International Journal of GEOMATE, April., 2021, Vol.20, Issue 80, pp.182-187
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.80.j2088
Geotechnique, Construction Materials and Environment

FINITE ELEMENT ANALYSIS OF BEAM USING 2X4 GLUED BAMBOO LAMINATED WITH PARA TIMBER AND 2X6 PARA TIMBER

*Svit Piriyasurawong[1] and Terdsak Techakitlachorn[2]

[1]Faculty of Architecture, Chulalongkorn University, Bangkok, Thailand; [1,2]

*Corresponding Author, Received: 16 Jan. 2021, Revised: 31 Jan. 2021, Accepted: 14 Feb. 2021

ABSTRACT: This research studies the analysis of 2" x 4" glued bamboo laminated with Para-timber beam, comparing with 2" x 6" glued Para-timber laminated structure to study the deformation behavior of the two types of timber beams. The method used in testing is Finite Element Analysis: FEM, and in processing the result, Computational Aided Engineering: CAE was used by ANSYS 2020 R2 program to find out the distance of the pillar that affects to the structure of the wood, both in the compression force from the gravity and from the vertical displacement. The study found that 2" x 4" glued bamboo laminated with Para-timber beam can replace 2" x 6" glued laminated Para-timber beam. Although the deformation distance property of Para-timber is 0.33141 mm. (27.96%) less than the glued bamboo laminated with Para-timber, it has the difference in the modulus of elastic value at 84 megapascal, which results in that the undeformed behavior of glued bamboo laminated with Para- timber beam was less than Para-timber. In comparison, 2" x 4" glued bamboo laminated and Para-timber is cheaper, and it is able to reduce the size of the 2" x 6" glued Para-timber laminated to 2" x 4" glued bamboo laminated with Para-timber and still maintains the strength of the structure.

Keywords: *Beam, Glued laminated timber, Two-by-Four construction, Finite elements analysis*

1. INTRODUCTION

Glued laminated timber was applied to parts of building structures such as beam, wall bearing, stud, etc. Finite Element method was introduced to engineering works such as stiffness matrices for truss, beam, and other elements [1]. As the composites from natural fiber has unique mechanical properties, with abundant raw material available and biodegradable, they are considered one of the most favorable materials [2]. Bamboo is an environmentally friendly construction material widely used in the construction of green buildings, which is in favor of global warming solution campaigns. Also, bamboo takes only 3-5 years in growing before it can be used in a construction [3]. There are 2 species of bamboo in Thailand which can be used as structure of building, combined with other materials: "Pai Tong" (Dendrocalamus asper Backer) and "Pai Laing" (Bambusa sp.). [4] Both can substitute materials for construction because they have similar mechanical properties as Para timber, if the bamboos are preserved properly. [5]

Finite element method is a process that gives confidence to solve the problem of the weak connection of bamboo material, that makes it cannot be utilized immediately due to the constrains of bolts connection system [6]. Nowadays, there is a short source of data about the structure of glued bamboo laminated timber that composed of the mixture of Para as the material and bamboo as the composition of building.

This research is comparing 2" x 4" glued bamboo laminated with Para-timber beam, with 2" x 6" glued Para laminated timber using Finite Element Method: FEM and processing by ANSYS 2020 R2 in order to find the distance of pillar that affects the structure of the wood in the compression force both from the gravity and from the vertical displacement. In designing the section of beam, Max Stress on Neutral Axis designing method is used to pass over the shear stress distance to acquire the Elastic behavior and allow that the beam can be repaired in case of the damage in the first stages. The best standard used in bamboo specimen testing was ASTM D 143 – 94 Standard Test Methods for Small Clear Specimens of bamboo parallel layer [7].

The 2" x 4" Glued bamboo laminated with Para-timber is quite more expensive, comparing with 2" x 6" Glued laminated Para-timber, therefore the use of 2" x 4" Glued bamboo laminated with Para-timber requires less materials than the 2" x 6" Glued laminated Para-timber. Also, the size of timber can be reduced from 2" x 6" to 2" x 4" and it can still maintain the strength of the structure in the acceptable level. The viscoelastic parameters were used to predict the creep behavior of glued laminated bamboo structure elements. [8]

2. MATERIAL AND METHOD

The analysis of Mesh Quality of 2” x 4” glued bamboo laminated beams with Para-timber beam and 2” x 6” glued laminated Para-timber beam uses Finite Element Analysis: FEM Method, ANSYS™ System, with acceptable skewness mesh metrics spectrum at $0.80 - 0.94$, or not exceed 0.95, and the orthogonal quality mesh metrics spectrum at 0.15 - 0.20, but not less than 0.1, according to ANSYS mesh quality recommendations.

