International Journal of GEOMATE, July 2019, Vol.17, Issue 59, pp.15 - 20
Geotec., Const. Mat. & Env., DOI: https://doi.org/10.21660/2019.59.4589
ISSN: 2186-2982 (Print), 2186-2990 (Online), Japan

IMPLEMENTATION OF CONNECTION SYSTEM OF WOODEN PLATE AND WOODEN CLAMP ON JOINT MODEL OF BAMBOO TRUSS STRUCTURES

*Astuti Masdar[1], Suprapto Siswosukarto[2], Noviarti[3], and Des Suryani[4]

Department of Civil Engineering, Sekolah Tinggi Teknologi Payakumbuh, Indonesia
[2,] Department of Civil and Environmental Engineering, Faculty of Engineering, Gadjah Mada University, Indonesia
[4]Department of Informatics, Faculty of Engineering, Universitas Islam Riau, Pekanbaru, Indonesia

*Corresponding Author, Received: 09 Nov. 2018, Revised: 03 Jan. 2019, Accepted: 20 Jan. 2019

ABSTRACT: The study of wooden plate bamboo connection system with the addition of wooden clamp was carried out taking into account the variety the angle of the stems at the joint. The loading was preceded through the application of compressive force at the joint's member understudied up to reaching the maximum load and the connection was collapsed. It is known that the strength of bamboo not parallel to the direction of the fiber is lower than those parallel to fiber. Therefore, the strength of connection must be determined considering the strength of bamboo not parallel to the fiber direction. The experiment was carried out under static loading on the bamboo truss connections model with the various angle of connection stems of 0^o, 30^o and 45^o toward bamboo fiber direction. From the test result, it was found that there is a decrease in the connection strength at stem angle of 30^o and 45^o for about 16,80% and 12,21%, respectively, compared to the strength of the stem angle of 0^o. The test results also resulted the value of average elastic stiffness *(S_e)* of the connection also indicates a decrease in the of elastic stiffness value *(S_e)* of the connection for the stem's angle 30^o and 45^o for about 42,62% and 82,95%, respectively, compared to stem angle of 0^o. It can be concluded that there is a decrease in the strength and stiffness of the joints along with the increase in stem's angle of the bamboo truss connection system using wooden plate and clamp.

Keywords: Bamboo, Connection system, Wooden plate, Wooden clamp, Truss

1. INTRODUCTION

Bamboo plants have been known as the plant of "source of livelihood". As a source of life, bamboo plants can produce a lot of oxygen. The roots of plants can store water and strengthen the soil to prevent erosion, especially in the slope of a steep cliff. For human life, the bamboo plant can be used to basic human needs such as the need for food, clothing, and housing.

Bamboo is highly an environmentally friendly construction material that suitable to support green building program as part of the program to combat global warming. Bamboo is the very fast growth of which can reach a maximum height of 15-18 cm in 4-6 weeks, while wood takes a year [1]. As a construction material, compared to wood, bamboo is a renewable material because of its rapid growth and fast growth as well as a short period of planting of about 3 - 5 years, can be used as a construction material [2].

Owing to its relatively high strength, stiffness and lightweight characteristics, bamboo is a potential substitute for wood. It is also easily worked using simple tools when employed in construction practices. Bamboo culms are available in a variety of length and have a high strength-weight ratio that makes it suitable to be used as a structural material. As a structural material, bamboo can be used in a variety of building components such as beams, columns, partitions, floors or as a truss structure. In truss structures, bamboo is commonly applied as structural members in roof construction and bridge structures.

High strength bamboo material cannot be fully utilized due to the constraints of the connection system. Researches to obtain a strong connection system to overcome the problem of the weakness of a connection have been widely done. Examples include the connection system with connecting bolts and filling cement mortar in internode of culm of bamboo [3], the connection system with gusset plate of steel and devices connecting bolts [4], the connection system with gusset plate of plywood materials and devices connecting bolts [5] and the connection system with gusset plate of plywood materials or hard wooden planks and devices connecting nails [6]. A connection system without filler material on bamboo culms with wooden gusset plate and wooden clamps used to increase the contribution to the shear at the connection has been proposed by Masdar [7].

In the development of connection system on bamboo truss structure, the behavior aspects must be considered, including the connections between components of the connection system. Furthermore, in a joint model of the bamboo truss structure, behavior the connection system for joint with variations of the angle between culm of bamboo need to know.

