Netherlands Enterprise Agency

Webinar
Ground model, Geotechnical parameters and Synthetic CPTs

Hollandse Kust (west) Wind Farm Zone

19 November 2020

Frank van Erp

Welcome

- Introduction of the webinar
- Presentation of Geotechnical ground model, Geotechnical parameters and Synthetic CPTs Hollandse Kust (west) by Fugro:
  - Kostas Kaltekis
  - Maddy Murali
  - Wessel van Kesteren

Welcome

- Alias assigned for private and public chat
- Expert panel:
  - John Carey (Windsupport)
  - Joek Peuchen, Sven Plasman, Dirk-Jan Karssen (Fugro)
  - Ben de Sonneville, Jeroen Godtschalk (BLIX)
  - Peter-Paul Lebbink (RVO)
- Presentation disclosed after webinar at https://offshorewind.rvo.nl

Ambition RVO for these works

- Provide a cutting-edge dataset for developers
  - Excellent characterization of the site with transparent identification of risks
  - Allowing various design approaches and foundation types (wide range of lab tests)
  - Use of cutting-edge techniques (machine learning, synthetic CPTs, geotechnical parameters)
  - Allowing tenderers optimum soil information to prepare bids

Hollandse Kust (west) Wind Farm Zone - Ground Model, Geotechnical Parameters & Synthetic CPTs

Webinar – 19 November 2020

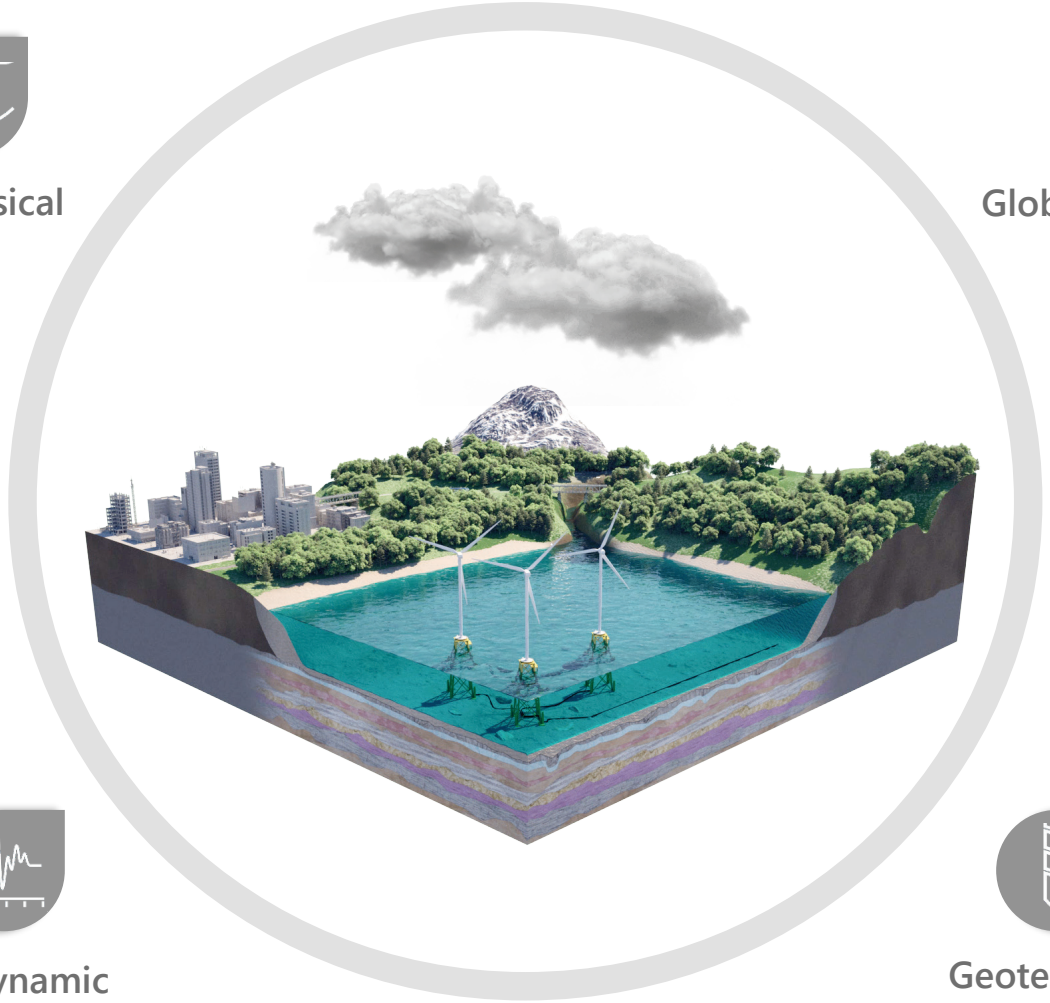
Fugro is the world's leading geo-data specialist

Geophysical

Metocean

Geohazard

Geodynamic



Global Positioning

Geospatial

Geochemical

Geotechnical

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Introduction

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Geotechnical Ground Model

03
Geotechnical Parameters

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Synthetic CPT Profiles

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Concluding Remarks

Presenters

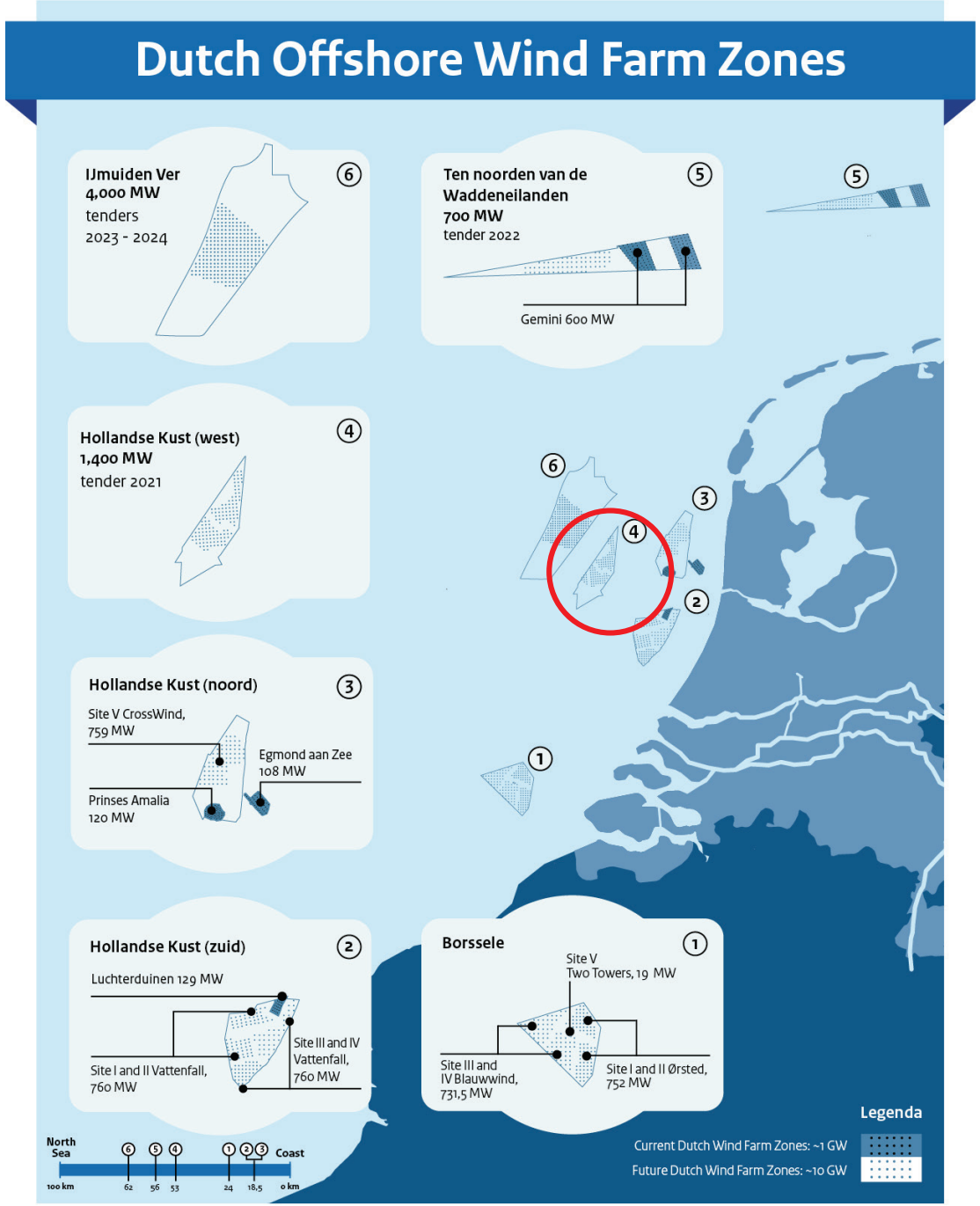
- Kostas Kaltekis – Senior Geotechnical Engineer
  - Introduction
  - Geotechnical Parameters
- Maddy Murali – Senior Geotechnical Engineer
  - Geotechnical Ground Model
- Wessel van Kesteren – Principal Geologist
  - Synthetic CPTs
  - Concluding Remarks

01

Introduction

Hollandse Kust (west) Wind Farm Zone

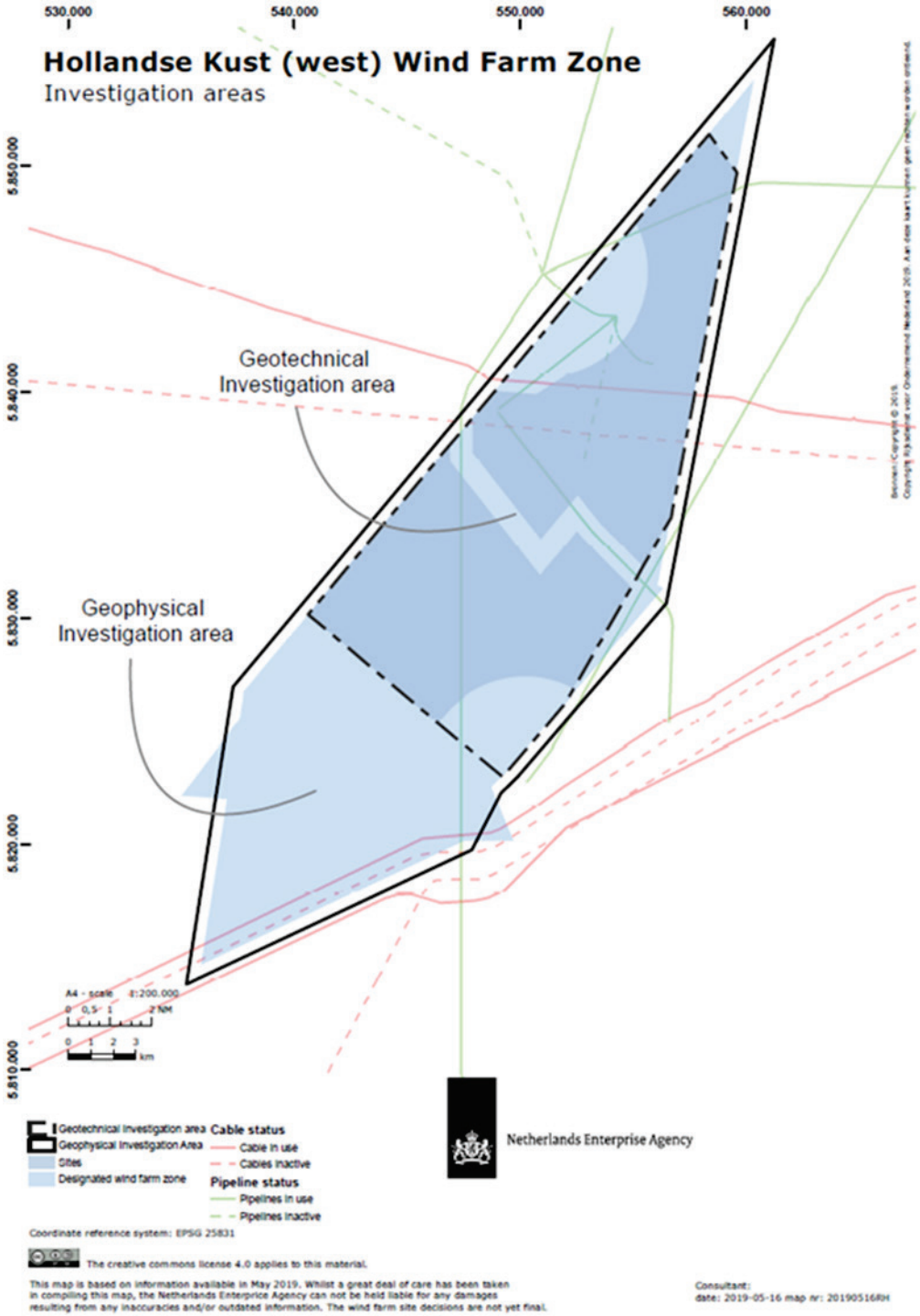
Source:
english.rvo.nl/topics/sustainability/offshore-wind-energy/hollandse-kust-west-wind-farm-zone



Hollandse Kust (west) Wind Farm Zone

RVO main objective:

Reduce design time and risks for tenderers preparing their bids for the HKW WFZ permit

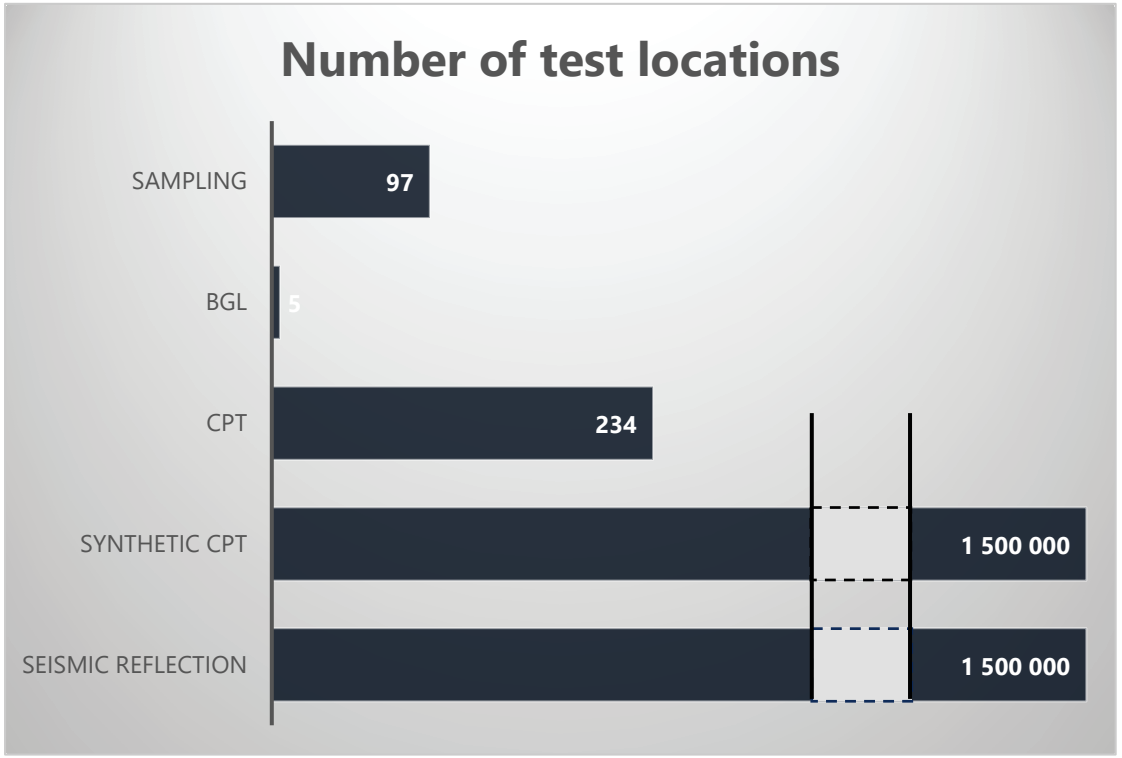


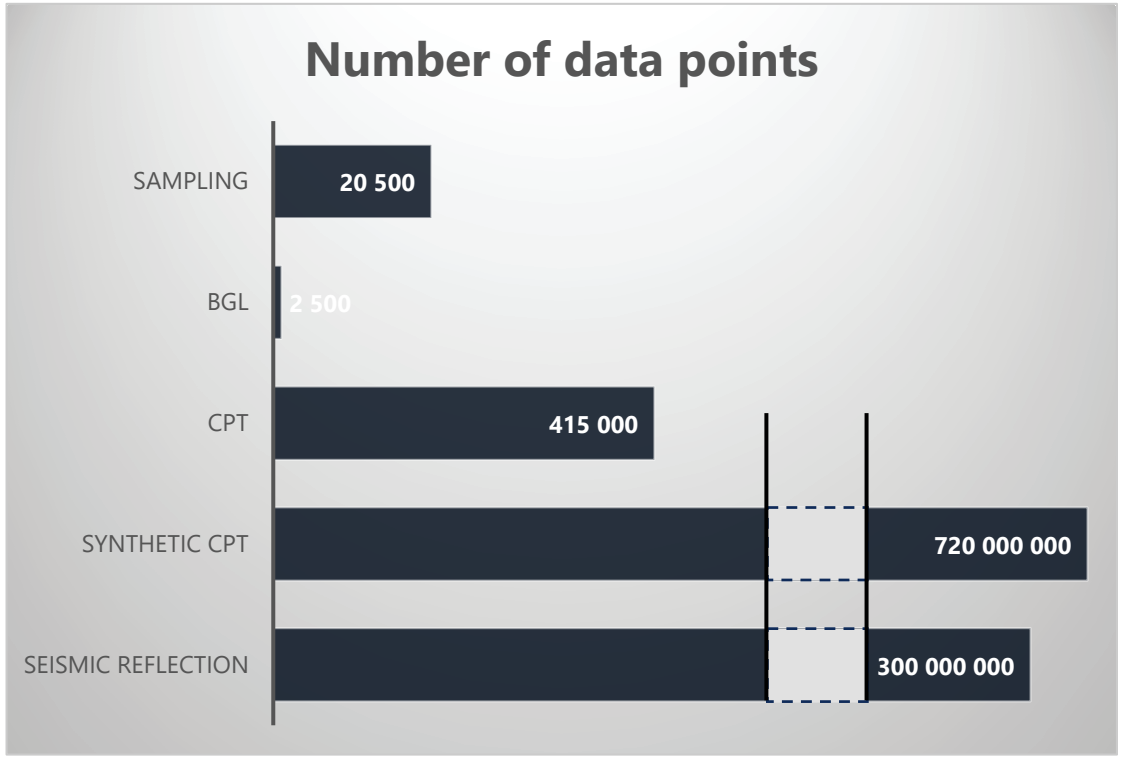
Road Map

Webinar 1

- Desk studies
- Geophysical site investigations
- Geophysical reporting
- Geotechnical site investigations
- Laboratory testing programme
- Geotechnical reporting
- Geological reporting

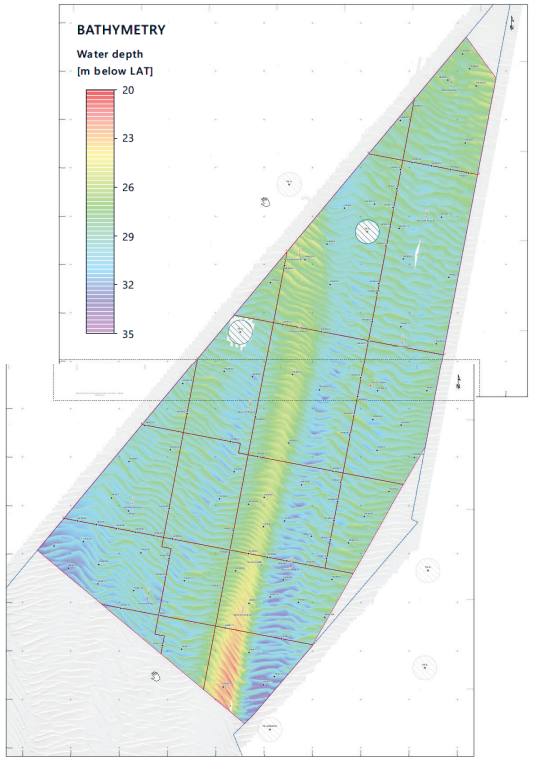
Testing Overview



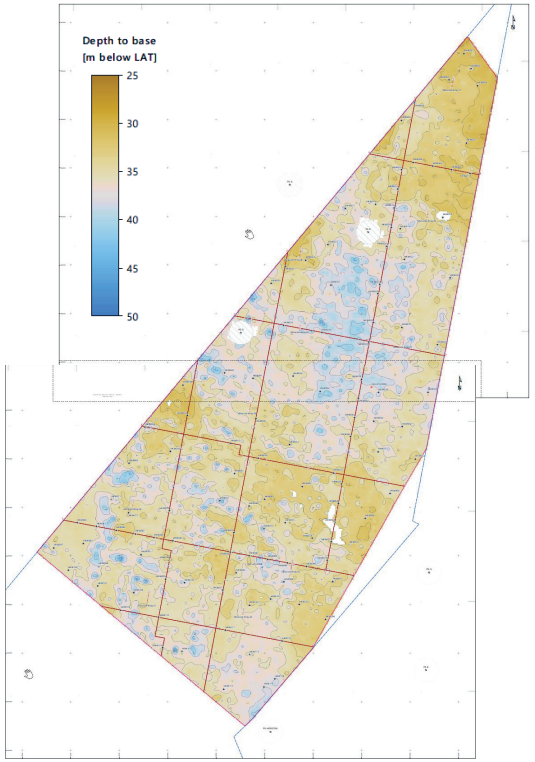


Geological Ground Model

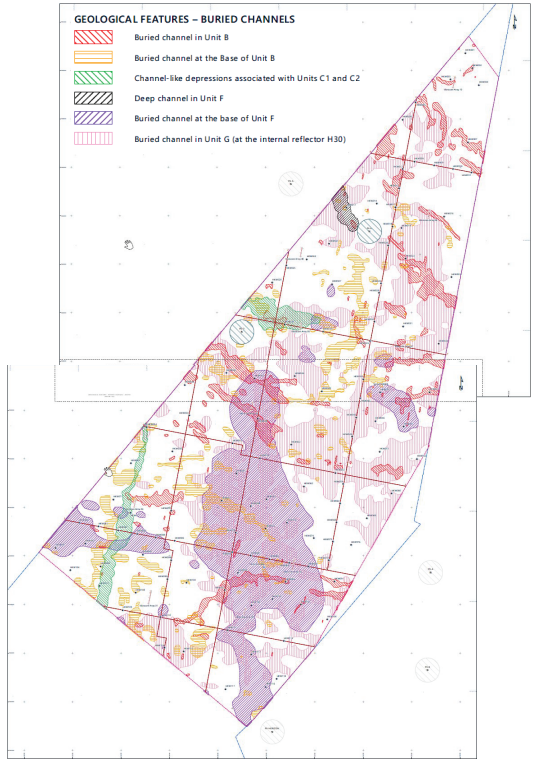
Bathymetry



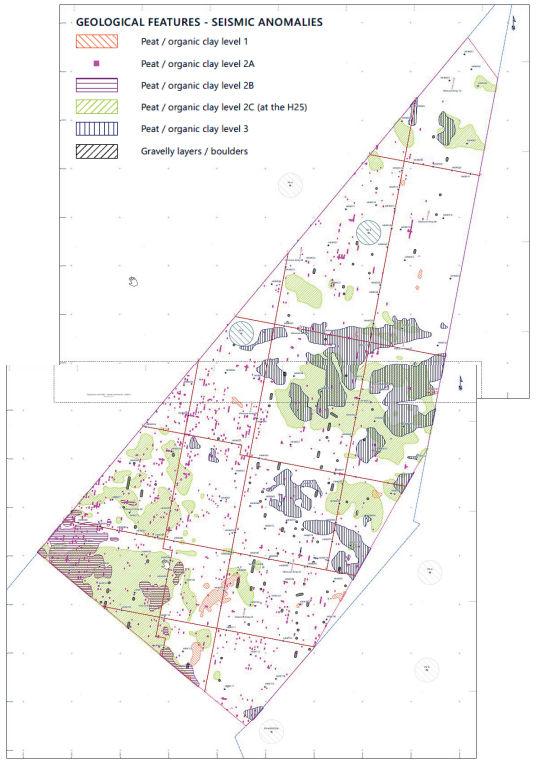
Depth to Base



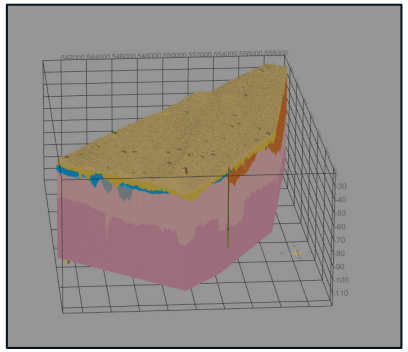
Buried Channels

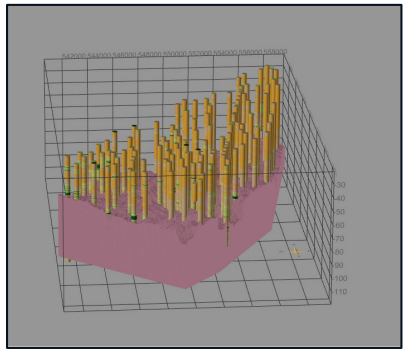


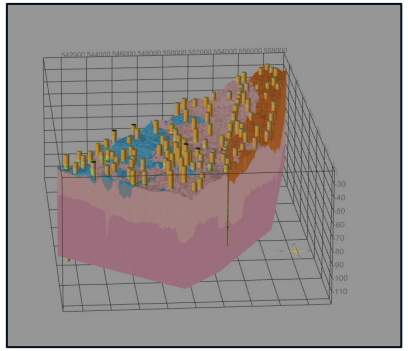
Geophysical Anomalies

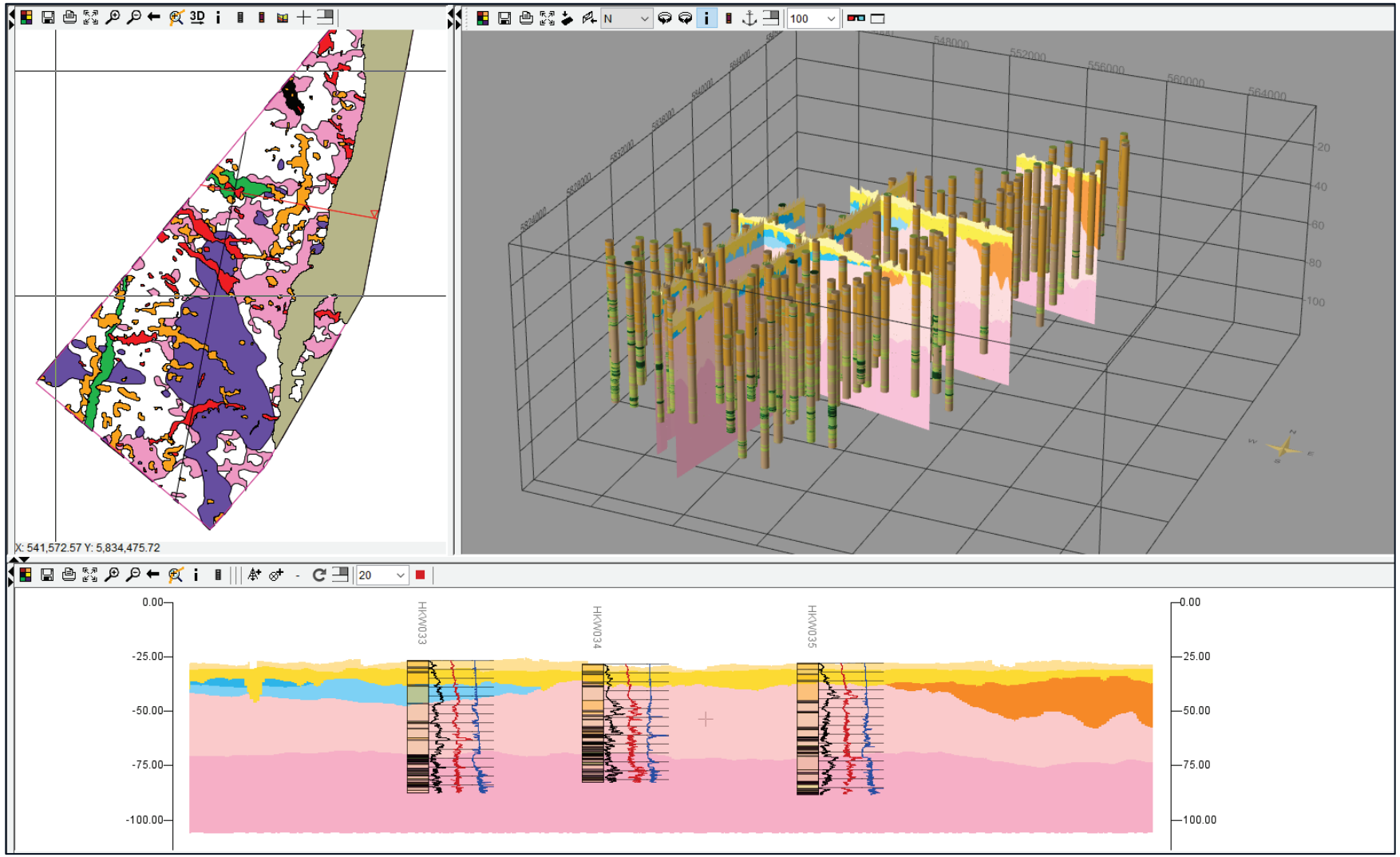


3D Ground Model









Road Map

Webinar 2

Desk studies

Geophysical site investigations

Geophysical reporting

Geotechnical site investigations

Laboratory testing programme

Geotechnical reporting

Geological reporting

Geotechnical parameters

Synthetic CPTs

Deliverables

Geotechnical Parameters

Report

- Geotechnical ground model
- Geotechnical parameters
- Seismic (earthquake) hazard assessment
- Corrosion of steel piles in soil

