

Example 11.3-DA3
T-shaped gravity wall retaining wet fill
Verification of drained strength (limit state GEO)

Design situation

Re-consider the design of the T-shaped gravity retaining wall from the previous worked example. Constraints during construction prevent a drain being placed at the heel of the wall. Therefore, the drain will be positioned behind the wall stem to reduce water level in the fill to a depth $d_w = 1.5\text{m}$ below the retained surface. The base of the wall is increased to $B = 4.3\text{m}$ wide but all other dimensions remain unchanged. Material properties are also unchanged. ❶

Design Approach 3

Geometrical parameters

Unplanned excavation $\Delta H = \min(10\% H, 0.5\text{m}) = 0.3\text{m}$

Design retained height $H_d = H + \Delta H = 3.3\text{m}$

Width of heel $b = B - t_s - x = 3.55\text{m}$

Actions

Characteristic vertical actions and moments due to self-weight ❷

Wall base: $W_{Gk_1} = \gamma_{ck} \times B \times t_b = 32.3\text{ kN/m}$

Moment from base: $M_{k_1} = W_{Gk_1} \times \frac{B}{2} = 69.3\text{ kNm/m}$

Wall stem: $W_{Gk_2} = \gamma_{ck} \times (H + d - t_b) \times t_s = 20\text{ kN/m}$

Moment from stem: $M_{k_2} = W_{Gk_2} \times \left(\frac{t_s}{2} + x \right) = 12.5\text{ kNm/m}$

Backfill: $W_{Gk_3} = \gamma_k \times b \times (H + d - t_b) = 204.5\text{ kN/m}$

Moment from backfill: $M_{k_3} = W_{Gk_3} \times \left(\frac{b}{2} + t_s + x \right) = 516.3\text{ kNm/m}$

Total characteristic self-weight $W_{Gk} = \sum W_{Gk} = 256.7\text{ kN/m}$

Total characteristic stabilizing moment $M_{Ek,stab} = \sum M_k = 598.1\text{ kNm/m}$

Characteristic surcharge (variable) $Q_{Qk} = q_{Qk} \times (B - x) = 38\text{ kN/m}$

Soil stresses at depth of water table along virtual back of wall

$$\text{vertical total stress } \sigma_{vk,w} = \gamma_k \times d_w = 27 \text{ kPa}$$

$$\text{pore pressure } u_w = 0 \text{ kPa}$$

$$\text{vertical effective stress } \sigma'_{vk,w} = \sigma_{vk,w} - u_w = 27 \text{ kPa} \textcircled{3}$$

Soil stresses at wall heel

$$\text{vertical total stress } \sigma_{vk,h} = \gamma_k \times (H + d) = 63 \text{ kPa}$$

$$\text{height of water table } h_w = H + d - d_w = 2 \text{ m}$$

$$\text{pore pressure } u_h = \gamma_w \times h_w = 19.6 \text{ kPa}$$

$$\text{vertical effective stress } \sigma'_{vk,h} = \sigma_{vk,h} - u_h = 43.4 \text{ kPa} \textcircled{3}$$

Effects of actions

Partial factors, sets A1/A2: $\gamma_{G, \text{str}} = 1.35$, $\gamma_G = 1$, $\gamma_{G, \text{fav}} = 1$, and

$$\gamma_Q = 1.3$$

Design vertical actions (unfavourable)

permanent unfavourable:

$$V_{Gd} = \gamma_{G, \text{str}} \times (W_{Gk} - \gamma_k \times b \times H) + \gamma_G \times (\gamma_k \times b \times H) = 279.5 \frac{\text{kN}}{\text{m}}$$

$$\text{variable unfavourable: } V_{Qd} = \gamma_Q \times Q_{Qk} = 49.4 \frac{\text{kN}}{\text{m}}$$

$$\text{total unfavourable: } V_d = V_{Gd} + V_{Qd} = 328.9 \frac{\text{kN}}{\text{m}}$$

$$\text{water upthrust } U_d = \gamma_G \times \frac{u_h}{2} \times B = 42.2 \frac{\text{kN}}{\text{m}} \textcircled{4}$$

