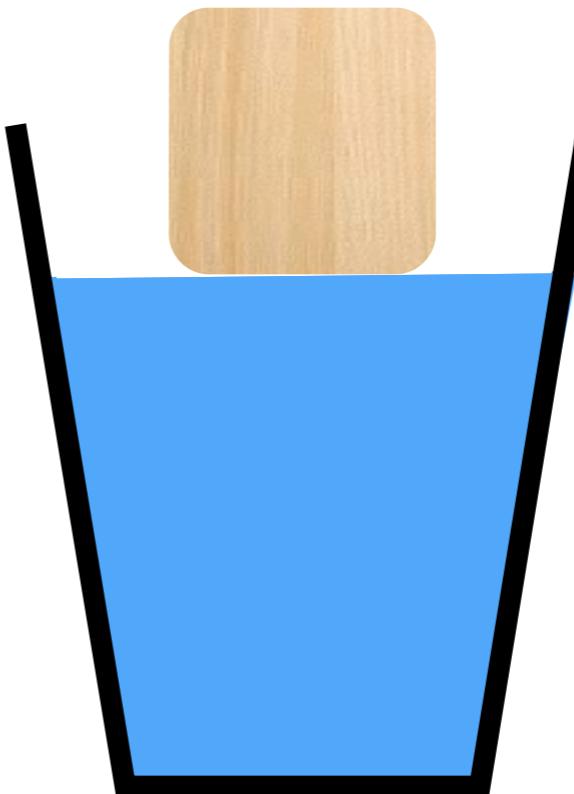
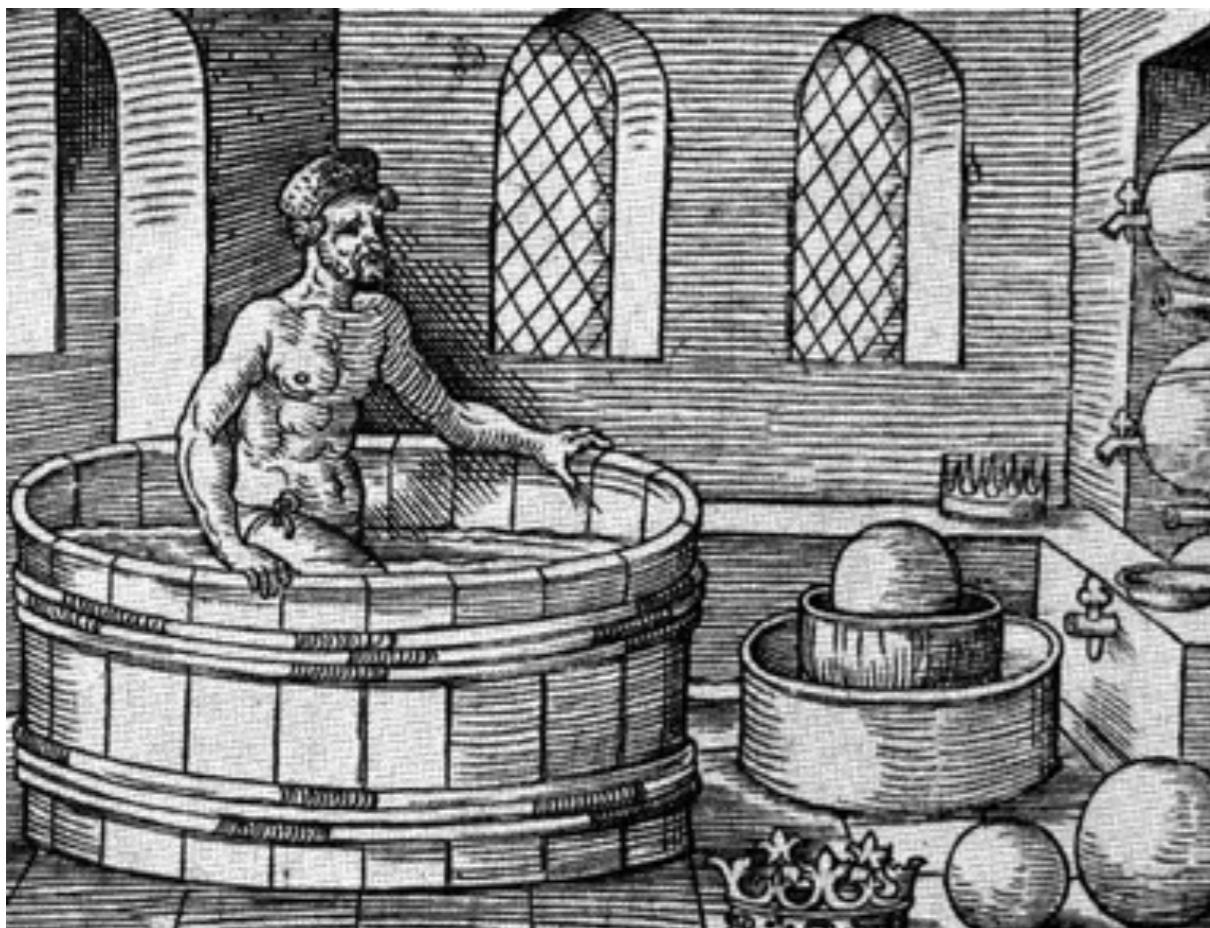


Modelos quantitativos de bacias sedimentares

Isostasia e Flexura da Litosfera

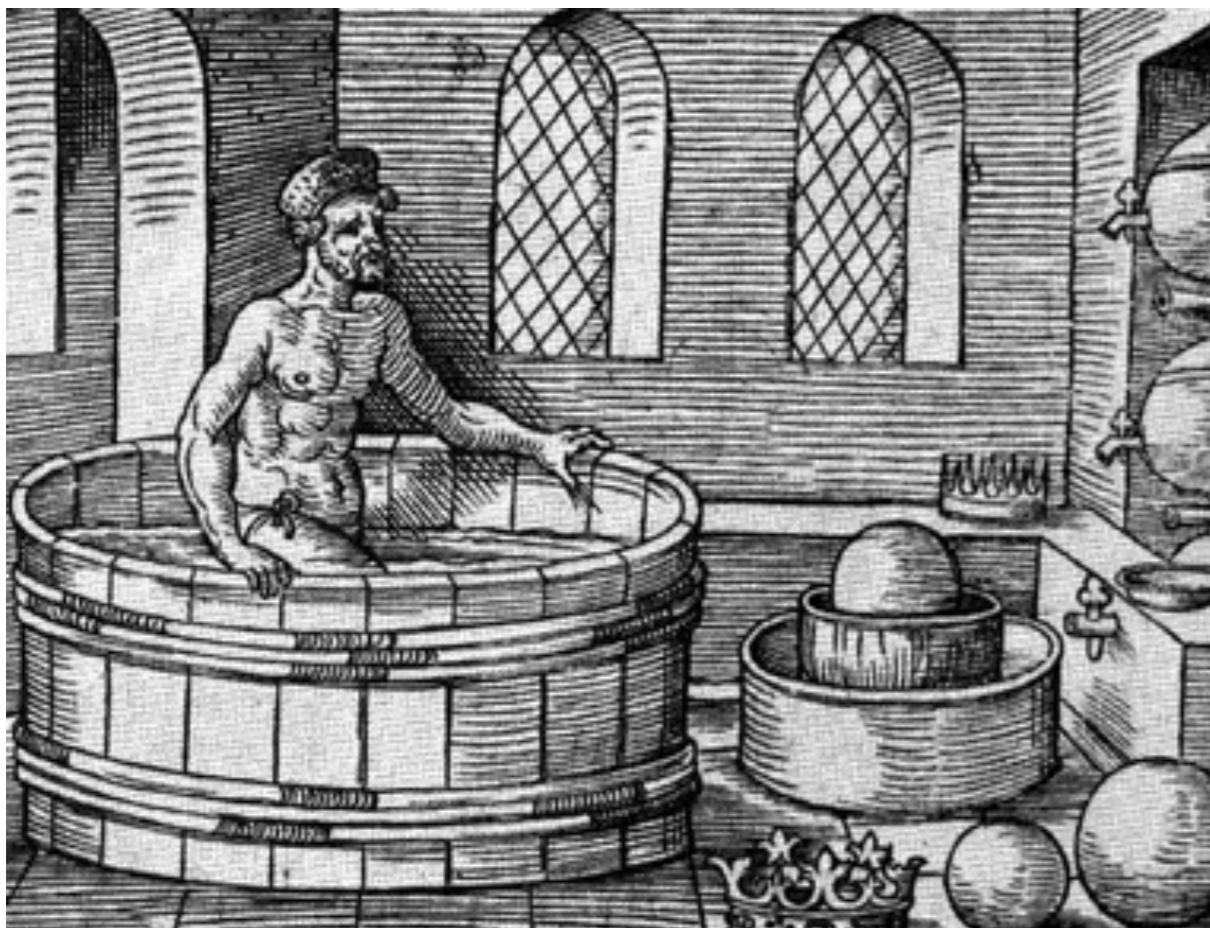
Princípio de Arquimedes



Any floating object displaces its own weight of fluid.

— Arquimedes de Siracusa

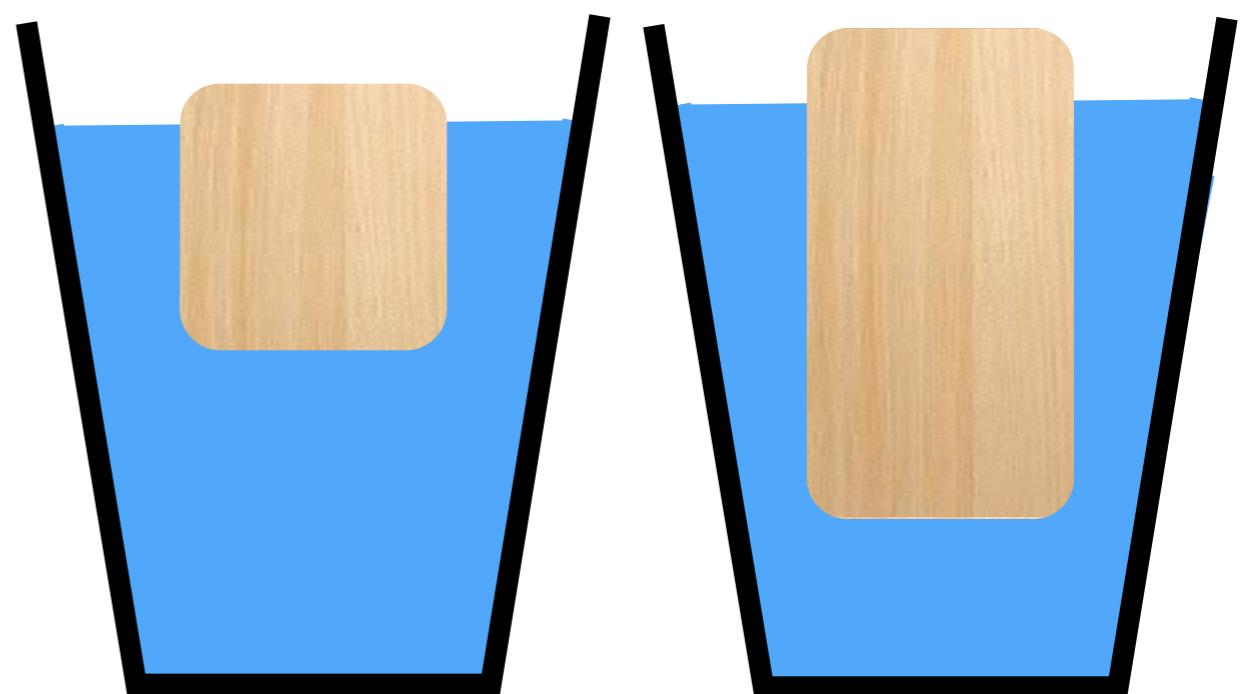
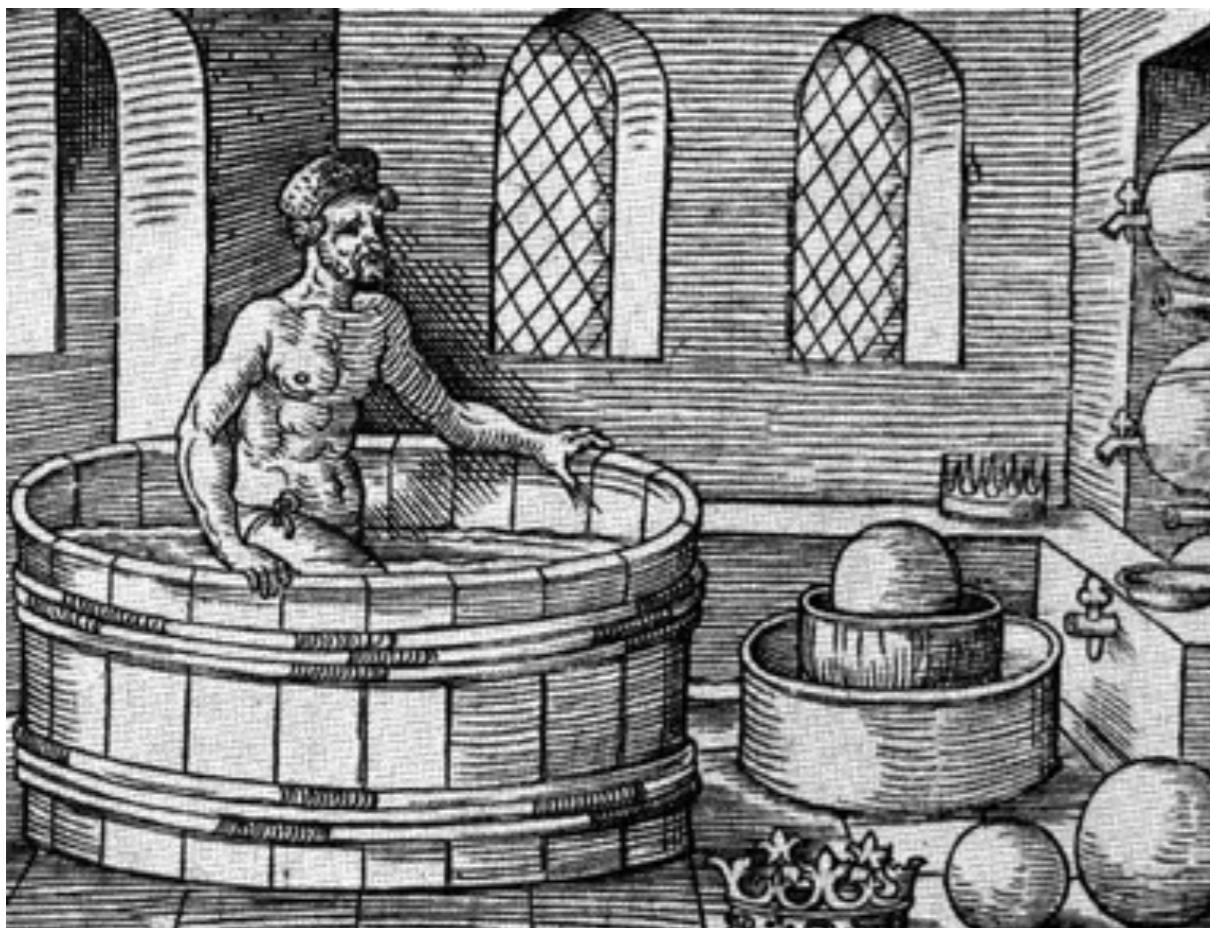
Princípio de Arquimedes



Any floating object displaces its own weight of fluid.

— Arquimedes de Siracusa

Princípio de Arquimedes



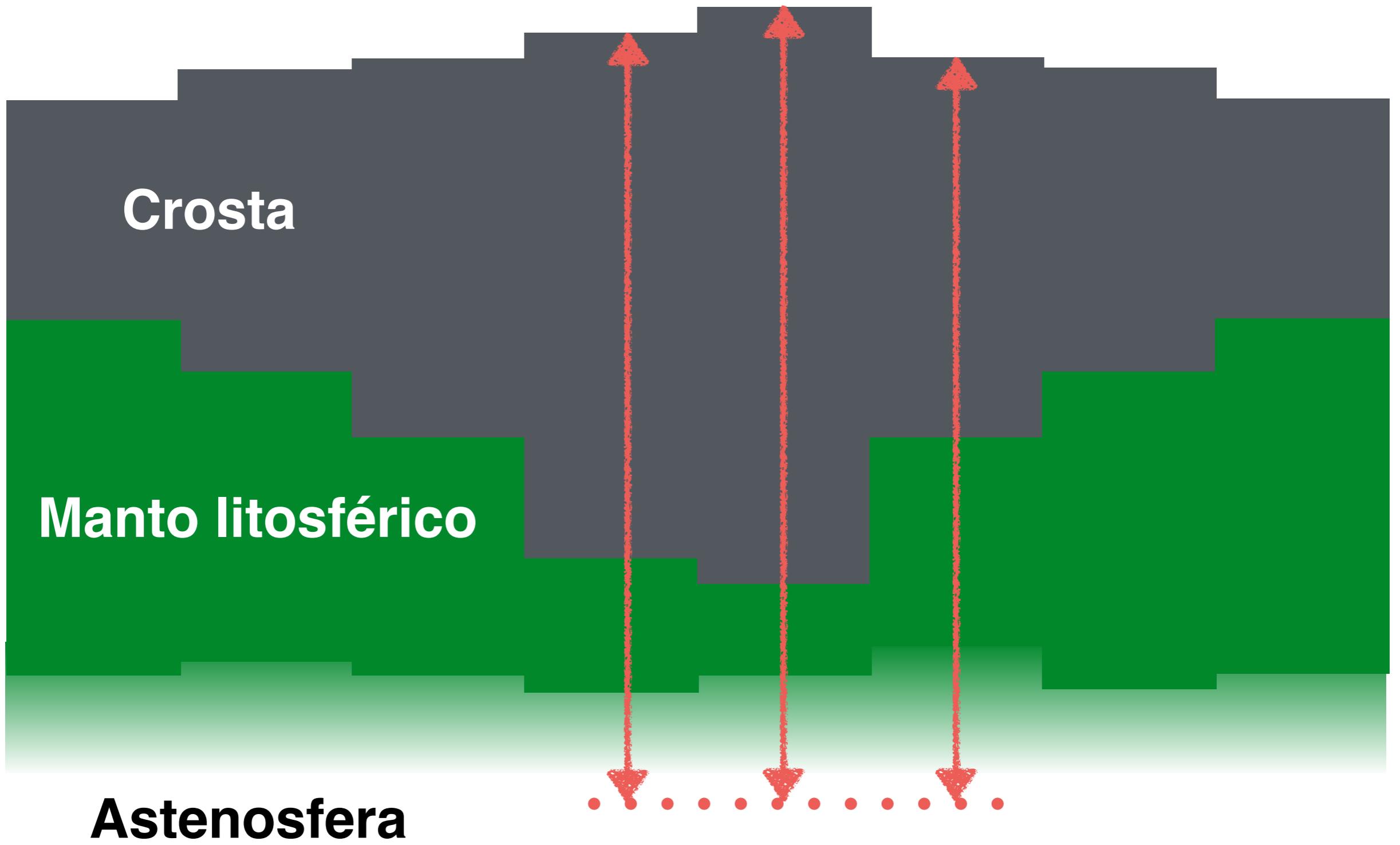
Any floating object displaces its own weight of fluid.
— Arquimedes de Siracusa