This paper addresses this subject, with the objective of the study (i) knowing the influence of variations of the angle between culm of bamboo on joint model against strength and stiffness of bamboo truss structure and (ii) experimentally, assessing their structural behavior and performance under statical loading.

2. DESCRIPTION OF CONNECTION SYSTEM

A connections systems that use of steel for gusset plates and relatively heavy infill material has made this connection system to be less desirable of the significant increase of structure weight and construction costs that make it uneconomical. A bamboo connection system that possesses lightweight nature but higher strength and lower cost while keeping the form of the bamboo being connected remains natural has been developed by Masdar [7], [8], [9].

The proposed bamboo connection system consists of bolts, wooden gusset plates and special wooden clamps that have been adjusted with the shape and dimension of the bamboos being connected as shown in Fig. 1. The wooden clamps were placed between the bamboo and wooden gusset plates make contact area that capable of mobilizing its friction capacity to transfer the applied load for stronger and reliable connection as shown in Fig. 2.

The wooden clamp with a ring angle of 90^o was determined to be optimal and thus recommended to be applied to connections of bamboo truss structure [7]. Based on the results of previous research conducted by Masdar [7], [8], [9] can be known that the strength of this bamboo connection system is influenced by several factors such as material characteristics in the connection system, the angle of wood clamps to the bamboo circumference and bolt tightening force.

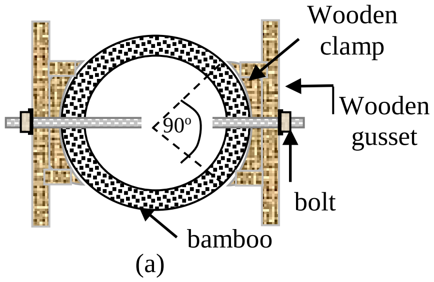


Fig. 1a The proposed bamboo connection system (truss structure) [8], [9]

Fig. 1b The component of the connection system [8], [9]

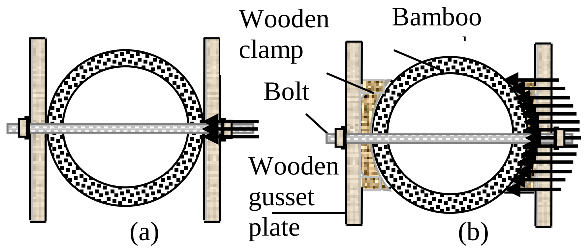


Fig. 2 Distribution of force on the bolt and wooden gusset plate to a bamboo culm (a) direct force into a bamboo culm (b) force through to a wooden clamps

3. EXPERIMENTAL INVESTIGATION

The study was conducted experimentally in two phases of testing. In the early stage of the research preliminary testing on basic properties of the materials used have been conducted. The second phase of the research involved designing and fabricating several types of joint model of bamboo truss structure with full-scale sizes and tested experimentally in the laboratory. The experiment was carried out under static loading on the bamboo truss connections model with the various angle of connection stems of 0^o, 30^o and 45^o toward bamboo fiber direction

3.1 Test Set-up

Tests on the joint model of bamboo truss structure are carried out in static loading. Static loading is carried out until it reaches ultimate load and observation on a deflection that occurs. In this test, the load-displacement relationship is measured with load instrument in the form of load cell capacity 10 Ton and displacement with LVDT capacity of 50 mm.

The testing method of basic material properties was based on ISO N22157-2 [10] for bamboo and ASTM D 143 for wood [11]. The testing method of bearing strength of bamboo was adopted from ASTM D 5764 standard test method for evaluating dowel bearing strength of wood and wood-based products [12]. Bearing strength test has been carried out on bamboo and wood with deformed bolt diameter of 12.2 mm.

The test set-up for joint models is shown in Fig. 3. The experiment was carried out under static loading on the joint model of bamboo truss structure with the various angle of connection stems toward bamboo fiber direction is shown in Fig. 4. The test is performed by giving compression test on bamboo culm with three of varied of the angle between bamboo culm.

