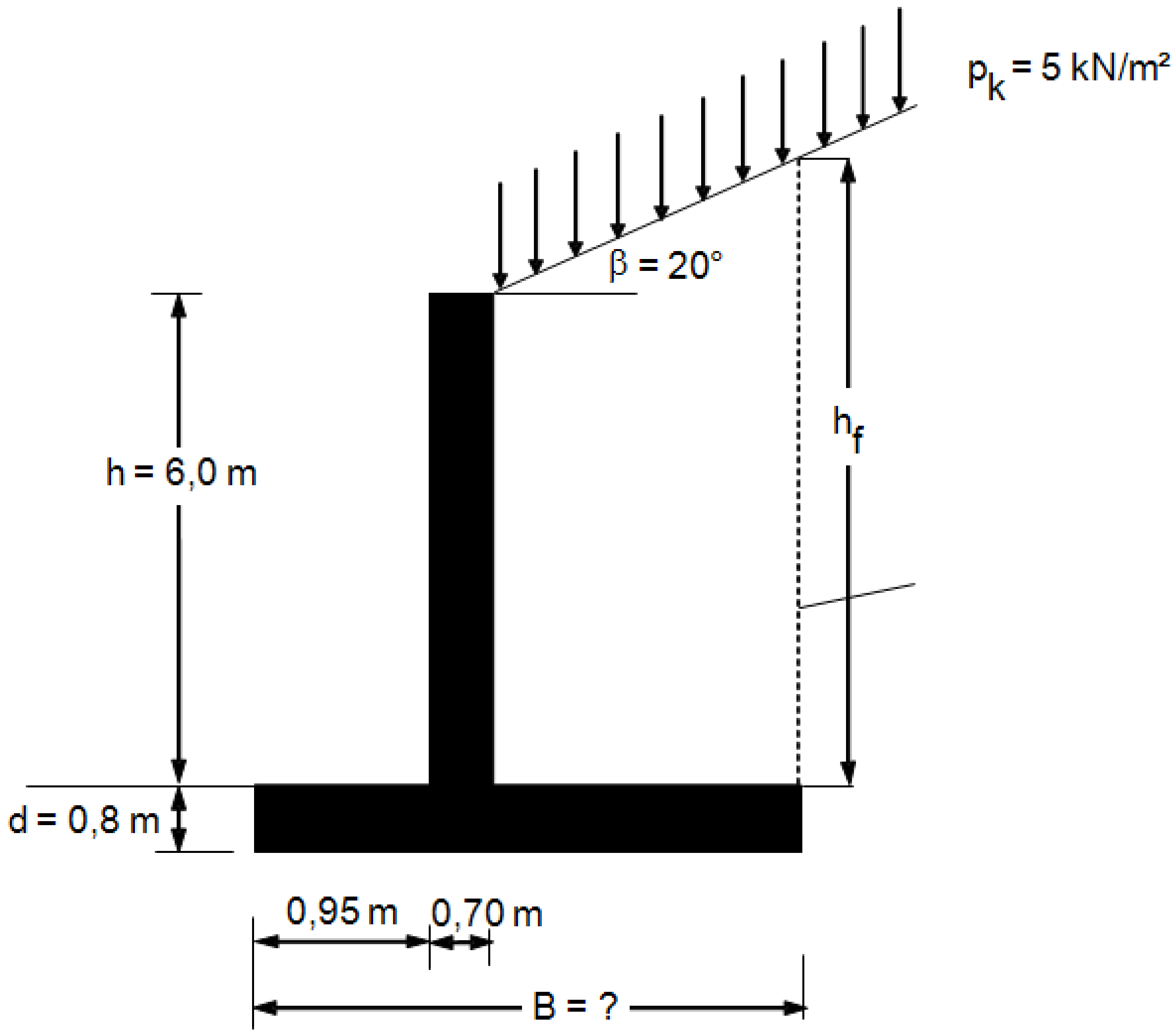
Example JRC-03
T-shaped wall
Verification of drained strength (limit state GEO)
Design Approach 2*

Design situation

Consider a T-shaped gravity wall with retained height $H = 6.0m$ that is required to support granular fill with characteristic weight density $\gamma_k = 19\frac{kN}{m^3}$ and drained strength parameters $\varphi_k = 32.5°$ and $c'_k = 0kPa$.

A variable surcharge $p_k = 5kPa$ acts behind the wall on ground that rises at an angle $\beta = 20°$ to the horizontal. The dimensions of the wall are as follows: overall breadth (assumed) $B = 3.9m$; base thickness $t_b = 0.8m$; toe width $b_t = 0.95m$; thickness of wall stem $t_s = 0.7m$. The weight density of reinforced concrete is $\gamma_{c,k} = 25\frac{kN}{m^3}$. The properties of the ground beneath the wall are the same as the fill. This ground and the fill are both dry.



