T-shaped Gravity Wall Design - EN 1997

This document shows the example of T-shaped wall design calculation according to Eurocode 7. The design situation is based on Eurocode 7: Geotechnical Design Worked examples ANNEX A.4 and involves T-shaped gravity wall with that is required to support granular fill. The ground and the fill are both dry.

References:
- Eurocode 7: Geotechnical Design Worked examples
- EN 1997

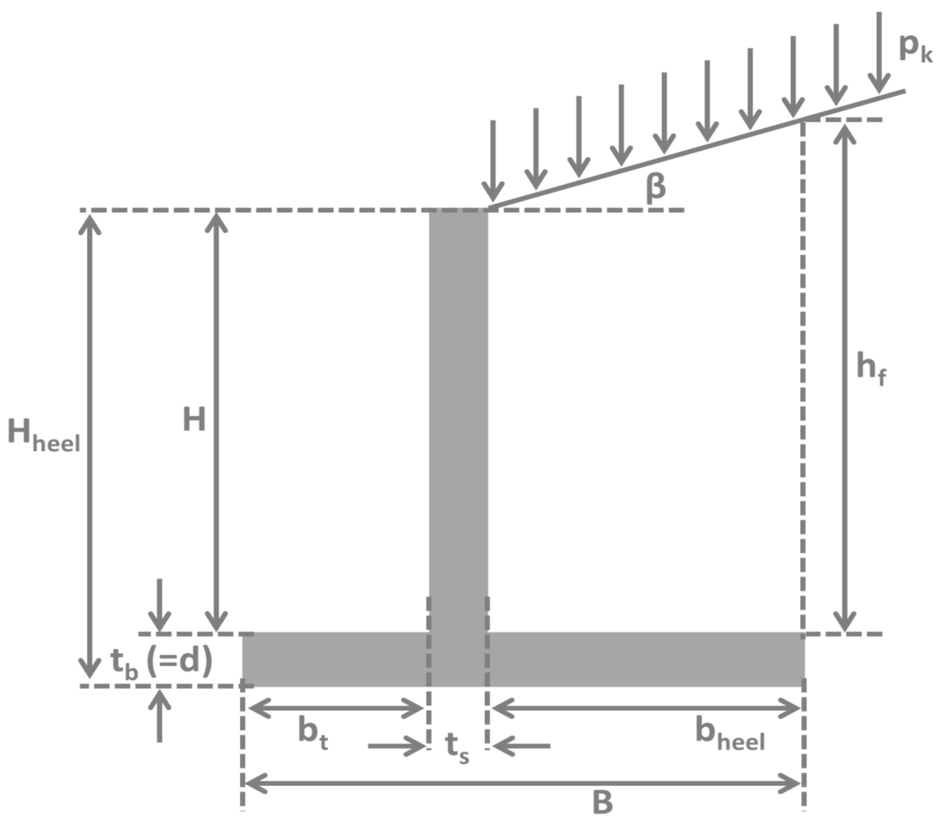

Figure 1 : T-shaped gravity wall with notation

1. Design Parameters and Conditions

Geometry

Retained height	$H := 6.0\,\mathrm{m}$
Overall breadth	$B := 3.9\,\mathrm{m}$
Base thickness	$t_b := 0.8\,\mathrm{m}$
Toe width	$b_t := 0.95\,\mathrm{m}$
Thickness of wall stem	$t_s := 0.7\,\mathrm{m}$
Angle to the horizontal	$\beta := 20\,\mathrm{deg}$
Width wall heel	$b_{heel} := B - b_t - t_s = 2.250\,\mathrm{m}$
Height of fill about wall heel	$h_f := H + b_{heel} \cdot \tan(\beta) = 6.819\,\mathrm{m}$
Height of wall about wall heel include thickness of base	$H_{heel} := h_f + t_b = 7.619\,\mathrm{m}$
Depth of base of footing	$d := t_b = 0.800\,\mathrm{m}$

Support granular fill

Characteristic weight density	$\gamma_k := 19\,\frac{\mathrm{kN}}{\mathrm{m}^3}$
Cohesion intercept	$\phi_k := 32.5\,\mathrm{deg}$
Angle of shearing resistance in terms of effective stress	$c_k := 0\,\mathrm{kPa}$
Variable surcharge	$p_k := 5\,\mathrm{kPa}$

Others

Weight density of reinforced concrete	$\gamma_{c\_k} := 25\,\frac{\mathrm{kN}}{\mathrm{m}^3}$