Isostasia da litosfera

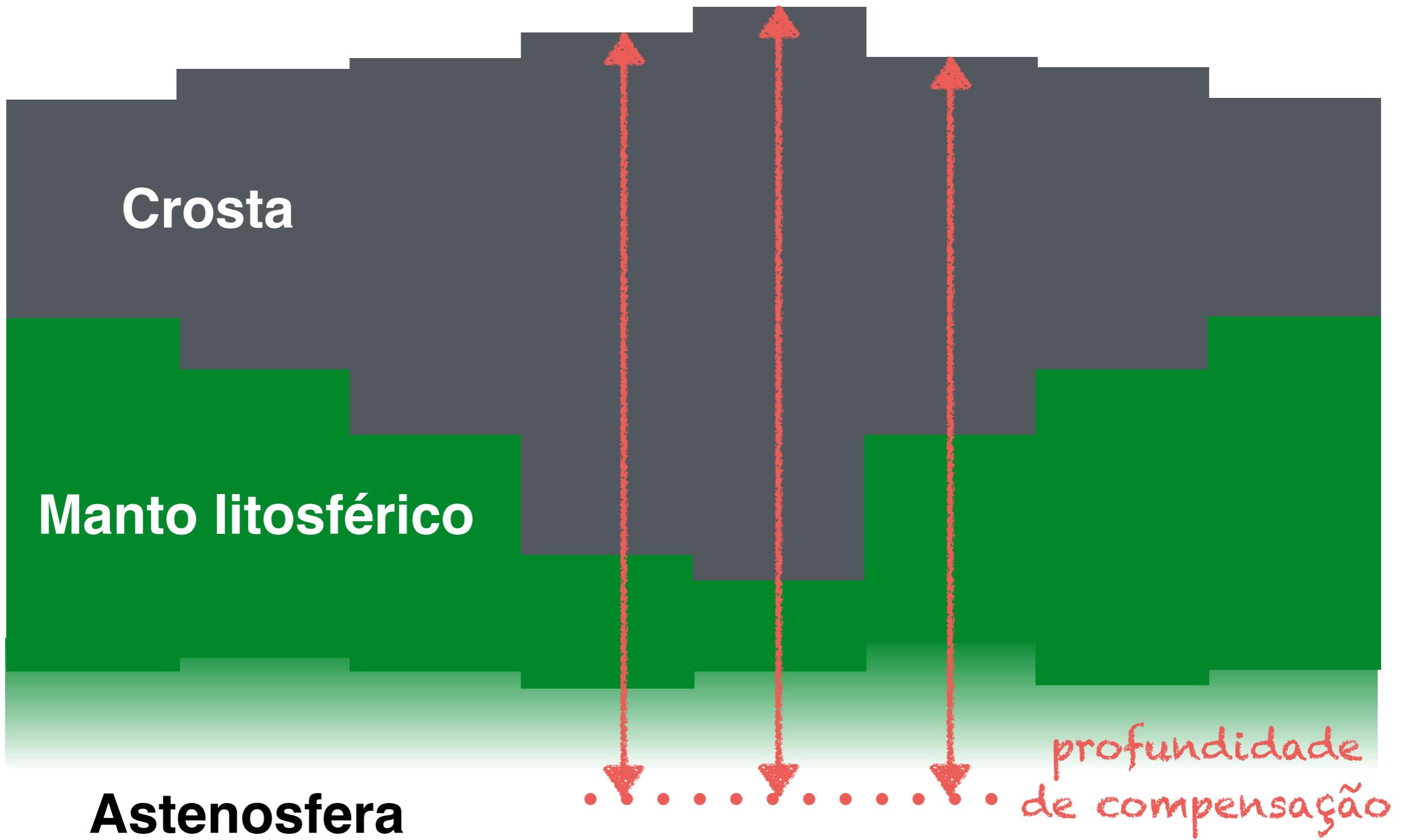


Astenosfera

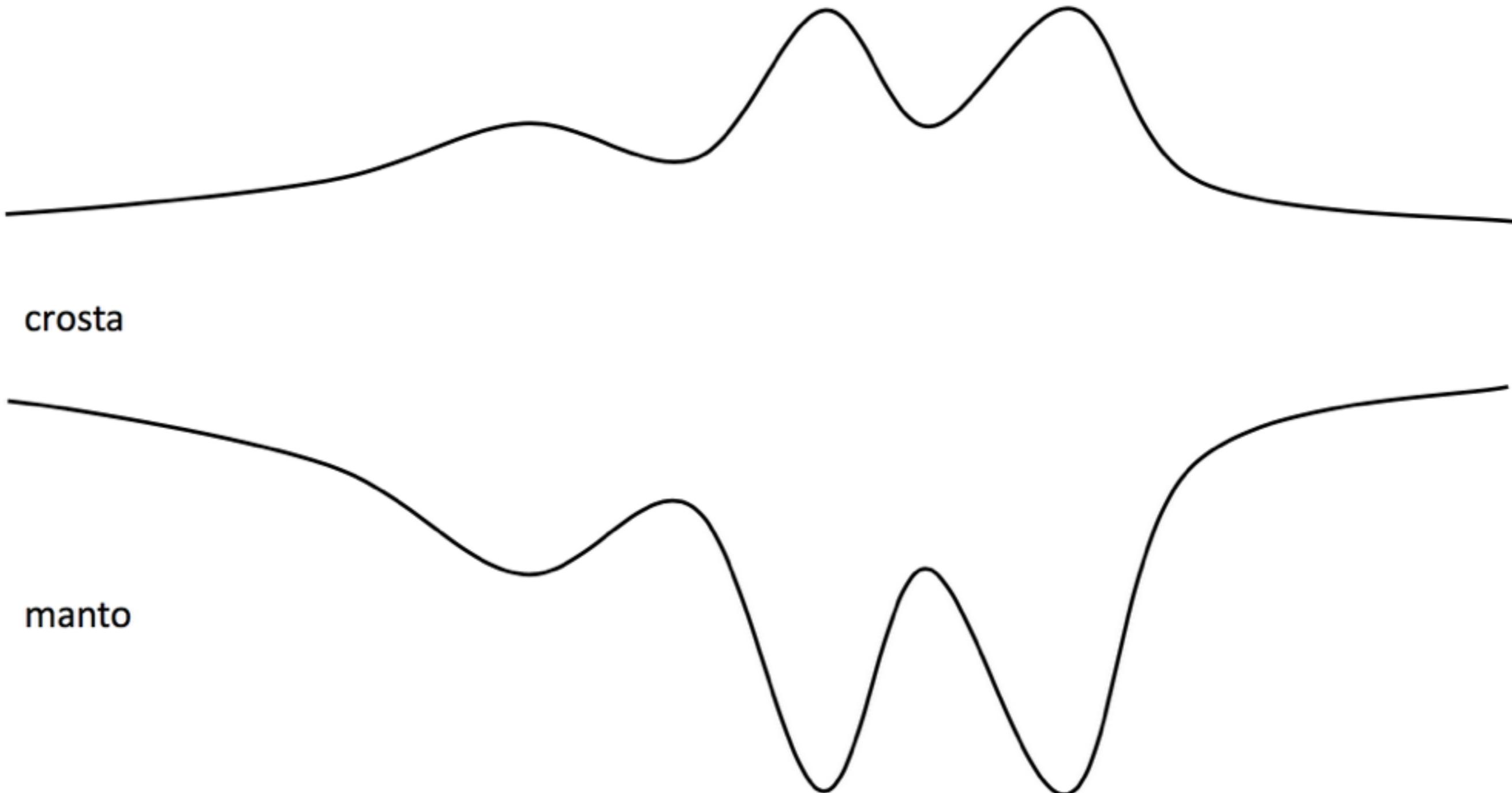
Isostasia da litosfera



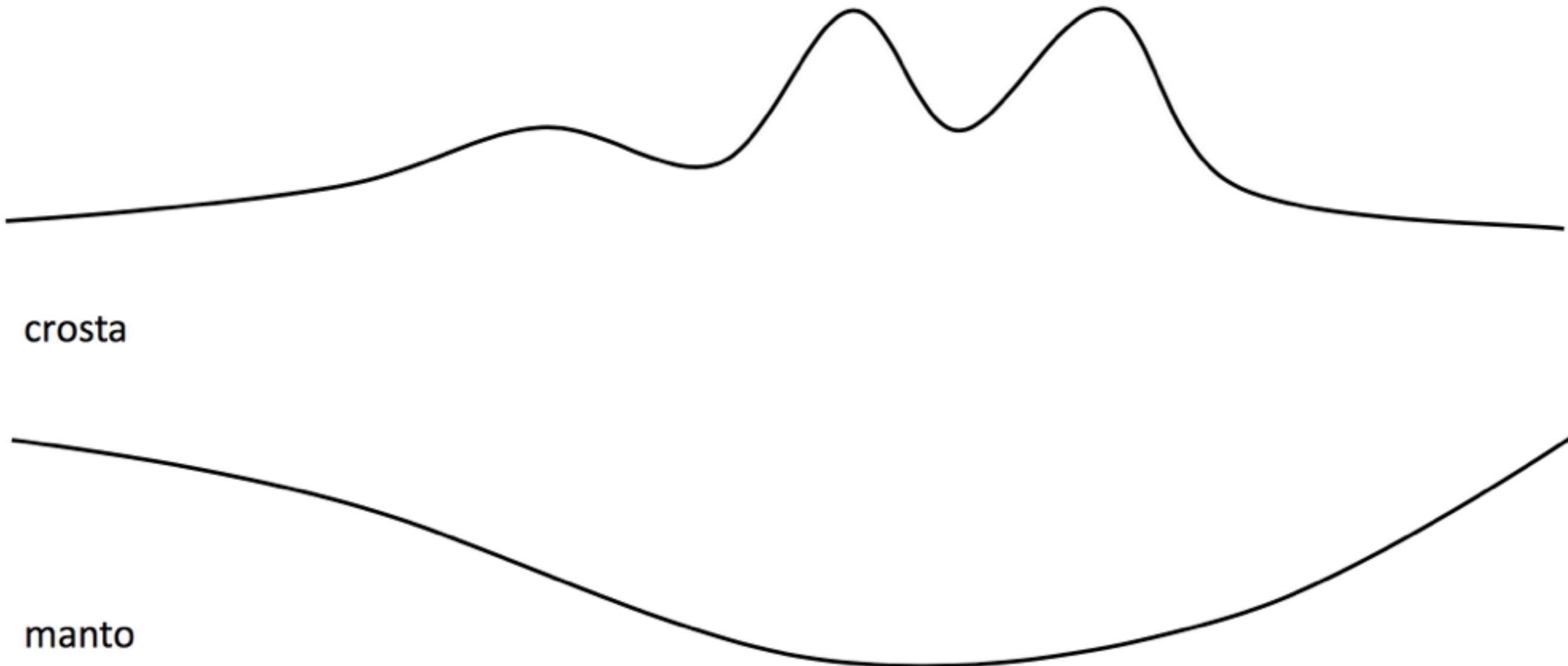
Isostasia da litosfera



Isostasia local



Isostasia regional



Flexura da litosfera: os primórdios

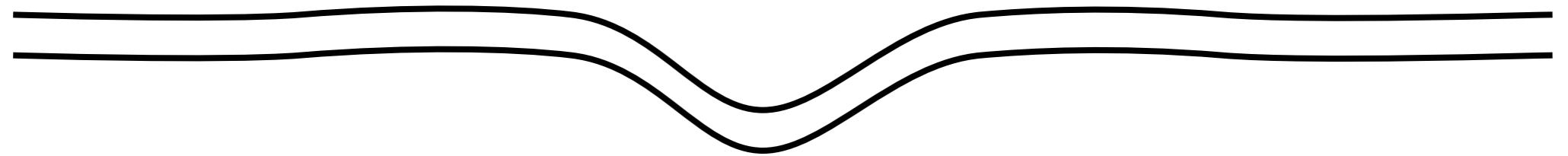
Para grandes blocos – por exemplo, um continente ou uma bacia oceânica inteira – a teoria da isostasia deve ser aceita sem dúvida; mas onde há feições menores, como montanhas individuais, a lei perde a sua validade. Tais feições podem ser sustentadas pela elasticidade do bloco todo.

Alfred Wegener (1929) *tradução livre*



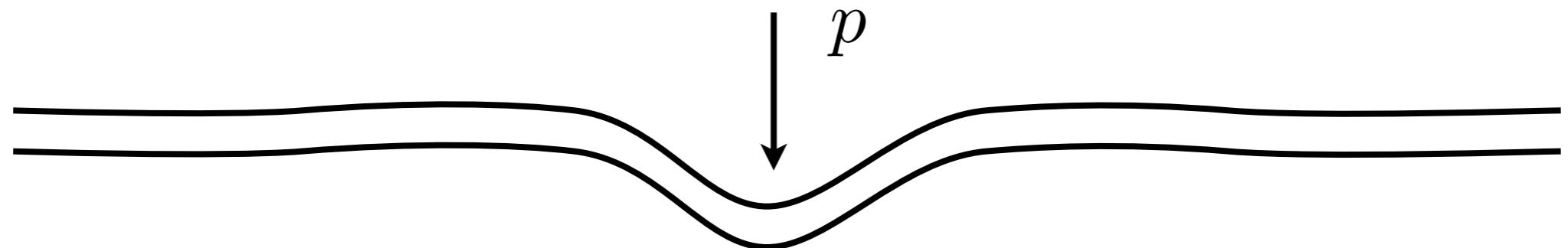
https://en.wikipedia.org/wiki/Alfred_Wegener#/media/File:Wegener_Expedition-1930_008.jpg

Litosfera



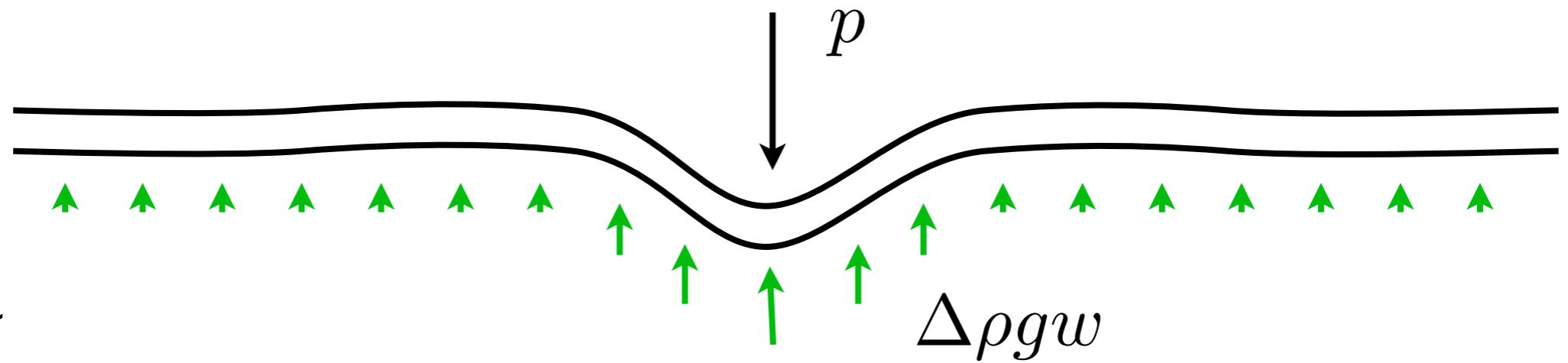
Astenosfera

Litosfera



Astenosfera

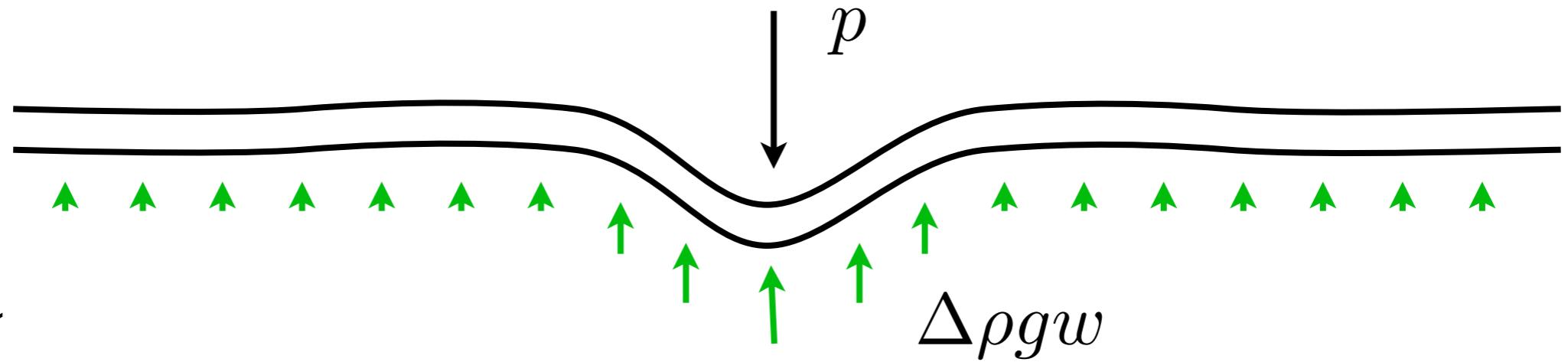
Litosfera



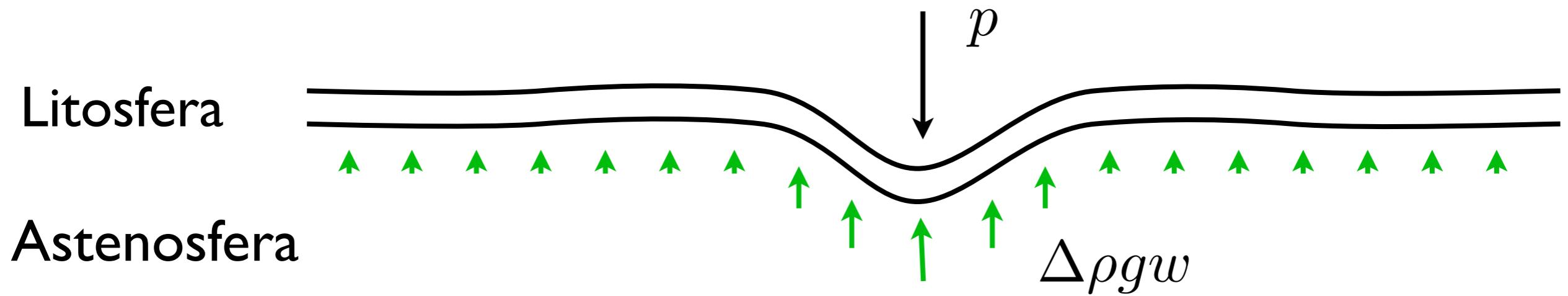
Astenosfera

Litosfera

Astenosfera

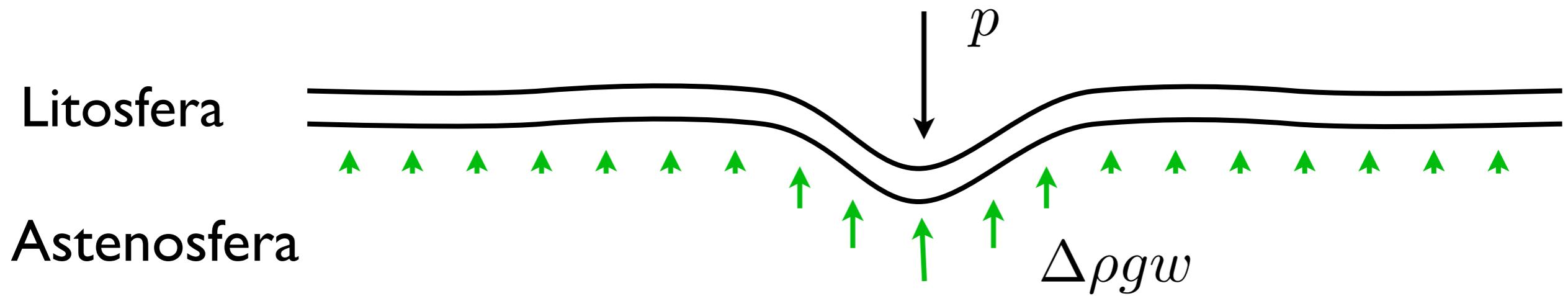


$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$



deslocamento
vertical da placa

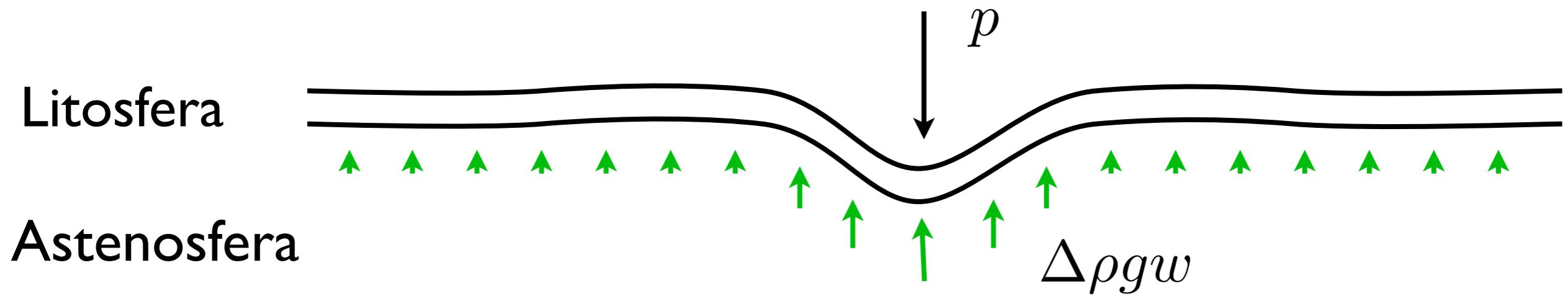
$$D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$$



deslocamento
vertical da placa

$$D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$$

Rigidez da placa
elástica

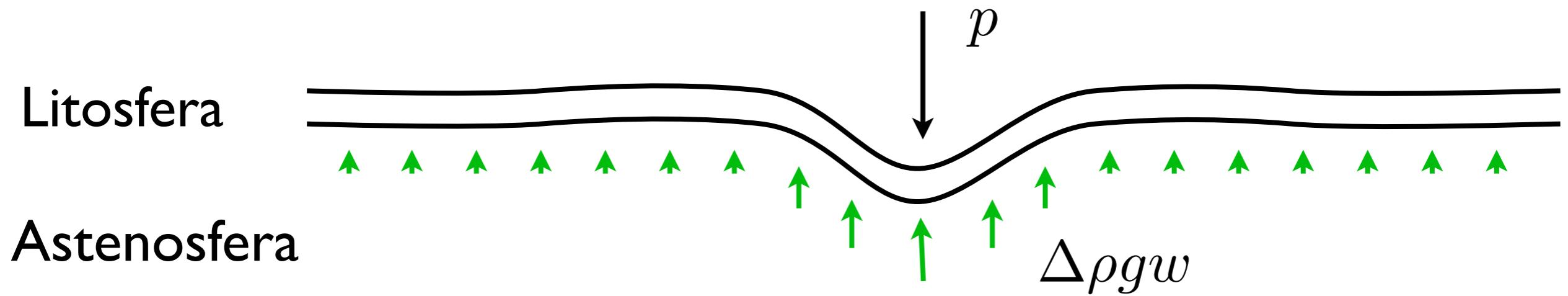


deslocamento
vertical da placa

Rigidez da placa
elástica

coordenada

$$D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$$



deslocamento vertical da placa

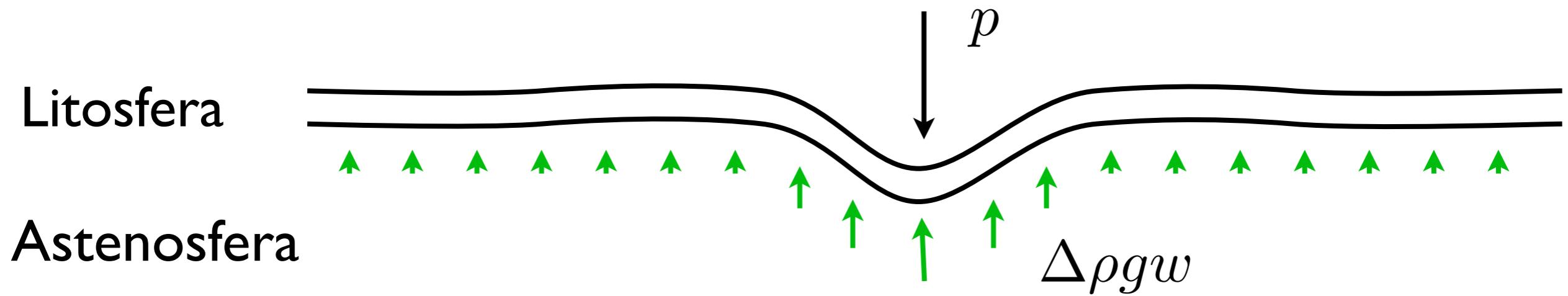
$$D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$$