Geometry

Width wall heel is:

$$b_{heel} = B - b_t - t_s = 2.25\,m$$

Height of fill above wall heel is:

$$h_f = H + b_{heel} \times \tan(\beta) = 6.82\,m$$

Height of wall above wall heel including the thickness of base is:

$$H_{heel} = h_f + t_b = 7.62\,m$$

Depth to base of footing is:

$$d = t_b = 0.8\,m$$

Material properties

Characteristic materialk properties are used throughout this calculation

Actions

Characteristic self-weight of wall (permanent action) is:

$$\text{wall stem } W_{stem,Gk} = \gamma_{c,k} \times t_s \times H = 105\,\frac{kN}{m}$$

$$\text{wall base } W_{base,Gk} = \gamma_{c,k} \times t_b \times B = 78\,\frac{kN}{m}$$

Characteristic total self-weight of wall is:

$$W_{wall,Gk} = W_{stem,Gk} + W_{base,Gk} = 183\,\frac{kN}{m}$$

Characteristic total self-weight of backfill is:

$$W_{fill,Gk} = \gamma_k \times b_{heel} \times \frac{\left(H + h_f\right)}{2} = 274\,\frac{kN}{m}$$

Characteristic total self-weight of wall including backfill is then:

$$W_{Gk} = W_{wall,Gk} + W_{fill,Gk} = 457\,\frac{kN}{m}$$

Characteristic surcharge (variable) is:

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

$$Q_{Qk} = q_{Qk} \times b_{heel} = 11.3\,\frac{kN}{m}$$

Characteristic active earth pressure coefficient (for calculating inclined thrust) is:

$$K_{a\beta,k} = \left(\frac{\cos(\beta) - \sqrt{\cos(\beta)^2 - \cos\left(\varphi_k\right)^2}}{\cos(\beta) + \sqrt{\cos(\beta)^2 - \cos\left(\varphi_k\right)^2}} \right) \times \cos(\beta) = 0.365$$

Equivalent coefficient for calculating horizontal thrust is: $K_{ah,k} = K_{a\beta,k} \cos(\beta) = 0.343$

Characteristic inclined thrust (at angle β to the horizontal) from earth pressure on back of virtual plane is:

from ground $E_{a,Gk} = K_{a\beta,k} \times \left(\frac{1}{2}\gamma_k H_{heel}^2\right) = 201\frac{kN}{m}$

from surcharge $E_{a,Qk} = K_{a\beta,k} \times q_{Qk} \times H_{heel} = 13.9\frac{kN}{m}$

total $E_{a,k} = E_{a,Gk} + E_{a,Qk} = 214.9\frac{kN}{m}$

Horizontal component of characteristic thrust is then: $H_{Ek} = E_{a,k}\cos(\beta) = 202\frac{kN}{m}$

Vertical (normal) component of characteristic weight and thrust: $N_{Ek} = W_{Gk} + E_{a,k}\sin(\beta) = 530.5\frac{kN}{m}$

Moments about wall toe

Characteristic overturning moments (destabilizing) about wall toe:

from ground $M_{Gk} = E_{a,Gk} \times \left(\frac{1}{3}H_{heel}\cos(\beta) - B\sin(\beta)\right) = 211.6\frac{kN\,m}{m}$

from surcharge $M_{Qk} = E_{a,Qk} \times \left(\frac{1}{2}H_{heel}\cos(\beta) - B\sin(\beta)\right) = 31.2\frac{kN\,m}{m}$

Total characteristic destabilising moment is: $M_{dst,k} = M_{Gk} + M_{Qk} = 242.8\frac{kN\,m}{m}$

Characteristic restoring moments (stabilizing) about wall toe:

from wall stem $M_{stem,Gk} = W_{stem,Gk} \times \left(b_t + \frac{t_s}{2}\right) = 136.5\frac{kN\,m}{m}$

from wall base $M_{base,Gk} = W_{base,Gk} \times \frac{B}{2} = 152.1\frac{kN\,m}{m}$

from backfill $M_{fill,Gk} = \gamma_k \times b_{heel} \times \left[H \times \left(B - \frac{b_{heel}}{2}\right) + \left(\frac{h_f - H}{2}\right) \times \left(B - \frac{b_{heel}}{3}\right)\right] = 766.9\frac{kN\,m}{m}$

Total characteristic stabilising moment is: $M_{stb,k} = M_{stem,Gk} + M_{base,Gk} + M_{fill,Gk} = 1055.5\frac{kN\,m}{m}$

Line of action of resultant force is a distance from the toe: $x = \left(\frac{M_{stb,k} - M_{dst,k}}{N_{Ek}}\right) = 1.53\,m$

Eccentricity of actions from centre line of base is: $e_k = \frac{B}{2} - x = 0.42\,m$

Effective width of base is then: $B' = B - 2e_k = 3.06\,m$

Bearing resistance

Characteristic bearing capacity factors:

$$N_{q,k} = e^{\pi\tan(\varphi_k)} \times \left(\tan\left(45° + \frac{\varphi_k}{2}\right)\right)^2 = 24.6$$

