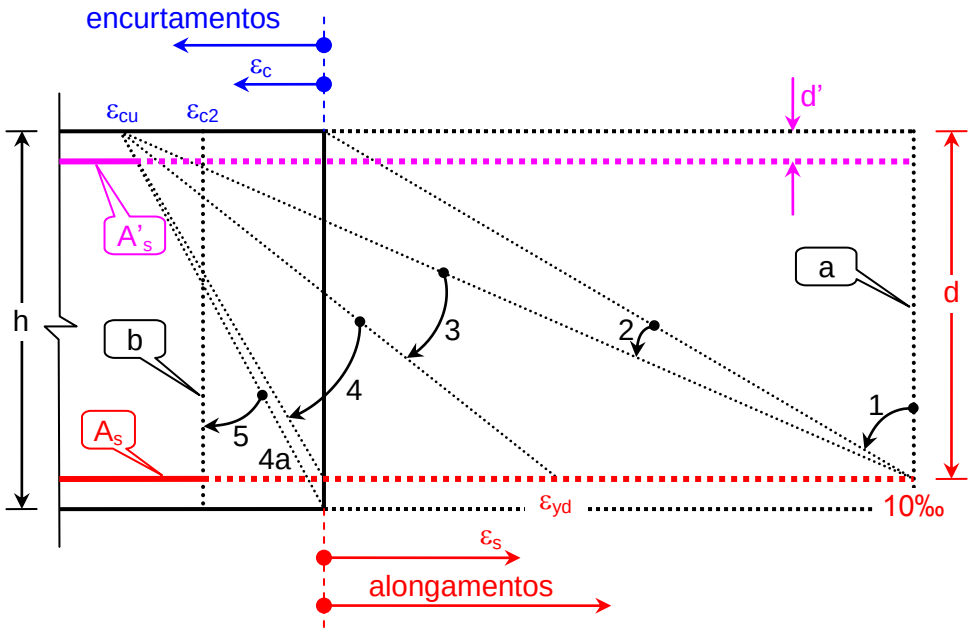
$F_d = \gamma_g F_{gk} + \gamma_{\varepsilon g} F_{\varepsilon gk} + \gamma_q (F_{q1k} + \sum \psi_{0j} F_{qjk}) + \gamma_{\varepsilon q} \psi_{0\varepsilon} F_{\varepsilon qk}$	(ELU - Normal)
$F_{d,fund} = F_{gk} + F_{\varepsilon gk} + (F_{q1k} + \sum \psi_{0j} F_{qjk}) + \psi_{0\varepsilon} F_{\varepsilon qk}$	(Fundações)
$S(F_{sd}) \geq S(F_{nd})$ $F_{sd} = \gamma_{gs} G_{sk} + R_d$ $F_{nd} = \gamma_{gn} G_{nk} + \gamma_q (Q_{1k} + \sum \psi_{0j} Q_{jk}) - \gamma_{qs} Q_{s,min}$	(ELU - Equilíbrio)



$\lambda = \begin{cases} 0{,}8 & \langle f_{ck} \leq 50\,MPa \rangle \\ 0{,}8 - \left(\frac{f_{ck} - 50}{400}\right) & \langle f_{ck} > 50\,MPa \rangle \end{cases}$			$\alpha_c = \begin{cases} 0{,}85 & \langle f_{ck} \leq 50\,MPa \rangle \\ 0{,}85\left(1 - \frac{f_{ck} - 50}{200}\right) & \langle f_{ck} > 50\,MPa \rangle \end{cases}$	
$F_d = \gamma_f F_k$	$f_{cd} = \frac{f_{ck}}{\gamma_c}$	$f_{yd} = \frac{f_{yk}}{\gamma_s}$	$\beta_s = \frac{\sigma_s}{f_{yd}}$	$\beta_s' = \frac{\sigma_s'}{f_{yd}}$
$\beta_x = \frac{x}{d} = \frac{\varepsilon_c}{\varepsilon_c + \varepsilon_s}$	$\beta_y = \frac{y}{d} = \lambda \beta_x$	$\beta_z = \frac{z}{d} = 1 - 0{,}5 \lambda \beta_x$	$\beta_c = \lambda \alpha_c \beta_x \beta_z = \lambda \alpha_c \beta_x (1 - 0{,}5 \lambda \beta_x)$	
$a_h \geq \max \begin{bmatrix} 2\,cm \\ \phi_\ell \\ 1{,}2\,d_{max} \end{bmatrix}$			$a_v \geq \max \begin{bmatrix} 2\,cm \\ \phi_\ell \\ 0{,}5\,d_{max} \end{bmatrix}$	

