MEMÓRIA DE CÁLCULO

PERDAS IMEDIATAS – ALONGAMENTO TEÓRICO

Bloco C

LOCAL	**Nova Sede do Tribunal Regional Federal da 1ª Região – TRF1**
ENDEREÇO	**Lote 3, Quadra 5, Setor de Administração Federal Sul, Brasília/DF**
FASE DO PROJETO	**Etapa 6**

AGOSTO DE 2017

REVISÕES					
REV.	**DATA**	**DESCRIÇÃO**	**ELAB.**	**CONF.**	**APROV.**
00	31/05/2017	Emissão Inicial	André Abreu	Guilherme Machado	Luís Oliveira

SUMÁRIO

1. INTRODUÇÃO

Este documento tem por objetivo fornecer informações sobre os parâmetros e critérios adotados para o cálculo do alongamento teórico dos cabos de protensão.

2. DESCRIÇÃO

Os cabos foram divididos em seções, e a cada duas seções foi medida a variação angular em elevação e em planta, da esquerda para a direita; no caso de cabos do tipo ativo-passivo e no caso de cabos do tipo ativo-ativo, também foram medidas as variações angulares da direita para a esquerda.

Estas variações angulares foram utilizadas para determinar as tensões devido as perdas por atrito em cada seção. A partir destes valores foi então construído o gráfico mostrando a variação da tensão ao longo dos cabos de protensão para as seguintes curvas:

- $\sigma(x)$ = Curva de perda de tensão no caso de cabo ativo-passivo.
- $\sigma_{esq}(x)$ = Curva de perda de tensão partindo da esquerda no caso de cabo do tipo ativo-ativo.
- $\sigma_{dir}(x)$ = Curva de perda de tensão partindo da direita no caso de cabo do tipo ativo-ativo.

Para os cabos do tipo ativo-passivo, foi calculada a área sob a curva $\sigma(x)$ do gráfico de variação da força ao longo do cabo de protensão e esta área foi dividida pelo comprimento do elemento estrutural, para que se pudesse determinar a tensão média.

Para os cabos do tipo ativo-passivo, foi calculada a área sob a curva $\sigma_{esq}(x)$, da seção inicial do gráfico até a interseção com a curva $\sigma_{dir}(x)$ e logo após, foi calculada a área sob a curva $\sigma_{dir}(x)$ da interseção com a curva $\sigma_{esq}(x)$ até a seção final do diagrama; estas áreas foram somadas e divididas pelo comprimento do elemento estrutural para que se pudesse determinar a tensão média.

Para determinação da força média, foi utilizada a tensão média multiplicada pela área teórica nominal da cordoalha.

3. PARÂMETROS DE PROJETO

Características das cordoalhas

Tabela 1 - Características das cordoalhas de sete fios com relaxação baixa - RB

Categoria	Designação[1]	Diâmetro nominal da cordoalha mm	Tolerância no diâmetro nominal mm	Área da seção de aço da cordoalha nominal mm²			Massa nominal kg/1 000 m	Carga de ruptura mínima kN	Carga a 1% de deformação mínima[2] kN	Alongamento total na ruptura mínimo[3] %	Relaxação máxima após 1 000 h[4] %
				Mínimo	Nominal	Máximo					
RB 190	CP 190 RB 9,5	9,5	+ 0,4 - 0,2	54,9	56,2	57,3	441,0	104,3	93,9	3,5	3,5
	CP 190 RB 12,7	12,7		98,6	100,9	102,9	792,0	187,3	168,6		
	CP 190 RB 15,2	15,2		139,9	143,4	146,3	1126,0	265,8	239,2		
RB 210	CP 210 RB 9,5	9,5		54,9	56,2	57,3	441,0	115,3	103,8		
	CP 210 RB 12,7	12,7		98,6	100,9	102,9	792,0	207,0	186,3		
	CP 210 RB 15,2	15,2		139,9	143,4	146,3	1126,0	293,8	264,4		

[1] Os três dígitos constantes na designação correspondem ao limite mínimo da resistência à tração na unidade kgf/mm². Para os efeitos desta Norma, considera-se 1kgf/mm² = 10MPa

[2] O valor da carga a 1% de alongamento é considerado equivalente à carga, a 0,2% de alongamento permanente.

[3] Base de medida: 600 mm mínimo.

[4] Medida a 20°C com aplicação de carga inicial correspondente a 80% da carga de ruptura conforme NBR 7484. Os resultados de relaxação após 1 000 h podem ser obtidos por extrapolação de ensaios de 100 h de duração.

NOTA Recomenda-se para cálculo estrutural a utilização do valor nominal da área.

Coeficientes para cálculo das perdas de protensão por atrito

μ = 0,50 entre cabo e concreto (sem bainha);

μ = 0,30 entre barras ou fios com mossas ou saliências e bainha metálica;

μ = 0,20 entre fios lisos ou cordoalhas e bainha metálica;

μ = 0,10 entre fios lisos ou cordoalhas e bainha metálica lubrificada;

μ = 0,05 entre cordoalha e bainha de polipropileno lubrificada;

k é o coeficiente de perda por metro provocada por curvaturas não intencionais do cabo. Na falta de dados experimentais, pode ser adotado o valor 0,01 μ (1/m).

4. DOCUMENTOS DE REFERÊNCIA

- 85EA16-EACE-PE-CXX-P02-PT-EST-008-R02
- 85EA16-EACE-PE-CXX-P02-PT-EST-009-R02
- 85EA16-EACE-PE-CXX-P02-PT-EST-010-R02
- 85EA16-EACE-PE-CXX-P02-PT-EST-011-R02
- 85EA16-EACE-PE-CXX-P02-PT-EST-012-R02
- 85EA16-EACE-PE-CXX-P02-PT-EST-013-R02
- 85EA16-EACE-PE-CXX-P02-PT-EST-014-R02
- DES - FORMA C

5. REFERÊNCIAS BIBLIOGRÁFICAS

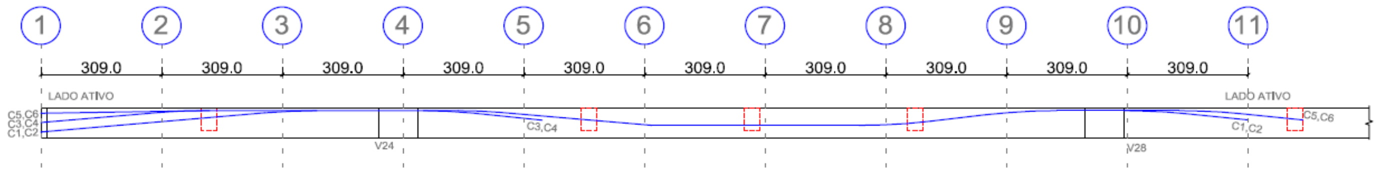
- NBR 7483:2004
- NBR 6118:2004

6. ANEXOS

BLOCO C

Devido a similaridade desse bloco, esta memória atende ao 2° pavimento e cobertura.

V2 - CABOS C1 a C28



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 30.90\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 309 \\ 618 \\ 927 \\ 1236 \\ 1545 \\ 1854 \\ 2163 \\ 2472 \\ 2781 \\ 3090 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 1.57 \\ 3.52 \\ 5.11 \\ 0 \\ 5.11 \\ 2.66 \\ 2.24 \\ 5.2 \\ 5.7 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 19.88 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13771.18 \\ 13569.82 \\ 13299.66 \\ 12968.88 \\ 12804.67 \\ 12486.2 \\ 12268.97 \\ 12069.55 \\ 11765.89 \\ 10879 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 5.7 \\ 5.2 \\ 2.24 \\ 2.66 \\ 5.11 \\ 0 \\ 5.11 \\ 3.52 \\ 1.57 \\ 0 \end{pmatrix} °
\qquad
\Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

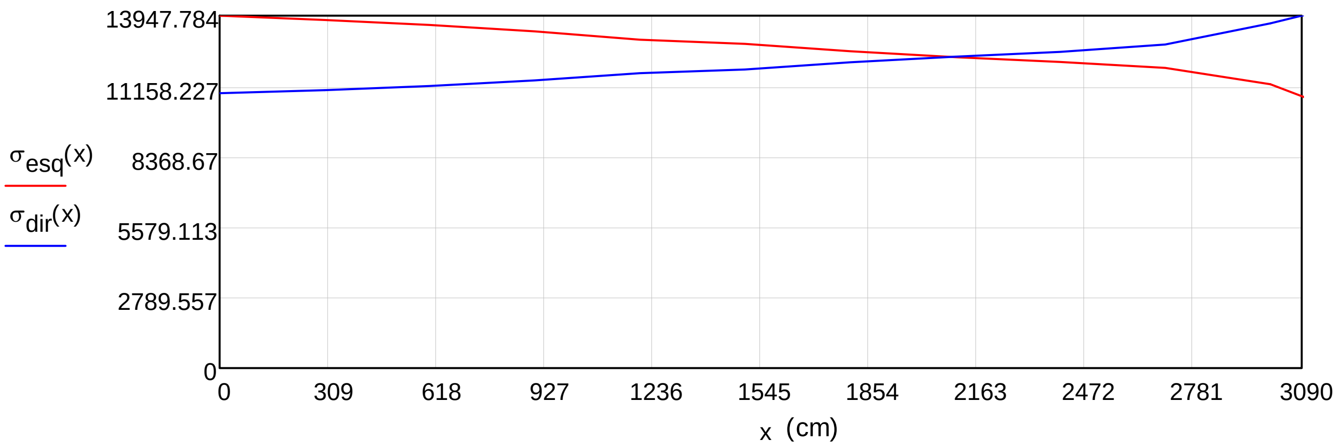
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12896.43 \\ 12571.96 \\ 12367.61 \\ 12152.45 \\ 11850.2 \\ 11700.16 \\ 11409.15 \\ 11182.01 \\ 11018.51 \\ 10879 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$$

$\text{interseção} = 2083.4 \cdot cm$

$$\sigma_{\text{interseção}} = 12316.62 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx \qquad Área_1 = 274525.17 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx \qquad Área_2 = 129139.47 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 403664.65 \cdot \frac{kg \cdot m}{cm^2}$$

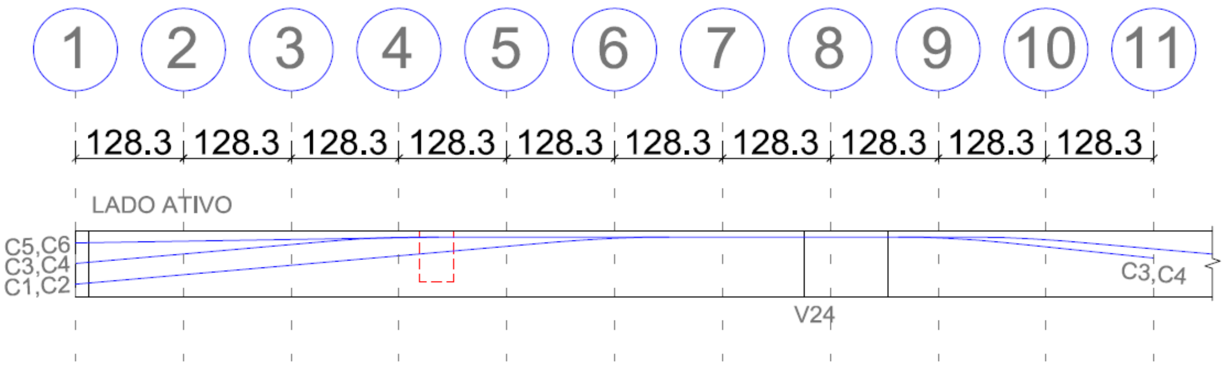
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13063.58 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 31.80m$ $\qquad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 213 \cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$Área_{teórica\_aço} = 143.4mm^2$ $\qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\, MPa$ $\qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\, MPa$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\, MPa$$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2}$ $\qquad \mu = 0.20$ $\qquad \beta = 0.01 \frac{rad}{m}$ $\qquad e = 2.72$ $\qquad L = 12.83m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m}$ $\qquad n = 11$ $\qquad i = 1, 2 .. n$

$$S := 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 128.3 \\ 256.6 \\ 384.9 \\ 513.2 \\ 641.5 \\ 769.8 \\ 898.1 \\ 1026.4 \\ 1154.7 \\ 1283 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 3.76 \\ 1.34 \\ 0 \\ 0 \\ 0 \\ 2.29 \\ 3.71 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \end{pmatrix}°$$

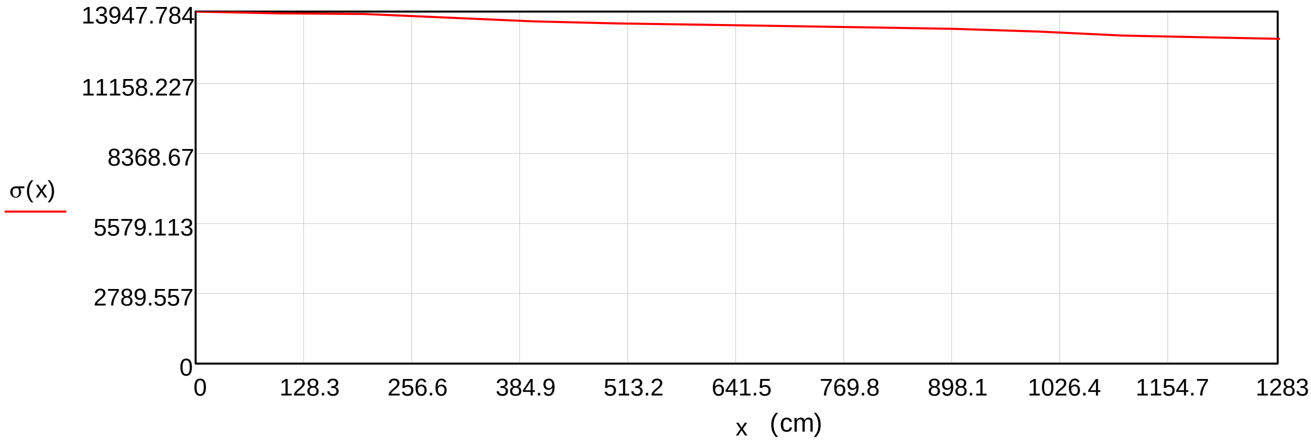
$$\alpha_i := \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} := \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13874.21 \\ 13801.03 \\ 13582.37 \\ 13474.44 \\ 13403.37 \\ 13332.67 \\ 13262.34 \\ 13117.12 \\ 12911.5 \\ 12843.4 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a := cspline\left(S, \sigma_{esq}\right)$$

$$\sigma(x) := interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma(x)\,dx \qquad Área = 172094.02 \cdot \frac{kg \cdot m}{cm^2}$$

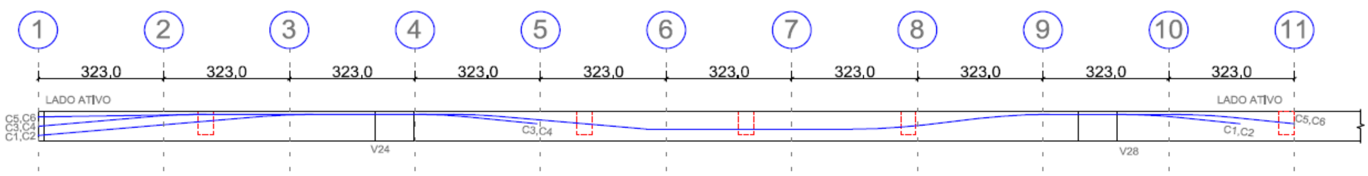
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13413.41 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 13.65m$ $\qquad$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.2 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 94 \cdot mm$$

CABOS C5=C6 (4ø15.2mm)



$Área_{teórica\_aço} = 143.4mm^2$ $\qquad$ $fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\qquad$ $fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2}$ $\qquad$ $\mu = 0.20$ $\qquad$ $\beta = 0.01 \frac{rad}{m}$ $\qquad$ $e = 2.72$ $\qquad$ $L = 32.30m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m}$ $\qquad$ $n = 11$ $\qquad$ $i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 323 \\ 646 \\ 969 \\ 1292 \\ 1615 \\ 1938 \\ 2261 \\ 2584 \\ 2907 \\ 3230 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0.93 \\ 0 \\ 5.11 \\ 5.11 \\ 0 \\ 6.43 \\ 5.82 \\ 0.61 \\ 6 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 19.97 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha + \kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13763 \\ 13570.79 \\ 13391 \\ 13052.85 \\ 12723.23 \\ 12554.67 \\ 12184.42 \\ 11849.08 \\ 11688.34 \\ 10797.82 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 6 \\ 0.61 \\ 5.82 \\ 6.43 \\ 0 \\ 5.11 \\ 5.11 \\ 0 \\ 0.93 \\ 0 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \end{pmatrix}°$$

$n = 11$

$$\theta_i = \begin{cases} 0\,rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

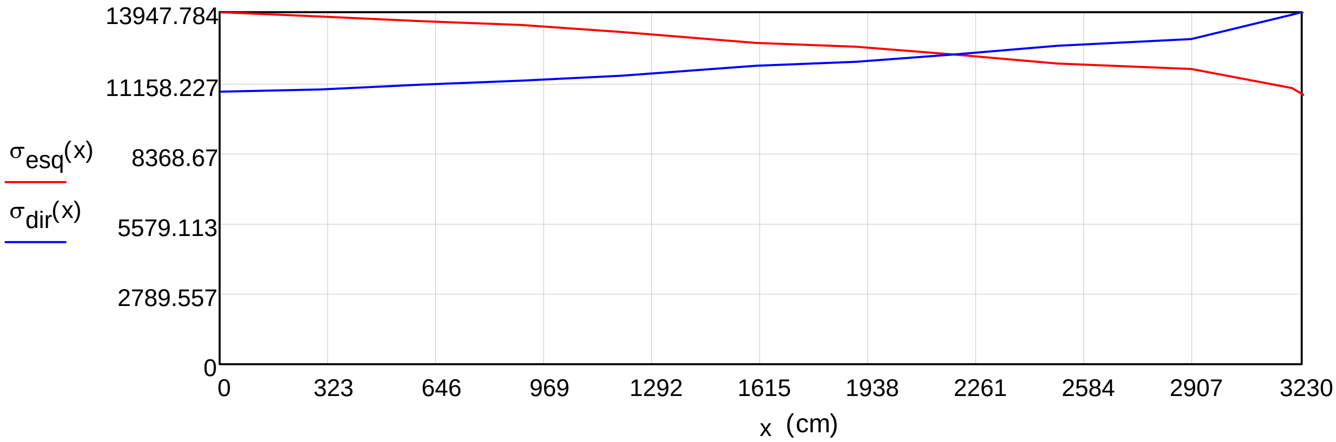
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12885.13 \\ 12710.33 \\ 12360.52 \\ 11995.99 \\ 11837.07 \\ 11538.15 \\ 11246.78 \\ 11097.78 \\ 10942.79 \\ 10797.82 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = cspline\left(S, \sigma_{esq}\right)$

$b = cspline\left(S, \sigma_{dir}\right)$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = interp\left(\frac{b}{g}, S, \frac{reverse\left(\sigma_{dir}\right)}{g}, x\right)$$



$c = \frac{L}{2}$ $\quad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$$ $\quad interseção = 2193.77 \cdot cm$

$$\sigma_{interseção} = 12272.58 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx \qquad Área_1 = 289404.76 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx \qquad Área_2 = 133415.01 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 422819.77 \cdot \frac{kg \cdot m}{cm^2}$$

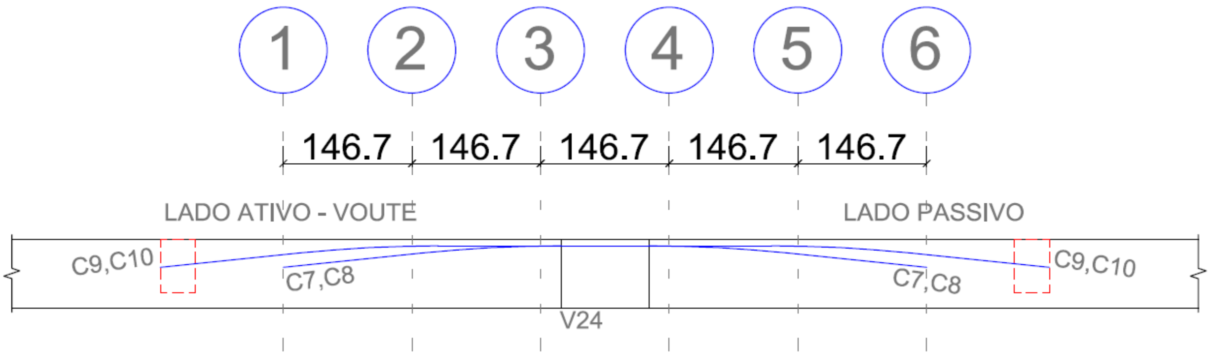
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13090.4 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 33.95m$ $\quad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\quad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 228 \cdot mm$$

CABOS C7=C8=C25=C26 (6ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2$ $\quad \text{fptk} = \dfrac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 7.34\,\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 6$ $\quad i = 1, 2 .. n$

$$S = 0\,\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 146.8 \\ 293.6 \\ 440.4 \\ 587.2 \\ 734 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 5.11 \\ 1.78 \\ 5.11 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 18.89 \\ 0.89 \\ 0.89 \\ 0.89 \\ 0.89 \end{pmatrix}°$$

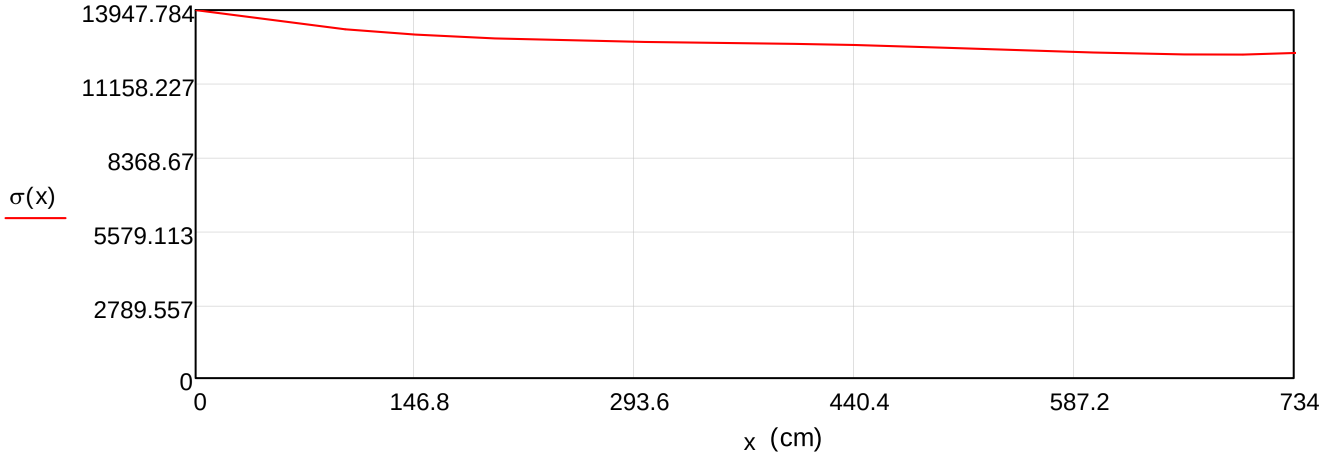
$$\alpha_i = \begin{vmatrix} 0\,\text{rad} \quad \text{if } \; i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if } \; i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13019.47 \\ 12748.38 \\ 12623.01 \\ 12360.18 \\ 12285.71 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 93560.75 \cdot \frac{kg \cdot m}{cm^2}$$

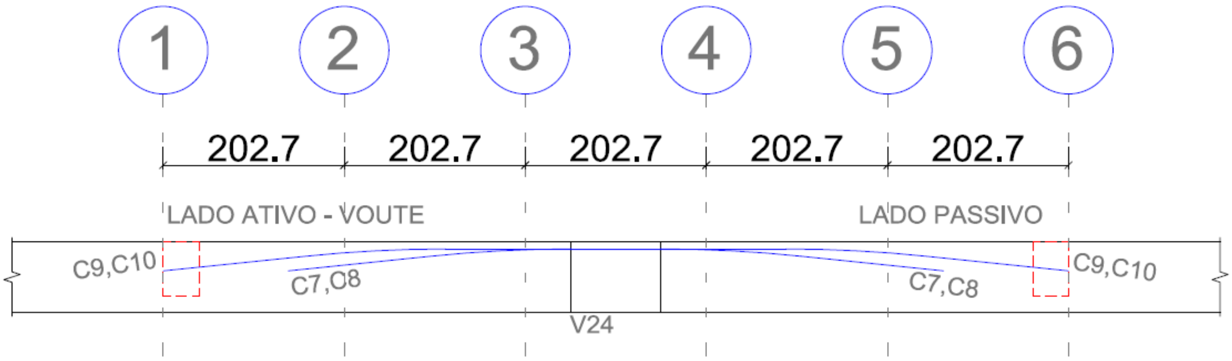
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12746.7 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 8.15m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 53 \cdot mm$$

CABOS C9=C10=C27=C28 (6ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 10.14\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 6 \qquad i = 1, 2 .. n$$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 202.8 \\ 405.6 \\ 608.4 \\ 811.2 \\ 1014 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 1.63 \\ 4.37 \\ 0 \\ 4.37 \\ 1.63 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.24 \\ 1.24 \\ 1.24 \\ 1.24 \\ 1.24 \end{pmatrix}°$$

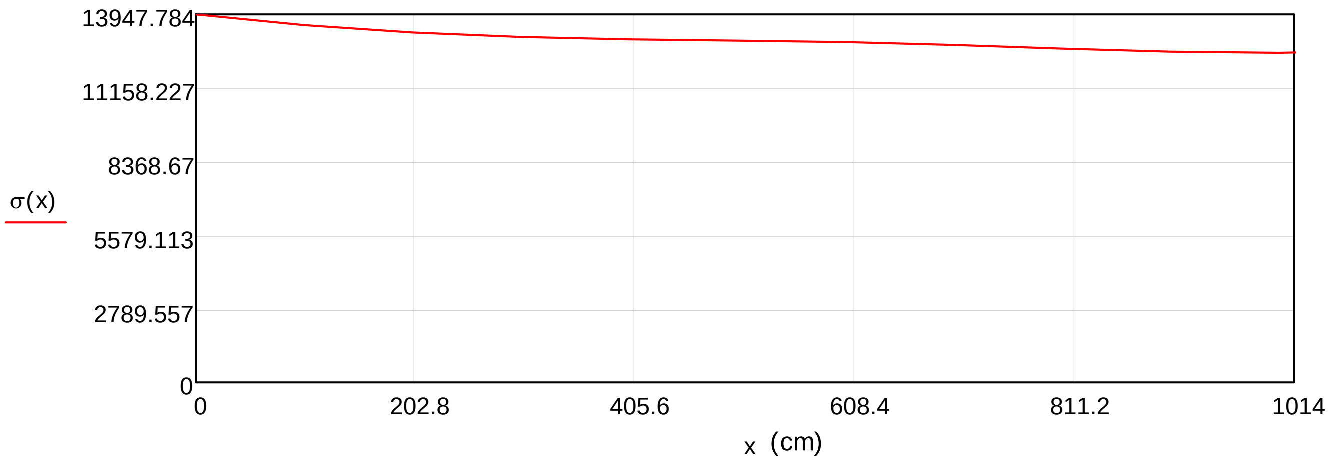
$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13259.3 \\ 12997.89 \\ 12889.37 \\ 12635.25 \\ 12494.46 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 131651.65 \cdot \frac{kg \cdot m}{cm^2}$$

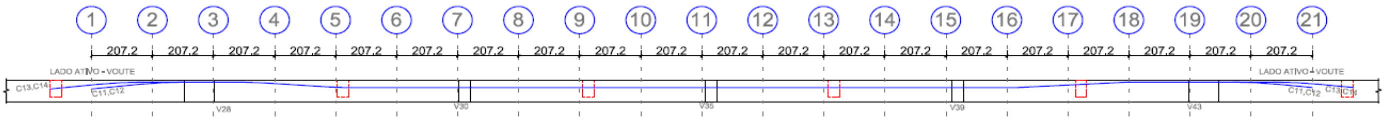
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12983.4 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 10.95m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.6 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m)\cdot(L_{cabo})}{E_{teórico\_aço}} = 73 \cdot mm$$

CABOS C11=C12 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 41.45\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 21$ $\quad$ $i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 207.25 \\ 414.5 \\ 621.75 \\ 829 \\ 1036.25 \\ 1243.5 \\ 1450.75 \\ 1658 \\ 1865.25 \\ 2072.5 \\ 2279.75 \\ 2487 \\ 2694.25 \\ 2901.5 \\ 3108.75 \\ 3316 \\ 3523.25 \\ 3730.5 \\ 3937.75 \\ 4145 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 1.79 \\ 4.21 \\ 3.87 \\ 1.26 \\ 2.61 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.1 \\ 3.1 \\ 0 \\ 2.39 \\ 3.61 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 17.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 17.26 \end{pmatrix}^{\circ}$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13073.71 \\ 12821.44 \\ 12588.29 \\ 12458.49 \\ 12282.07 \\ 12177.59 \\ 12074 \\ 11971.28 \\ 11869.45 \\ 11768.47 \\ 11668.36 \\ 11569.1 \\ 11470.68 \\ 11373.11 \\ 11276.36 \\ 11099.3 \\ 10925.03 \\ 10832.09 \\ 10686.03 \\ 10006.55 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$n = 21$ $\quad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 3.61 \\ 2.39 \\ 0 \\ 3.1 \\ 3.1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 2.61 \\ 1.26 \\ 3.87 \\ 4.21 \\ 1.79 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 17.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 1.26 \\ 17.26 \end{pmatrix}°$$

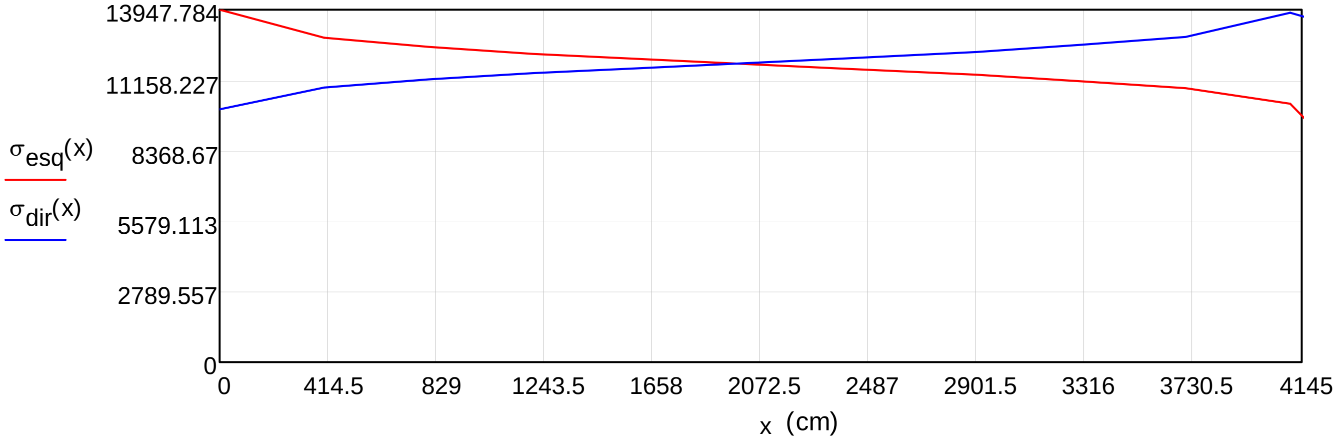
$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13060.9 \\ 12884.78 \\ 12775.18 \\ 12574.59 \\ 12377.15 \\ 12271.86 \\ 12167.47 \\ 12063.96 \\ 11961.34 \\ 11859.58 \\ 11758.7 \\ 11658.67 \\ 11559.49 \\ 11461.15 \\ 11363.66 \\ 11202.74 \\ 11087.22 \\ 10885.61 \\ 10675.56 \\ 10006.55 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq}) \qquad b = cspline(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = interp\left(\frac{b}{g}, S, \frac{reverse(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad$ $d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$$

$\text{interseção} = 1978.96 \cdot cm$

$$\sigma_{\text{interseção}} = 11813.9 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\, dx \qquad Área_1 = 246088.97 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\, dx \qquad Área_2 = 270393.11 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 516482.08 \cdot \frac{kg \cdot m}{cm^2}$$

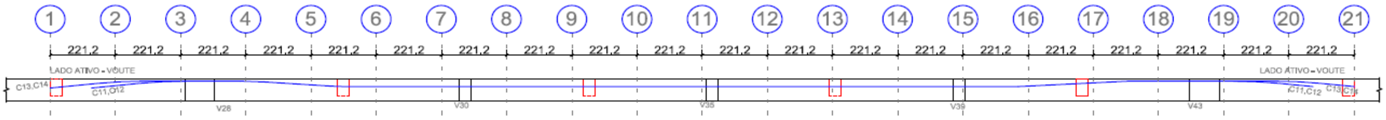
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12460.36 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 43.05m$ $\qquad$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 17.9 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 275 \cdot mm$$

CABOS C13=C14 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}\,,\,0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 44.25\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 21 \qquad i = 1,2..n$$

$$S = 0\text{cm}, \frac{L}{n-1}\,..\,L = \begin{pmatrix} 0 \\ 221.25 \\ 442.5 \\ 663.75 \\ 885 \\ 1106.25 \\ 1327.5 \\ 1548.75 \\ 1770 \\ 1991.25 \\ 2212.5 \\ 2433.75 \\ 2655 \\ 2876.25 \\ 3097.5 \\ 3318.75 \\ 3540 \\ 3761.25 \\ 3982.5 \\ 4203.75 \\ 4425 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 2.32 \\ 3.68 \\ 0.21 \\ 3.65 \\ 3.87 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.1 \\ 0 \\ 3.1 \\ 0 \\ 1.85 \\ 4.15 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 13.33 \end{pmatrix}^{\circ}$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13245.6 \\ 13008.22 \\ 12890.06 \\ 12660.3 \\ 12425.64 \\ 12313.48 \\ 12202.33 \\ 12092.18 \\ 11983.03 \\ 11874.87 \\ 11767.68 \\ 11661.46 \\ 11556.19 \\ 11451.88 \\ 11267.85 \\ 11166.14 \\ 10986.71 \\ 10887.54 \\ 10753.6 \\ 10196.88 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$n = 21$ $\qquad\qquad i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 4.15 \\ 1.85 \\ 0 \\ 3.1 \\ 0 \\ 3.1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.87 \\ 3.65 \\ 0.21 \\ 3.68 \\ 2.32 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 13.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 13.33 \end{pmatrix}°$$

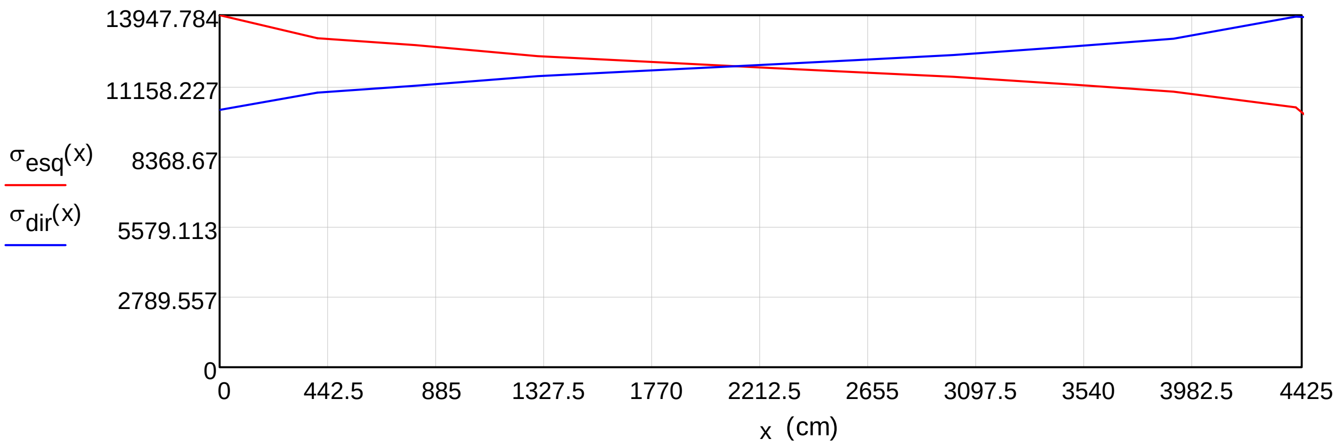
$$\theta_i = \begin{cases} 0\,rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13225.71 \\ 13063 \\ 12945.09 \\ 12737.07 \\ 12622.1 \\ 12419.27 \\ 12307.16 \\ 12196.07 \\ 12085.98 \\ 11976.89 \\ 11868.78 \\ 11761.64 \\ 11655.47 \\ 11550.27 \\ 11446.01 \\ 11233.85 \\ 11033.61 \\ 10933.39 \\ 10737.44 \\ 10196.88 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq}) \qquad b = \mathrm{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$$ $\text{interseção} = 2107.96 \cdot cm$

$$\sigma_{\text{interseção}} = 11925.85 \cdot \frac{kg}{cm^2}$$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\, dx$$ $\text{Área}_1 = 265568.16 \cdot \frac{kg \cdot m}{cm^2}$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\, dx$$ $\text{Área}_2 = 292642.43 \cdot \frac{kg \cdot m}{cm^2}$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2)$$ $\text{Área} = 558210.59 \cdot \frac{kg \cdot m}{cm^2}$

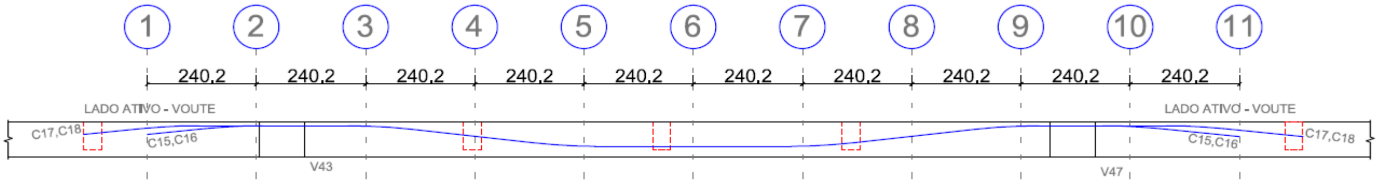
$$\sigma_m = \frac{\text{Área}}{L}$$ $\sigma_m = 12614.93 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 45.85m$ $\text{Área}_{\text{teórica\_aço}} = 143.4 \cdot mm^2$ $E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$

$$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 18.1 \cdot t$$

$$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 297 \cdot mm$$

CABOS C15=C16 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 24.02\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 11$ $\quad i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 240.2 \\ 480.4 \\ 720.6 \\ 960.8 \\ 1201 \\ 1441.2 \\ 1681.4 \\ 1921.6 \\ 2161.8 \\ 2402 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 5.37 \\ 2.48 \\ 4.78 \\ 7.33 \\ 0.7 \\ 1.16 \\ 5.48 \\ 4.98 \\ 4.56 \\ 3.09 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 19.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 19.46 \end{pmatrix}^{\circ}$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12936.46 \\ 12745.78 \\ 12465.31 \\ 12086.11 \\ 11960.39 \\ 11825.85 \\ 11538.48 \\ 11277.03 \\ 11036.97 \\ 10254 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\qquad\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 3.09 \\ 4.56 \\ 4.98 \\ 5.48 \\ 1.16 \\ 0.7 \\ 7.33 \\ 4.78 \\ 2.48 \\ 5.37 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 1.46 \\ 19.46 \end{pmatrix} \circ$$

$$\theta_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu\cdot\theta+\kappa\cdot S)}$$

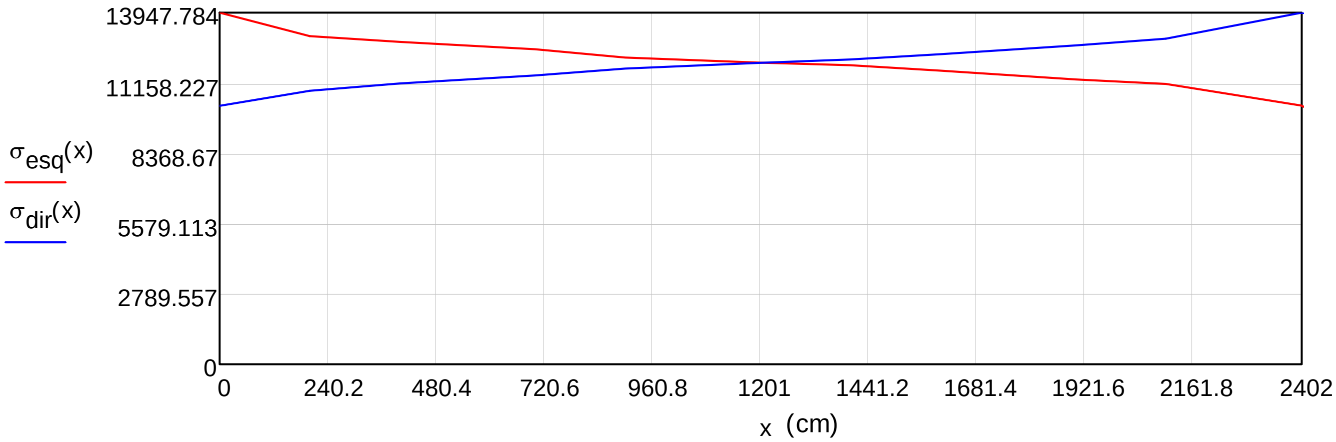
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12958.31 \\ 12682.46 \\ 12395.1 \\ 12093.9 \\ 11957.85 \\ 11833.47 \\ 11473.48 \\ 11221.02 \\ 11055.62 \\ 10254 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$

$\text{interseção} = 1203.35 \cdot cm$

$\sigma_{\text{interseção}} = 11959.66 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx$ $Área_1 = 151713.99 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx$ $Área_2 = 151510.78 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $Área = 303224.78 \cdot \frac{kg \cdot m}{cm^2}$

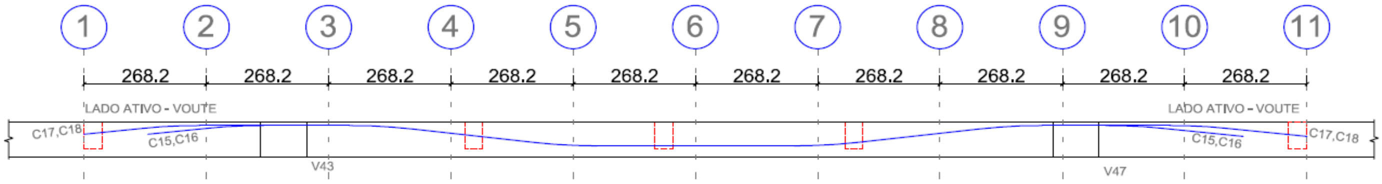
$\sigma_m = \frac{Área}{L}$ $\sigma_m = 12623.85 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 25.70m$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.1 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 166 \cdot mm$

CABOS C17=C18 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 26.82\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 268.2 \\ 536.4 \\ 804.6 \\ 1072.8 \\ 1341 \\ 1609.2 \\ 1877.4 \\ 2145.6 \\ 2413.8 \\ 2682 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 6 \\ 0 \\ 6.63 \\ 4.1 \\ 2.53 \\ 2.51 \\ 4.12 \\ 6.63 \\ 1.58 \\ 4.42 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 16.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 16.63 \end{pmatrix}^{\circ}$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13042.9 \\ 12899.53 \\ 12528.35 \\ 12270.88 \\ 12077.68 \\ 11888.23 \\ 11643.15 \\ 11308.13 \\ 11158.86 \\ 10452.12 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 4.42 \\ 1.58 \\ 6.63 \\ 4.12 \\ 2.51 \\ 2.53 \\ 4.1 \\ 6.63 \\ 0 \\ 6 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 16.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 1.63 \\ 16.63 \end{pmatrix} \circ$$

$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu\cdot\theta+\kappa\cdot S)}$$

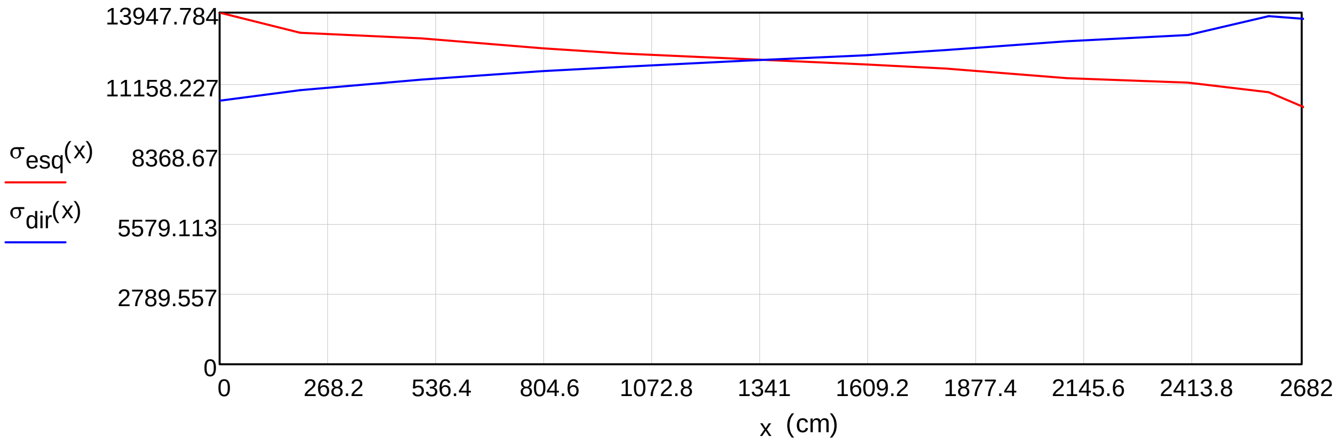
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13064.41 \\ 12891.96 \\ 12521 \\ 12262.88 \\ 12070.52 \\ 11880.48 \\ 11636.32 \\ 11301.5 \\ 11177.26 \\ 10452.12 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$

$\text{interseção} = 1346.02 \cdot cm$

$\sigma_{\text{interseção}} = 12074.16 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 171248.16 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 170641.06 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 341889.21 \cdot \frac{kg \cdot m}{cm^2}$$

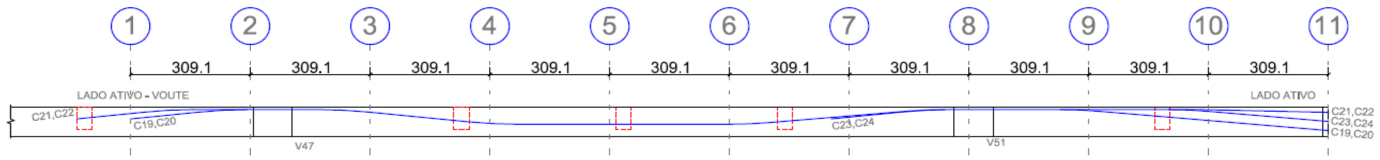
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12747.55 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 28.50m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 186 \cdot mm$$

CABOS C19=C20 (4ø15.2mm)



$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 30.91m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 309.1 \\ 618.2 \\ 927.3 \\ 1236.4 \\ 1545.5 \\ 1854.6 \\ 2163.7 \\ 2472.8 \\ 2781.9 \\ 3091 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 6 \\ 5.84 \\ 2.55 \\ 3.3 \\ 0.02 \\ 4.91 \\ 4.94 \\ 3.64 \\ 1.46 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 19.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \end{pmatrix} °$$

$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12892.59 \\ 12541.65 \\ 12327.27 \\ 12089.95 \\ 11936.85 \\ 11647.55 \\ 11364.14 \\ 11133.74 \\ 10973.57 \\ 10834.6 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11 \qquad i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 1.46 \\ 3.64 \\ 4.94 \\ 4.91 \\ 0.02 \\ 3.3 \\ 2.55 \\ 5.84 \\ 6 \end{pmatrix}°\qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 19.88 \end{pmatrix}°$$

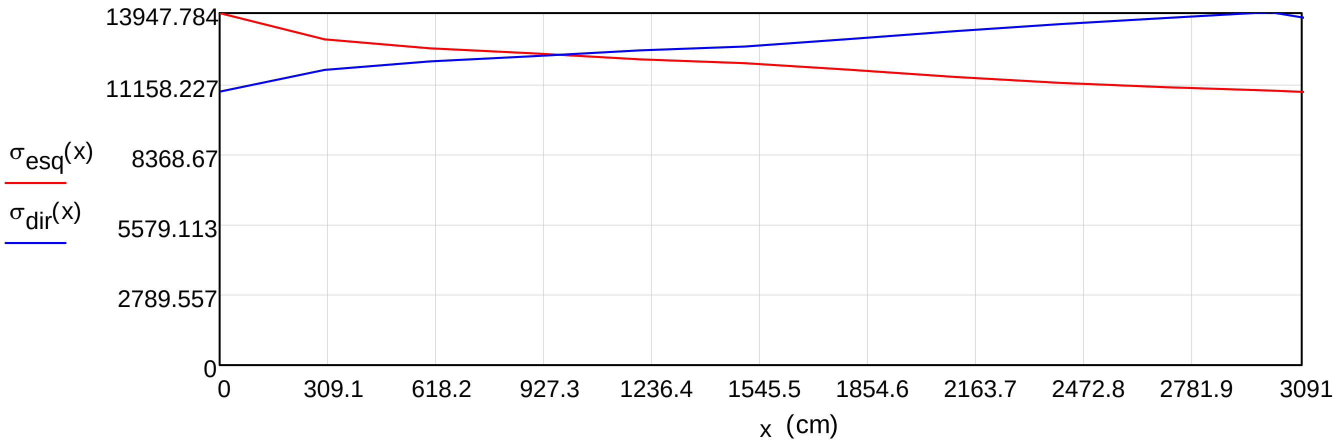
$$\theta_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13771.15 \\ 13573.04 \\ 13297.85 \\ 12974.3 \\ 12659.85 \\ 12499.53 \\ 12258.89 \\ 12049.35 \\ 11721.36 \\ 10834.6 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}\left(S, \sigma_{esq}\right) \qquad b = \text{cspline}\left(S, \sigma_{dir}\right)$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}\left(\sigma_{dir}\right)}{g}, x\right)$$



$$c = \frac{L}{2} \qquad d = 0m$$

Given

$$d = \sigma_{esq}(c) \qquad d = \sigma_{dir}(c)$$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d) \qquad interseção = 969.22 \cdot cm$$

$$\sigma_{interseção} = 12293.94 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx \qquad Área_1 = 124029.94 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx \qquad Área_2 = 279114.5 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 403144.45 \cdot \frac{kg \cdot m}{cm^2}$$

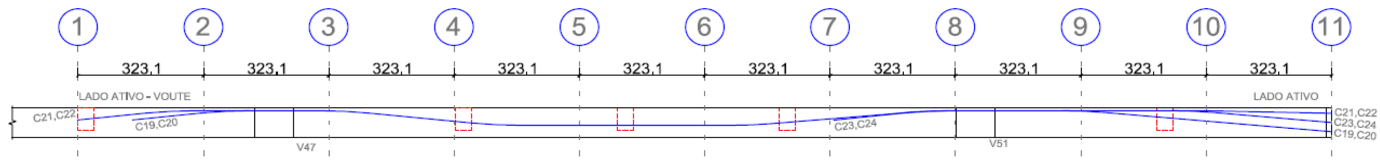
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13042.52 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 32.60m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 218 \cdot mm$$

CABOS C21=C22 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 32.31m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 323.1 \\ 646.2 \\ 969.3 \\ 1292.4 \\ 1615.5 \\ 1938.6 \\ 2261.7 \\ 2584.8 \\ 2907.9 \\ 3231 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 6 \\ 0.91 \\ 4.94 \\ 5.84 \\ 0 \\ 4.94 \\ 4.94 \\ 0 \\ 1.22 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 13.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \end{pmatrix} °$$

$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13141.65 \\ 12958.47 \\ 12638.19 \\ 12289.53 \\ 12126.69 \\ 11826.97 \\ 11534.66 \\ 11381.82 \\ 11217.41 \\ 11068.78 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11 \qquad i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 1.22 \\ 0 \\ 4.94 \\ 4.94 \\ 0 \\ 5.84 \\ 4.94 \\ 0.91 \\ 6 \end{pmatrix} {}^\circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 13.97 \end{pmatrix} {}^\circ$$

$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

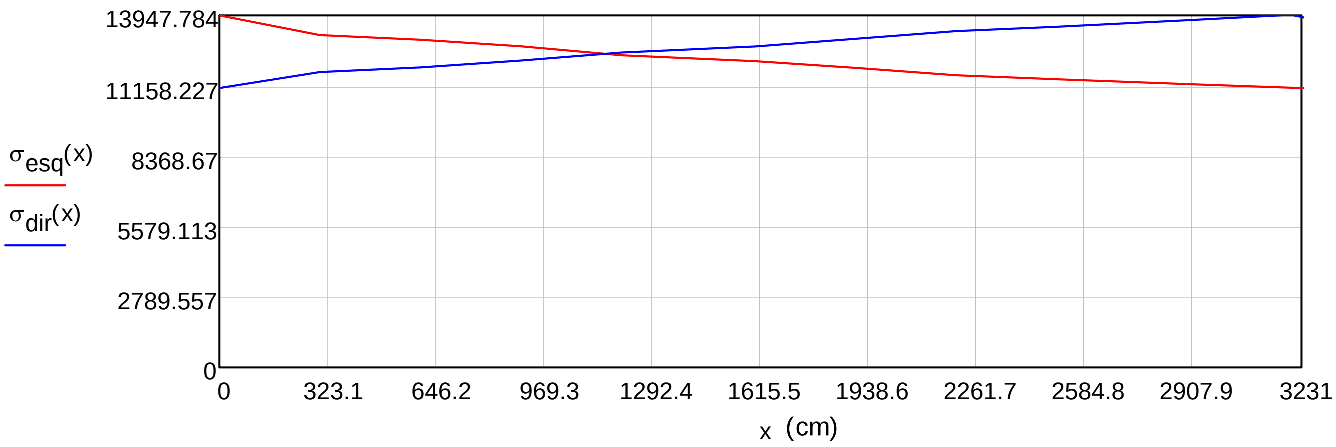
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13762.98 \\ 13564.17 \\ 13384.44 \\ 13053.63 \\ 12731 \\ 12562.32 \\ 12215.74 \\ 11913.82 \\ 11747.76 \\ 11068.78 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 1148.95 \cdot cm$