Rigidez da placa elástica

coordenada

diferença de densidade

This block contains the differential equation for plate bending, with handwritten labels in red pointing to its components: 'deslocamento vertical da placa' points to the deflection term $d^4 w / dx^4$; 'Rigidez da placa elástica' points to the constant D ; 'coordenada' points to the horizontal coordinate x ; and 'diferença de densidade' points to the density difference term $\Delta\rho gw$.



deslocamento vertical da placa

$$D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$$

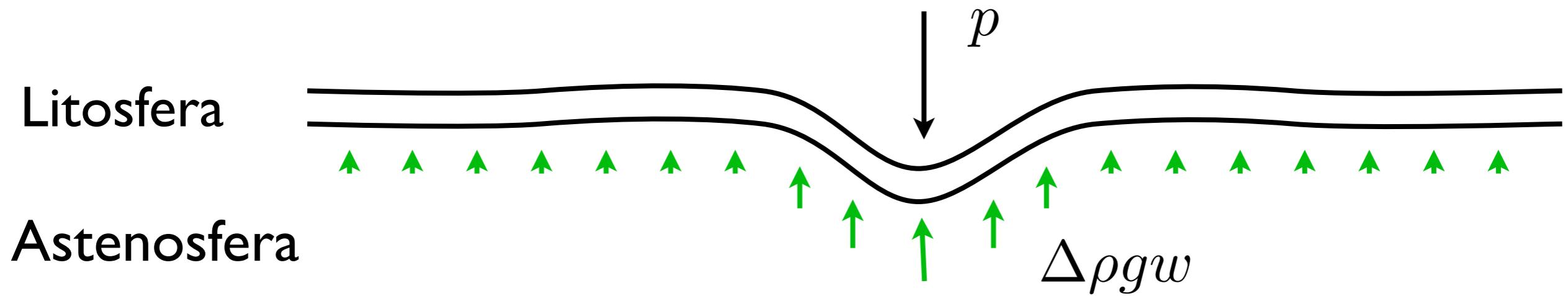
Rigidez da placa elástica

coordenada

gravidade

diferença de densidade

This block contains the differential equation for plate bending, $D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$, with handwritten annotations in red. The term $D \frac{d^4 w}{dx^4}$ is associated with the 'Rigidez da placa elástica' (elastic rigidity) and 'coordenada' (coordinate). The term $\Delta\rho gw$ is associated with 'gravidade' (gravity) and 'diferença de densidade' (density difference). The equation relates the deflection w to the applied pressure p .



deslocamento vertical da placa

carga

Rigidez da placa elástica

coordenada

gravidade diferença de densidade

$$D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$$

deslocamento vertical da placa

carga

Rigidez da placa elástica

coordenada

gravidade

diferença de densidade

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

deslocamento vertical da placa

carga

Rigidez da placa elástica

coordenada

gravidade

diferença de densidade

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$
$$D = \frac{ET_e^3}{12(1 - \nu^2)}$$

deslocamento vertical da placa

carga

Rigidez da placa elástica

coordenada

Módulo de elasticidade

$D = \frac{ET_e^3}{12(1 - \nu^2)}$

$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$

The diagram illustrates the derivation of the Euler-Bernoulli beam equation for a plate. It starts with the differential equation:

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

Annotations explain the components:

- deslocamento vertical da placa (vertical displacement) points to the term w .
- carga (load) points to the term p .
- gravidade (gravity) points to the term $\Delta \rho g w$.
- diferença de densidade (density difference) points to the term $\Delta \rho g$.
- Módulo de elasticidade (modulus of elasticity) points to the term D .
- coordenada (coordinate) points to the term dx^4 .
- Rigidez da placa elástica (rigidity of the elastic plate) points to the term D .

Below the equation, the rigidity term is expanded:

$$D = \frac{ET_e^3}{12(1 - \nu^2)}$$

deslocamento vertical da placa

carga

Rigidez da placa elástica

coordenada

Módulo de elasticidade

Espessura elástica efetiva

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$
$$D = \frac{ET_e^3}{12(1 - \nu^2)}$$