Digital

- Soil provinces (3D model)

Synthetic CPT Profiles

Report

- Study approach
- Comments on results

Digital

- Synthetic CPTs

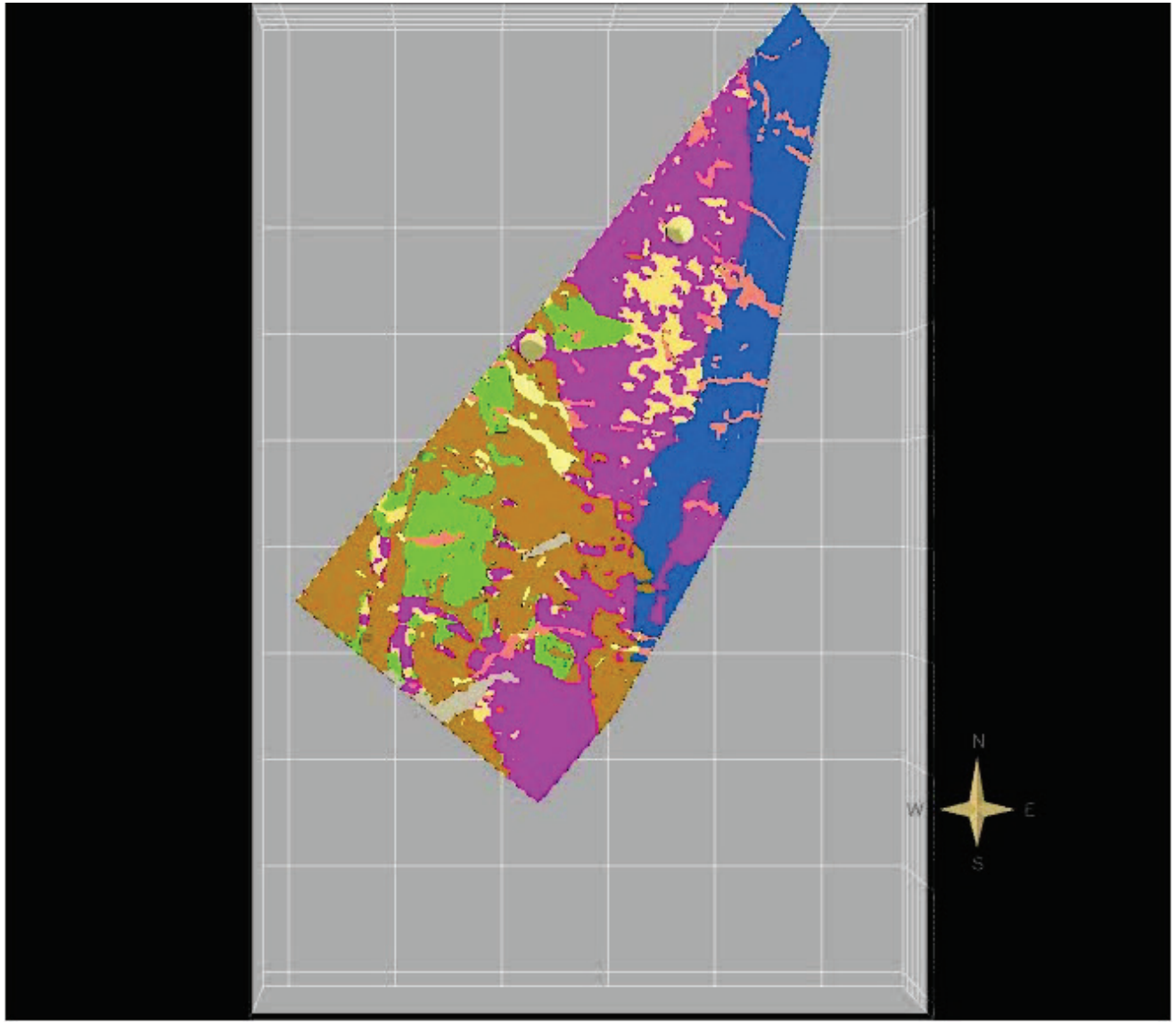
Reports available at:
https://offshorewind.rvo.nl/soilw

02

Geotechnical Ground Model

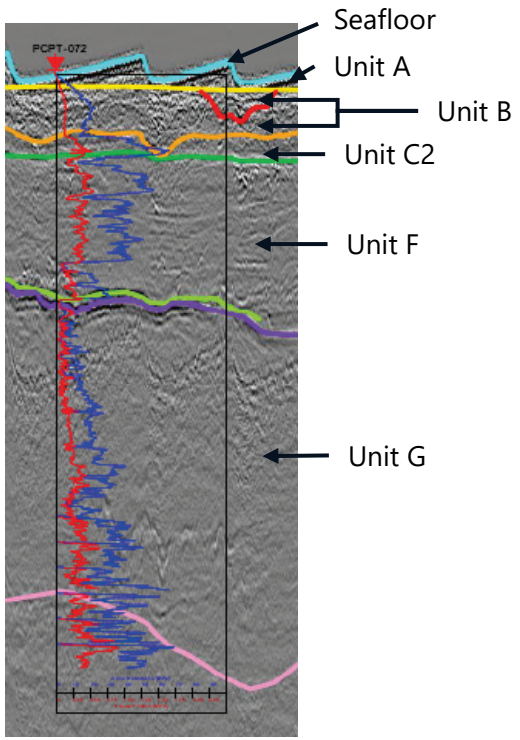
Geotechnical Ground Model

- Soil Unit A
- Soil Units B1 & B2
- Soil Unit C1
- Soil Unit C2
- Soil Unit D
- Soil Unit E
- Soil Unit F
- Soil Unit G

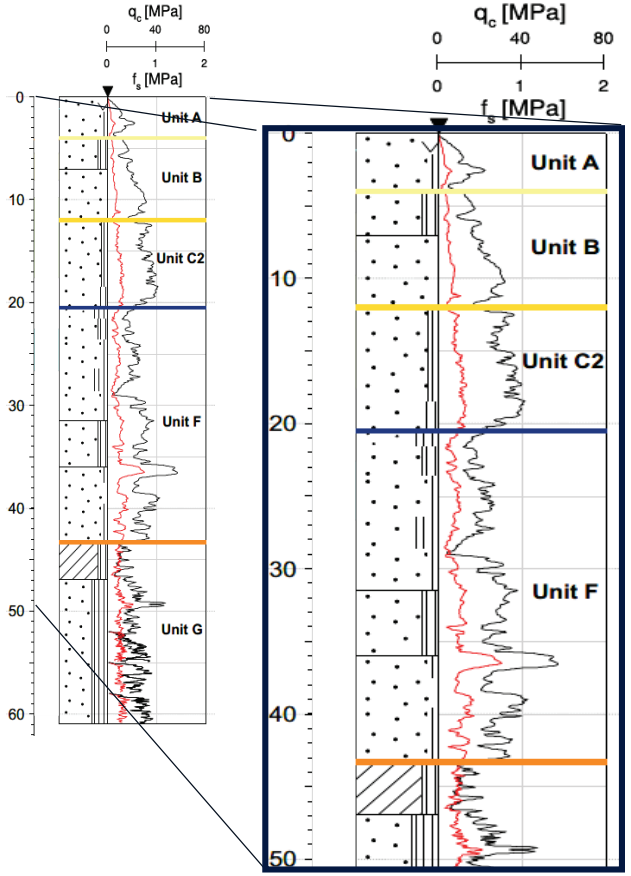


Fundamental features

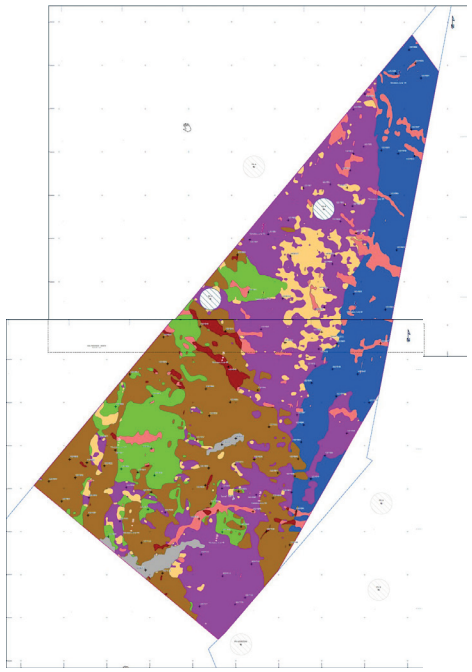
Connection to geological ground model



Depth range of interest (0 to 50 m BSF)

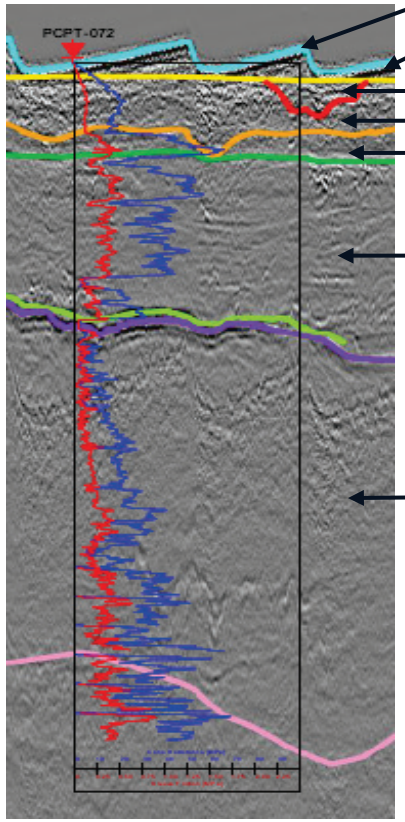


Spatial zonation of site – Soil Provinces



Fundamental features

Connection to geological ground model



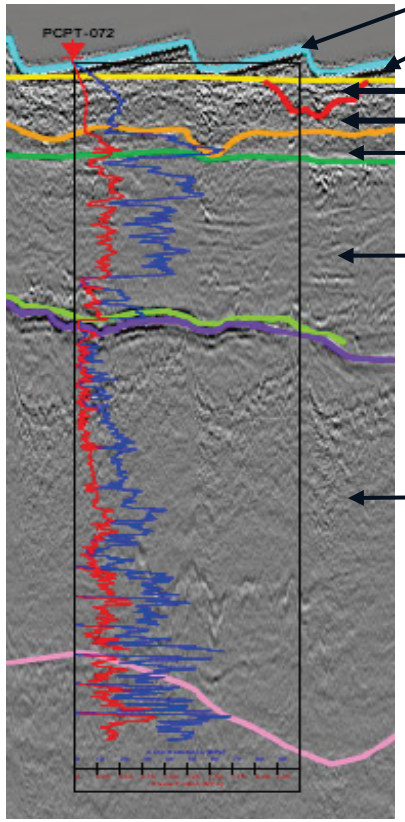
Seafloor
Unit A
Unit B
Unit C2
Unit F
Unit G

Identical to geological units

A
B
C1
C2
D
E
F
G

Fundamental features

Connection to geological ground model



Seafloor

Unit A

Unit B → **B1 (infill of channel features)**, **B2**

Unit C2

Unit F

Unit G

Identical to geological units

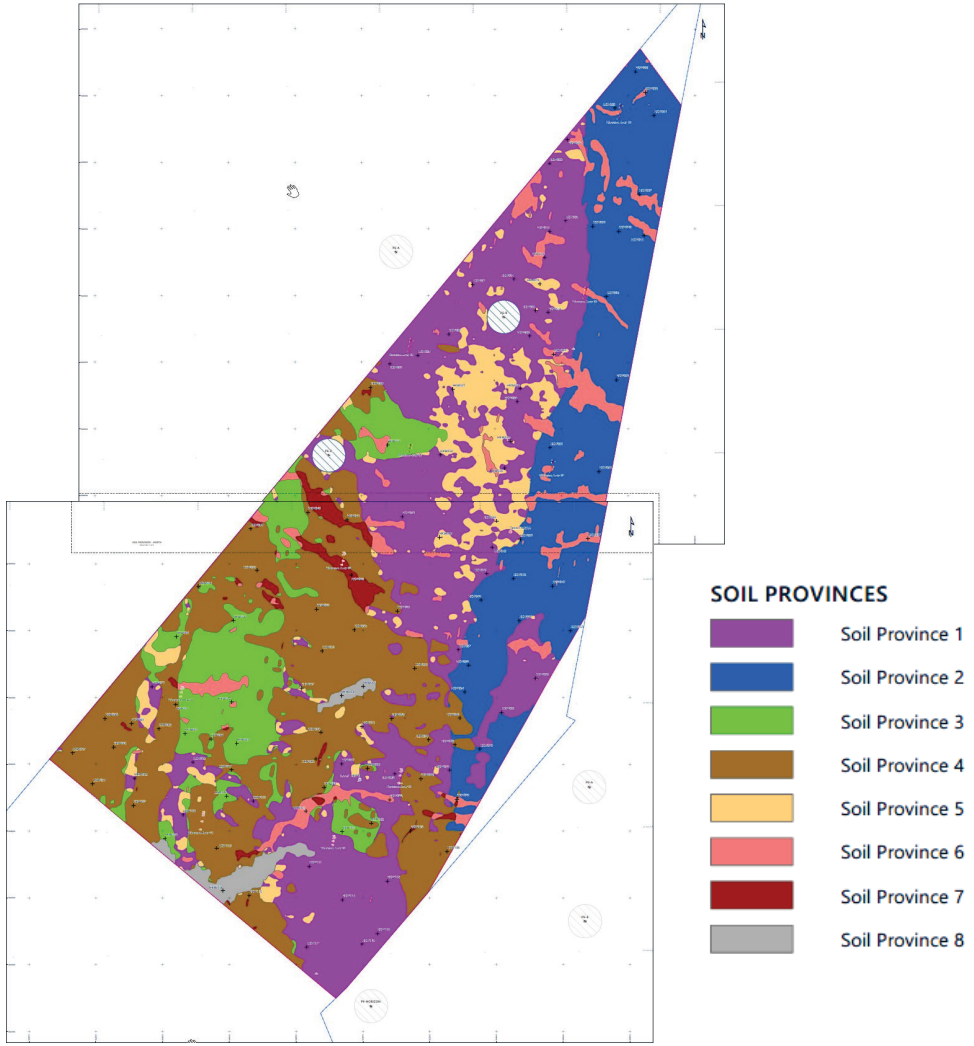
- A
- **B** → **B1**, **B2**
- C1
- C2
- D
- E
- F
- G

Fundamental features

Spatial zonation of site – Soil Provinces

Delineates a spatial zone within which geotechnical characteristics within a depth range of interest are similar

- 9 (geotechnical) soil units
- Presence of one or more distinguishing soil unit(s) within each soil province, i.e. a distinct soil unit that is likely to impact pile design
- Presence of specific (sequence of) soil units within the depth range of focus, i.e. 0 to 20 m BSF



Soil Provinces

Soil Province	Proportion of HKW WFZ [%]	Soil Unit									Primary Feature/ Comments
		A	B1	B2	C1	C2	D	E	F	G	
1	31.4	√		√					**√***	(√)	Presence of Soil Unit F
2	18.5	√		(√)				**√***	√	(√)	Presence of Soil Unit E
3	9.2	√		√		**√***			√	√	Presence of Soil Unit C2
4	25.8	√		(√)	**√***	(√)		(√)	√	(√)	Presence of Soil Unit C1
5	7.1	√		**√***					√	(√)	Presence of Soil Unit B2 with at least 7 m thickness
6	5.2	√	**√***	(√)		(√)		(√)	√	(√)	Presence of Soil Unit B1 (internal channels)
7	1.5	√	**√***	(√)	**√***	(√)		(√)	√	√	Presence of Soil Units B1 (internal channels) and C1
8	1.3	√	(√)	√	(√)	(√)	**√***		√	(√)	Presence of Soil Unit D

** denotes distinguishing soil unit(s) for the particular soil province*
() denotes partial presence of soil unit within soil province within the depth range of 0 m to 50 m BSF

Soil Provinces

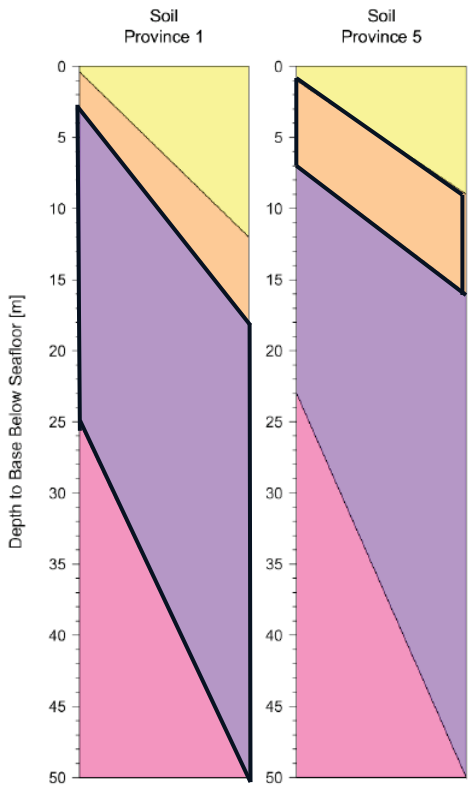
Soil Province	Proportion of HKW WFZ [%]	Soil Unit									Primary Feature/ Comments
		A	B1	B2	C1	C2	D	E	F	G	
1	31.4	√		√					**√***	(√)	Presence of Soil Unit F
2	18.5	√		(√)				**√***	√	(√)	Presence of Soil Unit E
3	9.2	√		√		**√***			√	√	Presence of Soil Unit C2
4	25.8	√		(√)	**√***	(√)		(√)	√	(√)	Presence of Soil Unit C1
5	7.1	√		**√***					√	(√)	Presence of Soil Unit B2 with at least 7 m thickness
6	5.2	√	**√***	(√)		(√)		(√)	√	(√)	Presence of Soil Unit B1 (internal channels)
7	1.5	√	**√***	(√)	**√***	(√)		(√)	√	√	Presence of Soil Units B1 (internal channels) and C1
8	1.3	√	(√)	√	(√)	(√)	**√***		√	(√)	Presence of Soil Unit D

** denotes distinguishing soil unit(s) for the particular soil province*
() denotes partial presence of soil unit within soil province within the depth range of 0 m to 50 m BSF

76 % of HKW WFZ

Soil Provinces

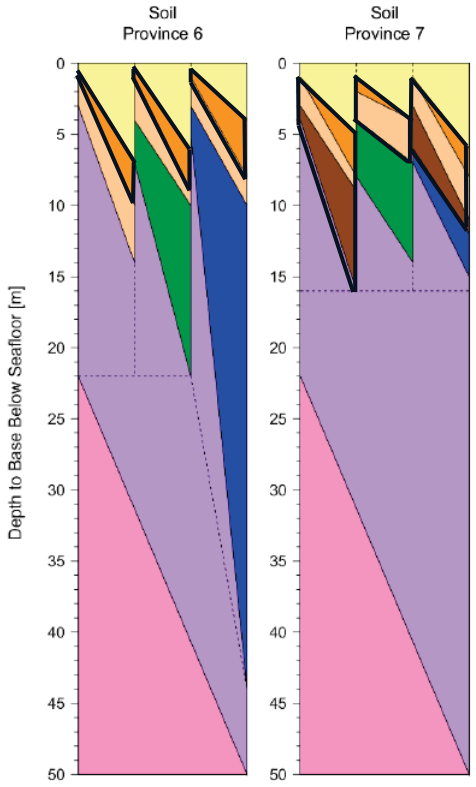
Soil Province	Proportion of HKW WFZ [%]	Soil Unit									Primary Feature/ Comments
		A	B1	B2	C1	C2	D	E	F	G	
1	31.4	√		√					**√***	(√)	Presence of Soil Unit F
2	18.5	√		(√)				**√***	√	(√)	Presence of Soil Unit E
3	9.2	√		√		**√***			√	√	Presence of Soil Unit C2
4	25.8	√		(√)	**√***	(√)		(√)	√	(√)	Presence of Soil Unit C1
5	7.1	√		**√***					√	(√)	Presence of Soil Unit B2 with at least 7 m thickness
6	5.2	√	**√***	(√)		(√)		(√)	√	(√)	Presence of Soil Unit B1 (internal channels)
7	1.5	√	**√***	(√)	**√***	(√)		(√)	√	√	Presence of Soil Units B1 (internal channels) and C1
8	1.3	√	(√)	√	(√)	(√)	**√***		√	(√)	Presence of Soil Unit D



Soil Unit A | Soil Unit B1 | Soil Unit B2 | Soil Unit C1 | Soil Unit C2 | Soil Unit D | Soil Unit E | Soil Unit F | Soil Unit G

Soil Provinces

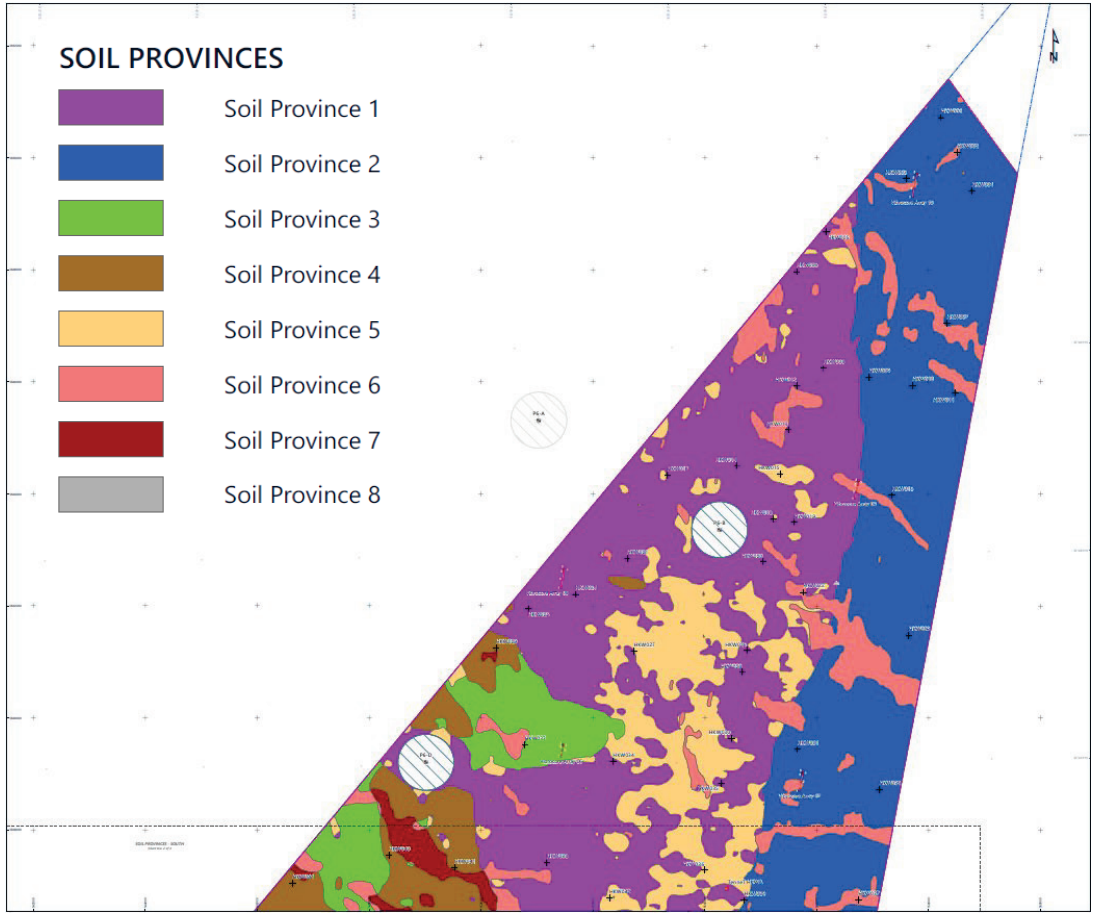
Soil Province	Proportion of HKW WFZ [%]	Soil Unit									Primary Feature/ Comments
		A	B1	B2	C1	C2	D	E	F	G	
1	31.4	√		√					**√***	(√)	Presence of Soil Unit F
2	18.5	√		(√)				**√***	√	(√)	Presence of Soil Unit E
3	9.2	√		√		**√***			√	√	Presence of Soil Unit C2
4	25.8	√		(√)	**√***	(√)		(√)	√	(√)	Presence of Soil Unit C1
5	7.1	√		**√***					√	(√)	Presence of Soil Unit B2 with at least 7 m thickness
6	5.2	√	**√***	(√)		(√)		(√)	√	(√)	Presence of Soil Unit B1 (internal channels)
7	1.5	√	**√***	(√)	**√***	(√)		(√)	√	√	Presence of Soil Units B1 (internal channels) and C1
8	1.3	√	(√)	√	(√)	(√)	**√***		√	(√)	Presence of Soil Unit D

