The Effect of Eccentricity to the Flexural Properties of Bamboo

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Bamboo bridge, Green School, Bali

Expertise:

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 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

(Widjaja 2011)


Dendrocalamus asper


Gigantochloa pseudoarundinacea


Gigantochloa nigrociliata

Indonesia has 2,104,000 ha bamboo plantation (forest land 690,000 ha and community forest 1,414,000 ha)


Gigantochloa robusta

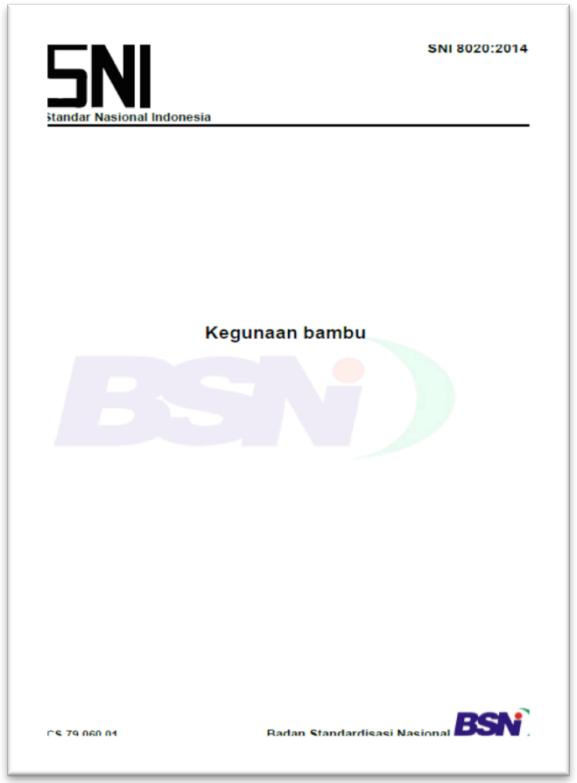

Gigantochloa atroviolacea


Gigantochloa apus

Indonesian Standard on Bamboo

No	Standard	Indonesian	English
1.	SNI 8020-2014	Kegunaan Bamboo	Bamboo Utilization
2	SNI 7944-2014	Bambu Lamina Penggunaan Umum	General Purposes of Bamboo Lamination
3	SNI 01-4033-1996	Rebung Bambu dalam Kaleng	Canned Bamboo Shoot
4	SNI 7555.22-2011	Furniture (Bagian 22) Kursi Tamu: Bambu	Furniture (Part 22) Guest Chair
5	SNI 7555.24-2011	Furniture (Bagian 22) Meja Tamu: Bambu	Furniture (Part 22) Guest Table

Indonesian Standard on Bamboo



- Bamboo as construction material
- Bamboo as furniture material
- Bamboo as handicraft and households ustensil
- Bamboo as music instrument

SNI 8020-2014 Bamboo Utilization

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

SNI 7944-2014 General Purposes of Bamboo Lamination

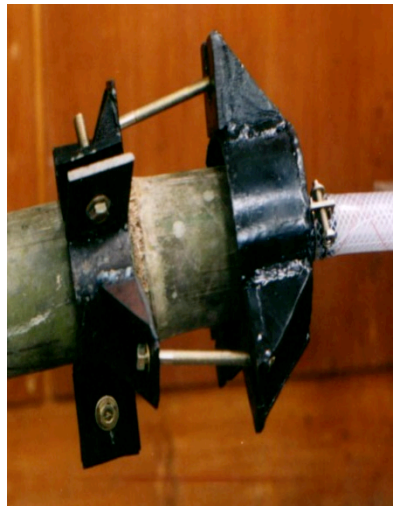
Indonesian Standard on Bamboo (adoption)

..... still in progress

No	Standard	Indonesian	English
1.	SNI ISO 22156-2015	Bambu- Desain Struktur	Bamboo–Design Structure
2	SNI ISO22157.1-20....	Bambu: Penentuam Sifat Fisis dan Mekanis-Bagian 1- Persyaratan	Bamboo-Determination of Physical and Mechanical Properties-Part 1: Requirements
3	SNI ISO 22157.2-20....	Bambu: Penentuam Sifat Fisis dan Mekanis-Bagian 1- Manual Laboratorium	Bamboo-Determination of Physical and Mechanical Properties-Part 2: Laboratory Manual

