \cdot l}{2 \cdot b \cdot h^2} \quad \text{(MPa)}
\]

Where:
- \( F_{\text{max}} \) – maximum load (N)
- \( l \) – distance between supports (mm)
- \( b \) – width of the sample (mm)
- \( h \) – height of the sample (mm)

The calculation formula for the ratio between the bending stress at the proportionality limit and \( \text{MOR} \) is:

\[
P_s = \frac{\sigma_{s0}}{\sigma_r} \cdot 100 \quad \text{(%)}
\]

After the test, all samples were weighed and then dried to an oven dry state to determine moisture content at the time of testing using Eq. 6:

\[
\nu_a = \frac{m - m_0}{m_0} \cdot 100 \quad \text{(%)}
\]

Where:
- \( m \) – sample mass at the time of testing (g)
- \( m_0 \) – sample mass in oven dry state (g)

In order to compare the obtained values of \( \text{MOR} \) and \( \text{MOE} \) with literature data, results of bending test were reduced to values at standard moisture content (12 %) using Eq. 7:

\[
\sigma_{12}(E_{\text{arw}}) = \sigma_{12}(E_{\text{arw}}) \cdot [1 + 0.02 \cdot (\nu_a - 12)] \quad \text{(MPa)}
\]

Table 3 shows the average values and other statistical indicators of \( \text{MOR} \) at standard moisture content by locations. Trees from GO have the lowest average values of \( \text{MOR} \) (84.23 MPa), and trees from S1 the largest (94.86 MPa). The smallest variation in \( \text{MOR} \) was found at S2 (12.19 %) and the largest at GO (16.17 %).

The average value of \( \text{MOR} \) at all locations (89.72 MPa) is slightly lower than the \( \text{MOR} \) at standard moisture content obtained in research by Lukić-Simonović (1970), namely 96.7 MPa. Studying the \( \text{MOR} \) of Serbian spruce wood from plantations in Germany, Kommer (1993) found that its average values at moisture content of 12 % are in the range of 57.6 MPa (average density of samples is 0.424 g/cm\(^3\)) to 86 MPa (average density of samples is 0.510 g/cm\(^3\)).

As the number of studies on the mechanical properties of Serbian spruce wood is limited, comparison with the mechanical properties of spruce wood was made. According to Karahasanović (1992), the \( \text{MOR} \) of spruce at a moisture content of (12 ± 3) % is 64 MPa. Gorišek et al. (2004) stated that the average \( \text{MOR} \) of spruce from Slovenia is 77.4 MPa, while Pushinskis et al. (2002) tested spruce from western Latvia and found that the average \( \text{MOR} \) is 106.42 MPa.

In addition to the \( \text{MOR} \), the bending stress at the proportionality limit was determined, as well as the ratio between the bending stress at the proportionality limit and \( \text{MOR} \). The obtained values are shown in Table 4 and 5.

The average bending stress at the proportionality limit for all three locations is 44.72 MPa, while the coefficient of variation is 15.92 %. The average ratio of

### Table 2

| Location | \( \text{arw} \) | \( \text{plw} \) | \( n \) | \( \nu_a \) | \( \rho \) |
| --- | --- | --- | --- | --- | --- |
| | \( AV, \text{mm} \) | \( AV, \% \) | | | |
| S1 | 1.66 | 15.64 | 88 | 14.77 | 0.534 | 0.035 | 6.61 |
| S2 | 1.68 | 15.44 | 83 | 15.15 | 0.509 | 0.024 | 4.62 |
| GO | 1.90 | 14.80 | 90 | 15.30 | 0.508 | 0.028 | 5.54 |
| | 1.76 | 15.24 | 261 | 15.07 | 0.517 | 0.032 | 6.12 |

