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ANALYSIS OF PERPENDICULAR COMPRESSION RESISTANCE AND DETERMINATION OF THE CIRCUMFERENTIAL ELASTICITY MODULUS OF GUADUA ANGUSTIFOLIA KUNTH FROM THE MUNICIPALITY OF PITALITO

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ABSTRACT

The behavior of compression resistance perpendicular to the fiber of guadua bamboo test pieces was evaluated through an analysis of multifactorial variance (ANOVA). The samples object of studies came from four areas located in the municipality of Pitalito to the south of Huila department. They were tested at the Institute of Extension and Research (IEI) of the National University of Colombia in Bogotá. The 112 samples tested with compression perpendicular to the fiber obtained an average moisture content in the samples of the SA Group of 98.86% and in the samples of the SB Group of 113.51%, with standard deviations of 14.98% and 27.21% respectively. The analysis of multifactorial variance of Guadua angustifolia in relation to 3 factors (Area, Guadua Section, Saturation) through an experimental design, allowed to identify that the 3 factors and their interactions of first and second-order do not have significant effects on the resistance to perpendicular compression with a p-value higher than 0.05. The admissible effort to perpendicular compression was also found according to the procedure described in the Colombian Seismic-Resistant Standard (NSR-10), finding that for the SA Group's test pieces, this effort is of greater magnitude than the one described in the standard. Finally, the Circumferential Elasticity Moduli were found according to the procedure described by L.A. Torres & García, (2007).

Keywords: guadua angustifolia; perpendicular fiber compression; circumferential elasticity moduli; allowable stress.

1. INTRODUCTION

Guadua bamboo is considered by architects and builders as "Plant Steel" and is one of the most used materials in Colombia. It is a material of great use due to its versatility, availability, and excellent physical and mechanical properties.

Chavarro (2016) mentions that it is a plant material that stands out for its flexibility, resistance, economy and easy availability in some regions of the world, whose use in constructions is common. In this regard, there are national and international standards that present procedures for the evaluation of its resistance and deformation; factors that must be reviewed given the variability of the natural conditions in which the material is sustained.

The standards for determining the physical and mechanical properties of guadua bamboo are ISO 22157. Bamboo: Determination of Physical and Mechanical Properties on Bamboo (ISO, 2004), Test Methods to Determine the Physical and Mechanical Properties of Guadua angustifolia Kunth. NTC 5525 (ICONTEC, 2008) and chapter G.12 of the Colombian Earthquake Resistant Construction Regulations NSR-10 (Ministry of Environment, Housing and Territorial Development, 2010).

According to Reyes & Rayo (2014), the interest in Guadua angustifolia Kunth arose from the good structural response of the buildings constructed with elements of this material to the earthquakes that have affected the Colombian Coffee Growing Region. An example of this capacity are the facilities that have not collapsed despite multiple seismic activity.

According to Ramírez (2019), the analysis of the mechanical properties of guadua has frequently been made in the last decades. However, due to its morphology and the number of variables, mostly of an environmental nature, that influence its behavior and use in constructive processes of medium and great magnitude still generates uncertainty.

In spite of the importance of this natural element, few investigations have been advanced at a national level on stress to compression perpendicular to the fiber and some investigations carried out by different research entities and universities from the departments of Quindío, Risaralda, Caldas, Cundinamarca and Valle del Cauca, stand out as main contributors to the elaboration of chapter G.12 for structures. Another important research project is that carried out by Ardila (2013) to determine the resistance of guadua to perpendicular compression in the department of Tolima in the work entitled "Determination of the admissible stress values of Guadua angustifolia Kunth bamboo in the department of Tolima, Colombia".

In the project "Validation of guadua angustifolia as a structural material for design, by the admissible stress method" Universidad Nacional at Bogotá, the test to Compression Perpendicular to the fiber and determination of the Circumferential Elasticity Modulus was carried out (Lozano *et al.*, 2010), as well as that done by Pachecho (2006) called "Resistance to perpendicular traction to the Guadua angustifolia fiber".

With respect to regions of the country, an evaluation of the ultimate resistance to parallel and compression perpendicular to the fiber was carried out in Guadua angustifolia Kunth canutes filled with different mortars in Palmira (Gonzales, Giraldo & Torres, 2014).

