

# Princípios de Biomecânica em Plantas

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2020



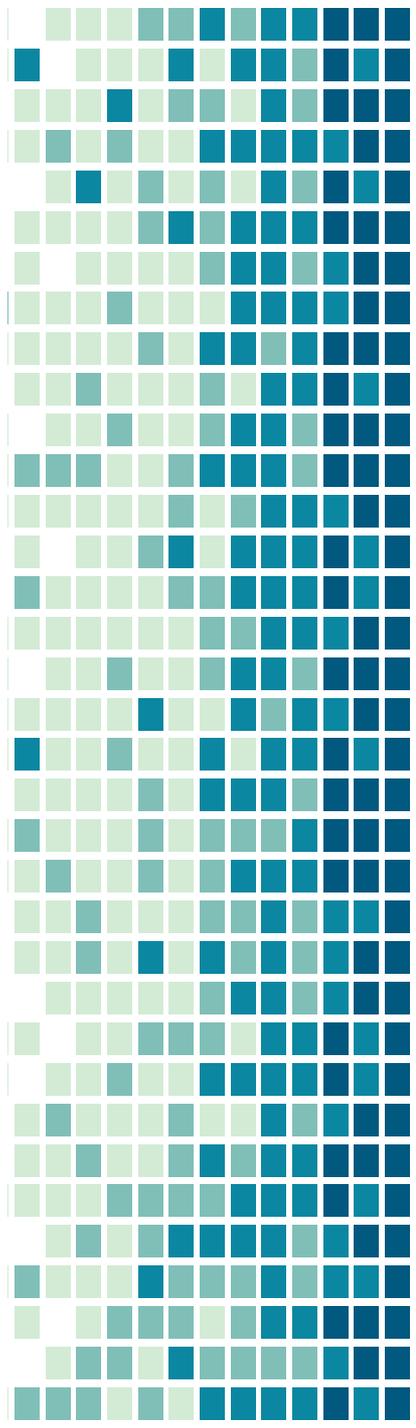
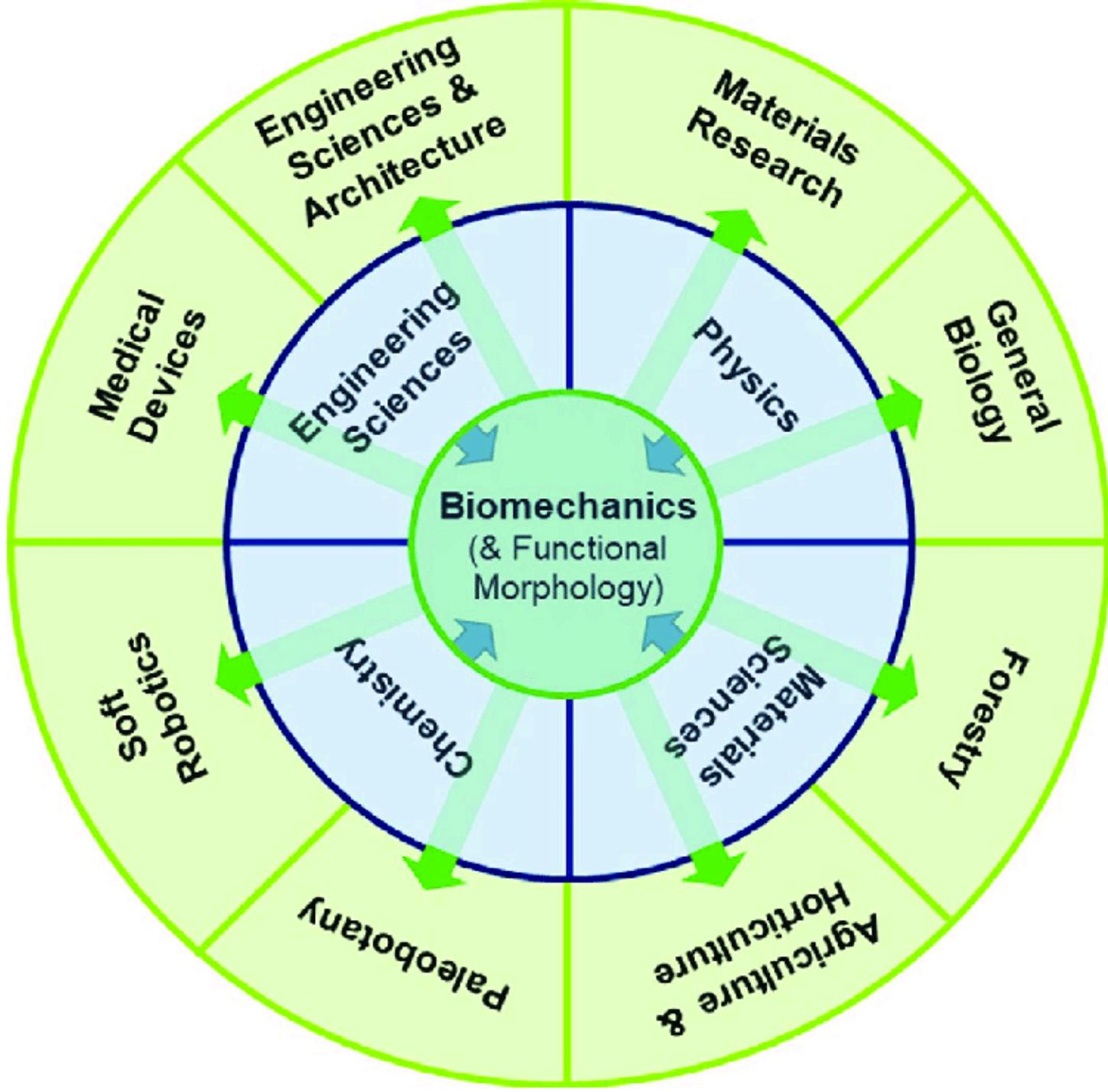
# 1. Biomecânica



# Biomecânica

- ✓ Ciência que investiga o movimento, sob aspectos mecânicos, suas causas e efeitos nos organismos (Donskoi 1960)
- ✓ Estudo das forças agindo sobre e dentro da estrutura biológica e os efeitos produzidos por tais forças (Hay 1973)





# Biomecânica



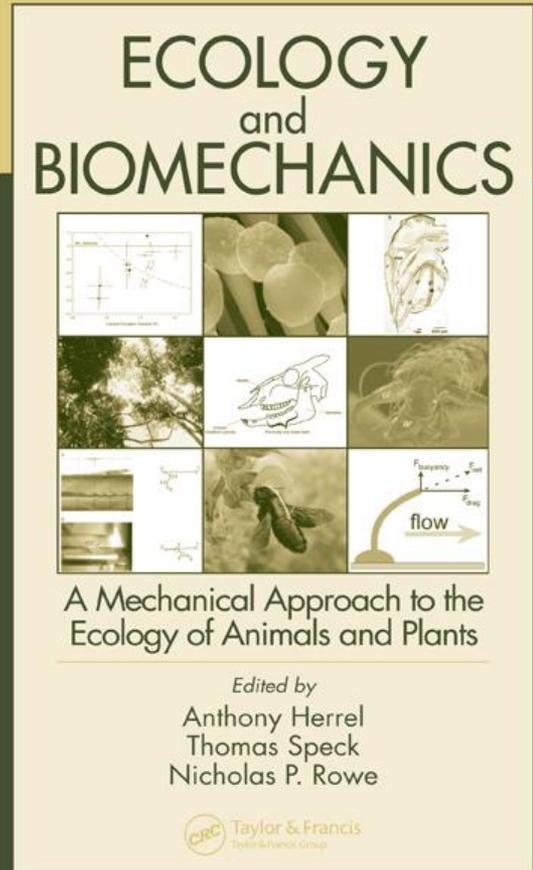
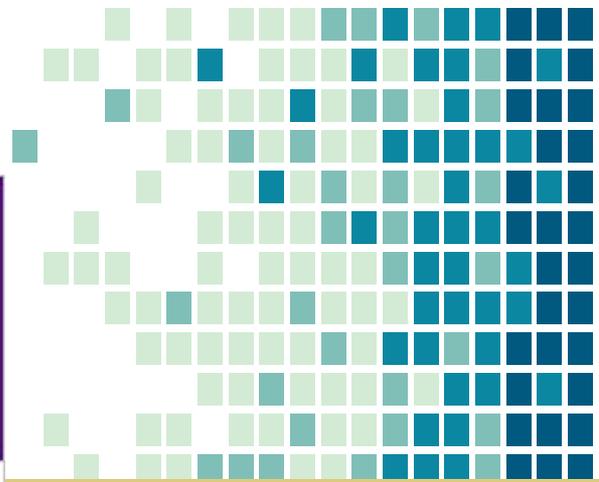
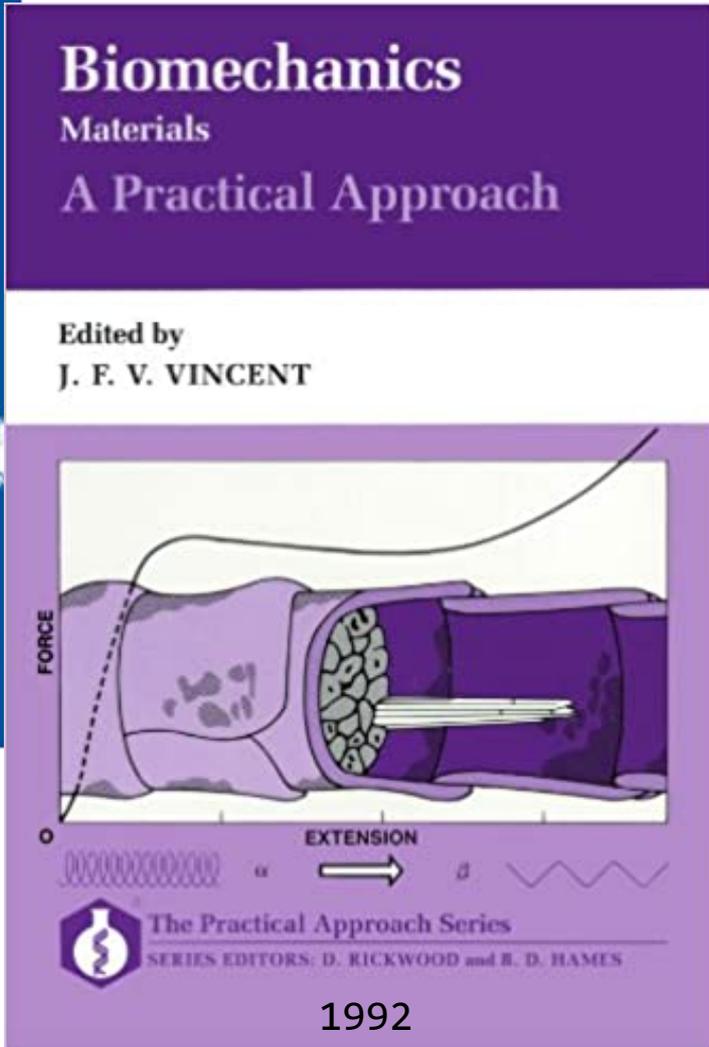
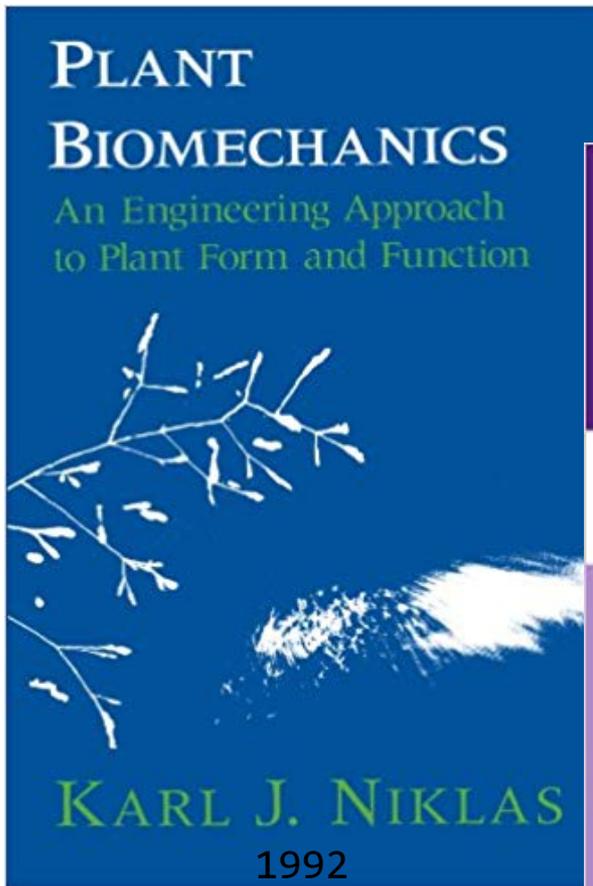
Ciência que investiga o movimento, sob aspectos mecânicos, suas causas e efeitos nos organismos vivos (Donskoi 1960)

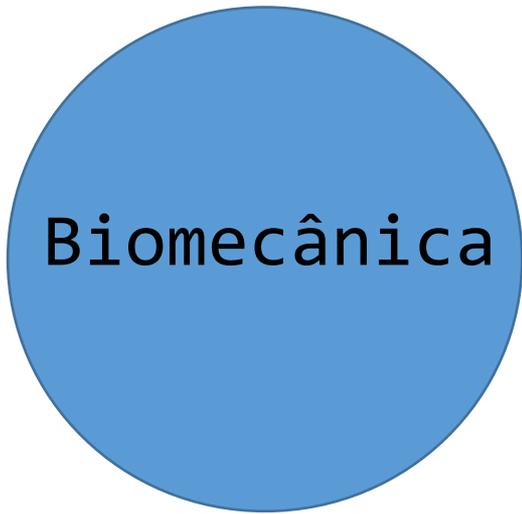


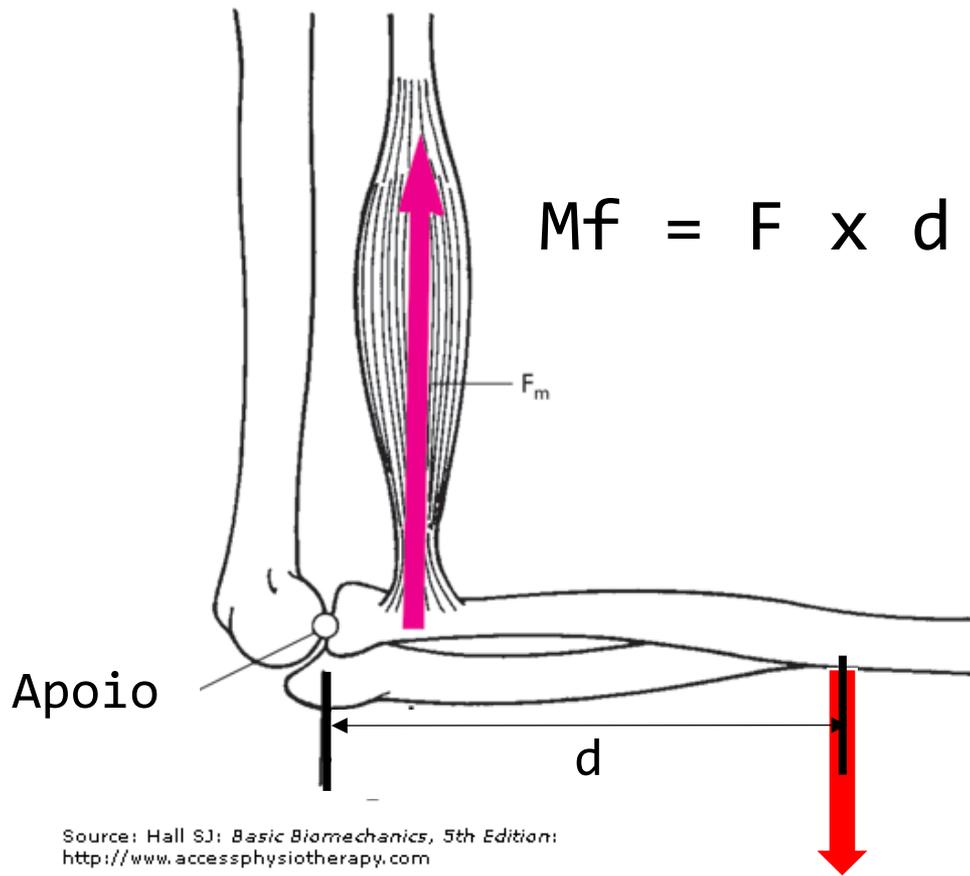
Estudo das forças agindo sobre e dentro da estrutura biológica e os efeitos produzidos por tais forças (Hay 1973)

Biomecânica em plantas - ciência interdisciplinar que descreve o comportamento das plantas sujeitas a forças e deslocamentos no nível de moléculas, células, tecidos, órgãos, organismos inteiros e ecossistemas.

Ação de uma força → Estrutura → Resultado







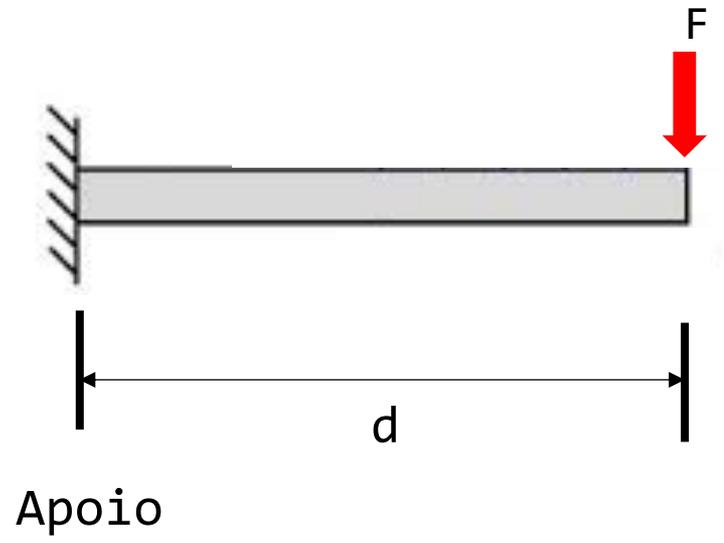
Source: Hall SJ: *Basic Biomechanics, 5th Edition*:  
<http://www.accessphysiotherapy.com>

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Momento Fletor ( $M_f$ )



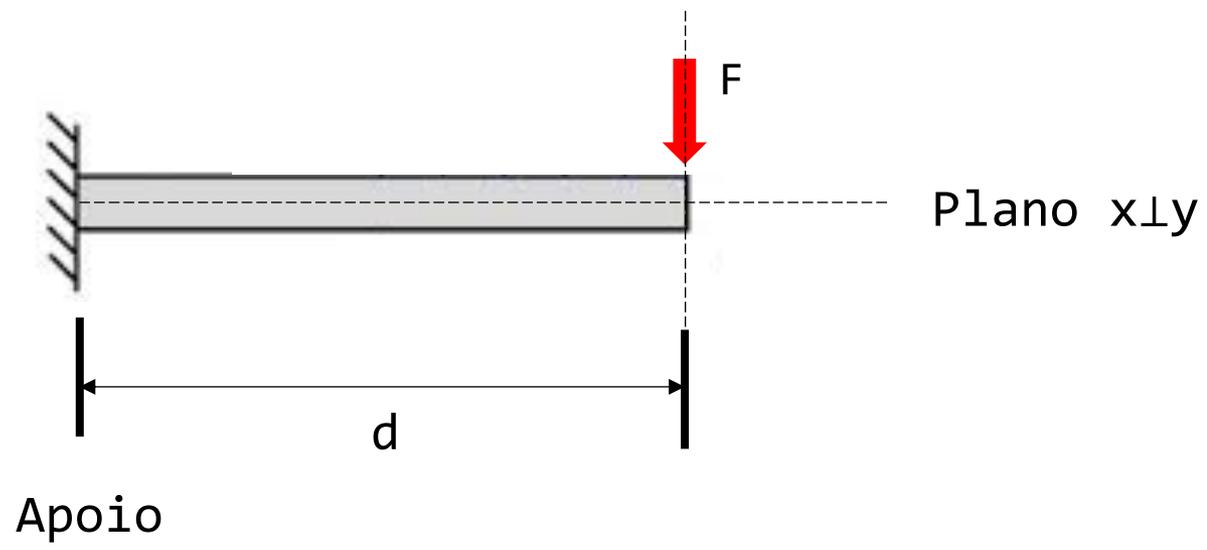
$$M_f = F \times d$$



Momento Fletor ( $M_f$ )



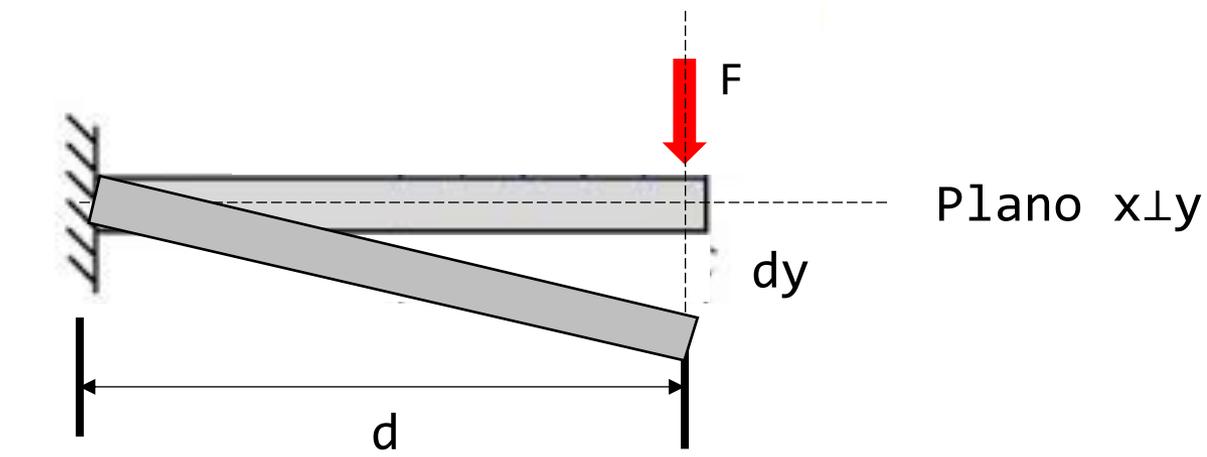
$$M_f = F \times d$$



Momento Fletor ( $M_f$ )



$$M_f = F \times d$$



Apoio

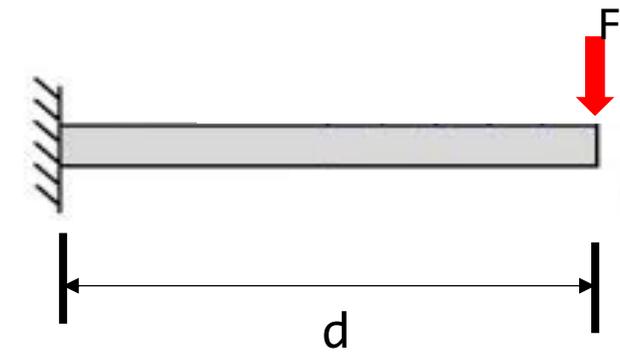
$d$

$dy$

Plano  $x \perp y$

Momento Fletor ( $M_f$ )



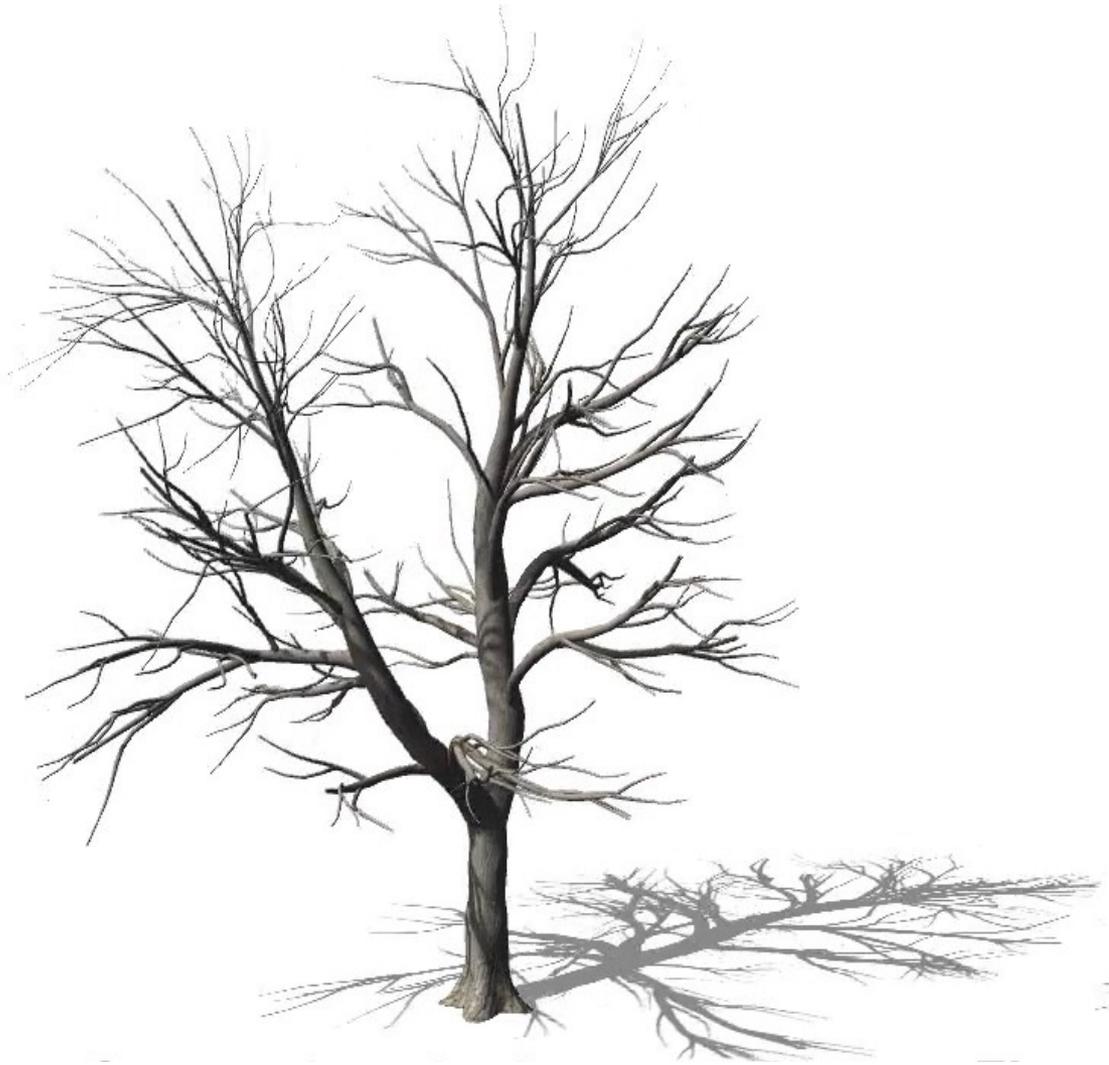


Apoio

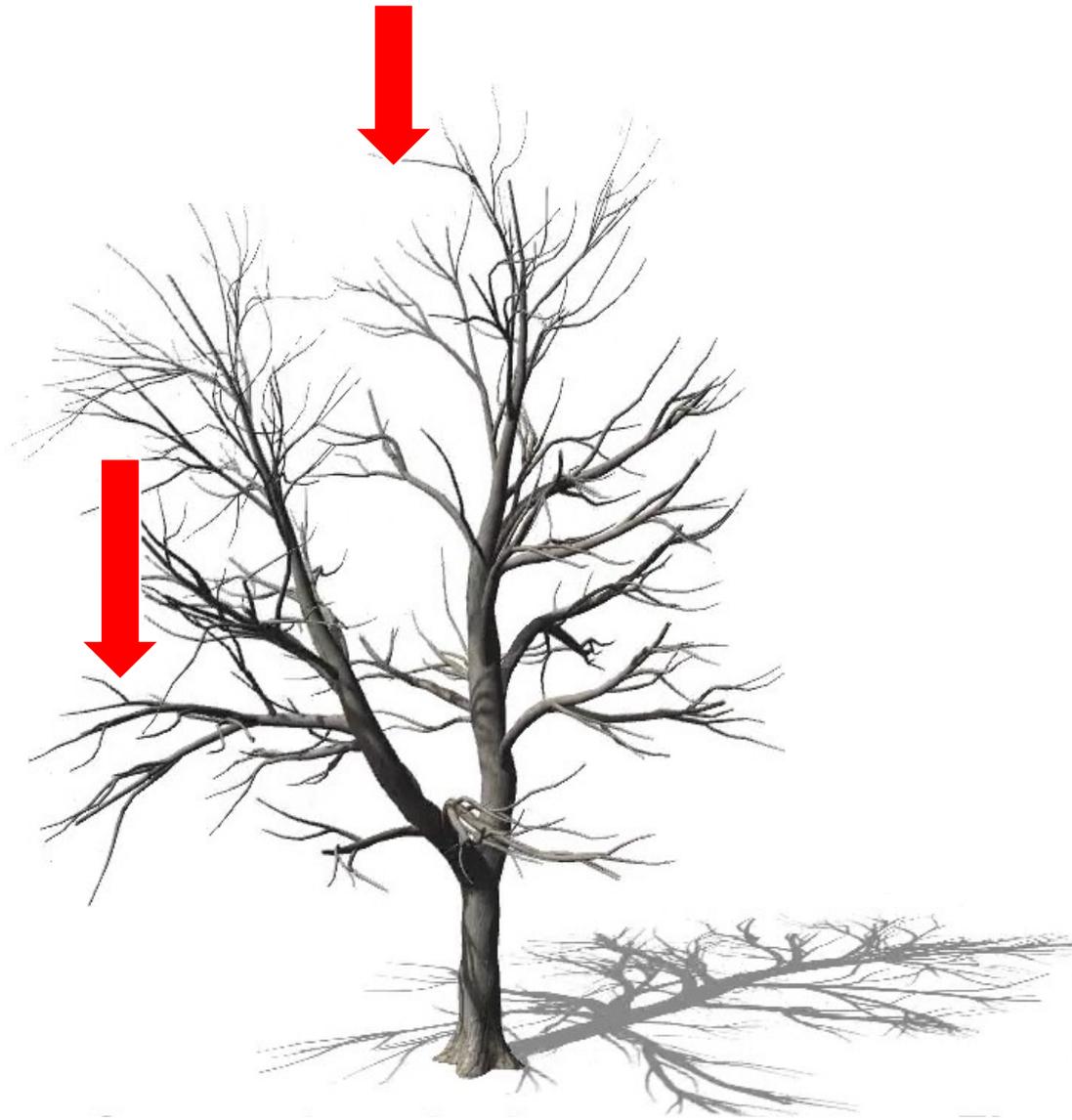
## Definições de Termos

- Força (Peso, Tração, etc)
- Deslocamento
- Distância
- Apoio
- Plano (X e Y)

