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Determinant of Critical Distance of Bolt on Bamboo Connection

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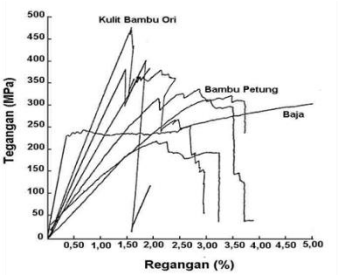
Graphical abstract



Abstract

Bamboo is a construction material that has great potential to be utilized as structural material on building construction. Bamboo available in variety length and high strength-weight ratio that make it ideal to be used as main structural component of buildings, such as column, beam, floor, partitions or trusses structural elements. High strength bamboo material can not be fully utilized due to the constraints in the connection system. The connection system adopted in joining bamboo elements on bamboo construction significantly influences the strength as well as behavior of the structure. The existence of nodes at the end of bamboo culms may improve the strength of connection. In practice, however, it is nearly impossible to have all bamboo element with nodes at the end of bamboo culms. Therefore in design of strength bamboo connection should be based on condition of end bamboo culms without nodes. In this research, analytical method considering two strength criterions is verified with result from experimental work. Results of research show that shear strength is the smallest strength among others. As bolt is used as connector in bamboo connections, shear strength commonly serves as critical criterion that determines the connection strength. This paper presents the result of study aiming at determination of minimum distance of bolt to the end of bamboo culms without node. Tests conducted by giving tensile force on the bolt with certain distance based on the analysis of shear strength and bearing strength of bamboo. The results showed that the critical distance of bolt to end of bamboo culms without node is 4-5 times the diameter of bamboo. Two main criterion of connection failure, namely shear and bearing failures are considered.

Keywords: Bamboo; bolt; critical distance; connection; mechanical properties

1.0 INTRODUCTION

Bamboo is an environmentally friendly construction material that has great potential to be used for building structures. Bamboo is a renewable and widely available natural resource that can grow in almost any geographical areas. The potential use for material construction is characterized by its high strength and low self-weight. The strength to weight ratio of bamboo is excellent compared to conventional construction materials, such as timber, steel and concrete. Estimate energy consumption for the production of several construction materials compared to stress when in use is presented in Table 1 [1].

Table 1 Energy, needed for production, compared with stress when in use

Material	Energy for Production (MJ/kg)	Density (MJ/m^3)	Energy for production (MJ/m^3)	Stress when in use (N/mm^2)	Ratio Energy per unit stress
(1)	(2)	(3)	(4)	(5)	(4)/(5)
Concrete	0,8	2400	1920	8	240
Steel	30	7800	234000	160	150
Wood	1	600	600	7,5	80
Bamboo	0,5	600	300	300	30

Table 1 shows that steel and concrete's production demand large part of energy resources, in contrary to wood and bamboo. Meanwhile, in terms of strength and density ratio, bamboo is comparable to steel but the energy production demand is only 0,1% to that of steel. Further, this information suggests that the use of bamboo for construction purposes may reduce the rate of over exploitation of energy from natural resources thereby preserving energy for future generation.

Bamboo structure is also known to have great flexibility for its formability into various structural shapes, and for its ease construction using only relatively simple tools. Another advantages of bamboo structures is characterized for its high resilient to wind, and even earthquake that make it suitable for construction materials in areas that prone to wind and earthquake treat. Bamboo is also known for its readability and repair ability in the event of damage. From economical view, the use of bamboo in building construction is very profitable owing to its cheap price and easy to obtain [2]. However, despite great advantages in utilizing bamboo for construction purposes, its application for constructing structural element is hindered due to several reasons, such as low durability, weak connection, flammable and lack of standardized technical specifications.

Bamboo is well known to have excellent strength, especially in tension. Previous research reported that bamboo has tensile

strength comparable to steel as shown in Figure 1 [3]. The strength of bamboo as a construction material is greatly influenced by its physical and mechanical properties. The mechanical properties of bamboo is affected by several aspects, such as density, botanical species of bamboo, age at which bamboo is cut, moisture content, position bamboo culms (top, middle or button culms) and existence of nodes in the culms that will produce different characteristics [4]. Therefore, tests on mechanical properties of bamboo are necessary in order to determine the variation of strength in the applications of bamboo as a material construction. The determination of mechanical properties of bamboo should follow procedures specified in Standard testing method for sizing specimen and testing procedures. Some test results of mechanical properties of bamboo, such as tensile strength, compressive strength, flexural strength, shear strength and modulus of elasticity is shown in Table 2.

High strength bamboo material can not be fully utilized due to the constraints in the connection system. The connection system adopted in joining bamboo elements on bamboo construction significantly influences the strength as well as behavior of the structure. Generally, bamboo is utilized as truss structures, hence each member of truss sustains axial forces. Therefore, in practice bamboo element will be subjected to either tension or compression forces.

