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SUSTITUCIÓN DEL HORMIGÓN ARMADO POR BAMBÚ EN VIVIENDAS SOCIALES EN ECUADOR, USANDO CONEXIONES RESISTENTES A MOMENTO

REPLACEMENT OF REINFORCED CONCRETE BY BAMBOO IN SOCIAL DWELLINGS IN ECUADOR, USING MOMENT CONNECTIONS

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RESUMEN

Este artículo de investigación se basa en un tema de tesis desarrollado en Ecuador, cuyo objetivo principal era reemplazar las casas sociales construidas en hormigón armado con bambú para disminuir los costos de construcción y colaborar con el medio ambiente. Normalmente, los nodos estructurales para edificios de bambú se consideran anclados entre vigas y columnas de acuerdo con el análisis estructural normativo, sin embargo, en la construcción, los nodos presentan una continuidad, debido al uso de hormigón o mortero dentro de los elementos de bambú, y también, acero de refuerzo. En esta investigación, se simuló un modelo analítico para un tipo de nodo con el fin de demostrar la transferencia de los momentos de flexión, y también demostró la viabilidad de la sustitución del concreto reforzado por bambú en hogares sociales en Ecuador. Los resultados indicaron que todos los nodos transmiten momentos de flexión.

Palabras clave: *edificaciones en bambú; conexiones en bambú; nodos en bambú; juntas en bambú*

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ABSTRACT

This research article is based on a theses theme developed in Ecuador, which main objective was to replace social houses built in reinforced concrete with bamboo in order to decrease construction costs and to be collaborative with environment. Normally, structural nodes for bamboo buildings are considered pinned between beams and columns according to structural analysis normative, but nevertheless, in construction, nodes present kind of continuity, due to the use of concrete or mortar inside the bamboo elements, also, reinforcing steel. In this research, an analytical model for one kind of node were simulated in order to demonstrate the bending moments transfer, and also, demonstrated the viability of the substitution of the reinforced concrete by bamboo in social dwellings in Ecuador. Results indicate that all joints transmit bending moments.

Keywords: *bamboo buildings; bamboo connections; bamboo nodes; bamboo joints*

1. INTRODUCTION

Construction in bamboo is nowadays rather common, especially in Latin American countries as Venezuela, Colombia, Ecuador, Brazil and Perú [1] [2] [3] [4]. In Ecuador, a proposal for decreasing costs in social dwellings is ongoing [5] [6] [7] by replacing reinforced concrete by bamboo. According to normative [8], nodes in structural model have to be considered as pinned, that is to say, with no bending moments transmission between beams and columns, in order to obtain an additional security factor for structural elements and avoid non-linear effects. This assumption results in calculations with only axial behavior for columns, and high bending effects for beams.

Bamboo Connections have been studied for some configurations and for specific structures typology due to the huge variety of construction methods. Some of those connections have been even tested, as could be seen in the research of [9] [10] [11] [12]. Several constructive methods suggest that connections in nodes could transmit bending moments from beam to columns and vice versa, discarding the hypotheses in normative. The use of concrete, mortar, and reinforcing steel in bamboo nodes or joints may transform them in rigid nodes. Supports of bamboo structure is assumed as rigid, due to the concrete involving the bamboo columns at the base, and the reinforcing steel according to Figure 1.

In addition, joints are filled with mortar or concrete, even reinforced with reinforcing steel. Bending moment's continuity is supposed in Figure 1 from superstructure to infrastructure, so that, in this analysis, bending moment transmission in joints were considered in the analysis. There are some studies about connections capable to transmit bending moments, tested experimentally but with a specific configuration as the proposal of [13] and [14].

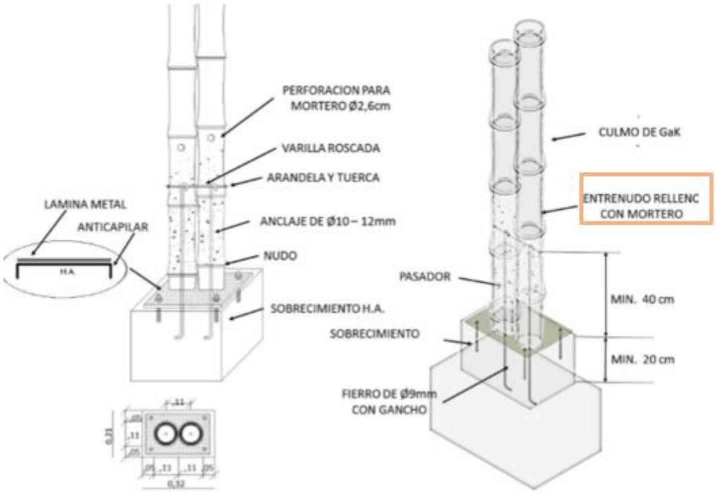

Figure 1. *Constructive method for columns. Source [8]*

2. DEVELOPMENT

2.1. Reinforced Concrete Structural Analisys

Structural analysis and design were according to regulations [15] [16] [17] [18] [19]. Figure 2 contain the whole structure, a social house for eight families, using minimal structural requirements in order to offer a low cost. Materials for this analysis were the common for these types of structures as f'c = 23,54 MPa and fy = 412,00 MPa. For this structure, structural members have the dimensions and reinforcement steel areas specified in Table 1.

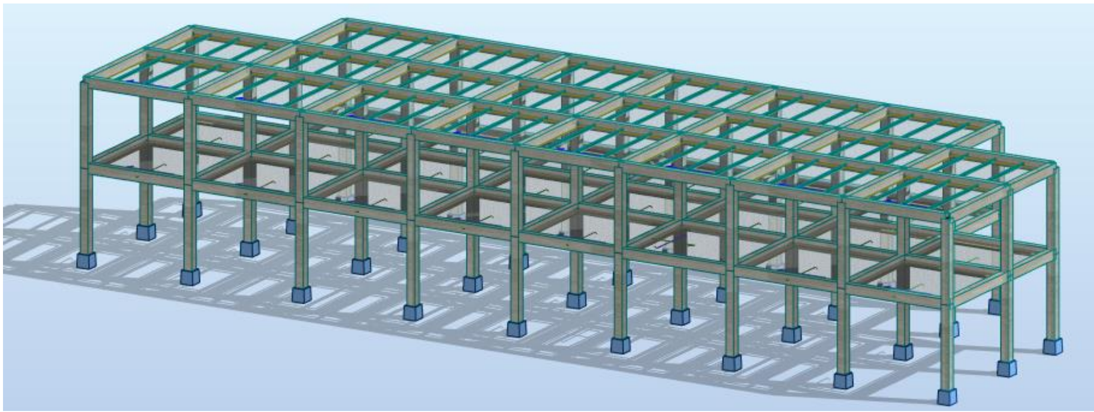

Figure 2. *Reinforced concrete structural model. Source: [6]*

Table 1. *Structural members design. Source: The authors.*

Element type	Width [cm]	Heigth [cm]	Longitudinal As [cm^2]	Transversal As [cm^2]
Beams	20,00	25,00	1,80	0,79
Columns	25,00	25,00	9,04	0,79

Dynamic response of the first three vibration modes of the structure are schematically

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represented in Figure 3. First and second vibrational modes present translation in each structural axis, while third mode and on present rotation. Interstory drifts for each seismic scenario are shown in Table 2.

