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Norwegian CCS Demonstration Project
Norcem Concept and FEED

406-01 – Design Report – Geotechnical Engineering

Norcem AS, Brevik

Norwegian CCS Demonstration Project

Norcem Concept and FEED

406-01 - Design Report - Geotechnical Engineering

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Norconsult

Client:	Norcem AS, Brevik
Client's Contact Person:	Tor Gautestad, Project Manager
Consultant:	Norconsult AS, Porselensvegen 20, NO-3920 Porsgrunn
Assignment Manager:	Øystein Bremseth
Technical Advisor:	Nicolai Lindskov
Other Key Personnel:	Banafshe Heidar, Arne Engen, Gunhild Hennum

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► Introduction

This document contains the framework for geotechnical engineering design during the front-end engineering phase of the Norwegian CCS Demonstration Project at Norcem. The purpose of the document is to summarise the design requirements for geotechnical design in terms of governing documents, design requirements and soil parameters. The document will also include an evaluation of axial and lateral capacity for three steel core pile dimensions as well as an assessment of site stability.

Where governing documents are referred to, the latest issue/revision shall be used. In case that any such documents referred to in this specification has been replaced, the new documents shall be regarded as being valid for the work.

Contents

1 General

The following definitions and abbreviations are used:

COMPANY	= Gassnova
CC Plant	= Norwegian CCS Demonstration Project – Norcem Concept and FEED, to be constructed at Norcem Plant Brevik (**CCP**)
Norcem Brevik	= The owner and operator of the site area facilitating the CC Plant **(NB)**
Norcem Plant Brevik	= Site area on which the CC Plant is to be constructed (**NPB**)
Aker Solutions	= Main process contractor for the feasibility study (**AS**)
Norconsult	= Civil Engineering contractor feasibility study (**NO**)
Contractor	= Company delivering equipment and/or performing construction work at site
Civil costs	= Description and cost by NO. Included in NO cost estimate
“Non-civil” costs	= Description by others. Cost by others or NO. Included in NO cost

2 Governing documents

Geotechnical design is based on the following standards and documents:

Document number	Title
NS-EN 1990:2002+A1:2005+NA:2016	Eurocode 0: Basis of structural design
NS-EN 1991:2002+NA:2008	Eurocode 1: Actions on structures
NS-EN 1993-5:2007+NA:2010	Eurocode 3: Design of steel structures - Part 1-5: General rules - Plated structural elements
NS-EN 1997-1:2004+A1:2013+NA:2016	Eurocode 7: Geotechnical design - Part 1: General rules
NS-EN 1998-1:2004+A1:2013+NA:2014	Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings
NS-EN 1998-5:2004+NA:2014	Eurocode 8: Design of structures for earthquake resistance – Part 5: Foundations, retaining structures and geotechnical aspects
RP 2A-WSD	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design, American Petroleum Institute

In addition, the following Norwegian documents, standards and laws are also applicable:

Document number	Title
NS 3458	Komprimering – Krav og utførelse
LOV-2008-06-27-71	Lov om planlegging og byggesaksbehandling (plan- og bygningsloven)
FOR-2010-03-26-488	Forskrift om byggesak (byggesaksforskriften)
R210	Laboratorieundersøkelser, SVV
V220	Geoteknikk i vegbygging, SVV
V221	Grunnforsterking, fyllinger og skråning, SVV
2/2011	Flaum- og skredfare I arealplanar, NVE
7/2014	Sikkerhet mot kvikkleireskredd, NVE
2012	Peleveiledningen, Den Norske Pelekomité, NGF
TEK17	Byggteknisk forskrift

3 Classifications

3.1 Geotechnical category

Geotechnical category is chosen from NS-EN 1997-1:2004+A1:2013+NA:2016 section 2.1. The project includes design of tip-bearing piles as well as evaluation of site stability due to the presence of quick clays.

Geotechnical category: 2.

3.2 Consequence class

Choice of consequence class is defined in NS-EN 1990:2002+A1:2005+NA:2016 appendix B section B3.1. Planned structures include installations for processing plant, tank farm and an administration and maintenance building. These are defined as being of medium consequence for loss of human life, economic, social og environmental consequences considerable:

Consequence class: 2.

3.3 Reliability class

Choice of reliability class is based on NS-EN 1990:2002+A1:2005+NA:2016 table NA.A1(901). Soil layers and depth to bedrock have been identified through soil investigations ultimo 2018. Supplementary information from prior soil investigations carried out during the past 50 years is also available. Soil type and layering is considered of medium complexity which leads to reliability class 2. In addition, the planned structures are for industrial use which also leads to reliability class 2.

Reliability class: 2.

3.4 Supervision level

Supervision level is directly inferred from reliability class 2 in accordance with NS-EN 1990:2002+A1:2005+ NA:2016 tables NA.A1(902) and NA.A1(903).

Design supervision level: 2

Inspection supervision level: 2

3.5 Importance class

The type of structure governs the choice of importance class for seismic design according to NS-EN 1998-1:2004+A1:2013+NA:2014 table NA.4(902). An overview of structures and corresponding importance class is shown in Table 3-1.

Table 3-1: Importance class for each type of structure.

Structure	Importance class	γ_I
Administration building	2	1,0
Quay structure	2	1,0
Industrial processing units	2	1,0
CO2-tanks	2	1,0

4 Site description

4.1 Topography

The different project areas are shown in Figure 4-1 below. Most of Area 1 is generally flat with the future CO_2-facilities at approximately 3-4 metres above mean sea level (MAMSL). In the north-western part of the area the terrain rises to approximately +20 MAMSL. Area 3 is also generally flat and lies at approximately +2 MAMSL.

Figure 4-1: Demarcation of project areas labelled as Area 1, Area 3 and Bay respectively. Source: norgeskart.no.

Navigation charts show depths ranging from 10 m in the western part of the bay to about 20 m in the eastern part.

4.2 Soil conditions

The reader is referred to Geotechnical Data Report (doc. no.: NC03-NOCON-G-RA-0002_406-02) for a detailed description of soil conditions and all data obtained from soil investigations ultimo 2018.

4.3 Bedrock

Elevation of the bedrock surface varies and generally dips to the south and east towards the bay. In Area 1, soil depth generally increases from 0 to 30 m going from north-west to south-east towards the bay. The northern and western parts of the bay are considered the most challenging areas in terms of foundation design due to a large probability of very steep bedrock surface.

Bedrock is considered suitable for tip-bearing piles for both onshore and offshore structures.

4.4 Seismic design

The design ground acceleration in Brevik, Porsgrunn, is:

$$a_g = \gamma_I \cdot 0{,}8 \cdot a_{g40Hz} = 1{,}0 \cdot 0{,}8 \cdot 0{,}5\ m/s^2 = 0{,}4\ m/s^2$$

where γ_I is given in NS-EN 1998-1:2004+A1:2013+ NA:2014 table NA.4(901) and chosen according to importance class recommended in table NA.4(902). All structures in this project fall into importance class 2 which yields $\gamma_I = 1{,}0$.

4.4.1 Ground type

Ground type for area 1 and 3 has been analysed in a spreadsheet (developed by Norconsult) due to the presence of sensitive clays and/or quick clays. Please see the attached ground type analysis in Appendix A.

Table 4-1: Ground type for project areas.

Project area	Ground type
Area 1	S_2
Area 3	E
Bay	E

4.4.2 Design response spectra

The design response spectrum for soil type E is given in Eurocode, whereas the response spectrum for type S_2 must be analysed for the specific soil profile. The program Strata (developed at the University of Texas) was used for a linear response analysis based on the shear wave velocities calculated for borehole B02 in Appendix A.

Design response spectra for type E and type S_2 are shown in Figure 4-2 and are based on the limits shown in Table 4-2.

Table 4-2: Soil factor and limits of constant spectral acceleration.

Ground type	S	T_b	T_c	T_d
E	1,65	0,10	0,30	1,40
S_2	1,85	0,20	0,60	0,95

The calculation assumes a behaviour factor of no more than 1,5.