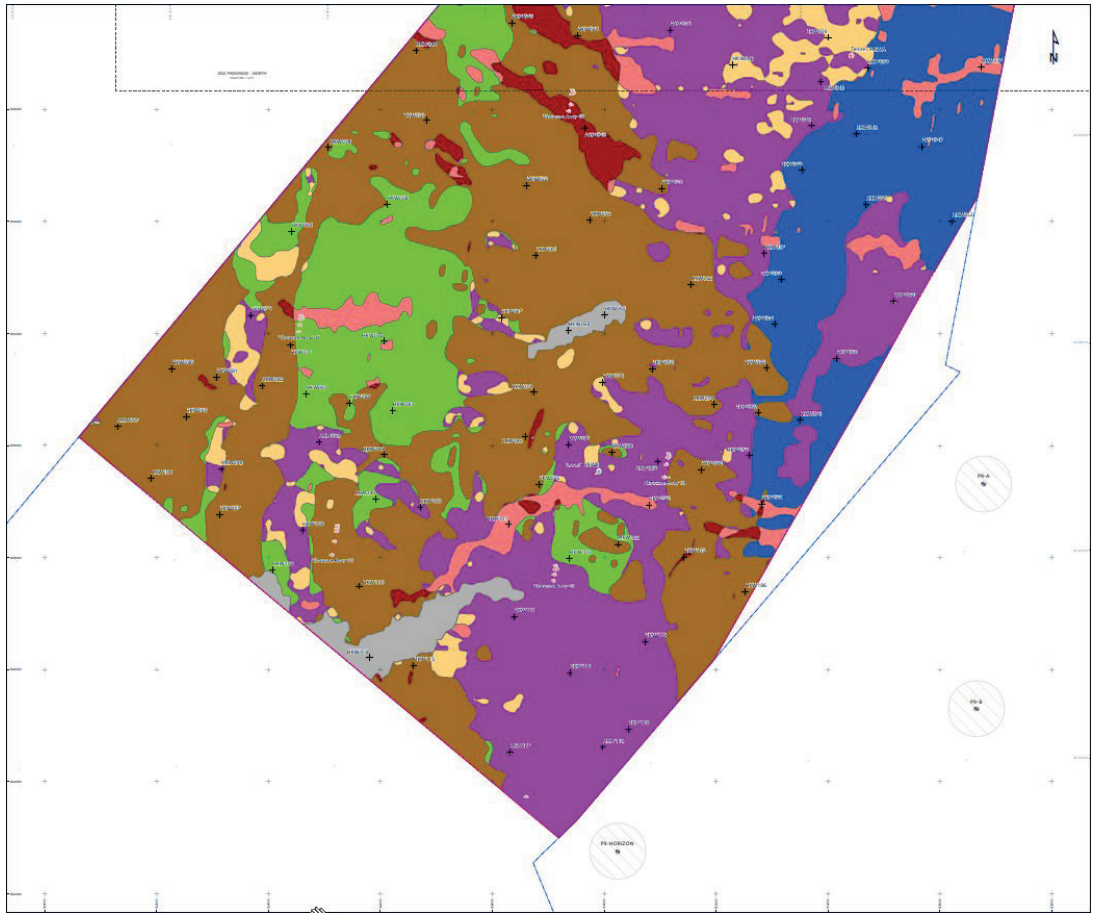


Soil Unit A | Soil Unit B1 | Soil Unit B2 | Soil Unit C1 | Soil Unit C2 | Soil Unit D | Soil Unit E | Soil Unit F | Soil Unit G

Soil Provinces

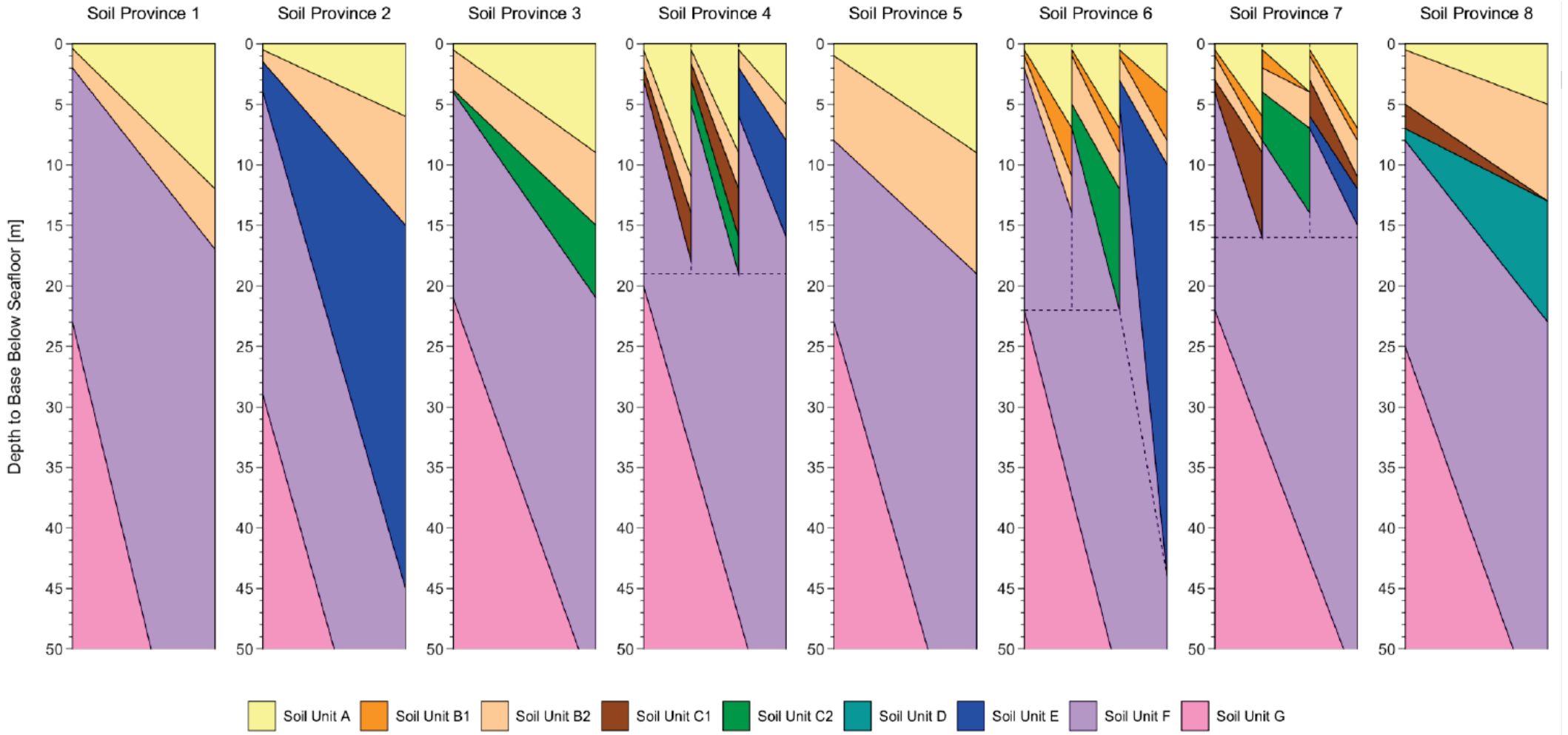
Results





Soil Provinces

Results



Soil Units – Classification

Soil Unit	Soil Group	Soil Classification
A	-	SAND
B1	B1-Sand	SAND and TRANSITIONAL SOIL
	B1-Transitional	
B2	-	SAND
C1	C1-Sand	SAND, TRANSITIONAL SOIL and CLAY
	C1-Transitional	
	C1-Clay	
C2	-	SAND
D	-	SAND, TRANSITIONAL SOIL and CLAY
E	-	SAND
F	F-Sand	SAND, TRANSITIONAL SOIL and CLAY
	F-Transitional	
	F-Clay	
G	G-Sand	SAND, TRANSITIONAL SOIL and CLAY
	G-Transitional	
	G-Clay	

Soil Units – Soil Classification

Sand

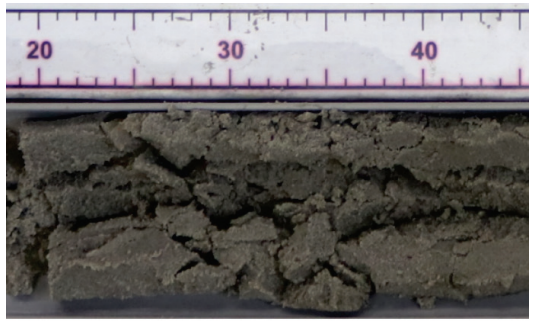
Upper limit of I_c
Percentage fines < 15%

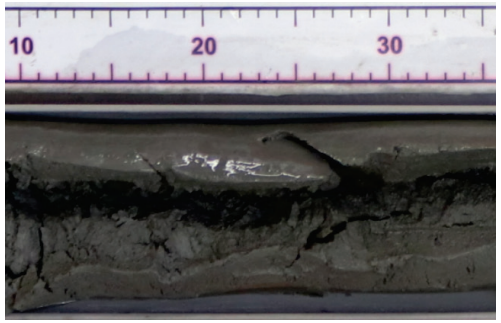
Transitional soil

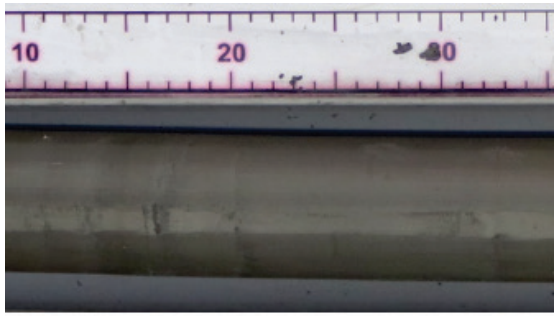
Classification criteria in between Sand and Clay

Clay

Lower limit of I_c
Percentage fines > 35%
Percentage clay > 10%

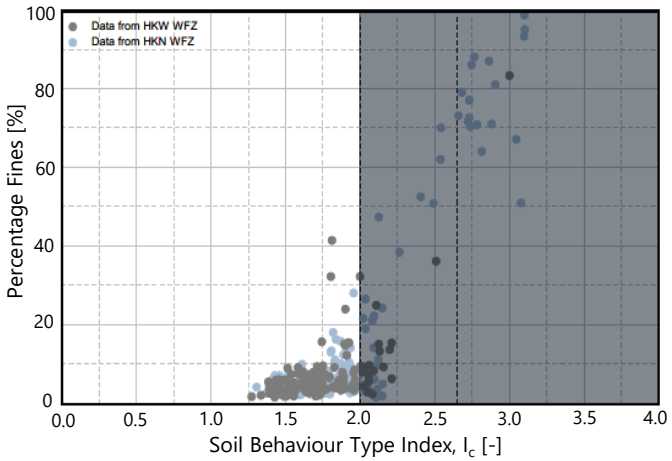


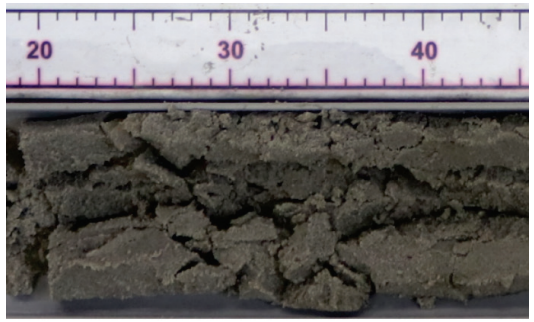




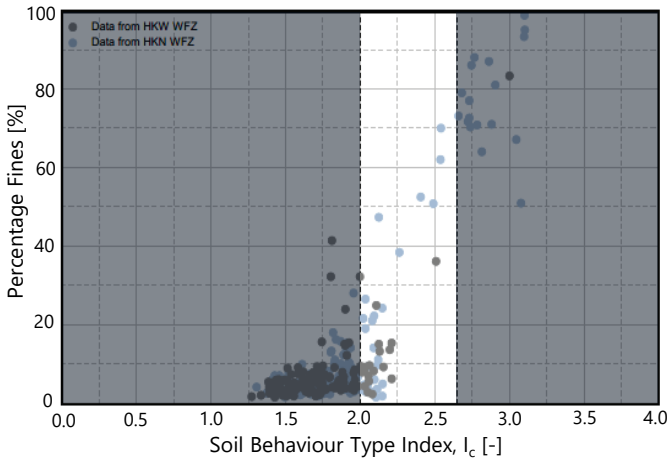
Soil Units – Soil Classification

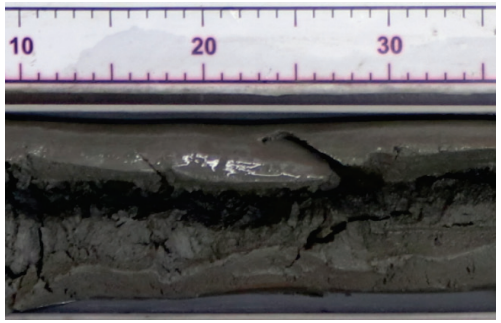
Sand



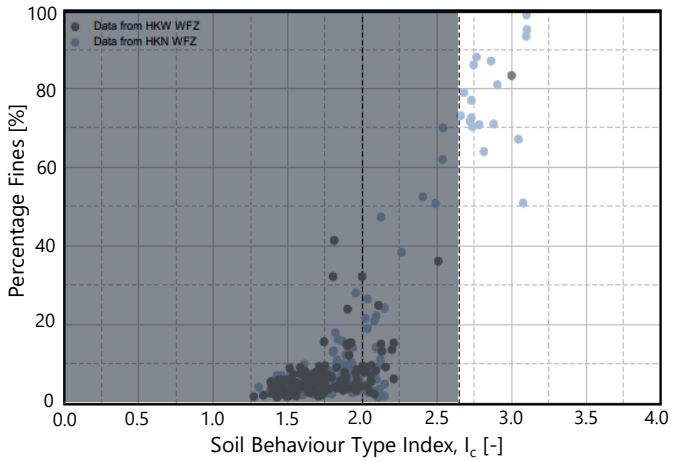


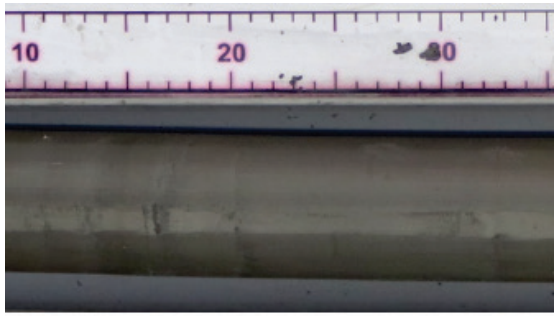
Transitional soil





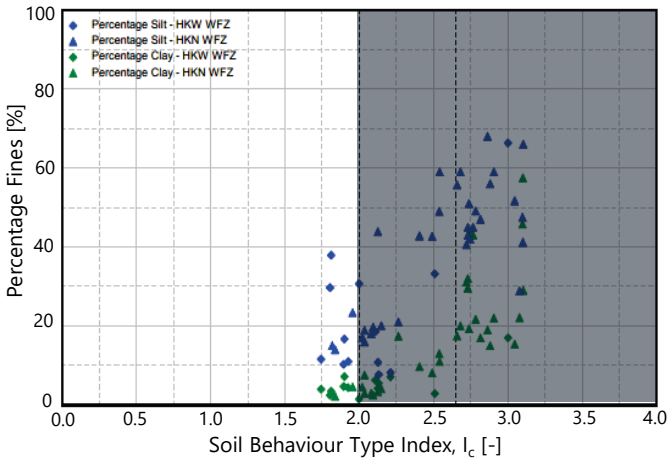
Clay

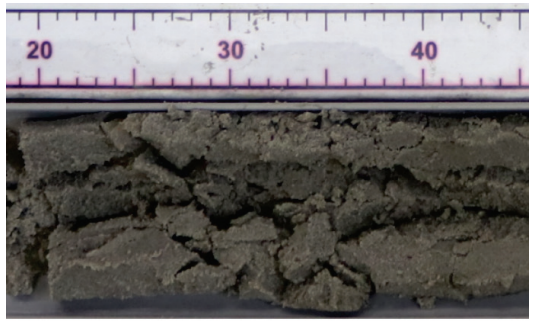




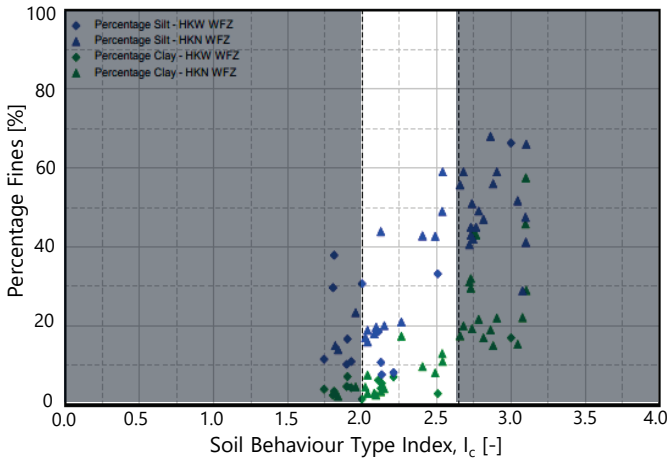
Soil Units – Soil Classification

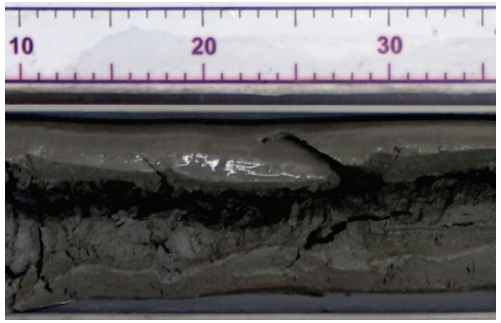
Sand



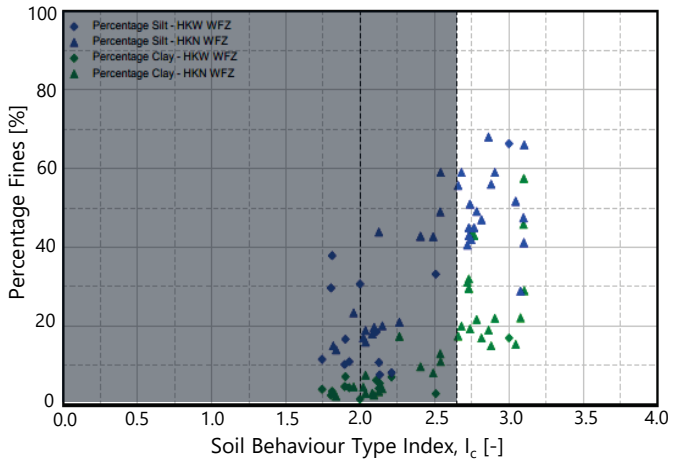


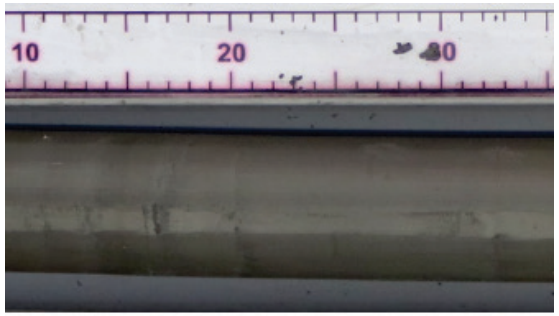
Transitional soil



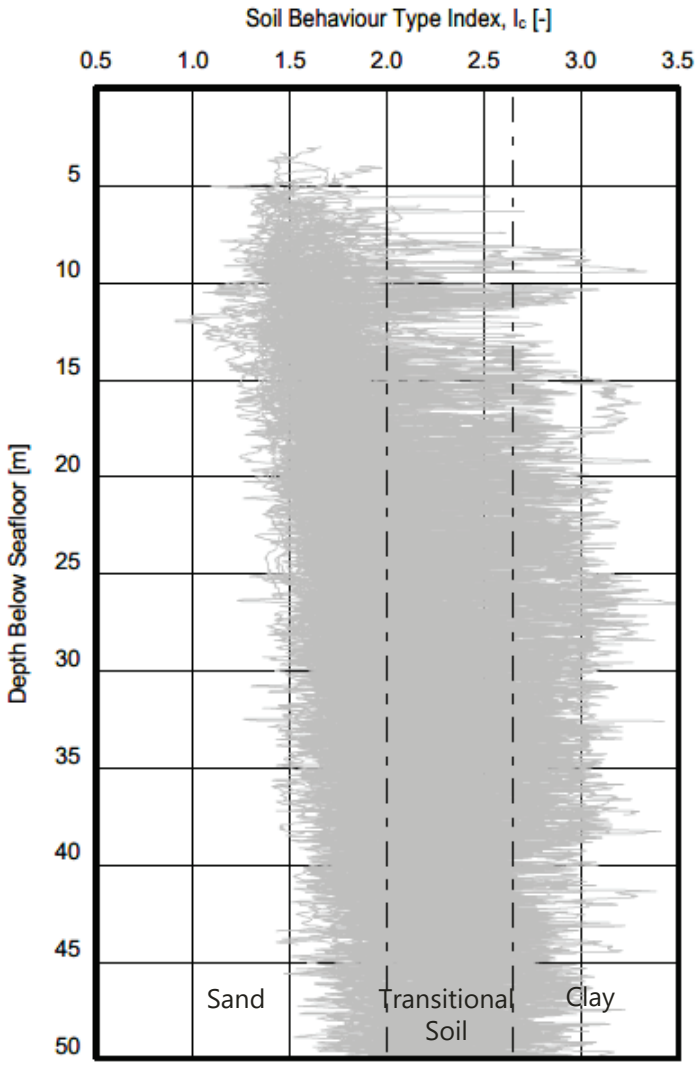


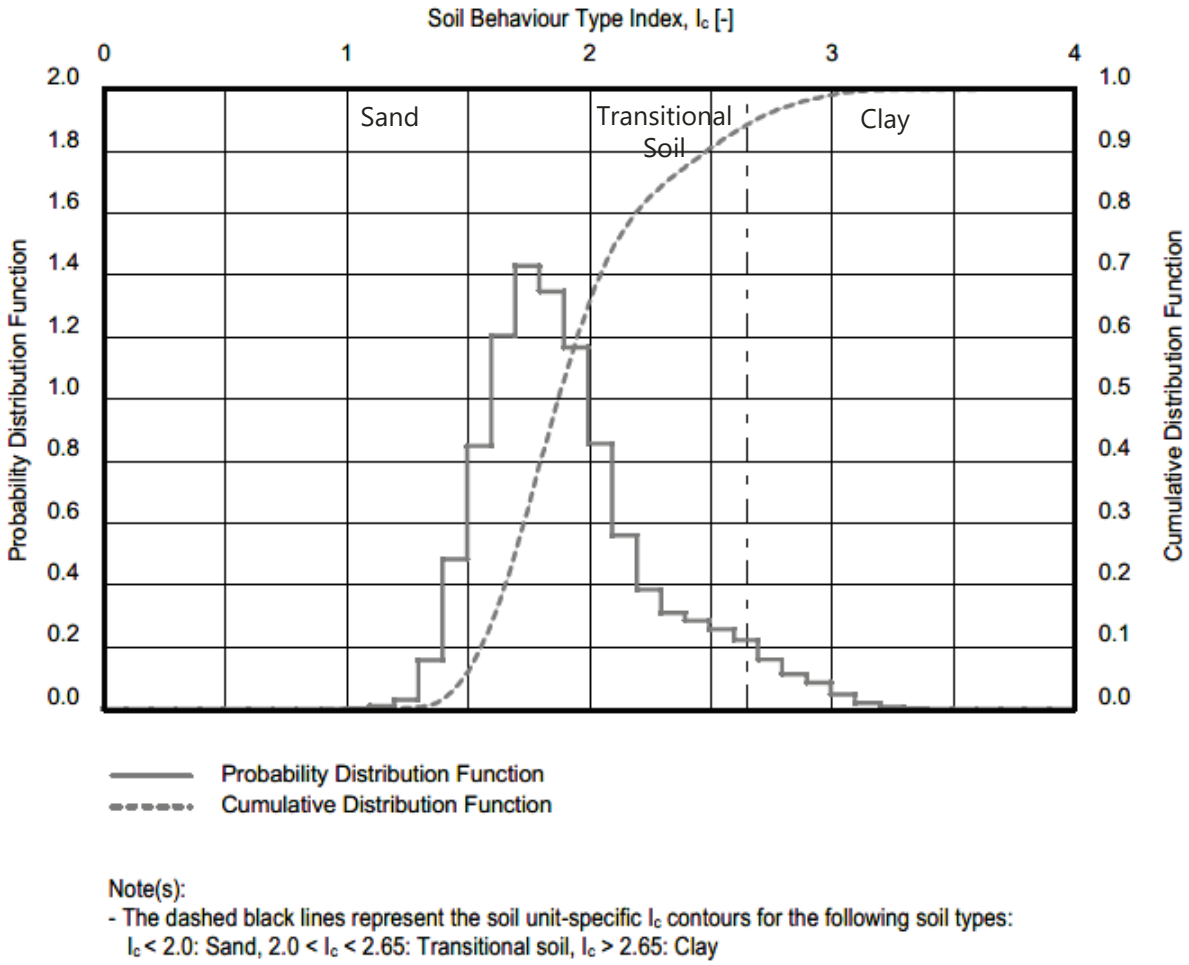
Clay





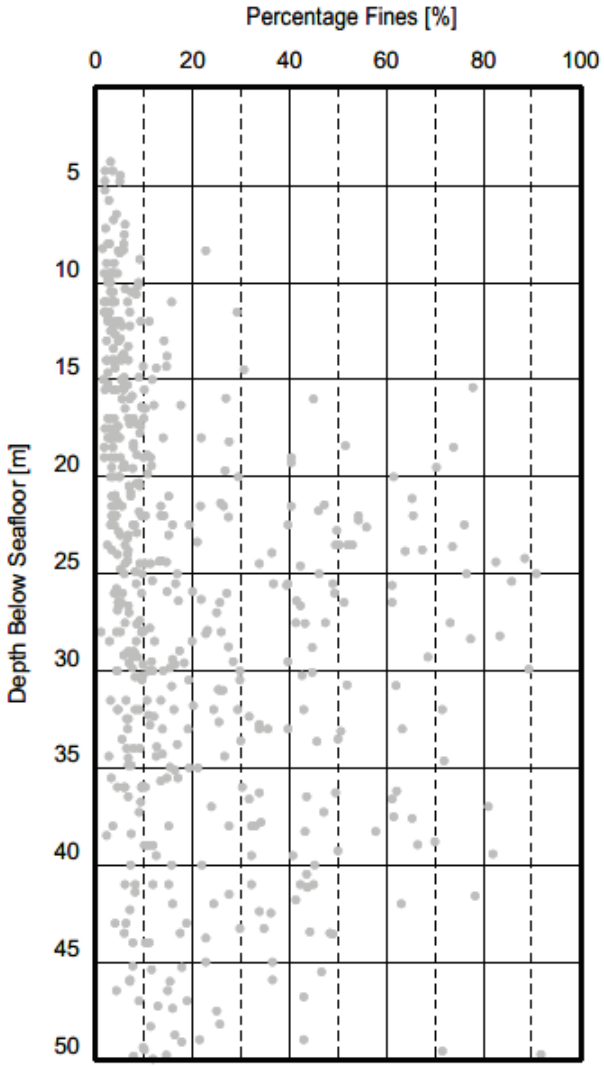
Soil Units – Classification (Soil Unit F)