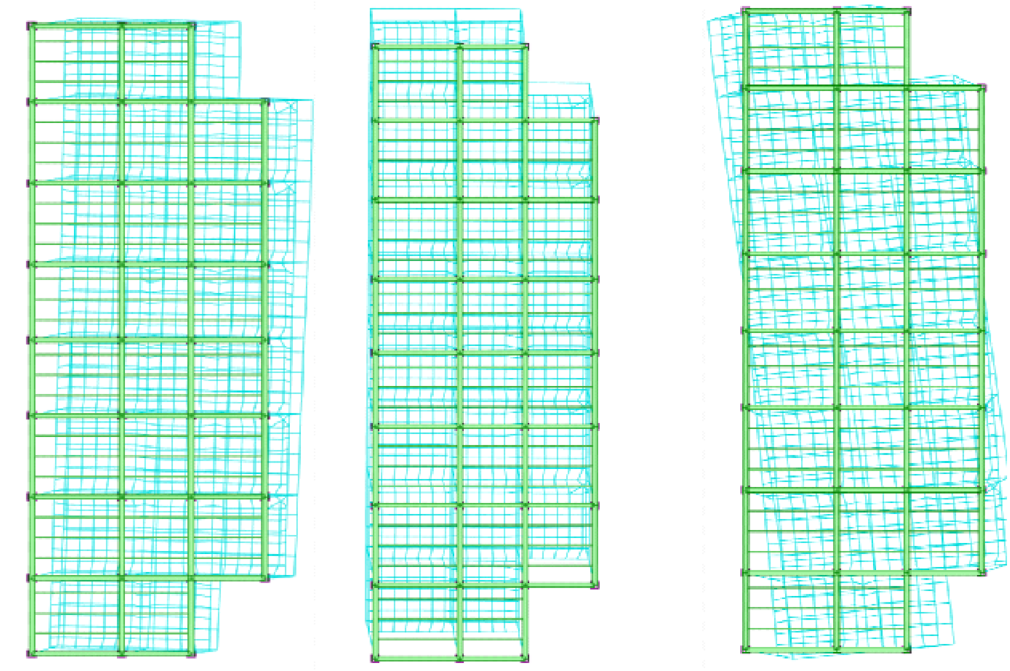

Figure 3. *Vibrational modes. Source: [6]*

Table 2. *Drifts for Sx and Sy. Source: The authors.*

Load	Level	Displacement [m]	drift [%]
Earthquake X	Nv+0,00	0,0000	0,00
	Nv+2,50	0,0050	0,45
	Nv+5,00	0,0080	0,27
Earthquake Y	Nv+0,00	0,0000	0,45
	Nv+2,50	0,0060	0,27
	Nv+5,00	0,0090	0,00

According to the results, the structure has a good behavior for gravitational and accidental [seismic] loads; therefore, the new bamboo structure must have a similar behavior in order to make possible the proposal substitution.

2.2. Bamboo Structural Analisys

Structural analysis and design were according to regulations [15] [16] [17] [18] [19]. For this structure, a mortar fill was use along 40 cm inside culms, for purlins, beams and columns, in order to increase the maximum shear stress, bending stress, torsional stress and normal stress,

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due to the composite member.

Structural members

The structural configuration for purlins, beams and columns is presented in Figure 4, Figure 5, and Figure 6, respectively. The structural configuration was based on [5], and related with some constructions along the country.

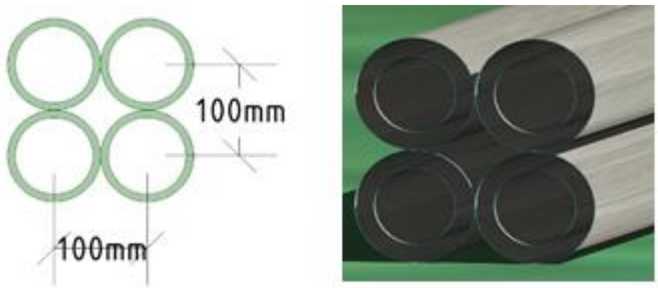

Figure 4. *Gak configuration for purlins. Source: The authors*

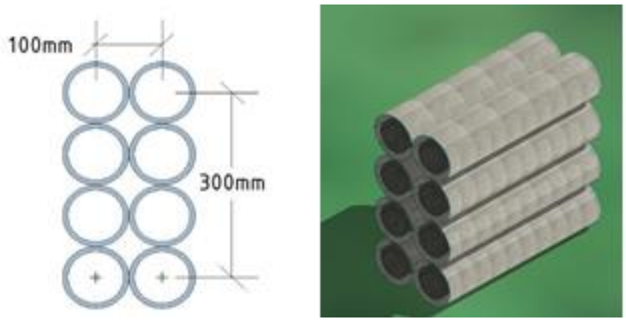

Figure 5. *Gak configuration for beams. Source: The authors*

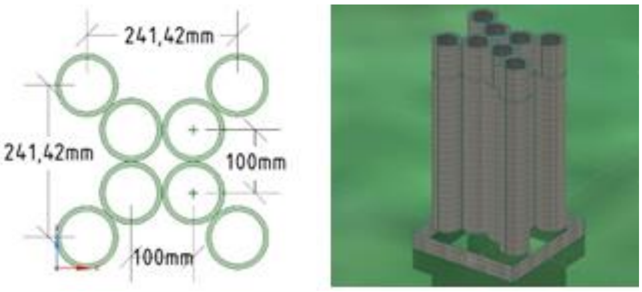

Figure 6. *Gak configuration for columns. Source: The authors*

Stiffness estimate

Due to the heterogeneous of the composite structural members, a finite elements model created in order to estimate the stiffness of each structural member. The finite elements model for beam is depicted in Figure 7, while the model of the column is in Figure 8. Stiffness was calculated using equation 1, representing the shear stiffness.

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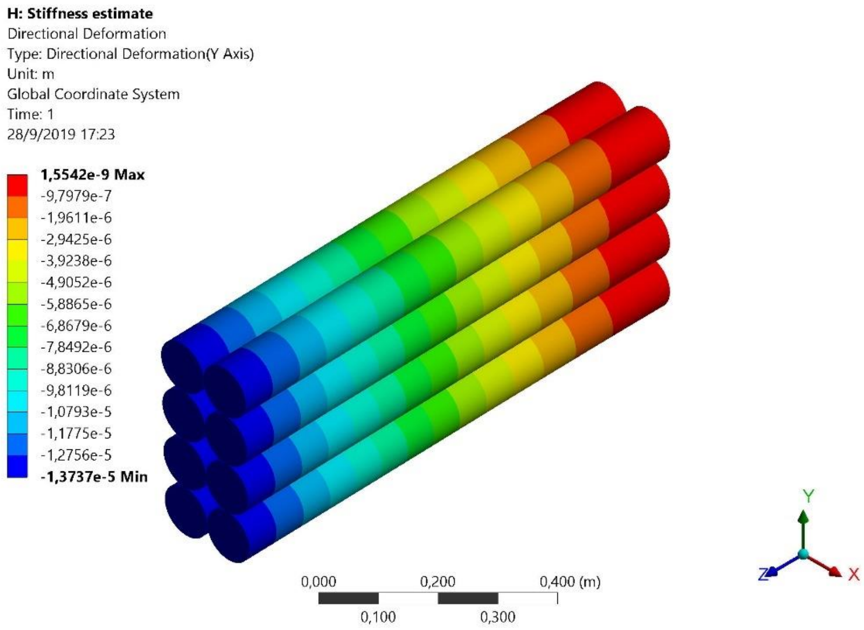

