

Structural Report

Custom House, The Terrace,
Gravesend, Kent, DA12 2BW

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Produced By

Mehrdad Bahari BEng, MSC, PhD, MCIQB, CEng,
MICE, MStructE

Revision A

Checked by:

David King BSc, IEng, MIET, MCIQB, CBuildE, MCABE,
FICE

Commercial property



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1. Purpose

- 1.1. In November 2023, Michael Keckes of Mile Property Group (hereafter referred to as 'Mile') reached out to our firm concerning the objections posed by the Environment Agency (EA) on their development project. Mile, as the project's initiator, expressed concerns regarding the validity and implications of the objections raised. Accordingly, our Adkins Consultants Ltd was commissioned to undertake an analysis of the EA's reservations, delving into the specifics and potential ramifications they hold for the proposed development.

2. Project Overview

- 1.1. The site is positioned in the heart of Gravesend, Kent, and pinpointed by OS coordinates 565199 174363, the subject site spans an approximate area of 0.4 hectares. Dominating this parcel is the Grade II Listed Custom House, a notable building previously utilised as offices and vacant since the year 2018.
- 1.2. The redevelopment strategy proposes a conversion of the Custom House alongside its supplementary structures. This plan aims to cultivate a residential precinct of 27 units, thoughtfully designed to incorporate essential amenities and landscaping. The intent is to meld the historical essence of the Custom House with the practicalities and aesthetics of contemporary living, creating a unique and desirable living space.
- 1.3. The existing sea wall is steel sheet piled wall encased in concrete & masonry. The length steel sheet piling encased in concrete and clad in masonry, with a reinforced concrete capping beam (hereafter referred to as 'Main Wall').
- 1.4. The length of wall at the North-West of the development site, comprises of cantilever steel sheet piling, with a reinforced concrete capping beam (hereafter referred to as 'Return Wall').



Figure 1 The general arrangement of the existing sea wall.

2.1.3.Tidal range:

2.1.3.1. The Mean Sea Level (MSL) at Gravesend, when referenced to Ordnance Datum (AOD), is approximately 1.98 meters AOD.

2.1.3.2. Mean High Water Springs (MHWS): Approximately 5.3 meters AOD at Gravesend.

2.1.4.Storm Surge height (Herrington Consulting, 2022): The maximum water level recorded at Gravesend can reach up to approximately 5.7 meters AODN during high tide combined with storm surges.

Sea wall height above high tide (freeboard):

$$8\text{mOD} - 5.7\text{mOD} = 2.3\text{mOD}$$

Design water level: high tide + Storm Surge= 5.7mOD

2.2. Geotechnical Investigations:

2.2.1.The soil in the area predominantly consists of medium-dense gravelly clay, which has been thoroughly examined as part of the soil investigation. The detailed findings of this investigation have been appended to the current report for your reference.

2.2.2.The table below presents a summary of the soil strata encountered during the investigation, highlighting the key characteristics and composition of the different layers within the site. This information is crucial for understanding the site's geotechnical properties and will inform the design and construction processes.

Depth (m)	Soil
2.00	Very soft silty clay
3.40	Medium dense fine to coarse gravel with some silty clay
11.00	Medium dense fine to coarse gravel (IV to V)

17.00	Fragmented and putty chalk with flints (II to III)
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2.3. Hydrostatic Loads:

2.3.1. Hydrostatic pressure:

$$P_{\text{base}} = \gamma_w \cdot h$$

2.3.2. Wave Force: using Goda's method

Wave Force Components:

Density of Seawater: 9.81kN/m³

Acceleration due to Gravity: 9.81 m/s²

Dynamic Pressure Coefficient(K_d): 1.25

Vertical Coefficient (K_v): 0.6

Horizontal Force

$$F_h = 0.5 \cdot \rho \cdot g \cdot H^2 \cdot K_d$$

$$= 0.5 * 1025 * 9.81 * (1.5)^2 * 1.25 = 10 \text{ kN/m}$$

Vertical Force

$$F_v = 0.6 \cdot \rho \cdot g \cdot H^2 \cdot K_v$$

$$= 0.6 * 1025 * 9.81 * (2)^2 * 0.6 = 7 \text{ kN/m}$$

4. Structural Analysis and Design

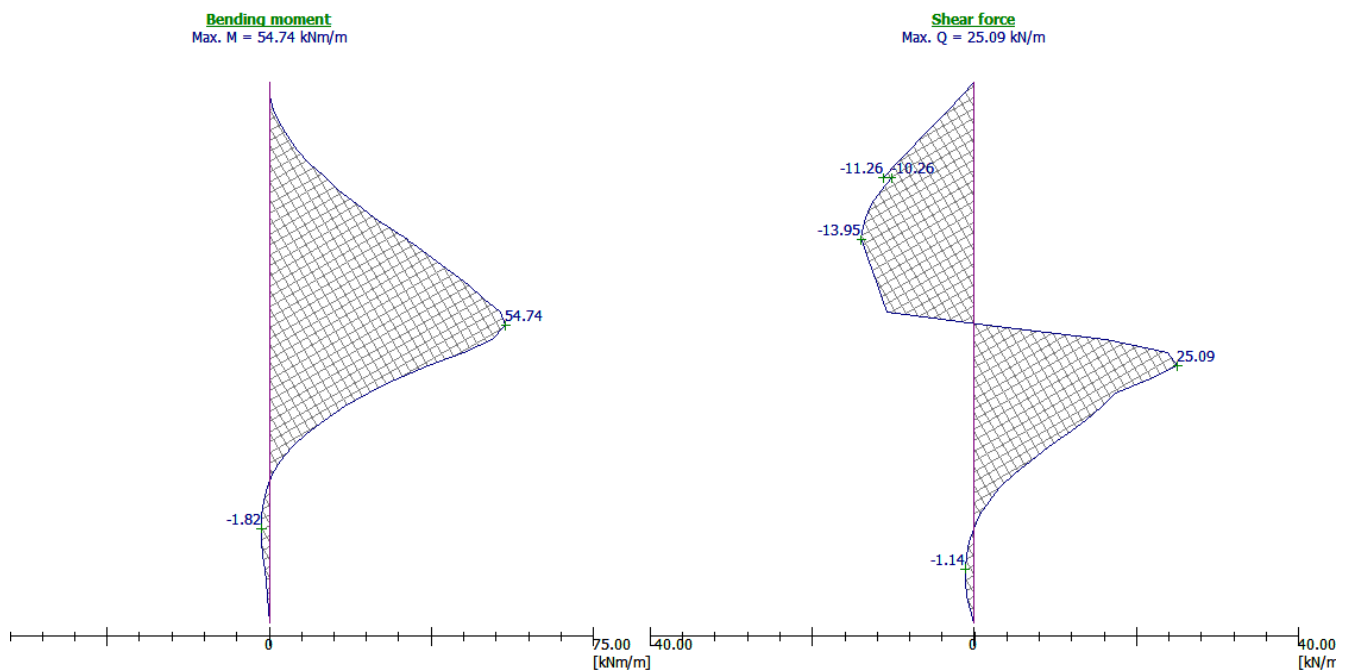
Seawall Geometry

- Height of Seawall (H_s) = 8mOD-4.20mOD= 3.8mOD

$$H_s = \text{DWL} + \text{Freeboard}$$

- Sheet Pile Length (L)= 3.8m x 2.0= 7.6m BGL plus 3.8m AGL=11.4m
 - Go for 13.00m to match the existing

Note: please see the appendix for the full results.



- Material properties:
- Yield strength $f_y = 355.00$ MPa
- Partial factors:
- Coefficient of cross-section resistance $\gamma_{M0} = 1.00$
- Cross-section resistance:

Bending capacity $M_{c,Rd} = W \cdot f_y / \gamma_{M0} = 681.60$ kNm/m

Shear capacity $V_{c,Rd} = I \cdot t / S \cdot f_y / (\sqrt{3} \cdot \gamma_{M0}) = 1394.65$ kN/m

- [Verification of steel section according to EN 1993-1-1](#)
- All construction stages are taken into the analysis.
- Reduct. coefficient of bearing capacity = 1.00
- Internal forces per 1 m of wall

$M_{\max} = 54.74$ kNm/m; $Q = 1.49$ kN/m

$Q_{\max} = 25.09 \text{ kN/m}; \quad M = 36.81 \text{ kNm/m}$

- Verification of max. moment $M_{\max} + Q$:
- Bending verification:
- $M_{\max}/M_{c,Rd} = 0.080 \leq 1$ **Is satisfied**
- Shear verification:
- $Q/V_{c,Rd} = 0.001 \leq 1$ **Is satisfied**
- Verification of plane state of stress:

Normal stress $\sigma_{x,Ed} = 26.87 \text{ MPa}$

Shear stress $\tau_{Ed} = 0.14 \text{ MPa}$

- Verification: $(\sigma_{x,Ed}/(f_y/\gamma_{M0}))^2 + 3*(\tau_{Ed}/(f_y/\gamma_{M0}))^2 = 0.006 \leq 1$ **Is satisfied**
- Verification of max. shear force $Q_{\max} + M$:
- Bending verification:
- $M/M_{c,Rd} = 0.054 \leq 1$ **Is satisfied**
- Shear verification:
- $Q_{\max}/V_{c,Rd} = 0.018 \leq 1$ **Is satisfied**
- Verification of plane state of stress:

Normal stress $\sigma_{x,Ed} = 18.07 \text{ MPa}$

Shear stress $\tau_{Ed} = 2.36 \text{ MPa}$

- Verification: $(\sigma_{x,Ed}/(f_y/\gamma_{M0}))^2 + 3*(\tau_{Ed}/(f_y/\gamma_{M0}))^2 = 0.003 \leq 1$ **Is satisfied**
- **Cross section is SATISFACTORY**

Type of wall :

Cross-section name : ☐ User def.

Section length : [m]

Cross-section

Name : **GU 20N**



Information

$A = 1.72E-02 \text{ [m}^2/\text{m]}$	$I = 4.13E-04 \text{ [m}^4/\text{m]}$
$W_{y1} = 1.920E-03 \text{ [m}^3/\text{m]}$	$W_{pl,y} = 2.280E-03 \text{ [m}^3/\text{m]}$

5. Verification of Analysis and Design using Tekla Tedds Calculations

STEEL SHEET PILING ANALYSIS & DESIGN

In accordance with BS EN1997-1:2004 - Code of Practice for Geotechnical design and the UK National Annex

Geometry

Total length of sheet pile provided;	$H_{pile} = 14040$ mm
Number of different types of soil;	$N_s = 1$
Retained height;	$d_{ret} = 3200$ mm
Depth of unplanned excavation;	$d_{ex} = 500$ mm
Total retained height;	$d_s = 3700$ mm
Angle of retained slope;	$\beta = 0.0$ deg
Depth from GL to top of water table retained side;	$d_w = 2300$ mm
Depth from GL to top of water table retaining side;	$d_{wp} = 3700$ mm

Loading

Soil layer 1

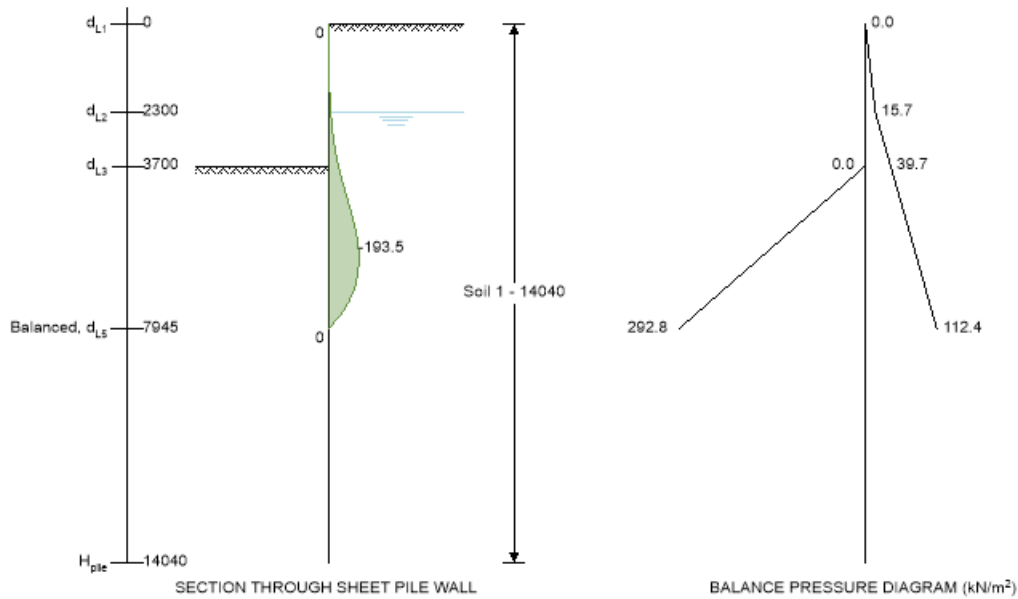
Characteristic shearing resistance angle;	$\phi'_{k,s1} = 30.0$ deg
Characteristic wall friction angle;	$\delta_{k,s1} = 20.0$ deg
Moist density of soil;	$\gamma_{m,s1} = 17.0$ kN/m ³
Characteristic saturated density of retained soil;	$\gamma_{s,s1} = 19.5$ kN/m ³
Height of soil 1;	$h_1 = 14040$ mm

Partial factors on actions - Section A.3.1 - Combination 1

Permanent unfavourable action;	$\gamma_G = 1.35$
Permanent favourable action;	$\gamma_{G,f} = 1.00$
Variable unfavourable action;	$\gamma_Q = 1.50$
Angle of shearing resistance;	$\gamma_\psi = 1.00$
Weight density;	$\gamma_\gamma = 1.00$

Design soil properties - soil 1

Design effective shearing resistance angle;	$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_\psi) = 30.0$ deg
Design wall friction angle;	$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_\psi) = 20.0$ deg
Design moist density of retained soil;	$\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.0$ kN/m ³
Design saturated density of retained soil;	$\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 19.5$ kN/m ³
Design buoyant density of retained soil;	$\gamma_{d,d1} = \gamma_{s,d1} - \gamma_w = 9.7$ kN/m ³
Active pressure using Coulomb theory;	$K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))^2}) = 0.297$
Passive pressure using Coulomb theory;	$K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))]^2) = 6.105$



Overburden on active side

Overburden at 0 mm below GL in soil 1;

$$OB'_{a11} = 0 \text{ kN/m}^2 = 0.0 \text{ kN/m}^2$$

Overburden at 2300 mm below GL in soil 1;

$$OB'_{a21} = \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 52.8 \text{ kN/m}^2$$

Overburden at 3700 mm below GL in soil 1;

$$OB'_{a31} = \gamma_G \times \gamma_{d,d1} \times h_{a2} + OB'_{a21} = 71.1 \text{ kN/m}^2$$

Overburden at 7945 mm below GL in soil 1;

$$OB'_{a41} = \gamma_G \times \gamma_{d,d1} \times h_{a3} + OB'_{a31} = 126.6 \text{ kN/m}^2$$

Overburden on passive side

Overburden at 3700 mm below GL in soil 1;

$$OB'_{p31} = 0 \text{ kN/m}^2 = 0.0 \text{ kN/m}^2$$

Overburden at 7945 mm below GL in soil 1;

$$OB'_{p41} = \gamma_{G,f} \times \gamma_{d,d1} \times h_{p3} + OB'_{p31} = 41.1 \text{ kN/m}^2$$

Pressure on active side

Active at 0 mm below GL in soil 1;

$$p'_{a11} = K_{a1} \times OB'_{a11} = 0.0 \text{ kN/m}^2$$

Active at 2300 mm below GL in soil 1;

$$p'_{a21} = K_{a1} \times OB'_{a21} = 15.7 \text{ kN/m}^2$$

Active at 3700 mm below GL in soil 1;

$$p'_{a31} = K_{a1} \times OB'_{a31} + \gamma_G \times \gamma_w \times (d_{L3} - d_w) = 39.7 \text{ kN/m}^2$$

