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Introduction

This dissertation continues a research program on non-conventional building materials, which has been developed since 1979 at the Civil Engineering Department of the Pontifical Catholic University of Rio de Janeiro – PUC-Rio, under the leadership of Professor Khosrow Ghavami. Scientific research on bamboo, oriented towards its physical, mechanical and microstructural properties study, has fostered its large-scale use as an engineering material. Based on its performance, there is a growing interest to make it available in shapes more suitable to current structural applications. Previous studies on this topic Sulastiningsih & Nurwati, 2009; Mahdavi et al, 2012; Correal & Lopez, 2008; Liu & Yang et al, 2008 assessed bamboo laminated boards made of strips taken indiscriminately from along the culm. However, bamboo is an anisotropic material as its properties vary in all directions. This condition restricts the analysis via traditional solid mechanics theory, and transmits bamboo heterogeneity to the laminate composite. Based on a pattern of property variation, it is possible to suggest divisions along the longitudinal axis initially, then across the wall in order to obtain less heterogeneous segments. Based on this observation it is possible to obtain groups of segments with similar properties and simultaneously heterogeneous among them. Generally, the composite materials theory addresses laminated board analysis, in which layers orientation and bonding turn out to be significant factors. However, while unidirectional layers arrangement has commonly poor transverse properties, for bamboo subjected to bending loads, alignment of fibers parallel to grain has proven to be the best orientation (Ghavami & Marinho, 1990).

Lamination solves shape and some anisotropic issues of bamboo culm but also increases the cost, labor and equipment, which generate obstacles for local and decentralized production. Furthermore, variation of properties between different species requires considerable research for structural applications. This demands detailed investigation on local environments and restricts the use of worldwide information almost as benchmark only. The discriminate segments arrangement of strips on bamboo-laminated beams reduces the anisotropic variation. Moreover, stable properties of those segments leads to maintain strip properties into laminated beam. Table 1 presents tensile modulus of elasticity (E_t) and tensile strength (τ) obtained by different authors for different bamboo species.

Bamboo species and source	Et (GPa)	τ (MPa)
Bambusa blumeana (Liese 1985)	4,1	4,5
Dendrocalamus asper (Liese 1985)	6,3	5,4
Guadua angustifolia (Ghavami & Marinho 2003)	15,1	NA
Phyllostachya pubescens Eb (Chung & Yu 2002)	11,4	NA
Dendrocalamus giganteus (Guatibonza 2009)	11,3	3,7
Dendrocalamus giganteus (Culzoni 1985)	13,1	NA
Dendrocalamus giganteus (Ghavami & Marinho 2001)	17,5	3,5

Table 1 Tensile modulus of elasticity E_t and τ tensile strength of some bamboo species.

Table 2 presents results of the investigations carried out by several researches on laminated bamboo arrangements tensile modulus of elasticity and the shear strength subjected to four points bending specimens. They allow establishing a range of values for both variables despite being of different species.

Type and source	Bamboo species	Et (GPa)	τ (MPa)
Glued Laminated Guadua (Correal, Ramirez & Yamin 2009)	Guadua angustifolia	19,14	9,32
Glued laminated Timber (Liu, Yang, Dong & Jiang 2008)	Standard timber	9,70	NA
Laminated bamboo lumber H-Beam (Nugroho & Ando 2001)	Phyllostachys pubescens Mazel	10,10	NA
Laminated bamboo lumber V-Beam (Nugroho & Ando 2001)	Phyllostachys pubescens Mazel	11,57	NA
Bamboo and tallow fiberboard (Li 2004)	Phyllostachys pubescens	2,19	NA

Table 2 Bending modulus of elasticity E_b and tensile strength τ of some laminated wood arrangements.

Length and wall division arises as an alternative to produce bamboo-laminated beams, which could improve its bending properties by strips arrangement and their place of origin. This provides a deep characterization on local species *Dendrocalamus giganteus*. Bamboo has turned out to be a suitable structural material due to its mechanical properties, principally regarding its specific weight and energy consumption, as collated by Ghavami, see Table 3. Where σ_t is the tensile strength, γ is the specific weight and R relates σ_t over γ. Then relating R with R_{steel} results an efficiency strength-weight indicator and the last columns shows energy consumed and tensile strength over volume.

Material	σ_t [MPa]	γ [N/mm³x10⁻²]	R=(σ_t/γ)*10²	R/R_{steel}	MJ/m³*MPa
Steel	500	7,83	0,64	1,00	1500
Aluminium	304	2,70	1,13	1,76	240
Pig iron	281	7,20	0,39	0,61	80
Bamboo	140	0,80	1,75	2,73	30

Table 3 Relation between σ_t, γ and energy consumed and strength over volume of some construction materials (Ghavami, 1992).

Research on non-conventional materials involves interdisciplinary work oriented towards characterization, procedures establishment, structural elements production, environmental impact analysis, durability, performance and failure mechanisms assessment. This interaction involves the creation of parameters for research on non-conventional materials, including sustainability, strength and durability concepts.

1.1. Thesis objectives

It was carried out a segmented characterization as the culm was cut along the length (bottom, middle and top) and then those strips obtained by radial cut of cross section were divided across the wall thickness (inner and outer), theoretically properties of those segments will be less heterogeneous than whole culm. This fact allows introducing the solid mechanics theory to analyze segments and beam assembled exclusively by a type of them. This enables to link properties of strips with beam element and assemble elements according applied bending loads. This research project has the following objectives.

- Determine tensile modulus of elasticity of test specimens and bending modulus of elasticity of beams specimens.
- Relate mechanical properties of individual test specimens with beams elements.
- Suggest segments arrangement for bamboo-laminated beams assembly subjected to bending loads.
- Determine the viability and accuracy of solid mechanics theory analyzing the test results of bamboo-laminated beams.