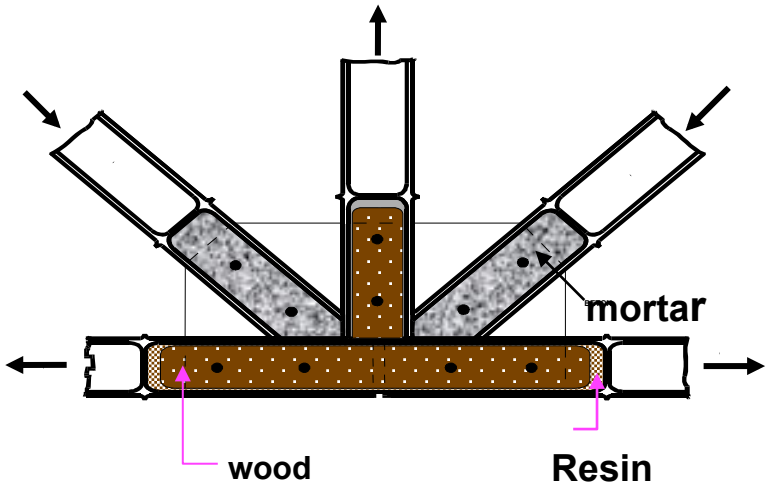
Bamboo Preservation and Drying





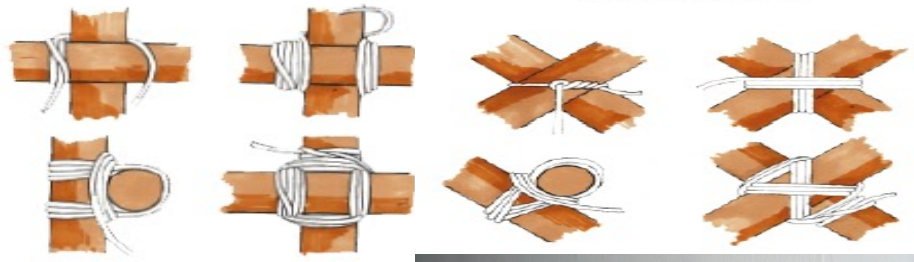


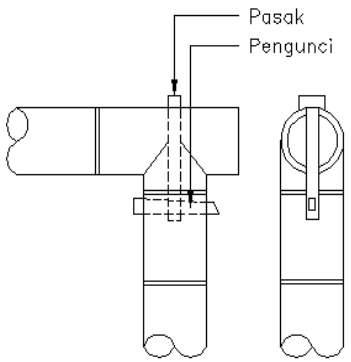
Bamboo joint connection



Traditional Square Lashing

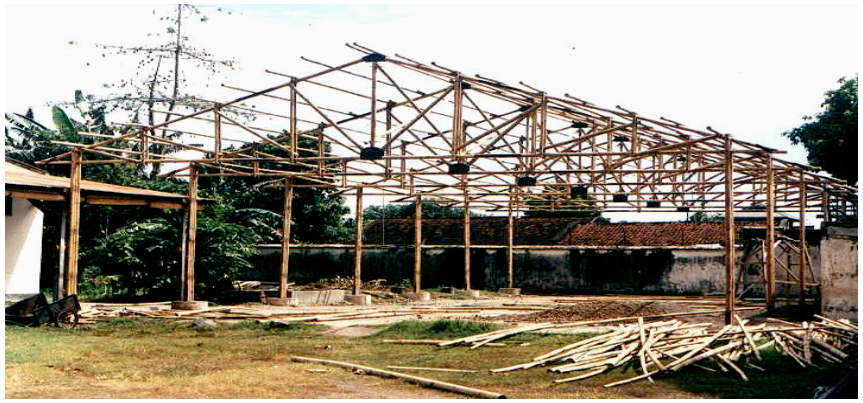
Diagonal Lashing

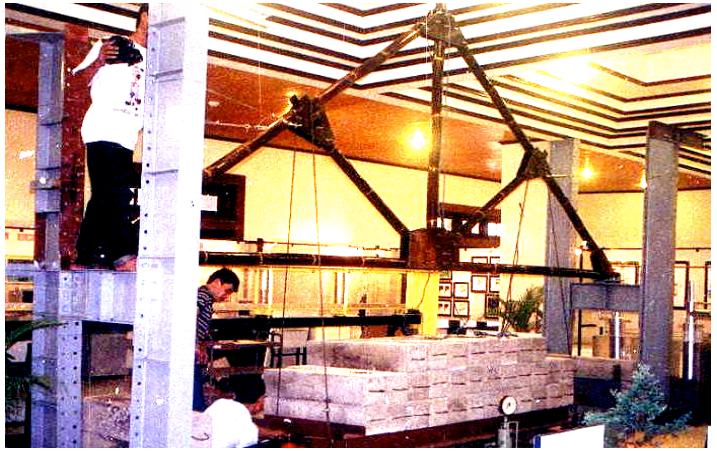


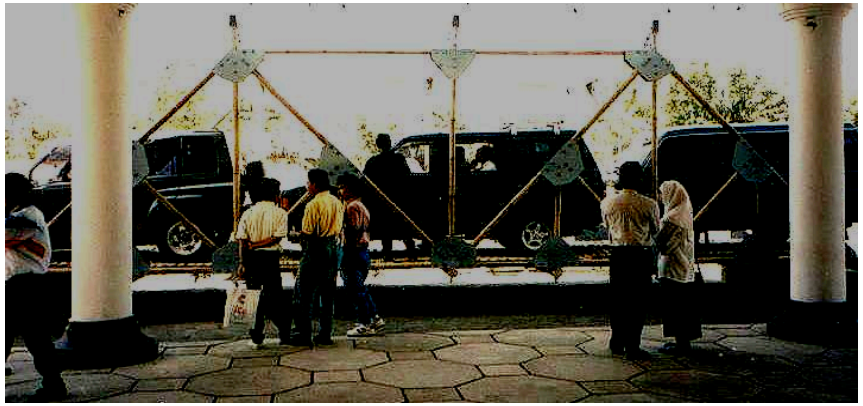


(Janssen, 1998)