deslocamento
 vertical da placa

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

carga
 gravidade
 diferença de densidade

Rigidez da placa elástica
 coordenada

Módulo de elasticidade
 Espessura elástica efetiva

$D = \frac{ET_e^3}{12(1 - \nu^2)}$
 Coeficiente de Poisson

Isostasia e Flexura da Litosfera

Isostasia
Local

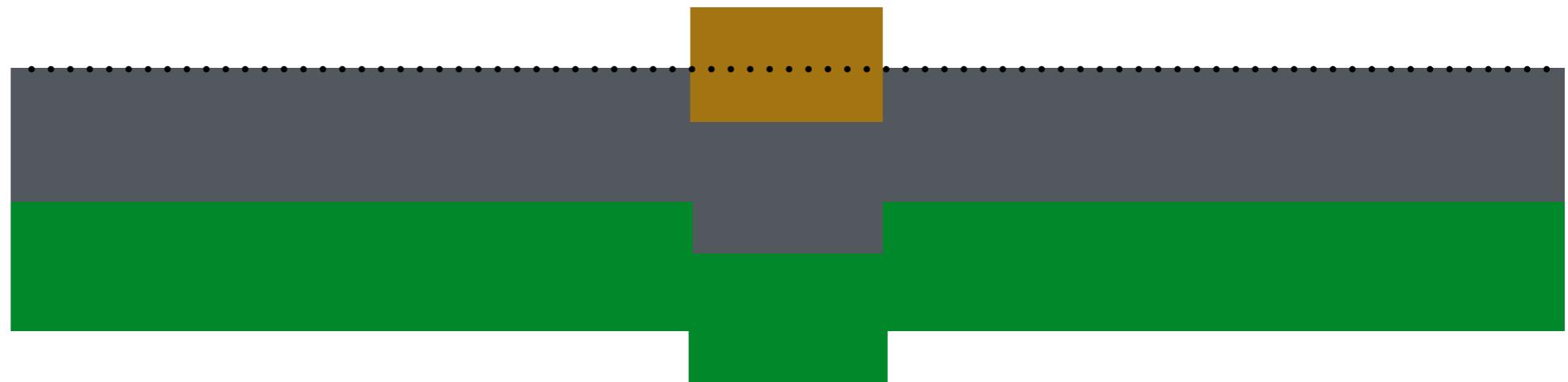


Isostasia
Flexural

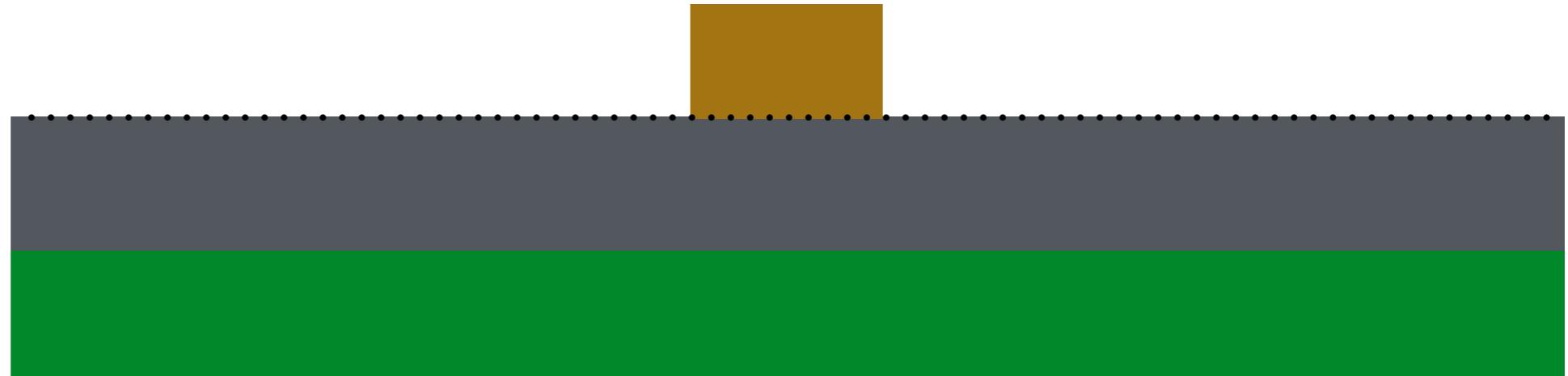


Isostasia e Flexura da Litosfera

Isostasia
Local

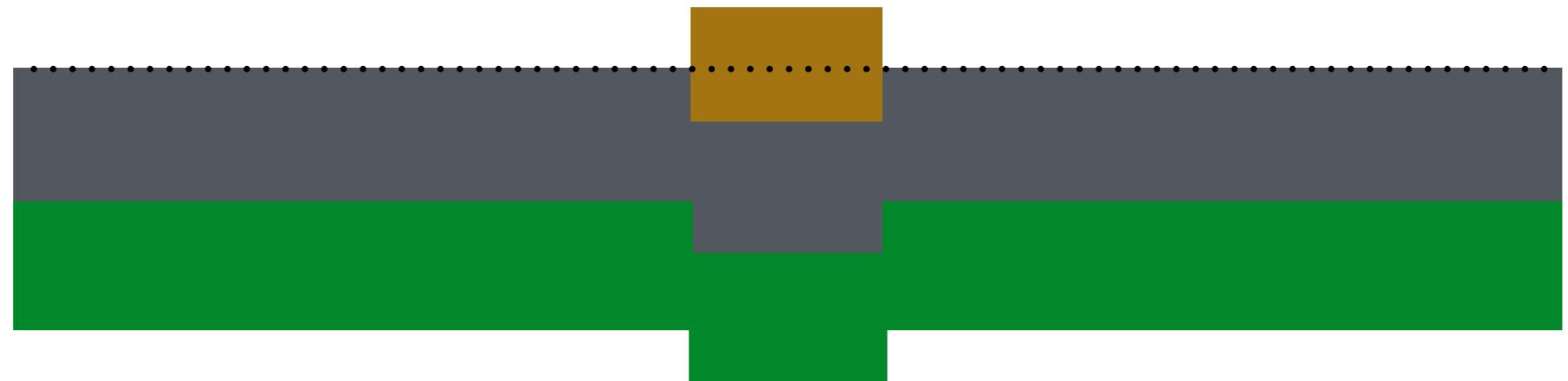


Isostasia
Flexural

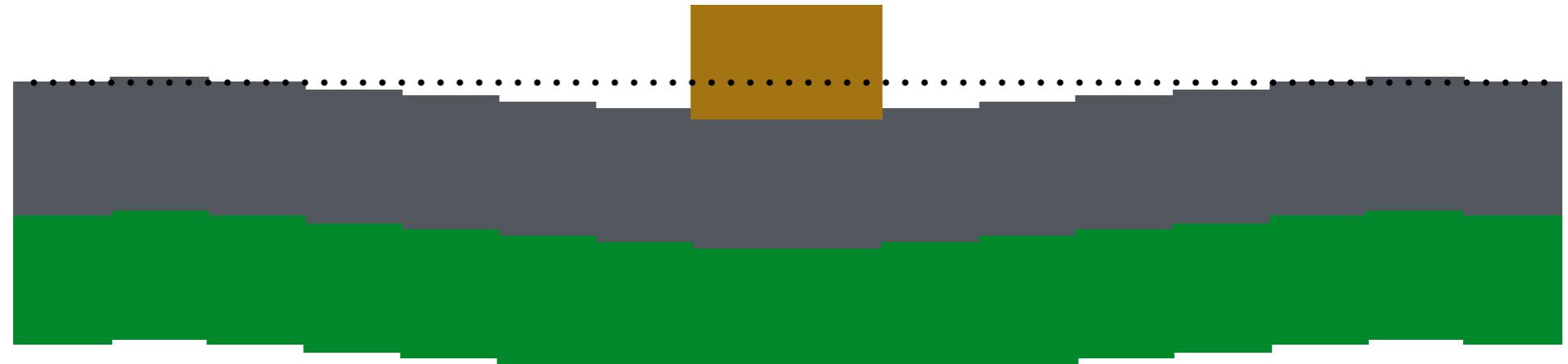


Isostasia e Flexura da Litosfera

Isostasia
Local

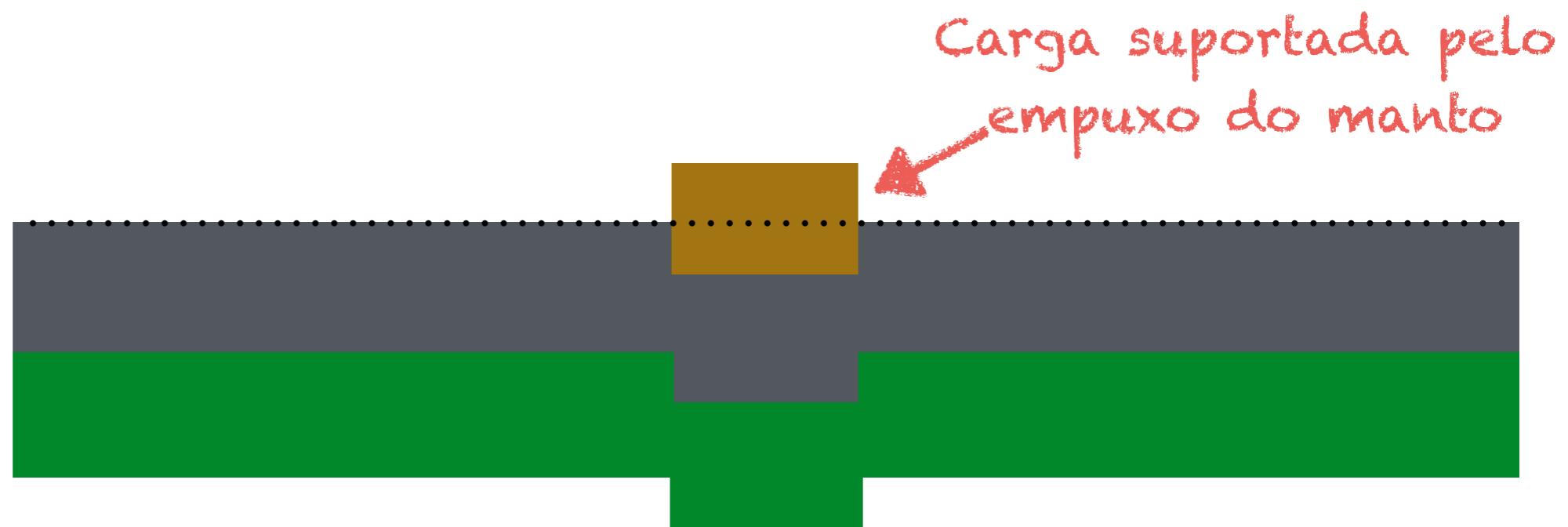


Isostasia
Flexural

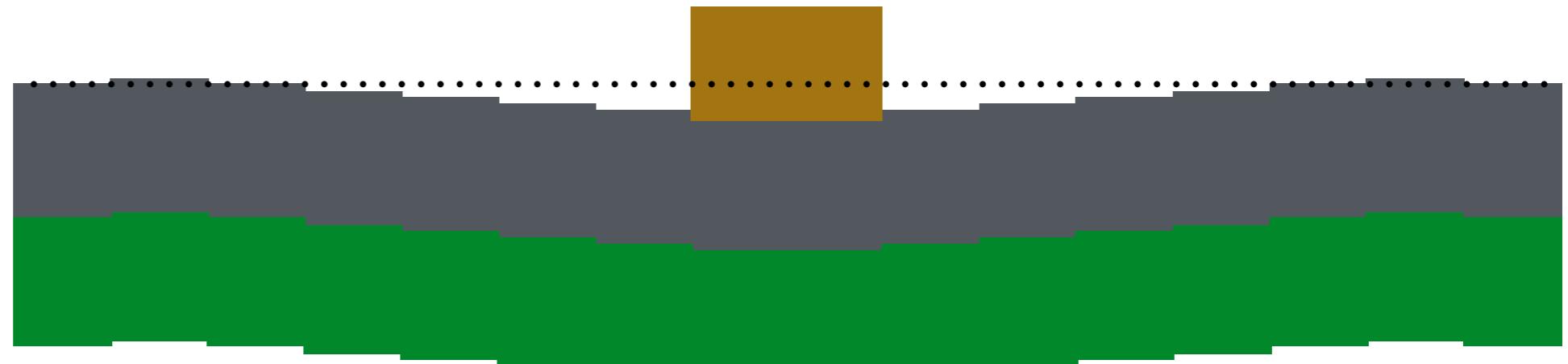


Isostasia e Flexura da Litosfera

Isostasia
Local

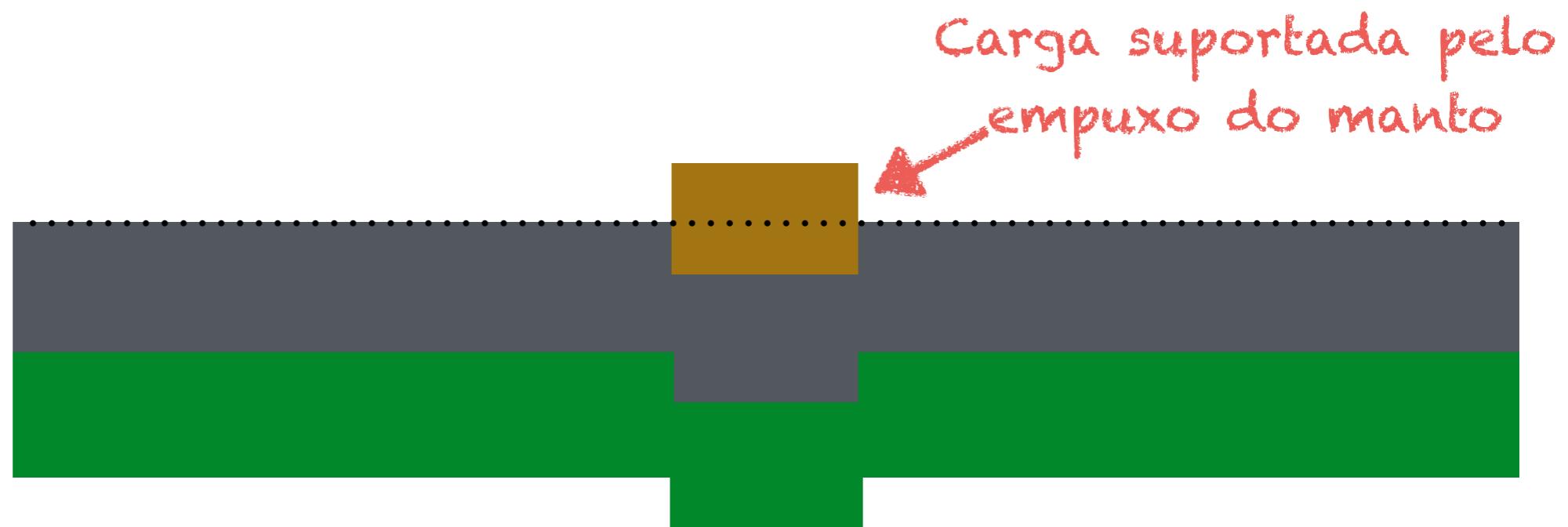


Isostasia
Flexural

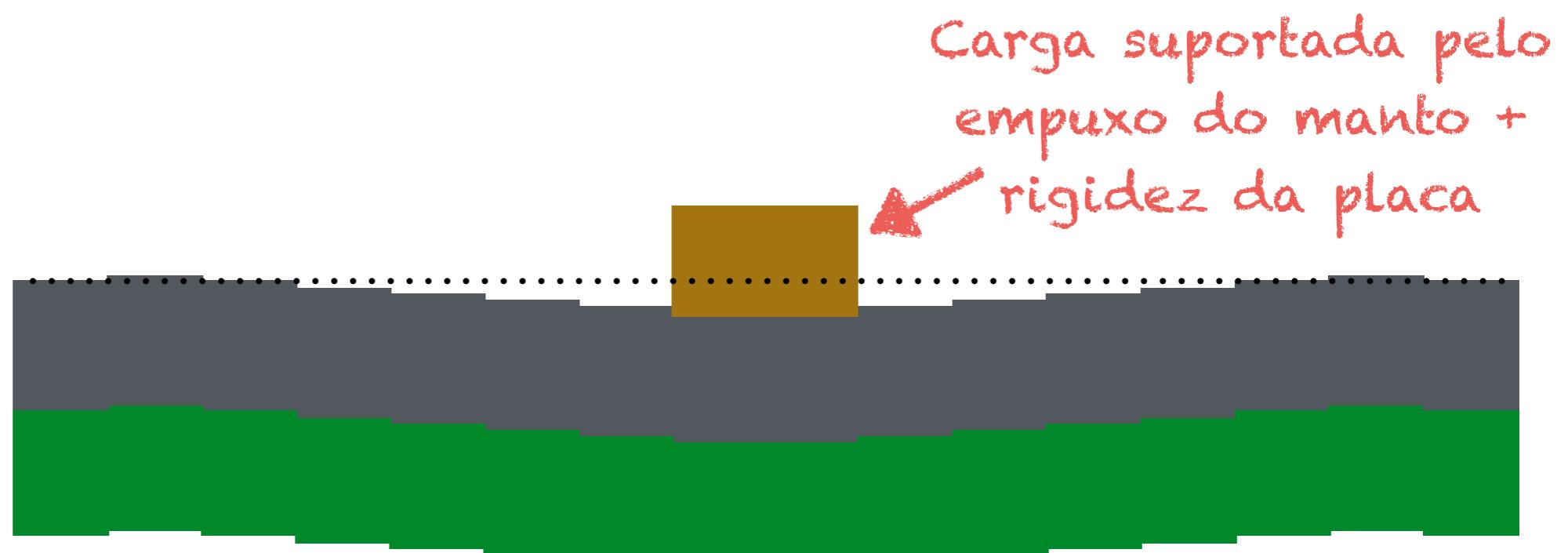


Isostasia e Flexura da Litosfera

Isostasia
Local



Isostasia
Flexural



Espessura da placa elástica

T_e : Espessura elástica efetiva

$T_e = 0$



T_e finite



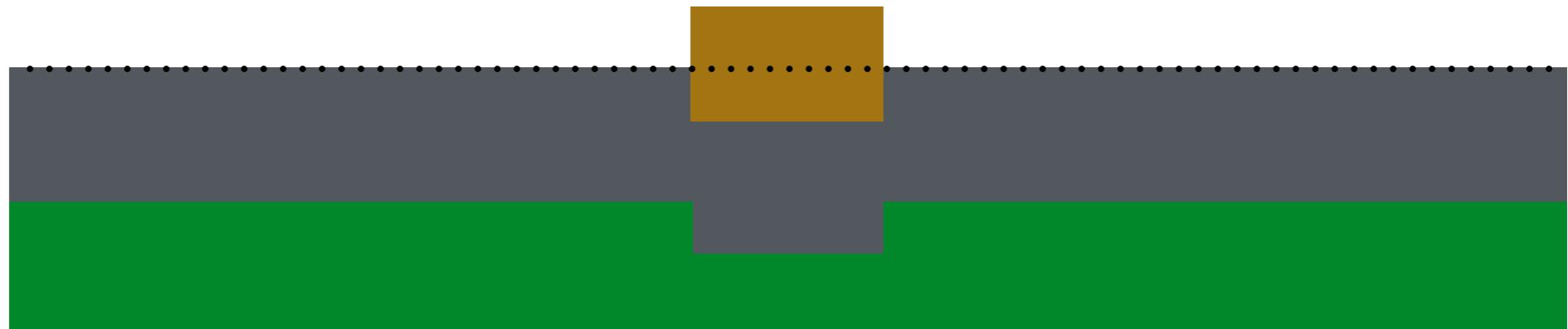
$T_e \rightarrow \infty$



Espessura da placa elástica

T_e : Espessura elástica efetiva

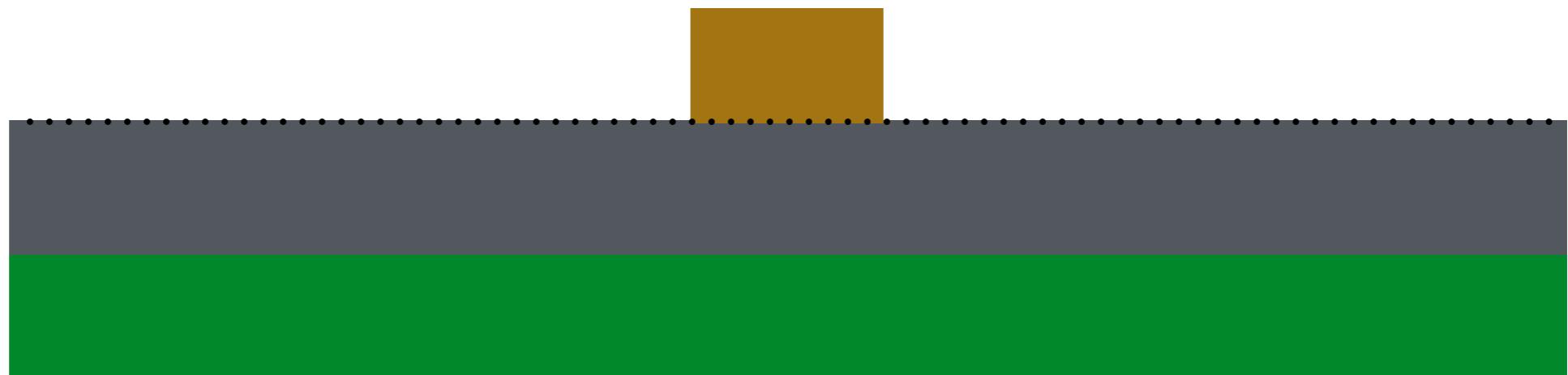
$$T_e = 0$$



$$T_e \text{ finite}$$



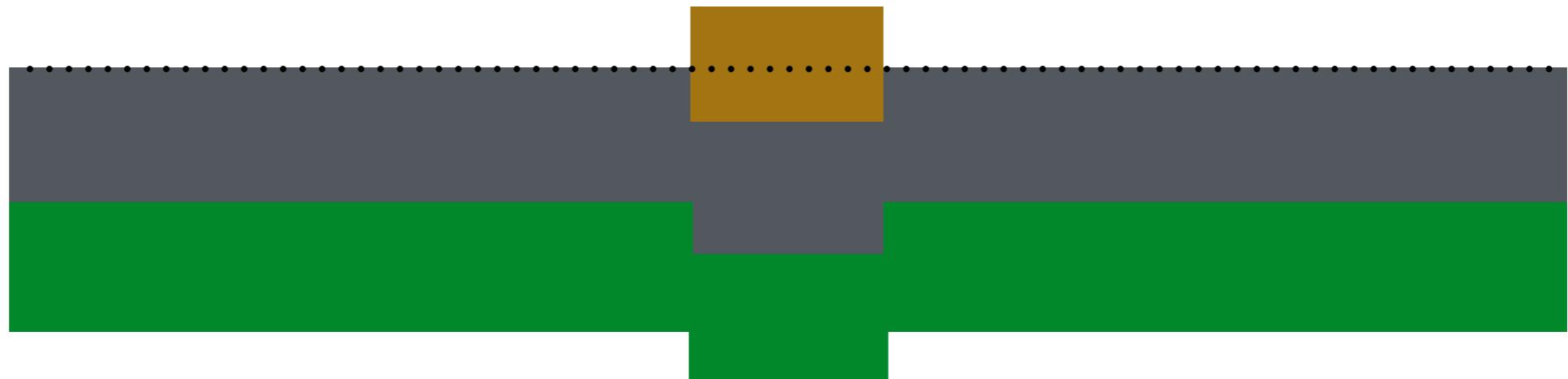
$$T_e \rightarrow \infty$$



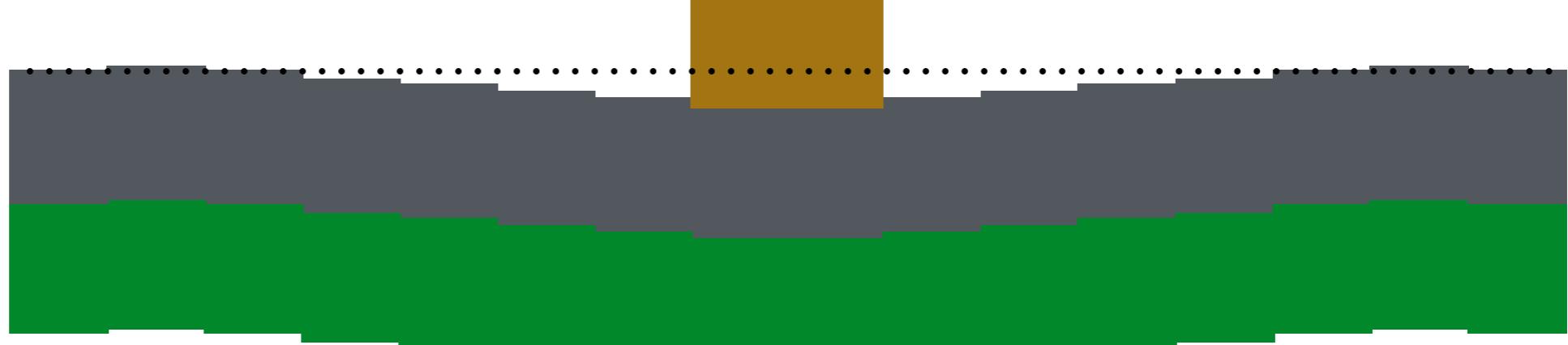
Espessura da placa elástica

T_e : Espessura elástica efetiva

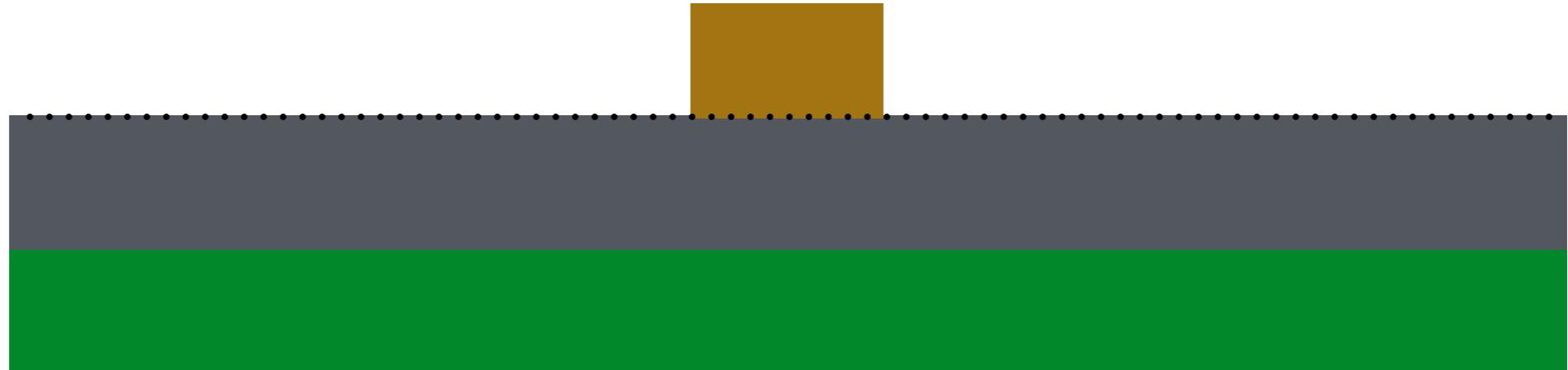
$$T_e = 0$$



$$T_e \text{ finite}$$



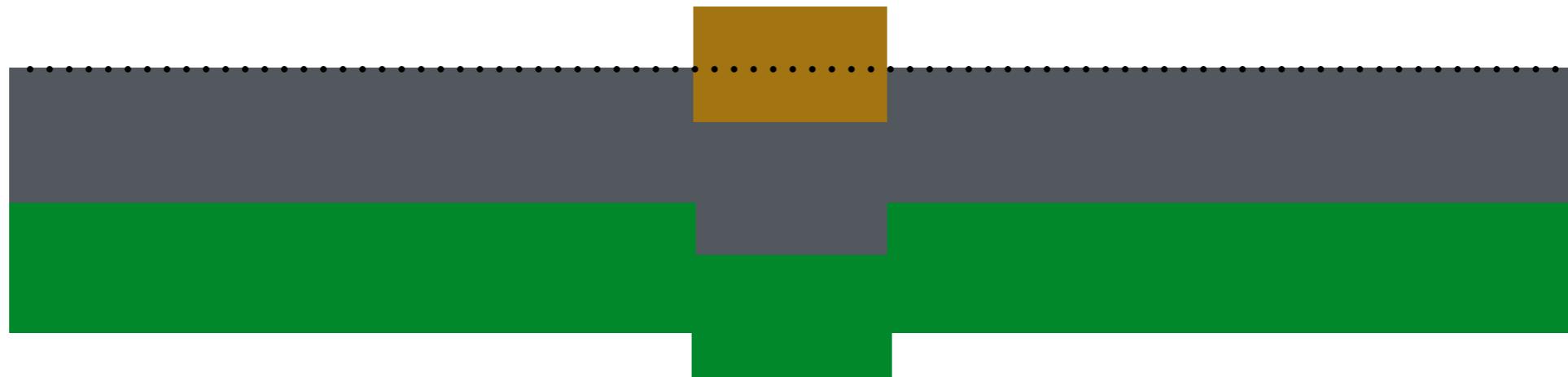
$$T_e \rightarrow \infty$$



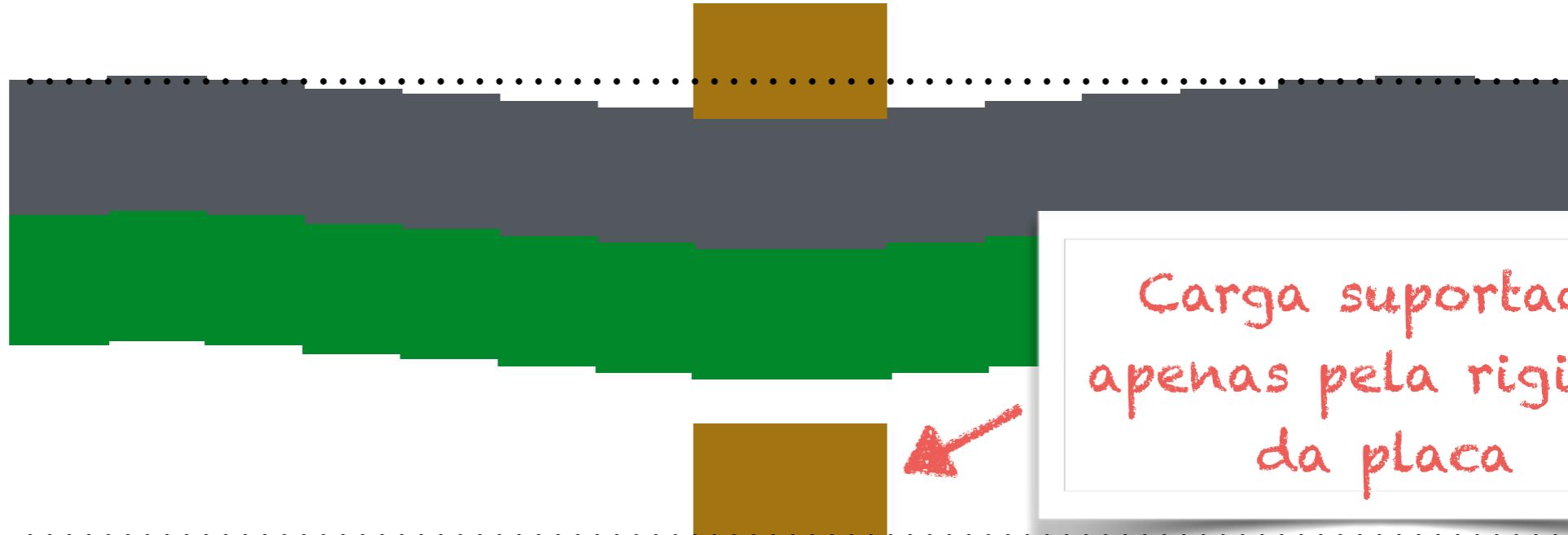
Espessura da placa elástica

T_e : Espessura elástica efetiva

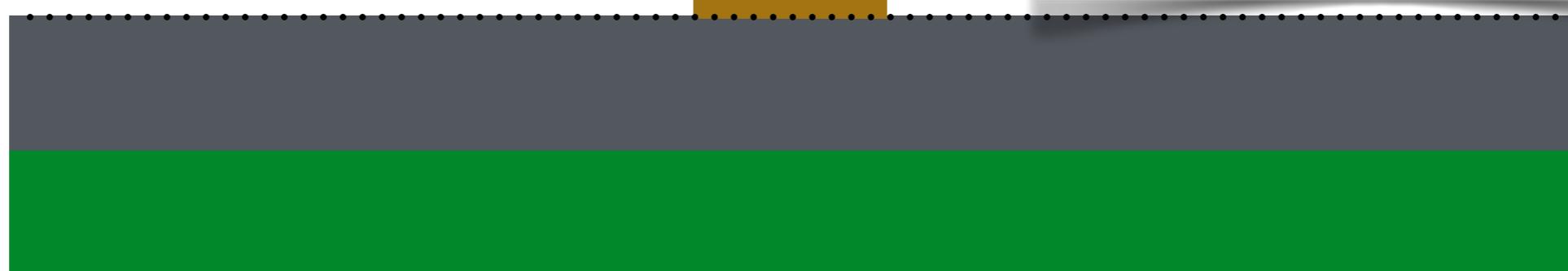
$$T_e = 0$$



$$T_e \text{ finite}$$



$$T_e \rightarrow \infty$$



Carga suportada
apenas pela rigidez
da placa

Size of the load $\times T_e$

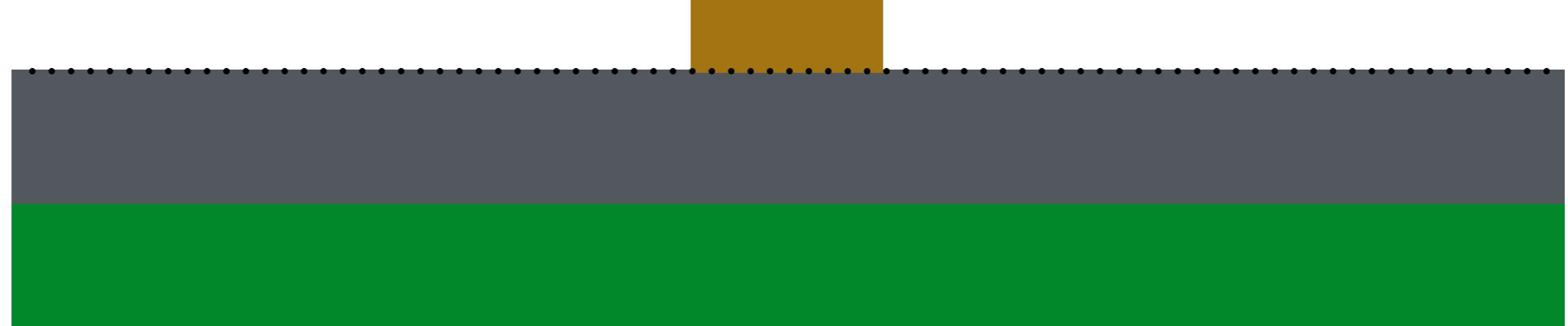
Para o mesmo T_e :

Carga
larga



Carga

intermediária



Carga estreita



Size of the load $\times T_e$

Para o mesmo T_e :

Carga
larga



Carga

intermediária



Carga estreita



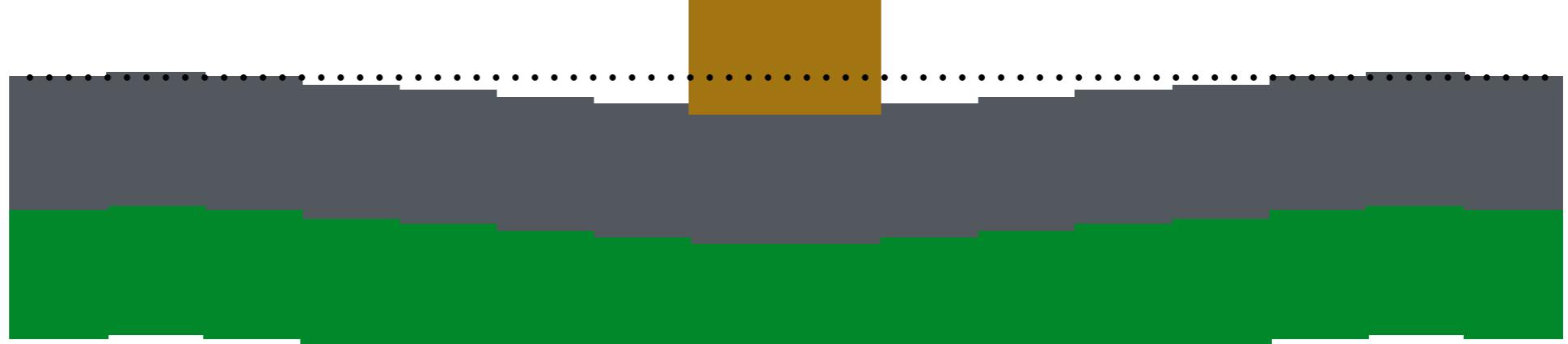
Size of the load $\times T_e$

Para o mesmo T_e :

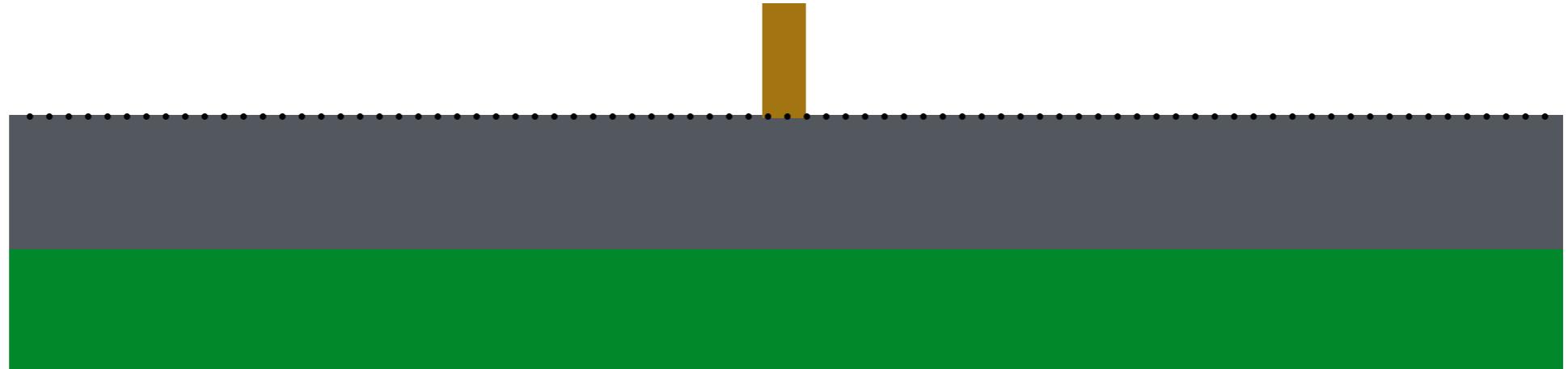
Carga
larga



Carga
intermediária



Carga estreita



Contribuições da isostasia e flexura para a tectônica de placas

- Existência de um fluido (astenosfera) que permite a compensação isostática e o deslocamento lateral das placas litosféricas.
- A camada externa da Terra (litosfera) preserva a sua rigidez ao longo do tempo geológico.