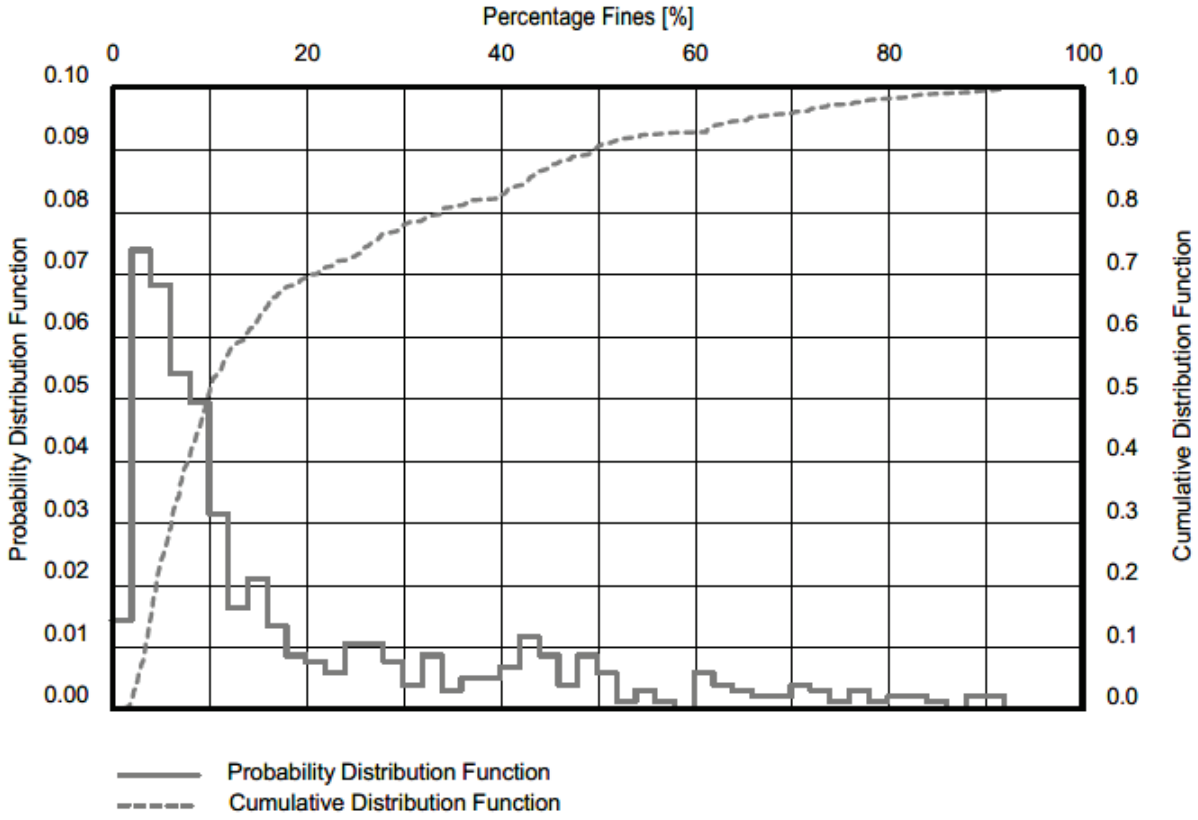




Note(s):
- The dashed black lines represent the soil unit-specific I_c contours for the following soil types:
  $I_c < 2.0$: Sand, $2.0 < I_c < 2.65$: Transitional soil, $I_c > 2.65$: Clay

Soil Units – Classification (Soil Unit F)





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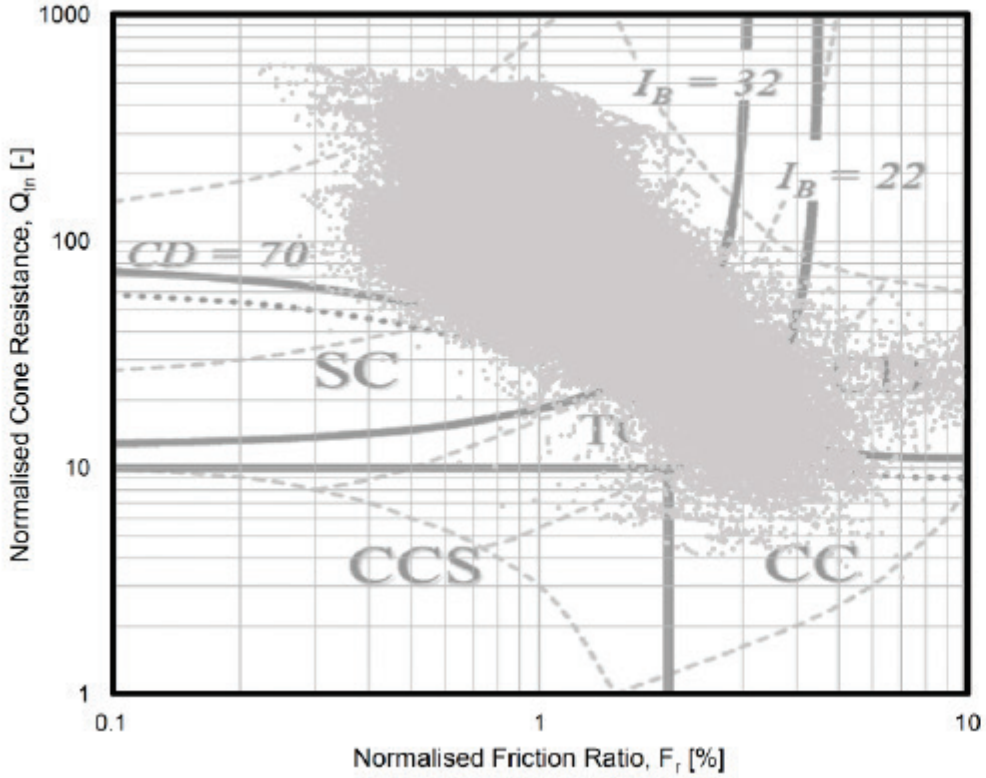
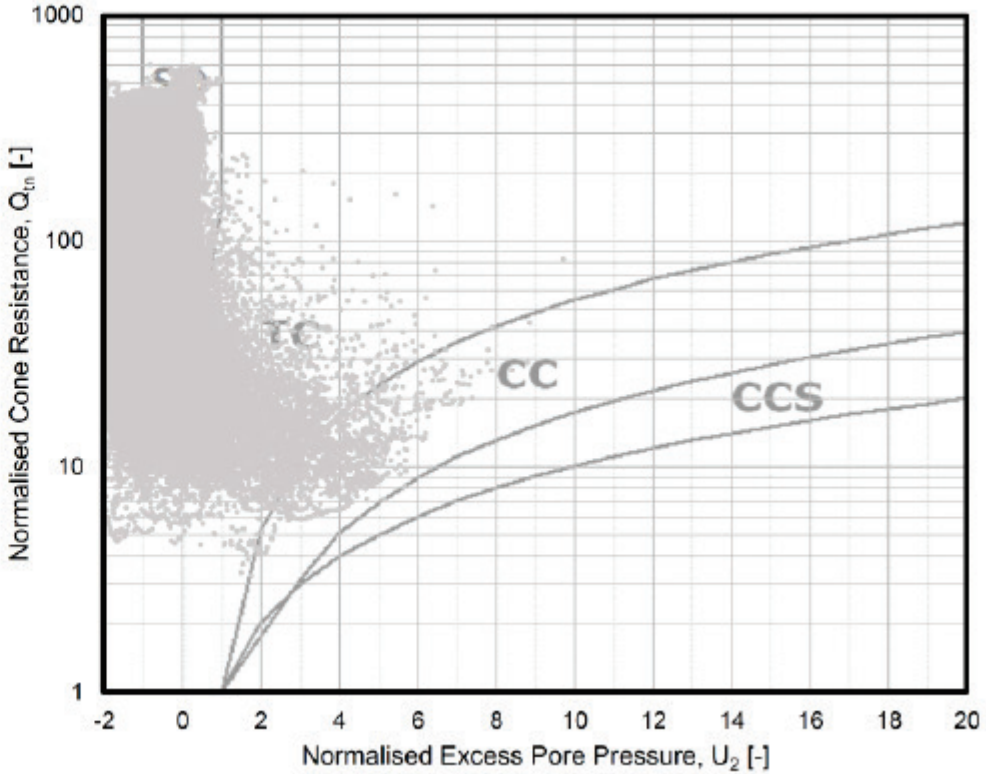
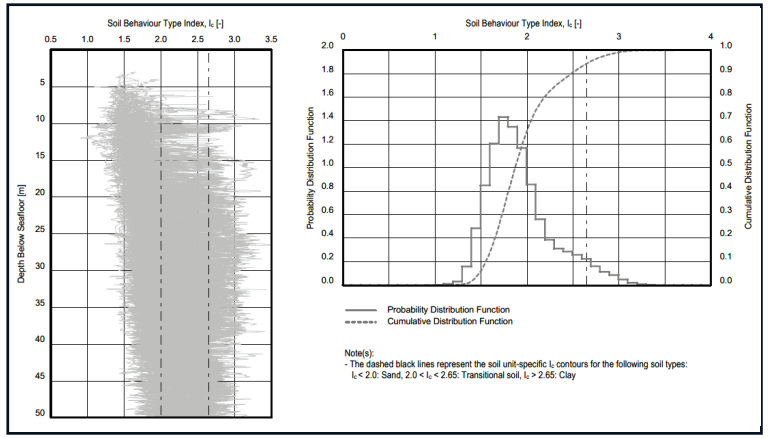
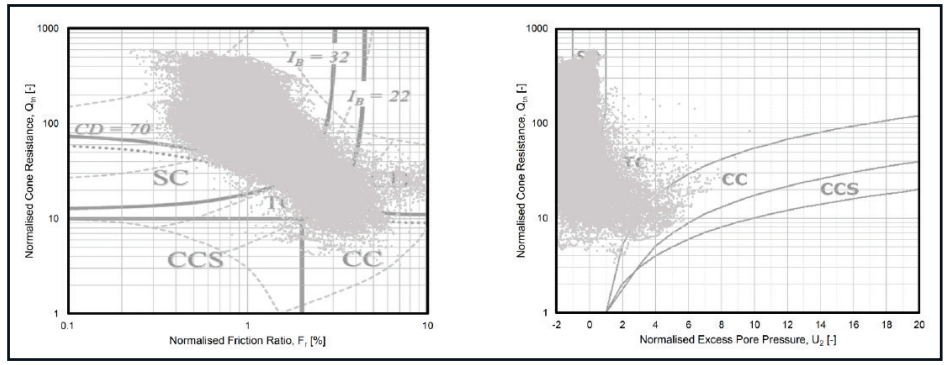
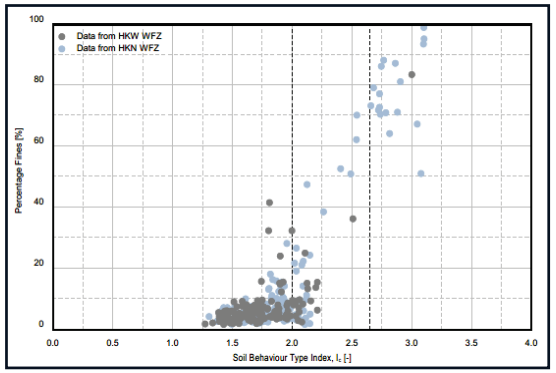




Soil Units – Classification (Soil Unit F)







SBT Index, I_c

Particle Size Distribution

Data Pairing

Soil Unit F –> SAND, TRANSITIONAL SOIL & CLAY

Potential Geohazards

Geological Feature/ Hazard	Occurrence Area	Hazard Probability				
		Pile Foundations	Jack-up Platforms	Gravity Base Foundations	Suction Caisson Foundations	Cables
Bedforms	Entire HKW WFZ	N [N]	L [N]	H [N]	L [N]	L [N]
Mobile seabed sediments	Entire HKW WFZ	H [L]	L [N]	H [N]	H [L]	H [N]
Loose to medium dense sand or silt	Locally Unit A & B	H [N]	L [N]	H [N]	L [N]	L [N]
Alternation of sand and clay/ silt	Infill of (paleo)channels	N [N]	L [N]	N [N]	L [N]	N [N]
Very dense sand	Entire HKW WFZ	L [N]	N [N]	N [N]	L [L]	L [N]
Peat, organic clay/ shallow gas	Locally in Units A, B, C1, D, F & G	N [N]	N [N]	L [N]	L [N]	N [N]
Gravel, cobbles and/or boulders	Locally all units except Unit A	L [N]	N [N]	N [N]	L [L]	L [N]
Glaciotectonic deformation feature	Locally in Units F & G	L [N]	N [N]	N [N]	N [N]	N [N]
Regional subsidence	Entire HKW WFZ	L [N]	N [N]	L [N]	L [N]	N [N]
Existing structures (e.g. cables)	Refer reports	H [N]	H [N]	H [N]	H [N]	H [L]
UXO	Entire HKW WFZ	L [N]	N [N]	L [N]	L [N]	N [N]
Future structures (e.g. wind farm)	Entire HKW WFZ	L [N]	N [N]	L [N]	L [N]	L [N]

- Negligible (N) ; Low (L) ; High (H)
- Descriptor between brackets refers to hazard probability after consideration of mitigation measures

Potential Geohazards

Geological Feature/ Hazard	Occurrence Area	Hazard Probability				
		Pile Foundations	Jack-up Platforms	Gravity Base Foundations	Suction Caisson Foundations	Cables
Bedforms	Entire HKW WFZ	N [N]	L [N]	H [N]	L [N]	L [N]
Mobile seabed sediments	Entire HKW WFZ	H [L]	L [N]	H [N]	H [L]	H [N]
Loose to medium dense sand or silt	Locally Unit A & B	H [N]	L [N]	H [N]	L [N]	L [N]
Alternation of sand and clay/ silt	Infill of (paleo)channels	N [N]	L [N]	N [N]	L [N]	N [N]
Very dense sand	Entire HKW WFZ	L [N]	N [N]	N [N]	L [L]	L [N]
Peat, organic clay/ shallow gas	Locally in Units A, B, C1, D, F & G	N [N]	N [N]	L [N]	L [N]	N [N]
Gravel, cobbles and/or boulders	Locally all units except Unit A	L [N]	N [N]	N [N]	L [L]	L [N]
Glaciotectonic deformation feature	Locally in Units F & G	L [N]	N [N]	N [N]	N [N]	N [N]
Regional subsidence	Entire HKW WFZ	L [N]	N [N]	L [N]	L [N]	N [N]
Existing structures (e.g. cables)	Refer reports	H [N]	H [N]	H [N]	H [N]	H [L]
UXO	Entire HKW WFZ	L [N]	N [N]	L [N]	L [N]	N [N]
Future structures (e.g. wind farm)	Entire HKW WFZ	L [N]	N [N]	L [N]	L [N]	L [N]

- Negligible (N) ; Low (L) ; High (H)
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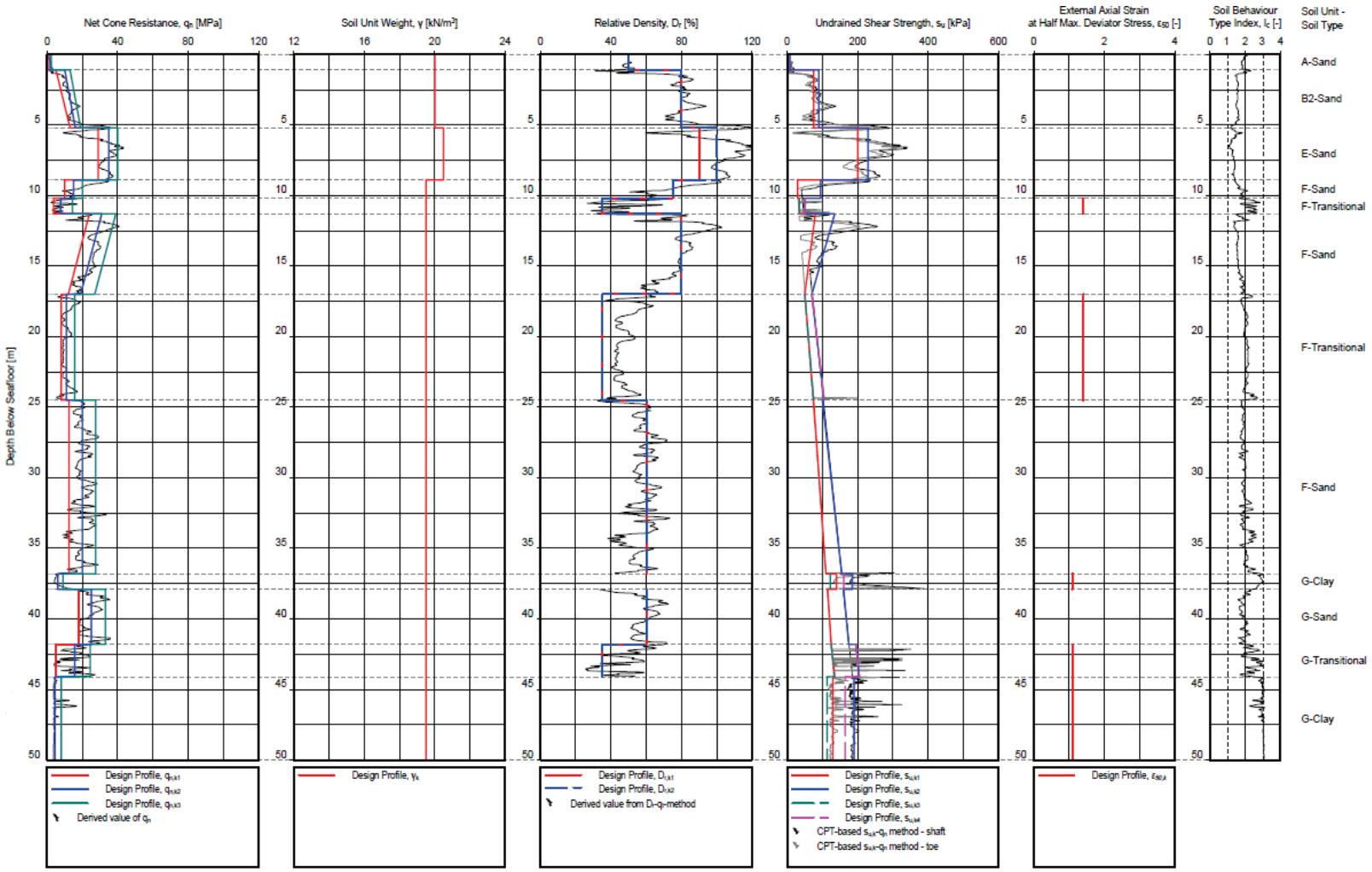
03

Geotechnical Parameters

Design Profiles

- Net cone resistance
- Soil unit weight
- Relative density
- Undrained shear strength
- Ext. axial strain at 50 % max deviator stress
- Peak friction angle
- Soil-steel interface friction angle
- Coef. of permeability
- Shear modulus at small strain



Scope for Characteristic Values

Soil Provinces

↓

CPT Clustering

↓

Design Locations

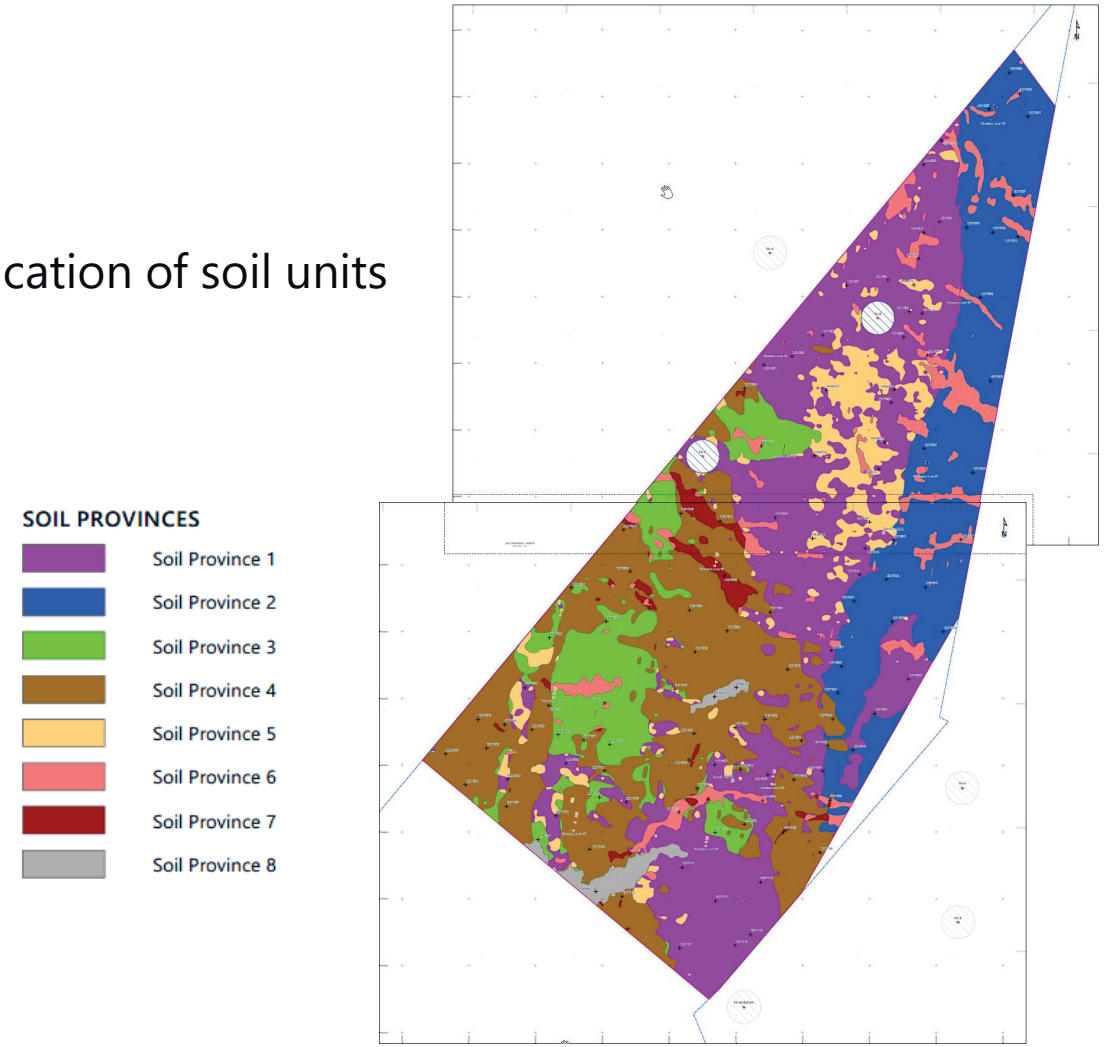
↓

Location Stratigraphy

↓

Characteristic Values

- 8 soil provinces
- 9 soil units
- Geotechnical classification of soil units



Scope for Characteristic Values

Soil Provinces

↓

CPT Clustering

↓

Design Locations

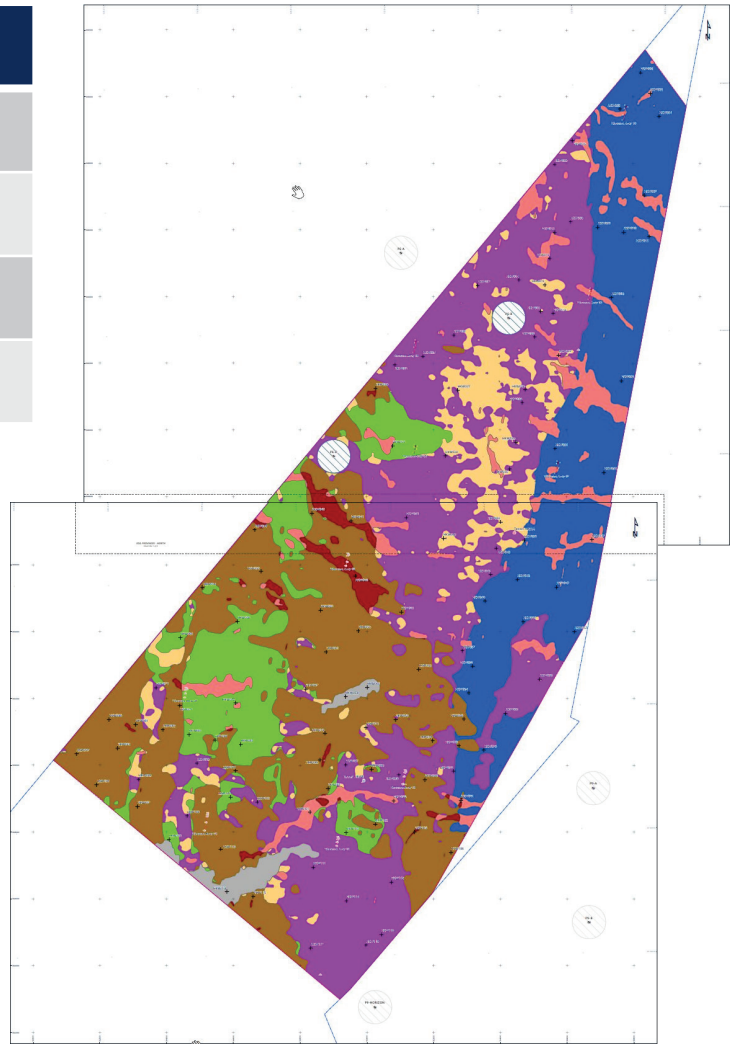
↓

Location Stratigraphy

↓

Characteristic Values

SP1	SP2	SP3	SP4	...
HKW005	HKW001	HKW033	HKW029	...
HKW006	HKW003	HKW058	HKW040	...
HKW008	HKW004	HKW063	HKW041	...
...	...	...	...	...