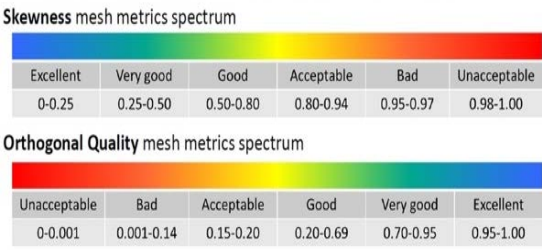

Fig.1 ANSYS™ Mesh Quality Recommendations [11]

2.1 Material Test

The species of bamboo chosen in this research is “Pai Tong” (Dendrocalamus asper Backer) with growth rate specified in 4-5 years, cut from Ratchaburi province on March, 2020, and Para timber (PB 235) with growth rate specified in 18 years, used for the production of timber, due to its high stem and less branches, which is proper to use in the production of glued laminated timber. The models of beam materials studied in this research are divided in 2 models that are 1) 2” x 6” Glued laminated Para-timber and 2) 2” x 4” Glued bamboo laminated with Para-timber. Both models use 4 bolts connection as shown in figure 10. the models are different in the section of timber in aspect of their material and the number of layers, as shown in figure 2 and 5.

2.2 Computational Aided Design (CAD)

The beam modeling with Computational Aided Design, CAD simulates 2 models of timber, that are 1) 2”x6” Glued laminated Para-timber and 2) 2”x4” Glued bamboo laminated with Para-timber. The two types of beam have the Rectangular cross-section of beam according to the suggestion of Bazan, 1980 about the analysis of linear relationship of stress between the strain up to the proportional limit [10] Bazan produced reasonable predictions of bending strength of clear wood from the results of axial tension and compression tests.

2.2.1 2” x 6” Glued laminated Para timber

2”x6” Glued laminated timber is conventional wood found in the industrial system. There is no glue PVAc class D4 with the standard of DIN EN 204/205. The layer of glue is designed in the range of max stress on neutral axis, that causes the edge of glue layer has maximum shear stress, as seen in Figure 2: Section of 2” x 6” Glued laminated timber (Para-timber)

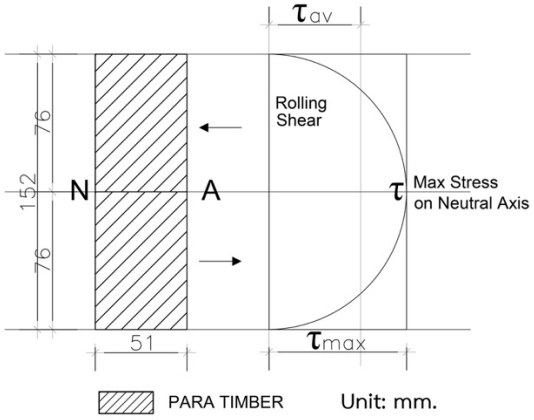

Fig. 2 Shear stress section of 2” x 6” Glued laminated Para-timber

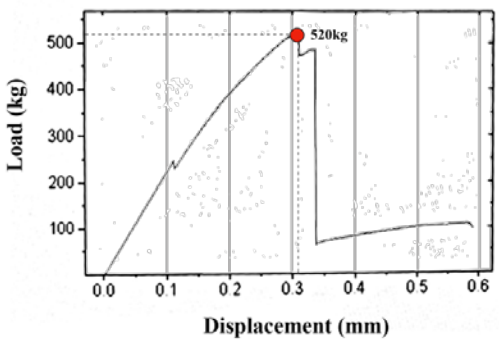

Fig. 3 Load Deflection of 2” x 6” Glued laminated Para-timber [9]

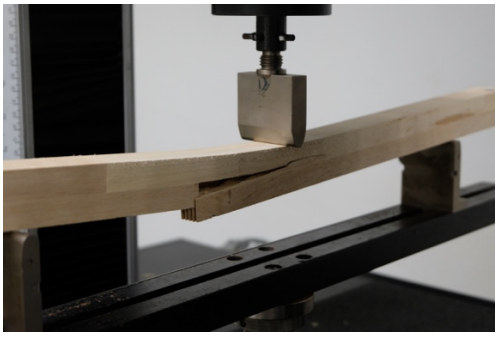

Fig. 4 The fracture at the tension tie of 2” x 6” Glued laminated Para-timber [9]

