MEMORIAL DE CÁLCULO - MURO DE ARRIMO (CONTENÇÃO 1)

OBRA: PONTE SOBRE O SANGRADOURO DA BARRAGEM JOÃO GOMES
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1) PARÂMETROS DE CÁLCULO

1.1) CARREGAMENTOS EXTERNOS:

$G_0 := 175 \ \frac{kN}{m}$ — **Carga evetualmente aplicada no topo.**

$b_{consolo} := 35 \ cm$

$q := 7 \ \frac{tonf}{m^2}$ — **Sobrecarga eventualmente aplicada no terreno adjacente**

1.2) DADOS DO SOLO:

$\varphi := 23 \ °$ — **Ângulo de atrito do solo**

$\delta := \frac{2}{3} \cdot \varphi = 15.3 \ °$ — **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:

$f_{ck} := 2.5\ MPa$ **Resistência à compressão do muro**

$\gamma_{conc} := 25\ \frac{kN}{m^3}$ **Peso específico do solo**

1.4) GEOMETRIA DO MURO:

$\alpha := 0\ °$ **Ângulo de inclinação do terreno adjacente**

$h := 4\ m$ **Altura do muro**

$b_0 := 0.7\ m$ **Largura do muro no topo** $b_{0\_estimado} := 0.14 \cdot h = 0.6\ m$

$b_m := 0\ m$ **Alargamento da base à jusante**

$b_n := 1.8\ m$ **Alargamento da base à montante**

$\theta_e := \operatorname{atan}\left(\frac{b_m}{h}\right) = 0\ °$ **Inclinação da face jusante do muro**

$\theta_i := \operatorname{atan}\left(\frac{b_n}{h}\right) = 24.2\ °$ **Inclinação da face montante do muro**

$b := b_0 + b_m + b_n = 2.5\ m$ **Largura da base do muro** $b_{estimado} := b_0 + \frac{h}{3} = 2\ m$

1.5) GEOMETRIA DA SAPATA:

$r := 2\ m$ **Ponta da sapata à jusante** $r_{estimado} := \frac{h}{6} = 0.7\ m$

$t := 0\ m$ **Ponta da sapata à montante** $t_{estimado} := \frac{h}{6} = 0.7\ m$

$h_s := 2.0\ m$ **Altura da sapata** $h_{s\_estimado} := r = 2\ m$

$h_{emb} := 0.5\ m$ **Altura de embutimento na rocha**

$b_s := r + b_0 + b_m + b_n + t = 4.5\ m$ **Largura da base da sapata**

2) CÁLCULOS PRELIMINARES

2.1) ALTURA DE TERRA EQUIVALENTE À SOBRECARGA:

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

$H := h + h_0 = 7\ m$ **Altura total**

2.2) PONTOS DE APLICAÇÃO DAS CARGAS:

(origem considerado é no vértice à montate de b0)

$x_m := \frac{b_m^{\,2} + 3 \cdot b_m \cdot b_0 + 3 \cdot b_0^{\,2} - b_n^{\,2}}{3 \cdot (b_0 + b)} = -0.18\ m$ **Peso Prórpio do muro**

$x_s := \frac{\frac{r^2 + b_m^{\,2} + b_0^{\,2} - b_n^{\,2} - t^2}{2} + r \cdot b_m + r \cdot b_0 + b_m \cdot b_0 - t \cdot b_n}{r + b_m + b_0 + b_n + t} = 0.45\ m$ **Peso Prórpio da Sapata**

$x_T := \frac{(t + b_n)^2 + (t + b_n) \cdot t + t^2}{3 \cdot (2 \cdot t + b_n)} = 0.6\ m$ **Peso da terra no talão**

$x_{Go} := b_0 = 0.7\ m$ **Carga aplicada em cima do muro**

2.3) CARGAS E BRAÇOS DE ALAVANCA:

Coeficiente de empuxo:

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

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

$K_{coulomb} := \frac{\cos(\varphi - \theta_i)^2}{\cos(\theta_i)^2 \cdot \cos(\delta + \theta_i) \cdot \left(1 + \sqrt{\frac{\sin(\delta + \varphi) \cdot \sin(\varphi - \alpha)}{\cos(\delta + \theta_i) \cdot \cos(\theta_i - \alpha)}}\right)^2} = 0.62$ **(Coulomb)**

$K := \max(K_{rankine}, K_{coulomb}) = 0.62$

$E := \frac{1}{2} \cdot K \cdot \gamma_{solo} \cdot \left(H^2 - {h_0}^2\right) = 258.2 \ \frac{kN}{m}$ **Empuxo de terra**

$E_h := E \cdot \cos\left(\theta_i + \delta\right) = 199 \ \frac{kN}{m}$ **Componente horizontal do empuxo**

$E_v := E \cdot \sin\left(\theta_i + \delta\right) = 164.4 \ \frac{kN}{m}$ **Componente vertical do empuxo**

$G_0 = 175 \ \frac{1}{m} \cdot kN$ **Carga no topo do muro**

$G_m := \frac{h}{2} \cdot \left(b + b_0\right) \cdot \gamma_{conc} = 160 \ \frac{kN}{m}$ **Peso-Próprio do muro**

$G_t := \frac{h}{2} \cdot \left(t + t + b_n\right) \cdot \gamma_{solo} = 75.6 \ \frac{kN}{m}$ **Peso da terra no talão**

$G_s := \left(r + b_m + b_0 + b_n + t\right) \cdot \left(h_s + h_{emb}\right) \cdot \gamma_{conc} = 281.3 \ \frac{kN}{m}$ **Peso-Próprio da sapata**

$R_{emb} := \sigma_{adm} \cdot h_{emb} = 122.6 \ \frac{kN}{m}$ **Reação de embutimento na Rocha**

$y := \frac{h}{3} \left(\frac{2 \cdot h_0 + H}{H + h_0}\right) = 1.731 \ m$ **Braço de alavanca do Eh**

$y_{emb} := \frac{h_{emb}}{2} = 0.3 \ m$ **Braço de alavanca da reação de embutimento**

$e_v := \frac{\left(r + b_m + b_0 + b_n + t\right)}{2} - \left(t + b_n\right) + \left(h - y\right) \cdot \tan\left(\theta_i\right) = 1.471 \ m$ **Braço de alavanca do Ev**

$e_0 := \frac{\left(r + b_m + b_0 + b_n + t\right)}{2} - \left(r - b_m\right) + b_{consolo} = 0.6 \ m$ **Braço da carga no topo do muro**

$e_m := \frac{\left(r + b_m + b_0 + b_n + t\right)}{2} - \left(t + b_n + x_m\right) = 0.6 \ m$ **Braço de alavanca do Peso-Próprio do muro**

$e_t := \frac{\left(r + b_m + b_0 + b_n + t\right)}{2} - x_T = 1.65 \ m$ **Braço de alavanca do Peso da terra no talão**

$e_s := 0 \ m$ **Braço de alavanca do Peso da sapata**

3) CÁLCULOS DAS CARGAS TOTAIS

3.1) COMPONENTE NORMAL:

$$N := G_0 + G_m + G_s + G_t + E_v = 856.3 \ \frac{kN}{m}$$

3.2) COMPONENTE TANGENCIAL:

$$T := E_h - R_{emb} = 76.4 \ \frac{kN}{m}$$

3.3) MOMENTO TOTAL:

$$M_1 := G_m \cdot e_m + G_s \cdot e_s + G_t \cdot e_t + E_v \cdot e_v + R_{emb} \cdot y_{emb} - E_h \cdot \left(y + h_s + h_{emb}\right) - G_0 \cdot e_0 = -448.4 \ \frac{kN \cdot m}{m}$$

