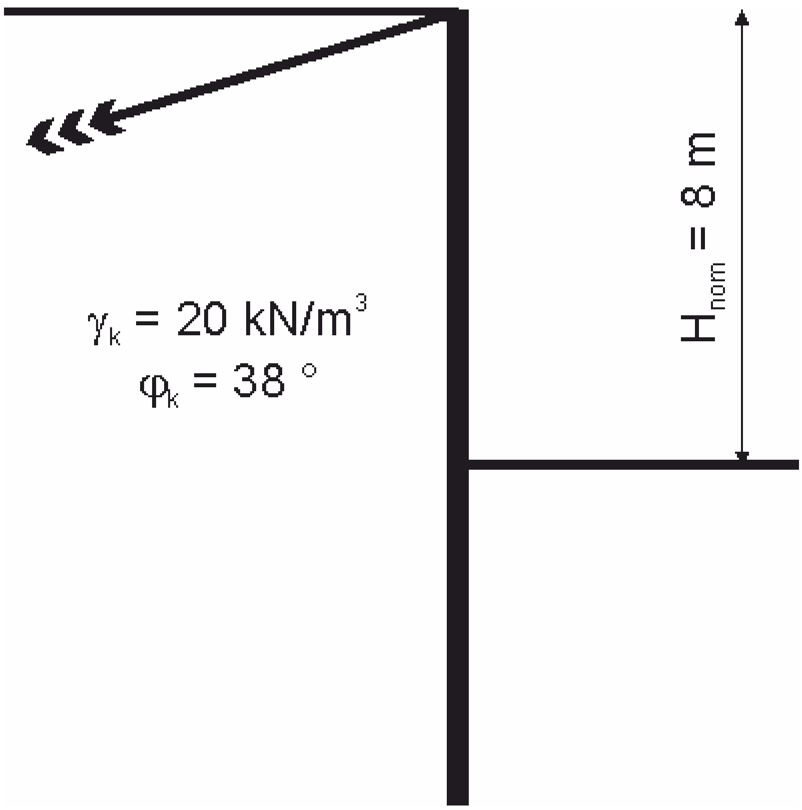
Example JRC-07
Anchored sheet pile wall
Verification of drained strength (limit state GEO)
Design Approach 1

Design situation

Consider a sheet pile wall that retains $H_{nom} = 8.0m$ of dense sand with characteristic weight density $\gamma_k = 20\frac{kN}{m^3}$ and drained angle of shearing resistance $\varphi_k = 38°$. The ground behind the wall is horizontal and subject to a blanket surcharge (representing traffic loading) - but, for simplificty, we will assume $q_k = 0kPa$. The ground is dry.

The sheet pile is a Z section with flange thickness $t_f = 8.5mm$, web thickness $t_w = 8.5mm$, web height $h = 302mm$, clutch-to-clutch breadth $b = 670mm$, elastic section modulus $W_{el} = 1400\frac{cm^3}{m}$, and characteristic yield strength $f_{yk} = 355MPa$.

An anchor with ultimate design resistance of $R_{a,d} = 130\frac{kN}{m}$ will be installed at an angle $\theta = 30°$ to the horizontal to stabilize the wall.



Geometry

Allowing for an unplanned excavation in ULS verifications, the design retained height of the wall is:

$$H_d = H_{nom} + \min\left(10\% \times H_{nom}, 0.5m\right) = 8.5\,m$$

Material properties

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

Design angle of shearing resistance:

$$\varphi_d = \text{atan}\left(\frac{\tan(\varphi_k)}{\gamma_\varphi}\right) = \begin{pmatrix} 38.0 \\ 32.0 \end{pmatrix}^\circ$$

Characteristic value of soil's constant-volume angle of shearing resistance is assumed to be:

$$\varphi_{cv,k} = 30°$$

Design value of soil's constant-volume angle of shearing resistance is:

$$\varphi_{cv,d} = \min(\varphi_d, \varphi_{cv,k}) = 30°$$

Angle of wall friction is $k = 0.67$ times the soil's constant-volume angle of shearing resistance:

$$\delta_d = k\varphi_{cv,d} = 20°$$

Earth pressure cofficients from Annex C of EN 1997-1:

$$K_{a,h} = \overrightarrow{K_{a\gamma}(\varphi_d, \delta_d, 0, 0)} = \begin{pmatrix} 0.21 \\ 0.26 \end{pmatrix}$$

$$K_{p,h} = \overrightarrow{K_{p\gamma}(\varphi_d, \delta_d, 0, 0)} = \begin{pmatrix} 7.39 \\ 5.18 \end{pmatrix}$$

Actions

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

'Single source principle' allows $\gamma_{G,fav} = \gamma_G = \begin{pmatrix} 1.35 \\ 1 \end{pmatrix}$

Ratio of variable and permanent partial factors is:

$$\gamma_{Q/G} = \frac{\gamma_Q}{\gamma_G} = \begin{pmatrix} 1.11 \\ 1.3 \end{pmatrix}$$

Assume a depth of embedment $d = \begin{pmatrix} 1.38 \\ 2.01 \end{pmatrix} m$

Overturning moment about anchor is:

$$M_{Ed,dst} = \overrightarrow{\left[\gamma_G K_{a,h} \times \left[\frac{1}{3}\gamma_k \times (H_d + d)^3 + \frac{1}{2}\gamma_{Q/G} \times q_k \times (H_d + d)^2\right]\right]} = \begin{pmatrix} 1790 \\ 2040 \end{pmatrix} \frac{kN\,m}{m}$$