Active at 7945 mm below GL in soil 1;

$$p'_{a41} = K_{a1} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = 112.4 \text{ kN/m}^2$$

Pressure on passive side

Passive at 3700 mm below GL in soil 1;

$$p'_{p31} = K_{p1} \times OB'_{p31} + \gamma_{G,f} \times \gamma_w \times (d_{L3} - \max(d_s, d_w)) = 0.0 \text{ kN/m}^2$$

Passive at 7945 mm below GL in soil 1;

$$p'_{p41} = K_{p1} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = 292.8 \text{ kN/m}^2$$

By iteration the depth at which the active moments equal the passive moments has been determined as 7945 mm as follows:-

Active moment about 7945 mm

Moment level 1;

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = 0.0 \text{ kNm/m}$$

Moment level 1;

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = 115.7 \text{ kNm/m}$$

Moment level 2;

$$M_{a21} = 0.5 \times p'_{a21} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = 56.9 \text{ kNm/m}$$

Moment level 2;

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = 130.9 \text{ kNm/m}$$

Moment level 3;

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = 238.3 \text{ kNm/m}$$

Moment level 3;

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = 337.6 \text{ kNm/m}$$

Passive moment about 7945 mm

Moment level 3;

$$M_{p31} = 0.5 \times p'_{p31} \times h_{p3} \times ((H - d_{L4}) + 2/3 \times h_{p3}) = 0.0 \text{ kNm/m}$$

Moment level 3;

$$M_{p32} = 0.5 \times p'_{p41} \times h_{p3} \times ((H - d_{L4}) + 1/3 \times h_{p3}) = 879.3 \text{ kNm/m}$$

Total moments about 7945 mm

Total active moment;	$\Sigma M_a = 879.6 \text{ kNm/m}$
Total passive moment;	$\Sigma M_p = 879.6 \text{ kNm/m}$

Required pile length

Length of pile required to balance moments;	$H = 7945 \text{ mm}$
Depth of equal pressure;	$d_{\text{contra}} = 4465 \text{ mm}$
Add 20% below this point;	$d_{\text{e-add}} = 1.2 \times (H - d_{\text{contra}}) = 4175 \text{ mm}$
Minimum required pile length;	$H_{\text{total}} = d_{\text{contra}} + d_{\text{e-add}} = 8641 \text{ mm}$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis);	$M_{\text{pile}} = \max(\text{abs}(M_{\text{min}}), \text{abs}(M_{\text{max}})) / 1\text{m} = 193.5 \text{ kNm/m}$
Maximum shear force in pile (from analysis);	$V_{\text{pile}} = 241.9 \text{ kN/m}$
Nominal yield strength of pile;	$f_{y,\text{pile}} = 270 \text{ N/mm}^2$
Name of pile;	Arcelor GU(20N)
Classification of pile;	2
Plastic modulus of pile;	$W_{\text{pl,y}} = 2280 \text{ cm}^3/\text{m}$

Shear buckling of web (cl.5.2.2(6))

Width of section;	$c = h / \sin(\alpha_{\text{pile}}) = 510 \text{ mm}$
Thickness of web;	$t_w = s = 9.5 \text{ mm}$
	$\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y,\text{pile}})} = 0.933$
	$c / t_w = 53.7 = 57.5 \times \varepsilon \leq 72 \times \varepsilon$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2);	$\beta_s = 0.75$
Design bending resistance (eqn.5.2);	$M_{c,Rd} = W_{\text{pl,y}} \times f_{y,\text{pile}} \times \beta_s / \gamma_{M0} = 461.7 \text{ kNm/m}$

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6);	$A_v = s \times (h - t) = 3969 \text{ mm}^2$
Design shear resistance (eqn.5.5);	$V_{s,Rd} = A_v \times f_{y,\text{pile}} / (\sqrt{3} \times \gamma_{M0}) / b = 1031.2 \text{ kN/m}$

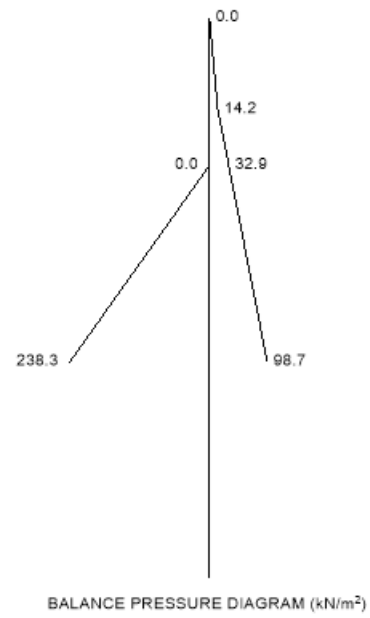
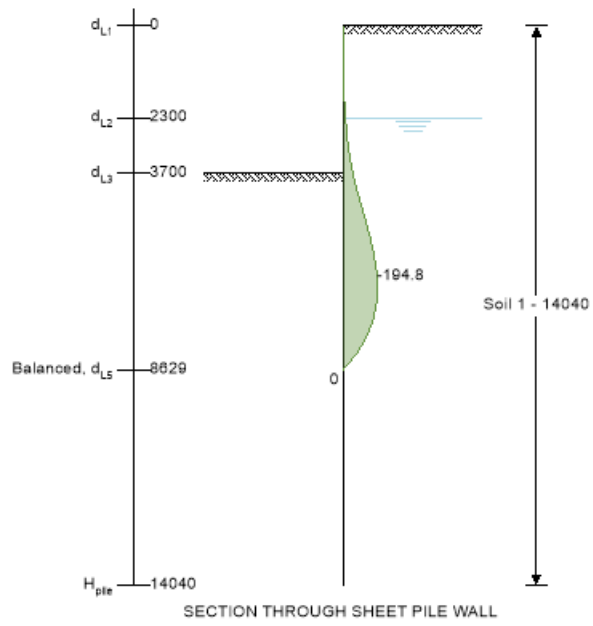
PASS - Shear capacity exceeds shear in pile

Partial factors on actions - Section A.3.1 - Combination 2

Permanent unfavourable action;	$\gamma_G = 1.00$
Permanent favourable action;	$\gamma_{G,r} = 1.00$
Variable unfavourable action;	$\gamma_Q = 1.30$
Angle of shearing resistance;	$\gamma_\psi = 1.25$
Weight density;	$\gamma_\gamma = 1.00$

Design soil properties - soil 1

Design effective shearing resistance angle;	$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_\psi) = 24.8 \text{ deg}$
Design wall friction angle;	$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_\psi) = 16.2 \text{ deg}$
Design moist density of retained soil;	$\gamma_{m,d1} = \gamma_m / \gamma_\gamma = 17.0 \text{ kN/m}^3$
Design saturated density of retained soil;	$\gamma_{s,d1} = \gamma_s / \gamma_\gamma = 19.5 \text{ kN/m}^3$
Design buoyant density of retained soil;	$\gamma_{a,d1} = \gamma_{s,d1} - \gamma_w = 9.7 \text{ kN/m}^3$
Active pressure using Coulomb theory;	$K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta)))})^2) = 0.364$



Passive pressure using Coulomb theory;

$$K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d)))^2}] = 3.977$$

Overburden on active side

Overburden at 0 mm below GL in soil 1;

$$OB'_{a11} = 0 \text{ kN/m}^2 = 0.0 \text{ kN/m}^2$$

Overburden at 2300 mm below GL in soil 1;

$$OB'_{a21} = \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} = 39.1 \text{ kN/m}^2$$

Overburden at 3700 mm below GL in soil 1;

$$OB'_{a31} = \gamma_G \times \gamma_{d,d1} \times h_{a2} + OB'_{a21} = 52.7 \text{ kN/m}^2$$

Overburden at 8629 mm below GL in soil 1;

$$OB'_{a41} = \gamma_G \times \gamma_{d,d1} \times h_{a3} + OB'_{a31} = 100.4 \text{ kN/m}^2$$

Overburden on passive side

Overburden at 3700 mm below GL in soil 1;

$$OB'_{p31} = 0 \text{ kN/m}^2 = 0.0 \text{ kN/m}^2$$

Overburden at 8629 mm below GL in soil 1;

$$OB'_{p41} = \gamma_{G,f} \times \gamma_{d,d1} \times h_{p3} + OB'_{p31} = 47.8 \text{ kN/m}^2$$

Pressure on active side

Active at 0 mm below GL in soil 1;

$$p'_{a11} = K_{a1} \times OB'_{a11} = 0.0 \text{ kN/m}^2$$

Active at 2300 mm below GL in soil 1;

$$p'_{a21} = K_{a1} \times OB'_{a21} = 14.2 \text{ kN/m}^2$$

Active at 3700 mm below GL in soil 1;

$$p'_{a31} = K_{a1} \times OB'_{a31} + \gamma_G \times \gamma_w \times (d_{L3} - d_w) = 32.9 \text{ kN/m}^2$$

Active at 8629 mm below GL in soil 1;

$$p'_{a41} = K_{a1} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) = 98.7 \text{ kN/m}^2$$

Pressure on passive side

Passive at 3700 mm below GL in soil 1;

$$p'_{p31} = K_{p1} \times OB'_{p31} + \gamma_{G,f} \times \gamma_w \times (d_{L3} - \max(d_s, d_w)) = 0.0 \text{ kN/m}^2$$

Passive at 8629 mm below GL in soil 1;

$$p'_{p41} = K_{p1} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) = 238.3 \text{ kN/m}^2$$

By iteration the depth at which the active moments equal the passive moments has been determined as 8629 mm as follows:-

Active moment about 8629 mm

Moment level 1;

$$M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) = 0.0 \text{ kNm/m}$$

Moment level 1;

$$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) = 116.2 \text{ kNm/m}$$

Moment level 2;

$$M_{a21} = 0.5 \times p'_{a21} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) = 58.4 \text{ kNm/m}$$

Moment level 2;

$$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) = 124.3 \text{ kNm/m}$$

Moment level 3;

$$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) = 266.5 \text{ kNm/m}$$

Moment level 3;

$$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) = 399.5 \text{ kNm/m}$$

Passive moment about 8629 mm

Moment level 3;

$$M_{p31} = 0.5 \times p'_{p31} \times h_{p3} \times ((H - d_{L4}) + 2/3 \times h_{p3}) = 0.0 \text{ kNm/m}$$

Moment level 3;

$$M_{p32} = 0.5 \times p'_{p41} \times h_{p3} \times ((H - d_{L4}) + 1/3 \times h_{p3}) = 964.9 \text{ kNm/m}$$

Total moments about 8629 mm

Total active moment;

$$\Sigma M_a = 964.8 \text{ kNm/m}$$

Total passive moment;

$$\Sigma M_p = 964.8 \text{ kNm/m}$$

Required pile length

Length of pile required to balance moments;

$$H = 8629 \text{ mm}$$

Depth of equal pressure;

$$d_{contra} = 4640 \text{ mm}$$

Add 20% below this point;

$$d_{e_add} = 1.2 \times (H - d_{contra}) = 4787 \text{ mm}$$

Minimum required pile length;

$$H_{total} = d_{contra} + d_{e_add} = 9427 \text{ mm}$$

Pass - Provided length of sheet pile greater than minimum required length of pile

Pile capacity (EN1993-5)

Maximum moment in pile (from analysis);

$$M_{pile} = \max(\text{abs}(M_{min}), \text{abs}(M_{max})) / 1\text{m} = 194.8 \text{ kNm/m}$$

Maximum shear force in pile (from analysis);

$$V_{pile} = 213.7 \text{ kN/m}$$

Nominal yield strength of pile;

$$f_{y_pile} = 270 \text{ N/mm}^2$$

Name of pile;

Arcelor GU(20N)

Classification of pile;

2

Plastic modulus of pile;

$$W_{pLy} = 2280 \text{ cm}^3/\text{m}$$

Shear buckling of web (cl.5.2.2(6))

Width of section;

$$c = h / \sin(\alpha_{pile}) = 510 \text{ mm}$$

Thickness of web;

$$t_w = s = 9.5 \text{ mm}$$

$$\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_{y_pile})} = 0.933$$

$$c / t_w = 53.7 = 57.5 \times \varepsilon \leq 72 \times \varepsilon$$

PASS - Shear buckling of web within limits

Bending

Interlock reduction factor (cl.5.2.2);

$$\beta_B = 0.75$$

Design bending resistance (eqn.5.2);

$$M_{c,Rd} = W_{pLy} \times f_{y_pile} \times \beta_B / \gamma_{M0} = 461.7 \text{ kNm/m}$$

PASS - Moment capacity exceeds moment in pile

Shear

Projected shear area of web (eqn.5.6);

$$A_v = s \times (h - t) = 3969 \text{ mm}^2$$

Design shear resistance (eqn.5.5);

$$V_{d,Rd} = A_v \times f_{y_pile} / (\sqrt{3} \times \gamma_{M0}) / b = 1031.2 \text{ kN/m}$$

PASS - Shear capacity exceeds shear in pile

6. Sheet Pile Cover Design and Corrosion Protection

6.1. Concrete cover:

Calculate Required Depth (h)

For the moment capacity calculation:

$$M_u = f_{ck} \cdot b \cdot d^2 \cdot k$$

f_{ck} : Characteristic strength of concrete |

b : Width of the section (250 mm).

d : Effective depth (to be calculated).

k : Coefficient depending on reinforcement (typically 0.138 for balanced sections).

$$M_u = 15 \text{ kN.m}$$

$$d = 41.75 \text{ mm}$$

This is impractically small, suggesting the need for a larger effective depth. Let's try assuming a practical depth, say 200 mm (common in practice).

Checking shear capacity:

$$V_u = \tau_c \cdot b \cdot d$$

Where:

- τ_c : Shear strength of concrete (varies, assume 0.25 MPa for conservative design).
- b : Width (250 mm).
- d : Effective depth (200 mm).

$$V_u = 13 \text{ kN} = 13,000 \text{ N}$$

Reinforcement Calculation:

$$M_u = 0.87 f_y A_s (d - 0.42 x_u)$$

Where:

- f_y : Yield strength of steel (assume 500 MPa).
- A_s : Area of tensile steel (to be calculated).
- d : Effective depth (200 mm).
- x_u : Depth of the neutral axis (assume 0.5d for simplicity).

Solving for A_s :

$$15,000 = 0.87 \cdot 500 \cdot A_s \cdot 158$$

$$A_s = \frac{15,000}{0.87 \cdot 500 \cdot 158} = 0.220 \text{ cm}^2 = 220 \text{ mm}^2$$

Width (b): 250 mm

Depth (h): 250 mm (with effective depth $d=200$ mm)

Tensile Reinforcement (A_s): 220 mm² (use minimum 2-10 mm diameter bars or equivalent)

Shear Reinforcement: the provided area of the steel sheet is larger than 220mm², therefore, additional bars are not required.

6.2. Concrete Mix Design

- **Low Permeability Concrete:** Use a concrete mix with low water-cement ratio (w/c ratio < 0.45) to reduce permeability.
- **Additives:** Include supplementary cementitious materials (SCMs) like fly ash, slag, or silica fume to enhance durability and reduce chloride ion penetration.

- **Admixtures:** Incorporate corrosion inhibitors (e.g., calcium nitrite) into the mix to provide additional protection to the reinforcing steel.

6.2.1. Adequate Concrete Cover

- **Cover Thickness:** Ensure sufficient concrete cover over the reinforcement bars. Typically, a minimum cover of 75mm is recommended for aggressive environments to protect against chloride ingress and carbonation.
- **Quality Control:** Ensure proper placement and compaction of concrete to eliminate voids and honeycombs.

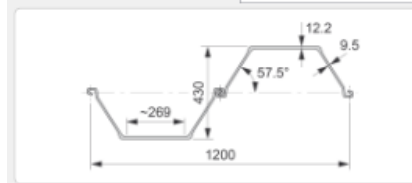
- **Epoxy-Coated Rebars:** Apply a fusion-bonded epoxy coating to the reinforcement bars to provide a barrier against corrosion.