2. Verification of Drained Strength (Geotechnical Limit State)

Use DA1 : Design Approach 1

Combination 1 : A1, M1, R1
Combination 2 : A2, M2, R1

2-1. Material Properties

Partial factors ([M1, M2])

Angle of shearing resistance $\gamma_\phi := [1, 1.25]$

Effective cohesion

$\gamma_c := [1, 1.25]$

Design angle of shearing resistance

$$\phi_d := \left[\text{seq}\left(\arctan\left(\frac{\tan(\phi_k)}{\gamma_\phi[i]} \right) \cdot \textbf{rad}, i = 1..2 \right) \right]$$

$\phi_d = [32.500\ \textbf{arcdeg}, 27.006\ \textbf{arcdeg}]$

Design effective cohesion

$$c_d := \left[\text{seq}\left(\frac{c_k}{\gamma_c[i]}, i = 1..2 \right) \right] = [0, 0.]$$

2-2. Actions

Partial factors ([A1, A2])

Permanent, Unfavorable $\gamma_G := [1.35, 1]$

Variable, Unfavorable $\gamma_Q := [1.5, 1.3]$

Characteristic self-weight of wall (Permanent action)

wall stem $W_{stem\_Gk} := \gamma_{c\_k} \cdot t_s \cdot H = 105.000 \ \frac{kN}{m}$

$W_{base\_Gk} := \gamma_{c\_k} \cdot t_b \cdot B = 78.000 \ \frac{kN}{m}$

wall base

Characteristic total self-weight of wall

$$W_{wall\_Gk} := W_{stem\_Gk} + W_{base\_Gk} = 183.000 \ \frac{kN}{m}$$

Characteristic total self-weight of backfill

$$W_{fill\_Gk} := \gamma_k \cdot b_{heel} \cdot \frac{H + h_f}{2} = 274.005 \ \frac{kN}{m}$$

Characteristic total self-weight of wall and backfill

$$W_{Gk} := W_{wall\_Gk} + W_{fill\_Gk} = 457.005 \ \frac{kN}{m}$$

Characteristic surcharge (variable)

$$q_{Qk} := p_k = 5 \ kPa$$

$$Q_{Qk} := q_{Qk} \cdot b_{heel} = 11.250 \ \frac{kN}{m}$$

Design active earth pressure coefficient

$$K_{a\beta\_d} := \left[seq\left(\left(\frac{\cos(\beta) - \sqrt{\cos(\beta)^2 - \cos(\phi_d[i])^2}}{\cos(\beta) + \sqrt{\cos(\beta)^2 - \cos(\phi_d[i])^2}} \right) \cdot \cos(\beta), i = 1 ..2 \right) \right]$$

$$K_{a\beta\_d} = [0.365, 0.486]$$

Equivalent coefficient to calculate horizontal thrust

$$K_{ah\_d} := \left[seq\left(K_{a\beta\_d}[i] \cdot \cos(\beta), i = 1 ..2 \right) \right] = [0.343, 0.457]$$

Design thrust from earth pressure on back of virtual plane (inclined at angle β to horizontal)

From ground

$$E_{a\_Gd} := \left[seq\left(\gamma_G[i] \cdot K_{a\beta\_d}[i] \cdot \left(\frac{1}{2} \cdot \gamma_k \cdot H_{heel}^2 \right), i = 1..2 \right) \right]$$

$$E_{a\_Gd} = \left[271.396 \, \frac{kN}{m}, 268.229 \, \frac{kN}{m} \right]$$

From surcharge

$$E_{a\_Qd} := \left[seq\left(\gamma_Q[i] \cdot K_{a\beta\_d}[i] \cdot q_{Qk} \cdot H_{heel}, i = 1..2 \right) \right]$$

$$E_{a\_Qd} = \left[20.831 \, \frac{kN}{m}, 24.088 \, \frac{kN}{m} \right]$$

Total

$$E_{a\_d} := \left[seq\left(E_{a\_Gd}[i] + E_{a\_Qd}[i], i = 1..2 \right) \right]$$

$$E_{a\_d} = \left[292.228 \, \frac{kN}{m}, 292.317 \, \frac{kN}{m} \right]$$

Horizontal design thrust

$$H_{Ed} := E_{a\_d} \cdot \cos(\beta)$$

$$H_{Ed} = \left[274.604 \, \frac{kN}{m}, 274.689 \, \frac{kN}{m} \right]$$

Vertical(normal) design weight and thrust

$$N_{Ed} := \left[seq\left(\gamma_G[i] \cdot W_{Gk} + E_{a\_d}[i] \cdot \sin(\beta), i = 1..2 \right) \right]$$

$$N_{Ed} = \left[716.904 \, \frac{kN}{m}, 556.983 \, \frac{kN}{m} \right]$$

2-3. Moments at Wall Toe - Bearing Design Situation

Partial factors (same value for both A1 and A2)

