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ASSESSING MECHANICAL PROPERTIES FOR STRUCTURAL UTILIZATION OF GUADUA ANGUSTIFOLIA KUNT

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This research focuses on guadua cane, one of the most representative bamboo species in Colombia, Ecuador, and Peru. Its importance lies in the physical-mechanical characteristics of each cluster, which will be presented in the development of this research. The study includes results for different structural solicitations, such as compression, flexural, and tensile strength, characterizing it as a suitable material for use in construction, distinguishing itself from wood due to its rapid growth. This research work outlines the criteria used for the experimental analysis of the material. Laboratory tests are employed to determine the physical-mechanical characteristics of guadua bamboo, including compressive strength, flexural strength, material elasticity modulus, and natural moisture content. The resulting experimental values obtained through laboratory tests will be compared with the permissible values indicated by the Ecuadorian Construction Standard NEC–SE–GUADÚA. If the values are lower than the permissible ones, the permissible value is considered. This process allows the use of these results in the structural design of houses with guadua bamboo.

Keywords: Bamboo, Viability, Compression, Strength, Construction, Material.

1 INTRODUCTION

Guadua cane is one of the most representative bamboo species in Colombia, Ecuador, and Peru. Its significance lies in the physical-mechanical characteristics of each cluster, which will be presented in the development of this research (De Navas 2011). The study includes results for different structural material solicitations, such as compression, flexion, and tension, characterizing it as a suitable material for use in construction, distinguishing itself from wood due to its rapid growth. Various factors, such as age, soil type, geography, natural moisture, precipitation, among other variables, determine construction using this material. The criteria used for the development of the experimental analysis of the material are presented, employing the MTE INEN 2 standard. The results are considered a fundamental basis for designing a house with guadua cane. Finally, the discussion will focus on the results determining the influence of determining the physical and mechanical properties of guadua cane for its use as a structural material.

2 MATERIALS AND TESTS

The specimens of guadua cane used for the tests were Guadua Angustifolia, also known as "caña brava," one of the 44 native bamboo species distributed in the Ecuadorian territory. Through visual analysis, it was determined that the canes used for the tests were 3 to 5 years old, following the guidelines stipulated in the INEN 2-MTE standard, "*Laboratory Manual on Test Methods For The*

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Determination Of Physical And Mechanical Properties Of Bamboo." (INEN 2004).

The analysis involved taking initial weights, placing them in an oven for 24 hours, and recording the weight again in a dry state to determine the moisture content. This process was applied to 15 specimens, and a comparative tabulation will be conducted with values given in "THE STRUCTURAL ENGINEER" Technical Guide, authored by Sebastián Kaminski. The moisture content requirements for conducting compression, flexural, and tensile strength tests fall between 12% and 19%, based on the type of bamboo used in this document, as specified in the INEN 2-MTE standard. The fracture of guadua cane under compression, as shown in Figure 1, is not clearly explained, primarily occurring in practical cases due to fiber crushing. Studies suggest that results in this strength indicate guadua cane as a suitable construction material. However, failures in compression parallel to the fiber suggest potential catastrophic consequences when used as a structural material due to the loss of verticality, especially in the case of pillars and columns.



Figure 1. Compression test, PUCE laboratory experiments.

For the flexural strength test, three specimens were subjected to experimentation. These specimens were entire guadua canes, each approximately 3 meters in length. The testing procedure adhered to the guidelines outlined in the INEN 2, MTE standard. The calculation of the clear span of the specimen Eq. (1) was performed in accordance with the standard, aiming to prevent failure induced by transverse forces. This approach aligns with the methodology presented in the research work conducted by Vaessen and Janssen.

$$L=30*D \tag{1}$$

To assess the flexural strength, complete guadua canes were employed in a four-point bending test. This specific testing method is designed to reveal the resulting resistances for elements subjected to both dead and low live loads. It is particularly suitable for scenarios where deflection values are of minor significance, such as in secondary beams. Additionally, the same test specimens underwent evaluation to determine deformations, calculate material-specific modulus of elasticity, and establish the Poisson's ratio characteristic of the guadua material.

3 RESULTS AND DISCUSSION

The mechanical properties of a guadua cane section refer to those characteristics that define its ability to withstand changes in size or shape when subjected to forces per unit area. The notable

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advantage of guadua cane lies in its high strength-to-weight ratio, primarily attributed to the robustness of its walls and overall structural composition. The inherent flexibility of guadua throughout its entire length provides a significant advantage in absorbing impact forces. This quality becomes particularly advantageous when designing curved elements subjected to tension. The flexibility of guadua allows for the efficient absorption of impacts, enhancing its performance in dynamic conditions and making it a suitable material for applications where flexibility is a key consideration. See Table 1 for allowable stresses for any type of bamboo.