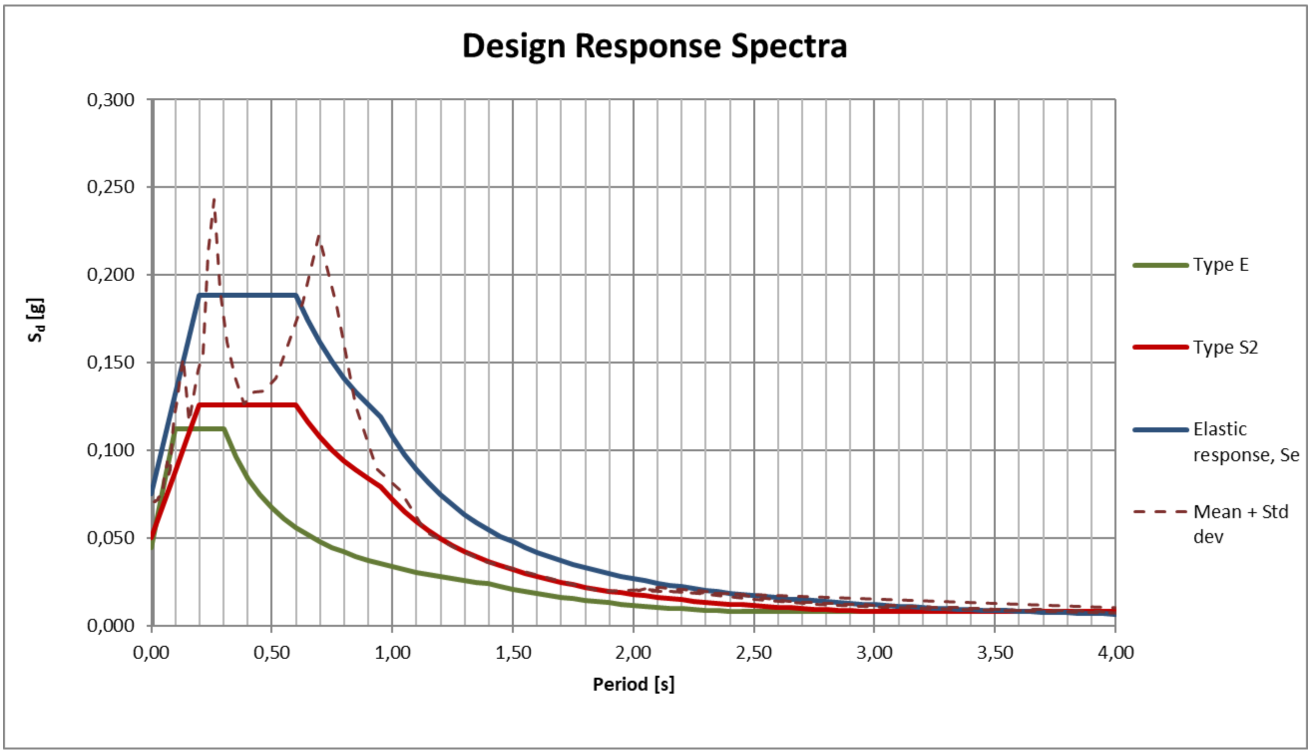

Figure 4-2: Design response spectra.

4.4.3 Low seismicity

Structures can be designed according to guidelines for areas with low seismicity if:

$$0{,}49\ m/s^2 \leq a_g S < 0{,}98\ m/s^2$$

From the values in Table 4-3 it is seen that these guidelines may be applied to all structures since they are all classified as Importance class 2 as seen in Table 3-1.

The guidelines for low seismicity state that actions from wind and sway imperfections are compared to seismic action. The higher value is the design load.

Table 4-3: Values for determining applicability of low seismicity criterion.

Project area	Ground type	Ground acceleration [m/s^2]	Soil factor (S) [-]	$a_g S$ [m/s^2]
Area 1	S_2	0,4	1,85	0,74
Area 3	E	0,4	1,65	0,66
Bay	E	0,4	1,65	0,66

5 Foundation design

It is recommended that deep foundations are used for all structures due to the nature of soil types and layering in the project area. For industrial structures and the administration and maintenance building this would be bored, tip-bearing steel cores piles and for the quay structure it would be driven, tip-bearing steel piles.

5.1 Steel core piles

In the following sections, axial and lateral capacity for vertical steel core piles are given for three different dimensions.

5.1.1 Axial capacity

The design axial capacity is the lower bound of installed capacity, bearing capacity of bedrock or buckling load. The former two may be further reduced by vertical loads from settling ground, which is a known issue in the project area.

Installed capacity

The cross-sectional pile capacity is determined from the following equation:

$$N_{c,rd} = \frac{f_\gamma \cdot A}{\gamma_{MO}}$$

f_γ = yield stress of steel
A = cross-sectional area of steel core
γ_{MO} = partial factor for material/cross-sectional capacity

Installed capacity, N_i, is then determined by multiplying the cross-sectional capacity with a reduction factor, f_a, to account for adverse and unexpected ground conditions during installation as well as the type of equipment and/or pile type that is used.

$$N_i = N_{c,Rd} \cdot f_a$$

For bored piles in well-known ground conditions, a reduction factor $f_a = 0{,}9$ is typical and will be used in this case.

Bearing capacity of bedrock

Bearing capacity of bedrock is determined from the following equation:

$$R_{b;d} = \frac{N_s \cdot \sigma_{tf} \cdot A}{\gamma_t \cdot \xi}$$

N_s = bearing capacity factor for tip-bearing piles on bedrock
σ_{tf} = uniaxial compression strength of bedrock
A = cross-sectional area of steel core
γ_t = partial factor for total bearing capacity of bored piles
ξ = correlation factor, conservatively chosen

No core samples from bedrock have been taken during soil investigations, but a limestone quarry exists just west of the project area. Geological maps indicate that the project area is part of the same bedrock formation as the quarry. It is therefore assumed that bedrock consists primarily of limestone with a compressive strength of 70-100 MPa.

Buckling

The theoretical characteristic buckling load is determined from the following equation:

$$R_{K;cal} = \frac{\pi \cdot E \cdot I}{l^2} + \frac{C \cdot l^2}{\pi^2}$$

E = Young's modulus for steel core
I = moment of inertia of steel core
l = pile length
C = soil reaction modulus

The first term in the above equation is Euler's buckling load. The second term accounts for lateral support from surrounding soil.

The length of a half wave (buckling length) is determined from the following expression:

$$L_k = 2 \cdot \sqrt[4]{\frac{E \cdot I}{C}}$$

If the pile length, l, is greater or equal to L_k, then $l = L_k$ in the above expression for the theoretical buckling load. The expression for the theoretical characteristic buckling load if $l \geq L_k$ is thus reduced to:

$$R_{K;cal} = 2 \cdot \sqrt{E \cdot I \cdot C}$$

The soil reaction modulus is based on the soil characteristics in a depth interval corresponding to the half wave length. For cohesionless soils it may be estimated from:

$$C = k \cdot d$$

k = gradient of soil reaction modulus (see Table 5-1 below).
d = pile diameter

Table 5-1: Gradient of soil reaction modulus for sand.

Soil type	Above ground water level [kN/m³]	Below ground water level [kN/m³]
Loose sand	5.000	4.500
Medium sand	22.000	15.000
Dense sand	60.000	34.000

For drained, cohesive soils the gradient of soil reaction may be estimated from:

$$k = 50c_{u,d}$$

$c_{u,d}$ = characteristic undrained direct shear strength

Vertical loads from settling soil

Determining vertical loads induced by settling ground around piles is bound by uncertainty since this depends on the magnitude of settlements and degree of soil mobilization with depth. This has not been studied in detail in this phase of the project, but an estimate has been provided based on the following assumptions:

- Skin friction factor for piles, β = 0,25
- Full mobilization of soil along the entire length of the pile

Mobilised side friction along a pile (additional vertical load) may then be calculated from the following equation:

$$R_{c,k} = \beta \cdot \sigma_{v,0}{}' \cdot \pi \cdot d \cdot l$$

β = skin friction factor
$\sigma_{v,0}{}'$ = average effective vertical stress

Design axial capacity

In Table 5-2 below, the design axial capacities for Ø100, Ø130 and Ø150 steel core piles are shown for different lengths.

Table 5-2: Design axial capacity for selected pile lengths based on "Peleveiledningen 2012". Spreadsheet with calculation is found in Appendix B.

Pile	Length [m]	Diameter casing [mm]	Design axial capacity [kN]
Ø100	20	139,7	1766
	30	139,7	1492
Ø130	20	193,7	3043
	30	193,7	2672
Ø150	20	219,1	3973
	30	219,1	3543

5.1.2 Lateral capacity

The lateral capacity of the foundation may be taken as a combination of passive earth pressure and lateral capacity of the piles. In this case, however, the deformation will not be enough to fully activate passive earth pressure and the steel core piles will therefore alone take any lateral action.

Designing piles for lateral loads is best achieved through calculating the force-deformation response for each pile. The force – deformation and moment - deformation curves for Ø100, Ø130 and Ø150 steel core piles (with casing) are shown in Figure 5-1 and Figure 5-2. The calculations assume fixed pile head ($k_{xx} = k_{yy} = 10^{11}\ kNm/rad$) and are calculated using a soil model from American Petroleum Institute.