Cinemática das placas



<http://www.bl.uk/voices-of-science/interviewees/dan-mckenzie>

McKenzie & Parker (1967)



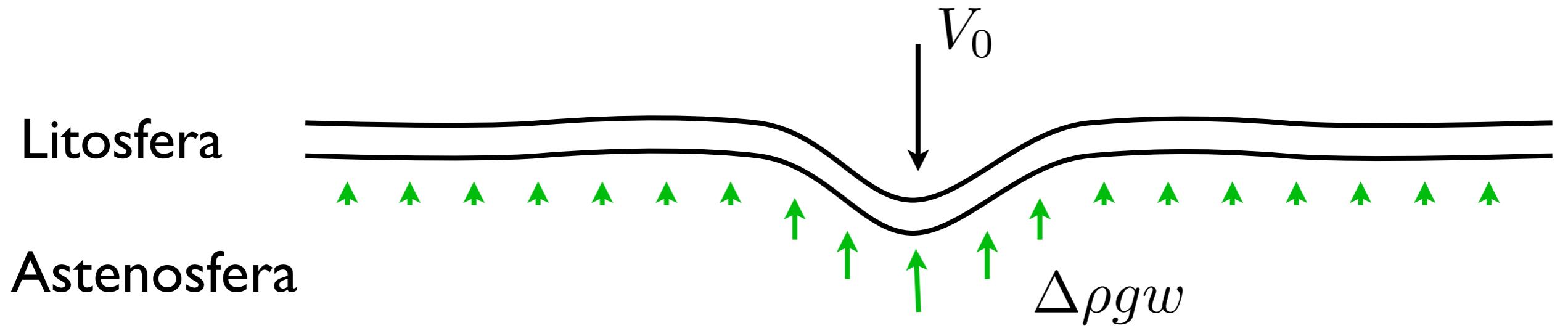
<https://www.onbeing.org/program/fragility-and-evolution-our-humanity/101>

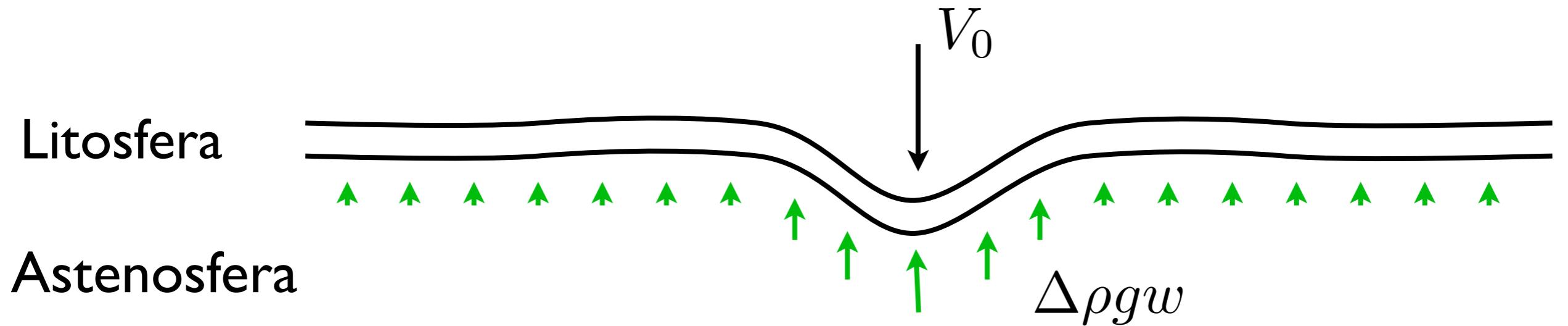
Le Pichon (1968)



https://en.wikipedia.org/wiki/W._Jason_Morgan#/media/File:Morgan,_W._Jason.jpg

Morgan (1968)

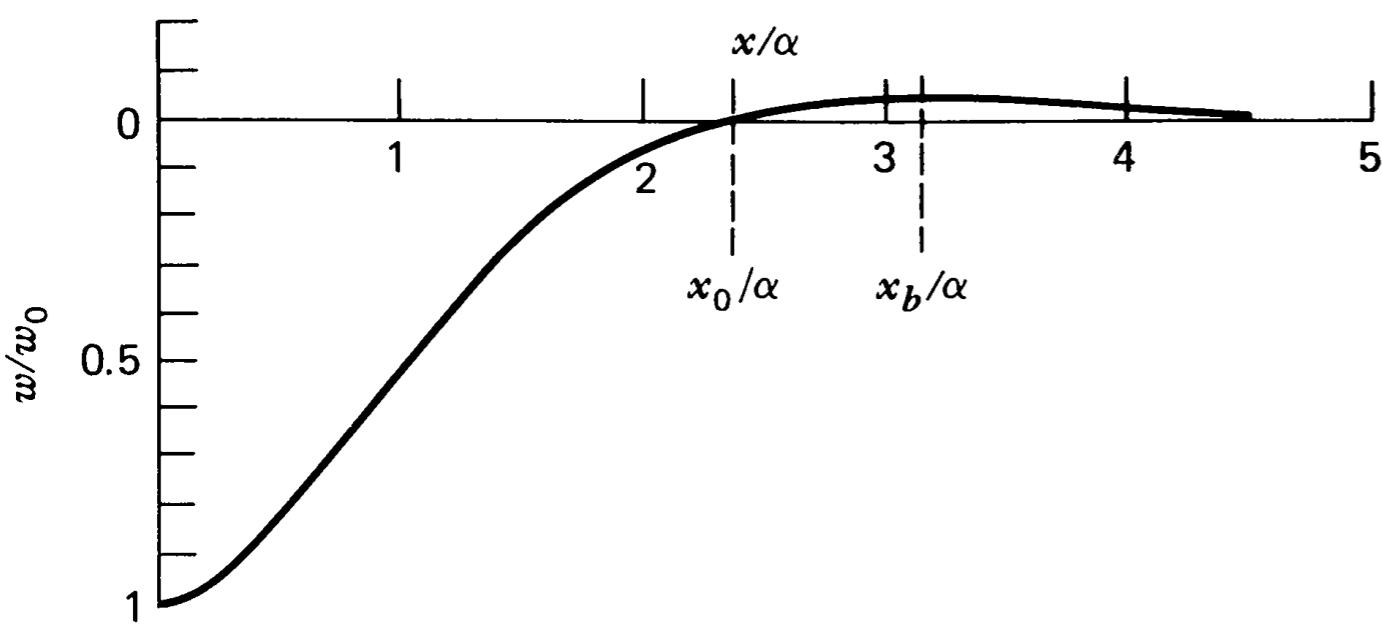




$$D \frac{d^4 w}{dx^4} + \Delta\rho gw = p$$

Solução analítica para o caso de uma carga pontual

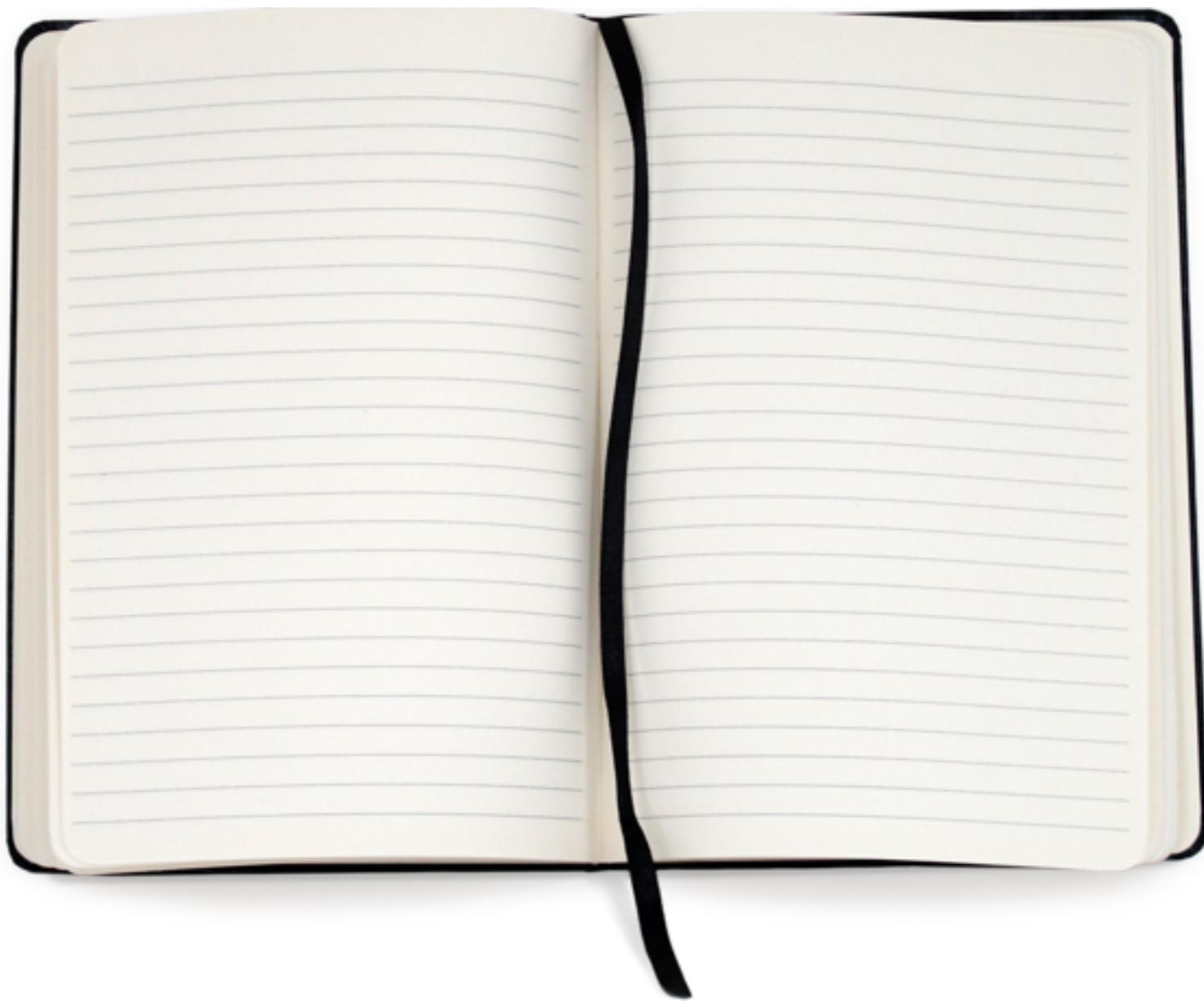
$$w = \frac{V_0 \alpha^3}{8D} e^{-x/\alpha} \left(\cos \frac{x}{\alpha} + \sin \frac{x}{\alpha} \right)$$