6.2.2. Additional steel thickness:

- A detailed analysis has been conducted to assess the potential corrosion that may occur over a 100-year period from the installation date. Based on this analysis, the thickness of the steel pile has been deliberately increased to account for the expected material loss due to corrosion. The enhanced thickness ensures that even after 100 years, the reduced thickness of the steel pile will still meet the necessary structural requirements, particularly in terms of withstanding the maximum bending moments and shear forces. This proactive measure guarantees the long-term integrity and durability of the structure, providing confidence that it will perform as intended throughout its design life.
- Maximum bending moment from the structural analysis 55 kN.m
- Required section modulus (Z):
 - $$Z = \frac{M_{max}}{f_y} = \frac{55000}{355} = 154.92 \text{ cm}^3/\text{m}$$
- GU 20N sheet pile

Sheet pile section

Type
 Name
 Sort by



AZ : common
☐ interlocks crimped/
 welded
 Filter
☐ Use Wel only
☐ Only valid sheet pile
☐ $I_{y \min}$ cm⁴/m
☐ $t_{w \min}$ mm
☐ $t_{f \min}$ mm

Steel grade

☐ Show all
☒ Reduce f_y to obtain Class 3

ϵ 0.814
 $(b/t_f)/\epsilon$ 29
 Class ini. 2

Sheet pile properties (initial values)

$W_{el, y}$	1,920 cm ² /m	$W_{pl, y}$	2,280 cm ² /m
I_y	41,320 cm ⁴ /m	A	172.3 cm ² /m
t_f	12.20 mm	t_w	9.50 mm
h	430.0 mm	α	57.5 °
b	288.5 mm	c	247.7 mm
A_v	66.2 cm ² /m	S_y	1,125 cm ² /m
r_o	15.0 mm	mass	135.2 kg/m ²
B	1,200 mm		

Corrosion rates

Show table

☒ Eurocode 3 - Part 5
☐ Manual

Eurocode 3 - Part 5. Table 4.1 and 4.2

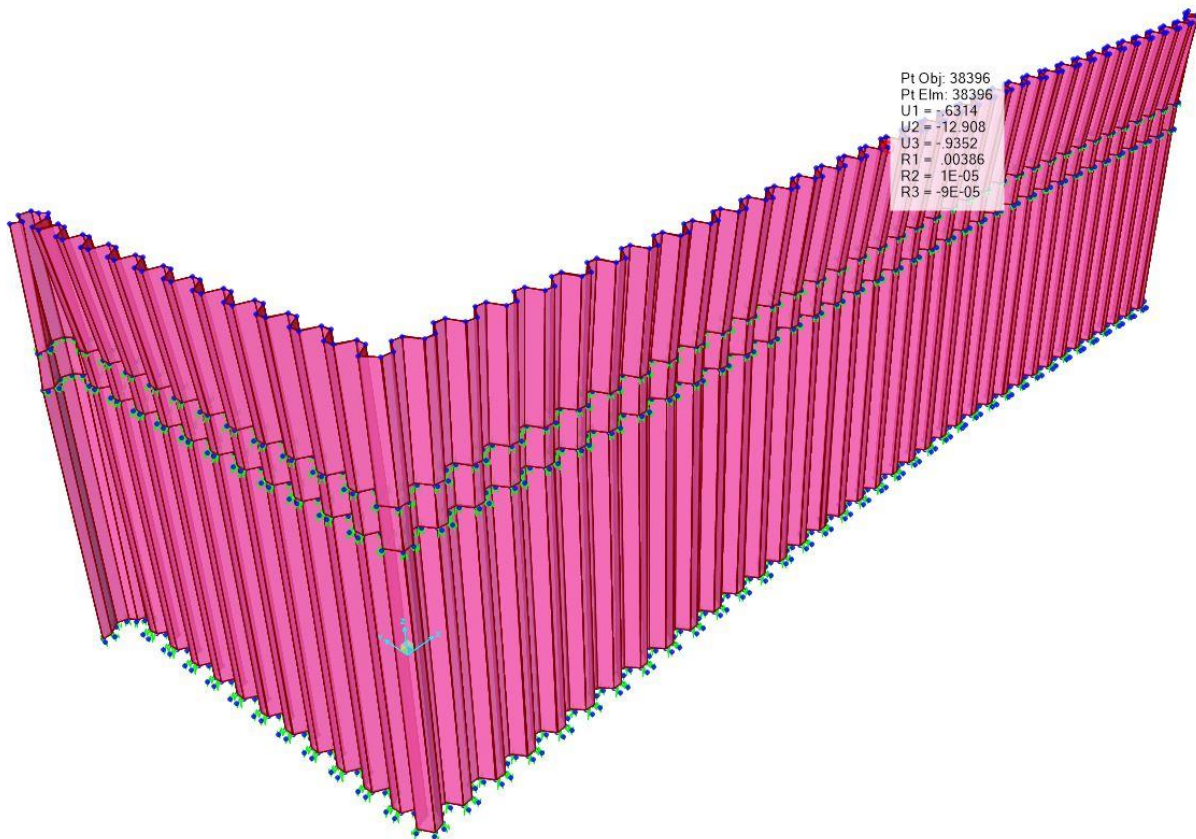
Zone	z bottom [m]	Corrosion front [mm]	Corrosion back [mm]	Protection Front [years]	Protection Back [years]	Total corrosion Front [mm]	Total corrosion Back [mm]	
1	4.00	Water. Sea water in temperate 3.50	Water. Sea water in temperate 3.50	0	0	3.50	3.50	×
2	-8.00	Water. Sea water in temperate 3.50	Water. Sea water in temperate 3.50	0	0	3.50	3.50	×



The corrosion analysis indicates that the maximum corrosion after 100 years, under Class C3 conditions, will result in a material loss of less than 5.04 mm. At that stage, the section modulus of the sheet pile will be 1310 cm³/m, which remains higher than the required section modulus. This ensures that the structural integrity of the sheet pile will be maintained even after a century of exposure to corrosive conditions.

7. Stability Analysis and Maximum Deflection of the Sheet Pile

A comprehensive finite element model of the sheet piling has been developed to assess its stability and determine the maximum deflection under tidal and wave forces. The analysis revealed a maximum deflection of 12.908 mm, which remains well within acceptable limits, as it is less than the L/240 ratio of the unsupported length of the sheet pile. This confirms that the design meets safety standards and is expected to perform reliably under high tide-level forces.



8. Maintenance Regime

8.1. Visual Inspections

- Frequency: Annually
- Purpose: To identify any visible signs of damage, corrosion, or structural weaknesses.
- Actions:
 - Inspect for surface rust, cracks, deformation, or displacement of sheet piles.
 - Check for signs of erosion or undermining at the base of the wall.
 - Record all findings in an inspection report and update the maintenance log.
 - Identify any immediate repairs needed to address visible corrosion or physical damage.

8.2. Intrusive OR Ultrasonic Surveys

- Frequency: the first one to be carried out after 3 years from the completion of the construction and then every 10 years.
- Purpose: To assess the internal condition of the steel sheet piles, including corrosion levels and structural integrity.
- Actions:
 - Conduct ultrasonic thickness testing to measure remaining wall thickness and compare with original specifications.
 - Perform corrosion rate analysis to project future material loss.
 - Evaluate the condition of any protective coatings or cathodic protection systems.
 - If significant degradation is detected, schedule more frequent inspections or consider early maintenance interventions.
 - Document findings and update the structural integrity assessment.
 - **Trigger for Corrective Maintenance:** If the thickness of the steel sheet pile is found to have reduced by more than 4 mm, schedule and conduct corrective maintenance.

8.3. Corrective Maintenance

- **Trigger:** As identified by visual inspections or intrusive surveys.

- **Purpose:** To repair any damage or degradation that could compromise the wall's integrity or lifespan.
- **Actions:**
 - Repair or replace damaged sheet pile section, especially if the thickness has fallen below acceptable levels.
 - Reapply or repair protective coatings to prevent further corrosion.
 - Restore any areas where erosion or scouring has occurred at the base of the wall.
 - Implement temporary measures to address immediate threats, such as deploying additional erosion protection.

8.4. Long-Term Monitoring and Planning

- **Frequency:** Every 25 years
- **Purpose:** To review the overall performance of the sea wall and plan for any major refurbishments or upgrades.
- **Actions:**
 - Conduct a comprehensive structural review, including both visual and intrusive assessments.
 - Plan for any significant repairs or overhauls that may be necessary to ensure the wall meets its 100-year design life.
 - Update the maintenance strategy based on new technologies or changes in environmental conditions.

Maintenance Schedule

Activity	Frequency	Actions
Visual Inspection	Annually	Inspect for visible signs of corrosion, damage, or erosion. Record and address any immediate issues.
Intrusive Survey	Every 10 years	Conduct ultrasonic testing, corrosion analysis, and structural assessments. Document and plan actions.
Corrective Maintenance	As needed	Repair or replace damaged piles, restore protective coatings, address erosion.
Long-Term Planning	Every 25 years	Comprehensive review and planning for major refurbishments or upgrades.

9. Note for the client and contractors

- 9.1. The new sea defence has been designed with a minimum lifespan of 100 years.
- 9.2. It is imperative that the contractor familiarises themselves with the soil reports appended to this document.
- 9.3. The sheet pile has been engineered to ensure both stability and structural integrity, with the appropriate depth and section modulus specified.
- 9.4. During the construction stage, the piling contractor is responsible for designing the piles in accordance with the site conditions.
- 9.5. A detailed construction method statement has been included with this report, alongside all relevant drawings and plans.
- 9.6. Please note that it is the responsibility of the client or contractor to obtain the necessary permissions and approvals from the Environment Agency (EA) and local authorities before commencing construction.
- 9.7. The contractor is responsible for providing the necessary temporary supports during the construction stage including the flooding protection.

Adkins Consultants Terms and Conditions

Terms and Conditions

1. Additional Services

In the event of additional services being required, the fees will be adjusted by prior agreement between us.

2. Diligence and Care

Adkins Consultants will exercise reasonable care, skill and diligence in the performance of the Services.

3. Disbursements and Expenses

Disbursements and expenses are not included in our quoted fees unless stated to the contrary in our fee proposal.

4. Document Formats

The proposed fees allow for a digital copy usually in PDF format.

Hard copies of documents may be subject to a fee dependent on the type of document. Our printing costs are available upon request.

5. Copyright

Adkins Consultants retain copyright in any document and works they produce; in all cases the copyright will remain vested in Adkins Consultants. The Client, subject to payment of fees and disbursements due under the Agreement, will have a license to copy and use all such documents for any purpose related to the project in question. They will not have a license to use these documents for any other project and no liability will be held by Adkins Consultants.

6. Value Added Tax

All quotations are subject to the addition of VAT at the current rate.

7. Liability

7.1 None of our employees, partners or consultants individually has a contract with you or owes you a duty of care or personal responsibility. You agree that you will not bring any claim against any such individuals personally in connection with our services."

7.2 The liability of Adkins Consultants Ltd to the client, (or any third party claiming through the client) shall in no circumstance (except in case of death or personal injury) exceed the lesser of:

(a) The amount that can be recovered from our professional indemnity insurance

(b) We will have proportionate liability and this will be limited to 25% (twenty five percent) of any loss.

(c) The diminution in value of the property concerned.

7.3 Adkins Consultants shall have no liability to the Client (or to any third party claiming through the Client) whether in contract or in tort (including but not limited to negligence) or for breach of statutory duty or otherwise for any claim arising in connection with:-

(a) pollution, contamination, terrorism, asbestos or any related risk or

(b) designs or reports prepared by other professionals and specialist sub-contractors/suppliers.

7.4 The limitation period, before which any claim must commence, is six years.

7.5 If you suffer loss as a result of our breach of contract or negligence, our liability shall be limited to a just and equitable proportion of your loss having regard to the extent of responsibility of any other party. Our liability shall not increase by reason of a shortfall in recovery from any other party.

8. Payments

Payment shall be received in full before Adkins Consultants will release any work, save for clients with an account with Adkins Consultants.

8.1 Where such an account is available our invoices will be issued monthly for the work completed in that month or upon completion of the work, whichever occurs soonest. Payment shall become due on submission of the invoice and the final date of payment shall be 7 days after the invoice date. We reserve the right to charge interest at the statutory rate on any overdue amounts. Please note that all invoices not settled within our payment terms will be referred to our debt recovery agents, and will be subject to a surcharge of 15% plus VAT in lieu of our recovery charges.

8.2 If you do not have an account with Adkins Consultants Ltd, then payment is required prior to the release of information, unless agreed otherwise in the quotation, which would be unusual.

8.3 Please note that all invoices not settled within our payment terms will be referred to our debt recovery agents, and will be subject to a surcharge of 15% plus VAT in lieu of our recovery charges.

9. CDM Regulations

Under the current CDM Regulations 2015 it is held to be our responsibility to inform you that the aforementioned regulations may be applicable to your project.

We have attached an information sheet for your benefit and should you have any queries in connection with this, please contact us.

10. Changes in Terms and Conditions

Terms and conditions are liable to change without notice. Amended versions will supersede any printed or electronic versions held in the clients' possession. You can find an up-to-date copy of this Terms and Conditions Statement on our website.

11. Terms and Conditions further information

Unless otherwise agreed in writing by the Company these Conditions will override any terms and conditions stipulated or referred to by the Customer in his order or pre-contract negotiations.

12. Cancellations

Adkins Consultants will only accept cancellations at the discretion of Adkins Consultants unless they are within the cooling-off period of 14 days. Acceptance of the cancellation will only be binding on the company if it is sent in writing. Any cost or expenses incurred by the company up to the date of cancellation and all loss and damage resulting from the cancellation will be paid by the customer to the company, including within the cooling-off period if Adkins Consultants have started works during this time, which is a likely course of events given Adkins Consultant's desire to dispatch customer's instructions at a speedy rate.

13. Exclusions

In dispute of any assertion that anything is excluded, all warranties, conditions and other terms, implied, statutory or otherwise, are expressly excluded excepting so far as they are contained in these conditions or otherwise expressly agreed by Adkins Consultants Ltd in writing. If any legislation makes it unlawful to exclude any term from the Contract this clause will naturally not apply to such.

14. Resolutions of Disputes

14.1 The parties will endeavour to resolve any dispute amicably. Each of them shall in good faith consider any proposal by the other that a dispute be referred to mediation.

14.2 Disputes shall be finally resolved by the English Courts.

15. Governing Law

The Agreement shall be solely within the jurisdiction of and governed by English Courts.

Structural Analysis

United Kingdom - EN 1997 (2)

Materials and standards

Concrete structures : EN 1992-1-1 (EC2)
Coefficients EN 1992-1-1 : standard
Steel structures : EN 1993-1-1 (EC3)
Partial factor on bearing capacity of steel cross section : $\gamma_{M0} = 1.00$

Excavations

Active earth pressure calculation Coulomb

:

Passive earth pressure Caquot-Kerisel

calculation :

Earthquake analysis : Mononobe-Okabe

Consider reduction of the modulus of subsoil reaction for a braced sheeting

Verification methodology : according to EN 1997

Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)						
Permanent design situation						
		Combination 1			Combination 2	
		Unfavourable	Favourable		Unfavourable	Favourable
Permanent actions :	$\gamma_G =$	1.35 [-]	1.00 [-]		1.00 [-]	1.00 [-]
Variable actions :	$\gamma_Q =$	1.50 [-]	0.00 [-]		1.30 [-]	0.00 [-]
Water load :	$\gamma_w =$	1.35 [-]			1.00 [-]	

Partial factors for soil parameters (M)				
Permanent design situation				
		Combination 1		Combination 2
Partial factor on internal friction :	$\gamma_\phi =$	1.00 [-]		1.25 [-]
Partial factor on effective cohesion :	$\gamma_c =$	1.00 [-]		1.25 [-]
Partial factor on undrained shear strength :	$\gamma_{cu} =$	1.00 [-]		1.40 [-]
Partial factor on Poisson's ratio :	$\gamma_v =$	1.00 [-]		1.00 [-]

Geometry of structure

Structure length = 13.00 m

Cross-section name : Sheet pile : GU 20N

Area of cross-section A = 1.72E-02 m²/m
Moment of inertia I = 4.13E-04 m⁴/m
Elastic modulus E = 210000.00 MPa
Shear modulus G = 81000.00 MPa
Sectional modulus W = 1.920E-03 m³/m
Plastic sectional modulus W_{pl} = 2.280E-03 m³/m

Material of structure

Structural steel: prEN 10113 : Fe E 355

Yield strength $f_y = 355.00$ MPa

Elasticity modulus E = 210000.00 MPa

Shear modulus G = 81000.00 MPa

Modulus of subsoil reaction determined according to the Schmitt theory.

