The Effect of Eccentricity to the Flexural Properties of Bamboo

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ABSTRACT

Bamboo culm's cross sectional area is never a perfect circle, but almost ellipse. Each ellipse shape has a unique value of eccentricity as parameter to denote its circularity. A perfect circle has a zero value of eccentricity. Conventional calculation for bamboo flexural properties as designated by ISO 22157-1:2004 resulted an overestimate or underestimate value compared to the actual value because of the perfect circle cross sectional assumption. We harvested 36 bamboo stems from 4 species namely Ampel (Bambusa *vulgaris* Schrad.), Tali (*Gigantochloa apus* (Bl.Ex Schult.f) Kurz), Gombong (*Gigantochloa verticillata* (Willd.) Munro), and Mayan (*Gigantochloa robusta* Kurz.), and found that the eccentricity value of bamboo stem could vary from 0.000 to 0.508. This paper studied the effect of eccentricity to the flexural properties of bamboo and aimed to create the strength ratio (C_e) between actual elliptical shape and assumed perfect circle shape. It was reported that the conventional calculation arise an under estimate result if the major axis (a) arranged horizontally, while overestimate result will be get if the major axis (a) arranged vertically. So the modulus of rupture (S_R) which is calculated by conventional calculation should be adjusted by the strength ratio of eccentricity (C_e) in order to define more precise value. This study result the exact relationship between C_e value and eccentricity for both conditions. For simplicity, the graphical sketches were made too.

Keyword: bamboo, eccentricity, flexural properties, strength ratio

INTRODUCTION

Bamboo is natural product which traditionally has become the rural community's main choice for many purposes in Indonesian villages because it is cheap and easy to find in their neighbourhood. Some bamboo species are used for construction material, e.g. Betung (*Dendrocalamus asper*), Tali (*Gigantochloa apus*), Andong (*Gigantochloa psedorundinaceae*), and Ampel (*Bambusa vulgaris* Schrad.). People commonly build their bamboo houses based on the traditional experiences without any engineering calculations. Since the demand for green and sustainable construction arises and spreads globally, recently bamboo construction attracts the engineer's attention because of its artistics, high performance, natural resources sustainability, and environmentally friendly. Many researcher reported the advantages of bamboo for environment (van der Lugt et al. 2006, 2012; Bahtiar et al. 2012) and, its properties compared to another materials (Hamid et al. 2012; Verma et al. 2012; Sakaray et al. 2012; Jiang et al. 2012; Yu et al. 2008; Huang et al. 2012; Li & Shen 2011), and its sustainability (Vogtlander et al. 2010; Nath et al. 2012).

As natural product, bamboo stem properties are influenced by many factors during its growth period, e.g. genetic and habitat condition. These factors create the variability in size and physical shape, then every stem could have various diameter size, taper, and eccentricity. Nugroho and Bahtiar (2012, 2013) conducted some researches of bamboo taper effect on its flexural properties. It was reported that the taper value didn't affect to flexural properties on centre point bending test, but significantly affected on third point loading bending test. So the bamboo modulus of rupture (S_R) should be adjusted by its taper strength ratio (C_t) when it was defined by third point loading bending test. Conventional method to measure the S_R of bamboo stem as designated in ISO 22157-1:2004 based on third point loading bending test resulted under estimate values than the actual ones because of no-taper assumption. Adjusting the resulted testing value with the coresponding strength ratio will result more precise value. Beside taper effect, the eccentricity on bamboo stem will affected to its flexural properties which will be studied in this paper.

Bamboo stem commonly assumed as hollow cylinder shape. Its cross sectional area is naturally never a perfect circle shape but almost ellipse. There are always maximum and minimum diameters on every pieces of cross sectional area. Some standards (e.g. ISO 22157-1:2004) designated the average value of diameter as standard value to calculate the bamboo mechanical properties. This assumption arise a new problem because it created an over or under estimate value compared to the actual properties. An overestimate mechanical properties of material could become dangerous in structural planning because the building could collapse since the overload condition, while the under estimate value created non-efficient building. It is important to study the effect of eccentricity on bamboo mechanical properties in order to plan the bamboo construction more reliable.