Figure 7. *FE model for beams. Source: The authors*

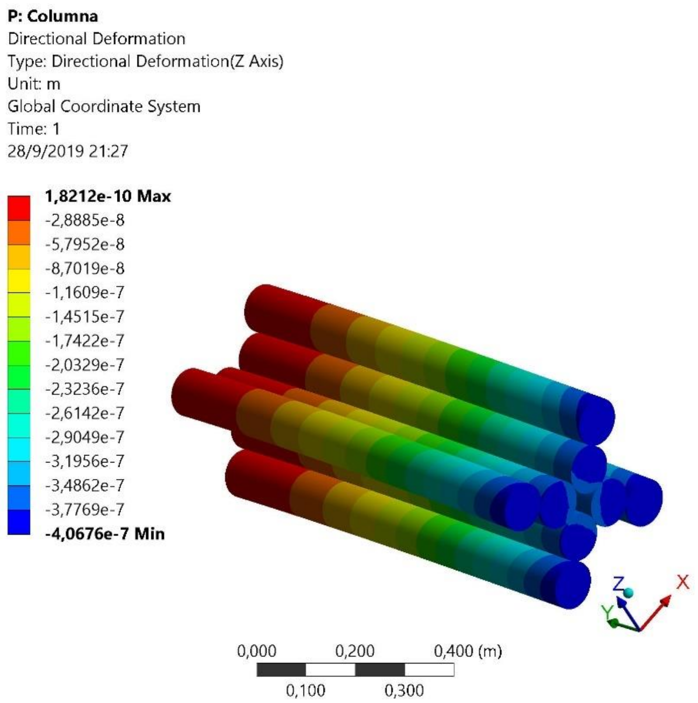

Figure 8. *FE model for the column. Source: The authors*

Applying the equation 2, it´s possible to calculate shear forces along the structural element [20] [21].

$$Kv = \frac{P}{y} \qquad [1]$$

$$P = Kv.y \qquad [2]$$

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Shear stiffness for beams and columns, are shown in Table 3. Stiffness of the composite cross section depends of the configuration of the culms, supports condition and materials [22].

Table 3. *Stiffness for beams y columns. Source: The authors*

Element type	P [N]	y [m]	Kv [N/m]
Beam	18,46	0,000013725	13193221,04
Column	8	0,000000407	19667617,27

Joint

Bamboo joints generally are considered as pinned from beams to columns, it means, columns are not able to transmit bending moments to the beams and vice versa [23]. Beams are able to transmit bending moments only when a member continuity can be constructed. Nevertheless, some joints have peculiar characteristics that suggest that beams can transmit bending moments to the columns [13] [14] [24] [25]. Some of those joint configurations implies steel plates and bolts, and others use only bolts or reinforcement steel, and a mortar fill in columns and beams [26]. In this research, a proposal for joint will be analyzed using finite elements.

- Corner joint FE analysis

Based on the hypotheses that joints are able to transmit bending moments, the bending moment transmitted from beams to columns must be continuous and the same in the joint, considering only self-weight. The value for this bending moment is 73,42 Nm and shear force is 367,10 kN [Figure 9 and Figure 10].

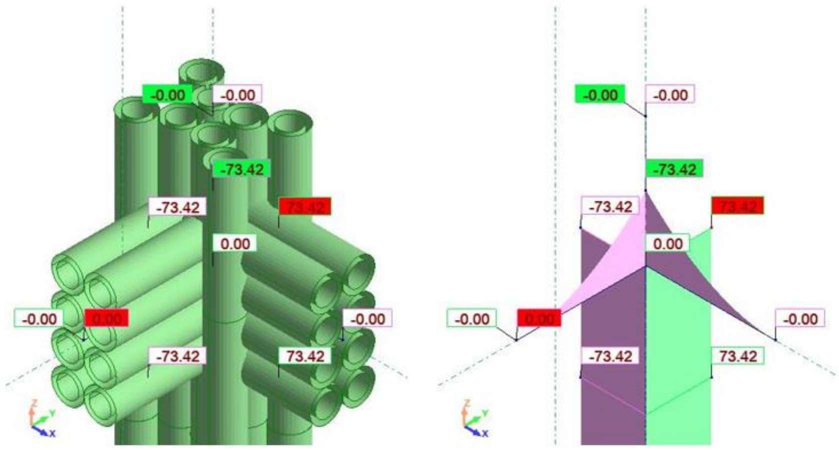

Figure 9. *Bending moments in the corner joint. Source: The authors*

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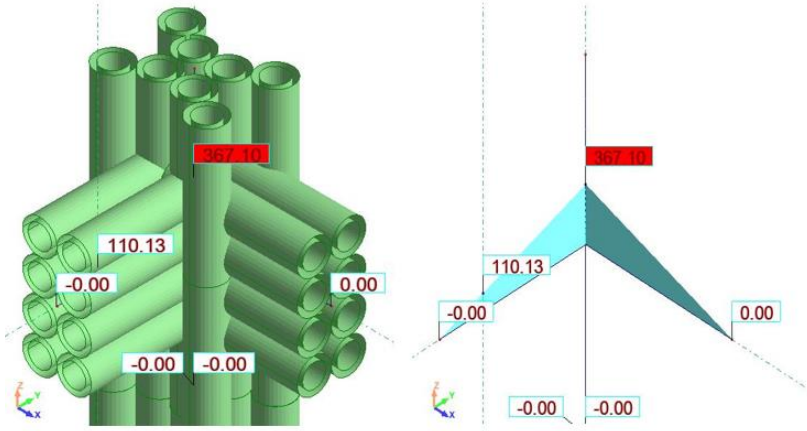

Figure 10. *Shear forces in the corner joint. Source: The authors*

In order to verify the hypotheses, a finite element model of the joint was analyzed, including steel reinforcement in culms. The model of the joint was based on the proposal of some local constructions and constructive methods available. There are eight culms conforming the columns, which four of them are located in the corners, giving continuity in the structural column, meanwhile, the four central culms are cut in order to make possible the connection with the beams (Figure 11).