2" x 6" Glued laminated Para-timber has a deformation behavior and can be diagonal shear crack. So, it is immediately deformed after the failure and couldn't continue bearing. It also has the fracture at the tension tie. And at the finger joint point there is a maximum stress load-bearing capacity at 52.73 MPa, with the toughness at 0.02 mm. [9], as demonstrated in the figure 3: Load displacement of 2" x 6" Glued laminated Para-timber

2.2.2 2" x 4" Glued bamboo laminated with Para Timber

2" x 4" Glued bamboo laminated with Para-timber is specially designed; it is not designed in the wood industry system. The type of glue used is PVAc class D4 with the standard of DIN EN 204/205, in the quantity of 200g/Square meters. The layer was designed out of max stress on neutral axis and bamboo layer was designed at rolling shear, The Position of Para timber of which the specimen has taken from outer layer (top, middle, and bottom) makes no fracture at the edge of the bamboo. as shown on figure 5: Section of 2" x 4" Glued bamboo laminated timber with Para-timber

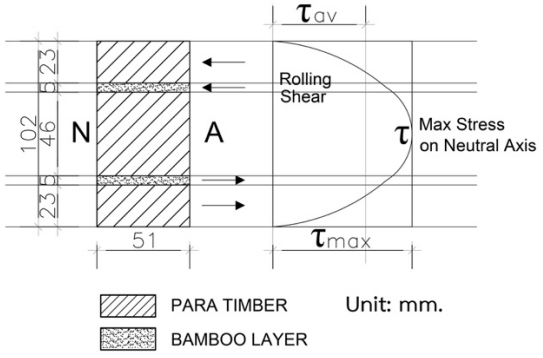

Fig. 5 Shear stress section of 2" x 4" Glued Bamboo laminated timber with Para-timber

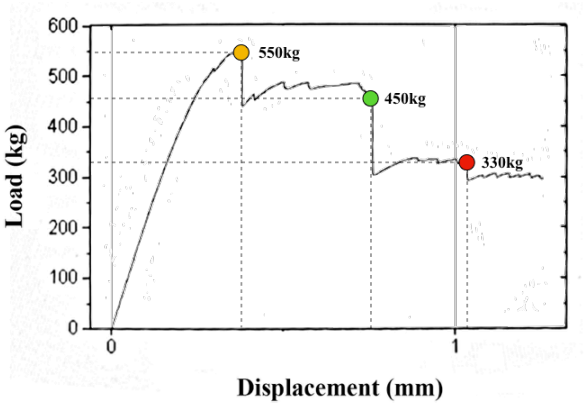

Fig. 6 Load Deflection of 2" x 4" Glued Bamboo laminated timber with Para-timber [9]

Fig. 7 The fracture at the tension tie of 2" x 4" Glued Bamboo laminated timber with Para-timber [9]

2" x 4" Glued Bamboo laminated with Para-timber was found the fracture at the finger joint point at 56.48 MPa with the restoration rate at 0.1396 mm, which is considered a better undeformed behavior comparing with Glued Para-timber (Para-timber) that is deformed immediately [4]. The behavior in figure 5: Load displacement of 2" x 4" Glued bamboo laminated with Para-timber shows that once the beam is deformed, it can be repaired before the deformation happens.

2.3 Computational Aided Engineer (CAE)

Computational Aided Engineering, CAE is used for analysis via ANSYS 2020 R2 in designing elements and processing the mechanic properties of each type of wood used in CAE model, depending on the characteristics of beam, with The Mesh properties number of elements at 21,363 points. The result found that the average mesh quality of Skewness mesh and Orthogonal quality mesh is at acceptable level. The beam has 4.8 meters of length, with the space between pillars at 2.6 meters, the cantilever span is at 1.10 meters both sides, glued with the same type of timber, and the length of both types of glued timbers is 1.20 meters with four ½ x 6 Inch Nuts Bolts. The design uses the same materials in the increase of all beam's distance to study the property of the only one material, as in the figure 8 and 9.