Eccentricity term commonly have used in physical and planetary science. Eccentricity is the parameter to measure the circularity of ellipse shape. The eccentricity value for a perfect circle is 0 (zero), while the value becomes higher for the thinner ellipse shape.

THEORETICAL BASIS

Bamboo stem's cross sectional area is commonly assumed as a perfect circle, while its actual shape is almost ellipse (Figure 1). The circle diameter (d) which calculated as average of maximum and minimum diameter of ellipse shape is commonly chosen as the standard value. The maximum and the minimum diameters in ellipse shape are called major axis (a) and minor axis (b) respectively. So the mathematical relationship between d, a, and b usually is defined as Equation 1.

$$d = \frac{a+b}{2} \tag{1}$$

The strength ratio of eccentricity (C_e) denoted as the ratio of maximum stress in actual ellipse shape (σ_e) and the assumed cylindrical shape (σ_c) (Equation 2):

$$C_e = \frac{\sigma_e}{\sigma_c} \tag{2}$$

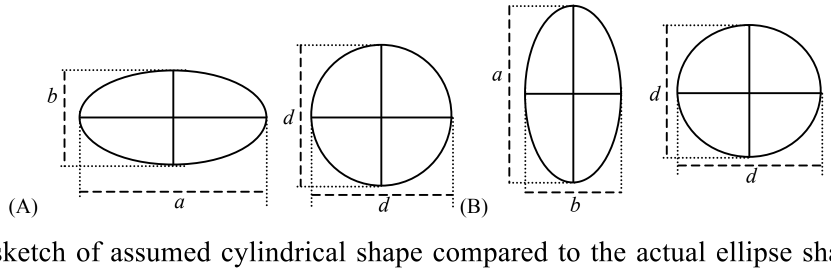


Figure 1. The sketch of assumed cylindrical shape compared to the actual ellipse shape where the major axis coincides with abscissa (A) and ordinate (B).

The bending stress in a beam under simple bending is known as Equation 3, where M, c, and I are the moment at neutral axis, centroid and moment inertia, respectively.

$$\sigma = \frac{Mc}{I} \quad . \tag{3}$$

So the eccentricity strength ratio could be defined as Equation 4, because the maximum length from centroid (*c*) is a half diameter (*d/*2) for a circle, while is a half minor axis (*b*/2) for an ellipse.

$$C_e = \frac{bI_c}{dI_e} \tag{4}$$

Substituting Equation 1 into Equation 4 it becomes:

$$C_e = \frac{2bI_c}{(a+b)I_e} \tag{5}$$

Since the moment of inertia for circle (I_c) and ellipse (I_e) shape are denoted by Equation 6 and 7 respectively, Equation 5 could be solved become Equation 8:

$$I_c = \frac{\pi}{64} d^4 \tag{6}$$

$$I_e = \frac{\pi}{64} ab^3 \tag{7}$$

$$C_e = \frac{(a+b)^3}{8ab^2} \tag{8}$$

Eccentricity is a measure of the deviation of an elliptical path, especially an orbit, from a perfect circle. It is equal to the ratio of the distance between the foci of the ellipse to the length of the major axis of the ellipse (the distance between the two points farthest apart on the ellipse). Furthermore, eccentricity can be defined as the ratio of the distance of any point on a conic section (ellipse, parabola, hyperbola, or circle) from a focus to its distance from the corresponding directrix. This ratio is describing the shape of a conic section and the value is constant for any particular conic section. By this definition, eccentricity (*e*) is known as Equation 9, so ratio of minor axis (*b*) to major axis (*a*) of ellipse could be defined as Equation 10.