Basic soil parameters

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]	γ_{su} [kN/m ³]	δ [°]
1	Silty sand (SM) soft1		15.00	5.00	14.00	5.00	15.00
2	Gravel with trace of fines (G-F), medium dense		32.50	0.00	18.00	9.00	15.00
3	Medium dense fine to coarse gravel (IV to V)		32.00	0.00	19.00	10.00	32.00
4	Fragmented and putty chalk with flints (II to III)		24.00	10.00	18.00	9.00	24.00
5	Null		1.00	0.00	0.05	0.00	1.00
6	Well graded gravel (GW), dense		41.50	0.00	21.00	12.00	24.00

All soils are considered as cohesionless for at rest pressure analysis.

Parameters of soils to compute modulus of subsoil reaction (Schmitt)

No.	Name	Pattern	ν [-]	E_{oed} [MPa]	E_{def} [MPa]
1	Silty sand (SM) soft1		0.30	1.00	-
2	Gravel with trace of fines (G-F), medium dense		0.25	40.00	-
3	Medium dense fine to coarse gravel (IV to V)		0.25	50.00	-
4	Fragmented and putty chalk with flints (II to III)		0.25	15.00	-
5	Null		0.01	0.01	-
6	Well graded gravel (GW), dense		0.20	478.00	-

Soil parameters

Silty sand (SM) soft1

Unit weight : $\gamma = 14.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 15.00^\circ$
 Cohesion of soil : $c_{ef} = 5.00 \text{ kPa}$
 Angle of friction struc.-soil : $\delta = 15.00^\circ$
 Soil : cohesionless
 Oedometric modulus : $E_{oed} = 1.00 \text{ MPa}$
 Saturated unit weight : $\gamma_{sat} = 15.00 \text{ kN/m}^3$

Gravel with trace of fines (G-F), medium dense

Unit weight : $\gamma = 18.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 32.50^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Angle of friction struc.-soil : $\delta = 15.00^\circ$
 Soil : cohesionless

Oedometric modulus : $E_{oed} = 40.00 \text{ MPa}$
 Saturated unit weight : $\gamma_{sat} = 19.00 \text{ kN/m}^3$

Medium dense fine to coarse gravel (IV to V)

Unit weight : $\gamma = 19.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 32.00^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Angle of friction struc.-soil : $\delta = 32.00^\circ$
 Soil : cohesionless
 Oedometric modulus : $E_{oed} = 50.00 \text{ MPa}$
 Saturated unit weight : $\gamma_{sat} = 20.00 \text{ kN/m}^3$

Fragmented and putty chalk with flints (II to III)

Unit weight : $\gamma = 18.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 24.00^\circ$
 Cohesion of soil : $c_{ef} = 10.00 \text{ kPa}$
 Angle of friction struc.-soil : $\delta = 24.00^\circ$
 Soil : cohesionless
 Oedometric modulus : $E_{oed} = 15.00 \text{ MPa}$
 Saturated unit weight : $\gamma_{sat} = 19.00 \text{ kN/m}^3$

Null

Unit weight : $\gamma = 0.05 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 1.00^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Angle of friction struc.-soil : $\delta = 1.00^\circ$
 Soil : cohesionless
 Oedometric modulus : $E_{oed} = 0.01 \text{ MPa}$
 Saturated unit weight : $\gamma_{sat} = 0.05 \text{ kN/m}^3$

Well graded gravel (GW), dense

Unit weight : $\gamma = 21.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 41.50^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Angle of friction struc.-soil : $\delta = 24.00^\circ$
 Soil : cohesionless
 Oedometric modulus : $E_{oed} = 478.00 \text{ MPa}$
 Saturated unit weight : $\gamma_{sat} = 22.00 \text{ kN/m}^3$

Geological profile and assigned soils

No.	Layer [m]	Assigned soil	Pattern
1	3.80	Null	
2	2.00	Silty sand (SM) soft1	
3	1.40	Medium dense fine to coarse gravel (IV to V)	
4	7.60	Fragmented and putty chalk with flints (II to III)	

No.	Layer [m]	Assigned soil	Pattern
5	-	Fragmented and putty chalk with flints (II to III)	

Excavation

Soil in front of wall is excavated to a depth of 3.80 m.

Terrain profile

No.	Coordinate x [m]	Depth z [m]
1	0.00	0.00
2	0.50	0.00
3	0.50	3.80
4	1.50	3.80

Origin [0,0] is located in upper right edge of construction.

Positive coordinate +z has downward direction.

Water influence

GWT behind the structure lies at a depth of 9.00 m

GWT in front of the structure lies at a depth of 2.30 m

Subgrade at the heel is not permeable.

Input surface surcharges

No.	Surcharge		Action	Mag.1 [kN/m ²]	Mag.2 [kN/m ²]	Ord.x x [m]	Length l [m]	Depth z [m]
	new	change						
1	YES		accidental	5.00				on terrain

Applied forces acting on the structure

No.	Force		Name	F [kN/m]	M [kNm/m]	Depth z [m]
	new	change				
1	YES		Force No. 2	1.00	0.00	2.30

Global settings

Number of FEs to discretize wall = 40

Analysis of depending pressures : do not reduce

Minimum dimensioning pressure is considered as $\sigma_{a,min} = 0.20\sigma_z$

Settings of the stage of construction

Design situation : permanent

Analysis results

Distribution of pressures acting on the structure (in front and behind the wall)

Depth [m]	Ta,p [kPa]	Tk,p [kPa]	Tp,p [kPa]	Ta,z [kPa]	Tk,z [kPa]	Tp,z [kPa]
0.00	-0.00	-0.00	-0.00	4.76	4.91	5.35
0.49	0.00	0.00	0.00	4.78	4.94	5.38
0.51	0.00	0.00	0.00	4.67	4.92	4.92
2.30	-0.00	-0.00	-0.00	4.67	4.92	4.92
3.80	-0.00	-0.00	-0.00	0.04	0.04	0.04
3.82	0.00	-0.06	-14.45	0.08	0.08	10.17
3.92	0.00	-0.45	-15.58	0.38	0.38	12.25
4.33	0.00	-1.95	-19.85	1.51	1.51	20.17

Depth [m]	Ta,p [kPa]	Tk,p [kPa]	Tp,p [kPa]	Ta,z [kPa]	Tk,z [kPa]	Tp,z [kPa]
4.68	0.00	-3.24	-23.55	2.49	2.49	27.04
4.68	0.00	-3.26	-23.61	2.50	2.50	27.15
5.80	-0.00	-7.41	-35.45	5.64	5.64	49.10
5.80	-2.35	-4.70	-67.27	5.64	5.64	186.98
7.20	-5.64	-11.28	-161.44	10.96	10.96	351.91
7.20	-0.00	-14.24	-125.14	10.96	10.96	207.34
7.70	-0.00	-16.89	-141.62	12.75	12.75	235.32
9.00	-3.95	-23.85	-184.84	17.44	17.44	308.74
13.00	-16.05	-45.21	-317.51	24.64	24.64	441.41

Distributions of the modulus of subsoil reaction and internal forces on the structure

Depth [m]	kh,p [MN/m ³]	kh,z [MN/m ³]	Displacement [mm]	Pressure [kPa]	Shear Force [kN/m]	Moment [kNm/m]
0.00	0.00	0.00	-13.10	4.89	-0.00	0.00
0.33	0.00	0.00	-12.27	4.90	-1.59	0.26
0.65	0.00	0.00	-11.44	4.89	-3.18	1.03
0.97	0.00	0.00	-10.61	4.90	-4.77	2.33
1.30	0.00	0.00	-9.79	4.90	-6.37	4.14
1.63	0.00	0.00	-8.97	4.90	-7.96	6.46
1.95	0.00	0.00	-8.16	4.90	-9.55	9.31
2.27	0.00	0.00	-7.36	4.90	-11.14	12.67
2.30	0.00	0.00	-7.30	4.83	-11.26	12.95
2.30	0.00	0.00	-7.30	4.83	-10.26	12.95
2.60	0.00	0.00	-6.58	3.93	-11.58	16.24
2.92	0.00	0.00	-5.81	2.87	-12.68	20.19
3.25	0.00	0.00	-5.07	1.82	-13.44	24.45
3.58	0.00	0.00	-4.36	0.76	-13.86	28.90
3.79	0.00	0.00	-3.91	0.06	-13.95	31.93
3.81	0.47	0.00	-3.88	-1.81	-13.94	32.15
3.90	0.47	0.00	-3.69	-1.80	-13.77	33.42
4.22	0.47	0.00	-3.06	-1.80	-13.19	37.81
4.55	0.47	0.00	-2.47	-1.81	-12.60	42.00
4.88	0.47	0.00	-1.93	-1.85	-12.01	46.00
5.20	0.47	0.00	-1.45	-1.92	-11.39	49.80
5.53	0.47	0.00	-1.03	-2.01	-10.76	53.41
5.85	87.37	0.00	-0.68	-58.40	1.49	54.74
6.17	87.37	0.00	-0.39	-33.45	16.26	51.64
6.50	87.37	0.00	-0.16	-13.97	23.83	44.95
6.83	0.00	87.37	0.01	5.50	25.09	36.81
7.15	0.00	87.37	0.14	17.05	21.33	29.17
7.47	17.55	17.55	0.23	4.18	17.44	22.94
7.80	17.55	17.55	0.29	5.83	15.78	17.53
8.13	17.55	17.55	0.33	6.74	13.72	12.73
8.45	17.55	17.55	0.36	7.09	11.47	8.63
8.78	17.55	17.55	0.37	7.08	9.15	5.29
9.10	17.55	17.55	0.38	6.66	6.92	2.68
9.43	17.55	17.55	0.39	5.72	4.90	0.77
9.75	17.55	17.55	0.39	4.75	3.20	-0.53

Depth [m]	kh,p [MN/m ³]	kh,z [MN/m ³]	Displacement [mm]	Pressure [kPa]	Shear Force [kN/m]	Moment [kNm/m]
10.07	17.55	17.55	0.40	3.81	1.81	-1.33
10.40	17.55	17.55	0.41	2.92	0.72	-1.73
10.72	17.55	17.55	0.42	2.11	-0.10	-1.82
11.05	17.55	17.55	0.43	1.38	-0.66	-1.68
11.38	17.55	17.55	0.44	0.73	-1.00	-1.40
11.70	17.55	17.55	0.46	0.14	-1.14	-1.04
12.03	17.55	17.55	0.48	-0.39	-1.10	-0.67
12.35	17.55	17.55	0.50	-0.89	-0.89	-0.33
12.68	17.55	17.55	0.51	-1.37	-0.52	-0.09
13.00	17.55	17.55	0.53	-1.84	-0.00	0.00

Maximum shear force = 25.09 kN/m

Maximum moment = 54.74 kNm/
m

Maximum displacement = 13.1 mm

Slope stability analysis

Input data

Project

Settings

United Kingdom - EN 1997 (2)

Materials and standards

SNiP - input coefficients according to SNiP standards

Coefficients according to SNiP			
Combination coefficient :	$\gamma_k =$	1.00	[-]
Coefficient of action conditions :	$\gamma_c =$	0.90	[-]
Coefficient of importance of structure :	$\gamma_n =$	1.10	[-]

Stability analysis

Earthquake analysis : Standard
Verification according to EN 1997

methodology :

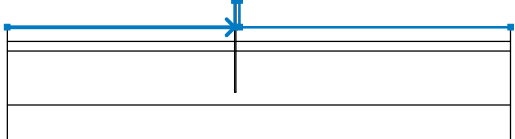
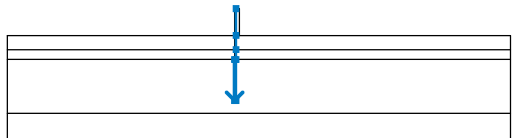
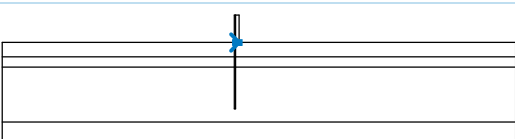
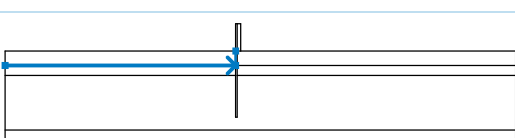
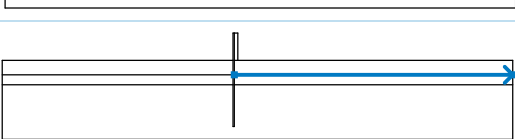
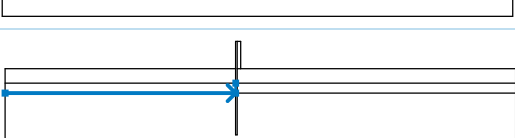
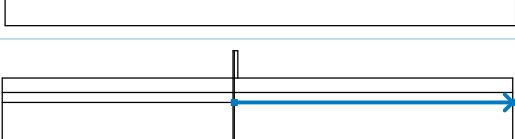
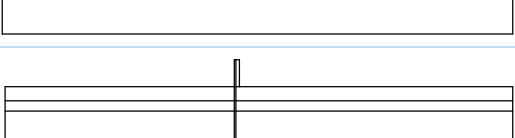
Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)					
Permanent design situation					
		Combination 1		Combination 2	
		Unfavourable	Favourable	Unfavourable	Favourable
Permanent actions :	$\gamma_G =$	1.35 [-]	1.00 [-]	1.00 [-]	1.00 [-]
Variable actions :	$\gamma_Q =$	1.50 [-]	0.00 [-]	1.30 [-]	0.00 [-]
Water load :	$\gamma_w =$	1.35 [-]		1.00 [-]	

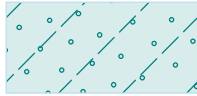
Partial factors for soil parameters (M)			
Permanent design situation			
		Combination 1	Combination 2
Partial factor on internal friction :	$\gamma_\phi =$	1.00 [-]	1.25 [-]
Partial factor on effective cohesion :	$\gamma_c =$	1.00 [-]	1.25 [-]

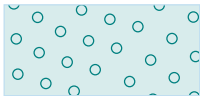
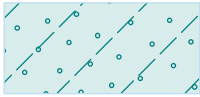
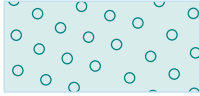
Partial factors for soil parameters (M)			
Permanent design situation			
Partial factor on undrained shear strength :	$\gamma_{cu} =$	1.00 [-]	1.40 [-]

Interface

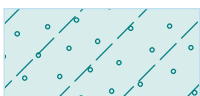
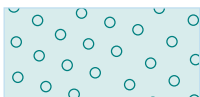
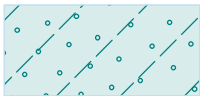
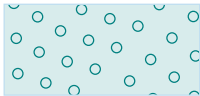
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		-32.50	-3.80	-0.20	-3.80	-0.20	0.00
		0.00	0.00	0.50	0.00	0.50	-3.80
		39.00	-3.80				
2		-0.20	-7.20	-0.20	-13.00	0.00	-13.00
		0.00	-7.20	0.00	-5.80	0.00	-3.80
		0.00	0.00				
3		0.00	-3.80	0.50	-3.80		
4		-32.50	-5.80	-0.20	-5.80	-0.20	-3.80
5		0.00	-5.80	39.00	-5.80		
6		-32.50	-7.20	-0.20	-7.20	-0.20	-5.80
7		0.00	-7.20	39.00	-7.20		
8		-32.50	-14.80	39.00	-14.80		

