TECHNICAL ARTICLE

THE POSITION EFFECT OF STRUCTURAL *Eucalyptus* ROUND TIMBER ON THE FLEXURAL MODULUS OF ELASTICITY

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ABSTRACT: Round timber has great use in civil construction, performing the function of beams, columns, foundations, poles for power distribution among others, with the advantage of not being processed, such as lumber. The structural design of round timber requires determining the elastic properties, mainly the modulus of elasticity. The Brazilian standards responsible for the stiffness and strength determination of round timber are in effect for over twenty years with no technical review. Round timber, for generally present an axis with non-zero curvature according to the position of the element in the bending test, may exhibit different values of modulus of elasticity. This study aims to analyze the position effect of *Eucalyptus grandis* round timber on the flexural modulus of elasticity. The three-point bending test was evaluated in two different positions based on the longitudinal rotation of the round timber element. The results revealed that at least two different positions of the round timber element are desired to obtain significant modulus of elasticity.

KEYWORDS: round timber, bending of beams, modulus of elasticity.

INFLUÊNCIA DA POSIÇÃO EM PEÇAS ROLIÇAS ESTRUTURAIS DE MADEIRA *Eucalyptus* NO CÁLCULO DO MÓDULO DE ELASTICIDADE NA FLEXÃO

RESUMO: A madeira roliça possui grande emprego nas construções civis, desempenhando a função de vigas, colunas, fundações, postes para distribuição de energia elétrica, entre outras, apresentando a vantagem de não ser processada, como é o caso da madeira serrada. O projeto envolvendo elementos roliços requer, além de outras variáveis estruturais, o conhecimento do módulo de elasticidade. No Brasil, os documentos normativos que tratam da determinação das propriedades de rigidez e resistência para peças roliças de madeira estão em vigência há mais de vinte anos sem revisão técnica. A madeira roliça, por geralmente possuir eixo com curvatura não nula, pode apresentar, segundo a posição da peça no ensaio de flexão, valores diferentes do módulo de elasticidade. Este trabalho tem como objetivo analisara influência da posição de peças roliças de madeira de *Eucalyptus grandis* na determinação do módulo de elasticidade na flexão. O ensaio de flexão utilizado é o de três pontos, sendo cada peça avaliada em duas posições distintas, definidas mediante o giro da seção transversal em torno do eixo. Os resultados encontrados indicam a necessidade do ensaio de flexão em, pelo menos, duas posições distintas da peça.

PALAVRAS-CHAVE: madeira roliça, flexão de vigas, módulo de elasticidade.

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INTRODUCTION

Because of its versatility and availability, wood has been used for centuries as a structural material. Over time, the demand for new technologies motivated the development of studies on this material, both in its original and processed forms, providing increased knowledge on their physical and chemical properties, as well as their uses.

In countries with a tradition in using wood in structures, it is common to use mixed systems, both solid wood and its derivatives. However, the demands associated with processing costs motivate research to find solutions that combine high efficiency of wood as a structural element at a low production cost. An alternative to this problem is to use wood in its original rounded shape, due to the natural growth of the tree, as shown by PARTEL (1999) in a study that surveyed the main round wood structural systems of housing, buildings, towers, bridges and electrification in Brazil and abroad.

The Brazilian Standard for the Design of Wood Structures, NBR 7190 (1997), from the Brazilian Association of Technical Standards (ABNT), specifies the rounded elements with base and top diameters, regardless of the species. This document also states that the properties of strength and stiffness are obtained by means of test-bodies of small dimensions and free from defects, even though the wood is not a homogeneous and an isotropic material.

The observation of differences in mechanical properties between the test-bodies and elements of structural dimensions is a theme for further investigation.

BATISTA et al. (2000) developed experimental research comparing values of the modulus of elasticity obtained from test-body free from defects and sawn of pieces structural dimensions. Of the three species studied, two of them, Eucalyptus and Cambará, showed accurate results, which were not true for Cupiúba wood, which showed values for the reduced models about 30% lower than those of structural models.

MINÁ et al. (2004) evaluated the strength and stiffness of *Eucalyptus citriodora* rounded wood poles compared with test-body. The results found for the structural elements for the modulus of elasticity were higher in the bending tests, being lower in the parallel compression.

CORSINI et al. (2004) used visual mechanical and grading on defect-free test-bodies and structural elements of the genus *Eucalyptus citriodora*. The wood elements were visually classified based on the revised norm NBR 7190 (1997) and tested for compression, tension, shear and bending. As part of the final completion of the work, the authors draw attention to the need of standardization of structural timber testing.

In Brazil, the official documents regarding round structural elements are primarily intended to tackle the pole market, being in force for at least 20 years without technical review.

The norm NBR 6231 (1980) (Wood Poles: Flexural Resistance) prescribes the method in which the test of the flexural resistance of wooden poles should be performed. One end of the element is crimped; and on the other end a concentrated force is applied, generating displacement. Through an equation in which factors are considered, such as the applied force, geometric characteristics and the displacement measured, it is possible to determine the elastic modulus of the element.