$\sigma_{\text{interseção}} = 12423.64 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 149505.26 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 275824.3 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 425329.55 \cdot \frac{kg \cdot m}{cm^2}$$

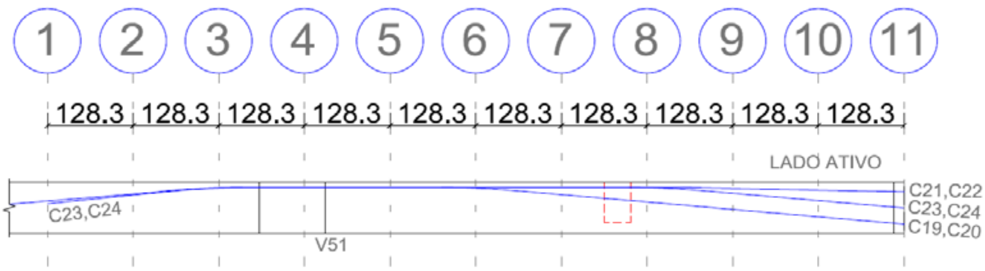
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13164.02 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 33.95m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.9 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 229 \cdot mm$$

CABOS C23=C24 (4ø15.2mm)



$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 12.83m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 128.3 \\ 256.6 \\ 384.9 \\ 513.2 \\ 641.5 \\ 769.8 \\ 898.1 \\ 1026.4 \\ 1154.7 \\ 1283 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 3.76 \\ 1.33 \\ 0 \\ 0 \\ 0 \\ 2.29 \\ 3.71 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \end{pmatrix}°$$

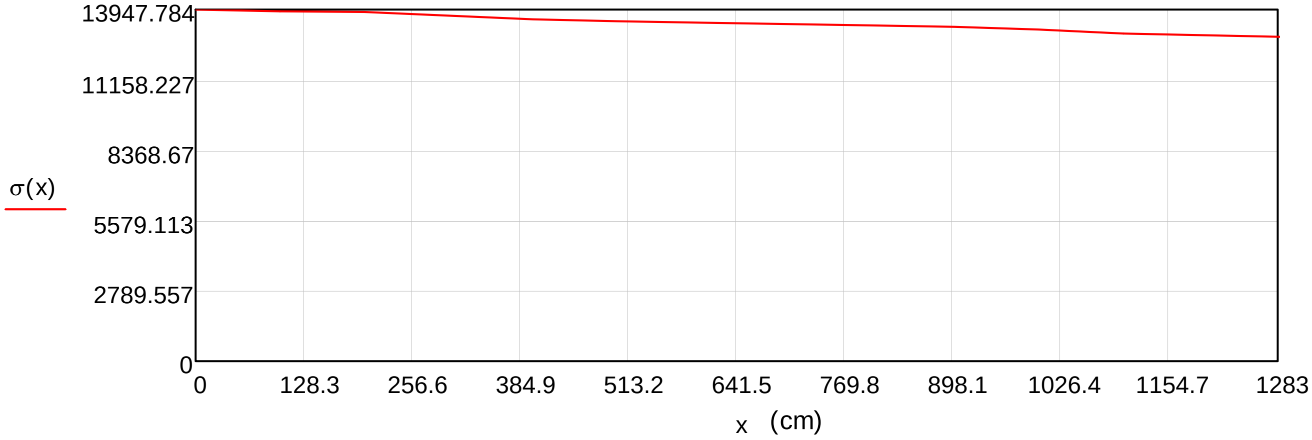
$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13874.21 \\ 13801.03 \\ 13582.37 \\ 13474.85 \\ 13403.77 \\ 13333.07 \\ 13262.74 \\ 13117.51 \\ 12911.89 \\ 12843.78 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}\left(S, \sigma_{esq}\right)$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 172097.33 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13413.67 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 13.65m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.2 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 94 \cdot mm$$

V2 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA (4ø15.2mm)

$b = 25\text{cm}$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 4 \cdot \sigma_1 \cdot \text{Área}_{teórica\_aço} = 784.58\,\text{kN}$

$a_0 = 18\text{cm}$ $\quad c = 7\text{cm}$

$d = 15\text{cm}$ $\quad a_1 = a_0 + c = 25\,\text{cm}$

$F_1 = F_{inicial} \cdot \cos(1°) = 784.46\,\text{kN}$ $\quad F_3 = F_{inicial} \cdot \cos(5°) = 781.59\,\text{kN}$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.91\,\text{kN} \qquad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,\text{kN}$$

$F_2 = F_{inicial} \cdot \cos(5°) = 781.59\,\text{kN}$

$$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,\text{kN}$$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 80\,\text{cm}$ $\quad k = 1 .. n$

$$F_k = \begin{pmatrix} 784.46 \\ 781.59 \\ 781.59 \end{pmatrix} \text{kN} \qquad T_k = \begin{pmatrix} 54.91 \\ 54.71 \\ 54.71 \end{pmatrix} \text{kN} \qquad \sum F = 2347.64\,\text{kN}$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 97.82\,\text{kN} \qquad fyd = 43.48 \frac{\text{kN}}{\text{cm}^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.26\,\text{cm}^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 4.5\,\text{cm}^2$$

$As_{fretagem} = As_1 = 1.26\,cm^2$

Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$As_{estribos} = \frac{As_2}{2} = 2.25\,cm^2$

EXTREMIDADE ATIVA (6ø15.2mm)

a_0 = Área da placa de distribuição

d = Distância entre a face do concreto ao eixo da ancoragem

n = Número de ancoragens

$n = 1$

$F_{inicial} = 6 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 1176.86\,kN$

$a_0 = 22cm$

$d = 18.5cm$

$a_3 = 2 \cdot d = 37 \cdot cm$

$F = n \cdot F_{inicial} \cdot \cos(6°) = 1170.42\,kN$

$T = 0.25 \cdot F \cdot \left(1 - \frac{a_0}{a_3}\right) = 118.62\,kN$

$fyd = 43.48\,\frac{kN}{cm^2}$

$As_3 = \frac{T}{fyd} = 2.73\,cm^2$

$As_{estribos} = \frac{\max(As_2, As_3)}{2} = 2.25\,cm^2$

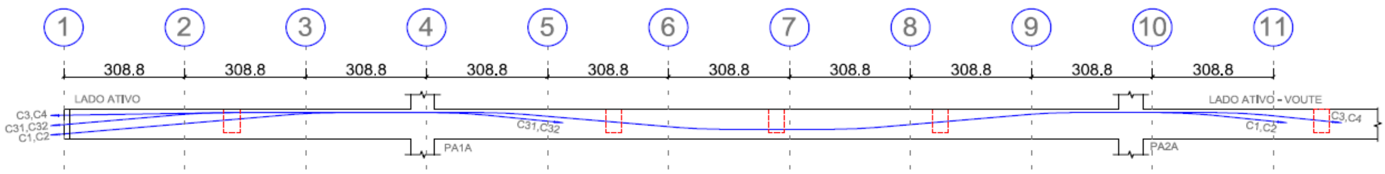
$L = \max(a_1, a_2, a_3) = 80\,cm$

$bitola_{estribo} = 10mm$

$adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 3$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V3 - CABOS C1 a C32



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2$ $\quad fptk = \dfrac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad fpyk = \dfrac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 30.88\,\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 11$ $\quad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 308.8 \\ 617.6 \\ 926.4 \\ 1235.2 \\ 1544 \\ 1852.8 \\ 2161.6 \\ 2470.4 \\ 2779.2 \\ 3088 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 1.32 \\ 3.79 \\ 5.16 \\ 0.01 \\ 5.17 \\ 5.1 \\ 0.32 \\ 4.64 \\ 6.2 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 19.88 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13771.24 \\ 13577.14 \\ 13295.74 \\ 12962.98 \\ 12798.9 \\ 12478.17 \\ 12168.26 \\ 12013.11 \\ 11732.31 \\ 10842.57 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 6.2 \\ 4.64 \\ 0.32 \\ 5.1 \\ 5.17 \\ 0.01 \\ 5.16 \\ 3.79 \\ 1.32 \\ 0 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \end{pmatrix} \circ$$

$$n = 11$$

$$\theta_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i\cdot rad & \text{otherwise} \end{array} \right.$$

$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$

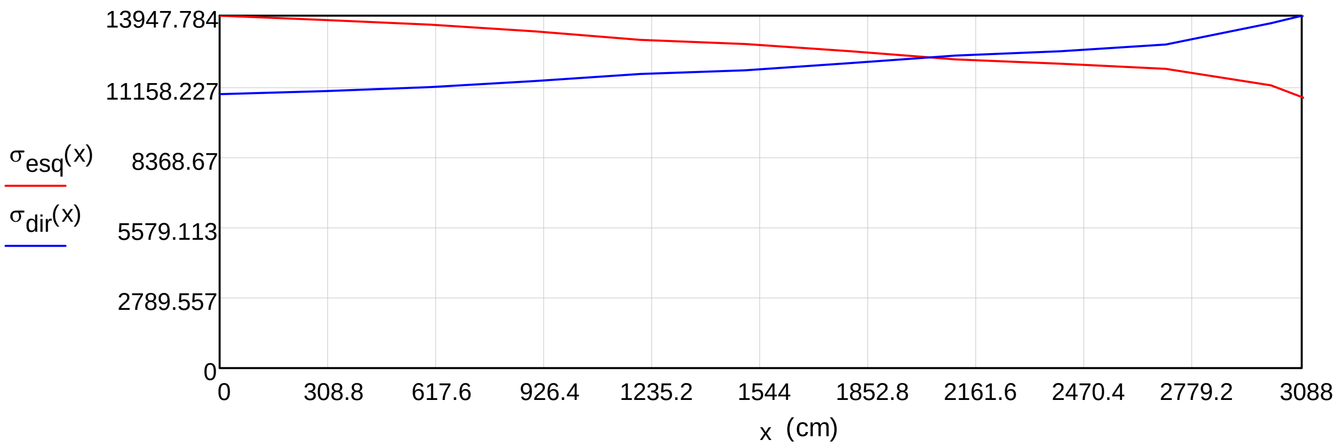
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12890.03 \\ 12588.73 \\ 12428.22 \\ 12119.55 \\ 11815.84 \\ 11666.28 \\ 11374.3 \\ 11138.56 \\ 10981.57 \\ 10842.57 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$

$\text{interseção} = 2017.47 \cdot cm$

$\sigma_{\text{interseção}} = 12294.82 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 266301.4 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 137180.13 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 403481.53 \cdot \frac{kg \cdot m}{cm^2}$$

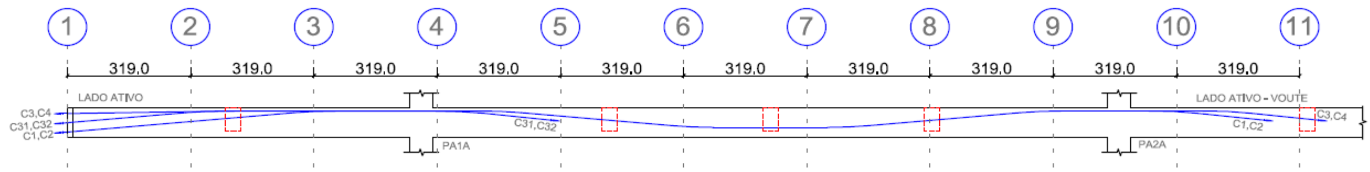
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13066.11 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 32.55m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 218 \cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 31.90m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 319 \\ 638 \\ 957 \\ 1276 \\ 1595 \\ 1914 \\ 2233 \\ 2552 \\ 2871 \\ 3190 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0.11 \\ 0.82 \\ 0.01 \\ 5.08 \\ 2.32 \\ 2.64 \\ 5.24 \\ 5.13 \\ 0.1 \\ 6.06 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 19.97 \end{pmatrix} °$$

$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13763.96 \\ 13574.93 \\ 13396.16 \\ 13060.19 \\ 12839.99 \\ 12612.48 \\ 12289.75 \\ 11979.58 \\ 11821.71 \\ 10921.25 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 6.06 \\ 0.1 \\ 5.13 \\ 5.24 \\ 2.64 \\ 2.32 \\ 5.08 \\ 0.01 \\ 0.82 \\ 0.11 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

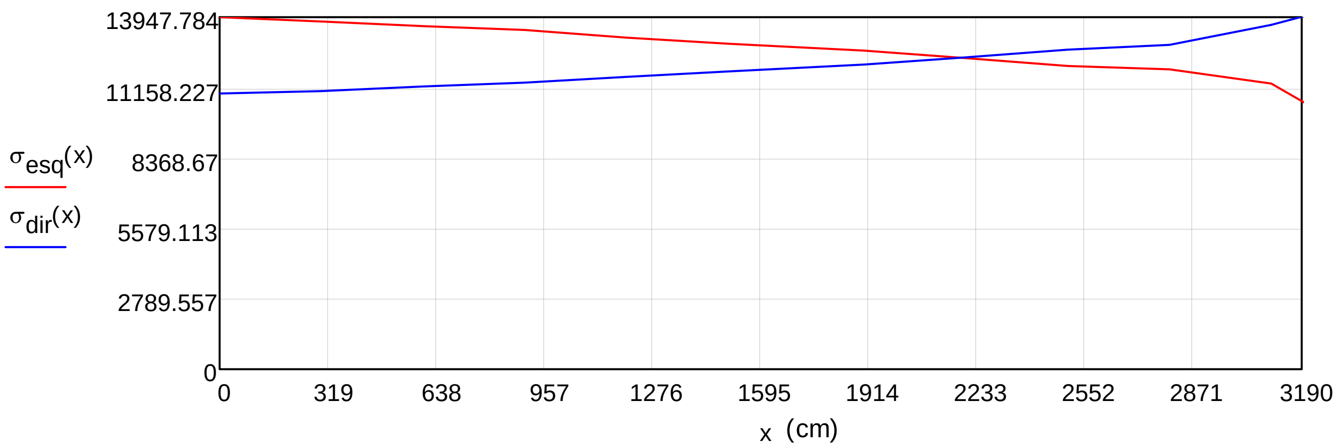
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12885.38 \\ 12715.58 \\ 12394.66 \\ 12077.51 \\ 11863.5 \\ 11663.48 \\ 11370.97 \\ 11221.22 \\ 11067.11 \\ 10921.25 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$$

$interseção = 2186.16 \cdot cm$

$$\sigma_{interseção} = 12342.21 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$$

$$Área_1 = 288937.63 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$$

$$Área_2 = 129444.02 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2)$$

$$Área = 418381.64 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{Área}{L}$$

$$\sigma_m = 13115.41 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 33.95m$

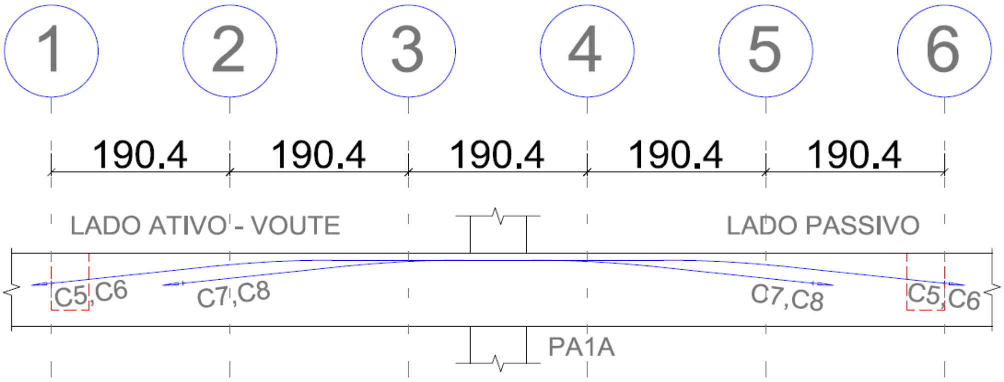
$Área_{teórica\_aço} = 143.4 \cdot mm^2$

$$E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 228 \cdot mm$$

CABOS C5=C6 (6ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 9.52\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 6$ $\quad$ $i = 1, 2 .. n$

$S = 0\text{cm}, \dfrac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 190.4 \\ 380.8 \\ 571.2 \\ 761.6 \\ 952 \end{pmatrix}\text{cm}$ $\quad$ $\Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.82 \\ 5.25 \\ 0 \\ 5.25 \\ 0.82 \end{pmatrix}°$ $\quad$ $\Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.24 \\ 1.24 \\ 1.24 \\ 1.24 \\ 1.24 \end{pmatrix}°$

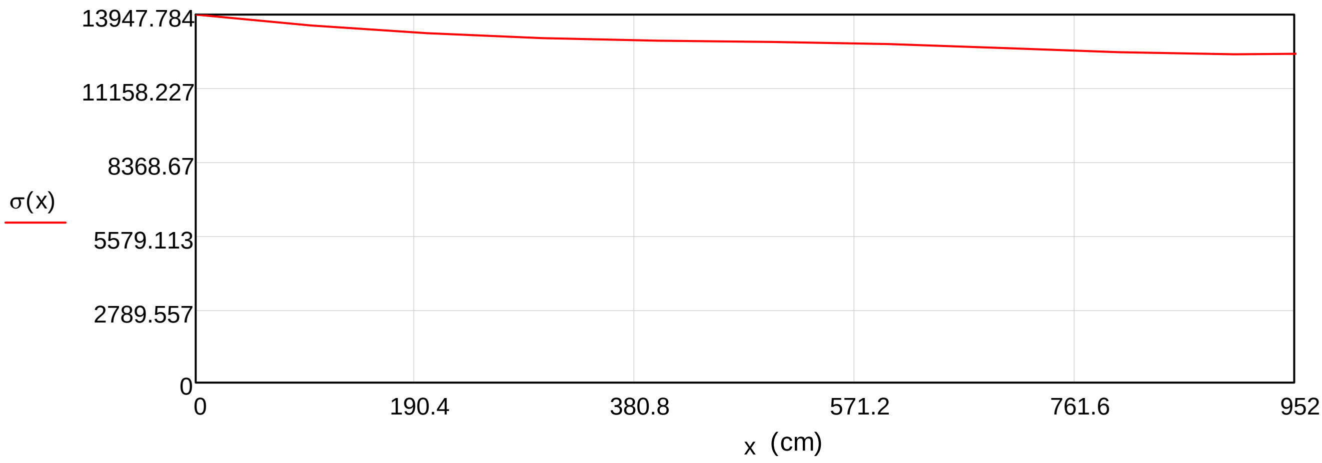
$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{vmatrix}$$

$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13266.04 \\ 12969.1 \\ 12864.01 \\ 12576.06 \\ 12463.42 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 123363.34 \cdot \frac{kg \cdot m}{cm^2}$$

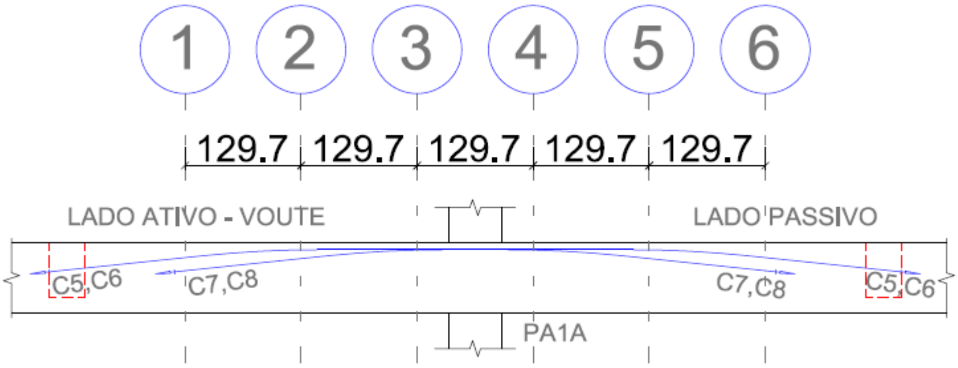
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12958.33 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 10.35m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.6 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 69 \cdot mm$$

CABOS C7=C8 (6ø15.2mm)



$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01 \dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 6.49m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 6$ $\quad i = 1, 2..\, n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 129.8 \\ 259.6 \\ 389.4 \\ 519.2 \\ 649 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.7 \\ 2.75 \\ 4.7 \\ 0 \end{pmatrix} ^\circ \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 18.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \end{pmatrix} ^\circ$$

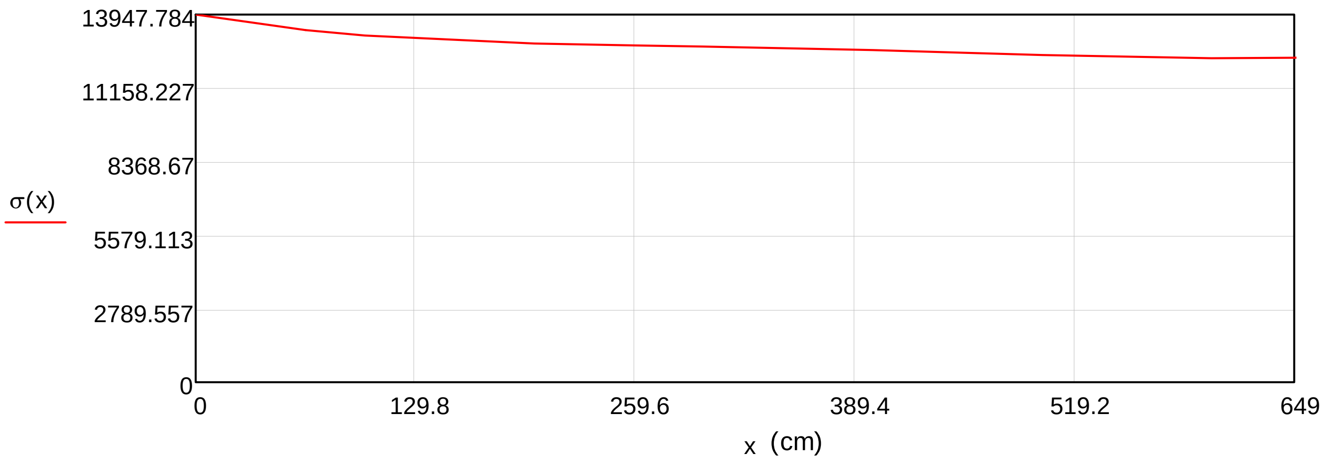
$$\alpha_i = \begin{array}{|l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13027.08 \\ 12778.71 \\ 12618.54 \\ 12377.96 \\ 12310.58 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 82808.77 \cdot \frac{kg \cdot m}{cm^2}$$

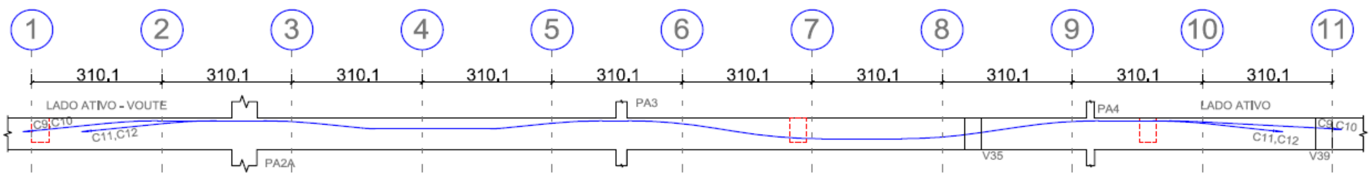
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12759.44 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 7.30m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 48 \cdot mm$$

CABOS C9=C10 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 31.01\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 310.1 \\ 620.2 \\ 930.3 \\ 1240.4 \\ 1550.5 \\ 1860.6 \\ 2170.7 \\ 2480.8 \\ 2790.9 \\ 3101 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 6.1 \\ 3.26 \\ 3.3 \\ 5.57 \\ 11.85 \\ 5.21 \\ 5.74 \\ 1.61 \\ 6.29 \\ 0.19 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \end{pmatrix}°$$

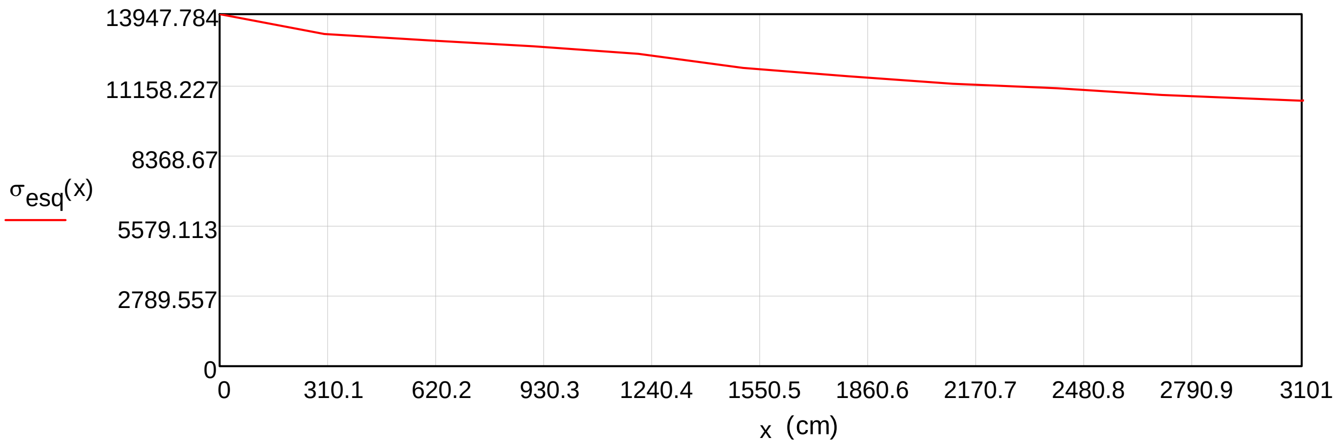
$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13146.61 \\ 12894.59 \\ 12645.88 \\ 12312.29 \\ 11734.21 \\ 11438.22 \\ 11130.22 \\ 10965.95 \\ 10651.15 \\ 10515.34 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\, dx \qquad Área = 369113.86 \cdot \frac{kg \cdot m}{cm^2}$$

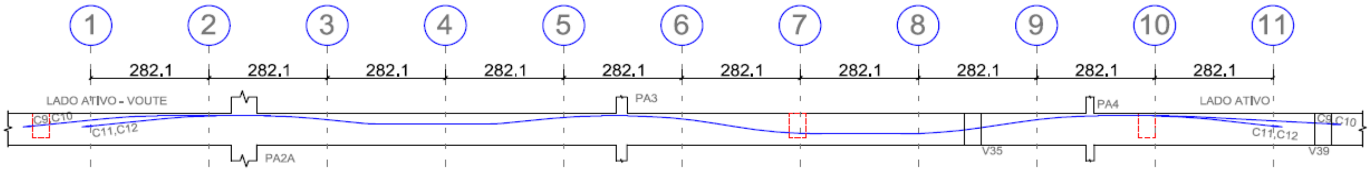
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 11903.06 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 31.90m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 17.1 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 195 \cdot mm$$

CABOS C11=C12 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot \text{fptk}, 0.82\cdot \text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 28.21\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 282.1 \\ 564.2 \\ 846.3 \\ 1128.4 \\ 1410.5 \\ 1692.6 \\ 1974.7 \\ 2256.8 \\ 2538.9 \\ 2821 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 5.03 \\ 6.9 \\ 5.99 \\ 4.31 \\ 10.62 \\ 3.83 \\ 4.34 \\ 5.18 \\ 7.63 \\ 5.97 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 19.74 \\ 1.74 \\ 1.74 \\ 1.74 \\ 1.74 \\ 1.74 \\ 1.74 \\ 1.74 \\ 1.74 \\ 1.74 \end{pmatrix}°$$

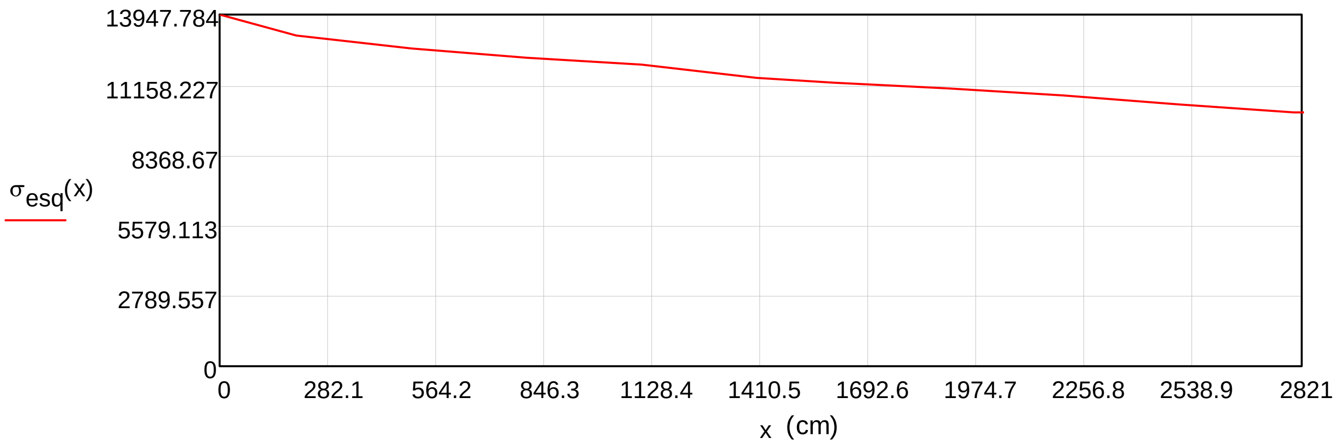
$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12917.35 \\ 12529.55 \\ 12190.71 \\ 11927.04 \\ 11422.68 \\ 11192.84 \\ 10949.69 \\ 10682.37 \\ 10336.02 \\ 10057.18 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$



$\text{Área} = \int_0^L \sigma_{esq}(x)\,dx$ $\text{Área} = 327321.12 \cdot \frac{kg \cdot m}{cm^2}$

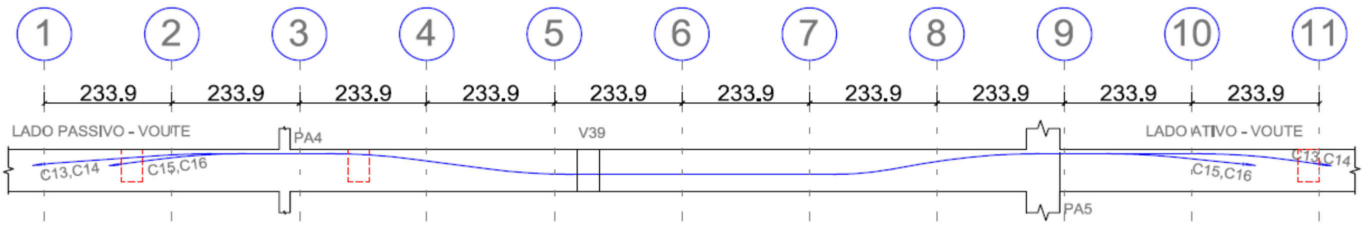
$\sigma_m = \frac{\text{Área}}{L}$ $\sigma_m = 11603.02 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 29.10m$ $\text{Área}_{teórica\_aço} = 143.4 \cdot mm^2$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 16.6 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 173 \cdot mm$

CABOS C13=C14 (6ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}\,,0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 23.39\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1,2..n$$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 233.9 \\ 467.8 \\ 701.7 \\ 935.6 \\ 1169.5 \\ 1403.4 \\ 1637.3 \\ 1871.2 \\ 2105.1 \\ 2339 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.84 \\ 3.46 \\ 7.68 \\ 5.98 \\ 1.71 \\ 0 \\ 9.02 \\ 9.02 \\ 0 \\ 8.13 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.47 \\ 1.47 \\ 1.47 \\ 1.47 \\ 1.47 \\ 1.47 \\ 1.47 \\ 1.47 \\ 1.47 \\ 13.47 \end{pmatrix}°$$

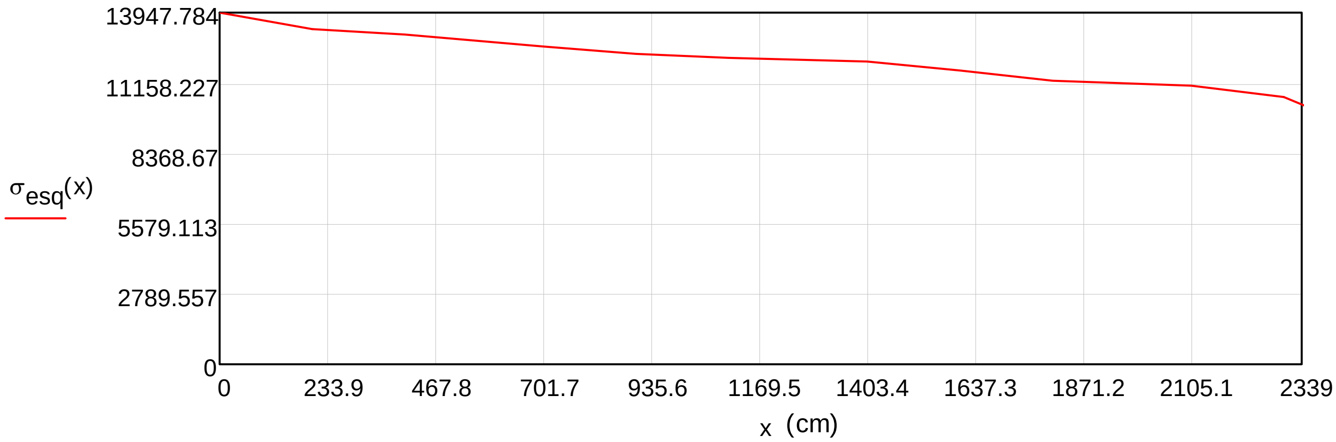
$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13243.83 \\ 13010.17 \\ 12600.78 \\ 12275.25 \\ 12122.17 \\ 12003.84 \\ 11572.68 \\ 11157.01 \\ 11048.1 \\ 10408.9 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\, dx \qquad Área = 283523.11 \cdot \frac{kg \cdot m}{cm^2}$$

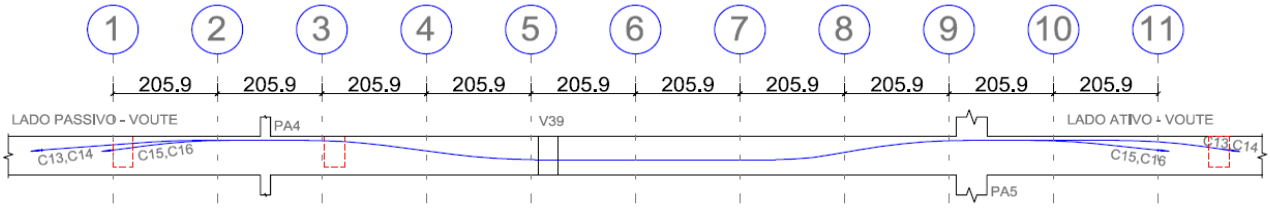
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12121.55 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 24.25m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 17.4 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 151 \cdot mm$$

CABOS C15=C16 (6ø15.2mm)



$Área_{teórica\_aço} = 143.4mm^2$ $\quad$ $fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad$ $fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{rad}{m}$ $\quad$ $e = 2.72$ $\quad$ $L = 20.59m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 205.9 \\ 411.8 \\ 617.7 \\ 823.6 \\ 1029.5 \\ 1235.4 \\ 1441.3 \\ 1647.2 \\ 1853.1 \\ 2059 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 6.41 \\ 3.69 \\ 5.15 \\ 7.68 \\ 0 \\ 0 \\ 10.3 \\ 9.33 \\ 3.16 \\ 3.88 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 13.3 \\ 1.3 \\ 1.3 \\ 1.3 \\ 1.3 \\ 1.3 \\ 1.3 \\ 1.3 \\ 1.3 \\ 13.3 \end{pmatrix} °$$

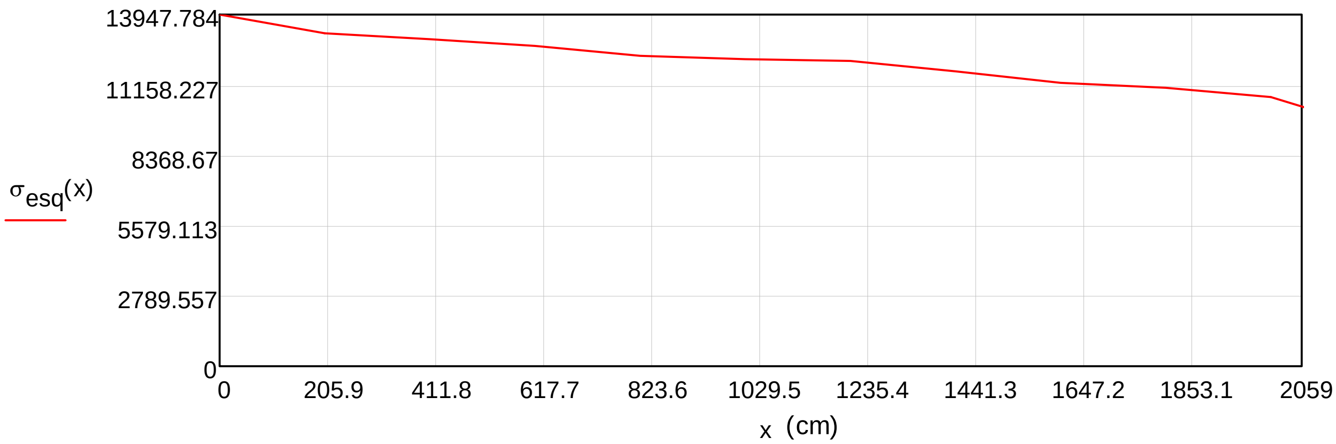
$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13192.73 \\ 12960.31 \\ 12669.95 \\ 12279.43 \\ 12173.6 \\ 12068.68 \\ 11591.32 \\ 11170.27 \\ 10992.47 \\ 10430.47 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}\left(S, \sigma_{esq}\right)$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\,dx \qquad \text{Área} = 249694.25 \cdot \frac{kg \cdot m}{cm^2}$$

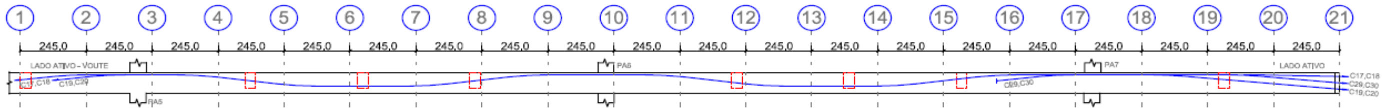
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12126.97 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 21.45m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 17.4 \cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right) \cdot \left(L_{cabo}\right)}{E_{teórico\_aço}} = 133 \cdot mm$$

CABOS C17=C18 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74 \cdot \text{fptk}, 0.82 \cdot \text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 49.00\text{m}$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{\text{rad}}{\text{m}} \qquad n = 21 \qquad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 245 \\ 490 \\ 735 \\ 980 \\ 1225 \\ 1470 \\ 1715 \\ 1960 \\ 2205 \\ 2450 \\ 2695 \\ 2940 \\ 3185 \\ 3430 \\ 3675 \\ 3920 \\ 4165 \\ 4410 \\ 4655 \\ 4900 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 5.73 \\ 0.34 \\ 6.89 \\ 1.34 \\ 5.55 \\ 1.04 \\ 5.84 \\ 6.78 \\ 0.11 \\ 6.18 \\ 0.52 \\ 6.7 \\ 0 \\ 6.89 \\ 5.63 \\ 1.26 \\ 0 \\ 0 \\ 1.17 \\ 0 \end{pmatrix} ^\circ \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 19.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \end{pmatrix} ^\circ$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12927.29 \\ 12793.48 \\ 12421.04 \\ 12272.56 \\ 11969.49 \\ 11833.97 \\ 11530.46 \\ 11198.98 \\ 11084.34 \\ 10787.64 \\ 10674.18 \\ 10370.14 \\ 10264.12 \\ 9965.31 \\ 9716.6 \\ 9602.18 \\ 9504.02 \\ 9406.86 \\ 9297.9 \\ 9202.84 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 21$ $\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 1.17 \\ 0 \\ 0 \\ 1.26 \\ 5.63 \\ 6.89 \\ 0 \\ 6.7 \\ 0.52 \\ 6.18 \\ 0.11 \\ 6.78 \\ 5.84 \\ 1.04 \\ 5.55 \\ 1.34 \\ 6.89 \\ 0.34 \\ 5.73 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 1.54 \\ 19.54 \end{pmatrix}°$$

$$\theta_i = \begin{array}{|l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

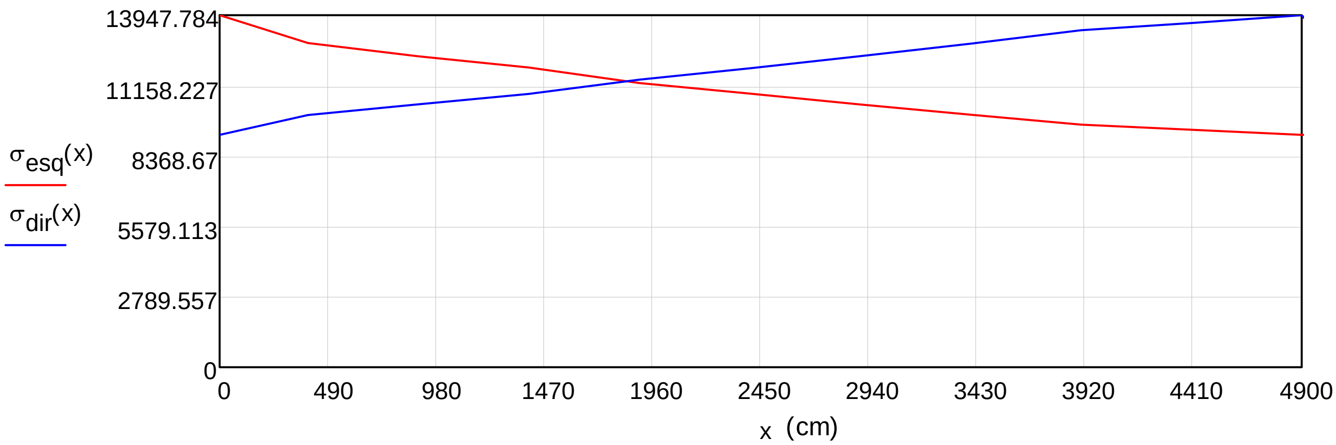
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13805.2 \\ 13645.28 \\ 13505.79 \\ 13367.72 \\ 13210.3 \\ 12880.61 \\ 12505.63 \\ 12377.78 \\ 12025.22 \\ 11898.73 \\ 11580.24 \\ 11461.7 \\ 11132.19 \\ 10846.68 \\ 10723.87 \\ 10459.05 \\ 10334.02 \\ 10033.18 \\ 9929.32 \\ 9202.84 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\qquad interseção = 1850.34 \cdot cm$

$\sigma_{interseção} = 11321.28 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx$ $\qquad Área_1 = 228174.86 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx$ $\qquad Área_2 = 388839.09 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\qquad Área = 617013.95 \cdot \frac{kg \cdot m}{cm^2}$

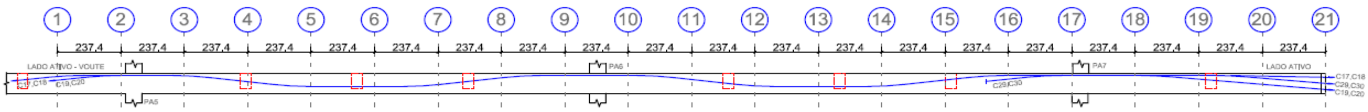
$\sigma_m = \frac{Área}{L}$ $\qquad \sigma_m = 12592.12 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 50.70m$ $\qquad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.1 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 327 \cdot mm$

CABOS C19=C20 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2 \qquad \text{fptk} = \frac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}\,,\,0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 47.48\,\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 21 \qquad i = 1, 2 .. n$$

$$S = 0\,\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 237.4 \\ 474.8 \\ 712.2 \\ 949.6 \\ 1187 \\ 1424.4 \\ 1661.8 \\ 1899.2 \\ 2136.6 \\ 2374 \\ 2611.4 \\ 2848.8 \\ 3086.2 \\ 3323.6 \\ 3561 \\ 3798.4 \\ 4035.8 \\ 4273.2 \\ 4510.6 \\ 4748 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 5.93 \\ 2.28 \\ 4.75 \\ 6.89 \\ 0 \\ 6.15 \\ 0.74 \\ 6.89 \\ 0 \\ 6.89 \\ 3.51 \\ 3.38 \\ 2.5 \\ 4.39 \\ 6.89 \\ 0 \\ 0 \\ 5.1 \\ 0 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 19.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \end{pmatrix}^{\circ}$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12928.41 \\ 12745.17 \\ 12466.15 \\ 12105.44 \\ 11985.18 \\ 11667.72 \\ 11544.85 \\ 11210.8 \\ 11099.43 \\ 10778.26 \\ 10585.23 \\ 10399.97 \\ 10245.91 \\ 10033.57 \\ 9743.25 \\ 9646.45 \\ 9550.62 \\ 9330.62 \\ 9237.93 \\ 9146.16 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$n = 21$ $\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 5.1 \\ 0 \\ 0 \\ 6.89 \\ 4.39 \\ 2.5 \\ 3.38 \\ 3.51 \\ 6.89 \\ 0 \\ 6.89 \\ 0.74 \\ 6.15 \\ 0 \\ 6.89 \\ 4.75 \\ 2.28 \\ 5.93 \end{pmatrix}^{\circ} \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 19.5 \end{pmatrix}^{\circ}$$

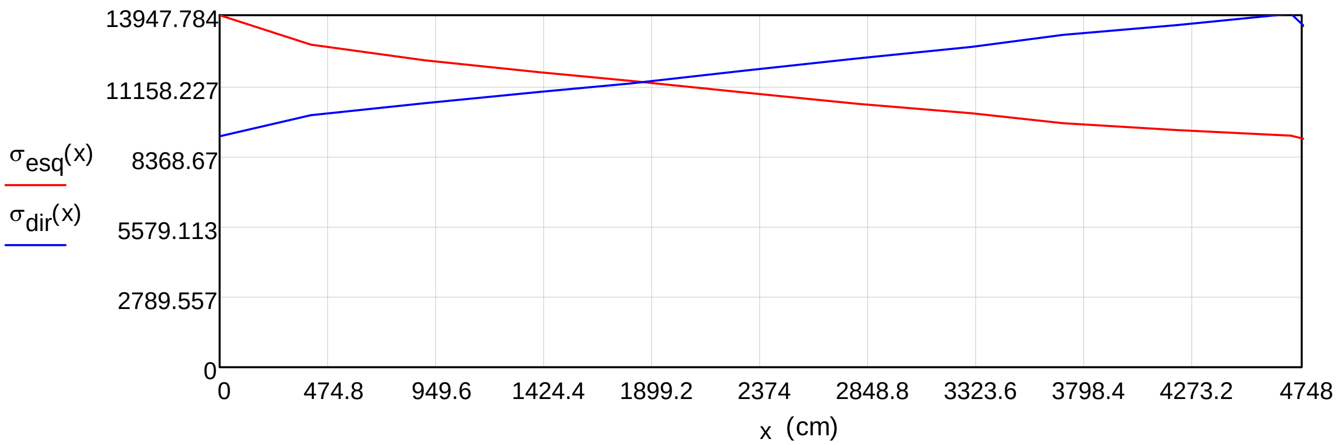
$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13809.22 \\ 13672.04 \\ 13357.1 \\ 13224.41 \\ 13093.03 \\ 12714.18 \\ 12450.7 \\ 12266.25 \\ 12051.58 \\ 11835.73 \\ 11493.27 \\ 11379.09 \\ 11049.83 \\ 10933.47 \\ 10643.87 \\ 10538.13 \\ 10233.21 \\ 10009.18 \\ 9867.31 \\ 9146.16 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq}) \qquad b = \mathrm{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$$

$interseção = 1834.71 \cdot cm$

$$\sigma_{interseção} = 11291.74 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$$ $$Área_1 = 225135.51 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$$ $$Área_2 = 369869.41 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2)$$ $$Área = 595004.92 \cdot \frac{kg \cdot m}{cm^2}$$

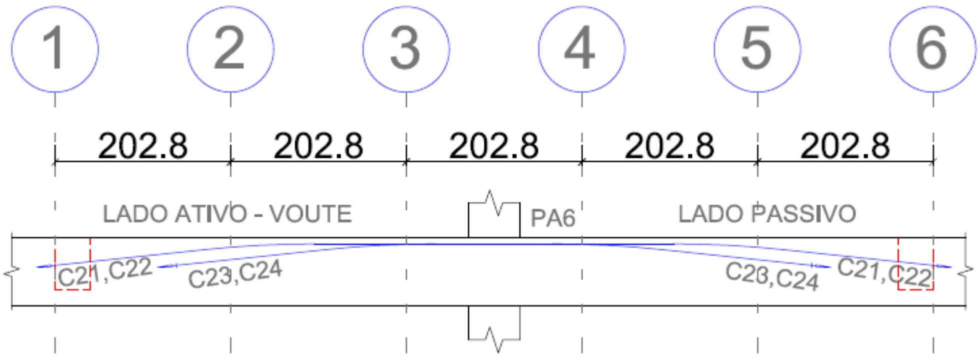
$$\sigma_m = \frac{Área}{L}$$ $$\sigma_m = 12531.7 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 49.20m$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 316 \cdot mm$$

CABOS C21=C22=C25=C26 (6ø15.2mm)



$t = tonne$

$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74\cdot fptk\,,0.82\cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 10.14m$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{rad}{m}$ $\quad n = 6$ $\quad i = 1,2..n$

$S = 0cm, \dfrac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 202.8 \\ 405.6 \\ 608.4 \\ 811.2 \\ 1014 \end{pmatrix} cm$ $\quad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 1.42 \\ 4.66 \\ 0 \\ 4.66 \\ 1.42 \end{pmatrix}°$ $\quad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 13.28 \\ 1.28 \\ 1.28 \\ 1.28 \\ 1.28 \end{pmatrix}°$

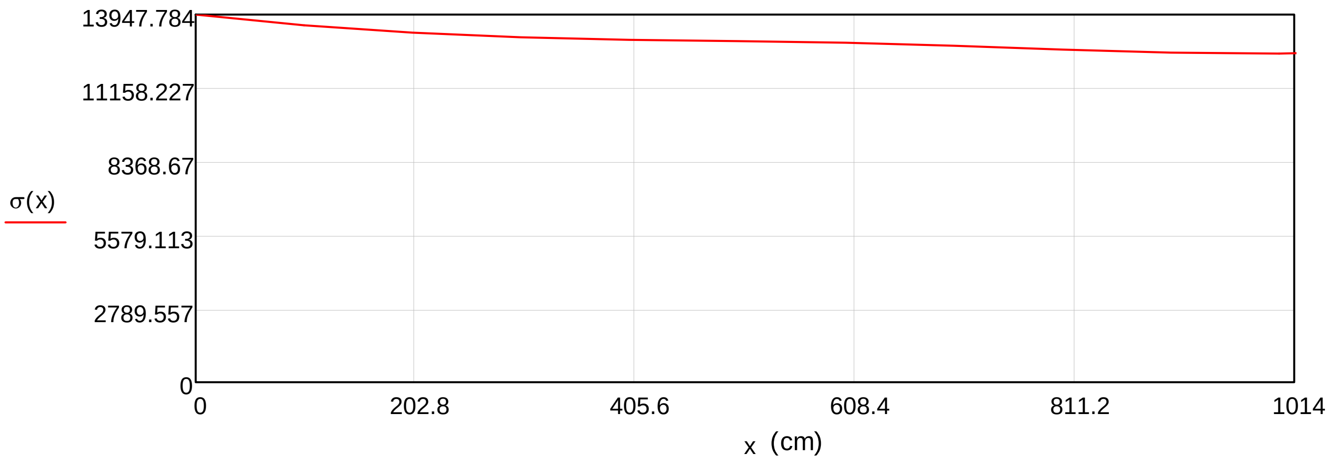
$$\alpha_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13258.57 \\ 12984.02 \\ 12873.82 \\ 12607.23 \\ 12472.69 \end{pmatrix}\cdot\frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 131509.53 \cdot \frac{kg \cdot m}{cm^2}$$

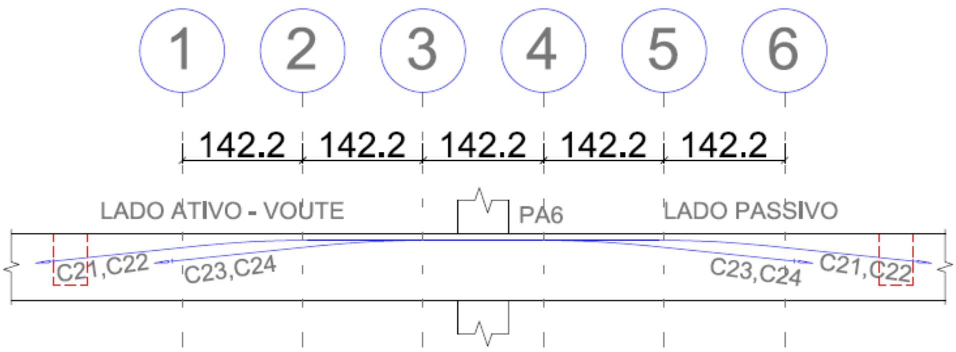
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12969.38 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 10.95m$ $\qquad$ $\text{Área}_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.6 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 73 \cdot mm$$

