Journal of the Brazilian Association of Agricultural Engineering
ISSN: 1809-4430 (on-line)

TECHNICAL PAPER

ELASTICITY MODULI IN ROUND WOODEN BEAMS OF *Pinus caribaea*

Doi:http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v36n3p566-570/2016

ANDRÉ L. ZANGIÁCOMO[1], ANDRÉ L. CHRISTOFORO[2], FRANCISCO A. R. LAHR[3]

ABSTRACT: This research aimed at estimating both longitudinal (*E*) and shear (*G*) elasticity moduli of round structural-sized beams made of *Pinus caribaea* timber, verifying thus the validity of the G = E/ 20 relationship established by the Brazilian standard ABNT NBR 7190: 1997 (Designing of Wooden Structures). We tested twenty pieces of green wood with average length, diameter and conicity of 750 cm, 30 cm and 4%, respectively. Two static bending tests were applied at three points of each piece, being nondestructive and using different distances between supports. In the first trial, the length and diameter relationship (L/ d) was set as being equal to 24; yet in the second test, it was set at 12. The elasticity moduli were estimated by a successive use of the Timoshenko beam theory equation, which takes into account the shearing stress effect on displacement calculations. The results of both longitudinal and shear moduli were related through the least square assessment method; thus, we could find a relationship of G = E/ 43. As a result, we observed that the tested wooden pieces are at odds with the Brazilian standards.

KEY WORDS: Stiffness, bending, beam theory, least square.

MÓDULOS DE ELASTICIDADE EM VIGAS ROLIÇAS DE MADEIRA *Pinus caribaea*

RESUMO: Este trabalho objetivou avaliar os valores dos módulos de elasticidade longitudinal (*E*) e transversal (*G*) em peças roliças estruturais de madeira *Pinus caribaea*, de maneira a se verificar a validade da relação *G=E/20* estabelecida pela norma brasileira ABNT NBR 7190:1997 (Projeto de Estruturas de Madeira). As vinte peças de madeira (verde) testadas apresentam comprimento médio de 750 cm, diâmetro médio de 30 cm e conicidade média de 4%. Foram realizados dois ensaios de flexão estática a três pontos por peça, conduzidos de forma não destrutiva, diferenciados apenas pelas distâncias entre os apoios. No primeiro ensaio, foi utilizada a relação (*L/d*) entre comprimento (*L*) e diâmetro (*d*) das peças igual a vinte e quatro; e, no segundo, realizado na sequência, com *L/d* igual a doze. Os módulos de elasticidade foram obtidos de acordo com o emprego sucessivo da equação da teoria de vigas de Timoshenko, que leva em consideração a influência dos esforços cisalhantes no cálculo dos deslocamentos. Os resultados obtidos entre os módulos de elasticidade longitudinal e transversal foram relacionados pelo método dos mínimos quadrados, sendo encontrada a relação *G=E/43*, evidenciando, para as peças de madeira aqui investigadas, a divergência de resultados para com a norma brasileira.

PALAVRAS-CHAVE: Rigidez, flexão, teoria de vigas, mínimos quadrados.

INTRODUCTION

As a natural material of great anatomical complexity and variability, timber has three symmetry axes (radial, tangential, and longitudinal); thus, an accurate estimate of its elastic parameters could be compromised. On the other hand, structural projects are carried out based on

[1] Engenheiro Civil, Prof. Doutor, Departamento de Engenharia (DEG), Universidade Federal de Lavras (UFLA) / Lavras – MG, Fone: (35) 3829-1481, andrezangiacomo@deg.ufla.br
[2] Engenheiro Civil, Prof. Doutor, Departamento de Engenharia Civil (DECiv), Universidade Federal de São carlos (UFSCar) / São Carlos – SP, christoforoal@yahoo.com.br
[3] Engenheiro Civil, Prof. Doutor, Departamento de Engenharia de Estruturas (SET), Escola de Engenharia de São Carlos, Universidade de São Paulo (EESC/USP) / São Carlos – SP, frocco@sc.usp.br
Recebido pelo Conselho Editorial em: 16/01/2013
Aprovado pelo Conselho Editorial em: 21/02/2016

equivalent mechanical properties. These properties are estimated via experimental tests, which are standardized by regulatory codes, and aim to quantify such variables regarding certain mechanical stress conditions.