Two common basis for determining the strength of bamboo connection are known, namely shear strength and bearing strength. Results of research show that shear strength is the smallest strength among others. As bolt is used as connector in bamboo connections, shear strength commonly serves as critical criterion that determines the connection strength. Split out failure might take place when bolt is mounted too close to the end of bamboo culms. The existence of nodes at the end of bamboo culms may improve the strength of connection. In practice, however, it is nearly impossible to have all bamboo element with nodes at the end of bamboo culms. Therefore in design of strength bamboo connection should be based on condition of end bamboo culms without nodes.

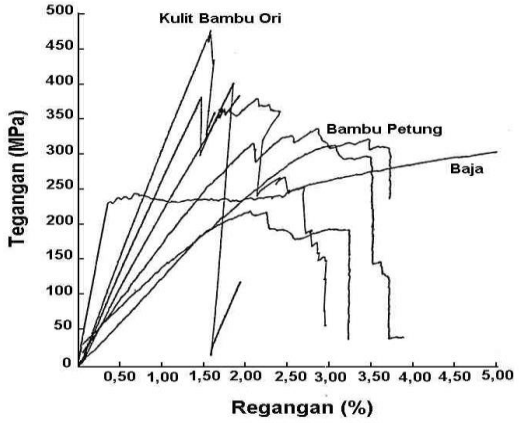


Figure 1 Testing the tensile strength of bamboo and steel [3]

Table 2 Results of the testing the mechanical properties of bamboo (dendrocolamus sp) ** [2]

Sample	Mechanical Properties				
	Compressive strength (MPa)	Tensile strength (MPa)	Shear strength (MPa)	Flexural strength (MPa)	elasticity modulus (MPa)
	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)
1.	45,11	421,44	8,06	110,79	15.099,41
2.	46,74	409,51	6,98	98,38	11.394,59
3.	61,33	375,58	7,83	177,23	14.744,99
Average	51,06	402,18	7,62	128,80	13.746,33

** Moisture content 12,63%

The bearing strength become critical as the distance between bolt and the end of bamboo culms or with other bolts exceed certain distance. When bearing strength is critical, it generally has higher strength than shear. This paper presents the result of study aiming at determination of minimum distance bolt to the end of bamboo culms without node. Two main criterion of connection failure, namely shear and bearing failures are considered.

2.0 CRITICAL DISTANCE OF BOLT

The term of critical distance is defined as failure situation when shear and bearing failures take place at the same time for certain position of bolt from the end of culms without nodes. As previously mentioned, this distance of bolt to the end culms determines the strength of connections. Formula to estimate the strength of connection is available. In this research, analytical method considering two strength criterions is verified with result from experimental work. The strength of connection of bamboo can be estimated from the following formulas shown in Figure 2 for two strength condition, namely shearing (P $_{shearing}$) and bearing (P $_{bearing}$).

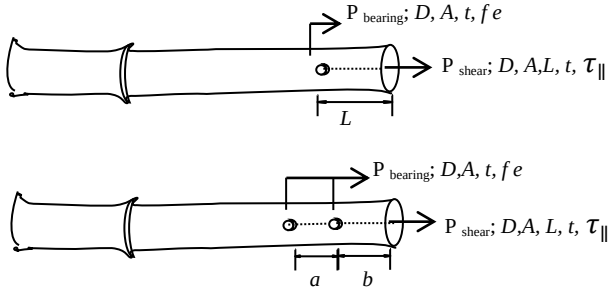


Figure 2 Arrangement of bolt, (a) specimen with one bolt (b) specimen with two bolts

From previous definition, the critical distance is obtained when P_{shear} and $P_{bearing}$ are in equilibrium. The magnitude of P_{shear} and $P_{bearing}$ can be determined from the following equation;

$$P_{shear} = A x \tau_{\parallel} \quad (1)$$

$$P_{bearing} = A x\, fe \quad (2)$$

where, $\tau_{\parallel}$ is the shear strength parallel to grain; fe is the bearing strength parallel to grain, and A is the shear area or bearing area per bolt.

For a bamboo culms with one bolt, the shear area is (see Figure 2.a):

$A = L\,(t_1 + t_2)$

Where L is the length of the shear plane; t_1 and t_2 is the thick of bamboo culms. t_1 and t_2 are introduced to accommodate the thickness difference in bamboo culms.

For a culms bamboo with one bolt, the bearing area is (see Figure 2.a):

$A = D\,(t_1 + t_2)$

Where D is the diameter of bolt; t_1 and t_2 is the thick of bamboo culms.