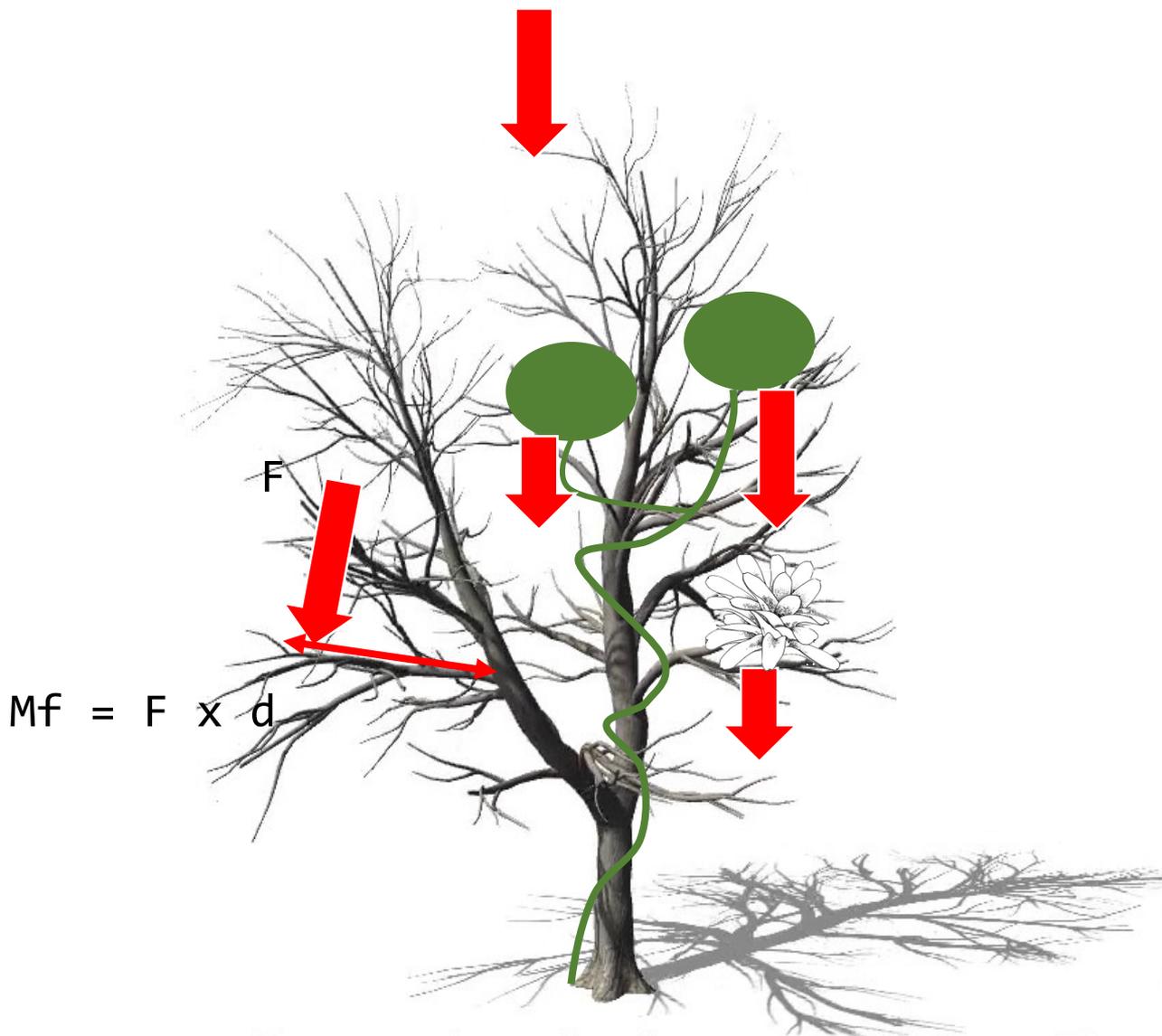




<https://gifs.com/watch?v= 2IWfAPYrBo>

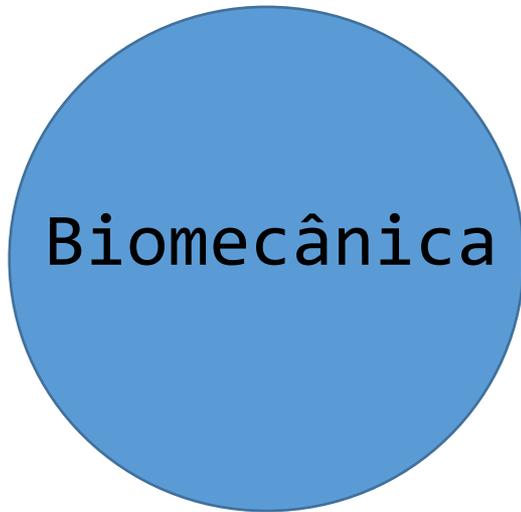


Ação de uma força → Estrutura → Resultado





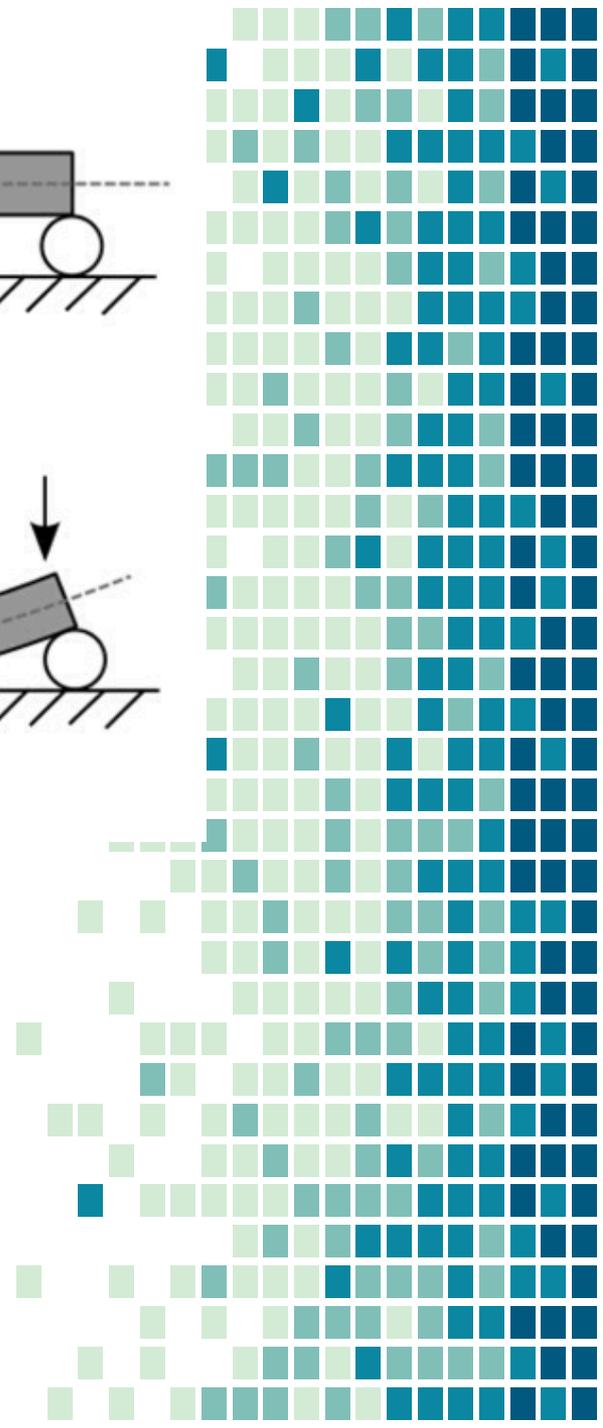
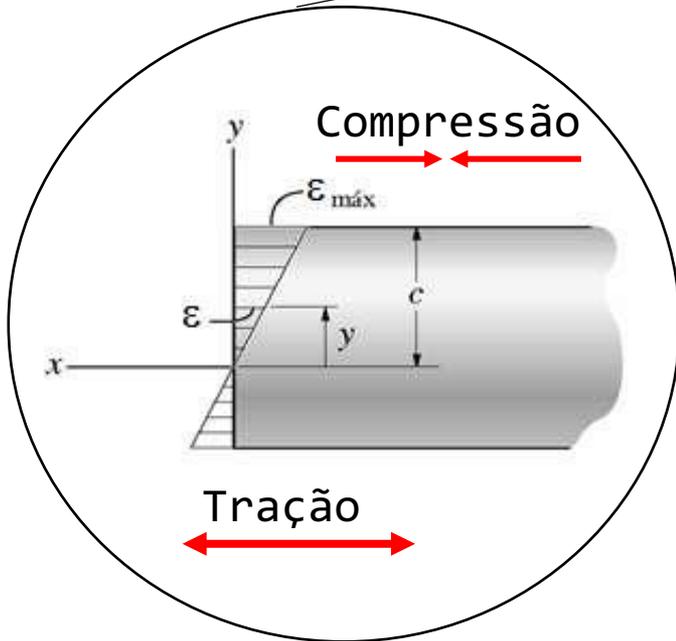
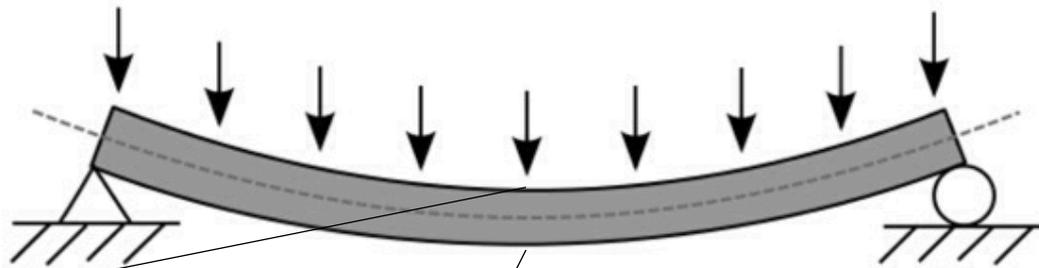
[gifs.com](https://gifs.com)

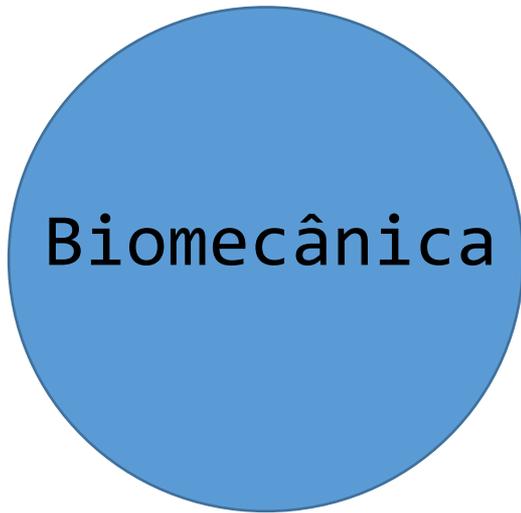


Rigidez / flexibilidade



Ação de uma força → Estrutura → Resultado





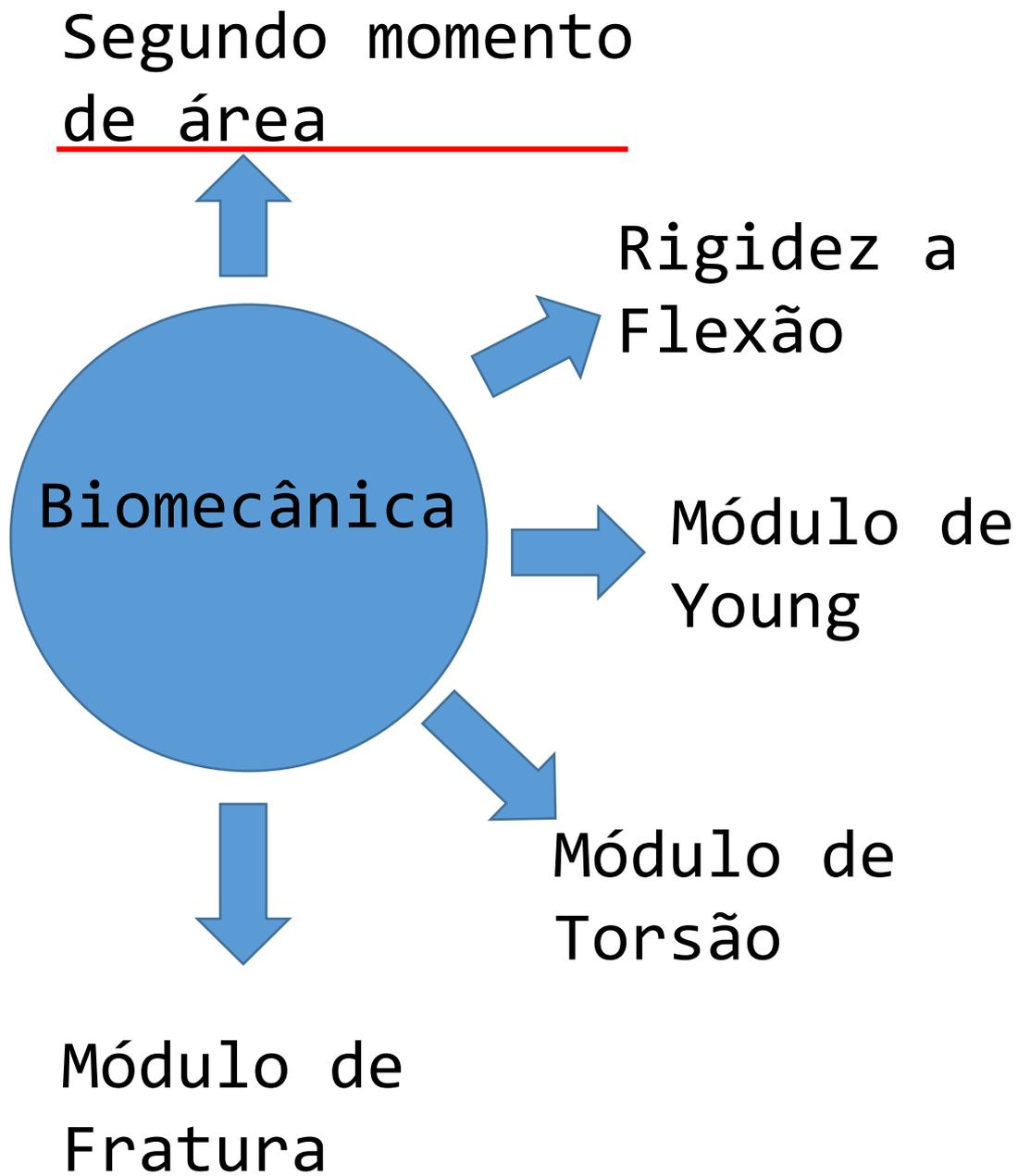
Rigidez / flexibilidade



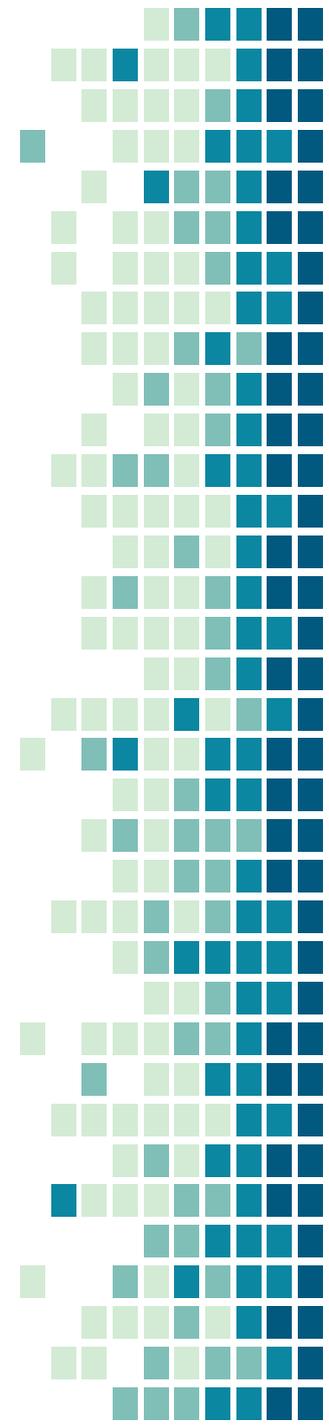
Anatomia



*Handroanthus heptaphyllus* (Bignoniaceae)



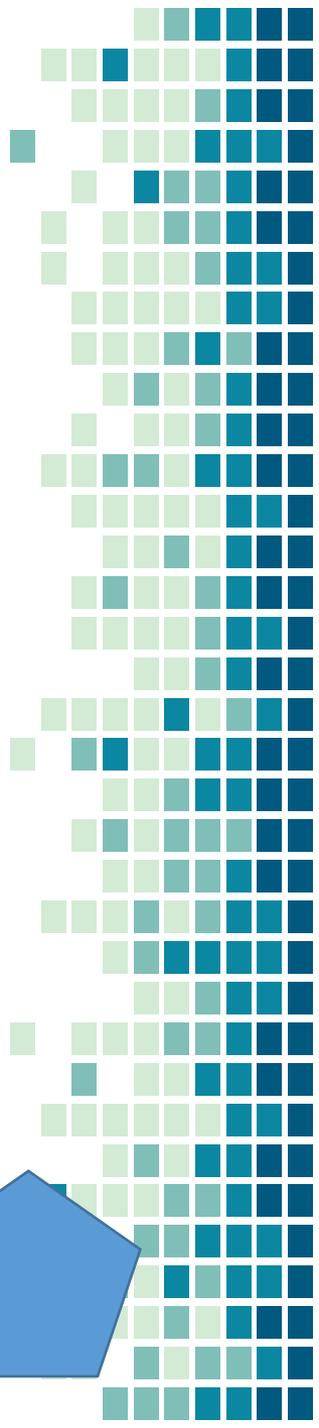
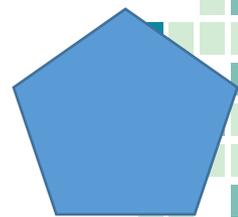
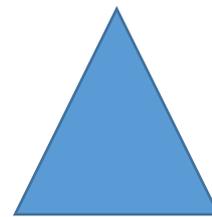
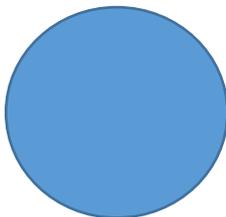
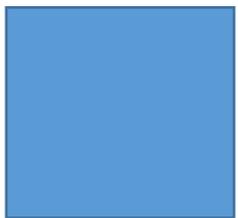
# Segundo momento de área (I)



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Característica geométrica das  
superfícies planas



# Segundo momento de área (I)

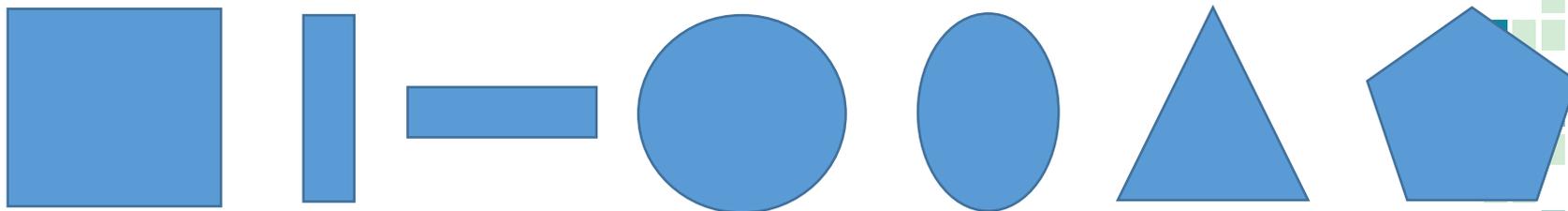


Característica geométrica das superfícies planas



Maior valor maior contribuição para a resistente a carga recebida

$$I = \sum (A \cdot d^2)$$



# Segundo momento de área (I)



Característica geométrica das superfícies planas

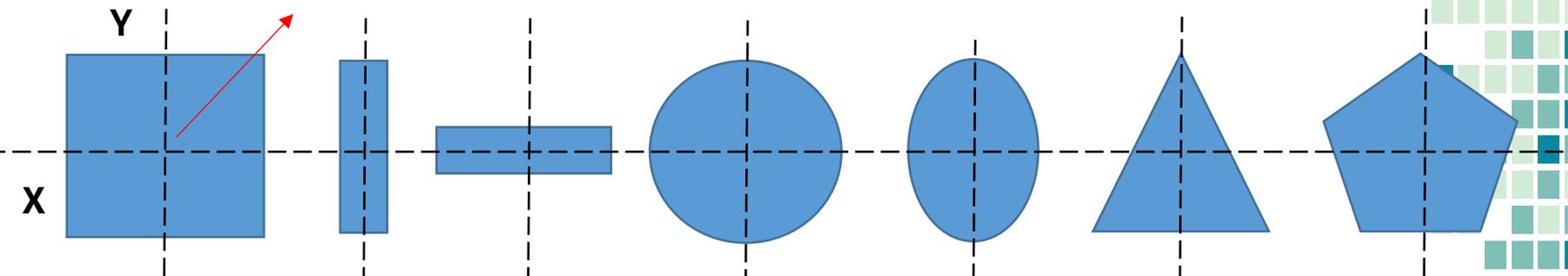


Maior valor maior contribuição para a resistente a carga recebida

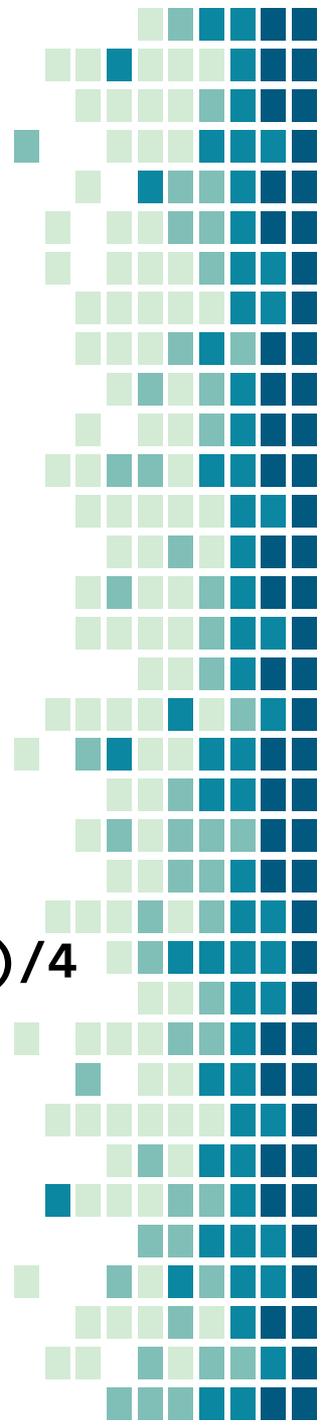
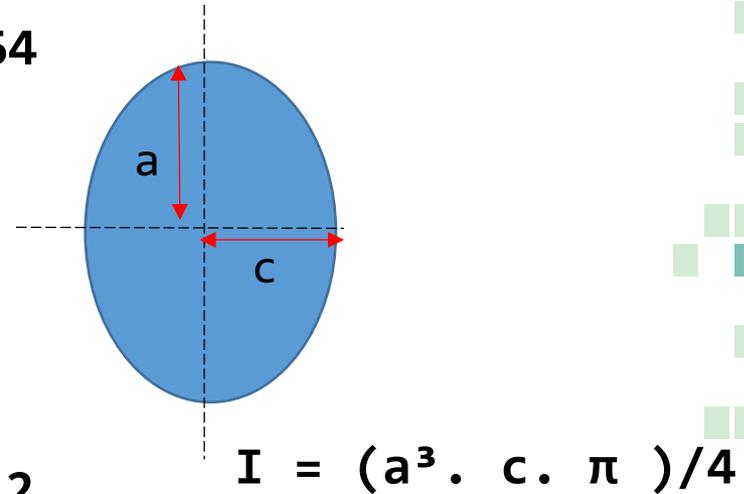
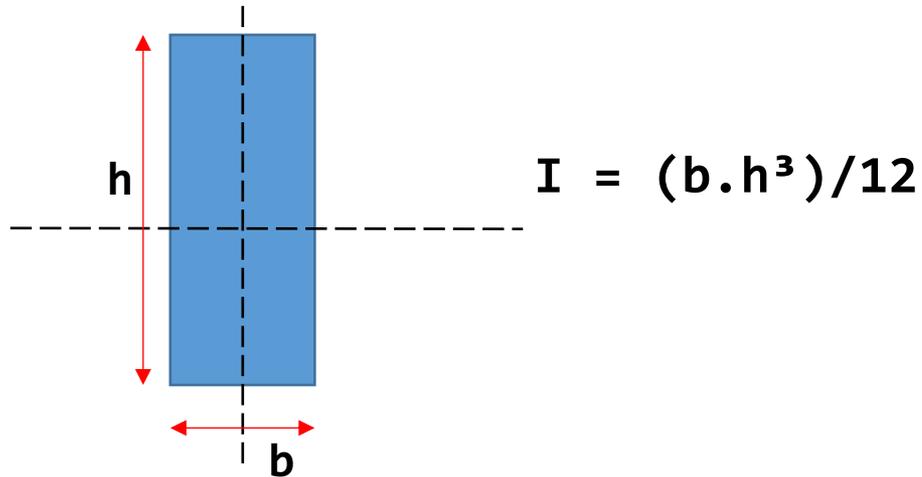
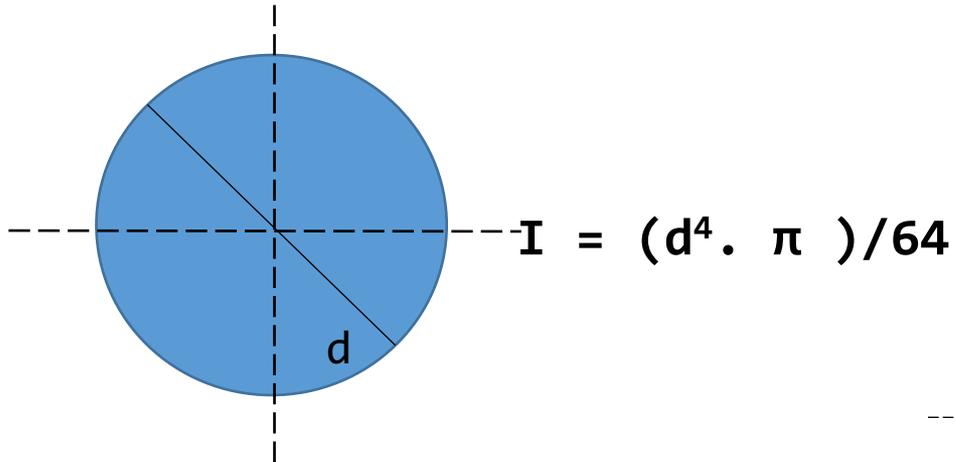
$$I = \sum (A \cdot d^2)$$

Centroide

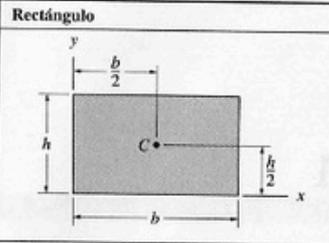
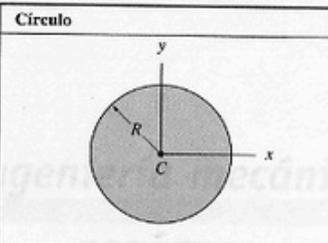
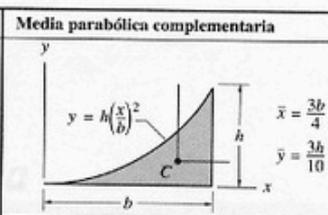
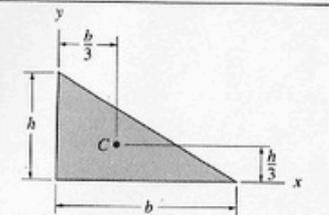
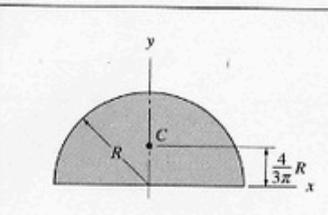
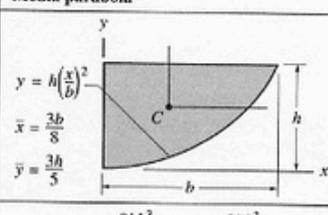
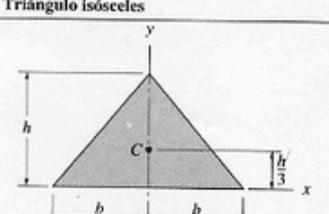
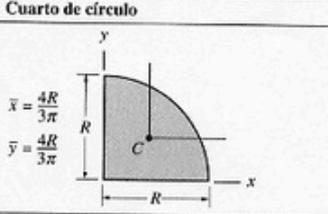
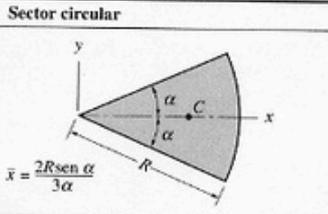
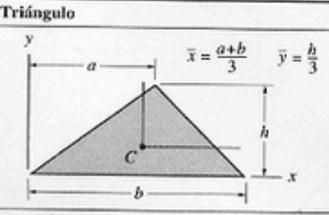
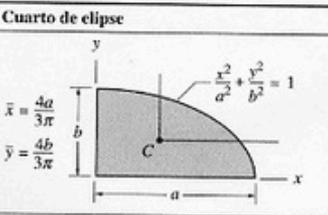
Eixo de referência



# Segundo momento de área (I)

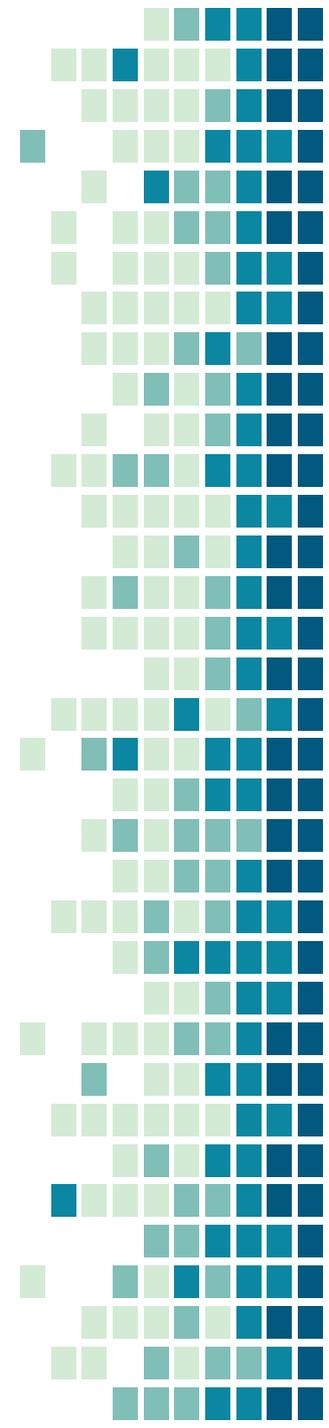
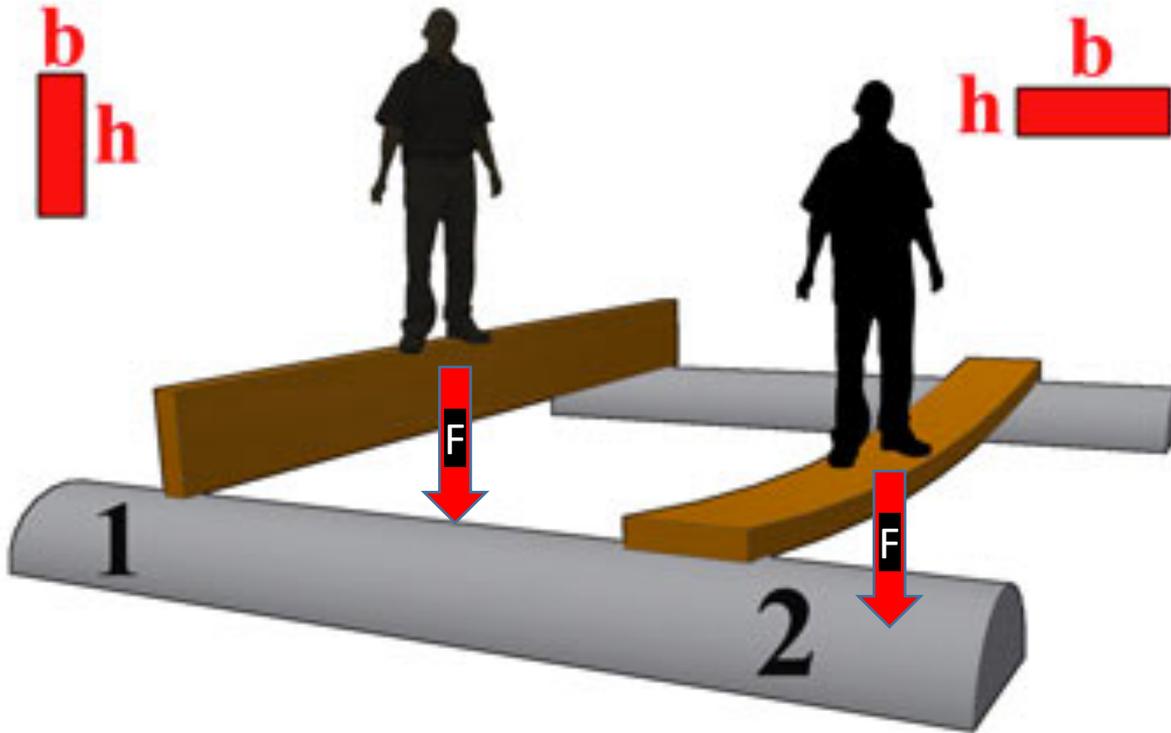


