The correlation between Ampel bamboo (Bambusa vulgaris) dimension and geometry with its modulus of elasticity

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Abstract. Traditionally, Indonesian people are used to using bamboo as construction material. Whole bamboo stems (bamboo culm) which is round and hollow, has several segments and tapered. Regarding the development of bamboo utilization for construction material, testing standards and code of practices are needed to ensure the users safety. The quality of bamboo construction can be improved by using a stress grading system. Therefore, this research is needed to obtain the grading variable that influences the modulus of elasticity of Ampel bamboo (Bambusa vulgaris). Based on analysis of their variable, bamboo's dimension and geometry are not affecting modulus elasticity value. This result shows that the further research for grading system is required to obtain identify characteristics parameter of Bambusa vulgaris that correlate with the modulus of elasticity.

1. Introduction

Bamboo has been used as a green construction material for a long time. Traditionally, bamboo is used for construction materials in culm form. As natural material such as wood, the process of determining the mechanical properties of bamboo is significantly different from factory-made materials, which the variation of quality can be controlled during the manufacturing process. The mechanical properties of each bamboo species are different. Along with the development of using bamboo for construction materials, standard test scripts and usage practices are needed to ensure user safety. Therefore, it is necessary to grading bamboo for the standard texts preparation of using bamboo for construction materials. Aside from structural grading, visual grading can also be performed on the entire surface of the bamboo, consisting of the dimensions and geometry. Visual grading is observing the condition of the geometry, size, and shape of bamboo in order to estimate the strength and capacity. Preliminary research on bamboo as a construction material was carried out by Janssen in 1981. [1] and [2] reported that stiffness and maximum moment could be used as indicators in bamboo grading. [3] reported the same thing by grading Guadua angustifolia.

Stiffness and flexural capacity determination are more reliable than the matter nature because of the dimension variety and affected by natural factors. The stiffness of a component is a function of its material and geometrical properties. The greater the stiffness value, the smaller the deflection that occurs. The moment of inertia is an important parameter to determine the stress on the structure. These parameters indicate the cross-sectional capacity to resist bending. [1] proposes bamboo as a structural product not as a material, so that sorting is better done using a basis of stiffness (EI) and bending moment when damage occurs, rather than measuring modulus of elasticity and strength. According to
[2], structural grading is better done by grading based on capacity. In line with this, [4] reported that the structural grading of *Gigantochloa apus* is better done by capacity-based grading rather than strength by relying on diameter and linear mass as predictors of stiffness and flexural capacity. By using a different species of Indonesian bamboo, this study analyzes *Bambusa vulgaris* dimensions and geometry, as a predictor in visual grading, and it correlation with the modulus of elasticity. Data can be used for recommendations on the preparation of standards for grading bamboo.

2. Material and Method

This study uses 60 pieces of *Bambusa vulgaris* (Ampel bamboo) from IPB Dramaga area (approximately length 3.5 m). Firstly, bamboo culms were dried naturally in the room temperature until the moisture content reaches equilibrium for about three months, then weighed and measured using a moisture meter. Measurement of bamboo culm dimensions refers to [5], including measurements of node distances, diameter (D), and thickness (t). The measurements of bamboo geometry include a taper, out of straightness, eccentricity and ovality referring to the method that [4] combined with [6]. Panter modulus elasticity (Ep) measurements were performed by one point loading flexure test using a Panter MPK-5 wood sorting machine with a span length of 2.5 m. This machine was operated manually by giving a fixed load in the middle of the span. Bamboo deflection was measured by using a deflectometer placed in the middle of the span and on both bamboo supports. Modulus of elasticity (Ep) and stiffness (Elp) values are obtained from Equations 1 and 2.

\[
E_p = \frac{4PL_p^3}{3\pi\Delta p(D^4 - (D - 2t)^4)} \quad (1)
\]

\[
El_p = \frac{PL_p^3}{48\Delta p} \quad (2)
\]