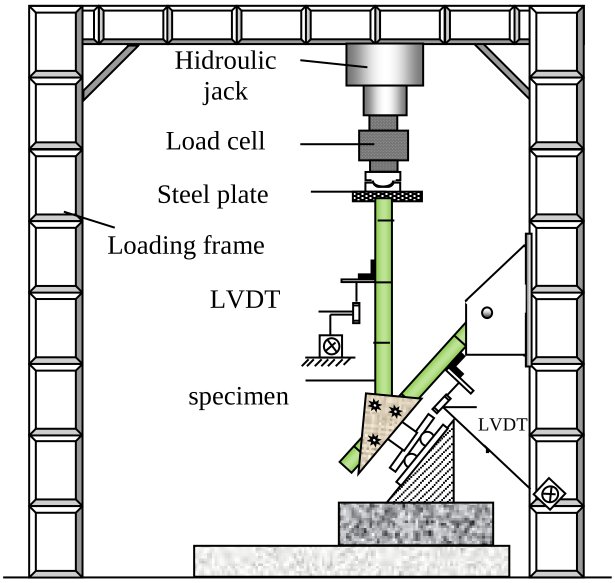


Fig. 3 Test set-up for compression tests of the specimen.

(a) (b) (c)

Fig. 4 Specimen of compression test (a) bamboo stem angle 0° (b) bamboo stem angle 30° (c) bamboo stem angle 45°

The connection system with three variations of the joint model on bamboo truss structure which is distinguished by the angle between bamboo culm, i.e. 0°, 30° and 45°, respectively. The result obtained with a compression test on a joint model of bamboo truss structure is the strength, stiffness, and behavior of the connection by observing the amount of load and deflection that occurred.

3.2 Material

The material used on the joint model of bamboo truss structure is a natural material and a bolt made of steel with a diameter of 12,2 mm. The type of bamboo used as the main structural material in this study was Gigantochloa atroviolacea. The gusset plates ware made of Keruing wood (Dipterocarpaceae), while Mahoni wood *(Swietenia Mahagoni)* was used for the clamps. The material properties used on the joint model of bamboo truss structure are shown in Tables 1, 2 and 3.

Table 1 Physical properties of the material

Material	Density gram/cm^3	Moisture Content %
Bamboo	0,62	12
Wooden clamp	0,56	12
Wooden gusset plate	0,75	12

Table 2 Mechanical properties of bamboo

Testing	Stress (MPa)	
	range	average
Compressive strength (σ_c)	51 – 56	54
Shear strength (τ)	7 – 8	7,8
Bearing strength (*fe*)	33 – 41	37
Tensile strength (σ_t)	150 – 263	217
Bending strength (σ_t)	55 – 79	58
Tensile MOE (E_t)	11219 – 18984	15450
Bending MOE (E_b)	12544 – 20620	16051

Table 3 Mechanical properties of wood

Material	Grain direction	Stress (MPa)		
		bearing (σ)	shear (τ)	Tensile (σ)
Wooden clamp	Parallel	46	6,2	
	Perpendicular	22		5,8
Wooden gusset plate	Parallel	62	8,4	
	Perpendicular	26		4,1

4. RESULTS AND DISCUSSION

4.1 The Strength and Stiffness of The Joints Model

The relationship between load and displacement obtained from the tests is shown in Fig. 5.

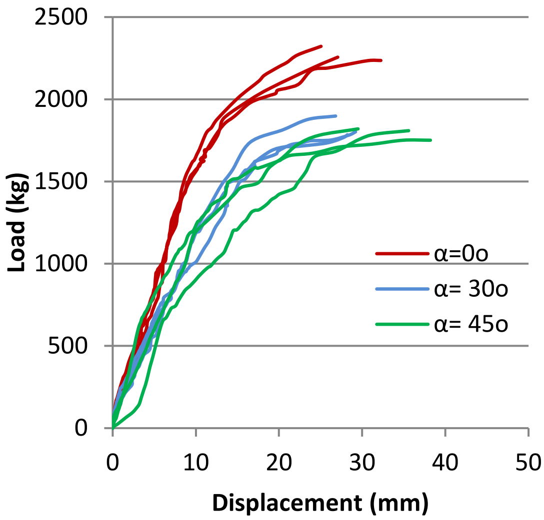


Fig. 5 The relationship between load and displacement on a joint model of the bamboo truss structure

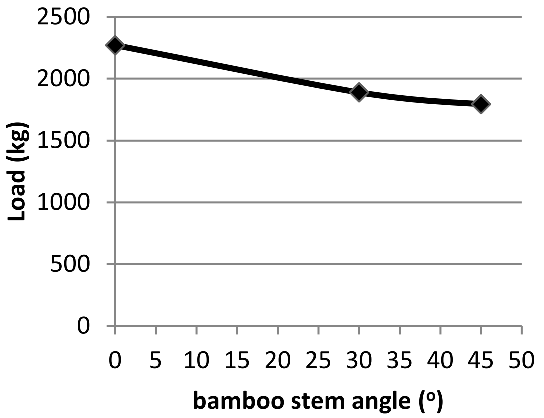


Fig. 6 Graph of the relationship between the maximum force average and bamboo stem angle variation