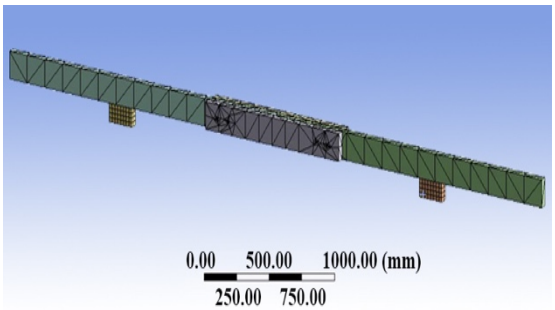

Fig. 8 Mesh Quality of 2" x 6" Glued laminated Para-timber

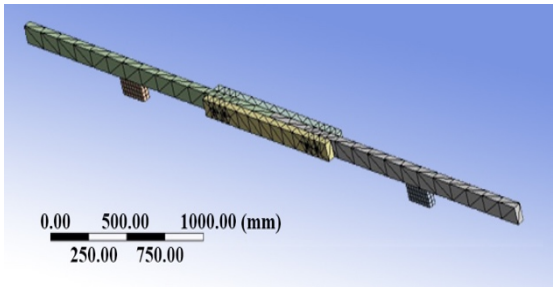

Fig. 9 Mesh of 2"x 4" Glued Bamboo laminated timber with Para-timber

3. EXPERIMENTS

The testing of both models was subjected to two loading conditions that consists of 1) Mid Press at the center area of the beam that has the max stress, setting pressure at 0.2082 MPa and force 1041N and 2) All body testing, setting pressure at 4660 MPa and force 275N Both analyses were conducted as transient dynamic analyses without consideration for vibration, dampening, or any harmonic effects. With respect to the Poisson's Ratio for wood when a material is compressed in one direction, it usually expands in two directions perpendicular to the direction of compression. Poisson's effect for rubber wood = 0.288 applying load to the middle of the beam and 2 support as shown in figure 10: Simulation set up 2"x6" and 2"x4" beams.

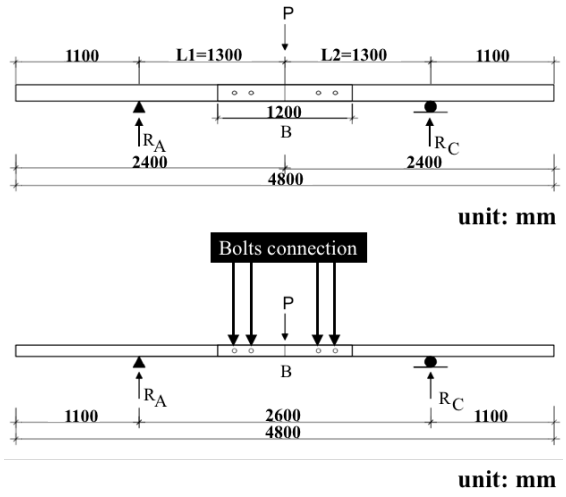

Fig. 10 Simulation set up 2"x6" and 2"x4" beams

3.1 Finite Element Analysis

Since Finite Element Analysis by ANSYS 2020 R2 Program is still lacks of MOE value data record of material, this research uses the references from other research that has the 2" x 4" Glued bamboo laminated with Para-timber property testing according to the ASTM D 143 – 94 Standard Test Methods for Small Clear Specimens of Timber, with the average of Glued laminated timber at 7480 Mpa, and of 2" x 4" Glued bamboo laminated with Para-timber at 7396 Mpa. [9] with the purpose of entering the simulation data for the analysis in the table 1 showing the parameter value of the property of the timber testing work.

Table 1 Parameter value of the property of the timber testing work [9]

Items	Density (kg/m^3)	Modulus of Elasticity (MPa)	*Poisson*'s Ratio (N/A)
2" x 6" Glued laminated Para timber	550	7480	0.288
2" x 4" Glued bamboo laminated with Para-timber	699	7396	0.288

4. RESULTS AND DISCUSSION

The result of the analysis using static structural method showed the total deformation on the top and bottom in the pillar area that are fully supported and against lateral side deflections.

The mid press and all body testing method have the maximum deformation value at the center area of the inner edge of the two beams, as in the figure 11 and 12 that demonstrate the deformation distance of the testing samples.

4.1 2" x 6" Glued laminated Para timber

The result of the analysis using static structural showed that the end boundary area of the cantilever span has the equal behavior of deformation as the center area of the beam, as seen from the Spectrums of total deformation that is 0.56939 mm., and has the maximum deformation value at the inner of center area of the edge of both timber beams at 0.85409 mm.