4) VERIFICAÇÃO DAS TENSÕES NA BASE DA SAPATA

$$\sigma_{med} := \frac{-N}{\left(r + b_m + b_0 + b_n + t\right)} = -1.9 \ \frac{kgf}{cm^2}$$

$$\sigma_{max} := \frac{-N}{\left(r + b_m + b_0 + b_n + t\right)} + \frac{M_1 \cdot 6}{\left(r + b_m + b_0 + b_n + t\right)^2} = -3.3 \ \frac{kgf}{cm^2}$$

$$\sigma_{min} := \frac{-N}{\left(r + b_m + b_0 + b_n + t\right)} - \frac{M_1 \cdot 6}{\left(r + b_m + b_0 + b_n + t\right)^2} = -0.59 \ \frac{kgf}{cm^2}$$

5) VERIFICAÇÃO DA ESTABILIDADE

5.1) DESLIZAMENTO:

$$\varepsilon_1 := \frac{\mu \cdot N}{T} = 3.4$$

5.2) TOMBAMENTO:

$$M_{equilíbrio} := G_m \cdot \left(e_m + \frac{b_s}{2}\right) + G_s \cdot \left(e_s + \frac{b_s}{2}\right) + G_t \cdot \left(e_t + \frac{b_s}{2}\right) + E_v \cdot \left(e_v + \frac{b_s}{2}\right) + R_{emb} \cdot y_{emb} + G_0 \cdot \left(\frac{b_s}{2} - e_0\right) = 2320.3 \ \frac{kN \cdot m}{m}$$

$$M_{tombamento} := E_h \cdot \left(y + h_s + h_{emb}\right) = 842.2 \ \frac{kN \cdot m}{m}$$

$$\varepsilon_2 := \frac{M_{equilíbrio}}{M_{tombamento}} = 2.8$$

6) VERIFICAÇÃO DAS JUNTAS

6.1) JUNTA 1:

$h_1 := 80\ cm$ $\qquad b_1 := b_0 + h_1 \cdot \left(\tan\left(\theta_i + \theta_e\right)\right) = 1.1\ m$ $\qquad H_1 := h_1 + h_0 = 3.8\ m$

$$x_c := \frac{\frac{{b_0}^2 \cdot h_1}{2} + \frac{{h_1}^3 \cdot \tan\left(\theta_i\right)^2}{6} + \frac{{h_1}^3 \cdot \tan\left(\theta_e\right)^2}{6} + \frac{{h_1}^2 \cdot \tan\left(\theta_e\right) \cdot b_0}{2}}{\frac{{h_1}^2 \cdot \tan\left(\theta_e\right)}{2} + \frac{{h_1}^2 \cdot \tan\left(\theta_i\right)}{2} + b_0 \cdot h_1} = 0.303\ m$$

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

$e_{01} := \frac{b_0}{4} + \frac{\left(b_1 - b_0\right)}{2} = 35.5\ cm$

$G_{m1} := \frac{\left(b_0 + b_1\right) \cdot h_1}{2} \cdot \gamma_{conc} = 17.6\ \frac{kN}{m}$

$e_{m1} := \frac{b_1}{2} - x_c = 22.7\ cm$

$G_{t1} := \frac{h_1 \cdot h_1 \cdot \tan\left(\theta_i\right)}{2} \cdot \gamma_{solo} = 3\ \frac{kN}{m}$

$e_{t1} := \frac{b_1}{2} + \frac{2 \cdot \left(b_1 - b_0\right)}{3} = 0.77\ m$

$E_{H1} := \left(\frac{\left({H_1}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \cos\left(\theta_i + \delta\right) = 27\ \frac{kN}{m}$

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

$E_{V1} := \left(\frac{\left({H_1}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \sin\left(\theta_i + \delta\right) = 22.3\ \frac{kN}{m}$

$e_{v1} := \frac{b_1}{2} + y_1 \cdot \tan\left(\theta_i\right) = 70.3\ cm$

$N_1 := G_0 + G_{m1} + G_{t1} + E_{V1} = 217.9\ \frac{kN}{m}$

$M_1 := -G_0 \cdot e_{01} + G_{m1} \cdot e_{m1} + G_{t1} \cdot e_{t1} + E_{V1} \cdot e_{v1} - E_{H1} \cdot y_1 = -50.5\ \frac{kN \cdot m}{m}$

