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RATIO ANALYSIS BETWEEN COMPRESSION AND SHEARING OF 72 BRAZILIAN WOOD SPECIES

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ABSTRACT

The Brazilian standard ABNT NBR 7190 (1997) governs the premises for the wood structure sizing through a table and the simplified method. Thus, this research aims to analyze whether the simplified method shown in the standard matches the resistance values of 72 Brazilian species, separated from class C20 to C60. In the end, it was possible to conclude that the value displayed by the standard between the ratio of shear and compression in the direction parallel to the fibers is half of what actually happens in Brazilian species, showing an urgent review in the standard premises.

KEYWORDS: Wooden structures, simplified characterization, Brazilian standard, sizing.

INTRODUCTION

Wood, being abundant in Brazil, can be considered an excellent structural material, in addition to having good resistance in traction and compression (Lahr et al. 2021, Almeida et al. 2019). Precisely because of this resistance in either efforts, wood is indicated for both small and large structures (Poleto et al. 2020, Silva et al. 2020). However, it is necessary to carry out reforestation in order not to harm the environment (Pigozzo et al. 2018a, Wolenski et al. 2020). In addition, with reforestation its source is renewable, another important point and should be highlighted, unlike the other structures usually used: reinforced concrete and metal (Pigozzo et al. 2018b, Oliveira et al. 2019).

According to Alves (2020), Brazil had 493.5 million hectares of forests in 2017, equivalent to 12% of all world forests. With a government incentive on the reforestation wood production, whether to recover deforested areas or for structural purposes, these trees can store up to 200 tons of CO_2 throughout their lives, thus showing their importance against environmental impacts (Christoforo et al. 2017, Santos et al. 2020). According to Gomes (2016), the steel structure emits more than 1600 kg of CO_2 per ton of steel produced. Concrete, on the other hand, emits around 1100 kg of CO_2 per ton of clinker produced (Felix and Possan 2018).

In Brazil, the Brazilian Association of Technical Standards (ABNT) which governs the premises for the design of structures: wood, concrete and steel, with NBR 7190 (1997) being the current standard for wooden structures (Nascimento et al. 2021). Tab. 1 below presents the strength classes with the respective properties stipulated by the standard, helping the engineer in structural calculation with only the wood strength class, without needing to carry out laboratory tests to determine physical and mechanical properties.

Tab. 1: Strength class with its respective physical and mechanical properties of hardwoods according to ABNT NBR 7190 (1997).

Classes	$f_{c0,k}$ (MPa)	$f_{v0,k}$ (MPa)	$E_{c0,m}$ (MPa)	$\rho_{12\%}$ (kg·m^{-3})
C20	20	4	9500	650
C30	30	5	14500	800
C40	40	6	19500	950
C60	60	8	24500	1000

In addition to this table, the current standard shows a simplified characterization of wood species according to the type: conifer or dicotyledonous (hardwood) (Christoforo et al. 2020, Almeida et al. 2020). With this simplified characterization and Tab. 1, the civil engineer is able to estimate other properties required for dimensioning, using relationships between the wood resistances. As an example, Tab. 1 shows only the compressive strength parallel to the fibers ($f_{c0,k}$), shear parallel to the fibers ($f_{v0,k}$), modulus of elasticity ($E_{c0,m}$) and the apparent density ($\rho_{12\%}$), these values being characteristic (Nogueira et al. 2020, Duarte et al. 2020). If the engineer needs the normal compressive strength to fibers ($f_{c90,k}$), he can adopt $f_{c0,k}$ as an estimator of this property ($f_{c90,k} = f_{c0,k} \cdot 0.25$).

For a correct and safe sizing of a structure, it is ideal to know all the properties of resistance and rigidity (Pigozzo et al. 2018c,d). However, according to Couto et al. (2020), these relations shown in the Brazilian standard (simplified method) may not match reality. In its study, 10 species of Brazilian wood were used, covering all resistance classes (C20 to C60) shown in Tab. 1. With the analysis, it was possible to conclude that no species had the relationship between the shear parallel to the fibers and the compression parallel to the fibers equal to the value shown in the standard. The average value obtained between this relationship was 0.22, while the Brazilian standard displays it as being 0.12.