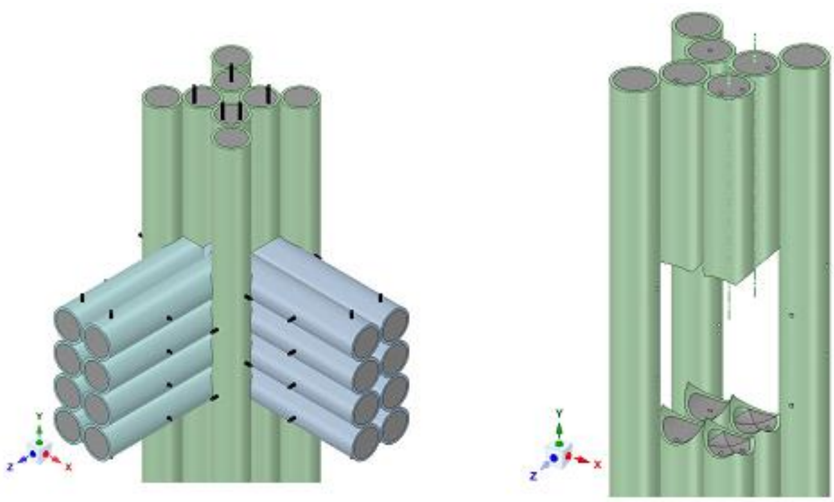

Figure 11. *Columns and beams configuration in the joint. Source: The authors*

Beams connection is created by alternating the culms inside the joint, and beams connected each other using standard cuts and reinforcement steel. All culms in the joint are filled with mortar. Inside the culms, there are natural rings, separated since 20 cm to 40 cm, creating cylinders inside the culms (Figure 12), and when they are filled with mortar, the sliding is not able to occur, so it can be assumed that bamboo and mortar work as a single element of composite section.

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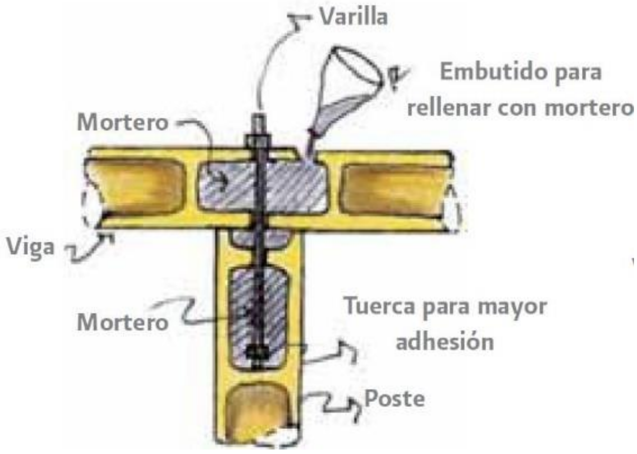

Figure 12. *Schema of rings inside bamboo culms and mortar fill. Source: [27]*

The beams of both directions intersect in the core, in the space that the central columns do not occupy, joined by steel rods that completely cross the core, creating a union between columns and beams (Figure 13 and Figure 14).

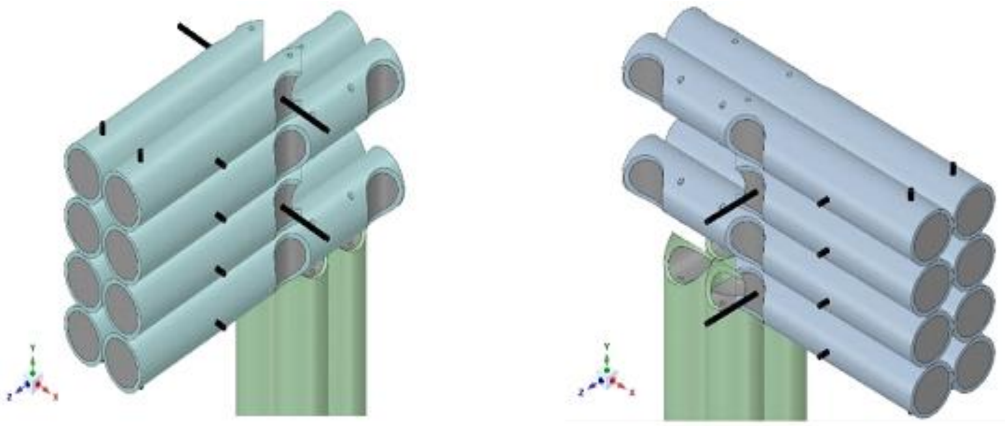

Figure 13. *Beams intersection inside core. Source: The authors*

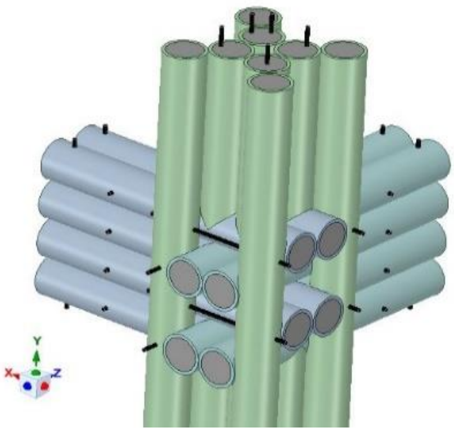

Figure 14. *Beams intersection inside core [back]. Source: The authors*

For the finite elements model, it was considered a frictional factor of 0,5 for contacts between bamboo and bamboo, and 0,62 [28] [29] for contacts between bamboo and concrete; contact

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between steel and mortar was considered as perfect. The mechanical properties for concrete mortar are shown in Table 4, while mechanical properties for bamboo are summarized in Table 5.

Table 4. *Mechanical properties for mortar. Source: [5] [6]*

Density [kg/m^3]	2.100,00
Young's Module [MPa]	14.710,00
Poisson's ratio	0,16
Tensile yield strength [MPa]	9,807
Compressive yield strength [MPa]	1,961

Table 5. *Mechanical properties for bamboo Gak. Source: [5] [6] [30]*

Density [kg/m^3]	850,00
Young's Module X [MPa]	14.500,00
Young's Module Y [MPa]	15.500,00
Young's Module Z [MPa]	668,00
Poisson's ratio	0,30
Tensile yield strength [MPa]	132,00
Compressive yield strength [MPa]	48,00
Shear yield strength [MPa]	775,00

In order to determine if the joint is capable to transmit bending moments from beams to columns and vice versa, vertical displacements in the beams was analyzed, applying the stiffness factor calculated with equation 1. Displacements of each culm were the initial condition to estimate the bending moment for each beam in the core. Displacements for two representative culms in each direction are depicted in Figure 15 and Figure 16.

