

**Example 11.4-DA3**  
**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  $\gamma_{\text{ck}} = 24 \frac{\text{kN}}{\text{m}^3}$  (as per

EN 1991-1-1 Table A.1). The backfill has characteristic drained strength

parameters  $\varphi_{\text{k}} = 36^\circ$ ,  $c'_{\text{k}} = 0\text{kPa}$ , and weight density  $\gamma_{\text{k}} = 19 \frac{\text{kN}}{\text{m}^3}$ . The fill's

constant volume angle of shearing resistance is  $\varphi_{\text{cv,k}} = 30^\circ$ . The

characteristic angle of shearing resistance of the rock beneath the wall base is  $\varphi_{\text{k,fdn}} = 40^\circ$ . The ground behind the wall slopes upwards at a slope of  $1\text{m}$

vertically to  $h = 4\text{m}$  horizontally, i.e. at an angle  $\beta = \tan^{-1}\left(\frac{1\text{m}}{h}\right) = 14^\circ$ . A

variable surcharge  $q_{\text{Qk}} = 10\text{kPa}$  acts on this ground surface during

persistent and transient situations. ❶

Design Approach 3

Geometrical parameters

There is no need to consider an unplanned excavation

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

Width of heel  $b_{\text{h}} = \frac{B - b}{2} = 0.5\text{m}$

Actions

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

Characteristic moment about toe (stabilizing)

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

### Material properties

Partial factors from set M2 are  $\gamma_\varphi = 1.25$  and  $\gamma_c = 1.25$

$$\text{Design shearing resistance of backfill } \varphi_d = \tan^{-1} \left( \frac{\tan(\varphi_k)}{\gamma_\varphi} \right) = 30.2^\circ$$

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

UK NA to BS EN 1997-1 allows  $\varphi_{cv,d}$  to be selected directly. Here, take the

$$\text{smaller of } \varphi_d \text{ and } \varphi_{cv,k}, \text{ i.e. } \varphi_{cv,d} = \min(\varphi_d, \varphi_{cv,k}) = 30^\circ$$

For cast in place concrete  $k = 1$

Interface friction between backfill and wall is  $\delta_d = k \times \varphi_{cv,d} = 30^\circ$  **2**

$$\text{Design shearing resistance of rock } \varphi_{d,fdn} = \tan^{-1} \left( \frac{\tan(\varphi_{k,fdn})}{\gamma_\varphi} \right) = 33.9^\circ$$

Interface friction between rock and wall is  $\delta_{d,fdn} = k \times \varphi_{d,fdn} = 33.9^\circ$  **3**

### Effects of actions

Active earth pressure coefficients (giving normal components of stress)

$$K_{a\gamma} = 0.385, K_{aq} = 0.377, \text{ and } K_{ac} = 1.032 \quad \mathbf{4}$$

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

$$\gamma_Q = 1.3$$

From backfill:

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

$$\text{vertical thrust: } P_{avd_1} = \left( P_{ahd_1} \times \tan(\theta + \delta_d) \right) = 44.1 \frac{\text{kN}}{\text{m}} \quad \mathbf{5}$$

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

From surcharge:

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

$$\text{vertical thrust: } P_{avd_2} = \left( P_{ahd_2} \times \tan(\theta + \delta_d) \right) = 14.7 \frac{\text{kN}}{\text{m}} \quad \mathbf{5}$$

$$\text{from surcharge } M_{d_2} = P_{ahd_2} \times \frac{H}{2} = 38.9 \frac{\text{kNm}}{\text{m}}$$

$$\text{Total design horizontal thrust } H_{Ed} = \sum_{i=1}^2 P_{ahd_i} = 77.6 \frac{\text{kN}}{\text{m}}$$

$$\text{Total design vertical thrust } P_{avd} = \sum_{i=1}^2 P_{avd_i} = 58.8 \frac{\text{kN}}{\text{m}}$$

$$\text{Total design destabilizing moment } M_{Ed,dst} = \sum_{i=1}^2 M_{d_i} = 116.4 \frac{\text{kNm}}{\text{m}}$$

$$\text{Vertical action (unfavourable) } V_d = \gamma_{G, \text{str}} \times W_{Gk} + P_{avd} = 253.2 \frac{\text{kN}}{\text{m}} \text{ ⑥}$$

$$\text{Vertical action (favourable) } V_{d, \text{fav}} = \gamma_{G, \text{fav}} \times W_{Gk} + P_{avd} = 202.8 \frac{\text{kN}}{\text{m}} \text{ ⑥}$$

### Sliding resistance

Partial factors from set R3:  $\gamma_{Rh} = 1$  and  $\gamma_{Rv} = 1$

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

$$\text{exp. 6.3a) } H'_{Rd} = \frac{V_{d, \text{fav}} \times \tan(\delta_{d, \text{fdn}})}{\gamma_{Rh}} = 136.1 \frac{\text{kN}}{\text{m}}$$

### Toppling resistance

Design stabilizing moments (about toe):

$$\text{From backfill: } M_{d_1} = \left[ P_{ahd_1} \times \tan(\theta + \delta_d) \times \left( B - \frac{b_h}{3} \right) \right] = 80.8 \frac{\text{kNm}}{\text{m}} \text{ ⑦}$$

$$\text{From surcharge: } M_{d_2} = \left[ P_{ahd_2} \times \tan(\theta + \delta_d) \times \left( B - \frac{b_h}{2} \right) \right] = 25.8 \frac{\text{kNm}}{\text{m}} \text{ ⑦}$$

$$\text{From wall } M_{d_3} = (\gamma_{G, \text{fav}} \times M_{Ek, \text{stb}}) = 144 \frac{\text{kNm}}{\text{m}}$$

$$\text{Total design stabilizing moment } M_{Ed, \text{stb}} = \sum_{i=1}^3 M_{d_i} = 250.6 \frac{\text{kNm}}{\text{m}}$$

$$\text{Eccentricity of load } e_B = \left( \frac{B}{2} - \frac{M_{Ed, stb} - M_{Ed, dst}}{V_d} \right) = 0.47 \text{ m}$$

To be within middle third of base,  $e_B$  must be not be  $> \frac{B}{6} = 0.33 \text{ m}$  ⑧

### Verifications

For drained sliding and  $H_{Ed} = 77.6 \frac{\text{kN}}{\text{m}}$  and  $H'_{Rd} = 136.1 \frac{\text{kN}}{\text{m}}$

$$\text{Degree of utilization } \Delta_{GEO,3} = \frac{H_{Ed}}{H'_{Rd}} = 57\% \text{ ⑨}$$

For toppling  $M_{Ed, dst} = 116.4 \frac{\text{kNm}}{\text{m}}$  and  $M_{Ed, stb} = 250.6 \frac{\text{kNm}}{\text{m}}$

$$\text{Degree of utilization } \Delta_{GEO,3} = \frac{M_{Ed, dst}}{M_{Ed, stb}} = 46\% \text{ ⑨}$$

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