CABOS C23=C24=C27=C28 (6ø15.2mm)



$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 7.10\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}} \qquad n = 6 \qquad i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 142 \\ 284 \\ 426 \\ 568 \\ 710 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 5.89 \\ 0.37 \\ 5.89 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 16.89 \\ 0.89 \\ 0.89 \\ 0.89 \\ 0.89 \end{pmatrix}^{\circ}$$

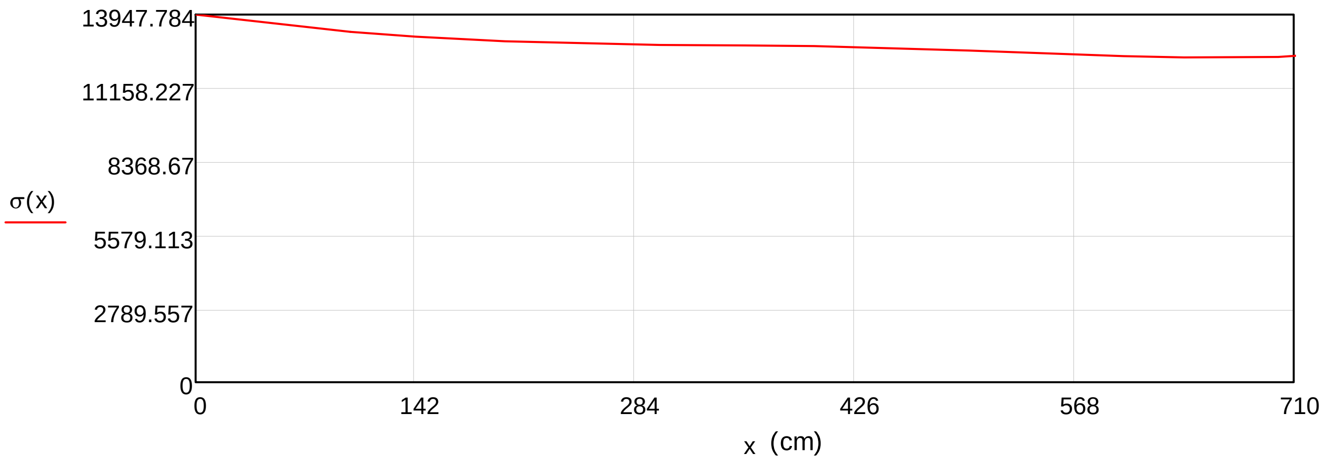
$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13111.94 \\ 12805.7 \\ 12726.49 \\ 12429.25 \\ 12355.55 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}\left(S, \sigma_{esq}\right)$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 91029.57 \cdot \frac{kg \cdot m}{cm^2}$$

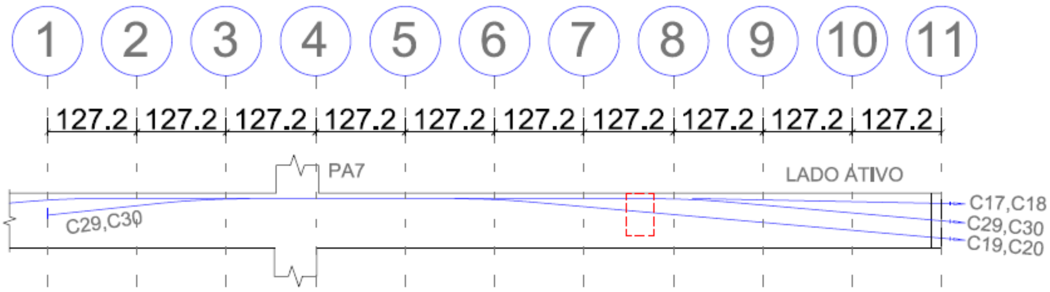
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12821.07 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 7.95m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.4 \cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right) \cdot \left(L_{cabo}\right)}{E_{teórico\_aço}} = 52 \cdot mm$$

CABOS C29=C30 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 12.72\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..\, n$

$$S = 0\text{cm}, \frac{L}{n-1}..\, L = \begin{pmatrix} 0 \\ 127.2 \\ 254.4 \\ 381.6 \\ 508.8 \\ 636 \\ 763.2 \\ 890.4 \\ 1017.6 \\ 1144.8 \\ 1272 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 4.48 \\ 1.59 \\ 0 \\ 0 \\ 0 \\ 1.5 \\ 3.6 \\ 0 \\ 0 \end{pmatrix}{}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \end{pmatrix}{}^{\circ}$$

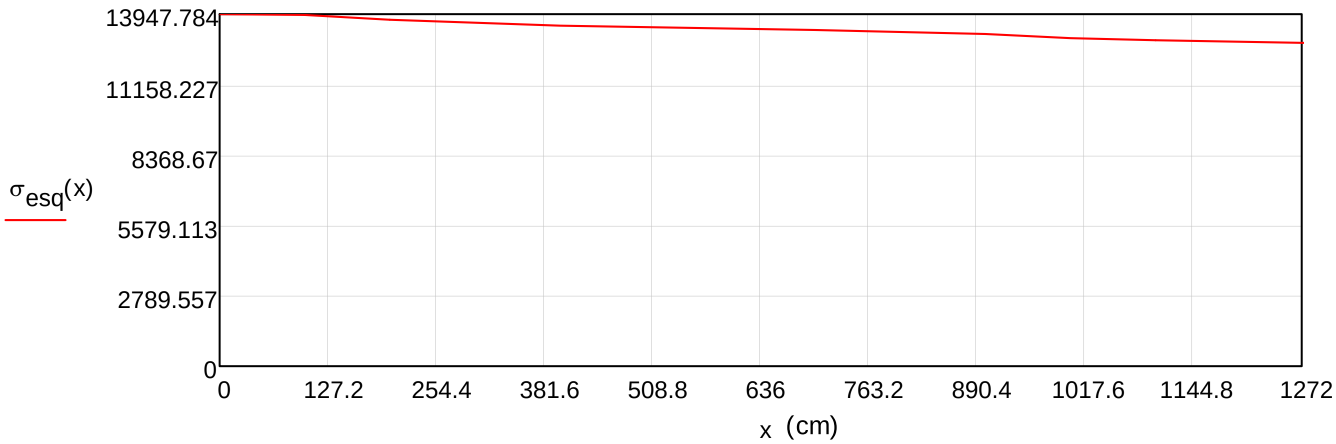
$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13873.55 \\ 13620.21 \\ 13501.46 \\ 13429.6 \\ 13358.12 \\ 13287.02 \\ 13174.85 \\ 12973.29 \\ 12904.25 \\ 12835.56 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\, dx \qquad Área = 169862.38 \cdot \frac{kg \cdot m}{cm^2}$$

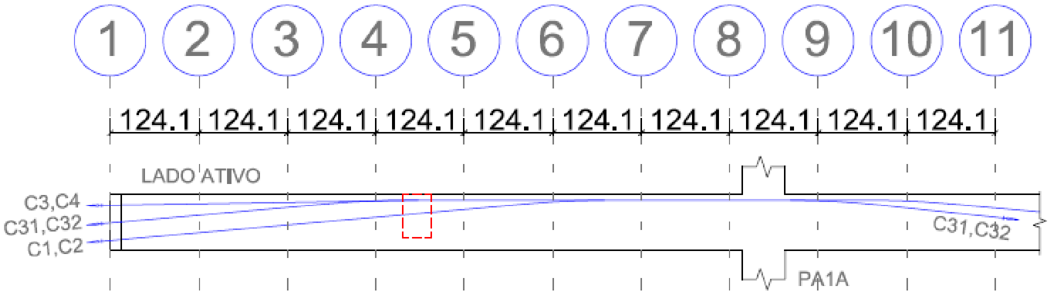
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13353.96 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 13.55m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.1 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 93 \cdot mm$$

CABOS C31=C32 (4ø15.2mm)



$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 12.41\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 124.1 \\ 248.2 \\ 372.3 \\ 496.4 \\ 620.5 \\ 744.6 \\ 868.7 \\ 992.8 \\ 1116.9 \\ 1241 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 3.14 \\ 1.95 \\ 0 \\ 0 \\ 0 \\ 1.9 \\ 4.18 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \end{pmatrix}°$$

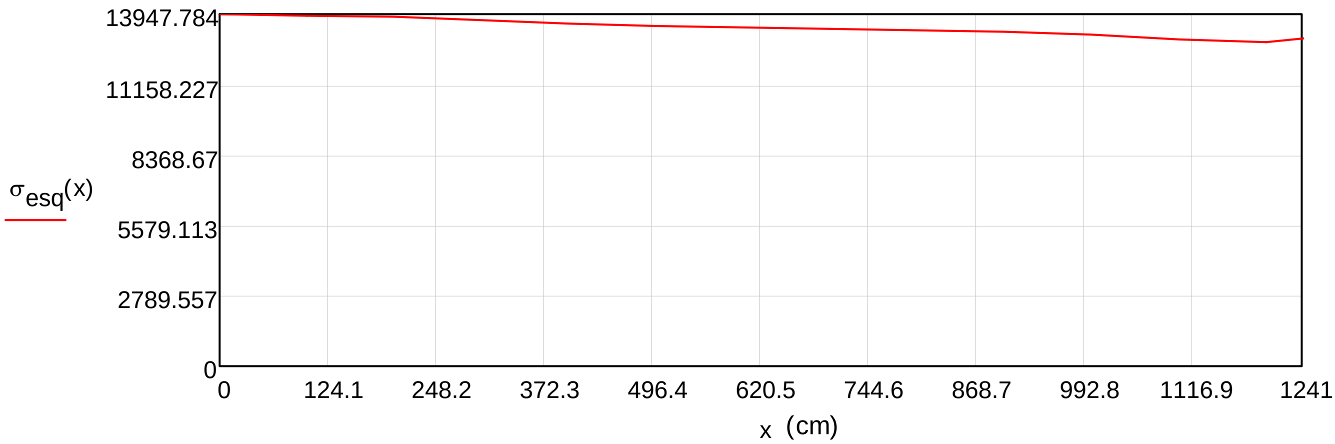
$$\alpha_i = \left| \begin{array}{ll} 0\text{rad} & \text{if } \; i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } \; i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13875.38 \\ 13803.35 \\ 13614.5 \\ 13481.55 \\ 13411.57 \\ 13341.95 \\ 13272.68 \\ 13145.2 \\ 12919.42 \\ 12852.36 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}\left(S, \sigma_{esq}\right)$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\,dx \qquad \text{Área} = 166596.34 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13424.36 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 13.25m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.3 \cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right) \cdot \left(L_{cabo}\right)}{E_{teórico\_aço}} = 91 \cdot mm$$

V3 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA (4ø15.2mm)

$b = 25\text{cm}$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 4\cdot\sigma_1\cdot\text{Área}_{teórica\_aço} = 784.58\,\text{kN}$

$a_0 = 18\text{cm}$ $\quad c = 7\text{cm}$

$d = 15\text{cm}$ $\quad a_1 = a_0 + c = 25\,\text{cm}$

$F_1 = F_{inicial}\cdot\cos(1°) = 784.46\,\text{kN}$ $\quad F_3 = F_{inicial}\cdot\cos(5°) = 781.59\,\text{kN}$

$$T_1 = 0.25\cdot F_1\cdot\left(1 - \frac{a_0}{a_1}\right) = 54.91\,\text{kN} \qquad T_3 = 0.25\cdot F_3\cdot\left(1 - \frac{a_0}{a_1}\right) = 54.71\,\text{kN}$$

$F_2 = F_{inicial}\cdot\cos(5°) = 781.59\,\text{kN}$

$$T_2 = 0.25\cdot F_2\cdot\left(1 - \frac{a_0}{a_1}\right) = 54.71\,\text{kN}$$

$a_2 = 2\cdot d + (n-1)\cdot b = 80\,\text{cm}$ $\quad k = 1..n$

$$F_k = \begin{pmatrix}784.46\\781.59\\781.59\end{pmatrix}\text{kN} \qquad T_k = \begin{pmatrix}54.91\\54.71\\54.71\end{pmatrix}\text{kN} \qquad \sum F = 2347.64\,\text{kN}$$

$$T_n = \frac{2}{3}\cdot\left(1 - \frac{n\cdot a_1}{a_2}\right)\cdot\sum F = 97.82\,\text{kN} \qquad fyd = 43.48\,\frac{\text{kN}}{\text{cm}^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.26\,\text{cm}^2 \qquad As_2 = q\cdot\left(\frac{T_n}{fyd}\right) = 4.5\,\text{cm}^2$$

$As_{fretagem} = As_1 = 1.26\,cm^2$

Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$$As_{estribos} = \frac{As_2}{2} = 2.25\,cm^2$$

EXTREMIDADE ATIVA (6ø15.2mm)

a_0 = Área da placa de distribuição

d = Distância entre a face do concreto ao eixo da ancoragem

n = Número de ancoragens

$n = 1$

$F_{inicial} = 6\cdot\sigma_1\cdot Área_{teórica\_aço} = 1176.86\,kN$

$a_0 = 22cm$

$d = 18.5cm$

$a_3 = 2\cdot d = 37\cdot cm$

$F = n\cdot F_{inicial}\cdot\cos(6°) = 1170.42\,kN$

$$T = 0.25\cdot F\cdot\left(1 - \frac{a_0}{a_3}\right) = 118.62\,kN$$

$$fyd = 43.48\,\frac{kN}{cm^2}$$

$$As_3 = \frac{T}{fyd} = 2.73\,cm^2$$

$$As_{estribos} = \frac{\max\left(As_2, As_3\right)}{2} = 2.25\,cm^2$$

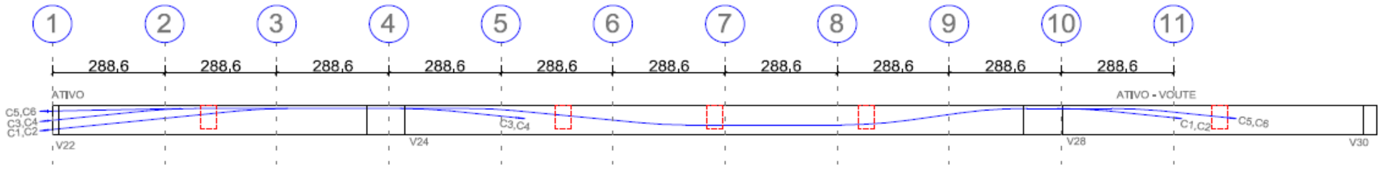
$L = \max\left(a_1, a_2, a_3\right) = 80\,cm$

$bitola_{estribo} = 10mm$

$$adotados = ceil\left[\frac{As_{estribos}}{\pi\frac{\left(bitola_{estribo}\right)^2}{4}}\right] = 3$$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V4 = V9 - CABOS C1 a C10



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 28.86\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2..\, n$

$$S = 0\text{cm}, \frac{L}{n-1}..\, L = \begin{pmatrix} 0 \\ 288.6 \\ 577.2 \\ 865.8 \\ 1154.4 \\ 1443 \\ 1731.6 \\ 2020.2 \\ 2308.8 \\ 2597.4 \\ 2886 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 4.61 \\ 1.39 \\ 4.14 \\ 1.61 \\ 5.75 \\ 0 \\ 8.28 \\ 8.78 \\ 5.58 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 19.88 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13776.8 \\ 13461.52 \\ 13275.26 \\ 12991.02 \\ 12805.14 \\ 12465.41 \\ 12312.6 \\ 11884.24 \\ 11451.24 \\ 10593.6 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 5.58 \\ 8.78 \\ 8.28 \\ 0 \\ 5.75 \\ 1.61 \\ 4.14 \\ 1.39 \\ 4.61 \\ 0 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \\ 1.88 \end{pmatrix}°$$

$$n = 11$$

$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

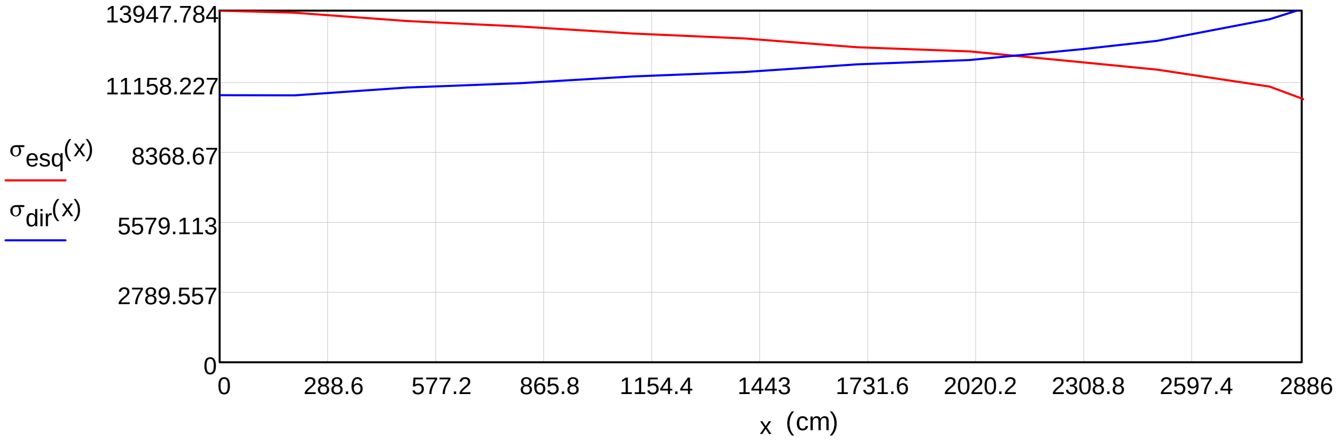
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12903.16 \\ 12433.05 \\ 12000.49 \\ 11853.38 \\ 11538.9 \\ 11373.8 \\ 11130.27 \\ 10976.27 \\ 10725.08 \\ 10593.6 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 2134.47 \cdot cm$

$\sigma_{\text{interseção}} = 12168.15 \cdot \frac{kg}{cm^2}$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx \qquad Área_1 = 279308.99 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx \qquad Área_2 = 96697.18 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 376006.17 \cdot \frac{kg \cdot m}{cm^2}$$

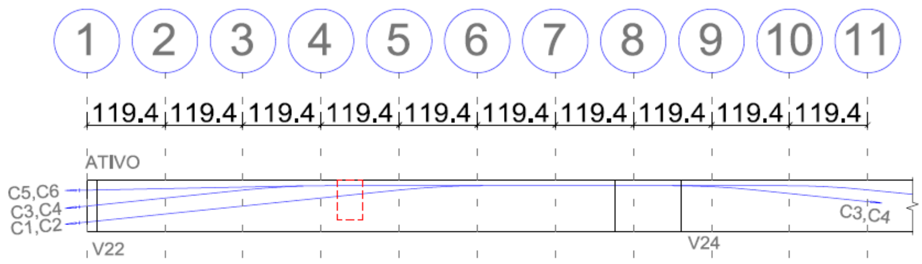
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13028.63 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 30.55m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 204 \cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 11.94m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 119.4 \\ 238.8 \\ 358.2 \\ 477.6 \\ 597 \\ 716.4 \\ 835.8 \\ 955.2 \\ 1074.6 \\ 1194 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 5.53 \\ 0.47 \\ 0 \\ 0 \\ 0 \\ 2.89 \\ 3.19 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \\ 0.78 \end{pmatrix} °$$

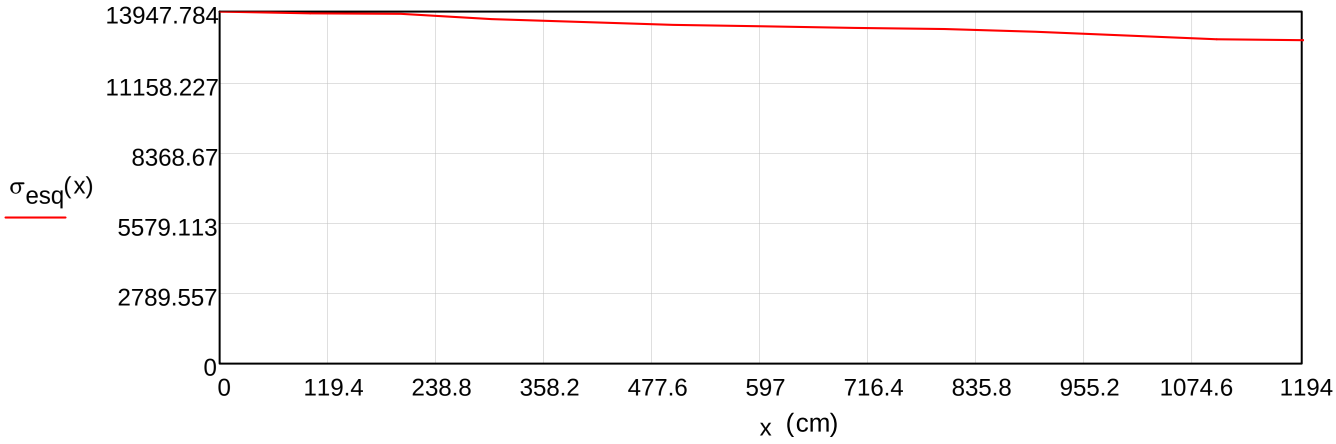
$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13876.68 \\ 13805.94 \\ 13507.12 \\ 13432.14 \\ 13363.66 \\ 13295.54 \\ 13227.76 \\ 13059.04 \\ 12879.41 \\ 12813.75 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline\left(S, \sigma_{esq}\right)$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\,dx \qquad \text{Área} = 159765.17 \cdot \frac{kg \cdot m}{cm^2}$$

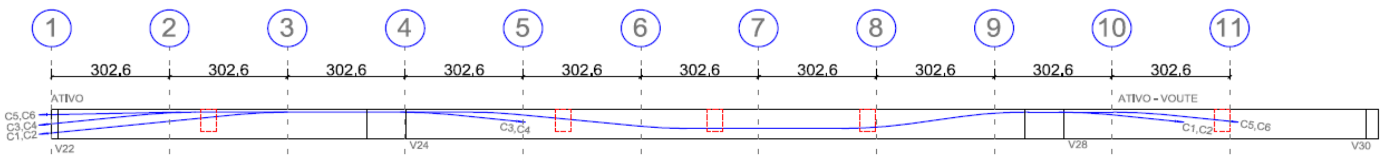
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13380.67 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 12.80m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.2 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 88 \cdot mm$$

CABOS C5=C6 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2 \qquad \text{fptk} = \frac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 30.26\,\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..n$$

$$S = 0\,\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 302.6 \\ 605.2 \\ 907.8 \\ 1210.4 \\ 1513 \\ 1815.6 \\ 2118.2 \\ 2420.8 \\ 2723.4 \\ 3026 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 1.17 \\ 0 \\ 5.75 \\ 0.18 \\ 5.57 \\ 4.3 \\ 0.06 \\ 4.24 \\ 6.07 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 18.97 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0\,\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13768.62 \\ 13576.52 \\ 13402.13 \\ 13041.61 \\ 12873.71 \\ 12534.85 \\ 12255.2 \\ 12097.74 \\ 11830.09 \\ 10968.96 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 6.07 \\ 4.24 \\ 0.06 \\ 4.3 \\ 5.57 \\ 0.18 \\ 5.75 \\ 0 \\ 1.17 \\ 0 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 18.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \end{pmatrix} \circ$$

$n = 11$

$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$

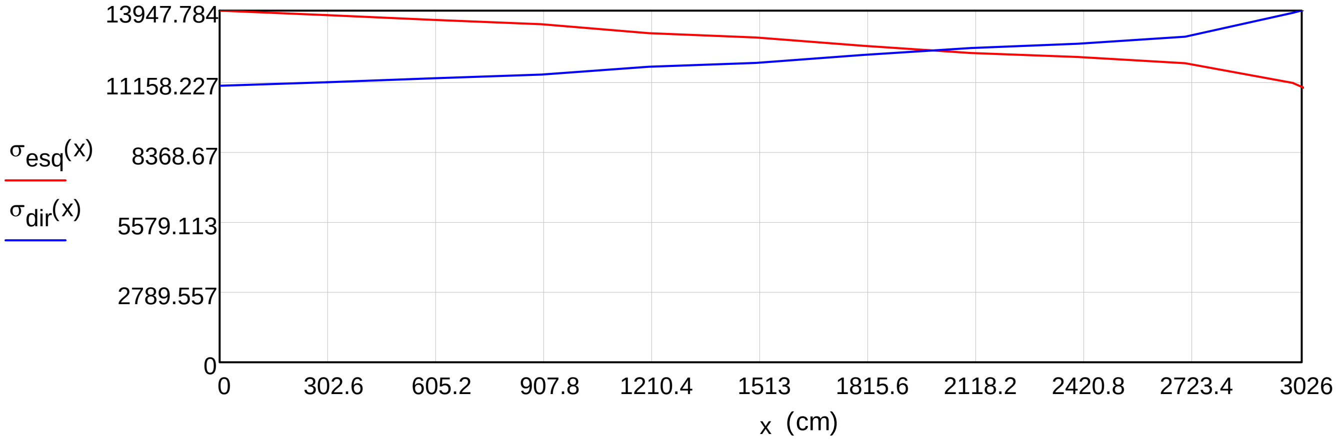
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12932.5 \\ 12646.39 \\ 12483.9 \\ 12205.39 \\ 11884.11 \\ 11731.12 \\ 11415.55 \\ 11268.92 \\ 11111.69 \\ 10968.96 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 1983.12 \cdot cm$

$\sigma_{\text{interseção}} = 12360.67 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 262694.52 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 134125.72 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 396820.24 \cdot \frac{kg \cdot m}{cm^2}$$

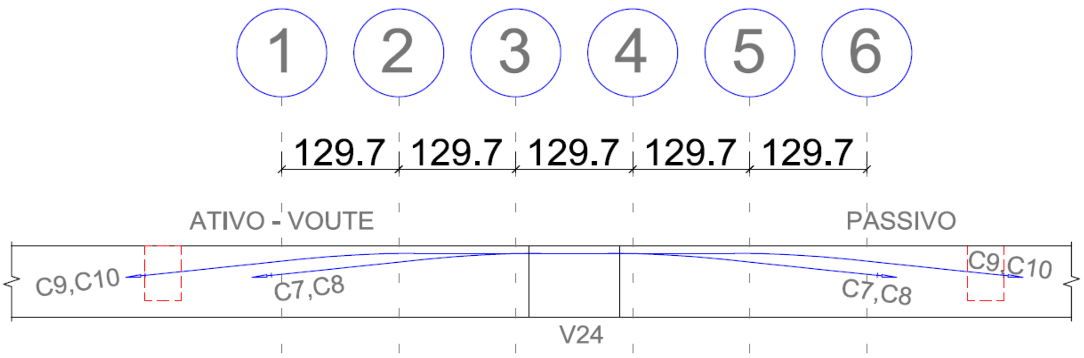
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13113.69 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 31.95m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 215 \cdot mm$$

CABOS C7=C8 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 6.49\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 6$ $\quad$ $i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 129.8 \\ 259.6 \\ 389.4 \\ 519.2 \\ 649 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 4.74 \\ 2.66 \\ 4.74 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 18.85 \\ 0.85 \\ 0.85 \\ 0.85 \\ 0.85 \end{pmatrix}^{\circ}$$

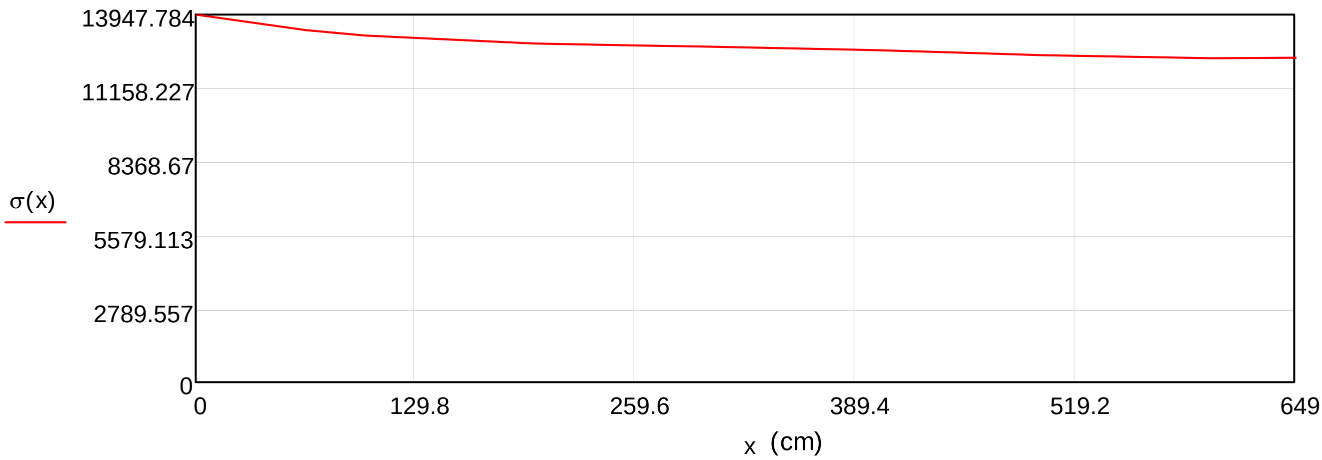
$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \ \ \text{if} \ \ i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \ \ \text{if} \ \ i > 1 \\ i\cdot\text{rad} \ \ \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13025.72 \\ 12775.38 \\ 12618.66 \\ 12376.14 \\ 12307.49 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 82798.44 \cdot \frac{kg \cdot m}{cm^2}$$

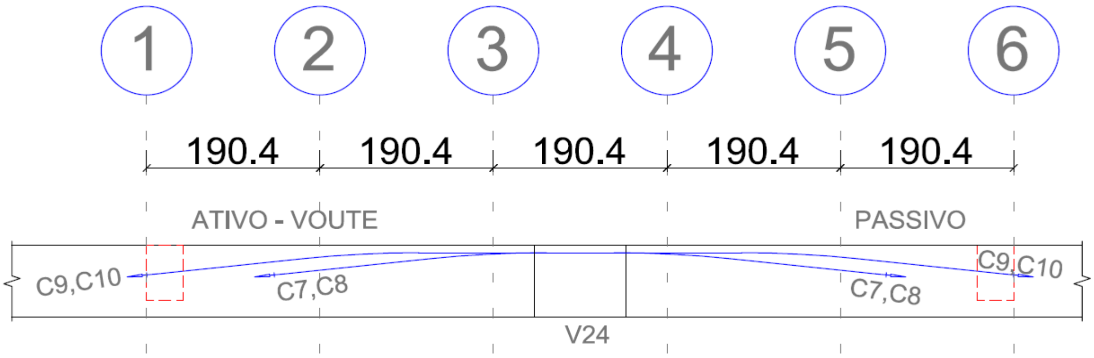
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12757.85 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 7.30m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 48 \cdot mm$$

CABOS C9=C10 (4ø15.2mm)



$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 9.52\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 6$ $\quad$ $i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 190.4 \\ 380.8 \\ 571.2 \\ 761.6 \\ 952 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.87 \\ 5.2 \\ 0 \\ 5.2 \\ 0.87 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.24 \\ 1.24 \\ 1.24 \\ 1.24 \\ 1.24 \end{pmatrix}°$$

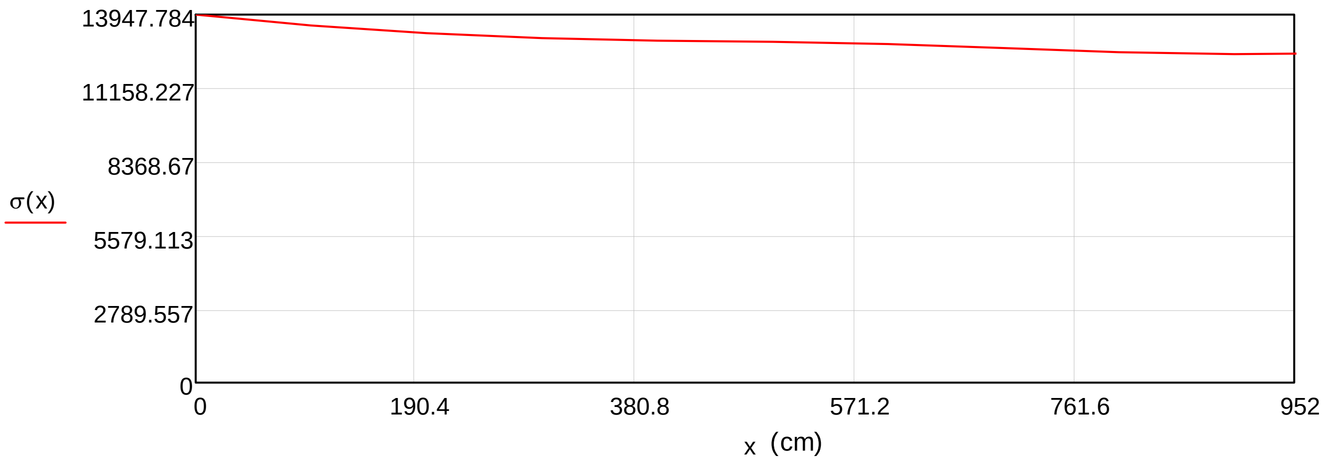
$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13265.9 \\ 12971.16 \\ 12866.05 \\ 12580.19 \\ 12466.29 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\, dx \qquad \text{Área} = 123381.78 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12960.27 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 10.35m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.6 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 69 \cdot mm$$

V4 = V9 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA (Esquerda)

$b = 25cm$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 4 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 784.58\,kN$

$a_0 = 18cm$ $\quad c = 7cm$

$d = 15cm$ $\quad a_1 = a_0 + c = 25\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 784.46\,kN$ $\quad F_3 = F_{inicial} \cdot \cos(5°) = 781.59\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.91\,kN \qquad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,kN$$

$F_2 = F_{inicial} \cdot \cos(5°) = 781.59\,kN$

$$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,kN$$

$a_2 = 2 \cdot d + (n-1) \cdot b = 80\,cm$ $\quad k = 1..n$

$$F_k = \begin{pmatrix} 784.46 \\ 781.59 \\ 781.59 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 54.91 \\ 54.71 \\ 54.71 \end{pmatrix} kN \qquad \sum F = 2347.64\,kN$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 97.82\,kN \qquad fyd = 43.48 \frac{kN}{cm^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.26\,cm^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 4.5\,cm^2$$

$As_{fretagem} = As_1 = 1.26\,cm^2$

Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa e passiva.

$As_{estribos} = \frac{As_2}{2} = 2.25\,cm^2$

EXTREMIDADE ATIVA (Direita)

a_0 = Área da placa de distribuição

d = Distância entre a face do concreto ao eixo da ancoragem

n = Número de ancoragens

$n = 1$

$F_{inicial} = 4 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 784.58\,kN$

$a_0 = 18cm$

$d = 33cm$

$a_3 = 2 \cdot d = 66 \cdot cm$

$F = n \cdot F_{inicial} \cdot \cos(6°) = 780.28\,kN$

$T = 0.25 \cdot F \cdot \left(1 - \frac{a_0}{a_3}\right) = 141.87\,kN$

$fyd = 43.48\,\frac{kN}{cm^2}$

$As_3 = \frac{T}{fyd} = 3.26\,cm^2$

$As_{estribos} = \frac{\max(As_2, As_3)}{2} = 2.25\,cm^2$

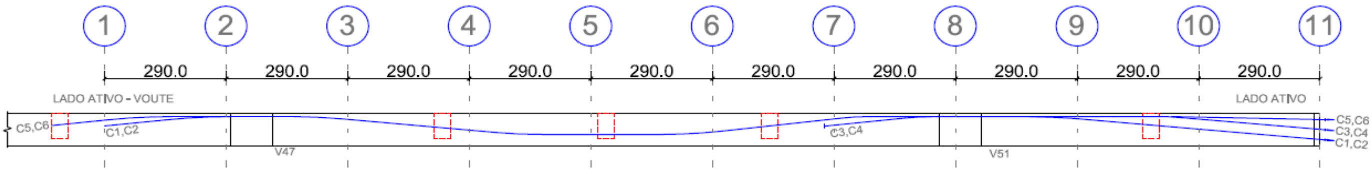
$L = \max(a_1, a_2, a_3) = 80\,cm$

$bitola_{estribo} = 10mm$

$adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 3$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V6 - CABOS C1 a C14



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 29.00\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 290 \\ 580 \\ 870 \\ 1160 \\ 1450 \\ 1740 \\ 2030 \\ 2320 \\ 2610 \\ 2900 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 5.58 \\ 5.68 \\ 0 \\ 5.26 \\ 5.65 \\ 0.91 \\ 6.56 \\ 5.1 \\ 0 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 19.89 \end{pmatrix}^{\circ}$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13584.86 \\ 13227 \\ 13064.03 \\ 12737.53 \\ 12403.22 \\ 12241.53 \\ 11884.13 \\ 11593.19 \\ 11450.36 \\ 10620.56 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 5.1 \\ 6.56 \\ 0.91 \\ 5.65 \\ 5.26 \\ 0 \\ 5.68 \\ 5.58 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \end{pmatrix} \circ$$

$n = 11$

$$\theta_i = \begin{cases} 0rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$

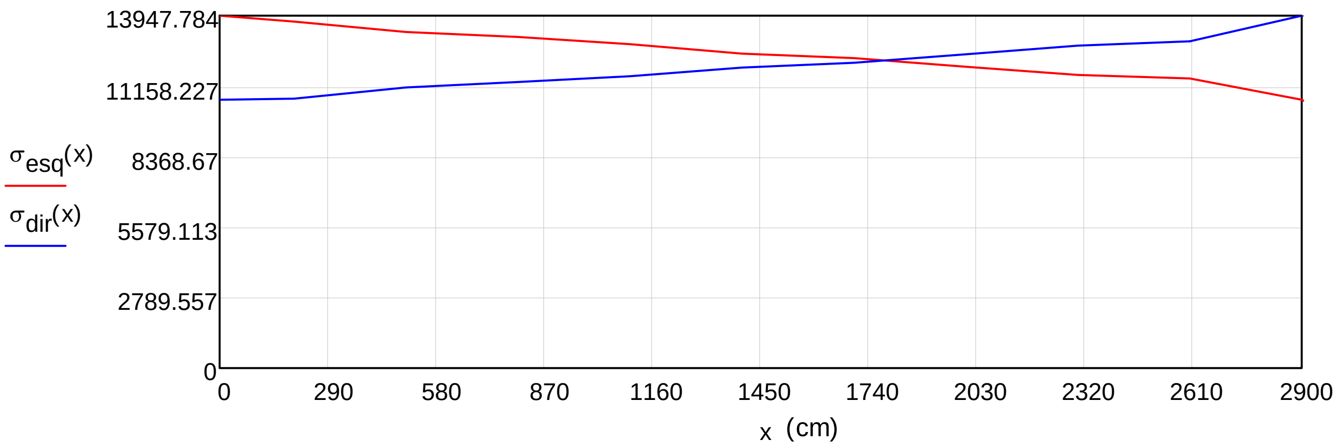
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12937 \\ 12777.61 \\ 12464.8 \\ 12100.88 \\ 11943.13 \\ 11629.67 \\ 11339.02 \\ 11199.31 \\ 10904.29 \\ 10620.56 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 1809.16 \cdot cm$

$\sigma_{\text{interseção}} = 12174.15 \cdot \frac{kg}{cm^2}$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx \qquad Área_1 = 234965.82 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx \qquad Área_2 = 140052.31 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 375018.12 \cdot \frac{kg \cdot m}{cm^2}$$

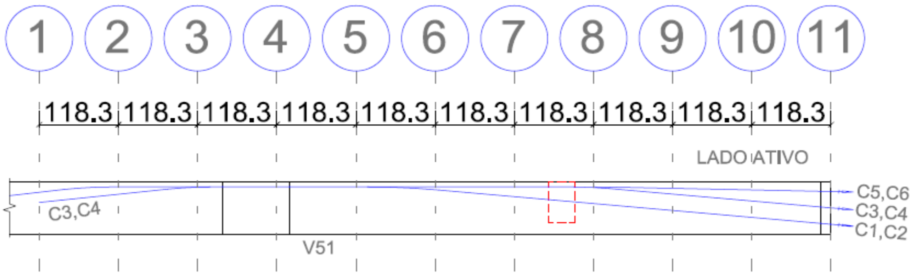
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12931.66 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 30.70m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.5 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 204 \cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 11.83m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S := 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 118.3 \\ 236.6 \\ 354.9 \\ 473.2 \\ 591.5 \\ 709.8 \\ 828.1 \\ 946.4 \\ 1064.7 \\ 1183 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} := \begin{pmatrix} 0 \\ 0 \\ 4.23 \\ 1.84 \\ 0 \\ 0 \\ 0 \\ 2.9 \\ 2.19 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} := \begin{pmatrix} 0 \\ 0.77 \\ 0.77 \\ 0.77 \\ 0.77 \\ 0.77 \\ 0.77 \\ 0.77 \\ 0.77 \\ 0.77 \\ 0.77 \end{pmatrix}°$$

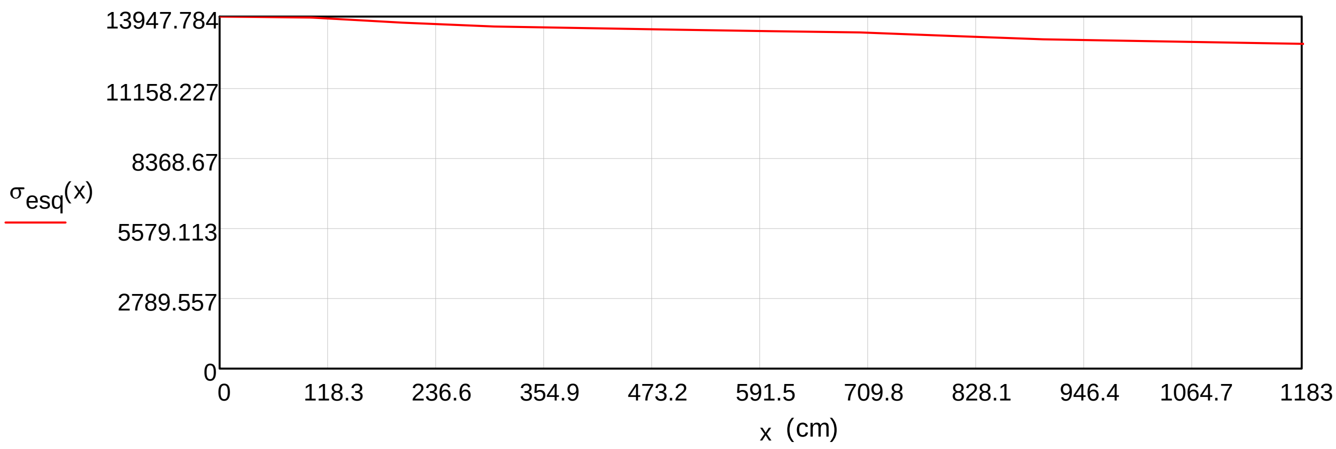
$$\alpha_i := \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} := \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13877.47 \\ 13638.45 \\ 13511.81 \\ 13443.7 \\ 13375.93 \\ 13308.5 \\ 13138.71 \\ 13001.88 \\ 12936.33 \\ 12871.12 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a := \mathrm{cspline}\left(S, \sigma_{esq}\right)$$

$$\sigma_{esq}(x) := \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\,dx \qquad Área = 158121.57 \cdot \frac{kg \cdot m}{cm^2}$$

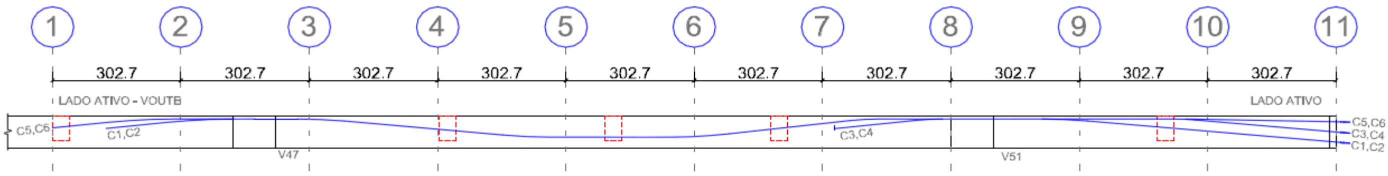
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13366.15 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 12.65m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.2 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 87 \cdot mm$$

CABOS C5=C6 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 30.27m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 302.7 \\ 605.4 \\ 908.1 \\ 1210.8 \\ 1513.5 \\ 1816.2 \\ 2118.9 \\ 2421.6 \\ 2724.3 \\ 3027 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 6 \\ 0 \\ 5.26 \\ 5.26 \\ 2.58 \\ 3.98 \\ 6.56 \\ 0 \\ 1.17 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 13.97 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13561.33 \\ 13387.11 \\ 13047.96 \\ 12717.4 \\ 12498.22 \\ 12231.7 \\ 11870.64 \\ 11718.13 \\ 11554.62 \\ 10938.26 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 1.17 \\ 0 \\ 6.56 \\ 3.98 \\ 2.58 \\ 5.26 \\ 5.26 \\ 0 \\ 6 \end{pmatrix}^{\circ} \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 13.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \end{pmatrix}^{\circ}$$

$$n = 11$$

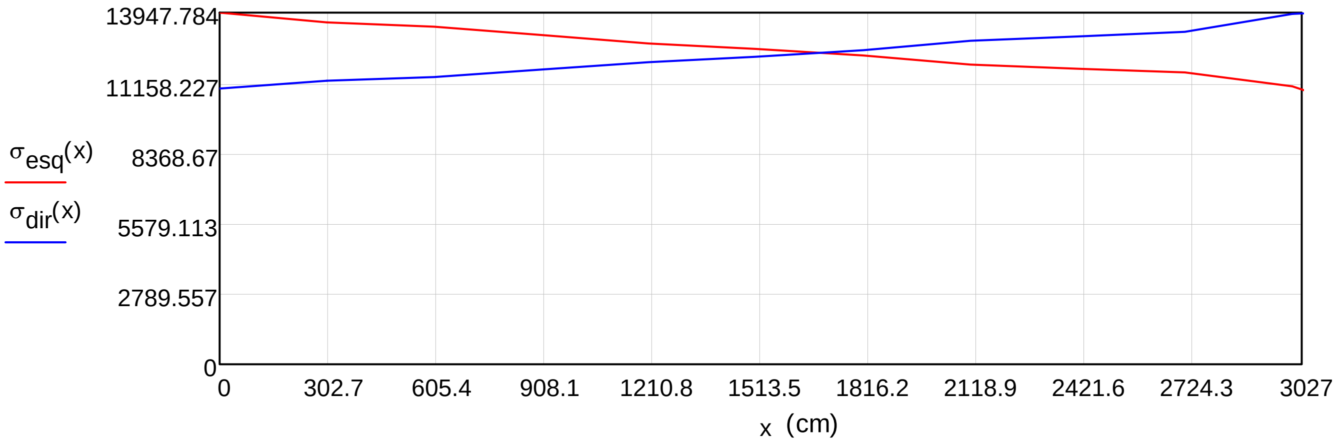
$$\theta_i = \left| \begin{array}{ll} 0rad & \text{if } \; i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } \; i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu\cdot\theta+\kappa\cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13203.77 \\ 13019.53 \\ 12852.26 \\ 12472.88 \\ 12206.9 \\ 11996.51 \\ 11692.59 \\ 11396.37 \\ 11249.96 \\ 10938.26 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq}) \qquad b = \text{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$$c = \frac{L}{2} \qquad d = 0m$$

Given

$$d = \sigma_{esq}(c) \qquad d = \sigma_{dir}(c)$$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d) \qquad \text{interseção} = 1685.5 \cdot cm$$

$$\sigma_{\text{interseção}} = 12364.24 \cdot \frac{kg}{cm^2}$$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 220862.04 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 174575.62 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 395437.67 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13063.68 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 31.95m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 214 \cdot mm$$

CABOS C7=C8 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 6.49\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 6$ $\quad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 129.8 \\ 259.6 \\ 389.4 \\ 519.2 \\ 649 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 4.74 \\ 2.66 \\ 4.74 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 18.85 \\ 0.85 \\ 0.85 \\ 0.85 \\ 0.85 \end{pmatrix}^{\circ}$$

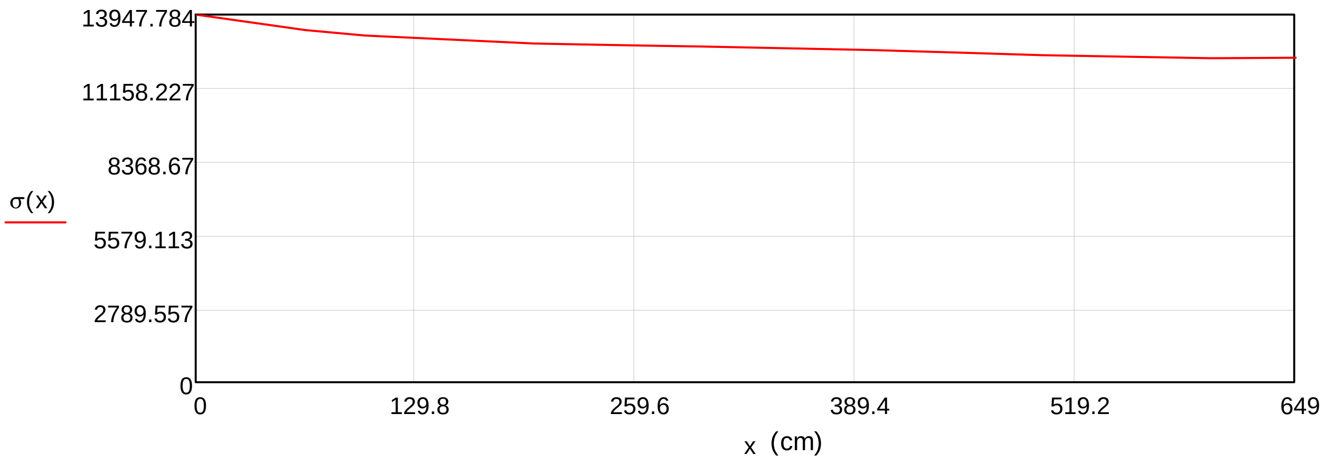
$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13025.72 \\ 12775.38 \\ 12618.66 \\ 12376.14 \\ 12307.49 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$a = \text{cspline}\left(S, \sigma_{esq}\right)$

$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$



$\text{Área} = \int_0^L \sigma(x)\,dx$ $\text{Área} = 82798.44 \cdot \frac{kg \cdot m}{cm^2}$

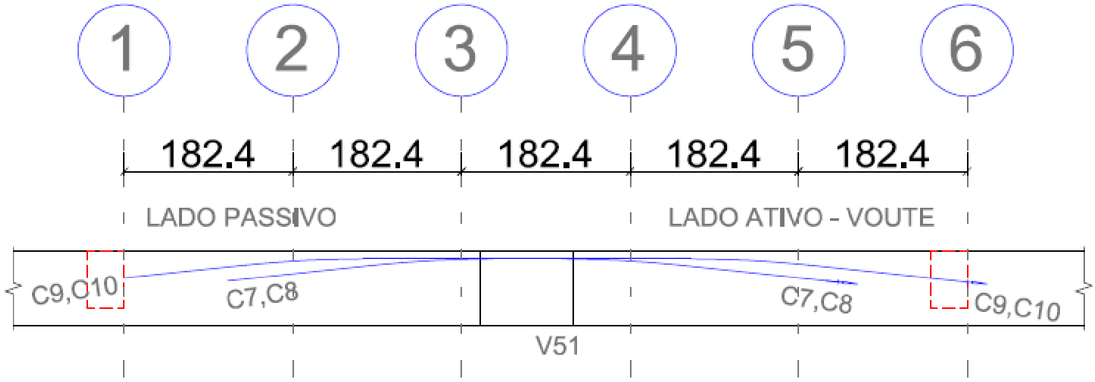
$\sigma_m = \frac{\text{Área}}{L}$ $\sigma_m = 12757.85 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 7.30m$ $\text{Área}_{teórica\_aço} = 143.4 \cdot mm^2$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 48 \cdot mm$

CABOS C9=C10 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2 \qquad \text{fptk} = \frac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 9.12\,\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 6 \qquad i = 1, 2 .. n$$

$$S = 0\,\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 182.4 \\ 364.8 \\ 547.2 \\ 729.6 \\ 912 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.48 \\ 5.59 \\ 0 \\ 3.67 \\ 2.41 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.19 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \end{pmatrix}^{\circ}$$