Lateral deformation primarily depends on the properties of the top 4-5 m soil, which is generally fill material throughout both area 1 and 3. Calculations based on a soil profile from both area 1 (B02) and area 3 (D02) have confirmed that there's only a slight variation in the deformation response. The deformation curves shown in Figure 5-1 and Figure 5-2 are based on the soil profile for borehole D02 and may be utilised for all onshore structures.

Deformation and internal moment as a function of depth below ground surface is shown in Figure 5-3. Correlating response to these curves is a method of determining soil springs in *FEM-Design*. Note that the applied lateral load varies as per Table 5-3.

Note: Based on experience, it is suggested that the lateral capacity is reduced approximately 25% due to seismic action. E.g. if the lateral capacity of a Ø130 steel core pile is set to 100 kN (based on allowable deformation), then the available lateral capacity for non-seismic loads will be 75 kN. An analysis of the exact percentage will be a part of the detailed design phase.

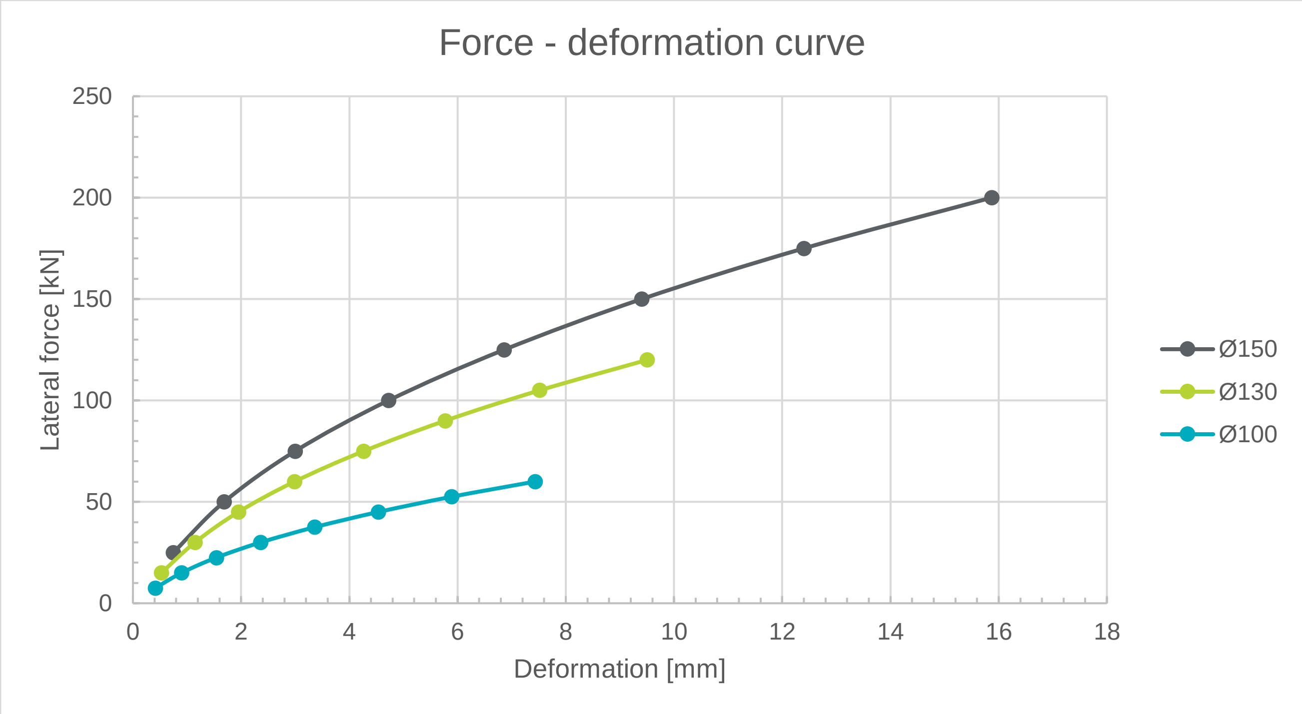

Figure 5-1: Force – deformation response for Ø100, Ø130 and Ø150 steel core piles. Calculation software: Novapoint GeoSuite.

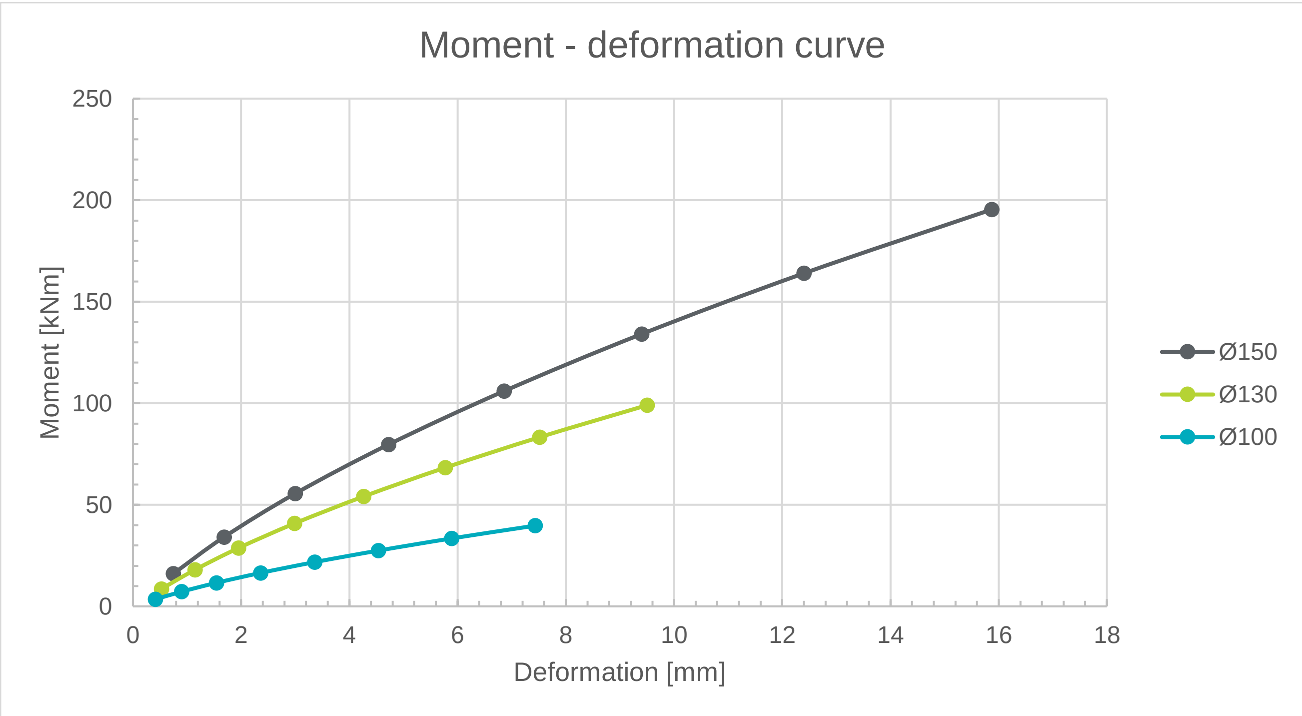

Figure 5-2: Moment – deformation response for Ø100, Ø130 and Ø150 steel core piles. Calculation software: Novapoint GeoSuite.