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Silty sand (SM) soft1		15.00	5.00	14.00

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
2	Gravel with trace of fines (G-F), medium dense		32.50	0.00	18.00
3	Medium dense fine to coarse gravel (IV to V)		32.00	0.00	19.00
4	Fragmented and putty chalk with flints (II to III)		24.00	10.00	18.00
5	Null		1.00	0.00	0.05
6	Well graded gravel (GW), dense		41.50	0.00	21.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Silty sand (SM) soft1		15.00		
2	Gravel with trace of fines (G-F), medium dense		19.00		
3	Medium dense fine to coarse gravel (IV to V)		20.00		
4	Fragmented and putty chalk with flints (II to III)		19.00		
5	Null		0.05		
6	Well graded gravel (GW), dense		22.00		

Soil parameters

Silty sand (SM) soft1

Unit weight : $\gamma = 14.00$ kN/m³
Stress-state : effective
Angle of internal friction : $\phi_{ef} = 15.00$ °
Cohesion of soil : $c_{ef} = 5.00$ kPa
Saturated unit weight : $\gamma_{sat} = 15.00$ kN/m³

Gravel with trace of fines (G-F), medium dense

Unit weight : $\gamma = 18.00$ kN/m³
Stress-state : effective

Angle of internal friction : $\phi_{ef} = 32.50^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 19.00 \text{ kN/m}^3$

Medium dense fine to coarse gravel (IV to V)

Unit weight : $\gamma = 19.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 32.00^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 20.00 \text{ kN/m}^3$

Fragmented and putty chalk with flints (II to III)

Unit weight : $\gamma = 18.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 24.00^\circ$
 Cohesion of soil : $c_{ef} = 10.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 19.00 \text{ kN/m}^3$

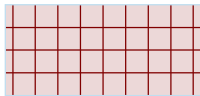
Null

Unit weight : $\gamma = 0.05 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 1.00^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 0.05 \text{ kN/m}^3$

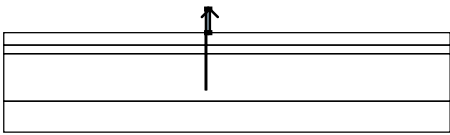
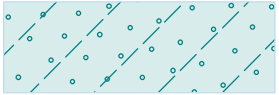
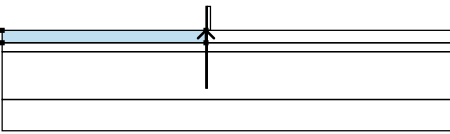
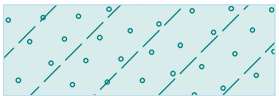
Well graded gravel (GW), dense

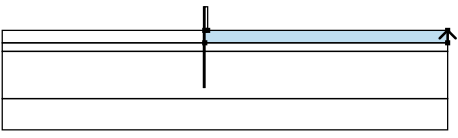
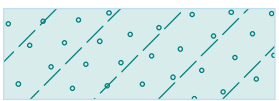
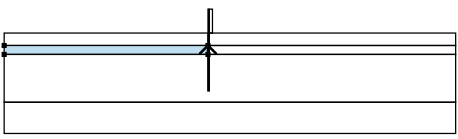
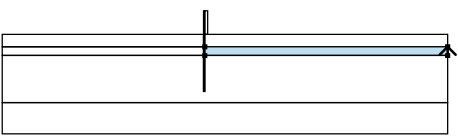
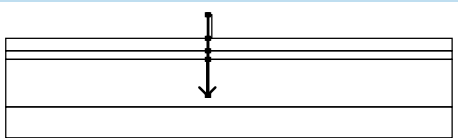
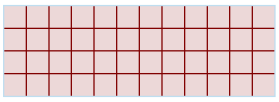
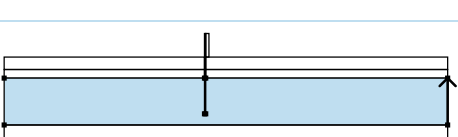
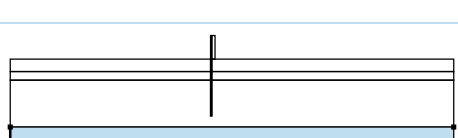
Unit weight : $\gamma = 21.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{ef} = 41.50^\circ$
 Cohesion of soil : $c_{ef} = 0.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 22.00 \text{ kN/m}^3$

Rigid bodies

No.	Name	Sample	γ [kN/m ³]
1	Wall material		23.56

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		0.50	-3.80	0.50	0.00	Null
		0.00	0.00	0.00	-3.80	
						
2		-0.20	-5.80	-0.20	-3.80	Silty sand (SM) soft1
		-32.50	-3.80	-32.50	-5.80	
						

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
3		39.00	-5.80	39.00	-3.80	Silty sand (SM) soft1 
		0.50	-3.80	0.00	-3.80	
		0.00	-5.80			
4		-0.20	-7.20	-0.20	-5.80	Medium dense fine to coarse gravel (IV to V) 
		-32.50	-5.80	-32.50	-7.20	
5		39.00	-7.20	39.00	-5.80	Medium dense fine to coarse gravel (IV to V) 
		0.00	-5.80	0.00	-7.20	
6		-0.20	-7.20	-0.20	-13.00	Wall material 
		0.00	-13.00	0.00	-7.20	
		0.00	-5.80	0.00	-3.80	
		0.00	0.00	-0.20	0.00	
		-0.20	-3.80	-0.20	-5.80	
7		39.00	-14.80	39.00	-7.20	Fragmented and putty chalk with flints (II to III) 
		0.00	-7.20	0.00	-13.00	
		-0.20	-13.00	-0.20	-7.20	
		-32.50	-7.20	-32.50	-14.80	
8		-32.50	-14.80	-32.50	-19.80	Fragmented and putty chalk with flints (II to III) 
		39.00	-19.80	39.00	-14.80	

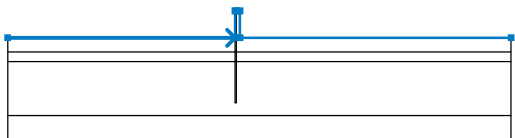
Surcharge

No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude		
								q, q ₁ , f, F	q ₂	unit
1	strip	accidental	on terrain	x = 0.00	l = 39.00		0.00	5.00		kN/m ²

Water

Water type GWT

:

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		-32.50	-2.30	0.00	-2.30	0.05	-9.00
		39.00	-9.00				

Tensile crack

Tensile crack not inputted.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation permanent
:

Results (Stage of construction 1)

Analysis 1

Circular slip surface

Slip surface parameters					
Center :	x =	14.51 [m]	Angles :	α_1 =	-84.55 [°]
	z =	-1.83 [m]		α_2 =	84.55 [°]
Radius :	R =	20.76 [m]			
The slip surface after optimization.					

Slope stability verification (Bishop)

Combination 1

Sum of active forces : $F_a = 523.77$ kN/m

Sum of passive forces : $F_p = 3982.64$ kN/m

Sliding moment : $M_a = 10873.55$ kNm/m

Resisting moment : $M_p = 82679.70$ kNm/m

Utilization 13.2 %
:

Slope stability ACCEPTABLE

Combination 2

Sum of active forces : $F_a = 11.50$ kN/m

Sum of passive forces : $F_p = 3039.20$ kN/m

Sliding moment : $M_a = 39.57$ kNm/m

Resisting moment : $M_p = 10454.84$ kNm/m

Utilization 0.4 %
:

Slope stability ACCEPTABLE

Optimized slip surface for : Combination 1

Optimization of circular slip surface (Bishop)

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
1	-2.72	-0.67	3.44	0.4 %	ACCEPTABLE
2	-2.72	-0.67	3.44	0.4 %	ACCEPTABLE
3	0.15	-2.12	14.67	6.8 %	ACCEPTABLE
4	0.15	13.83	33.76	1.8 %	ACCEPTABLE
5	0.15	13.83	33.76	1.8 %	ACCEPTABLE
6	14.37	-2.12	14.67	3.4 %	ACCEPTABLE
7	0.15	-2.17	28.84	-	Solution not found
8	-14.07	-2.12	14.67	4.9 %	ACCEPTABLE
9	0.15	21.62	38.41	-	Solution not found
10	0.15	-2.12	14.67	6.8 %	ACCEPTABLE
11	0.15	76.86	84.17	-	Solution not found
12	9.63	24.70	32.01	-	Solution not found

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
13	0.15	8.52	27.02	1.2 %	ACCEPTABLE
14	0.15	8.52	27.02	1.2 %	ACCEPTABLE
15	9.63	-2.12	14.67	1.0 %	ACCEPTABLE
16	0.15	-2.16	24.11	-	Solution not found
17	-9.33	11.90	21.42	-	Solution not found
18	0.15	-1.86	5.45	-	Solution not found
19	-9.33	-2.12	14.67	4.3 %	ACCEPTABLE
20	0.15	11.97	28.76	-	Solution not found
21	-4.59	479.64	483.54	-	Solution not found
22	4.89	1861.20	1865.10	-	Solution not found
23	4.89	479.64	483.54	-	Solution not found
24	0.15	-2.12	14.67	6.8 %	ACCEPTABLE
25	0.15	25.59	36.06	-	Solution not found
26	6.47	8.79	19.26	-	Solution not found
27	0.15	4.97	22.66	5.3 %	ACCEPTABLE
28	0.15	4.97	22.66	5.3 %	ACCEPTABLE
29	6.47	-2.12	14.67	7.4 %	ACCEPTABLE
30	6.47	25.59	36.06	-	Solution not found
31	12.79	8.79	19.26	-	Solution not found
32	6.47	4.97	22.66	4.0 %	ACCEPTABLE
33	6.47	4.97	22.66	4.0 %	ACCEPTABLE
34	12.79	-2.12	14.67	2.4 %	ACCEPTABLE
35	6.47	-2.15	20.96	9.9 %	ACCEPTABLE
36	6.47	18.21	35.00	-	Solution not found
37	12.79	6.51	23.30	1.3 %	ACCEPTABLE
38	6.47	4.69	28.51	8.6 %	ACCEPTABLE
39	6.47	4.69	28.51	8.6 %	ACCEPTABLE
40	12.79	-2.15	20.96	11.0 %	ACCEPTABLE
41	12.19	16.95	33.75	-	Solution not found
42	18.51	5.54	22.34	3.3 %	ACCEPTABLE
43	12.19	4.04	27.74	6.0 %	ACCEPTABLE
44	12.19	3.64	27.63	6.2 %	ACCEPTABLE
45	18.51	-2.80	20.32	4.3 %	ACCEPTABLE
46	12.19	-2.81	26.63	-	Solution not found
47	6.47	4.97	22.66	4.0 %	ACCEPTABLE
48	12.79	-2.12	14.67	2.4 %	ACCEPTABLE
49	6.47	-2.15	20.96	9.9 %	ACCEPTABLE
50	6.47	-3.18	20.90	-	Solution not found
51	12.19	4.87	27.99	5.6 %	ACCEPTABLE
52	18.51	-3.64	20.29	-	Solution not found
53	-3.01	647.49	651.39	-	Solution not found
54	3.31	1568.53	1572.43	-	Solution not found
55	3.31	647.49	651.39	-	Solution not found
56	12.79	-2.15	20.96	11.0 %	ACCEPTABLE
57	12.79	9.53	28.43	3.1 %	ACCEPTABLE
58	17.00	3.11	22.01	4.1 %	ACCEPTABLE
59	12.79	2.41	25.86	9.8 %	ACCEPTABLE
60	12.79	2.41	25.86	9.8 %	ACCEPTABLE
61	17.00	-2.15	20.96	-	Solution not found
62	12.79	-2.16	25.16	-	Solution not found
63	8.58	2.52	21.83	6.6 %	ACCEPTABLE
64	12.79	-2.13	16.76	2.6 %	ACCEPTABLE
65	8.58	-2.15	20.96	10.2 %	ACCEPTABLE
66	8.58	-2.61	20.93	-	Solution not found
67	12.79	2.87	25.98	9.5 %	ACCEPTABLE

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
68	17.00	-2.61	20.93	-	Solution not found
69	10.68	1761.15	1765.05	-	Solution not found
70	14.90	2641.52	2645.42	-	Solution not found
71	14.90	1761.15	1765.05	-	Solution not found
72	12.79	-2.15	20.96	11.0 %	ACCEPTABLE
73	15.60	-2.97	20.91	-	Solution not found
74	12.79	4.97	25.28	7.2 %	ACCEPTABLE
75	15.60	1.18	21.48	9.7 %	ACCEPTABLE
76	12.79	0.89	24.16	9.8 %	ACCEPTABLE
77	12.79	0.89	24.16	9.8 %	ACCEPTABLE
78	15.60	-2.15	20.96	-	Solution not found
79	12.79	-2.16	23.76	-	Solution not found
80	9.98	0.94	21.43	3.2 %	ACCEPTABLE
81	12.79	-2.14	18.16	10.0 %	ACCEPTABLE
82	9.98	-2.15	20.96	5.2 %	ACCEPTABLE
83	9.98	-2.97	20.91	5.7 %	ACCEPTABLE
84	9.98	-2.35	20.94	5.3 %	ACCEPTABLE
85	12.79	1.09	24.20	9.7 %	ACCEPTABLE
86	15.60	-2.35	20.94	-	Solution not found
87	11.39	1895.55	1899.45	-	Solution not found
88	14.19	2482.47	2486.37	-	Solution not found
89	14.19	1895.55	1899.45	-	Solution not found
90	12.79	-2.15	20.96	11.0 %	ACCEPTABLE
91	14.66	-2.51	20.93	-	Solution not found
92	12.79	2.34	23.58	5.0 %	ACCEPTABLE
93	14.66	0.00	21.24	11.5 %	ACCEPTABLE
94	16.53	-0.40	21.17	7.7 %	ACCEPTABLE
95	14.66	5.07	24.44	7.7 %	ACCEPTABLE
96	16.53	2.44	21.81	3.3 %	ACCEPTABLE
97	14.66	2.24	23.56	9.7 %	ACCEPTABLE
98	16.53	-2.24	20.96	8.6 %	ACCEPTABLE
99	14.66	2.24	23.56	9.7 %	ACCEPTABLE
100	16.53	0.00	21.24	7.6 %	ACCEPTABLE
101	14.66	-0.03	23.08	10.9 %	ACCEPTABLE
102	14.66	-2.24	19.09	7.0 %	ACCEPTABLE
103	12.79	2.33	21.78	7.7 %	ACCEPTABLE
104	14.66	0.04	19.41	3.0 %	ACCEPTABLE
105	12.79	0.00	21.24	9.6 %	ACCEPTABLE
106	13.72	-3.16	19.97	-	Solution not found
107	12.79	-0.40	21.17	9.9 %	ACCEPTABLE
108	14.66	-2.24	19.09	7.0 %	ACCEPTABLE
109	12.79	-2.24	20.96	11.1 %	ACCEPTABLE
110	12.79	-0.10	21.22	9.6 %	ACCEPTABLE
111	14.66	-2.14	19.10	6.9 %	ACCEPTABLE
112	14.66	2.34	23.58	9.5 %	ACCEPTABLE
113	16.53	-0.10	21.22	7.6 %	ACCEPTABLE
114	11.85	1987.89	1991.79	-	Solution not found
115	13.73	2379.17	2383.07	-	Solution not found
116	13.73	1987.89	1991.79	-	Solution not found
117	14.66	0.00	21.24	11.5 %	ACCEPTABLE
118	15.91	-0.18	21.21	7.3 %	ACCEPTABLE
119	14.66	3.25	23.24	5.1 %	ACCEPTABLE
120	15.91	1.59	21.58	3.3 %	ACCEPTABLE
121	14.66	1.50	22.77	6.0 %	ACCEPTABLE
122	15.91	-1.50	21.02	8.0 %	ACCEPTABLE

