

MEMORIAL DE CÁLCULO - MURO DE ARRIMO (CONTENÇÃO 2)

OBRA: PONTE SOBRE O SANGRADOURO DA BARRAGEM JOÃO GOMES

DATA: 15/09/2017

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1) PARÂMETROS DE CÁLCULO

1.1) CARREGAMENTOS EXTERNOS:

$$G_0 := 175 \frac{kN}{m}$$

Carga eventualmente aplicada no topo.

$$b_{consolo} := 35 \text{ cm}$$

$$q := 7 \frac{tonf}{m^2}$$

Sobrecarga eventualmente aplicada no terreno adjacente

1.2) DADOS DO SOLO:

$$\varphi := 23^\circ$$

Ângulo de atrito do solo

$$\delta := \frac{2}{3} \cdot \varphi = 15.3^\circ$$

Ângulo de rugosidade da parede

$$\mu := 0.3$$

Coeficiente de atrito do solo

$$\sigma_{adm} := 2.5 \frac{kgf}{cm^2}$$

Tensão adm do terreno

$$\gamma_{solo} := 21 \frac{kN}{m^3}$$

Peso específico do solo

1.3) PROPRIEDADES DA ARGAMASSA/CONCRETO:

$$f_{ck} := 2.5 \text{ MPa}$$

Resistência à compressão do muro

$$\gamma_{conc} := 25 \frac{kN}{m^3}$$

Peso específico do solo

1.4) GEOMETRIA DO MURO:

$$\alpha := 0^\circ$$

Ângulo de inclinação do terreno adjacente

$$h := 4 \text{ m}$$

Altura do muro

$$b_0 := 0.7 \text{ m}$$

Largura do muro no topo

$$b_{0_estimado} := 0.14 \cdot h = 0.6 \text{ m}$$

$$b_m := 0 \text{ m}$$

Alargamento da base à jusante

$$b_n := 1.3 \text{ m}$$

Alargamento da base à montante

$$\theta_e := \text{atan}\left(\frac{b_m}{h}\right) = 0^\circ$$

Inclinação da face jusante do muro

$$\theta_i := \text{atan}\left(\frac{b_n}{h}\right) = 18^\circ$$

Inclinação da face montante do muro

$$b := b_0 + b_m + b_n = 2 \text{ m}$$

Largura da base do muro

$$b_{estimado} := b_0 + \frac{h}{3} = 2 \text{ m}$$

1.5) GEOMETRIA DA SAPATA:

$$r := 1.3 \text{ m}$$

Ponta da sapata à jusante

$$r_{estimado} := \frac{h}{6} = 0.7 \text{ m}$$

$$t := 0 \text{ m}$$

Ponta da sapata à montante

$$t_{estimado} := \frac{h}{6} = 0.7 \text{ m}$$

$$h_s := 0 \text{ m}$$

Altura da sapata

$$h_{s_estimado} := r = 1.3 \text{ m}$$

$$h_{emb} := 0.75 \text{ m}$$

Altura de embutimento na rocha

$$b_s := r + b_0 + b_m + b_n + t = 3.3 \text{ m}$$

Largura da base da sapata

2) CÁLCULOS PRELIMINARES

2.1) ALTURA DE TERRA EQUIVALENTE À SOBRECARGA:

$$h_0 := \frac{q}{\gamma_{solo}} = 3 \text{ m} \quad \text{Altura equivalente}$$

$$H := h + h_0 = 7 \text{ m} \quad \text{Altura total}$$

2.2) PONTOS DE APLICAÇÃO DAS CARGAS:

(origem considerado é no vértice à montante de b0)

$$x_m := \frac{b_m^2 + 3 \cdot b_m \cdot b_0 + 3 \cdot b_0^2 - b_n^2}{3 \cdot (b_0 + b)} = -0.03 \text{ m} \quad \text{Peso Próprio do muro}$$

$$x_s := \frac{\frac{r^2 + b_m^2 + b_0^2 - b_n^2 - t^2}{2} + r \cdot b_m + r \cdot b_0 + b_m \cdot b_0 - t \cdot b_n}{r + b_m + b_0 + b_n + t} = 0.35 \text{ m} \quad \text{Peso Próprio da Sapata}$$

$$x_T := \frac{(t + b_n)^2 + (t + b_n) \cdot t + t^2}{3 \cdot (2 \cdot t + b_n)} = 0.4 \text{ m} \quad \text{Peso da terra no talão}$$

$$x_{Go} := \frac{3 \cdot b_0}{4} = 0.5 \text{ m} \quad \text{Carga aplicada em cima do muro}$$