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

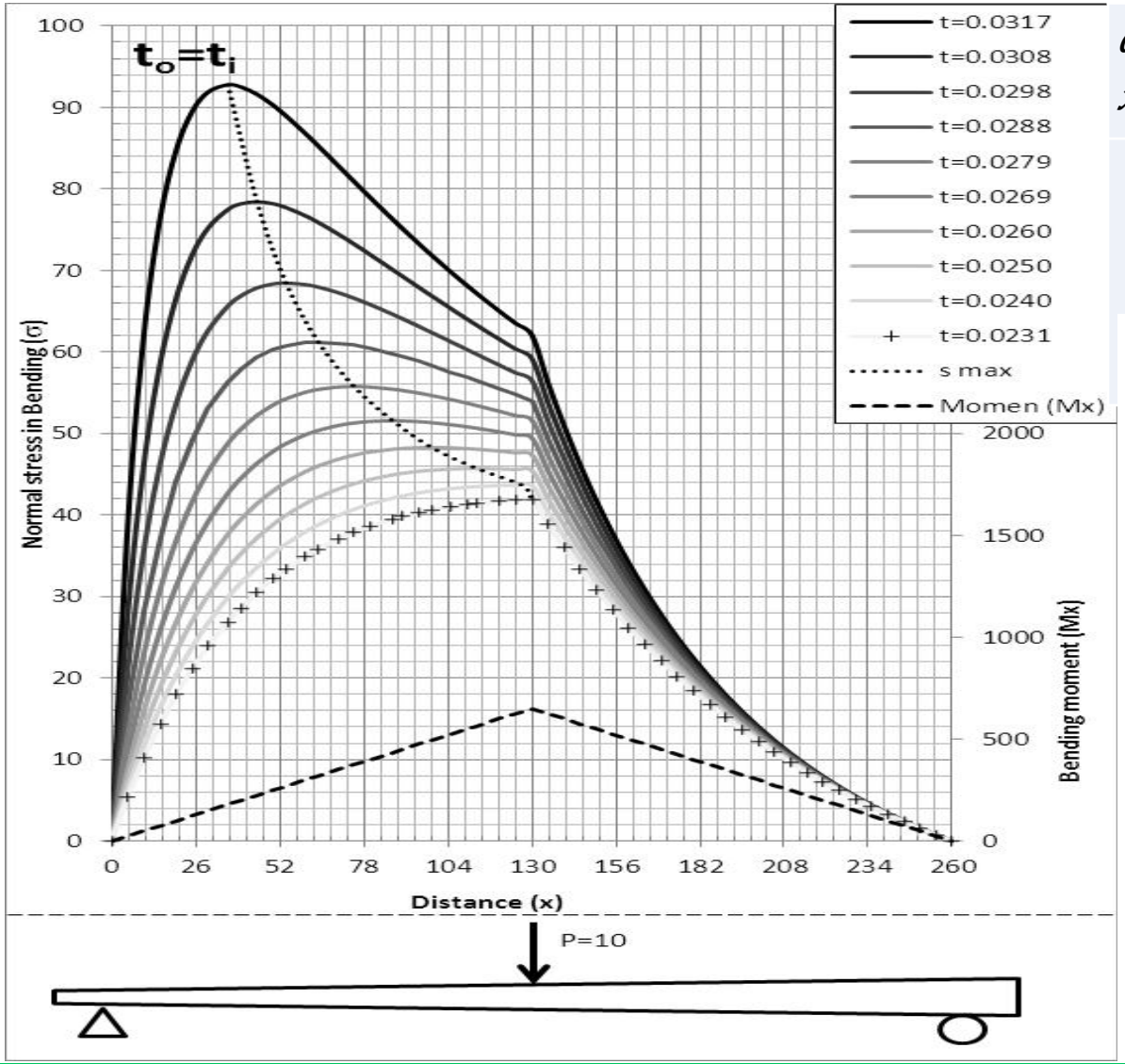
Deals with as under:

- Diameter and length of culm
- Taper of culm
- Straightness of culm
- Internodal length
- Wall thickness
- Density and strength
- Durability and seasoning