There are nine joint specimens with three variations of bamboo stem angle were tested under compression as shown in Fig. 5. The result of testing the connection model with the direction of force 0° toward the direction of bamboo fiber on each specimen shows the maximum load ranged from 2236 kg up to 2322 kg with displacement respectively is 32,24 mm and 25,05 mm. The result of testing the connection model with the direction of force 30° toward the direction of bamboo fiber on each specimen shows the maximum load ranged from 1802 kg up to 1967 kg with displacement respectively is 29,2 mm and 30,2 mm. The result of testing the connection model with the direction of force 45° toward the direction of bamboo fiber on each specimen shows the maximum load ranged from 1751 kg up to 1820 kg with displacement respectively is 38,2 mm and 29,58 mm.

Table 4 The average maximum strength of the connection on the compression test against the bamboo stem angle on the joint model of the bamboo truss structure

No.	Specimen	average maximum strength (kN)	Average elastis stiffness (S_e) N/mm
1.	MS (α= 0°)	22,71	2051,52
2.	MS (α= 30°)	18,89	1176,93
3.	MS (α= 45°)	17,93	1121,33

The compression test results showed that the maximum strength on a joint model of bamboo truss structure is affected by the angle of a bamboo joint. The greater the angle to the direction of bamboo fiber on the joint model of the bamboo truss structure, the strength, and stiffness of the joints are smaller as shown in Fig. 6 and listed in Table 4.

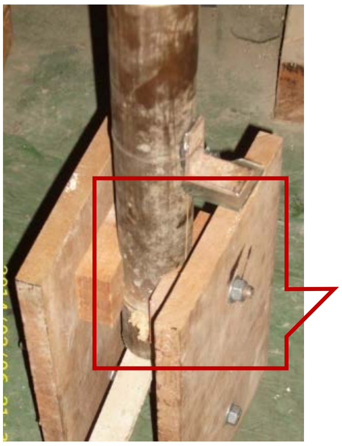
Fig. 6 showing the relationship between the maximum force average with the various angle of connection stems of 0°, 30° and 45° toward bamboo fiber direction, where the strength of the connection decreases as the angle of force increases in the connection system. The average maximum strength on the joint model of bamboo truss structure with bamboo stem angle of 0° 30° and 45° obtained from these compression tests was 22.71 kN, 18.89 kN, and 17.93 kN, respectively. From the test result, it was found that there is a decrease in the connection strength at stem angle of 30° and 45° for about 16,80% and 12,21%, respectively, compared to the strength of the stem angle of 0°.

Similarly, the test results also resulted the value of average elastic stiffness (S_e) of the connection also indicates a decrease in the of elastic stiffness value (S_e) of the connection for the stem's angle 30° and 45° for about 42,62% and 82,95%, respectively, compared to stem angle of 0°.

The maximum loads and the loads that correspond to the yielding of the connections were different among the variables of the bamboo stem angle. Based on the compression test results of the connections depicted in Fig. 6 and listed in Table 4, it can be concluded that the greater bamboo stem angle, α, the lower the strength and stiffness of the connection would be. It can be concluded that there is a decrease in the strength and stiffness of the joints along with the increase in stem's angle of the bamboo truss connection system using wooden plate and clamp.

4.2 Failure Modes of the Joints Model

Failure modes of a various angle of connection stems are presented in Fig. 7.



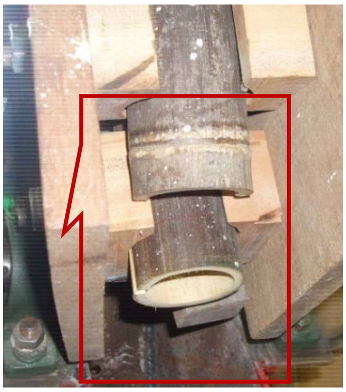
Bamboo bearing damage

(a)

Bamboo bearing damage

(b)

Bamboo bearing damage



(c)

Fig. 7 Failure modes of the specimen (a) bamboo stem angle 0º (b) bamboo stem angle 30º (c) bamboo stem angle 45º

In Fig. 7 can be seen the damage occurred on the bamboo is marked with a red line. In the specimen with stems angle of 0º, 30º and 45º, the most damage occurs in bamboo, while the other connection system components damage is not so big or just small damage.