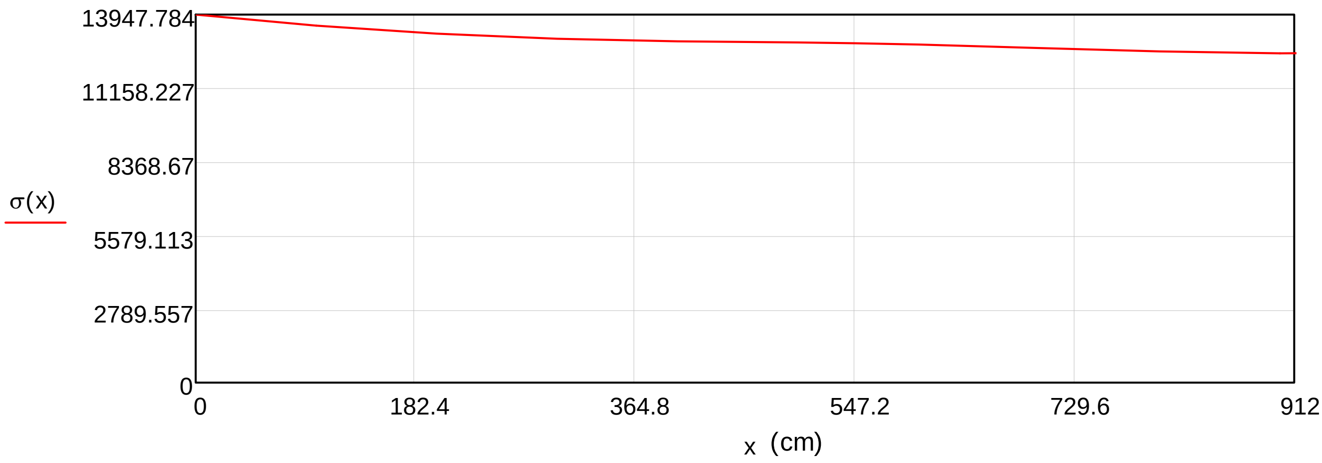
$$\alpha_i = \begin{cases} 0\,\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13271.25 \\ 12961.75 \\ 12861.01 \\ 12642.76 \\ 12479.1 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \mathrm{cspline}\left(S, \sigma_{esq}\right)$$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma(x)\,dx \qquad Área = 118339.1 \cdot \frac{kg \cdot m}{cm^2}$$

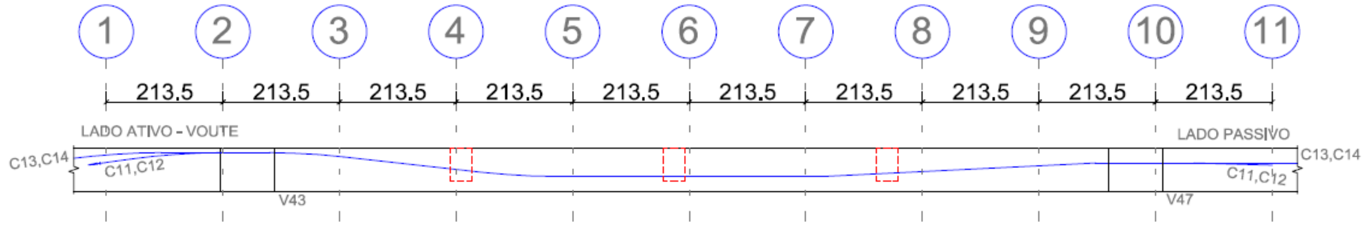
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12975.78 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 9.95m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.6 \cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right) \cdot \left(L_{cabo}\right)}{E_{teórico\_aço}} = 66 \cdot mm$$

CABOS C11=C12 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 21.35\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 213.5 \\ 427 \\ 640.5 \\ 854 \\ 1067.5 \\ 1281 \\ 1494.5 \\ 1708 \\ 1921.5 \\ 2135 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 7.38 \\ 6.26 \\ 1.02 \\ 6.52 \\ 0 \\ 0 \\ 2.88 \\ 0 \\ 2.88 \\ 1.54 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 19.39 \\ 1.39 \\ 1.39 \\ 1.39 \\ 1.39 \\ 1.39 \\ 1.39 \\ 1.39 \\ 1.39 \\ 1.39 \end{pmatrix}°$$

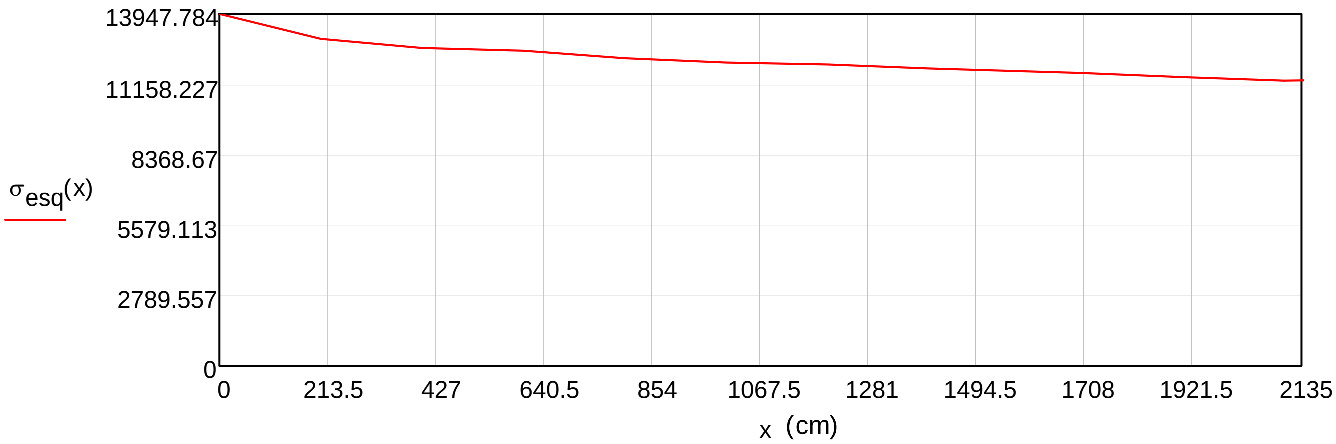
$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12918.11 \\ 12578.34 \\ 12449.6 \\ 12111.4 \\ 12001.43 \\ 11892.45 \\ 11710.32 \\ 11603.99 \\ 11426.28 \\ 11295.5 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\, dx \qquad Área = 258741.41 \cdot \frac{kg \cdot m}{cm^2}$$

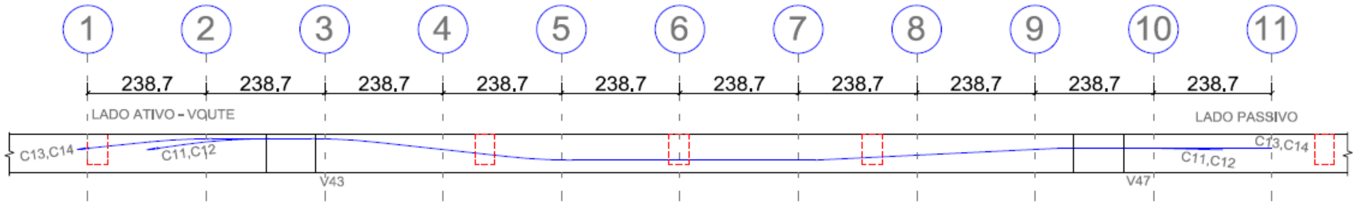
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12119.04 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 22.20m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 17.4 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 138 \cdot mm$$

CABOS C13=C14 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk\,,\,0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 23.87m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 238.7 \\ 477.4 \\ 716.1 \\ 954.8 \\ 1193.5 \\ 1432.2 \\ 1670.9 \\ 1909.6 \\ 2148.3 \\ 2387 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 5.43 \\ 1.95 \\ 5.21 \\ 5.43 \\ 1.09 \\ 0 \\ 2.88 \\ 0 \\ 2.88 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 13.55 \\ 1.55 \\ 1.55 \\ 1.55 \\ 1.55 \\ 1.55 \\ 1.55 \\ 1.55 \\ 1.55 \\ 1.55 \end{pmatrix}°$$

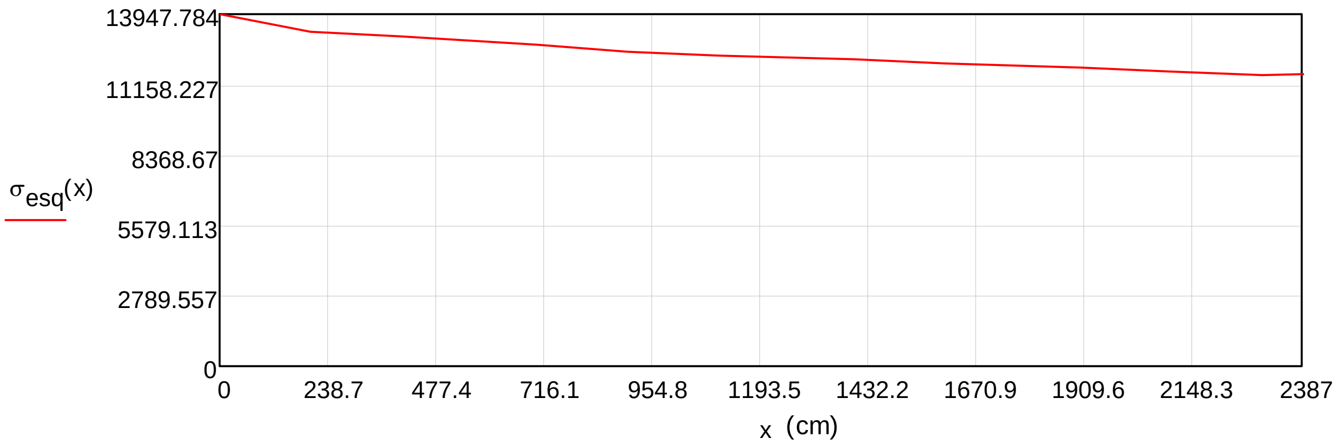
$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13191.75 \\ 13015.26 \\ 12709.81 \\ 12402.39 \\ 12261.95 \\ 12137.7 \\ 11942.76 \\ 11821.75 \\ 11631.89 \\ 11514.03 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\, dx \qquad \text{Área} = 295351.8 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12373.35 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 24.70m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 17.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 157 \cdot mm$$

V6 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA (Direita)

$b = 25cm$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 4 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 784.58\,kN$

$a_0 = 18cm$ $\quad c = 7cm$

$d = 15cm$ $\quad a_1 = a_0 + c = 25\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 784.46\,kN$ $\quad F_3 = F_{inicial} \cdot \cos(5°) = 781.59\,kN$

$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.91\,kN$ $\quad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,kN$

$F_2 = F_{inicial} \cdot \cos(5°) = 781.59\,kN$

$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,kN$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 80\,cm$ $\quad k = 1..n$

$F_k = \begin{pmatrix} 784.46 \\ 781.59 \\ 781.59 \end{pmatrix} kN$ $\quad T_k = \begin{pmatrix} 54.91 \\ 54.71 \\ 54.71 \end{pmatrix} kN$ $\quad \sum F = 2347.64\,kN$

$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 97.82\,kN$ $\quad fyd = 43.48 \frac{kN}{cm^2}$

$As_1 = \frac{\max(T)}{fyd} = 1.26\,cm^2$ $\quad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 4.5\,cm^2$

$As_{fretagem} = As_1 = 1.26\,cm^2$

Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$$As_{estribos} = \frac{As_2}{2} = 2.25\,cm^2$$

EXTREMIDADE ATIVA (Esquerda)

a_0 = Área da placa de distribuição

d = Distância entre a face do concreto ao eixo da ancoragem

n = Número de ancoragens

$n = 1$

$F_{inicial} = 4 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 784.58\,kN$

$a_0 = 22cm$

$d = 18.5cm$

$a_3 = 2 \cdot d = 37 \cdot cm$

$F = n \cdot F_{inicial} \cdot \cos(6°) = 780.28\,kN$

$$T = 0.25 \cdot F \cdot \left(1 - \frac{a_0}{a_3}\right) = 79.08\,kN$$

$$fyd = 43.48\,\frac{kN}{cm^2}$$

$$As_3 = \frac{T}{fyd} = 1.82\,cm^2$$

$$As_{estribos} = \frac{\max(As_2, As_3)}{2} = 2.25\,cm^2$$

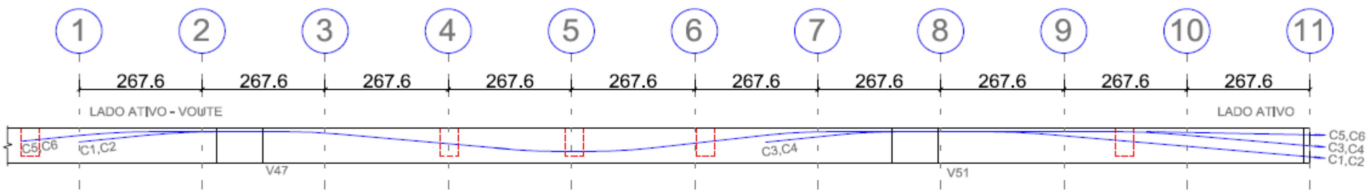
$L = \max(a_1, a_2, a_3) = 80\,cm$

$bitola_{estribo} = 10mm$

$$adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 3$$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V10 = V17 = V19 - CABOS C1 a C14



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01 \dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 26.76m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 11$ $\quad i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 267.6 \\ 535.2 \\ 802.8 \\ 1070.4 \\ 1338 \\ 1605.6 \\ 1873.2 \\ 2140.8 \\ 2408.4 \\ 2676 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 4.72 \\ 5.33 \\ 1.22 \\ 5.26 \\ 6.56 \\ 5.24 \\ 1.32 \\ 5.1 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 19.8 \\ 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \\ 1.8 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha + \kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12921.81 \\ 12602.91 \\ 12440.84 \\ 12136.61 \\ 11788.56 \\ 11501.04 \\ 11350.87 \\ 11079.13 \\ 10950.97 \\ 10824.29 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 5.1 \\ 1.32 \\ 5.24 \\ 6.56 \\ 5.26 \\ 1.22 \\ 5.33 \\ 4.72 \end{pmatrix} °
\qquad
\Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 19.89 \end{pmatrix} °$$

$$n = 11$$

$$\theta_i = \begin{cases} 0\,rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$

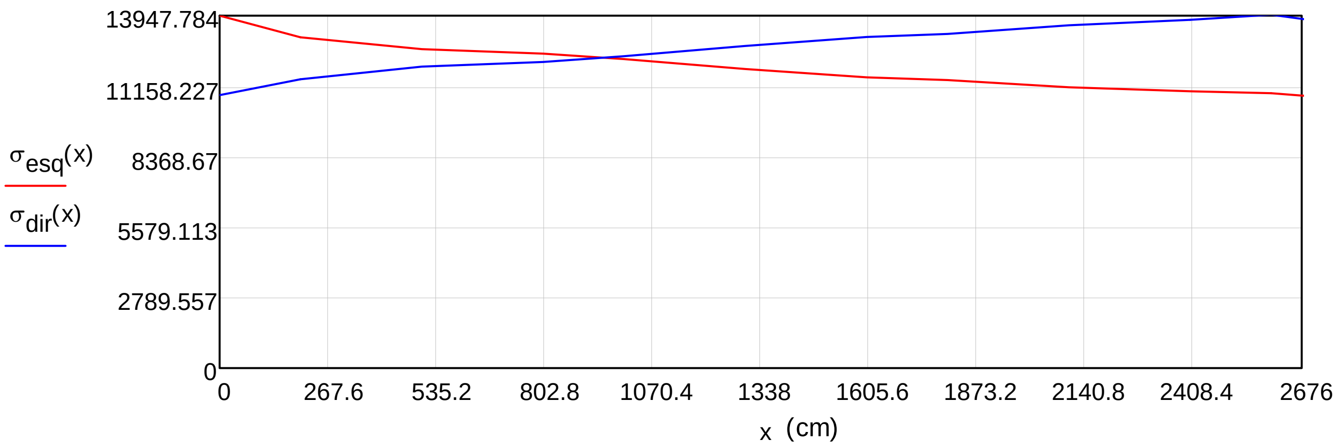
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13782.11 \\ 13618.4 \\ 13290.96 \\ 13114.07 \\ 12792.88 \\ 12424.95 \\ 12119.85 \\ 11960.87 \\ 11664.47 \\ 10803.16 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = cspline(S, \sigma_{esq})$

$b = cspline(S, \sigma_{dir})$

$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = interp\left(\frac{b}{g}, S, \frac{reverse(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$

$interseção = 951.7 \cdot cm$

$\sigma_{interseção} = 12286.55 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 121726.93 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 228412.55 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 350139.48 \cdot \frac{kg \cdot m}{cm^2}$$

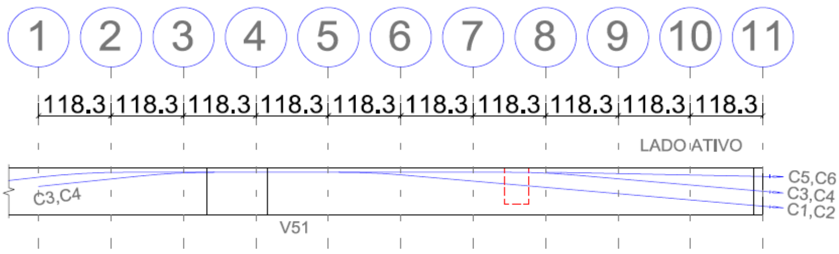
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13084.43 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 28.45m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 191 \cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 11.83m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S := 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 118.3 \\ 236.6 \\ 354.9 \\ 473.2 \\ 591.5 \\ 709.8 \\ 828.1 \\ 946.4 \\ 1064.7 \\ 1183 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} := \begin{pmatrix} 0 \\ 0 \\ 3.63 \\ 2.44 \\ 0 \\ 0 \\ 0 \\ 2.77 \\ 2.33 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} := \begin{pmatrix} 0 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \\ 0.8 \end{pmatrix}°$$

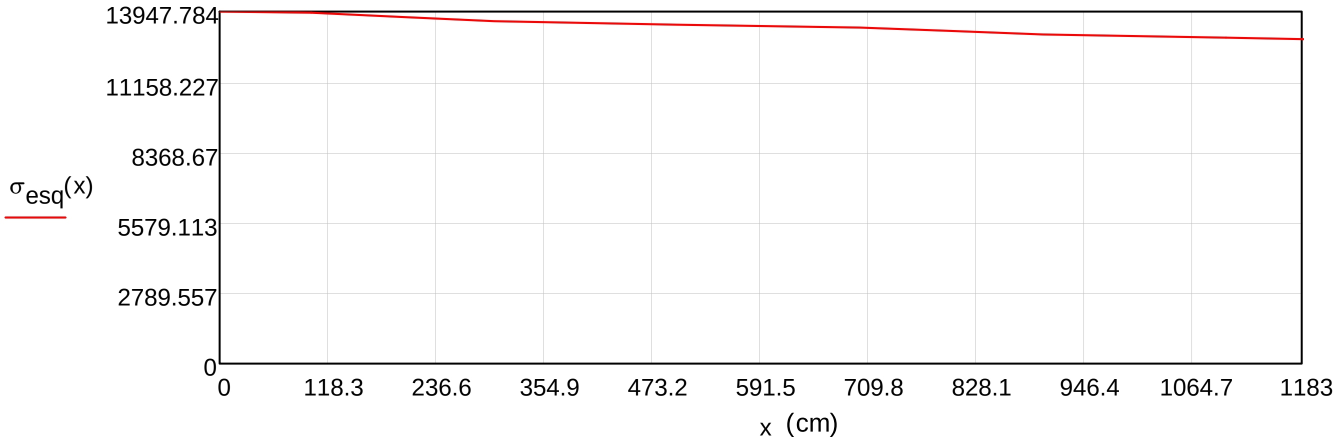
$$\alpha_i := \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} := \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13876.02 \\ 13664.77 \\ 13510.83 \\ 13441.31 \\ 13372.16 \\ 13303.35 \\ 13139.01 \\ 12995.72 \\ 12928.86 \\ 12862.34 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a := cspline\left(S, \sigma_{esq}\right)$$

$$\sigma_{esq}(x) := interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\,dx \qquad \text{Área} = 158110.01 \cdot \frac{kg \cdot m}{cm^2}$$

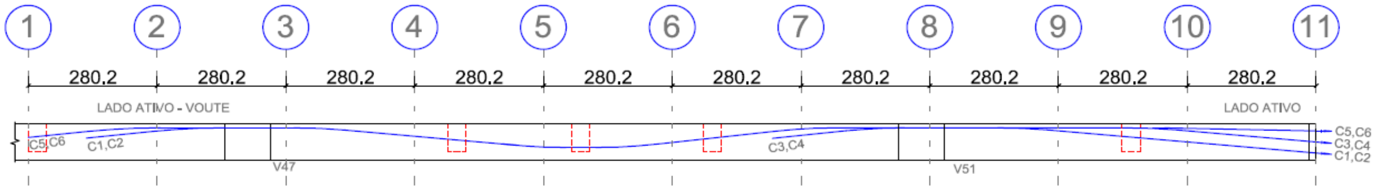
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13365.17 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 12.65m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.2 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 87 \cdot mm$$

CABOS C5=C6 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk\,,0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 28.02m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1\,,2\,..\,n$$

$$S = 0cm\,, \frac{L}{n-1}\,..\,L = \begin{pmatrix} 0 \\ 280.2 \\ 560.4 \\ 840.6 \\ 1120.8 \\ 1401 \\ 1681.2 \\ 1961.4 \\ 2241.6 \\ 2521.8 \\ 2802 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 5.72 \\ 0.28 \\ 5.26 \\ 2.89 \\ 8.93 \\ 2.76 \\ 3.8 \\ 0 \\ 1.17 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 13.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13161.31 \\ 13000.76 \\ 12678.32 \\ 12456.42 \\ 11998.36 \\ 11792.8 \\ 11554.45 \\ 11414.33 \\ 11262.81 \\ 11126.22 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 1.17 \\ 0 \\ 3.8 \\ 2.76 \\ 8.93 \\ 2.89 \\ 5.26 \\ 0.28 \\ 5.72 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 1.89 \\ 13.89 \end{pmatrix} °$$

$$n = 11$$

$$\theta_i = \begin{cases} 0rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

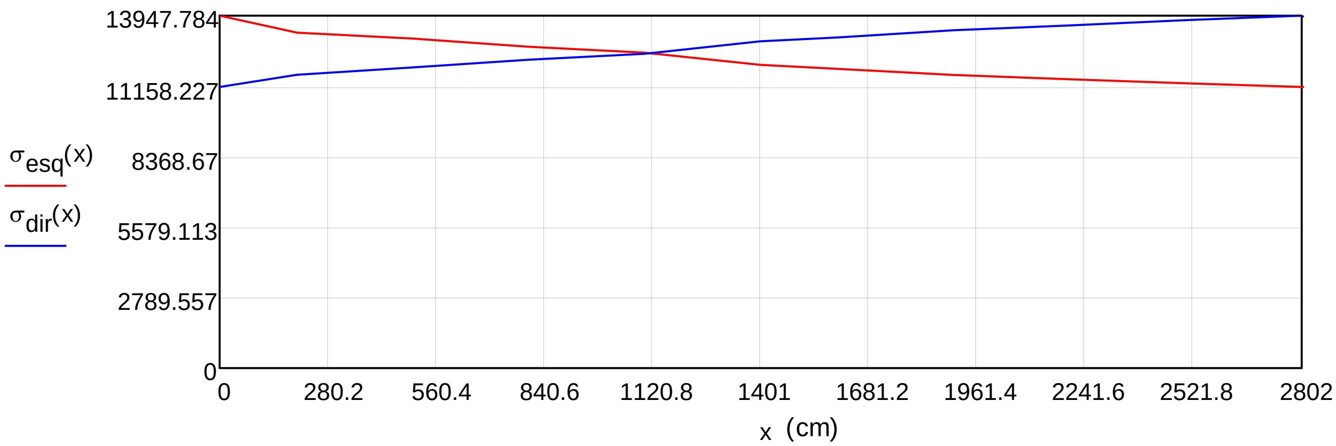
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13778.64 \\ 13595.73 \\ 13430.86 \\ 13159.4 \\ 12933.95 \\ 12458.33 \\ 12240.27 \\ 11936.7 \\ 11791.09 \\ 11126.22 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 1119.94 \cdot cm$

$\sigma_{\text{interseção}} = 12457.5 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 145453.58 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 224793.55 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 370247.12 \cdot \frac{kg \cdot m}{cm^2}$$

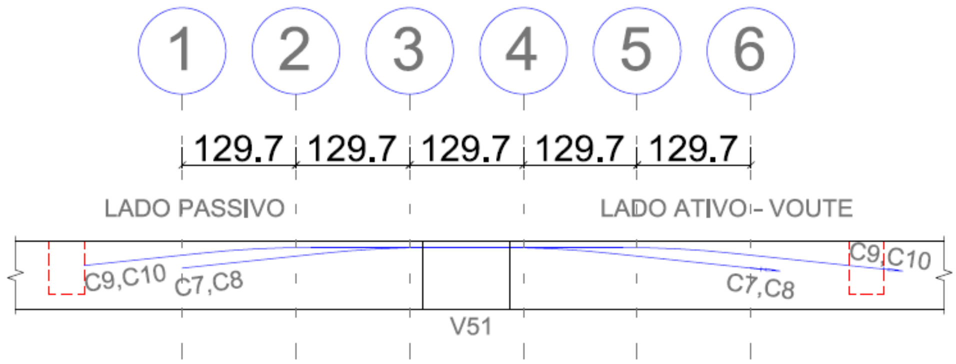
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13213.67 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 29.70m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.9 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 201 \cdot mm$$

CABOS C7=C8 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2$ $\quad \text{fptk} = \dfrac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 6.49\,\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 6$ $\quad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 129.8 \\ 259.6 \\ 389.4 \\ 519.2 \\ 649 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 4.74 \\ 2.66 \\ 4.74 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 18.88 \\ 0.88 \\ 0.88 \\ 0.88 \\ 0.88 \end{pmatrix}^{\circ}$$

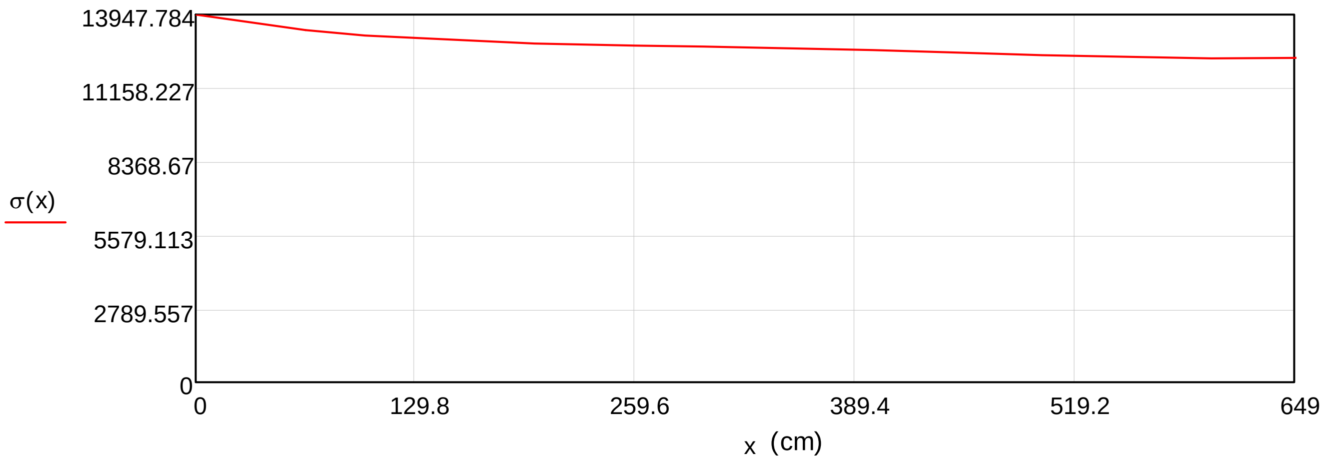
$$\alpha_i = \begin{cases} 0\,\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13024.35 \\ 12773.8 \\ 12616.69 \\ 12373.98 \\ 12304.05 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\, dx \qquad \text{Área} = 82787.02 \cdot \frac{kg \cdot m}{cm^2}$$

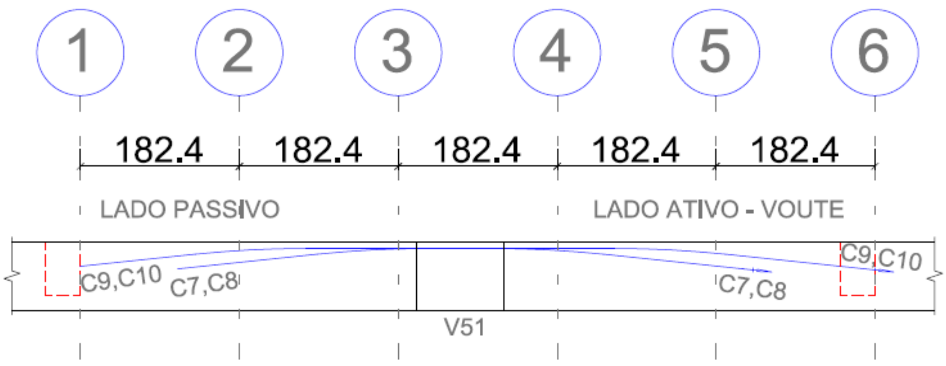
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12756.09 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 7.30m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 48 \cdot mm$$

CABOS C9=C10 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 9.12m$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{rad}{m} \qquad n = 6 \qquad i = 1, 2..n$$

$$S = 0cm, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 182.4 \\ 364.8 \\ 547.2 \\ 729.6 \\ 912 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0.48 \\ 5.59 \\ 0 \\ 3.67 \\ 2.41 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 13.23 \\ 1.23 \\ 1.23 \\ 1.23 \\ 1.23 \end{pmatrix}°$$

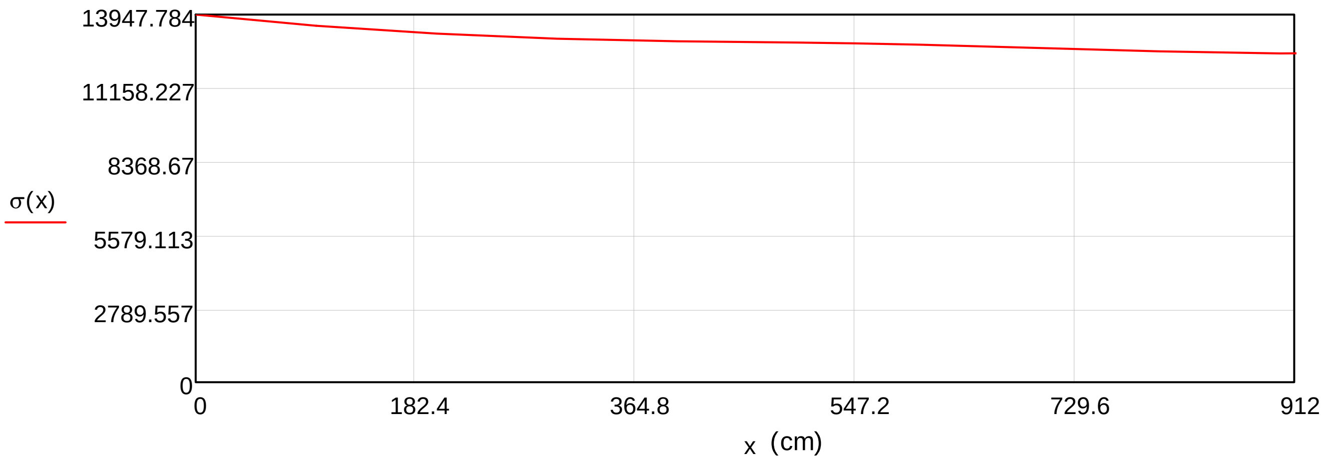
$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13269.4 \\ 12959.55 \\ 12857.04 \\ 12638.31 \\ 12473.92 \end{pmatrix}\cdot\frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 118311.29\cdot\frac{kg\cdot m}{cm^2}$$

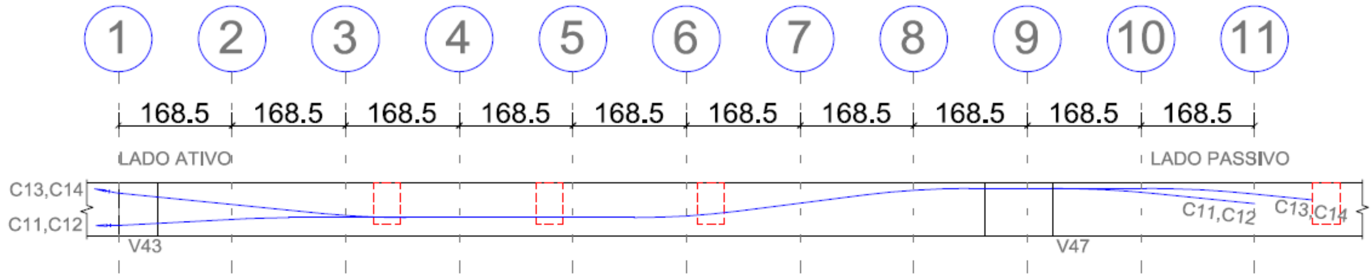
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12972.73\cdot\frac{kg}{cm^2}$$

$L_{cabo} = 9.95m$ $\qquad \text{Área}_{teórica\_aço} = 143.4\cdot mm^2$ $\qquad E_{teórico\_aço} = 1950000\,\frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m\cdot\text{Área}_{teórica\_aço} = 18.6\cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m)\cdot(L_{cabo})}{E_{teórico\_aço}} = 66\cdot mm$$

CABOS C11=C12 (4ø15.2mm)



$t = \text{tonne}$

$Área_{teórica\_aço} = 143.4\,mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 16.85m$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{rad}{m}$ $\quad n = 11$ $\quad i = 1, 2..n$

$$S = 0cm, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 168.5 \\ 337 \\ 505.5 \\ 674 \\ 842.5 \\ 1011 \\ 1179.5 \\ 1348 \\ 1516.5 \\ 1685 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 3.02 \\ 0 \\ 0 \\ 3.8 \\ 3.62 \\ 3.5 \\ 3.93 \\ 5.08 \\ 0.92 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 1.14 \\ 1.14 \\ 1.14 \\ 1.14 \\ 1.14 \\ 1.14 \\ 1.14 \\ 1.14 \\ 1.14 \\ 1.14 \end{pmatrix}°$$

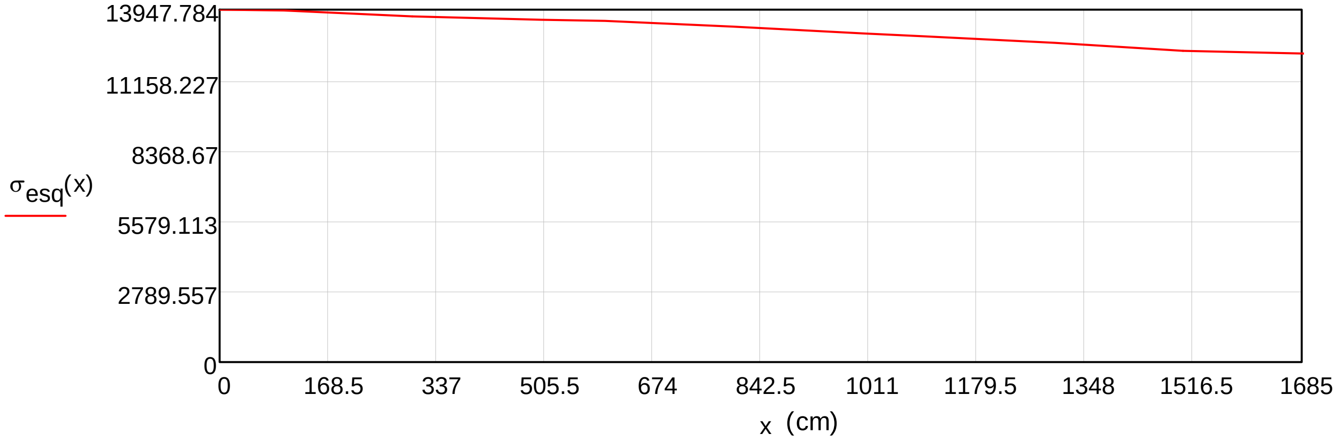
$$\alpha_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13845.65 \\ 13644.46 \\ 13544.55 \\ 13445.37 \\ 13215.84 \\ 12998.04 \\ 12788.92 \\ 12565.13 \\ 12297.33 \\ 12193.44 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\, dx \qquad \text{Área} = 221431.47 \cdot \frac{kg \cdot m}{cm^2}$$

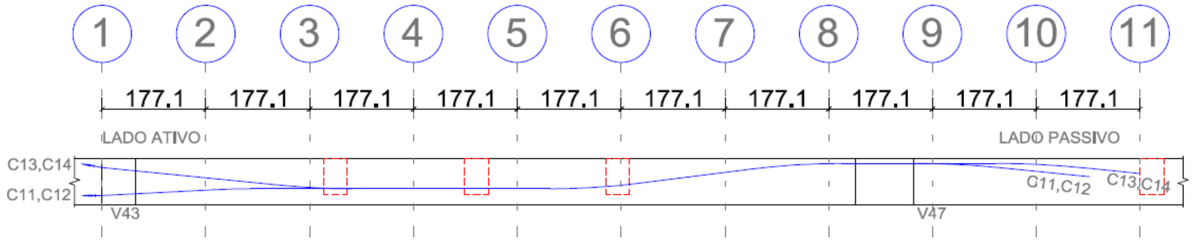
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13141.33 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 17.70m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 119 \cdot mm$$

CABOS C13=C14 (4ø15.2mm)



$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 17.71m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2..\, n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 177.1 \\ 354.2 \\ 531.3 \\ 708.4 \\ 885.5 \\ 1062.6 \\ 1239.7 \\ 1416.8 \\ 1593.9 \\ 1771 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 2.35 \\ 3.47 \\ 0 \\ 5.82 \\ 1.61 \\ 6.35 \\ 1.08 \\ 2.68 \\ 3.32 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \\ 1.19 \end{pmatrix}°$$

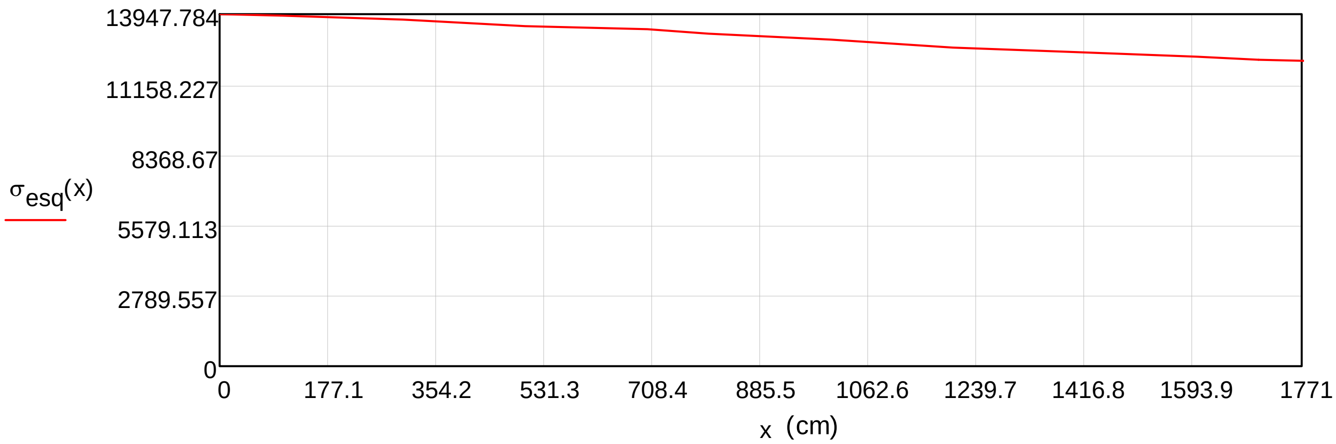
$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13840.86 \\ 13665.68 \\ 13444.11 \\ 13341.04 \\ 13021.05 \\ 12884.65 \\ 12552.79 \\ 12438.44 \\ 12268.24 \\ 12075.28 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\, dx \qquad \text{Área} = 231066.3 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13047.22 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 18.55m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 124 \cdot mm$$

V10 = V17 = V19 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA (Esquerda)

$a_0 = 18cm$ $\quad n = 2$ $\quad q = 2$ $\quad F_{inicial} = 4 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 784.58\,kN$

$d = 15cm$ $\quad a_1 = 2d = 30\,cm$

$F_1 = F_{inicial} \cdot \cos(2°) = 784.1\,kN$ $\quad F_2 = F_{inicial} \cdot \cos(8°) = 776.94\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 78.41\,kN \qquad T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 77.69\,kN$$

$k = 1..n$

$$F_k = \begin{pmatrix} 784.1 \\ 776.94 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 78.41 \\ 77.69 \end{pmatrix} kN \qquad \sum F = 1561.04\,kN$$

$$fyd = 43.48 \frac{kN}{cm^2} \qquad As_1 = \frac{\max(T)}{fyd} = 1.8\,cm^2$$

$$As_{fretagem} = As_1 = 1.8\,cm^2 \qquad As_{estribos} = \frac{As_1}{2} = 0.9\,cm^2$$

EXTREMIDADE ATIVA (Direita)

$b = 25cm$ $n = 3$ $q = 2$ $F_{inicial} = 784.58\,kN$

$a_0 = 18\,cm$ $c = 7cm$

$d = 15cm$ $a_3 = a_0 + c = 25\,cm$

$F_1 = F_{inicial}\cdot\cos(1°) = 784.46\,kN$ $F_3 = F_{inicial}\cdot\cos(5°) = 781.59\,kN$

$T_1 = 0.25\cdot F_1\cdot\left(1 - \frac{a_0}{a_3}\right) = 54.91\,kN$ $T_3 = 0.25\cdot F_3\cdot\left(1 - \frac{a_0}{a_3}\right) = 54.71\,kN$

$F_2 = F_{inicial}\cdot\cos(5°) = 781.59\,kN$

$T_2 = 0.25\cdot F_2\cdot\left(1 - \frac{a_0}{a_3}\right) = 54.71\,kN$

$a_4 = 2\cdot d + (n-1)\cdot b = 80\,cm$ $k = 1..n$

$F_k = \begin{pmatrix} 784.46 \\ 781.59 \\ 781.59 \end{pmatrix} kN$ $T_k = \begin{pmatrix} 54.91 \\ 54.71 \\ 54.71 \end{pmatrix} kN$ $\sum F = 2347.64\,kN$

$T_n = \frac{2}{3}\cdot\left(1 - \frac{n\cdot a_3}{a_4}\right)\cdot\sum F = 97.82\,kN$ $fyd = 43.48\frac{kN}{cm^2}$

$As_3 = \frac{\max(T)}{fyd} = 1.26\,cm^2$ $As_4 = q\cdot\left(\frac{T_n}{fyd}\right) = 4.5\,cm^2$

$As_{fretagem} = \max(As_1, As_3) = 1.8\,cm^2$

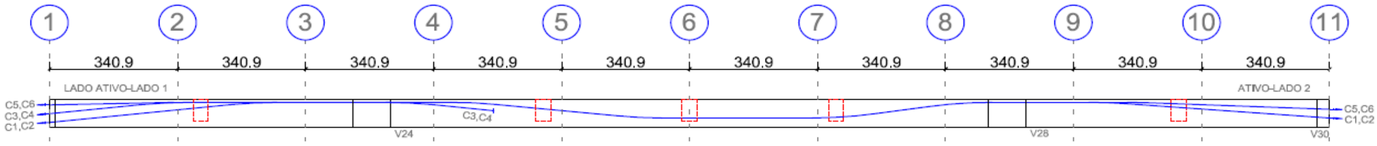
Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$As_{estribos} = \frac{\max(As_1, As_4)}{2} = 2.25\,cm^2$

$L = \max(a_1, a_4) = 80\,cm$ $bitola_{estribo} = 10mm$ $adotados = ceil\left[\frac{As_{estribos}}{\pi\frac{(bitola_{estribo})^2}{4}}\right] = 3$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V14 - CABOS C1 a C14



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 34.09\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 340.9 \\ 681.8 \\ 1022.7 \\ 1363.6 \\ 1704.5 \\ 2045.4 \\ 2386.3 \\ 2727.2 \\ 3068.1 \\ 3409 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 6 \\ 0 \\ 5.75 \\ 5.75 \\ 0.74 \\ 5.21 \\ 5.95 \\ 4.27 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \end{pmatrix}°$$

$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13738.4 \\ 13341.04 \\ 13140.77 \\ 12771.02 \\ 12411.68 \\ 12220.56 \\ 11897.26 \\ 11555.03 \\ 11282.34 \\ 11112.97 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.27 \\ 5.95 \\ 5.21 \\ 0.74 \\ 5.75 \\ 5.75 \\ 0 \\ 6 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \end{pmatrix} °$$

$n = 11$

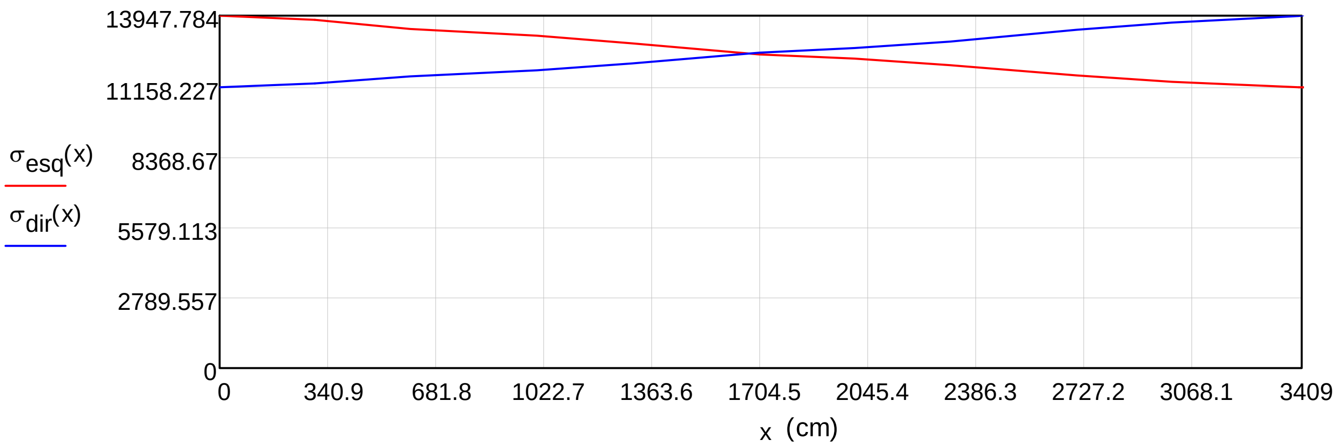
$$\theta_i = \begin{cases} 0rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13738.4 \\ 13414.19 \\ 13028.32 \\ 12683.65 \\ 12488.34 \\ 12136.95 \\ 11795.45 \\ 11618.38 \\ 11282.34 \\ 11112.97 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq}) \qquad b = cspline(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = interp\left(\frac{b}{g}, S, \frac{reverse(\sigma_{dir})}{g}, x\right)$$



$$c = \frac{L}{2} \qquad d = 0m$$

Given

$$d = \sigma_{esq}(c) \qquad d = \sigma_{dir}(c)$$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d) \qquad interseção = 1659.86 \cdot cm$$

$$\sigma_{interseção} = 12446.91 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx \qquad Área_1 = 220125.69\cdot\frac{kg\cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx \qquad Área_2 = 230744.71\cdot\frac{kg\cdot m}{cm^2}$$

$$Área = \left(Área_1\right) + \left(Área_2\right) \qquad Área = 450870.4\cdot\frac{kg\cdot m}{cm^2}$$

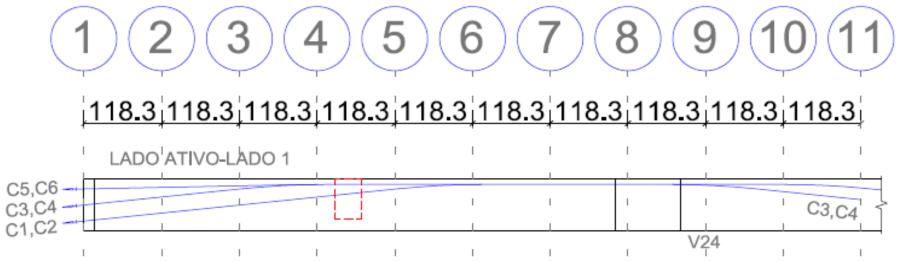
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13225.88\cdot\frac{kg}{cm^2}$$

$$L_{cabo} = 35.80m \qquad Área_{teórica\_aço} = 143.4\cdot mm^2 \qquad E_{teórico\_aço} = 1950000\frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m\cdot Área_{teórica\_aço} = 19\cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right)\cdot\left(L_{cabo}\right)}{E_{teórico\_aço}} = 243\cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 11.83m$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 118.3 \\ 236.6 \\ 354.9 \\ 473.2 \\ 591.5 \\ 709.8 \\ 828.1 \\ 946.4 \\ 1064.7 \\ 1183 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 5.37 \\ 0.63 \\ 0 \\ 0 \\ 0 \\ 2.44 \\ 3.63 \\ 0 \end{pmatrix} {}^{\circ} \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0.83 \\ 0.83 \\ 0.83 \\ 0.83 \\ 0.83 \\ 0.83 \\ 0.83 \\ 0.83 \\ 0.83 \\ 0.83 \end{pmatrix} {}^{\circ}$$

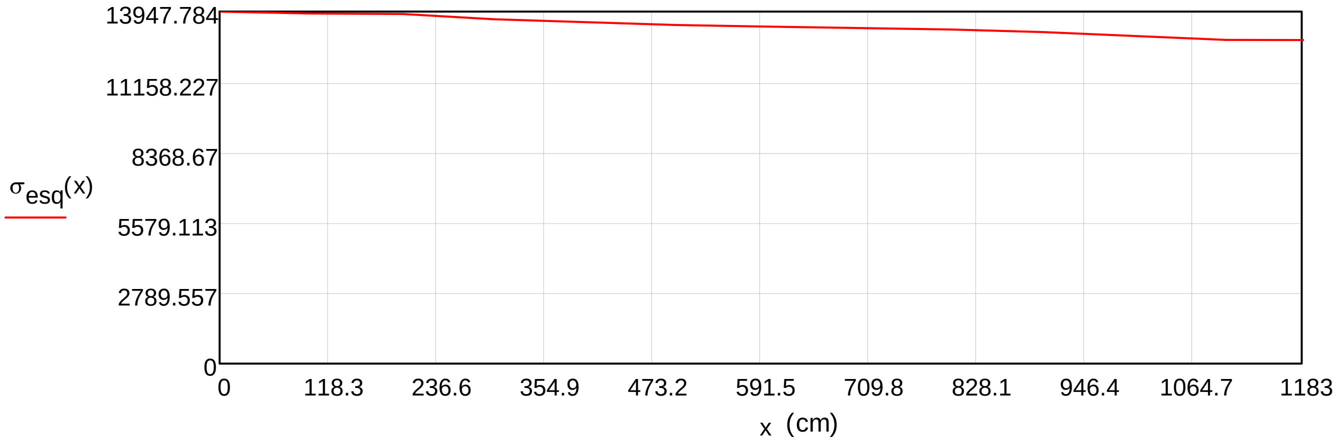
$$\alpha_i = \begin{cases} 0rad & \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if} \quad i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13874.57 \\ 13801.73 \\ 13510.41 \\ 13429.55 \\ 13359.05 \\ 13288.92 \\ 13219.16 \\ 13069.81 \\ 12870.54 \\ 12802.98 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline\left(S, \sigma_{esq}\right)$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\, dx \qquad \text{Área} = 158255.79 \cdot \frac{kg \cdot m}{cm^2}$$

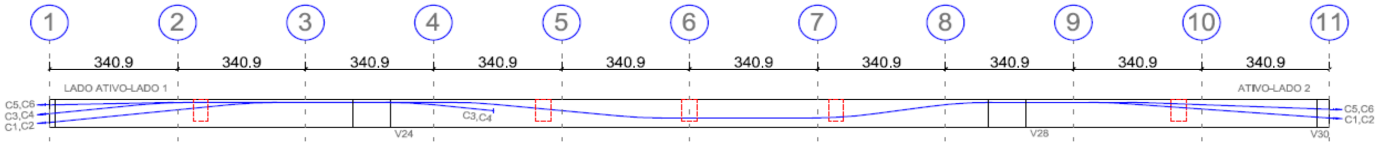
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13377.5 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 12.65m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.2 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 87 \cdot mm$$

CABOS C5=C6 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 34.09\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..n$$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 340.9 \\ 681.8 \\ 1022.7 \\ 1363.6 \\ 1704.5 \\ 2045.4 \\ 2386.3 \\ 2727.2 \\ 3068.1 \\ 3409 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.53 \\ 0.64 \\ 0 \\ 5.75 \\ 5.75 \\ 0.76 \\ 5.19 \\ 5.95 \\ 2.16 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13735.6 \\ 13525.41 \\ 13322.37 \\ 12947.52 \\ 12583.21 \\ 12389.19 \\ 12062.19 \\ 11715.21 \\ 11505.8 \\ 11333.08 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 2.16 \\ 5.95 \\ 5.19 \\ 0.76 \\ 5.75 \\ 5.75 \\ 0 \\ 0.64 \\ 0.53 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \\ 2.38 \end{pmatrix} \circ$$

$$n = 11$$

$$\theta_i = \left| \begin{array}{ll} 0rad & \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if} \quad i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

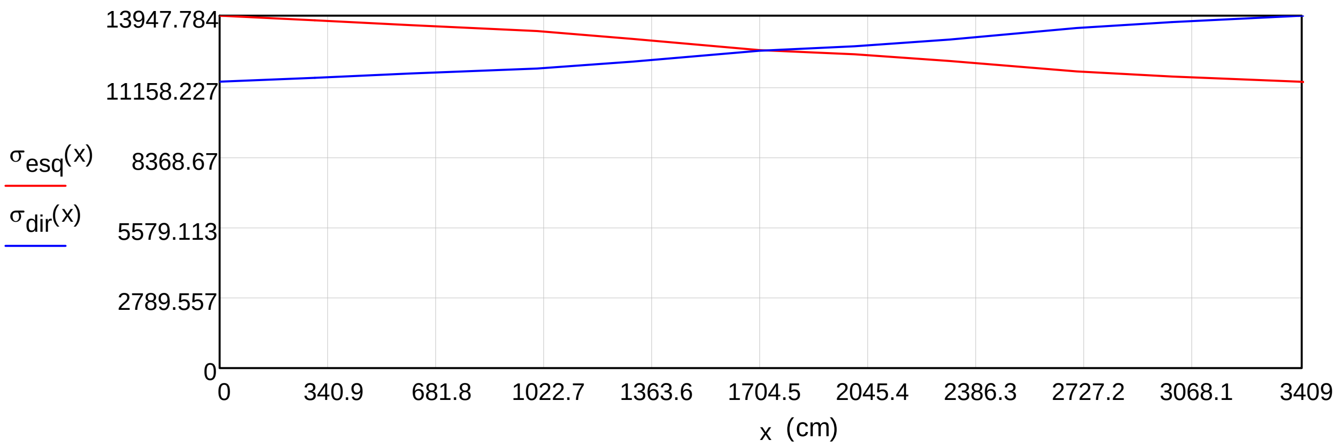
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13738.4 \\ 13492.82 \\ 13104.69 \\ 12758.81 \\ 12562.08 \\ 12208.62 \\ 11865.1 \\ 11686.98 \\ 11508.14 \\ 11333.08 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$$