$\sigma_{1min} := \frac{-N_1}{b_1} + \frac{M_1 \cdot 6}{{b_1}^2} = -475.2\ kPa$

$\sigma_{1max} := \frac{-N_1}{b_1} - \frac{M_1 \cdot 6}{{b_1}^2} = 64.1\ kPa$

$T_1 := E_{H1} = 27\ \frac{kN}{m}$

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

$$M_{tomb1} := E_{H1} \cdot y_1 = 10.4 \ \frac{kN \cdot m}{m}$$

$$M_{eq1} := G_0 \cdot \left(\frac{b_1}{2} - e_{01} \right) + G_{m1} \cdot \left(e_{m1} + \frac{b_1}{2} \right) + G_{t1} \cdot \left(e_{t1} + \frac{b_1}{2} \right) + E_{V1} \cdot \left(e_{v1} + \frac{b_1}{2} \right) = 75.4 \ \frac{kN \cdot m}{m}$$

$$\varepsilon_{21} := \frac{M_{eq1}}{M_{tomb1}} = 7.3$$

6.2) JUNTA 2:

$h_2 := 160\ cm$ $\quad b_2 := b_0 + h_2 \cdot \left(\tan\left(\theta_i + \theta_e\right)\right) = 1.4\ m$ $\quad H_2 := h_2 + h_0 = 4.6\ m$

$$x_c := \frac{\frac{{b_0}^2 \cdot h_2}{2} + \frac{{h_2}^3 \cdot \tan\left(\theta_i\right)^2}{6} + \frac{{h_2}^3 \cdot \tan\left(\theta_e\right)^2}{6} + \frac{{h_2}^2 \cdot \tan\left(\theta_e\right) \cdot b_0}{2}}{\frac{{h_2}^2 \cdot \tan\left(\theta_e\right)}{2} + \frac{{h_2}^2 \cdot \tan\left(\theta_i\right)}{2} + b_0 \cdot h_2} = 0.313\ m$$

$G_0 = 175\ \frac{kN}{m}$ $\quad e_{02} := \frac{b_0}{4} + \frac{\left(b_2 - b_0\right)}{2} = 53.5\ cm$

$G_{m2} := \frac{\left(b_0 + b_2\right) \cdot h_2}{2} \cdot \gamma_{conc} = 42.4\ \frac{kN}{m}$ $\quad e_{m2} := \frac{b_2}{2} - x_c = 39.7\ cm$

$G_{t2} := \frac{h_2 \cdot h_2 \cdot \tan\left(\theta_i\right)}{2} \cdot \gamma_{solo} = 12.1\ \frac{kN}{m}$ $\quad e_{t2} := \frac{b_2}{2} + \frac{2 \cdot \left(b_2 - b_0\right)}{3} = 1.19\ m$

$E_{H2} := \left(\frac{\left({H_2}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \cos\left(\theta_i + \delta\right) = 60.4\ \frac{kN}{m}$ $\quad y_2 := \frac{h_2}{3} \cdot \left(\frac{2 \cdot h_0 + H_2}{H_2 + h_0}\right) = 74.3\ cm$

$E_{V2} := \left(\frac{\left({H_2}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \sin\left(\theta_i + \delta\right) = 49.9\ \frac{kN}{m}$ $\quad e_{v2} := \frac{b_2}{2} + y_2 \cdot \tan\left(\theta_i\right) = 104.5\ cm$

$N_2 := G_0 + G_{m2} + G_{t2} + E_{V2} = 279.4\ \frac{kN}{m}$

$M_2 := -G_0 \cdot e_{02} + G_{m2} \cdot e_{m2} + G_{t2} \cdot e_{t2} + E_{V2} \cdot e_{v2} - E_{H2} \cdot y_2 = -55.2\ \frac{kN \cdot m}{m}$

