

Example JRC-07
Anchored sheet pile wall
Verification of drained strength (limit state GEO)
Design Approach 2*

Design situation

Consider a sheet pile wall that retains $H_{nom} = 8.0\text{m}$ of dense sand with characteristic weight density

$\gamma_k = 20 \frac{\text{kN}}{\text{m}^3}$ and drained angle of shearing resistance $\varphi_k = 38^\circ$. The ground behind the wall is horizontal and

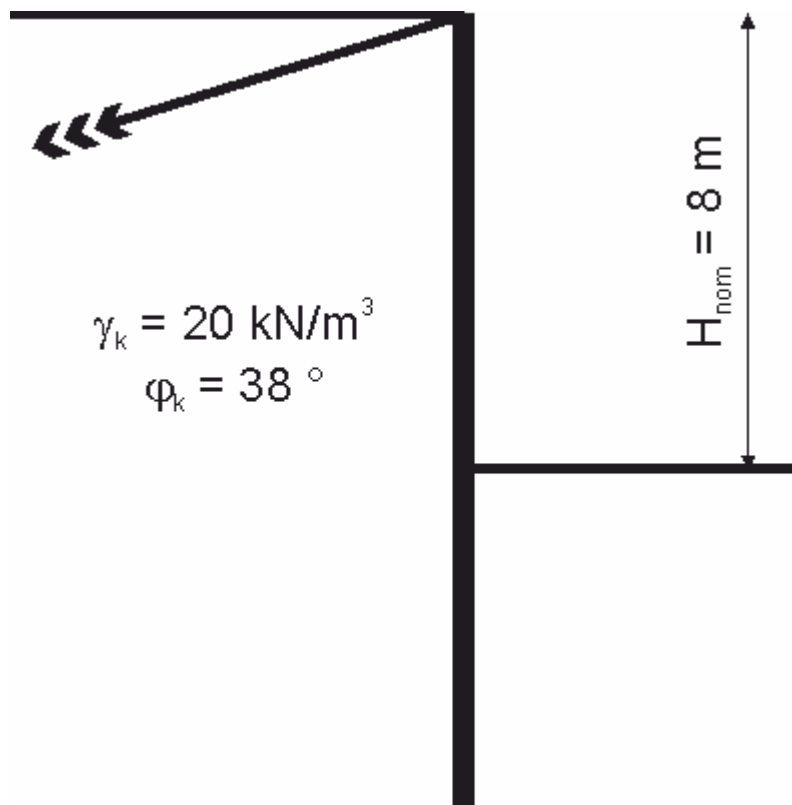
subject to a blanket surcharge (representing traffic loading) - but, for simplicity, we will assume $q_k = 0\text{kPa}$. The ground is dry.

The sheet pile is a Z section with flange thickness $t_f = 8.5\text{mm}$, web thickness $t_w = 8.5\text{mm}$, web height

$h = 302\text{mm}$, clutch-to-clutch breadth $b = 670\text{mm}$, elastic section modulus $W_{el} = 1400 \frac{\text{cm}^3}{\text{m}}$, and characteristic

yield strength $f_{yk} = 355\text{MPa}$.

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



Geometry

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

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

Material properties

Partial factors from Set M1: $\gamma_\varphi = 1$

Characteristic angle of shearing resistance:

$$\varphi_k = 38.0^\circ$$

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

$$\varphi_{cv,k} = 30^\circ$$

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

$$\delta_k = k\varphi_{cv,k} = 20^\circ$$

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

$$K_{a,h} = K_{a\gamma}(\varphi_k, \delta_k, 0, 0) = 0.21$$

$$K_{p,h} = K_{p\gamma}(\varphi_k, \delta_k, 0, 0) = 7.39$$

Actions

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

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

Ratio of variable and permanent partial factors is:

$$\gamma_{Q/G} = \frac{\gamma_Q}{\gamma_G} = 1.11$$

Assume a depth of embedment $d = 2.05\text{m}$

Overturning moment about anchor is:

$$M_{Ed,dst} = \left[\gamma_G K_{a,h} \times \left[\frac{1}{3} \gamma_k \times (H_d + d)^3 + \frac{1}{2} \gamma_{Q/G} \times q_k \times (H_d + d)^2 \right] \right] = 2180 \frac{\text{kNm}}{\text{m}}$$

