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# Safety Stresses of Red Pine Wood According to Site Index Grade

## Dopuštena naprezanja drva crvenog bora ovisno o indeksu staništa

**ABSTRACT** • *One of the most important indicators for using wooden materials as a building material is safety stress (SS). Site index is also an essential criterion for construction materials. This research was planned with the aim to reveal the relationship between safety stress and site index classes (I, II, III) of red pine wood, which is an important tree species of Turkey and the Mediterranean basin. Also, the safety coefficient was calculated. The safety stress tests for compression, bending, and tensile, tensile perpendicular to fibers, cleavage, and shearing strengths were calculated as 9.2, 9.7, 8.9, 0.35, 0.10, and 1.4 N/mm², respectively. The statistical analyses indicated that the site index difference had a significant effect on the safety stress in red pine wood as mentioned above. Again, the safety coefficient was calculated as 5.27 for red pine wood. In addition, it was determined that the safety stress values of red pine wood provided the desired lower limit values according to the standard (TS 647 and EN 1995-1-1), excluding class I. As a result of the regression and correlation analyses, the presence of a moderately increasing linear relationship ($R^2$ values equal to 0.41-0.68) was found between the density and safety stress values for all site indexes.*

**KEYWORDS:** *red pine; site index; mechanical properties; safety stress; safety coefficient*

**SAŽETAK** • *Jedan od najvažnijih pokazatelja za uporabu drva kao građevnog materijala jest njegovo dopušteno naprezanje. A za drvo kao građevni materijal bitan je i kriterij indeks staništa. Ovo je istraživanje poduzeto radi otkrivanja odnosa između dopuštenog naprezanja i razreda indeksa staništa (I., II., III.) drva crvenog bora, važne vrste drva u Turskoj i na području mediteranskog bazena. Usto je izračunan koeficijent sigurnosti. Ispitivanjem su dobivena dopuštena naprezanja na tlak, savijanje i vlak, dopuštena vlačna naprezanja okomito na vlakanca te naprezanja na cijepanje i smicajna naprezanja, koja su redom iznosila 9,2; 9,7; 8,9; 0,35; 0,10 i 1,4 N/mm². Statistička je analiza pokazala da razlika u indeksu staništa ima znatan učinak na dopušteno naprezanje drva crvenog bora, kao što je i navedeno. Za drvo crvenog bora izračunani koeficijent sigurnosti iznosi 5,27. Osim toga, utvrđeno je da vrijednosti dopuštenog naprezanja drva crvenog bora osiguravaju željene donje granične vrijednosti prema standardu TS 647 odnosno EN 1995-1-1, isključujući razred I. Kao rezultat regresijske i korelacijske analize utvrđeno je postojanje umjereno rastućega linearnog odnosa (vrijednosti $R^2$ iznose 0,41 – 0,68) između vrijednosti gustoće drva i dopuštenog naprezanja za sve indekse staništa.*

**KLJUČNE RIJEČI:** *drvo crvenog bora; indeks staništa; mehanička svojstva; dopušteno naprezanje; koeficijent sigurnosti*

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# 1 INTRODUCTION

Wood is a natural organic material that has many characteristics that make it suitable for constructing buildings. It has been used for many centuries in construction, bridges, and various other structures (Kržišnik *et al.,* 2020; Kathem *et al*., 2014; Harte, 2009). The wood material may also be particularly efficient in certain structural forms based on its mechanical properties (Yildrim *et al*., 2021; Ramage *et al*., 2016). Although concrete and steel are the most popular materials in construction around the world, lumber was relegated to minor structural uses (Echenique Racero *et al*., 2015). The wood material has very high strength, especially when compared with its low weight. However, it is very anisotropic with different properties in different directions due to its make-up of oriented fibers (Kathem *et al*., 2014). Ramage *et al*. (2016) confirmed that timber excels where strength (or stiffness) to weight is more important than absolute strength (or stiffness). Good quality material is one of the basic requirements to manufacture a strong building (Boen, 2014). Until recently, safety checking requirements for most construction materials have been based on allowable stress design (ASD) concepts (Ellingwood, 1997).

Nowadays, on the one hand, existing wooden structures are strengthened against seismic loadings; on the other hand, it is emphasized that mechanical properties of wood-based materials to be used for new timber structures should have standard values.

In addition, wood is a renewable building material whose structural properties vary by species, natural growth characteristics, and manufacturing practices. At the same time, the quality of the tree and the site index are a part of this definition.

According to the standard methods, the average strength values obtained from the experiments made on the small size and defect-free samples taken from the wood material cannot represent the wooden material with large defects in practice. The solid wood material is not a uniform structure like metals. Various defects such as knots, cracks, spiral fiber, moisture content, temperature grade, loading character, duration, and many other factors negatively affect strength values (Berkel, 1970). The results of mechanical properties are obtained from laboratory tests of straight-grained clear wood samples (without natural defects that would reduce strength, such as knots, checks, splits, etc.) (Winandy, 1994).