\( n \) – number of tested samples / broj testiranih uzoraka; \( \nu_a \) – moisture content at the moment of testing / sadržaj vode u trenutku ispitivanja; \( \text{arw} \) – annual ring width / širina goda; \( \text{plw} \) – proportion of late wood / udio kasnog drva; \( \rho \) – density of wood at the moment of testing / gustoća drva u trenutku ispitivanja; \( AV \) – average value / prosječna vrijednost; \( \text{SD} \) – standard deviation / standardna devijacija; \( CV \) – coefficient of variation / koeficijent varijacije
Table 3 Statistical analysis of MOR of Serbian spruce from three different stem heights

| Location | Height of stem | \( n \) | \( \sigma_{AV} \), MPa | -95, MPa | +95, MPa | SD, MPa | CV, % |
|----------|---------------|-------|-------------------------|----------|---------|--------|-------|
| S1       | I             | 30    | 94.97                   | 90.55    | 99.39   | 11.84  | 12.47 |
|          | II            | 30    | 95.82                   | 90.65    | 100.99  | 13.84  | 14.44 |
|          | III           | 28    | 94.47                   | 90.05    | 98.89   | 11.40  | 12.07 |
| S2       | I             | 25    | 84.61                   | 78.37    | 90.84   | 15.11  | 17.86 |
|          | II            | 31    | 94.61                   | 92.46    | 96.76   | 5.87   | 6.20  |
|          | III           | 27    | 89.59                   | 86.09    | 93.08   | 8.84   | 9.87  |
| GO       | I             | 30    | 84.00                   | 78.62    | 89.37   | 14.39  | 17.13 |
|          | II            | 30    | 84.13                   | 80.40    | 87.87   | 9.99   | 11.88 |
|          | III           | 30    | 84.55                   | 78.50    | 90.60   | 16.20  | 19.16 |
|          |                | 261   | 89.72                   | 88.12    | 91.32   | 13.14  | 14.64 |

\( \sigma \) – modulus of rupture, MOR / modul loma; \( n \) – number of tested samples / broj testiranih uzoraka; \( AV \) – average value / prosječna vrijednost; -95 – lower boundary of estimation interval with a probability of 95 % / donja granica intervala procjene s vjerojatnošću od 95 %; +95 – upper boundary of estimation interval with a probability of 95 % / gornja granica intervala procjene s vjerojatnošću od 95 %; SD – standard deviation / standardna devijacija; CV – coefficient of variation / koeficijent varijacije.

The bending stress at the proportionality limit for all tested samples is 50.18 % of the maximum bending stress, while the variation is 12.73 %. Popović (1990) states that the bending stress at the proportionality limit for beech wood is on average 54.4 % and 56 % in the radial and tangential direction, respectively, from the value of the maximum bending stress.

Table 4 Statistical analysis of bending stress at proportionality limit of Serbian spruce from three different stem heights

| Location | Height of stem | \( n \) | \( \sigma_{AV} \), MPa | -95, MPa | +95, MPa | SD, MPa | CV, % |
|----------|---------------|-------|-------------------------|----------|---------|--------|-------|
| S1       | I             | 30    | 49.67                   | 47.04    | 52.31   | 7.06   | 14.20 |
|          | II            | 30    | 47.10                   | 44.00    | 50.20   | 8.30   | 17.63 |
|          | III           | 28    | 47.85                   | 46.14    | 49.55   | 4.40   | 9.20  |
| S2       | I             | 25    | 42.73                   | 40.27    | 45.20   | 5.98   | 13.99 |
|          | II            | 31    | 45.45                   | 43.57    | 47.33   | 5.13   | 11.29 |
|          | III           | 27    | 42.78                   | 40.45    | 45.11   | 5.89   | 13.78 |
| GO       | I             | 30    | 43.76                   | 42.51    | 45.01   | 5.73   | 13.09 |
|          | II            | 30    | 41.17                   | 38.64    | 43.70   | 6.77   | 16.45 |
|          | III           | 30    | 41.47                   | 38.77    | 44.16   | 7.22   | 17.41 |
|          |                | 261   | 44.72                   | 43.85    | 45.58   | 7.12   | 15.92 |

\( \sigma_{AV} \) – bending stress at proportionality limit / savojno naprezanje u točki proporcionalnosti; \( n \) – number of tested samples / broj testiranih uzoraka; \( AV \) – average value / prosječna vrijednost; -95 – lower boundary of estimation interval with a probability of 95 % / donja granica intervala procjene s vjerojatnošću od 95 %; +95 – upper boundary of estimation interval with a probability of 95 % / gornja granica intervala procjene s vjerojatnošću od 95 %; SD – standard deviation / standardna devijacija; CV – coefficient of variation / koeficijent varijacije.
### Table 5: Statistical analysis of ratio between bending stress at proportionality limit and MOR of Serbian spruce from three different stem heights