For a culms bamboo with two bolts, the shear area is (see Figure 2.b):

$A = L\, x\, (t_1 + t_2)$

where L isthe length of the shear plane, L= $(a + b - 1{,}5D)$, so that:

$A = (a + b - 1{,}5D)\, x\, (t_1 + t_2)$

For a culms bamboo with two bolts, the bearing area is (see Figure 2.b):

$A=2x\ D\ (t_1 + t_2)$

where t_1 and $t_2$is the thick of culms bamboo; D is the diameter of bolt.

Determination of critical distance of bolt on culms bamboo based on condition in which shear failure and bearing are equally strong, so the equation becomes:

$$P_{shear} = P_{bearing} \quad (3)$$

Substituting Equation 1, 2 into Equation 3 will yield the following equation,

$$L\ (t_1 + t_2)\ x\ \tau_{\parallel} = D\ (t_1 + t_2)\ fe$$

$$L_{cr} = \frac{D(t_1+t_2)\ fe}{(t_1+t_2)\ x\ \tau_{\parallel}} \quad (4)$$

L_{cr} is parameter that is introduced to define the critical distance of bolt to the end of bamboo culms without nodes. In this research, the value of L_{cr} determined on the basis analytical method is verified with result from experimental work.

■3.0 EXPERIMENTAL

3.1 Material

The material of specimen consists of bamboo and bolt as shown in Figure 3. The species of bamboo used as the main structural material in this study is Gigantochloa atroviolacea from Purwodadi area in the Central Java Province, Indonesia. The bamboo used in this research has an average diameter 75 mm and varies age between 3 to 5 years. Screw type of bolts with a diameter of 12.2 mm were used as connector in the bamboo connection

Figure 3 Material of specimen (a) bamboo (b) bolt with a diameter of 12,2 mm

3.2 Specimen Preparations

The bamboo specimens for obtaining physical and mechanical properties, such as moisture content, density, shear strength and bearing were prepared based on ISO N22157-1 2004 standard for bamboo specimen preparation [5]. the data of moisture content is needed as control to minimize difference on physical condition of specimens. On the basis of the results of preliminary material testing, the magnitude of *Lcr* was determined. bamboo connection specimens were prepared adopting 3 various distance of bolt, i.e. L_1 = 3D, L2=5D, and L_3=6D, respectively, as shown in Figure 4.

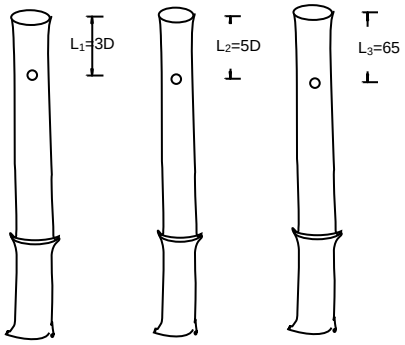


Figure 4 The specimens that depicts three variations of distance of bolt to the end of the culms bamboo without node for one bolt

3.3 Experimental Setup

The standard testing method available for strength bamboo is ISO N22157-2 2004 for shear, tension, compression and bending tests [6]. Testing on bearing strength of bamboo is not available in this ISO standard. Therefore, another standard testing method, ASTM D 5764 is adopted in this research [7]. This standard specifies the method and procedure testing of dowel bearing strength of wood and wood based product. Although this ASTM standard is specially for wood, the procedure for testing is adopted for testing bearing strength of bamboo.

Bamboo specimens were tested under compression and tensile using Universal Testing Machine connected to the data logger. The test set-up tensile test for critical distance of bolt is shown in Figure 6. Tensile load was applied gradually by a tensile testing machine. The relative displacement of joint was measured by two displacement transducers. The experiment was conducted to investigate the critical distance the bolt to the end of the culms bamboo without node.