In research on the behavior of the elements requested to be compressed, considering crushing and buckling as study criteria, reference values were established for resistance to these solicitations, for example, Uribe & Durán (2002) and Parada & Zambrano (2003). Jaramillo & Sanclemente (2003), studied the effect of the inclination of the structural elements that converge to a reinforcement connection, identifying failure mechanisms for each connection (Lamus, 2008).

1.1 Compression Perpendicular to the Fiber and Modulus of Circumferential Elasticity

Wood behaves as a group of elongated fibers. When exerting a pressure perpendicular to its longitudinal axis, its transversal sections will be crushed and, in effect, will suffer reduction in its dimensions under sufficiently high efforts (Sánchez, Gallardo & Delgado, 2018).

Sapuyes *et al*. (2018) state that Guadua angustifolia from the department of Huila, specifically from the municipalities of Pitalito and Timaná, presents favorable conditions in terms of ultimate bending strength and bending elasticity modulus.

1.2 Moisture Content

Guadua, like any other material of organic origin, presents particular conditions depending on its humidity content, starting with the difference in resistance to the different mechanical solicitations that it can experience throughout its useful life in a structure. (Ardila, 2013) The determination of the moisture content (CH) of Guadua angustifolia Kunth as a construction material is fundamental before its use in any project, since one of the main normative parameters for design depends on that. These are the coefficients of modification by moisture content that can affect admissible efforts and the elasticity modulus, depending on the type of solicitation a member is subjected to. (AIS, 2010).

According to Pilco (2016) on the physical properties of guadua, it can be highlighted that its drying and consequently, its humidity content are of fundamental importance since the sample is directly influenced in its mechanical properties, notably altering the results.

2. MATERIALS AND METHODS

In the southwest of Huila Department, an area of influence of the Colombian massif, the use of Guadua angustifolia kunth predominates; especially, in the municipality of Pitalito due to very favorable climate and soil conditions for its plant development.

Therefore, for the execution of this research project, 5 stages were proposed:

2.1 Selection of Sampling Sites

The selection of sampling sites was made following the Magna-Sirgas coordinates of Capera and Erazo in the study "Parallel compression resistance and elasticity modulus of the fiber of Guadua angustifolia kunth from the municipality of Pitalito", as it is observed in Table-1. For practical reasons, a letter was assigned to each plot or stand for their identification and differentiation. They will be referred to as Plots A, B, C and D.

Table-1. Location of the Pitalito plots.

Plot	Rural area	Latitude (N)	Longitude(O)	Altitude (m.a.s.l.)
A: La Dalia	Palmarito	1°47'13.80"	76°04'03.40"	1294
B: La Esperanza	San Francisco	1°50'06.00"	76°06'57.40"	1313
C: Villa Maria	Zanjones	1°50'26.11"	76°01'58.31"	1279
D: Yamboro	Aguadas	1°53'36.00"	76°05'25.10"	1331

2.2 Preparation and Cutting of Culms

The cutting of the stem was made approximately 1 meter above the neck of the guadua. The cutting was followed by the process of bleeding or vinegaring in the guadua stand (loss of moisture), for about 2 weeks. The cutting and harvesting permits were granted by the Agroforestry Company at the Pitalito-Huila headquarters. Once this process was finished, the stems were measured and marked in 3 longitudinal sections: Cepa (base or lower section) (1.5m), basa (midsection) (4.5m) and sobrebasa (upper thinner section) (3.0m). Afterwards, the diameter, thickness and length of the three sections of each guadua stem were measured and the name of the plot, culms, length and thickness of the sections were recorded in a format as indicated in the NTC5525 and NTC5300 standards.

In order to know the origin of the pieces used in the mechanical tests, which must include the place of origin of the culms, section of the guadua (cepa, basa or sobrebasa) and number of internodes (see Figure-1), a protocol for cutting culms and test pieces was established as shown below:

A	1	01	I
	b.	c.	d.

Where:

a. Plot of origin (A, B, C, and D)
b. Guadua number
c. Internode number
d. Guadua selection (B,M and U)

Figure-1. cepa, basa and sobrebasa measurement obtaining the test pieces.