$\text{interseção} = 1717.83 \cdot cm$

$$\sigma_{\text{interseção}} = 12573.45 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx \qquad Área_1 = 229405.15 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx \qquad Área_2 = 224481.6 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 453886.75 \cdot \frac{kg \cdot m}{cm^2}$$

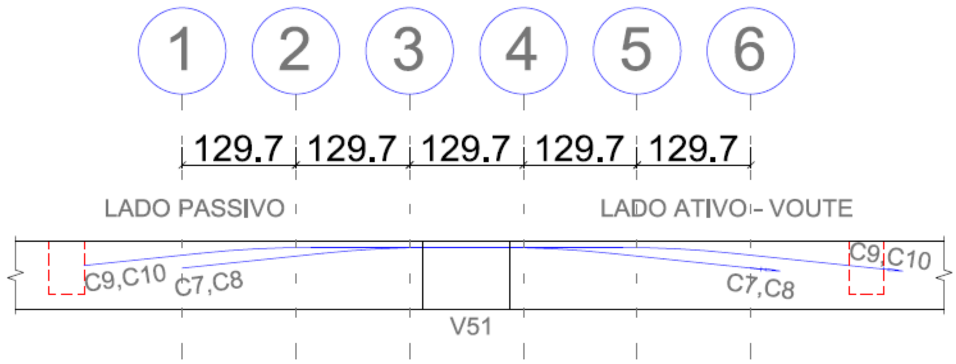
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13314.37 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 35.75m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.1 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 244 \cdot mm$$

CABOS C7=C8 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 6.49\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 6$ $\quad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 129.8 \\ 259.6 \\ 389.4 \\ 519.2 \\ 649 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 4.74 \\ 2.66 \\ 4.74 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 18.91 \\ 0.91 \\ 0.91 \\ 0.91 \\ 0.91 \end{pmatrix}^{\circ}$$

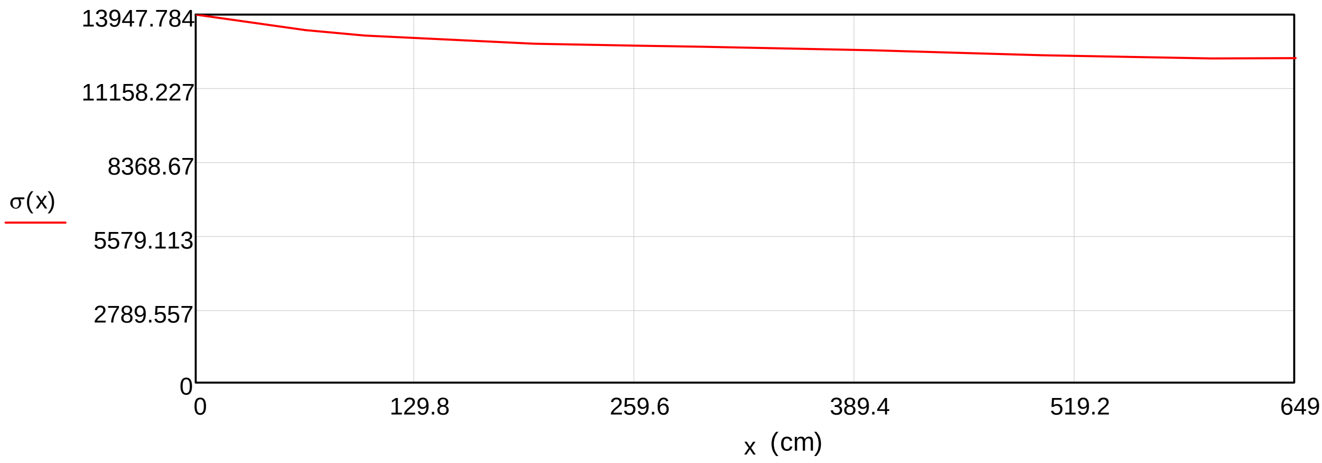
$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha + \kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13022.99 \\ 12772.22 \\ 12614.7 \\ 12371.79 \\ 12300.58 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 82775.5 \cdot \frac{kg \cdot m}{cm^2}$$

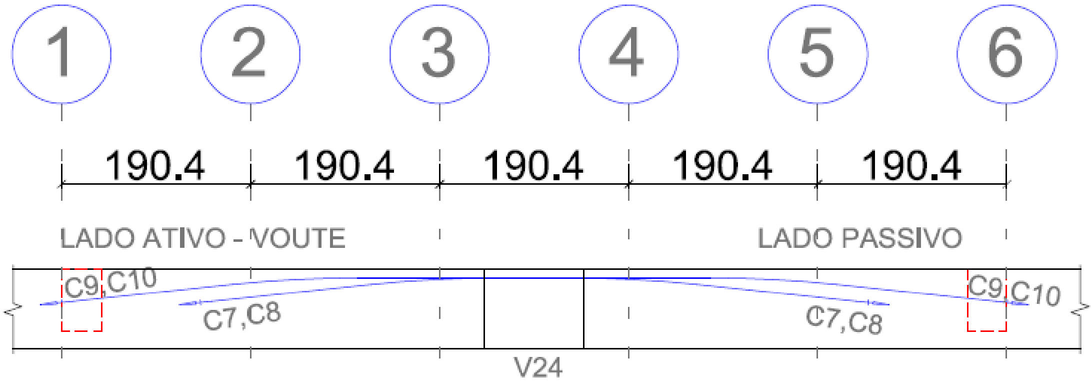
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12754.31 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 7.30m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 48 \cdot mm$$

CABOS C9=C10 (4ø15.2mm)



$$\text{Área}_{teórica\_aço} = 143.4\text{mm}^2 \qquad fptk = \frac{265.8\text{kN}}{\text{Área}_{teórica\_aço}} = 1853.56\,\text{MPa} \qquad fpyk = \frac{239.2\text{kN}}{\text{Área}_{teórica\_aço}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 9.52m$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{rad}{m} \qquad n = 6 \qquad i = 1, 2..n$$

$$S = 0cm, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 190.4 \\ 380.8 \\ 571.2 \\ 761.6 \\ 952 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0.87 \\ 5.2 \\ 0 \\ 5.2 \\ 0.87 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 13.33 \\ 1.33 \\ 1.33 \\ 1.33 \\ 1.33 \end{pmatrix}^{\circ}$$

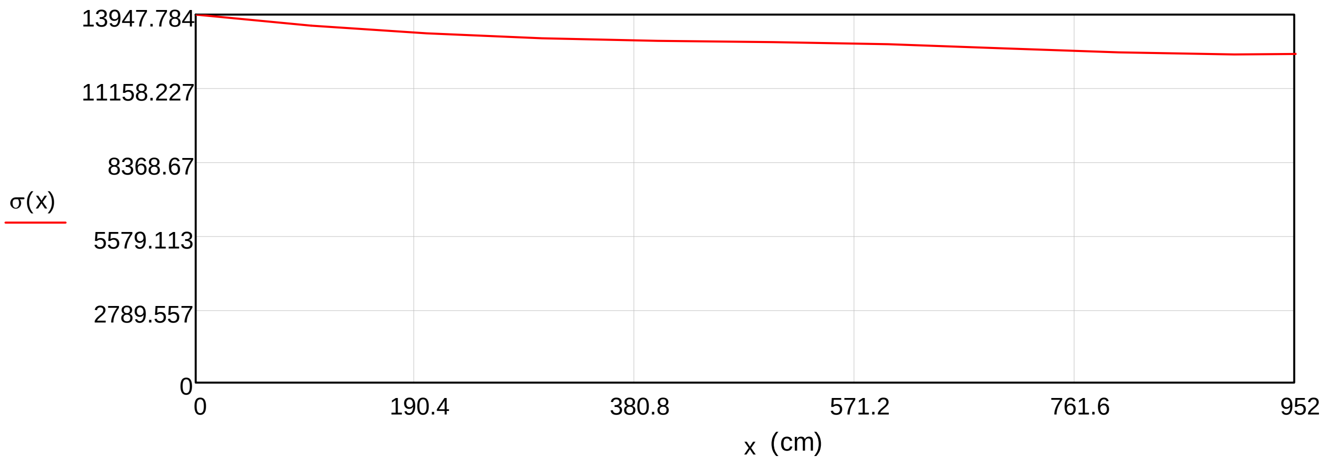
$$\alpha_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13261.74 \\ 12966.11 \\ 12857.01 \\ 12570.4 \\ 12453.35 \end{pmatrix}\cdot\frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 123315.81 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12953.34 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 10.35m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.6 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 69 \cdot mm$$

V14 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA (Direita)

$a_0 = 18\text{cm}$ $\quad n = 2$ $\quad q = 2$ $\quad F_{inicial} = 4 \cdot \sigma_1 \cdot \text{Área}_{teórica\_aço} = 784.58\,\text{kN}$

$d = 27.5\text{cm}$ $\quad a_1 = 2d = 55\,\text{cm}$

$F_1 = F_{inicial} \cdot \cos(2°) = 784.1\,\text{kN}$ $\quad F_2 = F_{inicial} \cdot \cos(4°) = 782.66\,\text{kN}$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 131.87\,\text{kN} \qquad T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 131.63\,\text{kN}$$

$k = 1..n$

$$F_k = \begin{pmatrix} 784.1 \\ 782.66 \end{pmatrix} \text{kN} \qquad T_k = \begin{pmatrix} 131.87 \\ 131.63 \end{pmatrix} \text{kN} \qquad \sum F = 1566.76\,\text{kN}$$

$$fyd = 43.48 \frac{\text{kN}}{\text{cm}^2} \qquad As_1 = \frac{\max(T)}{fyd} = 3.03\,\text{cm}^2$$

$$As_{fretagem} = As_1 = 3.03\,\text{cm}^2 \qquad As_{estribos} = \frac{As_1}{2} = 1.52\,\text{cm}^2$$

EXTREMIDADE ATIVA (Esquerda)

$b = 25cm$ $n = 3$ $q = 2$ $F_{inicial} = 784.58\,kN$

$a_0 = 18\,cm$ $c = 7cm$

$d = 15cm$ $a_3 = a_0 + c = 25\,cm$

$F_1 = F_{inicial}\cdot\cos(1°) = 784.46\,kN$ $F_3 = F_{inicial}\cdot\cos(5°) = 781.59\,kN$

$T_1 = 0.25\cdot F_1\cdot\left(1 - \frac{a_0}{a_3}\right) = 54.91\,kN$ $T_3 = 0.25\cdot F_3\cdot\left(1 - \frac{a_0}{a_3}\right) = 54.71\,kN$

$F_2 = F_{inicial}\cdot\cos(5°) = 781.59\,kN$

$T_2 = 0.25\cdot F_2\cdot\left(1 - \frac{a_0}{a_3}\right) = 54.71\,kN$

$a_4 = 2\cdot d + (n-1)\cdot b = 80\,cm$ $k = 1 .. n$

$F_k = \begin{pmatrix} 784.46 \\ 781.59 \\ 781.59 \end{pmatrix} kN$ $T_k = \begin{pmatrix} 54.91 \\ 54.71 \\ 54.71 \end{pmatrix} kN$ $\sum F = 2347.64\,kN$

$T_n = \frac{2}{3}\cdot\left(1 - \frac{n\cdot a_3}{a_4}\right)\cdot\sum F = 97.82\,kN$ $fyd = 43.48\,\frac{kN}{cm^2}$

$As_3 = \frac{\max(T)}{fyd} = 1.26\,cm^2$ $As_4 = q\cdot\left(\frac{T_n}{fyd}\right) = 4.5\,cm^2$

$As_{fretagem} = \max\left(As_1, As_3\right) = 3.03\,cm^2$

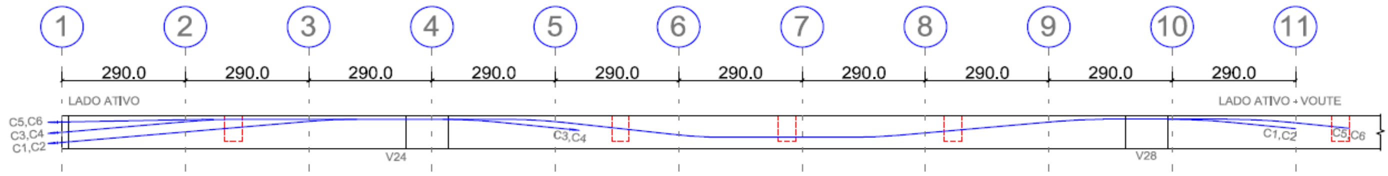
Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$As_{estribos} = \frac{\max\left(As_1, As_4\right)}{2} = 2.25\,cm^2$

$L = \max\left(a_1, a_4\right) = 80\,cm$ $bitola_{estribo} = 10mm$ $adotados = ceil\left[\frac{As_{estribos}}{\pi\frac{\left(bitola_{estribo}\right)^2}{4}}\right] = 3$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V18 - CABOS C1 a C18



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\qquad fptk = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\qquad fpyk = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{\text{kgf}}{\text{cm}^2}$ $\qquad \mu = 0.20$ $\qquad \beta = 0.01 \dfrac{\text{rad}}{\text{m}}$ $\qquad e = 2.72$ $\qquad L = 29.00\text{m}$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{\text{rad}}{\text{m}}$ $\qquad n = 11$ $\qquad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 290 \\ 580 \\ 870 \\ 1160 \\ 1450 \\ 1740 \\ 2030 \\ 2320 \\ 2610 \\ 2900 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 5.1 \\ 5.62 \\ 0.03 \\ 5.65 \\ 5.26 \\ 0 \\ 5.68 \\ 5.58 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 20.1 \end{pmatrix} °$$

$$\alpha_i = \left| \begin{array}{ll} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13765.84 \\ 13586.27 \\ 13250.13 \\ 12900.49 \\ 12732.2 \\ 12395 \\ 12082.08 \\ 11924.47 \\ 11607.53 \\ 10729.95 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 5.58 \\ 5.68 \\ 0 \\ 5.26 \\ 5.65 \\ 0.03 \\ 5.62 \\ 5.1 \\ 0 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 20.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \\ 2.1 \end{pmatrix} °$$

$$n = 11$$

$$\theta_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

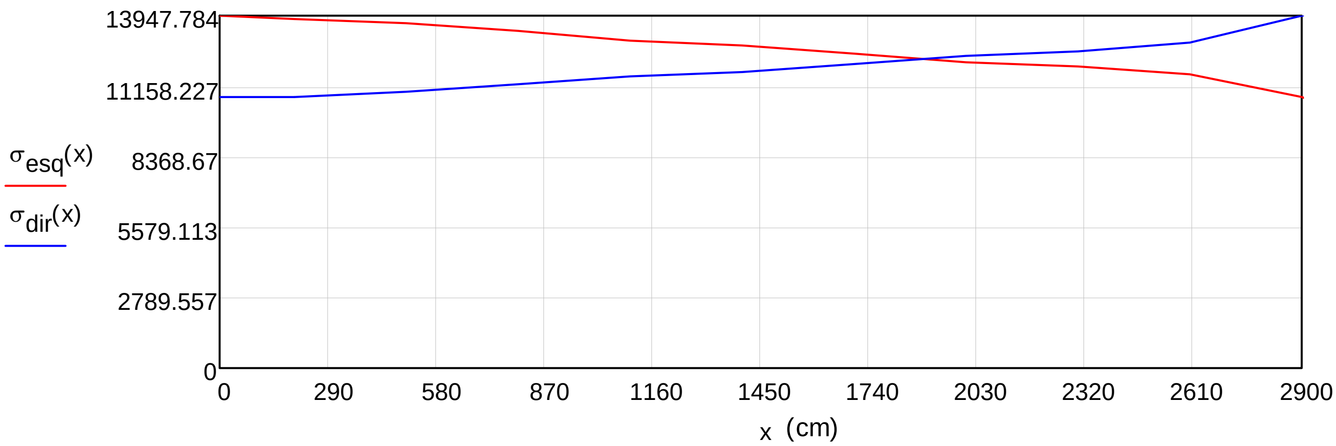
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12893.26 \\ 12550.57 \\ 12386.86 \\ 12074.14 \\ 11754.37 \\ 11601.03 \\ 11294.91 \\ 11015.46 \\ 10871.76 \\ 10729.95 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$

$\text{interseção} = 1871.96 \cdot cm$

$\sigma_{\text{interseção}} = 12233.09 \cdot \frac{kg}{cm^2}$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx \qquad Área_1 = 246554.05 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx \qquad Área_2 = 131396.29 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = \left(Área_1\right) + \left(Área_2\right) \qquad Área = 377950.34 \cdot \frac{kg \cdot m}{cm^2}$$

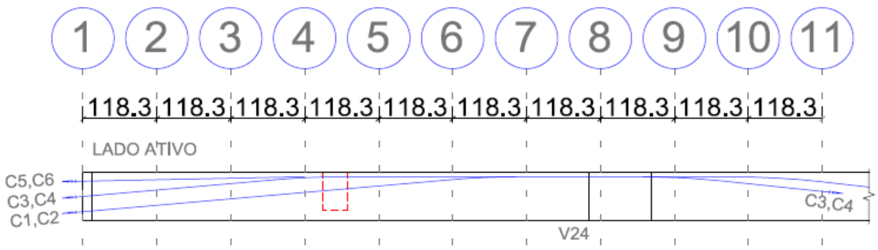
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13032.77 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 30.70m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right) \cdot \left(L_{cabo}\right)}{E_{teórico\_aço}} = 205 \cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 11.83m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S := 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 118.3 \\ 236.6 \\ 354.9 \\ 473.2 \\ 591.5 \\ 709.8 \\ 828.1 \\ 946.4 \\ 1064.7 \\ 1183 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 2.33 \\ 2.77 \\ 0 \\ 0 \\ 0 \\ 2.44 \\ 3.63 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0.86 \\ 0.86 \\ 0.86 \\ 0.86 \\ 0.86 \\ 0.86 \\ 0.86 \\ 0.86 \\ 0.86 \\ 0.86 \end{pmatrix} °$$

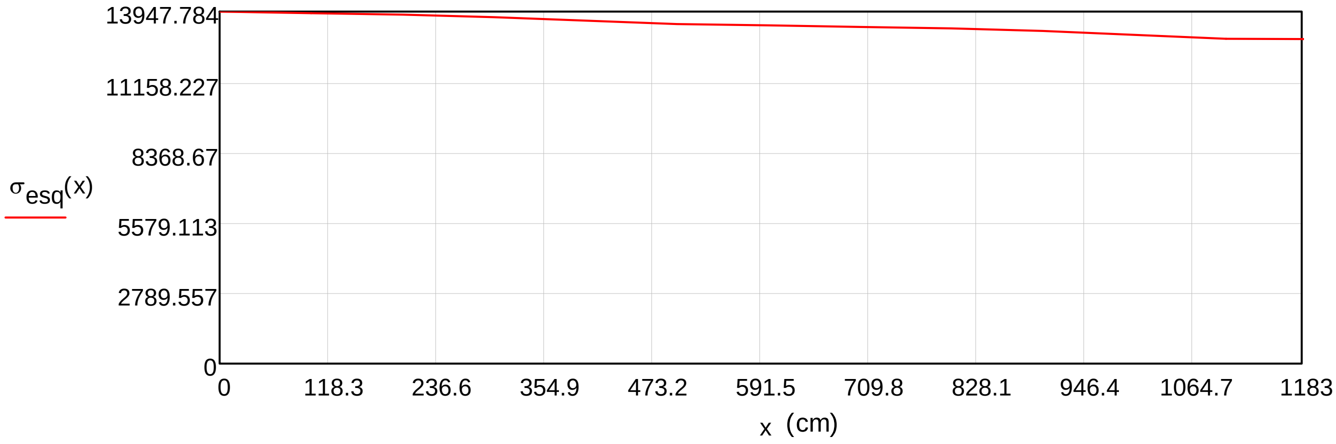
$$\alpha_i := \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} := \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13873.11 \\ 13798.84 \\ 13647.4 \\ 13478 \\ 13405.84 \\ 13334.07 \\ 13262.69 \\ 13112.4 \\ 12912.17 \\ 12843.04 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a := cspline\left(S, \sigma_{esq}\right)$$

$$\sigma_{esq}(x) := interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\,dx \qquad Área = 158764.73\cdot\frac{kg\cdot m}{cm^2}$$

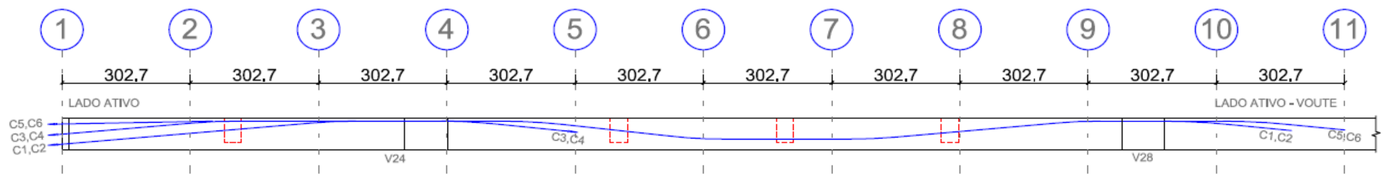
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13420.52\cdot\frac{kg}{cm^2}$$

$$L_{cabo} = 12.65m \qquad Área_{teórica\_aço} = 143.4\cdot mm^2 \qquad E_{teórico\_aço} = 1950000\,\frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m\cdot Área_{teórica\_aço} = 19.2\cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m)\cdot(L_{cabo})}{E_{teórico\_aço}} = 87\cdot mm$$

CABOS C5=C6 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 30.27\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 302.7 \\ 605.4 \\ 908.1 \\ 1210.8 \\ 1513.5 \\ 1816.2 \\ 2118.9 \\ 2421.6 \\ 2724.3 \\ 3027 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 1.17 \\ 0 \\ 6.56 \\ 3.98 \\ 2.58 \\ 5.26 \\ 3.94 \\ 1.32 \\ 6 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 20.2 \end{pmatrix}^{\circ}$$

$$\alpha_i = \left| \begin{array}{ll} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13757.54 \\ 13556.08 \\ 13371.18 \\ 12973.33 \\ 12691.95 \\ 12466.91 \\ 12147.48 \\ 11885.46 \\ 11708.4 \\ 10812.43 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 6 \\ 1.32 \\ 3.94 \\ 5.26 \\ 2.58 \\ 3.98 \\ 6.56 \\ 0 \\ 1.17 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 20.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \\ 2.2 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu\cdot\theta+\kappa\cdot S)}$$

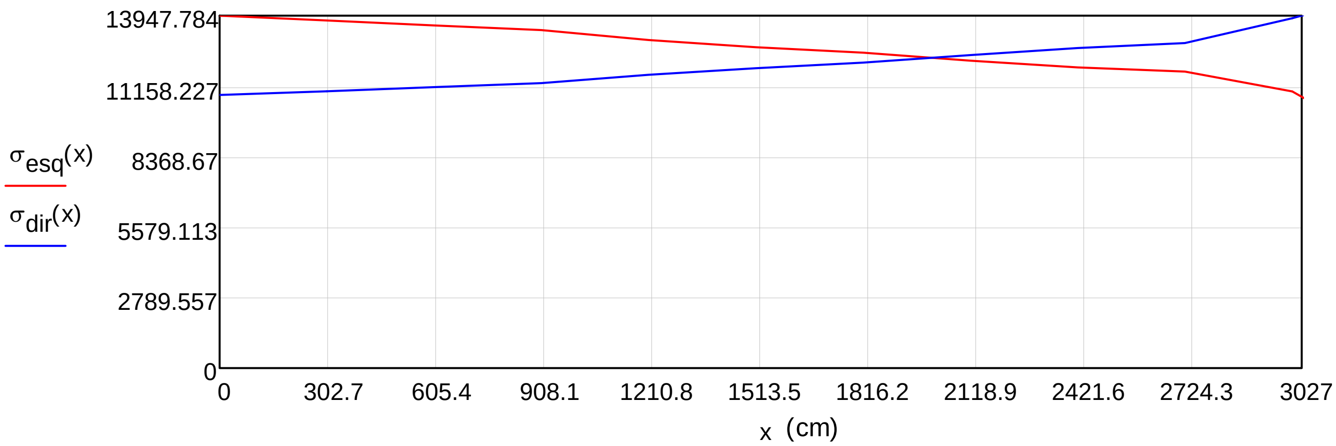
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12880.45 \\ 12688.56 \\ 12414.87 \\ 12096.77 \\ 11882.29 \\ 11624.57 \\ 11278.69 \\ 11124.85 \\ 10961.94 \\ 10812.43 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$$

$\text{interseção} = 2000.38 \cdot cm$

$$\sigma_{\text{interseção}} = 12278.44 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx \qquad Área_1 = 263648.52 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx \qquad Área_2 = 131887 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 395535.52 \cdot \frac{kg \cdot m}{cm^2}$$

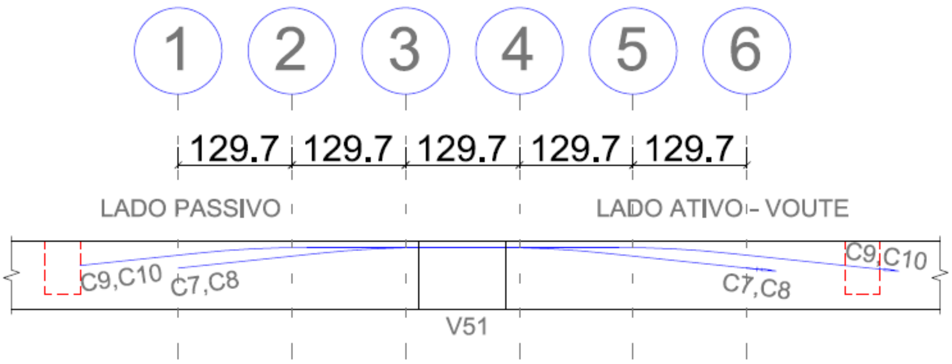
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13066.92 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 31.95m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 214 \cdot mm$$

CABOS C7=C8 (4ø15.2mm)



$t = tonne$

$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01 \dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 6.49m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 6$ $\quad i = 1, 2..n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 129.8 \\ 259.6 \\ 389.4 \\ 519.2 \\ 649 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.74 \\ 2.66 \\ 4.74 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 18.94 \\ 0.94 \\ 0.94 \\ 0.94 \\ 0.94 \end{pmatrix}°$$

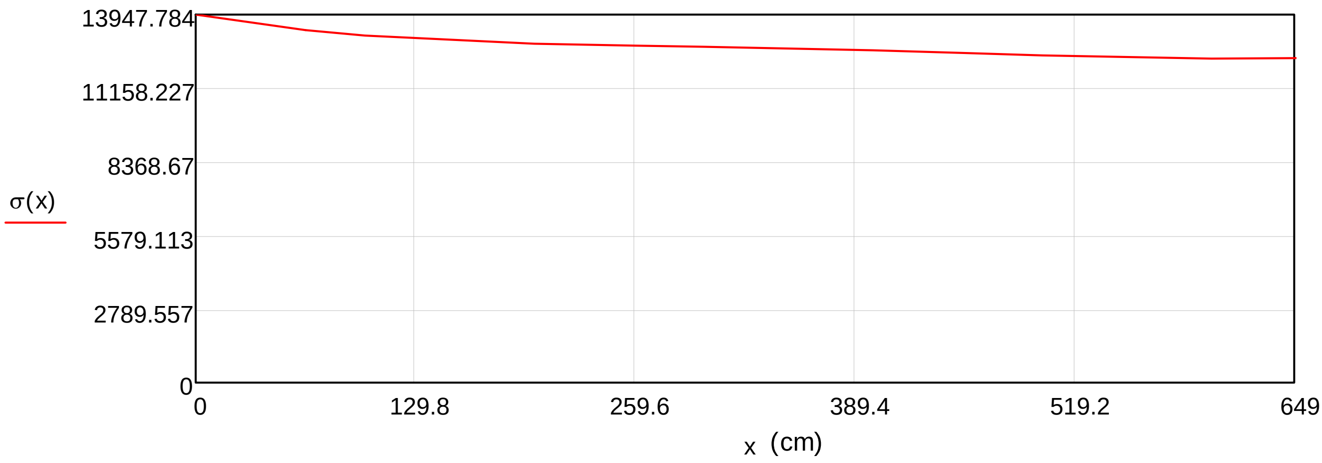
$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13021.63 \\ 12770.62 \\ 12612.69 \\ 12369.57 \\ 12297.09 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}\left(S, \sigma_{esq}\right)$$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 82763.9 \cdot \frac{kg \cdot m}{cm^2}$$

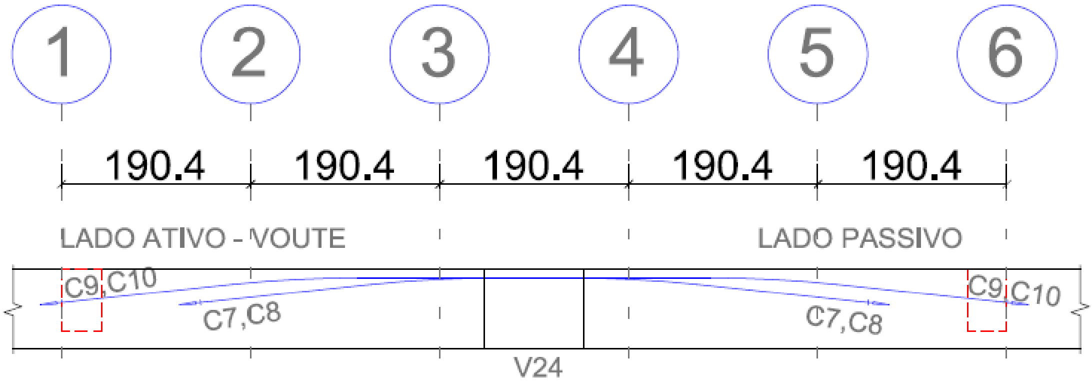
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12752.53 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 7.30m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right) \cdot \left(L_{cabo}\right)}{E_{teórico\_aço}} = 48 \cdot mm$$

CABOS C9=C10 (4ø15.2mm)



$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 9.52\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 6$ $\quad$ $i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 190.4 \\ 380.8 \\ 571.2 \\ 761.6 \\ 952 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.87 \\ 5.2 \\ 0 \\ 5.2 \\ 0.87 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.38 \\ 1.38 \\ 1.38 \\ 1.38 \\ 1.38 \end{pmatrix}°$$

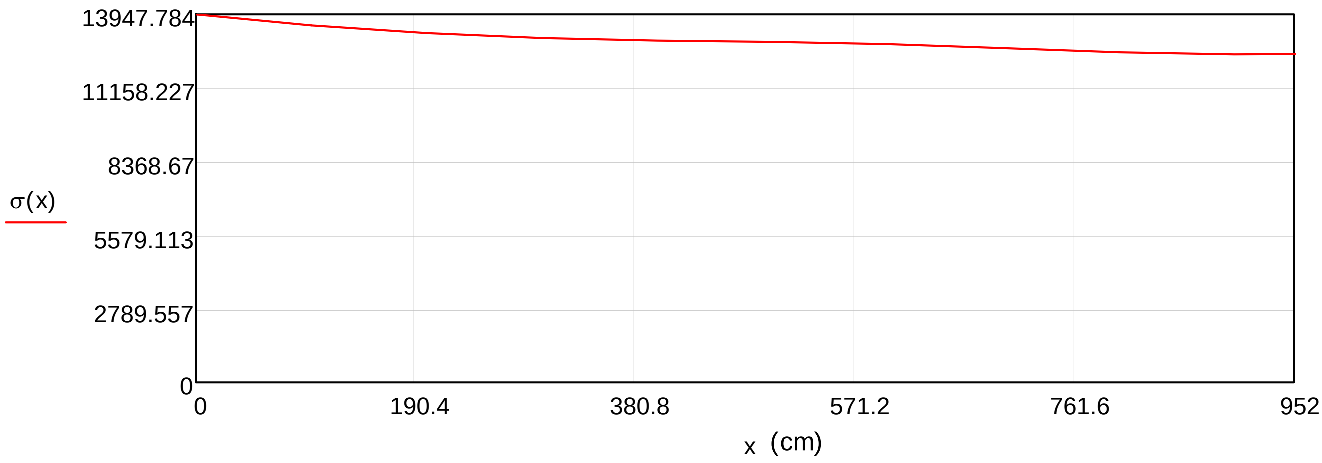
$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13259.43 \\ 12963.29 \\ 12851.96 \\ 12564.91 \\ 12446.08 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\, dx \qquad \text{Área} = 123278.91 \cdot \frac{kg \cdot m}{cm^2}$$

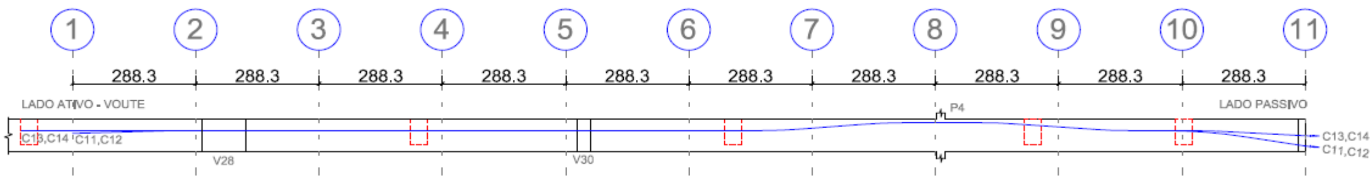
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12949.46 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 10.35m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.6 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 69 \cdot mm$$

CABOS C11=C12 (4ø15.2mm)



$t = tonne$

$Área_{teórica\_aço} = 143.4mm^2$ $\qquad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\qquad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\qquad \mu = 0.20$ $\qquad \beta = 0.01 \dfrac{rad}{m}$ $\qquad e = 2.72$ $\qquad L = 28.83m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\qquad n = 11$ $\qquad i = 1, 2..n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 288.3 \\ 576.6 \\ 864.9 \\ 1153.2 \\ 1441.5 \\ 1729.8 \\ 2018.1 \\ 2306.4 \\ 2594.7 \\ 2883 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 1.7 \\ 0 \\ 0 \\ 0 \\ 0 \\ 4.7 \\ 4.7 \\ 4.11 \\ 2.01 \\ 6.97 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 20.09 \\ 2.09 \\ 2.09 \\ 2.09 \\ 2.09 \\ 2.09 \\ 2.09 \\ 2.09 \\ 2.09 \\ 2.09 \end{pmatrix} °$$

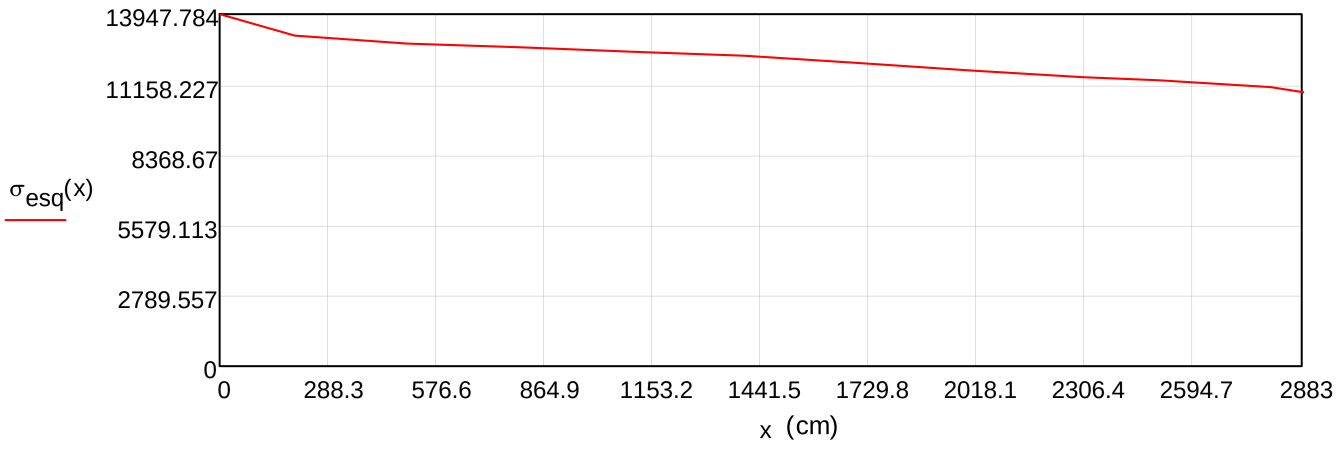
$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12925.17 \\ 12757.45 \\ 12591.9 \\ 12428.5 \\ 12267.22 \\ 11979.65 \\ 11698.83 \\ 11445.85 \\ 11265.44 \\ 10919.76 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\,dx \qquad Área = 350825.26 \cdot \frac{kg \cdot m}{cm^2}$$

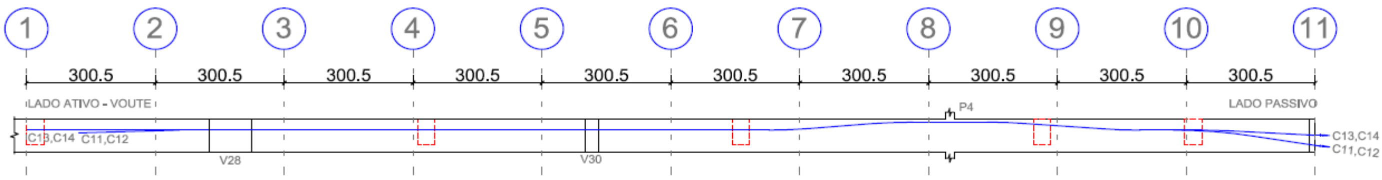
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12168.76 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 29.70m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 17.4 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 185 \cdot mm$$

CABOS C13=C14 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 30.05\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..n$$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 300.5 \\ 601 \\ 901.5 \\ 1202 \\ 1502.5 \\ 1803 \\ 2103.5 \\ 2404 \\ 2704.5 \\ 3005 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.45 \\ 3.45 \\ 4.11 \\ 4.11 \\ 3.05 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 14.18 \\ 2.18 \\ 2.18 \\ 2.18 \\ 2.18 \\ 2.18 \\ 2.18 \\ 2.18 \\ 2.18 \\ 2.18 \end{pmatrix}°$$

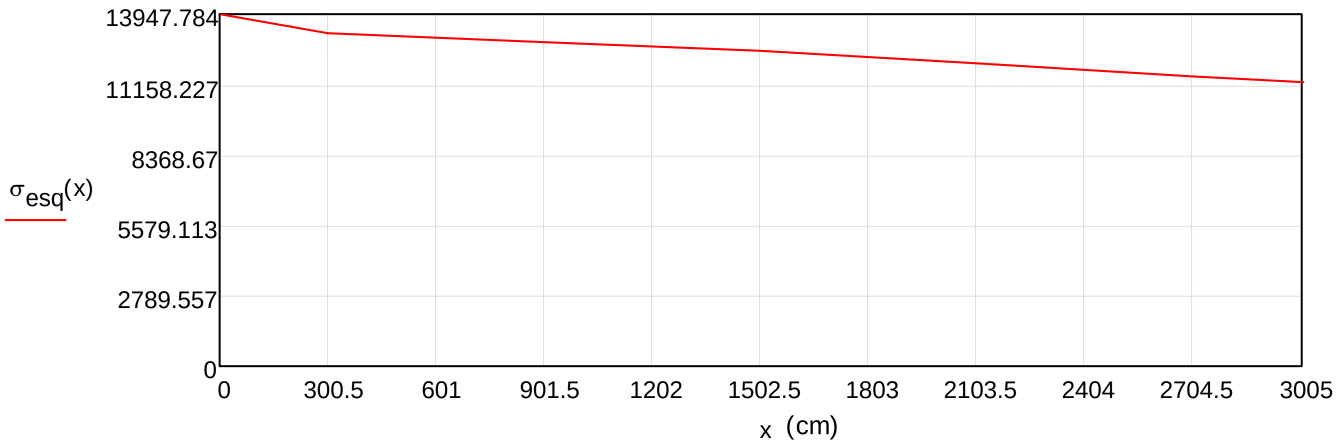
$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13194.67 \\ 13016.18 \\ 12840.11 \\ 12666.42 \\ 12495.07 \\ 12244.53 \\ 11999 \\ 11734.97 \\ 11476.76 \\ 11259.67 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\, dx \qquad \text{Área} = 373161.33 \cdot \frac{kg \cdot m}{cm^2}$$

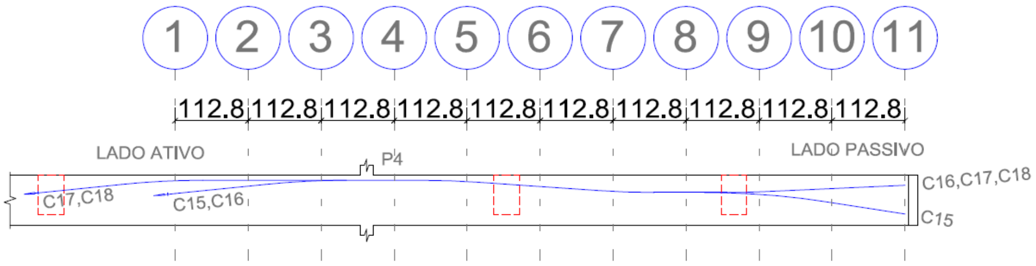
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12418.01 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 30.90m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 17.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 197 \cdot mm$$

CABO C15 (6ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 11.28m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 112.8 \\ 225.6 \\ 338.4 \\ 451.2 \\ 564 \\ 676.8 \\ 789.6 \\ 902.4 \\ 1015.2 \\ 1128 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.12 \\ 1.87 \\ 3.31 \\ 0.8 \\ 1.13 \\ 2.98 \\ 4.11 \\ 4.96 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 16.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \end{pmatrix} °$$

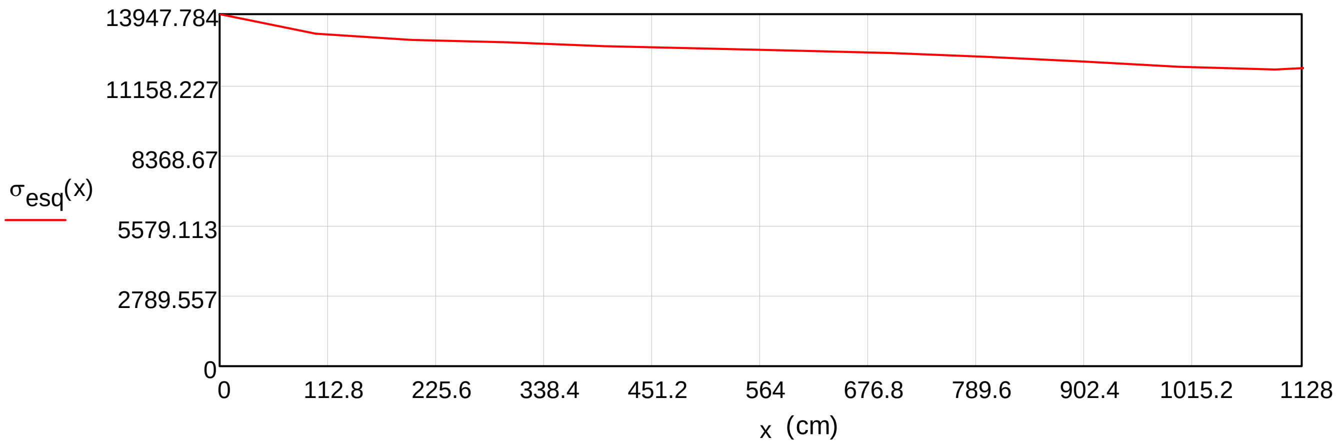
$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13122.81 \\ 12902.64 \\ 12782.14 \\ 12602.43 \\ 12523.84 \\ 12434.87 \\ 12273.72 \\ 12068.21 \\ 11831.55 \\ 11771.15 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma_{esq}(x)\,dx \qquad Área = 141318.45 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12528.23 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 12.10m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 78 \cdot mm$$

CABO C16 (6ø15.2mm)

$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 11.28m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 112.8 \\ 225.6 \\ 338.4 \\ 451.2 \\ 564 \\ 676.8 \\ 789.6 \\ 902.4 \\ 1015.2 \\ 1128 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.1 \\ 1.89 \\ 3.27 \\ 0.84 \\ 1.07 \\ 3.04 \\ 2.35 \\ 0.33 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 18.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \end{pmatrix} °$$

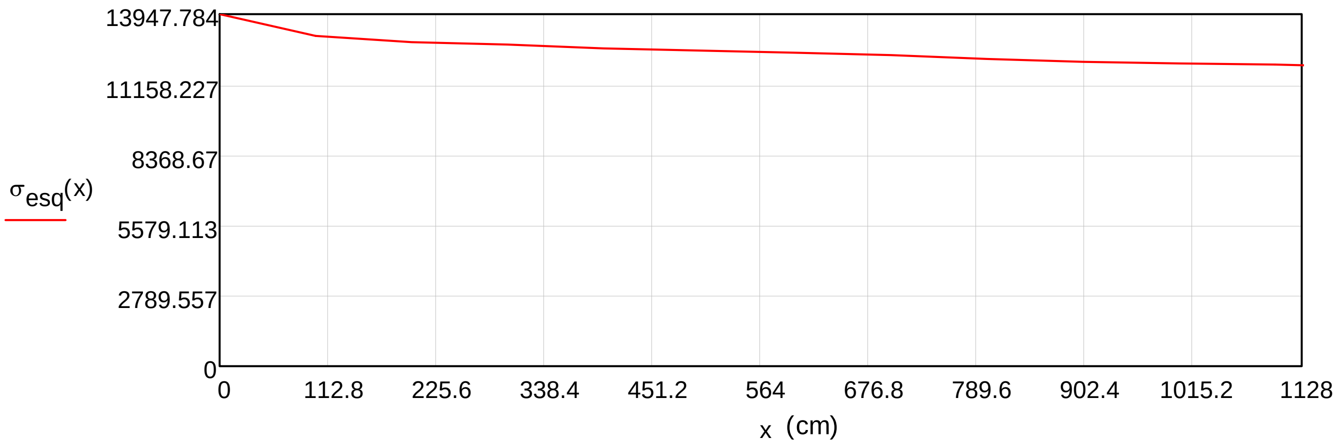
$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13031.51 \\ 12813.76 \\ 12693.27 \\ 12516.5 \\ 12437.23 \\ 12350.95 \\ 12188.41 \\ 12055.75 \\ 11991.53 \\ 11930.31 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\,dx \qquad \text{Área} = 140887.92 \cdot \frac{kg \cdot m}{cm^2}$$

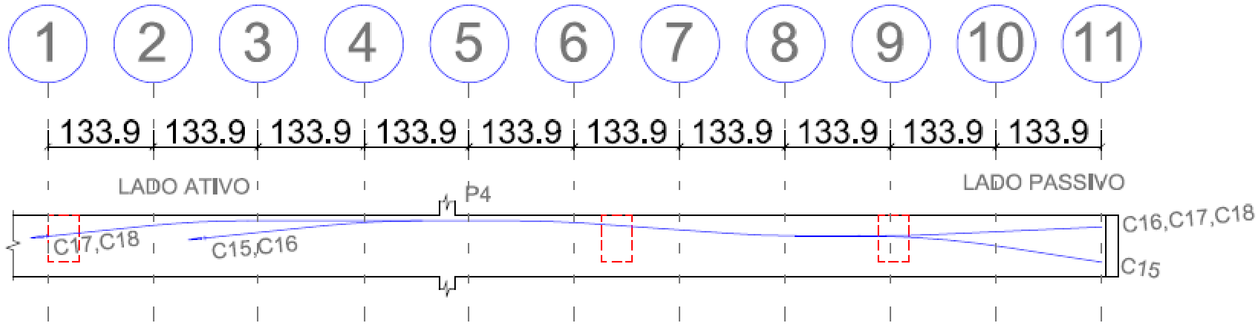
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12490.06 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 12.10m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 17.9 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m)\cdot(L_{cabo})}{E_{teórico\_aço}} = 78 \cdot mm$$

CABOS C17=C18 (6ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 13.39\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..\, n$$

$$S = 0\text{cm}, \frac{L}{n-1}..\, L = \begin{pmatrix} 0 \\ 133.9 \\ 267.8 \\ 401.7 \\ 535.6 \\ 669.5 \\ 803.4 \\ 937.3 \\ 1071.2 \\ 1205.1 \\ 1339 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.22 \\ 5.77 \\ 0 \\ 0 \\ 3.62 \\ 0.49 \\ 3.43 \\ 1.01 \\ 2.35 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 18.97 \\ 0.97 \\ 0.97 \\ 0.97 \\ 0.97 \\ 0.97 \\ 0.97 \\ 0.97 \\ 0.97 \\ 0.97 \end{pmatrix}^{\circ}$$

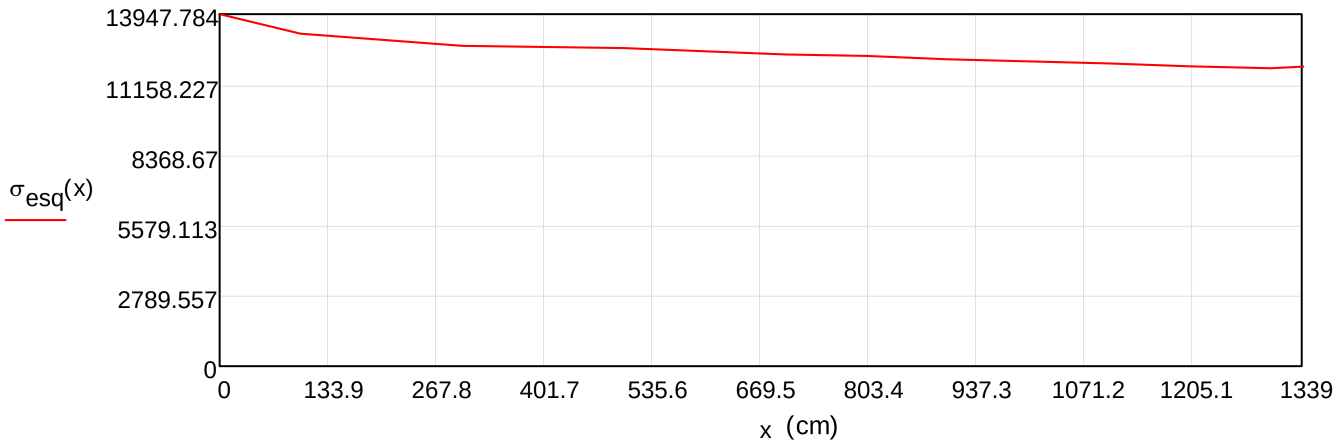
$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13019.14 \\ 12721.82 \\ 12644.91 \\ 12568.46 \\ 12371.94 \\ 12292.13 \\ 12107.67 \\ 12016.4 \\ 11878.38 \\ 11806.57 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma_{esq}(x)\, dx \qquad \text{Área} = 166543.01 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12437.87 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 14.20m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \cdot \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 17.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 91 \cdot mm$$

V18 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE PASSIVA (Direita)

$a_0 = 22\text{cm}$ $\quad n = 2$ $\quad q = 2$ $\quad F_{inicial} = 6 \cdot \sigma_1 \cdot \text{Área}_{teórica\_aço} = 1176.86\,\text{kN}$

$d = 15\text{cm}$ $\quad a_1 = 2d = 30\,\text{cm}$

$F_1 = F_{inicial} \cdot \cos(1°) = 1176.68\,\text{kN}$ $\quad F_2 = F_{inicial} \cdot \cos(6°) = 1170.42\,\text{kN}$

$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 78.45\,\text{kN}$ $\quad T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 78.03\,\text{kN}$

$k = 1 .. n$

$F_k = \begin{pmatrix} 1176.68 \\ 1170.42 \end{pmatrix} \text{kN}$ $\quad T_k = \begin{pmatrix} 78.45 \\ 78.03 \end{pmatrix} \text{kN}$ $\quad \sum F = 2347.1\,\text{kN}$

$fyd = 43.48 \frac{\text{kN}}{\text{cm}^2}$ $\quad As_1 = \frac{\max(T)}{fyd} = 1.8\,\text{cm}^2$

$As_{fretagem} = As_1 = 1.8\,\text{cm}^2$ $\quad As_{estribos} = \frac{As_1}{2} = 0.9\,\text{cm}^2$

EXTREMIDADE ATIVA (Esquerda)

$b = 25cm$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 1176.86\,kN$

$a_0 = 18cm$ $\quad c = 7cm$

$d = 15cm$ $\quad a_3 = a_0 + c = 25\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 1176.68\,kN$ $\quad F_3 = F_{inicial} \cdot \cos(5°) = 1172.39\,kN$

$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_3}\right) = 82.37\,kN$ $\quad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_3}\right) = 82.07\,kN$