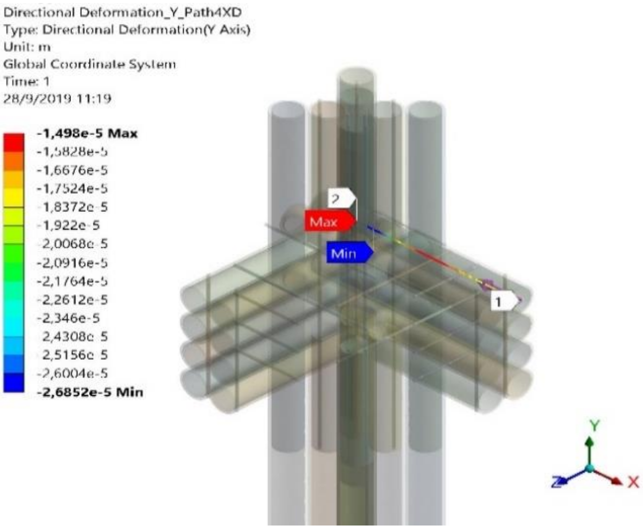

Figure 15. *Vertical displacements for one culm. X direction. Source: The authors*

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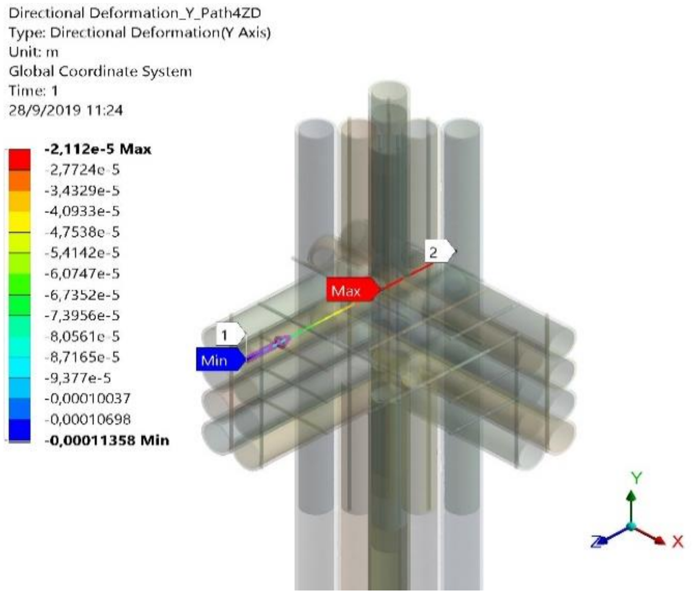

Figure 16. *Vertical displacements for one culm. Z direction. Source: The authors*

The average displacements in both beam directions could be observed in Figure 17, while shear forces are shown in Table 6, calculated with equation 2. Note that shear forces values are very similar to the results of Figure 10. Applying Equation 3, the bending moment in the joint can be calculated, as summarized in Table 6.

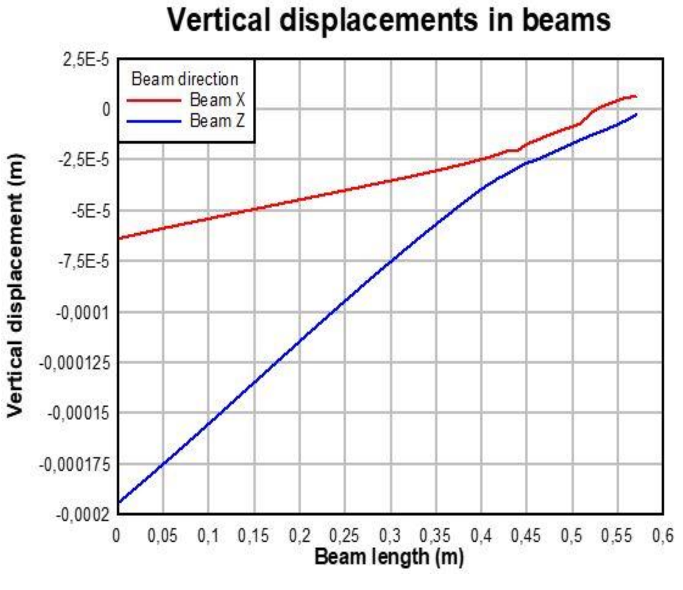

Figure 17. *Vertical displacements in beams. Source: The authors*

Table 6. *Shear forces and bending moments in beams. Source: The authors*

Element	Kv [N/m]	y [m]	V [N]	M [Nm]
Beam X	13.193.221,04	0,000024892	328,40	65,68
Beam Z	13.193.221,04	0,000025309	333,91	66,78

$$M = V.L \quad [3]$$

For the column, the same procedure was applicate, using displacements in the horizontal

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plane, according to Figure 18 and Table 7.

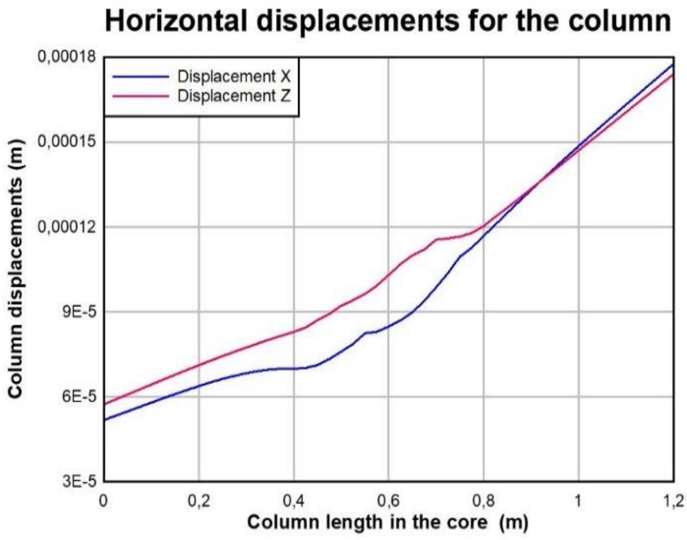

Figure 18. *Horizontal displacements in the column. Source: The authors*

Table 7. *Bending moments in columns. Source: The authors.*

Element	Kv [N/m]	Mx [N.m]	Mz [N.m]
Column [x]	19667617,27	0,00	43,55
Column [z]	19667617,27	46,00	0,00

Note that the joint is capable to transmit bending moments, with a low difference, but very close to the model in Figure 9 and Figure 10, so the structural model in bamboo can be created using bending moments connections in nodes.

Structural model

Structural model in bamboo was created according to the normative [23], but including the bending moment transmission in all nodes, in order to calculate columns under biaxial bending moments and compression loads.

- Floor slab

Floor slab was calculated with the common slab for structures with two floors, cutting bamboo members along their total length and then filled with structural concrete [f'c=23,54 MPa], see Figure 19. The slab configuration was tested by [7].

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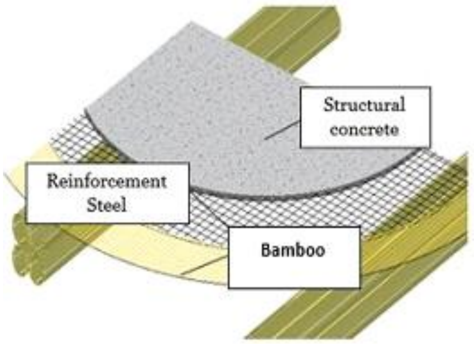

Figure 19. *Floor slab configuration. Source: [6]*

The combined cross section of the slab was calculated by using equation 4 for the equivalent bamboo area in concrete, and the equivalent length for the new combined cross section can be calculated using equation 5 [20]. The cross section is reproduced in Figure 20.

$$Aec = \frac{Eb}{Ec} Ab \qquad [4]$$

$$Aec = \frac{Aec}{Tb} \qquad [5]$$

Where:

Aec: equivalent bamboo area in concrete
Eb: bamboo Young's module
Ec: concrete Young's module
Ab: bamboo area to transforms in concrete area
Le: new Aec equivalent length
Tb: slab thickness

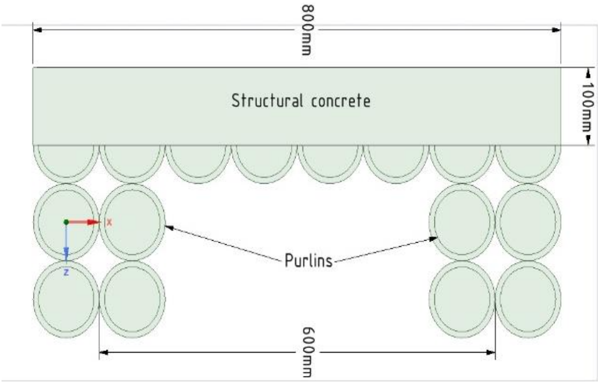

Figure 20. *Cross section for composite slab. Source: The authors*

Results for the slab structural model are summarized in Table 8, according to [23]. The results show that structural model for the floor slab is correct, similar to the results obtained by [7].