Where,
- P is weight of the mass (fixed load) (N)
- \(L_p\) is span length (mm)
- \(\Delta p\) is deflection of beam measured at midspan over distance between two support in Panter machine when applied by certain weight of mass (mm)

![Figure 1. Configuration of one point loading](image)

3. Results and Discussion

3.1 Conditional properties

Since bamboo is a hygroscopic material, its moisture content (MC) varies influence from the temperature of the surroundings. The process of drying bamboo in this study is done naturally for three to five months. The average moisture content of *Bambusa vulgaris* in this study was 15.29%. The different moisture content is influenced by bamboo species, culm age, and harvest season. The variation in water content of *Bambusa vulgaris* is not too high. It happens because bamboo culm have reached equilibrium water content simultaneously [7]. The measurement of water content is done after mechanical testing. Water content measurement samples are obtained from parts that are close to damage or parts that are near the middle of bamboo. According to [8], the harvest season has a large influence on the water content of bamboo. Bamboo that is cut down in the rainy season has a higher water content than bamboo that is cut down in the dry season.

3.2 Density and linear mass

Ampel bamboo density was calculated by assuming bamboo as a hollow cylinder. And the linear mass is calculated when the bamboo on air dried condition. Density and linear mass value are shows in
Table 1. Based on [9], the range of density values of *Bambusa vulgaris* can be categorized as medium to heavy construction materials. Ampel density on hollow cylinder assumption in this study is consistent with the research of [10], which is 400 to 900 kg/m$^3$.

### 3.3 Dimensional properties

Ampel bamboo thickness ranges from 4.64 mm to 12.66 mm. Thickness shows the same trend for each culm, that is, lower part of bamboo is thicker than upper part of bamboo. The difference of thickness occurs according to the bamboo growth pattern which shows the lower part of the bamboo grows earlier than the other parts of bamboo culm. Ampel bamboo diameter ranges from 51.42 mm to 77.03 mm which according to [7] can be used as a medium construction material. The diameter and thickness of bamboo in this study are higher than the diameter of bamboo kao jue and mao jue. According to [11], bamboo kao jue and mao jue are suitable for scaffolding. Based on [12], the size of ampel diameter is suitable for medium construction materials. Bamboo 5-20 cm in diameter can be used for structural purposes [13].

### Table 1. Moisture content, density, linear mass and dimensional properties of *Bambusa vulgaris*

|                | Mc (%) | $\rho$ (kg/m$^3$) | q (kg/m) | D (mm) | t (mm) | internode length (cm) |
|----------------|--------|-------------------|----------|--------|--------|-----------------------|
| Min            | 10.19  | 443.31            | 0.56     | 51.42  | 4.64   | 25.34                 |
| Max            | 20.56  | 999.75            | 1.54     | 77.03  | 12.66  | 40.68                 |
| Mean           | 15.29  | 718.20            | 1.00     | 62.98  | 8.15   | 33.82                 |
| SD             | 1.95   | 118.32            | 0.24     | 6.95   | 1.45   | 3.44                  |

### 3.4 Geometrical properties

Table 2 contains the geometrical properties of Ampel bamboo, that, taper, out of straighness, ovality and eccentricity. The ratio of differences between diameter of upper and lower part bamboo to bamboo length is called taper (t). Each species of bamboo has a different taper. Generally, the lower part of bamboo diameter is greater than the upper part diameter so the taper value will always be positive. However, there is a difference for ampel. This study found that the diameter of the upper part of Ampel bamboo is higher than the diameter of the lower part of Ampel bamboo so that Ampel bamboo has negative taper value. Taper of *Guadua angustifolia* [3], *Gigantochloa apus* [4], *Gigantochloa verticillata*, *Gigantochloa robusta* [14], and *Gigantochloa atroviolacea* [15] are positive.

Out of straightness (s) is an abnormality of geometry, deviations from the straight shape. The s-value of ampel is ranged from 0.0026 to 0.015. This value shows that Ampel bamboo does not have a perfectly straight shape.