vigas de seção retangular **sem** armadura de compressão

$$M_{Rd} = \max\begin{bmatrix} M_{d,min} \\ \\ M_{Sd} \end{bmatrix} = \max\begin{bmatrix} 0{,}8\, W_0\, f_{ctk,sup} \\ \\ M_{Sd} \end{bmatrix}$$

$$W_0 = \frac{b_w\, h^2}{6}$$

$$f_{ctk,sup} = \begin{cases} 0{,}39 \times \sqrt[3]{f_{ck}^2} & \langle f_{ck} \le 50\,MPa \rangle \\ \\ 2{,}756 \ln\left(1 + 0{,}11 f_{ck}\right) & \langle f_{ck} > 50\,MPa \rangle \end{cases}$$

$$\beta_c = \frac{M_{Rd}}{b_w\, d^2\, f_{cd}} \quad \Rightarrow \quad tab \begin{cases} \beta_x \\ \beta_z \\ \beta_s \end{cases}$$

$$\beta_x \le \beta_{x,dtl} = \begin{cases} 0{,}450 & \langle f_{ck} \le 50\,MPa \rangle \\ \\ 0{,}350 & \langle f_{ck} > 50\,MPa \rangle \end{cases}$$

$$A_s = \frac{M_{Rd}}{\beta_z\, d\, \beta_s\, f_{yd}} \begin{cases} \ge A_{s,min} = 0{,}15\%\, A_c \\ \\ \le A_{s,max} = 4\%\, A_c \end{cases}$$

$$\beta_s = \left(\frac{\lambda\, \alpha_c\, b_w\, d\, f_{cd}}{A_s\, f_{yd}} \right) \beta_x$$

$$A_c = b_w\, h$$

Concreto ≤ C50										
Aço CA-50					γ_s = 1,15					
β_x	β_y	β_z	β_c	β_s	β_x	β_y	β_z	β_c	β_s
0,010	0,008	0,996	0,007	1,000	0,260	0,208	0,896	0,158	1,000
0,020	0,016	0,992	0,013	1,000	0,270	0,216	0,892	0,164	1,000
0,030	0,024	0,988	0,020	1,000	0,280	0,224	0,888	0,169	1,000
0,040	0,032	0,984	0,027	1,000	0,290	0,232	0,884	0,174	1,000
0,050	0,040	0,980	0,033	1,000	0,300	0,240	0,880	0,180	1,000
0,060	0,048	0,976	0,040	1,000	0,310	0,248	0,876	0,185	1,000
0,070	0,056	0,972	0,046	1,000	0,320	0,256	0,872	0,190	1,000
0,080	0,064	0,968	0,053	1,000	0,330	0,264	0,868	0,195	1,000
0,090	0,072	0,964	0,059	1,000	0,340	0,272	0,864	0,200	1,000
0,100	0,080	0,960	0,065	1,000	0,350	0,280	0,860	0,205	1,000
0,110	0,088	0,956	0,072	1,000	0,360	0,288	0,856	0,210	1,000
0,120	0,096	0,952	0,078	1,000	0,370	0,296	0,852	0,214	1,000
0,130	0,104	0,948	0,084	1,000	0,380	0,304	0,848	0,219	1,000
0,140	0,112	0,944	0,090	1,000	0,390	0,312	0,844	0,224	1,000
0,150	0,120	0,940	0,096	1,000	0,400	0,320	0,840	0,228	1,000
0,160	0,128	0,936	0,102	1,000	0,410	0,328	0,836	0,233	1,000
0,170	0,136	0,932	0,108	1,000	0,420	0,336	0,832	0,238	1,000
0,180	0,144	0,928	0,114	1,000	0,430	0,344	0,828	0,242	1,000
0,190	0,152	0,924	0,119	1,000	0,440	0,352	0,824	0,247	1,000
0,200	0,160	0,920	0,125	1,000	$\beta_{x,dtl}$	0,360	0,820	0,251	1,000
0,210	0,168	0,916	0,131	1,000	0,460	0,368	0,816	0,255	1,000
0,220	0,176	0,912	0,136	1,000	0,470	0,376	0,812	0,260	1,000
0,230	0,184	0,908	0,142	1,000	0,480	0,384	0,808	0,264	1,000
0,240	0,192	0,904	0,148	1,000	0,490	0,392	0,804	0,268	1,000
0,250	0,200	0,900	0,153	1,000	0,500	0,400	0,800	0,272	1,000