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Table 8. *Results of structural design for the floor slab. Source: [6]*

Slab		Admissible values
Maximum bending moment [N.m]	138,81	-
Bending Stress [MPa]	0.21	15
Maximum Shear Force [N]	1.324,64	-
Shear stress [MPa]	0,0313	1,2
Maximum Compression Force [N]	2.481,24	-
Maximum Compression Stress [MPa]	0,06	1,40
Maximum vertical displacement [cm]	1,06	1,50

- Purlins

Purlins was modulated in the main structural model, see Figure 4. The entire structural model could be seen in Figure 21. Purlins were modeled as continuous due to the construction method, above the beams, without interrupting their continuity and their ability to perform hyper statically. Similar to the structural analysis for the slab, the design of purlins was conducted to withstand the stresses transmitted from the floor slab, as could be seen in Table 9, Figure 22 and Figure 23.

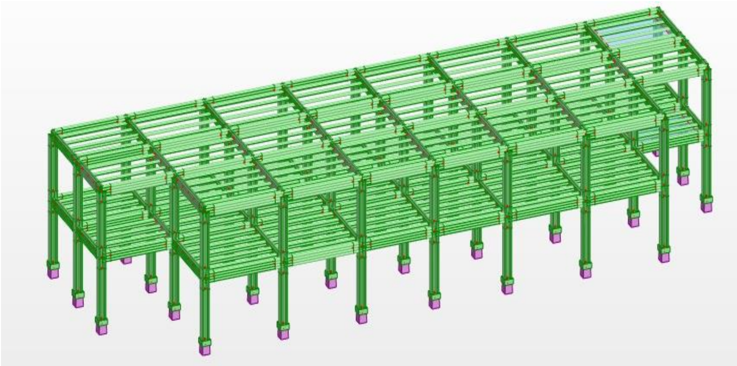

Figure 21. *Structural model for bamboo Gak. Source: [6]*

Table 9. *Results for beams. Source: [6]*

Purlins		Admissible values
Maximum bending moment [N.m]	3.193,73	-
Bending Stress [MPa]	5,54	15
Maximum Shear Force [N]	5.290,31	-
Shear stress [MPa]	0,42	1,2
Maximum Compression Force [N]	12.462,13	-
Maximum Compression Stress [MPa]	0,31	1,40
Maximum vertical displacement [cm]	0,99	1,29

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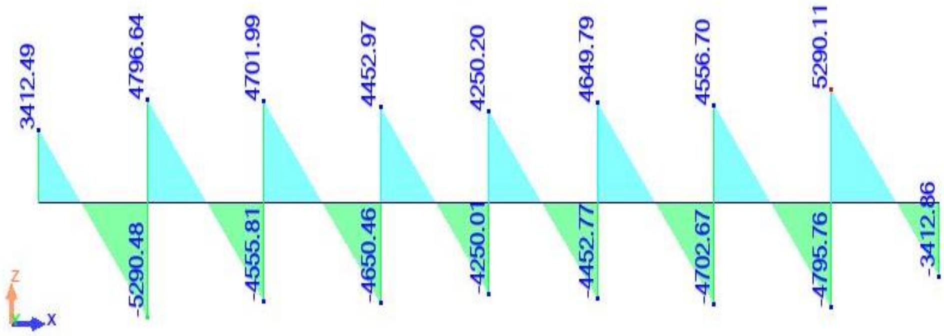

Figure 22. *Shear forces diagram for purlins [N]. Source: The authors*

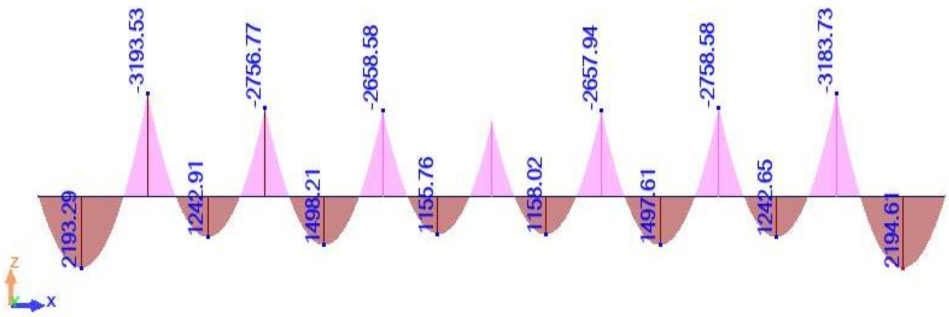

Figure 23. *Bending moment diagram for purlins [Nm]. Source: The authors*

- Beams

The beams were designed to withstand the stresses transmitted from the purlins. Diagrams for beams are available in Figure 24 and Figure 25.

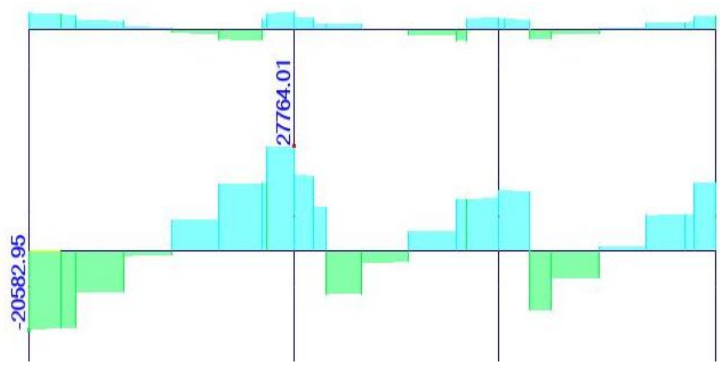

Figure 24. *Shear forces diagram for beams [N]. Source: The authors*

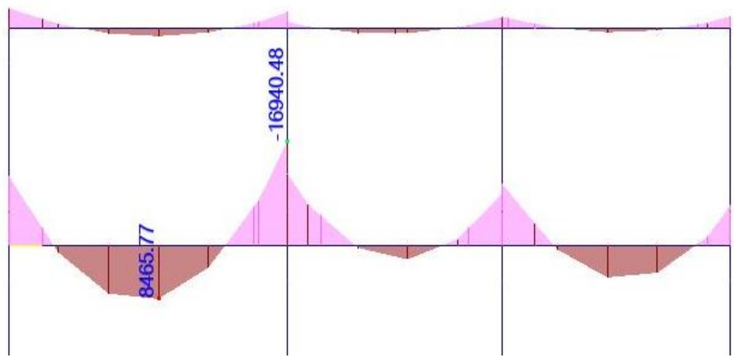

Figure 25. *Bending moment diagram for beams [Nm]. Source: The authors*

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Results for beams are summarized in Table 10.

