Wind farm zone Borssele
Geotechnical Investigations WFS I & II
10th June 2015

Rein de Wolff– BLIX Consultancy

Rijksdienst voor Ondernemend Nederland

Scope of Work

- **Generic Scope**
  - Alternating Borehole / PCPT's (target depth 50m - 80m)
  - Seabed PCPT's using bottom mounted PCPT unit with 20t thrust
  - Laboratory testing on relevant parameters

- **Deliverables**
  - Factual Borehole and lab testing report
  - Factual Seabed PCPT results report
  - Geological Ground model report
  - Advanced Static and Cyclic testing report

Source: Fugro Engineers

RVO.nl team

Responsible:

Rijksdienst voor Ondernemend Nederland

Project Management:

BLIX hands-on experience in wind energy

Geotechnical advisor

WINDSUPPORT

Offshore reps. / geotech. advisor

RPS Energy

Certification

DNV·GL

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Planning

March/April 2015:	Preparation Project Documentation/ Mobilization √
April/May 2015:	Execution Borehole/downhole PCPT campaign √
April/May 2015:	Execution Seabed PCPT campaign √
May/June 2015:	Lab testing/Reporting √
June/July 2015:	Review/Certification of report

Reports planned to be published end of July/ beginning of August, subject to certification

Advanced lab testing results will follow after provision final report

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Thank you for your attention

- More information: English.rvo.nl/offshore-wind-energy

- Questions:
  - woz@rvo.nl
  - Ruud de Bruijne, RVO.nl
  - Rein de Wolff, BLIX Consultancy

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Fugro Geotechnical Investigation Campaign Borssele – WFSI&II

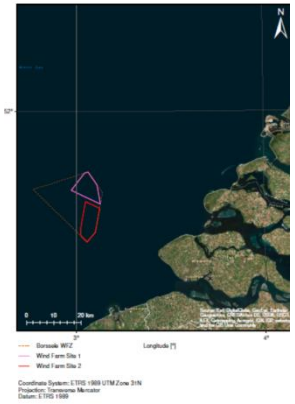
Workshop ‘Tender Borssele’, 10 June 2015, Martijn Klein (Fugro)

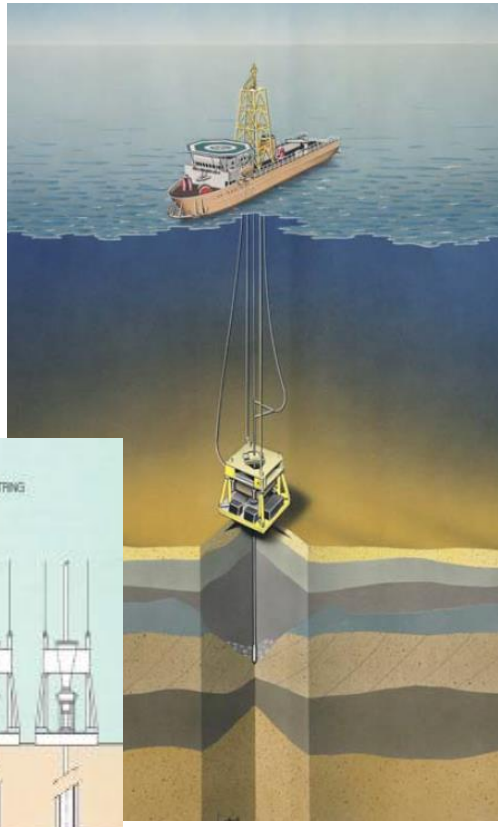
Table of Contents

Geotechnical Site Investigation – Overview

Purpose of the Geotechnical Site Investigation:

