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Analysis of concrete beams with additional reinforcement of the bamboo splints

Análisis de vigas de hormigón con refuerzo adicional a la armadura de talas de bambú

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Abstract

The aim of this paper is to evaluate, through bending tests, the structural behavior of reinforced concrete beams additionally reinforced by bamboo splints. The bamboo splints are prepared from the stems of the Bambusa vulgaris species. To examine the strength of adhesion between the bamboo splint and concrete, pull out tests are performed for the specimens. The results of the pullout tests of the test samples show the strengthening of the nodes leading to an increase of the normal tension and rupture of splint and not its slip. According to the results of the bending beams, the presence of bamboo splints increases their load capacity when compared with the reference beams. This is indicative of a reduction in the amount of steel required as the structural element. The insertion of the bamboo splints in the beams provides a better performance in terms of the deflection and also leads to a slight increase in the load capacity of the beams. It is worth mentioning that the beams additionally reinforced by bamboo splints exhibit the same pattern of cracking as for reference beams.

Keywords: *Concrete beam, reinforcement with bamboo, structural analysis, alternative material*

Resumen

El objetivo de este trabajo fue evaluar, a través de ensayos de flexión, el comportamiento estructural de vigas de hormigón armado reforzadas por talas de bambú. Las talas de bambú fueron preparadas a partir de la especie *Bambusa vulgaris*. Para examinar la resistencia al arrancamiento entre las talas de bambú y el concreto, se realizaron ensayos en cuerpos de prueba. Los resultados de los ensayos de arrancamiento mostraron el fortalecimiento de los nudos, llevando a un aumento de la tensión normal y de la ruptura de la tala y no de su deslizamiento. De acuerdo con los resultados de las vigas en los ensayos de flexión, la presencia de talas de bambú aumenta su capacidad de carga en comparación con las vigas de referencia. Esto es indicativo de una reducción en la cantidad de acero necesaria como elemento estructural. La inserción de las talas de bambú en las vigas proporciona un mejor desempeño en términos de deflexión y también lleva a un ligero aumento en la capacidad de carga de las vigas. Es importante resaltar que las vigas adicionalmente reforzadas por talas de bambú exhiben el mismo patrón de fisuración que las vigas de referencia.

Palabras clave: Viga de hormigón, refuerzo con bambu, análisis estructural, material alternativo

1. Introduction

Bamboo has been studied and researched to be used as a concrete strengthening element, in order to find an alternative to steel reinforcement, traditionally used in civil construction, in view of the need to apply renewable and alternative materials to this sector that grows more and more each day.

According to (Ferreira, 2007), the ideal percentage of bamboo "reinforcement" depends on the type of structure, the distribution of the load, the final dimensioned load and the economic aspects related to obtaining the materials. The author states that the ideal percentage is between 1.25% and 8.33%.

Due to the organic and hygroscopic characteristics of bamboo and its smooth surface, (Ghavami, 2005) considers that such characteristics limit the adhesion between the materials and, consequently, their application. However, (Ghavami, 2005) states that bamboo is a material that has mechanical properties suitable for use in structural elements of reinforced concrete.

In a study of longitudinally reinforced concrete beams with steel and bamboo, (Lima et al., 2005) concluded that, because of the low modulus of elasticity of bamboo over steel, bamboo-reinforced beams deformed more than steel reinforced ones. In addition, it is possible to apply the usual sizing procedures used for reinforced concrete beams in bamboo-reinforced beams, since they all obey the Bernoulli-Kirchoff theory.

(Ghavami, 2005) performed beams with and without steel reinforcement, using two percentages of bamboo frame in relation to the cross section of the beam (3.33% and 5%). The author applied two layers of Negrolin® on the bamboo pieces, placing fine sand after passing the second layer of waterproofing material. This treatment of bamboo made it possible to increase the value of the tension of adhesion between the materials. Considering the results obtained, it was concluded that the ideal amount to be used as reinforcement of beams is a rate of 3% of bamboo, in relation to the concrete cross-section. Bamboo-reinforced beams withstand 400% more load than beams without any reinforcement.

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(Ferreira, 2002) rehearsed beams of steel armor made of bamboo in the natural state and of bamboo treated with varnish and wrapped with barbed wire in order to improve the adhesion between the materials. When analyzing the results, the author noticed that the bamboo presented a satisfactory structural behavior when inserted as a structural reinforcement in the concrete. It is noteworthy that, with the increase of 8 cm² of bamboo reinforcement, the rupture load quadrupled.