2.3) CARGAS E BRAÇOS DE ALAVANCA:

Coefficiente de empuxo:

$$\delta := \frac{2}{3} \cdot \varphi = 15.3^\circ$$

$$K_{rankine} := \tan \left(45^\circ - \frac{\varphi}{2} \right)^2 = 0.44 \quad \text{(Rankine)}$$

$$K_{coulomb} := \frac{\cos(\varphi - \theta_i)^2}{\cos(\theta_i)^2 \cdot \cos(\delta + \theta_i) \cdot \left(1 + \sqrt{\frac{\sin(\delta + \varphi) \cdot \sin(\varphi - \alpha)}{\cos(\delta + \theta_i) \cdot \cos(\theta_i - \alpha)}} \right)^2} = 0.55 \quad \text{(Coulomb)}$$

$$K := \max(K_{rankine}, K_{coulomb}) = 0.55$$

$$E := \frac{1}{2} \cdot K \cdot \gamma_{solo} \cdot (H^2 - h_0^2) = 227.3 \frac{kN}{m}$$

Empuxo de terra

$$E_h := E \cdot \cos(\theta_i + \delta) = 189.9 \frac{kN}{m}$$

Componente horizontal do empuxo

$$E_v := E \cdot \sin(\theta_i + \delta) = 124.9 \frac{kN}{m}$$

Componente vertical do empuxo

$$G_0 = 175 \frac{1}{m} \cdot kN$$

Carga no topo do muro

$$G_m := \frac{h}{2} \cdot (b + b_0) \cdot \gamma_{conc} = 135 \frac{kN}{m}$$

Peso-Próprio do muro

$$G_t := \frac{h}{2} \cdot (t + t + b_n) \cdot \gamma_{solo} = 54.6 \frac{kN}{m}$$

Peso da terra no talão

$$G_s := (r + b_m + b_0 + b_n + t) \cdot (h_s + h_{emb}) \cdot \gamma_{conc} = 61.9 \frac{kN}{m} \quad \text{Peso-Próprio da sapata}$$

$$R_{emb} := \sigma_{adm} \cdot h_{emb} = 183.9 \frac{kN}{m}$$

Reação de embutimento na Rocha

$$y := \frac{h}{3} \left(\frac{2 \cdot h_0 + H}{H + h_0} \right) = 1.731 \text{ m}$$

Braço de alavanca do Eh

$$y_{emb} := \frac{h_{emb}}{2} = 0.4 \text{ m}$$

Braço de alavanca da reação de embutimento

$$e_v := \frac{(r + b_m + b_0 + b_n + t)}{2} - (t + b_n) + (h - y) \cdot \tan(\theta_i) = 1.087 \text{ m} \quad \text{Braço de alavanca do Ev}$$

$$e_0 := \frac{(r + b_m + b_0 + b_n + t)}{2} - (r - b_m) + b_{consolo} = 0.7 \text{ m} \quad \text{Braço da carga no topo do muro}$$

$$e_m := \frac{(r + b_m + b_0 + b_n + t)}{2} - (t + b_n + x_m) = 0.4 \text{ m} \quad \text{Braço de alavanca do Peso-Próprio do muro}$$

$$e_t := \frac{(r + b_m + b_0 + b_n + t)}{2} - x_T = 1.22 \text{ m}$$

Braço de alavanca do Peso da terra no talão

$$e_s := 0 \text{ m}$$

Braço de alavanca do Peso da sapata

3) CÁLCULOS DAS CARGAS TOTAIS

3.1) COMPONENTE NORMAL:

$$N := G_0 + G_m + G_s + G_t + E_v = 551.4 \frac{kN}{m}$$

3.2) COMPONENTE TANGENCIAL:

$$T := E_h - R_{emb} = 6.1 \frac{kN}{m}$$

3.3) MOMENTO TOTAL:

$$M_1 := G_m \cdot e_m + G_s \cdot e_s + G_t \cdot e_t + E_v \cdot e_v + R_{emb} \cdot y_{emb} - E_h \cdot (y + h_s + h_{emb}) - G_0 \cdot e_0 = -271.7 \frac{kN \cdot m}{m}$$