$$D = \frac{ET_e^3}{12(1 - \nu^2)}$$

$$\alpha = \left[\frac{4D}{(\rho_m - \rho_w)g} \right]^{1/4}$$

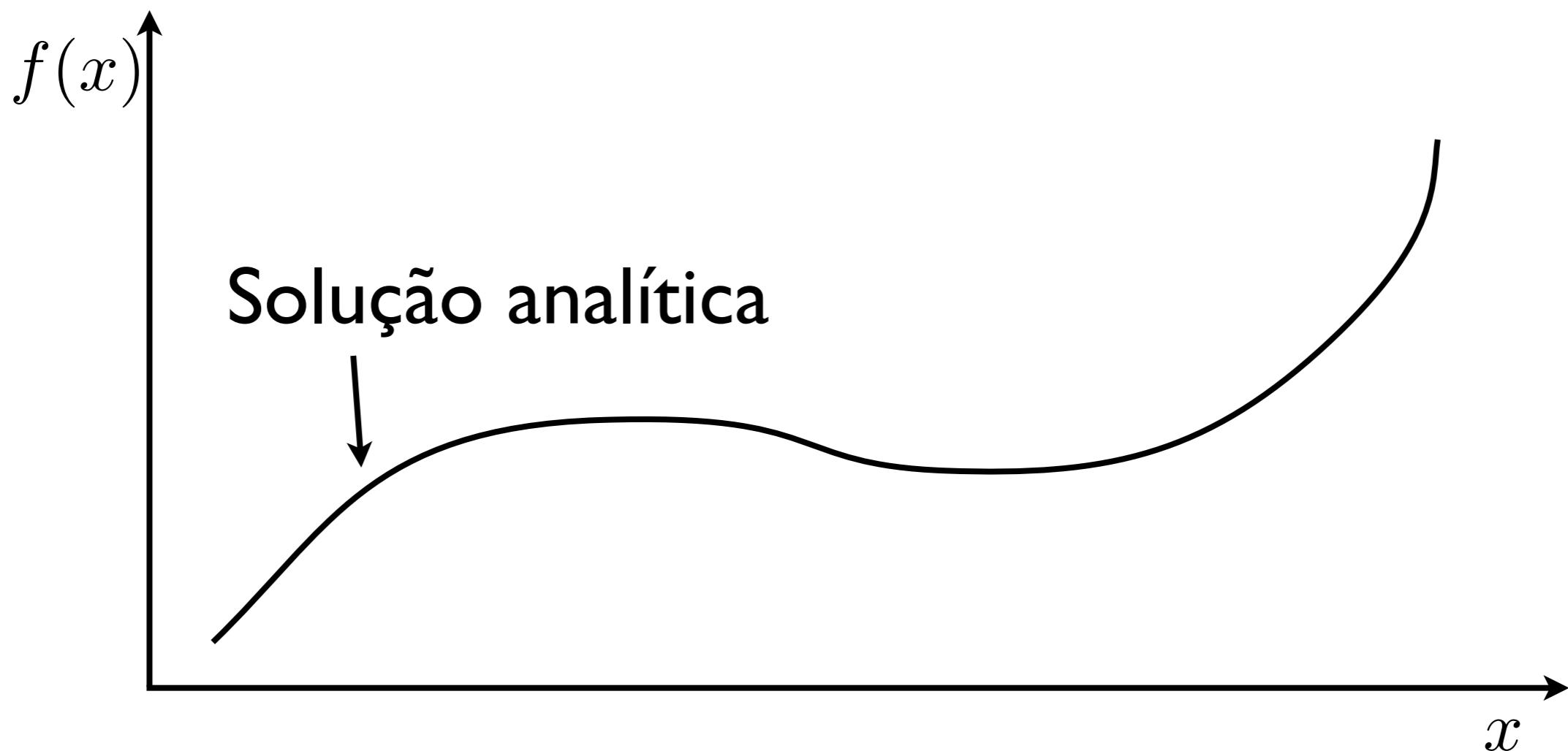
Prática: Flex_analitico



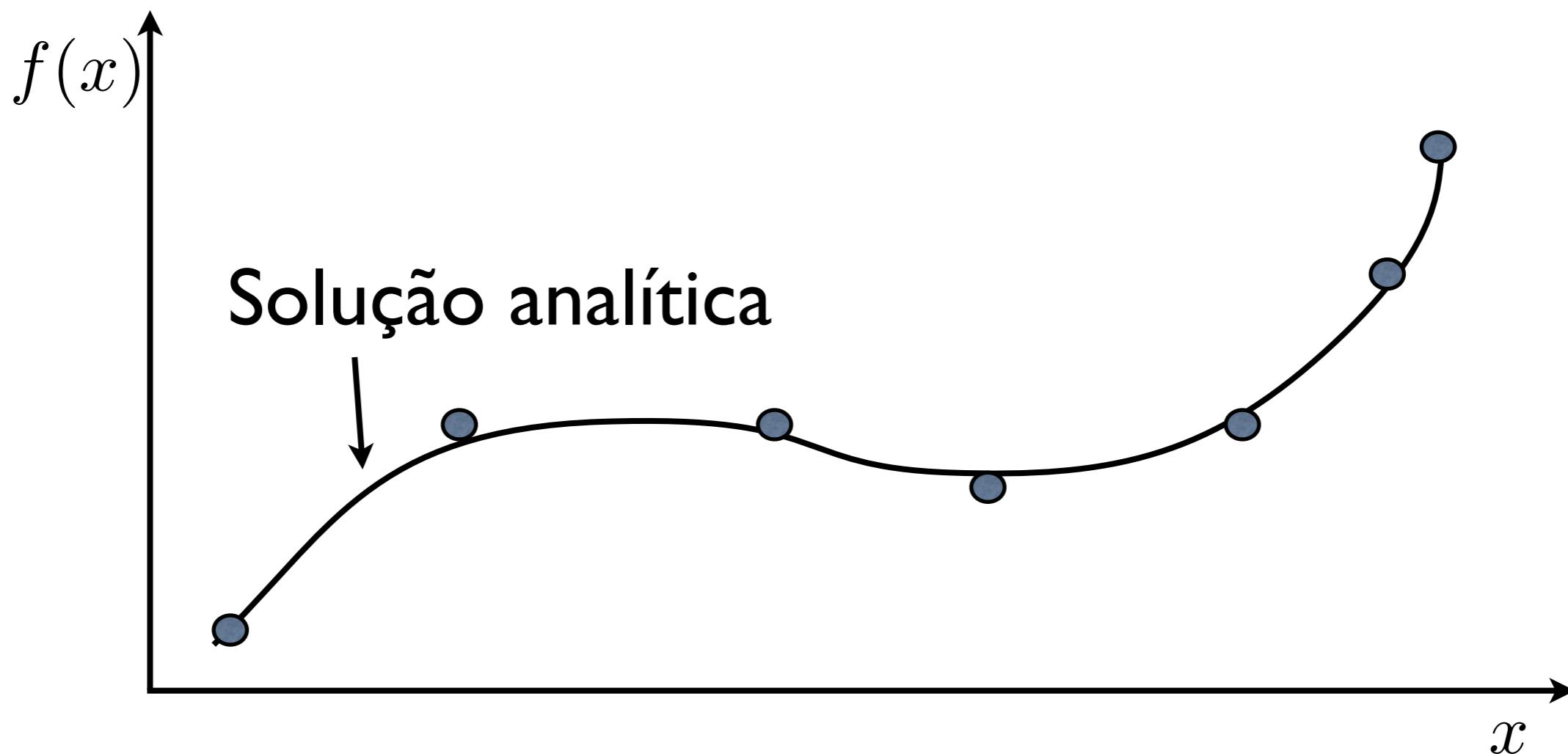
Aproximação numérica



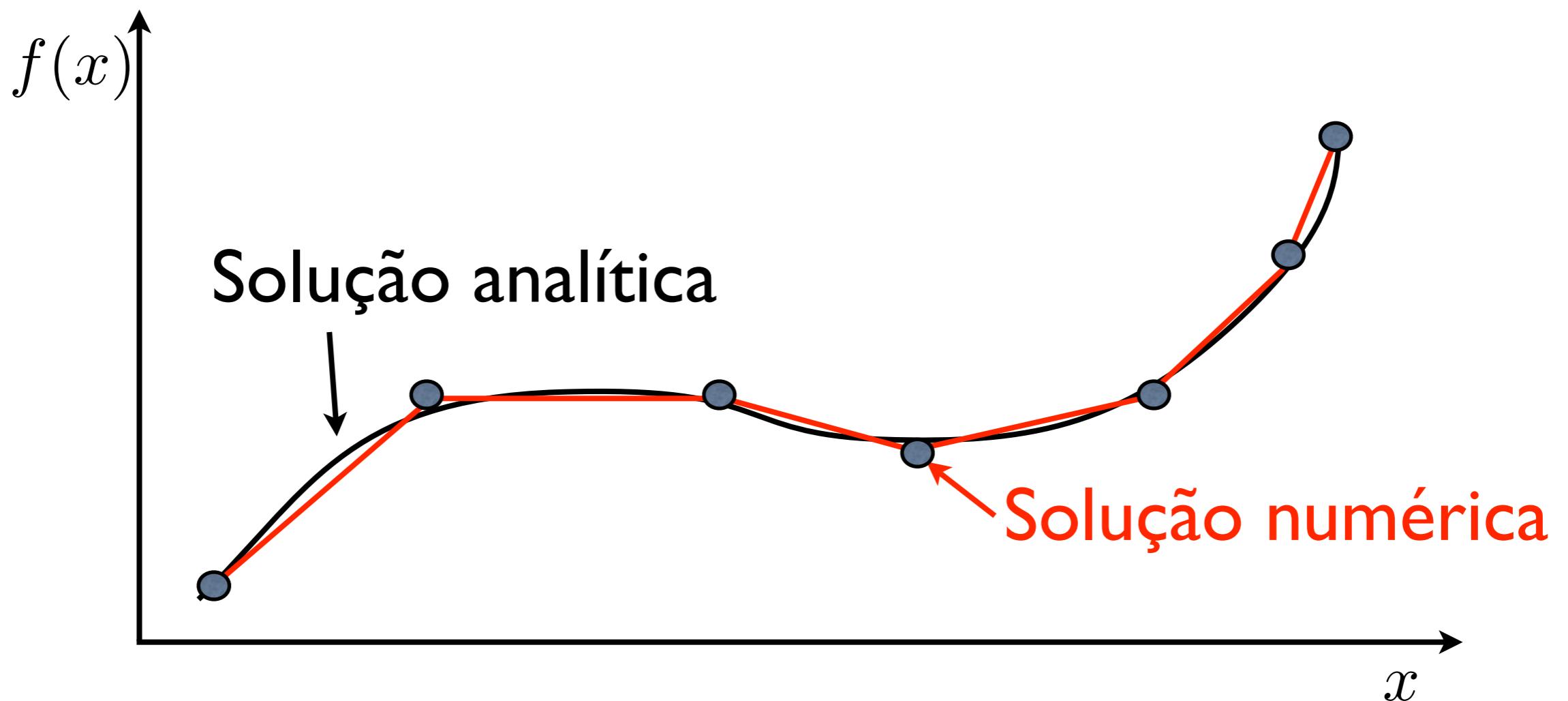
Aproximação numérica



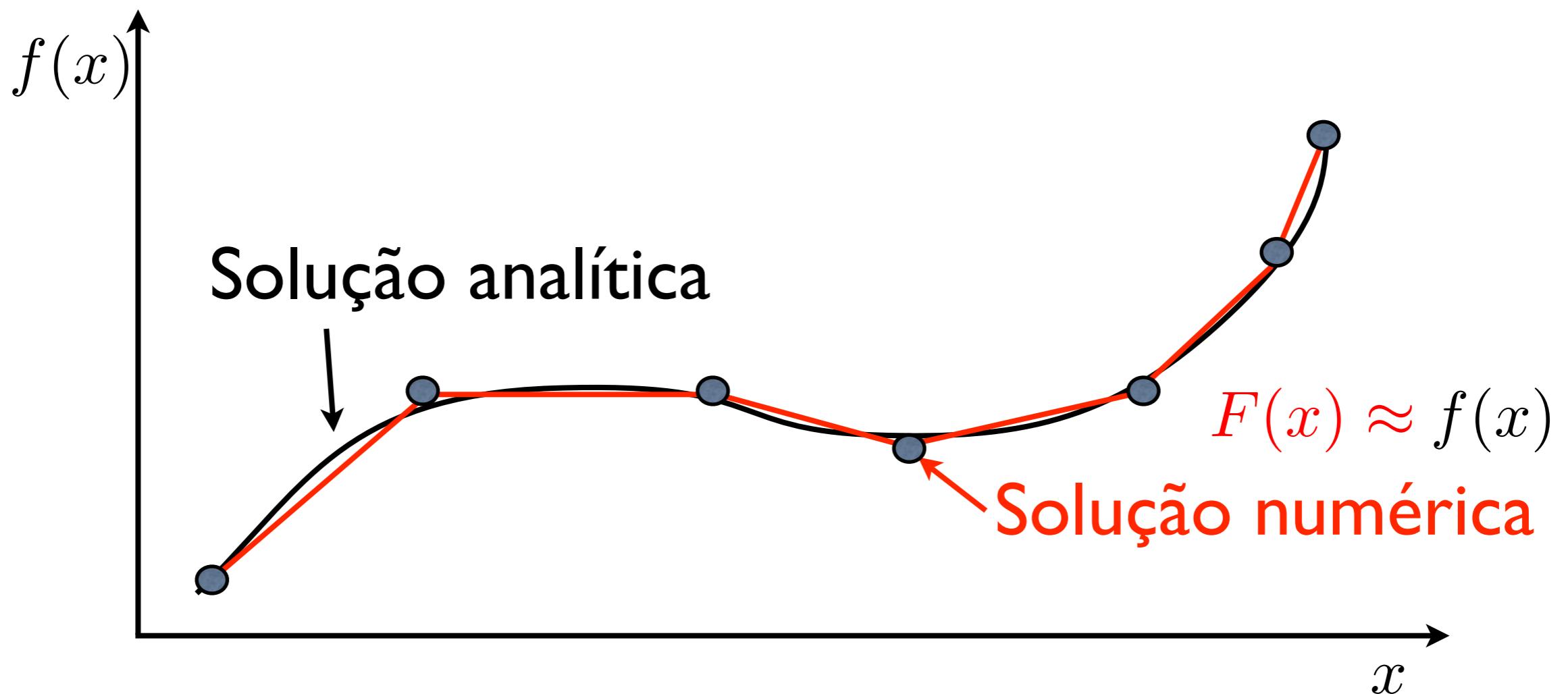
Aproximação numérica



Aproximação numérica



Aproximação numérica



Sol. analítica x Sol. numérica

Sol. analítica x Sol. numérica

- Solução exata

Sol. analítica x Sol. numérica

- Solução exata
- Solução aproximada

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Solução aproximada

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Solução aproximada
- Discreta

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Nada é escondido
- Solução aproximada
- Discreta

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Nada é escondido
- Solução aproximada
- Discreta
- Pode ser uma caixa preta

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Nada é escondido
- Todos os cenários
- Solução aproximada
- Discreta
- Pode ser uma caixa preta

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Nada é escondido
- Todos os cenários
- Solução aproximada
- Discreta
- Pode ser uma caixa preta
- 1 simulação por cenário

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Nada é escondido
- Todos os cenários
- Não exige validação
- Solução aproximada
- Discreta
- Pode ser uma caixa preta
- 1 simulação por cenário

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Nada é escondido
- Todos os cenários
- Não exige validação
- Solução aproximada
- Discreta
- Pode ser uma caixa preta
- 1 simulação por cenário
- Exige validação

Sol. analítica x Sol. numérica

- Solução exata
- Contínua
- Nada é escondido
- Todos os cenários
- Não exige validação
- Solução aproximada
- Discreta
- Pode ser uma caixa preta
- 1 simulação por cenário
- Exige validação

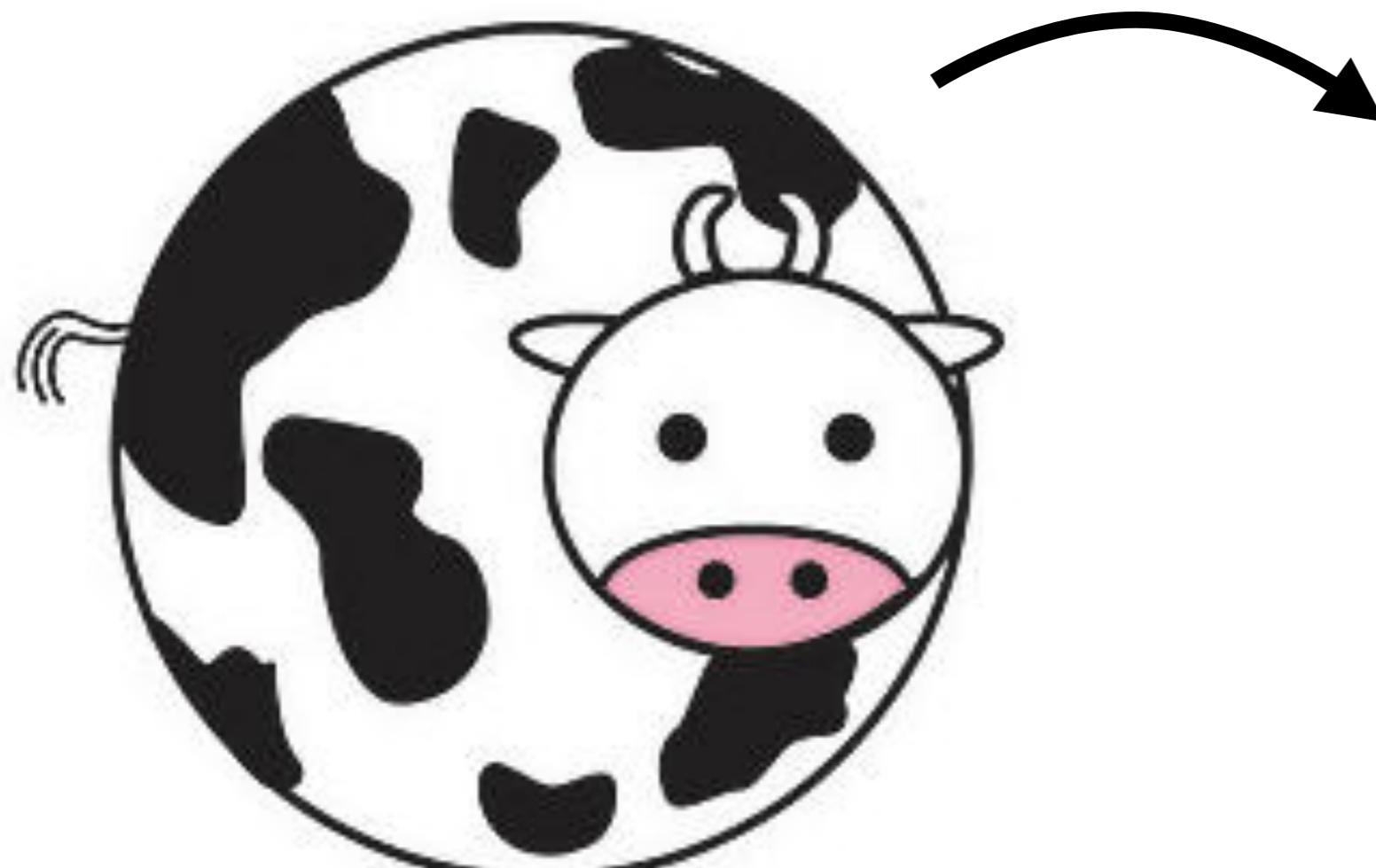
Ora bolas! Para que serve a modelagem numérica?

I. Geometria complicada

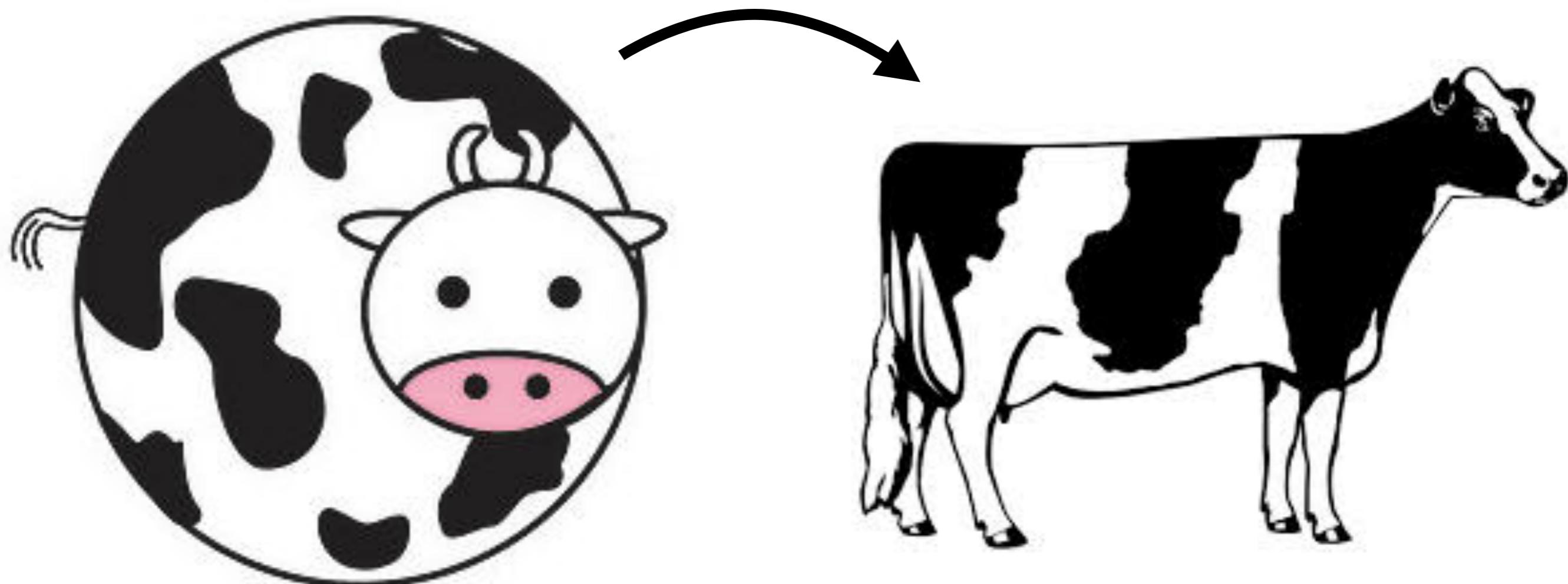
I. Geometria complicada



I. Geometria complicada



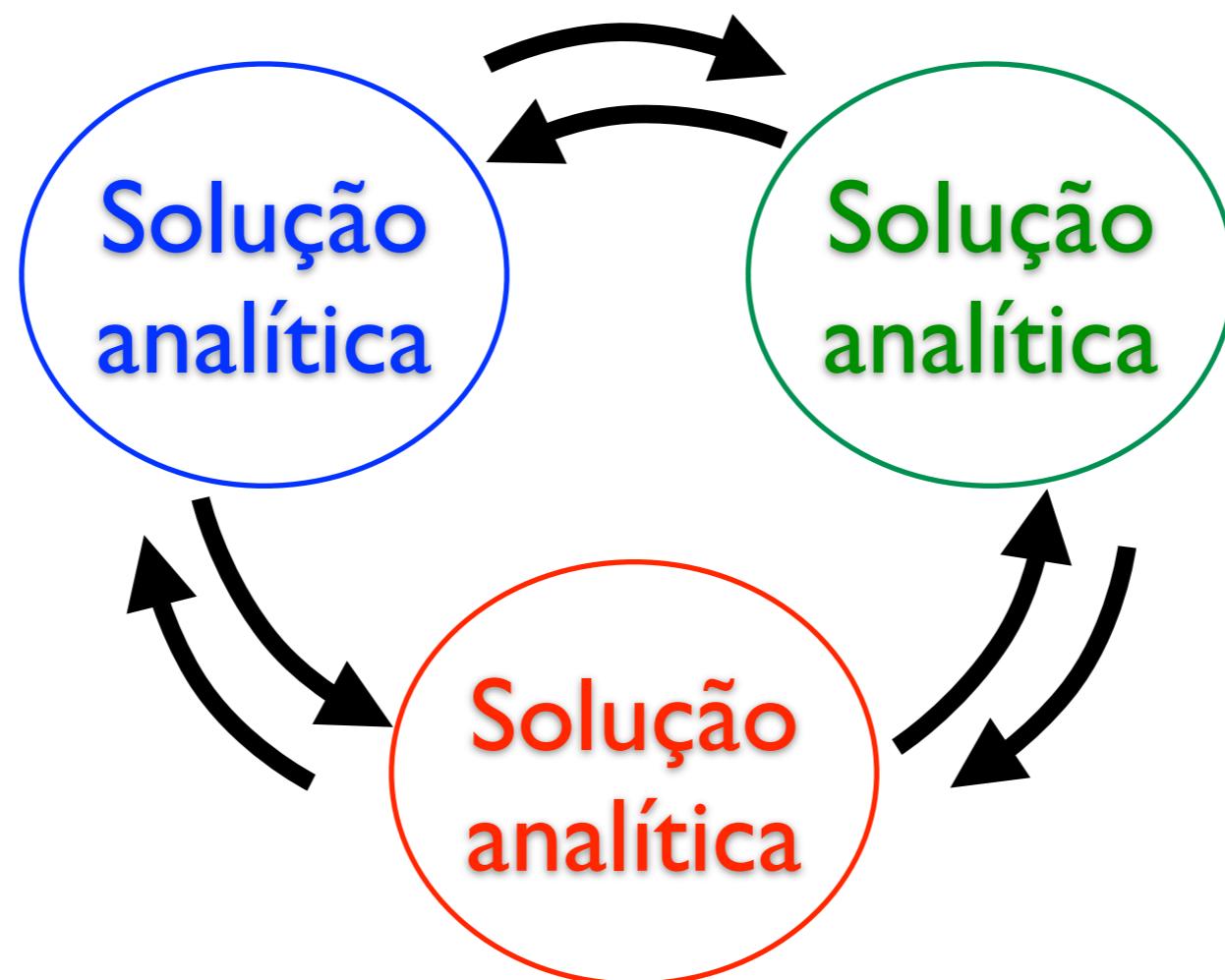
I. Geometria complicada



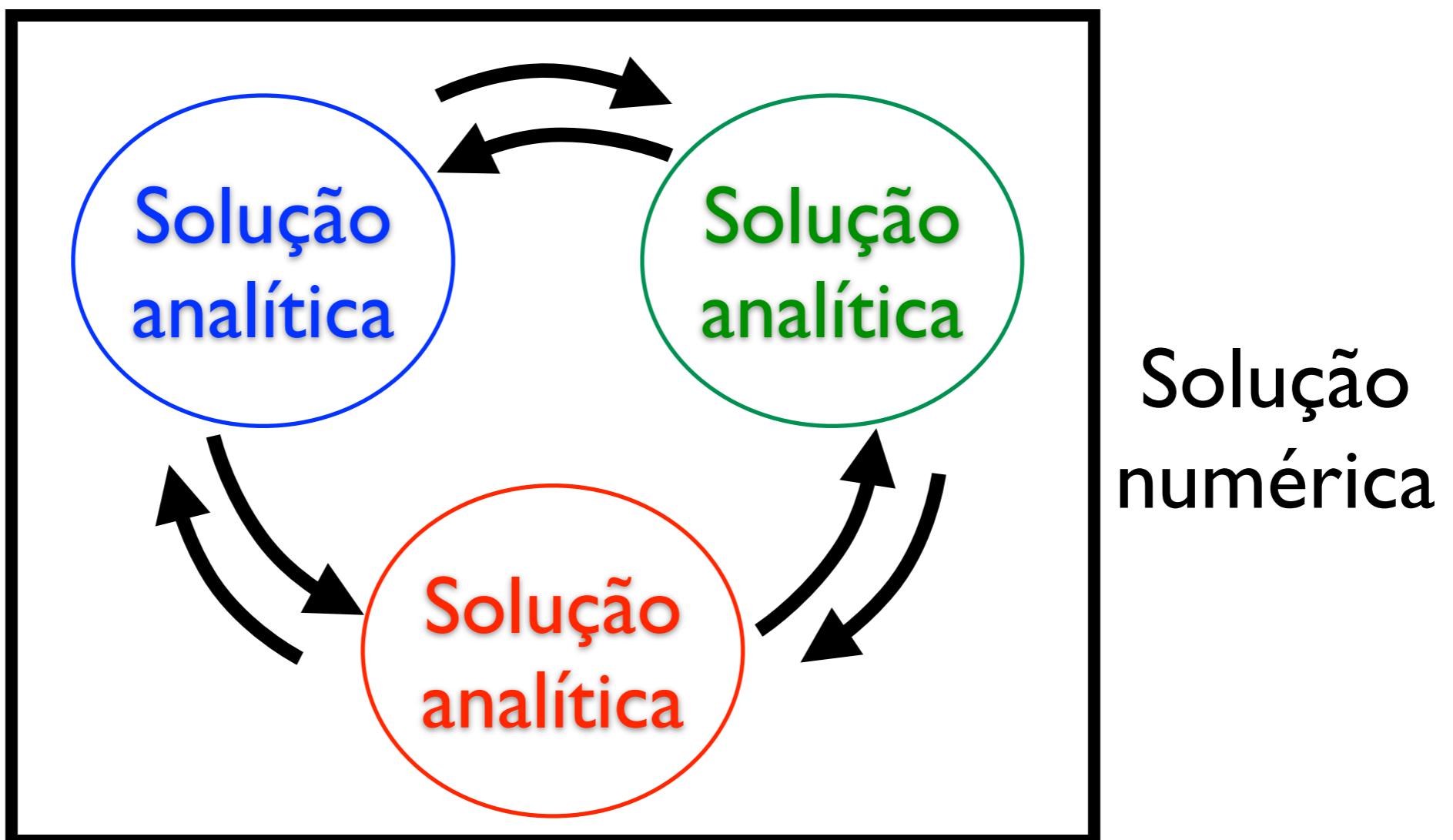
2. Acoplamento entre diferentes processos



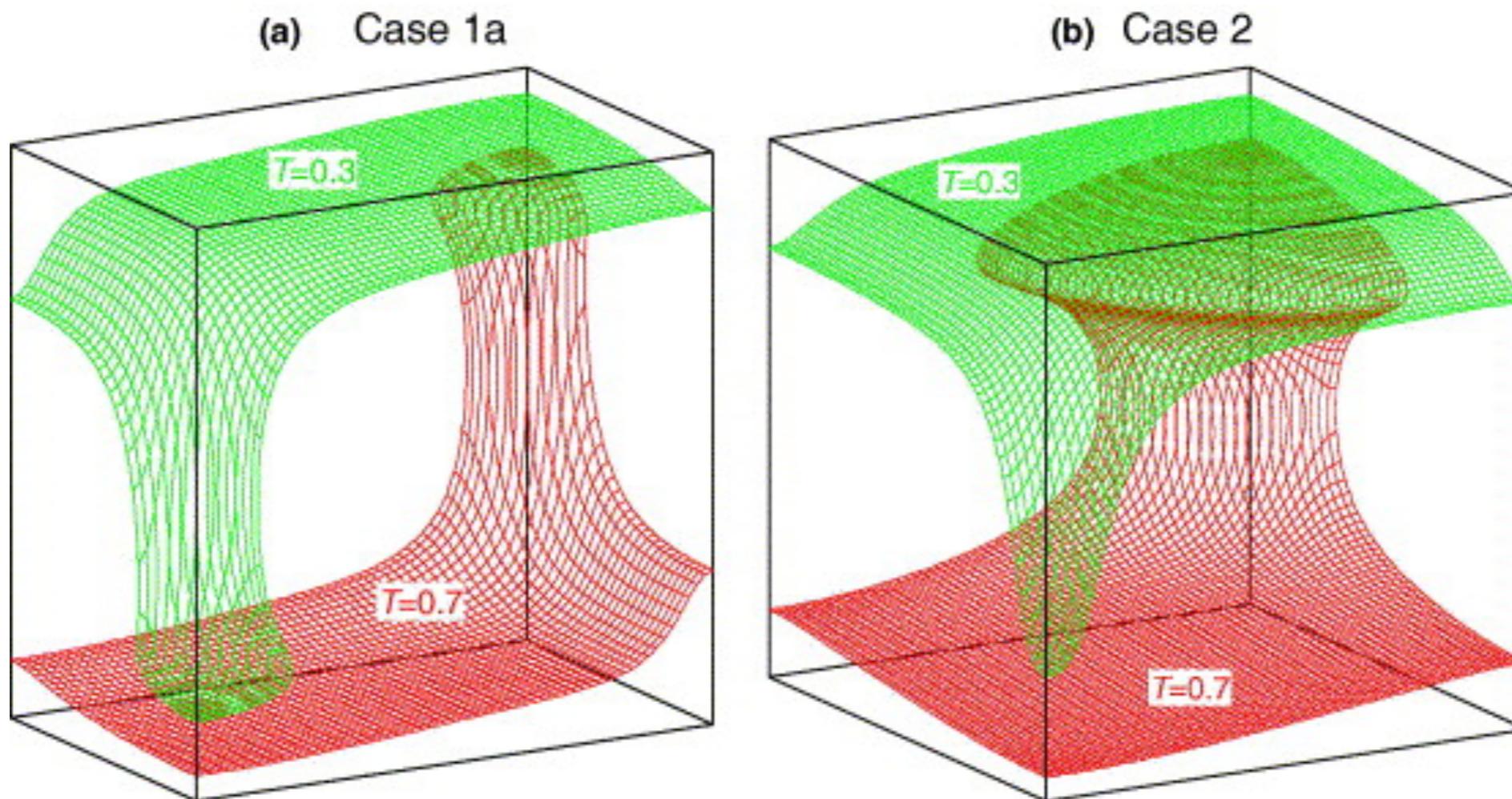
2. Acoplamento entre diferentes processos