Preliminary study

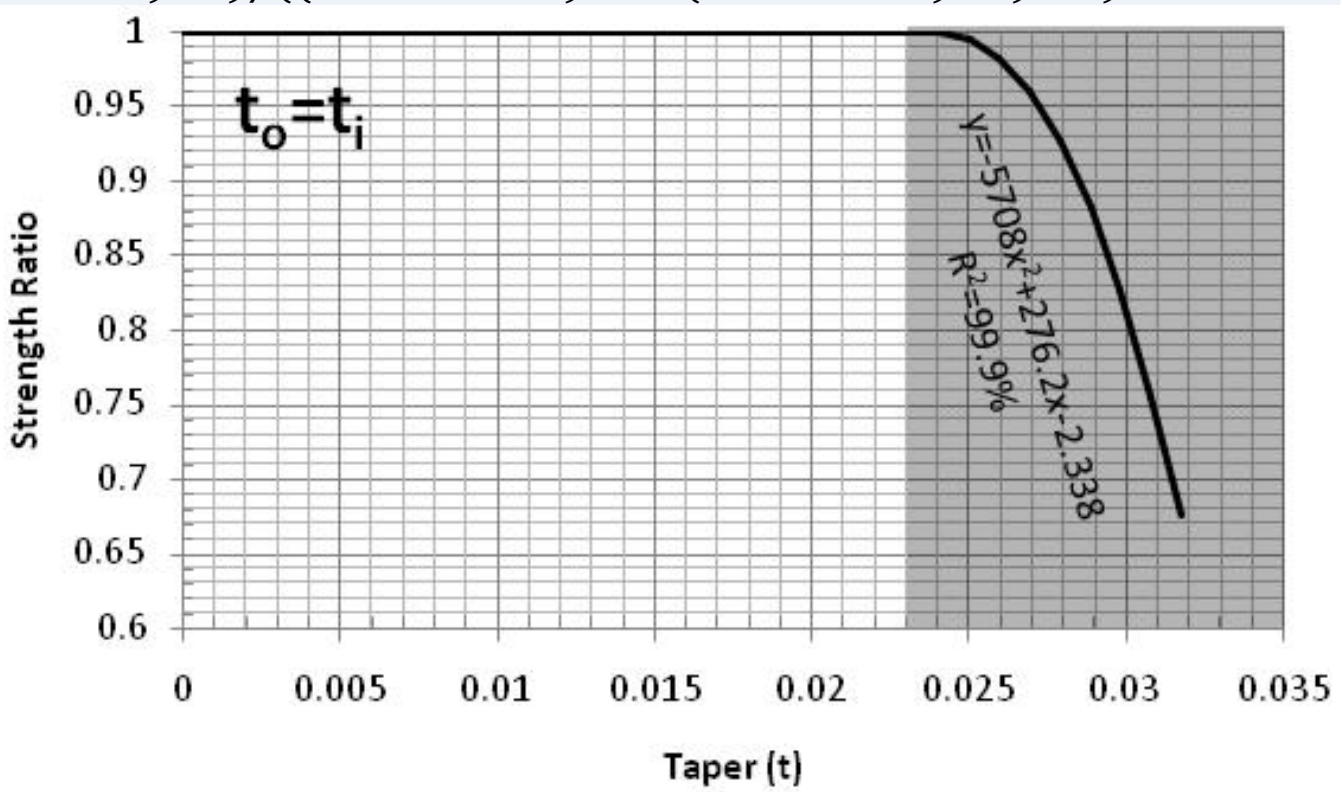
- As natural product, bamboo culm properties are influenced by many factors during its growth period, e.g. genetic and habitat condition.
- These factors create the variability in size and physical shape, then every stem could have various diameter size, taper, and eccentricity.
- Nugroho and Bahtiar (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



$$d/d\downarrow x\ (16Px(d\downarrow uo+t\downarrow o\ x)/((d\downarrow uo+t\downarrow o\ x)\uparrow 4-(d\downarrow ui+t\downarrow i\ x)\uparrow 4\ ))=0;\ for\ 0\le x\le L/2$$

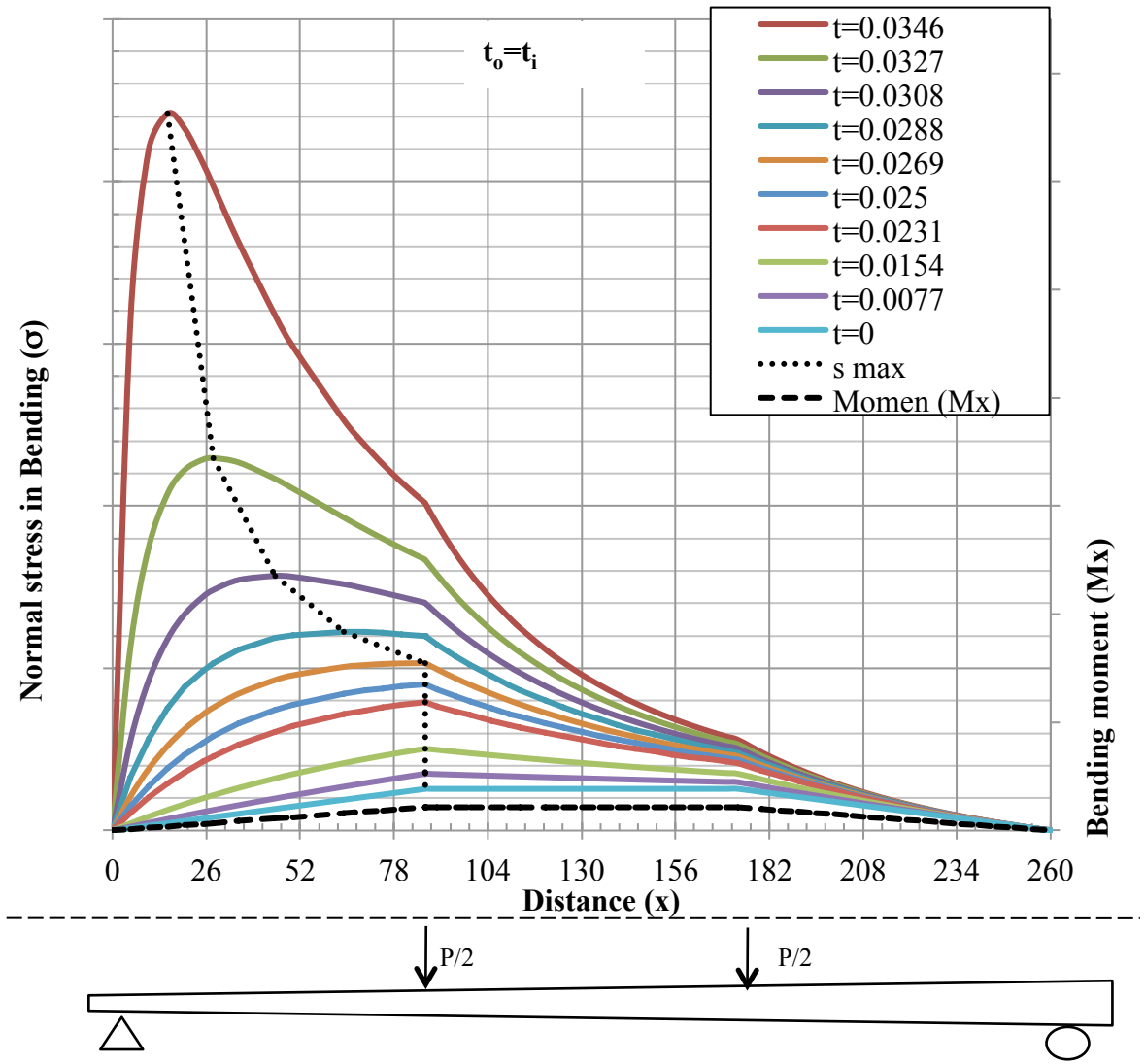
$$(16P(d\downarrow uo+2t\downarrow o\ x)/((d\downarrow uo+t\downarrow o\ x)\uparrow 4-(d\downarrow ui+t\downarrow i\ x)\uparrow 4\ ))-(16Px(d\downarrow uo+t\downarrow o\ x)(4t\downarrow o\ (d\downarrow uo+t\downarrow o\ x)\uparrow 3-4t\downarrow i\ (d\downarrow ui+t\downarrow i\ x)\uparrow 3\ )/((d\downarrow uo+t\downarrow o\ x)\uparrow 4-(d\downarrow ui+t\downarrow i\ x)\uparrow 4\ )\uparrow 2\ )=0;$$