$\sigma_{2min} := \frac{-N_2}{b_2} + \frac{M_2 \cdot 6}{{b_2}^2} = -360.9\ kPa$ $\quad T_2 := E_{H2} = 60.4\ \frac{kN}{m}$

$\sigma_{2max} := \frac{-N_2}{b_2} - \frac{M_2 \cdot 6}{{b_2}^2} = -32.6\ kPa$ $\quad \varepsilon_{12} := \frac{0.7 \cdot N_2}{T_2} = 3.2$

$M_{tomb2} := E_{H2} \cdot y_2 = 44.9\ \frac{kN \cdot m}{m}$

$M_{eq2} := G_0 \cdot \left(\frac{b_2}{2} - e_{02}\right) + G_{m2} \cdot \left(e_{m2} + \frac{b_2}{2}\right) + G_{t2} \cdot \left(e_{t2} + \frac{b_2}{2}\right) + E_{V2} \cdot \left(e_{v2} + \frac{b_2}{2}\right) = 188.1\ \frac{kN \cdot m}{m}$

$\varepsilon_{22} := \frac{M_{eq2}}{M_{tomb2}} = 4.2$

6.3) JUNTA 3:

$h_3 := 240\ cm$ $\quad b_3 := b_0 + h_3 \cdot \left(\tan\left(\theta_i + \theta_e\right)\right) = 1.8\ m$ $\quad H_3 := h_3 + h_0 = 5.4\ m$

$$x_c := \frac{\frac{{b_0}^2 \cdot h_3}{2} + \frac{{h_3}^3 \cdot \tan\left(\theta_i\right)^2}{6} + \frac{{h_3}^3 \cdot \tan\left(\theta_e\right)^2}{6} + \frac{{h_3}^2 \cdot \tan\left(\theta_e\right) \cdot b_0}{2}}{\frac{{h_3}^2 \cdot \tan\left(\theta_e\right)}{2} + \frac{{h_3}^2 \cdot \tan\left(\theta_i\right)}{2} + b_0 \cdot h_3} = 0.354\ m$$

$G_0 = 175\ \frac{kN}{m}$ $\quad e_{03} := \frac{b_0}{4} + \frac{\left(b_3 - b_0\right)}{2} = 71.5\ cm$

$G_{m3} := \frac{\left(b_0 + b_3\right) \cdot h_3}{2} \cdot \gamma_{conc} = 74.4\ \frac{kN}{m}$ $\quad e_{m3} := \frac{b_3}{2} - x_c = 53.6\ cm$

$G_{t3} := \frac{h_3 \cdot h_3 \cdot \tan\left(\theta_i\right)}{2} \cdot \gamma_{solo} = 27.2\ \frac{kN}{m}$ $\quad e_{t3} := \frac{b_3}{2} + \frac{2 \cdot \left(b_3 - b_0\right)}{3} = 1.61\ m$

$E_{H3} := \left(\frac{\left({H_3}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \cos\left(\theta_i + \delta\right) = 100.2\ \frac{kN}{m}$ $\quad y_3 := \frac{h_3}{3} \cdot \left(\frac{2 \cdot h_0 + H_3}{H_3 + h_0}\right) = 108.5\ cm$

$E_{V3} := \left(\frac{\left({H_3}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \sin\left(\theta_i + \delta\right) = 82.8\ \frac{kN}{m}$ $\quad e_{v3} := \frac{b_3}{2} + y_3 \cdot \tan\left(\theta_i\right) = 137.8\ cm$

$N_3 := G_0 + G_{m3} + G_{t3} + E_{V3} = 359.4\ \frac{kN}{m}$

$M_3 := -G_0 \cdot e_{03} + G_{m3} \cdot e_{m3} + G_{t3} \cdot e_{t3} + E_{V3} \cdot e_{v3} - E_{H3} \cdot y_3 = -36.1\ \frac{kN \cdot m}{m}$