The norm NBR 8456 (1984) (Preserved Poles of Eucalyptus for Power Grid) establishes the conditions for the preparation and receiving of preserved poles of Eucalyptus under pressure to be used in aerial networks for electricity distribution.

The norm NBR 8457 (1984) (Preserved Poles of Eucalyptus for Power Grid: Dimensions) regulates preserved poles of Eucalyptus for use also in aerial distribution of electricity. It specifies: pole length, type, nominal resistance, maximum deflection, length and diameter of the cantilever, (minimum and maximum) diameters at 20 cm from the top, and perimeter at the top and the base.

The technical standard NBR 6122 (1996) (Design and Implementation of Foundations) recommends the use of the NBR 7190:1997 norm for calculating the resistance of wooden poles, with the latter limited to tests of resistance in test-bodies of small dimensions and defect- free, even being convenient the use of the structural element to determine its mechanical properties.

The use of destructive and nondestructive tests for wood characterization as well as comparative studies of test-bodies and elements of structural dimensions has been the focus of research involving several rounded elements, as can be found in the studies of RANTA-MAUNUS (2000), WOLF & MOSELEY (2000), ROSS et al. (2001), PINTO et al. (2004), SALES et al. (2004), LARSON et al. (2004), MINÁ (2005), MINÁ & DIAS (2008), ZANGIÁCOMO & LAHR (2008), CARREIRA & DIAS (2009) and SALES et al. (2010) among others.

The rounded elements of structural dimensions usually do not have a straight axis, as assumed by theory. For this reason, changing the position of the element in the bending test may result in different values for the modulus of elasticity. This study aims to use the static bending test within three points to determine the elasticity modulus of *Eucalyptus grandis* wood in two different positions for the elements, defined by a rotation around the axis, to allow the analysis and result comparisons.

MATERIAL AND METHODS

To determine the longitudinal modulus of elasticity, 24 pieces of *Eucalyptus citriodora* structural wood elements were used, with average length of 750 cm and average diameter at breast height of around 30 cm.

In this study, an alternative to the proposals outlined by national norms, the modulus of elasticity was obtained by the three-point , because it is a test easy to perform, compared with the fixed cantilever, being this test the same model used to calculate the modulus of elasticity in timber test-bodies as proposed by the NBR 7190 (1997) (Figure 1).

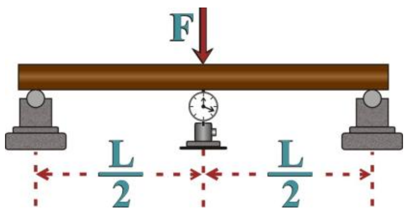

FIGURE 1. Bending test according to NBR 7190 (1997).

For this standard, the modulus of elasticity (E) is determined by means of Equation 1, ΔF is the load increment, L is the span of the element, I is the moment of inertia of the cross section, and δ is the arrow in the middle of the span.

$$E = \frac{\Delta F \cdot L^3}{48 \cdot \delta \cdot I} \quad (1)$$

The moment of inertia of the element is calculated from the measured circumference at the point of application of force in the bending test, giving rise to the diameter equivalent (DEQ), which is approximately the same as the arithmetic mean between the top and bottom diameters. This approach is valid assuming that the sections of the structural elements are perfectly circular, the diameters vary linearly in length and the maximum displacement of the element occurs at the point of application of force (short taper).

In this study, the elastic modulus is calculated by Equation 2. Thus, the threshold value of the measured displacement below the point of application of force is equal to L/200, where L is expressed in cm. This value ensures linear elastic behavior of the material and geometric linearity of the element, since it is a measure of small displacements.

$$E = \frac{3 \cdot F \cdot L^3}{4 \cdot \pi \cdot \delta \cdot D_{eq}^4} \tag{2}$$

From Equation 2, as an alternative, increments of force (ΔF) were not used to calculate the elastic modulus, but the force (F) responsible for inducing the measurement of small displacements (L/200), consisting of a non-destructive testing. Thus, the structural element is tested without the need of rupture.

According to equations 1 and 2, the round structural wood respect the relation $L/D_{eq}>21$, ignoring the effect of shearing forces in the deflection calculations.

For each of the 24 pieces, the two tests were performed, both of which differ only by the position of the element in the bending test, defined by the spin of the 90^o around the axis, as shown in Figure 2.

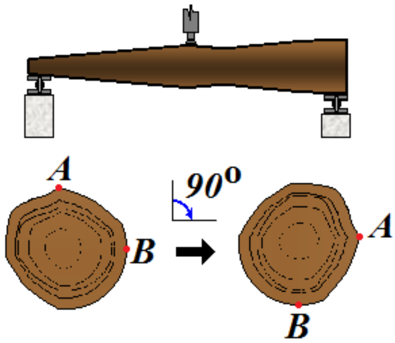

FIGURE 2.Change of element position on the bending test.