Preliminary study (cont.)

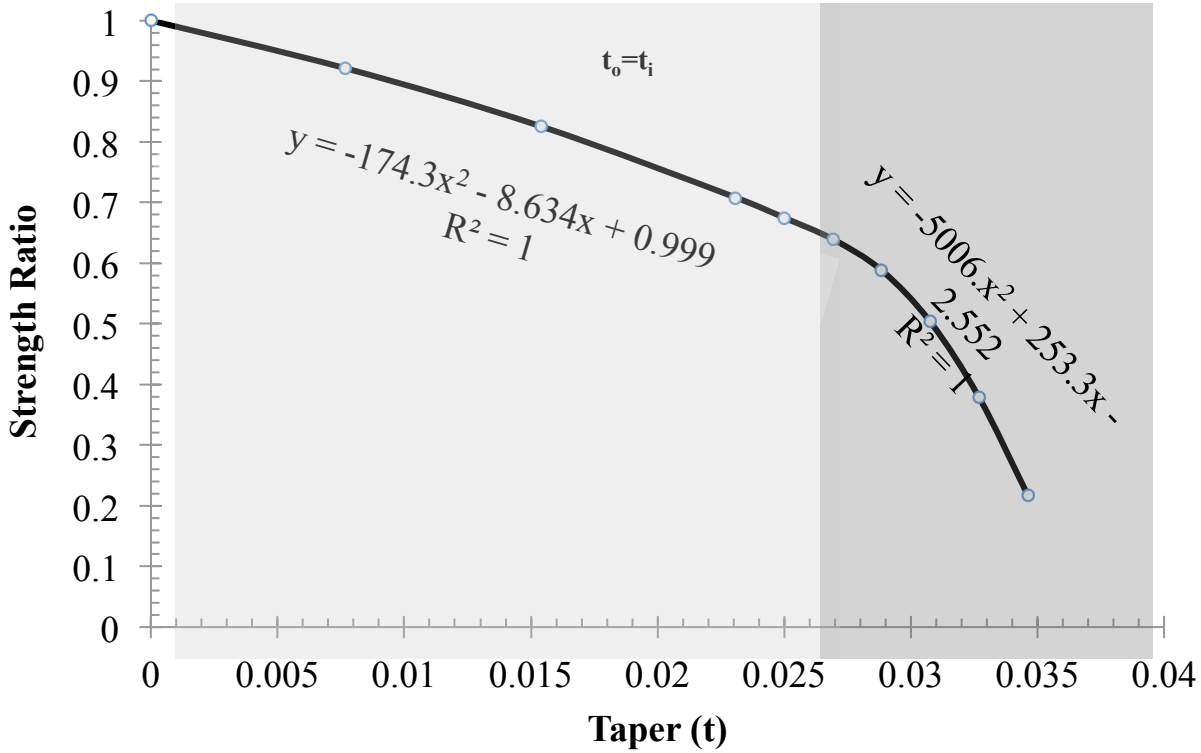
- The taper value didn't affect to flexural properties on centre point bending test, but significantly affected on third point loading bending test.
- The bamboo modulus of rupture (S_R) should be adjusted by its taper strength ratio (C_t) when it was defined by third point loading bending test.
- Conventional 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 coresponding strength ratio will result more precise value.