(Agarwal et al., 2014) made unreinforced beams, reinforced with steel, treated bamboo, and untreated bamboo. The percentage of reinforcement of samples with bamboo was 1.49%. The treatment of bamboo consisted of the application of Sikadur 32 Gel® and a layer of sand. The results of the bending tests showed that the reinforced beams with treated bamboo obtained a significant increase in the rupture force, being comparable to the steel. Quantitatively, with a treated bamboo reinforcement of only 1.5% there was a 29% increase in the resistant capacity. However, untreated beams presented worse results than non-reinforced beams.
Therefore, the present research evaluates the structural behavior of reinforced concrete beams additionally reinforced with bamboo splints, made from bamboo stems of the Bambusa vulgaris species, by conducting bending tests.

2. Material and methods

2.1. Dosing of concrete

The concrete dosage was based on the work by (Santos et al., 2010), which used the method proposed by (O'Reilly Díaz, 1998). The objective of this method was to obtain concrete with a minimum compressive strength of 25 MPa after completion of 28 days. The final dosage composition is shown in (Table1).

Table 1. *Final dosage composition of concrete*

Materials	Consumption (kg/m³)
Water	192
Cement	342
Sand	907.4
Gravel	1009.2
Relations	**Index**
Relation (1:m)	6.2
Content of dry mortar (%)	56.8
Volume ofmortar (%)	65.7
Water/Cement (W/C) ratio	0.6

Cylindrical test specimens measuring 15 cm in diameter and30 cm in height, densified using a vibrating table, were prepared to verify the characteristics of the concrete formed with the chosen dosage. The corresponding results are shown in (Table 2).

Table 2. *Mechanical properties of concrete after completion of 7 and 28 days.*

	Compressive strength on7th day (MPa)	Compressive strength on 28th day (MPa)	Modulus of elasticity on 28th day (MPa)	Splitting tensile strength on 28th day (MPa)	Water absorption on 28thday (%)
Concrete Reference Beams	16.6 ± 0.5	25.4 ± 0.5	31.5 ± 0.6	2.7 ± 0.2	5.2 ± 1.1
Concrete Reinforced Bamboo Beams	17.4 ± 0.1	26.3 ± 0.4	28.4 ± 1.5	3.0 ± 0.5	7.0 ± 0.1
Standards	NBR 5739 (ABNT, 2007)		NBR 8522 (ABNT, 2008)	NBR 7222 (ABNT, 2011)	NBR 9778 (ABNT, 2009)
Note: For maximum relative deviations > 6%, discrepant values and new averages were calculated as prescribed in item 3.6.4 of NBR 7215 (ABNT, 1997).					

2.2. Steel reinforcement

Cylindrical steel bars of 5 and 4.20 mm in diameters were used for forming the reinforcements for the beams. The bars were classified as class CA 60 (f_{yk} = 60 kN/cm^2). The characteristics of the steel bars are presented in (Table 3).

Table 3. *Geometric and mechanical characteristics of the steel bars [NBR 6892-1 (ABNT, 2013)]*

Diameter (mm)	Area (cm²)	Yieldstrength (MPa)*	Tensilestrength (MPa)	Modulus of elasticity (GPa)
4.20	0.138	694.9	769	189.4
5	0.196	592.8	690.3	168.5
*The yield strengthwas obtained graphically, considering a residual deformation of 2 per 1000.				

2.3. Bamboo splints

• Preparation of splints for the pullout test

Tenbamboosplints70 ×2 ×0.5 cm in size were prepared for the pullout tests. In each test, a 30cm long splint was immersed in the concrete used to fill the cylindrical specimens measuring 15 cm in diameter and 30 cm in height. Subsequently, the slabs were water proofed a latex immersion, and a total of four layers of latex was applied, corresponding to an increase of 0.15g of latex per cm² of the surface area of the splint. The latex was characterized and it was found to contain 41.7% rubber relative to the latex, with a pH of 11.

After the water proofing, grease was coated using a news paper and crepe tape, up to 5 cm from the two ends of the splint to be immerse in the concrete, leaving only 20 cm in the central part of the splint for the splint–concrete adhesion to occur. Thus, the adhering length was reduced from 30 to 20 cm with the aim of obtaining a lower pullout force and reducing the possibility of occurrence of rupture in the external node of the concrete specimen.