Table 1. Allowable stresses for any type of bamboo (Kaminski *et al.* 2016).

Characteristic Resistances for Design			
	Flexural Strength (N/mm2)	Tensile Strength (N/mm2)	Compression Strength (N/mm2)
Guadua Angustifolia	35-50	40	20
All bamboo species	30	40	20
Softwood, for Comparison	24	14	22

Guadua Angustifolia exhibits favorable characteristics for structural use, approaching the strength of woods with acceptable behavior in various structural applications, particularly in tension, flexion, and compression. However, it is essential to note certain limitations. The material performs well under stresses below 15 N/mm2 but demonstrates inadequacy when subjected to perpendicular tension forces, where wood significantly outperforms it. Additionally, guadua angustifolia shows unsatisfactory behavior when exposed to shear stresses, typically around 1.2 N/mm2, due to the inherent weakness of its walls in handling such solicitations. The material is not naturally designed to withstand tensile forces perpendicular to the fiber, given its cylindrical hollow structure.

To further illustrate the relationship between specimen-specific weight and the allowable tension strength, a direct proportional analysis was conducted. The comparative results are presented in the table below (Table 2).

Table 2. Comparative table of strength to weight ratio (Riera 1984).

Material	Allowable Tensile Strength (Kg/cm2)	Density (Kg/m3)	Strength-to-Weight Ratio
Guadua Cane	1400	650	2.15
Laminated Wood	400	500	0.8
Aluminum	1900	2700	0.7
Selected Wood	300	500	0.6
Steel	4400	7800	0.56
Common Wood	200	500	0.4

From the above relationships, we can observe that Guadua cane exhibits the highest strength-to-weight ratio, which provides an advantage in the construction field. However, being an

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unconventional material, these properties do not generate significant benefits. Finally, a resulting table was developed, in which the obtained values are compared with the characteristic values and the permissible values stipulated by NEC–SE–GUADÚA (Miduvi 2016). This allows the use of these results in the structural design of bamboo houses. In the event that the values are lower than the permissible ones, the permissible value is considered. See Table 3 and Table 4 below.

Table 3. Comparison of obtained results with characteristic and allowable results for compression.

Sample	Characteristic Compression Stress (Mpa)	Allowable Compression Stress (Mpa)	Obtained Compression Stress (Mpa)
1	20	14.00	36.64
2			36.15
3			30.74
4			38.15
5			28.65
6			38.16

Table 4. Comparison of obtained results with characteristic and allowable results for bending.

Sample	Characteristic Flexural Stress (Mpa)	Allowable Flexural Stress (Mpa)	Obtained Flexural Stress (Mpa)
1	35-50	15.00	41.4
2			47.44
3			41.66

4 CONCLUSIONS

Based on the results obtained from this research, the following conclusions are drawn regarding the influence of determining the physical-mechanical properties of Guadua Angustifolia in structural design:

- It was verified that the experimental results obtained through laboratory tests based on MTE INEN 2, for the determination of the physical-mechanical properties of bamboo, meet the requirements imposed by the NEC–SE–GUADÚA regulations. Therefore, the use of bamboo as a structural material is deemed acceptable.
- While it is true that in traditional construction systems of the last decade, such as concrete and steel, when their use aligns with earthquake-resistant design philosophy, structures demonstrate more than acceptable behavior in the event of an earthquake. It is important to clarify that these are not the only materials in the construction market. According to experimental results, bamboo can exhibit behavior similar to wood and steel. To the extent that in various parts of the world, it is known as "vegetable steel."
- Guadua bamboo is a material with surprising intrinsic properties, but this does not imply that it is sufficient to assume that its behavior is ideal in all structures. Just as concrete and steel are good construction materials, there is no doubt that poorly designed structures with these materials would result in a catastrophe, despite their effective behavior demonstrated in the laboratory. For this reason, a bamboo construction cannot rely solely on its physical-mechanical properties but must be based on a good design supported by construction codes or manuals.

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- Communities require a construction material that is strong, practical, and cost-effective to help provide safe and affordable housing. This largely untapped resource offers a climate-smart alternative, has minimal environmental impact, and is available in many low- and middle-income countries in tropical and subtropical regions where it grows naturally.
- Based on the experimental results, constructing a structure with this material would imply that it is highly flexible, resulting in a longer period compared to similar structures built with different materials. As a direct consequence, its response to ground accelerations during an earthquake is reduced. Unfortunately, this property also indicates that despite its flexibility, its behavior is not ductile. Excessive floor drifts could lead to brittle failures. Therefore, as stated in NEC-SE-GUADÚA, very tall structures are not recommended with this material

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