$F_2 = F_{inicial} \cdot \cos(5°) = 1172.39\,kN$

$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_3}\right) = 82.07\,kN$

$a_4 = 2 \cdot d + (n - 1) \cdot b = 80\,cm$ $\quad k = 1 .. n$

$F_k = \begin{pmatrix} 1176.68 \\ 1172.39 \\ 1172.39 \end{pmatrix} kN$ $\quad T_k = \begin{pmatrix} 82.37 \\ 82.07 \\ 82.07 \end{pmatrix} kN$ $\quad \sum F = 3521.46\,kN$

$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_3}{a_4}\right) \cdot \sum F = 146.73\,kN$ $\quad fyd = 43.48\,\frac{kN}{cm^2}$

$As_3 = \frac{\max(T)}{fyd} = 1.89\,cm^2$ $\quad As_4 = q \cdot \left(\frac{T_n}{fyd}\right) = 6.75\,cm^2$

$As_{fretagem} = \max(As_1, As_3) = 1.89\,cm^2$

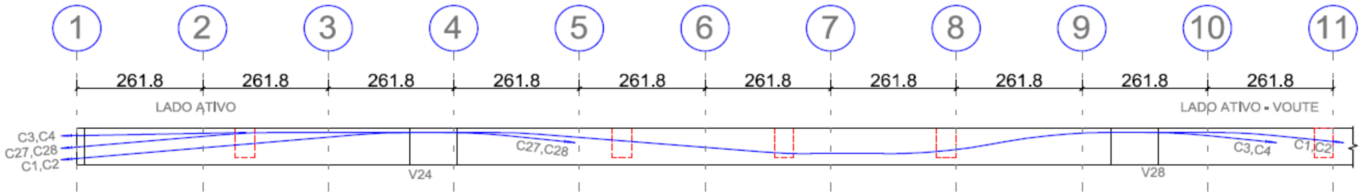
Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$As_{estribos} = \frac{\max(As_1, As_4)}{2} = 3.37\,cm^2$

$L = \max(a_1, a_4) = 80\,cm$ $\quad bitola_{estribo} = 10mm$ $\quad adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 5$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V20 - CABOS C1 a C28



CABOS C1=C2 (4ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 26.18\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 11$ $\quad i = 1, 2..\, n$

$$S = 0\text{cm}, \frac{L}{n-1}..\, L = \begin{pmatrix} 0 \\ 261.8 \\ 523.6 \\ 785.4 \\ 1047.2 \\ 1309 \\ 1570.8 \\ 1832.6 \\ 2094.4 \\ 2356.2 \\ 2618 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0.12 \\ 5.11 \\ 4.83 \\ 0.01 \\ 4.74 \\ 7.28 \\ 4.63 \\ 2.69 \\ 6.06 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 19.97 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{ll} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13779.86 \\ 13613.78 \\ 13286.25 \\ 12978.39 \\ 12822.13 \\ 12528.66 \\ 12139.41 \\ 11865.76 \\ 11667.21 \\ 10790.86 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 6.06 \\ 2.69 \\ 4.63 \\ 7.28 \\ 4.74 \\ 0.01 \\ 4.83 \\ 5.11 \\ 0.12 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \\ 1.97 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

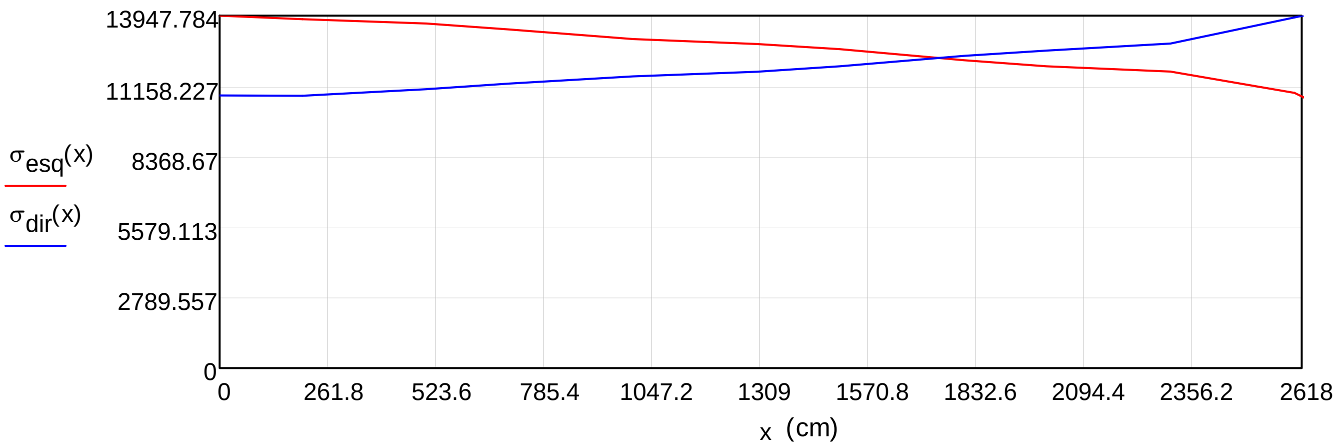
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12900.13 \\ 12684.27 \\ 12398.34 \\ 12013.14 \\ 11738.18 \\ 11596.86 \\ 11328.14 \\ 11055.6 \\ 10922.36 \\ 10790.86 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$

$\text{interseção} = 1739.87 \cdot cm$

$\sigma_{\text{interseção}} = 12274.48 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 229699.17 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 112883.36 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 342582.53 \cdot \frac{kg \cdot m}{cm^2}$$

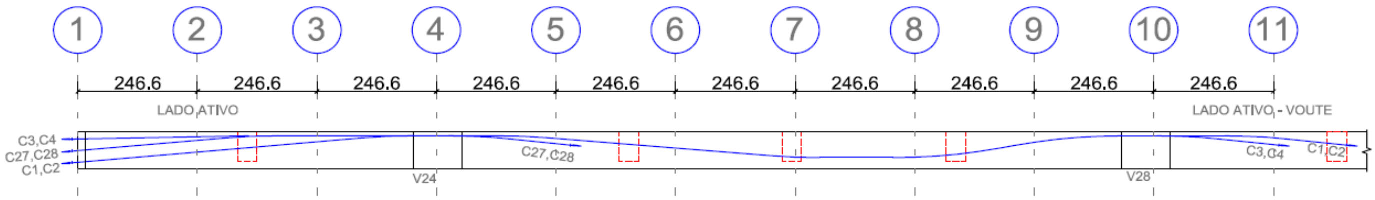
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13085.66 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 27.85m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.8 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 187 \cdot mm$$

CABOS C3=C4 (4ø15.2mm)



$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 24.66m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 246.6 \\ 493.2 \\ 739.8 \\ 986.4 \\ 1233 \\ 1479.6 \\ 1726.2 \\ 1972.8 \\ 2219.4 \\ 2466 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0.07 \\ 1.27 \\ 0.15 \\ 4.96 \\ 0.12 \\ 2.47 \\ 4.35 \\ 6.64 \\ 9.05 \\ 2.1 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 19.86 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13789.28 \\ 13613.99 \\ 13459.05 \\ 13147.46 \\ 12997.94 \\ 12795.14 \\ 12523.66 \\ 12165.66 \\ 11721.61 \\ 10878.54 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 2.1 \\ 9.05 \\ 6.64 \\ 4.35 \\ 2.47 \\ 0.12 \\ 4.96 \\ 0.15 \\ 1.27 \\ 0.07 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \\ 1.86 \end{pmatrix}°$$

$n = 11$

$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

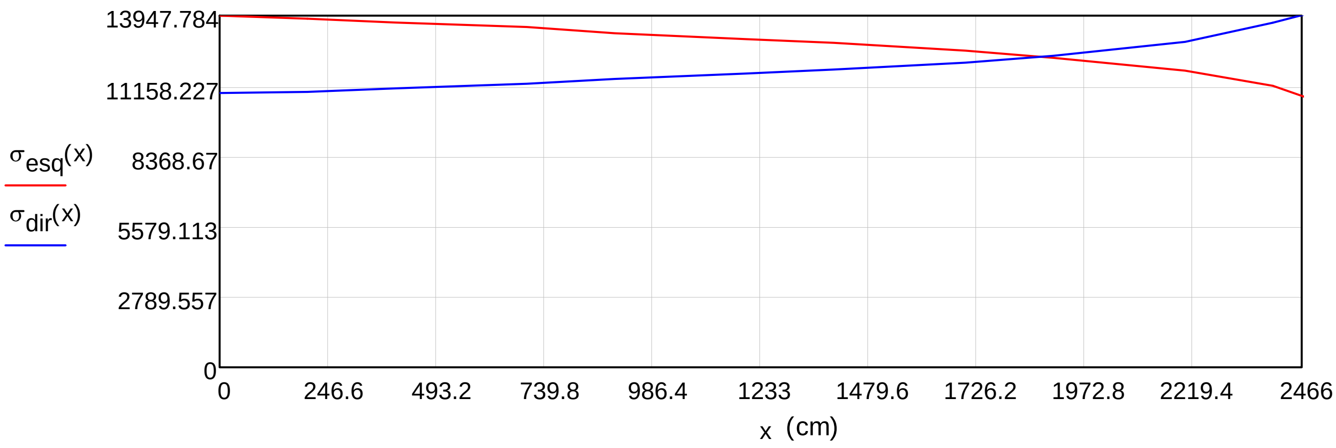
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12944.59 \\ 12472.11 \\ 12115.59 \\ 11858.52 \\ 11673.5 \\ 11540.74 \\ 11273.56 \\ 11145.26 \\ 11003.58 \\ 10878.54 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad$ $d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d) \qquad interseção = 1873.21 \cdot cm$$

$$\sigma_{interseção} = 12317.05 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx \qquad Área_1 = 247740.14 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx \qquad Área_2 = 76834.32 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 324574.46 \cdot \frac{kg \cdot m}{cm^2}$$

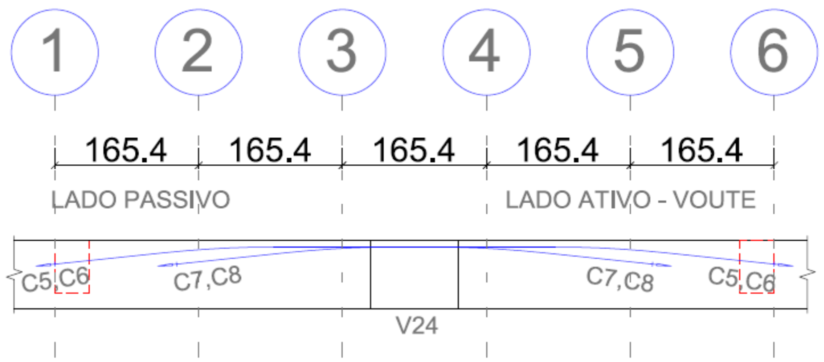
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13161.98 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 26.35m$ $\qquad$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.9 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 178 \cdot mm$$

CABOS C5=C6 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\qquad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\qquad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74 \cdot \text{fptk}, 0.82 \cdot \text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{\text{kgf}}{\text{cm}^2}$ $\qquad$ $\mu = 0.20$ $\qquad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\qquad$ $e = 2.72$ $\qquad$ $L = 8.27\text{m}$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{\text{rad}}{\text{m}}$ $\qquad$ $n = 6$ $\qquad$ $i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 165.4 \\ 330.8 \\ 496.2 \\ 661.6 \\ 827 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 1.93 \\ 4.14 \\ 0 \\ 4.14 \\ 1.93 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 15.25 \\ 1.25 \\ 1.25 \\ 1.25 \\ 1.25 \end{pmatrix}^{\circ}$$

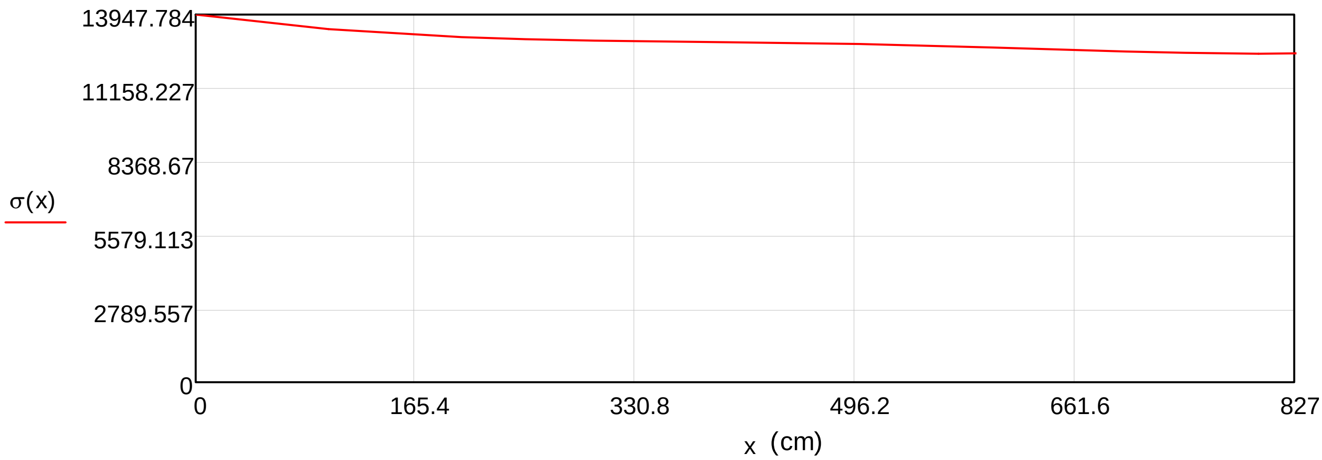
$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13175.45 \\ 12935.19 \\ 12836.34 \\ 12602.27 \\ 12460.23 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\, dx \qquad \text{Área} = 106937.93 \cdot \frac{kg \cdot m}{cm^2}$$

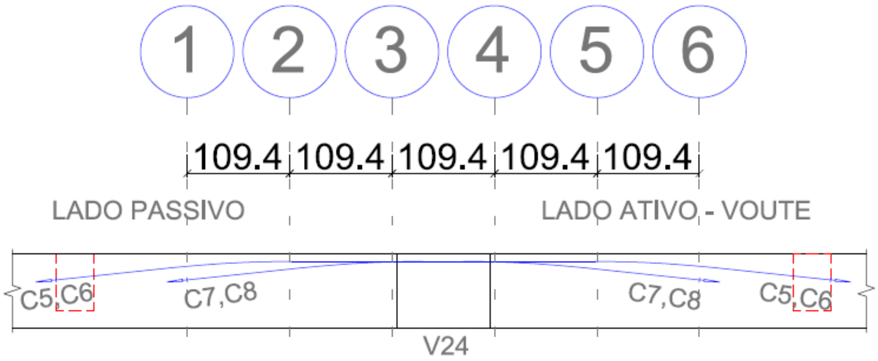
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12930.83 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 9.10m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.5 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 60 \cdot mm$$

CABOS C7=C8 (4ø15.2mm)



$Área_{teórica\_aço} = 143.4mm^2$ $\quad$ $fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad$ $fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01 \dfrac{rad}{m}$ $\quad$ $e = 2.72$ $\quad$ $L = 5.47m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad$ $n = 6$ $\quad$ $i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 109.4 \\ 218.8 \\ 328.2 \\ 437.6 \\ 547 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.5 \\ 3.15 \\ 4.5 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 18.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \end{pmatrix} °$$

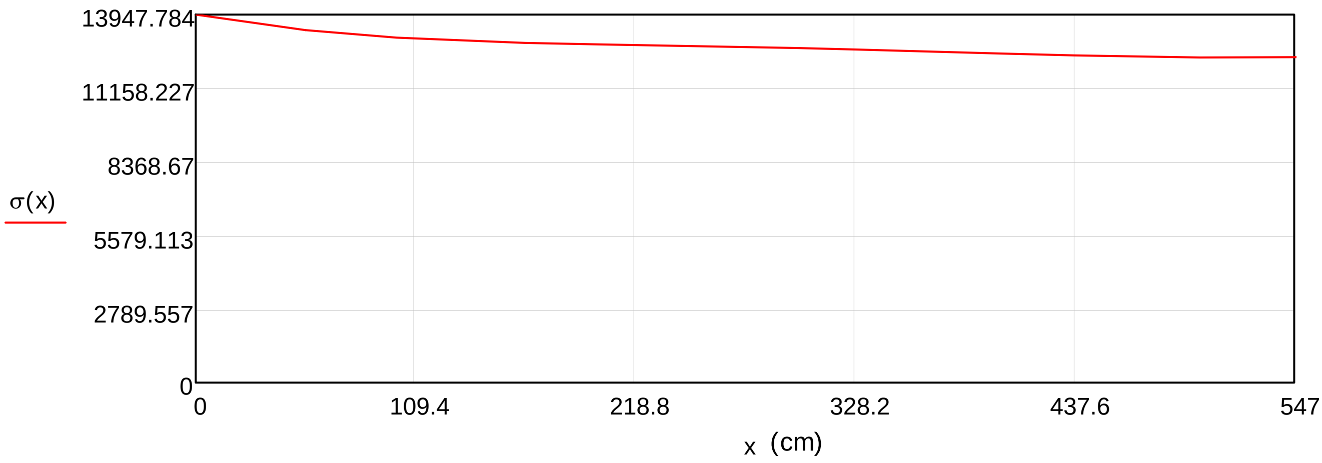
$$\alpha_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13032.4 \\ 12797.93 \\ 12625.69 \\ 12398.55 \\ 12336.09 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = cspline(S, \sigma_{esq})$

$$\sigma(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$Área = \int_0^L \sigma(x)\, dx \qquad Área = 69865.29 \cdot \frac{kg \cdot m}{cm^2}$$

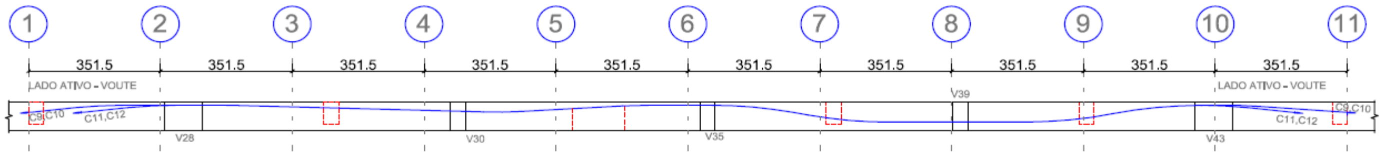
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12772.45 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 6.30m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 41 \cdot mm$$

CABOS C9=C10 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74 \cdot \text{fptk}, 0.82 \cdot \text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 35.15\,\text{m}$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 351.5 \\ 703 \\ 1054.5 \\ 1406 \\ 1757.5 \\ 2109 \\ 2460.5 \\ 2812 \\ 3163.5 \\ 3515 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 6.07 \\ 1.61 \\ 0 \\ 4.86 \\ 3.25 \\ 8.86 \\ 8.86 \\ 7.61 \\ 7.61 \\ 4.07 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 16.65 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{ll} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13533.54 \\ 13294.06 \\ 13079.38 \\ 12739.21 \\ 12466.15 \\ 11985.6 \\ 11523.57 \\ 11125.46 \\ 10741.1 \\ 10046.43 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 4.07 \\ 7.61 \\ 7.61 \\ 8.86 \\ 8.86 \\ 3.25 \\ 4.86 \\ 0 \\ 1.61 \\ 6.07 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 16.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \\ 2.65 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

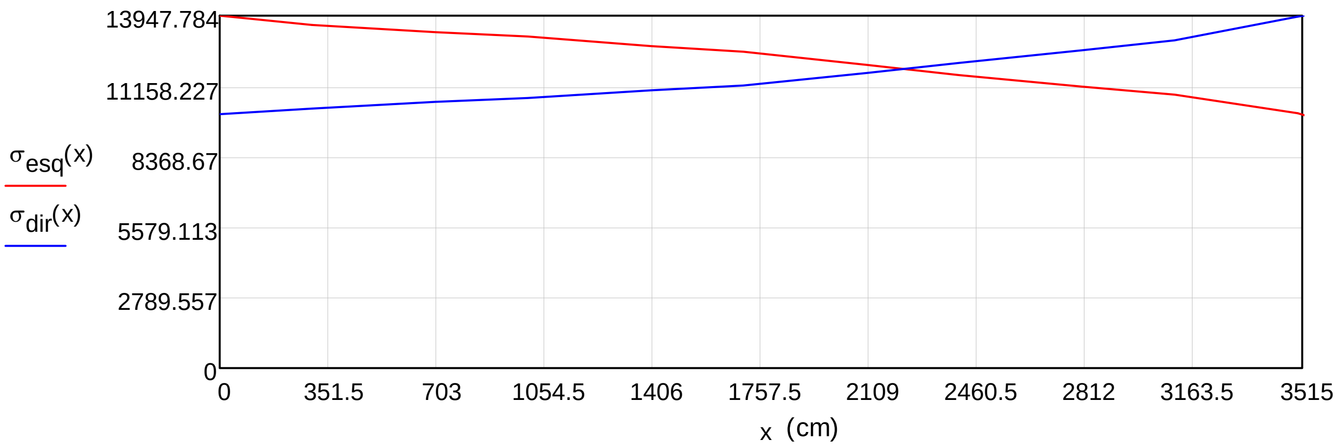
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13045.72 \\ 12595.02 \\ 12159.89 \\ 11691.15 \\ 11240.48 \\ 10999.54 \\ 10713.46 \\ 10540.45 \\ 10353.94 \\ 10046.43 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 2215.82 \cdot cm$

$\sigma_{\text{interseção}} = 11836.05 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 287160.5 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 165405.61 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 452566.11 \cdot \frac{kg \cdot m}{cm^2}$$

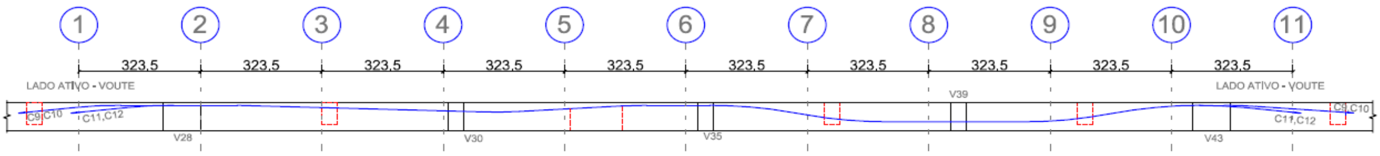
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12875.28 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 36.85m \qquad \text{Área}_{\text{teórica\_aço}} = 143.4 \cdot mm^2 \qquad E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$$

$$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 18.5 \cdot t$$

$$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 243 \cdot mm$$

CABOS C11=C12 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 32.35m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 323.5 \\ 647 \\ 970.5 \\ 1294 \\ 1617.5 \\ 1941 \\ 2264.5 \\ 2588 \\ 2911.5 \\ 3235 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 6.07 \\ 1.61 \\ 0 \\ 4.86 \\ 3.25 \\ 10.19 \\ 10.19 \\ 3.61 \\ 0 \\ 9.69 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 20.44 \end{pmatrix} °$$

$$\alpha_i = \begin{array}{|l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13544.96 \\ 13320.98 \\ 13122.82 \\ 12793.03 \\ 12531.49 \\ 12003.51 \\ 11497.78 \\ 11251.19 \\ 11083.83 \\ 10176.25 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 9.69 \\ 0 \\ 3.61 \\ 10.19 \\ 10.19 \\ 3.25 \\ 4.86 \\ 0 \\ 1.61 \\ 6.07 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 20.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \\ 2.44 \end{pmatrix} °$$

$n = 11$

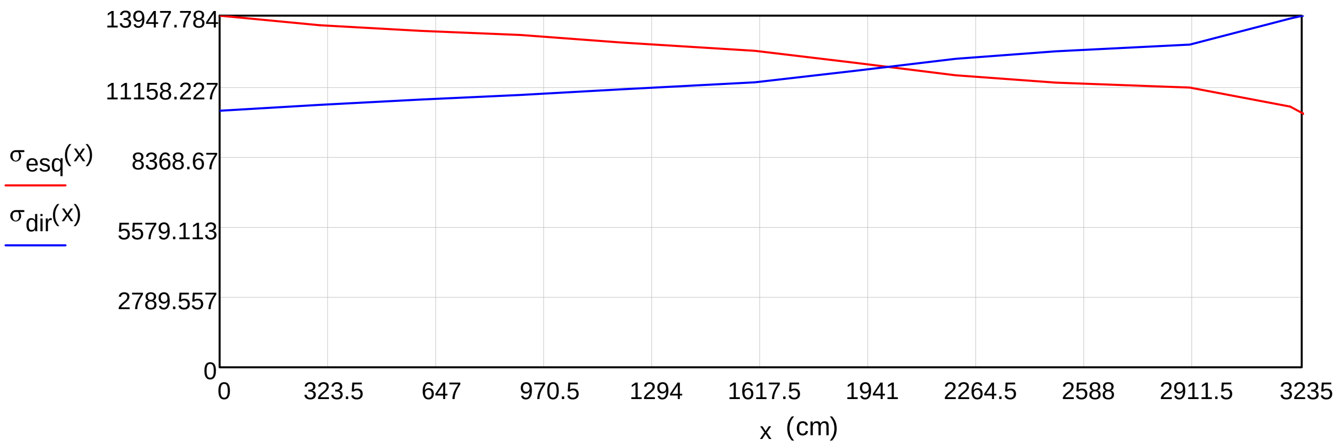
$$\theta_i = \begin{cases} 0\,rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu\cdot\theta + \kappa\cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 12805.69 \\ 12615.2 \\ 12344.65 \\ 11824.55 \\ 11326.36 \\ 11094.8 \\ 10815.97 \\ 10655.08 \\ 10478.89 \\ 10176.25 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq}) \qquad b = \text{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\quad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$$

$interseção = 1992.68 \cdot cm$

$$\sigma_{interseção} = 11911.37 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx \qquad Área_1 = 259458.37 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx \qquad Área_2 = 157765.92 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 417224.29 \cdot \frac{kg \cdot m}{cm^2}$$

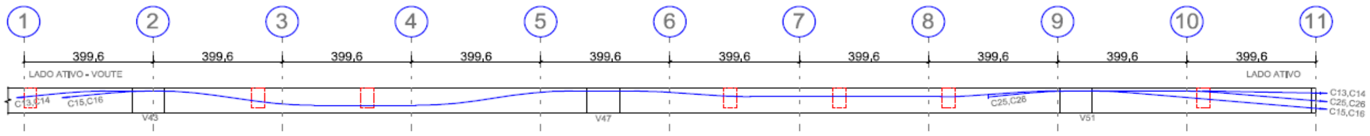
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12897.2 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 34.05m$ $\quad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\quad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.5 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 225 \cdot mm$$

CABOS C13=C14 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk\,,\,0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 39.96m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 399.6 \\ 799.2 \\ 1198.8 \\ 1598.4 \\ 1998 \\ 2397.6 \\ 2797.2 \\ 3196.8 \\ 3596.4 \\ 3996 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 6.07 \\ 4.76 \\ 4.76 \\ 4.88 \\ 8.94 \\ 4.06 \\ 0 \\ 0 \\ 0 \\ 1.14 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 17.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if} \quad i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12991.37 \\ 12637.07 \\ 12292.43 \\ 11952.94 \\ 11473.7 \\ 11183.32 \\ 10978.34 \\ 10777.12 \\ 10579.59 \\ 10378.12 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 1.14 \\ 0 \\ 0 \\ 0 \\ 4.06 \\ 8.94 \\ 4.88 \\ 4.76 \\ 4.76 \\ 6.07 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 3.01 \\ 17.01 \end{pmatrix} \circ$$

$$n = 11$$

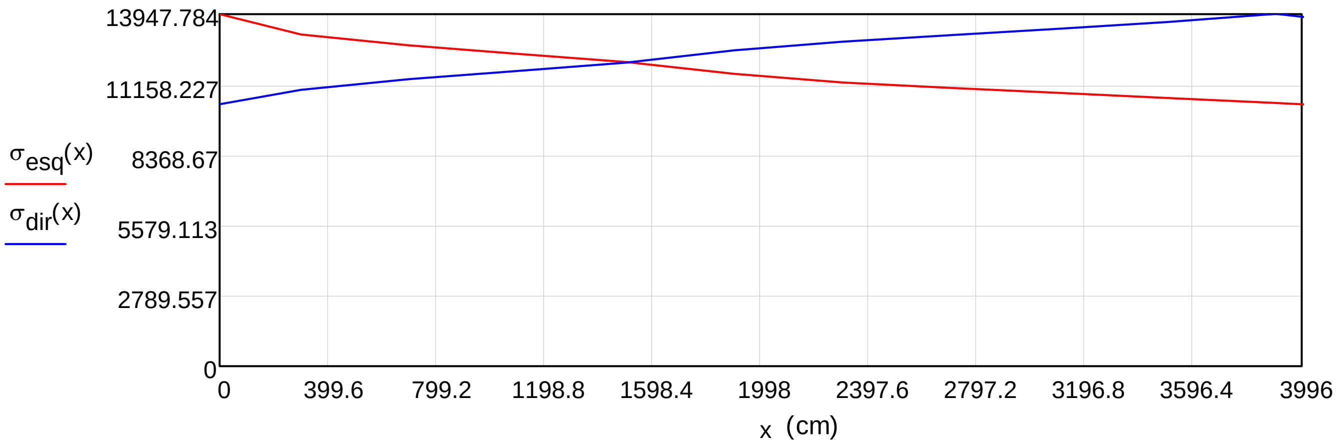
$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13682.17 \\ 13431.39 \\ 13185.21 \\ 12943.54 \\ 12615.96 \\ 12110.14 \\ 11775.68 \\ 11454.54 \\ 11142.15 \\ 10378.12 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq}) \qquad b = \text{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$$

$\text{interseção} = 1511.42 \cdot cm$

$$\sigma_{\text{interseção}} = 12039.03 \cdot \frac{kg}{cm^2}$$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 192484.08 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 326048.54 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 518532.61 \cdot \frac{kg \cdot m}{cm^2}$$

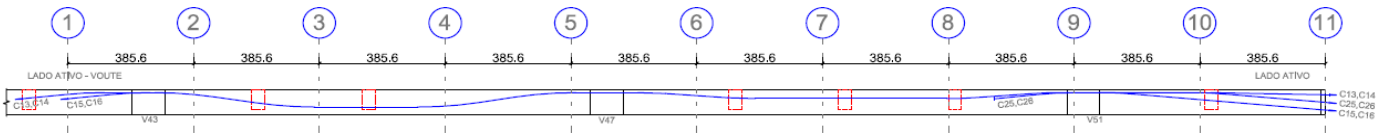
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12976.29 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 41.65m$ $\qquad \text{Área}_{\text{teórica\_aço}} = 143.4 \cdot mm^2$ $\qquad E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$

$$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 18.6 \cdot t$$

$$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 277 \cdot mm$$

CABOS C15=C16 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 38.56\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..\, n$$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 385.6 \\ 771.2 \\ 1156.8 \\ 1542.4 \\ 1928 \\ 2313.6 \\ 2699.2 \\ 3084.8 \\ 3470.4 \\ 3856 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 11.76 \\ 5.69 \\ 4.04 \\ 3.22 \\ 4.88 \\ 4.06 \\ 0.23 \\ 0.23 \\ 5.1 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 20.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \end{pmatrix}^{\circ}$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 12728.8 \\ 12352.35 \\ 12046.27 \\ 11773.99 \\ 11454.1 \\ 11169.64 \\ 10971.47 \\ 10776.81 \\ 10477.06 \\ 10291.5 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 5.1 \\ 0.23 \\ 0.23 \\ 4.06 \\ 4.88 \\ 3.22 \\ 4.04 \\ 5.69 \\ 11.76 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 2.91 \\ 20.91 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \begin{array}{|l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

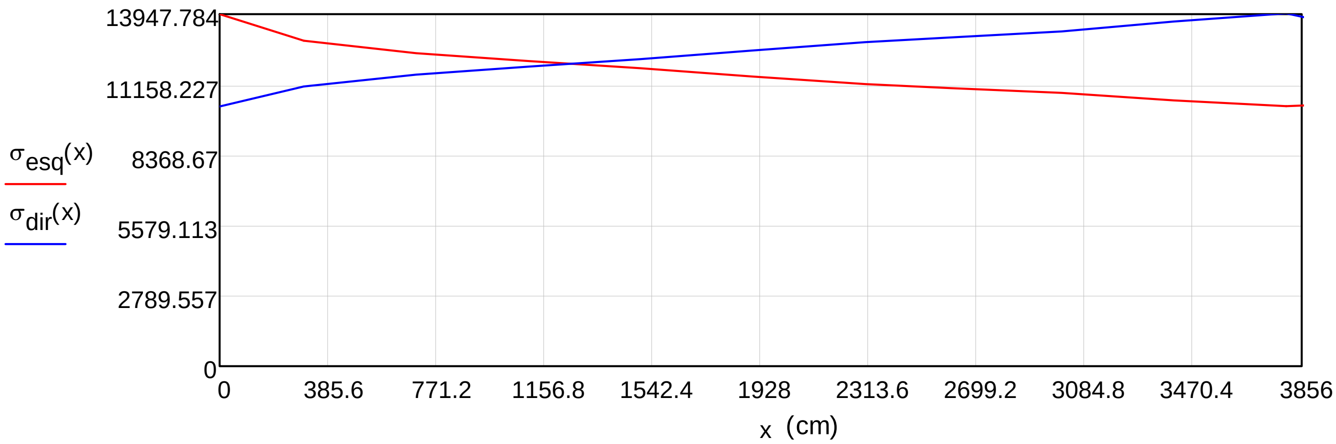
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13700.75 \\ 13319.68 \\ 13083.36 \\ 12851.23 \\ 12532.07 \\ 12191.58 \\ 11916.02 \\ 11620.75 \\ 11277.07 \\ 10291.5 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq})$$

$$b = cspline(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = interp\left(\frac{b}{g}, S, \frac{reverse(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\quad\quad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad\quad$ $d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$$

$interseção = 1243.3 \cdot cm$

$$\sigma_{interseção} = 11983.42 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx \qquad Área_1 = 156683.86 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx \qquad Área_2 = 339493.82 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 496177.68 \cdot \frac{kg \cdot m}{cm^2}$$

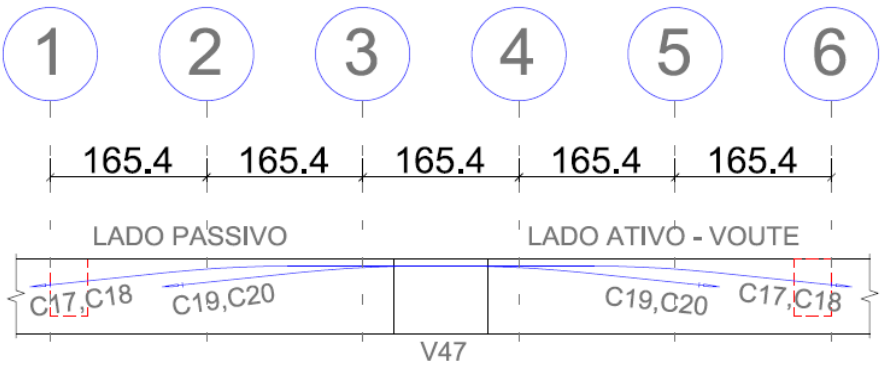
$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 12867.68 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 40.25m$ $\quad\quad$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\quad\quad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 18.5 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 266 \cdot mm$$

CABOS C17=C18=C21=C22 (4ø15.2mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\,\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\,\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 8.27\,\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}} \qquad n = 6 \qquad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 165.4 \\ 330.8 \\ 496.2 \\ 661.6 \\ 827 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 1.93 \\ 4.14 \\ 0 \\ 4.14 \\ 1.93 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 13.25 \\ 1.25 \\ 1.25 \\ 1.25 \\ 1.25 \end{pmatrix}°$$

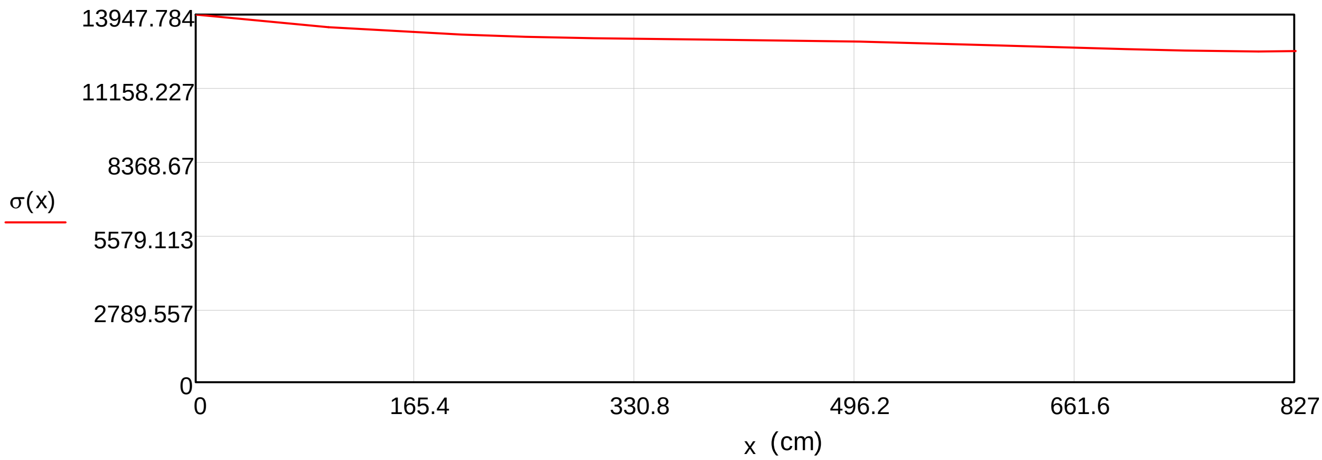
$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha + \kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13266.91 \\ 13024.99 \\ 12925.45 \\ 12689.75 \\ 12546.73 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq})$$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 107625.56 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13013.97 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 9.10m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.7 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 61 \cdot mm$$

CABOS C19=C20=C23=C24 (4ø15.2mm)

$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01 \dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 5.47m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 6$ $\quad i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 109.4 \\ 218.8 \\ 328.2 \\ 437.6 \\ 547 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.5 \\ 3.15 \\ 4.5 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 18.82 \\ 0.82 \\ 0.82 \\ 0.82 \\ 0.82 \end{pmatrix}°$$

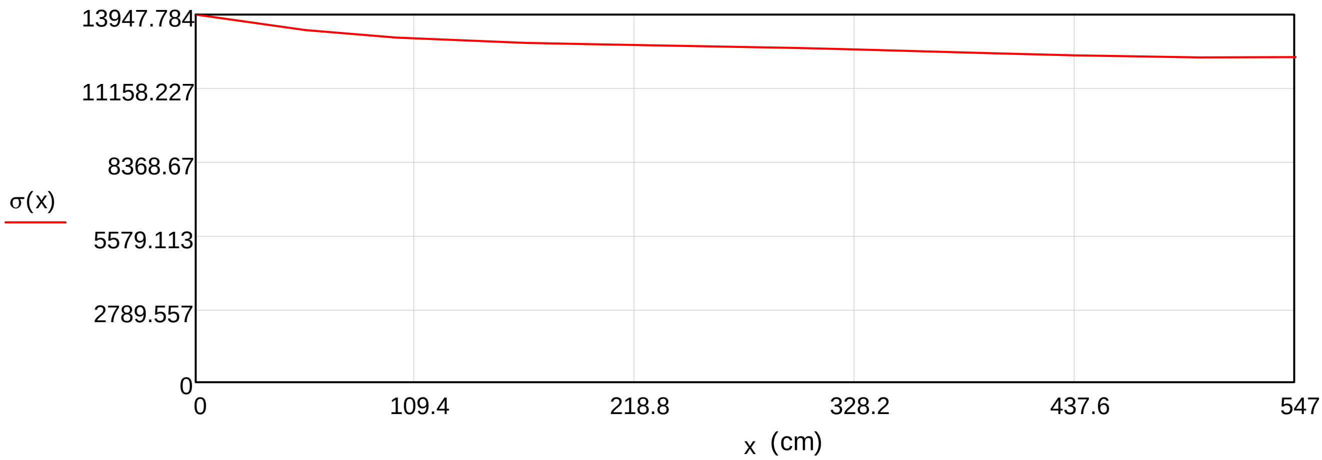
$$\alpha_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13032.4 \\ 12797.93 \\ 12625.69 \\ 12398.55 \\ 12336.09 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$$\sigma(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 69865.29 \cdot \frac{kg \cdot m}{cm^2}$$

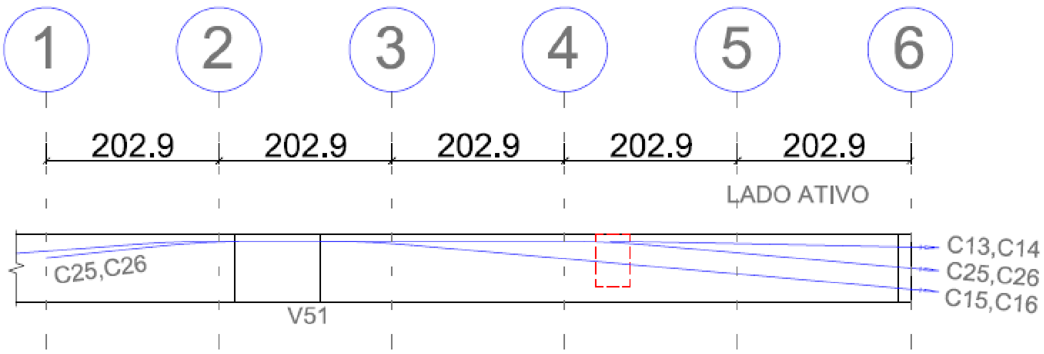
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12772.45 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 6.30m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 18.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 41 \cdot mm$$

CABOS C25=C26 (4ø15.2mm)



$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 10.15m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 6 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 203 \\ 406 \\ 609 \\ 812 \\ 1015 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.77 \\ 0.33 \\ 2.3 \\ 3.77 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 1.53 \\ 1.53 \\ 1.53 \\ 1.53 \\ 1.53 \end{pmatrix}°$$

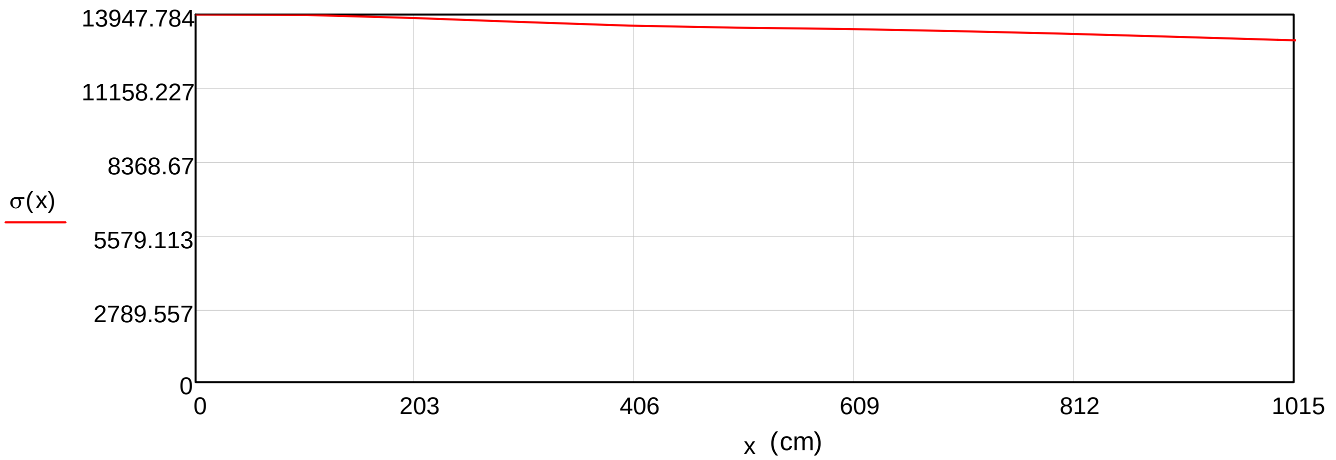
$$\alpha_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13817.28 \\ 13522.76 \\ 13394.58 \\ 13212.29 \\ 12973.2 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 136896.62 \cdot \frac{kg \cdot m}{cm^2}$$

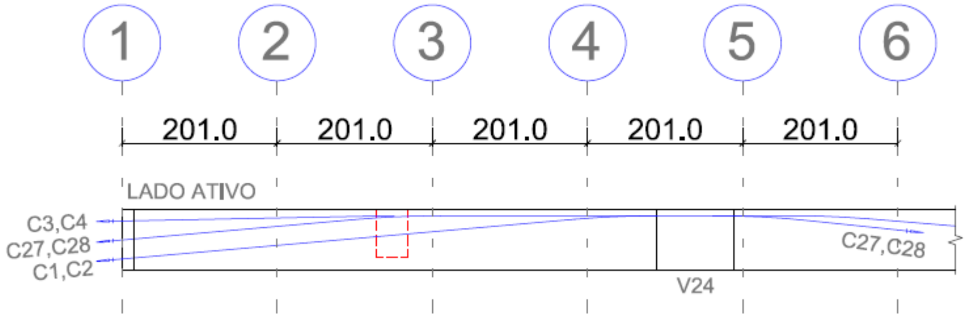
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13487.35 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 11.00m$ $\qquad$ $\text{Área}_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \dfrac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.3 \cdot t$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 76 \cdot mm$$

CABOS C27=C28 (4ø15.2mm)



$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 10.05\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 6 \qquad i = 1, 2..n$$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 201 \\ 402 \\ 603 \\ 804 \\ 1005 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0.02 \\ 4.56 \\ 0.57 \\ 1.76 \\ 4.23 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.52 \\ 1.52 \\ 1.52 \\ 1.52 \\ 1.52 \end{pmatrix}°$$

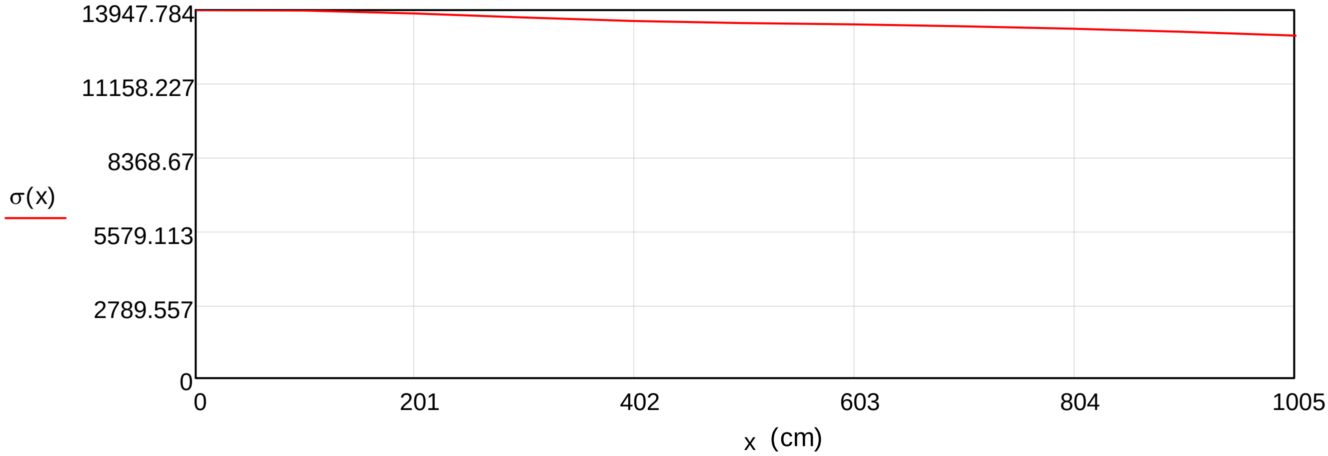
$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1\cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13818.31 \\ 13533.88 \\ 13403.41 \\ 13241.71 \\ 12983.27 \end{pmatrix}\cdot\frac{\text{kgf}}{\text{cm}^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 135668.08 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13499.31 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 10.90m$ $\qquad$ $\text{Área}_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.4 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 75 \cdot mm$$

V20 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA

$b = 25\text{cm}$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 4 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 784.58\,\text{kN}$

$a_0 = 18\text{cm}$ $\quad c = 7\text{cm}$

$d = 15\text{cm}$ $\quad a_1 = a_0 + c = 25\,\text{cm}$

$F_1 = F_{inicial} \cdot \cos(2°) = 784.1\,\text{kN}$ $\quad F_3 = F_{inicial} \cdot \cos(5°) = 781.59\,\text{kN}$

$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.89\,\text{kN}$ $\quad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,\text{kN}$

$F_2 = F_{inicial} \cdot \cos(5°) = 781.59\,\text{kN}$

$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 54.71\,\text{kN}$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 80\,\text{cm}$ $\quad k = 1 .. n$

$F_k = \begin{pmatrix} 784.1 \\ 781.59 \\ 781.59 \end{pmatrix} \text{kN}$ $\quad T_k = \begin{pmatrix} 54.89 \\ 54.71 \\ 54.71 \end{pmatrix} \text{kN}$ $\quad \sum F = 2347.28\,\text{kN}$

$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 97.8\,\text{kN}$ $\quad fyd = 43.48 \frac{\text{kN}}{\text{cm}^2}$

$As_1 = \frac{\max(T)}{fyd} = 1.26\,\text{cm}^2$ $\quad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 4.5\,\text{cm}^2$

$As_{fretagem} = As_1 = 1.26\,cm^2$

Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$As_{estribos} = \dfrac{As_2}{2} = 2.25\,cm^2$

EXTREMIDADE PASSIVA

a_0 = Área da placa de distribuição

d = Distância entre a face do concreto ao eixo da ancoragem

n = Número de ancoragens

$n = 1$

$F_{inicial} = 784.58\,kN$

$a_0 = 18\,cm$

$d = 28cm$

$a_3 = 2 \cdot d = 56 \cdot cm$

$F = n \cdot F_{inicial} \cdot \cos(6°) = 780.28\,kN$

$T = 0.25 \cdot F \cdot \left(1 - \dfrac{a_0}{a_3}\right) = 132.37\,kN$

$fyd = 43.48\,\dfrac{kN}{cm^2}$

$As_3 = \dfrac{T}{fyd} = 3.04\,cm^2$

$As_{estribos} = \dfrac{\max\left(As_2, As_3\right)}{2} = 2.25\,cm^2$

$L = \max\left(a_1, a_2, a_3\right) = 80\,cm$

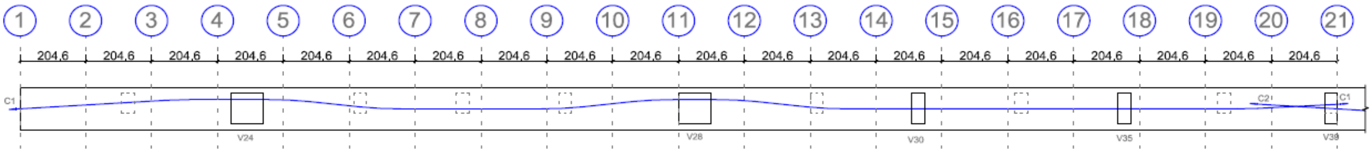
$bitola_{estribo} = 10mm$

$adotados = ceil\left[\dfrac{As_{estribos}}{\pi \dfrac{\left(bitola_{estribo}\right)^2}{4}}\right] = 3$

Estribos adotados 5ø10.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$ perpendiculares ao traçado do cabo em planta.