Considering that often there is no precise information about these factors, it is inevitable that the loads to be carried in wood material in practice are only a small fraction of the strength obtained in small-sized samples (Bozkurt and Göker, 1996).

Safety stresses are also determined by considering the contained defects that the maximum load can carry when the wood material is used on large products in practice. The safety stress is the ultimate tension limit that a structural element can reliably withstand, depending on the shape, dimensions, and mechanical properties of the material of which a structural part is made. Thus, there is a need to know the safety stresses and use a high safety factor to safely determine the load that the wood material will carry in practice (As, 1992).

The aforementioned 'safety stress' placed in TS 647 can be regarded as a concept equivalent to the 'working stress' and 'allowable stress' expressed in ASTM D2555 (2006) and ASTM D245 (2011). This issue is stated in ASTM D2555-16 (2017) as follows: "This practice covers the determination of strength values for clear wood of different species in the unseasoned condition, unadjusted for end use, applicable to the establishment of working stresses for different solid wood products such as lumber, laminated wood, plywood, and round wood". Similarly, the allowable stresses are derived from using ASTM D245 to establish acceptable properties for a particular combination of natural growth characteristics (strength-reducing features) in a given timber. ASTM D245 also defines the procedure for determining allowable design stresses for visually graded wood starting from the average breaking strength values given in ASTM D2555 for small clear wood specimens (Anthony and Nehil, 2018).

Eraslan (1982) defined site index as "a term that reveals the productivity of the growth area in which stands grow and develop, yield and power of production". Yeşil (1993) published a study named "site index research in the natural red pine forest" in Turkey. As a result of this study, the equations essential for the classification of site index have been obtained in pure red pine stands. The development of the measure based on the site index classification of the height and diameter of the same aged stands has been achieved.

Furthermore, the damage could start from the destruction of the wood component on the wooden structures. That is why the basic properties of wood (mechanical and physical) should be known well to be considered in structural design (Yoresta, 2015).

After these explanations in the literature, it can be said that safety stress is a significant factor that should be known in the construction sector, especially in wooden structures. The reduction in the average strength of the wood perfect for achieving safety stress is indispensable for conditions of structural use. In order to better understand the behavior of the wood, such as its mechanical properties and safety stresses, it is necessary to perform experimental tests. This study focused on change of safety stresses and safety coeffi-

cients according to the site index classes of red pine, one of the most important tree species of Turkey and the Mediterranean basin. As one of the most important properties of lignocellulosic materials and its effect on strength, performance, and the general quality of final products (Sedlar *et al*., 2021; Sedlar *et al*., 2020; Anjos *et al*., 2014; Priadi and Hızıroğlu, 2013), relationships between the wood density and safety stresses were investigated.

## 2  MATERIALS AND METHODS
## 2.  MATERIJALI I METODE

The material used in the experiment was collected from Turkey pine in accordance with the site index classes (I=SI1, site index II=SI2, and site index III=SI3) and the principles specified in TS 2470:1976 (≡ISO 3129:1975) and TS 4176: 1984 (≡ISO 4471:1982). In order to reveal site index variability, test trees were selected from trial areas with similar characteristics such as soil properties and ecological factors. For the same reason, test trees had ±5 years age, ±100 m height, and ±10 % slopes.

The test specimens were prepared according to the standards related to air-conditioning to reach a humidity level of 12 %.

The tests of the oven dry density ($D_0$), compression strength parallel to fibers (*CoS*), static bending strength (*BS*), tensile strength parallel to fibers (*TS*//), tensile strength perpendicular to fibers (*TS*⊥), cleavage strength (*CS*) and shear strength parallel to fibers (*SS*) tests were performed on the prepared test specimens in accordance with the relevant standards.

Safety stress was calculated using the following Eq. 1 (Bektaş *et al*., 2018):

$$Safety\ stress = strength\ value\ at\ 12\ \% -$$
$$[25\ \%\ reduction\ due\ to\ defects + 25\ \%\ reduction$$
$$due\ to\ changes + \frac{7}{16}\ reduction\ due\ to\ continuous \tag{1}$$
$$loads + \frac{2}{5}\ reduction\ for\ true\ safety]$$

Where:
- Reduction due to defects: Defects such as cracks, knots, fiber orientation, cork damage significantly reduce the resistance values depending on the usage area of the wood material. Therefore, these must be taken into account when calculating the safety stresses.
- Reduction due to changes: Wood is an anisotropic and hygroscopic material. This leads to significant changes in its properties in areas of use.
- Reduction due to continuous loads: Fatigue loads significantly reduce the resistance of the wood material depending on the usage period.
- Reduction for true safety: The true tolerance of safety is a vital ratio added to preserve life after all other factors are taken into account.

In the same way, the coefficient of safety (safety factor or reduction factor) was calculated using both strength value at 12 % humidity and safety stress value with the help of the following Eq. 2:

$$Coefficient\ of\ safety = (strength\ value\ at\ 12\ \%) /$$
$$(safety\ stress\ ) \tag{2}$$

Finally, the obtained results were statistically analyzed using one-way ANOVA and Duncan's mean separation test to populate homogeneity groups that showed significant differences at the 95 % confidence level. Again, analyses of the regression and correlation were made to evaluate the relationships between density and safety stresses.