The taper effect on third point bending test



$$C_t = \frac{\left(d_{to} + t_o \, L/3\right)}{\left(d_{to} + t_o \, L/2\right)} \frac{\left(\left(d_{to} + t_o \, L/2\right)^4 - \left(d_{ti} + t_i \, L/2\right)^4\right)}{\left(\left(d_{to} + t_o \, L/3\right)^4 - \left(d_{ti} + t_i \, L/3\right)^4\right)};$$

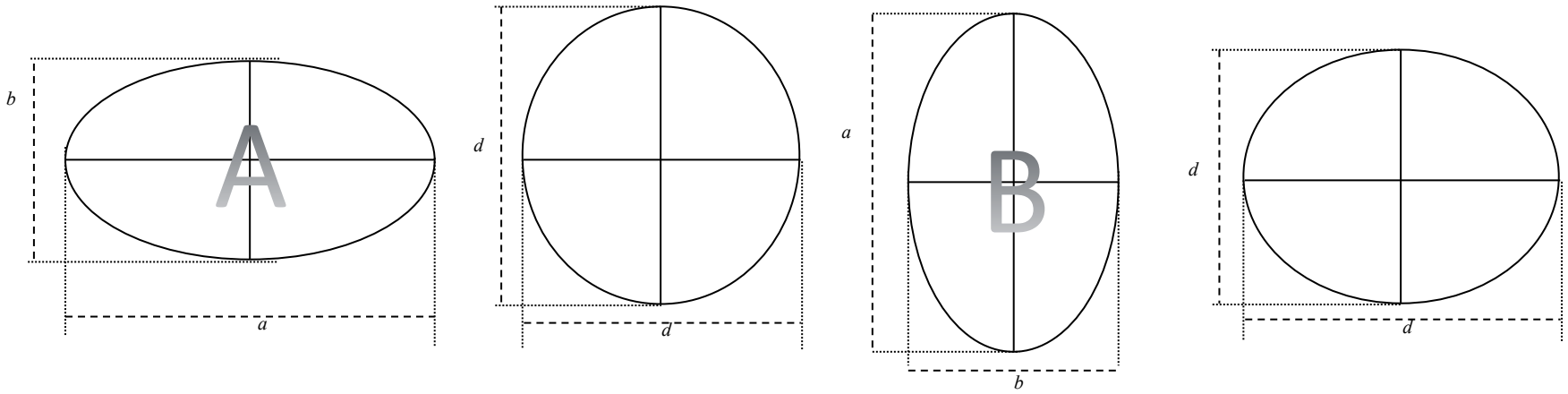
for $0 \le t \le 0.0269$



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 (σ_e) and the assumtion cylindrical shape (σ_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.

	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

- 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.