$\sigma_{3min} := \frac{-N_3}{b_3} + \frac{M_3 \cdot 6}{{b_3}^2} = -270.2\ kPa$ $\quad T_3 := E_{H3} = 100.2\ \frac{kN}{m}$

$\sigma_{3max} := \frac{-N_3}{b_3} - \frac{M_3 \cdot 6}{{b_3}^2} = -133.6\ kPa$ $\quad \varepsilon_{13} := \frac{0.7 \cdot N_3}{T_3} = 2.5$

$M_{tomb3} := E_{H3} \cdot y_3 = 108.7\ \frac{kN \cdot m}{m}$

$M_{eq3} := G_0 \cdot \left(\frac{b_3}{2} - e_{03}\right) + G_{m3} \cdot \left(e_{m3} + \frac{b_3}{2}\right) + G_{t3} \cdot \left(e_{t3} + \frac{b_3}{2}\right) + E_{V3} \cdot \left(e_{v3} + \frac{b_3}{2}\right) = 392.4\ \frac{kN \cdot m}{m}$

$\varepsilon_{23} := \frac{M_{eq3}}{M_{tomb3}} = 3.6$

6.4) JUNTA 4:

$h_4 := 320\ cm$ $\quad b_4 := b_0 + h_4 \cdot \left(\tan\left(\theta_i + \theta_e\right)\right) = 2.1\ m$ $\quad H_4 := h_4 + h_0 = 6.2\ m$

$$x_c := \frac{\frac{{b_0}^2 \cdot h_4}{2} + \frac{{h_4}^3 \cdot \tan\left(\theta_i\right)^2}{6} + \frac{{h_4}^3 \cdot \tan\left(\theta_e\right)^2}{6} + \frac{{h_4}^2 \cdot \tan\left(\theta_e\right) \cdot b_0}{2}}{\frac{{h_4}^2 \cdot \tan\left(\theta_e\right)}{2} + \frac{{h_4}^2 \cdot \tan\left(\theta_i\right)}{2} + b_0 \cdot h_4} = 0.416\ m$$

$G_0 = 175\ \frac{kN}{m}$ $\quad e_{04} := \frac{b_0}{4} + \frac{\left(b_4 - b_0\right)}{2} = 89.5\ cm$

$G_{m4} := \frac{\left(b_0 + b_4\right) \cdot h_4}{2} \cdot \gamma_{conc} = 113.6\ \frac{kN}{m}$ $\quad e_{m4} := \frac{b_4}{2} - x_c = 65.4\ cm$

$G_{t4} := \frac{h_4 \cdot h_4 \cdot \tan\left(\theta_i\right)}{2} \cdot \gamma_{solo} = 48.4\ \frac{kN}{m}$ $\quad e_{t4} := \frac{b_4}{2} + \frac{2 \cdot \left(b_4 - b_0\right)}{3} = 2.03\ m$

$E_{H4} := \left(\frac{\left({H_4}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \cos\left(\theta_i + \delta\right) = 146.4\ \frac{kN}{m}$ $\quad y_4 := \frac{h_4}{3} \cdot \left(\frac{2 \cdot h_0 + H_4}{H_4 + h_0}\right) = 141.3\ cm$

$E_{V4} := \left(\frac{\left({H_4}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \sin\left(\theta_i + \delta\right) = 120.9\ \frac{kN}{m}$ $\quad e_{v4} := \frac{b_4}{2} + y_4 \cdot \tan\left(\theta_i\right) = 170.6\ cm$

$N_4 := G_0 + G_{m4} + G_{t4} + E_{V4} = 457.9\ \frac{kN}{m}$

$M_4 := -G_0 \cdot e_{04} + G_{m4} \cdot e_{m4} + G_{t4} \cdot e_{t4} + E_{V4} \cdot e_{v4} - E_{H4} \cdot y_4 = 15.3\ \frac{kN \cdot m}{m}$

$\sigma_{4min} := \frac{-N_4}{b_4} + \frac{M_4 \cdot 6}{{b_4}^2} = -193.9\ kPa$ $\quad T_4 := E_{H4} = 146.4\ \frac{kN}{m}$