## 3  RESULTS AND DISCUSSION
## 3.  REZULTATI I RASPRAVA

### 3.1  Safety stresses
### 3.1.  Dopuštena naprezanja

The analysis results of the compression strength parallel to fibers test specimens prepared from the site index classes of red pine timber are shown in Table 1.

Table 1 shows that the site index class makes significant differences in the level of $p < 0.001$ on the

**Table 1** Safety stresses of compression strength as a function of site index
**Tablica 1.** Dopuštena naprezanja na tlak drva crvenog bora kao funkcija indeksa staništa

| Site index *Indeks staništa* | N* | Mean** *Srednja vrijednost**,* N/mm² | Standard deviation *Standardna devijacija* | Standard error *Standardna pogreška* | Coefficient of variation, % *Koeficijent varijacije, %* | Coefficient of safety *Koeficijent sigurnosti* | Probability Vjerojatnost |
|---|---|---|---|---|---|---|---|
| SI1 | 52 | 9.92A | 3.392 | 0.470 | 13.87 | 5.27 | *p* < 0.001 |
| SI2 | 48 | 9.03AB | 1.310 | 0.189 | 14.43 | 5.27 | |
| SI3 | 24 | 8.02B | 0.806 | 0.164 | 20.41 | 5.27 | |
| Total | 124 | 9.21 | 2.459 | 0.221 | 8.98 | 5.27 | - |

*Number of samples / broj uzoraka.
**Means with the same capital letter are not significantly different in Duncan's mean separation test. / *Srednje vrijednosti s jednakim velikim slovom nisu značajno različite prema Duncanovu testu razdvajanja srednjih vrijednosti.*

**Table 2** Analyses results of safety stresses for static bending strength experiments
**Tablica 2.** Rezultati analize dopuštenih naprezanja na savijanje

| Site index Indeks staništa | N* | Mean** Srednja vrijednost**, N/mm² | Standard deviation Standardna devijacija | Standard error Standardna pogreška | Coefficient of variation, % Koeficijent varijacije, % | Coefficient of safety Koeficijent sigurnosti | Probability Vjerojatnost |
|---|---|---|---|---|---|---|---|
| SI1 | 70 | 11.1A | 2.10 | 0.25 | 11.95 | 5.27 | |
| SI2 | 55 | 8.8B | 1.29 | 0.17 | 13.48 | 5.27 | p < 0.001 |
| SI3 | 32 | 8.0B | 2.09 | 0.37 | 17.68 | 5.27 | |
| Total | 157 | 9.7 | 2.27 | 0.18 | 7.98 | 5.27 | - |

*Number of samples / *broj uzoraka.*
**Means with the same capital letter are not significantly different in Duncan's mean separation test. / *Srednje vrijednosti s jednakim velikim slovom nisu značajno različite prema Duncanovu testu razdvajanja srednjih vrijednosti.*

compression strength parallel to fibers in the red pine wood. Again, the same table shows that the compression strength values of the samples also decrease statistically as the site index deteriorates (from SI1 to SI3). Since safety stresses are an important factor in using wood as building material, this difference in compression strength due to the site index class should be considered. Considering the effect of the fiber direction on the compression strength, Harte (2009) stated that the compressive strength parallel to the fibers is approximately 5 to 10 times the compression strength perpendicular to the fibers. Here, in compressive failure under pressure, the cells flatten, and the cell walls contact one another, increasing the density and compression strength of the material.

Table 2 shows the relationship between the bending stresses calculated for the static bending strength and the site index. Significant differences (*p* < 0.001) were also determined in safety stresses of bending strength between the first and the other two site index classes. No meaningful separation was observed between SI2 and SI3 classes. This negative relationship between SI2 and SI3 indices may be due to the fact that the prepared bending strength samples have properties close to each other, the location of the samples from the tree is similar to each other and other factors eliminated affecting mechanical performance.

These observations remind us that, in the use of red pine wood timber as a carrier member in timber construction systems, the grade of the site index must

be taken into account during the calculation of the safety stresses in the bending strength. It is generally accepted that wood-based main handling elements used in wooden structures have significant roles in building safety. Arroyo (1987) emphasized that the lumber to be used in construction as roof trusses, formworks, beams, scaffolds, and more, must have high rupture strength properties such as static bending strength, modulus of elasticity as well as maximum compression stress.

Table 3 shows that the safety strength values calculated based on the values of tensile strength parallel to the fibers have significant differences in the *p* < 0.001 confidence level among the site indexes. However, this deviation is mainly due to SI1. Table 3 also shows that there is no statistical difference between SI2 and SI3.

As is known, the tensile strength is much higher when loaded in parallel to the fiber direction, while it is deficient when loaded perpendicular to the fiber direction. This low strength perpendicular to the fiber direction needs to be addressed when designing timber structures (Kathem *et al*., 2014).

