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Contribution to the Development of a Method for Assessment of Modulus of Elasticity (E) of Timber Structures by Non-destructive Tests

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Abstract In restructuring and restoration of timber structures, it's necessary to evaluate the integrity of the structural elements, especially mechanical properties. For this study, two types of wood were used; a dicotyledonous - *Erisma sp* and a conifer - *Araucaria Augustifolia*. This study purposes an alternative methodology for determining the modulus of elasticity (E) with non-destructive tests in reduced samples. The proposed methodology helps in the productivity and execution of tests, respecting the parameters of the Brazilian standard NBR 7190:1997. The simple flexion tests in reduced models provide compatible values with the required by the Brazilian standard, being an additional tool to evaluate new and old structures.

Keywords Non-Destructive testing, Structural assessment, Timber structures

1. Introduction

Wood is one of the oldest construction materials [1]. However, the information about the integrity of structural elements, in the process of restoring a timber structure, is rarely available. The way to determine mechanical properties of the elements of a building can be a challenge for professionals, because the complexity of wood, which is biodegradable, hygroscopic and anisotropic. Obtaining this information can determinate the success of the intervention [1, 2]. Several studies have searched the determination of the modulus of elasticity (E) by non-destructive testing, in timber beams and as small specimens [3-9].

Visual inspection combined with a structural diagnosis of wood is a preliminary step in the process of preservation of assets. Principles for the conservation of historic timber structures were confirmed at the International Wood Committee, 1993 document of ICOMOS (International Council on Monuments and Sites), which recommends an accurate and thorough diagnosis of the causes and effects of degradation. A diagnosis should precede any intervention and should be grounded on documentary evidence from a site inspection and, if necessary, by determining the physical causes and nondestructive testing results [10].

The standard [11] establishes modification coefficients, which are responsible for adjusting the calculated resistance values as a function of some parameters that are not considered by the safety coefficient. These coefficients consider the class of the loading, humidity and quality of material used. These criteria require the designer to adopt more robust elements, which leaves less workable use of wood as a base less attractive, compared to other materials such as steel or concrete.

For flexion tests, the standard [11] suggests the use of a lot of raw material and a more complex processing, a factor that makes difficult the implementation of such tests. The test can be realized for two forms: 3 or 4 support points, with variable dimensions for the specimens [11-13].

The standard [12] recommends using specimens with large dimensions similar to real conditions of structural members to make visible the defects of wood. The standard [13] proposes the use of smaller specimens, which facilitates test execution.

The modification coefficients affect the design values of the properties of wood due to some parameters not covered. In the standard [11] the coefficient of $k_{mod,2}$ evaluates the humidity class and the type of material used in construction. For the purpose of this study the values of $k_{mod,2}$ range or vary from 0.8 to 1.0 according the humidity class, and for the complete saturation of the element must be considered the value 0.65.

The objective of this research is to present an alternative methodology to determine the modulus of elasticity (E) by non-destructive tests on specimens of small size and check the compatibility of the relationship suggested by the standard [11] when it comes to strength of the structural element when saturated.

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2. Materials and Methods

The experimental research was divided into four stages: (i) Making specimens with the chosen wood species; (ii) Preparation of specimens; (iii); Flexion test on reduced models and (iv) analysis of the results.

2.1. Material Selection and Preparation of Test Specimens

Two species of wood were used - *Erisma sp* and *Araucaria Augustifolia* – both C20 - the criteria to selection is chosen because their importance in local buildings. Six specimens were prepared for each specie. The dimensions were approximately 20.0 x 2.0 x 0.3 cm. The samples numbered from #1 to #6, were exposed at ambient condition, and the samples #1 $_{SAT}$ to #6$_{SAT}$ were saturated for 10 days.

2.2. Simple Flexion Test

For implementation of the simple flexion test, it was adopted the scheme presented in figure 1.