$\lambda = \begin{cases} 0{,}8 & \langle f_{ck} \le 50\,MPa \rangle \\ 0{,}8 - \left(\dfrac{f_{ck}-50}{400}\right) & \langle f_{ck} > 50\,MPa \rangle \end{cases}$			$\alpha_c = \begin{cases} 0{,}85 & \langle f_{ck} \le 50\,MPa \rangle \\ 0{,}85\left(1 - \dfrac{f_{ck}-50}{200}\right) & \langle f_{ck} > 50\,MPa \rangle \end{cases}$	
$F_d = \gamma_f F_k$	$f_{cd} = \dfrac{f_{ck}}{\gamma_c}$	$f_{yd} = \dfrac{f_{yk}}{\gamma_s}$	$\beta_s = \dfrac{\sigma_s}{f_{yd}}$	$\beta_s' = \dfrac{\sigma_s'}{f_{yd}}$
$\beta_x = \dfrac{x}{d} = \dfrac{\varepsilon_c}{\varepsilon_c + \varepsilon_s}$	$\beta_y = \dfrac{y}{d} = \lambda \beta_x$	$\beta_z = \dfrac{z}{d} = 1 - 0{,}5\lambda\beta_x$	$\beta_c = \lambda \alpha_c \beta_x \beta_z = \lambda \alpha_c \beta_x (1 - 0{,}5\lambda\beta_x)$	
$a_h \ge \max \begin{bmatrix} 2\,cm \\ \phi_\ell \\ 1{,}2\,d_{max} \end{bmatrix}$	$a_v \ge \max \begin{bmatrix} 2\,cm \\ \phi_\ell \\ 0{,}5\,d_{max} \end{bmatrix}$	$a = \begin{cases} 1{,}00\,\ell \\ 0{,}75\,\ell \\ 0{,}60\,\ell \\ 2{,}00\,\ell \end{cases}$	$b_1 \le \begin{cases} 0{,}1a \\ 0{,}5\,b_2 \end{cases}$ $\quad b_3 \le \begin{cases} 0{,}1a \\ b_4 \end{cases}$	

vigas de seção retangular **com** armadura de compressão

$$M_{Rd} = \max \begin{bmatrix} M_{d,min} \\ M_{Sd} \end{bmatrix} = \max \begin{bmatrix} 0{,}8\,W_0\,f_{ctk,sup} \\ M_{Sd} \end{bmatrix}$$

$$W_0 = \frac{b_w h^2}{6}$$

$$f_{ctk,sup} = \begin{cases} 0{,}39 \times \sqrt[3]{f_{ck}^2} & \langle f_{ck} \le 50\,MPa \rangle \\ 2{,}756 \ln(1 + 0{,}11 f_{ck}) & \langle f_{ck} > 50\,MPa \rangle \end{cases}$$

$$\beta_c = \frac{M_{Rd}}{b_w d^2 f_{cd}} \Rightarrow \text{tab} \begin{cases} \beta_x \\ \beta_z \\ \beta_s \end{cases}$$

$$\beta_x > \beta_{x,dtl} = \begin{cases} 0{,}450 & \langle f_{ck} \le 50\,MPa \rangle \\ 0{,}350 & \langle f_{ck} > 50\,MPa \rangle \end{cases}$$

$$\left.\begin{array}{l} \beta_x = \beta_{x,dtl} \\ \dfrac{d'}{d} \end{array}\right\} \Rightarrow \text{tab} \begin{cases} \beta_z \\ \beta_c \\ \beta_s \\ \beta_s' \end{cases}$$

$$M_{Rd1} = \beta_c\, b_w\, d^2\, f_{cd}$$

$$M_{Rd2} = M_{Rd} - M_{Rd1}$$

$$A_s = \left[\frac{M_{Rd1}}{\beta_z d} + \frac{M_{Rd2}}{(d - d')}\right] \frac{1}{\beta_s f_{yd}} \ge 0{,}15\%\, A_c$$

$$A_s' = \frac{M_{Rd2}}{(d - d')\,\beta_s'\, f_{yd}}$$

$$(A_s + A_s') \le 4\%\, A_c$$

$$\beta_s = \left(\frac{\lambda \alpha_c\, b_w\, d f_{cd}}{A_s f_{yd}}\right)\beta_x + \left(\frac{A_s'}{A_s}\right)\beta_s'$$

para vigas de seção retangular **sem** armadura de compressão, considerar:

$\beta_x \le \beta_{x,dtl}$	$M_{Rd1} = M_{Rd}$	$M_{Rd2} = d' = A_s' = \beta_s' = 0$

vigas de seção T sem armadura de compressão - $y \le h_f$

$$M_{Rd} = \max\begin{bmatrix} M_{d,min} \\ \\ M_{Sd} \end{bmatrix} = \max\begin{bmatrix} 0{,}8\, W_0\, f_{ctk,sup} \\ \\ M_{Sd} \end{bmatrix}$$

$$M_{Rd,mesa} = \alpha_c \left(b_f\, h_f\right)\left(d - \frac{h_f}{2}\right) f_{cd}$$

$M_{Rd} \le M_{Rd,mesa}$

$$\beta_c = \frac{M_{Rd}}{b_f\, d^2\, f_{cd}} \quad \Rightarrow \quad \text{tab}\begin{cases} \beta_x \\ \beta_y \\ \beta_z \\ \beta_s \end{cases}$$

$$\beta_x \le \beta_{x,dtl} = \begin{cases} 0{,}450 & \langle f_{ck} \le 50\,MPa \rangle \\ \\ 0{,}350 & \langle f_{ck} > 50\,MPa \rangle \end{cases}$$

$$y = \beta_y\, d \le h_f$$

$$A_s = \frac{M_{Rd}}{\beta_z\, d\, \beta_s\, f_{yd}} \begin{cases} \ge A_{s,min} = 0{,}15\%\, A_c \\ \\ \le A_{s,max} = 4\%\, b_w\, h \end{cases}$$

$$\beta_s = \left(\frac{\lambda\, \alpha_c\, b_f\, d\, f_{cd}}{A_s\, f_{yd}}\right)\beta_x$$

vigas de seção T sem armadura de compressão - $y > h_f$

$$M_{Rd} = \max\begin{bmatrix} M_{d,min} \\ \\ M_{Sd} \end{bmatrix} = \max\begin{bmatrix} 0{,}8\, W_0\, f_{ctk,sup} \\ \\ M_{Sd} \end{bmatrix}$$

$$M_{Rd,mesa} = \alpha_c \left(b_f\, h_f\right)\left(d - \frac{h_f}{2}\right) f_{cd}$$

$M_{Rd} > M_{Rd,mesa}$

$$M_{Rd3} = \alpha_c \left[\left(b_f - b_w\right) h_f \left(d - \frac{h_f}{2}\right)\right] f_{cd}$$

$$M_{Rd1} = M_{Rd} - M_{Rd3}$$

$$\beta_c = \frac{M_{Rd1}}{b_w\, d^2\, f_{cd}} \quad \Rightarrow \quad \text{tab}\begin{cases} \beta_x \\ \beta_y \\ \beta_z \\ \beta_s \end{cases}$$

$$\beta_x \le \beta_{x,dtl} = \begin{cases} 0{,}450 & \langle f_{ck} \le 50\,MPa \rangle \\ \\ 0{,}350 & \langle f_{ck} > 50\,MPa \rangle \end{cases}$$

$$y = \beta_y\, d > h_f$$

$$A_s = \left[\frac{M_{Rd1}}{\beta_z\, d} + \frac{M_{Rd3}}{\left(d - \frac{h_f}{2}\right)}\right]\frac{1}{\beta_s\, f_{yd}} \begin{cases} \ge A_{s,min} = 0{,}15\%\, A_c \\ \\ \le A_{s,max} = 4\%\, b_w\, h \end{cases}$$

$$\beta_s = \left(\frac{\lambda\, \alpha_c\, b_w\, d\, f_{cd}}{A_s\, f_{yd}}\right)\beta_x + \left\{\frac{\alpha_c \left[\left(b_f - b_w\right) h_f\right] f_{cd}}{A_s\, f_{yd}}\right\}$$

seção T - W_0	$A_c = b_w\, h + \left(b_f - b_w\right) h_f$	$W_0 = W_{0,w} = \frac{I}{y_w}$

$$y_w = \frac{\left(b_f\, h^2\right) - \left[\left(b_f - b_w\right)\left(h - h_f\right)^2\right]}{2\left\{\left[\left(b_f\, h\right) - \left[\left(b_f - b_w\right)\left(h - h_f\right)\right]\right\}}$$