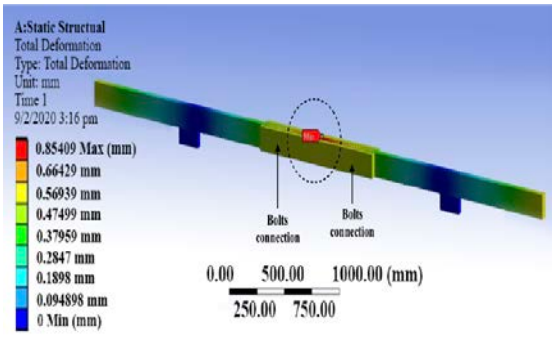

Fig. 11 Deformation of 2" x 6" Glued laminated Para-timber

4.2 2” x 4” Glued bamboo laminated with Para timber

The result of the analysis using static structural showed that the end boundary area of the extending beam has a better deformation behavior than the center area of the beam, as seen from the spectrums of total deformation that is 0.52691 mm. and has the maximum deformation value at the inner of center area of the edge of both timber beams at 1.1855 mm.

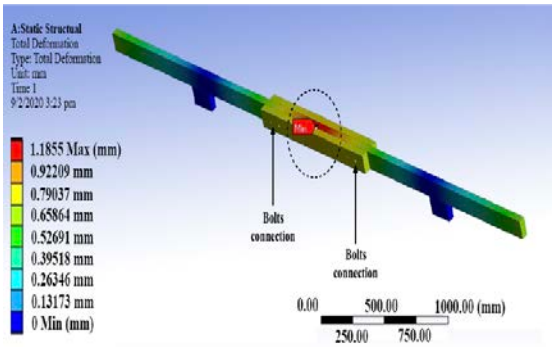

Fig. 12 Deformation of 2” x 4” Glued bamboo laminated with Para-timber

Table 2 Deformation of the timber testing work

Items	Maximum deformation (mm)
2” x 6” Glued laminated timber	0.85409
2” x 4” Glued bamboo laminated with Para-timber	1.185

The results of statistic test in the table 2 show the parameter of the timber value that compares the test results of the 2 types of beams. The results found that 2” x 6” Glued laminated Para timber has 0.33141 mm. less deformation distance than 2” x 4” Glued bamboo laminated with Para-timber, or 27.96%. This difference between deformation distance is caused by the difference between modulus of elastic value of 84 MPa, which resulted in that the undeformed behavior of 2” x 4” Glued bamboo laminated with Para-timber is lower than 2” x 6” Glued laminated Para-timber. Furthermore, the density of Glued bamboo laminated with Para-timber and Para-timber is different at 193 kg/m^3. The result is that their weight affects on the gravity on the timber structure, and consequently affects on the increase of deformation distance of the timber.

However, as the 2” x 4” Glued bamboo laminated with Para-timber is quite more expensive comparing with 2” x 6” Glued laminated Para timber, therefore the use of 2” x 4” Glued bamboo laminated with Para-timber requires less materials than the 2” x 6” Glued laminated Para-timber. Also, the size of timber can be reduced from 2” x 6” to 2” x 4” and it can still maintain the strength of the structure in the acceptable level.

4.3 Span of Supported Beam

The result from the statistic test of 2” x 4” beam is that Glued bamboo laminated with Para-timber has a possible span length of 2600 – 3000 mm., as shown in Table 3, that demonstrates the Span of supported beam with deformation value not more than 2.5 mm. [12] according to the ASTM standard D 143 – 94. The Allowable loads for cantilevered beams can support the bending force at the depth not more than 900 mm. in service cantilevered beam layup balanced

Table 3 Span of supported beam typical Glued bamboo laminated with Para-timber size 2” x 4”

Span (mm)	Cantilever Span (mm)	Deformation (mm)
2600	900	1.1855
2800	800	1.6402
3000	700	2.1639
3200	600	2.7647
3400	500	3.4313
3600	400	4.1818
3800	300	5.0228

The span of supported beam is typical 2600 mm length and the cantilever span is 900 mm. The total possible length of span is 3500 mm and maximum span of supported beam can be used as structure at 3000 mm of possible span, total possible length is 3700 mm in service cantilevered beam layup balanced.