Another important property of wood is its tensile strength, which is its ability to bend under pressure without breaking. This is one of the main reasons why wood is preferred as a building material; its remarkably strong qualities make it the perfect choice for heavy-duty building materials such as structural beams (AHEC 2017). Also, Raposo *et al*. (2017) reported that the tensile strength parallel to the fibers is superior to

**Table 3** Safety stresses of tensile strength parallel to fibers according to site index
**Tablica 3.** Vrijednosti dopuštenog naprezanja na vlak paralelno s vlakancima ovisno o indeksu staništa

| Site index Indeks staništa | N* | Mean** Srednja vrijednost**, N/mm² | Standard deviation Standardna devijacija | Standard error Standardna pogreška | Coefficient of variation, % Koeficijent varijacije, % | Coefficient of safety Koeficijent sigurnosti | Probability Vjerojatnost |
|---|---|---|---|---|---|---|---|
| SI1 | 35 | 9.5A | 0.818 | 0.138 | 11.61 | 5.27 | |
| SI2 | 37 | 8.8B | 1.329 | 0.218 | 11.92 | 5.27 | p < 0.001 |
| SI3 | 33 | 8.4B | 0.933 | 0.162 | 10.88 | 5.27 | |
| Total | 105 | 8.9 | 1.128 | 0.110 | 11.92 | 5.27 | - |

*Number of samples / *broj uzoraka.*
**Means with the same capital letter are not significantly different in Duncan's mean separation test. / *Srednje vrijednosti s jednakim velikim slovom nisu značajno različite prema Duncanovu testu razdvajanja srednjih vrijednosti.*

**Table 4** Safety stresses of tensile strength perpendicular to fibers according to site index
**Tablica 4.** Vrijednosti dopuštenih naprezanja na vlak okomito na vlakanca ovisno o indeksu staništa

| Site index / Indeks staništa | N* | Mean** / Srednja vrijednost**, N/mm² | Standard deviation / Standardna devijacija | Standard error / Standardna pogreška | Coefficient of variation, % / Koeficijent varijacije, % | Coefficient of safety / Koeficijent sigurnosti | Probability / Vjerojatnost |
|---|---|---|---|---|---|---|---|
| SI1 | 72 | 0.37A | 0.032 | 0.004 | 11.79 | 5.27 | |
| SI2 | 53 | 0.35B | 0.049 | 0.007 | 13.74 | 5.27 | p < 0.001 |
| SI3 | 38 | 0.34B | 0.037 | 0.006 | 16.22 | 5.27 | |
| Total | 163 | 0.35 | 0.041 | 0.003 | 7.83 | 5.27 | - |

*Number of samples / broj uzoraka.
**Means with the same capital letter are not significantly different in Duncan's mean separation test. / *Srednje vrijednosti s jednakim velikim slovom nisu značajno različite prema Duncanovu testu razdvajanja srednjih vrijednosti.*

compressive strength parallel to the fibers for specimens made without defects, thanks to the buckling of the fibers under compression.

The analysis of the safety stresses calculated according to the site index in the tensile strength perpendicular to fibers of the samples shows that the site index has a significant effect ($p < 0.001$) on the safety stresses. Moreover, as a result of the Duncan test, it was determined that this effect originated from the difference between SI1 and the others.

The analysis results of the safety stresses in Table 4 calculated according to the site index in the tensile strength perpendicular to fibers of the samples show that the site index has a significant effect ($p < 0.001$) on the safety stresses. Moreover, as a result of the Duncan test, it was determined that this effect originated from the difference between SI1 and the others. While wood has high strength and stiffness in the direction parallel to the fibers, it is an anisotropic material with generally low properties in the direction perpendicular to the fibers. Thus, Harte (2009) emphasized that this characteristic must be taken into account in the design of timber structures where it is important to determine tensile strength perpendicular to the fibers such as in joints, conical or curved members and notched beams, etc. When the data in Table 5 are examined, it can be seen that the analysis results of the ANOVA and Duncan tests of the safety stress calculated for the cleavage strength parallel to fibers were similar to the tensile strength perpendicular to fibers.

The cleavage strength and tensile strength perpendicular to fibers tests are very similar to each other in terms of the test procedure and the shape of the specimens. That is why the two test results are similar to each other. However, cleavage strength is less important in terms of the effect that occurs during use in wood structures than tensile strength perpendicular to fibers. Almeida *et al*. (2015) mentioned that cleavage strength in wood materials is important because it relates to the design of bolted and nailed joints in timber structures. Ferro *et al*. (2013), Segundinho (2010) and Junior *et al*. (2014) stated that wood material can also be applied for structural purposes like bridges, roofs, footbridges, frameworks, and packages if their physical strength and stiffness properties, including cleavage strength, are known. Table 6 depicts that the safety stress values calculated based on shear strength showed a significant difference ($p < 0.043$ level) between SI1 and SI3. In contrast, the SI2 did not show any statistical deviation from other quality classes.

