

Example 12.2-DA3
Anchored sheet pile wall
Verification of strength (limit state GEO)

Design situation

Consider an embedded sheet pile retaining wall which retains $H_{\text{nom}} = 6\text{m}$ of medium dense sand with characteristic weight density $\gamma_k = 19 \frac{\text{kN}}{\text{m}^3}$, angle of shearing resistance $\varphi_k = 36^\circ$, and effective cohesion $c'_k = 0\text{kPa}$. The soil's angle of shearing resistance under constant volume conditions is estimated to be $\varphi_{\text{cv},k} = 32^\circ$. Groundwater is located at ground level on both sides of the wall. A variable imposed surcharge of $q_{\text{Qk}} = 10\text{kPa}$ acts at the head of the wall. The wall is supported by a single row of anchors placed at $d_a = 1\text{m}$ below ground level. The wall toe is at a nominal depth $d_{\text{nom}} = 5.85\text{m}$ below formation level. The unit weight of water is $\gamma_w = 9.81 \frac{\text{kN}}{\text{m}^3}$

Design Approach 3

Geometry

Unplanned 'overdig' $\Delta H = \min[10\%(H_{\text{nom}} - d_a), 0.5\text{m}] = 0.5\text{m}$ **1**

Unplanned height of excavation $H_d = H_{\text{nom}} + \Delta H = 6.5\text{m}$

Reduced depth of embedment $d_d = d_{\text{nom}} - \Delta H = 5.4\text{m}$

Total length of wall $L_d = H_d + d_d = 11.9\text{m}$

Actions

Vertical total stresses (excluding surcharge) at...

ground level $\sigma_{v,k_1} = 0\text{kPa}$

wall toe (retained side) $\sigma_{v,k_2} = \sigma_{v,k_1} + \gamma_k \times (H_d + d_d) = 225.2\text{ kPa}$

formation level $\sigma_{v,k_3} = 0\text{kPa}$

wall toe (restrained side) $\sigma_{v,k_4} = \sigma_{v,k_3} + \gamma_k \times d_d = 101.7\text{ kPa}$

Difference in hydraulic head $\Delta h = H_d = 6.5\text{m}$

Distance around wall $x = H_d + 2d_d = 17.2 \text{ m}$

Hydraulic head at wall toe $h_{\text{toe}} = \frac{\Delta h}{x} \times (H_d + d_d) = 4.48 \text{ m}$

Pore water pressures at... (assuming head falls linearly around wall)

ground level $u_{k_1} = 0 \text{ kPa}$

formation level $u_{k_3} = u_{k_1} = 0 \text{ kPa}$

wall toe (retained side) $u_{k_2} = \gamma_w \times (H_d + d_d - h_{\text{toe}}) = 72.3 \text{ kPa}$ ②

wall toe (restraining side) $u_{k_4} = u_{k_2} = 72.3 \text{ kPa}$ ②

Vertical effective stresses (excluding surcharge) at...

ground level $\sigma'_{v,k_1} = \sigma_{v,k_1} - u_{k_1} = 0 \text{ kPa}$

wall toe (retained side) $\sigma'_{v,k_2} = \sigma_{v,k_2} - u_{k_2} = 152.9 \text{ kPa}$

formation level $\sigma'_{v,k_3} = \sigma_{v,k_3} - u_{k_3} = 0 \text{ kPa}$

wall toe (restraining side) $\sigma'_{v,k_4} = \sigma_{v,k_4} - u_{k_4} = 29.4 \text{ kPa}$

Material properties

Partial factors from Set M2: $\gamma_\varphi = 1.25$ and $\gamma_c = 1.25$

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

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

Constant volume angle of shearing resistance (partial factor applied)

$\varphi_{cv,d} = \tan^{-1} \left(\frac{\tan(\varphi_{cv,k})}{\gamma_\varphi} \right) = 26.6^\circ$

For soil/steel interface $k = \frac{2}{3}$

Design angle of wall friction $\delta_d = k \times \varphi_{cv,d} = 17.7 \text{ deg}$

Design friction/shearing ratio $\frac{\delta_d}{\varphi_d} = 0.59$

Effects of actions

Partial factors from Set A2: $\gamma_G = 1$ and $\gamma_Q = 1.3$

Active earth pressure coefficients $K_{a\gamma} = 0.287$ $K_{aq} = 0.287$ $K_{ac} = 1.226$