The material was transported from the study area to the facilities of the Surcolombiana University, where the specimens obtained to perform the different mechanical tests were measured with a length of 17 cm without a knot and duly labeled. The area of origin, the type and number of tests done, as well as the relative position and degree of saturation of the specimen in a culm are indicated, as shown below:

A	Cp	01	I	(SA)
e.	f.	g.	h.	i.

Where:

e. Plot of origin
f. Mechanical property to be tested
g. Test piece number
h. Guadua selection (B,M and U)
i. Degree of saturation (SA Group, SB Group)

Then, the test pieces were cut and rectified (with sandpaper) to avoid errors in the tests. After this, the test pieces were submerged in water for two weeks to avoid cracking due to loss of humidity and transported to the facilities of the Institute of Extension and Research (IEI) of the College of Engineering of the National University of Colombia in Bogota. There, they were weighed on an electronic scale with an accuracy of 0.1 g, and were measured with a calibrator working with a precision of 0.1 mm in the following dimensions: 3 lengths, 3 external diameters and 3 internal diameters (not from the same end) and finally they were tested to Perpendicular Compression solicitations and Circumferential Elasticity Modulus, dividing the specimens in two groups: Group SA: Specimens taken out from water immersion 24 hours before the destructive test and Group SB: Specimens tested immediately after being taken out from water immersion.

2.3 Preparation of the Machine

The machine used for the compression test perpendicular to the fiber in guadua samples without knots was the AGX 300 KN SHIMADZU, belonging to the Research Institute of the College of Engineering of the National University of Colombia in Bogota. This machine has control parameters of automatic tuning in real time, based on test force data and measured deformation. It also has a load sensor ± 0.5% of accuracy with a guaranteed wide range from 1/1 to 1/500 of the maximum capacity, which helps to improve the efficiency of the tests due to multiple tests that can be performed without the need to change the load sensor and accessories. In addition, high-speed data sampling is up to 1 ms (1 kHz), which ensures no resistance changes are lost

2.4 Determination of Compression Resistance Perpendicular to the Fiber and Elasticity Moduli

The tests to determine the compression resistance perpendicular to the fiber (see Figure-2), Circumferential Elasticity Moduli and Moisture Content were carried out at the Institute for Testing and Research (IEI).

144 knotless test pieces were tested at maximum load to determine the ultimate Compression resistance Perpendicular to the Fiber and Circumferential Elasticity Modulus. Out of the 144 test pieces, 60 were from the SA Group and 84 from the SB Group. Taking into account that the characteristics of the test pieces vary according to the humidity of the environment, the measurements and weights of each one of them were taken a few hours before being tested.

Figure-2. Perpendicular-to-the-fiber compression resistance test.

The ultimate stress equation to Perpendicular Compression according to NSR 10 (Eq. G.12.8- 11) is:

$$\sigma_{ult} = \frac{3*D_e*F}{2*L*t^2}$$

Where

σult = Ultimate Effort to Perpendicular Compression. (Mpa)
De = Average external diameter of the test piece (mm).
L= Average length (mm).
F = Fault load (N).
t = Average wall thickness (mm)

ARPN Journal of Engineering and Applied Sciences

The Circumferential Elasticity Modulus was calculated with the following equation:

$$E\theta = \left[\frac{\pi R}{4A} + \frac{R^3}{I}\left(\frac{\pi}{4} - \frac{2}{\pi}\right)\right] * S$$

Where

R = Average radius of the test piece (cm).
A= Average area of the compressed section (Lxh), where L is the average length of the specimen and h is the average thickness (cm^2).
I= Inertia of the test piece I = π R^4/4 (〖cm〗 ^4)
S= Slope of the load vs. deflection curve (N) (Value given by the software of the testing machine).

2.5 Test to Determine the Moisture Content

Once the perpendicular-to-the-fiber compression resistance test and circumferential elasticity modulus of the test pieces were completed, their moisture content was determined with samples of guadua sheets of approximately 3 cm wide with the respective length of the specimen previously marked, specifying the name of the place, section and number. The value of each sample is weighed and recorded on a balance with an accuracy of 0.01 gr and stored in sealable bags specifying the time of weighing and date. Then they are taken to the oven at a temperature as established in the standard (103°C), as shown in Figure-3. After 24 hours, the samples are taken out from the oven and weighed. Then, they are taken back to the oven and monitored one hour later until the weight is constant.