4) VERIFICAÇÃO DAS TENSÕES NA BASE DA SAPATA

$$\sigma_{med} := \frac{-N}{b_s} = -1.7 \frac{kgf}{cm^2}$$

$$\sigma_{max} := \frac{-N}{b_s} + \frac{M_1 \cdot 6}{b_s^2} = -3.23 \frac{kgf}{cm^2}$$

$$\sigma_{min} := \frac{-N}{b_s} - \frac{M_1 \cdot 6}{b_s^2} = -0.18 \frac{kgf}{cm^2}$$

$$M := \sigma_{max} \cdot r \cdot \frac{r}{2} = -267.7 \text{ kN}$$

$$\sigma := \frac{M \cdot 6}{(h_s + h_{emb})^2} = -2.9 \text{ MPa}$$

5) VERIFICAÇÃO DA ESTABILIDADE

5.1) DESLIZAMENTO:

$$\varepsilon_1 := \frac{\mu \cdot N}{T} = 27.3$$

5.2) TOMBAMENTO:

$$M_{equilíbrio} := G_m \cdot \left(e_m + \frac{b_s}{2} \right) + G_s \cdot \left(e_s + \frac{b_s}{2} \right) + G_t \cdot \left(e_t + \frac{b_s}{2} \right) + E_v \cdot \left(e_v + \frac{b_s}{2} \right) + R_{emb} \cdot y_{emb} + G_0 \cdot \left(\frac{b_s}{2} - e_0 \right) = 1109.5 \frac{kN \cdot m}{m}$$

$$M_{tombamento} := E_h \cdot (y + h_s + h_{emb}) = 471.3 \frac{kN \cdot m}{m}$$

$$\varepsilon_2 := \frac{M_{equilíbrio}}{M_{tombamento}} = 2.4$$

6) VERIFICAÇÃO DAS JUNTAS

6.1) JUNTA 1:

$$h_1 := 80 \text{ cm}$$

$$b_1 := b_0 + h_1 \cdot (\tan(\theta_i + \theta_e)) = 1 \text{ m}$$

$$H_1 := h_1 + h_0 = 3.8 \text{ m}$$

$$x_c := \frac{\frac{b_0^2 \cdot h_1}{2} + \frac{h_1^3 \cdot \tan(\theta_i)^2}{6} + \frac{h_1^3 \cdot \tan(\theta_e)^2}{6} + \frac{h_1^2 \cdot \tan(\theta_e) \cdot b_0}{2}}{\frac{h_1^2 \cdot \tan(\theta_e)}{2} + \frac{h_1^2 \cdot \tan(\theta_i)}{2} + b_0 \cdot h_1} = 0.309 \text{ m}$$

$$G_0 = 175 \frac{kN}{m}$$

$$e_{01} := \frac{b_0}{4} + \frac{(b_1 - b_0)}{2} = 30.5 \text{ cm}$$

$$G_{m1} := \frac{(b_0 + b_1) \cdot h_1}{2} \cdot \gamma_{conc} = 16.6 \frac{kN}{m}$$

$$e_{m1} := \frac{b_1}{2} - x_c = 17.1 \text{ cm}$$

$$G_{t1} := \frac{h_1 \cdot h_1 \cdot \tan(\theta_i)}{2} \cdot \gamma_{solo} = 2.2 \frac{kN}{m}$$

$$e_{t1} := \frac{b_1}{2} + \frac{2 \cdot (b_1 - b_0)}{3} = 0.653 \text{ m}$$

$$E_{H1} := \left(\frac{(H_1^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \cos(\theta_i + \delta) = 25.7 \frac{kN}{m}$$