Eccentricity (ec) is a parameter to measure the roundness of an ellipse shape. In this study, eccentricity was measured in two points, node and intenode. The ec value of Ampel bamboo shows that Ampel bamboo is not perfectly round.

Ovality (O) is the ratio between the smallest and largest diameters in one measuring point. Ampel bamboo has an oval shape, with an average ovality value of less than 1.

### Table 2. Geometrical properties of *Bambusa vulgaris*

| t   | s     | $E_c$ (node) | $E_c$ (internode) | $O_v$ (node) | $O_v$ (intenode) |
|-----|-------|--------------|-------------------|--------------|-----------------|

3
3.5 Modulus of elasticity and flexural stiffness

One point loading static bending test produces modulus of elasticity (Ep) apparent. The combination of Ep and moment of inertia (I) is called stiffness (EIp). Modulus of elasticity is measured using the assumption that bamboo is a hollow cylinder (Ep_w) and solid cylinder (Ep_c). The average of Ep in this study was smaller compared to Ep Gigantochloa apus (17954 N / mm²) [4] and larger than some tropical wood (13300 N / mm²) [8] on the hollow cylinder assumption. The stiffness (EI) of Ampel bamboo is also smaller than some other bamboo species due to its smaller diameter.

Table 3. Modulus of elasticity and flexural stiffness of Bambusa vulgaris

|            | Ep_w (N/mm²) | Ep_c (N/mm²) | EIp (Nm²) |
|------------|--------------|--------------|-----------|
| Min        | 3878         | 2657         | 1648      |
| Max        | 134664       | 81839        | 96407     |
| Mean       | 15300        | 10317        | 8893      |
| SD         | 21147        | 12904        | 16552     |

3.6 Determination of the best predictor for estimating the strength and capacity of B. Vulgaris

The modulus of elasticity that occurs at one point loading measurement is the visible modulus of elasticity. Measurement of elastic modulus (MOE) of bamboo carried out with static bending is in accordance with the principle of deflection of bending beams. In the loading configuration in the middle span, there is a sliding mechanism between the fibers. The strength and capacity of bamboo culm can be measured by nondestructive variables. However, Ep and EIp which are nondestructive variables in bamboo grading, are not influenced by the dimension and geometry of bamboo. The coefficient correlation between dimension and geometry on Ep and EI as a whole shows a low and insignificant correlation.

Table 4. Correlation of dimension and geometry on the modulus of elasticity and flexural stiffness of Bambusa vulgaris

| Pearson Correlation | Ep_w (N/mm²) | Ep_c (N/mm²) | EIp (Nm²) |
|---------------------|--------------|--------------|-----------|
| Diameter (mm)       | .102         | .070         | .286*     |
| Thickness (mm)      | -.137        | -.090        | -.049     |
| Internode length (cm)| .012         | -.014        | .102      |
### Table

| Property                        | A1  | A2  | A3  |
|--------------------------------|-----|-----|-----|
| Out of straighness             | 0.039 | 0.036 | 0.032 |
| Taper                          | 0.109 | 0.100 | 0.055 |
| Eccentricity (node)            | 0.001 | 0.009 | 0.003 |
| Eccentricity (internode)       | 0.097 | -1.06 | -1.118 |
| Ovality (node)                 | 0.046 | 0.047 | 0.035 |
| Ovality (internode)            | 0.095 | 0.106 | 0.105 |
| Moisture content (%)           | 0.058 | 0.064 | 0.092 |
| Wall density                   | 0.104 | 0.104 | 0.028 |
| Linear mass                    | 0.023 | 0.032 | 0.124 |

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed).

### 4. Conclusion
Dimensional and geometrical properties of Ampel bamboo are not correlate with its modulus of elasticity. This result shows that further research for the grading system is needed to identify characteristics paraemeter of *Bambusa vulgaris* that correlate with the modulus of elasticity.

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