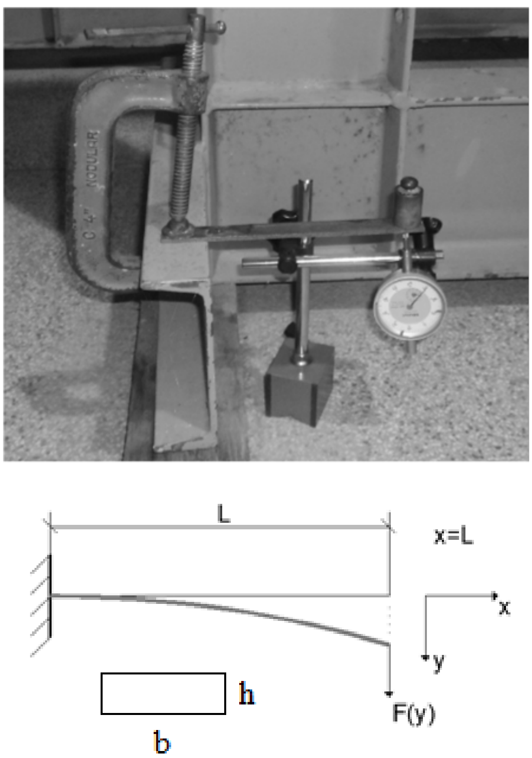

Figure 1. (1) Scheme for tests; (2) Diagram to obtain the elastic line equation and convention section adopted

To obtain the equation of the elastic line was considered only the displacement of the force applied at x = L in the general equation, therefore, we have the equation (1), the moment of inertia was calculated according to equation (2).

$$y = \frac{PL^3}{3EI} \tag{1}$$

Where: y is the vertical displacement; P is the applied load; L is the length of the beam; E is the modulus of elasticity of the material and; I is the inertia of the structural element.

$$Iz = \frac{bh^3}{12} \tag{2}$$

Where: Iz is the inertia of the element; b is the base and; h is the value assigned to the height of the section of the specimen.

Table 1. Results of the tests – *Erisma sp*

#	h (mm)	b (mm)	Iz (m^4)	y (mm)	E (GPa)	
Ambient conditions						
1	3,97	20,83	1,1E-10	2,91	12,06	
2	3,43	20,55	6,9E-11	4,16	13,25	
3	3,71	20,31	8,6E-11	2,62	16,83	14,03
4	4,17	19,59	1,2E-10	2,34	13,76	±1,63
5	4,27	19,68	1,3E-10	2,01	14,85	
6	3,94	19,68	1E-10	2,82	13,47	
Saturated						
#	h (mm)	b (mm)	Iz (m^4)	y(mm)	E (GPa)	
1$_{SAT}$	3,52	20,86	7,58E-11	4,98	10,09	
2$_{SAT}$	3,66	20,27	8,28E-11	4,35	10,58	
3$_{SAT}$	3,93	20,39	1,03E-10	3,23	11,44	11,58
4$_{SAT}$	4,08	19,55	1,11E-10	2,96	11,63	±1,42
5$_{SAT}$	4,41	19,65	1,40E-10	1,91	14,20	
6$_{SAT}$	3,68	19,67	8,17E-11	4,05	11,52	

Table 2. Results of the tests – *Araucaria Augustifolia*

CP	h (mm)	b (mm)	Iz (m^4)	y(mm)	E (GPa)	
Ambient conditions						
1	3,77	20,67	9,23E-11	2,83	13,39	
2	4,02	23,14	1,25E-10	2,05	13,63	
3	4,07	23,25	1,31E-10	2,64	10,15	13,28
4	4,00	20,96	1,12E-10	2,22	14,09	±1,57
5	4,07	20,97	1,18E-10	2,07	14,36	
6	4,38	20,75	1,45E-10	1,71	14,08	
Saturated						
CP	h (mm)	b (mm)	Iz (m^4)	y(mm)	E (GPa)	
1$_{SAT}$	4,13	23,18	1,36E-10	2,08	12,37	
2$_{SAT}$	3,42	23,19	7,73E-11	4,15	10,91	
3$_{SAT}$	4,07	20,42	1,15E-10	2,98	10,24	11,76
4$_{SAT}$	3,93	20,76	1,05E-10	2,39	13,95	±1,47
5$_{SAT}$	4,14	20,91	1,24E-10	2,23	12,70	
6$_{SAT}$	3,85	20,89	9,93E-11	3,39	10,40	

The axis of inertia was selected in order to emphasize the displacements, making them more visible. The length used was L=18 cm, to consider interference support during the test. To measure the displacement of the specimen it was used a dial comparator *Mitutoyo*, 12.5 mm with magnetic support. The dimensions were measured with a digital caliper with precision of a micrometer and an electronic balance with precision of 0.01g. The mass used was

199,80g - 1.96 N (using g = 9.81m/s²).

3. Results and Discussion

Table 1 and Table 2 presents the results of tests for the wood species selected.