$\sigma_{4max} := \frac{-N_4}{b_4} - \frac{M_4 \cdot 6}{{b_4}^2} = -234.1\ kPa$ $\quad \varepsilon_{14} := \frac{0.7 \cdot N_4}{T_4} = 2.2$

$M_{tomb4} := E_{H4} \cdot y_4 = 206.9\ \frac{kN \cdot m}{m}$

$M_{eq4} := G_0 \cdot \left(\frac{b_4}{2} - e_{04}\right) + G_{m4} \cdot \left(e_{m4} + \frac{b_4}{2}\right) + G_{t4} \cdot \left(e_{t4} + \frac{b_4}{2}\right) + E_{V4} \cdot \left(e_{v4} + \frac{b_4}{2}\right) = 712.2\ \frac{kN \cdot m}{m}$

$\varepsilon_{24} := \frac{M_{eq4}}{M_{tomb4}} = 3.4$

6.5) JUNTA 5:

$h_5 := 400\ cm$ $\quad b_5 := b_0 + h_5 \cdot \left(\tan\left(\theta_i + \theta_e\right)\right) = 2.5\ m$ $\quad H_5 := h_5 + h_0 = 7\ m$

$$x_c := \frac{\frac{{b_0}^2 \cdot h_5}{2} + \frac{{h_5}^3 \cdot \tan\left(\theta_i\right)^2}{6} + \frac{{h_5}^3 \cdot \tan\left(\theta_e\right)^2}{6} + \frac{{h_5}^2 \cdot \tan\left(\theta_e\right) \cdot b_0}{2}}{\frac{{h_5}^2 \cdot \tan\left(\theta_e\right)}{2} + \frac{{h_5}^2 \cdot \tan\left(\theta_i\right)}{2} + b_0 \cdot h_5} = 0.491\ m$$

$G_0 = 175\ \frac{kN}{m}$ $\quad e_{05} := \frac{b_0}{4} + \frac{\left(b_5 - b_0\right)}{2} = 107.5\ cm$

$G_{m5} := \frac{\left(b_0 + b_5\right) \cdot h_5}{2} \cdot \gamma_{conc} = 160\ \frac{kN}{m}$ $\quad e_{m5} := \frac{b_5}{2} - x_c = 75.9\ cm$

$G_{t5} := \frac{h_5 \cdot h_5 \cdot \tan\left(\theta_i\right)}{2} \cdot \gamma_{solo} = 75.6\ \frac{kN}{m}$ $\quad e_{t5} := \frac{b_5}{2} + \frac{2 \cdot \left(b_5 - b_0\right)}{3} = 2.45\ m$

$E_{H5} := \left(\frac{\left({H_5}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \cos\left(\theta_i + \delta\right) = 199\ \frac{kN}{m}$ $\quad y_5 := \frac{h_5}{3} \cdot \left(\frac{2 \cdot h_0 + H_5}{H_5 + h_0}\right) = 173.1\ cm$

$E_{V5} := \left(\frac{\left({H_5}^2 - {h_0}^2\right)}{2} \cdot K \cdot \gamma_{solo}\right) \cdot \sin\left(\theta_i + \delta\right) = 164.4\ \frac{kN}{m}$ $\quad e_{v5} := \frac{b_5}{2} + y_5 \cdot \tan\left(\theta_i\right) = 202.9\ cm$

$N_5 := G_0 + G_{m5} + G_{t5} + E_{V5} = 575\ \frac{kN}{m}$

$M_5 := -G_0 \cdot e_{05} + G_{m5} \cdot e_{m5} + G_{t5} \cdot e_{t5} + E_{V5} \cdot e_{v5} - E_{H5} \cdot y_5 = 107.6\ \frac{kN \cdot m}{m}$

$\sigma_{5min} := \frac{-N_5}{b_5} + \frac{M_5 \cdot 6}{{b_5}^2} = -126.7\ kPa$ $\quad T_5 := E_{H5} = 199\ \frac{kN}{m}$