Scope for Characteristic Values

Soil Provinces

↓

CPT Clustering

↓

Design Locations

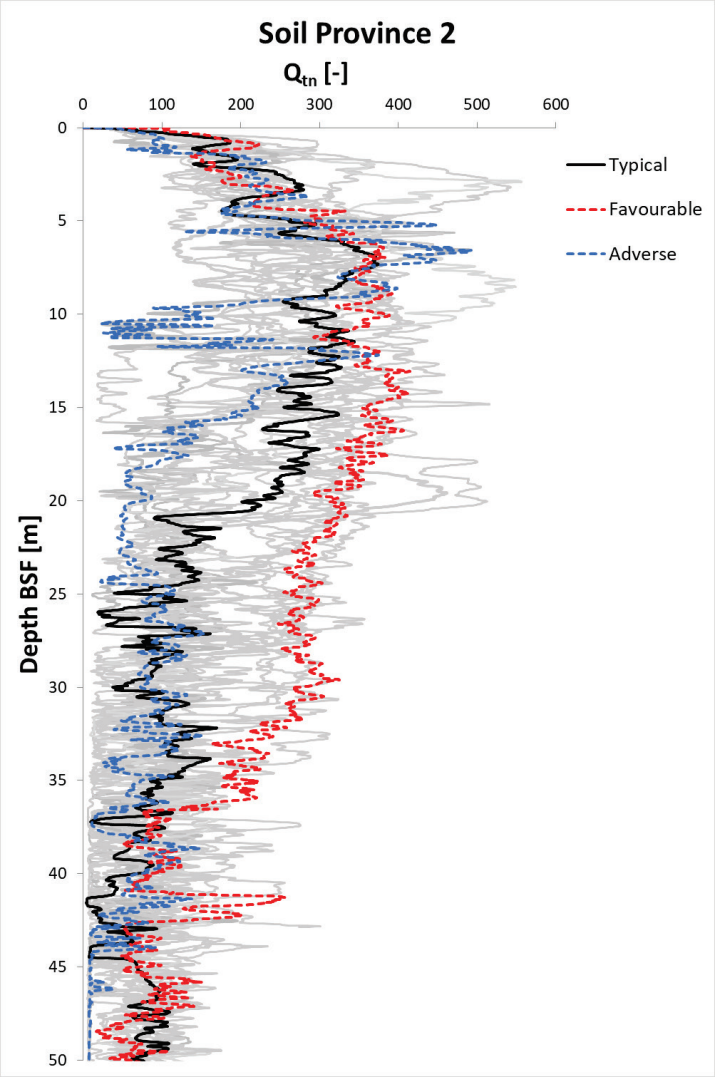
↓

Location Stratigraphy

↓

Characteristic Values

- Real CPT locations
- 3 design locations per soil province
  - Typical soil conditions
  - Favourable soil conditions
  - Adverse soil conditions



Scope for Characteristic Values

Soil Provinces

↓

CPT Clustering

↓

Design Locations

↓

Location Stratigraphy

↓

Characteristic Values

- Stratification at design location
- Considers:
  - Soil units
  - Soil types
  - Cone resistance trends
  - Minimum thickness of 0.5 m
  - Thin interbedding

HKW049-SCPT

Depth [m]	Soil Unit	Soil Type
0.0 1.1	A	Sand
1.1 5.2	B2	Sand
5.2 8.9	E	Sand
8.9 10.2	F	Sand
10.2 11.3	F	Transitional
11.3 17.0	F	Sand
17.0 24.5	F	Transitional
24.5 36.8	F	Sand
36.8 37.9	G	Clay
37.9 41.8	G	Sand
41.8 44.1	G	Transitional
44.1 50.0	G	Clay

Scope for Characteristic Values

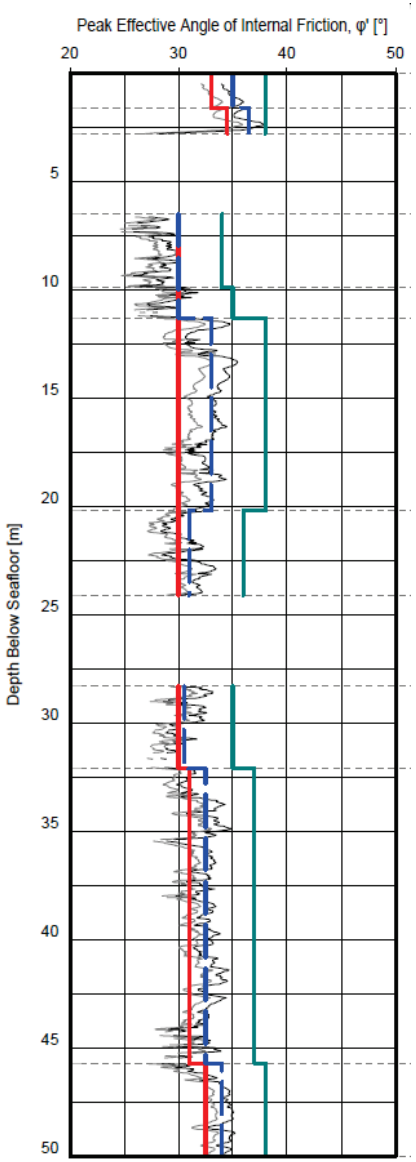
Soil Provinces
↓
CPT Clustering
↓
Design Locations
↓
Location Stratigraphy
↓
Characteristic Values

Limit states: ULS, SLS

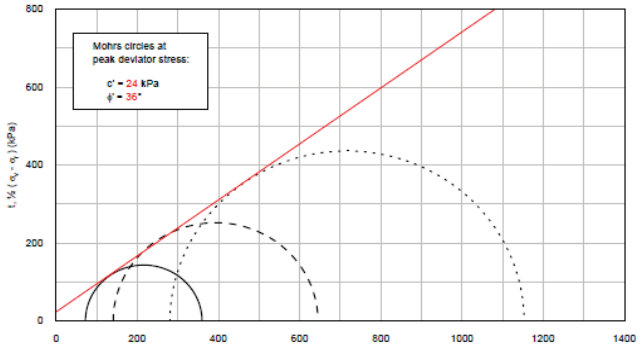
Foundation concept: Monopile, Jacket pile

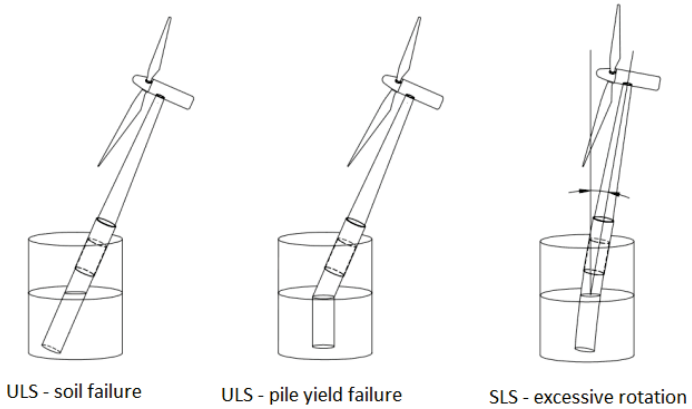
Installation method: Impact driving

Calculation Model	Pile Design Use	Foundation Concept	Geotechnical Parameters
PISA numerical-based method	Lateral resistance	Monopile	γ, s_u, φ', δ, G_{max}
PISA rule-based method (PISA design model)	Lateral resistance	Monopile	γ, s_u, G_{max}, D_r
ISO (2016) axial performance methods	Axial resistance	Jacket pile	γ, q_n, s_u, φ', δ, D_r
ISO (2016) p-y method	Lateral resistance	Jacket pile	γ, s_u, φ', ε_{50}
Alm and Hamre (2001) SRD method	Installation analysis	Jacket pile	γ, q_n, φ'
Maynard et al. (2018) SRD method	Installation analysis	Monopile	γ, q_n, φ'
Osman and Randolph (2012) analytical model	Assessment of drainage behaviour	Monopile / Jacket pile	γ, k



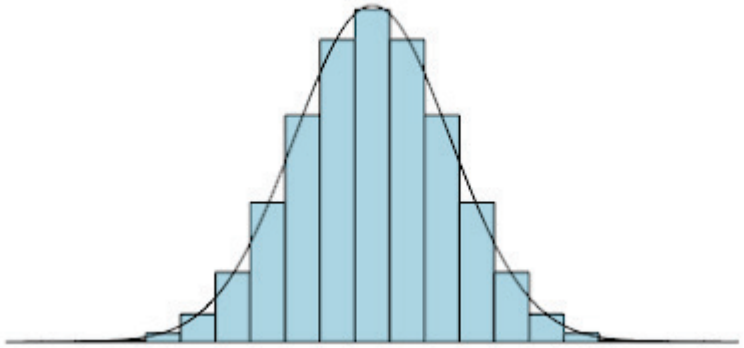
Geotechnical Parameters





Acquisition of data → **Results/Analysis** → **Calculation Model** → **Design Situation**

Acquisition of data	Results/Analysis	Calculation Model	Design Situation
Measured values	Derived values	Characteristic values	Design values

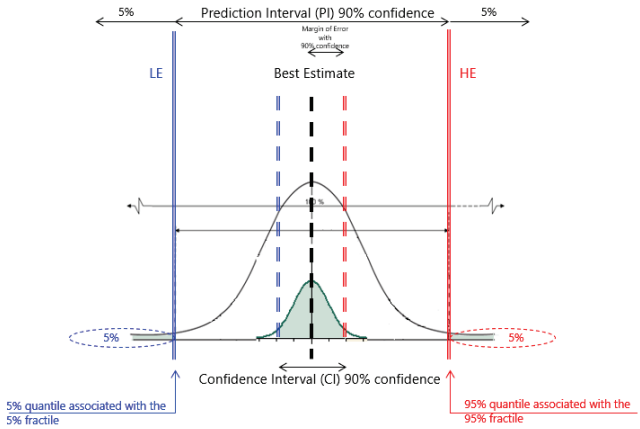


Derived Values

- Net cone resistance
- Soil unit weight
- Relative density
- Undrained shear strength
- Ext. axial strain at 50 % max deviator stress
- Peak friction angle
- Soil-steel interface friction angle
- Coef. of permeability
- Shear modulus at small strain
- Min/max index void ratios
- Yield stress ratio
- Coef. of lateral earth pressure at rest
- Constrained modulus
- Critical state line
- Friction angle at large strain
- Normalised shear modulus
- Cyclic strength

- Identification of test methods considering appropriateness and availability
- Presentation per:
  - Soil unit
  - Soil group
  - Soil type
  - Location cluster

  LE → 5 % fractile
  BE → 90 % confidence interval
  HE → 95 % fractile



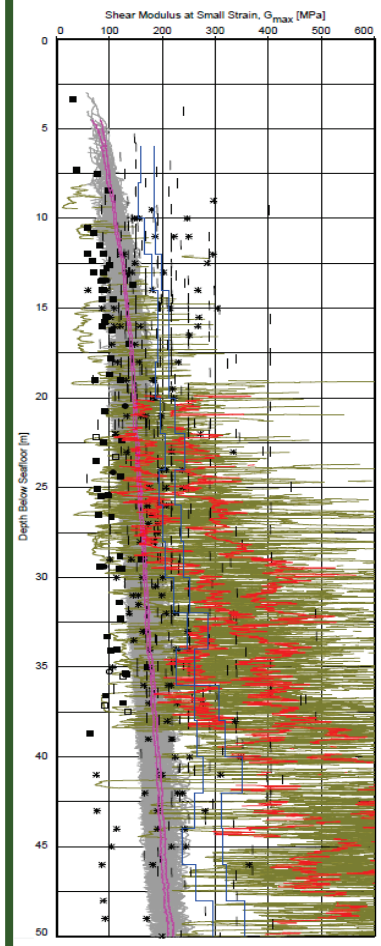
- Independent of specific limit states and calculation models
- Statistical evaluation captures the range of derived values within a soil unit/group/type
- Can serve as input in parameter selection for:
  - Design situations other than those considered for the characteristic values
  - Other foundation concepts, e.g. suction caissons, vibratory piles

Derived Values

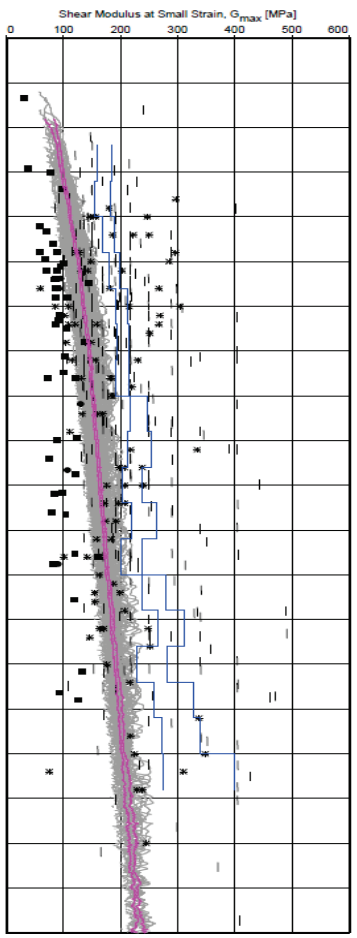
Presentation examples

Versus depth

Per soil unit

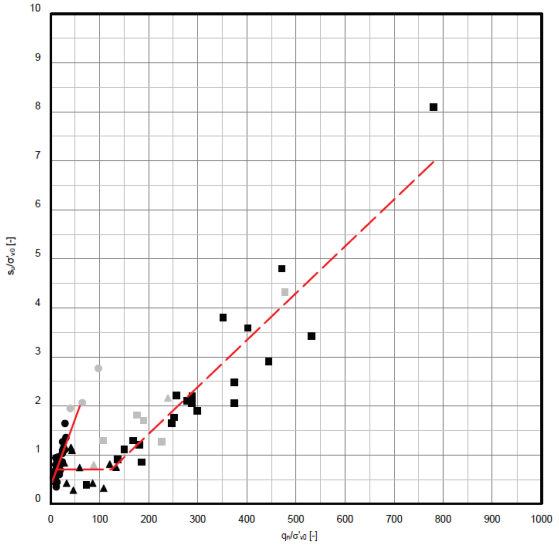


Per soil group

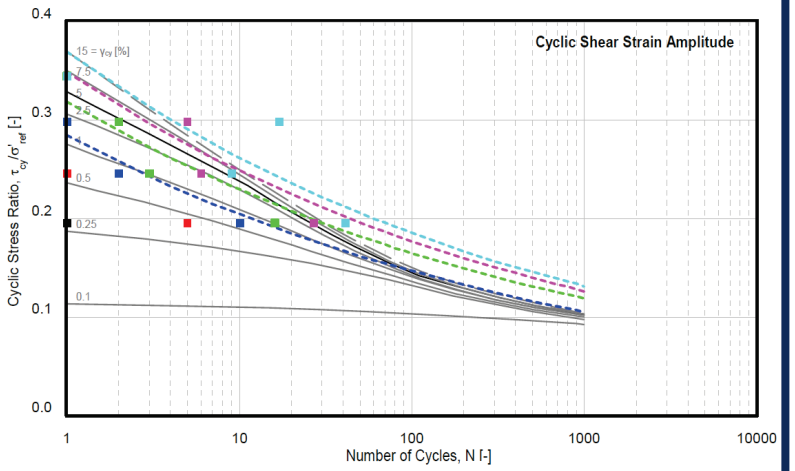


Other format

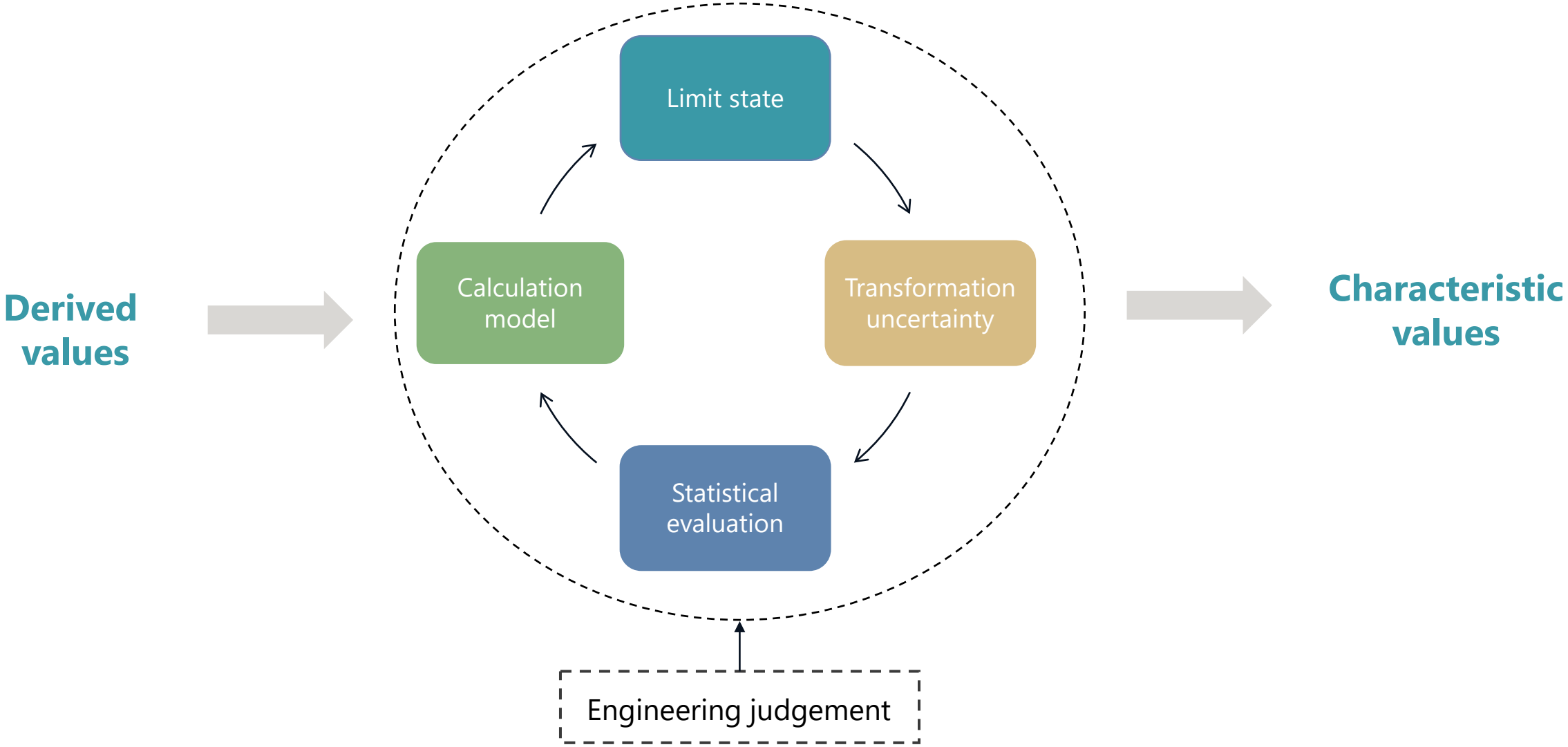
Per soil type



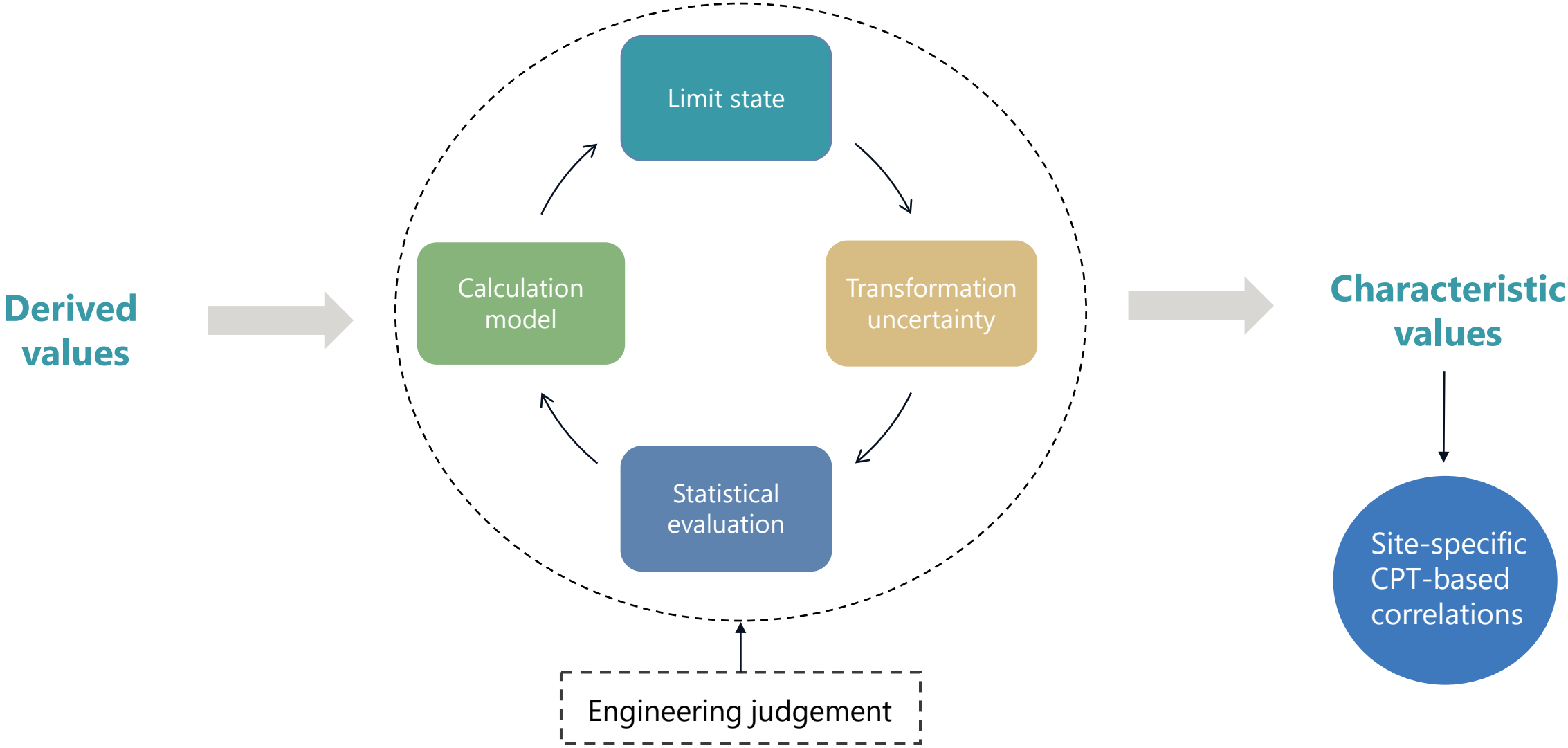
Per soil unit



Characteristic Values



Characteristic Values



G_{max} – Characteristic values

i. Corresponding calculation model and limit state: Calculation models 1 & 2 (PISA methods) - SLS
ii. Reference method for calculation model: SCPT
iii. Site-specific CPT-based correlation: $G_{max} = (1 + 4 \cdot B_q) \cdot YSR^b \cdot 1.634 \cdot (q_c)^{0.25} \cdot (\sigma'_{v0})^{0.375}$

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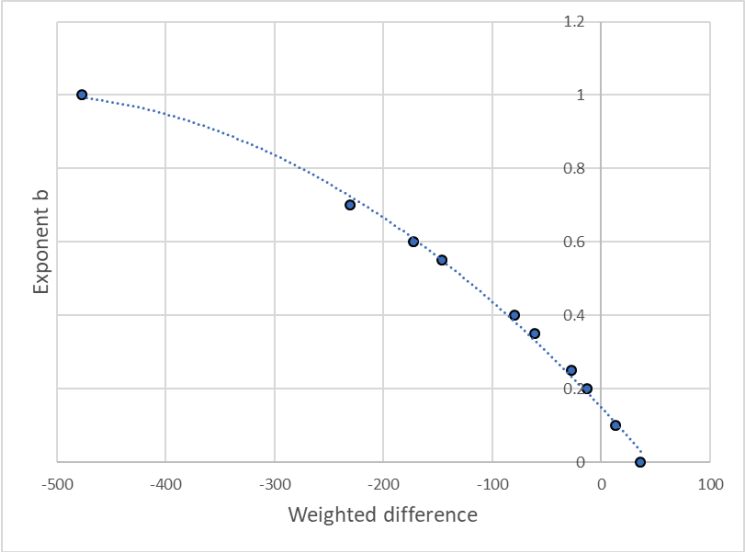
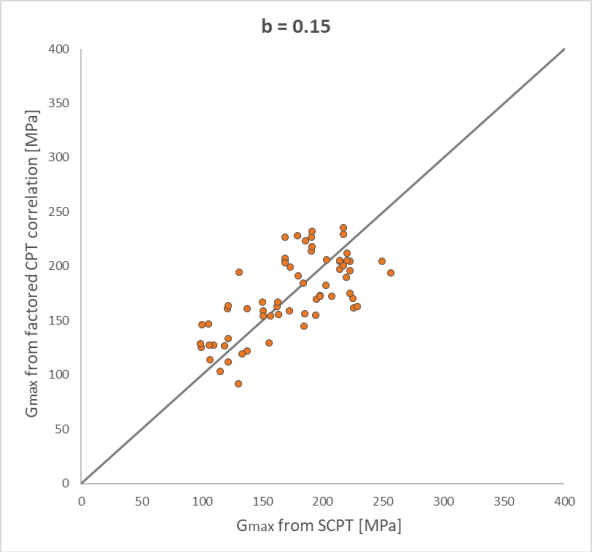
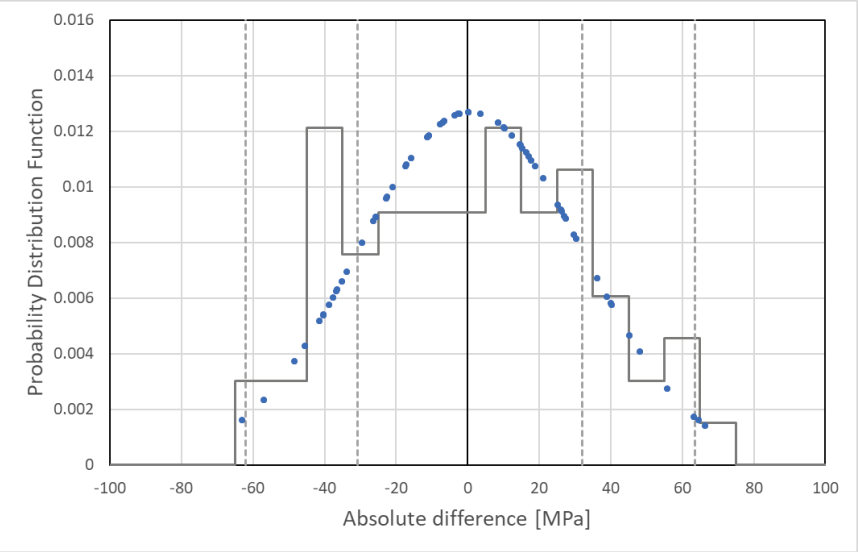
iv. Data pairing of G_{max} between SCPT and CPT-based correlation
   - Soil unit-specific
   - Depth-specific weight factoring
   - Factoring of exponent b to determine best-fit
   - Spread in distribution of soil unit-specific G_{max}







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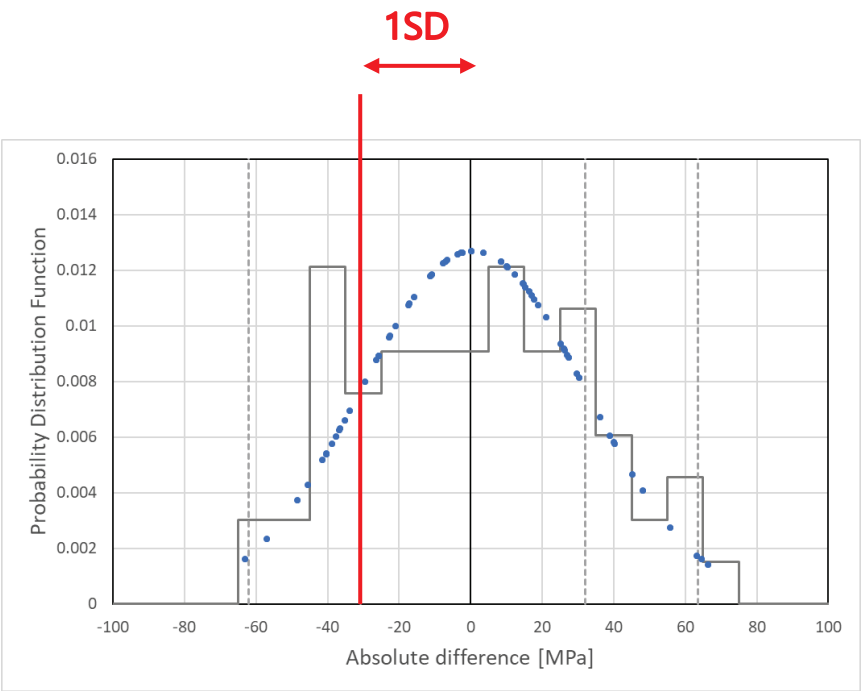
   - Spread in distribution of soil unit-specific G_{max}
v. Application of soil unit-specific factoring
   - Global monopile behaviour
   - Statistical fitting uncertainties → 16 % fractile