$$y_1 := \frac{h_1}{3} \cdot \left(\frac{2 \cdot h_0 + H_1}{H_1 + h_0} \right) = 38.4 \text{ cm}$$

$$E_{V1} := \left(\frac{(H_1^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \sin(\theta_i + \delta) = 16.9 \frac{kN}{m}$$

$$e_{v1} := \frac{b_1}{2} + y_1 \cdot \tan(\theta_i) = 60.5 \text{ cm}$$

$$N_1 := G_0 + G_{m1} + G_{t1} + E_{V1} = 210.7 \frac{kN}{m}$$

$$M_1 := -G_0 \cdot e_{01} + G_{m1} \cdot e_{m1} + G_{t1} \cdot e_{t1} + E_{V1} \cdot e_{v1} - E_{H1} \cdot y_1 = -48.8 \frac{kN \cdot m}{m}$$

$$\sigma_{1min} := \frac{-N_1}{b_1} + \frac{M_1 \cdot 6}{b_1^2} = -536.9 \text{ kPa}$$

$$T_1 := E_{H1} = 25.7 \frac{kN}{m}$$

$$\sigma_{1max} := \frac{-N_1}{b_1} - \frac{M_1 \cdot 6}{b_1^2} = 97.9 \text{ kPa}$$

$$\varepsilon_{11} := \frac{0.7 \cdot N_1}{T_1} = 5.7$$

$$M_{tomb1} := E_{H1} \cdot y_1 = 9.9 \frac{kN \cdot m}{m}$$

$$M_{eq1} := G_0 \cdot \left(\frac{b_1}{2} - e_{01}\right) + G_{m1} \cdot \left(e_{m1} + \frac{b_1}{2}\right) + G_{t1} \cdot \left(e_{t1} + \frac{b_1}{2}\right) + E_{V1} \cdot \left(e_{v1} + \frac{b_1}{2}\right) = 62.3 \frac{kN \cdot m}{m}$$

$$\varepsilon_{21} := \frac{M_{eq1}}{M_{tomb1}} = 6.3$$

6.2) JUNTA 2:

$$h_2 := 160 \text{ cm}$$

$$b_2 := b_0 + h_2 \cdot (\tan(\theta_i + \theta_e)) = 1.2 \text{ m}$$

$$H_2 := h_2 + h_0 = 4.6 \text{ m}$$

$$x_c := \frac{\frac{b_0^2 \cdot h_2}{2} + \frac{h_2^3 \cdot \tan(\theta_i)^2}{6} + \frac{h_2^3 \cdot \tan(\theta_e)^2}{6} + \frac{h_2^2 \cdot \tan(\theta_e) \cdot b_0}{2}}{\frac{h_2^2 \cdot \tan(\theta_e)}{2} + \frac{h_2^2 \cdot \tan(\theta_i)}{2} + b_0 \cdot h_2} = 0.302 \text{ m}$$

$$G_0 = 175 \frac{\text{kN}}{\text{m}}$$

$$e_{02} := \frac{b_0}{4} + \frac{(b_2 - b_0)}{2} = 43.5 \text{ cm}$$

$$G_{m2} := \frac{(b_0 + b_2) \cdot h_2}{2} \cdot \gamma_{conc} = 38.4 \frac{\text{kN}}{\text{m}}$$

$$e_{m2} := \frac{b_2}{2} - x_c = 30.8 \text{ cm}$$

$$G_{t2} := \frac{h_2 \cdot h_2 \cdot \tan(\theta_i)}{2} \cdot \gamma_{solo} = 8.7 \frac{\text{kN}}{\text{m}}$$

$$e_{t2} := \frac{b_2}{2} + \frac{2 \cdot (b_2 - b_0)}{3} = 0.957 \text{ m}$$

$$E_{H2} := \left(\frac{(H_2^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \cos(\theta_i + \delta) = 57.6 \frac{\text{kN}}{\text{m}} \quad y_2 := \frac{h_2}{3} \cdot \left(\frac{2 \cdot h_0 + H_2}{H_2 + h_0} \right) = 74.3 \text{ cm}$$