The choice of position of the element was done randomly, respecting only the ninety-degree rotation of the cross section. Without selection criteria, the round element was initially positioned in the bending test, and after obtaining the displacement of interest, the element was turned into the 90^o, consisting of the new position for the bending test.

In order to monitor the differences between the values of the modulus of elasticity calculated with and without changing the position of the element, statistical analysis of the confidence interval was used to test the difference between two means. Checking the statistical equivalence between the values of the longitudinal modulus of elasticity (E) and the longitudinal modulus of elasticity according to the rotation ($E_{90}{}^o$) is performed by means of Equation 3, where μ is the population mean of the differences, $\bar{x}_m$ is the arithmetic mean of the sample differences, n is the sample size, the S_m is sample standard deviation of the differences, and $t_{\alpha/2,n-1}$is the tabulated value for the distribution "t" of Student with n-1 degrees of freedom and significance level α.

$$\bar{x}_m - t_{\frac{\alpha}{2},n-1}\frac{S_m}{\sqrt{n}} \le \mu \le \bar{x}_m + t_{\frac{\alpha}{2},n-1}\frac{S_m}{\sqrt{n}} \tag{3}$$

RESULTS

The values of the longitudinal modulus of elasticity (E and $E_{90}{}^o$) obtained for the structural elements of *Eucalyptus citriodora* round wood are presented in Table 1.

TABLE 1.Elasticiy values obtained for the round timber.

Piece	E(MPa)	E_{90}°(MPa)	Piece	E(MPa)	E_{90}°(MPa)
1	20432	19373	**13**	21928	22886
2	21986	25318	**14**	19399	20967
3	19799	20981	**15**	19251	20665
4	20014	23108	**16**	16822	18322
5	17858	17020	**17**	16209	17146
6	19454	18935	**18**	19122	21508
7	18321	16416	**19**	19345	21262
8	21126	19350	**20**	15599	15971
9	21207	22159	**21**	16595	17994
10	16855	20557	**22**	18897	19090
11	15506	18205	**23**	16512	20926
12	20227	20723	**24**	16468	16876

The confidence interval between the values of E and E_{90}° is $434.90 \leq \mu \leq 1800.60$. As zero does not belong to the interval, it can be said that these are not statistically equivalent.

The linear regression between the elasticity values presented in Table 1 is illustrated in Figure 3, where the line adjustment $r(x) = 0.85 \cdot x + 3937.51$, with R^2 *coefficient* = 0.52.

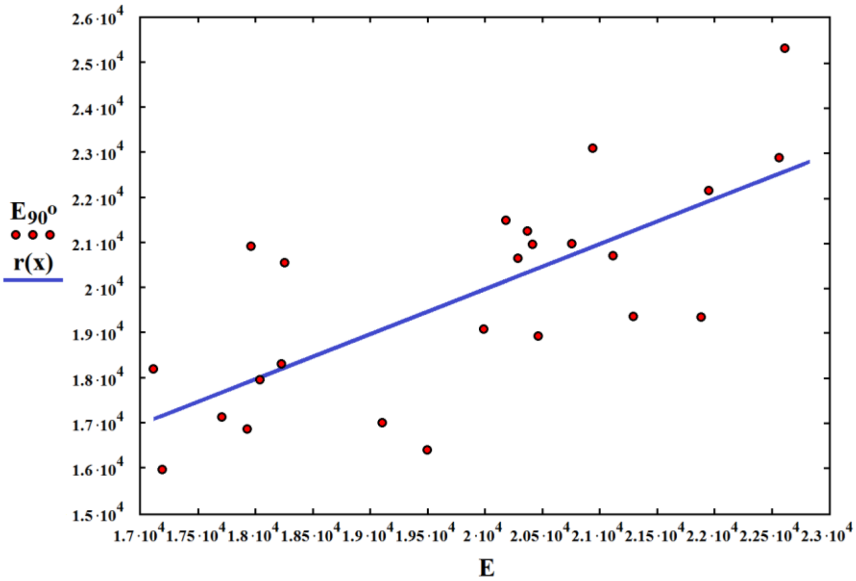

FIGURE 3. Linear regression.

CONCLUSIONS

The three-point bending model has been demonstrated to be easy to use, since the NBR 8457:1984 recommends the structural scheme of embedded beam in balance.

The consideration of the relation $L/D_{eq} > 21$ allowed acquisition of the longitudinal modulus of elasticity of cylindrical of round wood elements disregarding the effects of shear forces in the deflection calculations (Timoshenko's beam theory).

The restriction of small displacements allowed the development of non-destructive bending tests, presenting itself as an alternative for determining the modulus of elasticity in round elements of structural dimensions.

The results of statistical analysis for *Eucalyptus citriodora* elements revealed the non-equivalence found between the elasticity values obtained for the round elements with changes in their positions. Although this result applies only to wood elements evaluated here for safety and reliability, we suggest the modulus of elasticity to be obtained through the testing of elements in two different positions. The possibility of errors arising from the structure installation, for greater safety of the construction, indicates the choice of the lower elasticity values obtained from the static bending test.

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