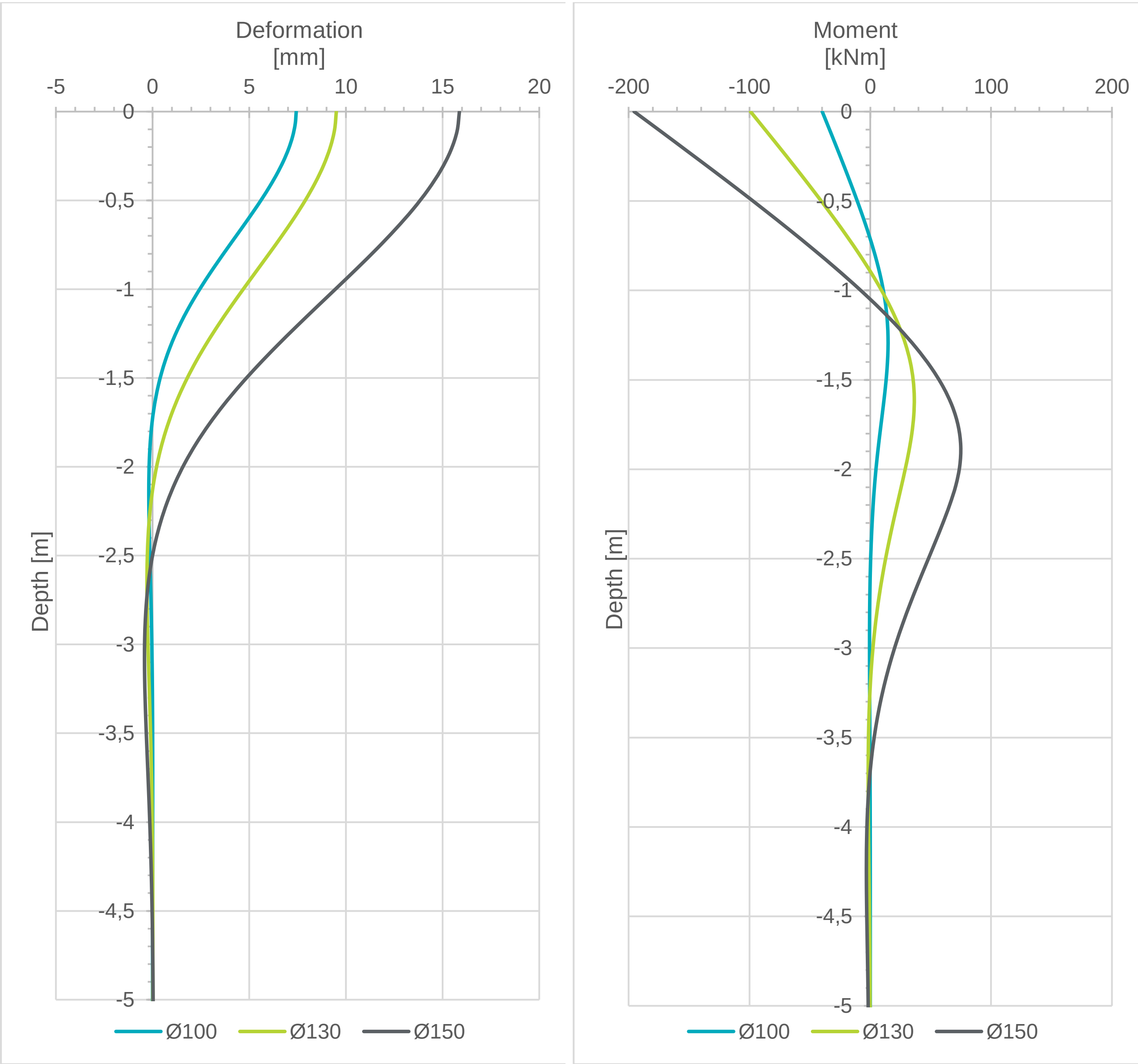

Figure 5-3: Deformation and internal moment plotted as a function of depth below ground surface. Calculation software: Novapoint GeoSuite. The applied lateral load varies and is given in Table 5-3.

Table 5-3: Applied lateral load.

Pile	Lateral load [kN]
Ø100	60
Ø130	120
Ø150	200

6 Site stability

The Planning and Building Act §28-1 states that a site can only be developed if there is satisfactory safety against natural og environmental hazards. Regulations on Technical Requirements for Construction Works (TEK17) further states in §7-1 that structures shall be located and designed in such a way that there is satisfactory safety against flood and landslides.

Soil investigations show presence of soil with a brittle failure mechanism in Area 1. The Norwegian Water Resources and Energy Directorate (NVE) has developed guidelines for evaluating the risk of landslides with brittle failure behaviour. This chapter evaluates topography and landslide risk in and around the project areas based on these guidelines.

6.1 Classification of structures

The Norwegian Water Resources and Energy Directorate (NVE) classifies project areas in five Enterprise Categories: K0 to K4. Since a significant amount of people will be present in and around the new structures the area is classified as K4. For Enterprise Category K4 site stability must be shown to have a safety factor of at least 1,4. If the safety factor is calculated to be less than 1,4 site stability must be "significantly improved" as defined in NVE guideline 7/2014.

6.2 Topography

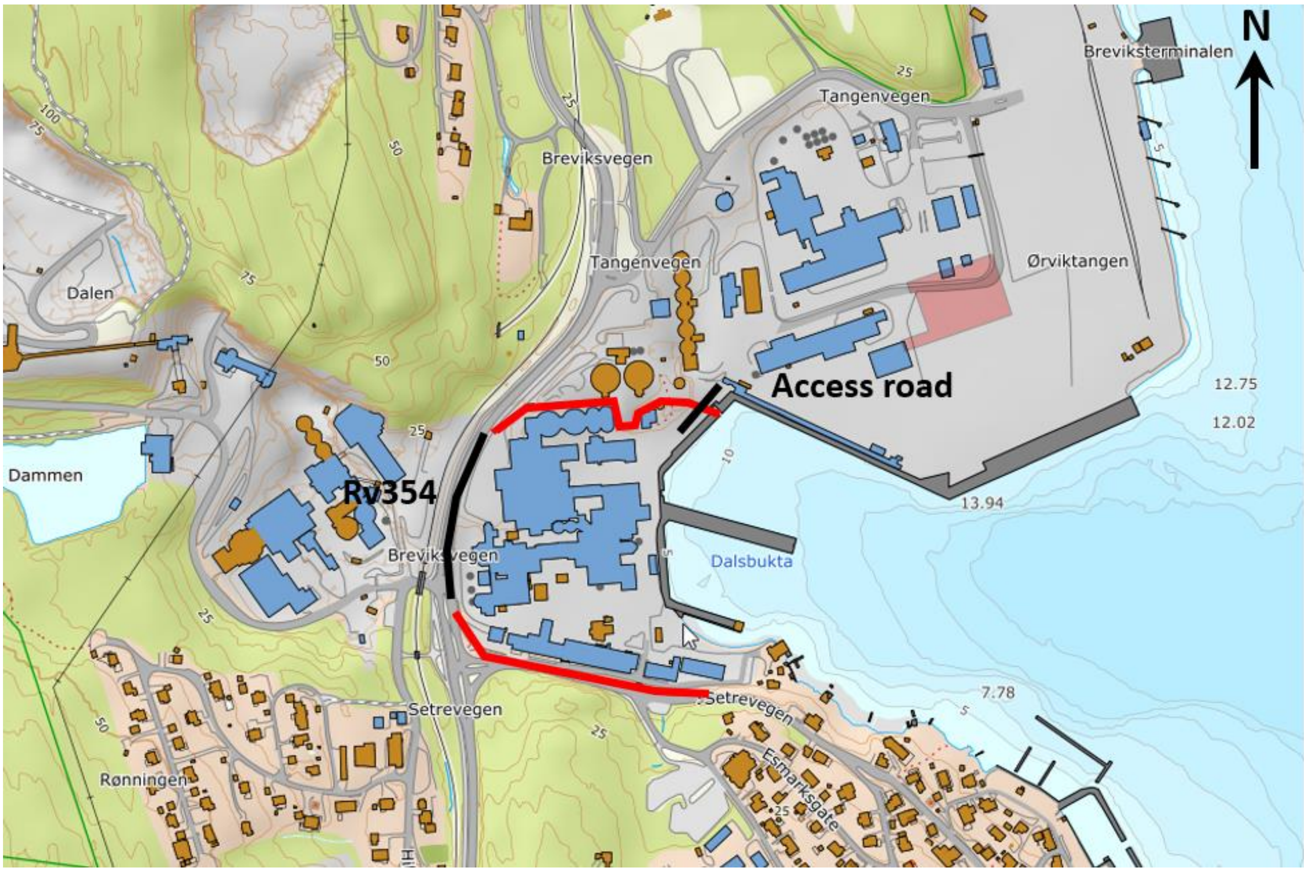

Figure 6-1: Red lines mark visible or near-surface bedrock less than 2 m below ground. Black lines mark roads.

Area 1 consists of mostly flat terrain at approximately 3-4 MAMSL with a small retaining wall of concrete towards the bay (<5 m tall). Bedrock is visible north and south of the area. To the west the road Rv354 delimits the area. Between the planning area and "Ørviktangen" there is an access road where bedrock is located <2 m below ground.

To the east, the height difference between Area 1 and "Dalsbukta" is approximately 10 m. The concrete wall is approximately 3 m tall with an inclined seabed towards the bay. The slope has an incline steeper than 1:20 and a height difference >5m. According to NVE this may cause a risk of landslide which may turn into a progressive ground failure.

6.3 Stability calculations

Site stability will effectively be determined by the stability on the seaside of the existing and planned quay structures. Two profiles have been developed in order to evaluate the safety factor along "Cementkai" and "Stavkaia" – Profile A and B respectively. The location of the profiles is shown in Figure 6-2 and the calculations are shown in Figure 6-3 and Figure 6-4.