From these data, it can be deduced that the deterioration in the site index classes (from SI1 to SI3) affects the shear resistance safety stress negatively. The shear strength of the wooden material is a factor that plays an important role during the use of wood material in structures. So, the shear strength should always be taken into account when wood is used as a carrier, support and bonding element in wooden structure walls, diaphragms, roofs and floors. Wood (1958) emphasized that most of the reduction in the average

**Table 5** Safety stresses of cleavage strength for site indexes
**Tablica 5.** Dopuštena naprezanja na cijepanje za različite indekse staništa

| Site index / Indeks staništa | N* | Mean** / Srednja vrijednost**, N/mm² | Standard deviation / Standardna devijacija | Standard error / Standardna pogreška | Coefficient of variation, % / Koeficijent varijacije, % | Coefficient of safety / Koeficijent sigurnosti | Probability / Vjerojatnost |
|---|---|---|---|---|---|---|---|
| SI1 | 72 | 0.11A | 0.011 | 0.001 | 11.79 | 5.27 | |
| SI2 | 53 | 0.09B | 0.014 | 0.002 | 13.74 | 5.27 | p < 0.001 |
| SI3 | 38 | 0.09B | 0.010 | 0.002 | 16.22 | 5.27 | |
| Total | 163 | 0.10 | 0.014 | 0.001 | 7.83 | 5.27 | - |

*Number of samples / broj uzoraka.
**Means with the same capital letter are not significantly different in Duncan's mean separation test. / *Srednje vrijednosti s jednakim velikim slovom nisu značajno različite prema Duncanovu testu razdvajanja srednjih vrijednosti.*

**Table 6** Calculated safety stress values according to site indexes for shearing strength
**Tablica 6.** Izračunane vrijednosti dopuštenog naprezanja na smicanje s obzirom na indekse staništa

| Site index *Indeks staništa* | N* | Mean** *Srednja vrijednost**,* N/mm² | Standard deviation *Standardna devijacija* | Standard error *Standardna pogreška* | Coefficient of variation, % *Koeficijent varijacije, %* | Coefficient of safety *Koeficijent sigurnosti* | Probability *Vjerojatnost* |
|---|---|---|---|---|---|---|---|
| SI1 | 41 | 1.46A | 0.360 | 0.056 | 15.62 | 5.27 | |
| SI2 | 49 | 1.35AB | 0.295 | 0.042 | 14.29 | 5.27 | $p < 0.043$ |
| SI3 | 24 | 1.25B | 0.174 | 0.041 | 23.57 | 5.27 | |
| Total | 114 | 1.35 | 0.312 | 0.030 | 9.62 | 5.27 | - |

*Number of samples / *broj uzoraka.*
**Means with the same capital letter are not significantly different in Duncan's mean separation test. / *Srednje vrijednosti s jednakim velikim slovom nisu značajno različite prema Duncanovu testu razdvajanja srednjih vrijednosti.*

strength of a flawless wood material made to achieve design stress is necessary for structural use conditions because it does not produce a margin for safety. Also, he reported that a simple way to estimate safety is to use near-minimum values for these conversion factors and make a further reduction for unforeseen conditions. Similarly, in a study by Kim *et al*. (2011), the clone and site differences significantly affected fiber length, microfibril angle, and density of Acacia wood. As is known, in wooden structures, the relations between the shear, tensile and compression strengths and the connections (especially the bolt connections) are very tight (Echenique Racero *et al*., 2015).

### 3.2 Safety coefficient
### 3.2. Koeficijent sigurnosti

As shown in Table 1-6, the safety coefficient was calculated as an average 5.3 at the 12 % moisture content regardless of site index difference. This value (5.3) is among the recommended limits in the literature. Bozkurt and Göker (1996) accept the safety coefficient for wood material range from 3 to 6. The safety coefficient is the same for all strength values in the same tree type, and in practice, safety stresses are commonly

calculated over the safety coefficient. On the other hand, Usta (2007) notes that safety factors for timber construction materials are calculated due to the variability of wood material strength, while safety factors much larger than those of other construction materials should be selected. Indeed, a "main stress" value is determined by considering the differences in each tree type, loading time, safety factor, and other factors suitable for the use of structural lumber and its nature (Wood, 1960).

### 3.3 Comparison of site indexes safety stresses with standard values
### 3.3. Usporedba dopuštenih naprezanja drva za različite indekse staništa sa standardnim vrijednostima

The results obtained are compared with the values presented in the Turkish National Codes of Eurocode 5 for the quality classes assigned by Turkish Standard TS 647. Table 7 shows the comparison of the requested safety stress values for coniferous timber quality classes according to TS 647 with calculated safety stress values for site indexes in red pine. The standard TS 647 proposes reference values for the me-