Figure-3. Moisture content test.

The Moisture Content as described in NTC 5525 with the following equation:

$$CH\% = \frac{m - m_0}{m_0} * 100$$

Where
m = Mass of the test piece before drying, in gr
m0 = Mass of the test piece after drying, in gr

2.6 Analysis of Multifactorial Variance

In the analysis of multifactorial variance, 112 test pieces were evaluated. For the statistical analysis, a totally randomized multifactorial variance design was used, where the perpendicular-to-the-fiber compression resistance of the tested pieces were evaluated. The statistical analysis was developed by means of the software STATGRAPHICS CENTURION XVI.I; assuming normality, homocedasticity, and data independence as hypothesis.

2.7 Factors, Factor Levels and Dependent Variables

The dependent variable for the multifactorial ANOVA design is the compression resistance perpendicular to the fiber and the factors that can affect it are: the origin of the guadua, the section of the culm, and the degree of saturation in the test pieces. Each of the factors, factor levels and dependent variables are listed below in Table-2.

Table-2. Factors and factor levels, whose effects on compressive resistance were evaluated:

FACTOR	FACTOR LEVELS	DEPENDENT VARIABLE
Plot	LaDalia La Esperanza Villa Maria Yamboró	Perpendicular-to-the-fiber Compression resistance (Mpa)
Section	Lower Medium Upper	
Degree of Saturation	SA Group SB Group	

According to the above, the data of resistance to ultimate compression, diameter, wall thickness, Modulus of Circumferential Elasticity and Moisture Content were analyzed independently and in an exploratory manner in their totality, by factors and factor levels to determine if they corresponded to a normal distribution. Normality was verified through the analysis of asymmetry and kurtosis coefficients.

2.8 Characteristic Values and Allowable Stress

The characteristic values and allowable stresses were calculated based on the statistical information shown by the Star graphics Centuriun XV.I program. The data used for this purpose are: resistance to average compressive, the standard deviation, and the coefficient of variation.

The characteristic value in MPa for a given number of specimens is determined with the following equation (G.12.7.1 - NSR-10):

$$\boldsymbol{fkc} = \mathbf{f0.05i} * \left(1 - \left(\frac{2{,}7 * \left(\frac{s}{m}\right)}{\sqrt{n}}\right)\right)$$

Where:

f0.05i: Value corresponding to the 5th percentile of the data (MPa)
m: Average data value (MPa)
s: Standard deviation of the data
n: Number of tests (at least 20)

2.9 Allowable Stress

The equation below represents the calculation of allowable stresses, which is calculated after obtaining the characteristic value:

$$Fc\ adm = \left(\left(\frac{FC}{FS*FDC}\right) * fkc\right)$$

Where:

Fcadm: Characteristic value of the allowable stress at compression (MPa)
fkc: Characteristic value of compressive stress (MPa)
FC: Reduction factor due to differences between the conditions of the tests in the laboratory and the real conditions of application of the loads on the structures (1.0 according to NSR-10)
FS: Safety factor (1.8 according to NSR-10)
FDC: Load Duration Factor (1.2 according to NSR-10)

3. RESULTS AND DISCUSSIONS

The data corresponding to the geometry of the specimens obtained during the physical characterization, allowed to calculate the areas of the cross sections of each one of the specimens from the average diameters and thicknesses.

