Example 12.2-DA2
Anchored sheet pile wall
Verification of strength (limit state GEO)

Design situation

Consider an embedded sheet pile retaining wall which retains $H_{nom} = 6m$ of medium dense sand with characteristic weight density $\gamma_k = 19\frac{kN}{m^3}$, angle of shearing resistance $\varphi_k = 36°$, and effective cohesion $c'_k = 0kPa$. The soil's angle of shearing resistance under constant volume conditions is estimated to be $\varphi_{cv,k} = 32°$. Groundwater is located at ground level on both sides of the wall. A variable imposed surcharge of $q_{Qk} = 10kPa$ acts at the head of the wall. The wall is supported by a single row of anchors placed at $d_a = 1m$ below ground level. The wall toe is at a nominal depth $d_{nom} = 7.49m$ below formation level. The unit weight of water is $\gamma_w = 9.81\frac{kN}{m^3}$

Design Approach 2

Geometry

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

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

Reduced depth of embedment $d_d = d_{nom} - \Delta H = 7\,m$

Total length of wall $L_d = H_d + d_d = 13.5\,m$

Actions

Vertical total stresses (excluding surcharge) at...

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

wall toe (retained side) $\sigma_{v,k_2} = \sigma_{v,k_1} + \gamma_k \times \left(H_d + d_d\right) = 256.3\,kPa$

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

wall toe (restrained side) $\sigma_{v,k_4} = \sigma_{v,k_3} + \gamma_k \times d_d = 132.8\,kPa$

Difference in hydraulic head $\Delta h = H_d = 6.5\,m$

Distance around wall $x = H_d + 2d_d = 20.5\,m$

Hydraulic head at wall toe $h_{toe} = \frac{\Delta h}{x} \times (H_d + d_d) = 4.28\,m$

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

ground level $u_{k_1} = 0kPa$

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

wall toe (retained side) $u_{k_2} = \gamma_w \times (H_d + d_d - h_{toe}) = 90.3\,kPa$ ❷

wall toe (restraining side) $u_{k_4} = u_{k_2} = 90.3\,kPa$ ❷

Vertical effective stresses (excluding surcharge) at...

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

wall toe (retained side) $\sigma'_{v,k_2} = \sigma_{v,k_2} - u_{k_2} = 166\,kPa$

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

wall toe (restraining side) $\sigma'_{v,k_4} = \sigma_{v,k_4} - u_{k_4} = 42.5\,kPa$

Material properties

Partial factors from Sets M1: $\gamma_\varphi = 1$ and $\gamma_c = 1$

Design angle of shearing resistance $\varphi_d = \tan^{-1}\left(\frac{\tan(\varphi_k)}{\gamma_\varphi}\right) = 36\,°$

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

Constant volume angle of shearing resistance (partial factor applied)

$$\varphi_{cv,d} = \tan^{-1}\left(\frac{\tan(\varphi_{cv,k})}{\gamma_\varphi}\right) = 32\,°$$

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

Design angle of wall friction $\delta_d = k \times \varphi_{cv,d} = 21.3\,deg$

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

Effects of actions

Partial factors from Sets A1: $\gamma_G = 1.35$ and $\gamma_Q = 1.5$

Active earth pressure coefficients $K_{a\gamma} = 0.222$ $K_{aq} = 0.222$ $K_{ac} = 1.07$

❸

Horizontal effective stresses (numbers refer to diagram)

$$\sigma'_{a,d_1} = \overrightarrow{\left[\gamma_G \times \left(K_{a\gamma}\sigma'_{v,k_1} - K_{ac}c'_d\right) + \gamma_Q \times K_{a\gamma}q_{Qk}\right]} = 3.3\,kPa$$

$$\sigma'_{a,d_2} = \overrightarrow{\left[\gamma_G \times \left(K_{a\gamma}\sigma'_{v,k_2} - K_{ac}c'_d\right) + \gamma_Q \times K_{a\gamma}q_{Qk}\right]} = 53.2\,kPa$$

$$\sigma'_{p,d_3} = \overrightarrow{\left(\left(K_{p\gamma}\sigma'_{v,k_3} + K_{pc}c'_d\right)\right)} = 0\,kPa$$ ❹

$$\sigma'_{p,d_4} = \overrightarrow{\left(\left(K_{p\gamma}\sigma'_{v,k_4} + K_{pc}c'_d\right)\right)} = 284.8\,kPa$$ ❹

Water pressures (numbers refer to diagram)

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

$$u_{a,d_2} = \gamma_G \times u_{k_2} = 121.9\,kPa$$

$$u_{p,d_3} = u_{k_3} = 0\,kPa$$ ❺

$$u_{p,d_4} = u_{k_4} = 90.3\,kPa$$ ❺

Horizontal total stresses (numbers refer to diagram)

$$\sigma_{a,d_1} = \overrightarrow{\left(\sigma'_{a,d_1} + u_{a,d_1}\right)} = 3.3\,kPa$$

$$\sigma_{a,d_2} = \overrightarrow{\left(\sigma'_{a,d_2} + u_{a,d_2}\right)} = 175.1\,kPa$$

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

$$\sigma_{p,d_4} = \overrightarrow{\left(\sigma'_{p,d_4} + u_{p,d_4}\right)} = 375.1\,kPa$$

Horizontal thrust $H_{Ed} = \left(\dfrac{\sigma_{a,d_1} + \sigma_{a,d_2}}{2}\right) \times L_d = 1203.5\,\dfrac{kN}{m}$

Overturning moment about point 'O'

$$M_{Ed_1} = \left(\frac{\sigma_{a,d_1} \times L_d}{2}\right) \times \left(\frac{L_d}{3} - d_a\right) = 78.7\,\frac{kNm}{m}$$

$$M_{Ed_2} = \left(\frac{\sigma_{a,d_2} \times L_d}{2}\right) \times \left(\frac{2L_d}{3} - d_a\right) = 9440.4 \frac{kNm}{m}$$

$$sum\ M_{Ed} = \sum_{i=1}^{2} M_{Ed_i} = 9519.1 \frac{kNm}{m}$$

Resistance

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

Horizontal resistance $H_{Rd} = \frac{\left(\frac{\sigma_{p,d_3} + \sigma_{p,d_4}}{2}\right) \times d_d}{\gamma_{Re}} = 936.4 \frac{kN}{m}$

Restoring moment about point 'O'

$$M_{Rd} = \frac{\left(\frac{\sigma_{p,d_4} d_d}{2}\right) \times \left(\frac{2d_d}{3} + H_d - d_a\right)}{\gamma_{Re}} = 9514.3 \frac{kNm}{m}$$

Verifications

Design values $M_{Ed} = 9519.1 \frac{kNm}{m}$ and $M_{Rd} = 9514.3 \frac{kNm}{m}$

Degree of utilization $\Lambda_{GEO,2} = \frac{M_{Ed}}{M_{Rd}} = 100\ \%$ ❻

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

For horizontal equilibrium, anchor must provide design resistance of

$$F_d = H_{Ed} - H_{Rd} = 267.1 \frac{kN}{m}$$ ❼

where $H_{Ed} = 1203.5 \frac{kN}{m}$ and $H_{Rd} = 936.4 \frac{kN}{m}$

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

Maximum bending moment in wall $M_{d,max} = -819 \frac{kNm}{m}$ ❽

Maximum shear force in wall $V_{d,max} = -257 \frac{kN}{m}$ ❽