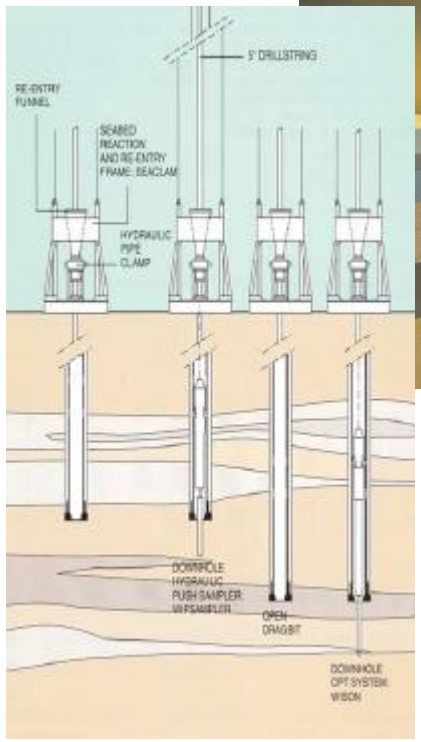
- Confirm the geological & geophysical model
- Determine vertical and lateral variation in seabed conditions
- Provide relevant geotechnical data for design, including foundations and cables
- Update geological desk study and provide geological model





Overview of Geotechnical Site Investigation:

- According to ISO 19901-8 (2014) Marine Soil Investigations
- Fieldwork campaign from 10 April to 26 May 2015 with MV Bucentaur and MV Fugro Commander
- Geotechnical borehole drilling, downhole sampling, downhole in situ testing and seafloor in situ testing
- In-office laboratory test programme completed
- Investigation Data and Geological Ground Model Reports submitted as drafts to RVO
- Advanced static and cyclic laboratory test programme ongoing



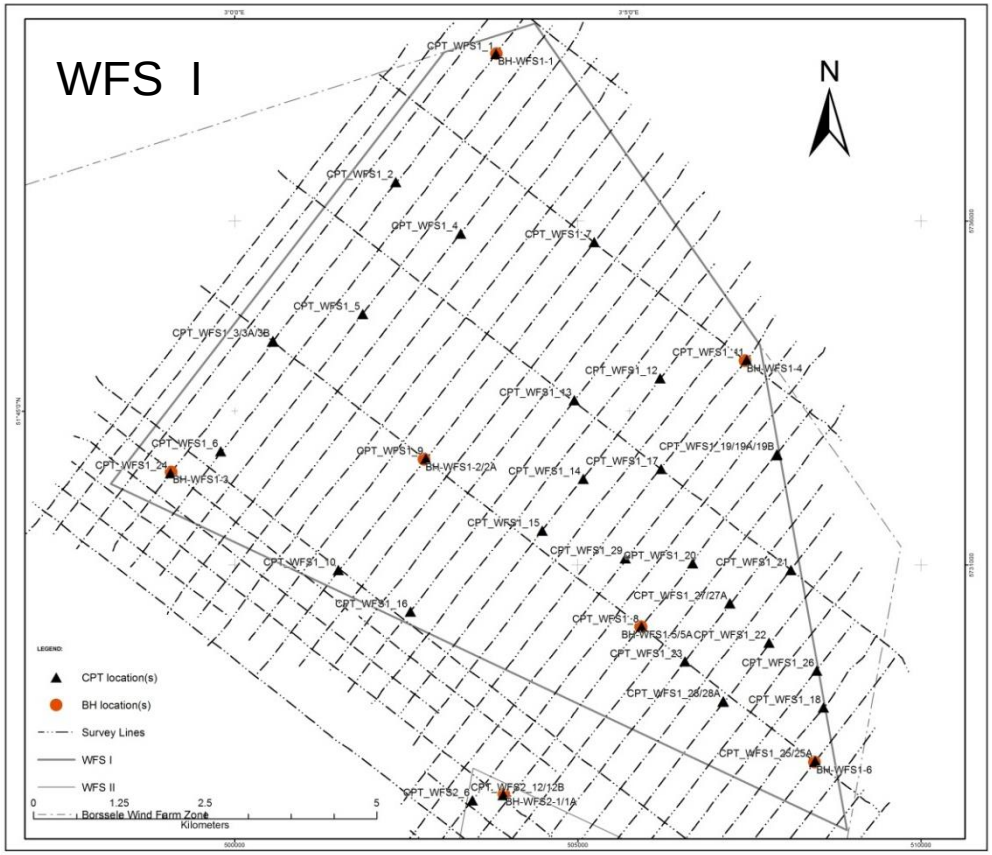
Geotechnical Site Investigation – Investigation Points