Permanent, favorable $\gamma_{G\_fav} := 1.0$

Design overturning moments at wall toe

From ground $M_{Gd} := \left[seq\left(E_{a\_Gd}[i] \cdot \left(\frac{1}{3} \cdot H_{heel} \cdot \cos(\beta) - B \cdot \sin(\beta) \right), i = 1..2 \right) \right]$

$M_{Gd} = [285.674\ kN, 282.340\ kN]$

From surcharge $M_{Qd} := \left[seq\left(E_{a\_Qd}[i] \cdot \left(\frac{1}{3} \cdot H_{heel} \cdot \cos(\beta) - B \cdot \sin(\beta) \right), i = 1..2 \right) \right]$

$M_{Qd} = [21.927\ kN, 25.355\ kN]$

Total $M_{dst\_d} := [seq(M_{Gd}[i] + M_{Qd}[i], i = 1..2)]$

$M_{dst\_d} = [307.601\ kN, 307.695\ kN]$

Design restoring moments at wall toe

From wall stem $M_{stem\_Gd} := \gamma_{G\_fav} \cdot W_{stem\_Gk} \cdot \left(b_t + \frac{t_s}{2} \right) = 136.500\ kN$

From wall base $M_{base\_Gd} := \gamma_{G\_fav} \cdot W_{base\_Gk} \cdot \frac{B}{2} = 152.100\ kN$

From backfill $M_{fill\_Gd} := \gamma_{G\_fav} \cdot \gamma_k \cdot b_{heel} \cdot \left(H \cdot \left(B - \frac{b_{heel}}{2} \right) + \frac{(h_f - H)}{2} \cdot \left(B - \frac{b_{heel}}{3} \right) \right)$

$M_{fill\_Gd} = 766.927\ kN$

From surcharge $M_{Qd\_fav} := \gamma_{G\_fav} \cdot Q_{Qk} \cdot \frac{b_{heel}}{2} = 12.656\ kN$

Total $M_{stb\_d} := M_{stem\_Gd} + M_{base\_Gd} + M_{fill\_Gd} + M_{Qd\_fav}$

$M_{stb\_d} = 1.068 \times 10^{3}\ \mathbf{kN}$

Line of action of resultant force

$$x := \left[seq\left(\frac{M_{stb\_d} - M_{dst\_d}[i]}{N_{Ed}[i]}, i = 1..2 \right) \right] = [1.061\ \mathbf{m}, 1.365\ \mathbf{m}]$$

Eccentricity of actions from center line of base

$$e_d := \left[seq\left(\frac{B}{2} - x[i], i = 1..2 \right) \right] = [0.889\ \mathbf{m}, 0.585\ \mathbf{m}]$$

Effective width of base

$$B_d := [seq(B - 2 \cdot e_d[i], i = 1..2)] = [2.122\ \mathbf{m}, 2.731\ \mathbf{m}]$$

2-4. Bearing resistance

Design bearing capacity factors

$$N_{q\_d} := \left[seq\left(e^{\pi \cdot \tan(\phi_d[i])} \cdot \left(\tan\left(45 \cdot \mathbf{deg} + \frac{\phi_d[i]}{2} \right) \right)^2, i = 1..2 \right) \right] = [24.585, 13.208]$$

$$N_{\gamma\_d} := [seq(2 \cdot (N_{q\_d}[i] - 1) \cdot \tan(\phi_d[i]), i = 1..2)] = [30.050, 12.443]$$

Shape factors (for an infinity long footing)

$s_q := 1.0$ $s_\gamma := 1.0$

Inclination factors (for an infinity long footing)

$m_B := 2$

$$i_q := \left[seq\left(\left(1 - \frac{H_{Ed}[i]}{N_{Ed}[i] + A \cdot c_d[i] \cdot \cot(\phi_d[i])} \right)^{m_B}, i = 1..2 \right) \right] = [0.381, 0.257]$$

$$i_\gamma := \left[seq\left(i_q[i]^{\frac{m_B + 1}{m_B}}, i = 1..2 \right) \right] = [0.235, 0.130]$$

Partial factors (R1)

Bearing $\gamma_{Rv} := 1$

Design bearing resistance

From overburden $q_{Rvq\_d} := \left[seq\left(\frac{\gamma_k \cdot d \cdot N_{q\_d}[i] \cdot s_q \cdot i_q[i]}{\gamma_{Rv}}, i = 1..2 \right) \right]$