G_{max} – Characteristic values

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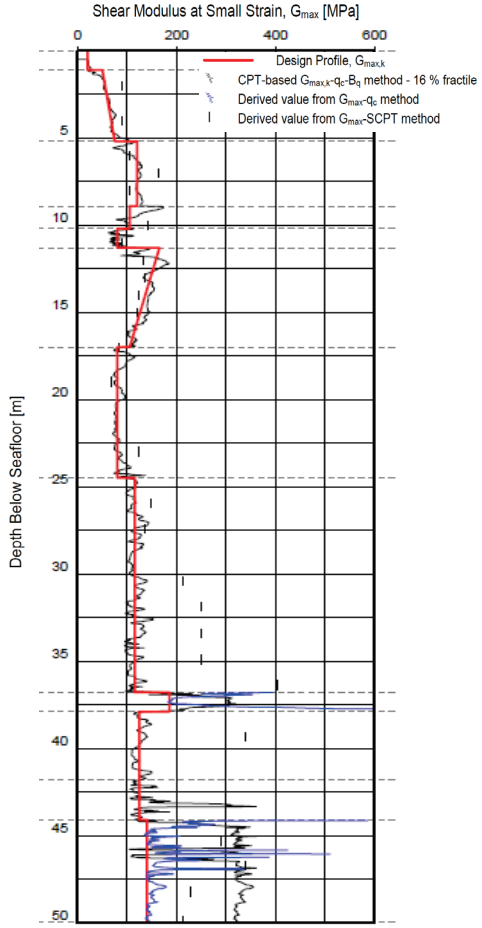
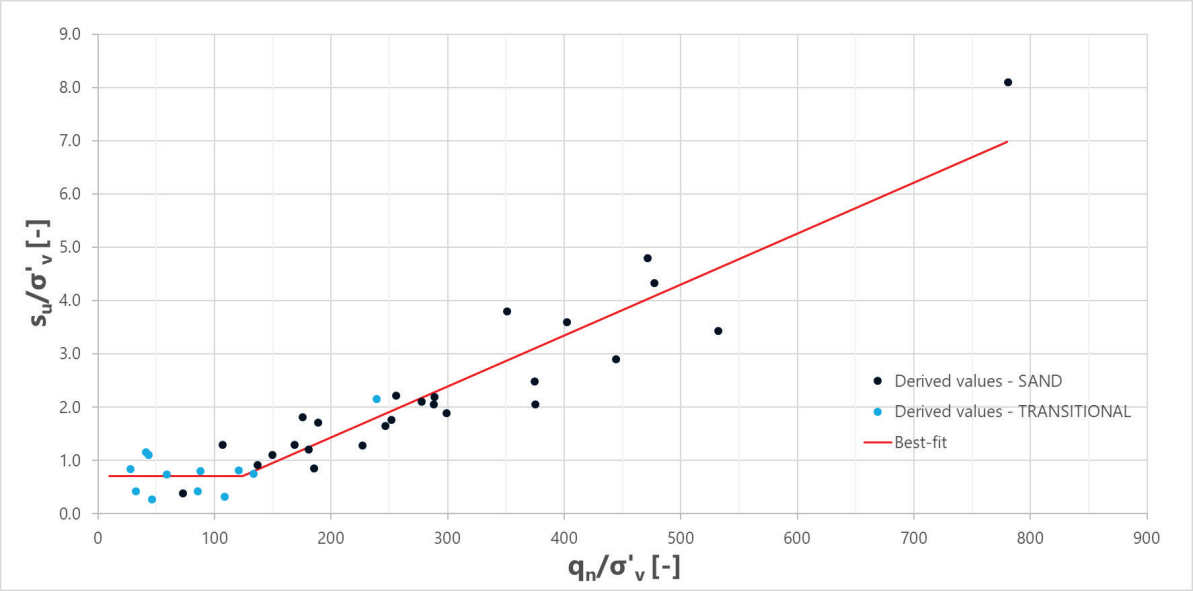
   - Factoring of exponent b to determine best-fit
   - Spread in distribution of soil unit-specific G_{max}
v. Application of soil unit-specific factoring
   - Global monopile behaviour
   - Statistical fitting uncertainties → 16 % fractile
vi. Checks for presence of clay layers
   - Consideration of clay CPT correlation: $G_{max} = 2.78 \cdot (q_c)^{1.335}$ (Mayne and Rix, 1993)

Design Profile $G_{max,k}$



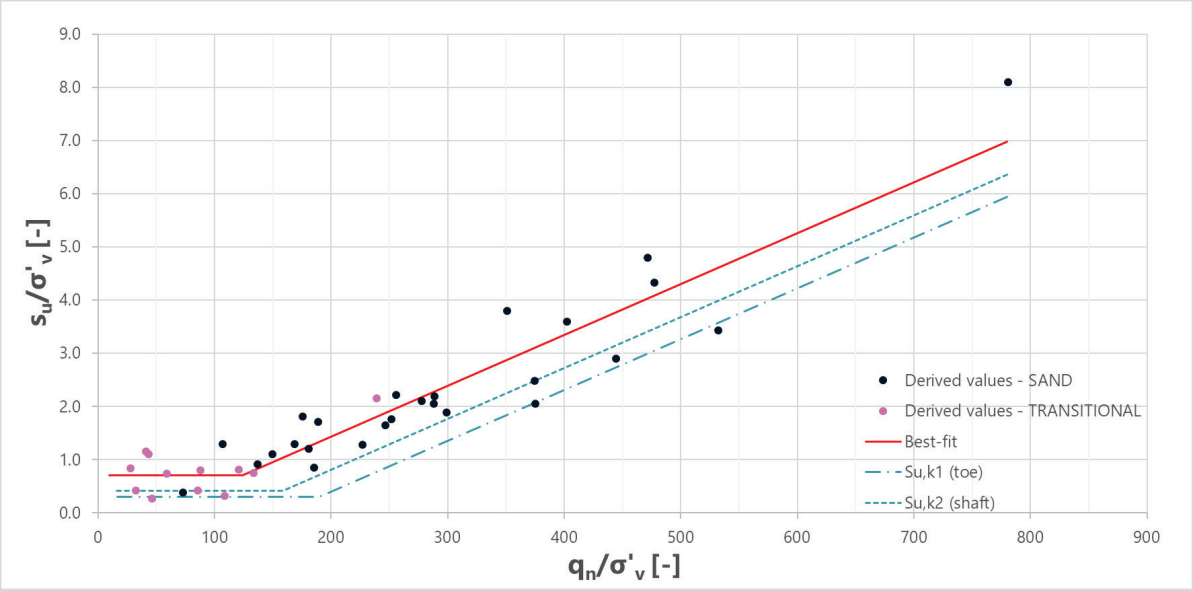
Undrained Shear Strength – Sand & Transitional soil

- Applicable to Calculation Models 1 & 2 (PISA methods)
- Reference method: Undrained TXC test



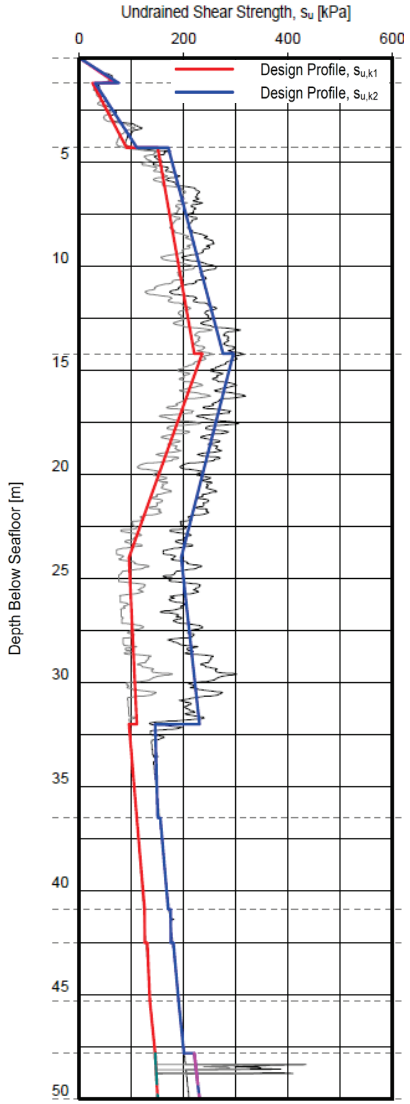
Undrained Shear Strength – Sand & Transitional soil

- Applicable to Calculation Models 1 & 2 (PISA methods)
- Reference method: Undrained TXC test
- Considering governing soil zone (shaft, toe)



$$s_u = \begin{cases} \alpha \cdot q_n + b \cdot \sigma'_{vo}, & for\ q_n/\sigma'_{v0} \geq A \\ c \cdot \sigma'_{vo} \quad , & for\ q_n/\sigma'_{v0} < A \end{cases}$$

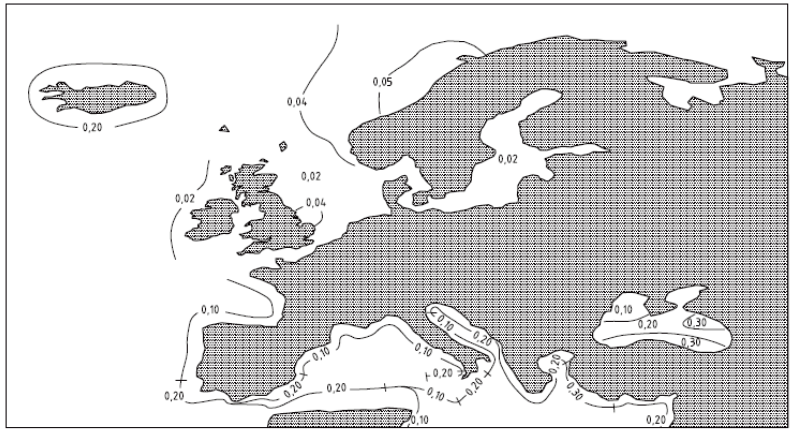
Profile	Fitting Parameters			
	a	b	c	A
Best-fit	0.0096	-0.4823	0.70	124
$s_{u,k1}$	0.0096	-1.5150	0.30	190
$s_{u,k2}$	0.0096	-1.0987	0.42	159



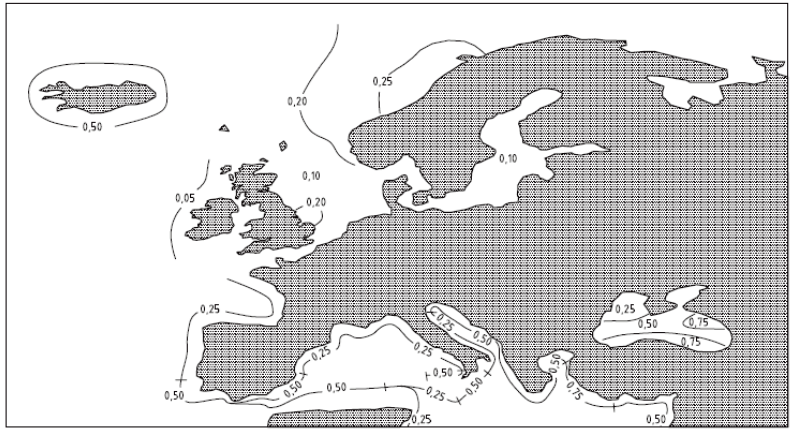
Seismic (Earthquake) Hazard Assessment

- Site-specific probabilistic seismic hazard analysis in accordance with ISO 19901-2:2017 and EC8
- Hazard model includes
  - 3 seismotectonic models
  - 5 ground-motion prediction equations
  - 200 samples for seismic activity parameters
- Micro-zonation analysis → representative v_{s30} = 300 m/s
- Seismic Risk Category 1 according to ISO 19901-2:2017

Design requirement	Return period [years]	Mean PGA [g]	Mean Sa(0.2s) [g]	Mean Sa(1.0s) [g]
"Damage limitation" (EC8)	95	0.0043	0.0107	0.0029
"No collapse" (EC8)	475	0.0171	0.0410	0.0121
ELE (ISO 19901-2)	624	0.0295	0.0689	0.0207
ALE (ISO 19901-2)	3000	0.0614	0.1372	0.0412



a) 1,0 s oscillator periods



b) 0,2 s oscillator periods

Microbiologically Influenced Corrosion

- Laboratory test programme covered 54 samples from 13 boreholes up to a depth of 51 m BSF
- Measurable microbial numbers at 78 % of samples
- Integrated approach providing corrosion rates in mm/year
  - for defined depth zones (exposure zones)
  - for exterior and interior of foundation piles
- Generally benign soil conditions at HKW WFZ

Exterior of Foundation					
Exposure Zone	Depth [m BSF]	Overall Corrosion Rate [mm/year]		Concentrated Corrosion Rate [mm/year]	
		LE	HE	LE	HE
AC-B	0 to 2	0.02	0.12	0.05	0.2
AC-A	0 to 2	0.02	0.12	0.3	0.4
SA-B	2 to 10	0.012	0.02	0.03	0.05
SA-A	2 to 10	0.02	0.06	0.3	0.4
ST-B	> 10	0	0.012	0	0.03
ST-A	> 10	0.02	0.06	0.3	0.4
Interior of Foundation					
ST-B	0 to 1	0.012	0.12	0.03	0.2
ST-B	> 1	0	0.012	0	0.03
ST-A	> 0	0.02	0.06	0.3	0.4

Geotechnical Parameters Report

Key benefits to designers:

- Improves geotechnical understanding of the HKW site
- Reduces design timeline, duplication of efforts and project risk
  - Design basis for geotechnical foundation design
  - Design profiles for concept design
  - Site-specific correlations for characteristic parameter values
  - Identification of key considerations for future design phases

DNV GL comment on the report:

This Geotechnical Parameter report is considered as 'cutting edge', defining a new baseline for offshore wind farm tender preparations


DNV·GL

HOLLANDSE KUST (WEST) WIND FARM ZONE

Certification Report
Geotechnical parameters

Netherlands Enterprise Agency

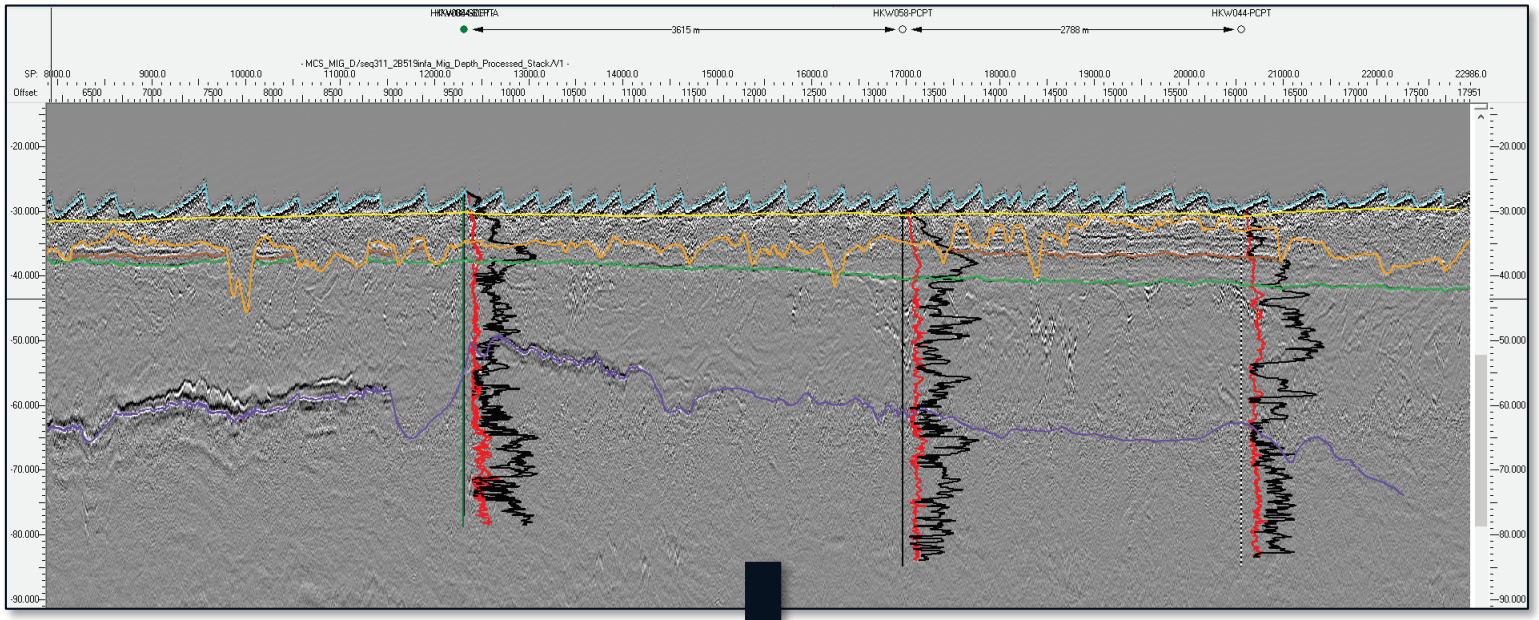
Report No.: CR-SC-DNVGL-SE-0190-05500-0 Geotechnical Parameters (HKW) Rev.1
Date: 2020-10-20

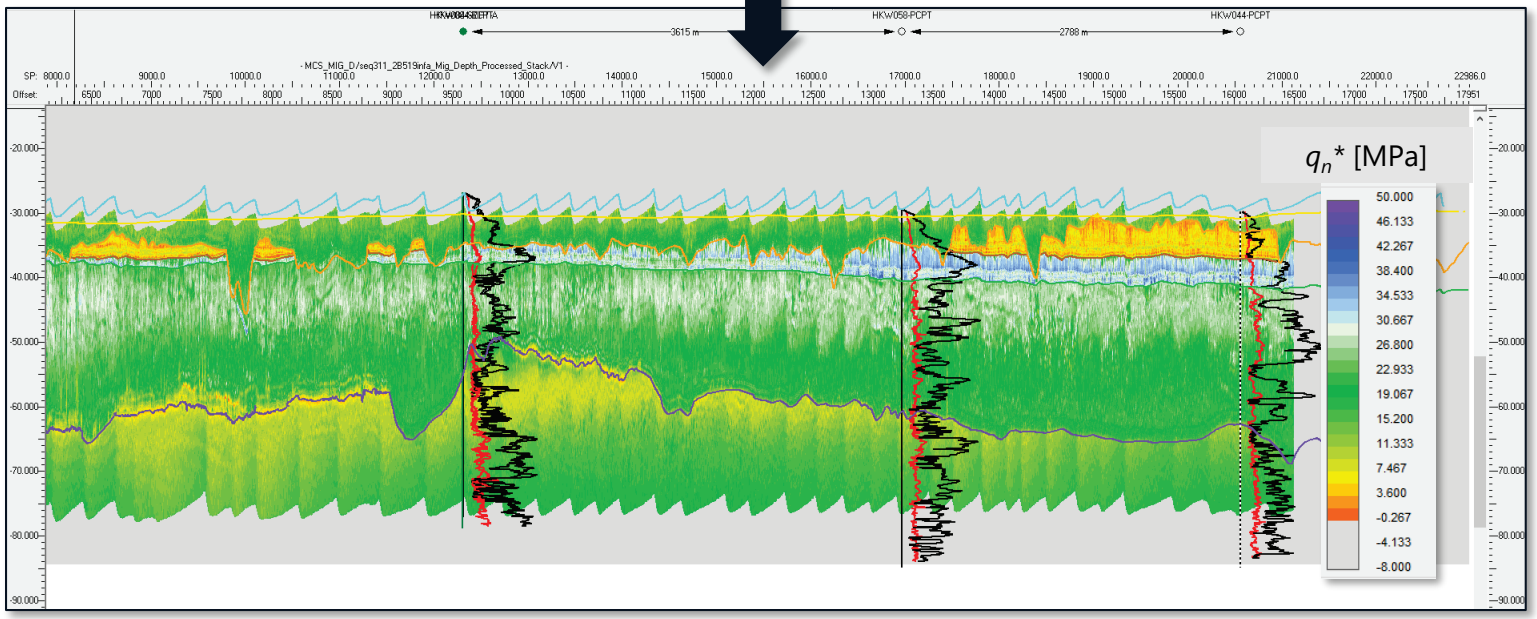
04

Synthetic CPT Profiles

Synthetic CPTs

- Predicted CPT parameters q_c, q_t, q_n ($q_n{}^*$)
- Innovative approach with aim to **add geotechnical value to information package for tenderers**





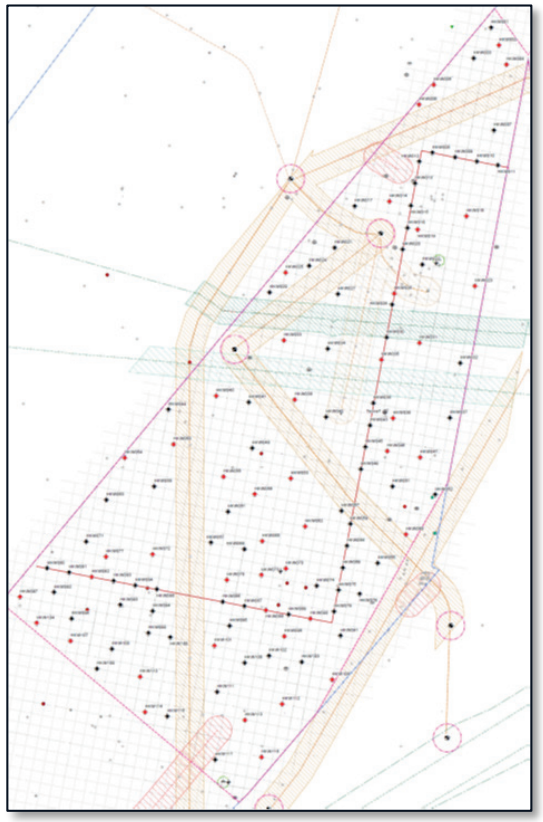
FUGRO

TNO innovation for life

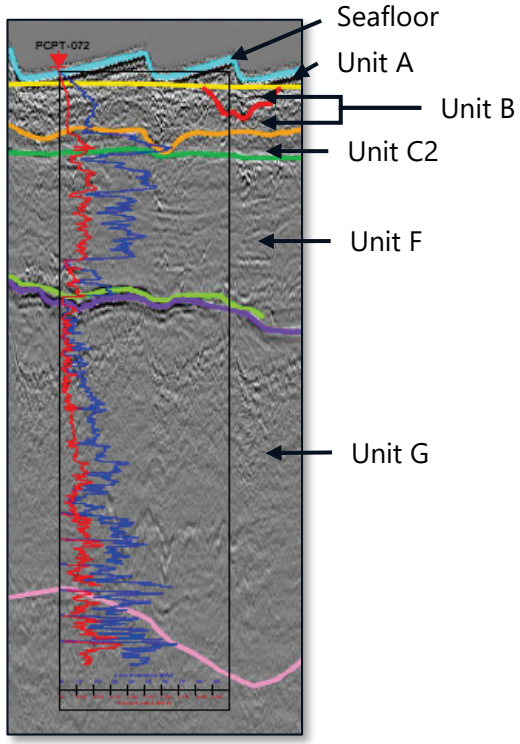
TU Delft Delft University of Technology

Fundamental features

Seafloor based CPTs
2D UHR MSC lines



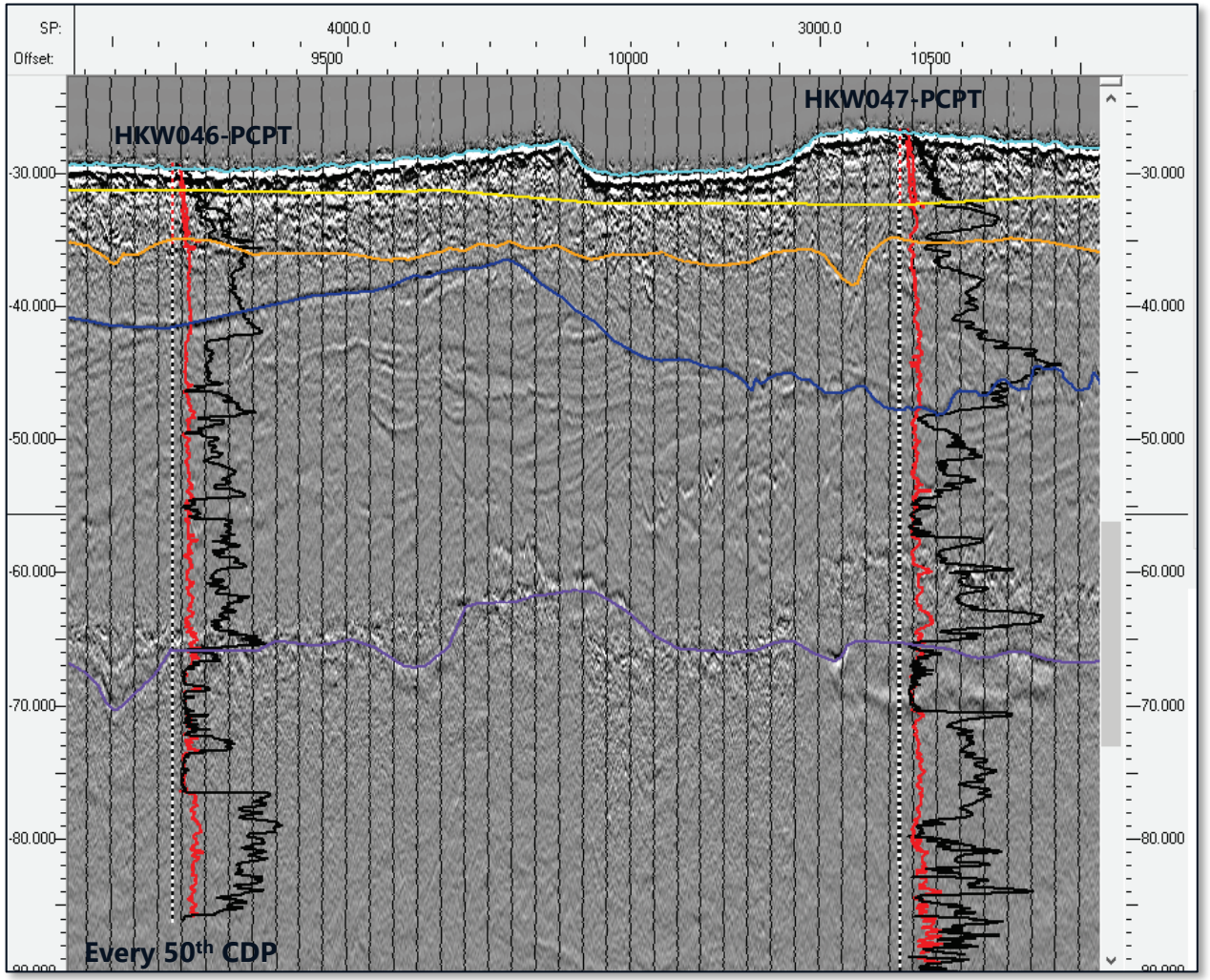
Connection to geological
ground model

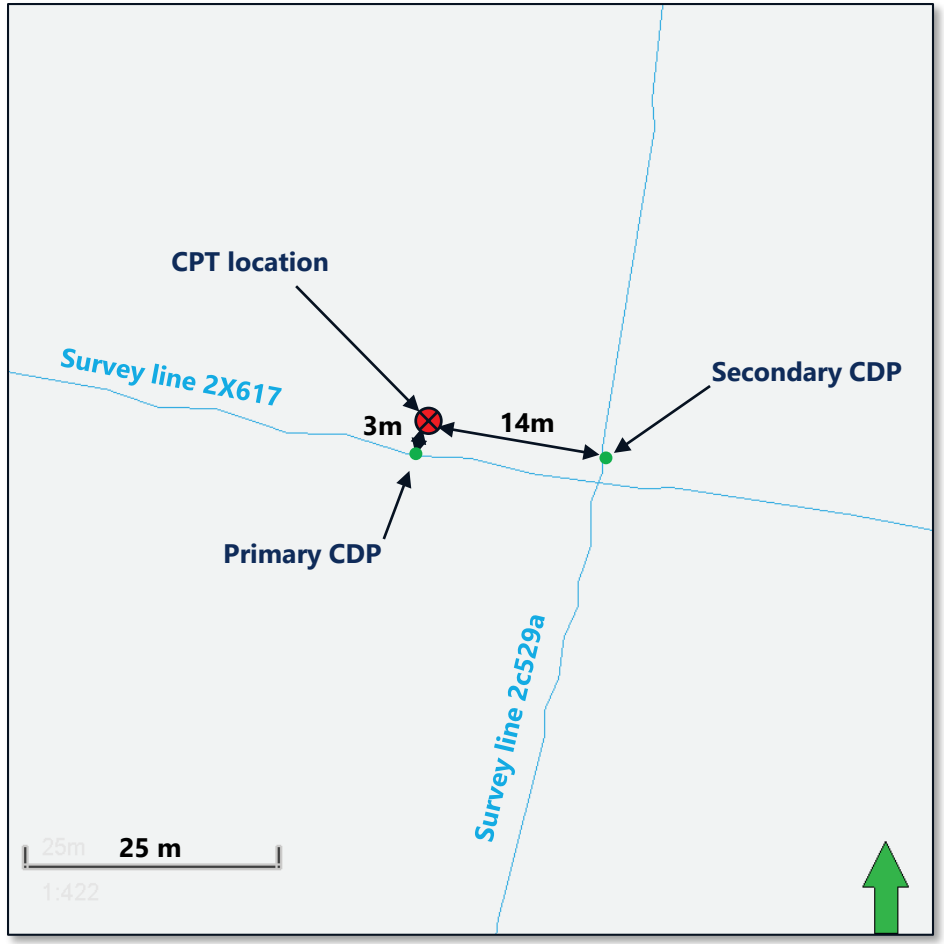


Depth range of interest
(2 to 50 m BSF)