$$I = \left\{\frac{b_f\, h^3 - \left[\left(b_f - b_w\right)\left(h - h_f\right)^3\right]}{3}\right\} - A_c\, y_w^2$$

$$F_d = \gamma_f F_k$$

vigas com estribos verticais - modelo I

$$V_{Sd} \le \begin{cases} V_{Rd2} \\ V_{Rd3} \end{cases}$$

$$V_{Rd2} = 0{,}27\,\alpha_{v2}\, f_{cd}\, b_w\, d$$

$$\alpha_{v2} = 1 - \frac{f_{ck}}{250} \quad \langle f_{ck} \text{ em MPa} \rangle$$

$$V_{Rd3} = V_c + V_{sw}$$

$$V_c = 0{,}6\, f_{ctd}\, b_w d$$

$$f_{ctd} = \begin{cases} \dfrac{0{,}21 \times \sqrt[3]{f_{ck}^2}}{\gamma_c} & \langle f_{ck} \le 50\,\text{MPa} \rangle \\ \dfrac{1{,}484 \times \ln(1 + 0{,}11 f_{ck})}{\gamma_c} & \langle f_{ck} > 50\,\text{MPa} \rangle \end{cases}$$

$$V_{sw} = \left(\frac{A_{sw}}{s}\right) 0{,}9\, d\, f_{ywd}$$

$$f_{ywd} = \frac{f_{yk}}{\gamma_s} \le 435\,\text{MPa}$$

$$\rho_{sw} = \frac{A_{sw}}{b_w\, s} \ge 0{,}2\,\frac{f_{ct,m}}{f_{ywk}}$$

$$f_{ct,m} = \begin{cases} 0{,}3 \times \sqrt[3]{f_{ck}^2} & \langle f_{ck} \le 50\,\text{MPa} \rangle \\ 2{,}12 \times \ln(1 + 0{,}11 f_{ck}) & \langle f_{ck} > 50\,\text{MPa} \rangle \end{cases}$$

$$f_{ywk} = f_{yk} \le 500\,\text{MPa}$$

vigas com estribos verticais - modelo II

$$V_{Sd} \le \begin{cases} V_{Rd2} \\ V_{Rd3} \end{cases}$$

$$V_{Rd2} = 0{,}54\,\alpha_{v2}\, f_{cd}\, b_w\, d \operatorname{sen}\theta \cos\theta$$

$$\alpha_{v2} = 1 - \frac{f_{ck}}{250} \quad \langle f_{ck} \text{ em MPa} \rangle$$

$$30° \le \theta \le 45°$$

$$V_{Rd3} = V_c + V_{sw}$$

$$V_c = V_{c0}\left(\frac{V_{Rd2} - V_{Sd}}{V_{Rd2} - V_{c0}}\right) \le V_{c0}$$

$$V_{c0} = 0{,}6\, f_{ctd}\, b_w d$$

$$f_{ctd} = \begin{cases} \dfrac{0{,}21 \times \sqrt[3]{f_{ck}^2}}{\gamma_c} & \langle f_{ck} \le 50\,\text{MPa} \rangle \\ \dfrac{1{,}484 \times \ln(1 + 0{,}11 f_{ck})}{\gamma_c} & \langle f_{ck} > 50\,\text{MPa} \rangle \end{cases}$$

$$V_{sw} = \left(\frac{A_{sw}}{s}\right) 0{,}9\, d\, f_{ywd} \cot\theta$$

$$f_{ywd} = \frac{f_{yk}}{\gamma_s} \le 435\,\text{MPa}$$

$$\rho_{sw} = \frac{A_{sw}}{b_w\, s} \ge 0{,}2\,\frac{f_{ct,m}}{f_{ywk}}$$

$$f_{ct,m} = \begin{cases} 0{,}3 \times \sqrt[3]{f_{ck}^2} & \langle f_{ck} \le 50\,\text{MPa} \rangle \\ 2{,}12 \times \ln(1 + 0{,}11 f_{ck}) & \langle f_{ck} > 50\,\text{MPa} \rangle \end{cases}$$

$$f_{ywk} = f_{yk} \le 500\,\text{MPa}$$

$5\,\text{mm} \le \phi_t \le \dfrac{b_w}{10}$	$\dfrac{V_{Sd}}{V_{Rd2}} \le 0{,}67 \Rightarrow 7\,\text{cm} \le s \le \min\begin{bmatrix} 0{,}6\,d \\ 30\,\text{cm} \end{bmatrix}$	$\dfrac{V_{Sd}}{V_{Rd2}} > 0{,}67 \Rightarrow 7\,\text{cm} \le s \le \min\begin{bmatrix} 0{,}3\,d \\ 20\,\text{cm} \end{bmatrix}$