The knowledge of longitudinal (E) and shear (G) elasticity moduli has great importance in a beam design, as well as other structural elements (ZANGIÁCOMO, 2007; CHRISTOFORO, 2011). In Brazil, wood bending is characterized in accordance with Brazilian standards as ABNT NBR 7190: 1997 (Designing of Wooden Structures), which recommends static bending tests at three points within a beam, using flawless small specimens. This determination consists of an empirical relationship for obtaining the shear modulus, knowing the longitudinal modulus, expressed by the equation G = E/ 20. It is noteworthy mention that national norms dealing with specifications for wood logs, which are commonly intended for power distribution poles, are over 20 years without any technical review (CHRISTOFORO et al., 2011). These norms specify, at ABNT NBR 1790:1197 standard, the mechanical properties of wood by testing in flawless small specimens; however, it is interesting to obtain strength and stiffness in pieces of structural dimensions.

In Brazil, researches on the characterization of wood pieces of structural dimensions follow methods and calculations recommended by international standards or even by the ABNT NBR 1790:1197 Brazilian standard adaptation for structural size pieces; among which, we may cite the studies developed by CARREIRA et al. (2010), BRITO & CALIL Jr. (2010) and CHRISTOFORO et al. (2012).

Nondestructive testing methods have been broadly employed in estimates of longitudinal elastic modulus for structural size wooden beams (MINÁ et al., 2008; SALES et al., 2011), among which ultrasound and transverse vibration should be highlighted by their ease and efficacy, once wood pieces can be used after test.

Regarding shear elasticity modulus (G), there are quite a few studies even for structural size beams or small specimens, among the studies found in literature, we may cite ROCCO LAHR (1983), BURDZIK & NKWERA (2002) and ZANGIÁCOMO & ROCCO LAHR (2008).

ROCCO LAHR (1983) evaluated the ratio of length and diameter (L/h) of lumber specimens responsible for decreasing significantly the effect of shear forces on displacement calculations. Therefore, estimates of longitudinal elasticity modulus (E) could be done through the Euler Bernoulli beam theory, considering only the existence of bending efforts (Equation 1):

$$E_m = \frac{F \cdot L^3}{48 \cdot \delta \cdot I} \tag{1}$$

where,

δ is the mean point displacement,

F is the applied load,

L is the span between supports,

E is the elasticity modulus, and,

I is the inertial moment of the cross section, using a static bending test at three different points without destruction.

Among others, the author concluded that for a proper use of the Equation 1, wood pieces must comply with the $L/h \geq 21$ relationship adopted by the Brazilian standard NBR 7190: 1997, for determining bending modulus and strength of specimens.

BURDZIK & NKWERA (2002) assessed longitudinal and shear elasticity moduli in beams made of *Eucalyptus grandis* timber by transverse wave vibration. Their results showed the feasibility of using this method to estimate elasticity moduli, showing consistent results when compared with wood properties arising in the standard document.

ZANGIÁCOMO & ROCCO LAHR (2008) studied the length and diameter relationship of round wooden beams, in which shear forces become negligible for displacement calculations, finding ratios of 12, 15 and 18 for *Pinus elliottii*, *Pinus caribaea* and *Corymbia citriodora*, respectively.

Broadly speaking, the tests in pieces of round wood or lumper of structural dimensions consist essentially of estimating longitudinal elasticity modulus. Therefore, with the help of the Brazilian standard NBR 7190: 1997 adapted for structural pieces, our study aimed to estimate the relationship between longitudinal (E) and shear (G) elasticity moduli in round beams made of *Pinus caribaea* timber, using a static bending test at three different points within each beam (nondestructively) and also applying the beam theory of Timoshenko. Thus, we could compare our results with the established Brazilian standard.