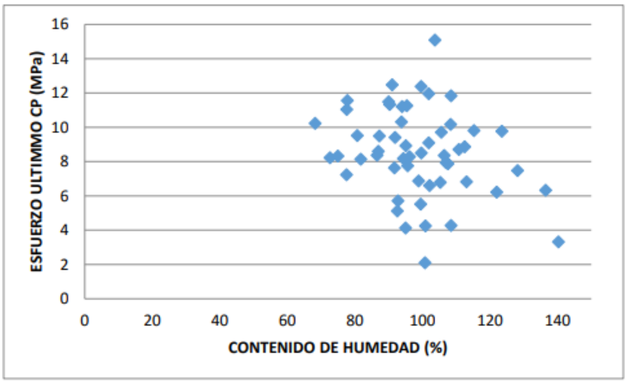
A decrease in diameter is observed along the section, being the lower part with a greater diameter and the upper part with a smaller diameter, situation that occurs naturally in guadua culms and can be appreciated during its growth and development. The smaller diameters were found in the specimens of Plot B (La Esperanza-San Francisco) with average diameters of 9.93cm, 8.42cm, 7.01cm of the Lower, Middle and Upper sections respectively. Also, in the works of Capera & Erazo (2012); Alarcon & Olarte (2013) carried out in Pitalito, it was found that the smaller average diameters correspond to the rural area of Esperanza-San Francisco. Plot C (Villa María-Zanjones) was the one that obtained the largest average diameters of 11.24 cm for the lower section, 10.22 cm for the middle section and 9.48 cm for the upper section. Also, in the work of Alarcón and Olarte 2013, it was found that Plot Villa María- Zanjones has the largest average diameters.

In the same way as in diameter, a decrease in wall thickness is observed in the guadua samples according to the section. The lower section has the highest average wall thickness and the upper section has the lowest wall thickness. This same trend was also found in the work of Capera & Erazo (2012) and Alarcón & Olarte (2013). The lowest average thickness was that of the specimens from Plot B (La Esperanza-San Francisco) with 1.58 cm lower section, 1.12 cm middle section, and 0.95 cm upper section. Moreover, in the work of Alarcón & Olarte (2013) it was found that the specimens from Plot la Esperanza-San Francisco are the ones with the lowest thickness. The Plot with the greatest average thickness was that of Sena Yamboró (Aguadas) with 1.85 cm lower section, 1.33 cm middle section and 1.07 cm upper section.

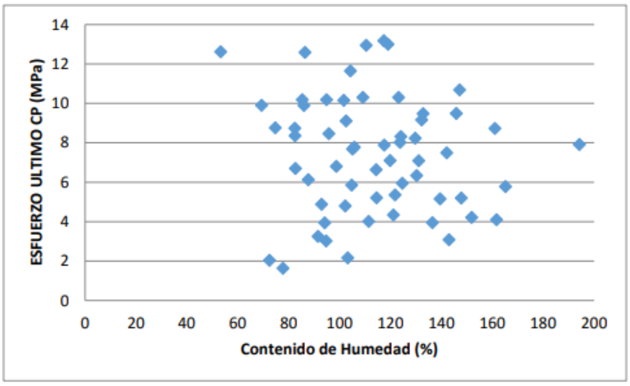
3.1 Perpendicular Compression Resistance vs Moisture Content

With the data of diameters and thickness, the ultimate stresses at perpendicular compression were calculated; also, moisture content values were obtained for all the specimens.

The Moisture Content of the SA Group and SB Group specimens at the time of the test showed a wide variation. The reason is the order in which they were crushed (one at a time), so that the longer exposure of some specimens to the action of air produced greater dehydration (Capera and Erazo, 2012). The descriptive analysis for the SA Group test pieces showed high values of %CH, due to the fact that in the days when the test pieces were tested, there were constant rainfalls.



Graph-1. Ultimate resistance to perpendicular compression test vs. humidity content, sa group test pieces.



Graph-2. Ultimate resistance test to perpendicular compression vs. humidity content, SB group test pieces.

Graphs -1 and -2 show that there is no relationship between the behavior of the resistance of guadua to perpendicular compression and the moisture content in a given range.

Characteristic values and allowable stresses were calculated after the statistical analysis of the results. With regard to the sampling sites, some parameters for physical characterization were generally identified.

Tables-3, -4, -5 and -6 below show the characteristic values and allowable stresses that were calculated based on the statistical information shown by the Star graphics Centuriun XV.I program. The data used for this purpose are: average compressive resistance, standard deviation and coefficient of variation.