Matos and Molina (2016) also analyzed the relationship between $f_{v0,k}$ and $f_{c0,k}$ of two Brazilian species: *Pinus elliotti* and *Eucalyptus saligna*. In his study it was possible to notice a greater discrepancy of this relationship in the pine species, since the relationship was 0.29 and the standard displays as being 0.15. For the eucalyptus species, the ratio was 0.13, very close to the standard (0.12).

In view of this, this research aims to assess whether the ratio between the shear parallel to the characteristic fibers ($f_{v0,k}$) and the parallel compression to the characteristic fibers ($f_{c0,k}$) of 72 Brazilian wood species are equivalent with those shown by the Brazilian standard NBR 7190 (1997). For that, the 72 species were divided between the four normative resistance classes (Tab. 1). At the end, he analyzed the ratio between these two properties by resistance class and considering all species together, besides using a linear regression model to stipulate which would be the best ratio value.

MATERIAL AND METHODS

The 72 species used in this research are shown in Tab. 2 below, with their respective resistance classes (RC) according to ABNT NBR 7190 (1997).

Tab. 2: Wood species evaluated.

Common name	RC	Common name	RC	Common name	RC	Common name	RC
Amescla	C20	Angelim Amargoso	C40	Angelim Saia	C60	Breu Vermelho	C60
Caixeta	C20	Angelim Araroba	C40	Casca Grossa	C60	Champanhe	C60
Cajueiro	C20	Angico Branco	C40	Castelo	C60	Cutiúba	C60
Cambará	C20	Bicuíba	C40	Catanudo	C60	Garrote	C60
Cambará Rosa	C20	Branquilho	C40	Envira Branca	C60	Guajará	C60
Cedro Doce	C20	Cafearana	C40	Envira	C60	Ipê	C60
Cedro	C20	Canafístula	C40	Garapa	C60	Angelim Vermelho	C60
Cedroarana	C20	Canela Parda	C40	Guaiçara	C60	Itaúba	C60
Marupá	C20	Canelão	C40	Guanandi	C60	Angico Preto	C60
Quarubarana	C20	Casca Grossa	C40	Guarucaia	C60	Jatobá	C60
Cambará	C30	Copaíba	C40	Ipê	C60	Tatajuba	C60
Castanheira	C30	Cupiúba	C40	Louro Preto	C60	Maçaranduba	C60
Cedro Amazonense	C30	Goiabão	C40	Oiticica Amarela	C60	Mandioqueira	C60
Cedro	C30	Louro Verde	C40	Parinari	C60	Oiuchu	C60
Cupiúba	C30	Mirarema	C40	Peroba Mica	C60	Quina Rosa	C60
Embireira	C30	Piolho	C40	Umirana	C60	Roxinho	C60
Tauari	C30	Quaruba Rosinha	C40	Angelim Pedra	C60	Sucupira	C60
Abiú	C40	Rabo de Arraia	C40	Angelim Ferro	C60	Tachi	C60

The wood from homogeneous lots was properly stored, resulting in a moisture content close to 12%, according to the premises of ABNT NBR 7190 (1997). The test methods of the Brazilian standard were also followed to obtain the mechanical properties.

Also, as recommended by the Brazilian standard, twelve specimens per species were manufactured and tested for compressive strength parallel to the fibers and shear strength (Fig. 1), resulting in 1896 experimental determinations altogether.

(a) (b)

Fig. 1: a) apparatus used to perform the compression tests parallel to the grain; b) apparatus used to perform the shear parallel to the fibers.