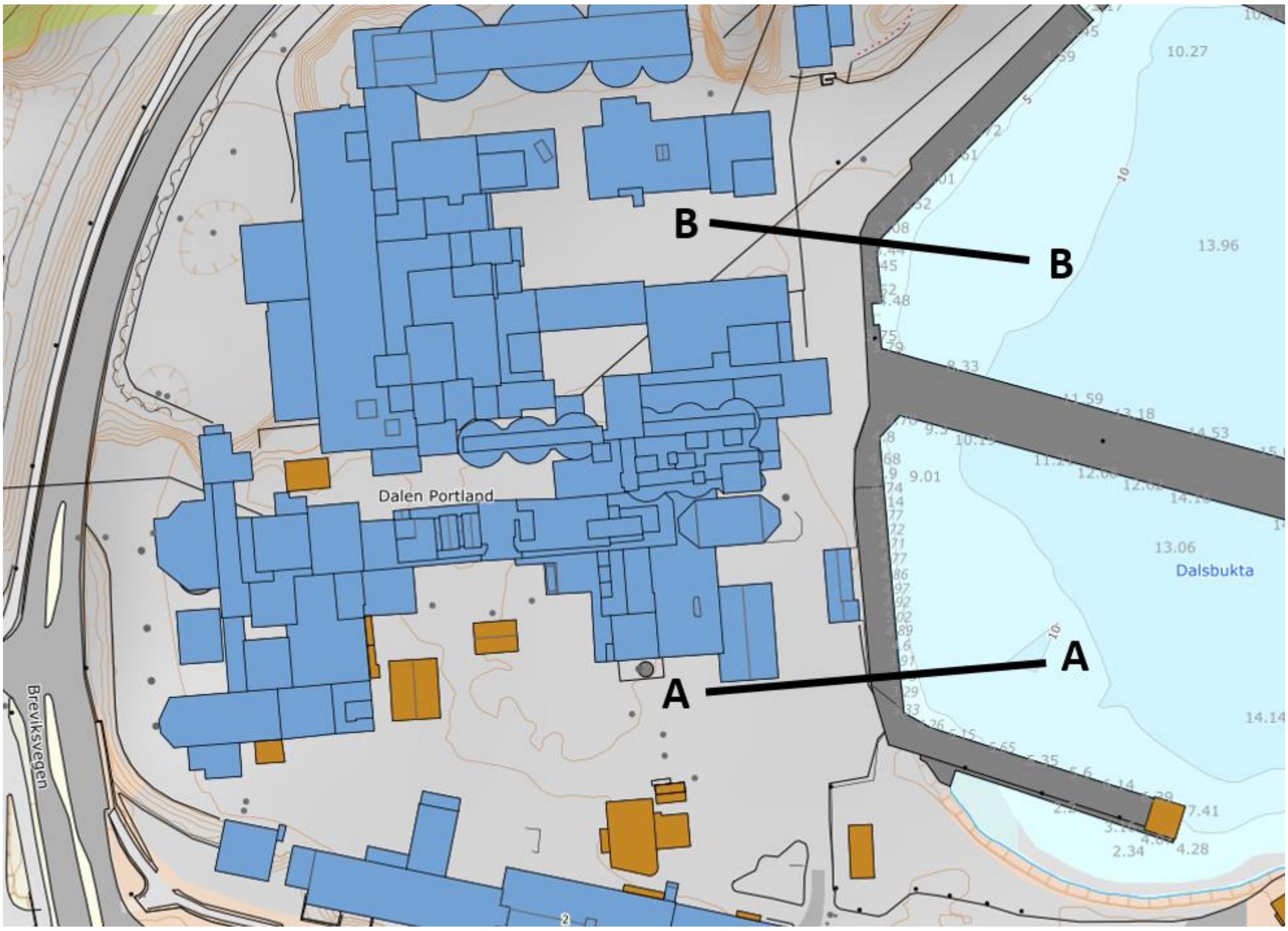

Figure 6-2: Profiles for stability analysis.

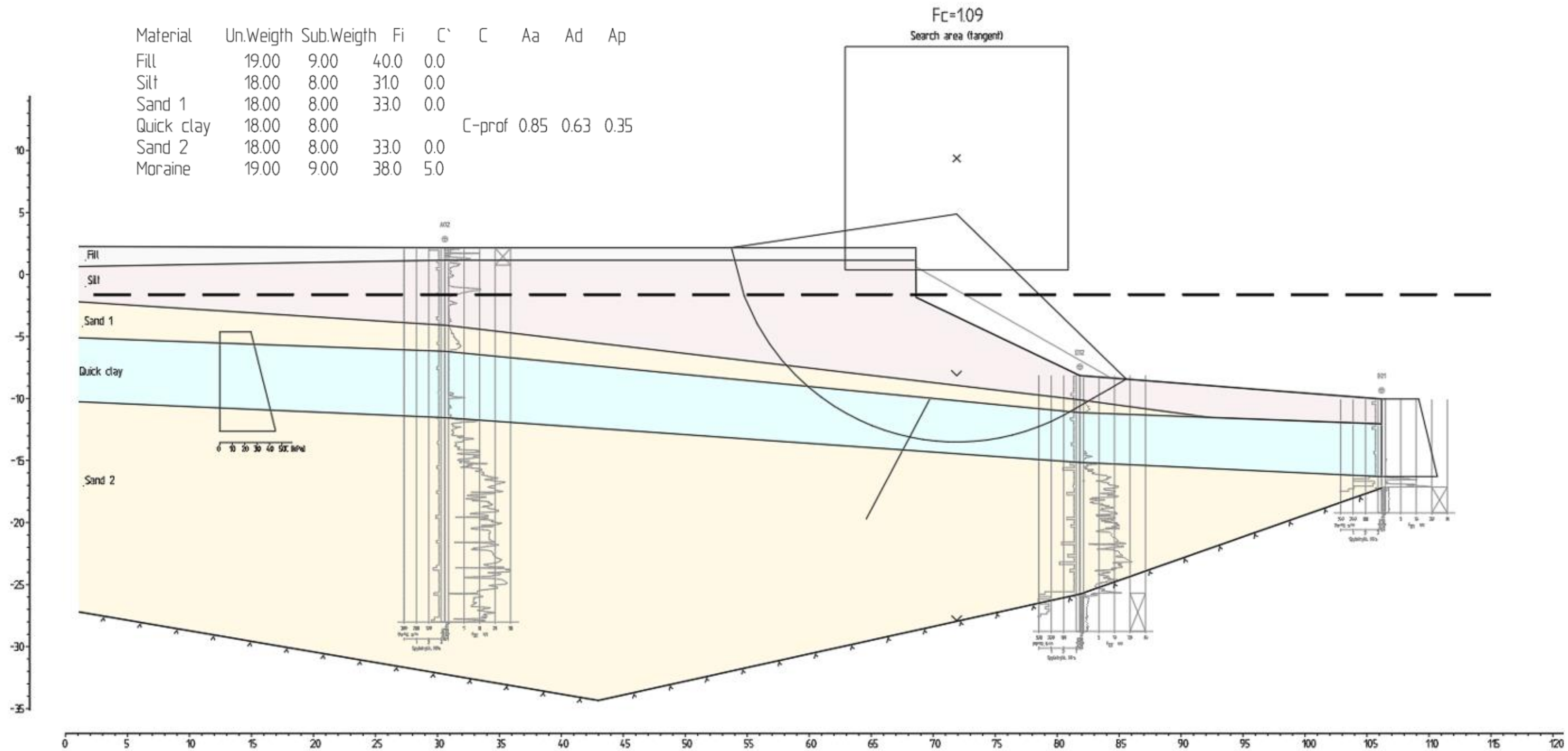

Figure 6-3: Stability calculation – Profile A. Safety factor 1,09. Software: GeoSuite GS Stability v15.4.