• Splints used in the concrete beams

For conducting the bending tests of the concrete beams, six bamboo splints with dimensions 160× 2 ×0.5 cm.

2.4. Elaboration of beams

In all, we constructed four beams of the following two types:

– Two steel reinforced-concrete beams that were used as reference, and are hereafter referred as reference beams;

– Two steel reinforced-concrete beams additionally reinforced with bamboo splints. These beams are hereafter defined as reinforced bamboo beams.

The percentage of the bamboo frame used in reference to the cross section of each beam was 1.6%, which was within the limit of 1.25 to 8.3% as stipulated by Raj (1991).

Four forms of plywood and plasticized wood, with dimensions 160 × 12.4 × 15 cm, were used for concreting of the beams.

For achieving longitudinal steel reinforcement on the lower face of the beams, two steel bars, each with a diameter of 5 mm were used; and on the upper face of the beam, two steel bars of 4.2 mm diameter were used as carriers. For shear reinforcement, stirrups with a diameter of 4.2 mm, spaced every 8 cm, were used with two vertical branches. To ensure a 1cm cover of the outermost reinforcement (in this case, the stirrup), spacers of the type EPR 24-4 were used.

To elaborate the reinforcement of the steel reinforced beams with additional reinforcement of bamboo splints, three splints were inserted done along the underside (centralized between the lower bars) and two along the lateral sides. The splints placed along the lateral sides were fixed at a distance of 1.5 cm relative to the bottom bar such that there were no problems during concreting.

Of the four beams produced, the main reinforcements of two of them were instrumented with extensometers (Figure 1). The two beams were a reference beam and a reinforced bamboo beam, which were used as additional reinforcement for the armature.

Figure 1. *Reinforcements of the steel reinforced beams with additional reinforcement of bamboo splints and instrumented with extensometers.*

Subsequently, all the beams were concreted and densified using a vibrating table. After at here day period, the beams were deformed and placed in a humid chamber where they remained for a period of 28 days.

It should be mentioned that before the concreting of the reinforced beams with the bamboo splints, an epoxy resin was applied at the ends of the splints to improve their anchoring ability in the supporting region.

2.5. Pullout tests on specimens

Ten test specimens were prepared using metallic molds with dimensions 15 cm in diameter and 30 cm in height. Five of these were reinforced at all nodes and five with reinforced splints in the nodes that were not in contact with the concrete. The splints were positioned in the center of the mold so that a part of their length was immersed inside the concrete used to fill it. The unmolding was achieved via an immersion vibrator. The unmolding was performed the day after the immersion and the specimens were placed in a humid chamber for 28 days.

After this period of time and before the arrangement test, the specimens were capped with gypsum, above which a metal plate was placed while the plaster was still in a plastic state. A kneecap was used to adjust the event of the test piece and, on top of it, to a rectangular metal plate, a uniform distributor or load from the test machine to the test sample.

The pullout tests were performed using a universal machine. The lower end of the splint, embodied within the specimen, was positioned below the central part of the test machine, while the other end, made up of the apparent bamboo, was secured by the grip on the upper part of the machine (Figure 2).

A comparator watch, used to measure the displacements, was positioned between the central and upper parts of the machine for measuring the elongation of the portion of the splint that was not immersed in the concrete.

The test was conducted with load increments of 50 kgf until the bamboo ruptured or slipped. After the pullout test, the specimens were sectioned longitudinally via the diametrical compression test, thereby allowing an analysis of the state of the slabs embedded in the concrete and of those which had slipped.

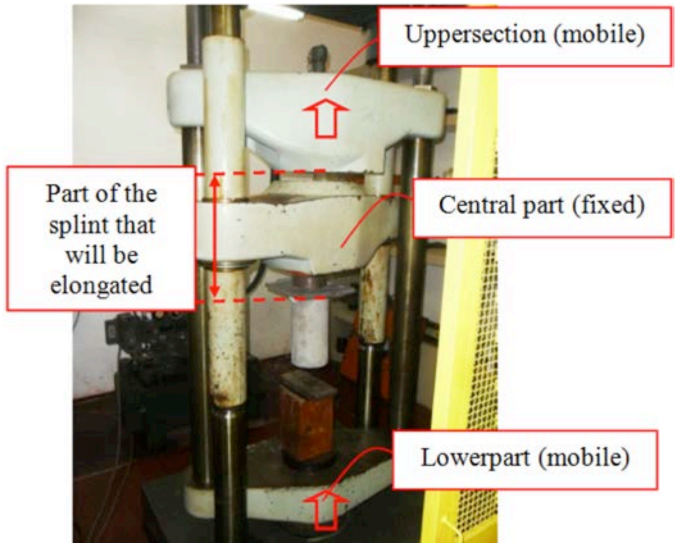

Figure 2. *Test sample positioned in the press for a pullout test.*

After the rupture of the splint or its slipping, adhesion and normal tensions were performed.