$$E_{V2} := \left(\frac{(H_2^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \sin(\theta_i + \delta) = 37.9 \frac{\text{kN}}{\text{m}} \quad e_{v2} := \frac{b_2}{2} + y_2 \cdot \tan(\theta_i) = 85.2 \text{ cm}$$

$$N_2 := G_0 + G_{m2} + G_{t2} + E_{V2} = 260 \frac{\text{kN}}{\text{m}}$$

$$M_2 := -G_0 \cdot e_{02} + G_{m2} \cdot e_{m2} + G_{t2} \cdot e_{t2} + E_{V2} \cdot e_{v2} - E_{H2} \cdot y_2 = -66.5 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\sigma_{2min} := \frac{-N_2}{b_2} + \frac{M_2 \cdot 6}{b_2^2} = -481.2 \text{ kPa}$$

$$T_2 := E_{H2} = 57.6 \frac{\text{kN}}{\text{m}}$$

$$\sigma_{2max} := \frac{-N_2}{b_2} - \frac{M_2 \cdot 6}{b_2^2} = 54.9 \text{ kPa}$$

$$\varepsilon_{12} := \frac{0.7 \cdot N_2}{T_2} = 3.2$$

$$M_{tomb2} := E_{H2} \cdot y_2 = 42.8 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$M_{eq2} := G_0 \cdot \left(\frac{b_2}{2} - e_{02} \right) + G_{m2} \cdot \left(e_{m2} + \frac{b_2}{2} \right) + G_{t2} \cdot \left(e_{t2} + \frac{b_2}{2} \right) + E_{V2} \cdot \left(e_{v2} + \frac{b_2}{2} \right) = 134.9 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\varepsilon_{22} := \frac{M_{eq2}}{M_{tomb2}} = 3.2$$

6.3) JUNTA 3:

$$h_3 := 240 \text{ cm}$$

$$b_3 := b_0 + h_3 \cdot (\tan(\theta_i + \theta_e)) = 1.5 \text{ m}$$

$$H_3 := h_3 + h_0 = 5.4 \text{ m}$$

$$x_c := \frac{\frac{b_0^2 \cdot h_3}{2} + \frac{h_3^3 \cdot \tan(\theta_i)^2}{6} + \frac{h_3^3 \cdot \tan(\theta_e)^2}{6} + \frac{h_3^2 \cdot \tan(\theta_e) \cdot b_0}{2}}{\frac{h_3^2 \cdot \tan(\theta_e)}{2} + \frac{h_3^2 \cdot \tan(\theta_i)}{2} + b_0 \cdot h_3} = 0.318 \text{ m}$$

$$G_0 = 175 \frac{\text{kN}}{\text{m}}$$

$$e_{03} := \frac{b_0}{4} + \frac{(b_3 - b_0)}{2} = 56.5 \text{ cm}$$

$$G_{m3} := \frac{(b_0 + b_3) \cdot h_3}{2} \cdot \gamma_{conc} = 65.4 \frac{\text{kN}}{\text{m}}$$

$$e_{m3} := \frac{b_3}{2} - x_c = 42.2 \text{ cm}$$

$$G_{t3} := \frac{h_3 \cdot h_3 \cdot \tan(\theta_i)}{2} \cdot \gamma_{solo} = 19.7 \frac{\text{kN}}{\text{m}}$$

$$e_{t3} := \frac{b_3}{2} + \frac{2 \cdot (b_3 - b_0)}{3} = 1.26 \text{ m}$$

$$E_{H3} := \left(\frac{(H_3^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \cos(\theta_i + \delta) = 95.6 \frac{\text{kN}}{\text{m}} \quad y_3 := \frac{h_3}{3} \cdot \left(\frac{2 \cdot h_0 + H_3}{H_3 + h_0} \right) = 108.5 \text{ cm}$$

$$E_{V3} := \left(\frac{(H_3^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \sin(\theta_i + \delta) = 62.9 \frac{\text{kN}}{\text{m}} \quad e_{v3} := \frac{b_3}{2} + y_3 \cdot \tan(\theta_i) = 109.3 \text{ cm}$$