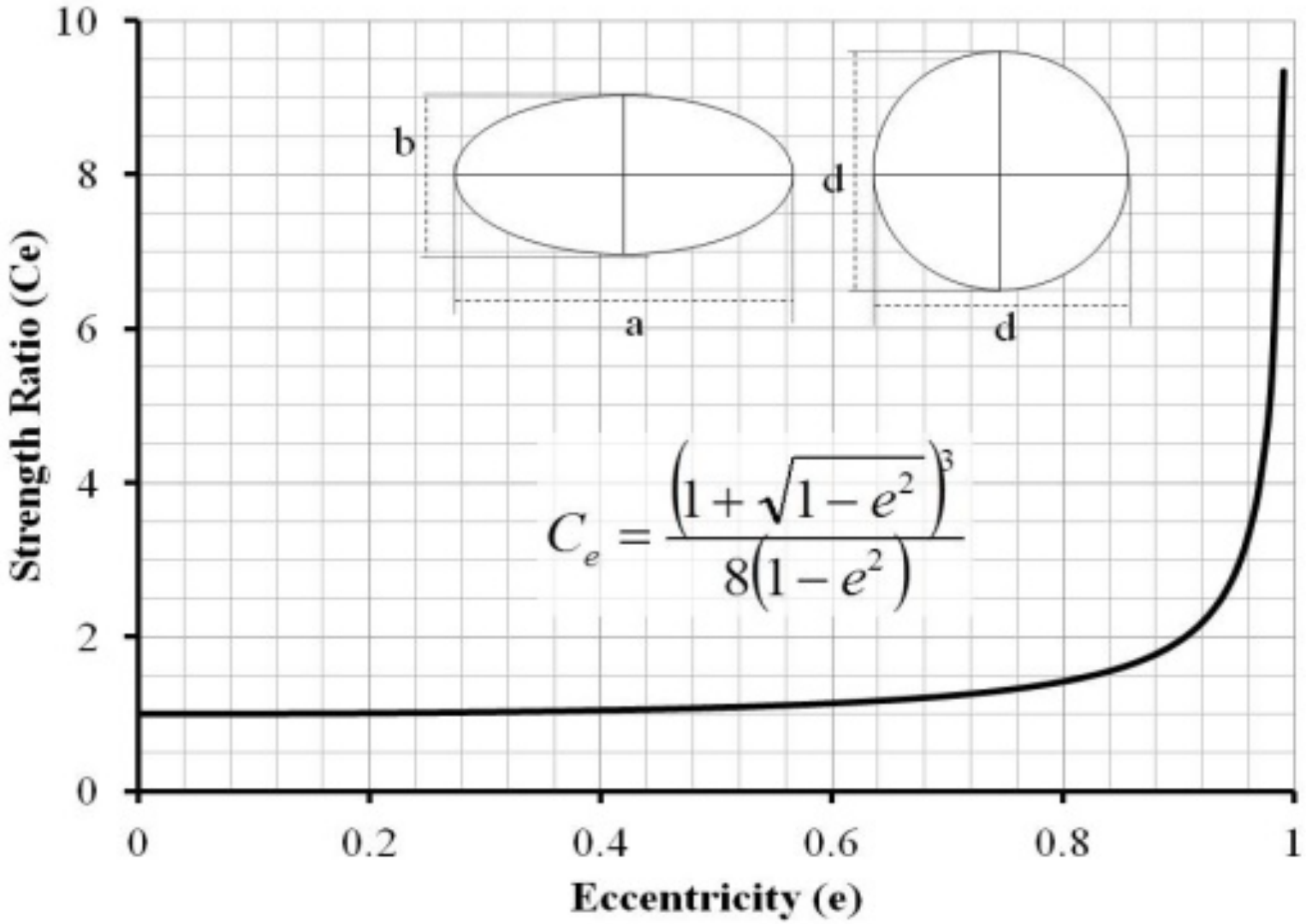
THE ECCENTRICITY OF BAMBOO CULM AND ITS STRENGTH RATIO

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

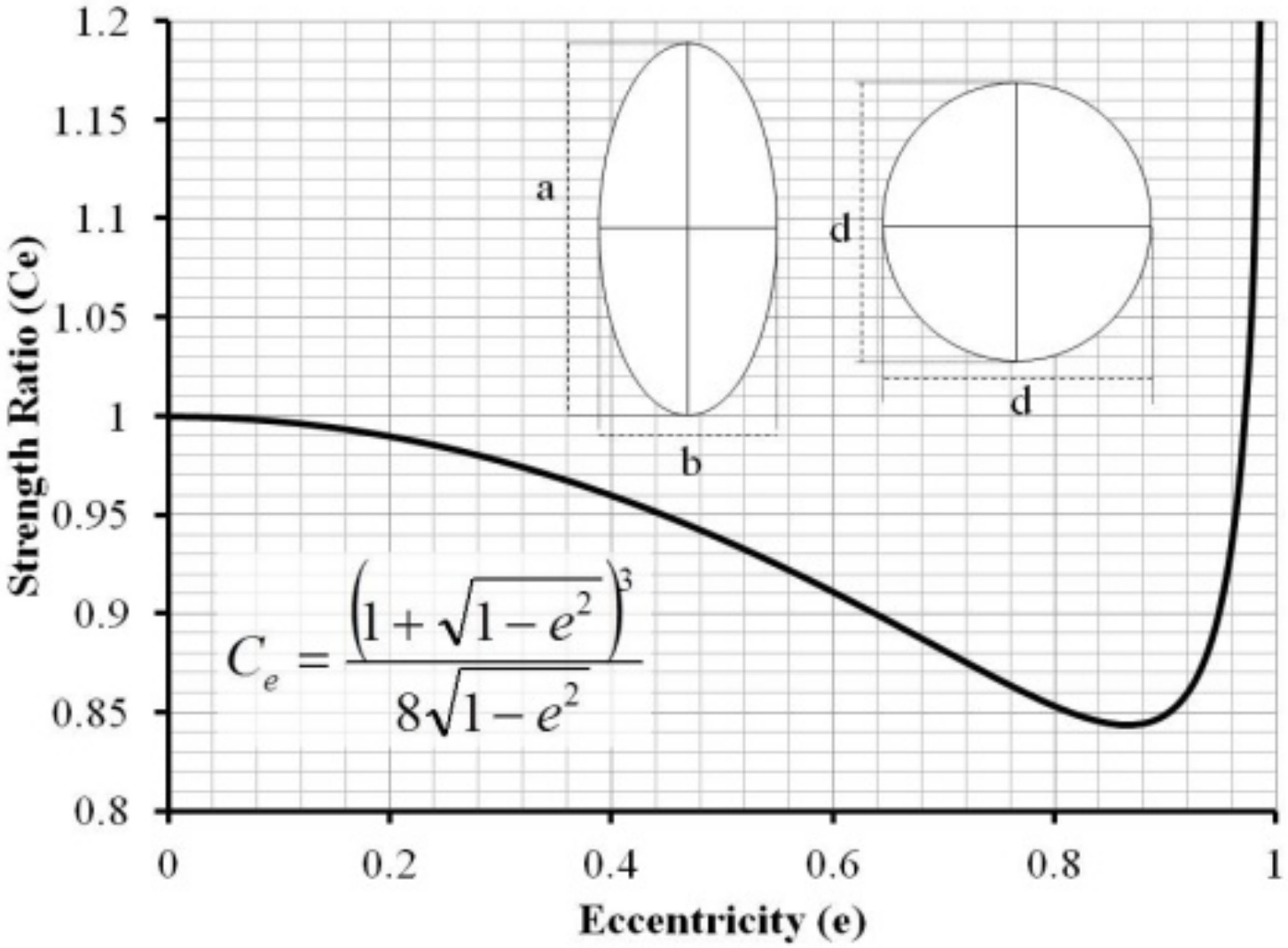
- we harvested 36 bamboo stems from 4 species namely Ampel (*Bambusa vulgaris* Schrad.), Tali (*Gigantochloa apus* (Bl.Ex Schult.f) Kurz), Gombong (*Gigantochloa verticillata* (Willd.) Munro), and Mayan (*Gigantochloa robusta* Kurz.), 9 stems from each species.
- Our measurement found that the bamboo 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 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

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 extremeem condition, the building could be collapse before estimated maximum load applied