2.6. Bending tests of the beams

The static scheme used in the bending test is presented in (Figure 3). It is proposed that the central region mimics pure flexion.

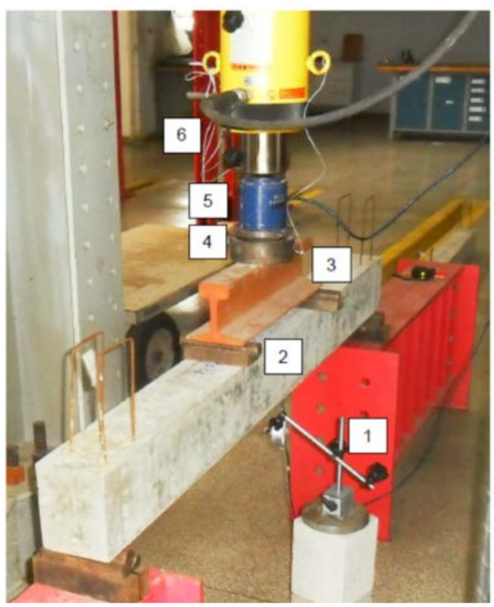

Figure 3. *Devices used in the bending test: 1) comparator watch, 2) roller, 3) metallic profile used to transfer the load to the beam at two points defining the central region, 4) patella, 5) load cell, and 6) hydraulic jack.*

The force is applied by a hydraulic actuator (or jack) coupled to a 30 tf load cell. A metal profile is used to distribute the force in the central span of the beam. A metal ball is placed between the load cell and metal profile, allowing the hydraulic cylinder to be accommodated owing to the possible imperfections in the profile surface. The vertical displacement in the middle region of the beam is measured via a dial indicator. The strain gauges, load cell, and comparator watch were connected to DAQbook 120 Data Acquisition System (Iotech) by interfacing with the DASYLab 5.0 program.

The beams were tested after28 days, during which a loading speed of 1kgf/s was applied. For the accommodation of the beams in the system and elimination of any slack between the devices, a loading cycle was performed, also known as a "primer." After the priming, the beams were loaded until no load gains could be observed by the hydraulic actuator or until the beam ruptured.

3. Results and discussions

3.1. Pullout tests on specimens

The normal tension and adhesion stress graphs corresponding to the pullout tests are shown in (Figure 4) and (Figure 5), respectively. The mean values of the normal stresses at the time of rupture (or slip) of the specimens with and without internal reinforcement of the bamboo splint nodes were 97 and 76.5 MPa, respectively, i.e., reinforcement of the internal nodes resulted in an increase of 28% of the normal stress.