The mechanical behavior of the components of the connection system of bamboo, wooden clamp, wooden gusset plate, and bolt connectors greatly affect the strength of the connection system on the bamboo truss structure. The mechanical behavior of material on connection system related to the strength of the connection components need to be considered to determine the strength of the connection. In this research, analytical method considering failure mode and the strength of bamboo connection will be verified with the result from experimental work. The strength of connection of bamboo and the failure mode can be estimated from the formula which was introduced by Masdar [7], [8]. In Fig. 7, it appears that the damage occurred is in the middle of the connection system (bamboo). Failure mode I occur in the specimens. Failure mode I occur when the bamboo bearing is reached. It can be concluded that the component of the connection system determines the strength of bamboo connections.

5. CONCLUSIONS

This paper presented a study about the implementation of the connection system of the wooden plate and wooden clamp on the joint model of the bamboo truss structure. The proposed connections system were implemented considering that information and references about the joint model of bamboo truss structure are very important. The following main conclusions may be drawn from this study:

1. There is a decrease in the connection strength at stem angle of 30º and 45º for about 16,80% and 12,21%, respectively, compared to the strength of the stem angle of 0º.
2. elastic stiffness (Se) of the connection also indicates a decrease in the of elastic stiffness value (Se) of the connection for the stem's angle 30º and 45º for about 42,62% and 82,95%, respectively, compared to stem angle of 0º.
3. There is a decrease in the strength and stiffness of the joints along with the increase in stem's angle of the bamboo truss connection system using wooden plate and clamp.
4. The mechanical properties of the basic material influenced the overall connection behavior, namely the bearing strength, shear strength and tensile strength perpendicular of grain, wherein the proposed connection system failure generally occurs in bamboo.

6. ACKNOWLEDGMENTS

This study was conducted by using the research funding of Hibah Berbasis Kompetensi. It is funded by DRPM DIKTI, Ministry of Research, Technology and Higher Education of Indonesia, Ref. No.065/K10/KONTRAK-PENELITIAN/2018 (DIPA Kopertis Wil X). The authors warmly thank all the sponsors and collaborators, especially to Bantuan Seminar Luar Negeri Program by directorate general strengthening research and development, DIKTI and all the bamboo lovers.

7. REFERENCES

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

[2] Morisco, Rekayasa Bambu, Nafiri Offset, 2000, pp. 1-87.

[3] Trujillo, D.J.A. Axially Loaded Connection in Guadua Bamboo, Proceedings of the 11th International Conference on Non-conventional Materials and Technologies, 2009, pp 1-8

[4] Morisco, Sambungan dengan Celah Pengisi. Jurnal Forum Teknik, Vol. 24 No.1, 2000, pp. 99-109.

[5] Davies C., Bamboo Connections. The Department of Architecture and Civil Engineering. Bath: The University of Bath, 2009, pp. 46-47.

[6] Misra, H. N. Know How of Bamboo House Construction, Proceedings of International Bambo Workshop, 1988. pp. 242-246.

[7] Masdar A., Suhendro B., Siswosukarto S., and Sulistyo J., The Study of Wooden Clamp for Strengthening of Connection on Bamboo Truss Structure. Jurnal Teknologi (Sciences Engineering), Vol. 72, Issue 5, 2015, pp. 97-103.

[8] Masdar A., Suhendro B., Siswosukarto S. and Sulistyo J., Development of Connection System Bamboo Truss Structure, Proceedings of 4th International Conference on Sustainable Future fo Human Security, 2013, pp. 78-86.

[9] Masdar A., Suhendro B., Siswosukarto S., and Sulistyo J., Influenced of a bolt of tightening force to The Strength of Connection System of Bamboo Truss Structure With Wooden Clamp, Procedia Engineering, 2017. Vol. 171. pp. 1370-1376.

[10] ISO N22157-2. Bamboo-Determination of Physical and Mechanical Properties, Part 2, Laboratory Manual, 2004.

[11] American Society for Testing and Materials. 2008. Annual Book of ASTM Standards 2008–Section 4 Volume 04.10 Wood. American Society for Testing and Materials.

[12] American Society of Mechanical Engineer, ASTM D5764: Standard Test Method for Evaluating Dowel-bearing Strength of Wood and Wood-based Products. Annual Book of ASTM Standard, 2002. Vol. 04.10., West Conshohocken, PA, USA.