The specimens were broken in the universal testing machine (AMSLER with load capacity of 25 tons). Their moisture content (U) at the time of the tests was obtained using the Marrari M5 contact moisture meter ($10.76 \leq U \leq 12.96\%$). With the samples moisture content, the resistance values (f_U) were corrected to the moisture content of 12%, as indicated by ABNT NBR 7190 (1997), with the aid of equation 1 below, in which f_U consists in the samples resistance associated with the moisture content U, while $f_{12\%}$ consists of the resistance to 12% moisture:

$$f_{12\%} = f_U \cdot \left[1 + \frac{2 \cdot (U - 12)}{100}\right] \quad (1)$$

Based on the corrected values for 12% moisture content ($f_{c0,12\%}$ and $f_{v0,12\%}$), Eq. 2 was used to determine the characteristic value ($f_{c0,k}$ and $f_{v0,k}$) for the woods categorization, in which f_1, f_2 to f_n denote the values of resistance in ascending order of the 12 (n) specimens tested, according to ABNT NBR 7190 (1997):

$$f_k \geq \begin{cases} f_1 \\ 0.70 \cdot \frac{\sum_{i=1}^{n} f_i}{n} \\ 1.10 \cdot \left[2 \cdot \left(\frac{f_1 + f_2 + \cdots + f_{(n/2)-1}}{(n/2) - 1}\right) - f_{n/2}\right] \end{cases} \quad (2)$$

Statistical analysis

The ratio between the characteristic shear strength in the direction parallel to the fibers ($f_{v0,k}$) and the compressive strength in the direction parallel to the fibers ($f_{c0,k}$) established by the Brazilian standard ABNT 7190 (1997) is expressed by Eq. 3:

$$\frac{f_{v0k}}{f_{c0,k}} = 0.12 \quad (3)$$

To evaluate the optimal ratio between the two properties by resistance classes and also for the set composed of all species, a linear regression model with one parameter was used (Eq. 4), with β_0 being the parameter (coefficient of the relationship between $f_{v0,k}$ and $f_{c0,k}$ using the least squares method:

$$f_{v0k} = \beta_0 \cdot f_{c0,k} \quad (4)$$

The average absolute percentage error (MAPE, Eq. 5) and the regression variation coefficient (CV) were used as measures of error and variability in the results obtained using Eq. 4, and the adjustment quality was determined using determination coefficient (R^2, Eq. 7).

$$MAPE(\%) = 100 \cdot \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{|Ypredito_i - Ydados_i|}{|Ydados_i|} \quad (5)$$

$$CV(\%) = 100 \cdot \frac{\sqrt{\sum_{i=1}^{n} \frac{(Ypredito_i - Ydados_i)^2}{n}}}{\bar{Y}dados} \quad (6)$$

$$R^2(\%) = 100 \cdot \left(1 - \frac{\sum_{i=1}^{n}(Ypredito_i - Ydados_i)^2}{\sum_{i=1}^{n}(Ydados_i - \bar{Y}dados)^2}\right) \quad (7)$$

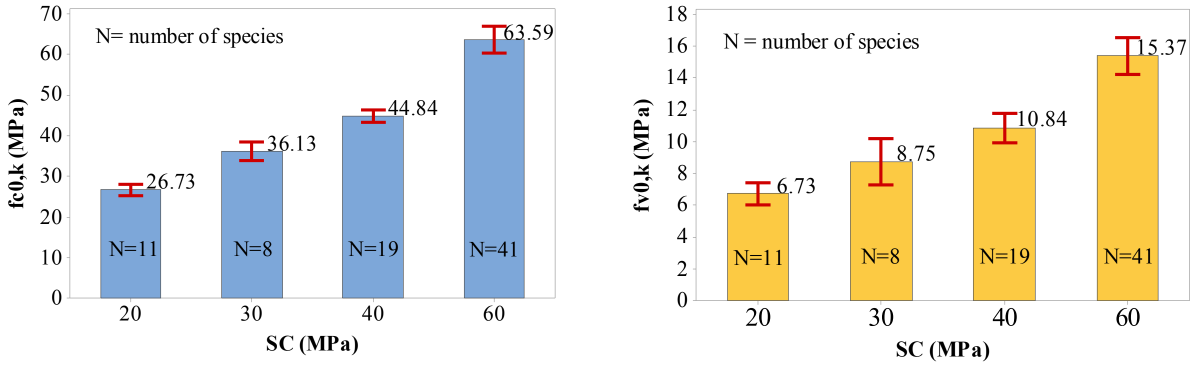
From Eqs. 5 to 7, n is the samples number considered, $Ypredict_i$ is the value estimated by the regression model, $Ydata_i$ is the experimentally determined value and $\bar{Y}data$ is the average value of the results determined experimentally.