# Segundo momento de área (I)

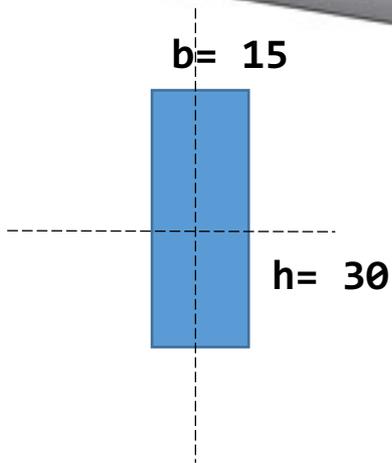
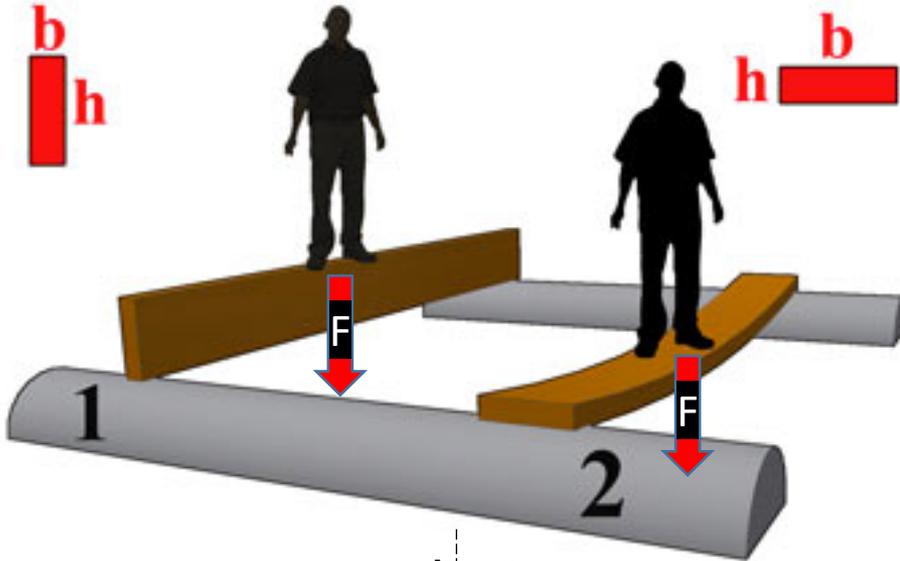
Área momento de inercia		
<b>Rectángulo</b>  $\bar{I}_x = \frac{bh^3}{12} \quad \bar{I}_y = \frac{b^3h}{12} \quad \bar{I}_{xy} = 0$ $I_x = \frac{bh^3}{3} \quad I_y = \frac{b^3h}{3} \quad I_{xy} = \frac{b^2h^2}{4}$	<b>Círculo</b>  $I_x = I_y = \frac{\pi R^4}{4} \quad I_{xy} = 0$	<b>Media parabólica complementaria</b>  $\bar{I}_x = \frac{37bh^3}{2100} \quad I_x = \frac{bh^3}{21}$ $\bar{I}_y = \frac{b^3h}{80} \quad I_y = \frac{b^3h}{5}$ $\bar{I}_{xy} = \frac{b^2h^2}{120} \quad I_{xy} = \frac{b^2h^2}{12}$
<b>Triángulo rectángulo</b>  $\bar{I}_x = \frac{bh^3}{36} \quad \bar{I}_y = \frac{b^3h}{36} \quad \bar{I}_{xy} = -\frac{b^2h^2}{72}$ $I_x = \frac{bh^3}{12} \quad I_y = \frac{b^3h}{12} \quad I_{xy} = \frac{b^2h^2}{24}$	<b>Semicírculo</b>  $\bar{I}_x = 0.1098R^4 \quad \bar{I}_{xy} = 0$ $I_x = I_y = \frac{\pi R^4}{8} \quad I_{xy} = 0$	<b>Media parábola</b>  $\bar{I}_x = \frac{8bh^3}{175} \quad I_x = \frac{2bh^3}{7}$ $\bar{I}_y = \frac{19b^3h}{480} \quad I_y = \frac{2b^3h}{15}$ $\bar{I}_{xy} = \frac{b^2h^2}{60} \quad I_{xy} = \frac{b^2h^2}{6}$
<b>Triángulo isósceles</b>  $\bar{I}_x = \frac{bh^3}{36} \quad \bar{I}_y = \frac{b^3h}{48} \quad \bar{I}_{xy} = 0$ $I_x = \frac{bh^3}{12} \quad I_{xy} = 0$	<b>Cuarto de círculo</b>  $\bar{I}_x = \bar{I}_y = 0.05488R^4 \quad I_x = I_y = \frac{\pi R^4}{16}$ $\bar{I}_{xy} = -0.01647R^4 \quad I_{xy} = \frac{R^4}{8}$	<b>Sector circular</b>  $I_x = \frac{R^4}{8}(2\alpha - \text{sen } 2\alpha)$ $I_y = \frac{R^4}{8}(2\alpha + \text{sen } 2\alpha)$ $I_{xy} = 0$
<b>Triángulo</b>  $\bar{I}_x = \frac{bh^3}{36} \quad I_x = \frac{bh^3}{12}$ $\bar{I}_y = \frac{bh}{36}(a^2 - ab + b^2) \quad I_y = \frac{bh}{12}(a^2 + ab + b^2)$ $\bar{I}_{xy} = \frac{bh^2}{72}(2a - b) \quad I_{xy} = \frac{bh^2}{24}(2a + b)$	<b>Cuarto de elipse</b>  $\bar{I}_x = 0.05488ab^3 \quad I_x = \frac{\pi ab^3}{16}$ $\bar{I}_y = 0.05488a^3b \quad I_y = \frac{\pi a^3b}{16}$ $\bar{I}_{xy} = -0.01647a^2b^2 \quad I_{xy} = \frac{a^2b^2}{8}$	

(I) -> Aspecto geométrico da rigidez a flexão

$$I = (b \cdot h^3) / 12$$

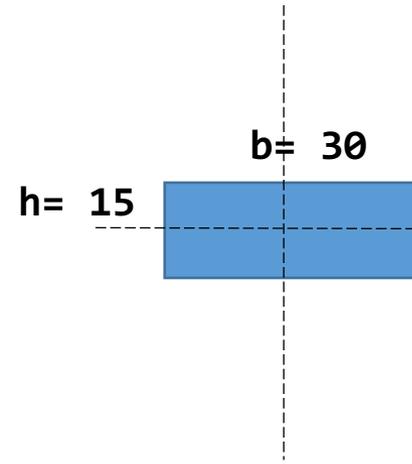


(I) -> Aspecto geométrico da rigidez a flexão

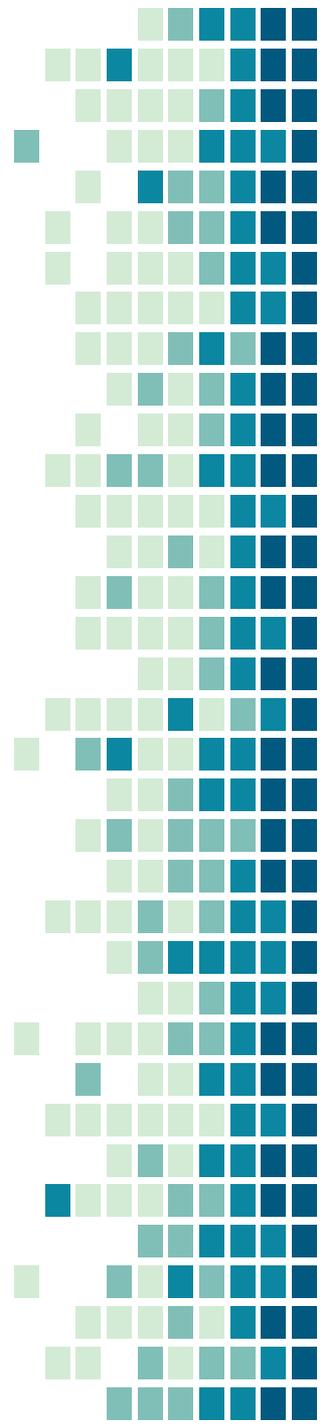


$$I = 33.750 \text{ mm}^4$$

$$I = (b \cdot h^3) / 12$$

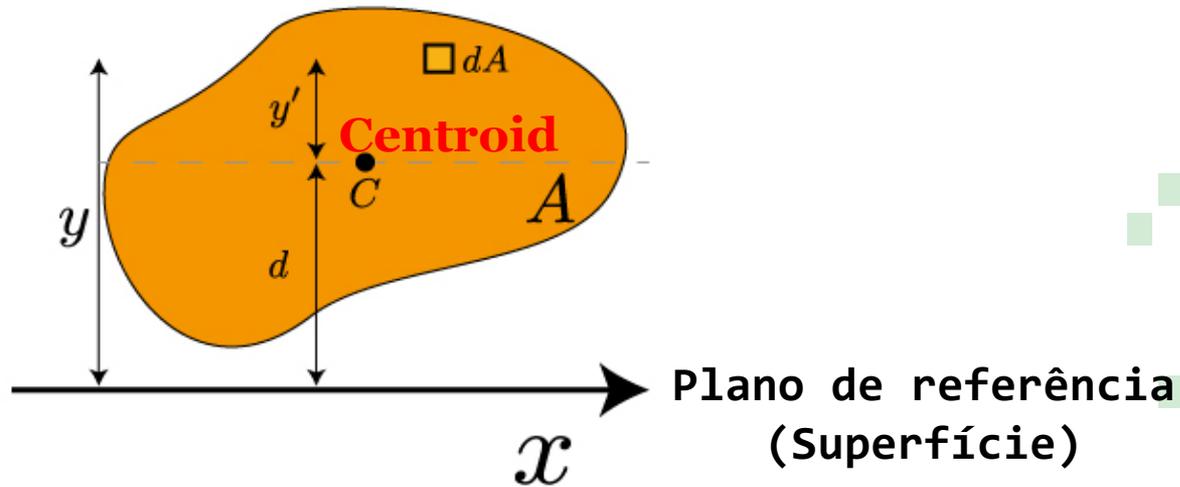


$$I = 8.430 \text{ mm}^4$$



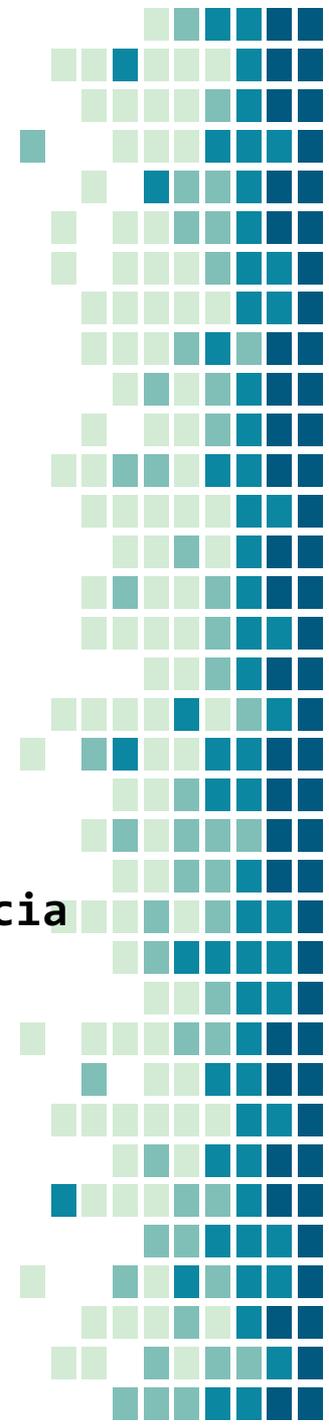
# Segundo momento de área (I)

Arbitrary Cross Section



$$I_x = \bar{I}_{x'} + Ad^2$$

Parallel Axis theorem



# Coordinates of the Centroid

$$Y_c = \Sigma (A \cdot dy) / \Sigma (A)$$

$Y_c$  = y coordinate of centroid

$\Sigma (Ay)$  = Sum of (each area times its centroid y coord)

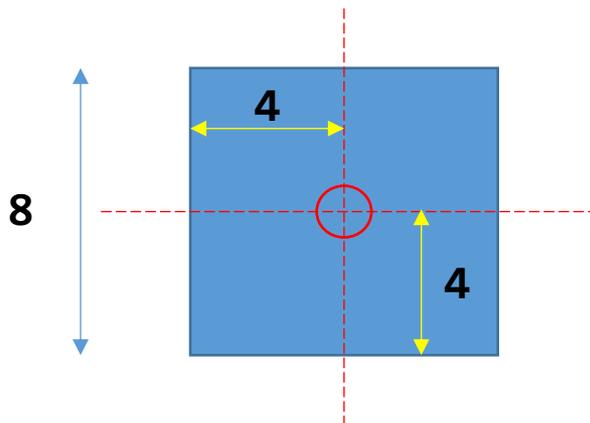
$\Sigma (A)$  = Sum of Areas

$$X_c = \Sigma (A \cdot dx) / \Sigma (A)$$

$X_c$  = x coordinate of centroid

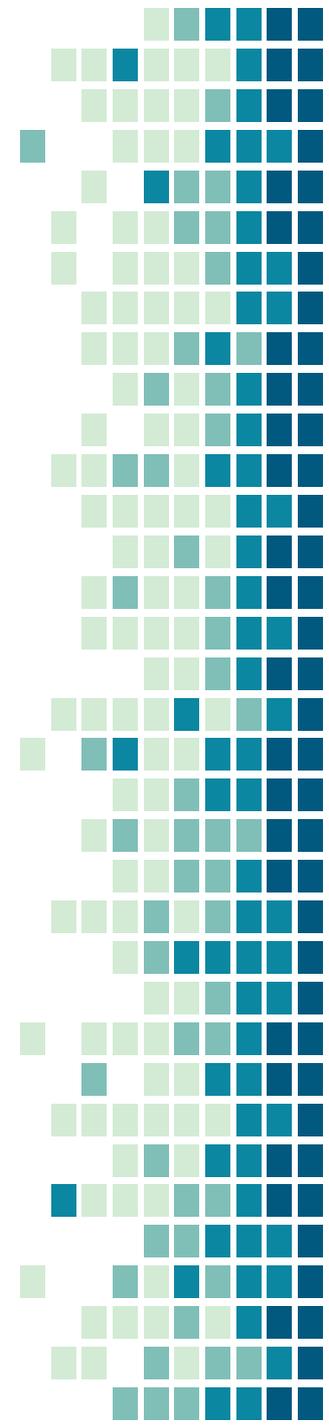
$\Sigma (Ax)$  = Sum of (each area times its centroid x coord)

$\Sigma (A)$  = Sum of Areas



$$Y_c = \\ [(8.8) \cdot 4] / (8.8) \\ = 4$$

$$X_c = \\ [(8.8) \cdot 4] / (8.8) \\ = 4$$



# Coordinates of the Centroid

$$Y_c = \Sigma (A \cdot dy) / \Sigma (A)$$

$Y_c$  = y coordinate of centroid

$\Sigma (A y)$  = Sum of (each area times its centroid y coord)  $[(8 \cdot 8) \cdot 4] / (8 \cdot 8)$

$\Sigma (A)$  = Sum of Areas

$$Y_c =$$

$$= 4$$

$$X_c = \Sigma (A \cdot dx) / \Sigma (A)$$

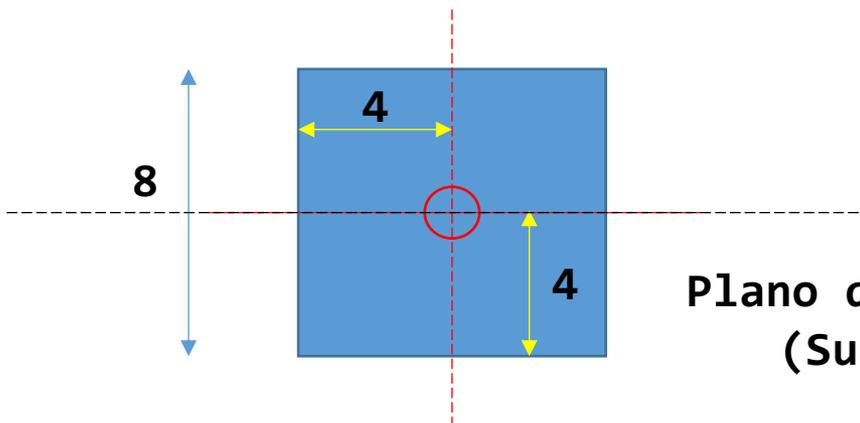
$X_c$  = x coordinate of centroid

$\Sigma (A x)$  = Sum of (each area times its centroid x coord)  $[(8 \cdot 8) \cdot 4] / (8 \cdot 8)$

$\Sigma (A)$  = Sum of Areas

$$X_c =$$

$$= 4$$



$$I = I_c + A d^2$$

$$I = (8^4/12) + 8 \times 8 \times 0^2$$

$$I = 341,33 \text{ mm}^4$$

# Coordinates of the Centroid

$$Y_c = \Sigma (A \cdot dy) / \Sigma (A)$$

$Y_c$  = y coordinate of centroid

$\Sigma (Ay)$  = Sum of (each are times its centroid y coord)

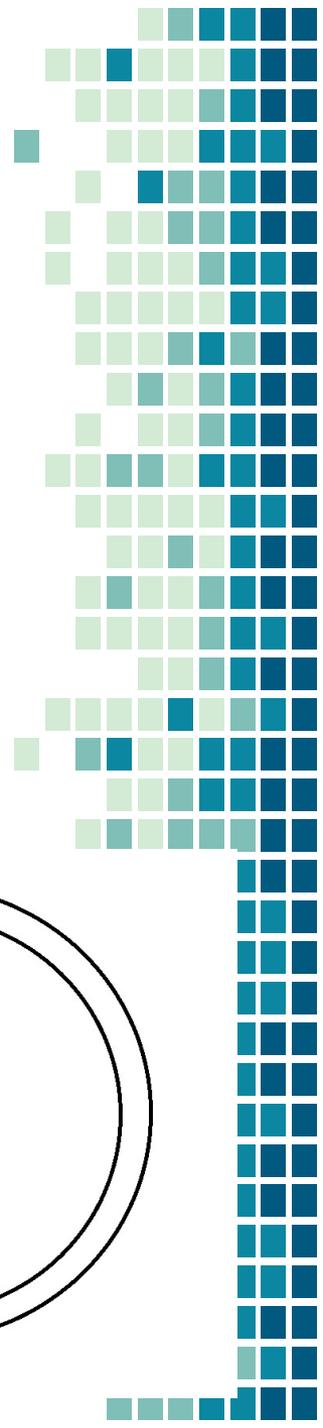
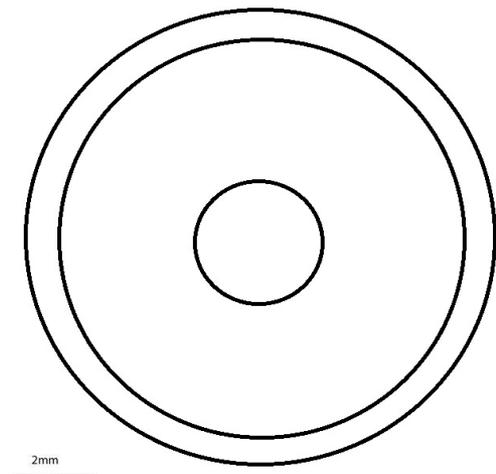
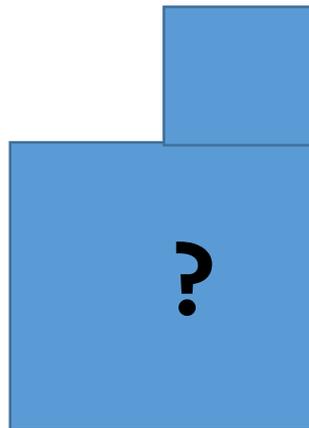
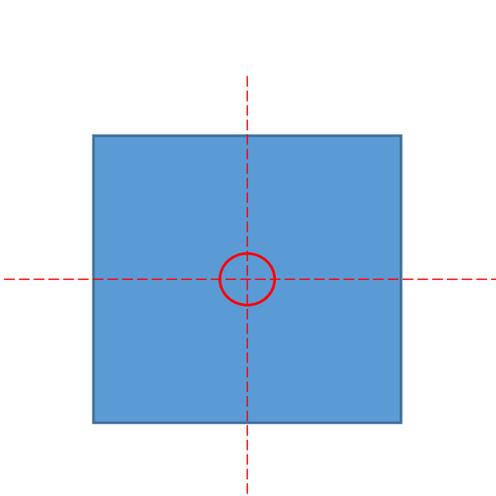
$\Sigma (A)$  = Sum of Areas

$$X_c = \Sigma (A \cdot dx) / \Sigma (A)$$

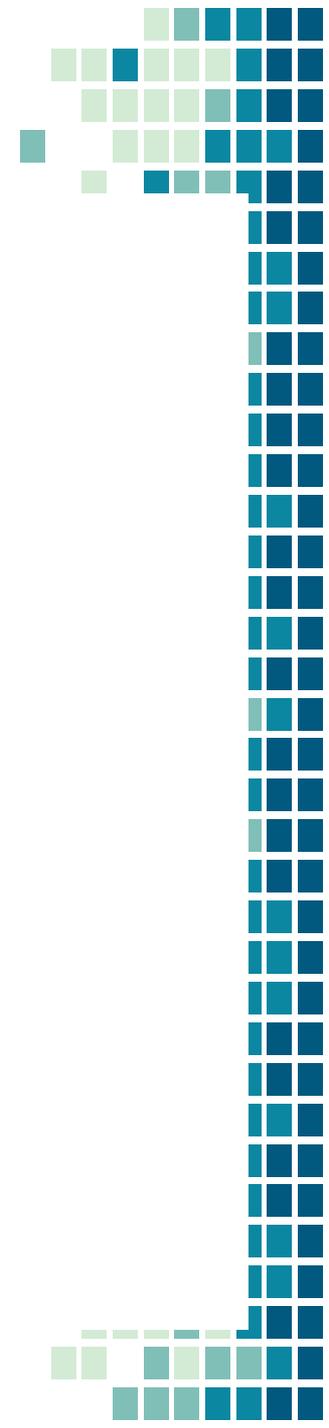
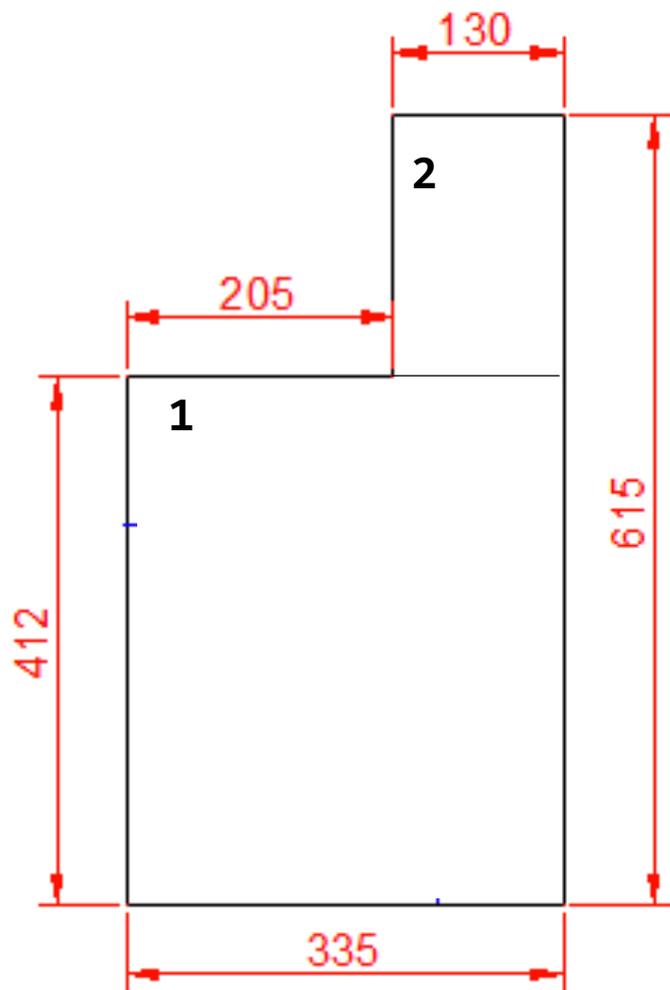
$X_c$  = x coordinate of centroid

$\Sigma (Ax)$  = Sum of (each are times its centroid x coord)

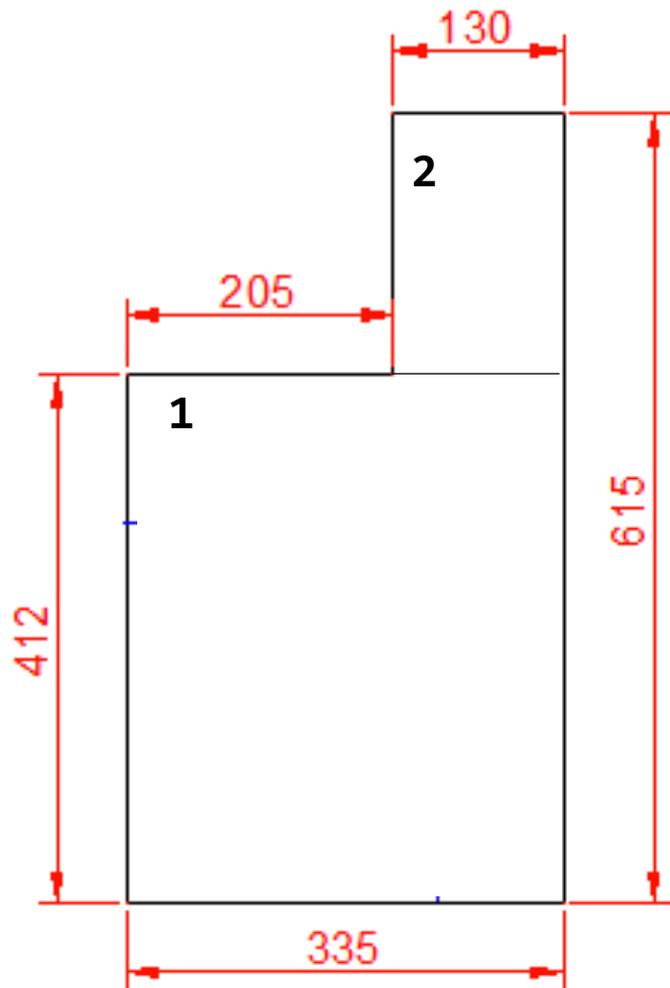
$\Sigma (A)$  = Sum of Areas



# Segundo momento de área (I)



## Segundo momento de área (I)



$$y_c = \frac{\Sigma (Ay)}{\Sigma (A)} \quad x_c = \frac{\Sigma (Ax)}{\Sigma (A)}$$

$$y_1 = 412/2 = 206 \text{ mm}$$

$$y_2 = (615-412)/2 + 412 = 513.5 \text{ mm}$$

$$A_1 = 335 \times 412 = 138020 \text{ mm}^2$$

$$A_2 = 130 \times (615-412) = 26390 \text{ mm}^2$$

$$A_1 y_1 = 138020 \times 206 = 28432120$$

$$A_2 y_2 = 26390 \times 513.5 = 13551265$$

$$\Sigma (Ay) = 28432120 + 13551265 = 41983385$$

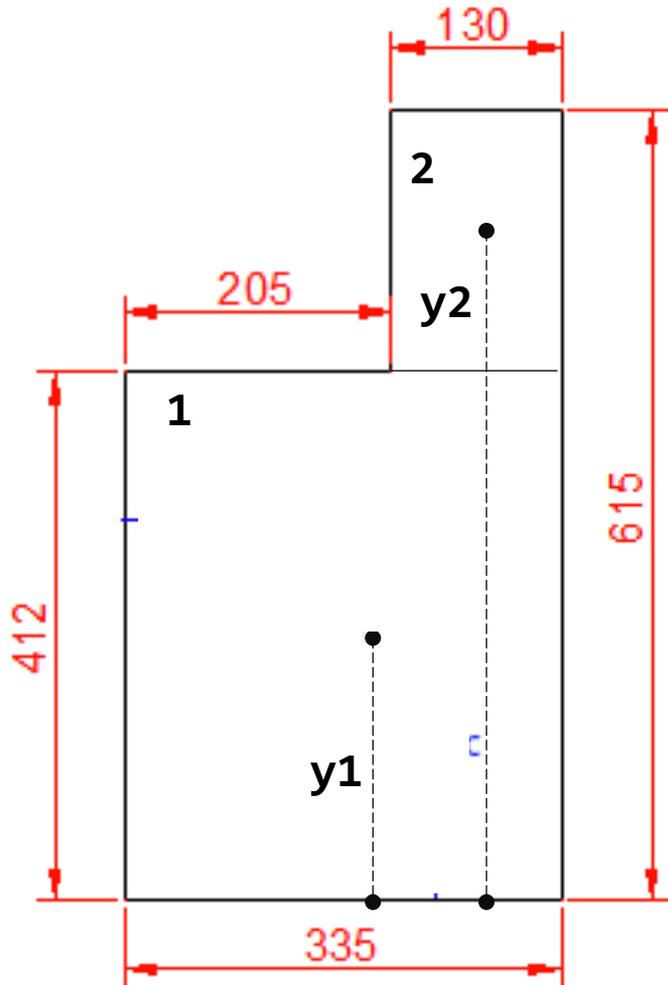
$$\Sigma (A) = 138020 + 26390 = 164410$$

$$y_c = \frac{\Sigma (Ay)}{\Sigma (A)} = 41983385 / 164410$$

$$= \mathbf{255.3579 \text{ mm}}$$

(Image: Tim Lovett 2007)

