The Effect of Eccentricity to the Flexural Properties of Bamboo

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10-th World Bamboo Congress
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Wood Based Material & Timber Engineering
Non Destructive Testing of Wood
Stress Grading of Bio-material
Innovation on Bamboo Sandwich Panel

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Bamboo bridge, Green School, Bali
Bamboo Diversity in Indonesia

Among 1400 bamboo species in the world, Indonesia has 161 species (11.5%)
126 origin species
94 endemic species
35 introduced species
20 species potential for industry

Sumatra 76 species
Java 59 species
Bali 36 species
Papua 32 species
Sulawesi 25 species
Kalimantan 23 species
Lesser Sunda Island 17 species
Moluccas 14 species

Notes: Value above (black) the line are the total number of species
Value under (red) the line are the total number of endemic species

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(Widjaja 2011)
Indonesia has 2,104,000 ha bamboo plantation (forest land 690,000 ha and community forest 1,414,000 ha)
<table>
<thead>
<tr>
<th>No</th>
<th>Standard</th>
<th>Indonesian</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SNI 8020-2014</td>
<td>Kegunaan Bamboo</td>
<td>Bamboo Utilization</td>
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<tr>
<td>2</td>
<td>SNI 7944-2014</td>
<td>Bambu Lamina Penggunaan Umum</td>
<td>General Purposes of Bamboo Lamination</td>
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<td>3</td>
<td>SNI 01-4033-1996</td>
<td>Rebung Bambu dalam Kaleng</td>
<td>Canned Bamboo Shoot</td>
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<tr>
<td>4</td>
<td>SNI 7555.22-2011</td>
<td>Furniture (Bagian 22) Kursi Tamu: Bambu</td>
<td>Furniture (Part 22) Guest Chair</td>
</tr>
<tr>
<td>5</td>
<td>SNI 7555.24-2011</td>
<td>Furniture (Bagian 22) Meja Tamu: Bambu</td>
<td>Furniture (Part 22) Guest Table</td>
</tr>
</tbody>
</table>
Indonesian Standard on Bamboo

SNI 8020-2014 Bamboo Utilization

- Bamboo as construction material
- Bamboo as furniture material
- Bamboo as handicraft and household utensils
- Bamboo as music instrument

SNI 7944-2014 General Purposes of Bamboo Lamination

- Classification
- Dimension requirement
- Moisture Content
- Delamination Test
- Sampling Method
- Testing
- Visual grade requirement
- Marketing and Packaging

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## Indonesian Standard on Bamboo (adoption)

...... still in progress

<table>
<thead>
<tr>
<th>No</th>
<th>Standard</th>
<th>Indonesian</th>
<th>English</th>
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<tbody>
<tr>
<td>1</td>
<td>SNI ISO 22156-2015</td>
<td>Bambu- Desain Struktur</td>
<td>Bamboo–Design Structure</td>
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<tr>
<td>2</td>
<td>SNI ISO22157.1-20....</td>
<td>Bambu: Penentuam Sifat Fisis dan Mekanis-Bagian 1- Persyaratan</td>
<td>Bamboo-Determination of Physical and Mechanical Properties-Part 1: Requirements</td>
</tr>
</tbody>
</table>
Bamboo Preservation and Drying

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Bamboo joint connection
Bamboo Truss and Bridge
Problem Areas

- Large Variation in properties of a species
- Large number of species
- ISO 22157: material properties sample
- Low values of safe stress
- Errors in property estimates as sample section is not uniform and round, constant thickness
- Analysis based on tube
Design with Bamboo Culms

1. Shape is restricted to approx. round only
2. Dimensions is also restricted
3. No standard tables for section properties
4. Requirements: Values of:
   • Elastic Modulus
   • Allowable Stress
   • Allowable deflection
   • Moment of Inertia and Section Modulus
Grading of Structural Bamboo for structural utilization

Deals with as under:

• Diameter and length of culm
• Taper of culm
• Straightness of culm
• Internodal length
• Wall thickness
• Density and strength
• Durability and seasoning
Preliminary study

• As natural product, bamboo culm 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.
• Bamboo diameter commonly is not the same size along the stem, but the basal diameter is higher than the top. We define taper as ratio between diameter difference and its length.
The taper effect on one point bending test

\[ \frac{d}{dx} \left( 16Px(d_{uo} + t \cdot l_o x)/(d_{uo} + t \cdot l_o x)^4 - (d_{ui} + t \cdot l_i x)^4 \right) = 0; \text{ for } 0 \leq x \leq L/2 \]

\[ (16P(d_{uo} + 2t \cdot l_o x)/(d_{uo} + t \cdot l_o x)^4 - (d_{ui} + t \cdot l_i x)^4 ) - (16Px(d_{uo} + t \cdot l_o x)(4t \cdot l_o (d_{uo} + t \cdot l_o x)^3 - 4t \cdot l_i (d_{ui} + t \cdot l_i x)^3 )/(d_{uo} + t \cdot l_o x)^4 - (d_{ui} + t \cdot l_i x)^4 )^2 = 0; \]
Preliminary study (cont.)

