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 \( H_{\text{nom}} = 8.0 \text{m} \) of dense sand with characteristic weight density \( \gamma_k = 20 \frac{kN}{m^3} \) 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 \( W_{el} = 1400 \frac{cm^3}{m} \), and characteristic yield strength \( f_{yk} = 355 \text{MPa} \).
An anchor with ultimate design resistance of \( R_{a,d} = 130 \frac{kN}{m} \) 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:
\[
H_d = H_{\text{nom}} + \min\{10\% \times H_{\text{nom}} \cdot 0.5\text{m}\} = 8.5 \text{m}
\]

**Material properties**
Partial factors from Set M1: \( \gamma_{\varphi} = 1 \)
Characteristic angle of shearing resistance:
\( \varphi_k = 38.0^\circ \)
Characterisitic 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:

\[ \frac{\gamma_Q}{\gamma_G} = 1.11 \]

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

Overturning moment about anchor is:

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

Restoring moment about anchor is:

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

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:

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

Passive thrust on restraining side of wall is:

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

Hence net thrust is:

\[ P_{Ed} = P_{a,Ed} - P_{p,Ed} = 88.2 \text{ kN m} \]

Hence axial force transferred to the anchor is:

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

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

\[ z = \frac{P_{Ed}}{\gamma_G K_{a,h} x \frac{1}{2} \gamma_k} = 5.63 \text{ m} \]
... and checked for accuracy using:

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

Hence the maximum bending moment in the wall is:

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

Maximum shear force in the wall is:

\[ V_{Ed} = P_{Ed} = 88.2 \text{kN/m} \]

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:

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

'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:

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

Design shear resistance of sheet pile section is:

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

'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: \( F_{a,Rd} = R_{a,d} = 130 \text{kN/m} \)

'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)