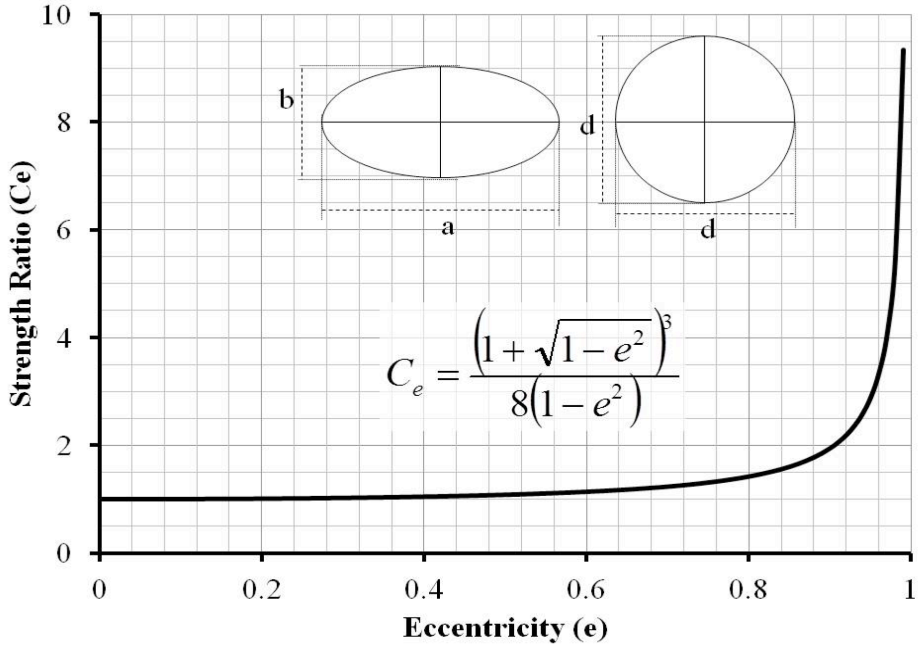
$$e = \sqrt{1 - \left(\frac{b}{a}\right)^2} \tag{9}$$

$$\frac{b}{a} = \sqrt{1 - e^2} \tag{10}$$

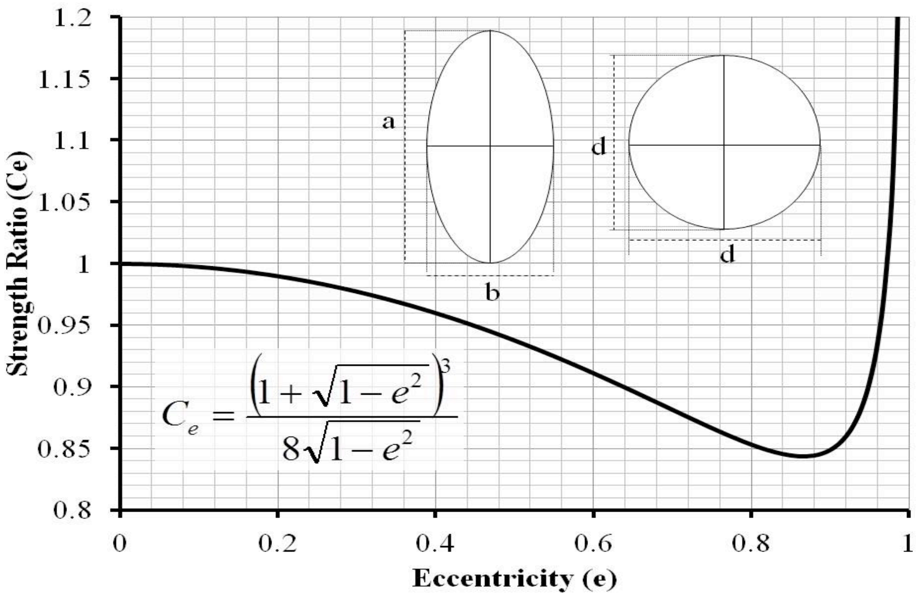
Substituting Equation 10 into Equation 8, we get the exact relationship between eccentricity with its strength ratio as seen in Equation 11, and the graphical sketch is shown in Figure 2(A).

$$C_e = \frac{\left(1+\sqrt{1-e^2}\right)^3}{8\left(1-e^2\right)} \tag{11}$$

As seen on Figure 2(A), strength ratio value for a perfect circle shape is 1 (one), while for ellipse shape is always higher than 1 (one). It is proved that the perfect circle assumption on conventional bending test resulted an under estimate flexural properties value when the major axis (a) configured horizontally during testing. The under estimate flexural properties value will made the oversize structural component. The building will be stronger but more expensive. Equation 11 and Figure 2(A) are suitable for major axis (a) arranged coincided with horizontal axis (abscissa) (Figure 1(A)).