2. Acoplamento entre diferentes processos



3. Não existência de solução analítica



Método numérico: Diferenças finitas

Método numérico: Diferenças finitas

$$\frac{dw(a)}{dx}$$

Método numérico: Diferenças finitas

$$\frac{dw(a)}{dx} = \lim_{\Delta x \rightarrow 0} \frac{w(a + \Delta x) - w(a)}{\Delta x}$$

Método numérico: Diferenças finitas

$$\begin{aligned}\frac{dw(a)}{dx} &= \lim_{\Delta x \rightarrow 0} \frac{w(a + \Delta x) - w(a)}{\Delta x} \\ &\approx \frac{w(a + \Delta x) - w(a)}{\Delta x}\end{aligned}$$

Método numérico: Diferenças finitas

$$\begin{aligned}\frac{dw(a)}{dx} &= \lim_{\Delta x \rightarrow 0} \frac{w(a + \Delta x) - w(a)}{\Delta x} \\ &\approx \frac{w(a + \Delta x) - w(a)}{\Delta x} = \frac{\Delta w}{\Delta x}\end{aligned}$$

w_{i-2} Δx w_{i-1} w_i w_{i+1} w_{i+2} 

$$w_{i-2}$$

$$\Delta x$$

$$w_{i-1}$$

$$w_i$$

$$w_{i+1}$$

$$w_{i+2}$$

$$D\frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

w_{i-2} Δx w_{i-1} w_i w_{i+1} w_{i+2}

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$



w_{i-2} Δx w_{i-1} w_i w_{i+1} w_{i+2}

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

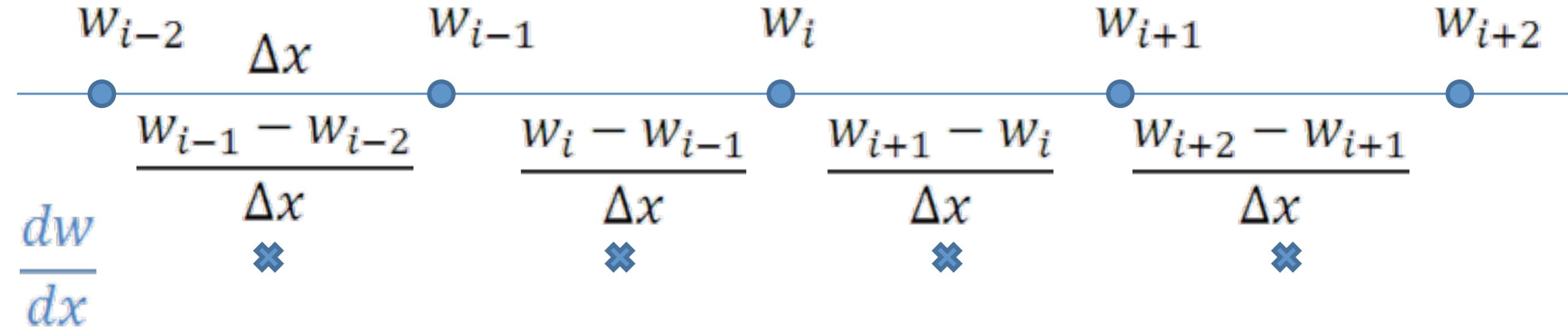


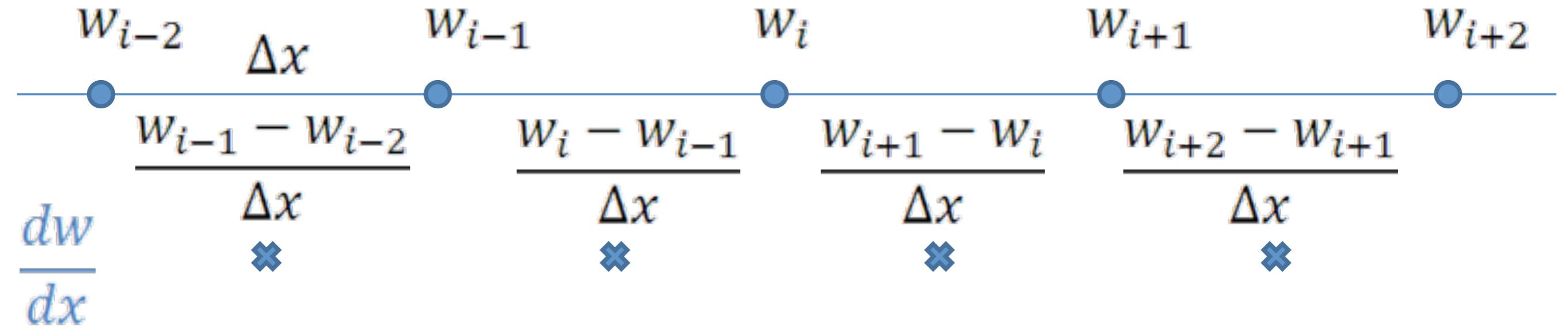
$$? + \Delta \rho g w_i = p_i$$

w_{i-2} Δx w_{i-1} w_i w_{i+1} w_{i+2}

$$\frac{dw}{dx}$$







$$w_{i-2} \quad \Delta x \quad w_{i-1} \quad w_i \quad w_{i+1} \quad w_{i+2}$$
$$\frac{w_{i-1} - w_{i-2}}{\Delta x} \quad \text{※}$$
$$\frac{w_i - w_{i-1}}{\Delta x} \quad \text{※}$$
$$\frac{w_{i+1} - w_i}{\Delta x} \quad \text{※}$$
$$\frac{w_{i+2} - w_{i+1}}{\Delta x} \quad \text{※}$$
$$\frac{dw}{dx}$$

$$\frac{d^2w}{dx^2}$$
$$\text{※}$$
$$\text{※}$$
$$\text{※}$$

w_{i-2} Δx w_{i-1} w_i w_{i+1} w_{i+2}

$$\frac{w_{i-1} - w_{i-2}}{\Delta x}$$

$$\frac{w_i - w_{i-1}}{\Delta x}$$

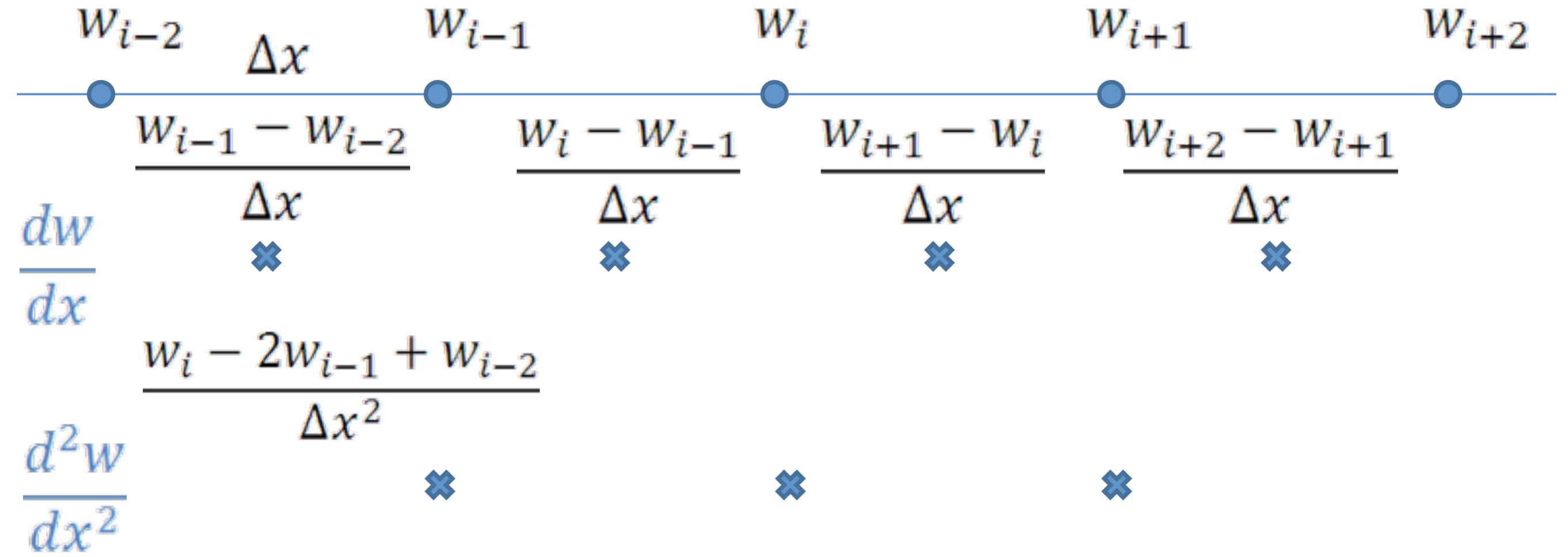
$$\frac{w_{i+1} - w_i}{\Delta x}$$

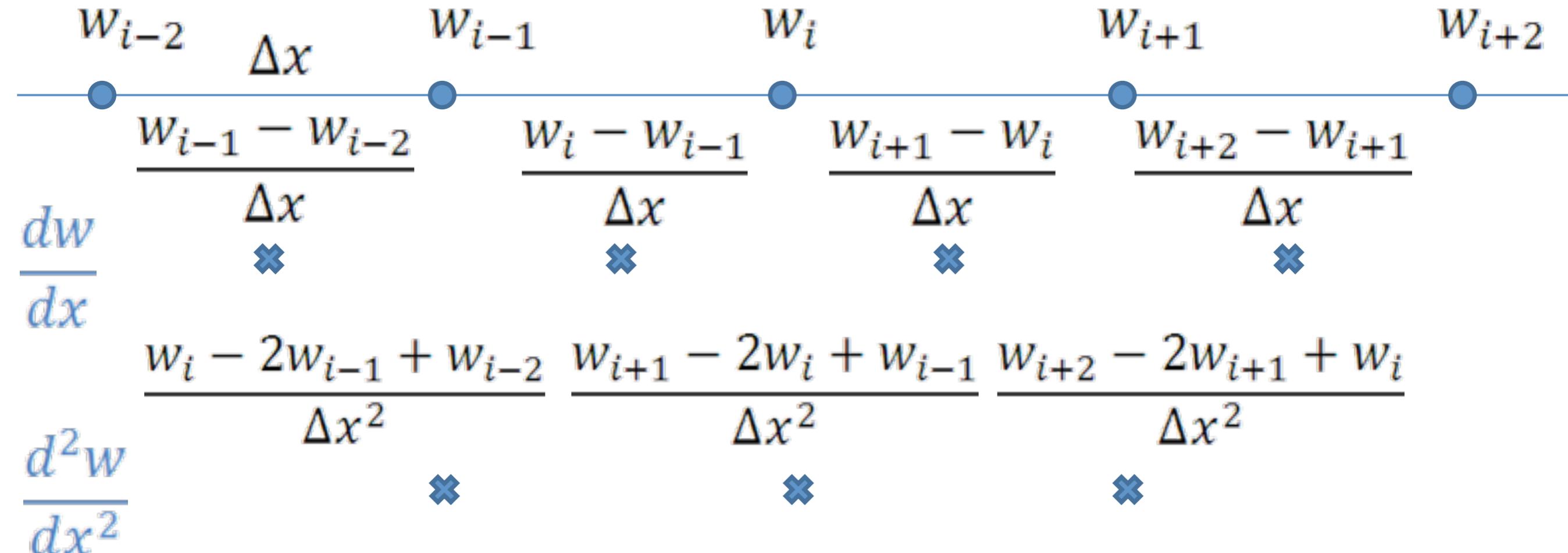
$$\frac{w_{i+2} - w_{i+1}}{\Delta x}$$

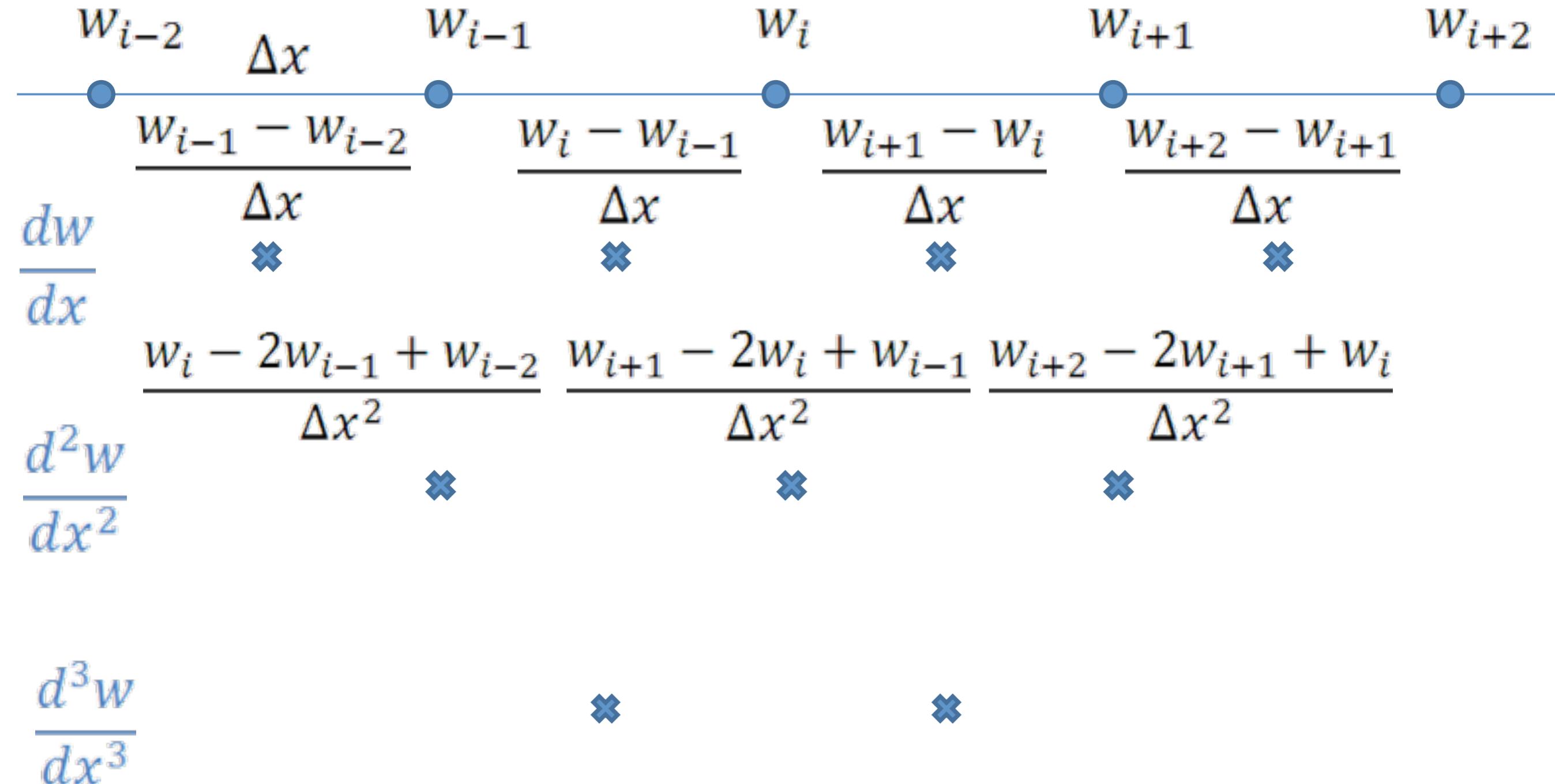
$$\frac{dw}{dx}$$

$$\frac{w_i - w_{i-1}}{\Delta x} - \frac{w_{i-1} - w_{i-2}}{\Delta x}$$

$$\frac{d^2w}{dx^2}$$







w_{i-2} Δx w_{i-1} w_i w_{i+1} w_{i+2}

$\frac{w_{i-1} - w_{i-2}}{\Delta x}$ $\frac{w_i - w_{i-1}}{\Delta x}$ $\frac{w_{i+1} - w_i}{\Delta x}$ $\frac{w_{i+2} - w_{i+1}}{\Delta x}$

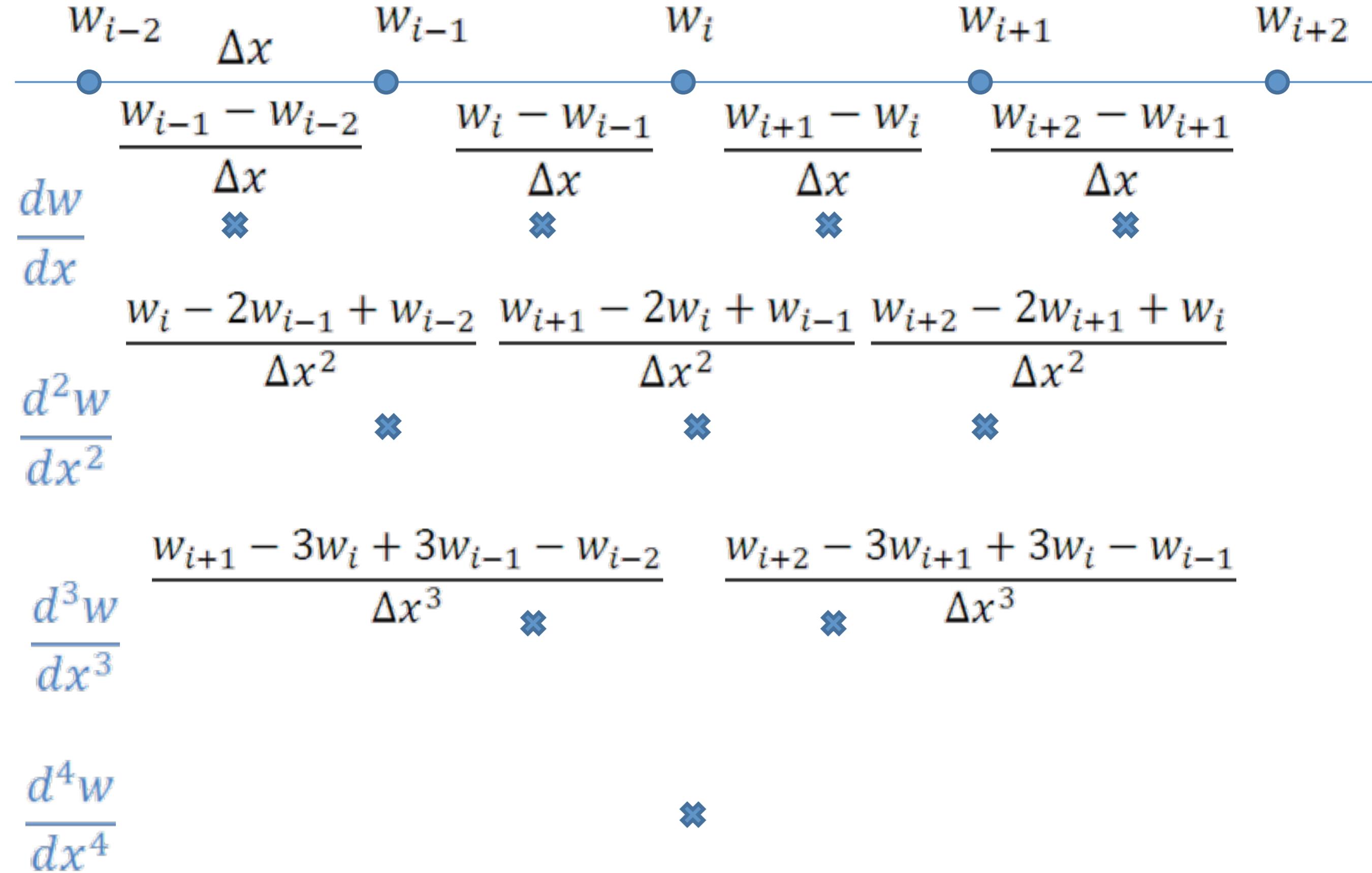
$\frac{dw}{dx}$

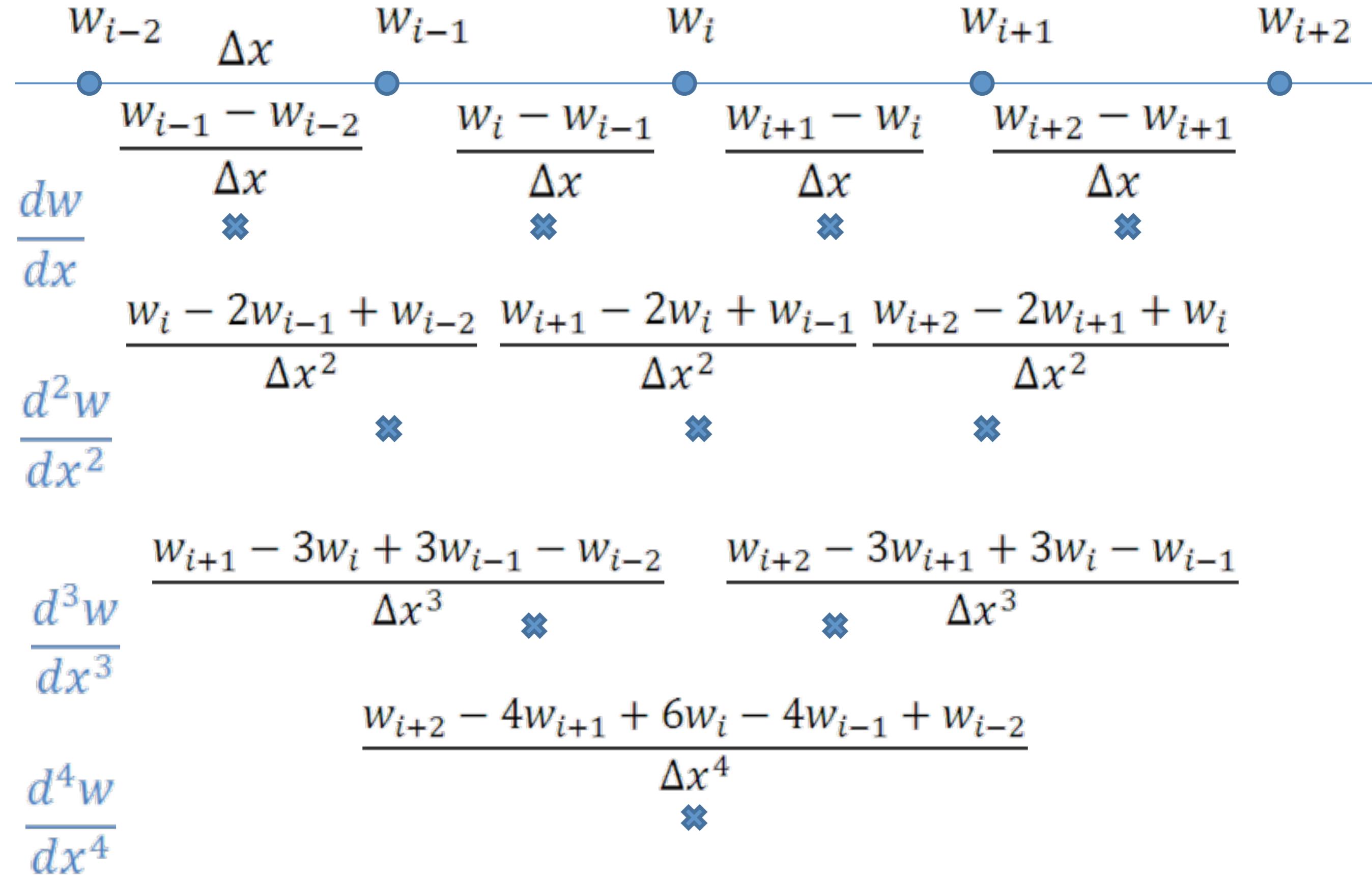
$\frac{w_i - 2w_{i-1} + w_{i-2}}{\Delta x^2}$ $\frac{w_{i+1} - 2w_i + w_{i-1}}{\Delta x^2}$ $\frac{w_{i+2} - 2w_{i+1} + w_i}{\Delta x^2}$

