Example 11.4
Mass concrete wall retaining granular fill
Verification of strength (limit state GEO)

Design situation

Consider a mass concrete gravity wall, $B = 2.0\text{m}$ wide, which retains $H = 4.0\text{m}$ of granular fill and sits upon a strong rock (so bearing failure is not a design issue). The top of the wall (which is symmetrical) is $b = 1.0\text{m}$ wide.The weight density of unreinforced concrete is $\gamma_{ck} = 24\frac{kN}{m^3}$ (as per EN 1991-1-1 Table A.1). The backfill has characteristic drained strength parameters $\varphi_k = 36°$, $c'_k = 0kPa$, and weight density $\gamma_k = 19\frac{kN}{m^3}$. The fill's constant volume angle of shearing resistance is $\varphi_{cv,k} = 30°$. The characteristic angle of shearing resistance of the rock beneath the wall base is $\varphi_{k,fdn} = 40°$. The ground behind the wall slopes upwards at a slope of 1m vertically to $h = 4m$ horizontally, i.e. at an angle $\beta = \tan^{-1}\left(\frac{1m}{h}\right) = 14°$. A variable surcharge $q_{Qk} = 10kPa$ acts on this ground surface during persistent and transient situations. ❶

Design Approach 1

Geometrical parameters

There is no need to consider an unplanned excavation

Inclination of wall surface (virtual plane) $\theta = \frac{B - b}{2H} = 7.2°$

Width of heel $b_h = \frac{B - b}{2} = 0.5\,m$

Actions

Characteristic self-weight of wall $W_{Gk} = \gamma_{ck} \times \left(\frac{B + b}{2}\right) \times H = 144\frac{kN}{m}$

Characteristic moment about toe (stabilizing)

$$M_{Ek,stb} = W_{Gk} \times \frac{B}{2} = 144\frac{kNm}{m}$$

Material properties

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

Design shearing resistance of backfill $\varphi_d = \tan^{-1}\left(\frac{\tan(\varphi_k)}{\gamma_\varphi}\right) = \begin{pmatrix} 36 \\ 30.2 \end{pmatrix}°$

Design effective cohesion of backfill $c'_d = \frac{c'_k}{\gamma_c} = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$ kPa

UK NA to BS EN 1997-1 allows $\varphi_{cv,d}$ to be selected directly. Here, take the smaller of φ_d and $\varphi_{cv,k}$, i.e. $\varphi_{cv,d} = \overrightarrow{\min(\varphi_d, \varphi_{cv,k})} = \begin{pmatrix} 30 \\ 30 \end{pmatrix}°$

For cast in place concrete $k = 1$

Interface friction between backfill and wall is $\delta_d = k \times \varphi_{cv,d} = \begin{pmatrix} 30 \\ 30 \end{pmatrix}°$ ❷

Design shearing resistance of rock $\varphi_{d,fdn} = \tan^{-1}\left(\frac{\tan(\varphi_{k,fdn})}{\gamma_\varphi}\right) = \begin{pmatrix} 40 \\ 33.9 \end{pmatrix}°$

Interface friction between rock and wall is $\delta_{d,fdn} = k \times \varphi_{d,fdn} = \begin{pmatrix} 40 \\ 33.9 \end{pmatrix}°$ ❸

Effects of actions

Active earth pressure coefficients (giving normal components of stress)

$K_{a\gamma} = \begin{pmatrix} 0.304 \\ 0.385 \end{pmatrix}$, $K_{aq} = \begin{pmatrix} 0.297 \\ 0.377 \end{pmatrix}$, and $K_{ac} = \begin{pmatrix} 0.942 \\ 1.032 \end{pmatrix}$ ❹

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

From backfill:

design thrust: $P_{ahd_1} = \overrightarrow{\left(\gamma_G \times K_{a\gamma}\cos(\theta) \times \frac{\gamma_k H^2}{2}\right)} = \begin{pmatrix} 61.9 \\ 58.1 \end{pmatrix}\frac{kN}{m}$

vertical thrust: $P_{avd_1} = \overrightarrow{\left(P_{ahd_1} \times \tan(\theta + \delta_d)\right)} = \begin{pmatrix} 46.9 \\ 44.1 \end{pmatrix}\frac{kN}{m}$ ❺

moment about toe: $M_{d_1} = P_{ahd_1} \times \frac{H}{3} = \begin{pmatrix} 82.5 \\ 77.5 \end{pmatrix}\frac{kNm}{m}$