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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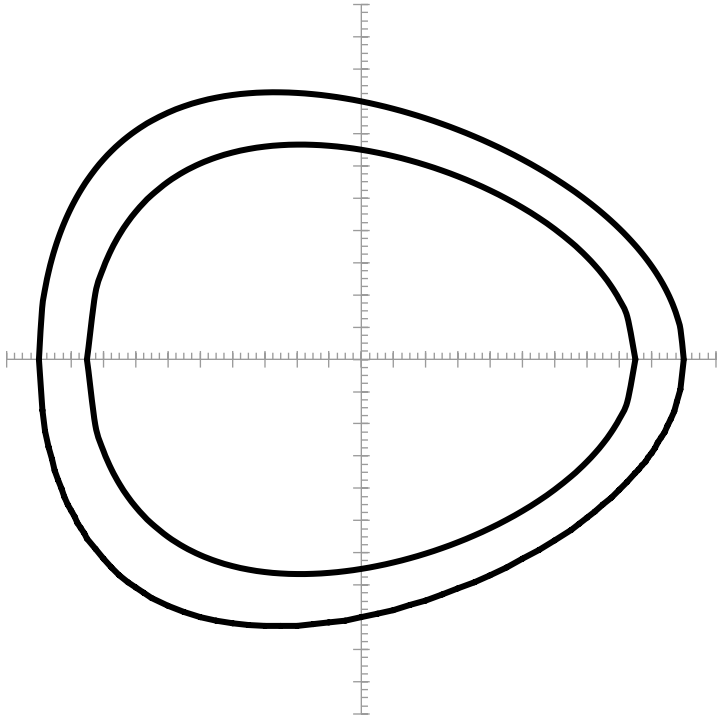
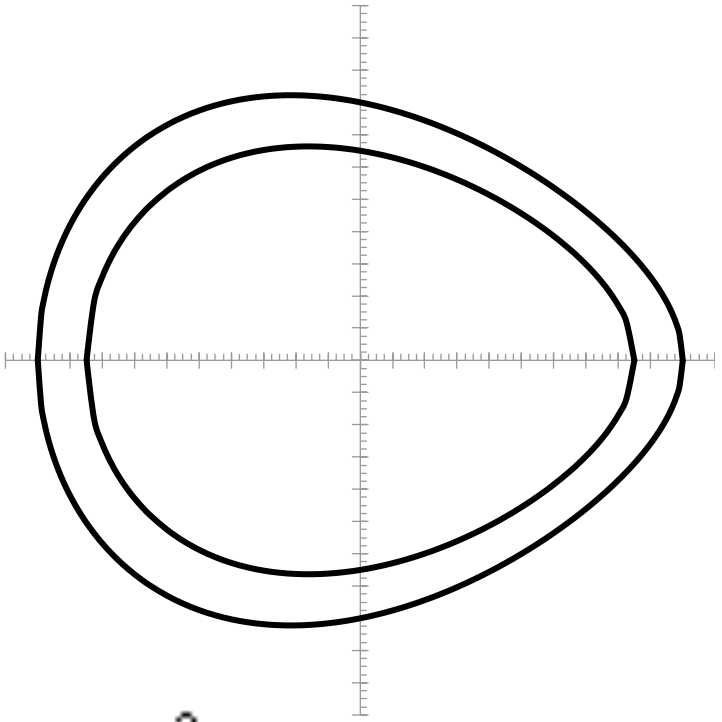
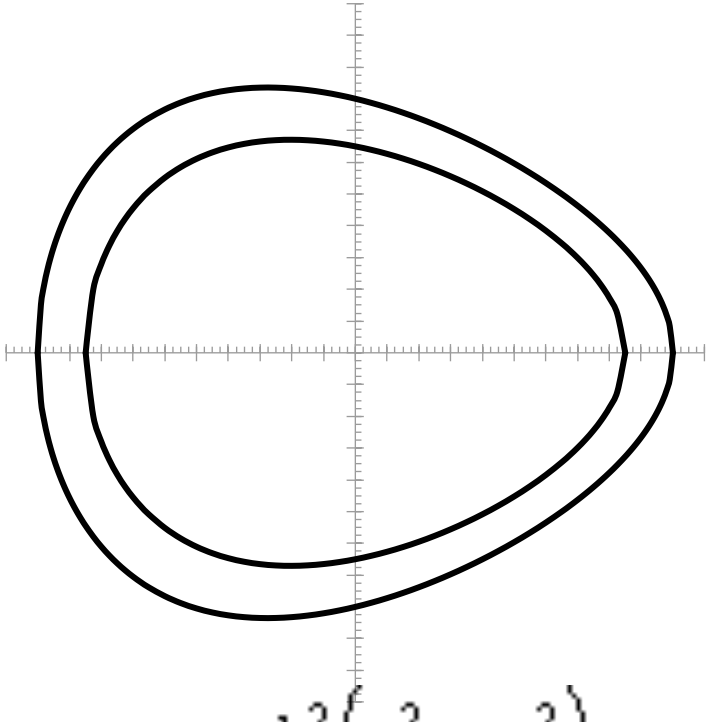
On going research in various ellips section ……



$$y^2 = \frac{b^2}{a^2(1+mx)}\left(a^2 - x^2\right)$$



$$y^2 = \frac{b^2}{a^2}\left(a^2 - x^2\right)(1 - mx)$$



$$y^2 = \frac{b^2\left(a^2 - x^2\right)}{a^2 e^{mx}}$$

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