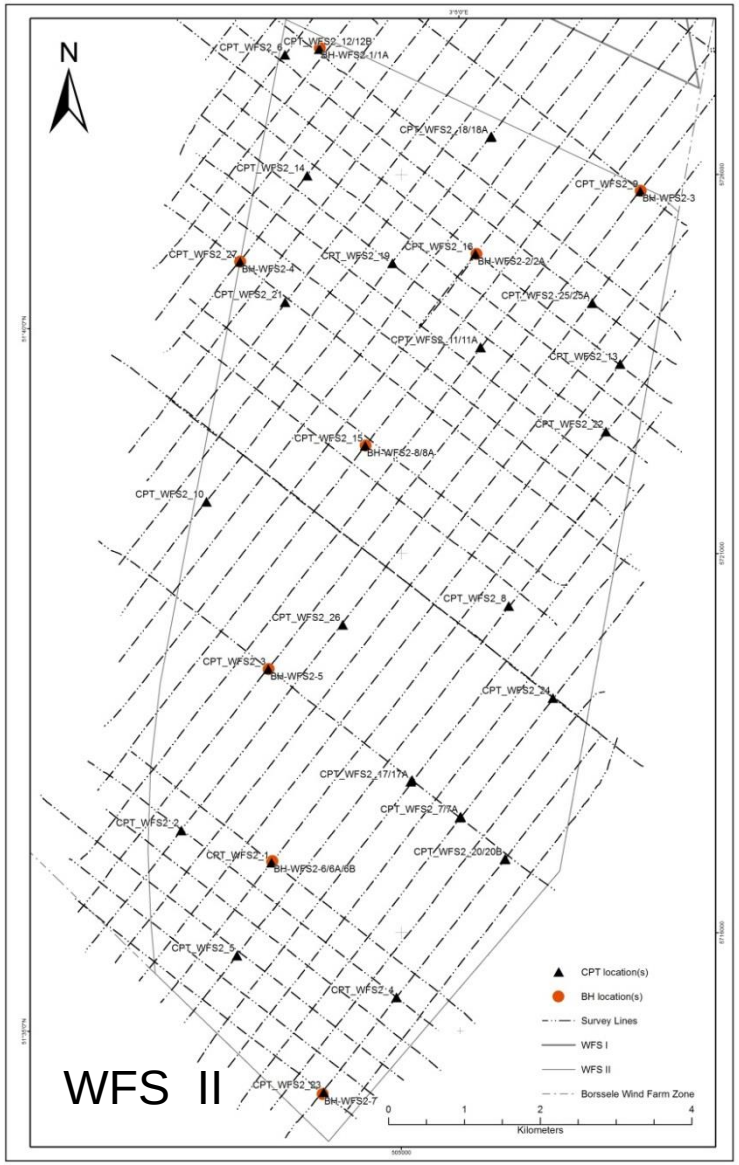
WFSI

- 6 borehole locations, downhole sampling and in situ testing
- 29 seafloor in situ test locations

WFSII

- 8 borehole locations, downhole sampling and in situ testing
- 27 seafloor in situ test locations





Geotechnical Site Investigation – Overview Available Information

Geotechnical logs for borehole locations and seafloor Cone Penetration Test (CPT) locations

- Interpretation of soil profile, strata description and CPT derived relative density and shear strength
- Selected results of laboratory tests

Results of Piezo- and Seismic CPT and Pore Pressure Dissipation tests

- Cone resistance (net/total), sleeve friction, pore pressure, friction ratio and pore pressure ratio
- Recorded shear waves (X&Y) and derived shear wave velocity
- Dissipation Tests, i.e. cone resistance and pore pressure versus time

On-site and in-office laboratory test programmes

- Geotechnical Index Testing
  Sample description, water content, unit weight, Particle Size Distribution, Atterberg Limits, Particle Density, Min/Max Index Unit Weight
- Geochemical Index Testing
  Carbonate content and Organic Content
- (Index) Strength Testing
  Pocket Penetrometer, Undrained Unconsolidated (UU) triaxial compression, Isotropically Consolidated Undrained (CIU) triaxial compression
- Compressibility Testing
  Incremental Loading and Constant Rate of Strain Oedometer tests

