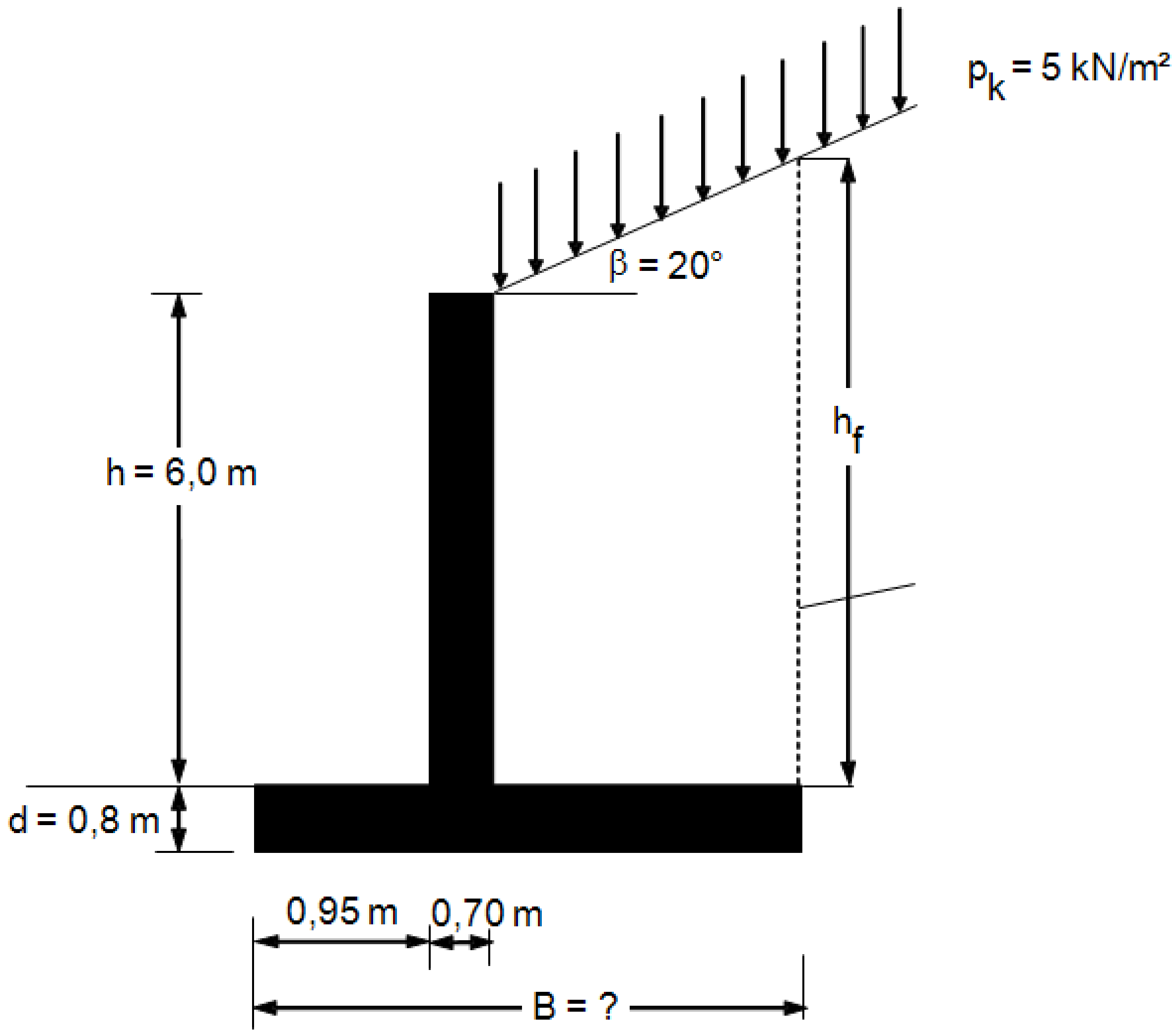
Example JRC-03
T-shaped wall
Verification of drained strength (limit state GEO)
Design Approach 1

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

Partial factors from Set $\begin{pmatrix} M1 \\ M2 \end{pmatrix}$: $\gamma_\varphi = \begin{pmatrix} 1 \\ 1.25 \end{pmatrix}$ and $\gamma_c = \begin{pmatrix} 1 \\ 1.25 \end{pmatrix}$