From surcharge:

design thrust $P_{ahd_2} = \overrightarrow{\left(\gamma_Q \times K_{aq} \cos(\theta) \times q_{Qk} H\right)} = \begin{pmatrix} 17.7 \\ 19.4 \end{pmatrix} \frac{kN}{m}$

vertical thrust: $P_{avd_2} = \overrightarrow{\left(P_{ahd_2} \times \tan\left(\theta + \delta_d\right)\right)} = \begin{pmatrix} 13.4 \\ 14.7 \end{pmatrix} \frac{kN}{m}$ ❺

from surcharge $M_{d_2} = P_{ahd_2} \times \frac{H}{2} = \begin{pmatrix} 35.3 \\ 38.9 \end{pmatrix} \frac{kNm}{m}$

Total design horizontal thrust $H_{Ed} = \sum_{i=1}^{2} \overrightarrow{P_{ahd_i}} = \begin{pmatrix} 79.5 \\ 77.6 \end{pmatrix} \frac{kN}{m}$

Total design vertical thrust $P_{avd} = \sum_{i=1}^{2} \overrightarrow{P_{avd_i}} = \begin{pmatrix} 60.3 \\ 58.8 \end{pmatrix} \frac{kN}{m}$

Total design destabilizing moment $M_{Ed,dst} = \sum_{i=1}^{2} \overrightarrow{M_{d_i}} = \begin{pmatrix} 117.8 \\ 116.4 \end{pmatrix} \frac{kNm}{m}$

Vertical action (unfavourable) $V_d = \gamma_G \times W_{Gk} + P_{avd} = \begin{pmatrix} 254.7 \\ 202.8 \end{pmatrix} \frac{kN}{m}$ ❻

Vertical action (favourable) $V_{d,fav} = \gamma_{G,fav} \times W_{Gk} + P_{avd} = \begin{pmatrix} 204.3 \\ 202.8 \end{pmatrix} \frac{kN}{m}$ ❻

Sliding resistance

Partial factors from Sets $\begin{pmatrix} R1 \\ R1 \end{pmatrix}$: $\gamma_{Rh} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$ and $\gamma_{Rv} = \begin{pmatrix} 1 \\ 1 \end{pmatrix}$

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

exp. 6.3a) $H'_{Rd} = \overrightarrow{\left(\frac{V_{d,fav} \times \tan\left(\delta_{d,fdn}\right)}{\gamma_{Rh}}\right)} = \begin{pmatrix} 171.4 \\ 136.1 \end{pmatrix} \frac{kN}{m}$

Toppling resistance

Design stabilizing moments (about toe):

From backfill: $M_{d_1} = \overrightarrow{\left[P_{ahd_1} \times \tan(\theta + \delta_d) \times \left(B - \frac{b_h}{3}\right)\right]} = \begin{pmatrix} 86 \\ 80.8 \end{pmatrix} \frac{kNm}{m}$ ❼

From surcharge: $M_{d_2} = \overrightarrow{\left[P_{ahd_2} \times \left[\tan(\theta + \delta_d) \times \left(B - \frac{b_h}{2}\right)\right]\right]} = \begin{pmatrix} 23.4 \\ 25.8 \end{pmatrix} \frac{kNm}{m}$ ❼

From wall $M_{d_3} = \overrightarrow{\left(\gamma_{G,fav} \times M_{Ek,stb}\right)} = \begin{pmatrix} 144 \\ 144 \end{pmatrix} \frac{kNm}{m}$

Total design stabilizing moment $M_{Ed,stb} = \sum_{i=1}^{3} \overrightarrow{M_{d_i}} = \begin{pmatrix} 253.4 \\ 250.6 \end{pmatrix} \frac{kNm}{m}$

Eccentricity of load $e_B = \overrightarrow{\left|\left(\frac{B}{2} - \frac{M_{Ed,stb} - M_{Ed,dst}}{V_d}\right)\right|} = \begin{pmatrix} 0.47 \\ 0.34 \end{pmatrix} m$

To be within middle third of base, e_B must be not be > $\frac{B}{6} = 0.33\,m$ ❽

Verifications

For drained sliding and $H_{Ed} = \begin{pmatrix} 79.5 \\ 77.6 \end{pmatrix} \frac{kN}{m}$ and $H'_{Rd} = \begin{pmatrix} 171.4 \\ 136.1 \end{pmatrix} \frac{kN}{m}$

Degree of utilization $\Lambda_{GEO,1} = \frac{H_{Ed}}{H'_{Rd}} = \begin{pmatrix} 46 \\ 57 \end{pmatrix} \%$ ❾

For toppling $M_{Ed,dst} = \begin{pmatrix} 117.8 \\ 116.4 \end{pmatrix} \frac{kNm}{m}$ and $M_{Ed,stb} = \begin{pmatrix} 253.4 \\ 250.6 \end{pmatrix} \frac{kNm}{m}$

Degree of utilization $\Lambda_{GEO,1} = \frac{M_{Ed,dst}}{M_{Ed,stb}} = \begin{pmatrix} 46 \\ 46 \end{pmatrix} \%$ ❾

Design is unacceptable if the degree of utilization is > 100%