(A)



(B)

Figure 2. Strength ratio of ellipse bamboo when major axis arranged horizontally (A) and vertically (B) during bending test

Different result will arise when the testing conducted with major axis (a) configured vertically as shown in Figure 1(B). If the major axis (a) aranged coincided with vertical axis (ordinate), the C_e value could be derived by similar way become Equation 12, and the graphical sketch is shown in Figure 2(B).

$$C_e = \frac{\left(1+\sqrt{1-e^2}\right)^3}{8\sqrt{\left(1-e^2\right)}} \tag{12}$$

Figure 2(B) showed that the strength ratio commonly lower than 1 (one). This condition proved that the conventional flexural properties are over estimate compared to the actual value. This condition could be dangerous because it leads the engineer to design smaller size structural component than the demand. In extremeem condition, the building could be collapse before estimated maximum load applied.

SURVEY ON BAMBOO ECCENTRICITY

We made a survey on a bamboo shop in Bogor, and measure the basal and top diameter of 162 bamboo tali (*Gigantochloa apus* (Bl.Ex Schult.f) Kurz) culms which have 50 – 110 cm length. The maximum diameter was defined as major axis, and minimum diameter was the minor axis. The result was shown in Table 1. Then we harvested 36 bamboo stems from 4 species namely Ampel (*Bambusa vulgaris* Schrad.), Tali (*Gigantochloa apus* (Bl.Ex Schult.f) Kurz), Gombong (*Gigantochloa verticillata* (Willd.) Munro), and Mayan (*Gigantochloa robusta* Kurz.), 9 stems from each species. Our measurement found that the bamboo cross sectional shape could vary from perfect circle into ellipse. Zero eccentricity which means a perfect circle shape found in Tali and Ampel, but it was not found in Gombong and Mayan.

Table 1
Summary of the dimensional properties of 162 culms from bamboo Tali shop in Bogor.

	Basal				**Top**				**Taper**
	d	**a**	**b**	**e**	**d**	**a**	**b**	**e**	
MIN	3.33	3.38	3.28	0.00	3.21	3.28	3.14	0.00	0.0000
MAX	7.40	7.50	7.30	0.47	7.17	7.23	7.10	0.51	0.0136
Average	5.12	5.19	5.05	0.21	4.84	4.90	4.78	0.1926	0.00439
St. dev	0.96	0.97	0.95	0.10	0.96	0.97	0.95	0.10	0.0033
Covariance	18.69	18.74	18.73	49.51	19.75	19.76	19.82	52.35	75.11

Note: d: average diameter, a: major axis (maximum diameter), b: minor axis (minimum diameter), e: eccentricity, N=162

Table 2
The eccentricity of bamboo culm and its strength ratio.

Species	**Sample size (n)**	**Major axis (a)**	**Minor axis (b)**	**Eccentricity (e)**	**Strength Ratio (C_e) for:**	
					Horizontal Major axis	**Vertical Major axis**
Tali	9	7.32 – 9.94	7.26 – 9.81	0.000 – 0.338	1.000 - 1.032	1.000 – 0.971
Ampel	9	5.73 – 8.60	4.94 – 8.12	0.000 – 0.508	1.000 – 1.087	1.000 – 0.936
Gombong	9	6.30 – 11.24	5.85 – 11.24	0.021 – 0.438	1.000 – 1.059	1.000 – 0.952
Mayan	9	7.05 – 9.89	6.32 – 9.78	0.126 – 0.498	1.004 – 1.082	0.996 – 0.938
Overall				0.000 – 0.508	1.000 – 1.087	1.000 – 0.935

Note: N= 4, a: major axis, b: minor axis, e: eccentricity

As seen on Table 2, the overall eccentricity for 36 measured bamboo stems was 0.000 – 0.508. It is similar with the survey result on the shop. This condition proved that most of bamboo cross sectional plane was almost ellipse than circle. So the conventional bamboo's flexural properties value which assumed circle shape of bamboo stem could make 0 – 8.7% under estimate value or 0 – 6.5% over estimated value compared to the actual modulus of rupture (S_R) which calculated by ellipse shape assumption

CONCLUSION

Bamboo culm cross sectional shape could vary from perfect circle into ellipse. The eccentricity which denoted the circularity of the shape affected to the measurement of bamboo stem's flexural properties.