V21 - CABOS C1 a C3

CABO C1 (7ø12.7mm)



$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 100.9\text{mm}^2$ $\qquad$ $\text{fptk} = \dfrac{187.3\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1856.29\,\text{MPa}$ $\qquad$ $\text{fpyk} = \dfrac{168.6\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1670.96\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1370.19\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13972.03\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\qquad$ $\mu = 0.20$ $\qquad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\qquad$ $e = 2.72$ $\qquad$ $L = 40.92\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\qquad$ $n = 21$ $\qquad$ $i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 204.6 \\ 409.2 \\ 613.8 \\ 818.4 \\ 1023 \\ 1227.6 \\ 1432.2 \\ 1636.8 \\ 1841.4 \\ 2046 \\ 2250.6 \\ 2455.2 \\ 2659.8 \\ 2864.4 \\ 3069 \\ 3273.6 \\ 3478.2 \\ 3682.8 \\ 3887.4 \\ 4092 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 3.5 \\ 1.36 \\ 4.69 \\ 6.05 \\ 0 \\ 1.59 \\ 4.46 \\ 6.05 \\ 4.54 \\ 0 \\ 4.54 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 3.07 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 19.62 \end{pmatrix}^{\circ}$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13972.03 \\ 13836.51 \\ 13702.3 \\ 13463.86 \\ 13310.24 \\ 13028.27 \\ 12694.48 \\ 12571.35 \\ 12421.2 \\ 12167.27 \\ 11855.53 \\ 11610.11 \\ 11497.5 \\ 11259.49 \\ 11150.28 \\ 11042.13 \\ 10935.02 \\ 10828.96 \\ 10723.92 \\ 10551.5 \\ 9812.82 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$n = 21$ $\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 3.07 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 4.54 \\ 0 \\ 4.54 \\ 6.05 \\ 4.46 \\ 1.59 \\ 0 \\ 6.05 \\ 4.69 \\ 1.36 \\ 3.5 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 19.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \\ 1.62 \end{pmatrix}°$$

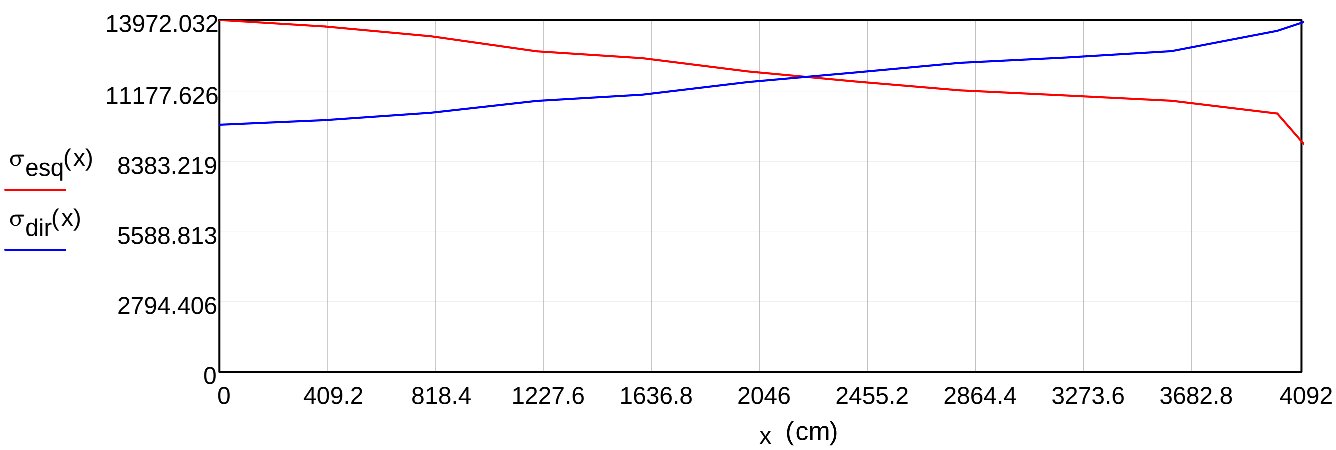
$$\theta_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13972.03 \\ 12993.89 \\ 12784.97 \\ 12660.96 \\ 12538.15 \\ 12416.54 \\ 12296.11 \\ 12176.84 \\ 11924.77 \\ 11809.1 \\ 11564.64 \\ 11268.35 \\ 11037.98 \\ 10906.15 \\ 10800.37 \\ 10523.65 \\ 10300.71 \\ 10183.18 \\ 10005.98 \\ 9908.93 \\ 9812.82 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq}) \qquad b = \mathrm{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\quad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad$ $d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$ $\quad$ $\text{interseção} = 2160.47 \cdot cm$

$\sigma_{\text{interseção}} = 11698.04 \cdot \frac{kg}{cm^2}$

$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\, dx$ $\quad$ $\text{Área}_1 = 279697.75 \cdot \frac{kg \cdot m}{cm^2}$

$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\, dx$ $\quad$ $\text{Área}_2 = 241120.65 \cdot \frac{kg \cdot m}{cm^2}$

$\text{Área} = (\text{Área}_1) + (\text{Área}_2)$ $\quad$ $\text{Área} = 520818.4 \cdot \frac{kg \cdot m}{cm^2}$

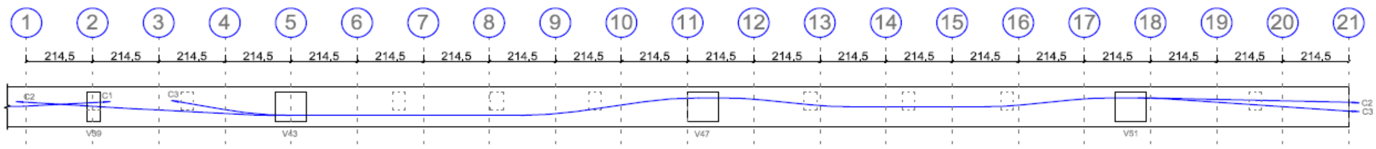
$\sigma_m = \frac{\text{Área}}{L}$ $\quad$ $\sigma_m = 12727.72 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 42.55m$ $\quad$ $\text{Área}_{\text{teórica\_aço}} = 100.9 \cdot mm^2$ $\quad$ $E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$

$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 12.8 \cdot t$

$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 278 \cdot mm$

CABO C2 (7ø12.7mm)



$$\text{Área}_{\text{teórica\_aço}} = 100.9\text{mm}^2 \qquad \text{fptk} = \frac{187.3\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1856.29\,\text{MPa} \qquad \text{fpyk} = \frac{168.6\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1670.96\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1370.19\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13972.03\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 42.90\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 21 \qquad i = 1, 2 .. n$$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 214.5 \\ 429 \\ 643.5 \\ 858 \\ 1072.5 \\ 1287 \\ 1501.5 \\ 1716 \\ 1930.5 \\ 2145 \\ 2359.5 \\ 2574 \\ 2788.5 \\ 3003 \\ 3217.5 \\ 3432 \\ 3646.5 \\ 3861 \\ 4075.5 \\ 4290 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0.5 \\ 0 \\ 3.15 \\ 0 \\ 0 \\ 0 \\ 6.38 \\ 2.24 \\ 6.54 \\ 6.61 \\ 0 \\ 4.54 \\ 0 \\ 4.54 \\ 0 \\ 4.54 \\ 1.34 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 19.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13972.03 \\ 12987.69 \\ 12852.34 \\ 12721.61 \\ 12509.86 \\ 12382.61 \\ 12256.66 \\ 12131.98 \\ 11804.82 \\ 11639.47 \\ 11319.47 \\ 11005.66 \\ 10893.71 \\ 10665.07 \\ 10556.58 \\ 10335.01 \\ 10229.89 \\ 10015.17 \\ 9897.23 \\ 9796.56 \\ 9696.91 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$n = 21$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1.34 \\ 4.54 \\ 0 \\ 4.54 \\ 0 \\ 4.54 \\ 0 \\ 6.61 \\ 6.54 \\ 2.24 \\ 6.38 \\ 0 \\ 0 \\ 0 \\ 3.15 \\ 0 \\ 0.5 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 1.7 \\ 19.7 \end{pmatrix}^{\circ}$$

$$\theta_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

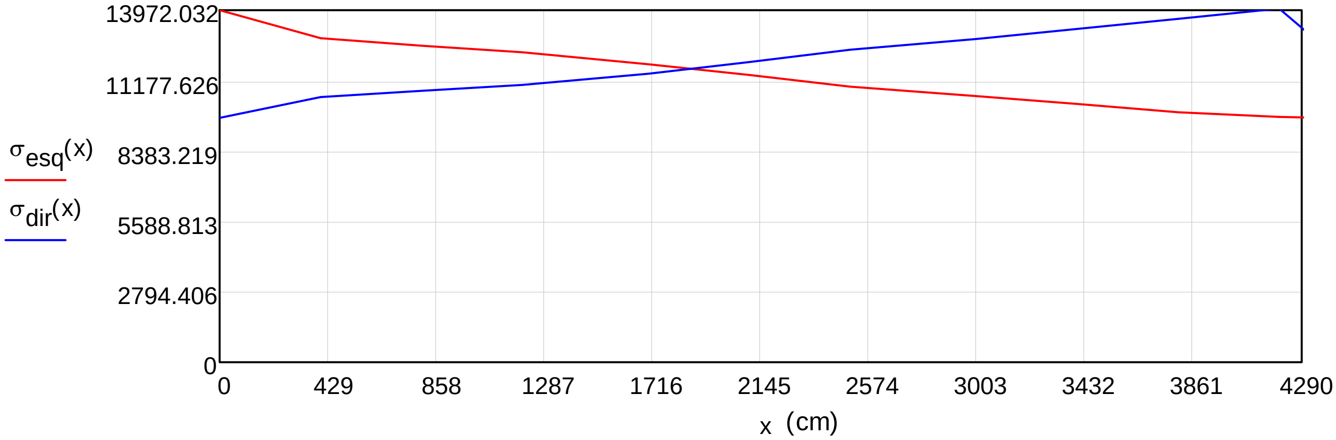
$$\sigma_{dir} = \begin{pmatrix} 13972.03 \\ 13829.91 \\ 13689.23 \\ 13528.02 \\ 13244.09 \\ 13109.37 \\ 12834.22 \\ 12703.67 \\ 12437.03 \\ 12310.52 \\ 11969.24 \\ 11640.18 \\ 11477.14 \\ 11167.63 \\ 11054.03 \\ 10941.59 \\ 10830.29 \\ 10650.03 \\ 10541.7 \\ 10431.84 \\ 9696.91 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma_{esq})$$

$$b = cspline(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = interp\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = interp\left(\frac{b}{g}, S, \frac{reverse(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\quad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad$ $d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$$

$\text{interseção} = 1929.98 \cdot cm$

$$\sigma_{\text{interseção}} = 11639.97 \cdot \frac{kg}{cm^2}$$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\, dx \qquad \text{Área}_1 = 240875.67 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\, dx \qquad \text{Área}_2 = 305835.95 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 546711.62 \cdot \frac{kg \cdot m}{cm^2}$$

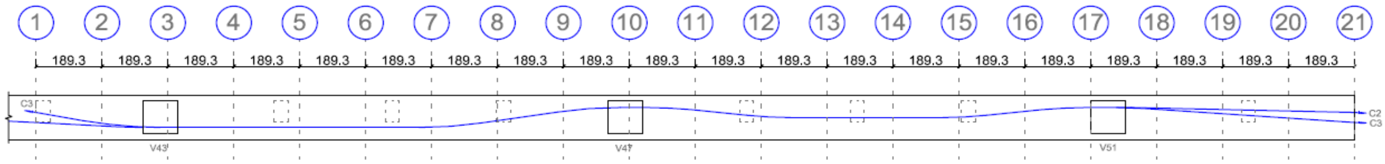
$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12743.86 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 44.60m$ $\quad$ $\text{Área}_{\text{teórica\_aço}} = 100.9 \cdot mm^2$ $\quad$ $E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$

$$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 12.9 \cdot t$$

$$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 291 \cdot mm$$

CABO C3 (7ø12.7mm)



$$Área_{teórica\_aço} = 100.9mm^2 \qquad fptk = \frac{187.3kN}{Área_{teórica\_aço}} = 1856.29\,MPa \qquad fpyk = \frac{168.6kN}{Área_{teórica\_aço}} = 1670.96\,MPa$$

$$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1370.19\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13972.03\cdot\frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{rad}{m} \qquad e = 2.72 \qquad L = 37.85m$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{rad}{m} \qquad n = 21 \qquad i = 1, 2..\, n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 189.25 \\ 378.5 \\ 567.75 \\ 757 \\ 946.25 \\ 1135.5 \\ 1324.75 \\ 1514 \\ 1703.25 \\ 1892.5 \\ 2081.75 \\ 2271 \\ 2460.25 \\ 2649.5 \\ 2838.75 \\ 3028 \\ 3217.25 \\ 3406.5 \\ 3595.75 \\ 3785 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 1.41 \\ 8.83 \\ 0 \\ 0 \\ 0 \\ 2.23 \\ 6.38 \\ 2.22 \\ 6.39 \\ 6.05 \\ 1.51 \\ 4.54 \\ 0 \\ 1.58 \\ 4.47 \\ 6.05 \\ 4.03 \\ 0 \\ 0 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 19.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \end{pmatrix}^{\circ}$$

$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13972.03 \\ 13001.01 \\ 12553.23 \\ 12440.5 \\ 12328.78 \\ 12218.06 \\ 12058.25 \\ 11740.99 \\ 11587.75 \\ 11282.49 \\ 10997.95 \\ 10875.31 \\ 10654.9 \\ 10559.21 \\ 10439.63 \\ 10230.42 \\ 9972.41 \\ 9786.73 \\ 9698.84 \\ 9611.74 \\ 9525.42 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 21$ $\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 4.03 \\ 6.05 \\ 4.47 \\ 1.58 \\ 0 \\ 4.54 \\ 1.51 \\ 6.05 \\ 6.39 \\ 2.22 \\ 6.38 \\ 2.23 \\ 0 \\ 0 \\ 0 \\ 8.83 \\ 1.41 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 1.5 \\ 19.5 \end{pmatrix}°$$

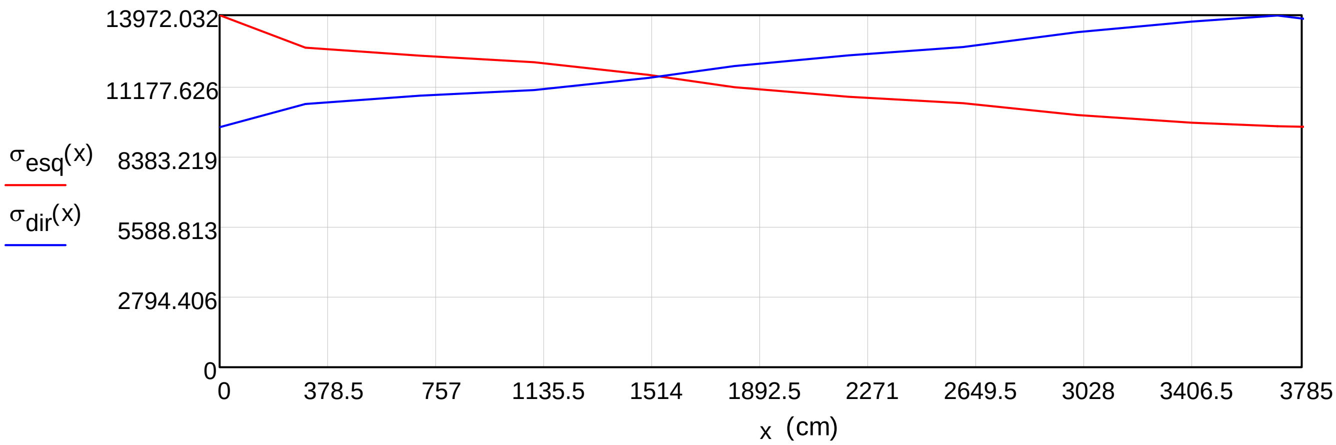
$$\theta_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13972.03 \\ 13846.56 \\ 13722.21 \\ 13598.98 \\ 13345.77 \\ 13009.2 \\ 12748.5 \\ 12604.12 \\ 12490.93 \\ 12237.77 \\ 12101.3 \\ 11796.11 \\ 11485.36 \\ 11335.46 \\ 11037.22 \\ 10892.85 \\ 10795.03 \\ 10698.09 \\ 10602.01 \\ 10236.86 \\ 9525.42 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq}) \qquad b = \mathrm{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d) \qquad \text{interseção} = 1548.48 \cdot cm$$

$$\sigma_{\text{interseção}} = 11546.41 \cdot \frac{kg}{cm^2}$$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\, dx \qquad \text{Área}_1 = 191404.75 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\, dx \qquad \text{Área}_2 = 288017.96 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 479422.7 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 12666.39 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 39.60m$ $\qquad \text{Área}_{\text{teórica\_aço}} = 100.9 \cdot mm^2$ $\qquad E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$

$$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 12.8 \cdot t$$

$$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 257 \cdot mm$$

V21 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

$n = 1$

$F_{inicial} = 7 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 967.76\,kN$

$a_0 = 18.5cm$

$d = 67.5cm$

$a_1 = 2 \cdot d = 135 \cdot cm$

$F = n \cdot F_{inicial} \cdot \cos(4°) = 965.41\,kN$

$T = 0.25 \cdot F \cdot \left(1 - \frac{a_0}{a_1}\right) = 208.28\,kN$

$fyd = 43.48\,\frac{kN}{cm^2}$

$As_1 = \frac{T}{fyd} = 4.79\,cm^2$

$As_{estribos} = \frac{As_1}{2} = 2.4\,cm^2$

$L = a_1 = 135\,cm$

$bitola_{estribo} = 8mm$

$adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 5$

EXTREMIDADE ATIVA

$b = 30cm$ $n = 2$ $q = 1$ $F_{inicial} = 7 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 967.76\,kN$

$a_0 = 18.5\,cm$ $c = 11.5cm$

$d = 52.5cm$ $a_1 = a_0 + c = 30\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 967.62\,kN$ $F_2 = F_{inicial} \cdot \cos(3°) = 966.44\,kN$

$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 92.73\,kN$ $T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 92.62\,kN$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 135\,cm$ $k = 1 .. n$

$F_k = \begin{pmatrix} 967.62 \\ 966.44 \end{pmatrix} kN$ $T_k = \begin{pmatrix} 92.73 \\ 92.62 \end{pmatrix} kN$ $\sum F = 1934.05\,kN$

$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 716.32\,kN$ $fyd = 43.48 \frac{kN}{cm^2}$

$As_1 = \frac{\max(T)}{fyd} = 2.13\,cm^2$ $As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 16.47\,cm^2$

$As_{fretagem} = As_1 = 2.13\,cm^2$

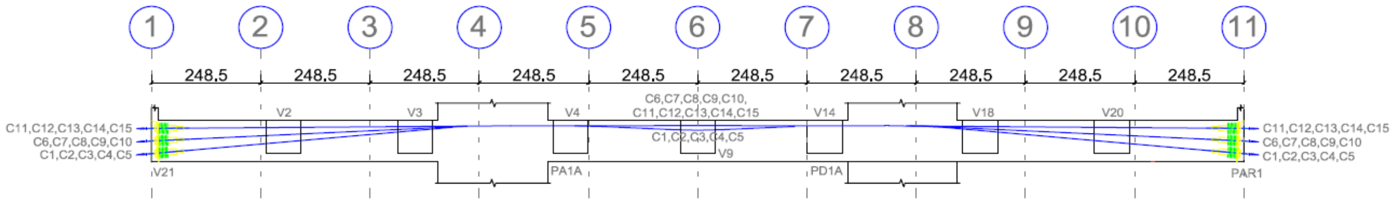
Adotado espiral ø8.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$As_{estribos} = \frac{As_2}{2} = 8.24\,cm^2$

$L = \max(a_1, a_2) = 135\,cm$ $bitola_{estribo} = 10mm$ $adotados = \mathrm{ceil}\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 11$

Estribos $adotados = 11$ ø10.0mm em cada trecho de ancoragem ativa distribuídos em $L = 135\,cm$

V24 = V28 - CABOS C1 a C15



CABOS C1=C2=C3=C4=C5 (7ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74 \cdot \text{fptk}, 0.82 \cdot \text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01 \dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 24.85\text{m}$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.5 \\ 497 \\ 745.5 \\ 994 \\ 1242.5 \\ 1491 \\ 1739.5 \\ 1988 \\ 2236.5 \\ 2485 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 4.83 \\ 1.82 \\ 1.41 \\ 2.77 \\ 3.19 \\ 4.83 \\ 0 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13511.63 \\ 13359.5 \\ 13228 \\ 13035.77 \\ 12827.5 \\ 12550.52 \\ 12488.29 \\ 12426.38 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 4.83 \\ 3.19 \\ 2.77 \\ 1.41 \\ 1.82 \\ 4.83 \\ 0 \\ 0 \end{pmatrix} {}^{\circ} \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} {}^{\circ}$$

$$n = 11$$

$$\theta_i = \begin{vmatrix} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

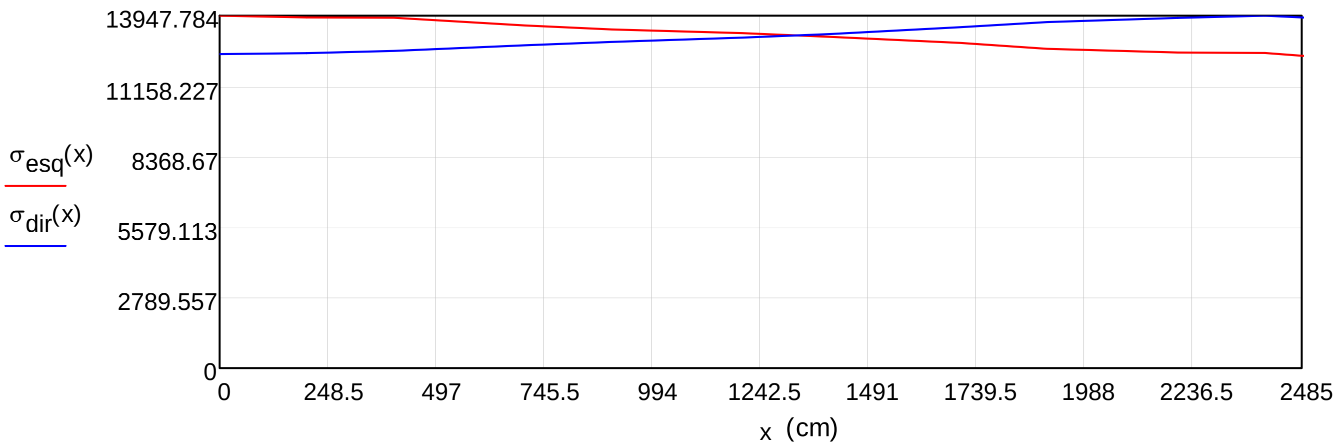
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13511.63 \\ 13295.76 \\ 13102.54 \\ 12973.57 \\ 12827.5 \\ 12550.52 \\ 12488.29 \\ 12426.38 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$$

$\text{interseção} = 1330.53 \cdot cm$

$$\sigma_{\text{interseção}} = 13163.28 \cdot \frac{kg}{cm^2}$$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 180954.59 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 157477.68 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 338432.26 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13619 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 26.50m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.5 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 185 \cdot mm$$

CABOS C6=C7=C8=C9=C10 (7ø15.2mm)

$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 24.85m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.5 \\ 497 \\ 745.5 \\ 994 \\ 1242.5 \\ 1491 \\ 1739.5 \\ 1988 \\ 2236.5 \\ 2485 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 2.38 \\ 0.42 \\ 0 \\ 0 \\ 0.42 \\ 2.38 \\ 0 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha + \kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13627.68 \\ 13540.25 \\ 13473.12 \\ 13406.33 \\ 13320.32 \\ 13144.62 \\ 13079.46 \\ 13014.61 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 2.38 \\ 0.42 \\ 0 \\ 0 \\ 0.42 \\ 2.38 \\ 0 \\ 0 \end{pmatrix} ^\circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} ^\circ$$

$$n = 11$$

$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

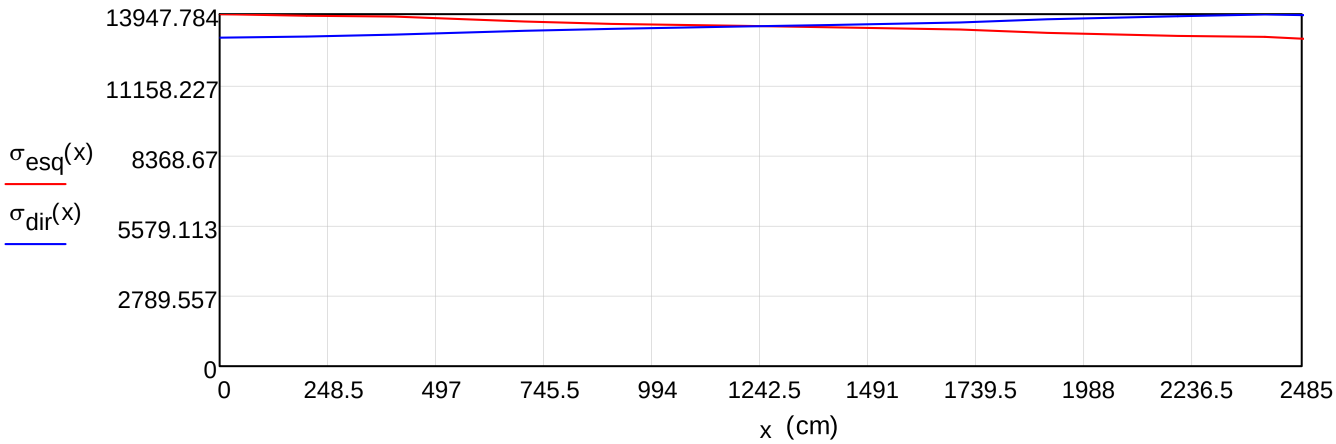
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13627.68 \\ 13540.25 \\ 13473.12 \\ 13406.33 \\ 13320.32 \\ 13144.62 \\ 13079.46 \\ 13014.61 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\qquad interseção = 1242.5 \cdot cm$

$\sigma_{interseção} = 13473.12 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$ $\qquad Área_1 = 170373.55 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$ $\qquad Área_2 = 170402.19 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\qquad Área = 340775.73 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$ $\qquad \sigma_m = 13713.31 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.45m$ $\qquad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.7 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 186 \cdot mm$

CABOS C11=C12=C13=C14=C15 (7ø15.2mm)

$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01 \dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 24.85m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 11$ $\quad i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.5 \\ 497 \\ 745.5 \\ 994 \\ 1242.5 \\ 1491 \\ 1739.5 \\ 1988 \\ 2236.5 \\ 2485 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13741.36 \\ 13653.21 \\ 13585.52 \\ 13518.17 \\ 13431.44 \\ 13364.85 \\ 13298.6 \\ 13232.67 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \circ$$

$n = 11$

$$\theta_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

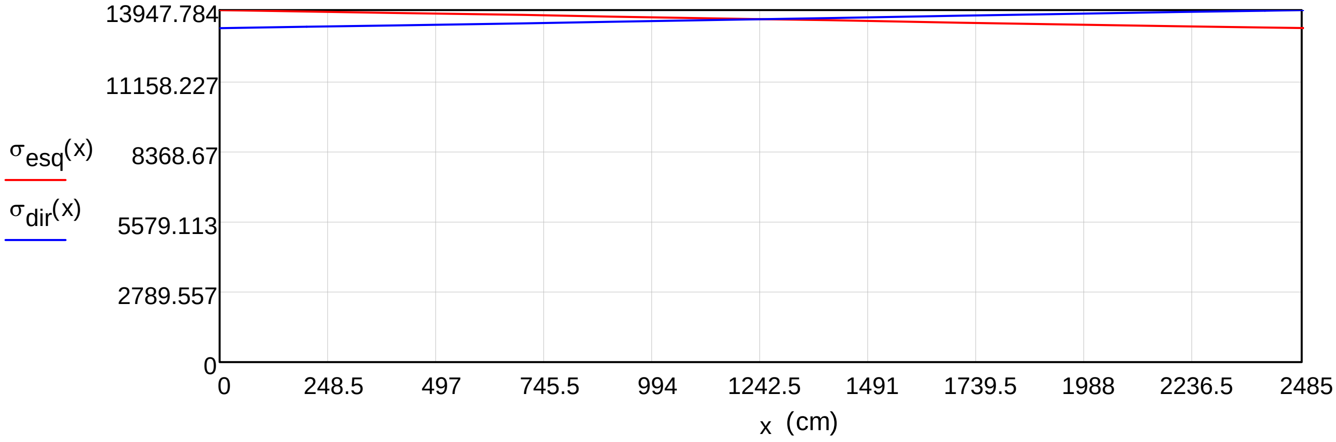
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13741.36 \\ 13653.21 \\ 13585.52 \\ 13518.17 \\ 13431.44 \\ 13364.85 \\ 13298.6 \\ 13232.67 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}\left(S, \sigma_{esq}\right)$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$b = \text{cspline}\left(S, \sigma_{dir}\right)$

$$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}\left(\sigma_{dir}\right)}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\qquad interseção = 1242.5 \cdot cm$

$\sigma_{interseção} = 13585.52 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$ $\qquad Área_1 = 171090.45 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$ $\qquad Área_2 = 171091.84 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\qquad Área = 342182.28 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$ $\qquad \sigma_m = 13769.91 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.45m$ $\qquad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.7 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 187 \cdot mm$

V24 = V28 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA

$b = 30cm$ $\quad n = 3$ $\quad q = 5$ $\quad F_{inicial} = 7 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 1373.01\,kN$

$a_0 = 25cm$ $\quad c = 5cm$

$d = 20cm$ $\quad a_1 = a_0 + c = 30\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 1372.8\,kN$ $\quad F_3 = F_{inicial} \cdot \cos(5°) = 1367.78\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 57.2\,kN \qquad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 56.99\,kN$$

$F_2 = F_{inicial} \cdot \cos(3°) = 1371.13\,kN$

$$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 57.13\,kN$$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 100\,cm$ $\quad k = 1 .. n$

$$F_k = \begin{pmatrix} 1372.8 \\ 1371.13 \\ 1367.78 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 57.2 \\ 57.13 \\ 56.99 \end{pmatrix} kN \qquad \sum F = 4111.71\,kN$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 274.11\,kN \qquad fyd = 43.48 \frac{kN}{cm^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.32\,cm^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 31.52\,cm^2$$

$As_{fretagem} = As_1 = 1.32\,cm^2$

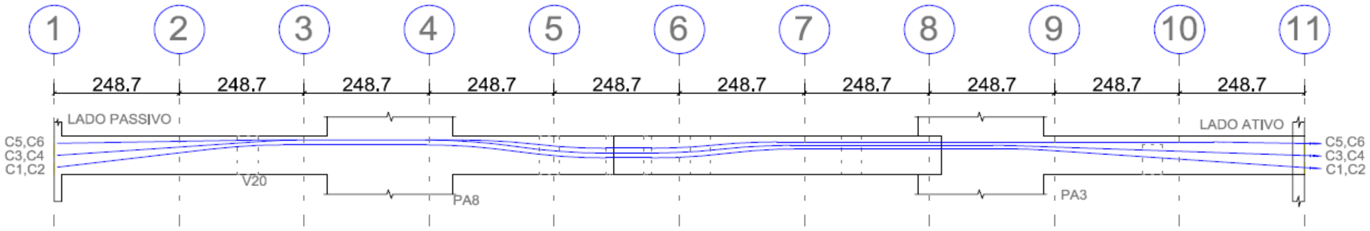
Adotado espiral ø12.5mm - 7 passos por cabo em cada trecho de ancoragem ativa.

$$As_{estribos} = \frac{As_2}{6} = 5.25\,cm^2$$

$L = max(a_1, a_2) = 100\,cm$ $\quad$ $bitola_{estribo} = 8mm$ $\quad$ $adotados = ceil\left[\dfrac{As_{estribos}}{\pi \dfrac{(bitola_{estribo})^2}{4}}\right] = 11$

Estribos triplos $adotados = 11$ ø8.0mm em cada trecho de ancoragem ativa distribuídos em $L = 100\,cm$

V30 - CABOS C1 a C6



CABOS C1=C2 (6ø12.7mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 100.9\text{mm}^2$ $\quad \text{fptk} = \dfrac{187.3\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1856.29\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{168.6\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1670.96\,\text{MPa}$

$\sigma_{pi} = \min(0.74 \cdot \text{fptk}, 0.82 \cdot \text{fpyk}) = 1370.19\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13972.03 \cdot \dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 24.87\text{m}$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{\text{rad}}{\text{m}}$ $\quad n = 11$ $\quad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 4.01 \\ 0 \\ 2.77 \\ 7.58 \\ 4.28 \\ 0.53 \\ 7 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

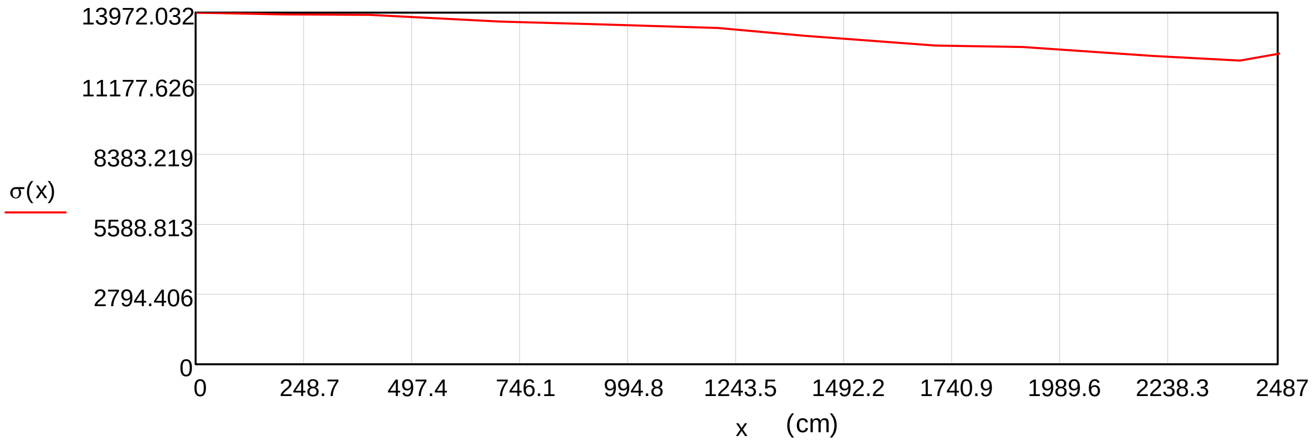
$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma = \begin{pmatrix} 13972.03 \\ 13902.71 \\ 13833.73 \\ 13573.75 \\ 13506.41 \\ 13310.07 \\ 12898.2 \\ 12643.89 \\ 12557.9 \\ 12193.96 \\ 12133.46 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma)$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\, dx \qquad \text{Área} = 326852.58 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13142.44 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 25.65m \qquad \text{Área}_{teórica\_aço} = 100.9 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 13.3 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 173 \cdot mm$$

CABOS C3=C4 (6ø12.7mm)

$Área_{teórica\_aço} = 100.9mm^2$ $\quad fptk = \dfrac{187.3kN}{Área_{teórica\_aço}} = 1856.29\,MPa$ $\quad fpyk = \dfrac{168.6kN}{Área_{teórica\_aço}} = 1670.96\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1370.19\,MPa$

$\sigma_1 = \sigma_{pi} = 13972.03 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01 \dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 24.87m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 11$ $\quad i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 2.01 \\ 0 \\ 2.78 \\ 7.56 \\ 4.22 \\ 0.56 \\ 4.01 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

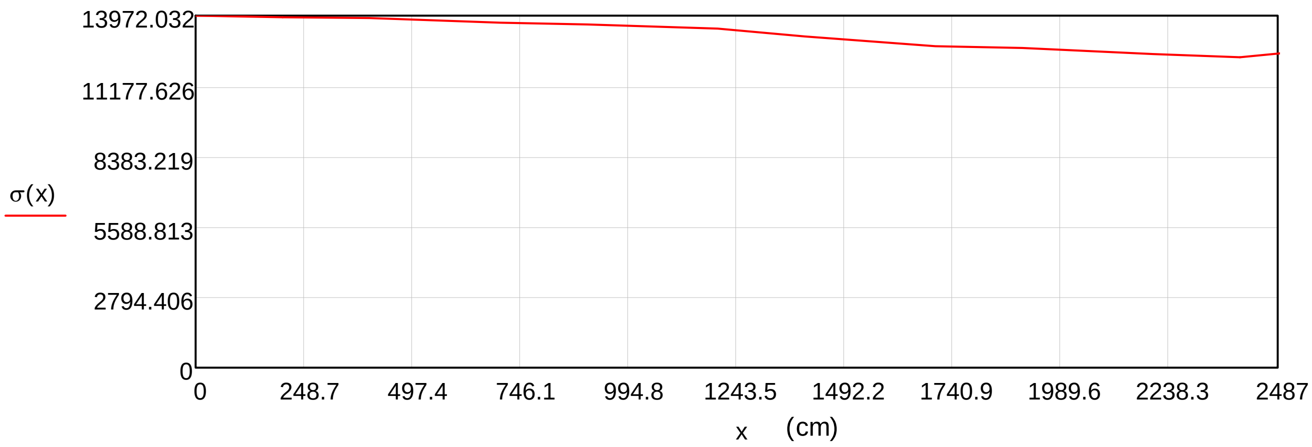
$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma = \begin{pmatrix} 13972.03 \\ 13902.71 \\ 13833.73 \\ 13668.85 \\ 13601.03 \\ 13402.85 \\ 12989.02 \\ 12735.58 \\ 12647.64 \\ 12409.96 \\ 12348.38 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma)$$

$$\sigma(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma}{g}, x\right)$$



$$\text{Área} = \int_0^L \sigma(x)\,dx \qquad \text{Área} = 329089.01 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13232.37 \cdot \frac{kg}{cm^2}$$

$L_{cabo} = 25.65m$ $\qquad$ $\text{Área}_{teórica\_aço} = 100.9 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 13.4 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 174 \cdot mm$$

CABOS C5=C6 (6ø12.7mm)

$Área_{teórica\_aço} = 100.9mm^2$ $\quad fptk = \dfrac{187.3kN}{Área_{teórica\_aço}} = 1856.29\,MPa$ $\quad fpyk = \dfrac{168.6kN}{Área_{teórica\_aço}} = 1670.96\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1370.19\,MPa$

$\sigma_1 = \sigma_{pi} = 13972.03 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 24.87m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 11$ $\quad i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 2.81 \\ 7.55 \\ 4.74 \\ 0 \\ 1 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

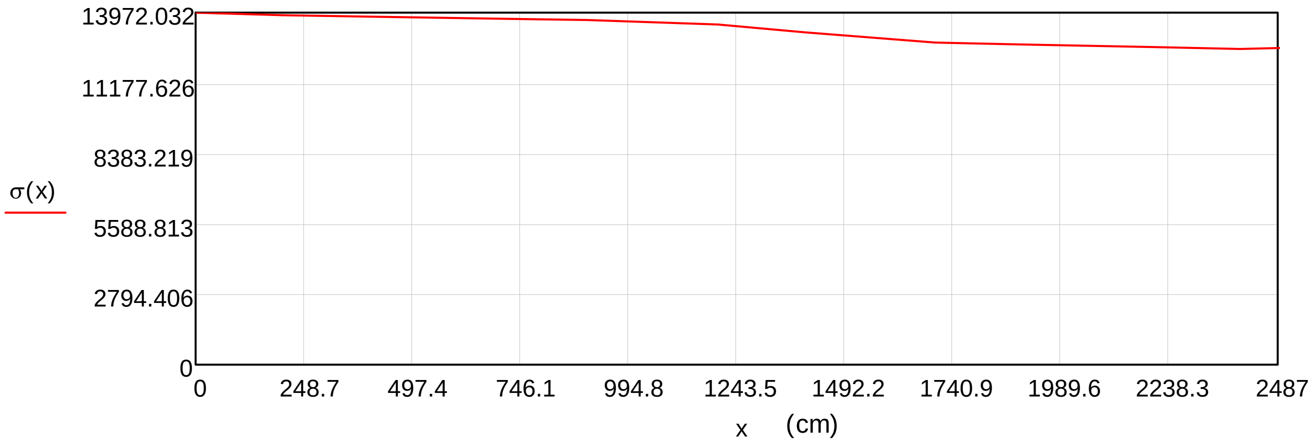
$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma = \begin{pmatrix} 13972.03 \\ 13854.26 \\ 13785.52 \\ 13717.12 \\ 13649.06 \\ 13448.78 \\ 13033.98 \\ 12756.49 \\ 12693.2 \\ 12586.21 \\ 12523.76 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = cspline(S, \sigma)$$

$$\sigma(x) = interp\left(\frac{a}{g}, S, \frac{\sigma}{g}, x\right)$$



$$Área = \int_0^L \sigma(x)\, dx \qquad Área = 330165.61 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13275.66 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 25.65m \qquad Área_{teórica\_aço} = 100.9 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 13.4 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 175 \cdot mm$$

V30 (2° PAVIMENTO) - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA

$b = 25cm$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 6 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 829.51\,kN$

$a_0 = 18.5cm$ $\quad c = 6.5cm$

$d = 15cm$ $\quad a_1 = a_0 + c = 25\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 829.39\,kN$ $\quad F_3 = F_{inicial} \cdot \cos(4°) = 827.49\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 53.91\,kN \qquad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 53.79\,kN$$

$F_2 = F_{inicial} \cdot \cos(2°) = 829.01\,kN$

$$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 53.89\,kN$$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 80\,cm$ $\quad k = 1 .. n$

$$F_k = \begin{pmatrix} 829.39 \\ 829.01 \\ 827.49 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 53.91 \\ 53.89 \\ 53.79 \end{pmatrix} kN \qquad \sum F = 2485.88\,kN$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 103.58\,kN \qquad fyd = 43.48\,\frac{kN}{cm^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.24\,cm^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 4.76\,cm^2$$

$$As_{fretagem} = As_1 = 1.24\,cm^2$$

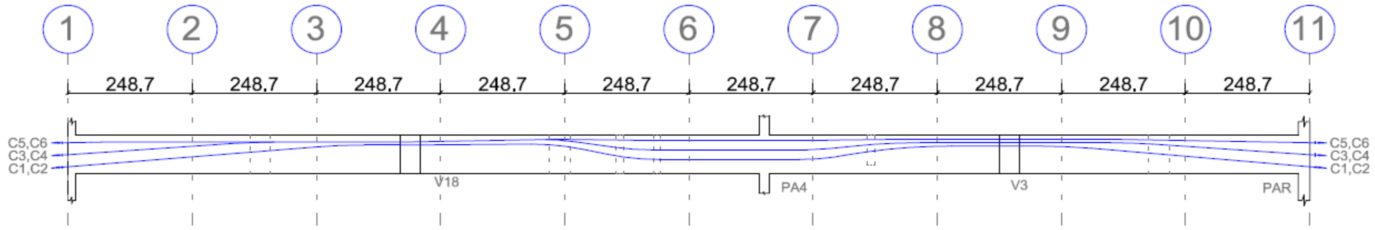
Adotado espiral ø8.0mm - 5 passos por cabo em cada trecho de ancoragem ativa e passiva.

$$As_{estribos} = \frac{As_2}{2} = 2.38\,cm^2$$

$L = \max\left(a_1, a_2\right) = 80\,cm$ $\quad$ $bitola_{estribo} = 8mm$ $\quad$ $adotados = ceil\left[\dfrac{As_{estribos}}{\pi\dfrac{\left(bitola_{estribo}\right)^2}{4}}\right] = 5$

Estribos adotados $= 5$ ø8.0mm em cada trecho de ancoragem ativa e passiva distribuídos em $L = 80\,cm$

V35 - CABOS C1 a C6



CABOS C1=C2 (6ø15.2mm)

$Área_{teórica\_aço} = 143.4mm^2$ $\quad$ $fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad$ $fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,MPa$$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{kgf}{cm^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{rad}{m}$ $\quad$ $e = 2.72$ $\quad$ $L = 24.87m$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{rad}{m}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0.12 \\ 4.17 \\ 6.37 \\ 5.93 \\ 2.05 \\ 0.63 \\ 3.59 \\ 2.83 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13803.94 \\ 13536.96 \\ 13173.59 \\ 12839.68 \\ 12684.88 \\ 12594.22 \\ 12375.67 \\ 12193.21 \\ 12132.72 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$$\Delta\theta_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 2.83 \\ 3.59 \\ 0.63 \\ 2.05 \\ 5.93 \\ 6.37 \\ 4.17 \\ 0.12 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{\text{elevação}_i}\right)^2 + \left(\Delta\theta_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

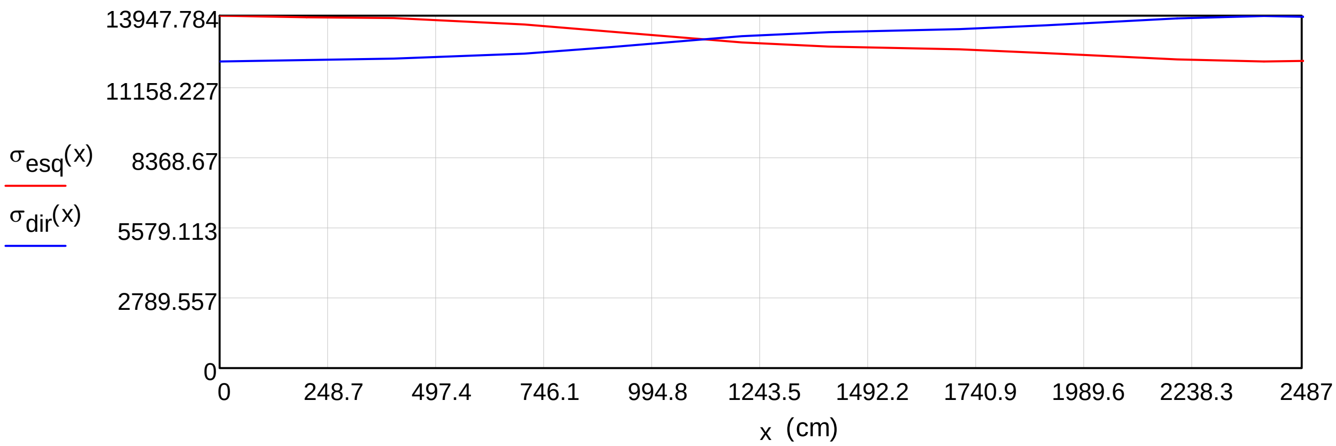
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13673.97 \\ 13436.68 \\ 13340.65 \\ 13179.8 \\ 12845.74 \\ 12500.92 \\ 12259.15 \\ 12193.21 \\ 12132.72 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \mathrm{cspline}(S, \sigma_{esq})$$

$$b = \mathrm{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$$



$$c = \frac{L}{2}$$

$$d = 0m$$

Given

$$d = \sigma_{esq}(c)$$

$$d = \sigma_{dir}(c)$$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$$

$$\text{interseção} = 1103.74 \cdot cm$$

$$\sigma_{\text{interseção}} = 13012.73 \cdot \frac{kg}{cm^2}$$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 150547.2 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 187136.89 \cdot \frac{kg \cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 337684.09 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13577.97 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 26.55m \qquad \text{Área}_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot \text{Área}_{teórica\_aço} = 19.5 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 185 \cdot mm$$

CABOS C3=C4 (6ø15.2mm)

$$\text{Área}_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{\text{Área}_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{\text{Área}_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 24.87m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.01 \\ 1.1 \\ 7.4 \\ 6.3 \\ 3.03 \\ 3.03 \\ 0 \\ 4.01 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13617.76 \\ 13498.27 \\ 13088.79 \\ 12740.57 \\ 12543.98 \\ 12350.42 \\ 12289.14 \\ 12058.19 \\ 11998.37 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.01 \\ 0 \\ 3.03 \\ 3.03 \\ 6.3 \\ 7.4 \\ 1.1 \\ 4.01 \\ 0 \end{pmatrix} ^\circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} ^\circ$$

$$n = 11$$

$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

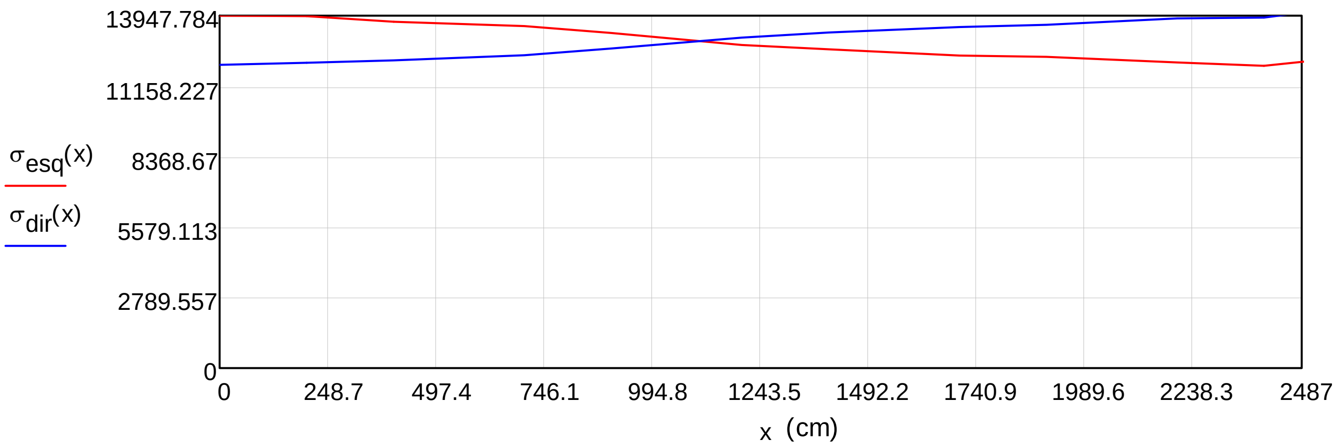
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13617.76 \\ 13550.2 \\ 13341.11 \\ 13135.25 \\ 12785.79 \\ 12397.93 \\ 12289.14 \\ 12058.19 \\ 11998.37 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 1093.42 \cdot cm$

$\sigma_{\text{interseção}} = 12927.02 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 148539.11\cdot\frac{kg\cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 188406.94\cdot\frac{kg\cdot m}{cm^2}$$

$$\text{Área} = (\text{Área}_1) + (\text{Área}_2) \qquad \text{Área} = 336946.05\cdot\frac{kg\cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13548.29\cdot\frac{kg}{cm^2}$$

$$L_{cabo} = 26.50m \qquad \text{Área}_{teórica\_aço} = 143.4\cdot mm^2 \qquad E_{teórico\_aço} = 1950000\,\frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m\cdot\text{Área}_{teórica\_aço} = 19.4\cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m)\cdot(L_{cabo})}{E_{teórico\_aço}} = 184\cdot mm$$

CABOS C5=C6 (6ø15.2mm)

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 24.87\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..\, n$

$$S = 0\text{cm}, \frac{L}{n-1} ..\, L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 1.1 \\ 1.85 \\ 0.75 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$$\alpha_i = \left|\begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array}\right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13830.22 \\ 13761.6 \\ 13640.84 \\ 13485.79 \\ 13383.79 \\ 13317.39 \\ 13251.31 \\ 13185.56 \\ 13074.42 \\ 13009.55 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0.75 \\ 1.85 \\ 1.1 \\ 0 \\ 1 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \circ$$

$$n = 11$$

$$\theta_i = \begin{array}{|l} 0rad \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

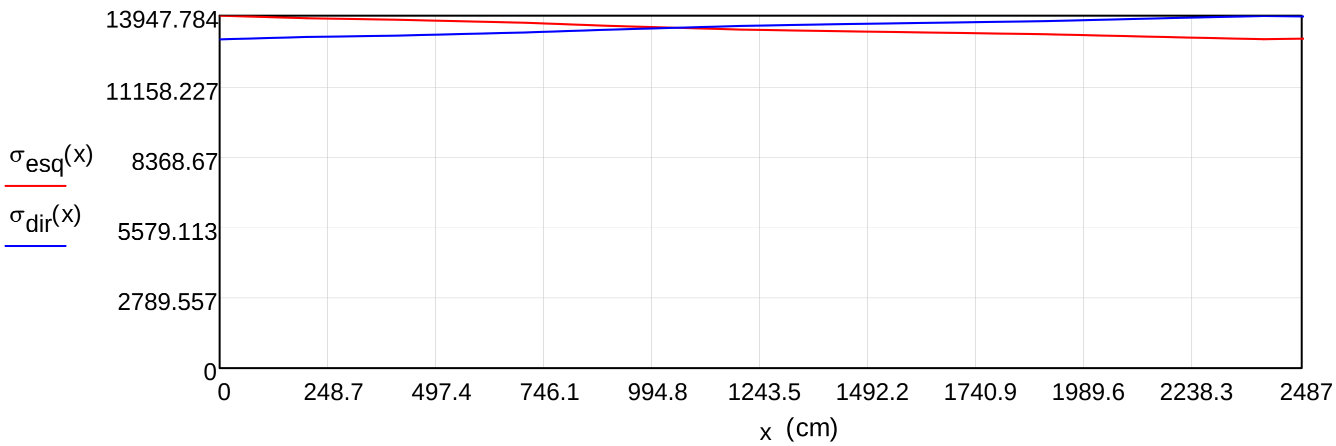
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13761.6 \\ 13693.32 \\ 13625.38 \\ 13557.77 \\ 13455.23 \\ 13302.29 \\ 13185.56 \\ 13120.14 \\ 13009.55 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$

$\text{interseção} = 1027.18 \cdot cm$

$\sigma_{\text{interseção}} = 13468.78 \cdot \frac{kg}{cm^2}$

$$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\,dx \qquad \text{Área}_1 = 141012.55\cdot\frac{kg\cdot m}{cm^2}$$

$$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\,dx \qquad \text{Área}_2 = 200140.04\cdot\frac{kg\cdot m}{cm^2}$$

$$\text{Área} = \left(\text{Área}_1\right) + \left(\text{Área}_2\right) \qquad \text{Área} = 341152.59\cdot\frac{kg\cdot m}{cm^2}$$

$$\sigma_m = \frac{\text{Área}}{L} \qquad \sigma_m = 13717.43\cdot\frac{kg}{cm^2}$$

$$L_{cabo} = 26.45m \qquad \text{Área}_{teórica\_aço} = 143.4\cdot mm^2 \qquad E_{teórico\_aço} = 1950000\,\frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m\cdot\text{Área}_{teórica\_aço} = 19.7\cdot t$$

$$\Delta L_{teórico} = \frac{\left(\sigma_m\right)\cdot\left(L_{cabo}\right)}{E_{teórico\_aço}} = 186\cdot mm$$

V35 (2° PAVIMENTO) - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA

$b = 25cm$ $\quad n = 3$ $\quad q = 2$ $\quad F_{inicial} = 6 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 1176.86\,kN$

$a_0 = 22cm$ $\quad c = 3cm$

$d = 15cm$ $\quad a_1 = a_0 + c = 25\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 1176.68\,kN$ $\quad F_3 = F_{inicial} \cdot \cos(5°) = 1172.39\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 35.3\,kN \qquad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 35.17\,kN$$