Design angle of shearing resistance:

$$\varphi_d = \operatorname{atan}\left(\frac{\tan(\varphi_k)}{\gamma_\varphi}\right) = \begin{pmatrix} 32.5 \\ 27 \end{pmatrix}^\circ$$

Design effective cohesion:

$$c'_d = \frac{c'_k}{\gamma_c} = \begin{pmatrix} 0 \\ 0 \end{pmatrix} kPa$$

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:

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

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:

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

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

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

$$K_{a\beta,d} = \left(\frac{\cos(\beta) - \sqrt{\cos(\beta)^2 - \cos(\varphi_d)^2}}{\cos(\beta) + \sqrt{\cos(\beta)^2 - \cos(\varphi_d)^2}}\right) \times \cos(\beta) = \begin{pmatrix} 0.365 \\ 0.486 \end{pmatrix}$$

Equivalent coefficient for calculating horizontal thrust is: $K_{ah,d} = K_{a\beta,d} \cos(\beta) = \begin{pmatrix} 0.343 \\ 0.457 \end{pmatrix}$

Partial factors from Set $\begin{pmatrix} A1 \\ A2 \end{pmatrix}$: $\gamma_G = \begin{pmatrix} 1.35 \\ 1 \end{pmatrix}$, $\gamma_{G,fav} = 1$, and $\gamma_Q = \begin{pmatrix} 1.5 \\ 1.3 \end{pmatrix}$

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

from ground $E_{a,Gd} = \overrightarrow{\left[\gamma_G \times K_{a\beta,d} \times \left(\frac{1}{2}\gamma_k H_{heel}^2\right)\right]} = \begin{pmatrix} 271.4 \\ 268.2 \end{pmatrix} \frac{kN}{m}$

from surcharge $E_{a,Qd} = \overrightarrow{\left(\gamma_Q \times K_{a\beta,d} \times q_{Qk} \times H_{heel}\right)} = \begin{pmatrix} 20.8 \\ 24.1 \end{pmatrix} \frac{kN}{m}$

total $E_{a,d} = E_{a,Gd} + E_{a,Qd} = \begin{pmatrix} 292.2 \\ 292.3 \end{pmatrix} \frac{kN}{m}$

Horizontal component of design thrust is then: $H_{Ed} = E_{a,d}\cos(\beta) = \begin{pmatrix} 274.6 \\ 274.7 \end{pmatrix} \frac{kN}{m}$

Vertical/normal component of design weight and thrust: $N_{Ed} = \gamma_G W_{Gk} + E_{a,d}\sin(\beta) = \begin{pmatrix} 716.9 \\ 557 \end{pmatrix} \frac{kN}{m}$

Moments about wall toe - bearing design situation

Design overturning moments (destabilizing) about wall toe:

from ground $M_{Gd} = E_{a,Gd} \times \left(\frac{1}{3}H_{heel}\cos(\beta) - B\sin(\beta)\right) = \begin{pmatrix} 285.7 \\ 282.3 \end{pmatrix} \frac{kN\,m}{m}$

from surcharge $M_{Qd} = E_{a,Qd} \times \left(\frac{1}{2}H_{heel}\cos(\beta) - B\sin(\beta)\right) = \begin{pmatrix} 46.8 \\ 54.1 \end{pmatrix} \frac{kN\,m}{m}$

Total design destabilising moment is: $M_{dst,d} = M_{Gd} + M_{Qd} = \begin{pmatrix} 332.5 \\ 336.4 \end{pmatrix} \frac{kN\,m}{m}$

Design restoring moments (stabilizing) about wall toe:

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

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

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

from surcharge $M_{Qd,fav} = \gamma_{G,fav} \times Q_{Qk} \times \frac{b_{heel}}{2} = 12.7 \frac{kN\,m}{m}$

Total design stabilising moment is: $M_{stb,d} = M_{stem,Gd} + M_{base,Gd} + M_{fill,Gd} + M_{Qd,fav} = 1068 \frac{kN\,m}{m}$

Line of action of resultant force is a distance from the toe: $x = \left(\frac{M_{stb,d} - M_{dst,d}}{N_{Ed}}\right) = \begin{pmatrix} 1.03 \\ 1.31 \end{pmatrix} m$

Eccentricity of actions from centre line of base is: $e_d = \frac{B}{2} - x = \begin{pmatrix} 0.92 \\ 0.64 \end{pmatrix} m$

Effective width of base is then: $B'_d = B - 2e_d = \begin{pmatrix} 2.05 \\ 2.63 \end{pmatrix} m$