METHODS

The Ecological Station in Itirapina, São Paulo State Department of Environment, donated twenty round pieces of green timber made of *Pinus caribaea* wood (green-saturated). The pieces had an average of 750 cm length, 30 cm in diameter, density of 0.55 g/cm^3, and an average conicity of 4%.

The elasticity moduli (E and G) of the structural size pieces of wood were calculated based on the report of ROCCO LAHR (1983). In addition, three-point static bending tests were performed, which were run in the Laboratory of Timber and Timber Structures (LaMEM) of the Department of Structural Engineering (SET), in the College of Engineering of São Carlos (EESC/USP), São Paulo State, Brazil.

The elasticity moduli were achieved in physical and geometric linearity, with the largest displacement in the experiment restricted to a measure of L/200, as foreboded by the Brazilian standard NBR 7190: 1997 for a serviceability limit state.

Two bending tests were carried out for each round piece (Figure 1). In the first (Figure 1a), the relationship (L_1/d_1) was 24, respecting the ratio of $L/d \geq 15$ found by ZANGIÁCOMO & ROCCO LAHR (2008). In the second (Figure 1b), this relation (L_2/d_2) was 12. The lengths (L_1 and L_2), diameters (d_1 and d_2), which were measured at the force application point, as well as the applied forces (F_1 and F_2) responsible for displacements of $L_1/200$ and $L_2/200$ in the first and second trial were used in [eq. (2)], in which A represented the cross section area. Thus, it was generated a system of two equations and two unknowns, whose results provide the values of longitudinal and shear elasticity moduli.

$$E_m = \frac{F \cdot L^3}{48 \cdot \delta \cdot I} + \frac{28}{100} \cdot \frac{F \cdot L}{A \cdot G} \tag{2}$$

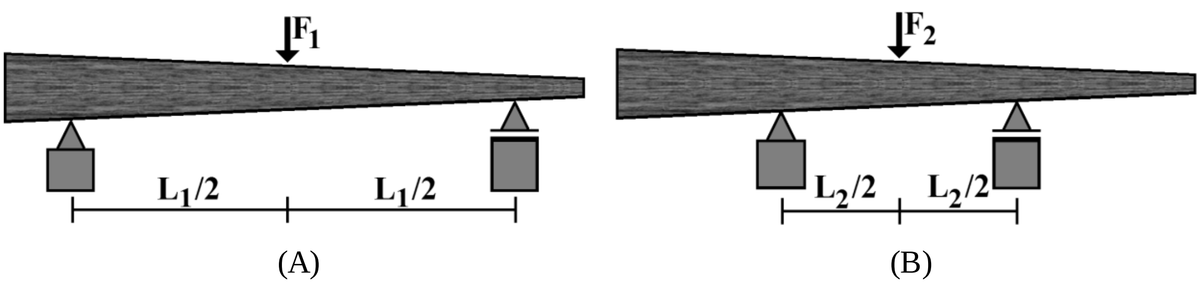

FIGURE 1. Schematic diagram of measurement of E and G moduli.

With the purpose of relating E and G values for the assessed round wood pieces, and further comparisons with the Brazilian standard ABNT NBR 7190:1997, we used the least square method, which is expressed in Equation 3 (CHRISTOFORO et al., 2011), wherein α is the coefficient fitted by the lowest residue method ($E = \alpha \cdot G$).

$$f(\alpha)=\frac{1}{2}\cdot\sum_{i=1}^{n}\left(E_i-\alpha\cdot G_i\right)^2 \qquad (3)$$

RESULTS AND DISCUSSION

Table 1 shows the mean values (X_m), standard deviations (SD), variation coefficients (VC) plus the maximum (Max) and minimum (Min) values of the longitudinal and shear elasticity moduli of round beams made of *Pinus caribaea* wood, which were estimated using [eq. (2)].

TABLE 1. Elasticity moduli (MPa) of round wooden beams.