**Table 7** Comparison of site indexes safety stresses with standard (TS 647)
**Tablica 7.** Usporedba dopuštenih naprezanja drva za različite indekse staništa sa standardom TS 647

| Safety stress *Dopušteno naprezanje* | Standard values (TS 647) *Standardne vrijednosti (TS 647)* | | | Values of red pine *Vrijednosti za drvo crvenog bora* | | |
|---|---|---|---|---|---|---|
| | Timber classes, N/mm²* *Klase kvalitete drva, N/mm²** | | | Site indexes, N/mm² *Indeks staništa, N/mm²* | | |
| | T1 | T2 | T3 | SI1 | SI2 | SI3 |
| Static bending strength *statička čvrstoća na savijanje* | 13 | 10 | 7 | 11.1 | 8.8 | 8.0 |
| Compression strength (parallel) *čvrstoća na tlak (paralelno)* | 11 | 8.5 | 6 | 9.9 | 9.0 | 8.0 |
| Tensile strength (parallel) *čvrstoća na vlak (paralelno)* | 10.5 | 8.5 | 0 | 9.5 | 8.8 | 8.4 |
| Shearing strength (parallel) *čvrstoća na smicanje (paralelno)* | 0.9 | 0.9 | 0.9 | 1.7 | 1.4 | 1.3 |
| Modulus of elasticity *modul elastičnosti* | 10 000 | | | 9 651** | | |

*Timber classes I, II, and III expressed in TS 647 are marked as T1, T2, and T3, respectively. / *Klase kvalitete drva I., II. i III. izražene u TS 647 označene su kao T1, T2 i T3.*
**Özkaya, 2013.

chanical properties of coniferous trees. If we compare them with those obtained experimentally for red pine grown in Turkey, it will be seen that most of these were higher than those proposed by the standard. At the same time, Turkey Wood Building Regulations divide the wood into three strength level classes for coniferous woods (class I, II, and III) (Table 7). In this classification, as the strength and quality of the wood increases, the class level also increases from 3 towards 1.

Table 7 shows that the safety stress values of the red pine wood calculated for the site index SI1 cannot provide the required standard values for grade T1 timber, except for the shear strength. Again, the same table shows that the safety stresses determined for the other site indexes (SI2 and SI3) meet the standard (for T1 and T2). It has also been found that the elasticity modulus value (9 651 N/mm$^2$) is very close to the requested standard value (10 000 N/mm$^2$) for all timber classes. For all classes, the results obtained from the statistical analysis of the *CoSS* and *TS* values were in total 4.7 % and 25.7 % higher than those proposed by TS 647, respectively. In contrast, the calculated BSS values are 7 % lower than the recommended standard values.

However, it should not be ruled out that the site index and the timber class values have not the same meaning. Despite all these, it is possible to say that the safety stresses calculated in the red pine wood provide the required safety stress values for wood materials to be used in wooden structures according to TS 647, excluding T1. Therefore, we could propose that the reference values established by the TS 647 standard be considered valid, especially for classes outside class T1. After all these evaluations, it can be said that the structural elements to be made with red pine wood are suitable for structural use according to the Turkey Wood Building Regulations. The National Design Specification (NDS) has, on the other hand, recognized the im-portance of these system effects by permitting an increase of 15 % in the allowable bending stress used to design assemblies where three or more members are used repetitively (Bezaleel, 2004). In the end, wood construction manufacturers will consider these standard and wood safety stress values for project calculations in structures.

### 3.4 Variation of safety stress and density with site index
### 3.4. Varijacija dopuštenog naprezanja i gustoće drva s promjenom indeksa staništa

Density values were also calculated on the sample where each mechanical resistance value was measured. Then, with the help of these calculated density values, graphs (Figures 1-3) showing relationships between the safety stress and density were obtained. In these charts, for a healthy display, the *TSS* (safety stress at tensile stress) and *CSS* (safety stress at cleavage stress) values were multiplied by 10, while the *SSS* (safety stress at shear stress) values (for SI3) were multiplied by 2.

As shown in Figure 1, there is a generally positive increasing relationship between safety stress and density for the first site index. In Table 8, the correlation coefficients ($R^2$) safety stress values were calculated between 0.49 and 0.63 for the first site index. The strongest correlation ($R^2$=0.63) was determined in the *SSS*, while the weakest ($R^2$=0.49) was found in the CSS.

Figure 2 shows the interaction between density and safety stress values measured for SI2. When the graph in Figure 2 is evaluated together with the data in Table 8, it can be said that the correlation coefficients calculated according to the relationship between the safety stress of the mechanical properties and densities are $R^2$>48. This means that the density can explain more than 50 % of the comparative safety stress values.
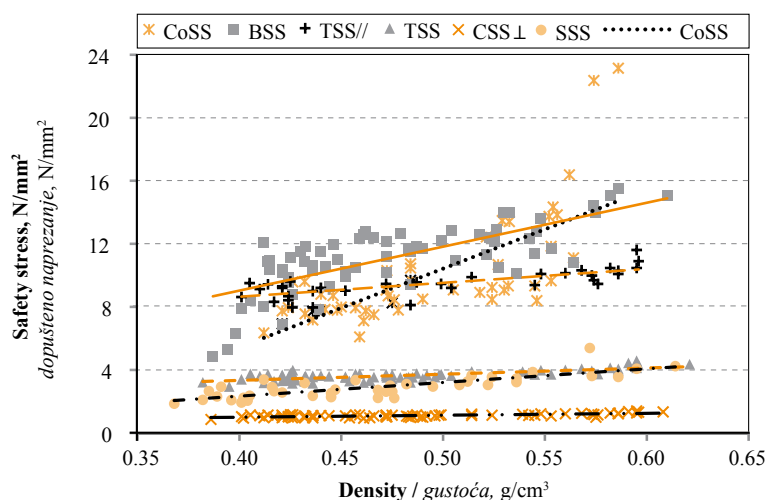