$\sigma_{4max} := \frac{-N_5}{b_5} - \frac{M_5 \cdot 6}{{b_5}^2} = -333.3\ kPa$ $\quad \varepsilon_{15} := \frac{0.7 \cdot N_5}{T_5} = 2$

$M_{tomb5} := E_{H5} \cdot y_5 = 344.6\ \frac{kN \cdot m}{m}$

$M_{eq5} := G_0 \cdot \left(\frac{b_5}{2} - e_{05}\right) + G_{m5} \cdot \left(e_{m5} + \frac{b_5}{2}\right) + G_{t5} \cdot \left(e_{t5} + \frac{b_5}{2}\right) + E_{V5} \cdot \left(e_{v5} + \frac{b_5}{2}\right) = 1171\ \frac{kN \cdot m}{m}$

$\varepsilon_{25} := \frac{M_{eq5}}{M_{tomb5}} = 3.4$

6.6) JUNTA 6:

$h_6 := 500\ cm$ $\qquad b_6 := b_s = 4.5\ m$ $\qquad H_6 := h_5 + h_0 = 7\ m$

$$x_c := \frac{\frac{{b_0}^2 \cdot h_5}{2} + \frac{{h_5}^3 \cdot \tan(\theta_i)^2}{6} + \frac{{h_5}^3 \cdot \tan(\theta_e)^2}{6} + \frac{{h_5}^2 \cdot \tan(\theta_e) \cdot b_0}{2}}{\frac{{h_5}^2 \cdot \tan(\theta_e)}{2} + \frac{{h_5}^2 \cdot \tan(\theta_i)}{2} + b_0 \cdot h_5} = 0.491\ m$$

$G_0 = 175\ \frac{kN}{m}$ $\qquad e_0 = 0.6\ m$

$G_m = 160\ \frac{kN}{m}$ $\qquad e_m = 0.6\ m$

$G_t = 75.6\ \frac{kN}{m}$ $\qquad e_t = 1.65\ m$

$E_h = 199\ \frac{kN}{m}$ $\qquad y = 1.7\ m$

$E_v = 164.4\ \frac{kN}{m}$ $\qquad e_v = 1.5\ m$

$G_{s6} := (h_6 - h) \cdot b_s \cdot \gamma_{conc} = 112.5\ \frac{kN}{m}$ $\qquad e_s = 0\ m$

$N_6 := G_0 + G_m + G_t + E_v + G_{s6} = 687.5\ \frac{kN}{m}$

$M_6 := -G_0 \cdot e_0 + G_m \cdot e_m + G_t \cdot e_t + E_v \cdot e_v - E_h \cdot (y + h_6 - h) = -180.6\ \frac{kN \cdot m}{m}$

$\sigma_{6min} := \frac{-N_6}{b_s} + \frac{M_6 \cdot 6}{{b_s}^2} = -206.3\ kPa$ $\qquad T_6 := E_h = 199\ \frac{kN}{m}$

$\sigma_{6max} := \frac{-N_6}{b_s} - \frac{M_6 \cdot 6}{{b_s}^2} = -99.3\ kPa$ $\qquad \varepsilon_{16} := \frac{0.7 \cdot N_6}{T_6} = 2.4$

$M_{tomb6} := E_h \cdot (y + h_6 - h) = 543.6\ \frac{kN \cdot m}{m}$

$$M_{eq6} := G_0 \cdot \left(\frac{b_s}{2} - e_0\right) + G_m \cdot \left(e_m + \frac{b_s}{2}\right) + G_t \cdot \left(e_t + \frac{b_s}{2}\right) + E_v \cdot \left(e_v + \frac{b_s}{2}\right) + G_s \cdot \frac{b_s}{2} = 2289.7\ \frac{kN \cdot m}{m}$$

$\varepsilon_{26} := \frac{M_{eq6}}{M_{tomb6}} = 4.2$