Advanced static and cyclic laboratory test programme (ongoing)

- Coarse-grained soils
  Isotropically Consolidated Undrained (CIU) triaxial compression, selected tests with Bender Element (BE), Cyclic Undrained Triaxial (CTXL)
- Fine-grained soils
  Direct Simple Shear (DSS), Cyclic Simple Shear (CSS), Isotropically Consolidated Undrained (CIUc) triaxial compression, selected tests with Bender Element (BE), Isotropically Consolidated Undrained (CIUe) triaxial extension

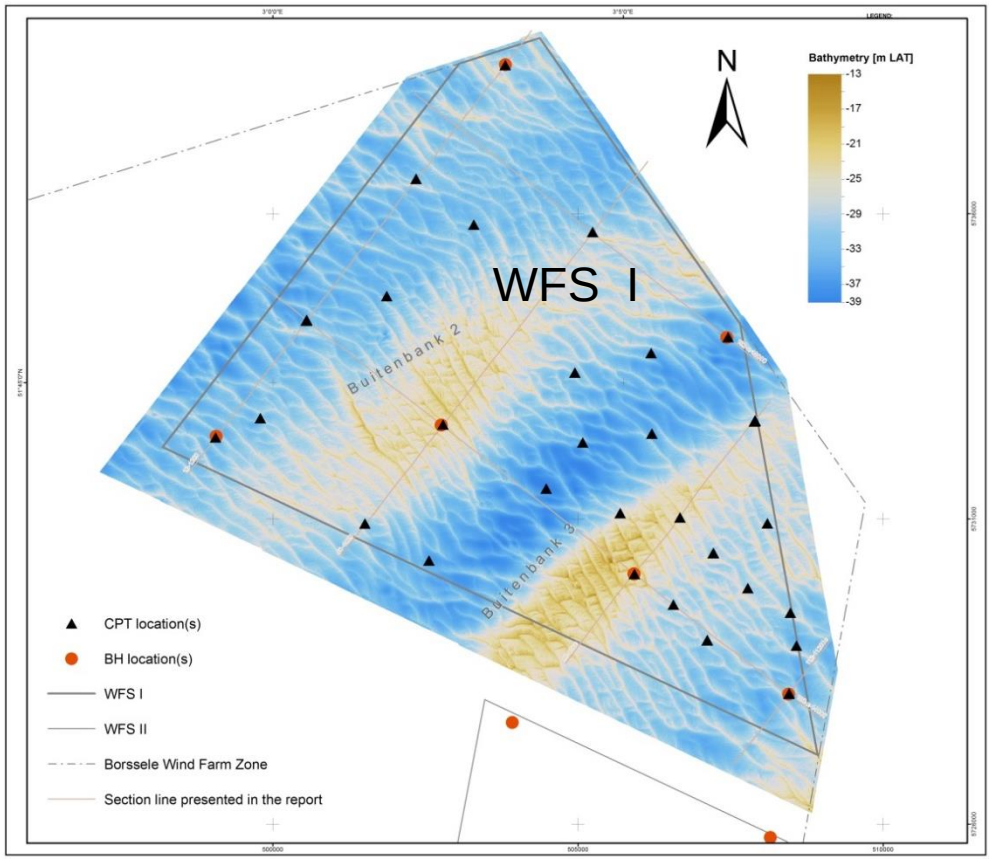
Geotechnical Site Investigation – Project Deliverables