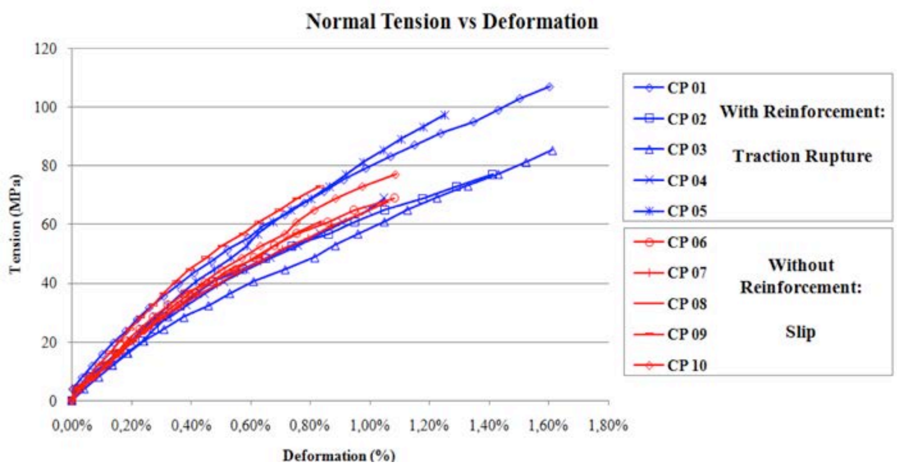

Figure 4. Pullout test: normal tension

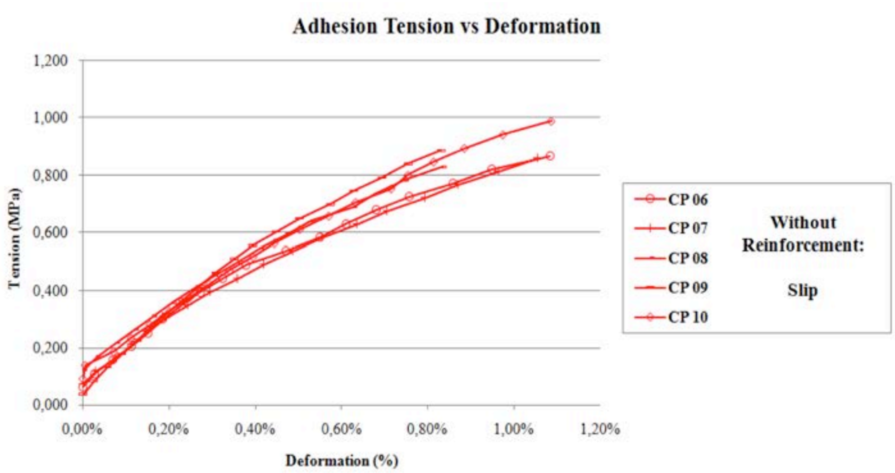

Figure 5. Pullout test: adhesion tension only for sliding specimens

The average value of the adhesion tension at the moment of slip for the specimens without internal reinforcement of the bamboo splint nodes was 0.9 MPa. For the specimens reinforced at all the nodes, tensile rupture was observed in the splints.

Considering the specimens reinforced at all the nodes, the following rupture forms were observed: for CP 01, the rupture occurred in the reinforced internal node; for CPs 02, 03, and 04, the rupture occurred in the reinforced external node after the detachment of the reinforcements; and for CP 05, the rupture of the splint was observed outside the nodal region, more specifically in the region of its attachment to the press clamp, although one of the reinforcements already showed a detachment.

3.2. Beam bending

The main parameters obtained by the beam bending tests are presented in (Figure 6) (Figure 7) (Figure 8) (Figure 9).

However, before discussing the results, it is important to mention that when a 6 mm deflection, corresponding to a deflection/span ratio of 1/250, is achieved in the middle of the beam, it is considered that the beam has reached a Serviceability Limit State in excessive visual displacement. In addition, to avoid causing possible damage to the measuring equipment during the test, the dial indicator was removed after an 8 mm deflection was reached.

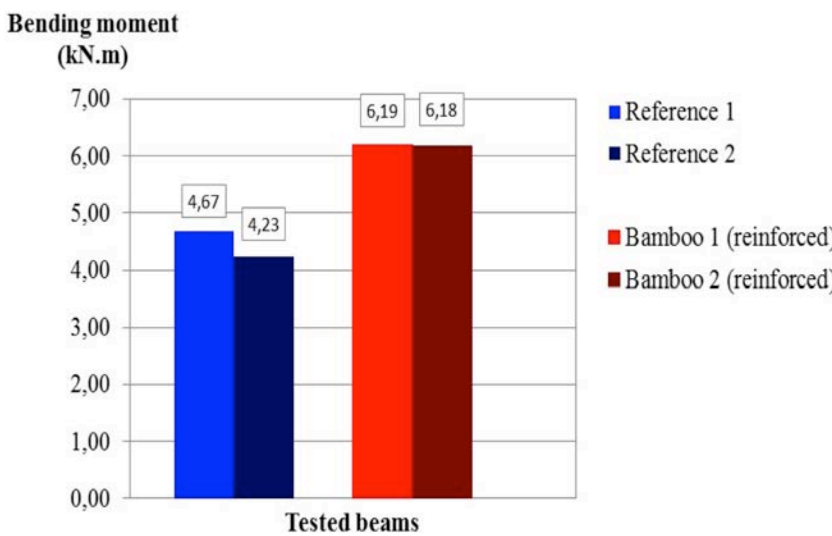

Figure 6. *Comparative graph of the maximum bending moment (rupture) supported for each beam tested.*