$$N_3 := G_0 + G_{m3} + G_{t3} + E_{V3} = 322.9 \frac{\text{kN}}{\text{m}}$$

$$M_3 := -G_0 \cdot e_{03} + G_{m3} \cdot e_{m3} + G_{t3} \cdot e_{t3} + E_{V3} \cdot e_{v3} - E_{H3} \cdot y_3 = -81.5 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\sigma_{3min} := \frac{-N_3}{b_3} + \frac{M_3 \cdot 6}{b_3^2} = -441.4 \text{ kPa}$$

$$T_3 := E_{H3} = 95.6 \frac{\text{kN}}{\text{m}}$$

$$\sigma_{3max} := \frac{-N_3}{b_3} - \frac{M_3 \cdot 6}{b_3^2} = 5 \text{ kPa}$$

$$\varepsilon_{13} := \frac{0.7 \cdot N_3}{T_3} = 2.4$$

$$M_{tomb3} := E_{H3} \cdot y_3 = 103.7 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$M_{eq3} := G_0 \cdot \left(\frac{b_3}{2} - e_{03} \right) + G_{m3} \cdot \left(e_{m3} + \frac{b_3}{2} \right) + G_{t3} \cdot \left(e_{t3} + \frac{b_3}{2} \right) + E_{V3} \cdot \left(e_{v3} + \frac{b_3}{2} \right) = 261.2 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\varepsilon_{23} := \frac{M_{eq3}}{M_{tomb3}} = 2.5$$

6.4) JUNTA 4:

$$h_4 := 320 \text{ cm}$$

$$b_4 := b_0 + h_4 \cdot \langle \tan(\theta_i + \theta_e) \rangle = 1.7 \text{ m}$$

$$H_4 := h_4 + h_0 = 6.2 \text{ m}$$

$$x_c := \frac{\frac{b_0^2 \cdot h_4}{2} + \frac{h_4^3 \cdot \tan(\theta_i)^2}{6} + \frac{h_4^3 \cdot \tan(\theta_e)^2}{6} + \frac{h_4^2 \cdot \tan(\theta_e) \cdot b_0}{2}}{\frac{h_4^2 \cdot \tan(\theta_e)}{2} + \frac{h_4^2 \cdot \tan(\theta_i)}{2} + b_0 \cdot h_4} = 0.349 \text{ m}$$

$$G_0 = 175 \frac{\text{kN}}{\text{m}}$$

$$e_{04} := \frac{b_0}{4} + \frac{(b_4 - b_0)}{2} = 69.5 \text{ cm}$$

$$G_{m4} := \frac{(b_0 + b_4) \cdot h_4}{2} \cdot \gamma_{conc} = 97.6 \frac{\text{kN}}{\text{m}}$$

$$e_{m4} := \frac{b_4}{2} - x_c = 52.1 \text{ cm}$$

$$G_{t4} := \frac{h_4 \cdot h_4 \cdot \tan(\theta_i)}{2} \cdot \gamma_{solo} = 34.9 \frac{\text{kN}}{\text{m}}$$

$$e_{t4} := \frac{b_4}{2} + \frac{2 \cdot (b_4 - b_0)}{3} = 1.563 \text{ m}$$

$$E_{H4} := \left(\frac{(H_4^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \cos(\theta_i + \delta) = 139.7 \frac{\text{kN}}{\text{m}} \quad y_4 := \frac{h_4}{3} \cdot \left(\frac{2 \cdot h_0 + H_4}{H_4 + h_0} \right) = 141.3 \text{ cm}$$

$$E_{V4} := \left(\frac{(H_4^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \sin(\theta_i + \delta) = 91.9 \frac{\text{kN}}{\text{m}} \quad e_{v4} := \frac{b_4}{2} + y_4 \cdot \tan(\theta_i) = 132.9 \text{ cm}$$

$$N_4 := G_0 + G_{m4} + G_{t4} + E_{V4} = 399.4 \frac{\text{kN}}{\text{m}}$$

$$M_4 := -G_0 \cdot e_{04} + G_{m4} \cdot e_{m4} + G_{t4} \cdot e_{t4} + E_{V4} \cdot e_{v4} - E_{H4} \cdot y_4 = -91.4 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\sigma_{4min} := \frac{-N_4}{b_4} + \frac{M_4 \cdot 6}{b_4^2} = -410.6 \text{ kPa}$$