## Segundo momento de área (I)



$$y_c = \frac{\Sigma (Ay)}{\Sigma (A)} \quad x_c = \frac{\Sigma (Ax)}{\Sigma (A)}$$

$$y_1 = 412/2 = 206 \text{ mm}$$

$$y_2 = (615-412)/2 + 412 = 513.5 \text{ mm}$$

$$A_1 = 335 \cdot 412 = 138020 \text{ mm}^2$$

$$A_2 = 130 \cdot (615-412) = 26390 \text{ mm}^2$$

$$A_1 y_1 = 138020 \cdot 206 = 28432120$$

$$A_2 y_2 = 26390 \cdot 513.5 = 13551265$$

$$\Sigma (Ay) = 28432120 + 13551265 = 41983385$$

$$\Sigma (A) = 138020 + 26390 = 164410$$

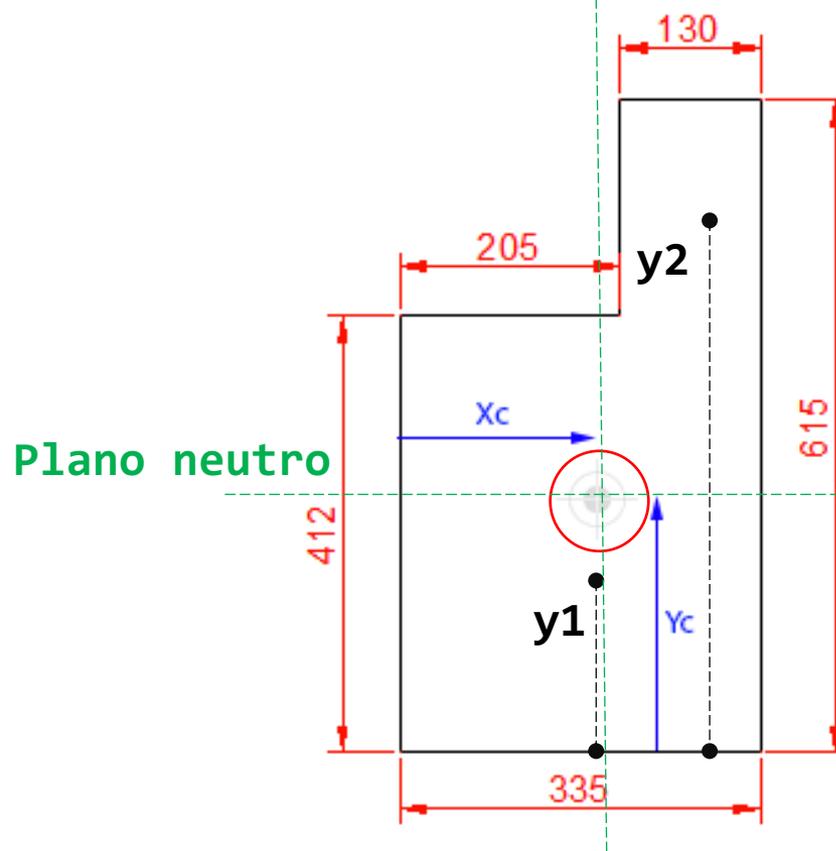
$$y_c = \frac{\Sigma (Ay)}{\Sigma (A)} = 41983385 / 164410 \\ = \mathbf{255.3579 \text{ mm}}$$

(Image: Tim Lovett 2007)

## Segundo momento de área (I)

$$X_c = \frac{\Sigma (A \cdot dx)}{\Sigma (A)}$$

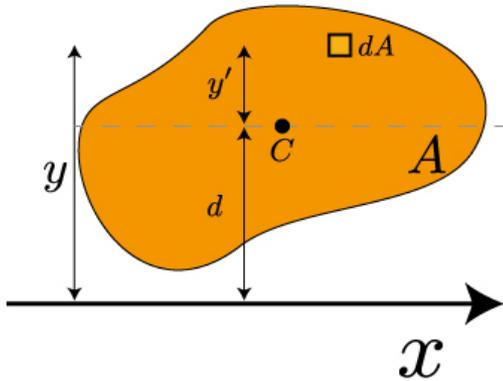
$$Y_c = \frac{\Sigma (A \cdot dy)}{\Sigma (A)}$$



Element	A	y	A*y	x	A*x
	<i>mm<sup>2</sup></i>	<i>mm</i>	<i>mm<sup>3</sup></i>	<i>mm</i>	<i>mm<sup>3</sup></i>
1	138020	206	28432120	167.5	23118350
2	26390	513.5	13551265	270	7125300
<b>Total</b>	<b>164410</b>		<b>41983385</b>		<b>30243650</b>
<b>Centroid</b>			<b>255.35786</b>		<b>183.9526</b>

Plano neutro

Arbitrary Cross Section



$$I_x = \bar{I}_{x'} + Ad^2$$

Segundo momento  
de área (I)



De cada parte

## Parallel Axis Theorem

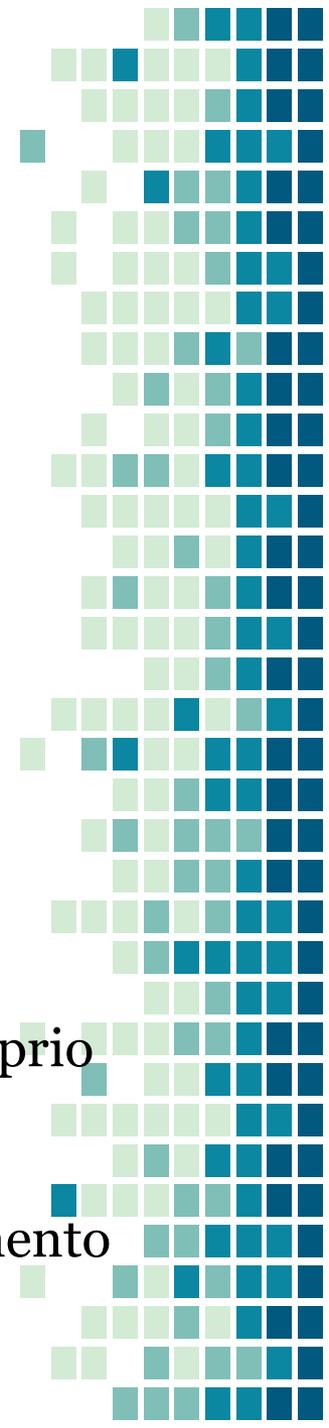
A contribuição de cada element ->  $I = I_c + Ad^2$

$I$  = Segundo momento de area da combinação do centroidal com Neutral plane (x-x)

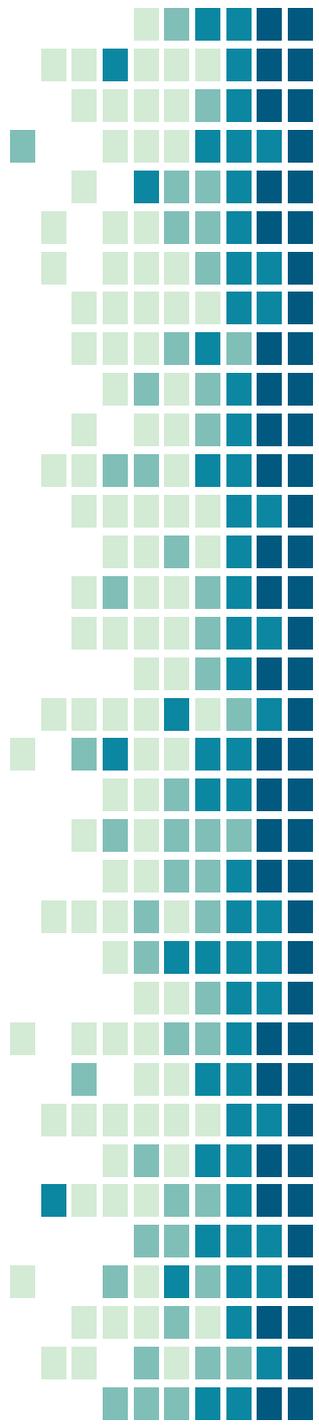
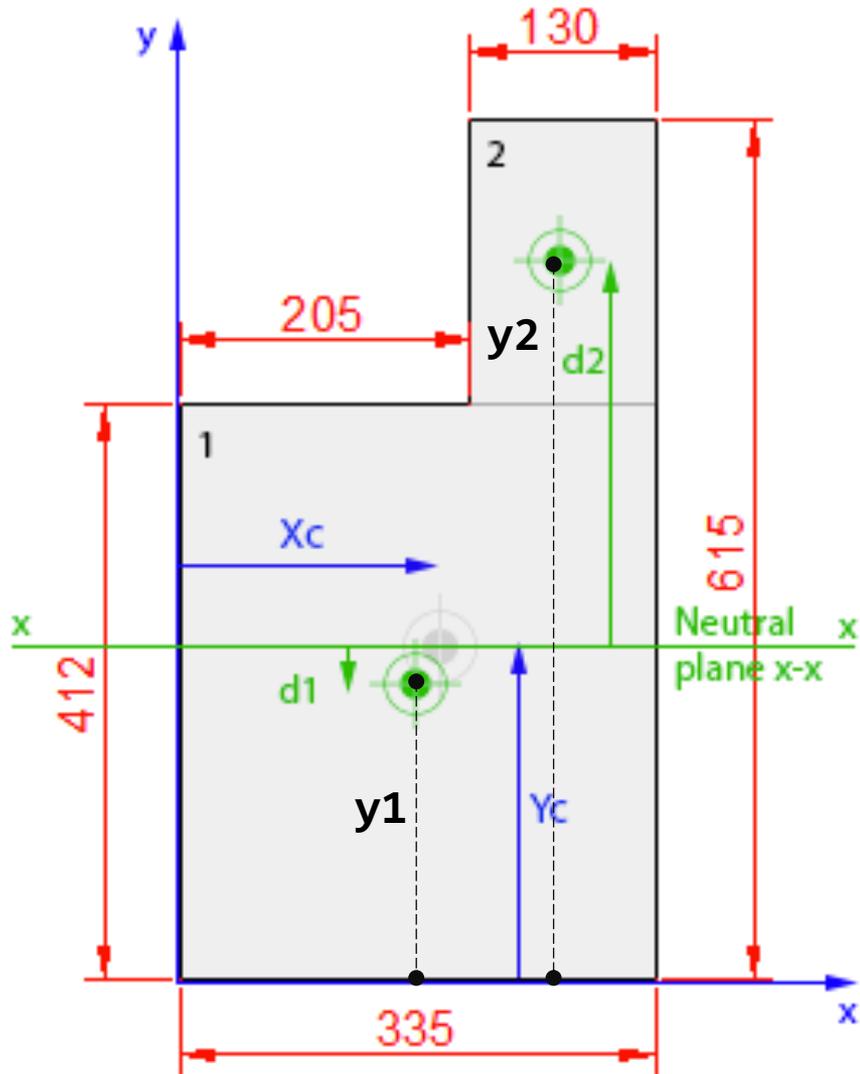
$I_c$  = Segundo momento de area de cada element referente ao proprio centroide

$A$  = Area do elemento

$d$  = distancia do Neutral plane (x-x) para o centroid de cada elemento

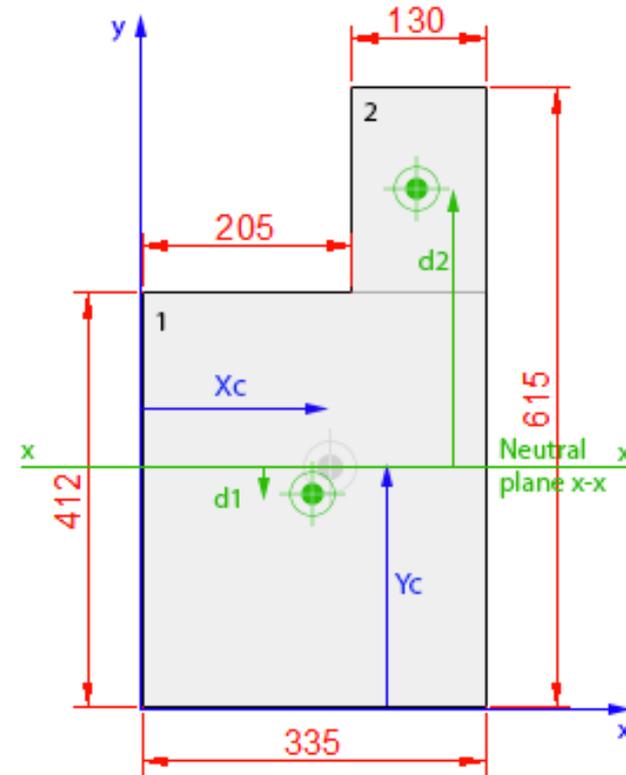


# Segundo momento de área (I)



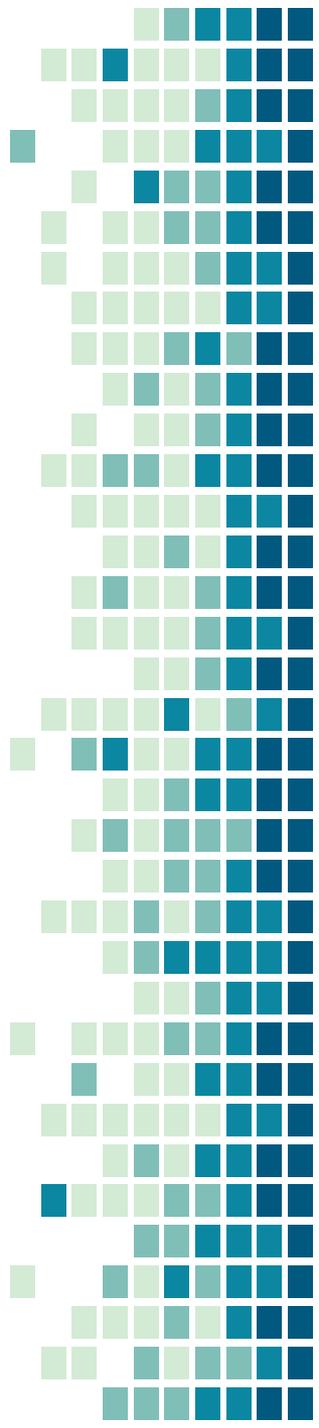
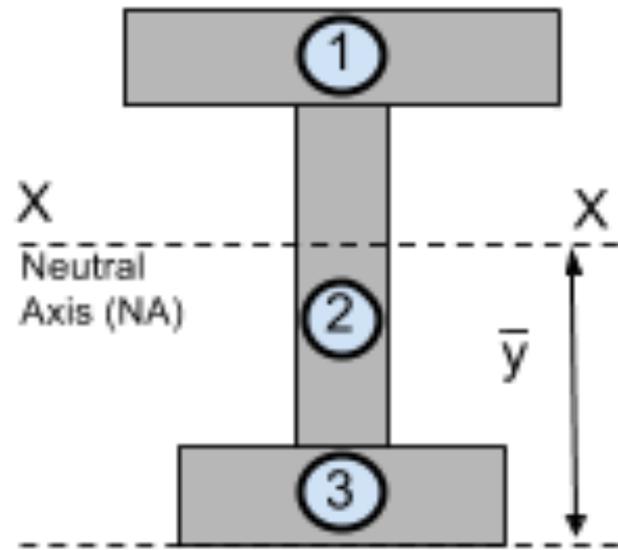
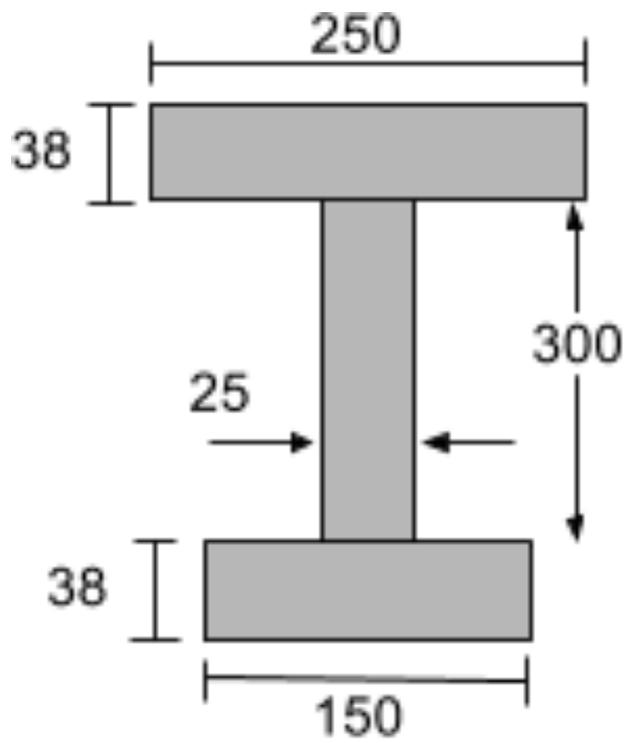
# Segundo momento de área (I)

$$I = I_c + Ad^2$$

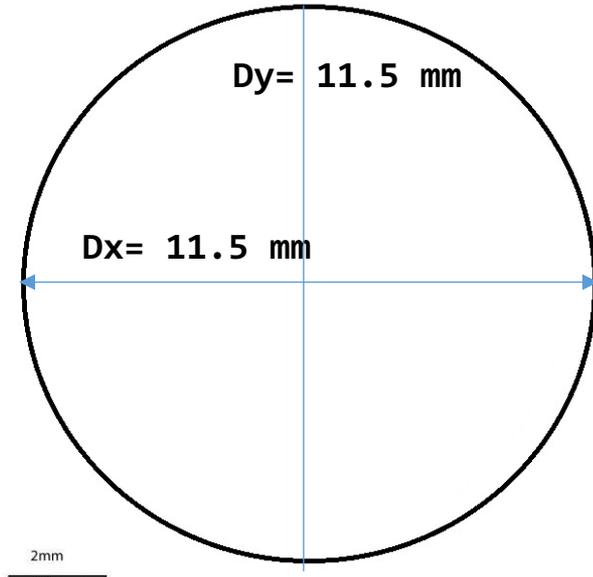


Element	A	y	A*y	Ic	d	Ad <sup>2</sup>	Ixx
	mm <sup>2</sup>	mm	mm <sup>3</sup>	mm <sup>4</sup>	mm	mm <sup>4</sup>	E6mm <sup>4</sup>
1	138020	206	28432120	1952338907	49.35786	33624409	2288.583
2	26390	513.5	13551265	90625459.17	258.14214	1.759E+09	1849.185
<b>Total</b>	<b>164410</b>		<b>41983385</b>			<b>5</b>	<b>4137.768</b>
<b>Centroid</b>			<b>255.35786</b>				

# Segundo momento de área (I)

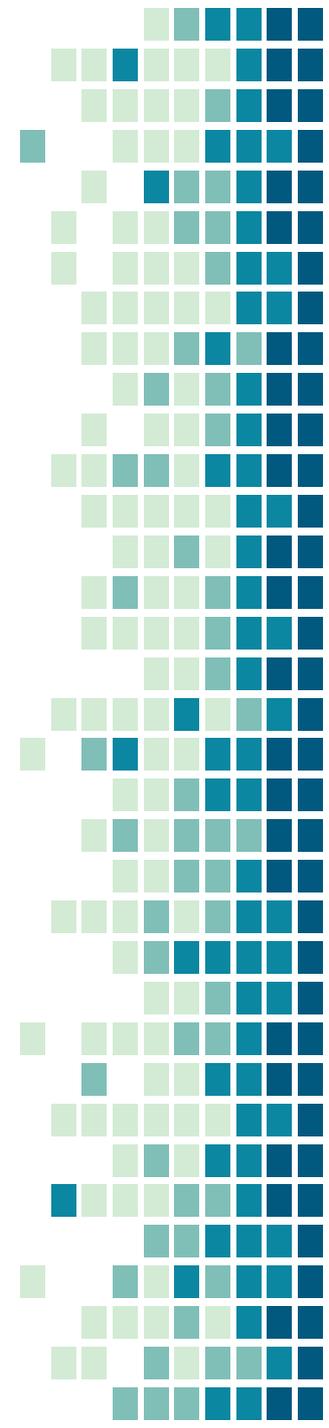


# Segundo momento de área (I)



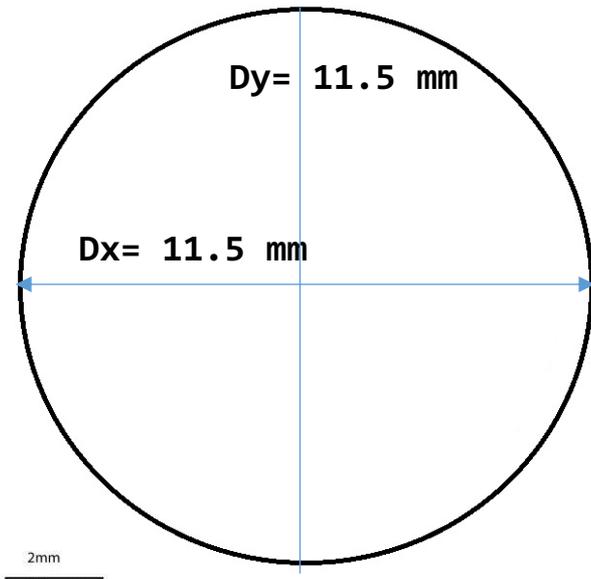
$$I = (d^4 \cdot \pi) / 64$$

$$I = 1197.8 \text{ mm}^4$$





# Segundo momento de área (I)



**Fórmula**

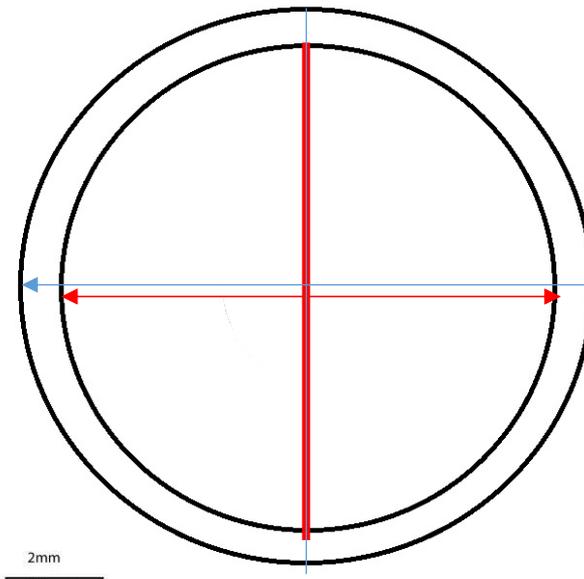
$$I = 858 \text{ mm}^4$$

$$A = 103 \text{ mm}^2$$

**Optimas**

$$I = 809 \text{ mm}^4$$

$$A = 100 \text{ mm}^2$$



**Fórmula**

$$I_{\text{casca}} = 367 \text{ mm}^4$$

$$A_{\text{casca}} = 25 \text{ mm}^2$$

$$I_{\text{wood}} = 490 \text{ mm}^4$$

$$A_{\text{wood}} = 78 \text{ mm}^2$$

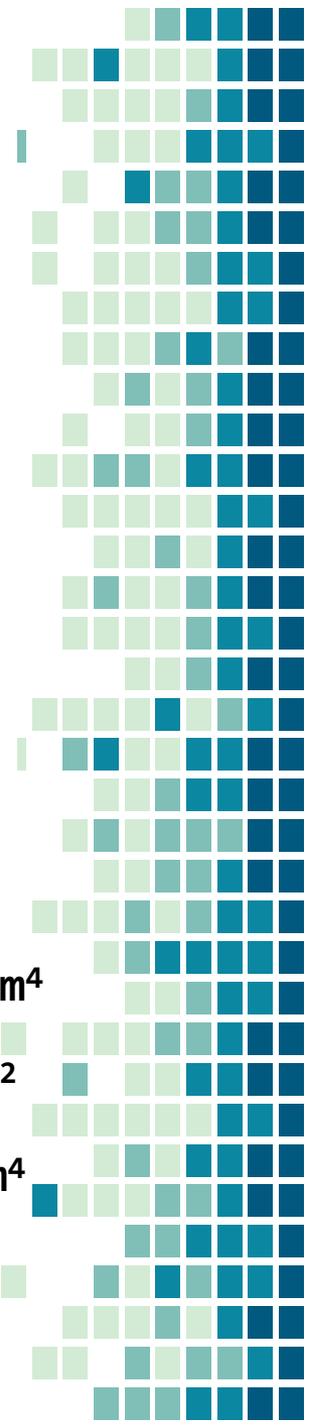
**Optimas**

$$I_{\text{casca}} = 361 \text{ mm}^4$$

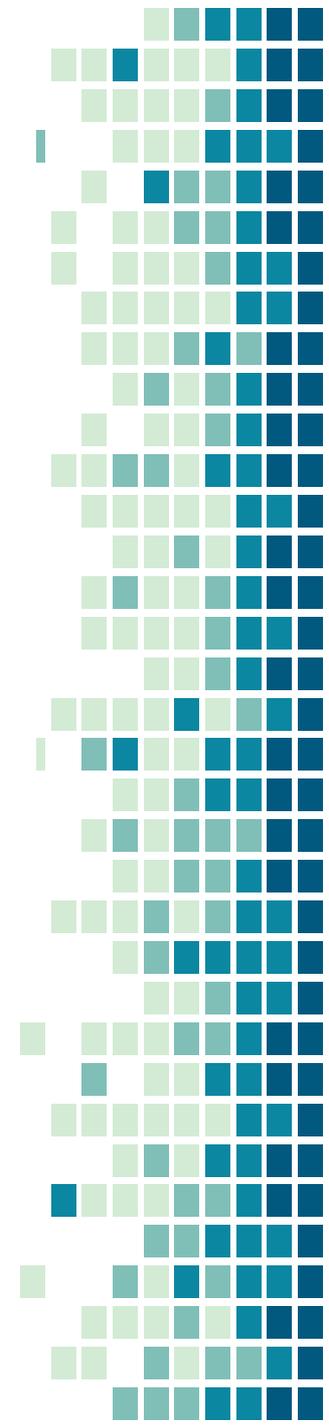
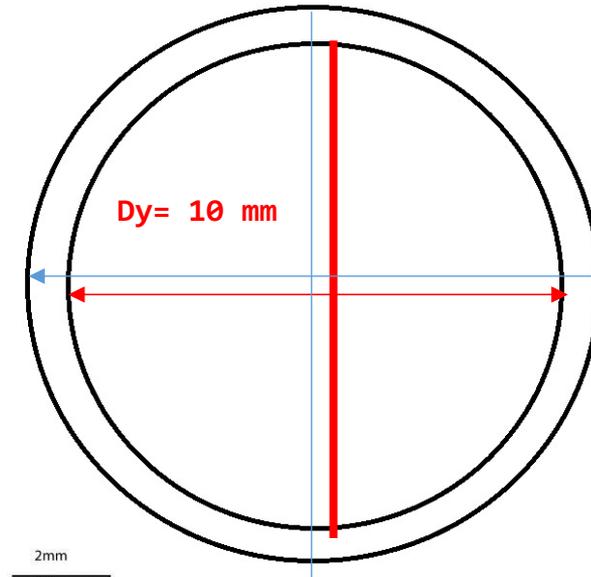
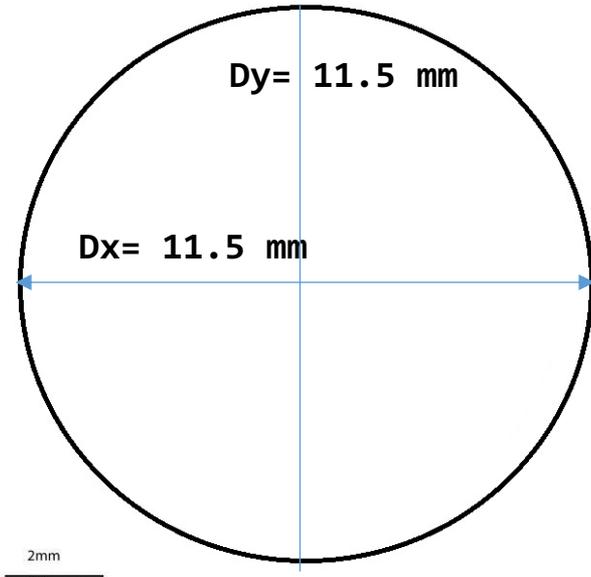
$$A_{\text{casca}} = 24 \text{ mm}^2$$

$$I_{\text{wood}} = 462 \text{ mm}^4$$

$$A_{\text{wood}} = 76 \text{ mm}^2$$



# Segundo momento de área (I)



local	centroid (x)	Centroid (y)	second moment area (y) (mm <sup>4</sup> )	second moment area (x) (mm <sup>4</sup> )	mean xy (mm <sup>4</sup> )
Casca	0	0	361.1	336.6	348.9
Wood	0.039	-0.039	462.5	458.9	460.7

## Fórmula

$$I_{casca} = 367 \text{ mm}^4$$

$$A_{casca} = 25 \text{ mm}^2$$

$$I_{wood} = 490 \text{ mm}^4$$

$$A_{wood} = 78 \text{ mm}^2$$

## Optimas

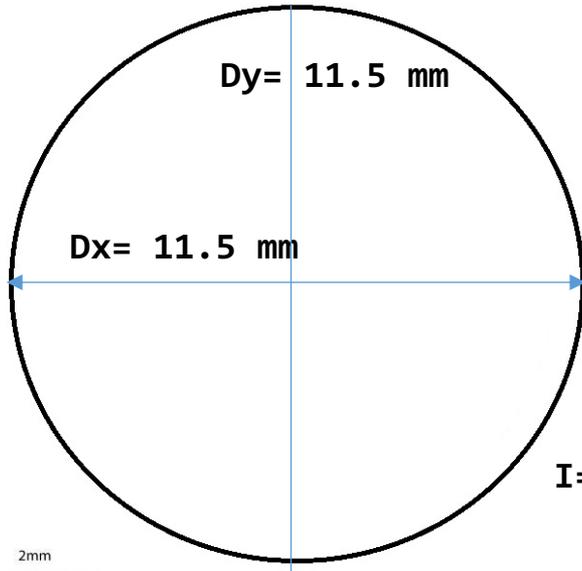
$$I_{casca} = 348 \text{ mm}^4$$

$$A_{casca} = 24 \text{ mm}^2$$

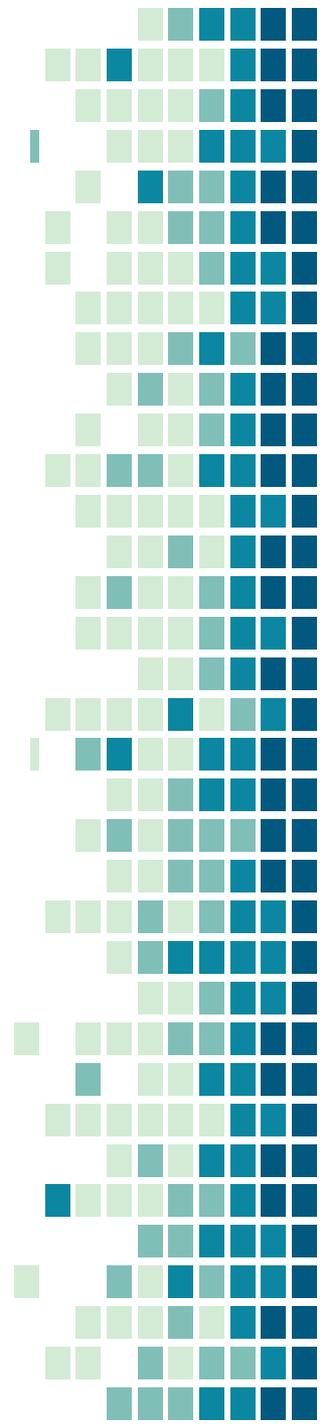
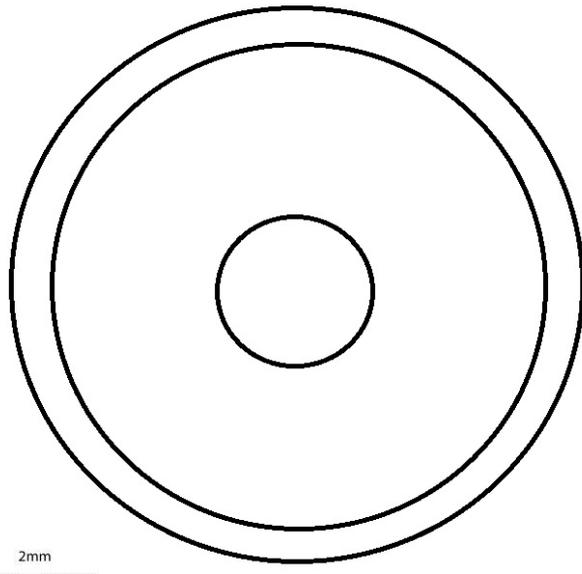
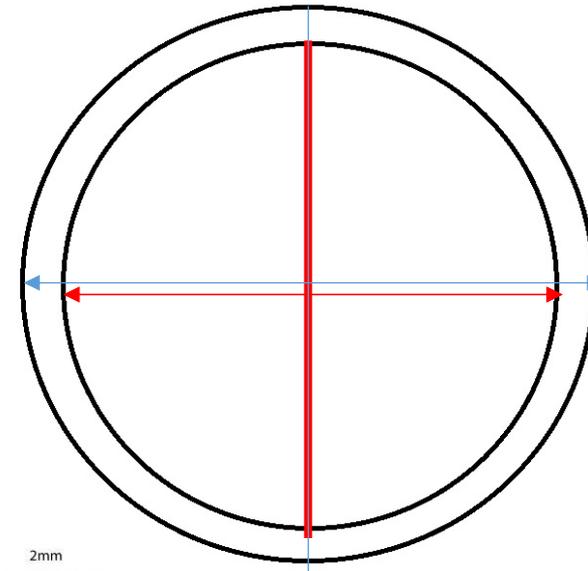
$$I_{wood} = 460 \text{ mm}^4$$

$$A_{wood} = 76 \text{ mm}^2$$

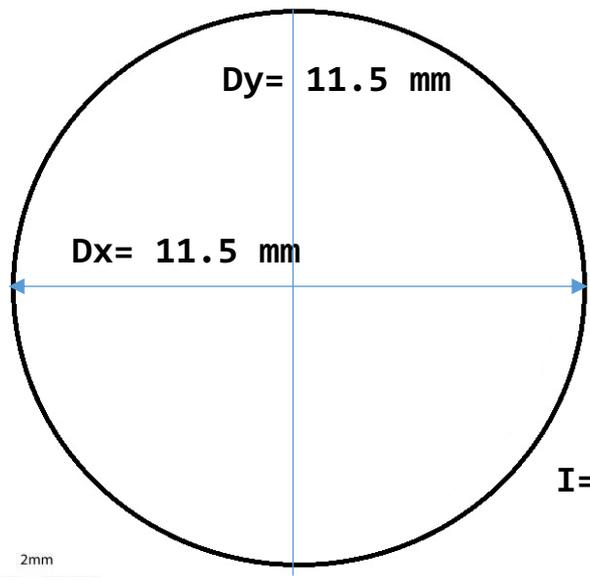
# Segundo momento de área (I)