Restoring moment about anchor is:

$$M_{Ed,stb} = \left[\frac{\gamma_{G,fav} K_{p,h} \times \left[\frac{1}{2} \gamma_k \times d^2 \times \left(H_d + \frac{2}{3}d \right) \right]}{\gamma_{Re}} \right] = 2188 \frac{\text{kNm}}{\text{m}}$$

Out of balance moment is:

$$\frac{M_{Ed,dst} - M_{Ed,stb}}{M_{Ed,stb}} = -0.4\%$$

Active thrust on retained side of wall is:

$$P_{a,Ed} = \left[\gamma_G K_{a,h} \times \left[\frac{1}{2} \gamma_k \times (H_d + d)^2 + \gamma_{Q/G} \times q_k \times (H_d + d) \right] \right] = 310 \frac{\text{kN}}{\text{m}}$$

Passive thrust on restraining side of wall is:

$$P_{p,Ed} = \left[\frac{\gamma_{G,fav} K_{p,h} \times \left(\frac{1}{2} \gamma_k \times d^2 \right)}{\gamma_{Re}} \right] = 222 \frac{\text{kN}}{\text{m}}$$

Hence net thrust is:

$$P_{Ed} = P_{a,Ed} - P_{p,Ed} = 88.2 \frac{\text{kN}}{\text{m}}$$

Hence axial force transferred to the anchor is:

$$F_{a,Ed} = \frac{P_{Ed}}{\cos(\theta)} = 101.9 \frac{\text{kN}}{\text{m}}$$

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

$$z = \sqrt{\frac{P_{Ed}}{\gamma_G K_{a,h} \times \frac{1}{2} \gamma_k}} = 5.63 \text{ m}$$

... and checked for accuracy using:

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

Hence the maximum bending moment in the wall is:

$$M_{Ed} = \left[P_{Ed} z - \gamma_G K_{a,h} \times \left(\frac{1}{6} \gamma_k \times z^3 + \frac{1}{2} \gamma_{Q/G} \times q_k \times z^2 \right) \right] = 331 \frac{\text{kNm}}{\text{m}}$$

Maximum shear force in the wall is:

$$V_{Ed} = P_{Ed} = 88.2 \frac{\text{kN}}{\text{m}}$$

Verifications

Verification of resistance to overturning

'Degree of utilization' $\Lambda = \frac{M_{Ed,dst}}{M_{Ed,stb}} = 100\%$ or 'Overdesign factor' $ODF = \frac{M_{Ed,stb}}{M_{Ed,dst}} = 1$

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:

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

'Degree of utilization' $\Lambda = \frac{M_{Ed}}{M_{c,Rd}} = 67\%$ or 'Overdesign factor' $ODF = \frac{M_{c,Rd}}{M_{Ed}} = 1.5$

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

Verification of shear resistance

Projected shear area is:

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

Design shear resistance of sheet pile section is:

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

'Degree of utilization' $\Lambda = \frac{V_{Ed}}{V_{pl,Rd}} = 12\%$ or 'Overdesign factor' $ODF = \frac{V_{pl,Rd}}{V_{Ed}} = 8.7$

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: $F_{a,Rd} = R_{a,d} = 130 \frac{\text{kN}}{\text{m}}$

'Degree of utilization' $\Lambda = \frac{F_{a,Ed}}{F_{a,Rd}} = 78\%$ or 'Overdesign factor' $ODF = \frac{F_{a,Rd}}{F_{a,Ed}} = 1.28$

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