| Location | Height of stem | n | $\sigma_s$, MPa | $P_s$, % | $E$, MPa | $\sigma_{sp}$, MPa | $P_{sp}$, % |
|----------|---------------|---|----------------|---------|---------|----------------|--------|
| S1       | I             | 24 | 11267.32       | 52.35   | 11287.27| 11126.82       | 11442.37|
|          | II            | 26 | 11442.37       | 51.61   | 11287.27| 11126.82       | 11442.37|
|          | III           | 27 | 11647.47       | 50.98   | 11287.27| 11126.82       | 11442.37|
| S2       | I             | 25 | 11699.33       | 50.31   | 11287.27| 11126.82       | 11442.37|
|          | II            | 26 | 11699.33       | 49.53   | 11287.27| 11126.82       | 11442.37|
|          | III           | 27 | 11899.33       | 48.01   | 11287.27| 11126.82       | 11442.37|
| GO       | I             | 26 | 11582.84       | 49.00   | 11287.27| 11126.82       | 11442.37|
|          | II            | 27 | 11782.84       | 48.01   | 11287.27| 11126.82       | 11442.37|
|          | III           | 28 | 12074.75       | 47.82   | 11287.27| 11126.82       | 11442.37|

$P_s$ – ratio between bending stress at proportionality limit and MOR / odnos savojnog naprezanja na granici proporcionalnosti i modula loma; $n$ – number of tested samples / broj testiranih uzoraka; $AV$ – average value / prosječna vrijednost; $-95$ – lower boundary of estimation interval with a probability of 95 % / donja granica intervala procjene s vjerojatnošću od 95 %; $+95$ – upper boundary of estimation interval with a probability of 95 % / gornja granica intervala procjene s vjerojatnošću od 95 %; $SD$ – standard deviation / standardna devijacija; $CV$ – coefficient of variation / koeficijent varijacije.

### Table 6: Statistical analysis of MOE of Serbian spruce from three different stem heights

| Location | Height of stem | n | $E_s$, MPa | $\sigma_{sp}$, MPa | $P_{sp}$, % |
|----------|---------------|---|-------------|----------------|---------|
| S1       | I             | 24 | 11647.47    | 48.21           | 50.88   |
|          | II            | 25 | 11699.33    | 49.53           | 50.98   |
|          | III           | 26 | 11899.33    | 48.01           | 50.31   |
| S2       | I             | 25 | 11699.33    | 49.53           | 50.98   |
|          | II            | 26 | 11699.33    | 48.21           | 50.88   |
|          | III           | 27 | 11899.33    | 47.82           | 50.31   |
| GO       | I             | 26 | 11582.84    | 49.00           | 50.98   |
|          | II            | 27 | 11782.84    | 48.01           | 50.98   |
|          | III           | 28 | 12074.75    | 47.82           | 50.98   |

$E_s$ – modulus of elasticity (MOE) / modul elastičnosti, $n$ – number of tested samples / broj testiranih uzoraka; $AV$ – average value / prosječna vrijednost; $-95$ – lower boundary of estimation interval with a probability of 95 % / donja granica intervala procjene s vjerojatnošću od 95 %; $+95$ – upper boundary of estimation interval with a probability of 95 % / gornja granica intervala procjene s vjerojatnošću od 95 %; $SD$ – standard deviation / standardna devijacija; $CV$ – coefficient of variation / koeficijent varijacije.

### Table 7: Analysis of variation of MOR, MOE, bending stress at proportionality limit, ratio between bending stress at proportionality limit and MOR

| Location | ANOVA |
|----------|-------|
| S1       |       |
| S2       |       |
| GO       |       |

$\sigma_s$, MPa – bending stress at proportionality limit / savojno naprezanje na granici proporcionalnosti; $E_s$, MPa – modulus of elasticity (MOE); $P_{sp}$, % – ratio between bending stress at proportionality limit and MOR / odnos savojnog naprezanja na granici proporcionalnosti i modula loma; $\sigma_{sp}$, MPa – bending stress at proportionality limit / savojno naprezanje na granici proporcionalnosti; $P_{sp}$, % – ratio between bending stress at proportionality limit and MOR / odnos savojnog naprezanja na granici proporcionalnosti i modula loma.