Factor	E (MPa)	G (MPa)
X_m	9045	196
SD	1826	57
VC (%)	20	29
Min	6720	109
Max	13083	308

The coefficient α found by the least square criterion for the round wood pieces was 43, being 1.15 times higher than the relationship between *E* and *G* proposed by the Brazilian standard NBR 7190: 1997, providing a shear elastic modulus 53% lower than that estimated by this standard.

CONCLUSIONS

The relationships between longitudinal and shear elasticity moduli were significantly different from those established by the Brazilian standard NBR 7190: 1997. It might be explained by the structural size of the wood pieces. This result corroborates with the insertion of tests with structural size specimens into the Brazilian standards, so a more reliable measurement of wood stiffness could be obtained. It is worth mentioning that the beam theory used here is appropriate, and considering isotropic material is consistent with round wood in natural conditions (ZANGIÁCOMO and ROCCO LAHR, 2008). This way, our results reveal the need for further studies using a larger number of samples and timber species to evaluate and fit, if need be, the empirical relationship proposed by the Brazilian standard for shear elasticity modulus based on the longitudinal one.

REFERENCES

ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - **NBR 7190**. Projeto de estruturas de madeira. Rio de Janeiro, 1997.

BRITO, L. D.; CALIL JR., C. Manual de projeto and construção de estruturas com peças roliças de madeira de reflorestamento. **Cadernos de Engenharia de Estruturas**, São Carlos, v. 12, n. 56, p. 57-77, 2010.

BURDZIK, W. M. G.; NKWERA, P. D. Transverse vibration tests for prediction of stiffness and strength properties of full size Eucalyptus grandis. **Forest Products Journal**, Madison, v. 52, n. 6, p. 63-67, 2002.

CARREIRA, M. R.; SEGUNDINHO, P. G. A.; DIAS, A. A. Estimativa do módulo de elasticidade à flexão de toras de madeira por meio de vibração transversal livre. **Madeira, Arquitetura and Engenharia**, São Carlos, v.11, n.27, p.37-44, 2010.

CHRISTOFORO, A. L.; PANZERA, T. H.; BATISTA, F. B.; BORGES, P. H.; ROCCO, F. A. L.; FRANCO, C. F. The position effect of structural Eucalyptus round timber on the flexural modulus of elasticity. **Engenharia Agrícola**, Jaboticabal, v. 31, p. 1219-1225, 2011.

CHRISTOFORO, A. L.; ROCCO, F. A. L.; MORALES, E. A. M.; PANZERA, T. H.; BORGES, P. H. Numerical Evaluation of Longitudinal Modulus of Elasticity of Eucalyptus grandis Timber Beams. **International Journal of Agriculture and Forestry**, Rosemead, v. 2, p. 166-170, 2012.

MINÁ, A. J. S.; DIAS, A. A. Estacas de madeira para fundações de pontes de madeira. **Cadernos de Engenharia de Estruturas**, São Carlos, v. 10, p. 129-155-155, 2008.

ROCCO LAHR, F. A. **Sobre a determinação de propriedades de elasticidade da madeira**. Tese (Doutorado em Engenharia de Estruturas). 1983. 216p. Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 1983.

SALES, A.; CANDIAN, M.; CARDIN, V. S. Evaluation of the mechanical properties of Brazilian lumber (Goupia glabra) by nondestructive techniques. **Construction and Building Materials**, Washington, v. 25, n. 3, p. 1450-1454, 2011.

ZANGIÁCOMO, A. L. **Estudo de elementos estruturais roliços de madeira**. 2007. 136 f. Tese (Doutorado em Engenharia de Estruturas). Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 2007.

ZANGIÁCOMO. A. L; ROCCO LAHR, F. A. Avaliação do efeito do cisalhamento na flexão de elementos roliços da espécie Eucalyptus Citriodora. In: ENCONTRO BRASILEIRO EM MADEIRAS AND EM ESTRUTURAS DE MADEIRA, 9., 2008, Londrina. **Anais...**