Table 10. *Results for beams. Source: [6]*

Beams		Admissible values
Maximum bending moment [Nm]	16941,00	-
Bending Stress [MPa]	7,48	15,00
Maximum Shear Force [N]	27.764,01	-
Shear stress [MPa]	0,49	1,20
Maximum Compression Force [N]	67989,87	-
Maximum Compression Stress [MPa]	0,85	1,40
Maximum vertical displacement [cm]	0,86	1,29

- Columns

Columns were calculated under compression forces and biaxial bending moments, according to the results of the FE model of the joint. In Table 11 the results for compression verification are shown.

Table 11. *Results for columns. Source: [6]*.

Columns		Admissible values
Maximum Compression Force [N]	68588,25	-
Maximum Compression Stress [MPa]	2,03	19,00

According to [23], biaxial bending effects needs to verify the equation 6.

$$\frac{N}{N\ adm} + \frac{k_m * |M_x|}{Z * F'b} + \frac{k_m * |M_y|}{Z * F'b} \leq 1 \quad [6]$$

Where:

N: maximum compression force
N adm: admissible compression load
Km: magnification factor for moments
M_x: maximum bending moment in X axis
M_y: maximum bending moment in Y axis
F´b: admissible bending stress
Z: transversal cross section module

Applying the equation 6, using the values from Figure 26, it´s obtained a value of 0,13 for the second-floor column and a value of 0,44 for the first-floor column.

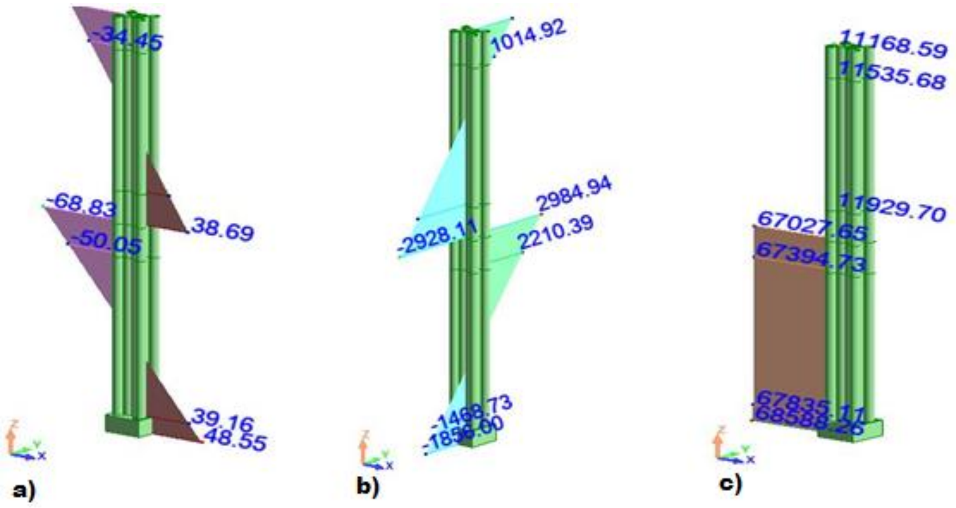

Figure 26. *a) Bending moment X, b) Bending moment Y, c) Axial force. Source: [6].*

- Modal-spectral response

Similar to the concrete structure, vibrational modes were calculated, see ***Figure 26***.

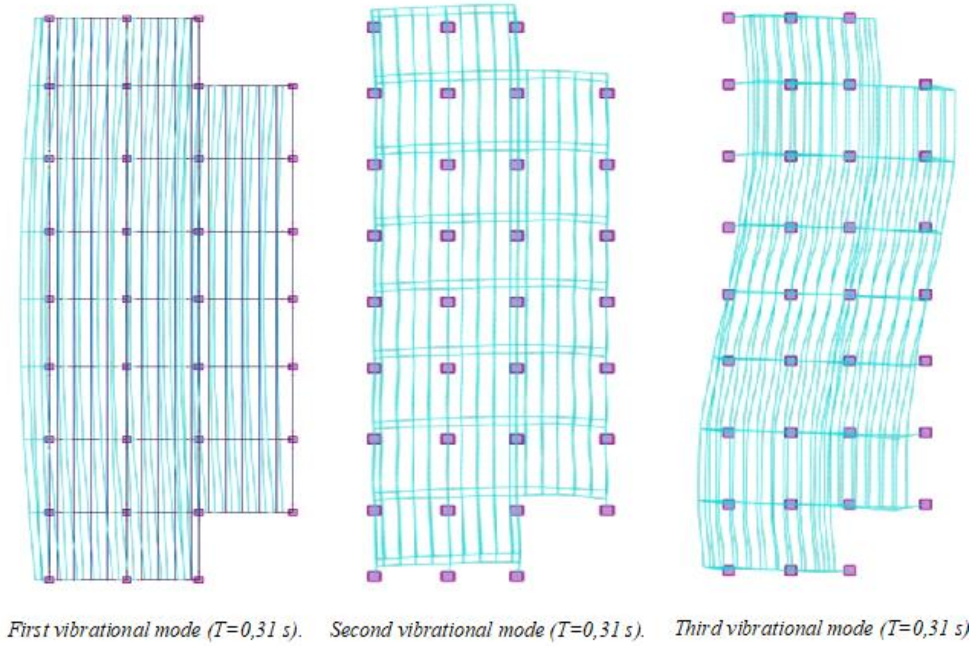

Figure 26. *Vibrational modes. Source: [6]*

Interstory drifts for the modal-spectral analysis are summarized in Table 12, being the drifts lower than 0,02 according to [23].

Table 12. *Displacements and drifts of the structure. Source: [6]*

Load	Level	Displacement [m]	drift [m/m]
Earthquake X	Nv+0,00	0,0010	0,00
	Nv+2,50	0,0048	0,34
	Nv+5,00	0,0062	0,13
Earthquake Y	Nv+0,00	0,0000	0,00
	Nv+2,50	0,0054	0,49
	Nv+5,00	0,0076	0,20

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3. RESULTS AND ANALYSIS

Nowadays, due to the environmental impact that construction causes, use alternative materials for common buildings is increasingly. According to the results above, it´s possible to replace concrete by bamboo for this type of structure. Differences between both structures are remarkable, but both of them meet the requirements established by the regulations. According to Table 13, structure in bamboo has lower displacements than concrete, although the bamboo structure is lighter, 208,00 T for concrete and 73,69 T for bamboo, and it´s because the stiffness of the structure.