Bearing resistance

Design bearing capacity factors:

$$N_{q,d} = \overrightarrow{\left[e^{\pi \tan(\varphi_d)} \times \left(\tan\left(45° + \frac{\varphi_d}{2}\right)\right)^2\right]} = \begin{pmatrix} 24.6 \\ 13.2 \end{pmatrix}$$

$$N_{\gamma,d} = \overrightarrow{\left[2\left(N_{q,d} - 1\right) \times \tan(\varphi_d)\right]} = \begin{pmatrix} 30.1 \\ 12.4 \end{pmatrix}$$

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

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

$$i_q = \overrightarrow{\left(1 - \frac{H_{Ed}}{N_{Ed} + A\,c'_d \cot(\varphi_d)}\right)^{m_B}} = \begin{pmatrix} 0.38 \\ 0.26 \end{pmatrix}$$

$$i_\gamma = i_q^{\frac{m_B+1}{m_B}} = \begin{pmatrix} 0.23 \\ 0.13 \end{pmatrix}$$

Partial factors from Set R1: $\gamma_{Rv} = 1$

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

from overburden $$q_{Rvq,d} = \overrightarrow{\left(\frac{\gamma_k \times d \times N_{q,d} \times s_q \times i_q}{\gamma_{Rv}}\right)} = \begin{pmatrix} 142.2 \\ 51.6 \end{pmatrix} \text{kPa}$$

from body-mass $$q_{Rv\gamma,d} = \overrightarrow{\left(\frac{1}{2} \frac{B'_d \times \gamma_k \times N_{\gamma,d} \times s_\gamma \times i_\gamma}{\gamma_{Rv}}\right)} = \begin{pmatrix} 137.6 \\ 40.4 \end{pmatrix} \text{kPa}$$

total $$q_{Rv,d} = q_{Rvq,d} + q_{Rv\gamma,d} = \begin{pmatrix} 279.8 \\ 92 \end{pmatrix} \text{kPa}$$

Characteristic bearing resistance (in terms of force) is:

$$N_{Rd} = \overrightarrow{\left(q_{Rv,d} \times B'_d\right)} = \begin{pmatrix} 574 \\ 242 \end{pmatrix} \frac{\text{kN}}{\text{m}}$$

Verifications

Verification of resistance to sliding

Partial factors from Set R1: $\gamma_{Rh} = 1$

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

Assume $\varphi_{cv,k} = 30°$

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

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

$$H_{Rd} = \frac{\gamma_{G,fav} \times N_{Ed} \times \tan(\delta_d)}{\gamma_{Rh}} = \begin{pmatrix} 413.9 \\ 321.6 \end{pmatrix} \frac{\text{kN}}{\text{m}}$$

'Degree of utilization' $\Lambda = \frac{H_{Ed}}{H_{Rd}} = \begin{pmatrix} 66 \\ 85 \end{pmatrix} \%$ or 'Overdesign factor' $ODF = \frac{H_{Rd}}{H_{Ed}} = \begin{pmatrix} 1.51 \\ 1.17 \end{pmatrix}$

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

Verification of bearing resistance

Design bearing resistance is:

$$N_{Rd} = \begin{pmatrix} 574.4 \\ 241.8 \end{pmatrix} \frac{kN}{m}$$

Design bearing force is:

$$N_{Ed} = \begin{pmatrix} 716.9 \\ 557 \end{pmatrix} \frac{kN}{m}$$

'Degree of utilization' $\Lambda = \frac{N_{Ed}}{N_{Rd}} = \begin{pmatrix} 125 \\ 230 \end{pmatrix} \%$ or 'Overdesign factor' $ODF = \frac{N_{Rd}}{N_{Ed}} = \begin{pmatrix} 0.8 \\ 0.43 \end{pmatrix}$

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:

$$M_{Ed,dst} = M_{Gd} + M_{Qd} = \begin{pmatrix} 332 \\ 336 \end{pmatrix} \frac{kN\,m}{m}$$

Design stabilizing moment is (approximately):

$$M_{Ed,stb} = M_{stb,d} = 1068 \frac{kN\,m}{m}$$

'Degree of utilization' $\Lambda = \frac{M_{Ed,dst}}{M_{Ed,stb}} = \begin{pmatrix} 31 \\ 31 \end{pmatrix} \%$ or 'Overdesign factor' $ODF = \frac{M_{Ed,stb}}{M_{Ed,dst}} = \begin{pmatrix} 3.21 \\ 3.17 \end{pmatrix}$

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