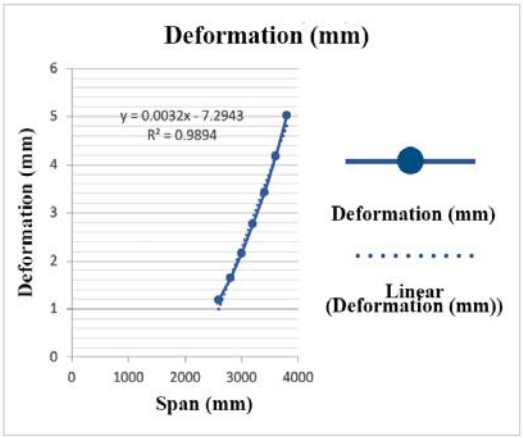

Fig. 13 Deformation graph of 2” x 4” Glued bamboo laminated with Para-timber

5. CONCLUSIONS

The following results have been observed from the Finite Element Analysis about their corresponding relationship:

5.1 Validity of Finite Element Analysis

The factors that cause the deformation behavior of the timber structure are: the layer of timber structure, size of timber, density of timber, modulus of Elastic value and distance between pillars. These make the difference on deformation. As the different mechanic properties of the elements of Glued laminated timber (Para-timber) and Glued bamboo laminated with Para-timber that affect on the different of strength and gravity on the weight. To calculate the distance between pillars, it's necessary to identify the conditions of properties of each type of timber.

In comparison, 2" x 4" glued bamboo laminated with Para timber is cheaper, and it is able to reduce the size of the 2" x 6" glued laminated Para timber laminated to 2" x 4" glued bamboo laminated with Para timber and still maintains the strength of the structure. The best result is pillar span distance of 2.60 meters, and should pass over 3.00 meters. The test of timber's property on the gravity in each distance of the pillars found that the distance of pillars that affects on each timber structure in compression force from the gravity and vertical displacement of beam.

To sum up, both type of beam can still be used as structure because the load-deflection should be at 0.10 inch (2.5 mm) according to ASTM D 143 [10] and mesh quality in finite elements analysis should be at acceptable skewness mesh metrics spectrum at 0.80 – 0.94

5.2 Future Research

The further studies could develop the glued laminated part by using other methods such as steel connector, to study the correlation between glued laminated timber connector and steel connecter. Also, the further researches could focus on different bamboo layers, as well as the method to decrease the weight of materials, since in most tests the deformation distance was caused by the weight of beam.

6. REFERENCES

[1] Turner M. J., Clough R. W., Martin H. C., and Topp L.J., Stiffness of deflection analysis of complex structures. Journal of Aeronautical Science Vol. 23, Issue 9, 1956, pp.805-824.

[2] Suryani S., Teuku R., and Shafira R., Enhanced mechanical properties of natural fiber bamboo/ pineapple leaf/ coconut husk reinforced composite for application in bio-board. Internaltional Journal of Geomate Vol. 19, Issue 75, 2020, pp.168-174.

[3] Akinlabi E. T., Fenin K. A., and Akwada D. R., Bamboo The Multi-Prpose Plant, Springer International Publishing, 2017, pp.1-3

[4] Suchat T., Physical and Mechanical of Five Bamboo Species in Thailand. Bangkok: Royal Forest Department International Tropical Timber Organization, 2004, pp.41-45

[5] Bounsong S., Vallayuth F., Piyawade B., and Warunyu R., The Physical and Mechanical Properties of Some Bamboo Species in Thailand for House Construction. Bangkok: Forest Research and Development Bureau, Royal Forest Department, 2013

[6] Davis C., Bamboo Connections. The Department of Arcihecture and Civil Engineering. Bath: The University of Bath, 2009, pp.46-47

[7] Martin C., Luis L., Ricard J., and Lessandro G., Assesment of testing protocols for bamboo for tension parallel to fiber. Internaltional Journal of Geomate Vol. 19, Issue 74, 2020, pp.31-36.

[8] Gudiyono N., Suhendro B., Awaludin A., and Triwiyono A, Creep shear deformation of glue-laminated bamboo. Internaltional Journal of Geomate Vol. 19, Issue 73, 2020, pp.185-192.

[9] Svit P., Terdsak T., and Songklod J., Mechanical Properties of Glued Bamboo Laminated with Para-Timber, Journal of KMUTNB, Vol. 30, Issue 4, 2020, pp. 689-697.

[10] Bazan I.M.M., Ultimate bending strength of timber beams, Ph.D Dissertation, Nova Scotia Technology College Halifax, N.S. 1980, pp. 269.

[11] ANSYS Inc., ANSYS Composites PrepPost User's Guide; ANSYS Inc: Canonsburg PA, USA, 2016.

[12] ASTM D143, Standard Test Methods for Small Clear Specimens of Timber. ASTM International, West Conshohocken, PA, 2007.