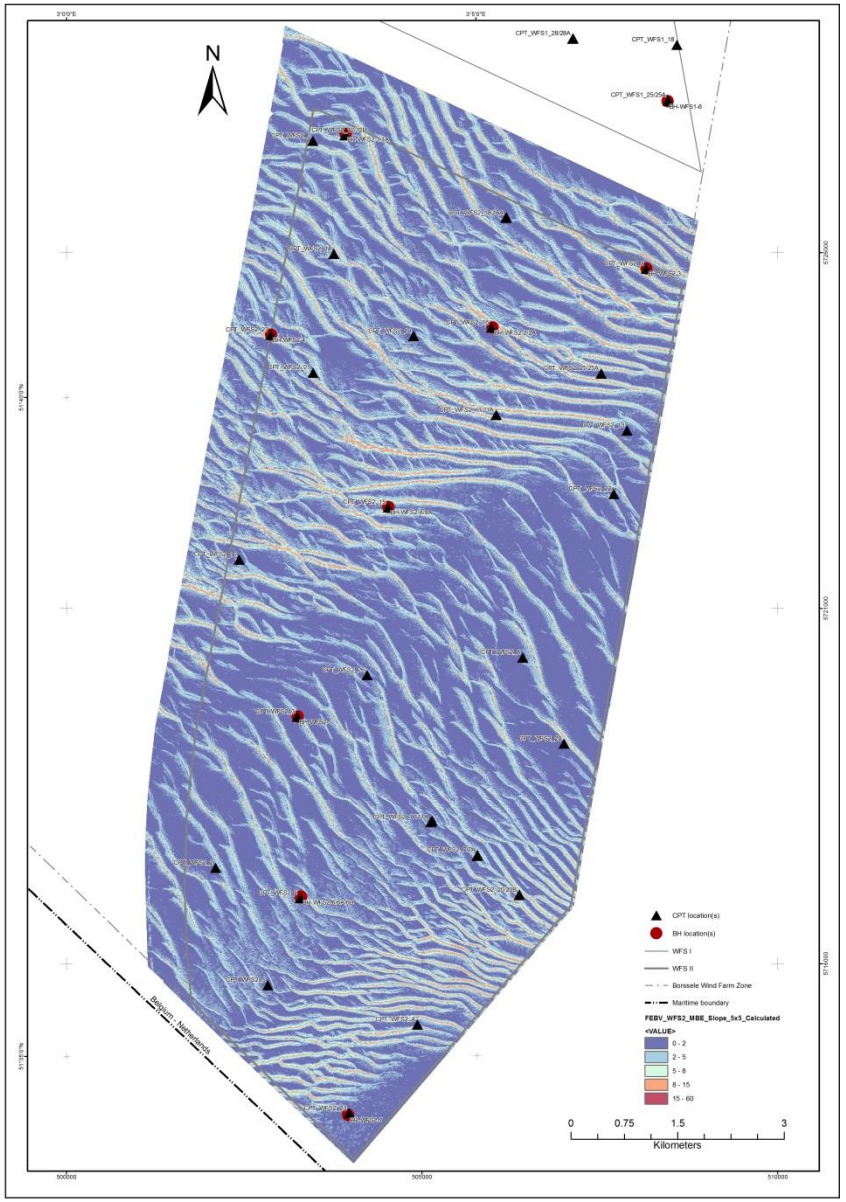
Report Type	Investigation Data	Contents
Geotechnical Reports – Investigation Data	WFSI 6 borehole locations to depths of 50m to 65m bsf • 4 sampling & (P)CPT • 2 sampling & (S/P)CPT	One report per site • Geotechnical logs; • Results of (P)CPT • Results of SCPT • Geotechnical laboratory tests
	WFSII 8 borehole locations to depths of 51m to 82m bsf • 6 sampling & (P)CPT • 2 sampling &(S/P)CPT	
	WFSI 29 seafloor PCPT to depths of 7m to 37m bsf, including 6 PPDT	One report per site • Interpreted PCPT logs • Results of PCPT • Results of PPDT
	WFSII 27 seafloor PCPT to depths of 4m to 50m bsf, including 14 PPDT	
Geological Ground Model Reports	One report per site • Geological ground model • Geotechnical Parameter per borehole location and per unit • Assessment of suitability of selected types of structures	
Laboratory Test Reports	• Results of advanced static and cyclic laboratory tests	

Key:
bsf = below seafloor
PCPT = Piezo-Cone Penetration Test / SCPT = Seismic Cone Penetration Test / PPDT = Pore Pressure Dissipation Test

Geological Ground Model - Seafloor Conditions

- Presence of sand waves (SW to NE) and sand dunes (approximately orthogonal to sand waves)
- Steep seafloor gradients present
- Cables and a pipeline present, ship wrecks, sonar contacts and magnetometer contacts near survey lines (e.g. anchors, chains, fallen cargo or garbage)