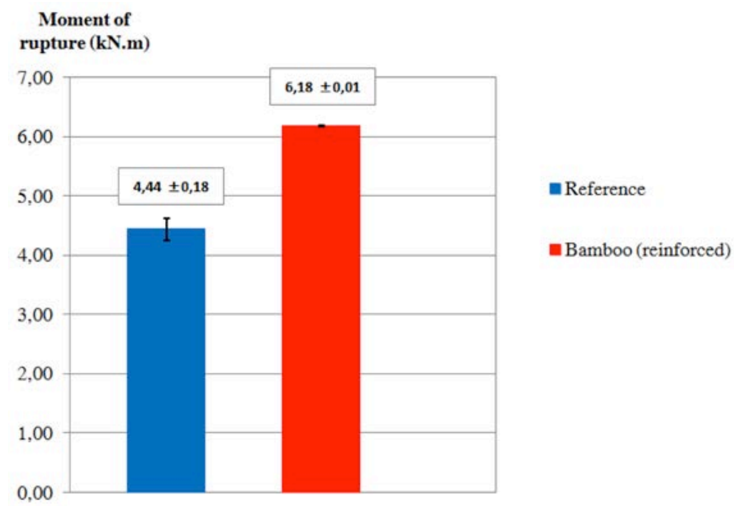

Figure 7. *Comparative graph of the mean values and deviations of the bending moment of rupture of the beams tested.*

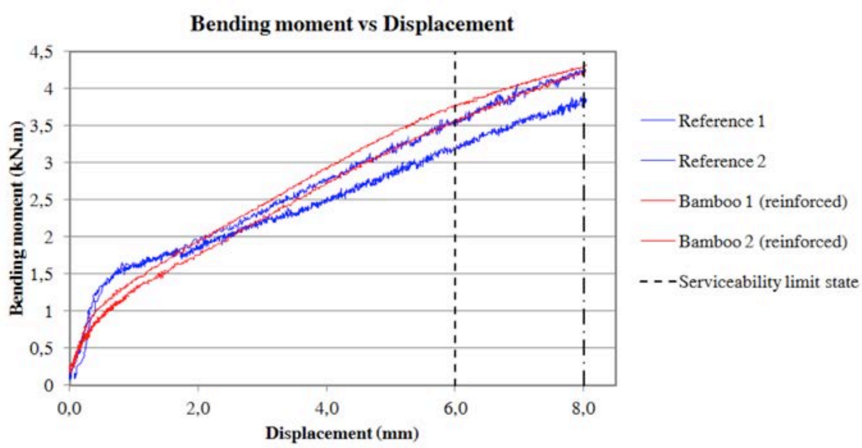

Figure 8. *Comparative graph of the variation of bending moment versus displacement (or deflection) of all the beams tested.*

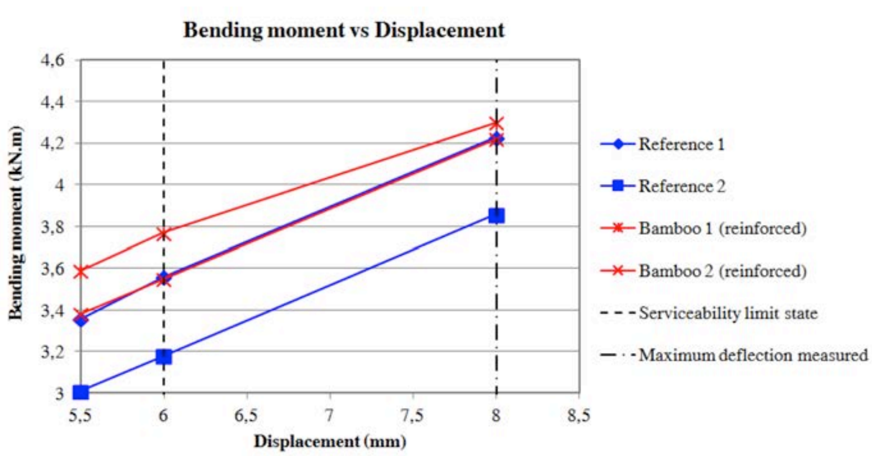

Figure 9. *Comparative graph of the variation of the bending moment versus displacement (or deflection) of all the beams tested between 6 and 8 mm deflections.*

The obtained results show that the additional reinforcement by bamboo splints waterproofed with latex causes a 39.4% increase in the resistance of the beam, suggesting that it can support a greater load than in the absence of the additional reinforcement.