$$T_4 := E_{H4} = 139.7 \frac{\text{kN}}{\text{m}}$$

$$\sigma_{4max} := \frac{-N_4}{b_4} - \frac{M_4 \cdot 6}{b_4^2} = -48.5 \text{ kPa}$$

$$\varepsilon_{14} := \frac{0.7 \cdot N_4}{T_4} = 2$$

$$M_{tomb4} := E_{H4} \cdot y_4 = 197.4 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$M_{eq4} := G_0 \cdot \left(\frac{b_4}{2} - e_{04} \right) + G_{m4} \cdot \left(e_{m4} + \frac{b_4}{2} \right) + G_{t4} \cdot \left(e_{t4} + \frac{b_4}{2} \right) + E_{V4} \cdot \left(e_{v4} + \frac{b_4}{2} \right) = 453.6 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\varepsilon_{24} := \frac{M_{eq4}}{M_{tomb4}} = 2.3$$

6.5) JUNTA 5:

$$h_5 := 400 \text{ cm}$$

$$b_5 := b_0 + h_5 \cdot (\tan(\theta_i + \theta_e)) = 2 \text{ m}$$

$$H_5 := h_5 + h_0 = 7 \text{ m}$$

$$x_c := \frac{\frac{b_0^2 \cdot h_5}{2} + \frac{h_5^3 \cdot \tan(\theta_i)^2}{6} + \frac{h_5^3 \cdot \tan(\theta_e)^2}{6} + \frac{h_5^2 \cdot \tan(\theta_e) \cdot b_0}{2}}{\frac{h_5^2 \cdot \tan(\theta_e)}{2} + \frac{h_5^2 \cdot \tan(\theta_i)}{2} + b_0 \cdot h_5} = 0.39 \text{ m}$$

$$G_0 = 175 \frac{\text{kN}}{\text{m}}$$

$$e_{05} := \frac{b_0}{4} + \frac{(b_5 - b_0)}{2} = 82.5 \text{ cm}$$

$$G_{m5} := \frac{(b_0 + b_5) \cdot h_5}{2} \cdot \gamma_{conc} = 135 \frac{\text{kN}}{\text{m}}$$

$$e_{m5} := \frac{b_5}{2} - x_c = 61 \text{ cm}$$

$$G_{t5} := \frac{h_5 \cdot h_5 \cdot \tan(\theta_i)}{2} \cdot \gamma_{solo} = 54.6 \frac{\text{kN}}{\text{m}}$$

$$e_{t5} := \frac{b_5}{2} + \frac{2 \cdot (b_5 - b_0)}{3} = 1.867 \text{ m}$$

$$E_{H5} := \left(\frac{(H_5^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \cos(\theta_i + \delta) = 189.9 \frac{\text{kN}}{\text{m}} \quad y_5 := \frac{h_5}{3} \cdot \left(\frac{2 \cdot h_0 + H_5}{H_5 + h_0} \right) = 173.1 \text{ cm}$$

$$E_{V5} := \left(\frac{(H_5^2 - h_0^2)}{2} \cdot K \cdot \gamma_{solo} \right) \cdot \sin(\theta_i + \delta) = 124.9 \frac{\text{kN}}{\text{m}} \quad e_{v5} := \frac{b_5}{2} + y_5 \cdot \tan(\theta_i) = 156.3 \text{ cm}$$

$$N_5 := G_0 + G_{m5} + G_{t5} + E_{V5} = 489.5 \frac{\text{kN}}{\text{m}}$$

$$M_5 := -G_0 \cdot e_{05} + G_{m5} \cdot e_{m5} + G_{t5} \cdot e_{t5} + E_{V5} \cdot e_{v5} - E_{H5} \cdot y_5 = -93.7 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\sigma_{5min} := \frac{-N_5}{b_5} + \frac{M_5 \cdot 6}{b_5^2} = -385.4 \text{ kPa}$$