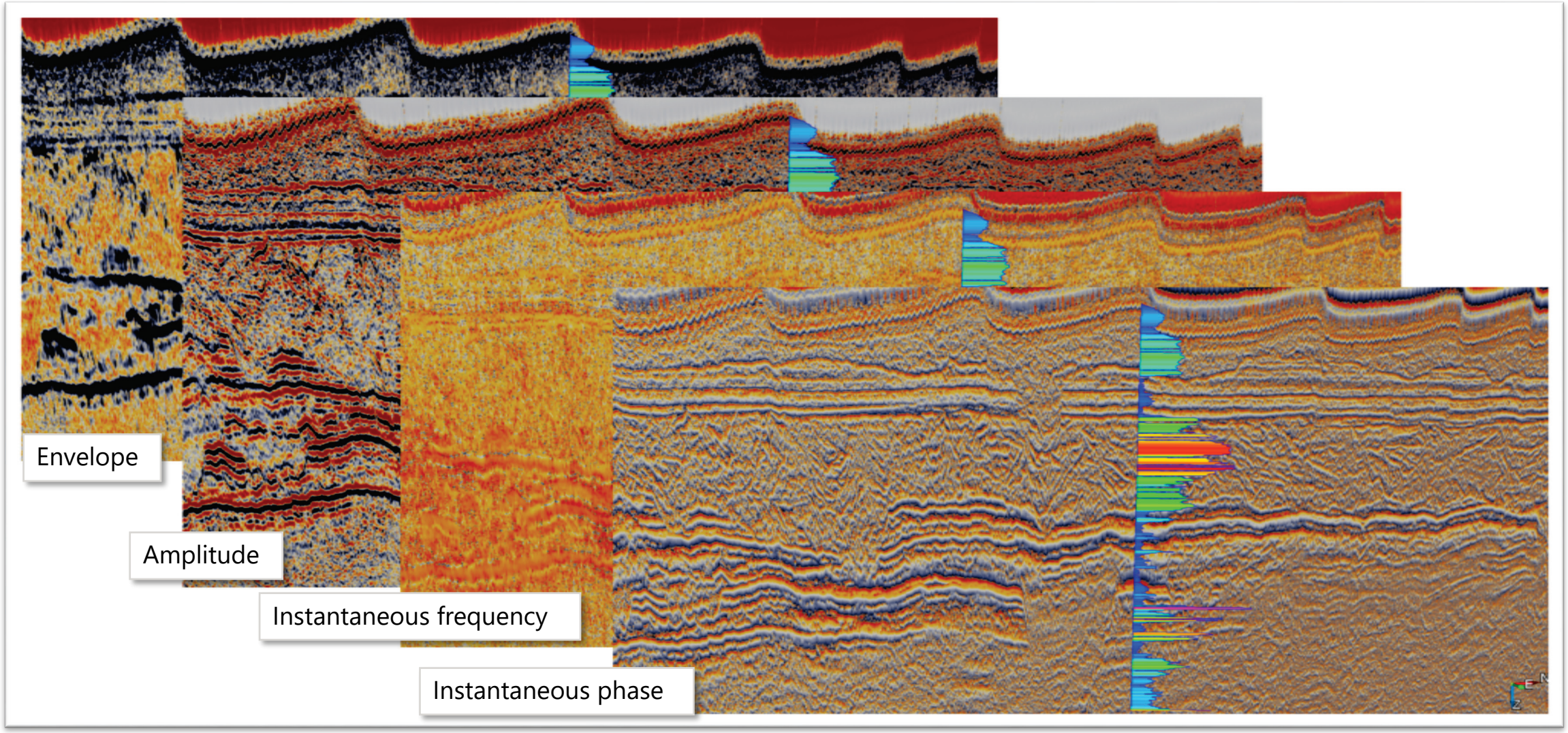
- Corresponds roughly to expected depth range for monopiles and jacket piles
- Exclusion 0 to 2m BSF: subject to seafloor mobility

CPT and UHR seismic reflection data





Seismic attributes

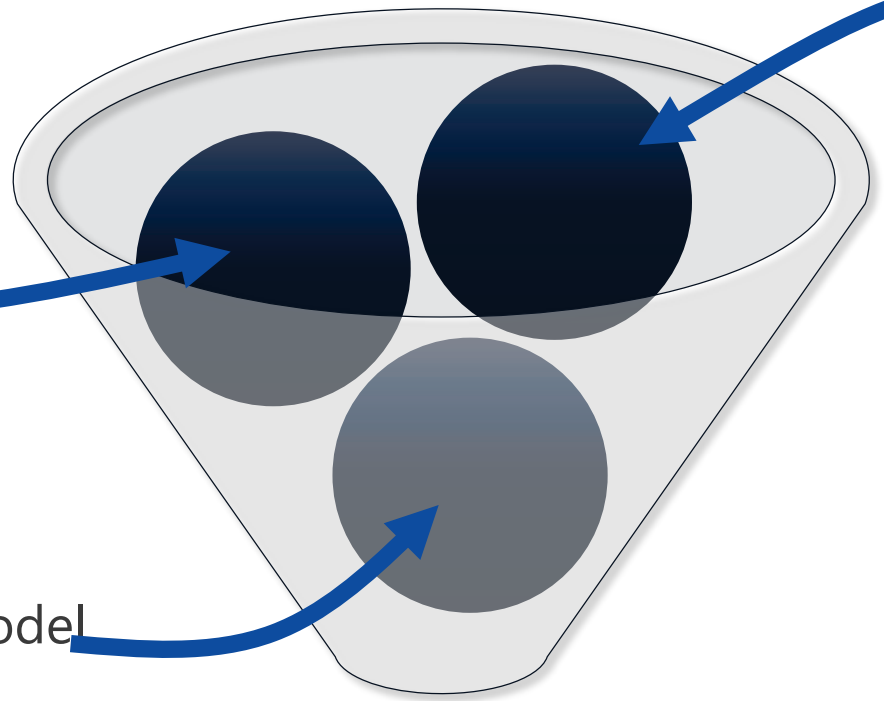


Synthetic CPT prediction

Machine Learning Model

122 Seafloor CPTs

- $q_n{}^*$



162 UHR MCS lines:

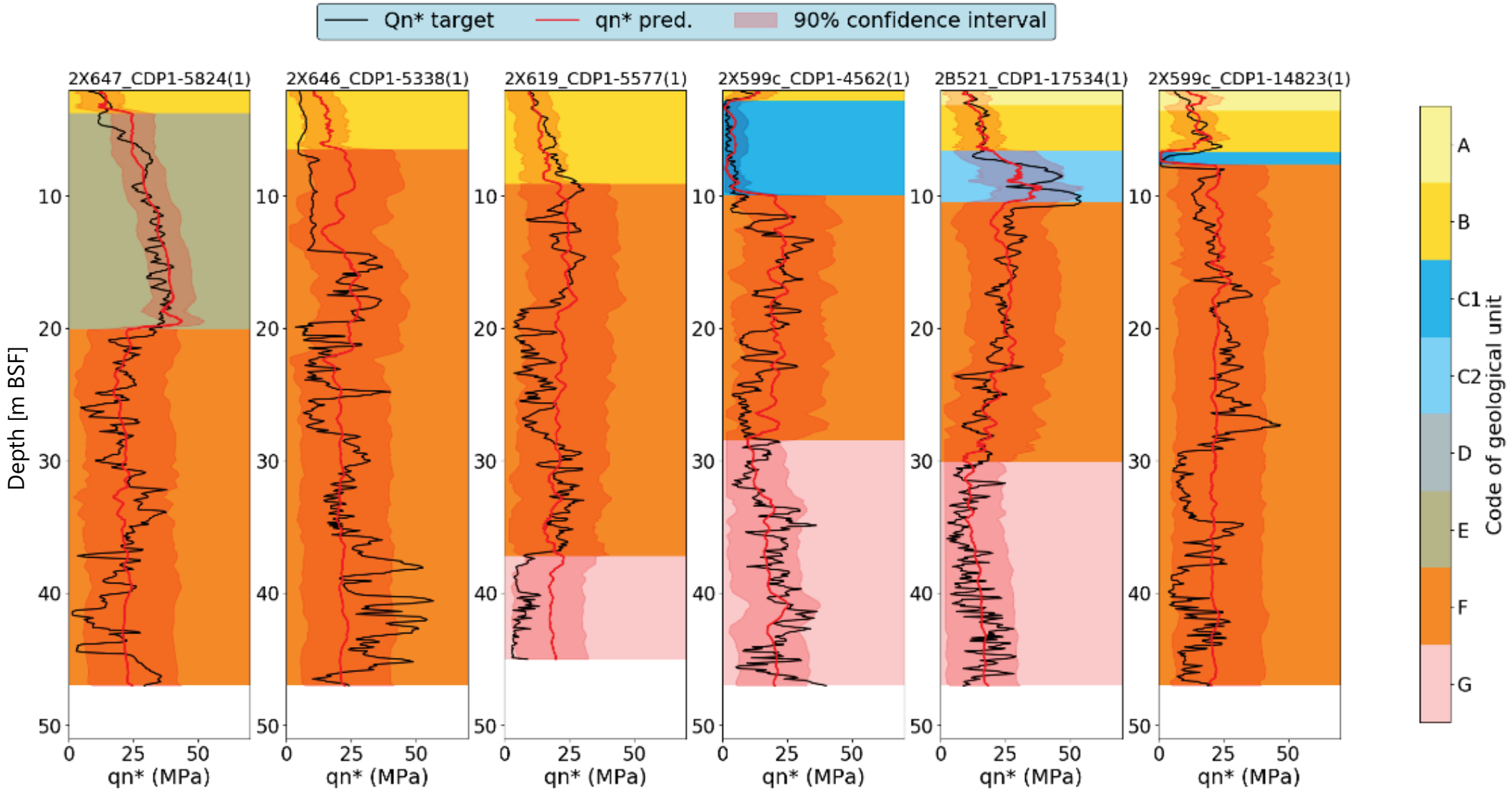
- 7-point average of seismic interval velocity
- 7-point average of seismic instantaneous amplitude (envelope)
- 7-point average of seismic model-based impedance

Information from ground model

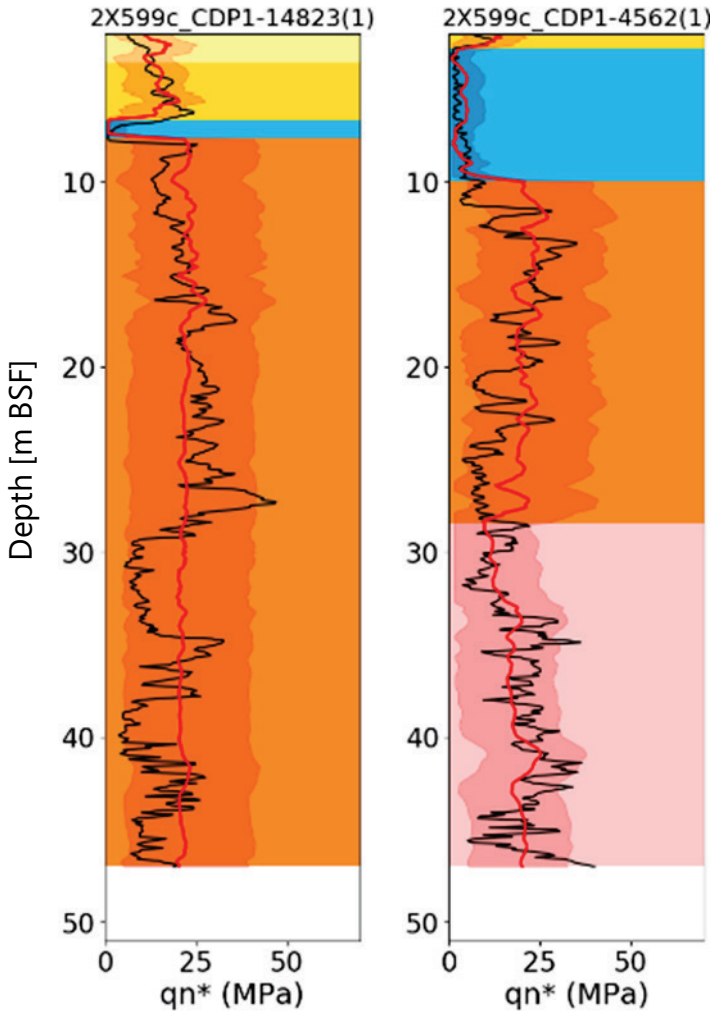
- Geological units
- Geotechnical units
- Depth

Predicted CPT parameter $q_n{}^*$ at all CDPs

Prediction results



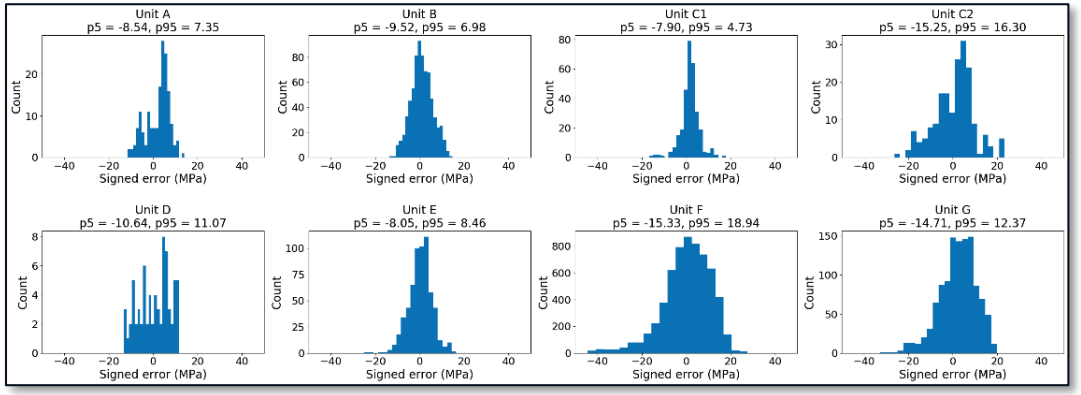
Accuracy



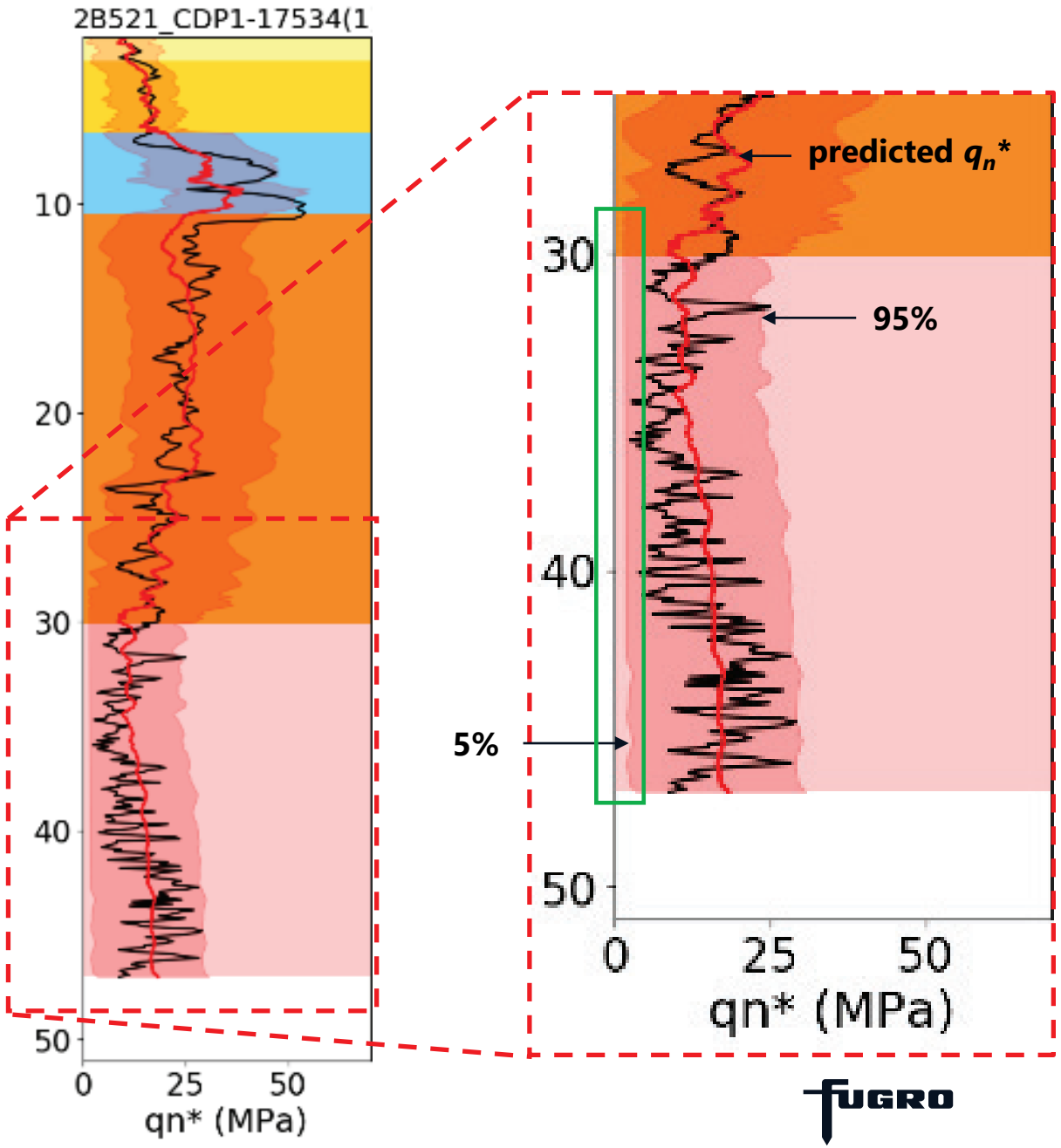
- Data point spacing of 0.1m (synthetic CPT) versus 0.02m (regular CPT) – less detailed information
- Reasonably good CPT prediction for upper 20m BSF
- Trend-type prediction for CPT profiles below 20m BSF including water-depth multiple
- Trend-type prediction applies to transitional and strongly layered (<1m scale) soil, as expected
- Model training affected by lateral distance between CPT and nearest UHR MCS data

Quality Indicators

- Confidence interval per geological unit: lower and upper limits associated with the synthetic CPT prediction; interval in which predictions are likely to fall (90% probability)

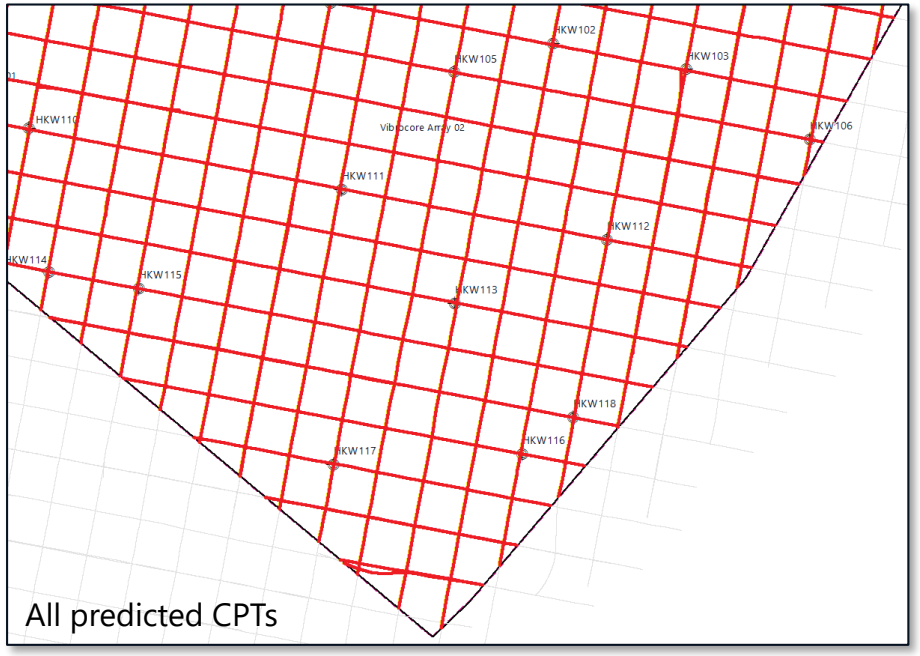


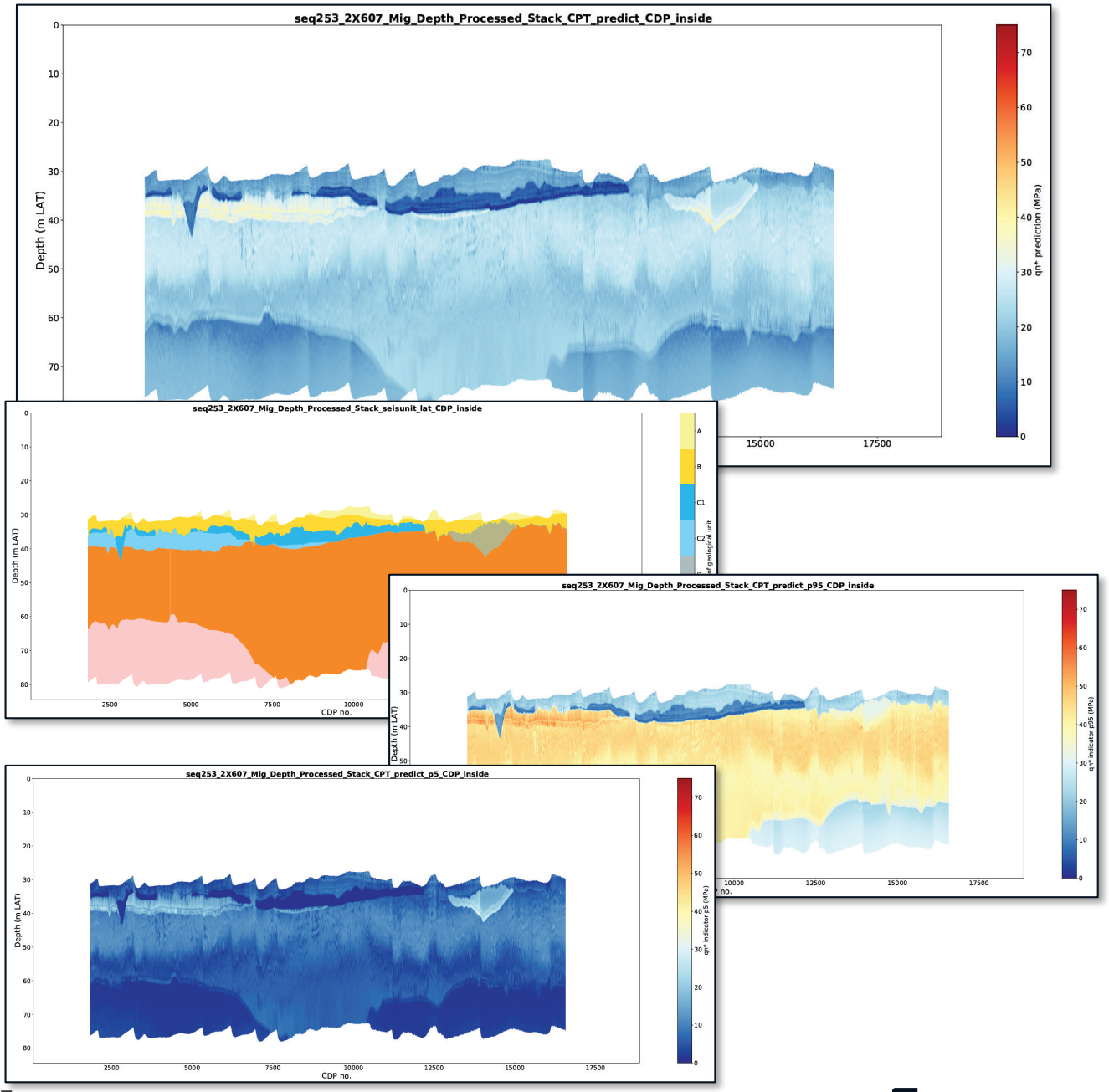
- The quality indicator can provide statistical values for q_n* that fall outside of credible ranges



Deliverables

- One predicted CPT at each CDP:
  ~ 1 500 000 CPTs
- Spacing between predicted CPTs:
  ~ 0.8 m along geophysical lines





