EXPERIMENTAL DETERMINATION OF ALLOWABLE STRESSES FOR BAMBOO *Guadua angustifolia* kunth STRUCTURES

Patricia Luna[1,a *], Jorge Lozano[2,b], Caori Takeuchi[3,c], Mateo Gutierrez[4,d]

[1,2,4]Carrera 30 #45-03 Edificio 304 Instituto de Investigaciones Tecnológicas, Bogotá – Colombia

[3]Carrera 30 #45-03 Edificio 406 Oficina 301, Bogotá – Colombia

[a]plunat@unal.edu.co, [b]jelozanop@unal.edu.co, [c]cptakeuchit@unal.edu.co, [d]mateo_gg@hotmail.com
*corresponding author

KEYWORDS: Bamboo Guadua, characteristic value, allowable stresses.

Abstract. The earthquake on 1999 in Armenia city (Colombia) showed the good seismic performance of structures using bamboo guadua as main material but also the mistakes caused by improper techniques of construction and the lack of parameters design for this type of structures. This work presents the experimental methodology used for the determination of allowable stresses for the design of bamboo guadua structures, used in the project "Validation of *Guadua Angustifolia* as a structural material for design, by the allowable stresses methodology" financed by the Ministry of Agriculture and Rural development of Colombia (*Ministerio de Agricultura y Desarrollo Rural de Colombia*) and developed by National University of Colombia (*Universidad Nacional de Colombia*) since the year 2008 when there were no allowable stress design standards for this structures in Colombia. For the determination of the allowable stresses were carried out tests of samples in compression, tension, and shear parallel to the fiber, compression perpendicular of the fiber and bending beams with bamboo guadua from three different areas of Colombia. It was found also the flexural elastic modulus for the material.

Introduction

Nowadays, the use of bamboo guadua as structural material is limited due to the use of conventional and industrialized materials as concrete, steel and masonry and the absence of standardized and validated design parameters. In Colombia at 1998 the earthquake resistant building code [1], in chapter E-7 contemplates the use of bamboo guadua as essential material to the formation of bahareque walls; in 2001 it was published the ISO22165 [2] that gives some general parameters that must be taken into account for the design of bamboo structures; in 2006 in Colombia was published the NTC5407 [3] which makes a qualitative description of the different joints that can be used for bamboo guadua structures. None of the mentioned codes set values of allowable stresses for different loads necessary for the design of bamboo guadua structures.

Just in 2010 the bamboo guadua was recognized as structural material in Colombia being included in the new earthquake resistant building code [4], in chapter G.12, which sets the requirements for structural design for buildings using bamboo Guadua Angustifolia Kunth as the main material, being their use limited for structures with maximum height of two floors. Likewise presents values of allowable stresses for different loads, which were obtained from a bibliographic compilation of various research made in Colombia.

This paper presents the experimental methodology used for determining allowable stresses values, used in the project "Validation of *Guadua angustifolia* as a structural material for design, by the allowable stresses methodology" made by National University of Colombia (*Universidad Nacional de Colombia*).

Cut and identification of culms and specimens

In order to know the physical and mechanical properties of bamboo guadua for different regions of Colombia and not skew the results to a region in particular, the material used for the preparation of the samples comes from three areas of Colombia: department of Quindío (municipality of Circasia, Quimbaya and Montenegro), department of Cundinamarca (municipality of Pacho and Yacopí) and department of Valle del Cauca (municipality of Buga).

To know the exact origin of each specimens used in mechanical tests, was established a protocol for cut the culms and the specimens that includes the place of origin of the culm, part of bamboo guadua (bottom, middle or top) and internode number; the procedure is described below:

Step 0. Selection of bamboo guadua culms aged 3 and 6 years, which are suitable for the construction of structural elements [5]; this selection is made through the experience and knowledge of the material.
Step 1. Coding and marking of each culm selected using alphabetic characters to identify the plantation and numeric characters to identify the culm.
Step 2. Identification of the neck culm, which corresponds to the point between the rhizome and culm.
Step 3. Measure the diameter and length of the first five internodes.
Step 4. Cut off the culm.
Step 5. Counting and marking all the internodes.
Step 6. Culm division in three parts with 1.50m, 4.50m, 3.00m of length, that corresponds to bottom, middle and top of the guadua respectively. Transportation of the culms parts to Bogota.