deslocamento de diagrama

vigas com estribos verticais - modelo I

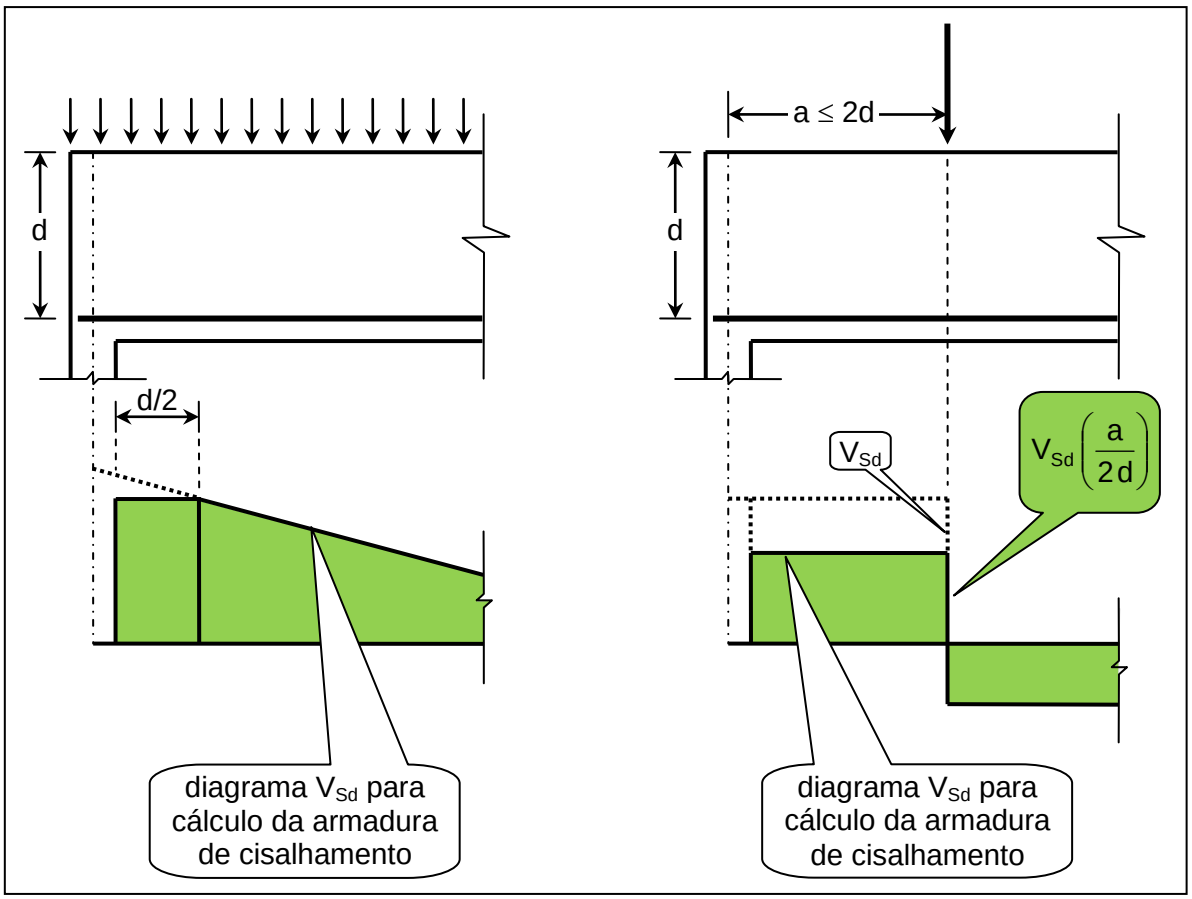
$$a_\ell = \frac{d}{2}\left(\frac{V_{Sd,max}}{(V_{Sd,max} - V_c)}\right) \begin{cases} \ge 0{,}5\,d \\ \le d \end{cases}$$

$$a_\ell = d \quad \langle |V_{Sd,max}| \le |V_c| \rangle$$

vigas com estribos verticais - modelo II

$$a_\ell = 0{,}5\, d \cot g\theta$$

$$30° \le \theta \le 45°$$



θ	sen	cos	cot
30º	0,500	0,866	1,732
35º	0,574	0,819	1,428
40º	0,643	0,766	1,192
45º	0,707	0,707	1,000