$q_{Rvq\_d} = [142.239\ \mathbf{kPa}, 51.569\ \mathbf{kPa}]$

From body-mass $q_{Rv\gamma\_d} := \left[seq\left(\frac{1}{2} \cdot \left(\frac{B_d[i] \cdot \gamma_k \cdot N_{\gamma\_d}[i] \cdot s_\gamma \cdot i_\gamma[i]}{\gamma_{Rv}} \right), i = 1..2 \right) \right]$

$q_{Rv\gamma\_d} = [142.250\ \mathbf{kPa}, 42.027\ \mathbf{kPa}]$

Total $q_{Rv\_d} := [seq(q_{Rvq\_d}[i] + q_{Rv\gamma\_d}[i], i = 1..2)]$

$q_{Rv\_d} = [284.488\ \mathbf{kPa}, 93.596\ \mathbf{kPa}]$

Characteristic bearing resistance

$$N_{Rd} := [seq(q_{Rv\_d}[i] \cdot B_d[i], i = 1..2)] = \left[603.643\ \frac{\mathbf{kN}}{\mathbf{m}}, 255.586\ \frac{\mathbf{kN}}{\mathbf{m}} \right]$$

3. Verifications

3-1. Verification of resistance to sliding

Partial factors (R1)

Sliding $\gamma_{Rh} := 1$

Interface friction angle

$k := 1$ $\phi_{cv\_k} := 30\ \mathbf{deg}$ $\sigma_d := k \cdot \phi_{cv\_k} = 30\ \mathbf{arcdeg}$

Design sliding resistance

(ignoring adhesion, as required by EN 1997-1 exp 6.3 a)

$$H_{Rd} := \left[\text{seq}\left(\frac{\gamma_{G\_fav} \cdot N_{Ed}[i] \cdot \tan(\sigma_d)}{\gamma_{Rh}}, i = 1..2 \right) \right] = \left[413.905\ \frac{\mathbf{kN}}{\mathbf{m}}, 321.574\ \frac{\mathbf{kN}}{\mathbf{m}} \right]$$

Overdesign factor

Calculation

$$ODF := \left[seq\left(\frac{H_{Rd}[i]}{H_{Ed}[i]}, i = 1..2 \right) \right] = [1.507, 1.171]$$

Check

$$\left[\text{seq}\left(\begin{cases} \text{"OK"} & ODF[i] \geq 1 \\ \text{"NG"} & \text{otherwise} \end{cases}, i = 1..2 \right) \right] = [\text{"OK"}, \text{"OK"}]$$

Degree of utilization

Calculation

$$\Lambda := \left[\text{seq}\left(\frac{H_{Ed}[i]}{H_{Rd}[i]}, i = 1..2 \right) \right] = [66.34\%, 85.42\%]$$

Check

$$\left[\text{seq}\left(\begin{cases} \text{"OK"} & \Lambda[i] \leq 1 \\ \text{"NG"} & \text{otherwise} \end{cases}, i = 1..2 \right) \right] = [\text{"OK"}, \text{"OK"}]$$

3-2. Verification of Bearing Resistance

Design bearing resistance

$$N_{Rd} = \left[603.643\ \frac{\mathbf{kN}}{\mathbf{m}}, 255.586\ \frac{\mathbf{kN}}{\mathbf{m}}\right]$$

Design bearing force

$$N_{Ed} = \left[716.904\ \frac{\mathbf{kN}}{\mathbf{m}}, 556.983\ \frac{\mathbf{kN}}{\mathbf{m}}\right]$$

Overdesign factor

Calculation

$$ODF := \left[seq\left(\frac{N_{Rd}[i]}{N_{Ed}[i]}, i = 1..2\right)\right] = [0.842, 0.459]$$

Check

$$\left[seq\left(\begin{cases} \text{"OK"} & ODF[i] < 1 \\ \text{"NG"} & \text{otherwise} \end{cases}, i = 1..2\right)\right] = [\text{"OK"}, \text{"OK"}]$$

Degree of utilization

Calculation

$$\Lambda := \left[seq\left(\frac{N_{Ed}[i]}{N_{Rd}[i]}, i = 1..2\right)\right] = [118.76\%, 217.92\%]$$

Check

$$\left[seq\left(\begin{cases} \text{"OK"} & \Lambda[i] > 1 \\ \text{"NG"} & \text{otherwise} \end{cases}, i = 1..2\right)\right] = [\text{"OK"}, \text{"OK"}]$$