When the culm parts came to Bogotá a second characterization was made, in order to know the exact origin of each specimen that would be use in the mechanical test. The procedure is described below:

Step 0: Identification of each part of the culm, according to the nomenclature used at the time of the bamboo guadua court, as well as the area of the country of origin. Similarly the part of the bamboo guadua belongs each part of the culm should identify: lower corresponds to bottom, medium corresponds to the middle part and superior corresponds to the top.
Step 1: Count of the number of internodes from each part of the culm.
Step 2: Measurement of two perpendicular diameters for the upper and lower culm transverse section, identified from the bamboo guadua sense growth.
Step 3: Measurement of four thicknesses for each cross section, in the same places where the diameter was measured.
Step 4: Marking and measuring each internode.
Step 5: Digitalization of information for internodes length and diameters for the development of schemes of cutting of each culm, where the position of each sample for the mechanical resistance determination to the different loads must be fully identified. The length of each sample follows the guidelines established in the Colombian Technical standard NTC5525 [6] and its distribution is performed randomly and according to the nomenclature shown in Figure 1.

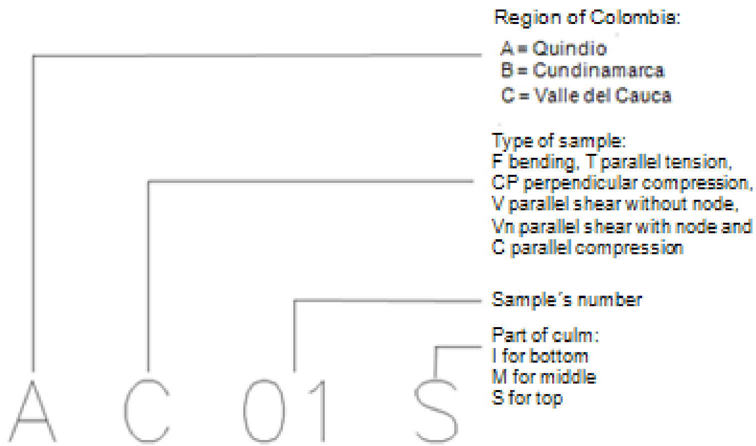

Figure 1 - Samples identification nomenclature

Step 6: Marking of each part of the culm according to the scheme of cutting carried out in the previous step, fully identifying each sample according to the presented nomenclature.
Step 7: Cutting each sample. The samples that will be used in the shear and parallel compression test must go through the process make that each end of specimen is perfectly at right angles to the length.
Step 8: Immersion of each sample in water for a minimum period of two weeks before each test, aimed to reduce the resistance of the material and design guides will give a conservative value of allowable stress for each solicitation.

Physical and mechanical test

Bending, compression, shear and tension parallel tests have followed the test parameters of the Colombian standard NTC5525. In addition to the mentioned tests, there were tests in compression perpendicular because of its importance for the sizing of requested items to bending structures of guadua, at the points where there are concentrated loads. Because this type of testing is not covered in national and international standards, was followed the procedure used in a research of Lamus [7]; they were tested, samples from the bottom, middle and top of the guadua culms, with a length of 17 cm without knot. After each mechanical testing, samples were taken to determine the moisture content at the time of the failure; these samples were extracted from regions close to the failure place of each test piece, and it's also followed the procedure written in the NTC5525.
Table 1 presents the total amount of samples tested by type of load; the shown values correspond to the sum of the samples tested for each area of the country. Bending tests from the bottom part of the culm were not carrying out because according to the guidelines set out in the NTC5525 the length of the culms to bending test should be 30 times the diameter of the culm, measure which surpasses the average length of the botton part of guadua culms.

Table 1 – Samples testes for each type of load

Guadua section	Bending	Parallel tensile	Parallel compression	Perpendicular compression	Parallel shear
Bottom	-	38	44	34	55
Middle	45	89	92	60	102
Top	44	84	91	60	106

Characteristics values and allowable stresses

Once all tests for each solicitation and subsequent statistical analysis for experimental results, were found allowable stresses using the equation of the ISO22156 [2], presented in Eq. 1 where σ_{admi} is the allowable stress, R_{ki} is the characteristic values calculated with Eq. 2, G is the modification factor for the difference between laboratory quality and practice (default value 0.5), D is the modification factor for duration of load (1.00 for dead load, 1.25 for dead load plus live load, and 1.50 for dead load plus live load and wind load), and S is the safety factor (default value 2.25).

$$\sigma_{admi} = R_{ki} \frac{G \times D}{S} \tag{1}$$

In Eq. 2 $R_{0.05}$ is the 5 percentile from the test data, s is the standard deviation from the test data, m the mean value from the test data and n is the number of test

$$R_{ki} = R_{0.05} \left(1 - \frac{2.7 \frac{s}{m}}{\sqrt{n}} \right) \tag{2}$$

The characteristics values are shown in Table 2 and allowable stresses values are shown in Table 3. Table 3 presents' values for different load conditions, A row for dead load, the B row for dead load plus live load and in the row C, for dead load plus live load plus wind or earthquake loads.