• The taper value didn’t affect to flexural properties on centre point bending test, but significantly affected on third point loading bending test.

• 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 corresponding strength ratio will result more precise value.
The taper effect on third point bending test

\[ C_t = \frac{(d_{to} + t_o \frac{L}{2})^3 - (d_{to} + t_o \frac{L}{2})^3}{(d_{to} + t_o \frac{L}{3})^3 - (d_{to} + t_o \frac{L}{3})^3}; \]

for \(0 \leq t \leq 0.0269\)

\[ y = -174.3x^2 - 8.634x + 0.999 \quad R^2 = 1 \]

\[ y = -506.8x^2 - 253.3x - 2.552 \quad R^2 = 1 \]
Cross section variability .....

• 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, than 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.

• This presentation will investigate the eccentricity on bamboo culm that affected to its flexural properties
• 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.

• The strength ratio of eccentricity ($C_e$) denoted as the ratio of maximum stress in actual ellipse shape ($\sigma_e$) and the assumption cylindrical shape ($\sigma_c$)

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

• cylindrical shape compared to the actual ellipse shape where the major axis coincides with horizontally (A) and vertically (B).
Survey on bamboo taper and eccentricity

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

<table>
<thead>
<tr>
<th></th>
<th>Basal</th>
<th></th>
<th>Top</th>
<th></th>
<th>Taper</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d</td>
<td>a</td>
<td>b</td>
<td>e</td>
<td>d</td>
</tr>
<tr>
<td>MIN</td>
<td>3.33</td>
<td>3.38</td>
<td>3.28</td>
<td>0.00</td>
<td>3.21</td>
</tr>
<tr>
<td>MAX</td>
<td>7.40</td>
<td>7.50</td>
<td>7.30</td>
<td>0.47</td>
<td>7.17</td>
</tr>
<tr>
<td>Average</td>
<td>5.12</td>
<td>5.19</td>
<td>5.05</td>
<td>0.21</td>
<td>4.84</td>
</tr>
<tr>
<td>St. dev</td>
<td>0.96</td>
<td>0.97</td>
<td>0.95</td>
<td>0.10</td>
<td>0.96</td>
</tr>
<tr>
<td>Covariance</td>
<td>18.69</td>
<td>18.74</td>
<td>18.73</td>
<td>49.51</td>
<td>19.75</td>
</tr>
</tbody>
</table>

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

- Measurement of 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 Eccentricity of Bamboo Culm and Its Strength Ratio

<table>
<thead>
<tr>
<th>Species</th>
<th>Sample size (n)</th>
<th>Major axis (a)</th>
<th>Minor axis (b)</th>
<th>Eccentricity (e)</th>
<th>Strength Ratio ($C_e$) for:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Horizontal Major axis</td>
</tr>
<tr>
<td>Tali</td>
<td>9</td>
<td>7.32 – 9.94</td>
<td>7.26 – 9.81</td>
<td>0.000 – 0.338</td>
<td>1.000 - 1.032</td>
</tr>
<tr>
<td>Ampel</td>
<td>9</td>
<td>5.73 – 8.60</td>
<td>4.94 – 8.12</td>
<td>0.000 – 0.508</td>
<td>1.000 – 1.087</td>
</tr>
<tr>
<td>Gombong</td>
<td>9</td>
<td>6.30 – 11.24</td>
<td>5.85 – 11.24</td>
<td>0.021 – 0.438</td>
<td>1.000 – 1.059</td>
</tr>
<tr>
<td>Mayan</td>
<td>9</td>
<td>7.05 – 9.89</td>
<td>6.32 – 9.78</td>
<td>0.126 – 0.498</td>
<td>1.004 – 1.082</td>
</tr>
<tr>
<td>Overall</td>
<td></td>
<td>7.05 – 9.89</td>
<td>6.32 – 9.78</td>
<td>0.000 – 0.508</td>
<td>1.000 – 1.087</td>
</tr>
</tbody>
</table>

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

- 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.
Strength ratio of ellipse bamboo when major axis arranged horizontally

- 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 underestimate flexural properties value when the major axis (a) configured horizontally during testing.
- The underestimate flexural properties value will make the oversize structural component.
- The building will be stronger but more expensive.
Strength ratio of ellipse bamboo when major axis arranged vertically

- 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 extreme condition, the building could be collapse before estimated maximum load applied.
Conclussion

• 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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On going research in various ellips section ......

\[ y^2 = \frac{b^2}{a^2 (1 + mx)} (a^2 - x^2) \]

\[ y^2 = \frac{b^2}{a^2} (a^2 - x^2)(1 - mx) \]

\[ y^2 = \frac{b^2 (a^2 - x^2)}{a^2 e^{mx}} \]
TERIMA KASIH ...
THANK YOU ...
ありがとうございます...
감사합니다...