**Figure 1** Slope lines of relations between safety stress and density for SI1
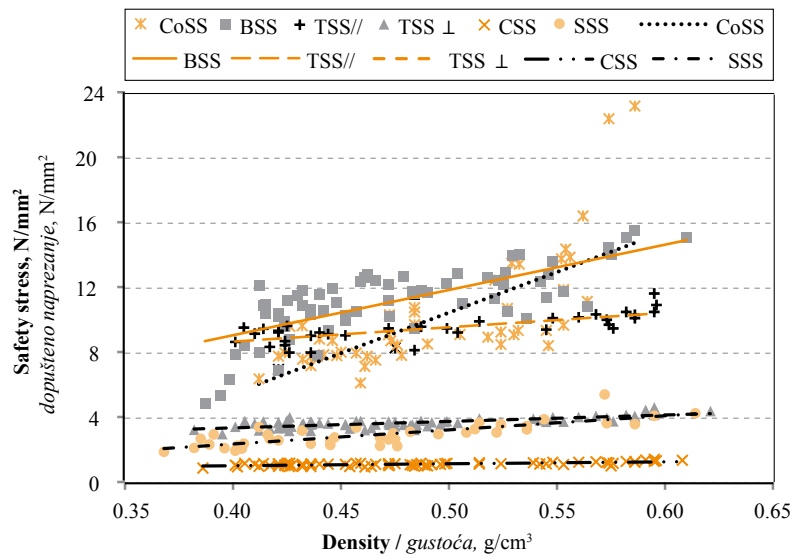**Slika 1.** Nagibi odnosa između dopuštenog naprezanja i gustoće drva za SI1

**Figure 2** Relationships between safety stress and density for SI2
**Slika 2.** Odnos između dopuštenog naprezanja i gustoće drva za SI2

In general, it can be said that there is a moderate correlation between density and safety stresses for SI2.

For the SI3, it is seen that $R^2$ values calculated in Table 8 through the slope lines formed in the graph (Figure 3) are ranging between 0.41-0.68. Again, it is understood from Figure 3 and Table 8 that the relationship of the weakest correlation is between density and TSS// ($R^2 = 0.41$), and the most substantial relationship is between density and CoSS (safety stress at compression stress) ($R^2 = 0.68$).

When the correlation coefficients calculated in Table 8 were evaluated according to site index classes, the highest $R^2$ values were calculated in TSS and SSS for SI1. Also, CSS was obtained for SI2 and determined in CoSS and BSS for SI3. The same table shows close correlation coefficient averages ($R^2 = 0.55$, 0.54, and 0.55) calculated for the site indexes. Machado and Cruz (2005) reported that the relationship between wood density and strength properties is acknowledged

in part because density is a measure of the relative amount of solid cell wall. In several researches (Bektaş *et al*., 2020; Sedlar *et al*., 2019; Güler, 2004; Yang and Evans, 2003; Evans and Ilic, 2001; Rozenberg *et al*., 1999; Cave and Walker, 1994), various factors, such as cell wall thickness, wood component ratio, microfibril angle, and fiber angle, are reported to affect the relationship between wood density and mechanical properties. In general, the presence of a linear relationship between density and strength values is agreed to a large extent. It can be said that this determination is generally consistent with the results to be deduced from the slope lines drawn in Figures 1-3 for density and safety stresses. It is also a fact that the wood quality assessment involves considering wood density and mechanical properties (Anoop, 2014).

Again, when the regression equations given in Table 8 are examined in terms of site index classes, it will be easily seen that the sign of b values is "positive"
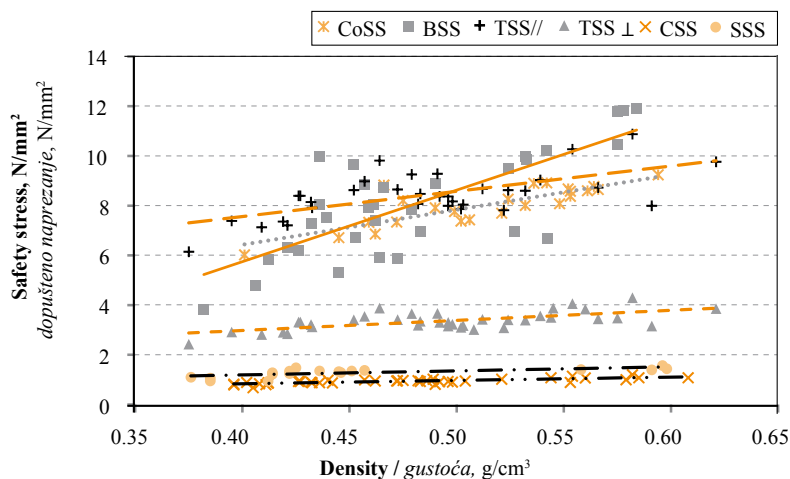