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
123	14.66	1.50	22.77	6.0 %	ACCEPTABLE
124	15.91	0.00	21.24	7.2 %	ACCEPTABLE
125	14.66	-0.02	22.47	6.9 %	ACCEPTABLE
126	14.66	-1.50	19.78	10.9 %	ACCEPTABLE
127	13.41	1.54	21.57	9.3 %	ACCEPTABLE
128	14.66	0.03	20.02	9.9 %	ACCEPTABLE
129	13.41	0.00	21.24	10.4 %	ACCEPTABLE
130	14.04	-2.16	20.34	6.9 %	ACCEPTABLE
131	14.66	-2.81	19.67	-	Solution not found
132	13.41	-0.18	21.21	10.6 %	ACCEPTABLE
133	14.66	-1.50	19.78	10.9 %	ACCEPTABLE
134	13.41	-1.50	21.02	11.5 %	ACCEPTABLE
135	13.41	-0.04	21.23	10.2 %	ACCEPTABLE
136	14.66	-1.45	19.79	10.9 %	ACCEPTABLE
137	14.66	1.54	22.78	6.0 %	ACCEPTABLE
138	15.91	-0.04	21.23	7.2 %	ACCEPTABLE
139	14.04	2051.15	2055.05	-	Solution not found
140	15.28	2312.03	2315.93	-	Solution not found
141	15.28	2051.15	2055.05	-	Solution not found
142	14.66	0.00	21.24	11.5 %	ACCEPTABLE
143	15.49	-0.08	21.23	10.3 %	ACCEPTABLE
144	14.66	2.11	22.52	5.3 %	ACCEPTABLE
145	15.49	1.04	21.45	9.9 %	ACCEPTABLE
146	14.66	1.00	22.25	5.9 %	ACCEPTABLE
147	15.49	-1.01	21.08	11.5 %	ACCEPTABLE
148	14.66	1.00	22.25	5.9 %	ACCEPTABLE
149	15.49	0.00	21.24	10.8 %	ACCEPTABLE
150	14.66	-0.02	22.06	6.4 %	ACCEPTABLE
151	14.66	-1.00	20.26	10.3 %	ACCEPTABLE
152	13.83	1.02	21.45	5.3 %	ACCEPTABLE
153	14.66	0.02	20.42	9.6 %	ACCEPTABLE
154	13.83	0.00	21.24	5.9 %	ACCEPTABLE
155	14.24	-1.46	20.61	6.6 %	ACCEPTABLE
156	14.66	-1.92	20.15	10.9 %	ACCEPTABLE
157	13.83	-0.08	21.23	6.0 %	ACCEPTABLE
158	14.66	-1.00	20.26	10.3 %	ACCEPTABLE
159	13.83	-1.01	21.08	6.4 %	ACCEPTABLE
160	13.83	-0.02	21.24	6.0 %	ACCEPTABLE
161	14.66	-0.98	20.26	10.2 %	ACCEPTABLE
162	14.66	1.02	22.26	5.9 %	ACCEPTABLE
163	15.49	-0.02	21.24	10.8 %	ACCEPTABLE
164	14.24	2093.54	2097.44	-	Solution not found
165	15.08	2267.46	2271.36	-	Solution not found
166	15.08	2093.54	2097.44	-	Solution not found
167	14.66	0.00	21.24	11.5 %	ACCEPTABLE
168	15.21	-0.04	21.23	9.9 %	ACCEPTABLE
169	14.66	1.38	22.07	5.7 %	ACCEPTABLE
170	15.21	0.69	21.37	9.7 %	ACCEPTABLE
171	14.66	0.66	21.91	5.8 %	ACCEPTABLE
172	15.21	-0.67	21.13	10.3 %	ACCEPTABLE
173	14.66	0.66	21.91	5.8 %	ACCEPTABLE
174	15.21	0.00	21.24	9.9 %	ACCEPTABLE
175	14.66	-0.01	21.78	6.2 %	ACCEPTABLE
176	14.66	-0.66	20.58	10.3 %	ACCEPTABLE
177	14.11	0.68	21.37	6.0 %	ACCEPTABLE

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
178	14.66	0.01	20.70	9.6 %	ACCEPTABLE
179	14.11	0.00	21.24	6.0 %	ACCEPTABLE
180	14.38	-0.99	20.81	6.3 %	ACCEPTABLE
181	14.66	-1.30	20.50	10.5 %	ACCEPTABLE
182	14.11	-0.04	21.23	6.3 %	ACCEPTABLE
183	14.66	-0.66	20.58	10.3 %	ACCEPTABLE
184	14.11	-0.67	21.13	6.4 %	ACCEPTABLE
185	14.11	-0.01	21.24	6.0 %	ACCEPTABLE
186	14.66	-0.66	20.58	10.3 %	ACCEPTABLE
187	14.66	0.67	21.91	5.8 %	ACCEPTABLE
188	15.21	-0.01	21.24	9.9 %	ACCEPTABLE
189	14.38	2122.05	2125.95	-	Solution not found
190	14.94	2238.00	2241.90	-	Solution not found
191	14.94	2122.05	2125.95	-	Solution not found
192	14.66	0.00	21.24	11.5 %	ACCEPTABLE
193	15.03	-0.02	21.24	10.0 %	ACCEPTABLE
194	14.66	0.91	21.78	5.7 %	ACCEPTABLE
195	15.03	0.46	21.33	9.6 %	ACCEPTABLE
196	14.66	0.44	21.69	5.9 %	ACCEPTABLE
197	15.03	-0.45	21.16	10.2 %	ACCEPTABLE
198	14.66	0.44	21.69	5.9 %	ACCEPTABLE
199	15.03	0.00	21.24	9.9 %	ACCEPTABLE
200	14.66	-0.01	21.60	6.1 %	ACCEPTABLE
201	14.66	-0.44	20.80	10.0 %	ACCEPTABLE
202	14.29	0.45	21.33	5.5 %	ACCEPTABLE
203	14.66	0.01	20.88	9.7 %	ACCEPTABLE
204	14.29	0.00	21.24	5.8 %	ACCEPTABLE
205	14.48	-0.66	20.95	11.9 %	ACCEPTABLE
206	14.85	-0.68	20.95	10.2 %	ACCEPTABLE
207	14.48	0.22	21.46	5.8 %	ACCEPTABLE
208	14.85	-0.22	21.02	10.1 %	ACCEPTABLE
209	14.48	-0.23	21.38	6.1 %	ACCEPTABLE
210	14.85	-1.09	20.89	10.5 %	ACCEPTABLE
211	14.48	-0.23	21.38	6.1 %	ACCEPTABLE
212	14.85	-0.66	20.95	10.2 %	ACCEPTABLE
213	14.48	-0.66	21.32	6.3 %	ACCEPTABLE
214	14.48	-1.09	20.52	10.6 %	ACCEPTABLE
215	14.11	-0.22	21.02	5.9 %	ACCEPTABLE
216	14.48	-0.65	20.59	10.3 %	ACCEPTABLE
217	14.11	-0.66	20.95	6.2 %	ACCEPTABLE
218	14.30	-1.30	20.68	6.4 %	ACCEPTABLE
219	14.48	-1.51	20.47	10.9 %	ACCEPTABLE
220	14.11	-0.68	20.95	6.2 %	ACCEPTABLE
221	14.48	-1.09	20.52	10.6 %	ACCEPTABLE
222	14.11	-1.09	20.89	6.4 %	ACCEPTABLE
223	14.11	-0.66	20.95	6.2 %	ACCEPTABLE
224	14.48	-1.09	20.52	10.6 %	ACCEPTABLE
225	14.48	-0.23	21.38	6.1 %	ACCEPTABLE
226	14.85	-0.66	20.95	10.2 %	ACCEPTABLE
227	14.48	2141.16	2145.06	-	Solution not found
228	14.84	2218.46	2222.36	-	Solution not found
229	14.84	2141.16	2145.06	-	Solution not found
230	14.48	-0.66	20.95	11.9 %	ACCEPTABLE
231	14.73	-0.67	20.95	10.5 %	ACCEPTABLE
232	14.48	-0.08	21.29	6.3 %	ACCEPTABLE

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
233	14.73	-0.37	21.00	10.3 %	ACCEPTABLE
234	14.48	-0.37	21.24	6.5 %	ACCEPTABLE
235	14.73	-0.95	20.91	10.7 %	ACCEPTABLE
236	14.48	-0.37	21.24	6.5 %	ACCEPTABLE
237	14.73	-0.66	20.95	10.5 %	ACCEPTABLE
238	14.48	-0.66	21.19	6.6 %	ACCEPTABLE
239	14.48	-0.95	20.66	10.4 %	ACCEPTABLE
240	14.23	-0.37	21.00	5.9 %	ACCEPTABLE
241	14.48	-0.66	20.71	10.2 %	ACCEPTABLE
242	14.23	-0.66	20.95	6.0 %	ACCEPTABLE
243	14.36	-1.09	20.77	6.4 %	ACCEPTABLE
244	14.48	-1.23	20.63	10.6 %	ACCEPTABLE
245	14.23	-0.67	20.95	6.0 %	ACCEPTABLE
246	14.48	-0.95	20.66	10.4 %	ACCEPTABLE
247	14.23	-0.95	20.91	6.2 %	ACCEPTABLE
248	14.23	-0.66	20.95	6.0 %	ACCEPTABLE
249	14.48	-0.95	20.66	10.4 %	ACCEPTABLE
250	14.48	-0.37	21.24	6.5 %	ACCEPTABLE
251	14.73	-0.66	20.95	10.5 %	ACCEPTABLE
252	14.36	2115.90	2119.80	-	Solution not found
253	14.60	2166.98	2170.88	-	Solution not found
254	14.60	2115.90	2119.80	-	Solution not found
255	14.48	-0.66	20.95	11.9 %	ACCEPTABLE
256	14.64	-0.66	20.95	10.3 %	ACCEPTABLE
257	14.48	-0.27	21.17	6.2 %	ACCEPTABLE
258	14.64	-0.47	20.98	10.2 %	ACCEPTABLE
259	14.48	-0.47	21.14	6.3 %	ACCEPTABLE
260	14.64	-0.85	20.92	10.4 %	ACCEPTABLE
261	14.48	-0.47	21.14	6.3 %	ACCEPTABLE
262	14.64	-0.66	20.95	10.3 %	ACCEPTABLE
263	14.48	-0.66	21.11	6.4 %	ACCEPTABLE
264	14.48	-0.85	20.76	11.7 %	ACCEPTABLE
265	14.32	-0.47	20.98	6.4 %	ACCEPTABLE
266	14.48	-0.66	20.79	11.6 %	ACCEPTABLE
267	14.32	-0.66	20.95	6.4 %	ACCEPTABLE
268	14.40	-0.95	20.83	12.0 %	ACCEPTABLE
269	14.56	-0.95	20.83	10.4 %	ACCEPTABLE
270	14.40	-0.57	21.05	6.5 %	ACCEPTABLE
271	14.56	-0.76	20.86	10.5 %	ACCEPTABLE
272	14.40	-0.76	21.02	6.6 %	ACCEPTABLE
273	14.56	-1.14	20.80	10.5 %	ACCEPTABLE
274	14.40	-0.76	21.02	6.6 %	ACCEPTABLE
275	14.56	-0.95	20.83	10.4 %	ACCEPTABLE
276	14.40	-0.95	20.99	6.7 %	ACCEPTABLE
277	14.40	-1.14	20.64	12.0 %	ACCEPTABLE
278	14.24	-0.76	20.86	6.2 %	ACCEPTABLE
279	14.40	-0.95	20.67	11.8 %	ACCEPTABLE
280	14.24	-0.95	20.83	7.6 %	ACCEPTABLE
281	14.32	-1.23	20.71	6.5 %	ACCEPTABLE
282	14.40	-1.33	20.62	12.2 %	ACCEPTABLE
283	14.56	-1.33	20.62	10.8 %	ACCEPTABLE
284	14.40	-0.95	20.83	12.0 %	ACCEPTABLE
285	14.56	-1.14	20.64	10.7 %	ACCEPTABLE
286	14.40	-1.14	20.81	11.8 %	ACCEPTABLE
287	14.56	-1.52	20.60	11.0 %	ACCEPTABLE

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
288	14.40	-1.14	20.81	11.8 %	ACCEPTABLE
289	14.56	-1.33	20.62	10.8 %	ACCEPTABLE
290	14.40	-1.33	20.78	12.4 %	ACCEPTABLE
291	14.56	-1.33	20.78	10.7 %	ACCEPTABLE
292	14.40	-0.95	20.99	6.7 %	ACCEPTABLE
293	14.56	-1.14	20.80	10.5 %	ACCEPTABLE
294	14.40	-1.14	20.97	6.8 %	ACCEPTABLE
295	14.56	-1.52	20.76	10.8 %	ACCEPTABLE
296	14.40	-1.14	20.97	6.8 %	ACCEPTABLE
297	14.56	-1.33	20.78	10.7 %	ACCEPTABLE
298	14.40	-1.33	20.94	6.9 %	ACCEPTABLE
299	14.40	-1.52	20.60	12.3 %	ACCEPTABLE
300	14.24	-1.14	20.80	7.4 %	ACCEPTABLE
301	14.40	-1.33	20.62	12.2 %	ACCEPTABLE
302	14.24	-1.33	20.78	7.7 %	ACCEPTABLE
303	14.32	-1.61	20.67	6.6 %	ACCEPTABLE
304	14.40	-1.70	20.58	12.5 %	ACCEPTABLE
305	14.56	-1.70	20.58	11.2 %	ACCEPTABLE
306	14.40	-1.33	20.78	12.4 %	ACCEPTABLE
307	14.56	-1.52	20.60	11.0 %	ACCEPTABLE
308	14.40	-1.52	20.76	12.6 %	ACCEPTABLE
309	14.56	-1.52	20.76	10.8 %	ACCEPTABLE
310	14.40	-1.15	20.97	6.8 %	ACCEPTABLE
311	14.56	-1.33	20.78	10.7 %	ACCEPTABLE
312	14.40	-1.34	20.94	6.9 %	ACCEPTABLE
313	14.56	-1.70	20.74	10.9 %	ACCEPTABLE
314	14.40	-1.34	20.94	6.9 %	ACCEPTABLE
315	14.56	-1.52	20.76	10.8 %	ACCEPTABLE
316	14.40	-1.52	20.92	7.0 %	ACCEPTABLE
317	14.40	-1.70	20.58	12.5 %	ACCEPTABLE
318	14.24	-1.34	20.78	7.7 %	ACCEPTABLE
319	14.40	-1.52	20.60	12.3 %	ACCEPTABLE
320	14.24	-1.52	20.76	7.8 %	ACCEPTABLE
321	14.32	-1.79	20.65	6.7 %	ACCEPTABLE
322	14.40	-1.88	20.56	12.7 %	ACCEPTABLE
323	14.56	-1.88	20.56	11.2 %	ACCEPTABLE
324	14.40	-1.51	20.76	12.6 %	ACCEPTABLE
325	14.56	-1.70	20.58	11.2 %	ACCEPTABLE
326	14.40	-1.70	20.74	12.8 %	ACCEPTABLE
327	14.56	-1.70	20.74	10.9 %	ACCEPTABLE
328	14.40	-1.33	20.94	6.9 %	ACCEPTABLE
329	14.56	-1.52	20.76	10.8 %	ACCEPTABLE
330	14.40	-1.52	20.92	7.0 %	ACCEPTABLE
331	14.56	-1.88	20.72	11.1 %	ACCEPTABLE
332	14.40	-1.52	20.92	7.0 %	ACCEPTABLE
333	14.56	-1.70	20.74	10.9 %	ACCEPTABLE
334	14.40	-1.70	20.90	7.1 %	ACCEPTABLE
335	14.40	-1.88	20.56	12.7 %	ACCEPTABLE
336	14.24	-1.52	20.76	7.8 %	ACCEPTABLE
337	14.40	-1.70	20.58	12.5 %	ACCEPTABLE
338	14.24	-1.70	20.74	7.9 %	ACCEPTABLE
339	14.32	-1.97	20.63	6.8 %	ACCEPTABLE
340	14.40	-2.06	20.54	-	Solution not found
341	14.24	-1.70	20.74	7.9 %	ACCEPTABLE
342	14.40	-1.88	20.56	12.7 %	ACCEPTABLE