Table-3. Characteristic values and allowable stresses for the 4 areas, SA group samples (%CH=98.86):

Statistical data	Lower	Middle	Upper	Total
Number of data (N)	15	20	18	53
Average (MPa)	8,51	8,36	8,64	8,50
Standard deviation (s)	3,08	2,10	2,69	2,56
Coefficient of Variation (%)	36,16	25,17	31,11	30,11
5th percentile (MPa)	3,45	4,90	4,22	4,29
Characteristic Value (MPa)	2,58	4,16	3,38	3,81
Allowable Stress (MPa)	1,19	1,93	1,56	1,76

Table-4. Characteristic values and allowable stresses for the 4 areas, group SB samples (%CH=113,51):

Statistical data	Lower	Middle	Upper	Total
Number of data (N)	12	26	21	59
Average (MPa)	8,90	7,26	6,7	7,39
Standard deviation (s)	2,87	2,94	2,88	2,96
Coefficient of Variation (%)	32,23	40,44	42,97	40,09
5th percentile (MPa)	4,18	2,43	1,96	2,52
Characteristic Value (MPa)	3,00	1,91	1,46	2,16
Allowable Stress (MPa)	1,39	0,88	0,68	1,00

Table-5. Characteristic values and allowable stresses for areas A, B, C and D, group SA samples (%CH=98,86):

Statistical data	Area A	Area B	Area C	Area D
Number of data (N)	14	9	14	16
Average (MPa)	8,46	8,05	7,51	9,65
Standard deviation (s)	2,80	2,46	2,48	2,20
Coefficient of Variation (%)	33,16	30,56	33,07	22,82
5th percentile (MPa)	3,84	4,00	3,42	6,03
Characteristic Value (MPa)	2,92	2,90	2,60	5,10
Allowable Stress (MPa)	1,35	1,34	1,20	2,36

ARPN Journal of Engineering and Applied Sciences

Table-6. Characteristic Values and Admissible Efforts for zones A, B, C and D, group SB samples (%CH= 113,51).

Statistical data	Area A	Area B	Area C	Area D
Number of data (N)	15	16	18	10
Average (MPa)	7,71	6,75	7,51	7,74
Standard deviation (s)	3,30	3,16	3,16	1,76
Coefficient of Variation (%)	42,73	46,89	42,09	22,75
5th percentile (MPa)	2,29	1,54	2,31	4,84
Characteristic Value (MPa)	1,61	1,05	1,69	3,90
Allowable Stress (MPa)	0,74	0,49	0,78	1,81

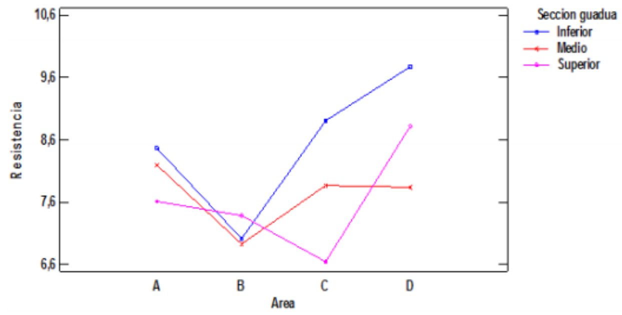
3.2 Multifactorial ANOVA (Resistance)

The analysis of multifactorial variance allowed identifying that none of the factors affects the variable of Perpendicular Compression Resistance in guadua with a 95% confidence level, due to the fact that p values are higher than 0.05. The result that the factor section does not affect the resistance to Perpendicular Compression can be validated by the results obtained from (Ardila and Cesar, 2013) in specimens with an average %CH of 83.60 from Tolima. On their result and analysis of the Perpendicular Compression test, they wrote "The results obtained show that there is not a great variation of resistance to Perpendicular Compression for each portion of guadua, so it is inferred that the distribution and concentration of the fibers in the longitudinal direction does not affect the resistance to Perpendicular Compression". This same result is also found in an article of Maderas, Ciencia y Tecnología published in 2014 by Patricia Luna, Jorge Lozano and Caori Takeuchi with percentages of CH higher than 80% in the test pieces.

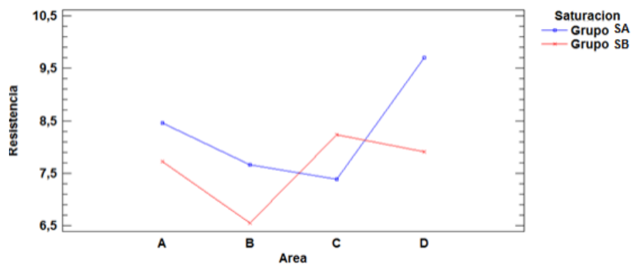
In the first-order interactions, it is observed that none of these significantly affects the variable of resistance to perpendicular compression; however, the second-order interaction (ABC) presents the value closest to p 0.05, which would mean that this interaction is the one that most affects the variable of resistance to perpendicular compression.