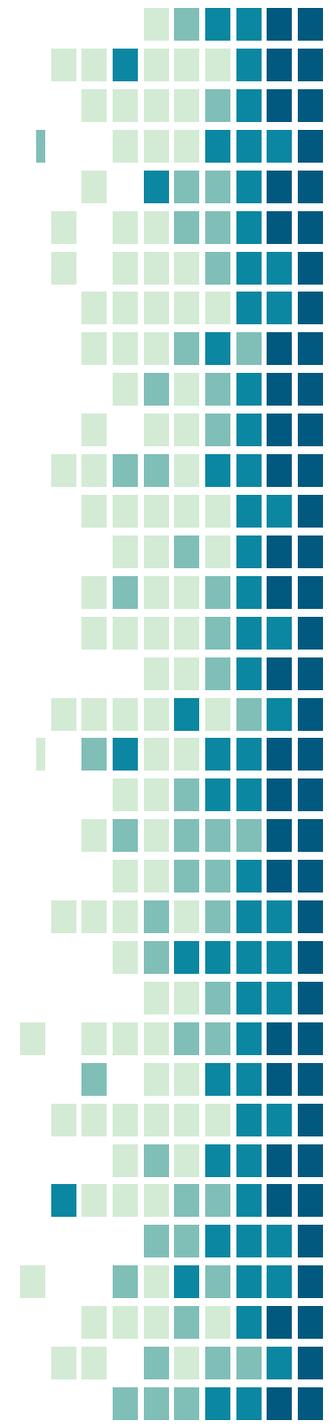
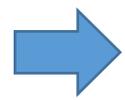
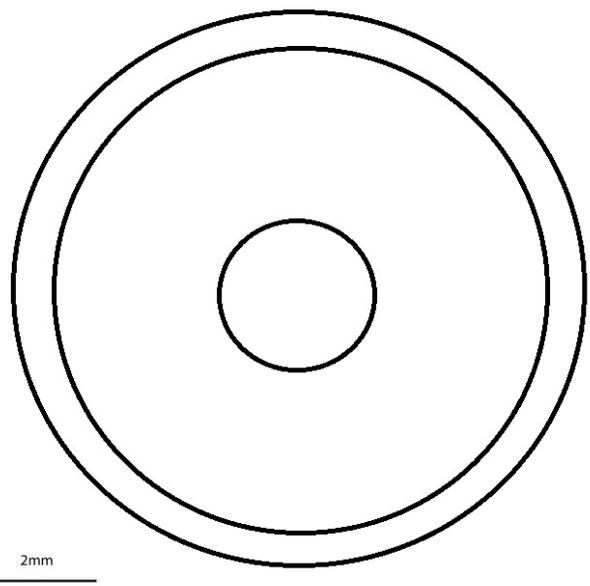
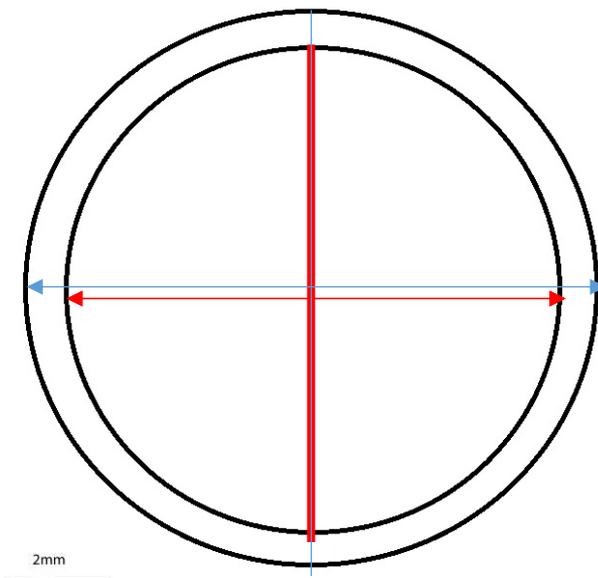
$$I = 1197.8 \text{ mm}^4$$



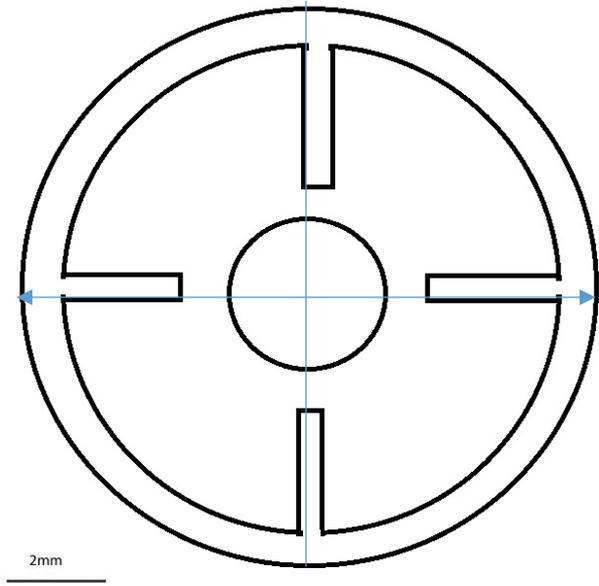
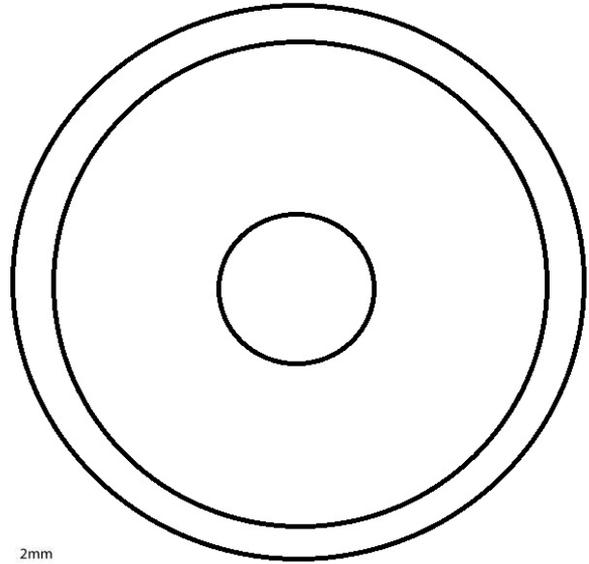
# Segundo momento de área (I)



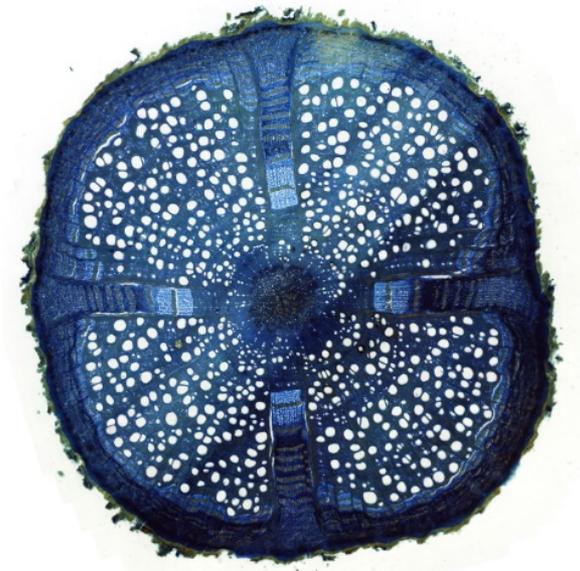
$I = 1197.8 \text{ mm}^4$



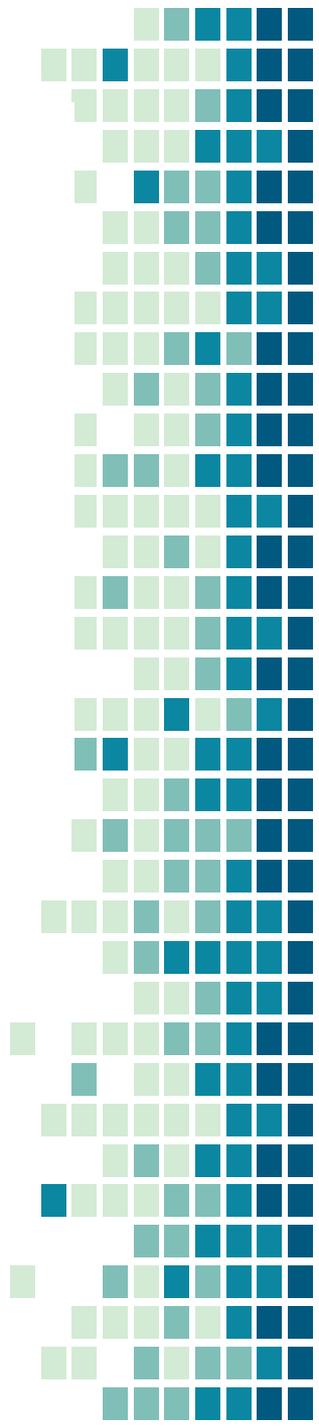
# Segundo momento de área (I)



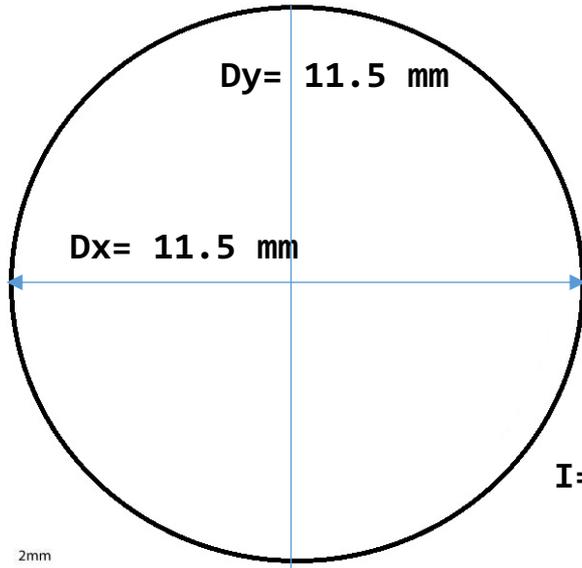
*Handroanthus heptaphyllus*(Bignoniaceae)



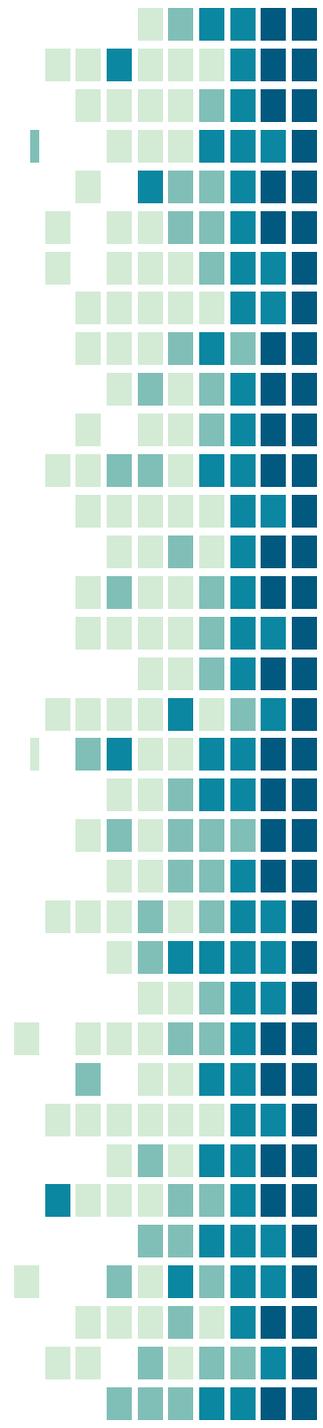
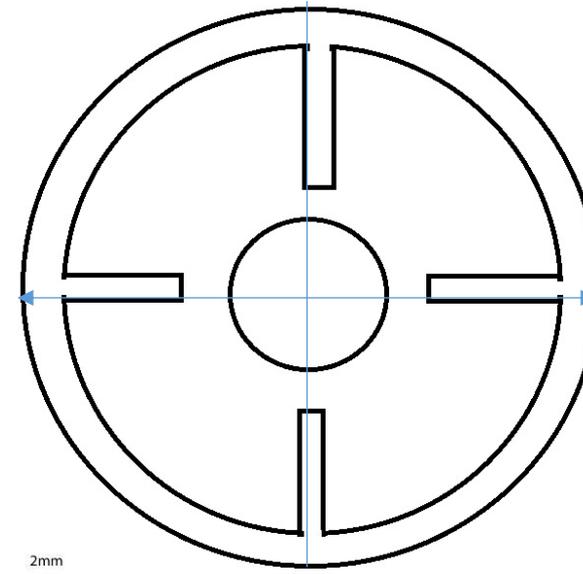
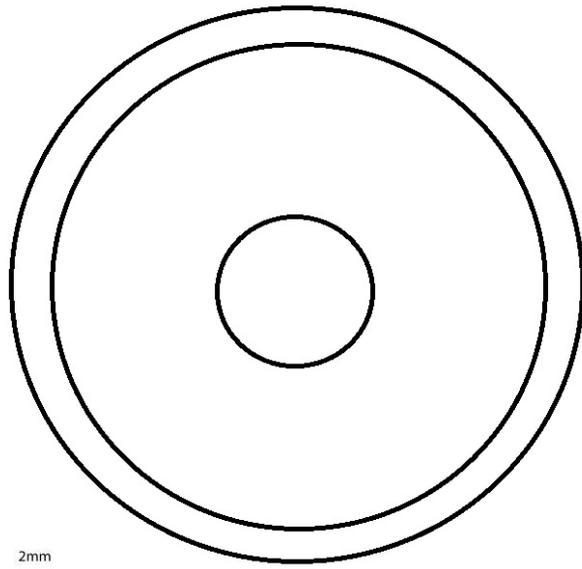
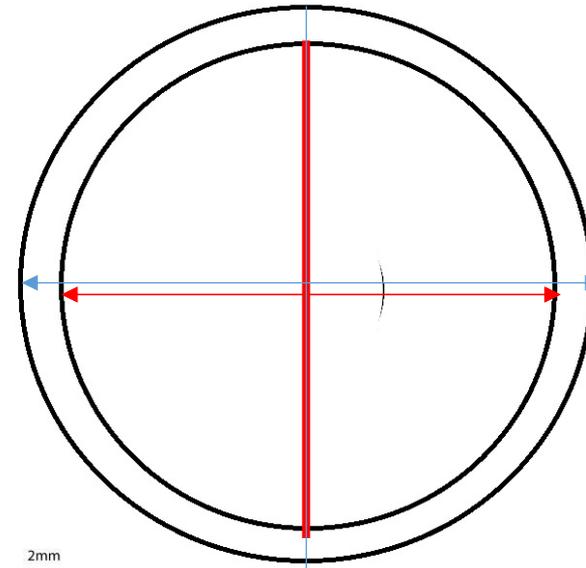
*Pachyptera aromatica* (Bignoniaceae)



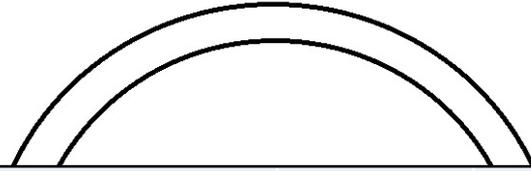
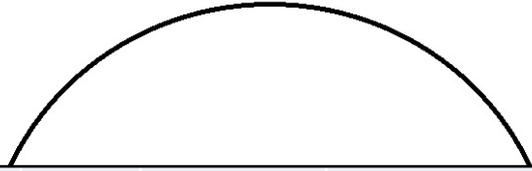
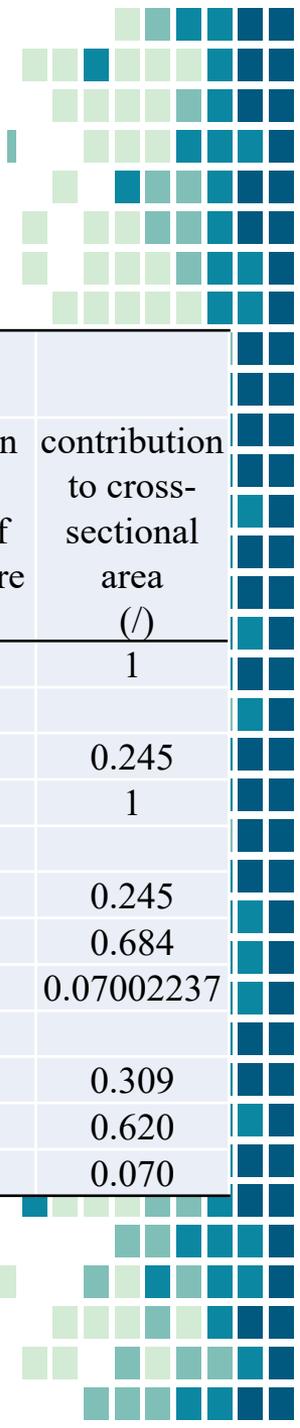
# Segundo momento de área (I)



$$I = 1197.8 \text{ mm}^4$$



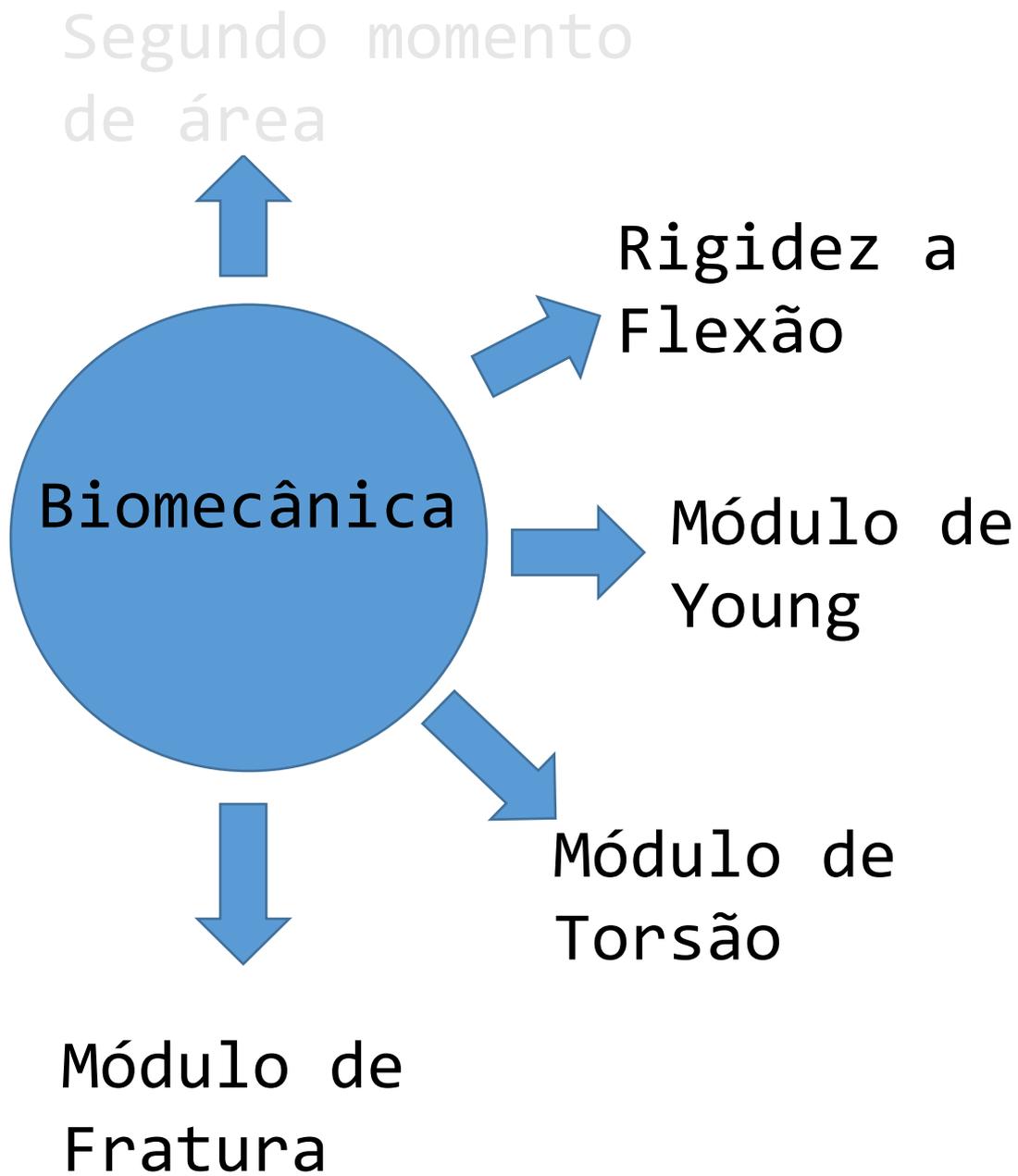
# Segundo momento de área (I)

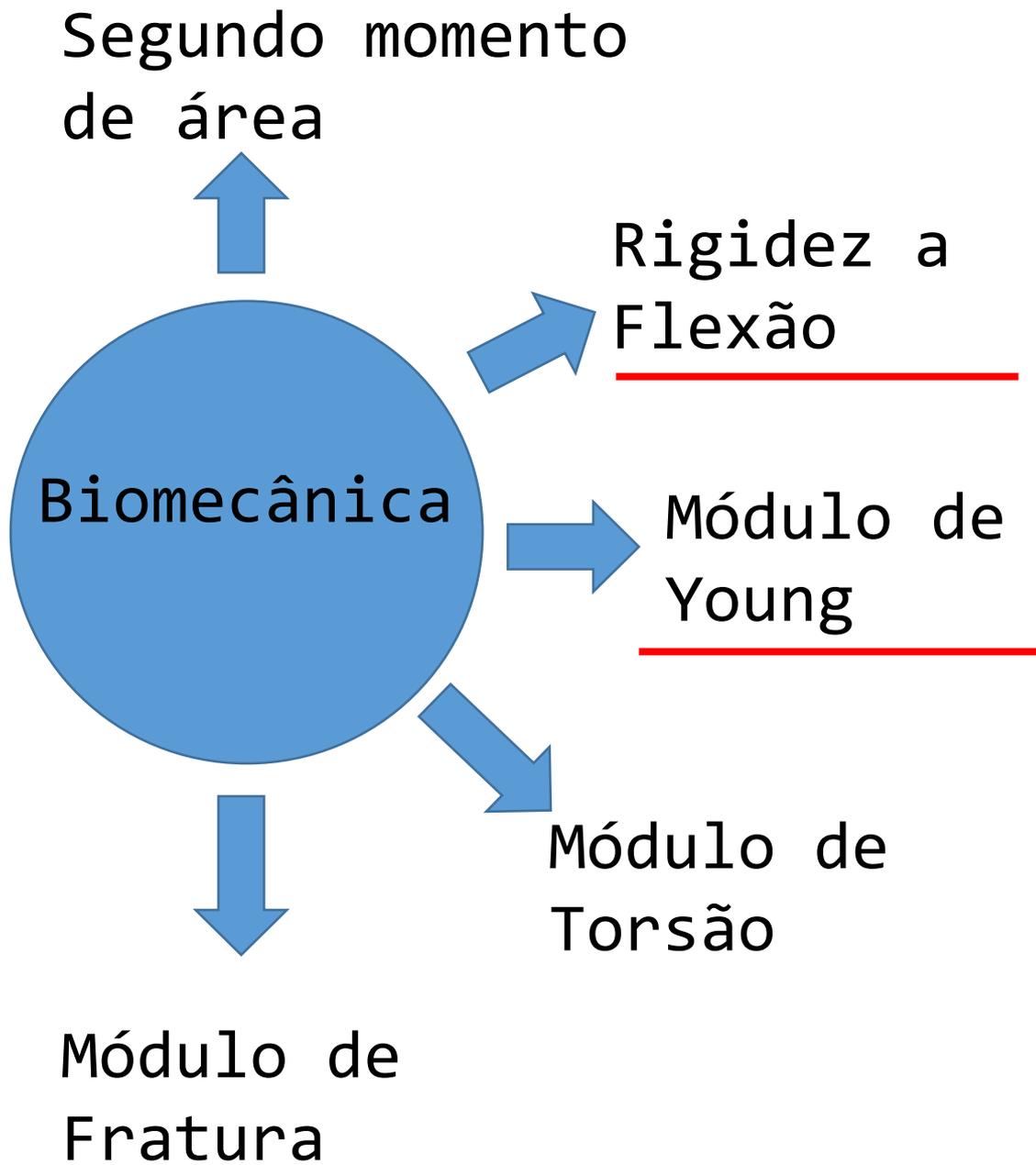


Optimas (Almeras França)									
Name	Tissue	Area (mm <sup>2</sup> )	centroid (x)	cantroid (y)	second moment area (y) (mm <sup>4</sup> )	second moment area (x) (mm <sup>4</sup> )	mean xy (mm <sup>4</sup> )	contribution to second moment of area of entire stem (I)	contribution to cross-sectional area (I)
Elipse		100.859	0.00	0.00	823.687	795.567	809.6	1.0	1
Casca Wood		24.78	0.00	0.00	361.18	336.63	0.16	348.90	0.430
		76.08	0.04	-0.04	462.51	458.93	-0.13	460.72	1.00
Casca Wood		24.78	0.00	0.00	361.18	336.63	0.16	348.90	0.4309
		69.02	0.04	-0.04	458.42	454.93	-0.17	456.67	0.5641
Pith		7.06	-0.04	-0.14	4.08	4.00	0.04	4.042	0.0050
									0.07002237
Casca e cunhas Wood		31.83	0.00	0.00	420.31	396.81	1.18	408.558	0.4851
		63.83	0.03	-0.06	432.24	426.57	-1.19	429.404	0.5099
Pith		7.20	-0.04	-0.14	4.25	4.16	0.04	4.205	0.0050
									0.070

2mm

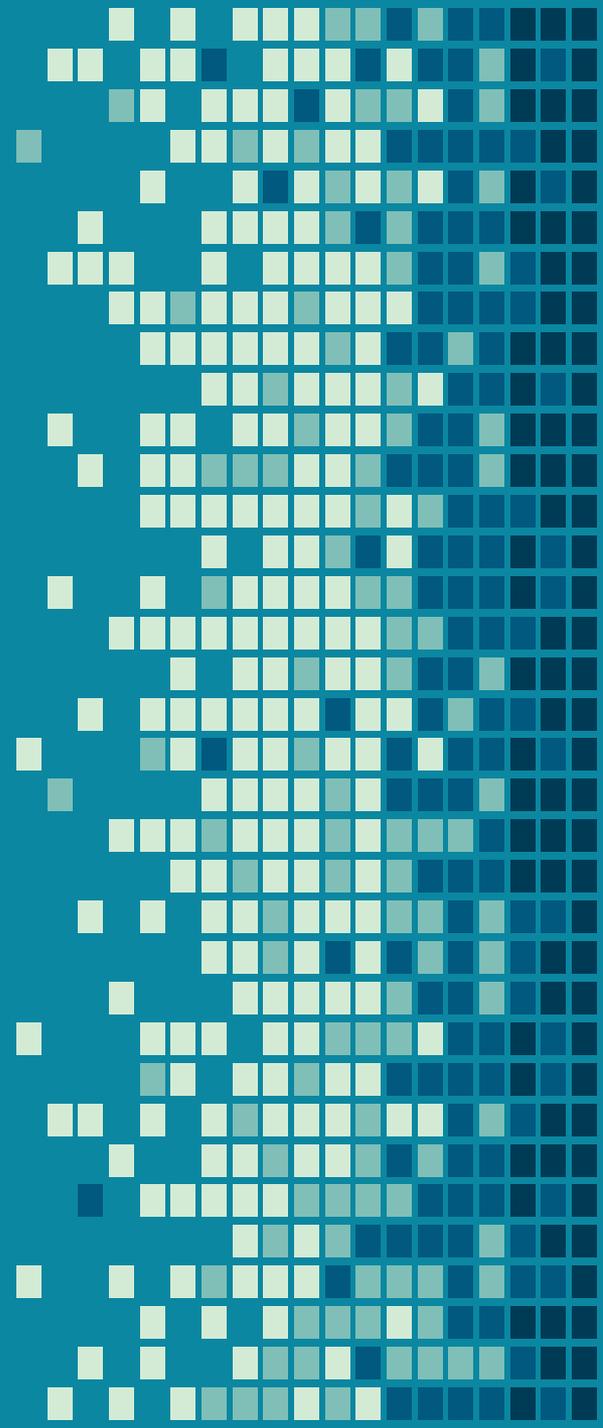
2mm





“

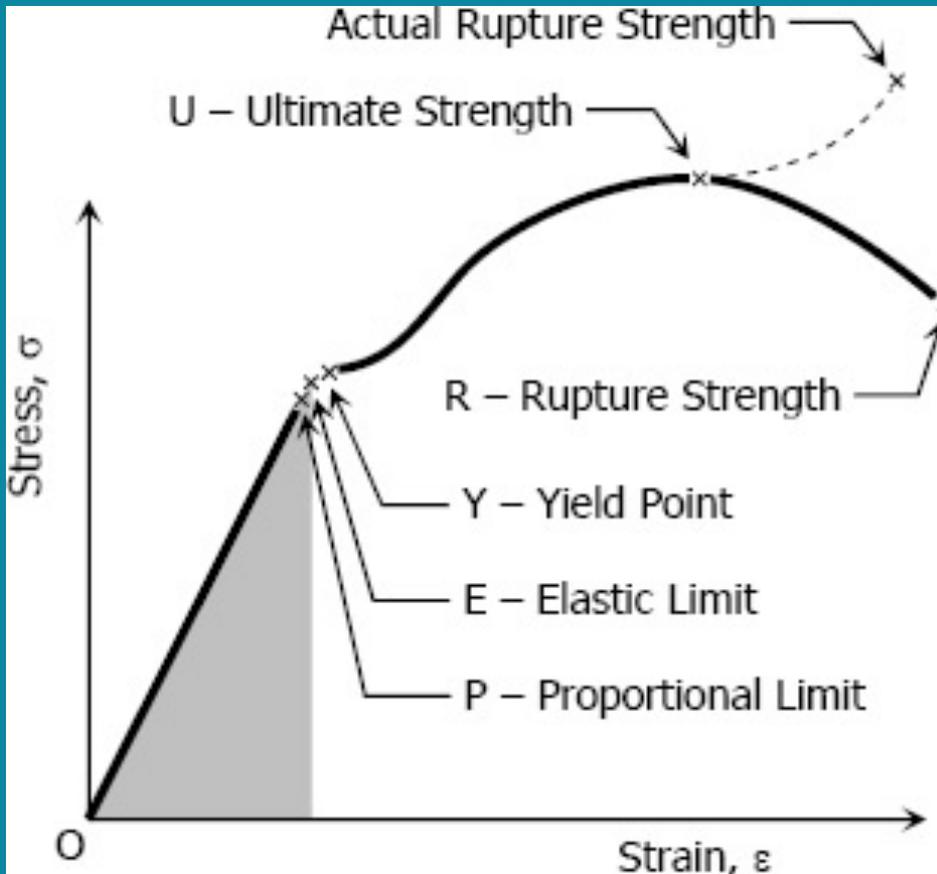
*Gráfico Força  
x  
Deslocamento*



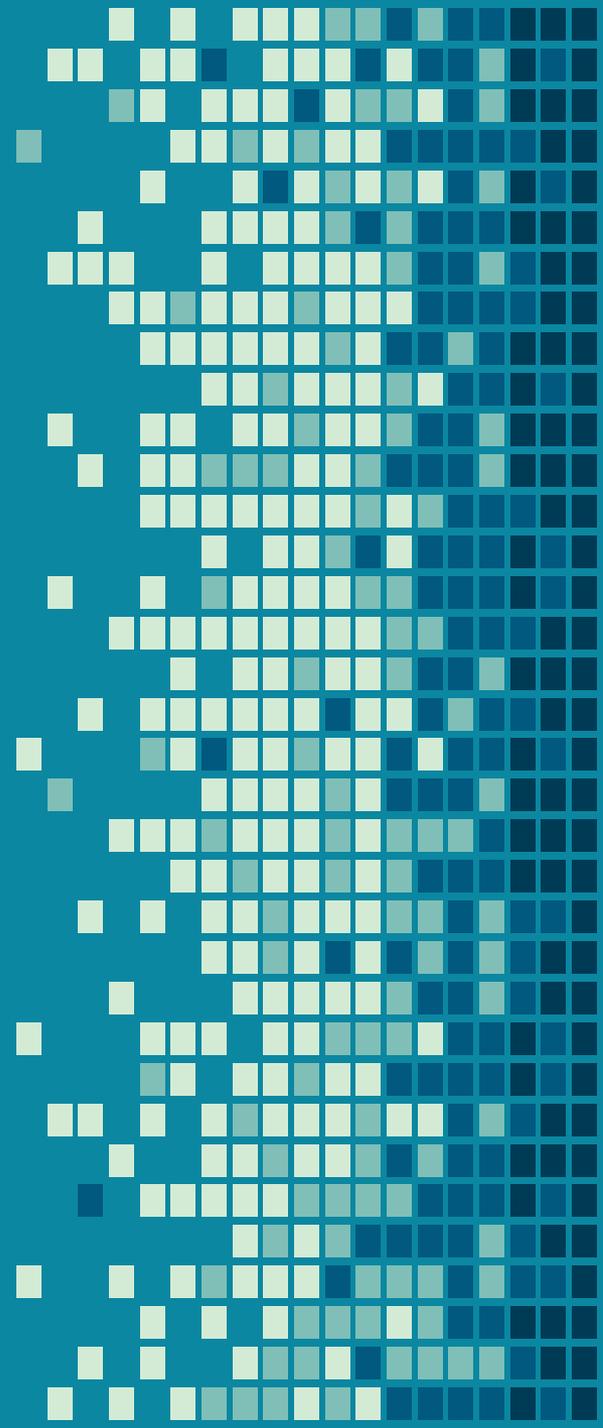
“

# Gráfico Força x Deslocamento

Força por área



Deslocamento ( $\Delta L/l_0$ )