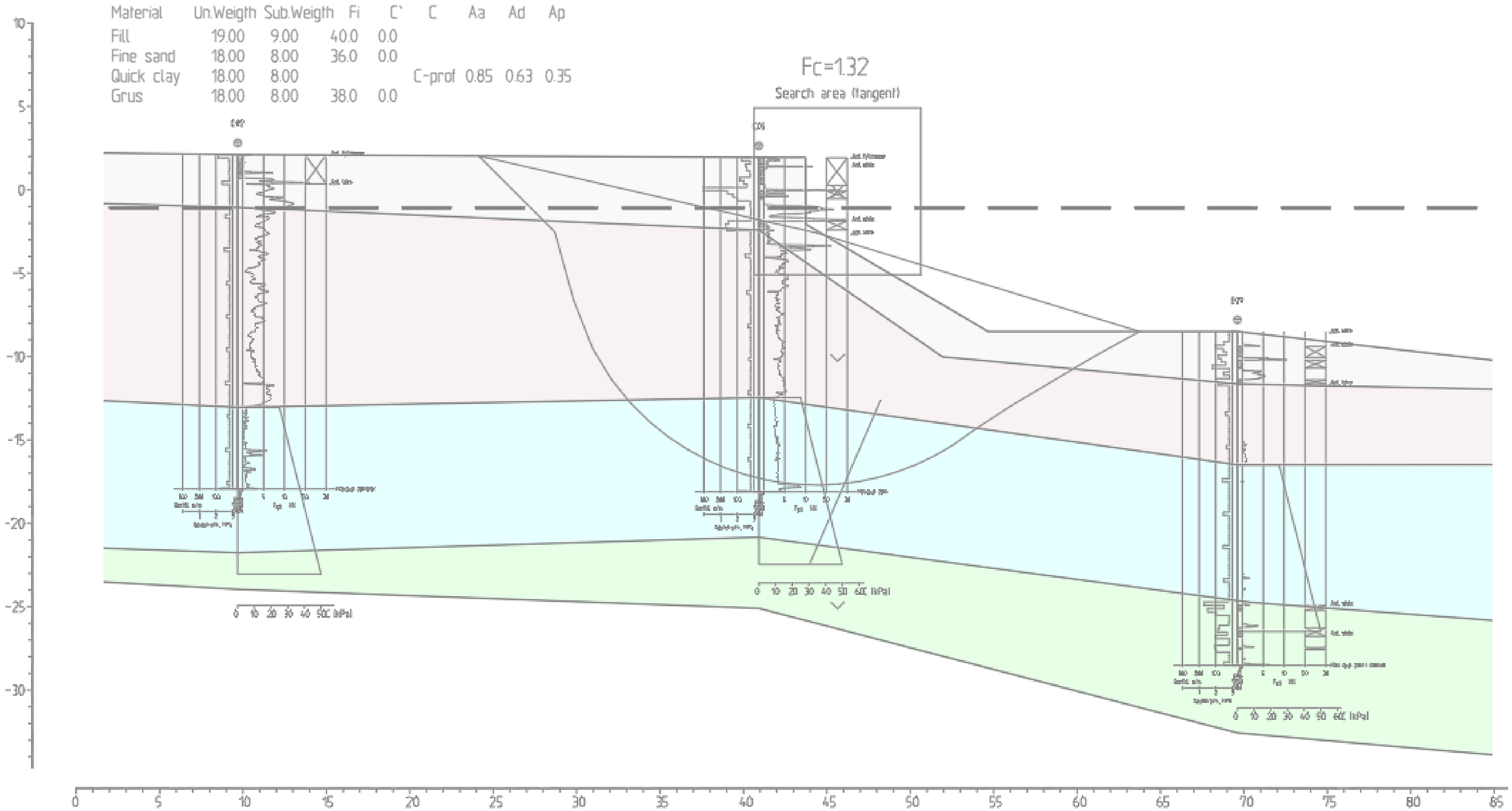

Figure 6-4: Stability calculation - Profile B. Safety factor 1,32. Software: GeoSuite GS Stability v15.4.

The profiles are based on soil investigations performed ultimo 2018 and reported in Geotechnical Data Report (doc. no.: NC03-NOCON-G-RA-0002_406-02). Strength parameters have been derived from CPTs performed in nearby boreholes and supplemented with data from previous soil investigations. Specifically, geotechnical data reports 4991 from 1962 and 17437 from 1977 since these contain test series with strength parameters that can be used for Profile A and B.

6.4 Conclusion

Profile A:

The calculated safety factor is 1,09 and does not meet the requirement of being at least 1,4. However, the existing quay structure at “Cementkai” is planned for renewal and the stability of the slope will have to meet the safety requirement. This may be achieved through lime-cement stabilisation behind the quay area and/or adjusting the inclination of the slope on the seaside of “Cementkai”. These calculations are deferred to the design of the new quay, since the boundary conditions for the quay structure and the stability of the seaside slope are linked.

Profile B:

The calculated safety factor is 1,32 and does not meet the requirement of being at least 1,4. However, a triaxial test performed in 1977, as part of geotechnical report 17437, suggests an internal angle of friction of $\phi = 37{,}6°$ for the sand layer. In the above calculations $\phi = 36°$ was used based on empirical values, but calculations show that increasing to $\phi = 37{,}6°$ would yield a safety factor of 1,4 and thus meet the requirement. Supplementary soil investigations would be necessary in order to confirm such a strength parameter and, additionally, give better input to the stability calculation. Alternatively, lime-cement stabilisation could be used to increase the strength of the soil beneath “Stavkai”.

Final comment:

NVE requires a separate report that documents a safety factor of 1,4, alternatively, “significant improvement” if the calculated safety factor is less than 1,4. This report shall follow the framework set out in NVE guideline 7/2014.

It is recommended that supplementary soil investigations are performed in order to determine the strength parameters of the soil layers near “Cementkai” and “Stavkai” in more detail. Specifically, it is necessary to include test samples that may be analysed at a geotechnical laboratory.

7 Attachments

Attachment	Title	Pages
A	Ground type analysis	2
B	Design axial capacity	1

Appendix A

Prosjekt:	5151309 Norcem FEED - borhull B02	Dybde til grunnvann	2,5 m
		Dybde til fjell	21,0 m

Valg av jordtype:

- *1 - Sand (friksjon jordart)*
- *2- Morene*
- *3 - Leire (kohesjon jordart)*
- *4 - Kvikkleire / sensitive leire*