$$\text{effective } V'_d = V_d - U_d = 286.7 \frac{\text{kN}}{\text{m}}$$

Design vertical actions (favourable)

$$\text{total } V_{d, \text{fav}} = \gamma_{G, \text{fav}} \times W_{Gk} = 256.7 \frac{\text{kN}}{\text{m}}$$

$$\text{water upthrust } U_{d, \text{fav}} = \gamma_{G, \text{fav}} \times \frac{u_h}{2} \times B = 42.2 \frac{\text{kN}}{\text{m}}$$

$$\text{effective } V'_{d, \text{fav}} = V_{d, \text{fav}} - U_{d, \text{fav}} = 214.6 \frac{\text{kN}}{\text{m}}$$

$$\text{Active earth pressure coefficient } K_a = \frac{1 - \sin(\varphi_d)}{1 + \sin(\varphi_d)} = 0.331$$

Design thrust on virtual back and destabilizing moments (about toe)

$$\text{Dry backfill } P_{ad_1} = \left(\frac{\gamma G \times K_a \times \sigma'_{vk,w} \times d_w}{2} \right) = 6.7 \frac{\text{kN}}{\text{m}}$$

$$\text{Moment from dry backfill } M_{d_1} = P_{ad_1} \times \left(h_w + \frac{d_w}{3} \right) = 16.8 \frac{\text{kNm}}{\text{m}}$$

$$\text{Wet backfill (part) } P_{ad_2} = \left(\frac{\gamma G \times K_a \times \sigma'_{vk,w} \times h_w}{2} \right) = 8.9 \frac{\text{kN}}{\text{m}}$$

$$\text{Moment from wet backfill (part) } M_{d_2} = P_{ad_2} \times \left(\frac{2 h_w}{3} \right) = 11.9 \frac{\text{kNm}}{\text{m}}$$

$$\text{Wet backfill (part) } P_{ad_3} = \left(\frac{\gamma G \times K_a \times \sigma'_{vk,h} \times h_w}{2} \right) = 14.4 \frac{\text{kN}}{\text{m}}$$

$$\text{Moment from wet backfill (part) } M_{d_3} = P_{ad_3} \times \left(\frac{h_w}{3} \right) = 9.6 \frac{\text{kNm}}{\text{m}}$$

$$\text{Surcharge } P_{ad_4} = \left[\gamma Q \times K_a \times q_{Qk} \times (H + d) \right] = 15.1 \frac{\text{kN}}{\text{m}}$$

$$\text{Moment from surcharge } M_{d_4} = P_{ad_4} \times \left(\frac{H + d}{2} \right) = 26.4 \frac{\text{kNm}}{\text{m}}$$

$$\text{Water } U_{ad} = \left(\frac{\gamma G \times u_h \times h_w}{2} \right) = 19.6 \frac{\text{kN}}{\text{m}}$$

$$\text{Moment from water } M_{d_5} = U_{ad} \times \left(\frac{h_w}{3} \right) = 13.1 \frac{\text{kNm}}{\text{m}}$$

$$\text{Moment from water uplift } M_{d_6} = U_{ad} \times \left(\frac{2 B}{3} \right) = 120.9 \frac{\text{kNm}}{\text{m}}$$

$$\text{Total design horizontal thrust } H_{Ed} = \left(\sum_{i=1}^4 P_{ad_i} \right) + U_{ad} = 64.7 \frac{\text{kN}}{\text{m}}$$

$$\text{Total design destabilizing moment } M_{Ed,dst} = \left(\sum_{i=1}^6 M_{d_i} \right) = 198.6 \frac{\text{kNm}}{\text{m}}$$

Sliding resistance

Partial factors from set R2 $\gamma_{Rh} = 1$ and $\gamma_{Rv} = 1$

Design drained sliding resistance (ignoring adhesion, as required by EN 1997-1

$$\text{exp. 6.3a) } H_{Rd} = \left[\frac{(V_{d,fav} - U_d) \times \tan(\delta_{d,fdn})}{\gamma_{Rh}} \right] = 78.1 \frac{\text{kN}}{\text{m}} \text{ 5}$$