### 3 - Point bending

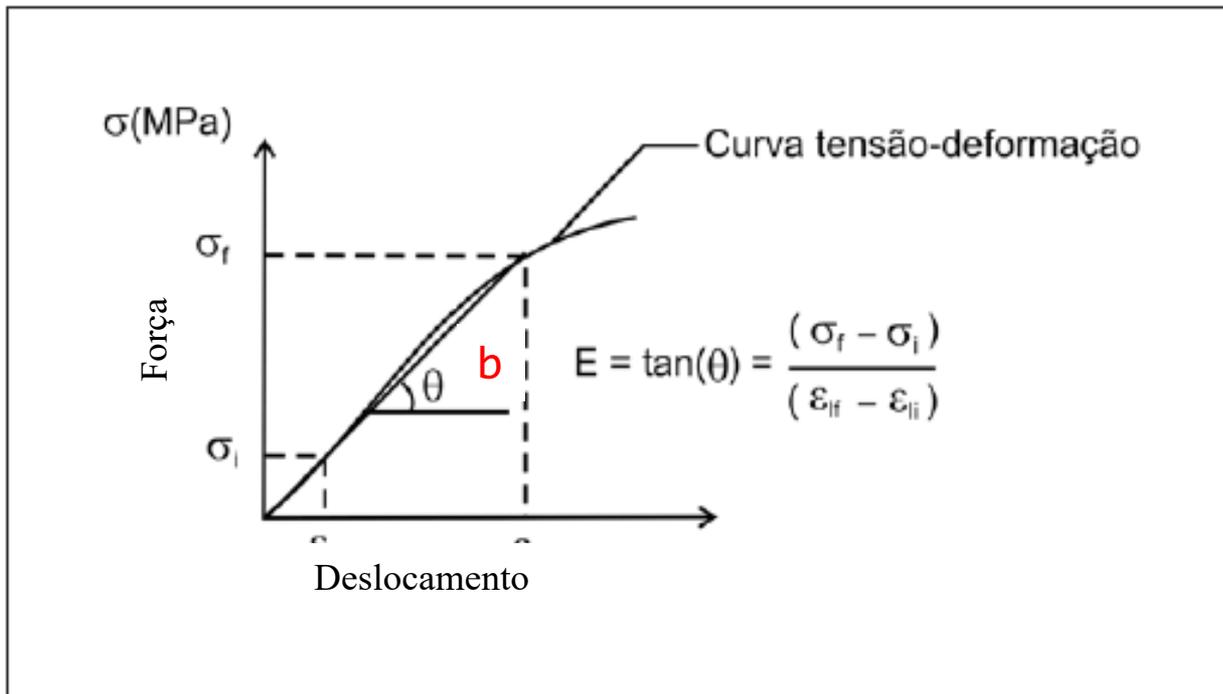
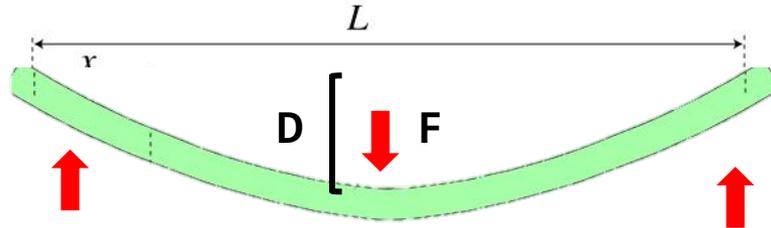
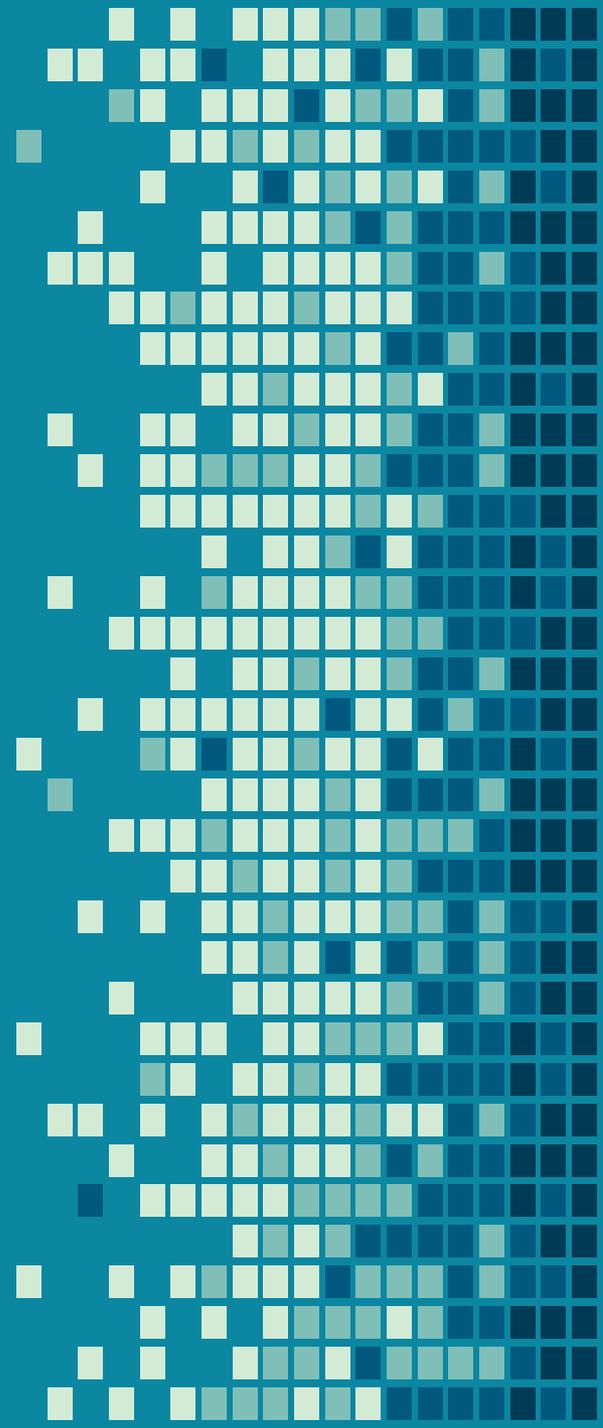


Figura 4 - Esquema para cálculo do módulo de elasticidade.

# Máquina Universal de Ensaio Mecânicos



”



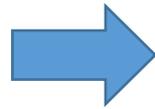


## Máquina Universal de Ensaio MBI0 I

	MBIO – I 200	MBIO I – 500
Capacidade de carga (KN)	2	5
Velocidade Mínima de Ensaio (mm/min)	0,005	0,005
Velocidade Máxima de Ensaio (mm/min)	1000	1000
Curso Máximo (mm)	900	900
Profundidade Útil de Ensaio (mm)	120	120
Altura (mm)	1310	1400
Largura (mm)	510	510
Profundidade (mm)	685	685
Peso (Kg)	100	120
Potência Máxima (VA)	1100	1200
Tensão (V)	110	110
Garantia (ano)	1	1



Tração



Compressão

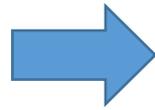


Flexão





Tração



Compressão

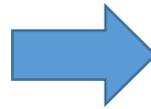


Flexão





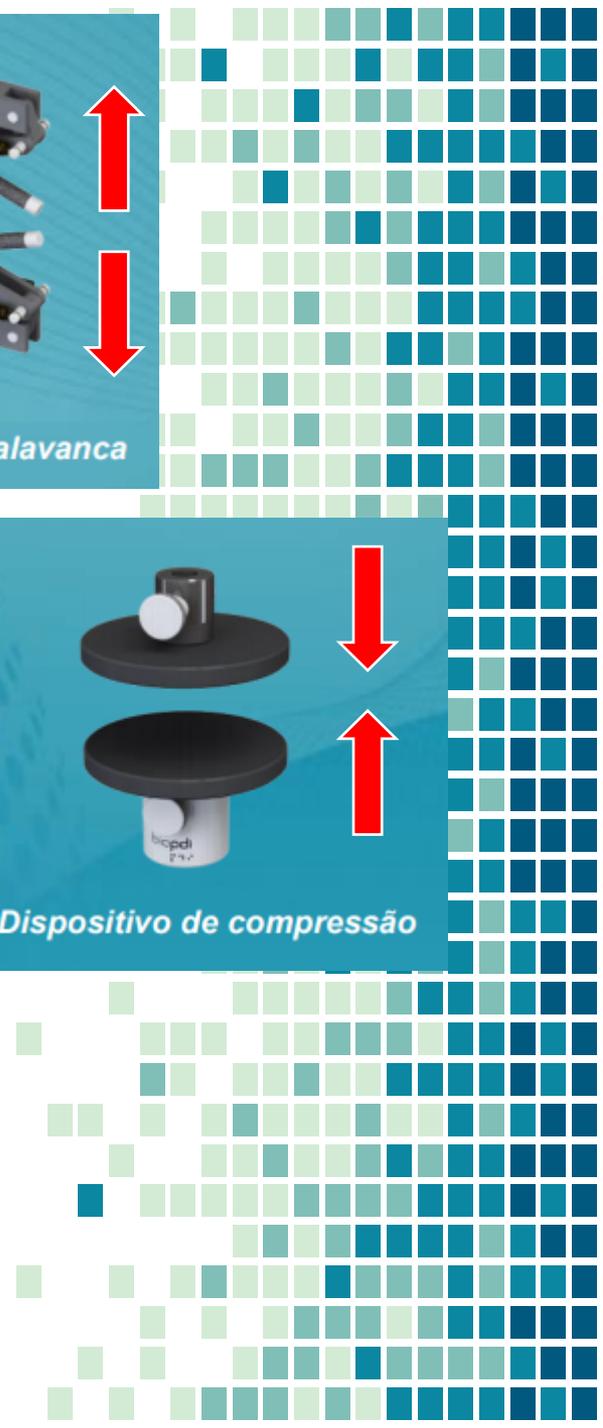
Tração



Compressão



Flexão

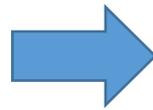




Tração



*Garra efeito alavanca*



Compressão



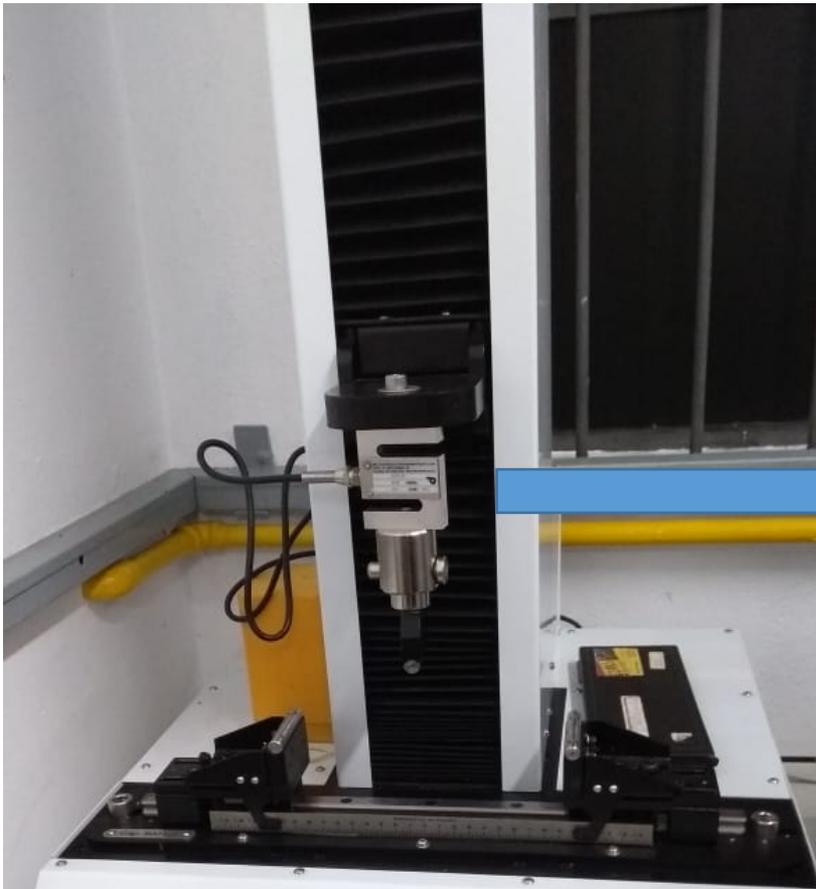
*Dispositivo de compressão*



Flexão



*Dispositivo de flexão*



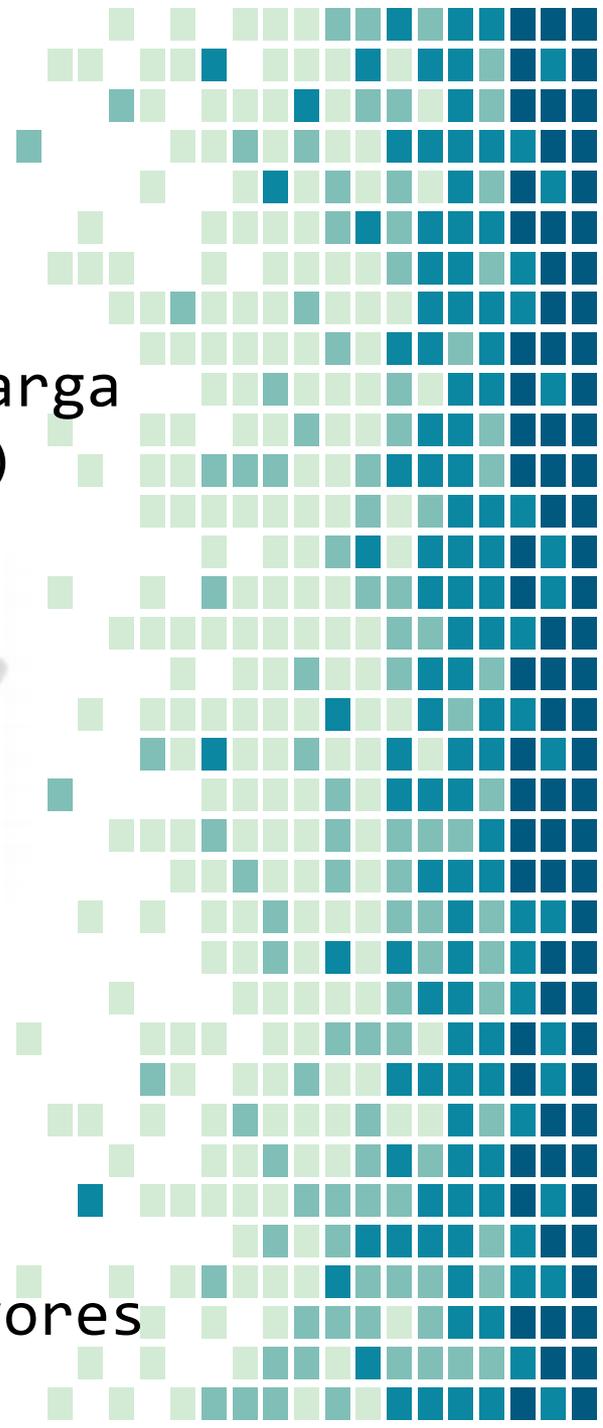
Células de carga  
(1 - 500 Kgf)



Folhas & folíolos



Ramos de árvores



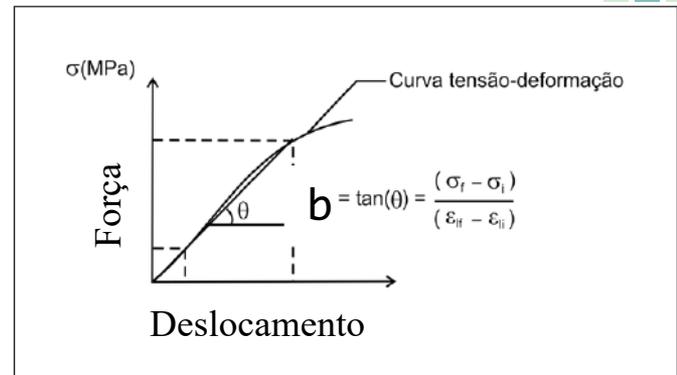
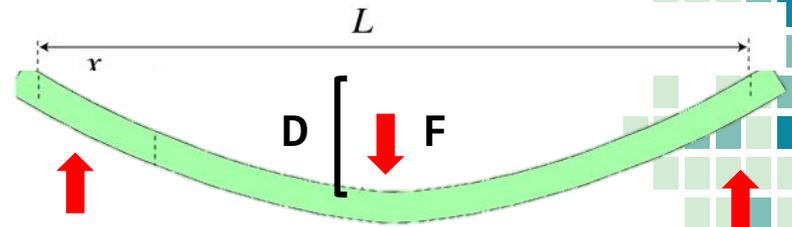
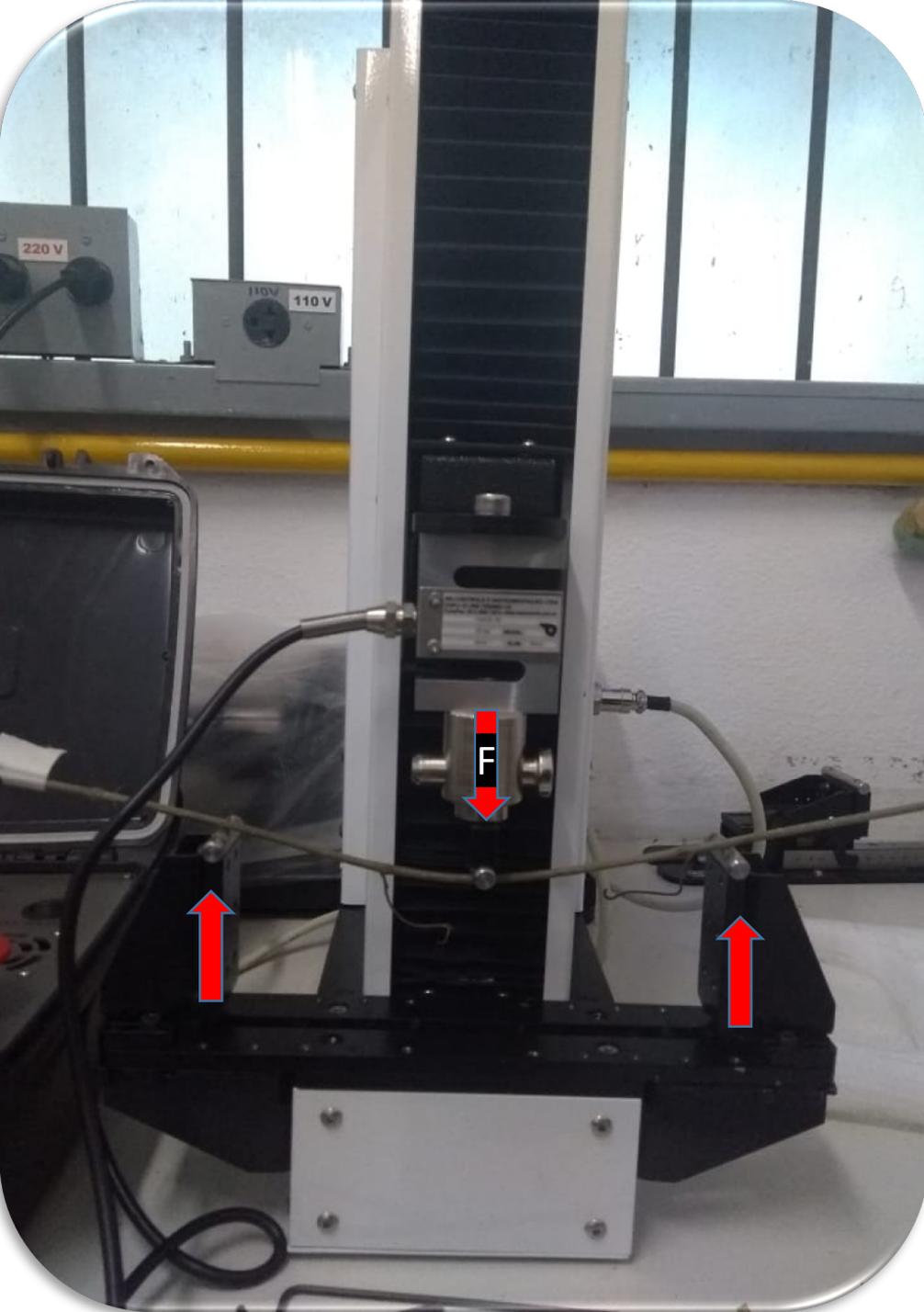
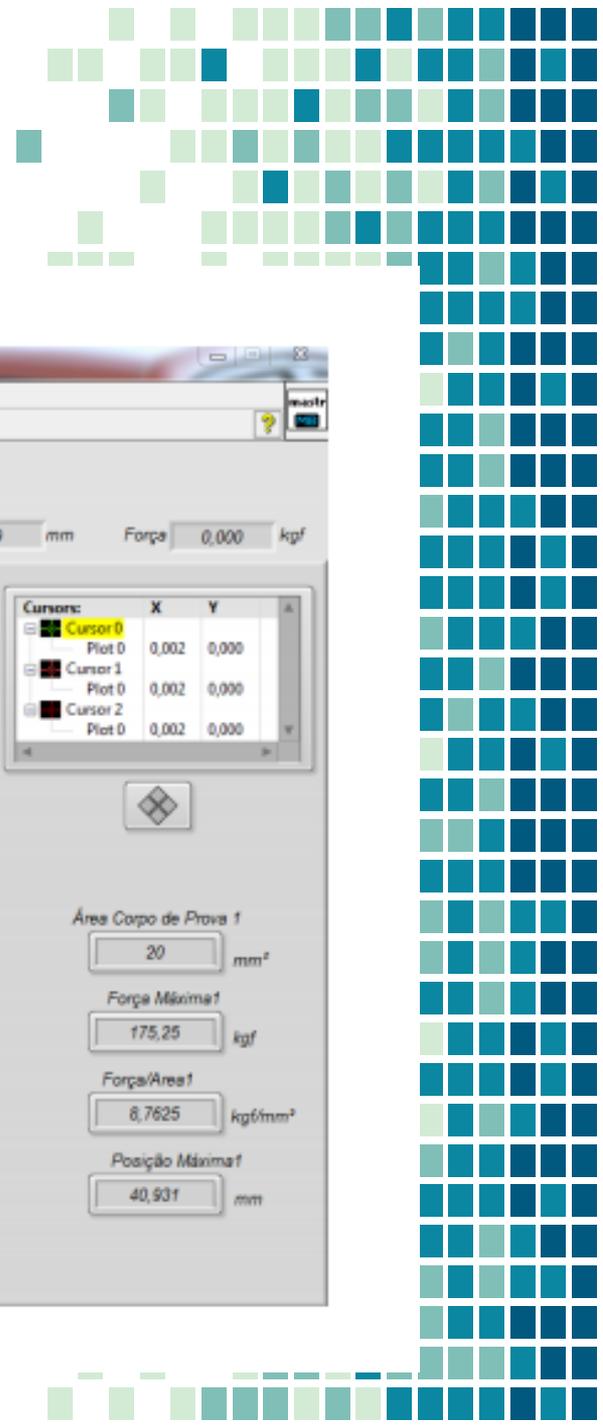
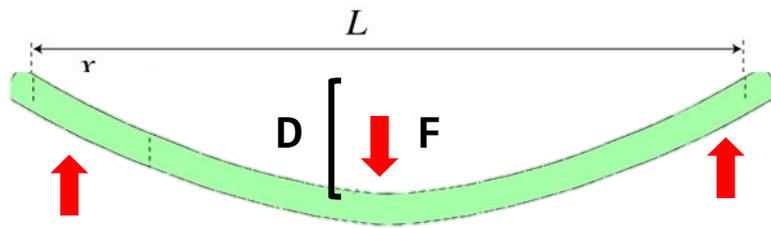
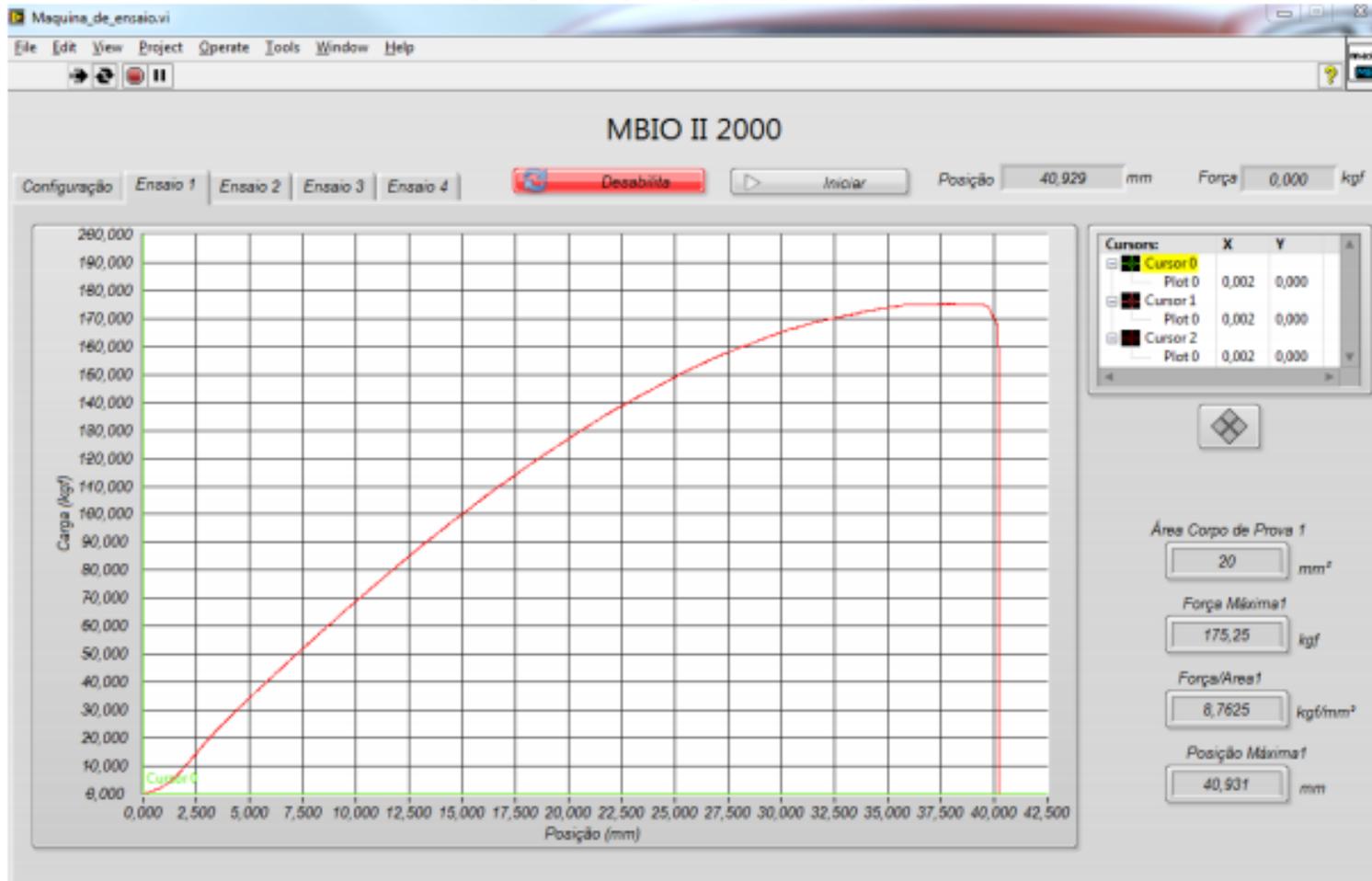
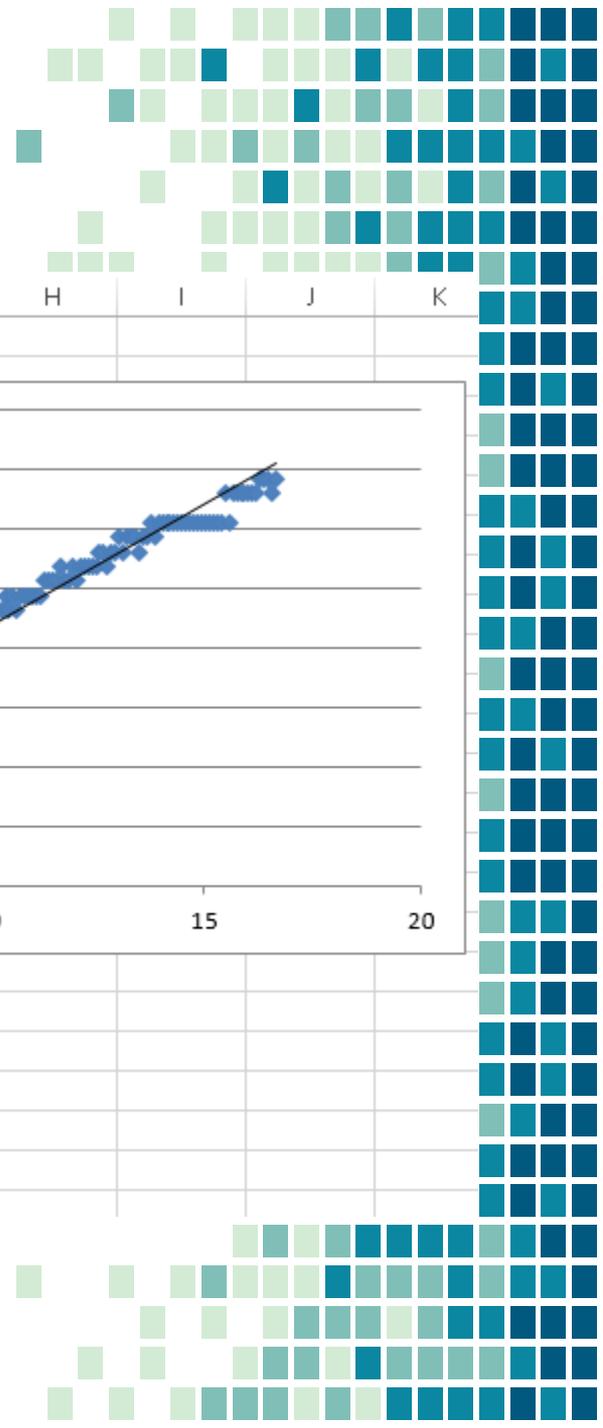
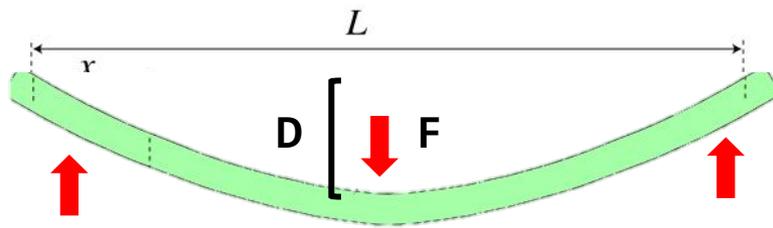


Figura 4 - Esquema para cálculo do módulo de elasticidade.