Restoring moment about anchor is:

$$M_{Ed,stb} = \overrightarrow{\left[\gamma_{G,fav} K_{p,h} \times \left[\frac{1}{2}\gamma_k \times d^2 \times \left(H_d + \frac{2}{3}d\right)\right]\right]} = \begin{pmatrix} 1789 \\ 2061 \end{pmatrix} \frac{kN\,m}{m}$$

Out of balance mnoment is:

$$\frac{M_{Ed,dst} - M_{Ed,stb}}{M_{Ed,stb}} = \begin{pmatrix} 0.1 \\ -1 \end{pmatrix} \%$$

Active thrust on retained side of wall is:

$$P_{a,Ed} = \overrightarrow{\left[\gamma_G K_{a,h} \times \left[\frac{1}{2}\gamma_k \times (H_d + d)^2 + \gamma_{Q/G} \times q_k \times (H_d + d)\right]\right]} = \begin{pmatrix} 272 \\ 291 \end{pmatrix} \frac{kN}{m}$$

Passive thrust thrust on restraining side of wall is:

$$P_{p,Ed} = \overrightarrow{\left[\gamma_{G,fav} K_{p,h} \times \left(\frac{1}{2}\gamma_k \times d^2\right)\right]} = \begin{pmatrix} 190 \\ 209 \end{pmatrix} \frac{kN}{m}$$

Hence net thrust is:

$$P_{Ed} = P_{a,Ed} - P_{p,Ed} = \begin{pmatrix} 81.9 \\ 81.7 \end{pmatrix} \frac{kN}{m}$$

Hence axial force transfered to the anchor is:

$$F_{a,Ed} = \frac{\max\left(P_{Ed_1}, P_{Ed_2}\right)}{\cos(\theta)} = 94.6 \frac{kN}{m}$$

The depth of zero shear force in the retaining wall can be found (approximately) from:

$$z = \overrightarrow{\sqrt{\frac{P_{Ed}}{\gamma_G K_{a,h} \times \frac{1}{2}\gamma_k}}} = \begin{pmatrix} 5.42 \\ 5.57 \end{pmatrix} m$$

... and checked for accuracy using:

$$V_{z,Ed} = \overrightarrow{P_{Ed} - \left[\gamma_G K_{a,h} \times \left(\frac{1}{2}\gamma_k \times z^2 + \gamma_{Q/G} \times q_k \times z\right)\right]} = \begin{pmatrix} 0.0 \\ 0.0 \end{pmatrix} \frac{kN}{m}$$

Hence the maximum bending moment in the wall is:

$$M_{Ed} = \overrightarrow{\left[P_{Ed} z - \gamma_G K_{a,h} \times \left(\frac{1}{6}\gamma_k \times z^3 + \frac{1}{2}\gamma_{Q/G} \times q_k \times z^2\right)\right]} = \begin{pmatrix} 296 \\ 303 \end{pmatrix} \frac{kNm}{m}$$

Maximum bending moment from either combination is:

$$M_{Ed} = \max\left(M_{Ed_1}, M_{Ed_2}\right) = 303 \frac{kNm}{m}$$

Maximum shear force in the wall is:

$$V_{Ed} = \max\left(P_{Ed_1}, P_{Ed_2}\right) = 81.9 \frac{kN}{m}$$

Verifications

Verification of resistance to overturning

'Degree of utilization' $\boxed{\Lambda = \frac{M_{Ed,dst}}{M_{Ed,stb}} = \begin{pmatrix} 100 \\ 99 \end{pmatrix} \%}$ or 'Overdesign factor' $\boxed{ODF = \frac{M_{Ed,stb}}{M_{Ed,dst}} = \begin{pmatrix} 1 \\ 1.01 \end{pmatrix}}$

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

Verification of bending resistance

Partial factor on yield strength of steel is $\gamma_{M0} = 1.0$ (from EN 1993-1-1)

Factor for reduced shear force in interlocks $\beta_B = 1.0$

Design bending resistance of sheet pile section is:

$$M_{c,Rd} = \frac{\beta_B W_{el} f_{yk}}{\gamma_{M0}} = 497 \frac{kNm}{m}$$

'Degree of utilization' $\boxed{\Lambda = \frac{M_{Ed}}{M_{c,Rd}} = 61\,\%}$ or 'Overdesign factor' $\boxed{ODF = \frac{M_{c,Rd}}{M_{Ed}} = 1.64}$

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

Verification of shear resistance

Projected shear area is:

$$A_v = \frac{t_w\left(h - t_f\right)}{b} = 3724 \frac{mm^2}{m}$$

Design shear resistance of sheet pile section is:

$$V_{pl,Rd} = \frac{A_v f_{yk}}{\sqrt{3}\gamma_{M0}} = 763.2 \frac{kN}{m}$$

'Degree of utilization' $\boxed{\Lambda = \frac{V_{Ed}}{V_{pl,Rd}} = 11\,\%}$ or 'Overdesign factor' $\boxed{ODF = \frac{V_{pl,Rd}}{V_{Ed}} = 9.3}$

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

Verification of resistance to anchor pull-out

Design pull-out resistance of anchor is: $F_{a,Rd} = R_{a,d} = 130\frac{kN}{m}$

'Degree of utilization' $\boxed{\Lambda = \frac{F_{a,Ed}}{F_{a,Rd}} = 73\,\%}$ or 'Overdesign factor' $\boxed{ODF = \frac{F_{a,Rd}}{F_{a,Ed}} = 1.37}$

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