The relationship between eccentricity and its strength ratio was determined by mathematical equation, and it was proved that circle assumption on bending test lead under estimate value if the major axis arranged horizontally on test configuration, and lead over estimate value if the major axis arranged vertically.

The measured Modulus of Rupture (SR) could be 0 – 8.7% lower or 0 – 6.5% higher than the actual value.

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REFERENCES

Bahtiar E.T , N. Nugroho, A. Carolina, A.C. Maulana. 20112. *Measuring Carbondioxide sink of Betung Bamboo (Dendrocalamus asper (Schult f.) Backer ex Heyne) by Sinusoidal Curve Fitting on Its Daily Photosynthesis Light Response*. Journal of Agricultural Science and Technology, vol. 2(7B), pp. 780-788, July 2012.

Hamid N.H., O. Sulaiman, A. Mohammad, and N.A. Ludin, 2012. *The Decay Resistance and Hyphae Penetration of Bamboo Gigantochloa scortechinii Decayed by White and Brown Rot Fungi*, International Journal of Forestry Research, vol.12, Article ID 572903, 5 pages. doi:10.1155/2012/572903.

Huang D.S., A.P Zhou, H.T. Li, Y.Su, G. Chen. 2012. *Experimental Study on the Tensile Properties of Bamboo Related to its Distribution of Vascular Bundles.* Key Engineering Materials, vol. 517, pp. 112-117.

Jiang Z., F. Chen, G. Wang, X. Liu, S.Q. Shi, H. Cheng. 2012. .*The circumferential mechanical properties of bamboo with uniaxial and biaxial compression tests*. Bioresources, vol. 7(4), pp. 4806-4816.

Li H.B. and S.P. Shen . 2011. *The mechanical properties of bamboo and vascular bundles*. Journal of Materials Research, vol. 26, pp 2749-2756.

Nath A.J., D.C. Franklin, M.J. Lawes, M.C. Das, A.K Das. 2012. *Impact of Culm Harvest on Seed Production in a Monocarpic Bamboo*. Biotropica, vol. 44, Issue 5, pages 699–704.

Nugroho, N. and E.T. Bahtiar. 2012. *Bamboo Taper Effects on Center Point Bending Test*. Journal of Physical Science and Application, vol 2(9) Sept 2012: pp.386-391.

Nugroho N. and E.T. Bahtiar. 2013. *Bamboo Taper Effects on Third Point Loading Bending Test*. Journal of Engineering and Technology.Vol 5 No.3 Jun-Jul 2013. pp 2379-2384.

Sakaray H, N.V. Vamsi Krishna Togati, I.V. Ramana Reddy. 2012. *Investigation on Properties of Bamboo as Reinforcing Material in Concrete*. International Journal of Engineering Research and Applications (IJERA), vol. 2, issue 1, pp.077-083, Jan-Feb 2012.

van der Lugt P., A.A.J.F van den Dobbelsteen, and J.J.A Janssen. 2006. *An environmental, economic and practical assessment of bamboo as a building material for supporting structures*. Construction and Building Materials, vol. 20, pp. 648-656.

van der Lugt P., J.G. Vogtländer, J.H. van der Vegte, J.C. Brezet. 2012. *Life Cycle Assessment and Carbon Sequestration; the Environmental Impact of Industrial Bamboo Products.* Proceedings 9th World Bamboo Congress, Antwerp, Belgium,

Verma C.S., V.M. Chariar, R. Purohit. 2012. *Tensile Strength Analysis of bamboo and Layered Laminate Bamboo composites*. International Journal of Engineering Research and Applications (IJERA), vol. 2, Issue 2, pp.1253-1264, Mar-Apr 2012.

Vogtländer J., P. van der Lugt, H. Brezet. 2010. *The sustainability of bamboo products for local and Western European applications*. *LCAs and land-use*. Journal of Cleaner Production, vol. 18, pp.1260-1269.

Yu H.Q., Z.H. Jiang, C.Y. Hse, T.F. Shupe. 2008. *Selected physical and mechanical properties of moso bamboo* (Phyllostachys pubescens). Journal of Tropical Forest Science, vol. 20(4), pp. 258-263,