3.3 Effect of Interactions

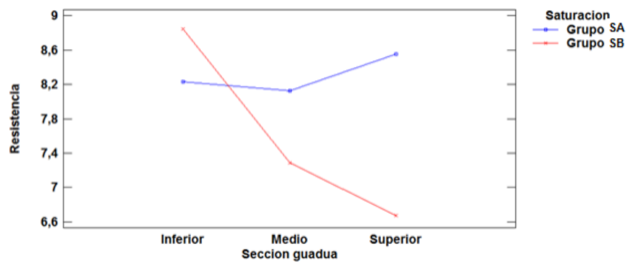
The effects of the combinations of two factors on the Compression resistance perpendicular to the fiber, in spite of not being significant, produce changes in the variable response as it is observed in the graphs of interactions of graphs -3, -4 and -5. For the case of the culms from areas A, C and D, greater resistance is observed in the lower section (Graph-3), a tendency that varies for the case of the medium and upper sections of the areas. In Graph-4, in most cases, greater resistance is observed in the SA Group specimens and in Graph-5, it is observed that similar efforts were obtained in each of the sections for the SA Group specimens; however, in the SB Group specimens, better resistance was obtained in the lower section.



Graph-3. Effect on perpendicular-to-the-fiber compression resistance of the interaction between the area and section factors.



Graph-4. Effect on perpendicular - to - the - fiber compression resistance of the interaction between zone and saturation state factors.



Graph-5. Effect on perpendicular - to - the - fiber compression resistance of the interactionbetween section and saturation state factors.

ARPN Journal of Engineering and Applied Sciences

3.4 Descriptive and Comparative Analysis for the Circumferential Modulus of Elasticity

The data analyzed for the Circumferential Elasticity Modulus by sections and total, in the 4 areas of the SA and SB Group test pieces, come from a normal distribution and confidence intervals are 95% for the mean Elasticity Modulus.

In addition, it was observed that with respect to the section, the Circumferential Elasticity Modulus by sections of the test pieces of the SA Group does not vary significantly in its value, the highest value being that of the middle section and the lowest value that of the upper part. Next, the descriptive analysis for the Circumferential Elasticity Modulus by sections of the SB Group's test pieces shows that it does not vary significantly in its value, being the highest value that of the lower section and the lowest value that of the middle section.

With respect to the degree of saturation, the value of the Circumferential Elasticity Modulus varies considerably, with the value of SA Group test pieces being the highest at 567.99 MPa. The difference in values between the average Modulus of Elasticity of the test pieces of the SA Group and those of the SB Group is 60%.

Table-7 shows that the SA Group samples (%CH=98.86) obtained an average and minimum value of the Circumferential Elasticity Modulus lower than that of Lamus (668.51 MPa) and higher than that of Lozano (564.06 MPa) and Torres (400 MPa). On the other hand, the SB Group test pieces (%CH=113.51) obtained the lowest average value with respect to the consulted authors.

Table-7. Results of the minimum and average values of the Circumferential Elasticity Modulus from different authors.

Author	Minimum value (Mpa)	Average value (Mpa)	%CH
Lamus	329,78	668,51	Less than 80%
Towers	-	400	-
Lozano	29,08	564,06	81,47
Lopez and Salcedo	98,54	567,99	98,86
Lopez and Salcedo	81,76	228,12	113,51

Source: Lamus Baez, Fabian. 2008, modified by the authors.

3.5 Comparative Analysis of Allowable Stresses for Perpendicular Compression

Table-8 shows that the highest allowable stress for perpendicular compression is that of the SA Group test pieces (CH=98.86%) of Pitalito (Huila). This Allowable Stress is only 0.7% (0.01Mpa) difference with respect to NSR-10, which indicates practically an equality between this value and that described in the Colombian Earthquake Resistance Standard. The other admissible stresses are below the 2010 Earthquake Resistant Standard.

Table-8. Results obtained (following the Colombian seismic-resistant regulation NSR10) of the allowable stress to compression perpendicular to Guadua fiber for different regions of Colombia.