$$T_5 := E_{H5} = 189.9 \frac{\text{kN}}{\text{m}}$$

$$\sigma_{4max} := \frac{-N_5}{b_5} - \frac{M_5 \cdot 6}{b_5^2} = -104.2 \text{ kPa}$$

$$\varepsilon_{15} := \frac{0.7 \cdot N_5}{T_5} = 1.8$$

$$M_{tomb5} := E_{H5} \cdot y_5 = 328.9 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$M_{eq5} := G_0 \cdot \left(\frac{b_5}{2} - e_{05} \right) + G_{m5} \cdot \left(e_{m5} + \frac{b_5}{2} \right) + G_{t5} \cdot \left(e_{t5} + \frac{b_5}{2} \right) + E_{V5} \cdot \left(e_{v5} + \frac{b_5}{2} \right) = 724.7 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\varepsilon_{25} := \frac{M_{eq5}}{M_{tomb5}} = 2.2$$

6.6) JUNTA 6:

$$h_6 := 425 \text{ cm}$$

$$b_6 := b_s = 3.3 \text{ m}$$

$$H_6 := h_5 + h_0 = 7 \text{ m}$$

$$x_c := \frac{\frac{b_0^2 \cdot h_5}{2} + \frac{h_5^3 \cdot \tan(\theta_i)^2}{6} + \frac{h_5^3 \cdot \tan(\theta_e)^2}{6} + \frac{h_5^2 \cdot \tan(\theta_e) \cdot b_0}{2}}{\frac{h_5^2 \cdot \tan(\theta_e)}{2} + \frac{h_5^2 \cdot \tan(\theta_i)}{2} + b_0 \cdot h_5} = 0.39 \text{ m}$$

$$G_0 = 175 \frac{\text{kN}}{\text{m}}$$

$$e_0 = 0.7 \text{ m}$$

$$G_m = 135 \frac{\text{kN}}{\text{m}}$$

$$e_m = 0.4 \text{ m}$$

$$G_t = 54.6 \frac{\text{kN}}{\text{m}}$$

$$e_t = 1.217 \text{ m}$$

$$E_h = 189.9 \frac{\text{kN}}{\text{m}}$$

$$y = 1.7 \text{ m}$$

$$E_v = 124.9 \frac{\text{kN}}{\text{m}}$$

$$e_v = 1.1 \text{ m}$$

$$G_{s6} := (h_6 - h) \cdot b_s \cdot \gamma_{conc} = 20.6 \frac{\text{kN}}{\text{m}}$$

$$e_s = 0 \text{ m}$$

$$N_6 := G_0 + G_m + G_t + E_v + G_{s6} = 510.2 \frac{\text{kN}}{\text{m}}$$

$$M_6 := -G_0 \cdot e_0 + G_m \cdot e_m + G_t \cdot e_t + E_v \cdot e_v - E_h \cdot (y + h_6 - h) = -245.7 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\sigma_{6min} := \frac{-N_6}{b_s} + \frac{M_6 \cdot 6}{b_s^2} = -289.9 \text{ kPa}$$

$$T_6 := E_h = 189.9 \frac{\text{kN}}{\text{m}}$$

$$\sigma_{6max} := \frac{-N_6}{b_s} - \frac{M_6 \cdot 6}{b_s^2} = -19.2 \text{ kPa}$$

$$\varepsilon_{16} := \frac{0.7 \cdot N_6}{T_6} = 1.9$$

$$M_{tomb6} := E_h \cdot (y + h_6 - h) = 376.3 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$M_{eq6} := G_0 \cdot \left(\frac{b_s}{2} - e_0 \right) + G_m \cdot \left(e_m + \frac{b_s}{2} \right) + G_t \cdot \left(e_t + \frac{b_s}{2} \right) + E_v \cdot \left(e_v + \frac{b_s}{2} \right) + G_s \cdot \frac{b_s}{2} = 1040.5 \frac{\text{kN} \cdot \text{m}}{\text{m}}$$

$$\varepsilon_{26} := \frac{M_{eq6}}{M_{tomb6}} = 2.8$$