$N_{\gamma,k} = 2(N_{q,k} - 1) \times \tan(\varphi_k) = 30.1$ (in DEU, use $N_{b,k} = (N_{q,k} - 1) \times \tan(\varphi_k) = 15.0$)

Characteristic shape factors (for an infinitely long footing): $s_q = 1.0$ and $s_\gamma = 1.0$

Characteristic inclination factors: (using $m_B = 2$ for an infinitely long footing)

$$i_q = \left(1 - \frac{H_{Ek}}{N_{Ek} + A\,c'_k \cot(\varphi_k)}\right)^{m_B} = 0.38 \quad \text{and} \quad i_\gamma = i_q^{\frac{m_B+1}{m_B}} = 0.24$$

Characteristic bearing resistance (in terms of stress/pressure) is:

from overburden $q_{Rvq,k} = \gamma_k \times d \times N_{q,k} \times s_q \times i_q = 143.3\,\text{kPa}$

from body-mass $q_{Rv\gamma,k} = \frac{1}{2} B' \times \gamma_k \times N_{\gamma,k} \times s_\gamma \times i_\gamma = 207.8\,\text{kPa}$

total $q_{Rv,k} = q_{Rvq,k} + q_{Rv\gamma,k} = 351.1\,\text{kPa}$

Characteristic bearing resistance (in terms of force) is:

$$N_{Rk} = q_{Rv,k} \times B' = 1076\,\frac{\text{kN}}{\text{m}}$$

Verificiations

Verification of resistance to sliding

Partial factors from Set A1: $\gamma_G = 1.35$, $\gamma_{G,fav} = 1$, and $\gamma_Q = 1.5$

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

from ground $E_{a,Gd} = \gamma_G \times E_{a,Gk} = 271.4 \frac{kN}{m}$

from surcharge $E_{a,Qd} = \gamma_Q \times E_{a,Qk} = 20.8 \frac{kN}{m}$

total $E_{a,d} = E_{a,Gd} + E_{a,Qd} = 292.2 \frac{kN}{m}$

Horizontal component of design thrust is then: $H_{Ed} = E_{a,d} \cos(\beta) = 274.6 \frac{kN}{m}$

Vertical (normal) component of design weight and thrust: $N_{Ed} = \gamma_G W_{Gk} + E_{a,d} \sin(\beta) = 716.9 \frac{kN}{m}$

Partial factors from Set R2: $\gamma_{Rh} = 1.1$

For cast-in-place concrete, interface friction angle is $k = 1$ times the constant-volume angle of shearing

Assume $\varphi_{cv,k} = 30°$

$\delta_k = k \times \varphi_{cv,k} = 30°$

Design sliding resistance (drained), ignoring adhesion (as required by EN 1997-1 exp. 6.3a)

$$H_{Rd} = \frac{\gamma_{G,fav} \times N_{Ek} \times \tan(\delta_k)}{\gamma_{Rh}} = 278.4 \frac{kN}{m}$$

'Degree of utilization' $\boxed{\Lambda = \frac{H_{Ed}}{H_{Rd}} = 99\,\%}$ or 'Overdesign factor' $\boxed{ODF = \frac{H_{Rd}}{H_{Ed}} = 1.01}$

The design is unacceptable if the degree of utilization is > 100% (or overdesign factor is < 1)

Verification of bearing resistance

Partial factor from Set R2: $\gamma_{Rv} = 1.4$

Design bearing resistance is:

$$N_{Rd} = \frac{N_{Rk}}{\gamma_{Rv}} = 768.4 \frac{kN}{m}$$

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

$$N_{Ed} = 716.9 \frac{kN}{m}$$

'Degree of utilization' $\boxed{\Lambda = \frac{N_{Ed}}{N_{Rd}} = 93\,\%}$ or 'Overdesign factor' $\boxed{ODF = \frac{N_{Rd}}{N_{Ed}} = 1.07}$

The design is unacceptable if the degree of utilization is > 100% (or overdesign factor is < 1)

Verification of resistance to toppling

Design de-stabilizing moment is:

$$M_{Ed,dst} = (\gamma_G \times M_{Gk}) + (\gamma_Q \times M_{Qk}) = 332 \frac{kN\,m}{m}$$

Design stabilizing moment is (approximately):

$$M_{Ed,stb} = \gamma_{G,fav} \times M_{stb,k} = 1056 \frac{kN\,m}{m}$$

'Degree of utilization' $\boxed{\Lambda = \frac{M_{Ed,dst}}{M_{Ed,stb}} = 31\,\%}$ or 'Overdesign factor' $\boxed{ODF = \frac{M_{Ed,stb}}{M_{Ed,dst}} = 3.17}$

The design is unacceptable if the degree of utilization is > 100% (or overdesign factor is < 1)