Year	Author	Source	Test number	Fkc (MPa)	Fc (MPa)	%CH	*Fcm (Mpa) (%CH=12%)
2016	Lopez and Salcedo	Pitalito	59	2,16	1,00	113,51	0,80
2016	Lopez and Salcedo	Pitalito	53	3,81	1,76	98,86	1,41
2013	Ardila	Tolima	69	2,32	1,07	83,60	0,86
2010	NSR-10	N/A	>20	3,04	1,40	12,00	1,40
2010	MADRC Project	Quindi	47	3,01	1,38	73,84	0,49
		C/brand	50	1,33	0,61	93,86	0,49
		V/ Cauca	53	1,31	0,60	93,86	0,48

***Fcm:** Allowable Stress modified by Moisture Content (CH≥19%). The correction factor used was Cm=0.8, which is that indicated in regulation (NSR-10) in Chapter 12 (Wood and guadua bamboo structures), Table G 12 7-5, for Perpendicular Compression. Source: Ardila Cesar, 2013, modified by the authors

CONCLUSIONS

a) The diameter of the cross section in the culms decreases with height. The average for the four areas for the lower section was 10.84 cm, for the middle section 9.60 cm, and 8.41 cm for the upper section. Smaller diameters in culms were presented in Plot B (La Esperanza-San Francisco) and larger diameters in culms in Plot C (Villa María-Zanjones) in all three sections.

b) Wall thickness, as well as diameter, also decreases with the height of guadua bamboo. The lowest average value of thickness was that of specimens of Plot B (La Esperanza-San Francisco). The plot with the highest average thickness was that of (Sena Yamboró-Aguadas). The averages for the four areas for the lower, middle and upper section were 1.74cm, 1.20cm and 1.01cm respectively. The average value of Moisture Content for the SA Group test pieces for the four areas was 98.86%, with a minimum and maximum value of 68.25% and 140.28% respectively, and a standard deviation of 14.98%.

c) The average value of Moisture Content for the SB Group of the four areas was 113.51%, with a minimum and maximum value of 53.28% and 194.24% respectively, and a standard deviation of 27.21%.
d) The variation between factor levels for the zone factor is not significant on the variable resistance to Perpendicular Compression, with a p-value of 0.2694.
e) The section of the culm is not a determining factor in the resistance to Perpendicular Compression with a p-value of 0.4300. The lower section is the most resistant and does not differ significantly from the average values of the middle and upper sections.
f) The presence of saturation state in the test pieces with average % CH of 98.86 and 113.51 does not produce statistically significant effects on compression resistance perpendicular to the fiber with a p-value of 0.2243. The average value of the stress to Perpendicular Compression for specimens of SB Group and SA Group was 7.39 and 8.5 MPa respectively.
g) The effects of interactions between factors are not significant. The p-value for the interaction between area and section was 0.8049, for the section and saturation factors 0.2523, and for area and saturation 0.3827. The p-value for the interaction between Area, Section, and Saturation (ABC) was 0.0607 with the value closest to p=0.05.
h) The characteristic value for Perpendicular Compression for the four areas of test pieces Group SB and Group SA was 2.16 MPa and 3.81 MPa. The characteristic value of the Group 68 SA test pieces of 3.81 MPa was higher than that found by Lozano et al (2010), Ardila Cesar (2013) and the Colombian Earthquake Resistant Standard.
i) The modified Allowable Stress (%CH=12%) for Perpendicular Compression for the four plots of the SB Group and SA Group test pieces was 0.80 MPa and 1.41 MPa. The modified Allowable Stress of the Group SA test pieces of 1.41 MPa was higher than that found by Lozano et al (2010), Ardila Cesar (2013) and the Colombian Earthquake Resistance Standard.
j) The Modulus of Circumferential Elasticity (M.E.C.) for the four areas of test pieces of Group SB and Group SA was 228.12 MPa and 567.99 MPa. The specimens of the SA Group obtained an average C.E.M. value lower than that of Lamus (2008) and higher than that of Lozano et al (2010) and Torres (2007). On the other hand, the SB Group test pieces had an average C.E.M. value lower than that of Lamus (2008). Lozano et al (2010) and Torres (2007).

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