Table 13. *Drifts differences between both materials. Source: The authors*

Load	Level	Drift [%]		
		Concrete	Bamboo	Difference
Earthquake X	Nv+0,00	0,00	0,00	0,00
	Nv+2,50	0,45	0,34	0,11
	Nv+5,00	0,27	0,13	0,14
Earthquake Y	Nv+0,00	0,00	0,00	0,00
	Nv+2,50	0,45	0,49	-0,04
	Nv+5,00	0,27	0,20	0,07

Seismic response of both structures is similar, having between them a 0,02 s of difference in period terms, related with the relationship between the structure mass and stiffness. In addition, this behavior is related with the fact of considering rigid nodes in both structures, according to the FE joint model.

4. CONCLUSION

According to the results of this analytical research, it´s possible to replace the social houses projects from concrete to bamboo, with the configuration set in this research. The bamboo structure presented a good behavior under gravitational loads, presenting admissible vertical displacements and stresses lower than the bamboo admissible stresses and the composite section in combination with concrete mortar.

Beam-column bamboo connections are able to transmit bending moments from each structural member, according to the above mentioned results. Although the transmitted bending moment is not 100 %, if not considering this fact can cause discrepancies in the structural analysis, for instance, oversizing beams due to bending moments and no considering bending effects in columns. Drifts also can be magnified if not considering bending moments in the bamboo structure, meaning this that columns cross section must be higher. It´s highly recommended to continue with this research in terms of construction costs and maintenance, in order to establish which structure is cheaper, regardless bamboo construction has positive environmental impact. In addition, it´s recommended an experimental analysis for the joints in order to calibrate the real transmitted bending moment.

5. REFERENCIAS

[1] C. A. Rodríguez Alonso y E. Morales Días, «El Bambú como material estructural: análisis de un caso práctico», 2008

[2] A. Texeira Alves, «Painéis de bambu para habitações econômicas: avaliação do desempenho de painéis revestidos com argamassa», Brasilia, 2006

[3] G. Serrano-Barba, et al., «Vivienda emergente y sustentable con sistemas estructurales de bambú» Guadalajara, 2016

[4] B. Torres, M. Segarra, & L. Bragança, «El bambú como alternativa de construcción sostenible» EXTENSIONISMO, INNOVACIÓN Y TRANSFERENCIA TECNOLÓGICA. CLAVES PARA EL DESARROLLO, V 5, pp. 389-400, 2019

[5] D. Andrade & M. Asimbaya, «Análisis comparativo de sistemas constructivos en un módulo de departamentos tipo de interés social empleando caña guadúa Angustifolia Kunth y hormigón armado, ubicado en la parroquia Guale, cantón Paján, de la provincia de Manabí» Quito, 2019

[6] P. Aguilar, «Análisis del comportamiento estructural del bambú del tipo "Guadúa Angustifolia Kunth" como material de construcción en sustitución del hormigón armado» Quito, 2019

[7] N. Chamorro & L. Sebastián, «Desarrollo de losas con caña de guadua angustifolia y análisis comparativo estructural y económico con los sistemas de losas tradicionales utilizados en nuestro medio» Quito, 2013

[8] M. Duarte, V. Bravo, J. Morales & J. Arias, «Estructuras de Guadúa [GaK]» Ministerio de Desarrollo Urbano y Vivienda [MIDUVI], Quito, 2016

[9] L. Villegas, R. Morán & J. García, «A new joint to assemble light structures of bamboo slats» Construction and Building Materials, 61-68, 2015

[10] T. Paraskeva, N. Pradhan, & E. Dimitrakopoulos, «Monotonic loading testing and characterization of new multi-full-culm bamboo to steel connections» Construction and Building Materials, 201, 473-483, 2019

[11] B. Lefevre, R. West, P. O'Reilly, & D. Taylor, «A new method for joining bamboo culms» Engineering Structures, 190, 1-8, 2019

[12] G. Tang, L. Yin, Z. Li, Y. Li & L. You, «Structural behaviors of bolted connections using laminated bamboo and steel plates» Structures, *20*, 324-339, 2019

[13] R. Morán, J. Muñoz, H. Silvac & J. García, «A Bamboo Beam-Column Connection Capable to Transmit Moment» 17th International Conference on Non-Conventional Materials and Technologies, 2017

Revista Gaceta Técnica. Artículo de Investigación. 22(1), 32-51, enero-junio, 2021
ISSN 1856-9560 (Impreso) ISSN: 2477-9539 (Internet) Depósito Legal pp 1999907LA22 ppi201602LA4730

[14] R. Morán & J. García, «Bamboo joints with steel clamps capable of transmiting moment» Construction and Building Materials, 249-260, 2019

[15] NEC-SE-DS, «Peligro Sísmico. Normativa» Quito, Ecuador, 2015

[16] American Concrete Institute, «Building Code Requirements for Structural Concrete [ACI 318-14]: Commentary on Building Code Requirements for Structural Concrete [ACI 318R-14]: an ACI Report» American Concrete Institute, ACI, 2014

[17] American Concrete Institute, «Building Code Requirements for Structural Concrete [ACI 318-19]» 2019

[18] Norma Ecuatoriana de la Construcción, NEC–SE–VIVIENDA, «Viviendas de hasta 2 pisos con luces de hasta 5m» Quito, 2014

[19] Norma Ecuatoriana de la Construcción, NEC–SE–VIVIENDA, «Cargas [No Símicas» Código: NEC-SECG, Quito, 2015

[20] F. P. Beer & E. R. Johnston, «Mechanics of Materials» McGraw Hill.C. A., 2010

[21] E. Popov, «Introduction to mechanics of solids» 1968

[22] R. A. Sá Ribeiro, M. G. Sá Ribeiro & P. Miranda Ires, «Bending strength and nondestructive evaluation of structural bambo» Construction and Building Materials, 146, 38-42, 2017

[23] Norma Ecuatoriana de la Construcción, «Estructuras de Guadúa [Gak] » Quito, 2006

[24] M.A.G.A.P, «Reporte post-sismo sobre estructuras de bambú, y recomendaciones para la reconstrucción con bambú en la Costa Ecuatoriana» Quito, 2015

[25] G. Minke, «Building with bamboo: design and technology of a sustainable architecture» Basel: Birkhäuser, 2012

[26] J. Janssen, «Designing and building with bamboo» 2000

[27] C. Ordóñez, R. Víctor, Mejía M. T. Saulés & G. Bárcenas Pazos, «Manual para la construcción sustentable en Bambú» Jalisco, 2015

[27] Engineers Edge, https://www.engineersedge.com, 2020

[29] A. Dey & C. Nayanmoni, «Experimental study of Bamboo Reinforced Concrete beams having various frictional properties» Materials Today: Proceedings, *5*[1], 436-444, 2018

[30] F. A. Báez & C. P. Takeuchi Tan, «Determinación de la rigidez de un tipo de conexión viga-columna en Guadua angustifolia» Epsilon, 13, 193-204, 2009

[31] V. Popov, «Contact mechanics and friction» Berlin: Springer Berlin Heidelberg, 2010

Revista Gaceta Técnica. Artículo de Investigación. 22(1), 32-51, enero-junio, 2021
ISSN 1856-9560 (Impreso) ISSN: 2477-9539 (Internet) Depósito Legal pp 1999907LA22 ppi201602LA4730