With respect to the moment corresponding to a deflection of 6 mm in the middle of the beam (Serviceability Limit State), the presence of the reinforcement results in an increase of 8.9%. This suggests that the Serviceability Limit State would be reached first for the reference beam and only then for the reinforced bamboo beam. For a deflection of 8 mm, it is observed that the additional reinforcement provided by the bamboo splints causes an increase of 6.8%.

Regarding the beginning of the cracking, the effect of bamboo is not favorable because the cracking time for the reinforced bamboo beam is12.4% lower than that of the reference. It can be observed that the deflection at which cracking occurs is practically the same.

The deformations in the concrete, the lower longitudinal reinforcement, and the bamboo splints were evaluated via extensometers positioned in the middle of the beam. (Figure 10) and (Figure 11) present the data obtained through the extensometers present in the reference and reinforced bamboo beams, respectively.

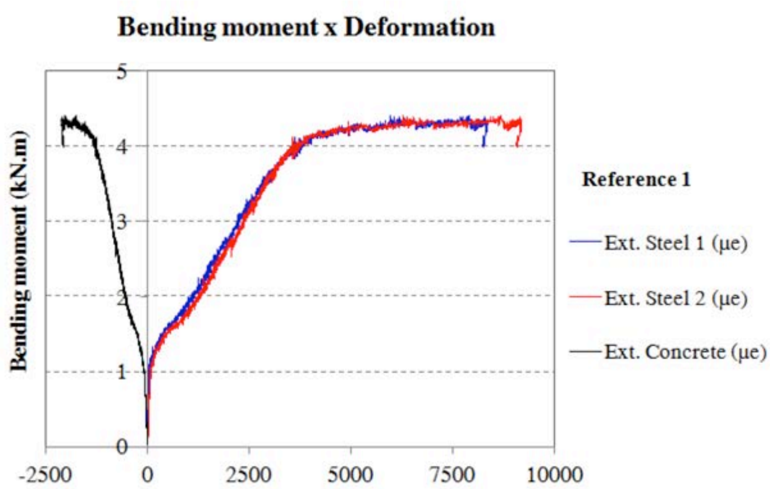

Figure 10. *Data from the extensometers positioned in reference beam 1*

In the case of reference beam 1, for the traction reinforcement in the situation corresponding to the last bending moment, a typical flow level is observed with deformations above 8 per thousand.

The concrete exhibits a linear behavior and only near the rupture a sudden elevation of the neutral line occurs, and consequently, there is a reduction in the compressed concrete area and in its crushing. Before the crushing began, the deformation in the concrete was 1.25 per thousand.

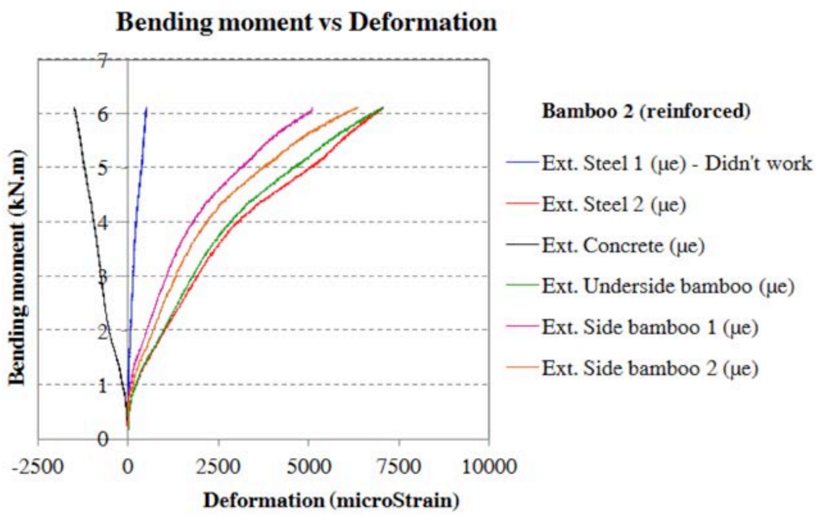

Figure 11. *Data from the extensometers fixed in reinforced bamboo beam2*

In reinforced bamboo beam2, the deformation in the concrete is 1.5 per thousand. In steel, however, it is above 7.2per thousand, which almost coincides with the deformation of the bamboo positioned on the underside of the beam, which shows that the bamboo was well adhered to the concrete.

The lateral bamboo undergoes a deformation of 5.2 per thousand, a value that is coherent as the position of its center of gravity is above the lower bamboo (and steel).