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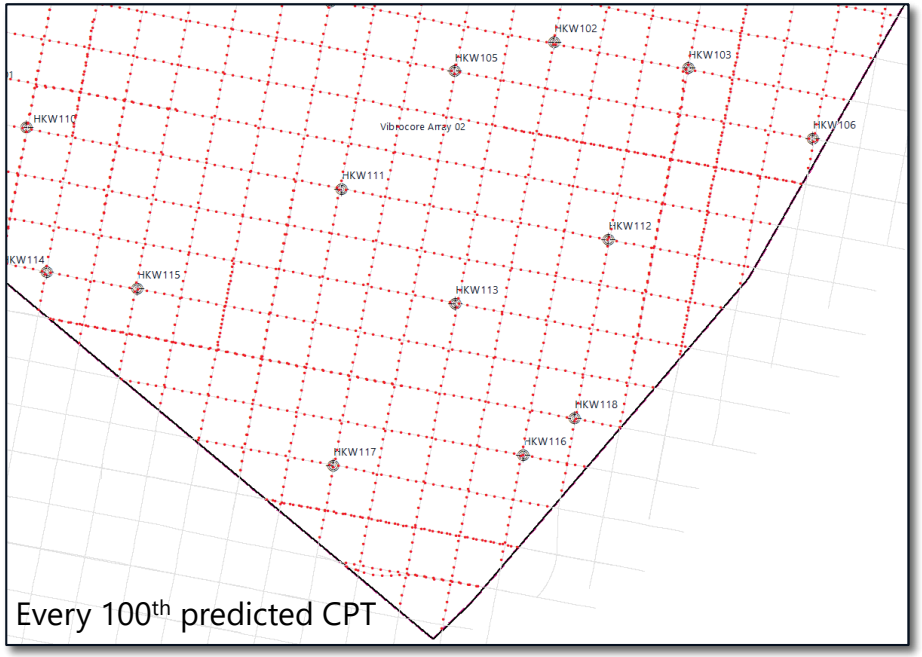
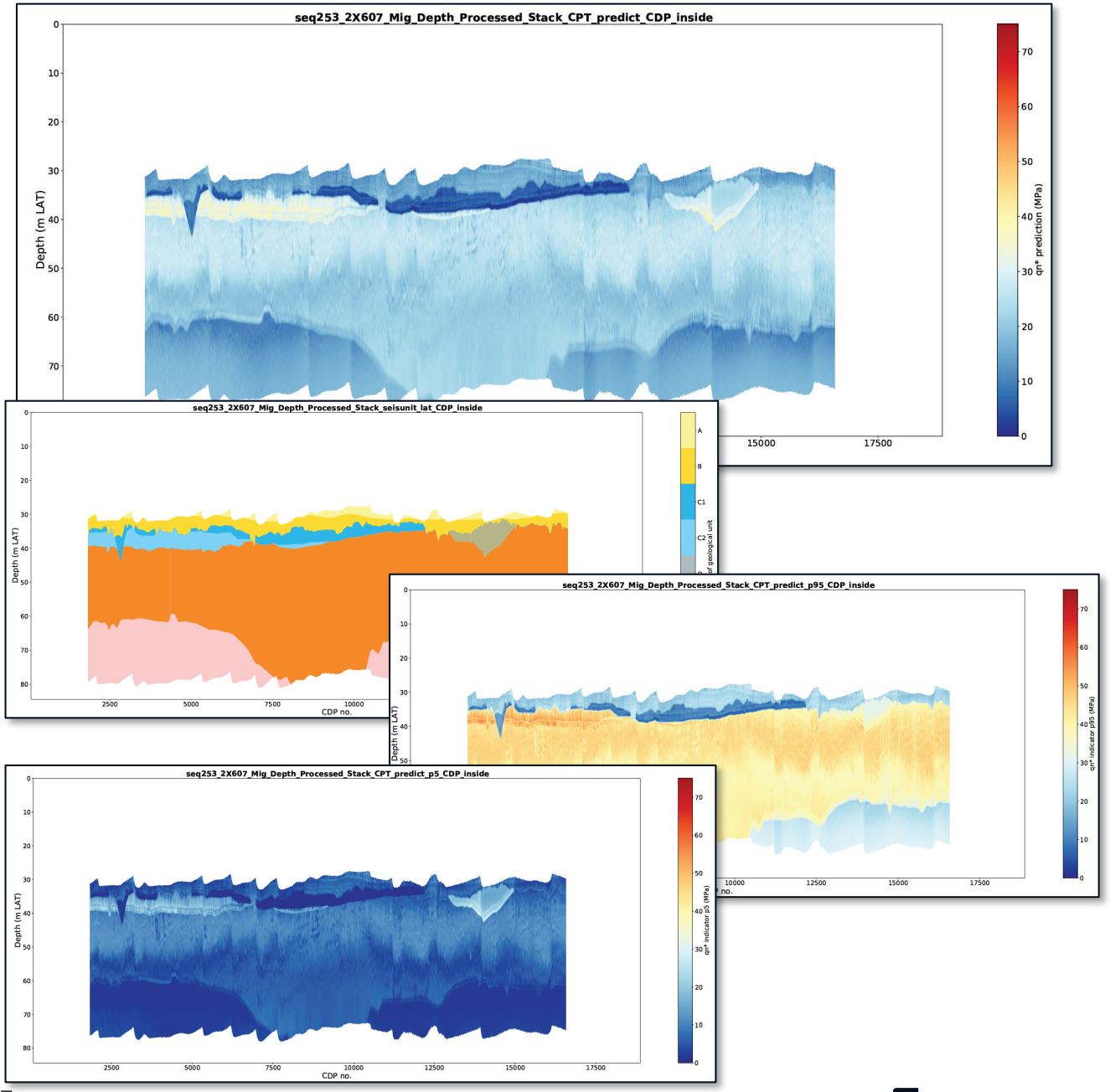
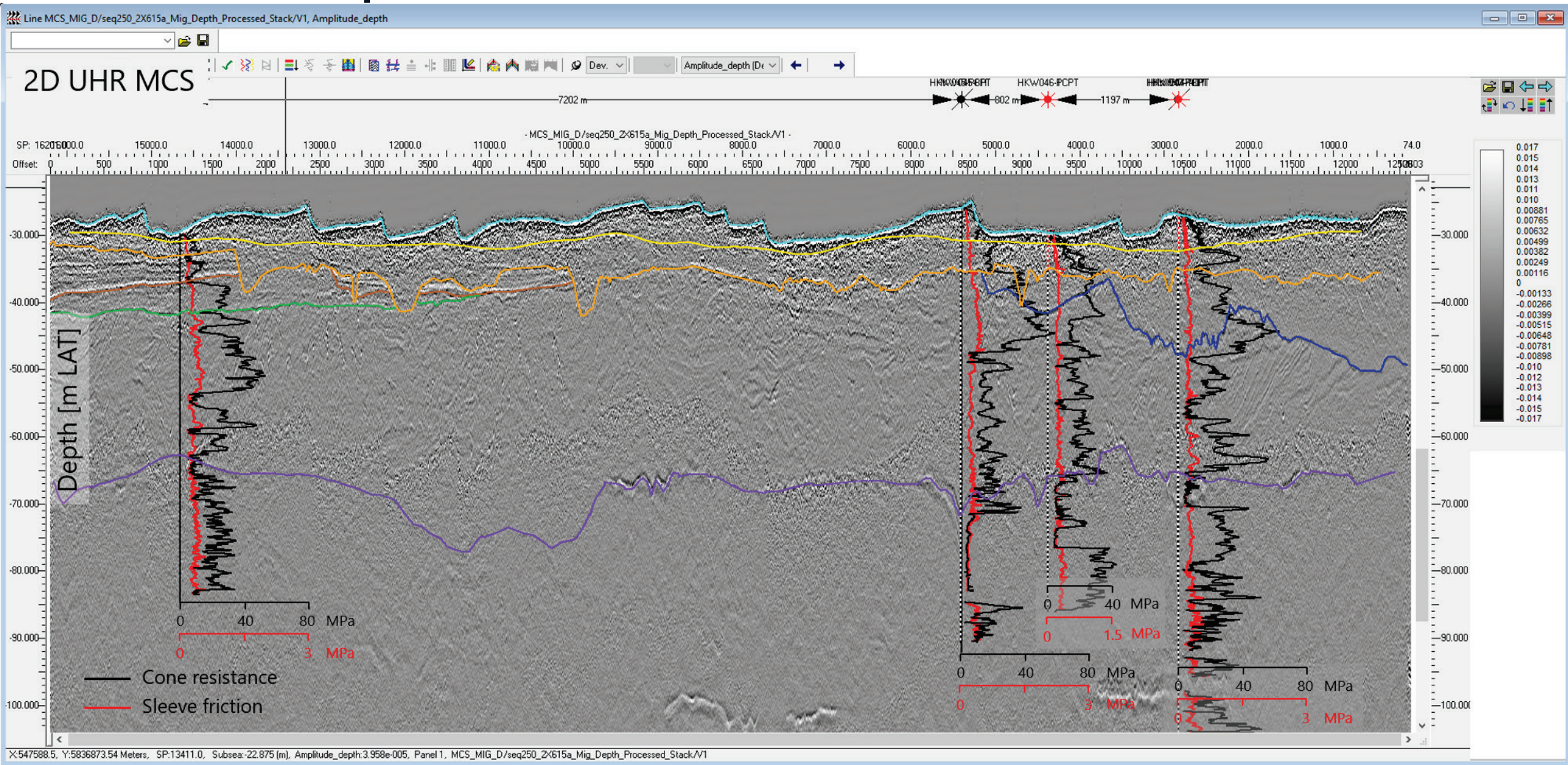
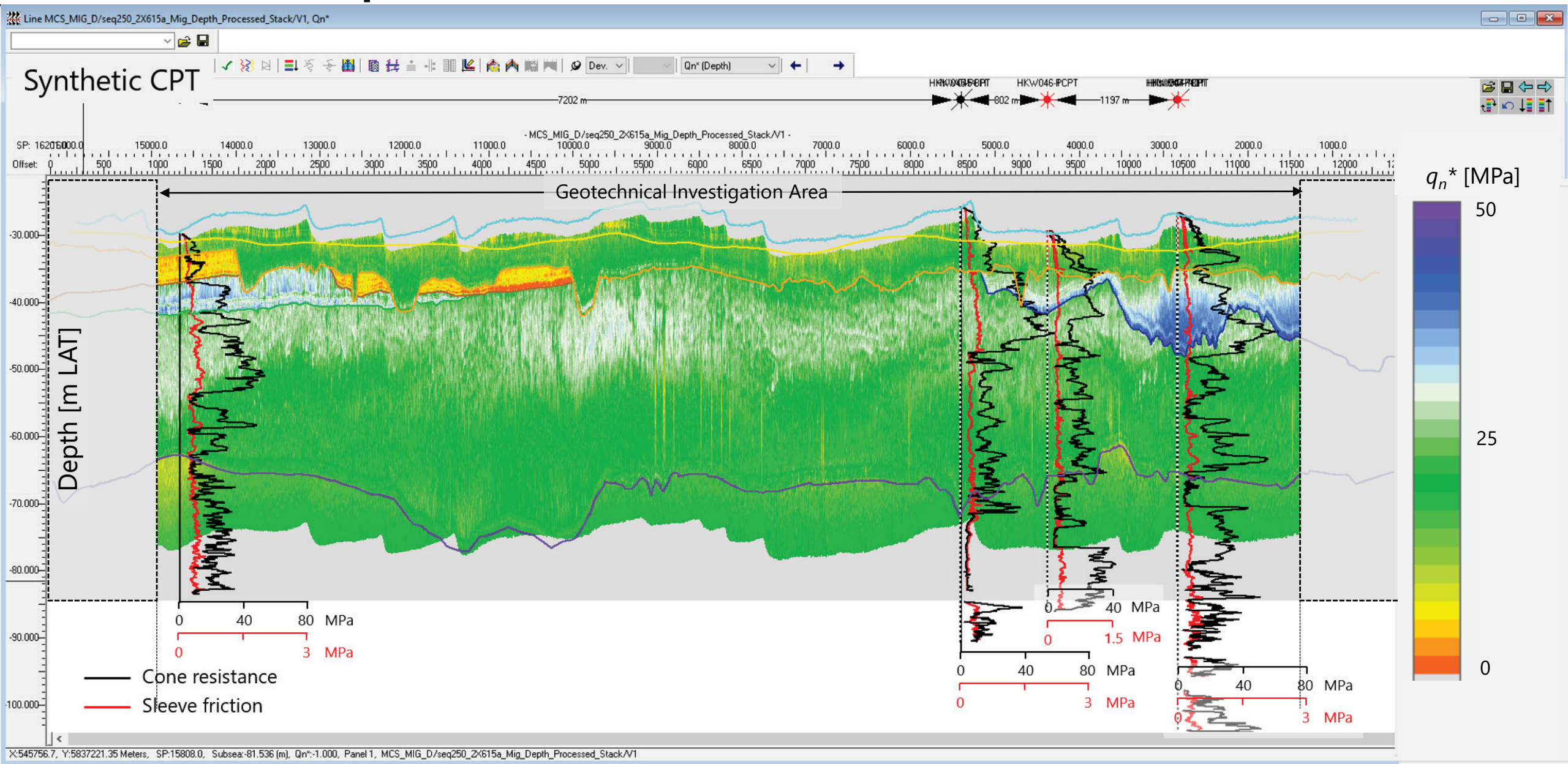




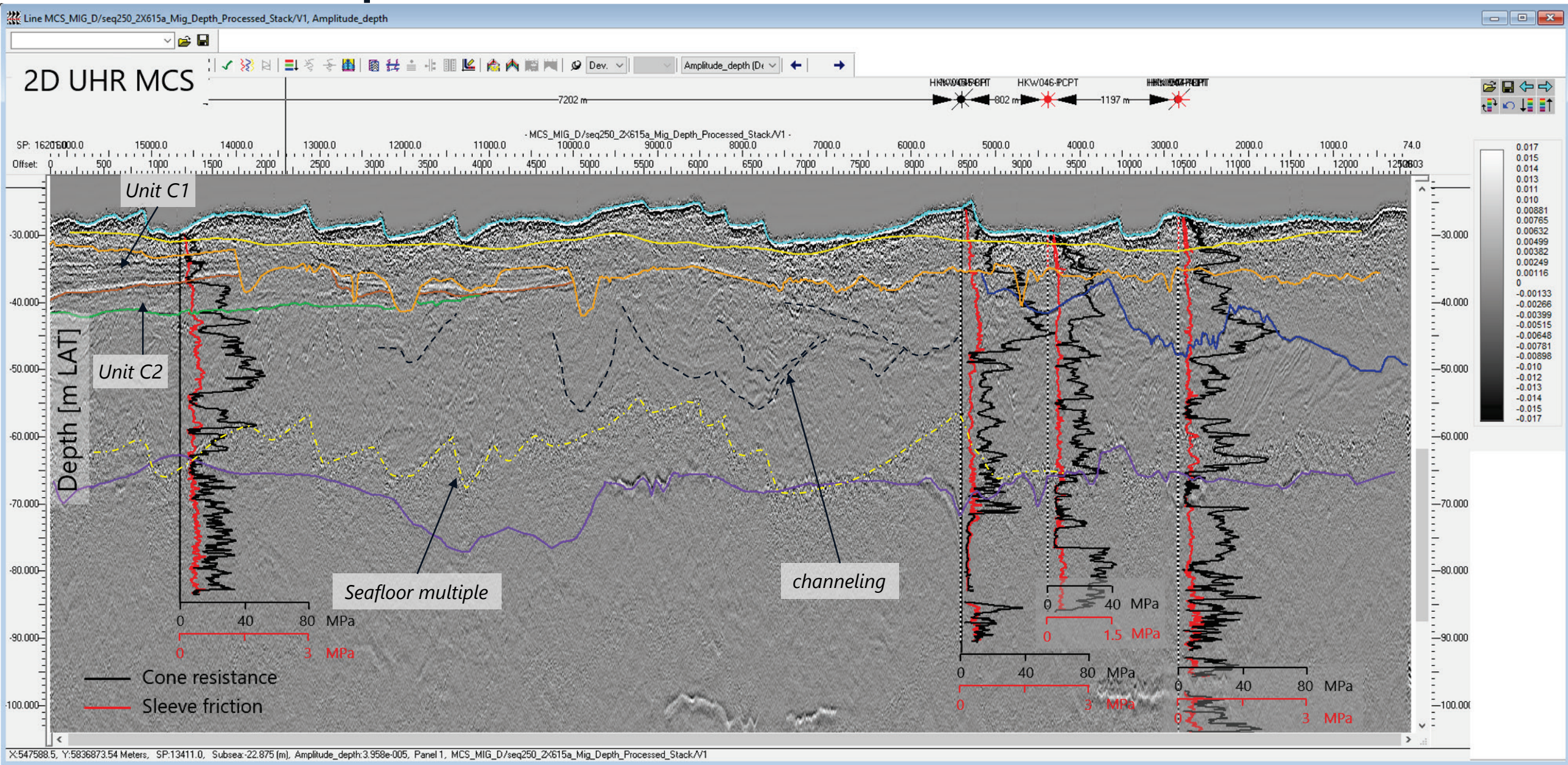
Data Example



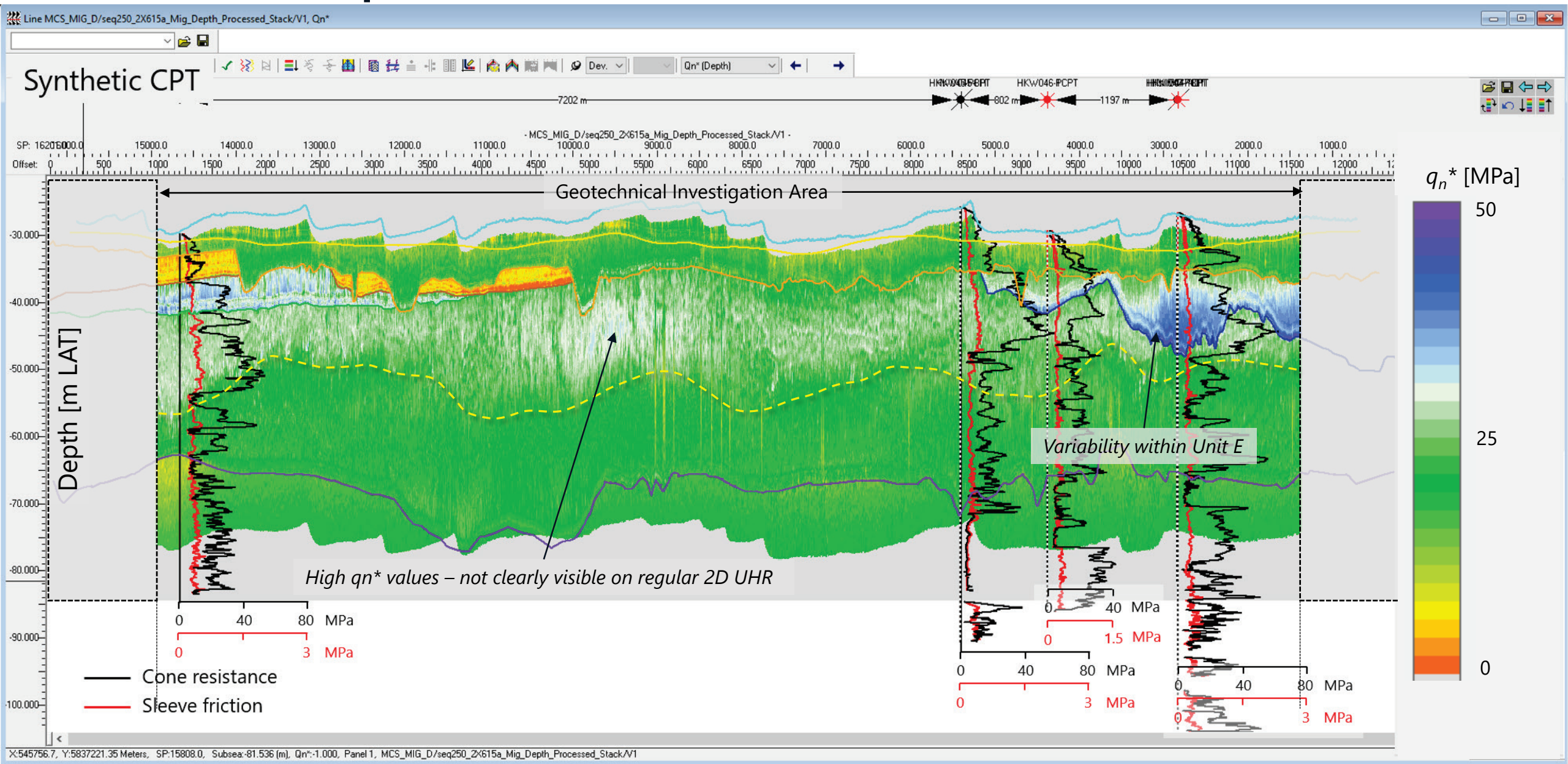
Data Example



Data Example



Data Example



Synthetic CPT Profiles

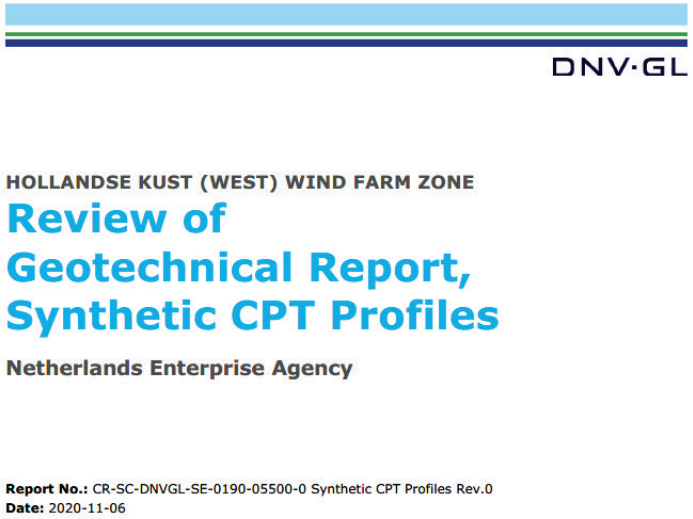
Key benefits to designers:

- Improves geotechnical understanding of the HKW site
- Provides cone resistance estimates along 2D UHR seismic lines
- Identifies areas where possibly more geotechnical data are required
- Potentially refines existing geological ground model
- Potentially fills geotechnical data gaps using seismic data (e.g. wind turbine locations where limited geotechnical data are available)

DNV GL comment on the report:

A cutting-edge development and a huge step forward in terms of project area overview with respect to geotechnical site conditions and also as a valuable tool to improve and understand the correlation between future geological, geophysical and geotechnical investigations.

The synthetic CPT profiles can be used as background information to support design basis for design of future offshore wind turbines.


DNV·GL

HOLLANDSE KUST (WEST) WIND FARM ZONE

Review of Geotechnical Report, Synthetic CPT Profiles

Netherlands Enterprise Agency

Report No.: CR-SC-DNVGL-SE-0190-05500-0 Synthetic CPT Profiles Rev.0
Date: 2020-11-06

05

Concluding Remarks

Concluding Remarks

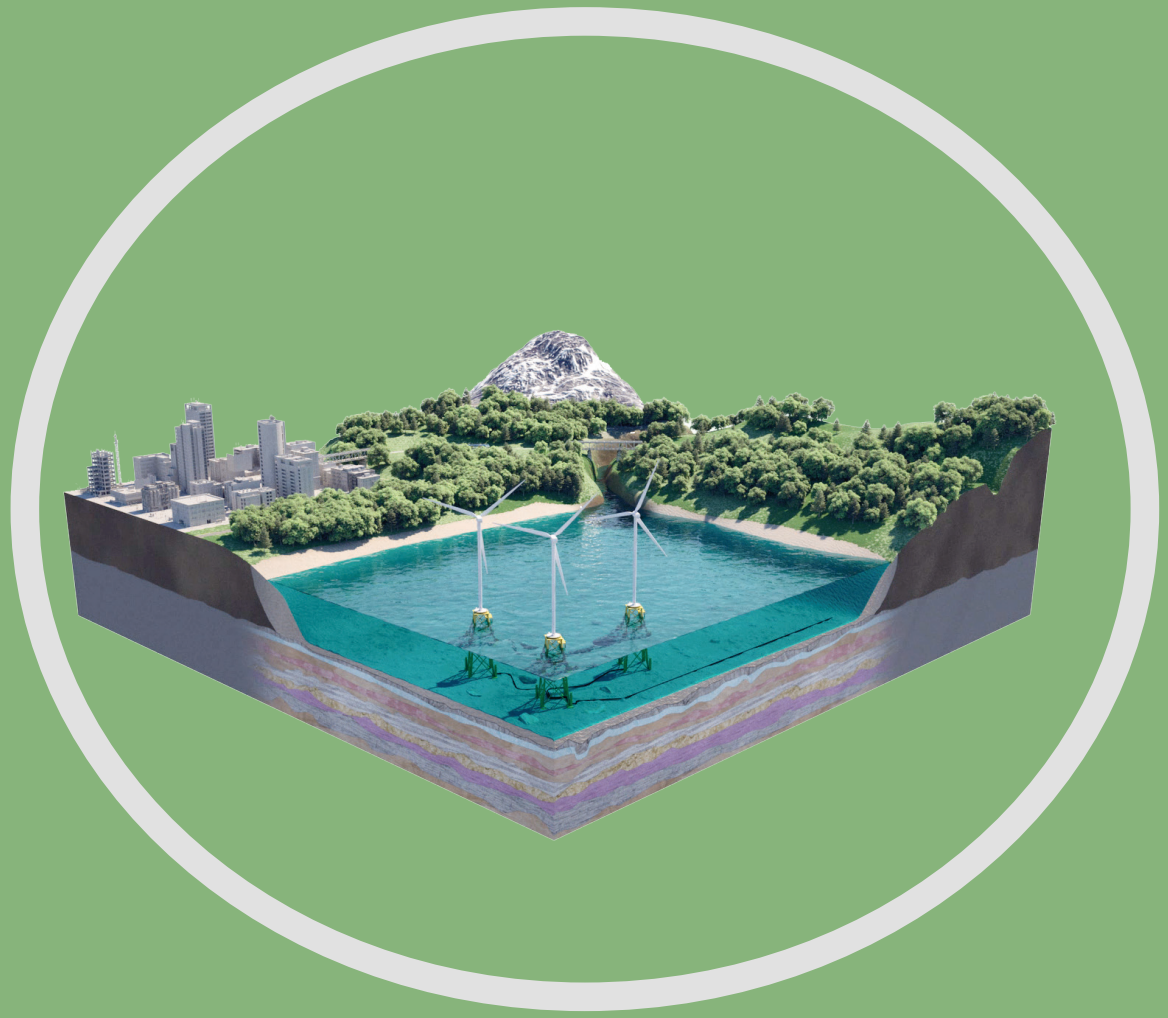
- Acquired data comprise geophysical data, geotechnical data and soil thermal properties, particularly CPTs and laboratory test data
- Detailed 3D ground model is based on integrated interpretation of geophysical, geological and geotechnical data
- Ground model includes soil provinces: delineation of a spatial zone within which geotechnical characteristics within a depth range of interest are similar
- Design profiles cover characteristic values of geotechnical parameters for concept foundation design
- Synthetic CPTs provided for ~1.5 million locations by means of a machine learning approach

Concluding Remarks

Reports and digital deliverables provide the following for end users:

- A robust and reliable data set which covers the full site, and which can be used for optimizing preliminary OWF design and assist in fine-tuning of development costing
- Additional (physical) sample material which can directly be used for any additional laboratory tests, if required
- Possible minimization of additional site investigation requirements, in most cases limited to additional cone penetration testing for verification purposes
- Overall de-risking of ground conditions

Together we create a safe and liveable world



Thank you

k.kaltekis@fugro.com
m.murali@fugro.com
w.vankesteren@fugro.com
www.fugro.com

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Netherlands Enterprise Agency

Closing the webinar

- Please fill in the questionnaire (appears after last slide)
- Deliverables, this webinar and Q&A at https://offshorewind.rvo.nl

Thank you for participating in this webinar!

Webinars Hollandse Kust (west) Wind Farm Zone on https://offshorewind.rvo.nl