The summary of the results obtained for comparison with the literature available are presented in Table 3.

Table 3. Comparison of the results obtained with the literature available

(1)	(2)	(3)	(4)	(5)	(6)
Specie	Ambient conditions	(I) (II)	Var. (%)*	Saturated	(5)/(2)
Araucaria Augustifolia	13,28	15,23	-12,77%	11,26	0,85
Erisma sp	14,03	13,23	+6,05%	11,85	0,84

Note: * Adopted the reference values described in [11] for the specie *Araucaria Augustifolia* and [14] for *Erisma sp*. *** Variation of results in relation to literature.

The results of this study are consistent when comparated with [14], which evaluated the modulus of elasticity (E) in determining the rigidity in compression parallel to the fibers for the species *Erisma sp. T*he variation 0.80 GPa or 6.05% compared to the results obtained in the mentioned research was verified. The same happened when it was analyzed the results of the species of Araucaria in the reference values contained in [11] standard, in which the variation of the modulus of elasticity was 1.95 GPa or 12.77%. The results indicated that the proposed methodology of this study is consistent with other studies in literature. However, it is worth mentioning that the variation in modulus of elasticity values may change according to their position in the tree trunk, from the center until the bark tree [15].

For other side, further analysis can be made from the specimens immersed for 10 days, which may be considered fully saturated. This new analysis consists in applying the coefficient of modification $k_{mod,2}$ = 0.65 to the saturated value, in order to obtain the value that would be that corresponding to the reference standard humidity, that, according to NBR 7190: 97, is 12% of equilibrium humidity. The tests realized in ambient humidity were not monitored, therefore, the ambient humidity and balance timber at the time of the tests was not known. So, this new analysis, the saturation reference value given by $k_{mod, 2}$ = 0.65 can discuss which ambient humidity the samples were indeed tested.

The results of this further analysis are shown in Table 4.

On table 5 can be observed that the percentage variation of the values assumed in the standard reference condition is greater than that observed in tests made at the humidity which was not known. The difference indicates that the equilibrium humidity of the tested species was above 12%, since the resulting values of the modulus of elasticity are lower than those obtained in this new analysis. Anyway, these results indicate the importance to realize tests in environments with known and controlled temperature, and also to determine the equilibrium humidity of the specimens at the time of the test.

Table 4. Estimates of the modulus of elasticity values for standard reference condition

Species	$k_{mod,2}$ (fixed)	E (GPa) Medium Saturated	E (GPa) Medium (U=12%)	E (GPa) Literature	Variation (%)
Araucaria Augustifolia	0.65	11,26	17,32	15,23	+13,72%
Erisma sp	0.65	11,85	18,23	13,23	+37,79%

In this proposed methodology, the axis of inertia of the selected specimen significantly influences the modulus of elasticity (E). The variation of 0.10 mm in specimen height implies a variation of 1.00 GPa in modulus of elasticity of the material. This methodology uses less material and does not require large equipment to benefit them and can be used in evaluations of new and existing structures. It is important to indicate the limitations of this research being the small number of specimens used and the influence of the variability of the dimensions in the results.

According the Brazilian standard [10] the factor responsible for considering the effect of saturation of the wood structural member is kmod, 2. For the specific case of fully saturated lumber it is suggested the relation: kmod, 2. = 0.65. This coefficient influences the mechanical properties, decreasing the strength and modulus of elasticity (E). According to the research [15] the value provided by standard [10] is an approach with conservatism, thus it can be improved. This fact helps to confirm the results obtained in this study as an alternative method, therefore it is possible to adopt individual coefficients for each species of wood in order to reduce the effects of decrease factor in structural design.

4. Conclusions

The conclusions of this research are:

(1) The simple flexion tests with loading on a bean with reduced models provides consistent values with those suggested by literature;

(2) The value of the resistance coefficient for saturated, according NBR 7190: 1997 is similar to values obtained experimentally;

(3) Tests carried out in environments with controlled and known temperature may provide more accurate results;

(4) The value of $k_{mod,2}$ for saturated situation recommended in NBR 7190: 97 may be conservative but is important to consider the great variety of wood species whose density and porosity can vary significantly;

(5) Other tests with different boundary conditions, all based on the equations of the elastic line from the theory of strength of materials must be made to give

reliability to the method; (6) The proposed methodology provides a tool to assist in the evaluation of new and existing structures by non-destructive testing.

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