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
343	14.24	-1.88	20.72	7.9 %	ACCEPTABLE
344	14.24	-1.70	20.74	7.9 %	ACCEPTABLE
345	14.40	-1.88	20.56	12.7 %	ACCEPTABLE
346	14.40	-1.52	20.92	7.0 %	ACCEPTABLE
347	14.56	-1.70	20.74	10.9 %	ACCEPTABLE
348	14.40	2124.37	2128.27	-	Solution not found
349	14.56	2158.42	2162.32	-	Solution not found
350	14.56	2124.37	2128.27	-	Solution not found
351	14.40	-1.70	20.74	12.8 %	ACCEPTABLE
352	14.51	-1.70	20.74	12.6 %	ACCEPTABLE
353	14.40	-1.46	20.88	6.7 %	ACCEPTABLE
354	14.51	-1.58	20.75	12.6 %	ACCEPTABLE
355	14.40	-1.58	20.86	6.8 %	ACCEPTABLE
356	14.51	-1.82	20.73	12.8 %	ACCEPTABLE
357	14.62	-1.82	20.73	11.1 %	ACCEPTABLE
358	14.51	-1.58	20.86	12.8 %	ACCEPTABLE
359	14.62	-1.70	20.74	11.0 %	ACCEPTABLE
360	14.51	-1.70	20.85	13.0 %	ACCEPTABLE
361	14.62	-1.70	20.85	11.6 %	ACCEPTABLE
362	14.51	-1.46	20.98	6.7 %	ACCEPTABLE
363	14.62	-1.58	20.86	11.1 %	ACCEPTABLE
364	14.51	-1.58	20.97	6.8 %	ACCEPTABLE
365	14.62	-1.82	20.84	12.6 %	ACCEPTABLE
366	14.51	-1.58	20.97	6.8 %	ACCEPTABLE
367	14.62	-1.70	20.85	11.6 %	ACCEPTABLE
368	14.51	-1.70	20.96	6.9 %	ACCEPTABLE
369	14.51	-1.82	20.73	12.8 %	ACCEPTABLE
370	14.40	-1.58	20.86	6.8 %	ACCEPTABLE
371	14.51	-1.70	20.74	12.6 %	ACCEPTABLE
372	14.40	-1.70	20.85	6.9 %	ACCEPTABLE
373	14.46	-1.88	20.78	13.0 %	ACCEPTABLE
374	14.57	-1.88	20.78	12.8 %	ACCEPTABLE
375	14.46	-1.64	20.91	7.3 %	ACCEPTABLE
376	14.57	-1.76	20.79	12.2 %	ACCEPTABLE
377	14.46	-1.76	20.90	7.1 %	ACCEPTABLE
378	14.57	-2.00	20.77	-	Solution not found
379	14.46	-1.76	20.90	7.1 %	ACCEPTABLE
380	14.57	-1.88	20.78	12.8 %	ACCEPTABLE
381	14.46	-1.88	20.89	7.2 %	ACCEPTABLE
382	14.46	-2.00	20.66	-	Solution not found
383	14.35	-1.76	20.79	6.8 %	ACCEPTABLE
384	14.46	-1.88	20.67	13.0 %	ACCEPTABLE
385	14.35	-1.88	20.78	6.9 %	ACCEPTABLE
386	14.41	-2.06	20.71	-	Solution not found
387	14.46	-2.12	20.65	-	Solution not found
388	14.35	-1.88	20.78	6.9 %	ACCEPTABLE
389	14.46	-2.00	20.66	-	Solution not found
390	14.35	-2.00	20.77	6.9 %	ACCEPTABLE
391	14.35	-1.88	20.78	6.9 %	ACCEPTABLE
392	14.46	-2.00	20.66	-	Solution not found
393	14.46	-1.76	20.90	7.1 %	ACCEPTABLE
394	14.57	-1.88	20.78	12.8 %	ACCEPTABLE
395	14.35	2113.55	2117.45	-	Solution not found
396	14.45	2136.16	2140.06	-	Solution not found
397	14.45	2113.55	2117.45	-	Solution not found

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
398	14.46	-1.88	20.78	13.0 %	ACCEPTABLE
399	14.53	-1.88	20.78	-	Solution not found
400	14.46	-1.72	20.87	6.9 %	ACCEPTABLE
401	14.53	-1.80	20.79	13.1 %	ACCEPTABLE
402	14.60	-1.80	20.79	11.1 %	ACCEPTABLE
403	14.53	-1.64	20.88	12.9 %	ACCEPTABLE
404	14.60	-1.72	20.80	11.2 %	ACCEPTABLE
405	14.53	-1.72	20.87	12.9 %	ACCEPTABLE
406	14.60	-1.88	20.78	11.0 %	ACCEPTABLE
407	14.53	-1.72	20.87	12.9 %	ACCEPTABLE
408	14.60	-1.80	20.79	11.1 %	ACCEPTABLE
409	14.53	-1.80	20.86	13.1 %	ACCEPTABLE
410	14.53	-1.88	20.71	12.7 %	ACCEPTABLE
411	14.46	-1.72	20.80	12.9 %	ACCEPTABLE
412	14.53	-1.80	20.72	12.7 %	ACCEPTABLE
413	14.46	-1.80	20.79	13.0 %	ACCEPTABLE
414	14.49	-1.92	20.74	-	Solution not found
415	14.53	-1.96	20.70	-	Solution not found
416	14.46	-1.80	20.79	13.0 %	ACCEPTABLE
417	14.53	-1.88	20.71	12.7 %	ACCEPTABLE
418	14.46	-1.88	20.78	13.0 %	ACCEPTABLE
419	14.46	-1.80	20.79	13.0 %	ACCEPTABLE
420	14.53	-1.88	20.71	12.7 %	ACCEPTABLE
421	14.53	-1.72	20.87	12.9 %	ACCEPTABLE
422	14.60	-1.80	20.79	11.1 %	ACCEPTABLE
423	14.42	2129.21	2133.11	-	Solution not found
424	14.50	2144.33	2148.23	-	Solution not found
425	14.50	2129.21	2133.11	-	Solution not found
426	14.53	-1.80	20.79	13.1 %	ACCEPTABLE
427	14.58	-1.80	20.79	12.7 %	ACCEPTABLE
428	14.53	-1.69	20.85	13.0 %	ACCEPTABLE
429	14.58	-1.75	20.80	12.7 %	ACCEPTABLE
430	14.53	-1.75	20.84	13.1 %	ACCEPTABLE
431	14.58	-1.75	20.84	12.7 %	ACCEPTABLE
432	14.53	-1.64	20.90	12.9 %	ACCEPTABLE
433	14.58	-1.70	20.85	12.7 %	ACCEPTABLE
434	14.53	-1.70	20.89	12.9 %	ACCEPTABLE
435	14.58	-1.80	20.83	12.7 %	ACCEPTABLE
436	14.53	-1.70	20.89	12.9 %	ACCEPTABLE
437	14.58	-1.75	20.84	12.7 %	ACCEPTABLE
438	14.53	-1.75	20.89	13.0 %	ACCEPTABLE
439	14.53	-1.80	20.79	13.1 %	ACCEPTABLE
440	14.48	-1.70	20.85	12.8 %	ACCEPTABLE
441	14.53	-1.75	20.79	13.1 %	ACCEPTABLE
442	14.48	-1.75	20.84	12.9 %	ACCEPTABLE
443	14.51	-1.83	20.81	13.1 %	ACCEPTABLE
444	14.56	-1.83	20.81	12.8 %	ACCEPTABLE
445	14.51	-1.72	20.87	12.9 %	ACCEPTABLE
446	14.56	-1.78	20.82	12.8 %	ACCEPTABLE
447	14.51	-1.78	20.86	13.0 %	ACCEPTABLE
448	14.56	-1.88	20.80	12.8 %	ACCEPTABLE
449	14.51	-1.78	20.86	13.0 %	ACCEPTABLE
450	14.56	-1.83	20.81	12.8 %	ACCEPTABLE
451	14.51	-1.83	20.86	13.0 %	ACCEPTABLE
452	14.51	-1.88	20.76	-	Solution not found

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
453	14.46	-1.78	20.82	12.8 %	ACCEPTABLE
454	14.51	-1.83	20.76	13.2 %	ACCEPTABLE
455	14.56	-1.83	20.76	12.7 %	ACCEPTABLE
456	14.51	-1.72	20.82	13.0 %	ACCEPTABLE
457	14.56	-1.78	20.77	12.7 %	ACCEPTABLE
458	14.51	-1.78	20.81	13.1 %	ACCEPTABLE
459	14.56	-1.88	20.75	12.7 %	ACCEPTABLE
460	14.51	-1.78	20.81	13.1 %	ACCEPTABLE
461	14.56	-1.83	20.76	12.7 %	ACCEPTABLE
462	14.51	-1.83	20.81	13.1 %	ACCEPTABLE
463	14.51	-1.88	20.71	12.8 %	ACCEPTABLE
464	14.46	-1.78	20.77	12.9 %	ACCEPTABLE
465	14.51	-1.83	20.71	12.7 %	ACCEPTABLE
466	14.46	-1.83	20.76	13.0 %	ACCEPTABLE
467	14.49	-1.91	20.73	-	Solution not found
468	14.51	-1.94	20.70	-	Solution not found
469	14.46	-1.83	20.76	13.0 %	ACCEPTABLE
470	14.51	-1.88	20.71	12.8 %	ACCEPTABLE
471	14.46	-1.88	20.75	-	Solution not found
472	14.46	-1.83	20.76	13.0 %	ACCEPTABLE
473	14.51	-1.88	20.71	12.8 %	ACCEPTABLE
474	14.51	-1.78	20.81	13.1 %	ACCEPTABLE
475	14.56	-1.83	20.76	12.7 %	ACCEPTABLE
476	14.51	2132.23	2136.13	-	Solution not found
477	14.55	2142.31	2146.21	-	Solution not found
478	14.55	2132.23	2136.13	-	Solution not found
479	14.51	-1.83	20.76	13.2 %	ACCEPTABLE
480	-2.72	-0.67	3.44	0.4 %	ACCEPTABLE
481	-2.72	-0.67	3.44	0.4 %	ACCEPTABLE
482	0.15	-2.12	14.67	-	Solution not found
483	0.15	-2.06	9.98	-	Solution not found
484	0.15	-1.97	6.92	-	Solution not found
485	-6.87	60.70	64.06	-	Solution not found
486	0.15	-1.80	4.98	-	Solution not found
487	-5.05	29.28	32.65	0.0 %	ACCEPTABLE
488	0.15	-1.42	3.95	-	Solution not found
489	-3.91	14.49	17.89	0.1 %	ACCEPTABLE
490	0.15	-0.25	4.18	-	Solution not found
491	-3.23	7.38	10.82	0.1 %	ACCEPTABLE
492	0.15	81.97	85.79	-	Solution not found
493	-2.88	3.85	7.37	0.2 %	ACCEPTABLE
494	4.75	-0.52	4.46	0.0 %	ACCEPTABLE
495	-2.74	2.04	5.65	0.3 %	ACCEPTABLE
496	14.00	-0.87	13.54	0.0 %	ACCEPTABLE
497	11.52	0.91	11.20	0.0 %	ACCEPTABLE
498	-67.07	15.68	69.12	0.1 %	ACCEPTABLE
499	-2.74	1.07	4.81	0.3 %	ACCEPTABLE
500	-11.85	-0.87	12.39	0.1 %	ACCEPTABLE
501	8.89	0.26	8.72	0.0 %	ACCEPTABLE
502	-66.88	15.68	69.12	0.2 %	ACCEPTABLE
503	-2.82	0.53	4.41	0.4 %	ACCEPTABLE
504	-5.44	-0.76	6.05	0.3 %	ACCEPTABLE
505	-2.92	0.22	4.22	0.4 %	ACCEPTABLE
506	-4.23	-0.64	4.89	0.4 %	ACCEPTABLE
507	-3.96	-0.54	4.50	-	Solution not found

No.	Center		Radius R [m]	Utilization	Verification
	x [m]	z [m]			
508	-3.02	0.04	4.15	0.4 %	ACCEPTABLE
509	-3.80	-0.54	4.50	0.4 %	ACCEPTABLE
510	-3.71	-0.46	4.34	0.4 %	ACCEPTABLE
511	-3.10	-0.08	4.13	0.4 %	ACCEPTABLE
512	-3.60	-0.46	4.34	0.4 %	ACCEPTABLE
513	-3.57	-0.41	4.26	0.4 %	ACCEPTABLE
514	-3.17	-0.15	4.13	0.4 %	ACCEPTABLE
515	-3.50	-0.41	4.26	0.4 %	ACCEPTABLE
516	-3.49	-0.37	4.22	0.4 %	ACCEPTABLE
517	-3.23	-0.20	4.13	0.4 %	ACCEPTABLE
518	-3.44	-0.37	4.22	0.4 %	ACCEPTABLE
519	-2.72	-0.67	3.44	0.4 %	ACCEPTABLE

Dimensioning No. 1

	Disp. min [mm]	Disp. max [mm]	Shear force min. [kN/m]	Shear force max [kN/m]	Moment min. [kNm/m]	Moment max. [kNm/m]
0.00	-13.10	-13.10	-0.00	-0.00	0.00	0.00
0.33	-12.27	-12.27	-1.59	-1.59	0.26	0.26
0.65	-11.44	-11.44	-3.18	-3.18	1.03	1.03
0.97	-10.61	-10.61	-4.77	-4.77	2.33	2.33
1.30	-9.79	-9.79	-6.37	-6.37	4.14	4.14
1.63	-8.97	-8.97	-7.96	-7.96	6.46	6.46
1.95	-8.16	-8.16	-9.55	-9.55	9.31	9.31
2.27	-7.36	-7.36	-11.14	-11.14	12.67	12.67
2.30	-7.30	-7.30	-11.26	-11.26	12.95	12.95
2.30	-7.30	-7.30	-10.26	-10.26	12.95	12.95
2.60	-6.58	-6.58	-11.58	-11.58	16.24	16.24
2.92	-5.81	-5.81	-12.68	-12.68	20.19	20.19
3.25	-5.07	-5.07	-13.44	-13.44	24.45	24.45
3.58	-4.36	-4.36	-13.86	-13.86	28.90	28.90
3.79	-3.91	-3.91	-13.95	-13.95	31.93	31.93
3.81	-3.88	-3.88	-13.94	-13.94	32.15	32.15
3.90	-3.69	-3.69	-13.77	-13.77	33.42	33.42
4.22	-3.06	-3.06	-13.19	-13.19	37.81	37.81
4.55	-2.47	-2.47	-12.60	-12.60	42.00	42.00
4.88	-1.93	-1.93	-12.01	-12.01	46.00	46.00
5.20	-1.45	-1.45	-11.39	-11.39	49.80	49.80
5.53	-1.03	-1.03	-10.76	-10.76	53.41	53.41
5.85	-0.68	-0.68	1.49	1.49	54.74	54.74
6.17	-0.39	-0.39	16.26	16.26	51.64	51.64
6.50	-0.16	-0.16	23.83	23.83	44.95	44.95
6.83	0.01	0.01	25.09	25.09	36.81	36.81
7.15	0.14	0.14	21.33	21.33	29.17	29.17
7.47	0.23	0.23	17.44	17.44	22.94	22.94
7.80	0.29	0.29	15.78	15.78	17.53	17.53
8.13	0.33	0.33	13.72	13.72	12.73	12.73
8.45	0.36	0.36	11.47	11.47	8.63	8.63
8.78	0.37	0.37	9.15	9.15	5.29	5.29
9.10	0.38	0.38	6.92	6.92	2.68	2.68
9.43	0.39	0.39	4.90	4.90	0.77	0.77