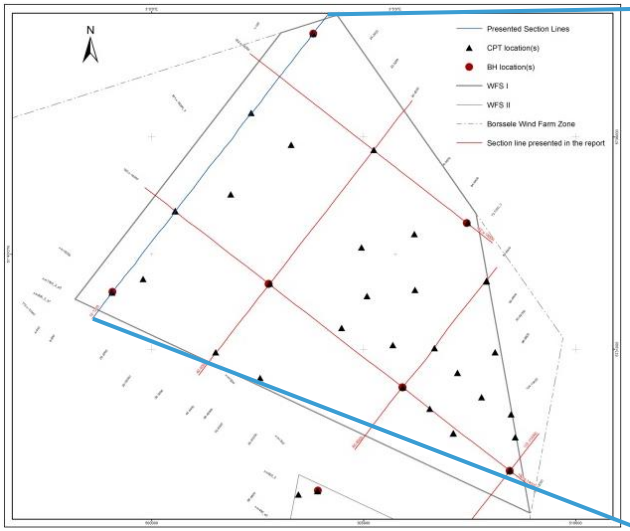


Geological Ground Model – Stratigraphic Correlation

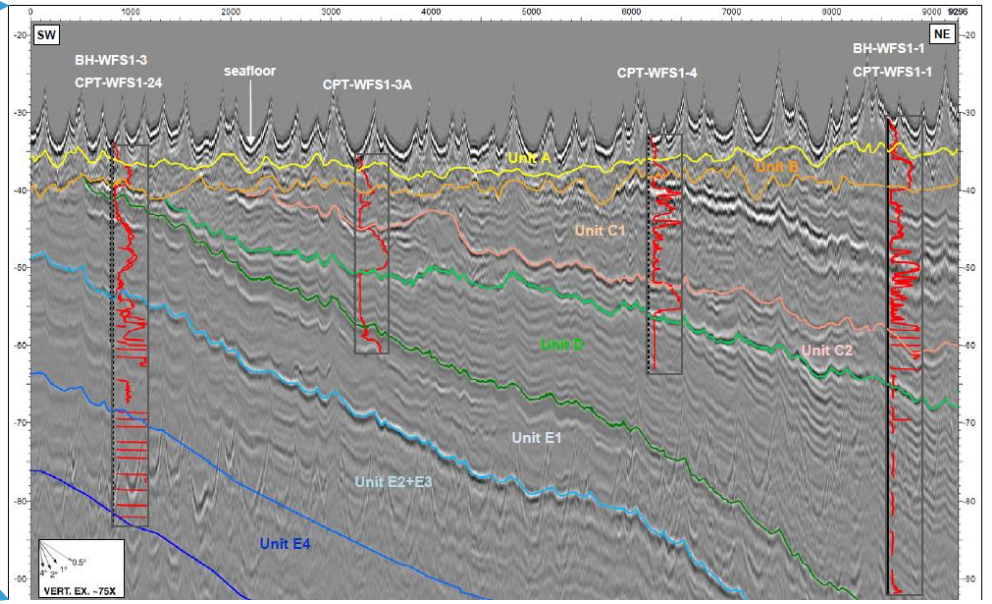
Unit	Lithostratigraphy Belgium (Vandenberghe, 2004)		Lithostratigraphy Netherlands (Rijsdijk, 2005) (TNO, 2003)		Seismostratigraphy	Chronostratigraphy			
						Age	Epoch		Period
A			Southern Bight Fm.		Southern Bight Fm.		Holocene		Quaternary
B			Kreftenheye Fm./ Eem Fm.		Kreftenheye Fm./ Eem Fm.	Saalian/Eemian	Pleistocene		Quaternary
C1			Westkapelle Ground Fm.		Westkapelle Ground Fm.		Pliocene		Neogene / Tertiary
C2									
D	Boom Clay	Boom Fm.	Rupel Clay Mb.		Rupel Fm.	Rupelian	Early	Oligocene	Palaeogene / Tertiary
E1	Ruisbroek Sand	Zelzate Fm.	Ruisbroek Sand	Zelzate Fm.	Tongeren Fm.				
E2	Watervliet Clay		Watervliet Clay						
E3	Bassevelde Sand (Ba3)		Bassevelde Sand						
E4	Bassevelde Sand (Ba2)					Priabonian	Late	Eocene	Palaeogene / Tertiary
E5a	Bassevelde Sand (Ba1)								
E5b	Bassevelde Sand (Ba1)								
F1a	Onderdijke Clay	Maldegem Fm.	Asse Mb.		Dongen Fm.	Bartonian	Middle	Eocene	Palaeogene / Tertiary
F1b	Onderdijke Clay								
F2	Buisputten Sand								
F3	Zomergem Clay								