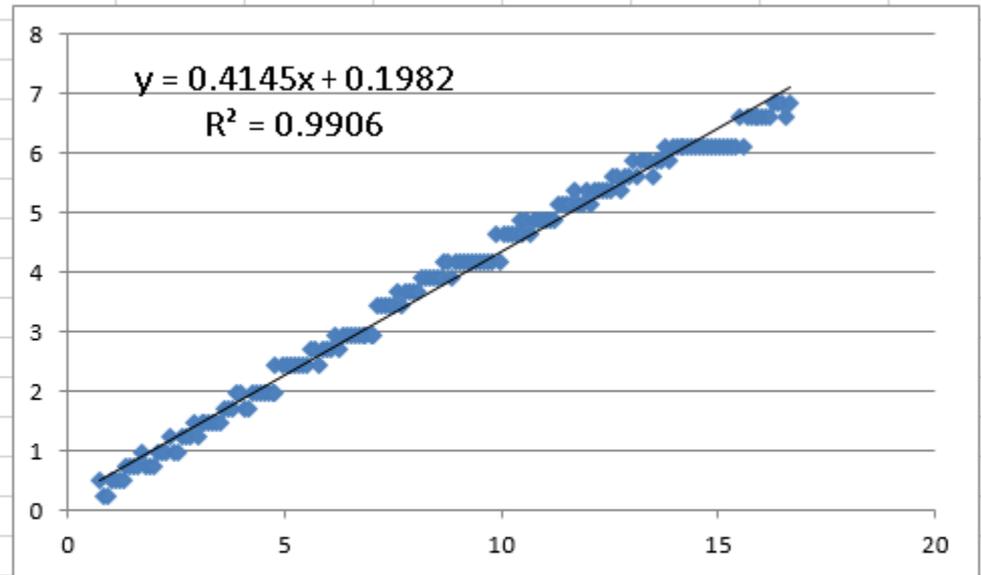


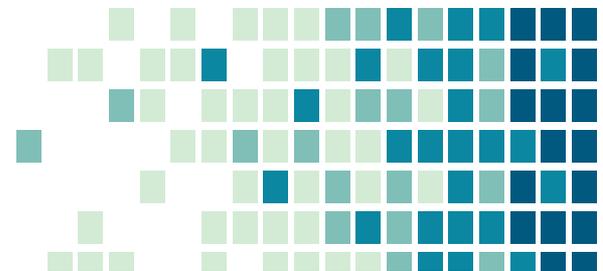
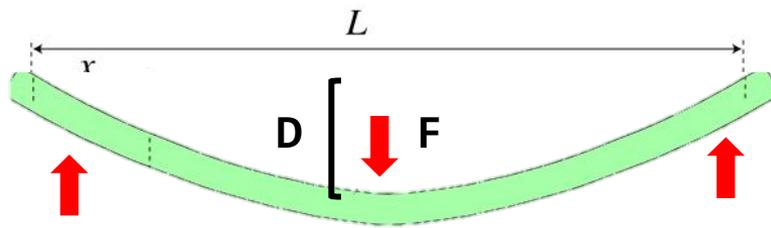
## Software: Tela de Ensaio



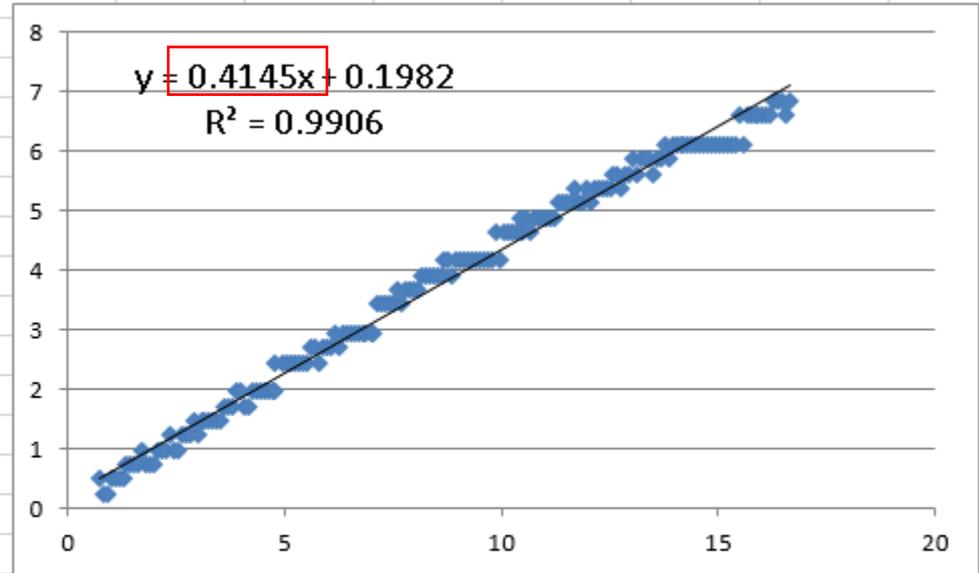


	A	B	C	D	E	F	G
1	Posição (mm) - Plot 0	Força (N) - Plot 0					
2	0	0					
3	0	0					
4	0	0					
5	0	0					
6	0.083	0					
7	0.174	0					
8	0.266	0					
9	0.358	0					
10	0.449	0					
11	0.541	0.244					
12	0.624	0					
13	0.724	0.489					
14	0.808	0.244					
15	0.899	0.244					
16	0.991	0.489					
17	1.083	0.489					
18	1.174	0.489					
19	1.266	0.489					
20	1.349	0.734					
21	1.441	0.734					
22	1.533	0.734					
23	1.624	0.734					

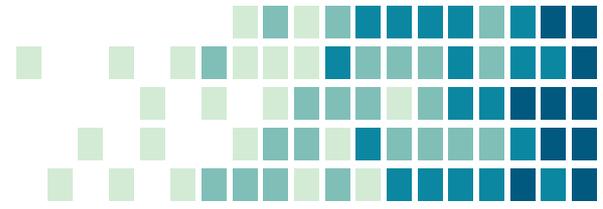




	A	B	C	D	E	F	G	H	I	J	K
1	Posição (mm) - Plot 0	Força (N) - Plot 0									
2	0	0									
3	0	0									
4	0	0									
5	0	0									
6	0.083	0									
7	0.174	0									
8	0.266	0									
9	0.358	0									
10	0.449	0									
11	0.541	0.244									
12	0.624	0									
13	0.724	0.489									
14	0.808	0.244									
15	0.899	0.244									
16	0.991	0.489									
17	1.083	0.489									
18	1.174	0.489									
19	1.266	0.489									
20	1.349	0.734									
21	1.441	0.734									
22	1.533	0.734									
23	1.624	0.734									



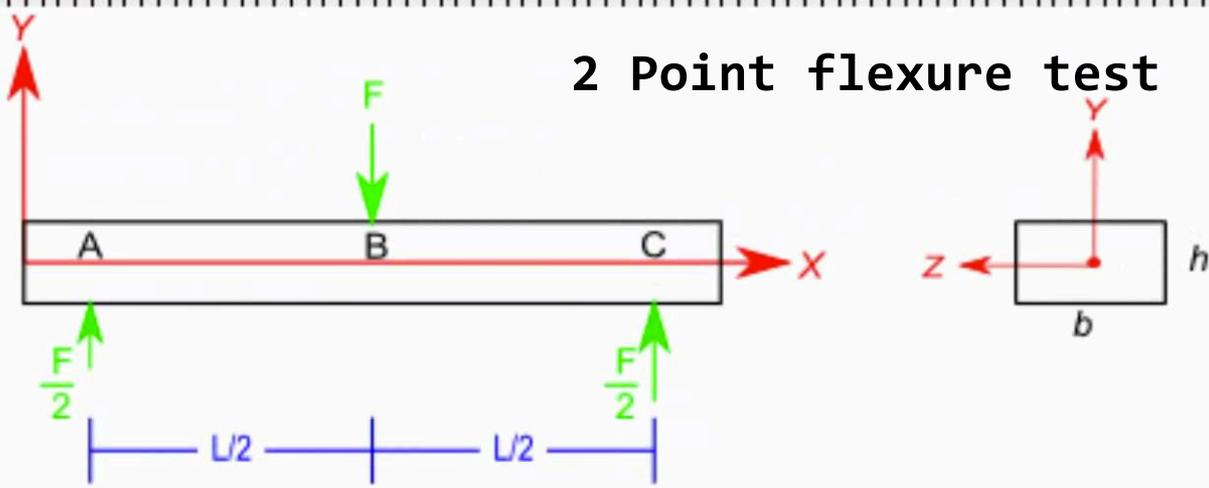
**Rigidez a Flexão(EI)**  
 $EI = (L^3 \times b) / 48$

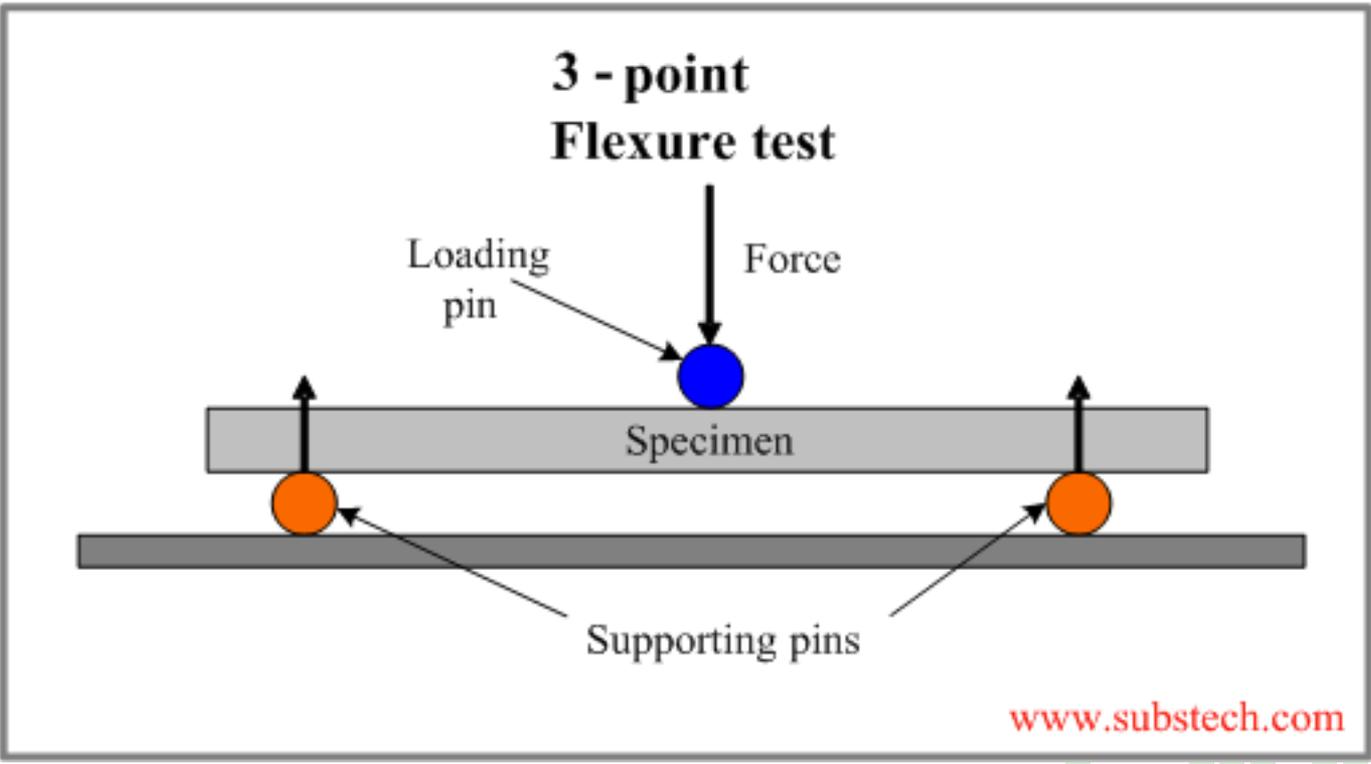
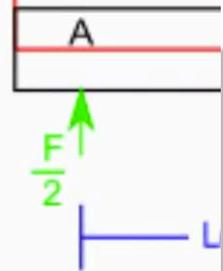


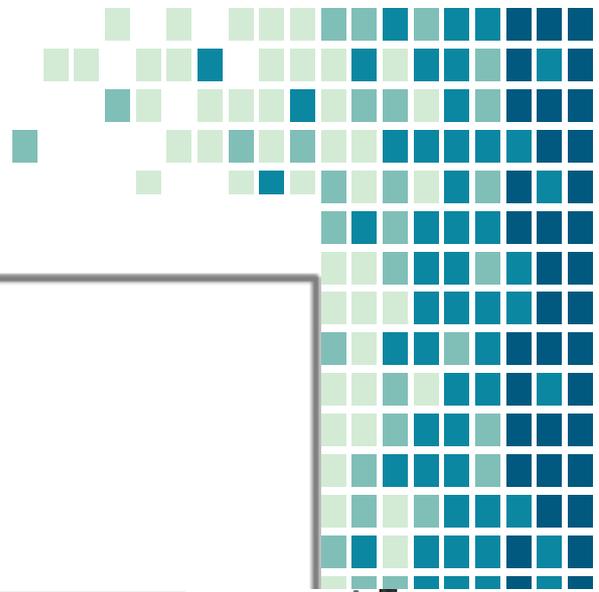
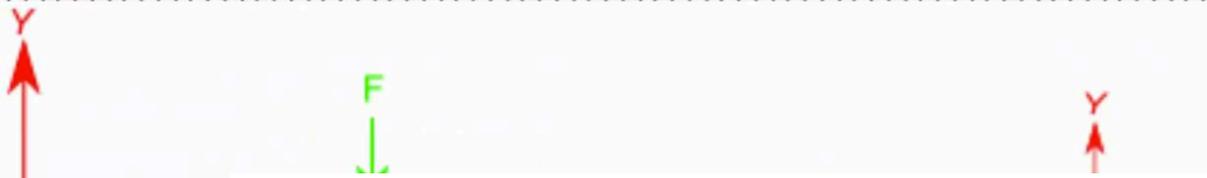
- Procedimentos Biomecânicos (Realizados na Reserva Ducke)



## 2 Point flexure test



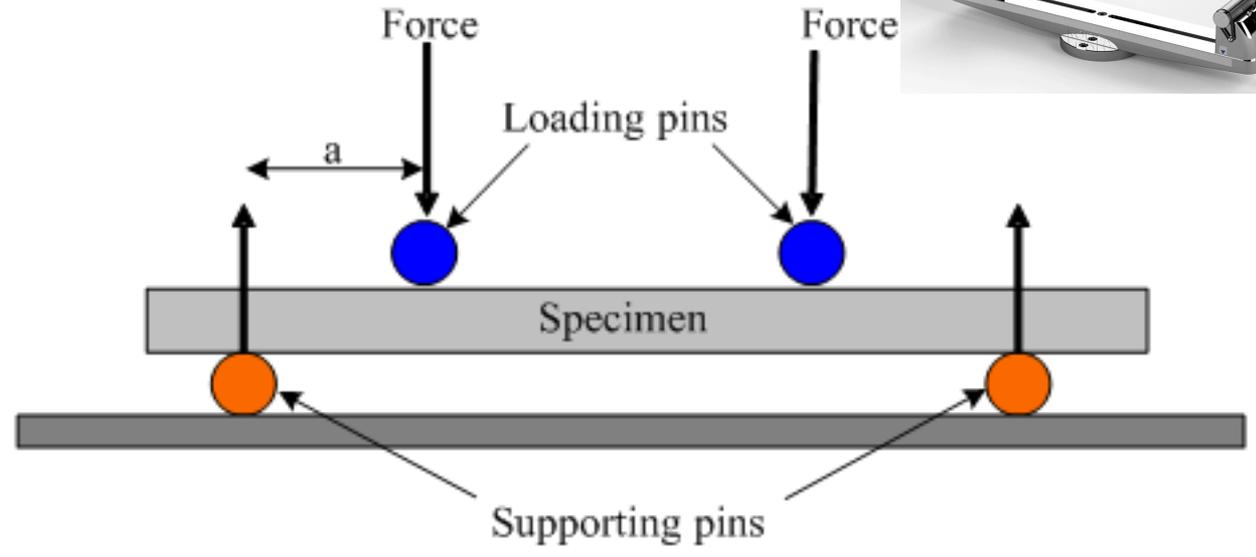


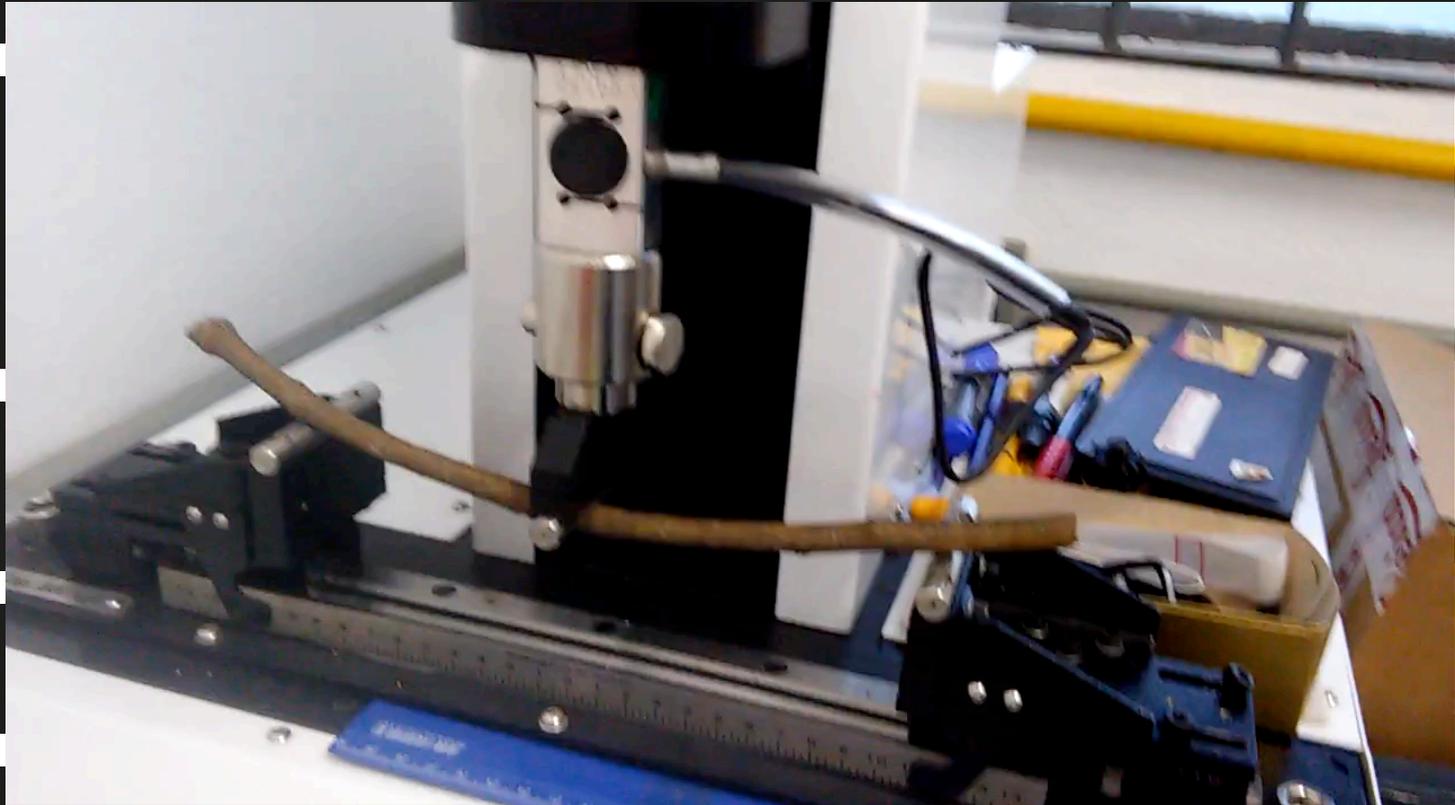


### 3 - point Flexure test

Loading pin  
Force

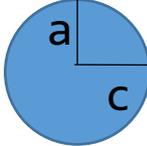
### 4 - point Flexure test







Segundo momento de  
área (I)


$$I = (a^3 \cdot c \cdot \pi) / 4$$

Rigidez a Flexão(EI)

$$EI = (L^3 \times b) / 48$$

Módulo de Young (E)

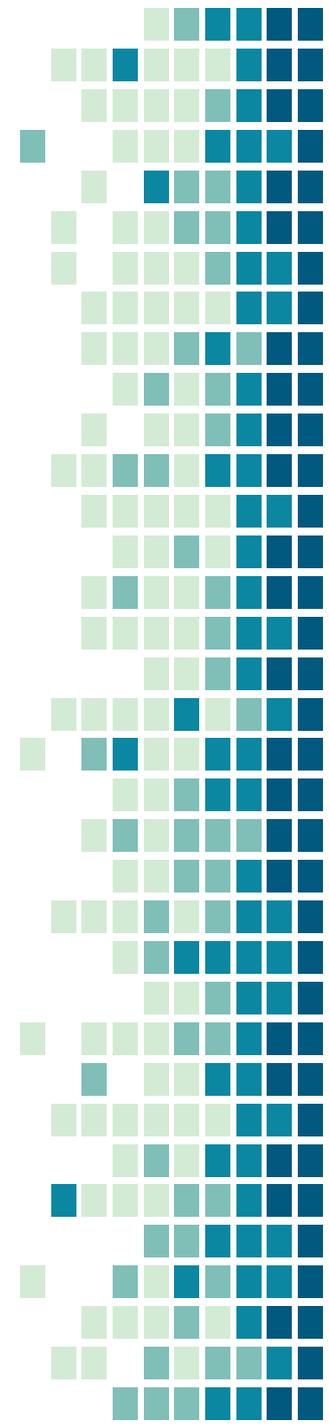
$$E = EI / I$$



Rigidez do material

# Modulo de Young

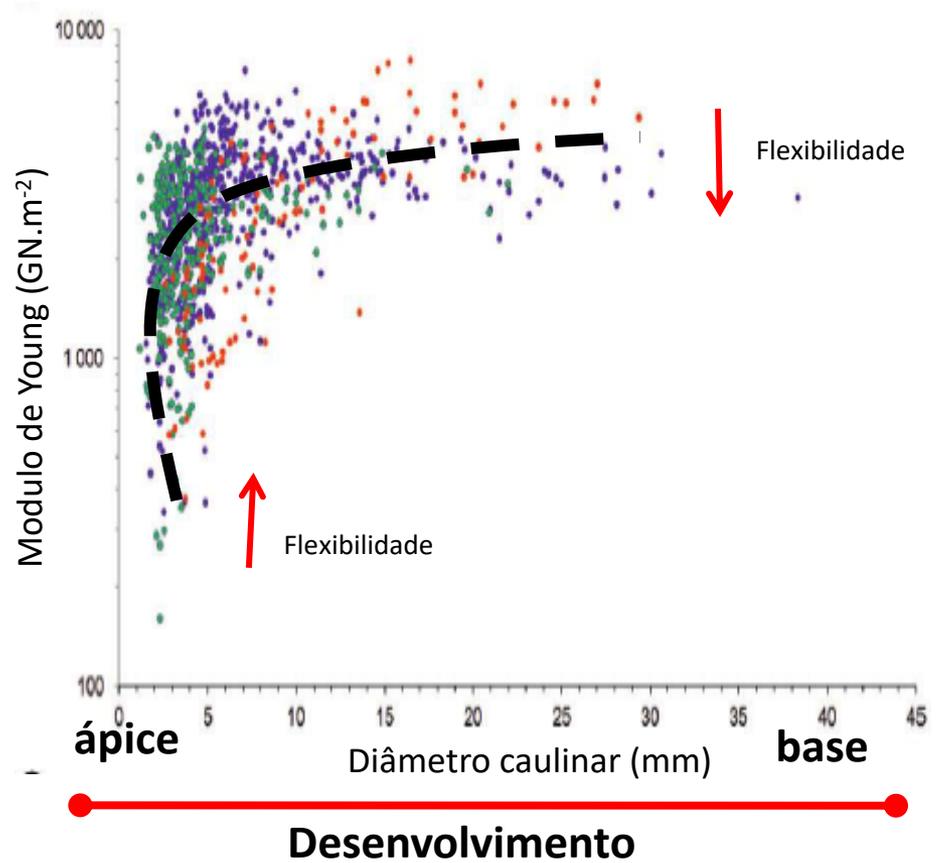
- Aplicações →
  - Descrever Resistência física dos materiais biológicos
  - Descrever Resistência física de plantas fósseis
  - Prevenção de danos (queda de árvores)
  - Resistência física de frutos e folhas usadas por herbívoros
  - Descrever relações de forma e função
  - ETC



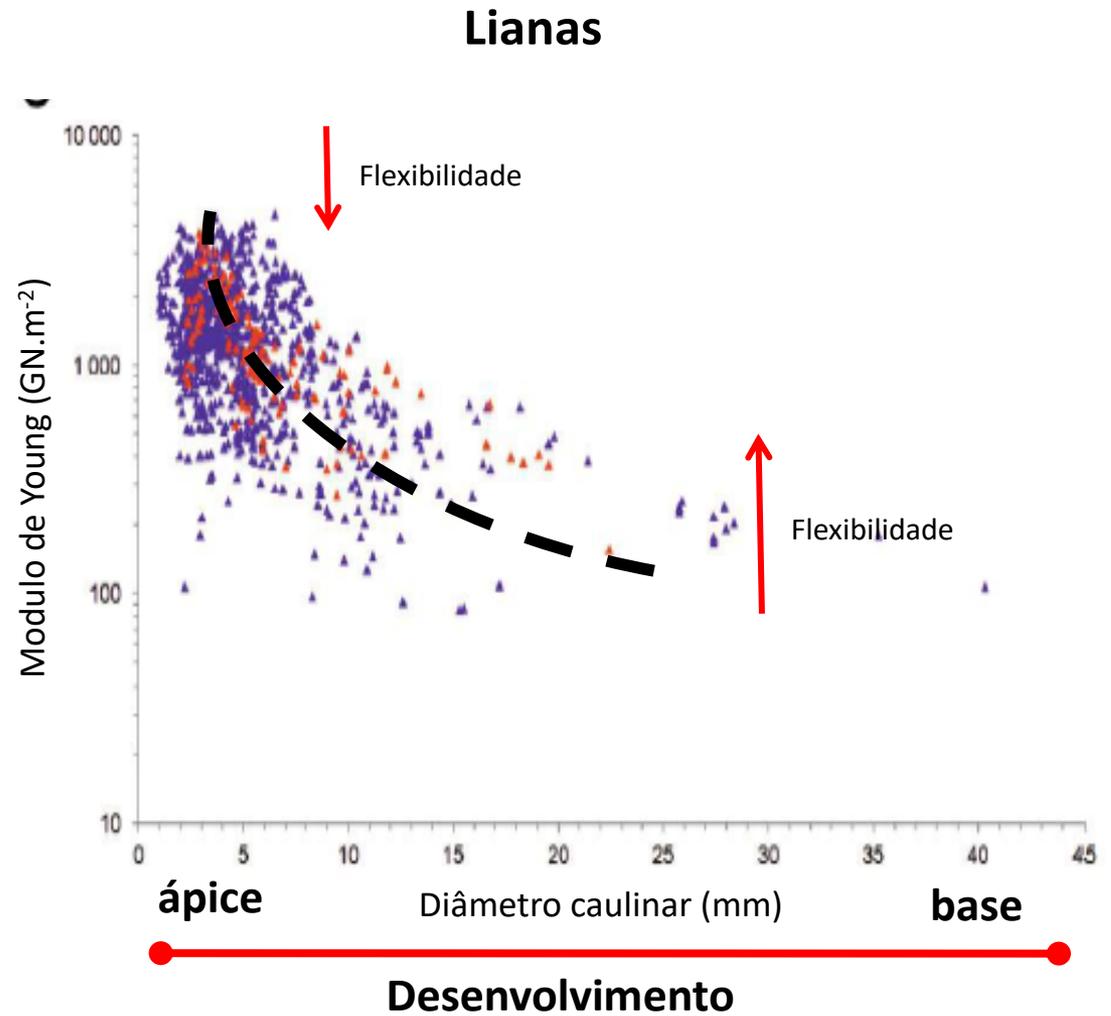
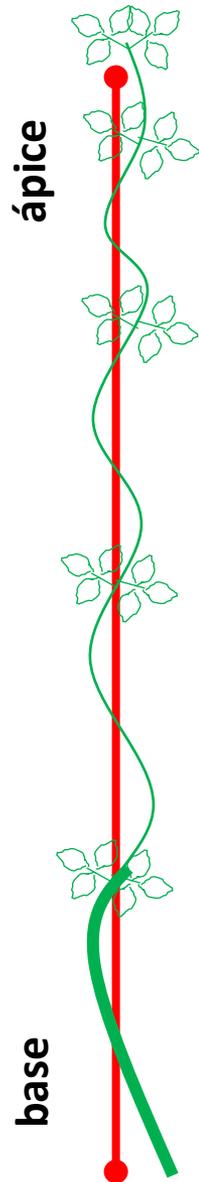
- Biomecânica de plantas