*Number of homogeneous groups by Duncan's test / broj homogenih grupa prema Duncanovu testu
s, k – Homogeneous groups / homogene grupe
groups, i.e. the analysis showed that there is no statistically significant difference between sites S2 and GO (Table 7).

In addition to wood density, which is considered to be the most significant factor affecting wood properties, the influence of compression and juvenile wood, the angle of the microfibrils and the width of the growth ring, which have the same, if not greater, influence on the wood properties, should not be neglected (Alteryac et al., 2006). The influence of the annual ring width on the MOR and MOE can be seen in Figure 2. According to Roemer-Orphal table for determining the strength of correlation dependence (according to Vasilj, 2000), there is a strong negative correlation between these parameters.

Proportion of late wood has a positive effect on MOR and MOE (Figure 3). Based on the correlation coefficients, it can be concluded that the correlation is moderate.

The dependence of MOR on wood density has been tested by a number of researchers. Thus, Schlyter (1927) states that this dependence is linear, while according to Baumann (1922) it is curvilinear. In any case, as the density of wood increases, the bending strength also increases, which is confirmed by this research (Figure 4). As wood density of Serbian spruce grows, so does the modulus of elasticity, although these correlations are slightly smaller than the correlations between density and MOR. In their study, Raiski et al. (2006) state that the same is the case with spruce wood.

In order to obtain a model for strength estimation, the regression analysis included the dependence of MOR on annual ring width and wood density. Multiple regression equation (Function 8) was obtained by stepwise multiple regression method. The parameters of the obtained equation and the regression characteristics (Table 8) show that there is a pronounced dependence of MOR on the included elements. All regression coefficients are statistically significant at the \( p<0.001 \) level, as is the regression as a whole. On the basis of the coefficient of determination, 33 \% of the variation of the MOR value is explained by the variation of the observed elements.

\[
\sigma_r = a + b \cdot w^2 + c \cdot \beta^2 \tag{8}
\]

![Figure 2](image2.png)  
**Figure 2** Dependence of MOR and MOE on annual ring width  
**Slika 2.** Ovisnost modula loma i modula elastičnosti o širini goda

![Figure 3](image3.png)  
**Figure 3** Dependence of MOR and MOE on proportion of late wood  
**Slika 3.** Ovisnost modula loma i modula elastičnosti o udjelu kasnog drva
Generally, the MOE is considered the most important strength predictor parameter (Baar et al., 2015). Investigating the correlation between MOR and MOE in spruce, Johansson and Kliger (2000) found that the coefficient of determination was 0.51. The equation of relation between bending strength and modulus of elasticity reported by Johansson et al. (1992) is:

\[ \sigma_y = 0.00383 \cdot E_x - 2.4 \]  

(9)

The dependence of MOR on MOE examined in this paper can be seen in Figure 5. The correlation is linear and positive, and based on the correlation coefficient of 0.77, it can be concluded that the correlation is very strong.

4 CONCLUSIONS
4. ZAKLJUČAK

The results obtained in this paper have substantially improved the knowledge of certain mechanical properties of Serbian spruce from the territory of Bosnia and Herzegovina. It can be observed that Serbian spruce

| Regression coefficient | Std. Err. of coeff. | t | p | S_y, mm | R | R² | F | p | n |
|------------------------|--------------------|---|---|---------|---|----|---|---|---|
| a 60.1964              | 10.77431           | 5.58703 | 0.000000 |
| b -2.0408              | 0.56226            | -3.62969 | 0.000453 |
| c 111.4477            | 36.67212           | 3.03903 | 0.003043 |

\[ y = 0.0054 \cdot x + 25.538 \]  

\[ R^2 = 0.589 \]  

Figure 4 Dependence of MOR and MOE on wood density at the moment of testing
Slika 4. Ovisnost modula loma i modula elastičnosti o gustoći drva u trenutku ispitivanja

Figure 5 Dependence of MOR on MOE
Slika 5. Ovisnost modula loma o modulu elastičnosti
has quite high values of MOR and MOE. Serbian spruce is known to be a protected species and not industrially significant. However, given its good mechanical properties, consideration should be given to establishing larger surfaces of planted forests with the aim of using Serbian spruce wood as a technical wood. Since there is a correlation between the width of the annual rings and MOR, care should be taken to achieve optimum growth in establishing and managing the new forest.

The modulus of elasticity may be a good predictor for determining the bending strength, given the very strong correlation between these two parameters.

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