Thus, owing to the fact that the bamboo absorbs part of the tensile stress, the deformation in the steel might be smaller. For reinforcement, a well-defined flow threshold is not observed as in reference beam1; however, plastification starts. Furthermore, what is observed is the crushing of the concrete resulting from the ascent of the neutral line with a deformation in the concrete that is larger than that of reference beam 2 because of the resulting increased strength of the compressed concrete to balance the resultant tensile provided by the steel reinforcement and bamboo.

3.3. Cracking pattern of beams

(Figure 12) and (Figure 13) show the behavior of the reference and reinforced bamboo beams in relation to the cracking pattern.

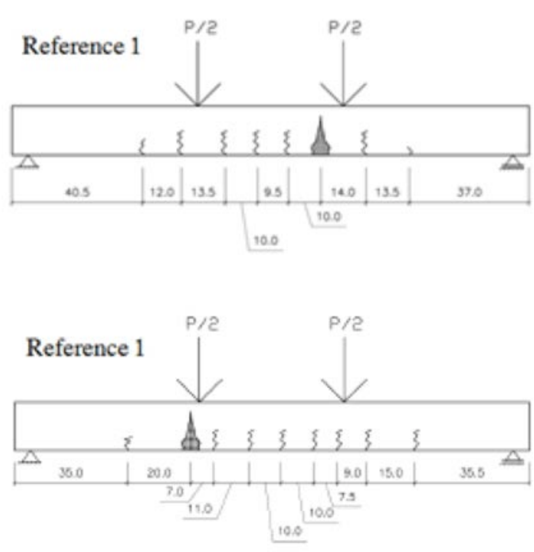

Figure 12. Cracking of reference beams1 and 2 measured in centimeters.

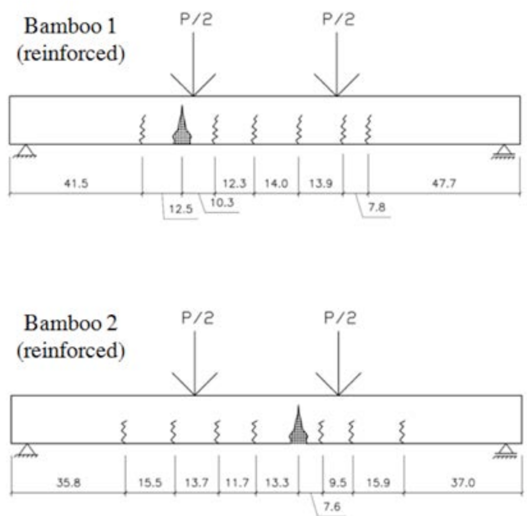

Figure 13. Cracking of reinforced bamboo beams 1 and 2 measured in centimeters.

It is possible to verify that the rupture of the beams occurs in the central region, as expected, precisely in the region submitted to the largest bending moments. Apparently, the cracking pattern is basically the same for all the beams tested.

4. Final considerations

Bamboo is a renewable, perennial and tropical plant, and that presents a number of advantages, such as: growth quickly, high mechanical resistance, versatility, beauty, and does not require the replanting of culms. Certainly it is clear that bamboo is a great potential material for various industries, especially construction, where it has been used since ancient times. Therefore, the pullout tests showed that the reinforcement at the nodes of the bamboo splints resulted in a 28% increase in normal tension (76.5 to 97 MPa), causing the splint to rupture and not slip. The average value of the adhesion tension observed for the non-reinforced steels was 0.9 MPa.

The bending tests of the beams verified that:

- *The placement of the bamboo splints increased the strength of the beams by 39.4%;*
- *The insertion of the bamboo splints in the beams (1.6% bamboo rate in relation to the cross-section of the beam) resulted in a slight improvement in their serviceability;*
- *The inclusion of the splints in the beams induced cracking at smaller load. It is noteworthy that for both the reference and reinforced bamboo beams, the cracking time was low and the deflection at which cracking occurred was also very small;*
- *Beams ruptured in the central region, where the bending moment was maximum a significant change in the cracking pattern of the beams was not noticed;*
- *The reinforced bamboo beams showed that for the maximum deflection measured before the comparator watch was removed, the modulus of elasticity was equal to 7.5 GPa.*

Thus, it can be concluded that additional reinforcement with a bamboo increased the resistance of the beams, indicating a possibility in the reduction in the amount of steel required to be used as the structural element.

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