Eccentricity of loads

Design stabilizing moment

$$M_{Ed,stb} = \gamma_G \times M_{EK,stb} + \gamma_Q \times Q_{QK} \times \frac{(B+x)}{2} = 716.7 \frac{\text{kNm}}{\text{m}}$$

$$\text{Eccentricity of load } e_B = \left[\frac{\frac{B}{2} - \frac{M_{Ed,stb} - M_{Ed,dst}}{V_d - U_d}}{\frac{B}{2}} \right] = 0.34 \text{ m}$$

Load is within middle-third of base if $e_B \leq \frac{B}{6} = 0.72 \text{ m}$

Effective breadth is $B' = B - 2 e_B = 3.61 \text{ m}$

Effective area is then $A' = B' = 3.61 \frac{\text{m}^2}{\text{m}}$

Drained bearing capacity factors

$$N_q = \left[e^{(\pi \tan(\varphi_{d,fdn}))} \left(\tan \left(45^\circ + \frac{\varphi_{d,fdn}}{2} \right) \right)^2 \right] = 7.3$$

$$N_c = \left[(N_q - 1) \times \cot(\varphi_{d,fdn}) \right] = 16.1$$

$$N_\gamma = \left[2 (N_q - 1) \times \tan(\varphi_{d,fdn}) \right] = 4.91$$

Drained inclination factors

Effective length $L' = \infty$ m and exponent $m_B = \frac{\left(2 + \frac{B'}{L'}\right)}{\left(1 + \frac{B'}{L'}\right)} = 2$

$$i_q = \left[1 - \left(\frac{H_{Ed}}{V'_d + A' \times c'_{d,fdn} \times \cot(\varphi_{d,fdn})} \right)^{m_B} \right] = 0.64$$

$$i_c = \left[i_q - \left[\frac{(1 - i_q)}{N_c \times \tan(\varphi_{d,fdn})} \right] \right] = 0.58$$

$$i_\gamma = \left[1 - \left(\frac{H_{Ed}}{V'_d + A' \times c'_{d,fdn} \times \cot(\varphi_{d,fdn})} \right)^{m_B + 1} \right] = 0.51$$

Drained bearing resistance

Drained overburden at foundation base $\sigma'_{vk,b} = \gamma_{k,fdn} \times (d - \Delta H) = 4.4$ kPa

Ultimate resistance

$$\text{from overburden } q_{ult_1} = \left(N_q \times i_q \times \sigma'_{vk,b} \right) = 20.6 \text{ kPa}$$

$$\text{from cohesion } q_{ult_2} = \left(N_c \times i_c \times c'_{d,fdn} \right) = 37.7 \text{ kPa}$$

$$\text{from self-weight } q_{ult_3} = \left[N_\gamma \times i_\gamma \times (\gamma_{k,fdn} - \gamma_w) \times \frac{B'}{2} \right] = 55.5 \text{ kPa}$$

$$\text{total } q_{ult} = \sum_{i=1}^3 q_{ult_i} = 113.7 \text{ kPa}$$

$$\text{Design resistance } q'_{Rd} = \frac{q_{ult}}{\gamma_{Rv}} = 113.7 \text{ kPa}$$

Verifications

For drained sliding $H_{Rd} = 78.1 \frac{\text{kN}}{\text{m}}$ and $H_{Ed} = 78.1 \frac{\text{kN}}{\text{m}}$

Degree of utilization $\Delta_{GEO,3} = \frac{H_{Ed}}{H_{Rd}} = 83 \% \text{ ⑥}$

For drained bearing $q'_{Ed} = \frac{V'_d}{B'} = 79.3 \text{ kPa}$ and $q'_{Rd} = 113.7 \text{ kPa}$

Degree of utilization $\Delta_{GEO,3} = \frac{q'_{Ed}}{q'_{Rd}} = 70 \%$

Design is unacceptable if degree of utilization is $> 100\%$