$F_2 = F_{inicial} \cdot \cos(4°) = 1174\,kN$

$$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 35.22\,kN$$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 80\,cm$ $\quad k = 1..\,n$

$$F_k = \begin{pmatrix} 1176.68 \\ 1174 \\ 1172.39 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 35.3 \\ 35.22 \\ 35.17 \end{pmatrix} kN \qquad \sum F = 3523.07\,kN$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 146.79\,kN \qquad fyd = 43.48 \frac{kN}{cm^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 0.81\,cm^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 6.75\,cm^2$$

$$As_{fretagem} = As_1 = 0.81\,cm^2$$

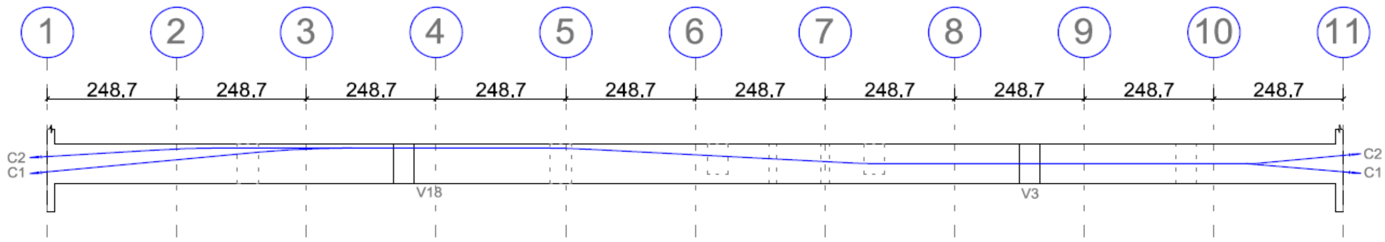
Adotado espiral ø10.0mm - 5 passos por cabo em cada trecho de ancoragem ativa.

$$As_{estribos} = \frac{As_2}{2} = 3.38\,cm^2$$

$L = max(a_1, a_2) = 80\,cm$ $\quad$ $bitola_{estribo} = 8mm$ $\quad$ $adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 7$

Estribos $adotados = 7$ ø8.0mm em cada trecho de ancoragem ativa distribuídos em $L = 80\,cm$

V38 - CABOS C1 e C2



CABO C1 (7ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\dfrac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 24.87\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2 .. n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 3.02 \\ 2.53 \\ 1.53 \\ 1.58 \\ 0 \\ 3.1 \\ 0 \\ 0 \\ 4.98 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}^{\circ}$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13664.9 \\ 13477.55 \\ 13339.25 \\ 13200.06 \\ 13134.57 \\ 12928.74 \\ 12864.59 \\ 12800.76 \\ 12517.74 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 4.98 \\ 0 \\ 0 \\ 3.1 \\ 0 \\ 1.58 \\ 1.53 \\ 2.53 \\ 3.02 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}^{\circ}$$

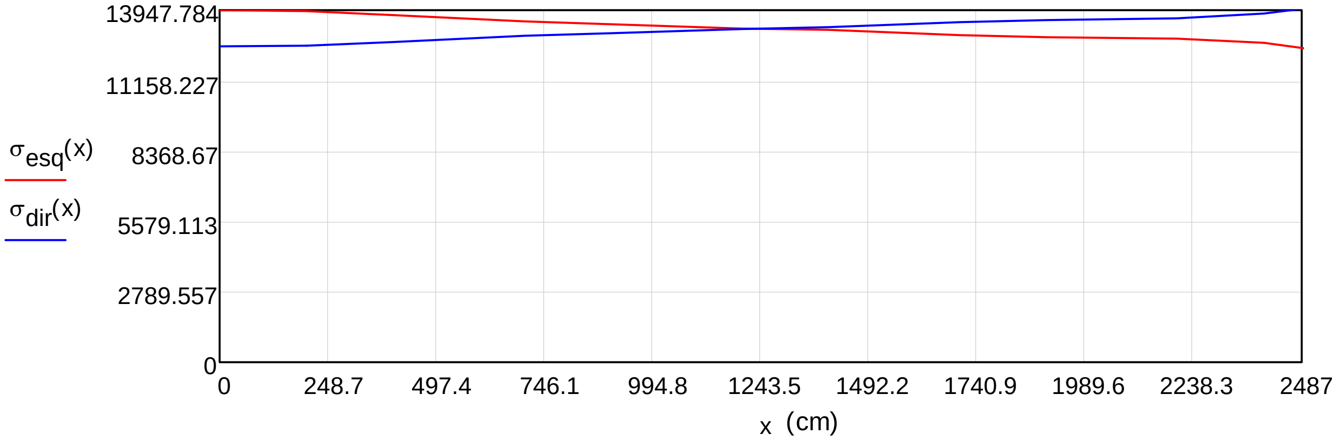
$$\theta_i = \begin{cases} 0rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13639.41 \\ 13571.73 \\ 13504.39 \\ 13292.77 \\ 13226.81 \\ 13088.8 \\ 12954.49 \\ 12776.87 \\ 12580.16 \\ 12517.74 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$a = \text{cspline}(S, \sigma_{esq}) \qquad b = \text{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$$

$interseção = 1214.33 \cdot cm$

$\sigma_{interseção} = 13210.87 \cdot \frac{kg}{cm^2}$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$$

$Área_1 = 165131.02 \cdot \frac{kg \cdot m}{cm^2}$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$$

$Área_2 = 171937.42 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$

$Área = 337068.44 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$

$\sigma_m = 13553.21 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.50m$

$Área_{teórica\_aço} = 143.4 \cdot mm^2$

$E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.4 \cdot t$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 184 \cdot mm$$

CABO C2 (7ø15.2mm)

$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01 \dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 24.87m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $\quad n = 11$ $\quad i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0.97 \\ 2.53 \\ 0 \\ 1.56 \\ 1.55 \\ 0 \\ 3.1 \\ 0 \\ 0 \\ 5.5 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13831.67 \\ 13642.03 \\ 13574.34 \\ 13433.64 \\ 13294.86 \\ 13228.89 \\ 13021.58 \\ 12956.98 \\ 12892.69 \\ 12584.77 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\qquad\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 5.5 \\ 0 \\ 0 \\ 3.1 \\ 0 \\ 1.55 \\ 1.56 \\ 0 \\ 2.53 \\ 0.97 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{\text{elevação}_i}\right)^2 + \left(\Delta\theta_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

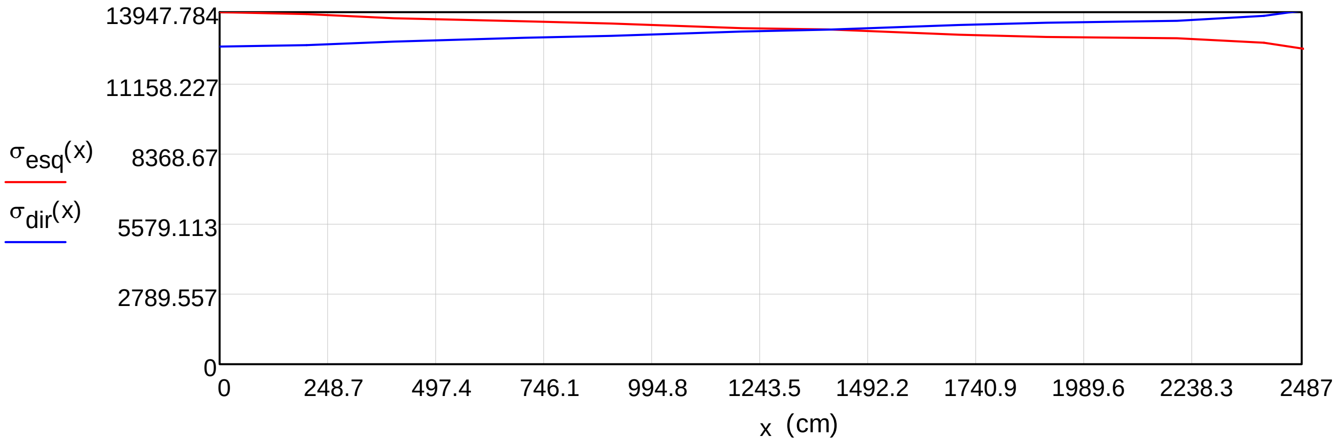
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13614.67 \\ 13547.12 \\ 13479.9 \\ 13268.66 \\ 13202.83 \\ 13066.43 \\ 12930.99 \\ 12866.83 \\ 12690.42 \\ 12584.77 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$ $\quad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\quad interseção = 1423.48 \cdot cm$

$\sigma_{interseção} = 13258.16 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$ $\quad Área_1 = 193287.99 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$ $\quad Área_2 = 143994.26 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\quad Área = 337282.25 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$ $\quad \sigma_m = 13561.81 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.50m$ $\quad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\quad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.4 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 184 \cdot mm$

V38 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA

$b = 30cm$ $\quad n = 2$ $\quad q = 1$ $\quad F_{inicial} = 7 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 1373.01\,kN$

$a_0 = 25cm$ $\quad c = 5cm$

$d = 25cm$ $\quad a_1 = a_0 + c = 30\,cm$

$F_1 = F_{inicial} \cdot \cos(3°) = 1371.13\,kN$ $\quad F_2 = F_{inicial} \cdot \cos(6°) = 1365.49\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 57.13\,kN \qquad T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 56.9\,kN$$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 80\,cm$ $\quad k = 1 .. n$

$$F_k = \begin{pmatrix} 1371.13 \\ 1365.49 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 57.13 \\ 56.9 \end{pmatrix} kN \qquad \sum F = 2736.61\,kN$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 456.1\,kN \qquad fyd = 43.48 \frac{kN}{cm^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.31\,cm^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 10.49\,cm^2$$

$As_{fretagem} = As_1 = 1.31\,cm^2$

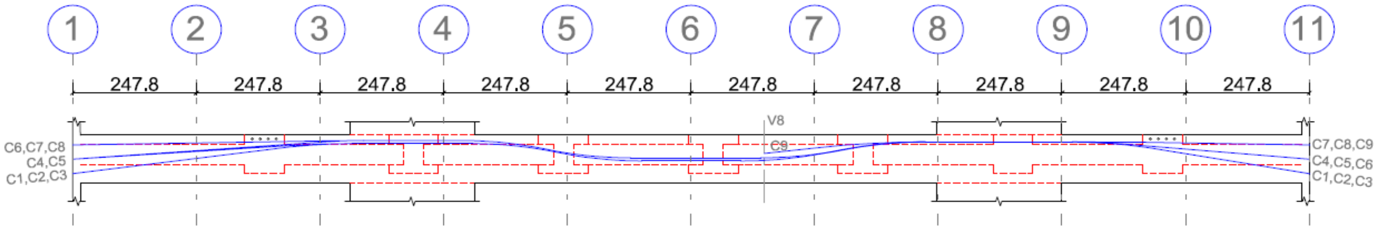
Adotado espiral ø12.5mm - 7 passos por cabo em cada trecho de ancoragem ativa.

$$As_{estribos} = \frac{As_2}{2} = 5.24\,cm^2$$

$L = \max(a_1, a_2) = 80\,cm$ $\quad$ $bitola_{estribo} = 8mm$ $\quad$ $adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 11$

Estribos $adotados = 11$ ø8.0mm em cada trecho de ancoragem ativa distribuídos em $L = 80\,cm$

V43- CABOS C1 a C9



CABOS C1=C2=C3 (7ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad$ $\text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad$ $\text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad$ $\mu = 0.20$ $\quad$ $\beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad$ $e = 2.72$ $\quad$ $L = 24.78\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad$ $n = 11$ $\quad$ $i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 247.8 \\ 495.6 \\ 743.4 \\ 991.2 \\ 1239 \\ 1486.8 \\ 1734.6 \\ 1982.4 \\ 2230.2 \\ 2478 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 3.93 \\ 3.34 \\ 10.01 \\ 10.01 \\ 10.09 \\ 10.09 \\ 0 \\ 9.54 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$$\alpha_i = \begin{vmatrix} 0\text{rad} \quad \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if } i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.83 \\ 13622.06 \\ 13397.6 \\ 12873.59 \\ 12370.08 \\ 11882.94 \\ 11414.99 \\ 11358.55 \\ 10932.22 \\ 10878.17 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 9.54 \\ 0 \\ 10.09 \\ 10.09 \\ 10.01 \\ 10.01 \\ 3.34 \\ 3.93 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

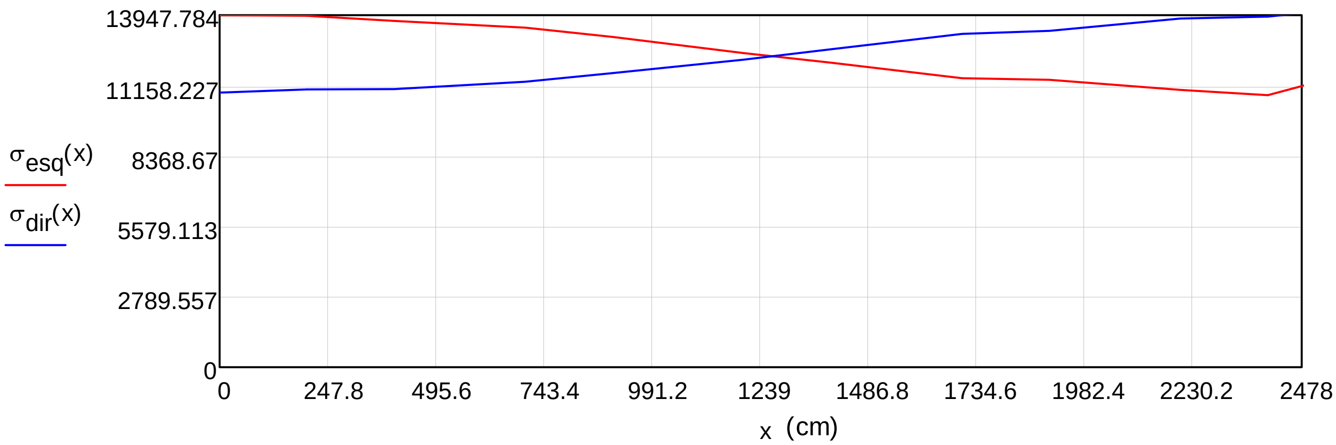
$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{\text{elevação}_i}\right)^2 + \left(\Delta\theta_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i\cdot\text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu\cdot\theta+\kappa\cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.83 \\ 13357.9 \\ 13291.86 \\ 12768.42 \\ 12265.6 \\ 11785.86 \\ 11324.89 \\ 11138.29 \\ 10932.22 \\ 10878.17 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$$a = \text{cspline}(S, \sigma_{esq}) \qquad b = \text{cspline}(S, \sigma_{dir})$$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\quad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\quad interseção = 1265.27 \cdot cm$

$\sigma_{interseção} = 12320.91 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx$ $\quad Área_1 = 169227.92 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx$ $\quad Área_2 = 161196.28 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\quad Área = 330424.2 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$ $\quad \sigma_m = 13334.31 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.50m$ $\quad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\quad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.1 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 181 \cdot mm$

CABOS C4=C5 (7ø15.2mm)

$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad \text{fptk} = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad \text{fpyk} = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74 \cdot \text{fptk}, 0.82 \cdot \text{fpyk}) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 24.87\text{m}$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0\text{cm}, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} \text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 4.11 \\ 8.7 \\ 8.7 \\ 6.97 \\ 6.97 \\ 0 \\ 4.85 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}^{\circ}$$

$$\alpha_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13809.72 \\ 13545.47 \\ 13075.1 \\ 12621.06 \\ 12256.58 \\ 11902.62 \\ 11843.57 \\ 11586.97 \\ 11529.48 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\qquad\qquad\qquad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.85 \\ 0 \\ 6.97 \\ 6.97 \\ 8.7 \\ 8.7 \\ 4.11 \\ 0 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

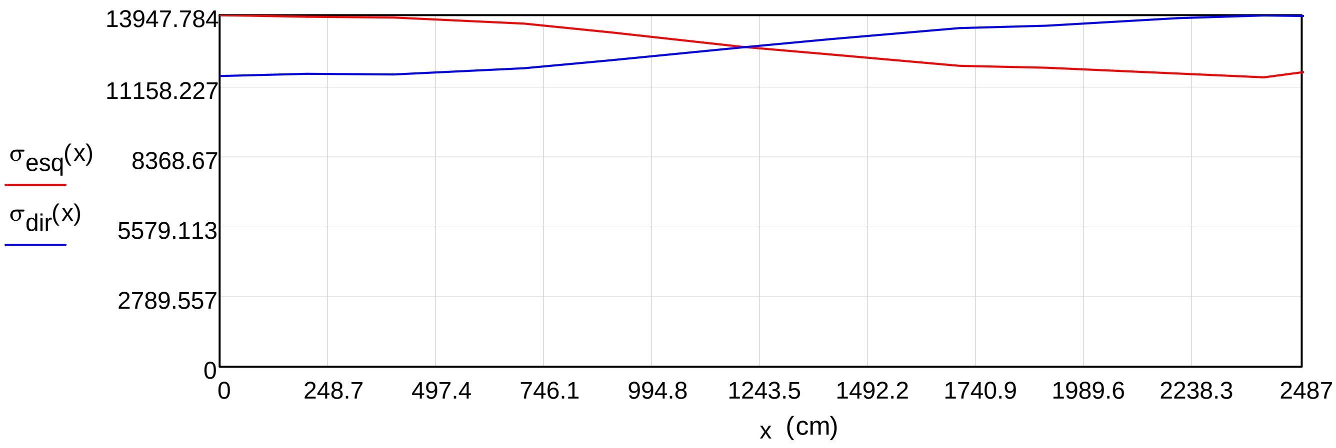
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13577.89 \\ 13510.52 \\ 13120.36 \\ 12741.46 \\ 12299.01 \\ 11871.92 \\ 11644.75 \\ 11586.97 \\ 11529.48 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$ $\quad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad$ $d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$ $\quad$ $\text{interseção} = 1207.9 \cdot cm$

$\sigma_{\text{interseção}} = 12678.58 \cdot \frac{kg}{cm^2}$

$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\, dx$ $\quad$ $\text{Área}_1 = 163651.69 \cdot \frac{kg \cdot m}{cm^2}$

$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\, dx$ $\quad$ $\text{Área}_2 = 172171.29 \cdot \frac{kg \cdot m}{cm^2}$

$\text{Área} = (\text{Área}_1) + (\text{Área}_2)$ $\quad$ $\text{Área} = 335822.99 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{\text{Área}}{L}$ $\quad$ $\sigma_m = 13503.14 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.45m$ $\quad$ $\text{Área}_{\text{teórica\_aço}} = 143.4 \cdot mm^2$ $\quad$ $E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$

$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 19.4 \cdot t$

$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 183 \cdot mm$

CABO C6 (7ø15.2mm)

$$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2 \qquad fptk = \frac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa} \qquad fpyk = \frac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$$

$$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,\text{MPa}$$

$$\sigma_1 = \sigma_{pi} = 13947.78\cdot\frac{\text{kgf}}{\text{cm}^2} \qquad \mu = 0.20 \qquad \beta = 0.01\frac{\text{rad}}{\text{m}} \qquad e = 2.72 \qquad L = 24.87\text{m}$$

$$\kappa = \beta\cdot\mu = 0.002\cdot\frac{\text{rad}}{\text{m}} \qquad n = 11 \qquad i = 1, 2..n$$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0.91 \\ 8.7 \\ 8.7 \\ 6.97 \\ 6.97 \\ 0 \\ 4.85 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13809.72 \\ 13697.62 \\ 13221.96 \\ 12762.83 \\ 12394.25 \\ 12036.32 \\ 11976.6 \\ 11717.12 \\ 11658.99 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\quad\quad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 4.85 \\ 0 \\ 6.97 \\ 6.97 \\ 8.7 \\ 8.7 \\ 0.91 \\ 0 \\ 0 \end{pmatrix} ° \quad\quad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\theta_i = \begin{cases} 0\,\mathrm{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i\cdot \mathrm{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu\cdot\theta + \kappa\cdot S)}$$

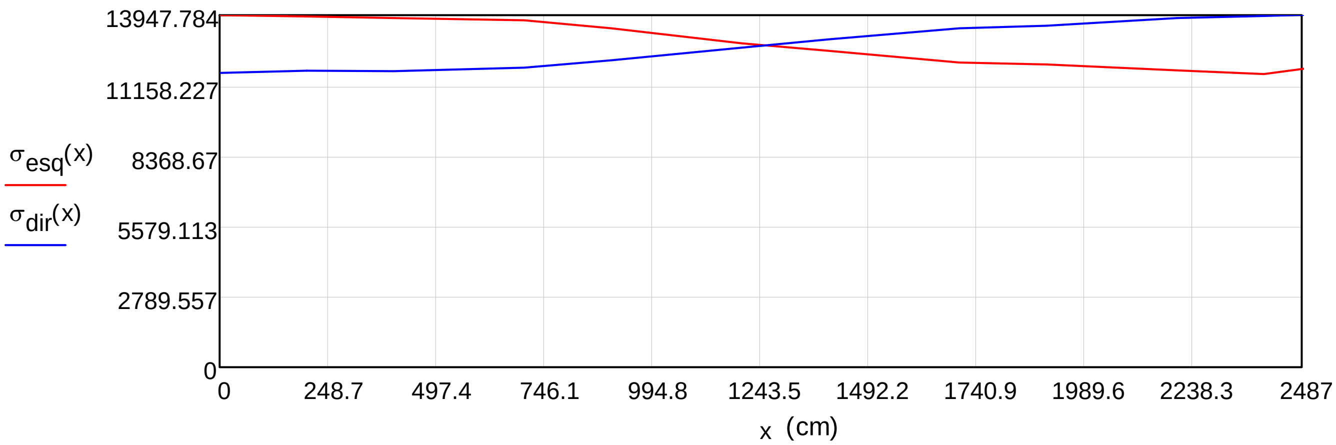
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13577.89 \\ 13510.52 \\ 13120.36 \\ 12741.46 \\ 12299.01 \\ 11871.92 \\ 11775.55 \\ 11717.12 \\ 11658.99 \end{pmatrix} \cdot \frac{\mathrm{kgf}}{\mathrm{cm}^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $d = \sigma_{dir}(c)$

$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \text{Find}(c, d)$ $\text{interseção} = 1249.98 \cdot cm$

$\sigma_{\text{interseção}} = 12752.77 \cdot \frac{kg}{cm^2}$

$\text{Área}_1 = \int_0^{\text{interseção}} \sigma_{esq}(x)\, dx$ $\text{Área}_1 = 169923.3 \cdot \frac{kg \cdot m}{cm^2}$

$\text{Área}_2 = \int_{\text{interseção}}^{L} \sigma_{dir}(x)\, dx$ $\text{Área}_2 = 166796.88 \cdot \frac{kg \cdot m}{cm^2}$

$\text{Área} = (\text{Área}_1) + (\text{Área}_2)$ $\text{Área} = 336720.18 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{\text{Área}}{L}$ $\sigma_m = 13539.21 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.45m$ $\text{Área}_{\text{teórica\_aço}} = 143.4 \cdot mm^2$ $E_{\text{teórico\_aço}} = 1950000 \frac{kg}{cm^2}$

$F_{\text{média\_cabo}} = \sigma_m \cdot \text{Área}_{\text{teórica\_aço}} = 19.4 \cdot t$

$\Delta L_{\text{teórico}} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{\text{teórico\_aço}}} = 184 \cdot mm$

CABOS C7=C8 (7ø15.2mm)

$Área_{teórica\_aço} = 143.4mm^2$ $\quad fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $\quad fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74\cdot fptk, 0.82\cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{kgf}{cm^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{rad}{m}$ $\quad e = 2.72$ $\quad L = 24.87m$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{rad}{m}$ $\quad n = 11$ $\quad i = 1, 2..n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.7 \\ 497.4 \\ 746.1 \\ 994.8 \\ 1243.5 \\ 1492.2 \\ 1740.9 \\ 1989.6 \\ 2238.3 \\ 2487 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0.91 \\ 8.7 \\ 8.7 \\ 6.97 \\ 6.97 \\ 0 \\ 0.92 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$$\alpha_i = \begin{cases} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i\cdot rad & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13809.72 \\ 13697.62 \\ 13221.96 \\ 12762.83 \\ 12394.25 \\ 12036.32 \\ 11976.6 \\ 11878.97 \\ 11820.03 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\quad\quad\quad$ $i = 1, 2 .. n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0.92 \\ 0 \\ 6.97 \\ 6.97 \\ 8.7 \\ 8.7 \\ 0.91 \\ 0 \\ 0 \end{pmatrix} ° \quad\quad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

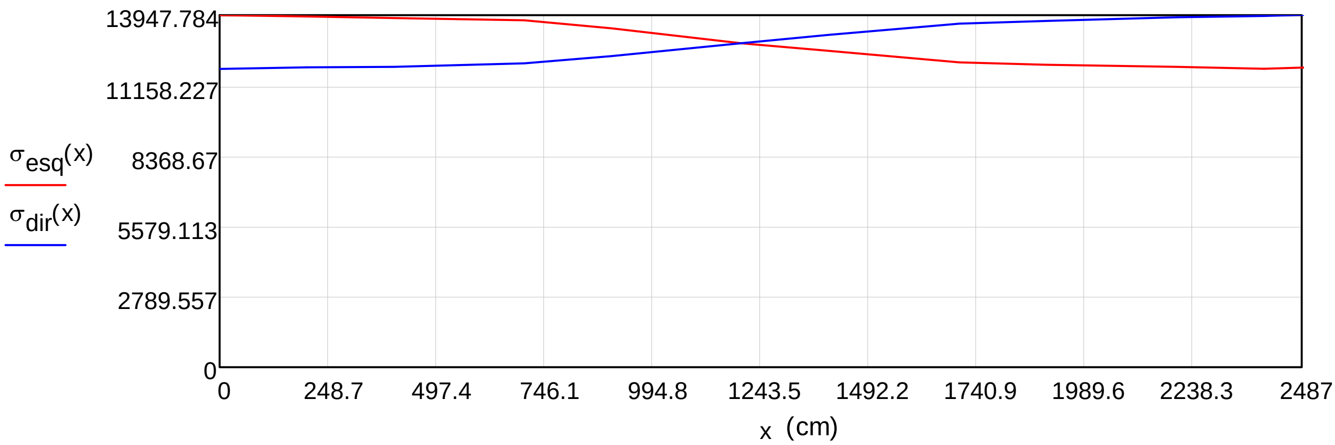
$$\theta_i = \begin{cases} 0\,\mathrm{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \mathrm{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.58 \\ 13765.44 \\ 13697.14 \\ 13301.59 \\ 12917.45 \\ 12468.89 \\ 12035.9 \\ 11938.2 \\ 11878.97 \\ 11820.03 \end{pmatrix} \cdot \frac{\mathrm{kgf}}{\mathrm{cm}^2}$$

$$a = \mathrm{cspline}\left(S, \sigma_{esq}\right) \qquad b = \mathrm{cspline}\left(S, \sigma_{dir}\right)$$

$$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right) \qquad \sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}\left(\sigma_{dir}\right)}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad$ $d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\qquad$ $interseção = 1198.33 \cdot cm$

$\sigma_{interseção} = 12835.85 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$ $\qquad$ $Área_1 = 163314.72 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$ $\qquad$ $Área_2 = 175045.11 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\qquad$ $Área = 338359.83 \cdot \frac{kg \cdot m}{cm^2}$

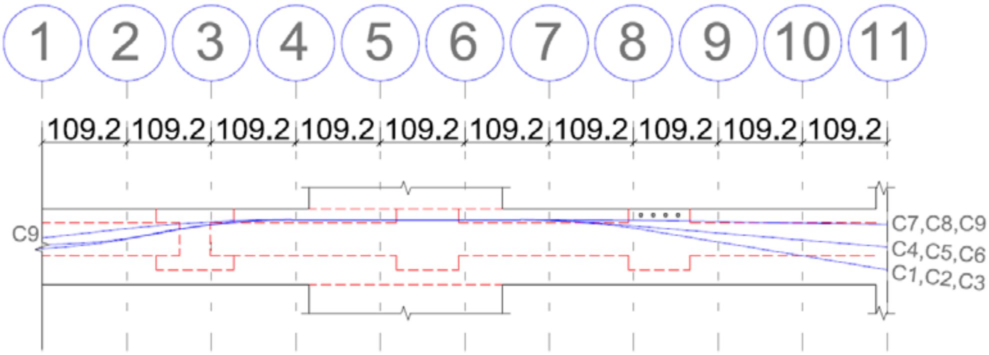
$\sigma_m = \frac{Área}{L}$ $\qquad$ $\sigma_m = 13605.14 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.45m$ $\qquad$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.5 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 185 \cdot mm$

CABO C9 (7ø15.2mm)



$Área_{teórica\_aço} = 143.4mm^2$ $fptk = \dfrac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa$ $fpyk = \dfrac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$

$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$

$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \dfrac{kgf}{cm^2}$ $\mu = 0.20$ $\beta = 0.01 \dfrac{rad}{m}$ $e = 2.72$ $L = 10.92m$

$\kappa = \beta \cdot \mu = 0.002 \cdot \dfrac{rad}{m}$ $n = 11$ $i = 1, 2 .. n$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 109.2 \\ 218.4 \\ 327.6 \\ 436.8 \\ 546 \\ 655.2 \\ 764.4 \\ 873.6 \\ 982.8 \\ 1092 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0.18 \\ 3.2 \\ 3.07 \\ 0 \\ 0 \\ 0.15 \\ 0.44 \\ 0.33 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13908.61 \\ 13724.11 \\ 13548.2 \\ 13518.65 \\ 13489.15 \\ 13452.68 \\ 13402.73 \\ 13358.09 \\ 13328.95 \\ 13299.87 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$n = 11$ $\qquad$ $i = 1, 2..n$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0.33 \\ 0.44 \\ 0.15 \\ 0 \\ 0 \\ 3.07 \\ 3.2 \\ 0.18 \end{pmatrix} \circ \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \circ$$

$$\theta_i = \begin{cases} 0\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{\text{elevação}_i}\right)^2 + \left(\Delta\theta_{\text{planta}_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

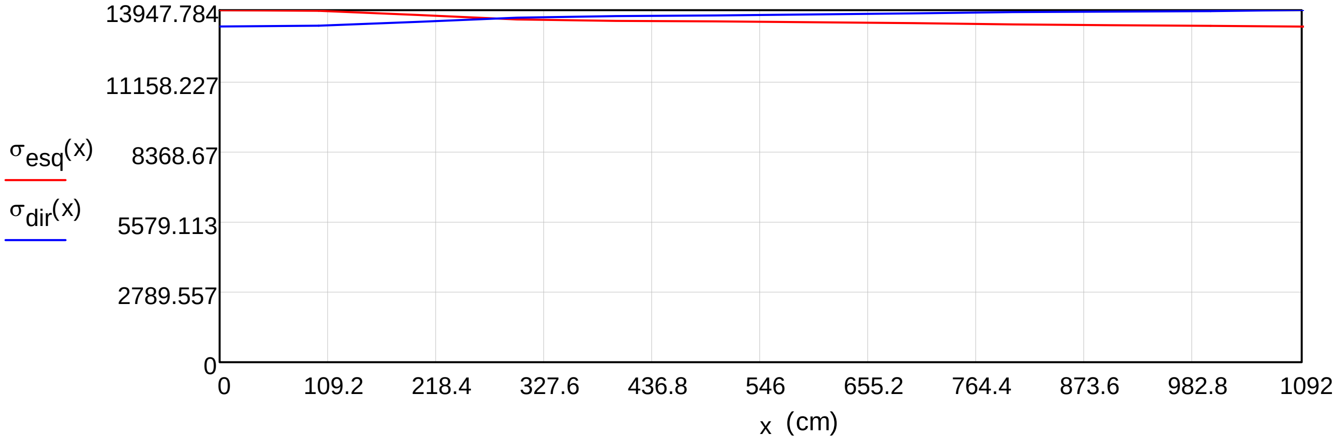
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13917.35 \\ 13886.99 \\ 13840.74 \\ 13789.35 \\ 13752.07 \\ 13722.07 \\ 13692.13 \\ 13516.63 \\ 13337.33 \\ 13299.87 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$a = \text{cspline}\left(S, \sigma_{esq}\right)$

$b = \text{cspline}\left(S, \sigma_{dir}\right)$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}\left(\sigma_{dir}\right)}{g}, x\right)$$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$$

$interseção = 277.77 \cdot cm$

$\sigma_{interseção} = 13613.92 \cdot \frac{kg}{cm^2}$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$$

$Área_1 = 38438.16 \cdot \frac{kg \cdot m}{cm^2}$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$$

$Área_2 = 112419.67 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$

$Área = 150857.83 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$

$\sigma_m = 13814.82 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 12.55m$

$Área_{teórica\_aço} = 143.4 \cdot mm^2$

$E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.8 \cdot t$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 89 \cdot mm$$

V43 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA

$b = 30cm$ $\quad n = 3$ $\quad q = 3$ $\quad F_{inicial} = 7 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 1373.01\,kN$

$a_0 = 25cm$ $\quad c = 5cm$

$d = 20cm$ $\quad a_1 = a_0 + c = 30\,cm$

$F_1 = F_{inicial} \cdot \cos(1°) = 1372.8\,kN$ $\quad F_3 = F_{inicial} \cdot \cos(7°) = 1362.77\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 57.2\,kN \qquad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 56.78\,kN$$

$F_2 = F_{inicial} \cdot \cos(4°) = 1369.66\,kN$

$$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 57.07\,kN$$

$a_2 = 2 \cdot d + (n - 1) \cdot b = 100\,cm$ $\quad k = 1..n$

$$F_k = \begin{pmatrix} 1372.8 \\ 1369.66 \\ 1362.77 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 57.2 \\ 57.07 \\ 56.78 \end{pmatrix} kN \qquad \sum F = 4105.24\,kN$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 273.68\,kN \qquad fyd = 43.48\,\frac{kN}{cm^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.32\,cm^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 18.88\,cm^2$$

$As_{fretagem} = As_1 = 1.32\,cm^2$

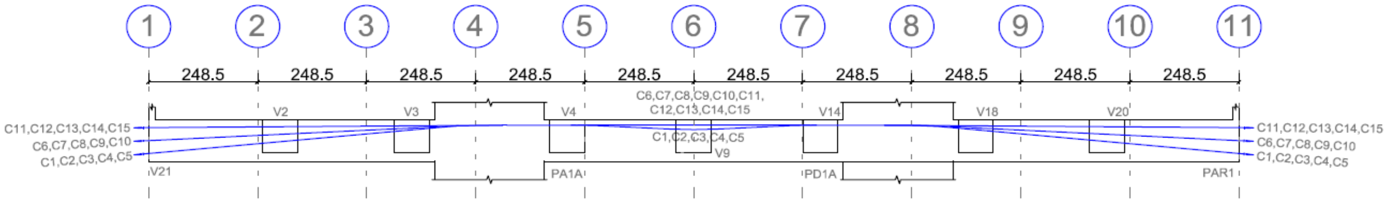
Adotado espiral ø12.5mm - 7 passos por cabo em cada trecho de ancoragem ativa.

$$As_{estribos} = \frac{As_2}{4} = 4.72\,cm^2$$

$L = max(a_1, a_2) = 100\,cm$ $\quad$ $bitola_{estribo} = 8mm$ $\quad$ $adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 10$

Estribos duplos $adotados = 10$ ø8.0mm em cada trecho de ancoragem ativa distribuídos em $L = 100\,cm$

V47 = V51 - CABOS C1 a C15



CABOS C1=C2=C3=C4=C5 (7ø15.2mm)

$t = \text{tonne}$

$\text{Área}_{\text{teórica\_aço}} = 143.4\text{mm}^2$ $\quad \text{fptk} = \dfrac{265.8\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1853.56\,\text{MPa}$ $\quad \text{fpyk} = \dfrac{239.2\text{kN}}{\text{Área}_{\text{teórica\_aço}}} = 1668.06\,\text{MPa}$

$\sigma_{pi} = \min(0.74\cdot\text{fptk}, 0.82\cdot\text{fpyk}) = 1367.81\,\text{MPa}$

$\sigma_1 = \sigma_{pi} = 13947.78\cdot\dfrac{\text{kgf}}{\text{cm}^2}$ $\quad \mu = 0.20$ $\quad \beta = 0.01\dfrac{\text{rad}}{\text{m}}$ $\quad e = 2.72$ $\quad L = 24.85\text{m}$

$\kappa = \beta\cdot\mu = 0.002\cdot\dfrac{\text{rad}}{\text{m}}$ $\quad n = 11$ $\quad i = 1, 2..n$

$$S = 0\text{cm}, \frac{L}{n-1}..L = \begin{pmatrix} 0 \\ 248.5 \\ 497 \\ 745.5 \\ 994 \\ 1242.5 \\ 1491 \\ 1739.5 \\ 1988 \\ 2236.5 \\ 2485 \end{pmatrix}\text{cm} \qquad \Delta\alpha_{\text{elevação}} = \begin{pmatrix} 0 \\ 0 \\ 0.05 \\ 5.22 \\ 1.58 \\ 1.39 \\ 1.59 \\ 2.36 \\ 4.6 \\ 0.01 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\alpha_{\text{planta}} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}^{\circ}$$

$$\alpha_i = \left| \begin{array}{l} 0\text{rad} \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{\text{elevação}_i}\right)^2 + \left(\Delta\alpha_{\text{planta}_i}\right)^2} \quad \text{if} \quad i > 1 \\ i\cdot\text{rad} \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu\cdot\alpha+\kappa\cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13807.42 \\ 13490.89 \\ 13350.18 \\ 13219.69 \\ 13081.35 \\ 12909.71 \\ 12641.09 \\ 12577.98 \\ 12515.62 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0.01 \\ 4.6 \\ 2.36 \\ 1.59 \\ 1.39 \\ 1.58 \\ 5.22 \\ 0.05 \\ 0 \end{pmatrix} ° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$n = 11$

$$\theta_i = \left| \begin{array}{ll} 0rad & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i\cdot rad & \text{otherwise} \end{array} \right.$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

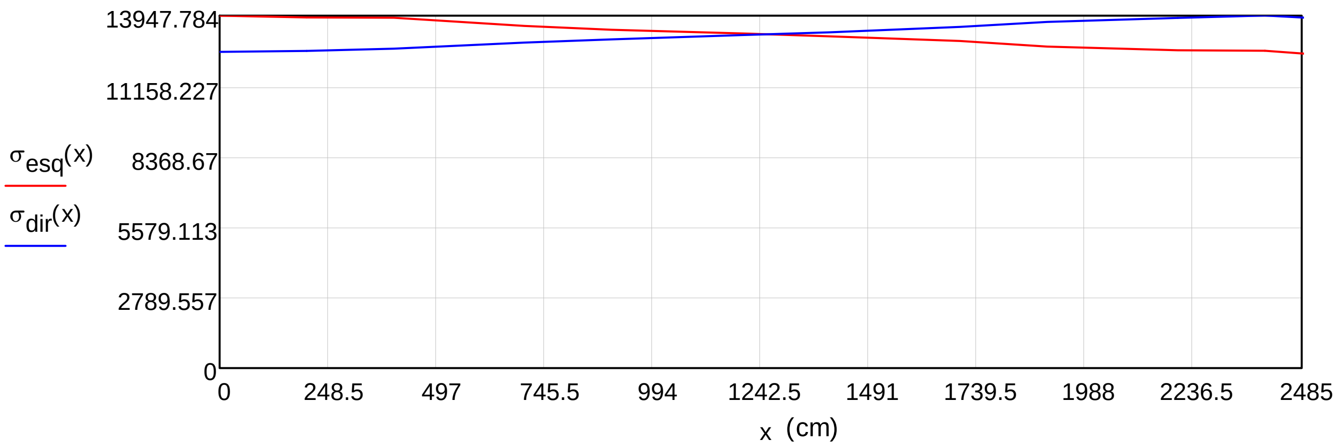
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.35 \\ 13522.01 \\ 13344.59 \\ 13204.93 \\ 13075.87 \\ 12939.48 \\ 12642.85 \\ 12577.98 \\ 12515.62 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \mathrm{cspline}(S, \sigma_{esq})$

$b = \mathrm{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \mathrm{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \mathrm{interp}\left(\frac{b}{g}, S, \frac{\mathrm{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$

$d = 0m$

Given

$d = \sigma_{esq}(c)$

$d = \sigma_{dir}(c)$

$$\begin{pmatrix} \text{interseção} \\ \sigma_{\text{interseção}} \end{pmatrix} = \mathrm{Find}(c, d)$$

interseção = 1256.14·cm

$$\sigma_{\text{interseção}} = 13211.89 \cdot \frac{kg}{cm^2}$$

$$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx \qquad Área_1 = 171041.52 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx \qquad Área_2 = 167516.02 \cdot \frac{kg \cdot m}{cm^2}$$

$$Área = (Área_1) + (Área_2) \qquad Área = 338557.53 \cdot \frac{kg \cdot m}{cm^2}$$

$$\sigma_m = \frac{Área}{L} \qquad \sigma_m = 13624.05 \cdot \frac{kg}{cm^2}$$

$$L_{cabo} = 26.45m \qquad Área_{teórica\_aço} = 143.4 \cdot mm^2 \qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$$

$$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.5 \cdot t$$

$$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 185 \cdot mm$$

CABOS C6=C7=C8=C9=C10 (7ø15.2mm)

$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 24.85m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2..n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.5 \\ 497 \\ 745.5 \\ 994 \\ 1242.5 \\ 1491 \\ 1739.5 \\ 1988 \\ 2236.5 \\ 2485 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 2.09 \\ 0.77 \\ 0 \\ 0 \\ 0.42 \\ 2.43 \\ 0 \\ 0 \end{pmatrix} ° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} °$$

$$\alpha_i = \begin{cases} 0\,\text{rad} & \text{if } i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13641.48 \\ 13537.41 \\ 13470.3 \\ 13403.52 \\ 13317.53 \\ 13139.58 \\ 13074.44 \\ 13009.62 \end{pmatrix} \cdot \frac{\text{kgf}}{\text{cm}^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 2.43 \\ 0.42 \\ 0 \\ 0 \\ 0.77 \\ 2.09 \\ 0 \\ 0 \end{pmatrix}^{\circ} \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}^{\circ}$$

$$n = 11$$

$$\theta_i = \begin{cases} 0\,\text{rad} & \text{if } i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} & \text{if } i > 1 \\ i \cdot \text{rad} & \text{otherwise} \end{cases}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

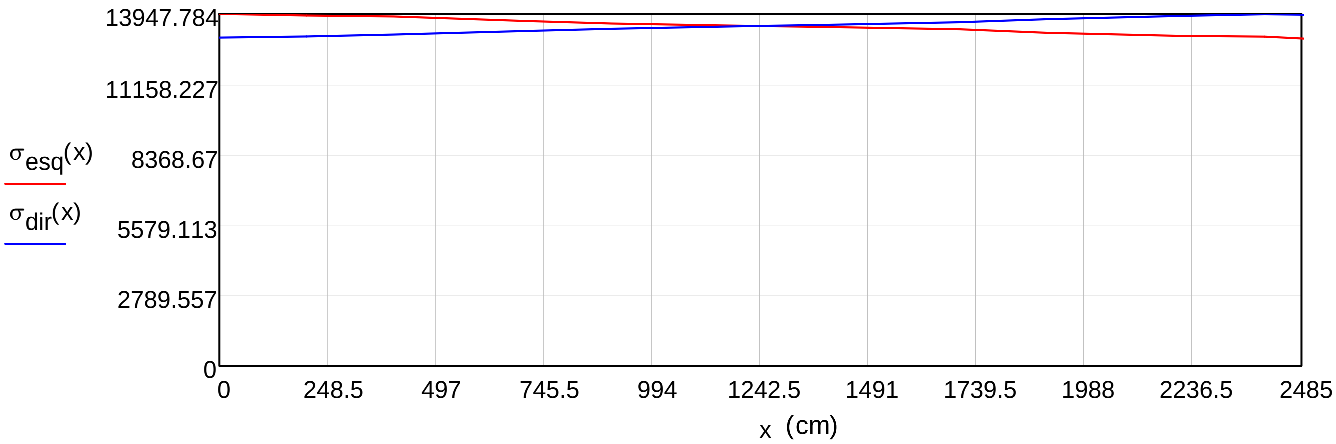
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13625.3 \\ 13537.89 \\ 13470.77 \\ 13403.99 \\ 13301.73 \\ 13139.58 \\ 13074.44 \\ 13009.62 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$

$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$



$c = \frac{L}{2}$ $\quad$ $d = 0m$

Given

$d = \sigma_{esq}(c)$ $\quad$ $d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\quad$ $interseção = 1241.63 \cdot cm$

$\sigma_{interseção} = 13470.54 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\,dx$ $\quad$ $Área_1 = 170281.51 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\,dx$ $\quad$ $Área_2 = 170503.53 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\quad$ $Área = 340785.03 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$ $\quad$ $\sigma_m = 13713.68 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.45m$ $\quad$ $Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\quad$ $E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.7 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 186 \cdot mm$

CABOS C11=C12=C13=C14=C15 (7ø15.2mm)

$$Área_{teórica\_aço} = 143.4mm^2 \qquad fptk = \frac{265.8kN}{Área_{teórica\_aço}} = 1853.56\,MPa \qquad fpyk = \frac{239.2kN}{Área_{teórica\_aço}} = 1668.06\,MPa$$

$$\sigma_{pi} = \min(0.74 \cdot fptk, 0.82 \cdot fpyk) = 1367.81\,MPa$$

$$\sigma_1 = \sigma_{pi} = 13947.78 \cdot \frac{kgf}{cm^2} \qquad \mu = 0.20 \qquad \beta = 0.01 \frac{rad}{m} \qquad e = 2.72 \qquad L = 24.85m$$

$$\kappa = \beta \cdot \mu = 0.002 \cdot \frac{rad}{m} \qquad n = 11 \qquad i = 1, 2 .. n$$

$$S = 0cm, \frac{L}{n-1} .. L = \begin{pmatrix} 0 \\ 248.5 \\ 497 \\ 745.5 \\ 994 \\ 1242.5 \\ 1491 \\ 1739.5 \\ 1988 \\ 2236.5 \\ 2485 \end{pmatrix} cm \qquad \Delta\alpha_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\alpha_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$$\alpha_i = \left| \begin{array}{l} 0rad \quad \text{if} \quad i = 1 \\ \alpha_{(i-1)} + \sqrt{\left(\Delta\alpha_{elevação_i}\right)^2 + \left(\Delta\alpha_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot rad \quad \text{otherwise} \end{array} \right.$$

$$\sigma_{esq} = \sigma_1 \cdot e^{-(\mu \cdot \alpha + \kappa \cdot S)}$$

$$\sigma_{esq} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13741.36 \\ 13653.21 \\ 13585.52 \\ 13518.17 \\ 13431.44 \\ 13364.85 \\ 13298.6 \\ 13232.67 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$$\Delta\theta_{elevação} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0.42 \\ 0 \\ 0 \\ 0 \end{pmatrix}° \qquad \Delta\theta_{planta} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}°$$

$n = 11$

$$\theta_i = \begin{vmatrix} 0\text{rad} \quad \text{if} \quad i = 1 \\ \theta_{(i-1)} + \sqrt{\left(\Delta\theta_{elevação_i}\right)^2 + \left(\Delta\theta_{planta_i}\right)^2} \quad \text{if} \quad i > 1 \\ i \cdot \text{rad} \quad \text{otherwise} \end{vmatrix}$$

$$\sigma_{dir} = \sigma_1 \cdot e^{-(\mu \cdot \theta + \kappa \cdot S)}$$

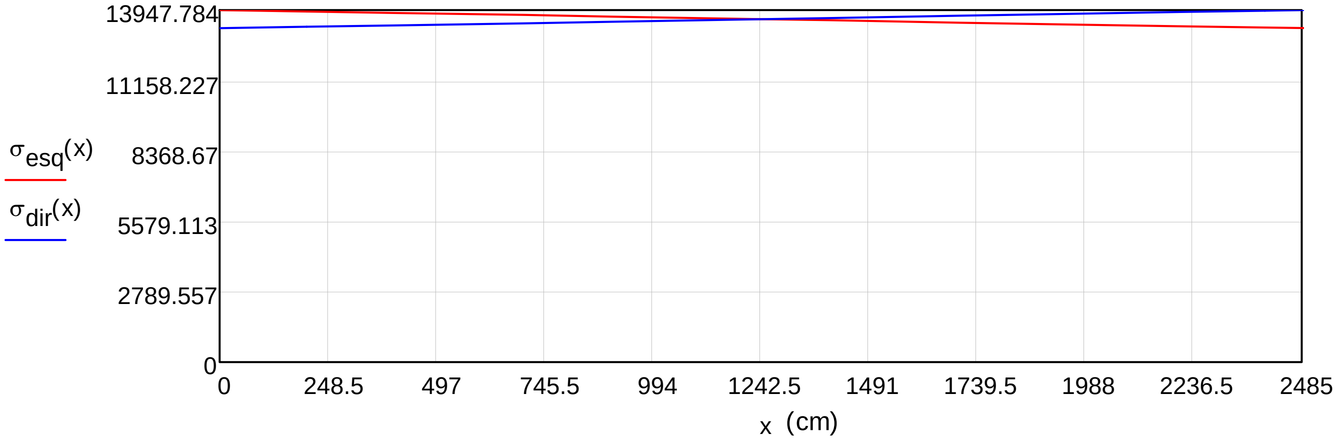
$$\sigma_{dir} = \begin{pmatrix} 13947.78 \\ 13878.64 \\ 13809.83 \\ 13741.36 \\ 13653.21 \\ 13585.52 \\ 13518.17 \\ 13431.44 \\ 13364.85 \\ 13298.6 \\ 13232.67 \end{pmatrix} \cdot \frac{kgf}{cm^2}$$

$a = \text{cspline}(S, \sigma_{esq})$

$b = \text{cspline}(S, \sigma_{dir})$

$$\sigma_{esq}(x) = \text{interp}\left(\frac{a}{g}, S, \frac{\sigma_{esq}}{g}, x\right)$$

$$\sigma_{dir}(x) = \text{interp}\left(\frac{b}{g}, S, \frac{\text{reverse}(\sigma_{dir})}{g}, x\right)$$



$c = \frac{L}{2}$ $\qquad d = 0m$

Given

$d = \sigma_{esq}(c)$ $\qquad d = \sigma_{dir}(c)$

$\begin{pmatrix} interseção \\ \sigma_{interseção} \end{pmatrix} = Find(c, d)$ $\qquad interseção = 1242.5 \cdot cm$

$\sigma_{interseção} = 13585.52 \cdot \frac{kg}{cm^2}$

$Área_1 = \int_0^{interseção} \sigma_{esq}(x)\, dx$ $\qquad Área_1 = 171090.45 \cdot \frac{kg \cdot m}{cm^2}$

$Área_2 = \int_{interseção}^{L} \sigma_{dir}(x)\, dx$ $\qquad Área_2 = 171091.84 \cdot \frac{kg \cdot m}{cm^2}$

$Área = (Área_1) + (Área_2)$ $\qquad Área = 342182.28 \cdot \frac{kg \cdot m}{cm^2}$

$\sigma_m = \frac{Área}{L}$ $\qquad \sigma_m = 13769.91 \cdot \frac{kg}{cm^2}$

$L_{cabo} = 26.45m$ $\qquad Área_{teórica\_aço} = 143.4 \cdot mm^2$ $\qquad E_{teórico\_aço} = 1950000 \frac{kg}{cm^2}$

$F_{média\_cabo} = \sigma_m \cdot Área_{teórica\_aço} = 19.7 \cdot t$

$\Delta L_{teórico} = \frac{(\sigma_m) \cdot (L_{cabo})}{E_{teórico\_aço}} = 187 \cdot mm$

V47 = V51 - CÁLCULO DAS ARMADURAS DE FRETAGEM

a_0 = Área da placa de distribuição

b = Distância entre eixos das ancoragens

c = Distância entre as ancoragens

d = Distância entre a face do concreto ao eixo da ancoragem

n = Quantidade de ancoragens em elevação

q = Quantidade de cabos alinhados em cada grupo (seção transversal)

EXTREMIDADE ATIVA

$b = 30cm$ $n = 3$ $q = 5$ $F_{inicial} = 7 \cdot \sigma_1 \cdot Área_{teórica\_aço} = 1373.01\,kN$

$a_0 = 25cm$ $c = 5cm$

$d = 20cm$ $a_1 = a_0 + c = 30\,cm$

$F_1 = F_{inicial} \cdot \cos(0.3°) = 1372.99\,kN$ $F_3 = F_{inicial} \cdot \cos(5°) = 1367.78\,kN$

$$T_1 = 0.25 \cdot F_1 \cdot \left(1 - \frac{a_0}{a_1}\right) = 57.21\,kN \qquad T_3 = 0.25 \cdot F_3 \cdot \left(1 - \frac{a_0}{a_1}\right) = 56.99\,kN$$

$F_2 = F_{inicial} \cdot \cos(3°) = 1371.13\,kN$

$$T_2 = 0.25 \cdot F_2 \cdot \left(1 - \frac{a_0}{a_1}\right) = 57.13\,kN$$

$a_2 = 2 \cdot d + (n-1) \cdot b = 100\,cm$ $k = 1..n$

$$F_k = \begin{pmatrix} 1372.99 \\ 1371.13 \\ 1367.78 \end{pmatrix} kN \qquad T_k = \begin{pmatrix} 57.21 \\ 57.13 \\ 56.99 \end{pmatrix} kN \qquad \sum F = 4111.9\,kN$$

$$T_n = \frac{2}{3} \cdot \left(1 - \frac{n \cdot a_1}{a_2}\right) \cdot \sum F = 274.13\,kN \qquad fyd = 43.48\,\frac{kN}{cm^2}$$

$$As_1 = \frac{\max(T)}{fyd} = 1.32\,cm^2 \qquad As_2 = q \cdot \left(\frac{T_n}{fyd}\right) = 31.52\,cm^2$$

$$As_{fretagem} = As_1 = 1.32\,cm^2$$

Adotado espiral ø12.5mm - 7 passos por cabo em cada trecho de ancoragem ativa.

$$As_{estribos} = \frac{As_2}{6} = 5.25\,cm^2$$

$L = \max(a_1, a_2) = 100\,cm$ $\qquad bitola_{estribo} = 8mm$ $\qquad adotados = ceil\left[\frac{As_{estribos}}{\pi \frac{(bitola_{estribo})^2}{4}}\right] = 11$

Estribos triplos $adotados = 11$ ø8.0mm em cada trecho de ancoragem ativa distribuídos em $L = 100\,cm$