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Horizontal effective stresses (numbers refer to diagram)

$$\sigma'_{a,d_1} = \left[\gamma_G \times (K_{a\gamma} \sigma'_{v,k_1} - K_{ac} c' d) + \gamma_Q \times K_{a\gamma} q_{Qk} \right] = 3.7 \text{ kPa}$$

$$\sigma'_{a,d_2} = \left[\gamma_G \times (K_{a\gamma} \sigma'_{v,k_2} - K_{ac} c' d) + \gamma_Q \times K_{a\gamma} q_{Qk} \right] = 47.7 \text{ kPa}$$

$$\sigma'_{p,d_3} = \left[\gamma_G \times (K_{p\gamma} \sigma'_{v,k_3} + K_{pc} c' d) \right] = 0 \text{ kPa} \text{ 4}$$

$$\sigma'_{p,d_4} = \left[\gamma_G \times (K_{p\gamma} \sigma'_{v,k_4} + K_{pc} c' d) \right] = 132.8 \text{ kPa} \text{ 4}$$

Water pressures (numbers refer to diagram)

$$u_{a,d_1} = \gamma_G \times u_{k_1} = 0 \text{ kPa}$$

$$u_{a,d_2} = \gamma_G \times u_{k_2} = 72.3 \text{ kPa}$$

$$u_{p,d_3} = \gamma_G \times u_{k_3} = 0 \text{ kPa} \text{ 5}$$

$$u_{p,d_4} = \gamma_G \times u_{k_4} = 72.3 \text{ kPa} \text{ 5}$$

Horizontal total stresses (numbers refer to diagram)

$$\sigma_{a,d_1} = (\sigma'_{a,d_1} + u_{a,d_1}) = 3.7 \text{ kPa}$$

$$\sigma_{a,d_2} = (\sigma'_{a,d_2} + u_{a,d_2}) = 120 \text{ kPa}$$

$$\sigma_{p,d_3} = (\sigma'_{p,d_3} + u_{p,d_3}) = 0 \text{ kPa}$$

$$\sigma_{p,d_4} = (\sigma'_{p,d_4} + u_{p,d_4}) = 205.1 \text{ kPa}$$

$$\text{Horizontal thrust } H_{Ed} = \left(\frac{\sigma_{a,d_1} + \sigma_{a,d_2}}{2} \right) \times L_d = 732.9 \frac{\text{kN}}{\text{m}}$$

Overturning moment about point 'O'

$$M_{Ed_1} = \left(\frac{\sigma_{a,d_1} \times L_d}{2} \right) \times \left(\frac{L_d}{3} - d_a \right) = 65.3 \frac{\text{kNm}}{\text{m}}$$

$$M_{Ed_2} = \left(\frac{\sigma_{a,d_2} \times L_d}{2} \right) \times \left(\frac{2L_d}{3} - d_a \right) = 4904 \frac{\text{kNm}}{\text{m}}$$

$$\text{sum } M_{Ed} = \sum_{i=1}^2 M_{Ed_i} = 4969.3 \frac{\text{kNm}}{\text{m}}$$

Resistance

Partial factor from Set R3: $\gamma_{Re} = 1$

$$\text{Horizontal resistance } H_{Rd} = \frac{\left(\frac{\sigma_{p,d_3} + \sigma_{p,d_4}}{2} \right) \times d_d}{\gamma_{Re}} = 548.6 \frac{\text{kN}}{\text{m}}$$

Restoring moment about point 'O'

$$M_{Rd} = \frac{\left(\frac{\sigma_{p,d_4} d_d}{2} \right) \times \left(\frac{2d_d}{3} + H_d - d_a \right)}{\gamma_{Re}} = 4973.8 \frac{\text{kNm}}{\text{m}}$$

Verifications

Design values $M_{Ed} = 4969.3 \frac{\text{kNm}}{\text{m}}$ and $M_{Rd} = 4973.8 \frac{\text{kNm}}{\text{m}}$

$$\text{Degree of utilization } \Delta_{GEO,3} = \frac{M_{Ed}}{M_{Rd}} = 100\% \text{ ⑥}$$

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

For horizontal equilibrium, anchor must provide design resistance of

$$F_d = H_{Ed} - H_{Rd} = 184.3 \frac{\text{kN}}{\text{m}} \text{ ⑦}$$

where $H_{Ed} = 732.9 \frac{\text{kN}}{\text{m}}$ and $H_{Rd} = 548.6 \frac{\text{kN}}{\text{m}}$

The wall cross-section must now be designed to withstand...

Maximum bending moment in wall $M_{d,max} = -502.8 \frac{\text{kNm}}{\text{m}} \text{ ⑧}$

Maximum shear force in wall $V_{d,max} = -176 \frac{\text{kN}}{\text{m}} \text{ ⑧}$