**Figure 3** Relationships between safety stress and density for SI3
**Slika 3.** Odnos između dopuštenog naprezanja i gustoće drva za SI3

**Table 8** Equations derived from regression analyses for safety stresses
**Tablica 8.** Jednadžbe izvedene iz regresijske analize za vrijednosti dopuštenih naprezanja

| Parameter *Parametar* | SI1 | | SI2 | | SI3 | |
|---|---|---|---|---|---|---|
| | Equation / *Jednadžba* | $R^2$ | Equation / *Jednadžba* | $R^2$ | Equation / *Jednadžba* | $R^2$ |
| CoSS | $y = -14.5 + 49.9 \cdot x$ | 0.51 | $y = 0.51 + 8 \cdot x$ | 0.53 | $y = 0.8 + 14.1 \cdot x$ | 0.68 |
| BSS | $y = -2.1 + 27.9 \cdot x$ | 0.54 | $y = 0.7 + 16.4 \cdot x$ | 0.57 | $y = -5.8 + 28.9 \cdot x$ | 0.58 |
| TSS// | $y = 5.1 + 8.8 \cdot x$ | 0.59 | $y = 1.7 + 14.2 \cdot x$ | 0.55 | $y = 3.5 + 10.2 \cdot x$ | 0.41 |
| TSS⊥ | $y = 1.8 + 3.9 \cdot x$ | 0.59 | $y = 0.7 + 5.6 \cdot x$ | 0.50 | $y = 1.4 + 4.1 \cdot x$ | 0.42 |
| CSS | $y = 0.5 + 1.2 \cdot x$ | 0.49 | $y = 0.1 + 1.9 \cdot x$ | 0.62 | $y = 0.3 + 1.3 \cdot x$ | 0.61 |
| SSS | $y = -1.1 + 8.7 \cdot 6x$ | 0.63 | $y = -0.2 + 3.3 \cdot x$ | 0.48 | $y = 0.5 + 1.6 \cdot x$ | 0.48 |
| Average | - | 0.55 | - | 0.54 | - | 0.55 |

for all site index classes. As is known, in the equations $(a + b \cdot x)$ obtained by the regression analysis, if the sign of b is positive, then the variables of the compared societies either increase or decrease together (Başar and Oktay, 2007).

## 4 CONCLUSIONS
## 4. ZAKLJUČAK

In the scope of the study, safety stress and safety coefficients for the compression strength, bending strength, tensile strength parallel to fibers, tensile strength perpendicular to fibers, cleavage strength, and shearing strength were calculated for the red pine wood. As a result of the analyses, the values of CoSS, BSS (safety stress at bending stress), TSS//, TSS⊥, CSS and SSS were determined as average 9.2 N/mm², 9.7 N/mm², 8.9 N/mm², 0.35 N/mm², 0.10 N/mm² and 1.4 N/mm², respectively.

Again, the results of statistical analyses (ANOVA and Duncan's mean separation test) showed that site index had a significant effect ($p$ <0.05-0.001 levels) on the safety stresses.

When the data obtained in the study are evaluated in total, it can be said that the safety stress values of red pine wood provided other lower limit standard values (For SI2 and SI3) according to TS 647 excluding T1.

However, when the indexes and classes were compared one to one, it was determined that site index 1 satisfied only SSS of class 1, site index 2 satisfied CoSS, TSS //, TS⊥ , and SSS of class 2, and site index 3 satisfied all values of class 3. On the other hand, the safety coefficient was calculated as 5.27 for red pine wood.

The results of regression and correlation analyses revealed a relationship between density and safety stresses that varies according to site index and strength values. Calculated $R^2$ values were between 0.49-0.63 for SI1, 0.48-0.62 for SI2, and 0.41-0.68 for SI3. It can be assumed that there is a medium degree-strong relationship for all site indexes between density and safety stress in red pine wood.

In the guidance of these results and evaluations, it can be said that red pine wood can be used safely in construction and especially in wood structures where mechanical strength is important. Thus, this wood can be recommended for use in wood building structures (columns, beams, and floor).

In the future, as emphasized in a study (Heräjärvi, 2004), the building industries will need predictable, homogeneous, and cost-competitive wood products with structural safety in increasing quantity and quality.

The final word of this research is the necessity of dealing with new species-origin combinations in studies to determine the properties of the wood material used, which is one of the essential issues of timber structures. And also, it is necessary to know the standard values in practice for each wood element of wood construction, the safety stresses as calculated by standard methods of engineering mechanics.

After all, it is recommended that further studies be carried out under the guidance of the developing technology for the use of wood materials for structural purposes, as this issue is critically important and has not been thoroughly investigated so for.

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