$\frac{d^2w}{dx^2}$

$\frac{w_{i+1} - 3w_i + 3w_{i-1} - w_{i-2}}{\Delta x^3}$ $\frac{w_{i+2} - 3w_{i+1} + 3w_i - w_{i-1}}{\Delta x^3}$

$\frac{d^3w}{dx^3}$





$$D\frac{d^4w}{dx^4}+\Delta\rho gw=p$$

$$D\frac{d^4w}{dx^4}+\Delta\rho gw=p$$

$$D\frac{w_{i+2}-4w_{i+1}+6w_i-4w_{i-1}+w_{i-2}}{\Delta x^4}\!+\!\Delta\rho gw_i=p_i$$

$$D\frac{d^4w}{dx^4}+\Delta\rho gw=p$$

$$D\frac{w_{i+2}-4w_{i+1}+6w_i-4w_{i-1}+w_{i-2}}{\Delta x^4}+\Delta\rho gw_i=p_i$$

$$D[w_{i+2}-4w_{i+1}+6w_i-4w_{i-1}+w_{i-2}]+\Delta x^4\Delta\rho gw_i=\Delta x^4p_i$$

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

$$D \frac{w_{i+2} - 4w_{i+1} + 6w_i - 4w_{i-1} + w_{i-2}}{\Delta x^4} + \Delta \rho g w_i = p_i$$

$$D[w_{i+2} - 4w_{i+1} + 6w_i - 4w_{i-1} + w_{i-2}] + \Delta x^4 \Delta \rho g w_i = \Delta x^4 p_i$$

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

$$D \frac{w_{i+2} - 4w_{i+1} + 6w_i - 4w_{i-1} + w_{i-2}}{\Delta x^4} + \Delta \rho g w_i = p_i$$

$$D[w_{i+2} - 4w_{i+1} + 6w_i - 4w_{i-1} + w_{i-2}] + \Delta x^4 \Delta \rho g w_i = \Delta x^4 p_i$$

$$Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g]w_i - 4Dw_{i+1} + Dw_{i+2} = \\ = \Delta x^4 p_i$$

$$D \frac{d^4 w}{dx^4} + \Delta \rho g w = p$$

$$D \frac{w_{i+2} - 4w_{i+1} + 6w_i - 4w_{i-1} + w_{i-2}}{\Delta x^4} + \Delta \rho g w_i = p_i$$

$$D[w_{i+2} - 4w_{i+1} + 6w_i - 4w_{i-1} + w_{i-2}] + \Delta x^4 \Delta \rho g w_i = \Delta x^4 p_i$$

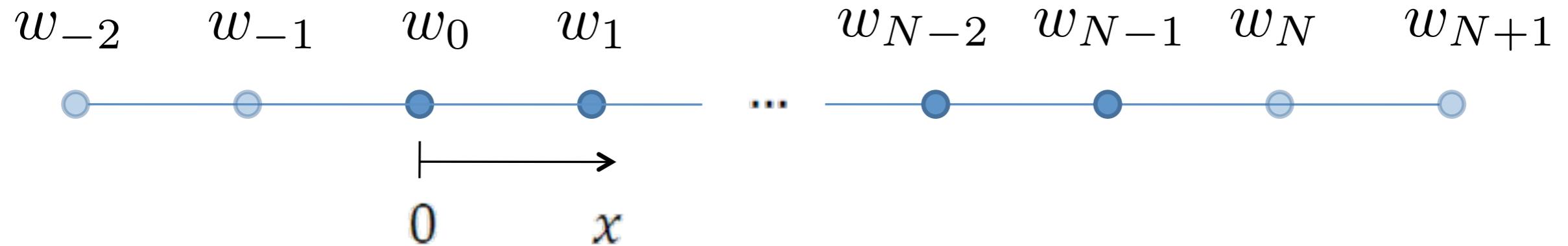
$$\boxed{Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g]w_i - 4Dw_{i+1} + Dw_{i+2} = \\ = \Delta x^4 p_i}$$

Condição de contorno

Placa contínua:

$$w \rightarrow 0 \text{ para } x \rightarrow 0$$

$$w \rightarrow 0 \text{ para } x \rightarrow x_n$$



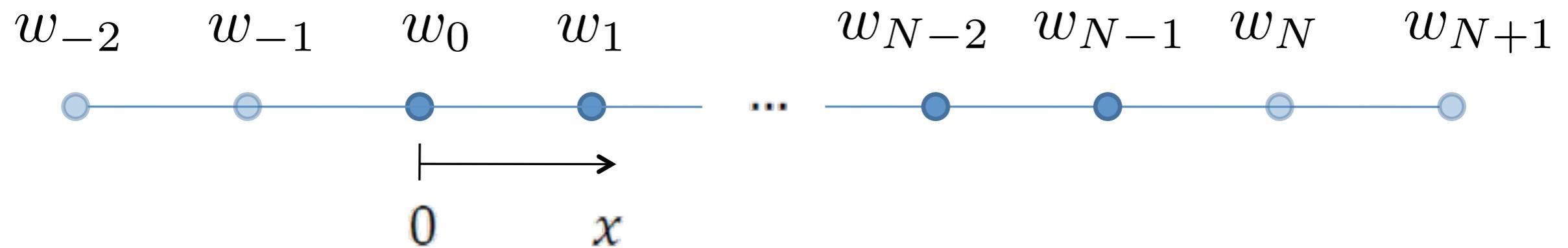
Condição de contorno

Placa contínua:

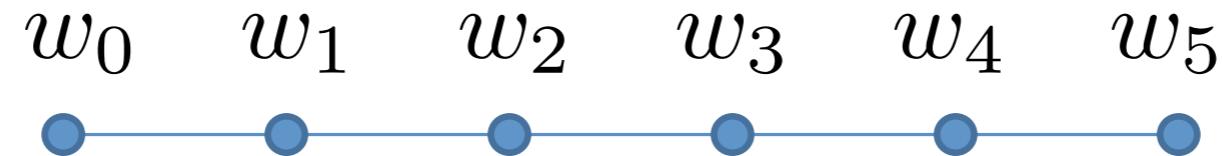
$$w \rightarrow 0 \text{ para } x \rightarrow 0$$

$$w \rightarrow 0 \text{ para } x \rightarrow x_n$$

$$w_{-2}, w_{-1}, w_N, w_{N-1} = 0$$

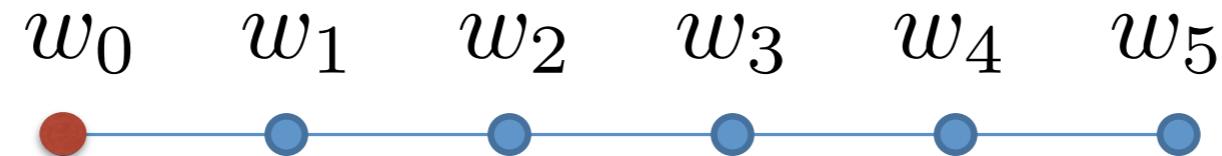


Exemplo



$$Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g]w_i - 4Dw_{i+1} + Dw_{i+2} = \\ = \Delta x^4 p_i$$

Exemplo

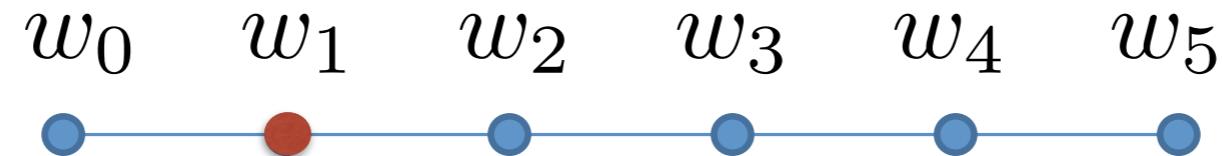


$w_0 :$

$$[6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0$$

$$\begin{aligned} D w_{i-2} - 4 D w_{i-1} + [6D + \Delta x^4 \Delta \rho g] w_i - 4 D w_{i+1} + D w_{i+2} = \\ = \Delta x^4 p_i \end{aligned}$$

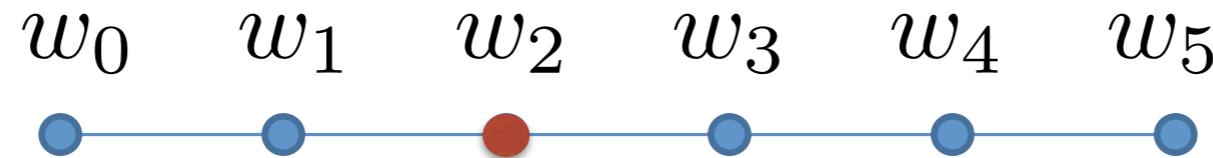
Exemplo



$$w_0 : [6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0$$
$$w_1 : -4Dw_0 + [6D + \Delta x^4 \Delta \rho g] w_1 - 4Dw_2 + Dw_3 = \Delta x^4 p_1$$

$$Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g]w_i - 4Dw_{i+1} + Dw_{i+2} = \\ = \Delta x^4 p_i$$

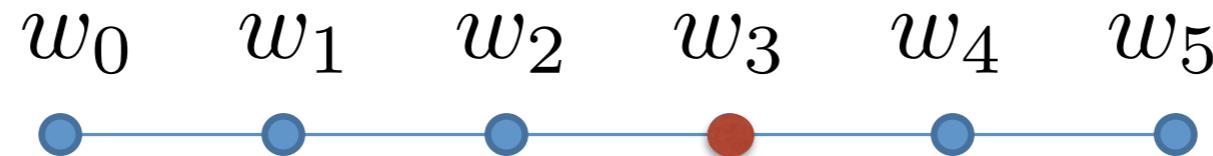
Exemplo



$$\begin{aligned}w_0 : \quad & [6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0 \\w_1 : \quad & -4Dw_0 + [6D + \Delta x^4 \Delta \rho g] w_1 - 4Dw_2 + Dw_3 = \Delta x^4 p_1 \\w_2 : \quad & Dw_0 - 4Dw_1 + [6D + \Delta x^4 \Delta \rho g] w_2 - 4Dw_3 + Dw_4 = \Delta x^4 p_2\end{aligned}$$

$$\begin{aligned}Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g] w_i - 4Dw_{i+1} + Dw_{i+2} = \\= \Delta x^4 p_i\end{aligned}$$

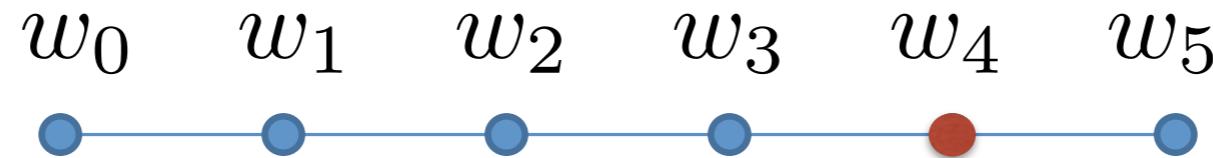
Exemplo



$$\begin{aligned}w_0 : \quad & [6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0 \\w_1 : \quad & -4Dw_0 + [6D + \Delta x^4 \Delta \rho g] w_1 - 4Dw_2 + Dw_3 = \Delta x^4 p_1 \\w_2 : \quad & Dw_0 - 4Dw_1 + [6D + \Delta x^4 \Delta \rho g] w_2 - 4Dw_3 + Dw_4 = \Delta x^4 p_2 \\w_3 : \quad & Dw_1 - 4Dw_2 + [6D + \Delta x^4 \Delta \rho g] w_3 - 4Dw_4 + Dw_5 = \Delta x^4 p_3\end{aligned}$$

$$\begin{aligned}Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g] w_i - 4Dw_{i+1} + Dw_{i+2} = \\= \Delta x^4 p_i\end{aligned}$$

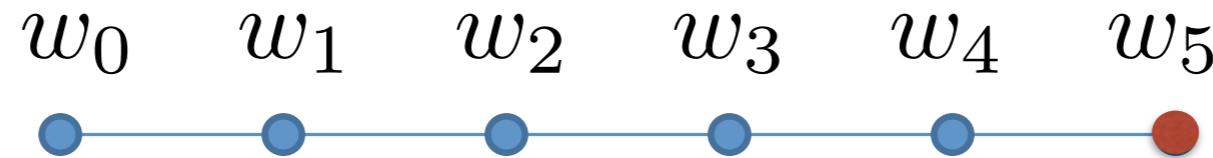
Exemplo



$$\begin{aligned}w_0 : \quad & [6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0 \\w_1 : \quad & -4Dw_0 + [6D + \Delta x^4 \Delta \rho g] w_1 - 4Dw_2 + Dw_3 = \Delta x^4 p_1 \\w_2 : \quad & Dw_0 - 4Dw_1 + [6D + \Delta x^4 \Delta \rho g] w_2 - 4Dw_3 + Dw_4 = \Delta x^4 p_2 \\w_3 : \quad & Dw_1 - 4Dw_2 + [6D + \Delta x^4 \Delta \rho g] w_3 - 4Dw_4 + Dw_5 = \Delta x^4 p_3 \\w_4 : \quad & Dw_2 - 4Dw_3 + [6D + \Delta x^4 \Delta \rho g] w_4 - 4Dw_5 = \Delta x^4 p_4\end{aligned}$$

$$\begin{aligned}Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g] w_i - 4Dw_{i+1} + Dw_{i+2} = \\= \Delta x^4 p_i\end{aligned}$$

Exemplo



$$\begin{aligned}w_0 : \quad & [6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0 \\w_1 : \quad & -4Dw_0 + [6D + \Delta x^4 \Delta \rho g] w_1 - 4Dw_2 + Dw_3 = \Delta x^4 p_1 \\w_2 : \quad & Dw_0 - 4Dw_1 + [6D + \Delta x^4 \Delta \rho g] w_2 - 4Dw_3 + Dw_4 = \Delta x^4 p_2 \\w_3 : \quad & Dw_1 - 4Dw_2 + [6D + \Delta x^4 \Delta \rho g] w_3 - 4Dw_4 + Dw_5 = \Delta x^4 p_3 \\w_4 : \quad & Dw_2 - 4Dw_3 + [6D + \Delta x^4 \Delta \rho g] w_4 - 4Dw_5 = \Delta x^4 p_4 \\w_5 : \quad & Dw_3 - 4Dw_4 + [6D + \Delta x^4 \Delta \rho g] w_5 = \Delta x^4 p_5\end{aligned}$$

$$\begin{aligned}Dw_{i-2} - 4Dw_{i-1} + [6D + \Delta x^4 \Delta \rho g] w_i - 4Dw_{i+1} + Dw_{i+2} = \\= \Delta x^4 p_i\end{aligned}$$

$$[6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0$$

$$-4Dw_0 + [6D + \Delta x^4 \Delta \rho g] w_1 - 4Dw_2 + Dw_3 = \Delta x^4 p_1$$

$$Dw_0 - 4Dw_1 + [6D + \Delta x^4 \Delta \rho g] w_2 - 4Dw_3 + Dw_4 = \Delta x^4 p_2$$

$$Dw_1 - 4Dw_2 + [6D + \Delta x^4 \Delta \rho g] w_3 - 4Dw_4 + Dw_5 = \Delta x^4 p_3$$

$$Dw_2 - 4Dw_3 + [6D + \Delta x^4 \Delta \rho g] w_4 - 4Dw_5 = \Delta x^4 p_4$$

$$Dw_3 - 4Dw_4 + [6D + \Delta x^4 \Delta \rho g] w_5 = \Delta x^4 p_5$$

$$\begin{aligned}
& [6D + \Delta x^4 \Delta \rho g] w_0 - 4Dw_1 + Dw_2 = \Delta x^4 p_0 \\
& -4Dw_0 + [6D + \Delta x^4 \Delta \rho g] w_1 - 4Dw_2 + Dw_3 = \Delta x^4 p_1 \\
& Dw_0 - 4Dw_1 + [6D + \Delta x^4 \Delta \rho g] w_2 - 4Dw_3 + Dw_4 = \Delta x^4 p_2 \\
& Dw_1 - 4Dw_2 + [6D + \Delta x^4 \Delta \rho g] w_3 - 4Dw_4 + Dw_5 = \Delta x^4 p_3 \\
& Dw_2 - 4Dw_3 + [6D + \Delta x^4 \Delta \rho g] w_4 - 4Dw_5 = \Delta x^4 p_4 \\
& Dw_3 - 4Dw_4 + [6D + \Delta x^4 \Delta \rho g] w_5 = \Delta x^4 p_5
\end{aligned}$$

$$\left[\begin{array}{cccccc}
6D + \Delta x^4 \Delta \rho g & -4D & D & 0 & 0 & 0 \\
-4D & 6D + \Delta x^4 \Delta \rho g & -4D & D & 0 & 0 \\
D & -4D & 6D + \Delta x^4 \Delta \rho g & -4D & D & 0 \\
0 & D & -4D & 6D + \Delta x^4 \Delta \rho g & -4D & D \\
0 & 0 & D & -4D & 6D + \Delta x^4 \Delta \rho g & -4D \\
0 & 0 & 0 & D & -4D & 6D + \Delta x^4 \Delta \rho g
\end{array} \right] \begin{bmatrix} w_0 \\ w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \end{bmatrix} =$$

$$= \Delta x^4 \begin{bmatrix} p_0 \\ p_1 \\ p_2 \\ p_3 \\ p_4 \\ p_5 \end{bmatrix}$$

$$\begin{bmatrix} 6D + \Delta x^4 \Delta \rho g & -4D & D & 0 & 0 & 0 \\ -4D & 6D + \Delta x^4 \Delta \rho g & -4D & D & 0 & 0 \\ D & -4D & 6D + \Delta x^4 \Delta \rho g & -4D & D & 0 \\ 0 & D & -4D & 6D + \Delta x^4 \Delta \rho g & -4D & D \\ 0 & 0 & D & -4D & 6D + \Delta x^4 \Delta \rho g & -4D \\ 0 & 0 & 0 & D & -4D & 6D + \Delta x^4 \Delta \rho g \end{bmatrix} \begin{bmatrix} w_0 \\ w_1 \\ w_2 \\ w_3 \\ w_4 \\ w_5 \end{bmatrix} = \Delta x^4 \begin{bmatrix} p_0 \\ p_1 \\ p_2 \\ p_3 \\ p_4 \\ p_5 \end{bmatrix}$$

$$\mathbf{Aw} = \mathbf{p}$$

$$A(i, j = i - 2) = D$$

$$A(i, j = i - 1) = -4D$$

$$A(i, j = i) = 6D + \Delta x^4 \Delta \rho g$$

$$A(i, j = i + 1) = -4D$$

$$A(i, j = i + 2) = D$$

Prática: Flex_numerico