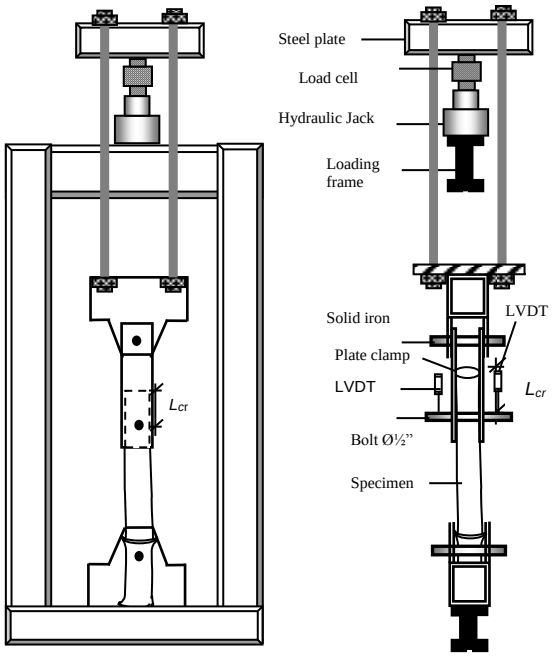


Figure 5 test set-up for tensile test of specimen

4.0 RESULTS AND DISCUSSION

The results of experiment of the physical and mechanical properties of bamboo for density, moisture content, shear strength and bearing strength of the bamboo were obtained and listed in Table 3. The specimens were tested with moisture content of about 11 to 13%. Given the inherent imperfections in bamboo as a natural material, the results obtained from the current testing are in good agreement with the results of other researchers [8, 9]. The relationship between shear strength and deflection of specimen obtained from the tests is shown in Figure 6 and the relationship between bearing strength and slip of specimen obtained from the tests is shown in Figure 7. Figure 8 shows the testing of the shear strength and bearing strength on the specimen.

Resulting of specimen of the tensile test on connection system of bamboo were obtained and listed in Table 4. Based on the observation made after testing, on the specimen showed the failure sign (see Figure 8). The type of failure on the specimen depends on the distance of bolts to the end of the culms bamboo. The result of the testing of the distance of bolts to the end of the bamboo culms without node on bamboo specimens was conducted as shown in Figure 9.

Table 3 Results of the testing of the physical properties and the mechanical properties of bamboo (Gigantochloa atroviolacea)

	Density (g/cm^3)	Moisture Content (%)	Shear strength (MPa)	Bearing Strength (MPa)
Min	0.60	11	7,5	34
Max	0.65	13	8,2	49
Ave	0.62	13	7,8	37

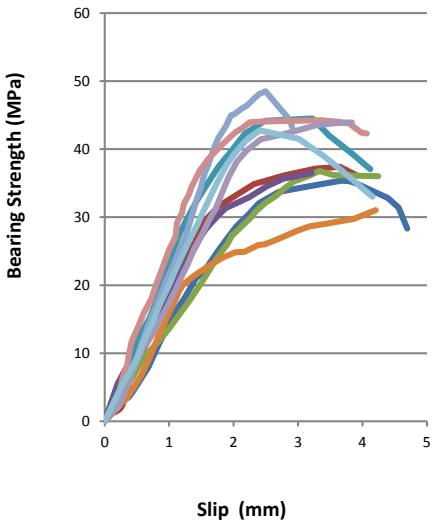


Figure 6 Graph of relationship between bearing strength and slip of specimen

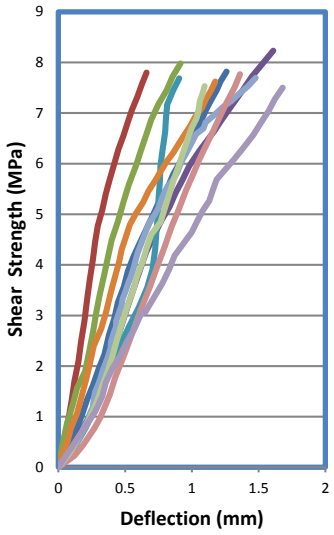


Figure 7 Graph of relationship between shear strength and deflection of specimen

Figure 8 Testing of mechanical properties of bamboo (a) shear strength (b) bearing strength

Table 4 Recapitulation of the results of testing the tensile strength of bamboo connection

Distance of bolt	Average Shear strength (MPa)	Average Bearing Strength (MPa)	Type of failure
3D	8,7	24,39	Shear failure $\tau > \tau$ $\sigma < \sigma$
5D	5,52	28,78	$\tau < \tau$ $\sigma < \sigma$
6D	7,16	40,12	Bearing failure $\tau < \tau$ $\sigma > \sigma$

Figure 9 Failure mode in the joints in tension (a) shear failure, (b) shearand bending failure occurred almost simultaneously, (c) bearing failure

Shear failure occurs in the specimen with the distance of bolts 3D, shear failure and bearing failure occurred almost simultaneously in the specimen with the distance of bolts 5D while the failure that beginning with bearing failure occurs in the specimen with the distance of bolts 6D.

■5.0 CONCLUSION

The term of critical distance is defined as failure situation when shear and bearing failures take place at the same time for certain position of bolt from the end of culms without nodes. L_{cr} is parameter that is introduced to define the critical distance of bolt to the end of bamboo culms without nodes. A comprehension verification of the analysis results against the experimental data has been performed. A good agreement has been found between the analysis results and the experimental data. In conclusion, shear strength and bearing strength is a main properties of mechanical properties of bamboo is used to analyse the distance of bolt to the end of culms bamboo without node. The proposed critical distance from the end of bamboo culms without node to the bolt is 4-5 times the bamboo diameter.

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