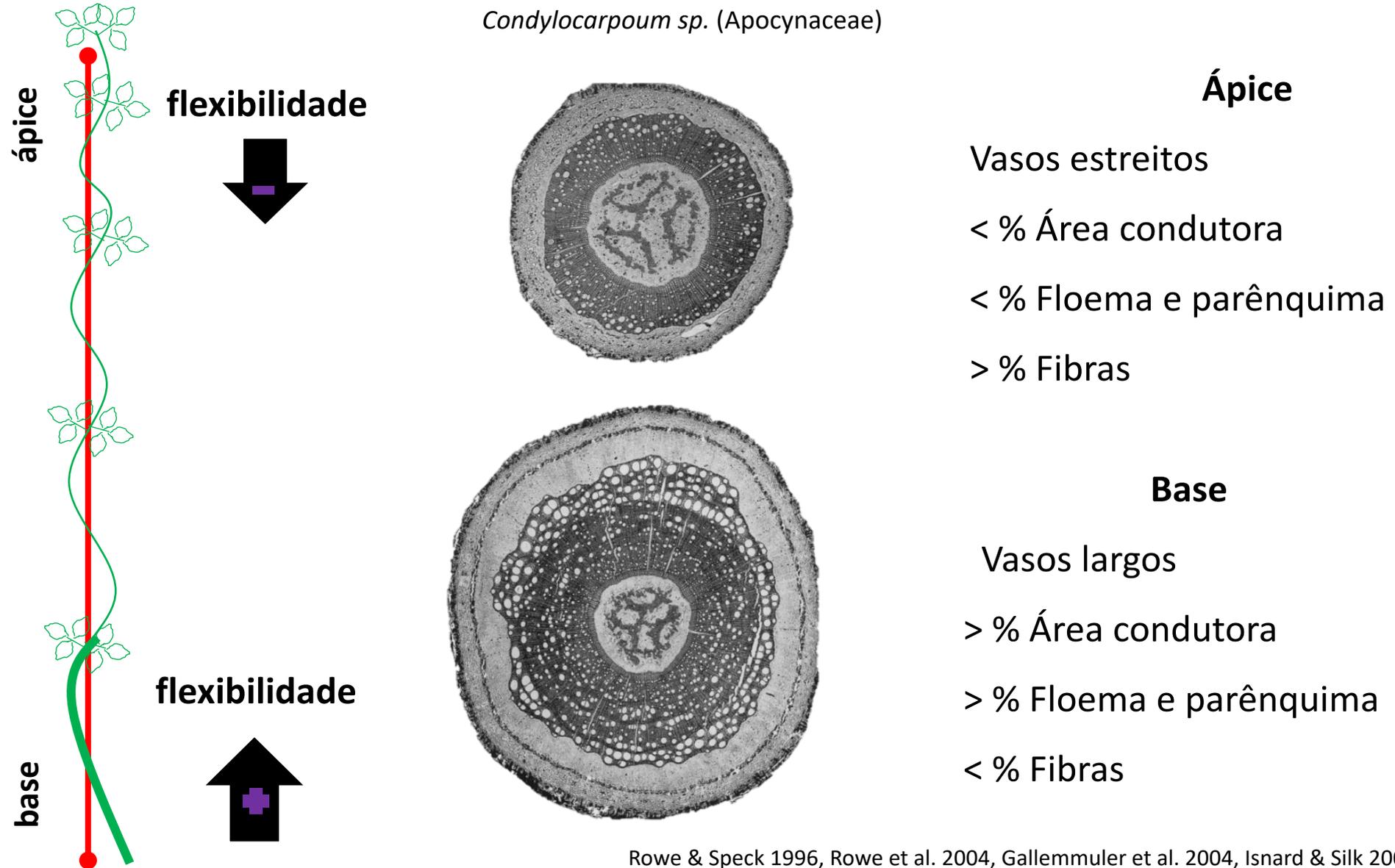
### Autossuportante



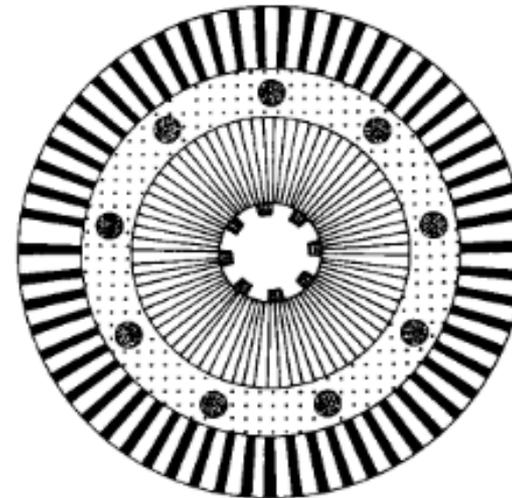
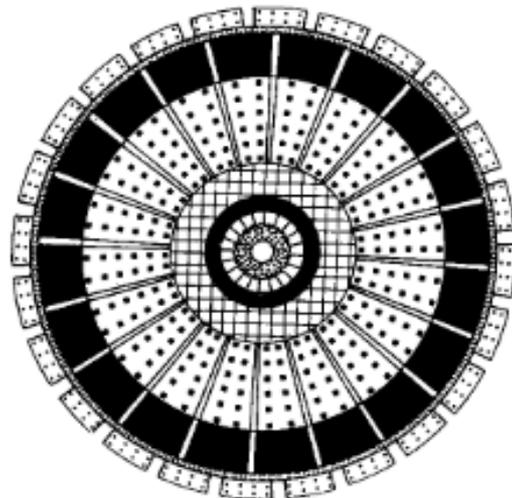
# • Biomecânica de plantas



• Biomecânica x Anatomia



• Biomecânica x Anatomia

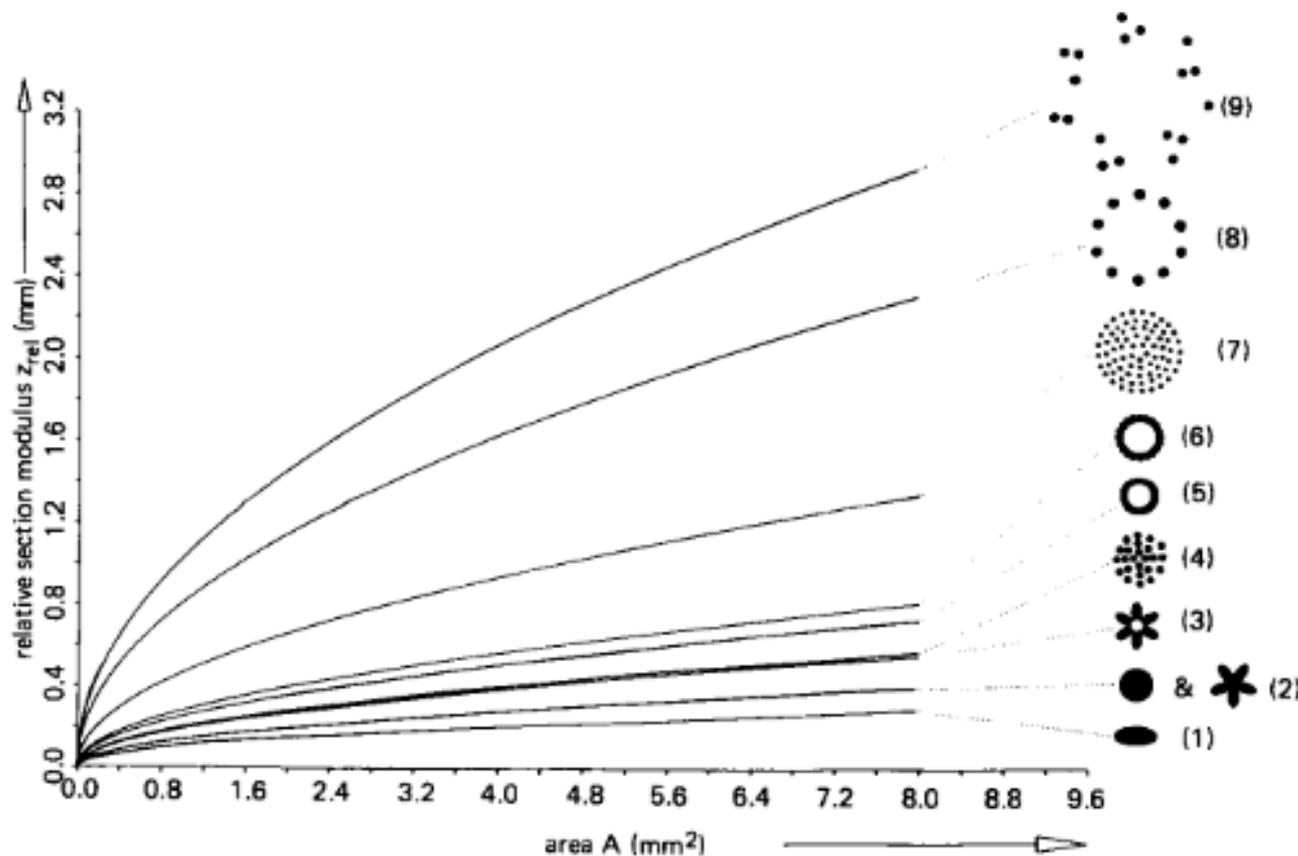


- ⋯⋯⋯ leaf cushions
- ▨ outer secondary cortex
- sclerenchymatous inner secondary cortex
- ▬ parenchymatous regions
- ⋯⋯⋯ sclerenchymatous outer primary cortex
- ▧ lacunar middle primary cortex
- inner primary cortex & pricycle
- ▬ phloem & vascular cambium
- ⌒ secondary xylem
- ▧ primary xylem
- pith

- sclerenchymatous outer cortex
- parenchymatous outer cortex
- ⋯⋯⋯ inner cortex (incl. pricycle, phloem & vascular cambium)
- leaf traces
- ⌒ secondary xylem
- ▧ primary xylem
- pith

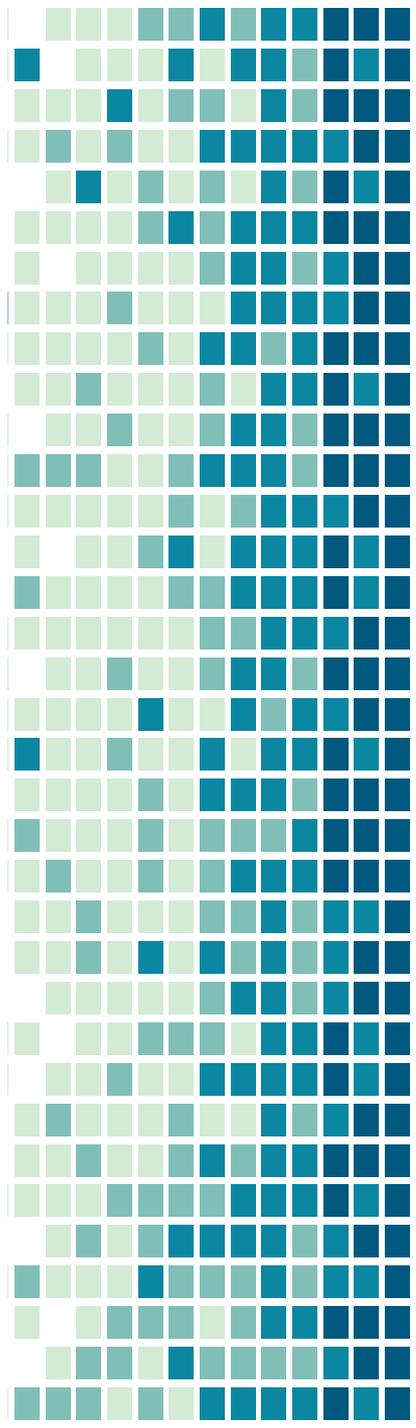
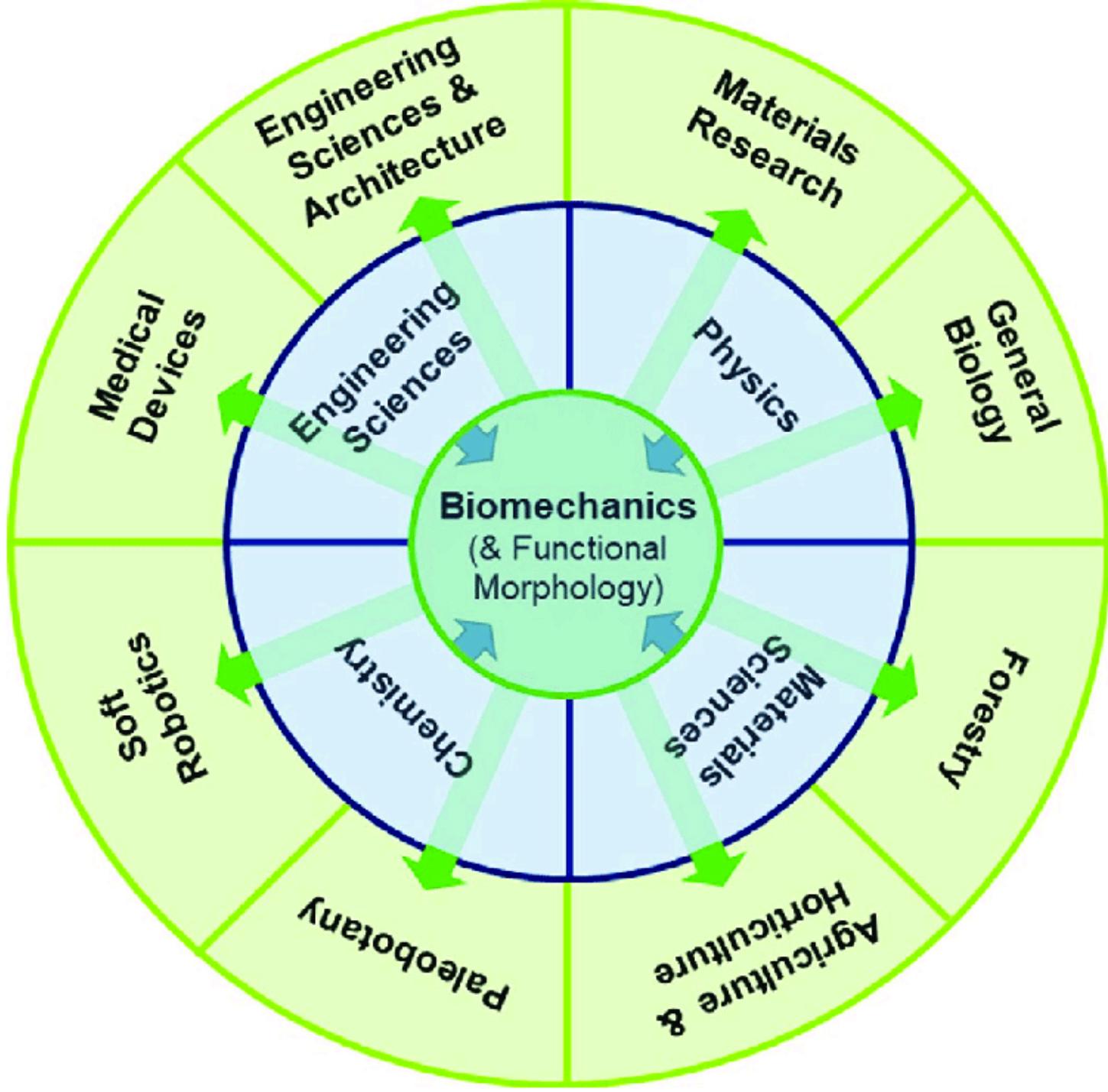
**Fig. 8** Schematic cross-sections of plant stems computerdrawn using the formulae for calculating the areas and the second moments of area of the different cross-sections. These drawings represent the quantitatively calculated distribution of tissues for stems of a given radius of the different taxa. (A) *Lepidodendron* sp. (radius about 11 mm), the segmentation is a result of the alteration of sclerenchymatous and parenchymatous cortex tissues. (B) *Lyginopteris oldhamia* (radius about 9 mm), (C) *Pinus silvestris* (radius about 6 mm), (D) *Psaronius* sp. (radius about 125 mm).

- Biomecânica x Anatomia

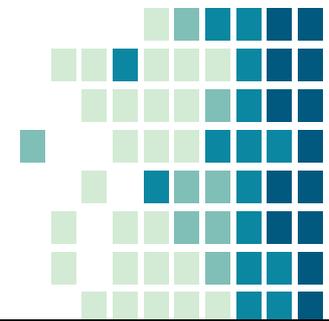


**Fig. 3** Plot of the relative section modulus against the cross-sectional area for some important stele types. Cross-sections of stele types (anatomical nomenclature in parentheses):

- 1 ellipse\* (haplostele),
- 2 circle (protosteles) and star-shaped formation\* (actinosteles),
- 3 star-shaped ring\* (plectosteles),
- 4 circles arranged in several concentric circles\* (polycyclical polysteles),
- 5 circular ring (medullated protosteles or siphonosteles),
- 6 star-shaped ring\* (medullated actinosteles),
- 7 circles arranged in several concentric circles\* (atactosteles without medullation),
- 8 circles arranged in a single circle\* ((monocyclical) eusteles or monocyclical polysteles),
- 9 circles arranged in several concentric circles\* (medullated atactosteles).



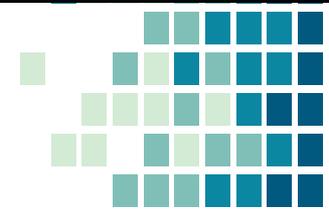
O que não sabemos ?



O que sabemos não é muito. O que não sabemos é imenso.

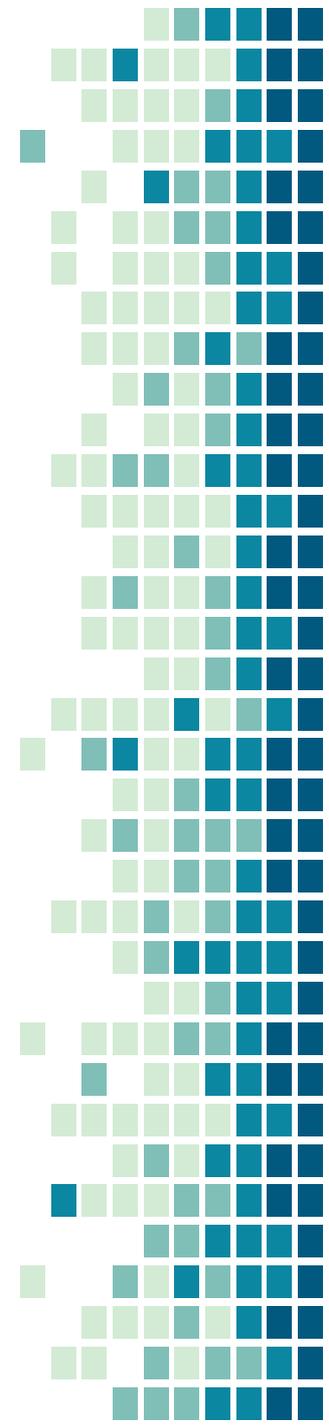
(Pierre Simon Laplace)

**kd**frases

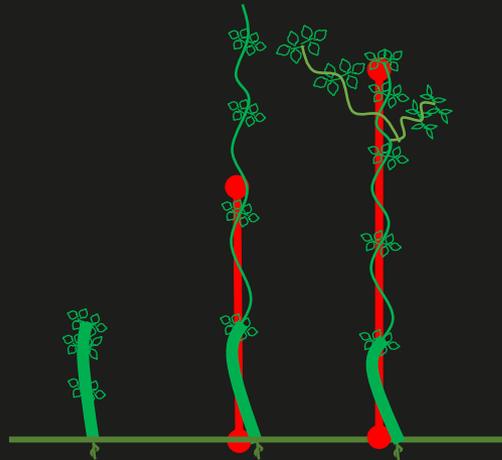


# Biomecânica de Plantas

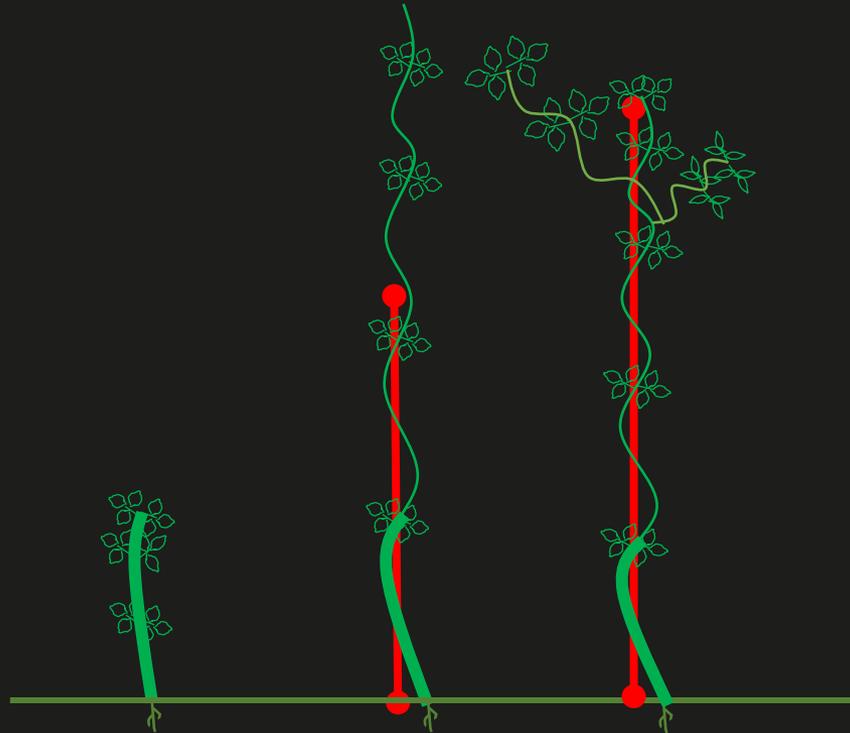
- Contextualizar
- Definir conceitos chave (Segundo momento de área, Rigidez a flexão e Modulo Young)
- Como calcular parâmetros da biomecânica de plantas



# Agradecimentos

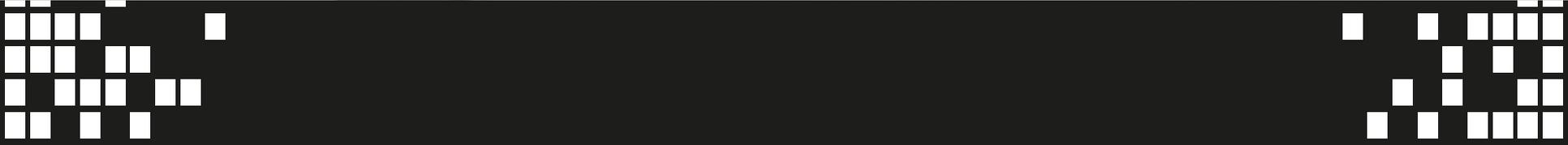
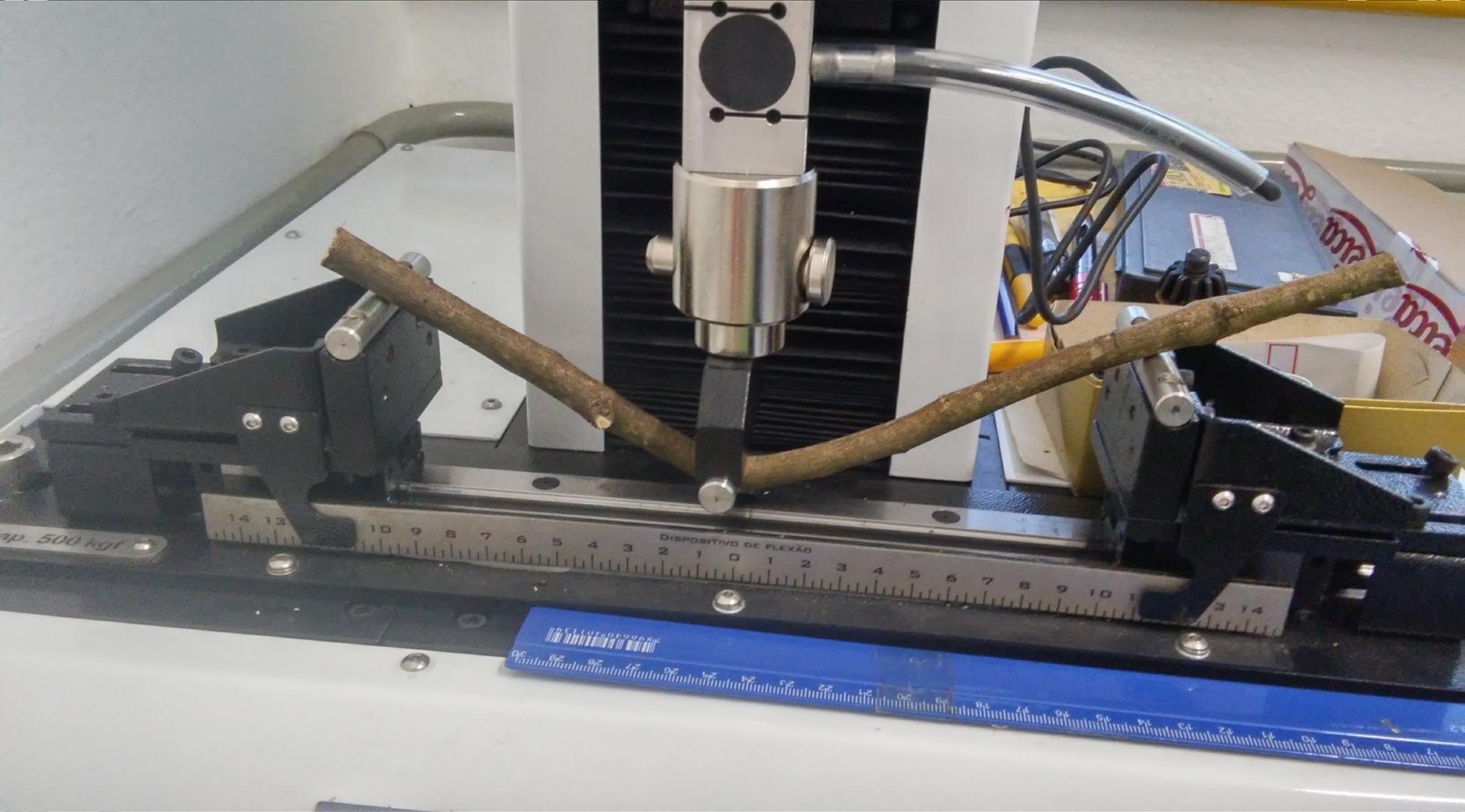
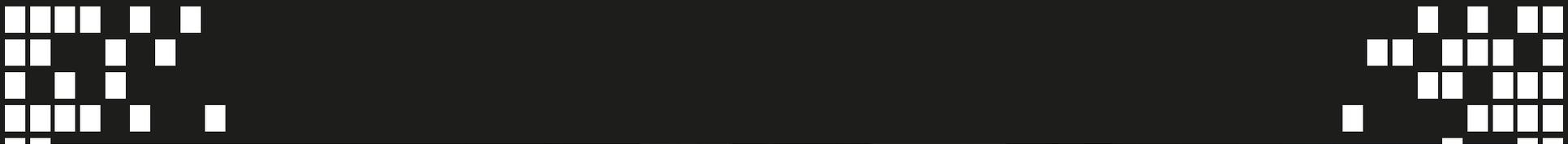


caiansg@gmail.com



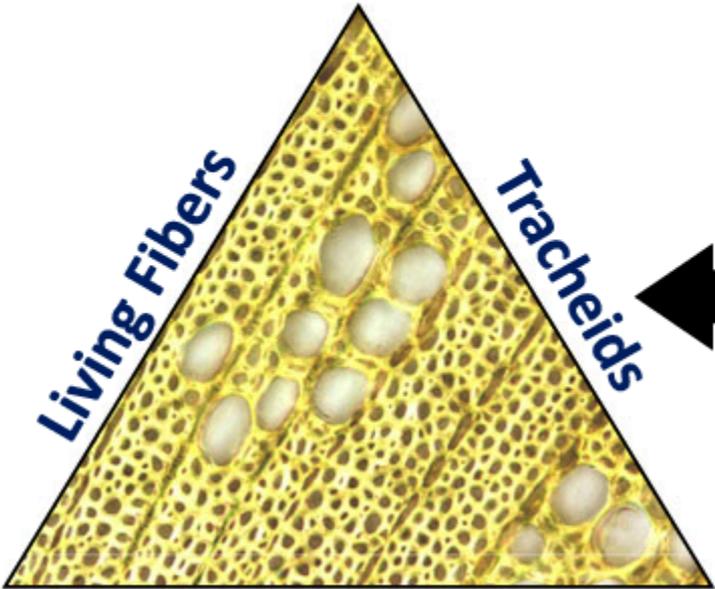
# Referências Bibliográficas

- Gallenmüller F, Rowe N, Speck T (2004) Development and growth form of the neotropical liana *Croton nuntians*: The effect of light and mode of attachment on the biomechanics of the stem. *J Plant Growth Regul* 23:83–97. <https://doi.org/10.1007/s00344-004-0045-z>
- Isnard S, Silk WK (2009) Moving with climbing plants from Charles Darwin's time into the 21st century. *Am J Bot* 96:1205–1221. <https://doi.org/10.3732/ajb.0900045>
- Niklas KJ (1992) *Plant biomechanics : an engineering approach to plant form and function*. University of Chicago press
- Rowe N, Isnard S, Gallenmüller F, Speck T (2006) Diversity of mechanical architecture in climbing plants: an ecological perspective. In: Herrel A, Speck T, Rowe NP (eds) *Ecology and biomechanics: a mechanical approach to the ecology of animals and plants*. Boca Raton, FL: Taylor & Francis, pp 35–60
- Rowe N, Speck T (2004) Hydraulics and mechanics of plants: Novelty, innovation and evolution. *Evol Plant Physiol* 297–325. <https://doi.org/10.1016/B978-012339552-8/50017-2>
- Rowe NP, Speck T (1996) Biomechanical Characteristics of the Ontogeny and Growth Habit of the Tropical Liana *Condylocarpon guianense* (Apocynaceae). *Int J Plant Sci* 157:406–417
- Speck T (1994) Bending Stability of Plant Stem: Ontogenetical, Ecological, and Phylogenetical Aspects. *Biomimetics* 2:109–129
- Speck T, Vogellehner D (1988) Biophysical Examinations of the Bending Stability of Various Stele Types and the Upright Axes of Early "Vascular" Land Plants. *Bot Acta* 101:262–268. <https://doi.org/10.1111/j.1438-8677.1988.tb00042.x>
- Vicent J (1992) *Biomechanics—materials: a practical approach*. Oxford University Press



# Structure

Fibers

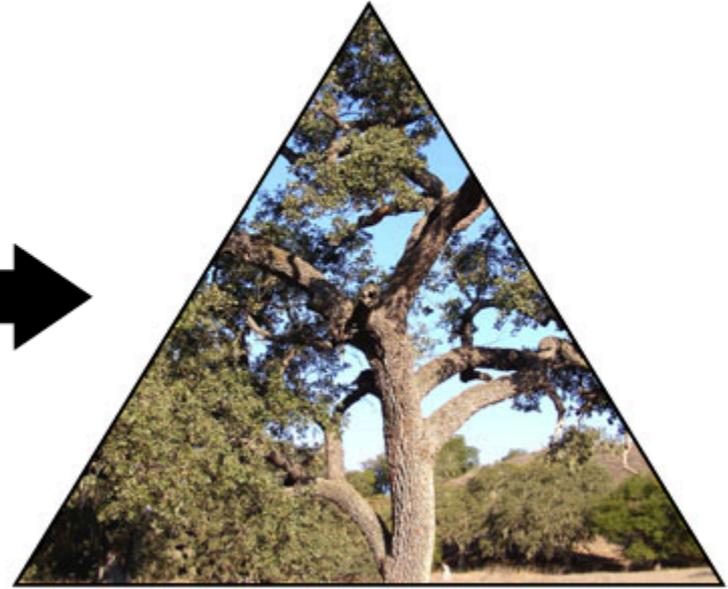


Parenchyma

Vessels

# Function

Support



Storage

Transport