			Grunntype	S	TB	TC	TD
$V_{S;ave=}$	148	m/s	S2	--	--	--	--

	Total tykkelse :	21,0	OK																				Gmax/Su								G/Gmax 0,8	Vs/Vsmax 0,9
	Beskrivelse	Type jord	Tykkelse (m)	γ (kN/m³)	φ (°)	$K_{2,max}$ (-)	IP (%)	w_L (%)	OCR (-)	ν (-)	Kote (m)	z (m)	σ_v (kPa)	u (kPa)	σ'_v (kPa)	K_0 (-)	σ'_3 (kPa)	σ'_m (kPa)	c_u/P'_0 (NC-leire)	c_u/P'_0 (OC-leire)	c_u c_u/P'_0 basert	Benyttes	NGI (2010)	Larsson (1991)	Benyttes	Seed (1984) (Sand - kPa)	Lin (2000) (Morene - kPa)	kvikkleire 8	Gmax (kPa)	Vs max (m/s)	G (kPa)	Vs (m/s)
	Grus										2,0	0,0	0,0	0	0		0,00	0,0														
1		1	1,0 m	19,0	38	70					1,5	0,5	9,5	0	9,5	0,38	3,65	5,6								36 451			36 451	137	29 161	123
	Type: Sand										1,0	1,0	19,0	0,0	19,0		7,31	11,2														
	Sand										1,0	1,0	19,0	0,0	19,0		8,66	12,1														
2		1	1,0 m	17,5	33	70					0,5	1,5	27,8	0,0	27,8	0,46	12,64	17,7								64 751			64 751	191	51 801	171
	Type: Sand										0,0	2,0	36,5	0,0	36,5		16,63	23,3														
	Sand										0,0	2,0	36,5	0,0	36,5		16,63	23,3														
3		1	1,0 m	17,5	33	70					-0,5	2,5	45,3	0,0	45,3	0,46	20,62	28,8								82 684			82 684	215	66 148	194
	Type: Sand										-1,0	3,0	54,0	4,9	49,1		22,37	31,3														
	Sand										-1,0	3,0	54,0	4,9	49,1		22,37	31,3														
4		1	1,0 m	17,5	33	70					-1,5	3,5	62,8	9,8	52,9	0,46	24,12	33,7								89 435			89 435	224	71 548	202
	Type: Sand										-2,0	4,0	71,5	14,7	56,8		25,87	36,2														
	Siltig leire										-2,0	4,0	71,5	14,7	56,8		56,79	56,8														
5	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-2,5	4,5	80,5	19,6	60,9	1,00	60,88	60,9		0,00	0	20	850	ikke for kvikkleire	850			1	17 000	96	13 600	87
	Type: Kvikkleire										-3,0	5,0	89,5	24,5	65,0		64,98	65,0														
	Siltig leire										-3,0	5,0	89,5	24,5	65,0		64,98	65,0														
6	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-3,5	5,5	98,5	29,4	69,1	1,00	69,07	69,1		0,00	0	20	850	ikke for kvikkleire	850			1	17 000	96	13 600	87
	Type: Kvikkleire										-4,0	6,0	107,5	34,3	73,2		73,17	73,2														
	Siltig leire										-4,0	6,0	107,5	34,3	73,2		73,17	73,2														
7	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-4,5	6,5	116,5	39,2	77,3	1,00	77,26	77,3		0,00	0	20	850	ikke for kvikkleire	850			1	17 000	96	13 600	87
	Type: Kvikkleire										-5,0	7,0	125,5	44,1	81,4		81,36	81,4														
	Siltig leire										-5,0	7,0	125,5	44,1	81,4		81,36	81,4														
8	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-5,5	7,5	134,5	49,1	85,5	1,00	85,45	85,5		0,00	0	20	850	ikke for kvikkleire	850			1	17 000	96	13 600	87
	Type: Kvikkleire										-6,0	8,0	143,5	54,0	89,5		89,55	89,5														
	Siltig leire										-6,0	8,0	143,5	54,0	89,5		89,55	89,5														
9	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-6,5	8,5	152,5	58,9	93,6	1,00	93,64	93,6		0,00	0	20	850	ikke for kvikkleire	850			1	17 000	96	13 600	87
	Type: Kvikkleire										-7,0	9,0	161,5	63,8	97,7		97,74	97,7														
	Siltig sand										-7,0	9,0	161,5	63,8	97,7		51,87	67,2														
10		1	1,0 m	17,5	28	70					-7,5	9,5	170,3	68,7	101,6	0,53	53,91	69,8								128 663			128 663	269	102 931	242
	Type: Sand										-8,0	10,0	179,0	73,6	105,4		55,95	72,4														
	Siltig leire										-8,0	10,0	179,0	73,6	105,4		70,28	82,0														
11		3	1,0 m	18,0			20	40	1	0,4	-8,5	10,5	188,0	78,5	109,5	0,67	73,01	85,2		0,00	0	27	1700	1260	1700				45 900	158	36 720	142
	Type: Leire										-9,0	11,0	197,0	83,4	113,6		75,74	88,4														
	Siltig leire										-9,0	11,0	197,0	83,4	113,6		113,62	113,6														
12	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-9,5	11,5	206,0	88,3	117,7	1,00	117,71	117,7		0,00	0	27	850	ikke for kvikkleire	850			1	22 950	112	18 360	101
	Type: Kvikkleire										-10,0	12,0	215,0	93,2	121,8		121,81	121,8														
	Siltig leire										-10,0	12,0	215,0	93,2	121,8		81,20	94,7														
13		3	1,0 m	18,0			20	40	1	0,4	-10,5	12,5	224,0	98,1	125,9	0,67	83,93	97,9		0,00	0	27	1700	1260	1700				45 900	158	36 720	142
	Type: Leire										-11,0	13,0	233,0	103,0	130,0		86,66	101,1														
	Siltig leire										-11,0	13,0	233,0	103,0	130,0		130,00	130,0														
14	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-11,5	13,5	242,0	107,9	134,1	1,00	134,09	134,1		0,00	0	27	850	ikke for kvikkleire	850			1	22 950	112	18 360	101
	Type: Kvikkleire										-12,0	14,0	251,0	112,8	138,2		138,19	138,2														
	Siltig sand										-12,0	14,0	251,0	112,8	138,2		69,12	92,1														
15		1	1,0 m	17,5	30	70					-12,5	14,5	259,8	117,7	142,0	0,50	71,05	94,7								149 870			149 870	290	119 896	261
	Type: Sand										-13,0	15,0	268,5	122,6	145,9		72,97	97,3														
	Siltig leire										-13,0	15,0	268,5	122,6	145,9		145,88	145,9														
16	sprøbruddsmateriale	4	1,0 m	18,0			20		1		-13,5	15,5	277,5	127,5	150,0	1,00	149,97	150,0		0,00	0	27	850	ikke for kvikkleire	850			1	22 950	112	18 360	101
	Type: Kvikkleire										-14,0	16,0	286,5	132,4	154,1		154,07	154,1														
	Siltig leire										-14,0	16,0	286,5	132,4	154,1		102,71	119,8														
17		3	1,0 m	18,0			20	40	1	0,4	-14,5	16,5	295,5	137,3	158,2	0,67	105,44	123,0		0,00	0	33	1700	1260	1700				56 100	175	44 880	157
	Type: Leire										-15,0	17,0	304,5	142,2	162,3		108,17	126,2														
	Siltig leire										-15,0	17,0	304,5	142,2	162,3		108,17	126,2														
18		3	1,0 m	18,0			20	40	1	0,4	-15,5	17,5	313,5	147,2	166,4	0,67	110,90	129,4		0,00	0	33	1700	1260	1700				56 100	175	44 880	157
	Type: Leire										-16,0	18,0	322,5	152,1	170,4		113,63	132,6														
	Siltig sand										-16,0	18,0	322,5	152,1	170,4		77,66	108,6														
19		1	1,0 m	17,5	33	70					-16,5	18,5	331,3	157,0	174,3	0,46	79,41	111,0								162 275			162 275	302	129 820	271
	Type: Sand										-17,0	19,0	340,0	161,9	178,1		81,16	113,5														
	Siltig sand										-17,0	19,0	340,0	161,9	178,1		81,16	113,5														
20		1	1,0 m	17,5	33	70					-17,5	19,5	348,8	166,8	182,0	0,46	82,91	115,9								165 816			165 816	305	132 653	274
	Type: Sand										-18,0	20,0	357,5	171,7	185,8		84,66	118,4														
	Siltig sand										-18,0	20,0	357,5	171,7	185,8		84,66	118,4														
21		1	1,0 m	17,5	33	70					-18,5	20,5	366,3	176,6	189,7	0,46	86,41	120,8								169 283			169 283	308	135 427	277
	Type: Sand										-19,0	21,0	375,0	181,5	193,5		88,17	123,3														
22	--																															
23	--																															
24	--																															

Prosjekt: 5151309
Norcem FEED - borhull D02

Dybde til grunnvann	2,5 m
Dybde til fjell	20,0 m

Valg av jordtype:
1 - Sand (friksjon jordart)
2- Morene
3 - Leire (kohesjon jordart)
4 - Kvikkleire / sensitive leire