	Disp. min [mm]	Disp. max [mm]	Shear force min. [kN/m]	Shear force max [kN/m]	Moment min. [kNm/m]	Moment max. [kNm/m]
9.75	0.39	0.39	3.20	3.20	-0.53	-0.53
10.07	0.40	0.40	1.81	1.81	-1.33	-1.33
10.40	0.41	0.41	0.72	0.72	-1.73	-1.73
10.72	0.42	0.42	-0.10	-0.10	-1.82	-1.82
11.05	0.43	0.43	-0.66	-0.66	-1.68	-1.68
11.38	0.44	0.44	-1.00	-1.00	-1.40	-1.40
11.70	0.46	0.46	-1.14	-1.14	-1.04	-1.04
12.03	0.48	0.48	-1.10	-1.10	-0.67	-0.67
12.35	0.50	0.50	-0.89	-0.89	-0.33	-0.33
12.68	0.51	0.51	-0.52	-0.52	-0.09	-0.09
13.00	0.53	0.53	-0.00	-0.00	0.00	0.00

Maximum values of internal forces

Maximum displacement = -13.1 mm
 Minimum displacement = 0.5 mm
 Maximum bending moment = 54.74 kNm/m
 Minimum bending moment = -1.82 kNm/m
 Maximum shear force = 25.09 kN/m

Cross-section verification - detailed results

Cross-sectional characteristics per 1 m of wall:

Area of cross section $A = 1.723\text{E-}02 \text{ m}^2/\text{m}$
 Sectional modulus $W = 1.920\text{E-}03 \text{ m}^3/\text{m}$
 Plastic sectional modulus $W_{pl} = 2.280\text{E-}03 \text{ m}^3/\text{m}$
 Moment of inertia $I = 4.132\text{E-}04 \text{ m}^4/\text{m}$
 First moment of area of cross-section $S = 1.140\text{E-}03 \text{ m}^3/\text{m}$
 First moment of area $S_1 = 7.307\text{E-}04 \text{ m}^3/\text{m}$
 Thickness of cross-section cut $t = 18.8 \text{ mm}/\text{m}$

Material properties:

Yield strength $f_y = 355.00 \text{ MPa}$

Partial factors:

Coefficient of cross-section resistance $\gamma_{M0} = 1.00$

Cross-section resistance:

Bending capacity $M_{c,Rd} = W \cdot f_y / \gamma_{M0} = 681.60 \text{ kNm/m}$
 Shear capacity $V_{c,Rd} = I \cdot t \cdot S \cdot f_y / (\sqrt{3} \cdot \gamma_{M0}) = 1394.65 \text{ kN/m}$

Verification of steel section according to EN 1993-1-1

All construction stages are taken into the analysis.

Reduct. coefficient of bearing capacity = 1.00

Internal forces per 1 m of wall

$M_{\max} = 54.74 \text{ kNm/m}$ $Q = 1.49 \text{ kN/m}$
 ;
 $Q_{\max} = 25.09 \text{ kN/m}$; $M = 36.81 \text{ kNm/m}$

Verification of max. moment $M_{\max} + Q$:

Bending verification:

$M_{\max} / M_{c,Rd} = 0.080 \leq 1$ **Is satisfied**

Shear verification:

$$Q/V_{c,Rd} = 0.001 \leq 1 \quad \text{Is satisfied}$$

Verification of plane state of stress:

$$\text{Normal stress } \sigma_{x,Ed} = 26.87 \text{ MPa}$$

$$\text{Shear stress } \tau_{Ed} = 0.14 \text{ MPa}$$

$$\text{Verification: } (\sigma_{x,Ed}/(f_y/\gamma_{M0}))^2 + 3*(\tau_{Ed}/(f_y/\gamma_{M0}))^2 = 0.006 \leq 1 \quad \text{Is satisfied}$$

Verification of max. shear force $Q_{max} + M$:

Bending verification:

$$M/M_{c,Rd} = 0.054 \leq 1 \quad \text{Is satisfied}$$

Shear verification:

$$Q_{max}/V_{c,Rd} = 0.018 \leq 1 \quad \text{Is satisfied}$$

Verification of plane state of stress:

$$\text{Normal stress } \sigma_{x,Ed} = 18.07 \text{ MPa}$$

$$\text{Shear stress } \tau_{Ed} = 2.36 \text{ MPa}$$

$$\text{Verification: } (\sigma_{x,Ed}/(f_y/\gamma_{M0}))^2 + 3*(\tau_{Ed}/(f_y/\gamma_{M0}))^2 = 0.003 \leq 1 \quad \text{Is satisfied}$$

Cross section is SATISFACTORY

Durability design

Calculation method: Eurocode 3 - Part 5

Head wall

Geometry

Z _{top}	4.00	m
Z _{w front}	1.50	m
Z _{w back}	-4.00	m
Buckling length	12.00	m

Partial safety factors

Project specific	
γ _{M0}	1.50
γ _{M1}	1.50
γ _{M2}	1.00
γ _{Mt,ser}	1.00

Sheet pile properties (initial values)

W _{el,y} [cm ³ /m]	W _{pl,y} [cm ³ /m]	I _y [cm ⁴ /m]	A [cm ² /m]	t _f [mm]	t _w [mm]	h [mm]	α [°]
1,920	2,280	41,320	172.3	12.20	9.50	430.0	57.5
b [mm]	c [mm]	A _v [cm ² /m]	S _y [cm ³ /m]	r ₀ [mm]	mass [kg/m ²]	B [mm]	
288.5	247.7	66.2	1,125	15.0	135.2	1,200	

Steel grade

f _{y ini}	355.0	MPa
ε	0.814	
(b/t _f)/ε	29	
Class ini.	2	

Steel quantities

L _{wall}	60.0	m
L _{ssp}	0.00	m
Steel weight	0.00	t

Reduction factors (U-piles)

β _B	1.00
β _D	1.00

Service life

100 years

Actions

Position	Z [m]	M _{Ed} [kNm/m]	V _{Ed} [kN/m]	N _{Ed} [kN/m]	e [mm]
1	1.50	10	-7	20	0
2	0.00	17	-13	40	0
3	-3.00	53	22	60	0
4	-8.00	-3	-10	80	0

Corrosion

Approach : Eurocode 3 - Part 5. Table 4.1 and 4.2

Zone	Z bottom [m]	Loss of steel Front [mm]	Loss of steel Back [mm]	Protection Front [years]	Protection Back [years]	Total loss Front [mm]	Total loss Back [mm]
1	4.00	WATER_4 3.50	WATER_4 3.50	0	0	3.50	3.50
2	-8.00	WATER_4 3.50	WATER_4 3.50	0	0	3.50	3.50

Legend

WATER_4 Water. Sea water in temperate climate in the zone of permanent immersion or in the intertidal zone

Results

N°	Z [m]	Bending	Bending & shear	Web shear buckling	Buckling	Bending & axial	Bending & shear & axial	Uf
1	1.50	✓	✓	✓	✓	✓	-	0.10
2	0.00	✓	✓	✓	✓	✓	-	0.17
3	-3.00	✓	✓	✓	✓	✓	-	0.53
4	-8.00	✓	✓	✓	✓	✓	-	0.10

Numerical details : level n°1 (z = 1.50 m)

Section classification

Property	Ini.	Red.	Red. class 3
f_y	355.0	355.0	187.0
ϵ	0.814	0.814	1.121
$(b/t_f)/\epsilon$	29	68	49
Class	2	4	3

Selected section properties

Property	Ini.	Red.	Unit
$W_{el,y}$	1,920	805	cm ³ /m
$W_{pl,y}$	2,280	...	cm ³ /m
I_y	41,320	17,280	cm ⁴ /m
A	172.3	73.8	cm ² /m
t_f	12.20	5.20	mm
t_w	9.50	2.50	mm
h	430.0	423.0	mm
α	57.5	-	°
b	288.5	-	mm
c	247.7	-	mm
A_v	66.2	17.4	cm ² /m
S_y	1,125	-	cm ³ /m
r_0	15.0	-	mm
mass	135.2	-	kg/m ²
B	1,200	-	mm

Bending

$$M_{Ed} = 10 \text{ kNm/m} \leq M_{c,Rd} = \frac{\beta_B W_{el} f_y}{\gamma_{M0}} = 100 \text{ kNm/m}$$

$$W_{el} = 805 \text{ cm}^3/\text{m}$$

Bending & shear

$$V_{Ed} = 7 \text{ kN/m} \leq V_{pl,Rd} = \frac{A_t f_y}{\sqrt{3} \gamma_{M0}} = 125 \text{ kN/m}$$

$$V_{Ed} = 7 \text{ kN/m} \leq 0.50 V_{pl,Rd} = 63 \text{ kN/m}$$

No further verification needed

Web shear buckling

$$\frac{c}{t_w \cdot z} = 88.4 > 72$$

$$\bar{\lambda} = 0.346 \frac{c}{t_w} \sqrt{\frac{f_y}{E}} = 1.023$$

$$f_{wv} = 87.7 \text{ MPa}$$

$$V_{Ed} = 7 \text{ kN/m} \leq V_{b,Rd} = \frac{2(h-t_f)t_w f_{wv}}{B \cdot \gamma_{M0}} = 102 \text{ kN/m}$$

Buckling

$$N_{Ed} = 20 \text{ kN/m} \leq N_{pl,Rd} = \frac{A f_y}{\gamma_{M0}} = 920 \text{ kN/m}$$

$$N_{cr} = \frac{EI \beta_D \pi^2}{l^2} = 2484 \text{ kN/m}$$

$$0.04 \cdot N_{cr} = 99 \text{ kN/m} \geq N_{Ed} = 20 \text{ kN/m}$$

No further verification needed

Bending & axial

$$N_{Ed} = 20 \text{ kN/m} \leq k_1 N_{pl,Rd} = k_1 \frac{A f_y}{\gamma_{M0}} = 92 \text{ kN/m with } k_1 = 0.10$$

✓ Correct sheet pile selected

Numerical details : level n°2 (z = 0.00 m)

Section classification

Property	Ini.	Red.	Red. class 3
f_y	355.0	355.0	187.0
ϵ	0.814	0.814	1.121
$(b/t_f)/\epsilon$	29	68	49
Class	2	4	3

Selected section properties

Property	Ini.	Red. Unit
$W_{el,y}$	1,920	805 cm ³ /m
$W_{pl,y}$	2,280	... cm ³ /m
I_y	41,320	17,260 cm ⁴ /m
A	172.3	73.8 cm ² /m
t_f	12.20	5.20 mm
t_w	9.50	2.50 mm
h	430.0	423.0 mm
α	57.5	- °
b	288.5	- mm
c	247.7	- mm
A_v	66.2	17.4 cm ² /m
S_y	1,125	- cm ³ /m
r_0	15.0	- mm
mass	135.2	- kg/m ²
B	1,200	- mm

Bending

$$M_{Ed} = 17 \text{ kNm/m} \leq M_{c,Rd} = \frac{\beta_B W_{el} f_y}{\gamma_{M0}} = 100 \text{ kNm/m}$$

$$W_{el} = 805 \text{ cm}^3/\text{m}$$

Bending & shear

$$V_{Ed} = 13 \text{ kN/m} \leq V_{pl,Rd} = \frac{A_w f_y}{\sqrt{3} \gamma_{M0}} = 125 \text{ kN/m}$$

$$V_{Ed} = 13 \text{ kN/m} \leq 0.50 V_{pl,Rd} = 63 \text{ kN/m}$$

No further verification needed

Web shear buckling

$$\frac{c}{t_w \cdot z} = 88.4 > 72$$

$$\bar{\lambda} = 0.346 \frac{c}{t_w} \sqrt{\frac{f_y}{E}} = 1.023$$

$$f_{bw} = 87.7 \text{ MPa}$$

$$V_{Ed} = 13 \text{ kN/m} \leq V_{b,Rd} = \frac{2(h - t_f)t_w f_{bw}}{B \cdot \gamma_{M0}} = 102 \text{ kN/m}$$

Buckling

$$N_{Ed} = 40 \text{ kN/m} \leq N_{pl,Rd} = \frac{A f_y}{\gamma_{M0}} = 920 \text{ kN/m}$$

$$N_{cr} = \frac{EI \beta_D \pi^2}{l^2} = 2484 \text{ kN/m}$$

$$0.04 \cdot N_{cr} = 99 \text{ kN/m} \geq N_{Ed} = 40 \text{ kN/m}$$

No further verification needed

Bending & axial

$$N_{Ed} = 40 \text{ kN/m} \leq k_1 N_{pl,Rd} = k_1 \frac{A f_y}{\gamma_{M0}} = 92 \text{ kN/m with } k_1 = 0.10$$

✔ Correct sheet pile selected

Numerical details : level n°3 (z = -3.00 m)

Section classification

Property	Ini.	Red.	Red. class 3
f_y	355.0	355.0	187.0
ϵ	0.814	0.814	1.121
$(b/t_f)/\epsilon$	29	68	49
Class	2	4	3

Selected section properties

Property	Ini.	Red. Unit
$W_{el,y}$	1,920	805 cm ³ /m
$W_{pl,y}$	2,280	... cm ³ /m
I_y	41,320	17,260 cm ⁴ /m
A	172.3	73.8 cm ² /m
t_f	12.20	5.20 mm
t_w	9.50	2.50 mm
h	430.0	423.0 mm
α	57.5	- °
b	288.5	- mm
c	247.7	- mm
A_v	66.2	17.4 cm ² /m
S_y	1,125	- cm ³ /m
r_0	15.0	- mm
mass	135.2	- kg/m ²
B	1,200	- mm

Bending

$$M_{Ed} = 53 \text{ kNm/m} \leq M_{c,Rd} = \frac{\beta_B W_{el} f_y}{\gamma_{M0}} = 100 \text{ kNm/m}$$

$$W_{el} = 805 \text{ cm}^3/\text{m}$$

Bending & shear

$$V_{Ed} = 22 \text{ kN/m} \leq V_{pl,Rd} = \frac{A_w f_y}{\sqrt{3} \gamma_{M0}} = 125 \text{ kN/m}$$

$$V_{Ed} = 22 \text{ kN/m} \leq 0.50 V_{pl,Rd} = 63 \text{ kN/m}$$

No further verification needed

Web shear buckling

$$\frac{c}{t_w \cdot z} = 88.4 > 72$$

$$\bar{\lambda} = 0.346 \frac{c}{t_w} \sqrt{\frac{f_y}{E}} = 1.023$$

$$f_{bw} = 87.7 \text{ MPa}$$

$$V_{Ed} = 22 \text{ kN/m} \leq V_{b,Rd} = \frac{2(h - t_f)t_w f_{bw}}{B \cdot \gamma_{M0}} = 102 \text{ kN/m}$$

Buckling

$$N_{Ed} = 60 \text{ kN/m} \leq N_{pl,Rd} = \frac{A f_y}{\gamma_{M0}} = 920 \text{ kN/m}$$

$$N_{cr} = \frac{EI \beta_D \pi^2}{l^2} = 2484 \text{ kN/m}$$

$$0.04 \cdot N_{cr} = 99 \text{ kN/m} \geq N_{Ed} = 60 \text{ kN/m}$$

No further verification needed

Bending & axial

$$N_{Ed} = 60 \text{ kN/m} \leq k_1 N_{pl,Rd} = k_1 \frac{A f_y}{\gamma_{M0}} = 92 \text{ kN/m with } k_1 = 0.10$$

✔ Correct sheet pile selected

Existing site services plan (based on both desktop search & intrusive verification)