RESULTS AND DISCUSSION

Fig. 2 shows the result of the strengths obtained in the compression and shear strength tests in the direction parallel to the fibers by strength class (SC).

From this figure, it is possible to observe that the greater the compressive strength of the wood, the greater the shear strength. The standard deviations, and consequently the coefficients of variation (CV), were low. ABNT NBR 7190 (1997) advises that the CV must be less than 18% to demonstrate quality in the tests performed. The maximum CV obtained from the samples was 11.84% and 18.29% for compression and shear, respectively, showing this quality.

Tab. 3 shows the results of the ratio between shear and compression in the direction parallel to the fibers of the 4 strength classes, as well as the ratio considering all species together.



(a) (b)

Fig. 2: Synthesis of the characteristic values of compressive strength (a) and shear (b) in the direction parallel to the fibers of the studied wood species.

Tab. 1: Linear models results ($f_{v0,k} = \beta_0 \cdot f_{c0,k}$).

Groups	Coefficient (β_0)	CV (%)	MAPE (%)	R^2 (%)
C20	0.25	13.44	10.08	11.73
C30	0.24	18.72	16.01	6.24
C40	0.24	18.01	15.82	15.89
C60	0.24	17.27	14.62	43.14
All species	0.24	17.97	14.22	73.30

As can be seen, the ideal ratio between shear and compression in compression parallel to the fibers is 0.25 for class C20 and 0.24 for the rest. The standard displays a value of 0.12, regardless of the resistance class. Considering all species together, also from the NBR 7190 (1997) standard, this ratio should be 0.24. The determination coefficient for this relationship considering all species was 73.30%, higher than the 70% required by Montgomery (2013), indicating the quality of the chosen regression model. With this difference of 100% (double), the structural engineer would have a resistance 50% lower than what the wood actually resists, causing the structure to be oversized if it uses compression to estimate the shear. If using shear to estimate compression, the standard would be doubling the value of what actually resists, causing the structure to be undersized, which can cause pathologies and compromise the structure (Andrade Jr et al. 2014).

Thus, it is evident that the Brazilian standard for wooden structures (NBR 7190, 1997) needs to undergo revision, since civil engineers are carrying out structural design with data that does not match reality. This failure was also evidenced in the work of Matos and Molina (2016) and Couto et al. (2020), in which they found a discrepancy of 83% in 10 species studied (Couto et al. 2020) and a difference of 93% for the species of *Pinus elliotti* (Matos and Molina 2016). The only work that obtained a small difference in relation to the norm was in the work of Couto et al. (2020) for the species of *Eucalyptus saligna*, being only 8%.

CONCLUSIONS

The results obtained from this research made it possible to conclude that: *(1)* Although the quantity of samples taken (1896) is high, the variation CV obtained met the limit imposed by the Brazilian standard for wooden structures (NBR 7190, 1997) of 18%, showing the quality of the tests carried out. *(2)* The ideal value for the ratio between shear strength and compression, both in the direction parallel to the fibers, should be 0.25 for class C20 and 0.24 for the others, instead of the value imposed by the standard. *(3)* The ideal ratio value, considering all species, should be 0.24 and not 0.12, showing that the Brazilian standard needs to be revised because it is oversizing or under-sizing wooden structures in Brazil. With this correction, the engineers would adopt the value that the wood really resists, making the sizing is correct and don't occur pathologies or over-sizing in the structure. *(4)* The linear regression model adopted showed excellent quality, as it was higher than the 70% required by Montgomery (2013), showing that the relationship should be 0.24.

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