Table 2 – Characteristics values [MPa]

Bending	Parallel tensile	Parallel compression	Perpendicular compression	Parallel shear
37.4	40.7	20.3	1.7	3.5

Table 3 – Allowable stresses [MPa]

	Bending	Parallel tensile	Parallel compression	Perpendicular compression	Parallel shear
A	8.3	9.0	4.5	0.4	0.8
B	10.4	11.3	5.6	0.5	1.0
C	12.5	13.6	6.8	0.6	1.2

The differences among values shown in Tables 2 and 3 of this article and the values contained in the chapter G.12 of Colombian earthquake resistant code NSR10, are the result of the reduction factors worked, because the NSR10 works with different values of reduction for the characteristics values that depend on the type of load and to the status of perpendicular compression presented in NSR10, corresponding to internodes filled with cement wich increases the material strength. In addition, the values given in the NSR10 were determined for a moisture content of 12% and the moisture content average of the samples tested on this research was 90%.

Longitudinal Young´s modulus

In order to determine the longitudinal Young´s modulus of the material, in bending tests was measured the deflections of the culms at the center. The Table 4 presents the experimental results.

Tabla 4 - Longitudinal Young´s modulus (MPa)

Average modulus $E_{0.5}$	5 percentile modulus $E_{0.05}$	Minimum modulus E_{min}
13900	7800	3000

The modulus used for the analysis of structural elements should be the average modulus; in the case of the structure works under critical condition service, that require a higher level of security, the deflections should be calculated using the percentile 5 modulus. In any case, the choice of suitable young´s modulus depends of the criterion of the structural engineer and shall correspond to any of the values shown in Table 4.

The differences between the results shown in Table 4 with the values of Colombian standard NSR10 may be due to the lengths of the culms tested, but in the Colombian standard does not specify how were obtained the values.

Conclusions

It was presented the characteristic values and allowable stresses for different loads required for structural design of bamboo guadua structures. Differences between the values shown in this paper and the values of NSR10 are caused for the difference in the reduction factors for characteristic values. The authors hope to make a wide broadcast of the results with the objective of stimulate the used of bamboo guadua of quality, that satisfy the resistant parameters for the construction.

Acknowledgements

The authors are grateful for the financial support of the Ministry of Agriculture and Rural Development of Colombia (Ministerio de Agricultura y Desarrollo Rural de Colombia), as well as Arme ideas en guadua and the Colombian Society of bamboo (Sociedad Colombiana del Bambú) for advice on the selection, cutting and transport of material.

References

[1] Asociación Colombiana de Ingeniería Sísmica. Normas Colombianas de Diseño y Construcción Sismo Resistente. Bogotá: AIS, 1998 (NSR-98).
[2] International Organization for Standarization. Bamboo structural design. ISO, 2001 (ISO 22156).
[3] Instituto Colombiano de Normas Técnicas. Uniones de estructuras con Guadua Angustifolia Kunth. Bogotá: ICONTEC, 2006 (NTC5407).
[4] Asociación Colombiana de Ingeniería Sísmica. Normas Colombianas de Diseño y Construcción Sismo Resistente. Bogotá: AIS, 2010 (NSR-10).
[5] HIDALGO O. Bamboo the gift of the gods. 1 ed. Colombia: Editorial D'VINNI Ltda.; 2003.
[6] Instituto Colombiano de Normas Técnicas. Métodos de ensayo para determinar las propiedades físicas y mecánicas de la Guadua Angustifolia Kunth. Bogotá: ICONTEC, 2007 (NTC5525).
[7] LAMUS F. Calificación de una conexión viga-columna resistente a momento en Guadua Angustifolia [tesis de maestría]. Bogotá: Departamento de Ingeniería Civil y Agrícola, Facultad de Ingeniería, Universidad Nacional de Colombia; 2008.