$V_{S,ave=}$	184	m/s	Grunntype	S	TB	TC	TD
			E	1,65	0,1	0,3	1,4

Total tykkelse : 20,0 OK

G/Gmax	Vs/Vsmax
0,8	0,9

Nr	Beskrivelse	Type jord	Tykkelse (m)	γ (kN/m³)	φ (°)	$K_{2,max}$ (-)	IP (%)	w_L (%)	OCR (-)	ν (-)	Kote (m)	z (m)	σ_v (kPa)	u (kPa)	σ'_v (kPa)	K_0 (-)	σ'_3 (kPa)	σ'_m (kPa)	c_u/P'_0 (NC-leire)	c_u/P'_0 (OC-leire)	c_u: c_u/P'_0 basert	c_u: Benyttes	Gmax/Su: NGI (2010)	Gmax/Su: Larsson (1991)	Gmax/Su: Benyttes	Seed (1984) (Sand - kPa)	Lin (2000) (Morene - kPa)	kvikkleire 2	Gmax (kPa)	Vs max (m/s)	G (kPa)	Vs (m/s)
	Grus										2,0	0,0	0,0	0	0		0,00	0,0														
1		1	1,0 m	19,0	38	70					1,5	0,5	9,5	0	9,5	0,38	3,65	5,6								36 451			36 451	137	29 161	123
	Type: Sand										1,0	1,0	19,0	0,0	19,0		7,31	11,2														
	Grus										1,0	1,0	19,0	0,0	19,0		7,31	11,2														
2		1	1,0 m	19,0	38	70					0,5	1,5	28,5	0,0	28,5	0,38	10,96	16,8								63 135			63 135	181	50 508	162
	Type: Sand										0,0	2,0	38,0	0,0	38,0		14,61	22,4														
	Grus										0,0	2,0	38,0	0,0	38,0		14,61	22,4														
3		1	1,0 m	19,0	38	70					-0,5	2,5	47,5	0,0	47,5	0,38	18,27	28,0								81 507			81 507	205	65 206	185
	Type: Sand										-1,0	3,0	57,0	4,9	52,1		20,04	30,7														
	Grus										-1,0	3,0	57,0	4,9	52,1		20,04	30,7														
4		1	1,0 m	19,0	38	70					-1,5	3,5	66,5	9,8	56,7	0,38	21,80	33,4								89 044			89 044	214	71 235	193
	Type: Sand										-2,0	4,0	76,0	14,7	61,3		23,57	36,1														
	Sand										-2,0	4,0	76,0	14,7	61,3		27,92	39,0														
5		1	1,0 m	17,5	33	70					-2,5	4,5	84,8	19,6	65,1	0,46	29,67	41,5								99 198			99 198	236	79 359	212
	Type: Sand										-3,0	5,0	93,5	24,5	69,0		31,43	43,9														
	Leirig silt/Leire										-3,0	5,0	93,5	24,5	69,0		45,98	53,6														
6		3	1,0 m	19,0			20	40	1	0,4	-3,5	5,5	103,0	29,4	73,6	0,67	49,05	57,2		0,00	0	37	1700	1260	1260				46 620	155	37 296	140
	Type: Leire										-4,0	6,0	112,5	34,3	78,2		52,11	60,8														
	Siltig sand										-4,0	6,0	112,5	34,3	78,2		39,10	52,1														
7		1	1,0 m	17,5	30	70					-4,5	6,5	121,3	39,2	82,0	0,50	41,02	54,7								113 883			113 883	253	91 106	227
	Type: Sand										-5,0	7,0	130,0	44,1	85,9		42,95	57,2														
	Leire										-5,0	7,0	130,0	44,1	85,9		57,24	66,8														
8		3	1,0 m	18,0			20	40	1	0,4	-5,5	7,5	139,0	49,1	90,0	0,67	59,97	70,0		0,00	0	24	1700	1260	1260				30 240	128	24 192	116
	Type: Leire										-6,0	8,0	148,0	54,0	94,0		62,70	73,1														
	Siltig leire - mulig										-6,0	8,0	148,0	54,0	94,0		94,05	94,0														
9	sprøbruddmateriale	4	1,0 m	18,0			20		1		-6,5	8,5	157,0	58,9	98,1	1,00	98,14	98,1		0,00	0	25	850	ikke for kvikkleire	850			1	21 250	108	17 000	97
	Type: Kvikkleire										-7,0	9,0	166,0	63,8	102,2		102,24	102,2														
	Leire										-7,0	9,0	166,0	63,8	102,2		68,16	79,5														
10		3	1,0 m	18,0			20	40	1	0,4	-7,5	9,5	175,0	68,7	106,3	0,67	70,89	82,7		0,00	0	26	1700	1260	1260				32 760	134	26 208	120
	Type: Leire										-8,0	10,0	184,0	73,6	110,4		73,62	85,9														
	Siltig sand										-8,0	10,0	184,0	73,6	110,4		55,24	73,6														
11		1	1,0 m	17,5	30	70					-8,5	10,5	192,8	78,5	114,3	0,50	57,16	76,2								134 428			134 428	275	107 543	247
	Type: Sand										-9,0	11,0	201,5	83,4	118,1		59,08	78,8														
	Siltig sand										-9,0	11,0	201,5	83,4	118,1		59,08	78,8														
12		1	1,0 m	17,5	30	70					-9,5	11,5	210,3	88,3	122,0	0,50	61,01	81,3								138 878			138 878	279	111 102	251
	Type: Sand										-10,0	12,0	219,0	93,2	125,8		62,93	83,9														
	Siltig sand										-10,0	12,0	219,0	93,2	125,8		62,93	83,9														
13		1	1,0 m	17,5	30	70					-10,5	12,5	227,8	98,1	129,7	0,50	64,85	86,5								143 190			143 190	283	114 552	255
	Type: Sand										-11,0	13,0	236,5	103,0	133,5		66,78	89,0														
	Siltig leire - mulig										-11,0	13,0	236,5	103,0	133,5		133,50	133,5														
14	sprøbruddmateriale	4	1,0 m	18,0			20		1		-11,5	13,5	245,5	107,9	137,6	1,00	137,59	137,6		0,00	0	27	850	ikke for kvikkleire	850			1	22 950	112	18 360	101
	Type: Kvikkleire										-12,0	14,0	254,5	112,8	141,7		141,69	141,7														
	Leire										-12,0	14,0	254,5	112,8	141,7		94,46	110,2														
15		3	1,0 m	18,0			20	40	1	0,4	-12,5	14,5	263,5	117,7	145,8	0,67	97,19	113,4		0,00	0	28	1700	1260	1260				35 280	139	28 224	125
	Type: Leire										-13,0	15,0	272,5	122,6	149,9		99,92	116,6														
	Leire										-13,0	15,0	272,5	122,6	149,9		99,92	116,6														
16		3	1,0 m	18,0			20	40	1	0,4	-13,5	15,5	281,5	127,5	154,0	0,67	102,65	119,8		0,00	0	29	1700	1260	1260				36 540	141	29 232	127
	Type: Leire										-14,0	16,0	290,5	132,4	158,1		105,38	122,9														
	Sand										-14,0	16,0	290,5	132,4	158,1		72,02	100,7														
17		1	1,0 m	17,5	33	70					-14,5	16,5	299,3	137,3	161,9	0,46	73,77	103,1								156 405			156 405	296	125 124	266
	Type: Sand										-15,0	17,0	308,0	142,2	165,8		75,52	105,6														
	Sand										-15,0	17,0	308,0	142,2	165,8		75,52	105,6														
18		1	1,0 m	17,5	33	70					-15,5	17,5	316,8	147,2	169,6	0,46	77,27	108,0								160 076			160 076	300	128 061	270
	Type: Sand										-16,0	18,0	325,5	152,1	173,4		79,02	110,5														
	Sand										-16,0	18,0	325,5	152,1	173,4		79,02	110,5														
19		1	1,0 m	17,5	33	70					-16,5	18,5	334,3	157,0	177,3	0,46	80,77	112,9								163 665			163 665	303	130 932	273
	Type: Sand										-17,0	19,0	343,0	161,9	181,1		82,53	115,4														
	Sand										-17,0	19,0	343,0	161,9	181,1		82,53	115,4														
20		1	1,0 m	17,5	33	70					-17,5	19,5	351,8	166,8	185,0	0,46	84,28	117,8								167 177			167 177	306	133 742	276
	Type: Sand										-18,0	20,0	360,5	171,7	188,8		86,03	120,3														
21	--																															
22	--																															
23	--																															
24	--																															

Appendix B

γ_{M0}=1,05

S355

						Installed capacity		Bearing capacity of bedrock Chapter 4.2.4 in NPH						Vertical loads from settlement of surrounding soil Chapter 4.2.7 in NPH								Buckling Chapter 4.4. in NPH							
Diameter steel core pile	Diameter casing	Yield stress of steel	Cross sectional area of steel core	Total cross sectional area	Cross-sectional pile capacity	Reduction factor	Installed capacity	Uniaxial compression strength of bedrock	Embedment depth of steel core into bedrock	Bearing capacity factor in bedrock	Partial factor for bearing capacity	Correlation factor	Bearing capacity	Pile length	Representative effective unit weight of soil	Average effective vertikal stress	Skin friction factor	Calculated skin friction	Calculated skin friction	Pile capacity if bearing capacity on bedrock is critical	Pile capacity if installed capacity is critical	Young's modulus of steel core	Soil reaction modulus	Moment of inertia of steel core	Length of half wave (buckling length)	Partial factor buckling load	Theoretical buckling load	Pile capacity	Design axial capacity (compression)
D		f_y	A_steel	A_tot	$N_{c,rd}$	f_a	N_i	σ_{tf}	z_F	N_s	γ_τ	ξ	$R_{b,d}$	l	γ'	$\sigma'_{v,0}$	β	$\tau_{s,cal}$	$R_{c,k}$			E	C	I	L_k	γ_t	$R_{K;cal}$	$R_{K;d}$	
mm	mm	N/mm2	mm2	mm2	kN	-	kN	MPa	m	-	-	-	kN	m	kN/m3	kPa	-	kPa	kN	kN	kN	kPa	kPa	cm4	m	-	kN	kN	kN
100	139,7	295	7854	15328	2207	0,9	1986	80	1,0	9	1,3	1,45	3000	20	10	100	0,25	25,0	219	2780	1766	2,1E+08	2000	491	2,7	1,1	2872	1800	**1766**
130	193,7	295	13273	29468	3729	0,9	3356	80	1,0	9	1,3	1,45	5070	20	10	100	0,25	25,0	304	4766	3052	2,1E+08	2000	1402	3,5	1,1	4853	3043	**3043**
150	219,1	285	17671	37703	4797	0,9	4317	80	1,0	9	1,3	1,45	6750	20	10	100	0,25	25,0	344	6406	3973	2,1E+08	2000	2485	4,0	1,1	6461	4051	**3973**
100	139,7	295	7854	15328	2207	0,9	1986	80	1,0	9	1,3	1,45	3000	30	10	150	0,25	37,5	494	2506	1492	2,1E+08	2000	491	2,7	1,1	2872	1800	**1492**
130	193,7	295	13273	29468	3729	0,9	3356	80	1,0	9	1,3	1,45	5070	30	10	150	0,25	37,5	685	4385	2672	2,1E+08	2000	1402	3,5	1,1	4853	3043	**2672**
150	219,1	285	17671	37703	4797	0,9	4317	80	1,0	9	1,3	1,45	6750	30	10	150	0,25	37,5	774	5975	3543	2,1E+08	2000	2485	4,0	1,1	6461	4051	**3543**