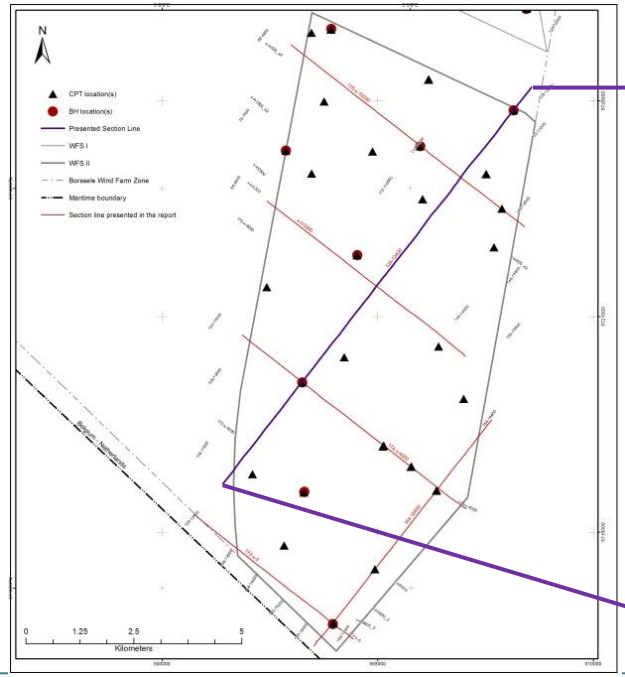
Notes:
- Fm. = Formation
- Mb. = Member

Geological Ground Model – Examples of Cross Sections

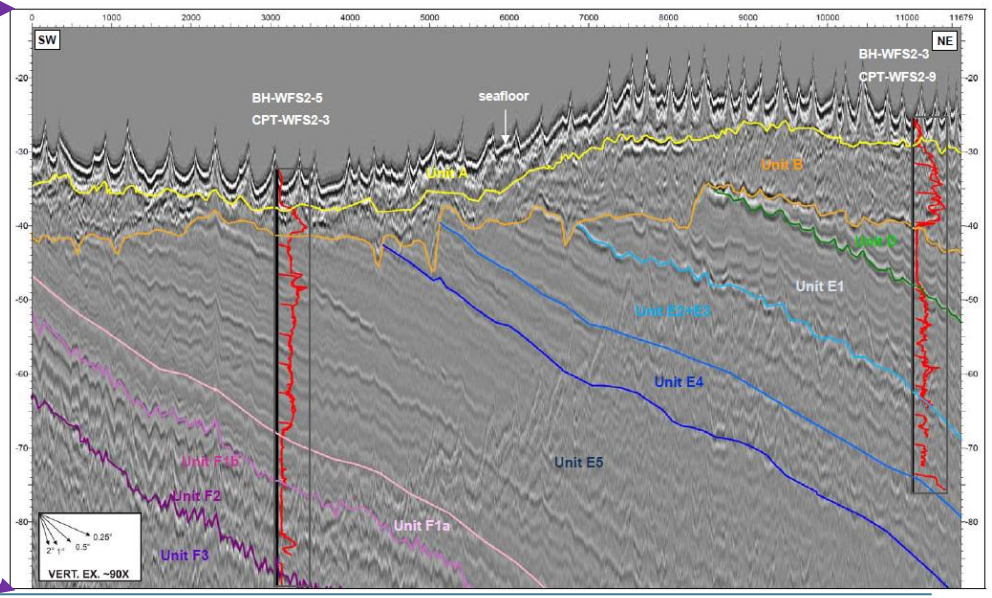


WFS I





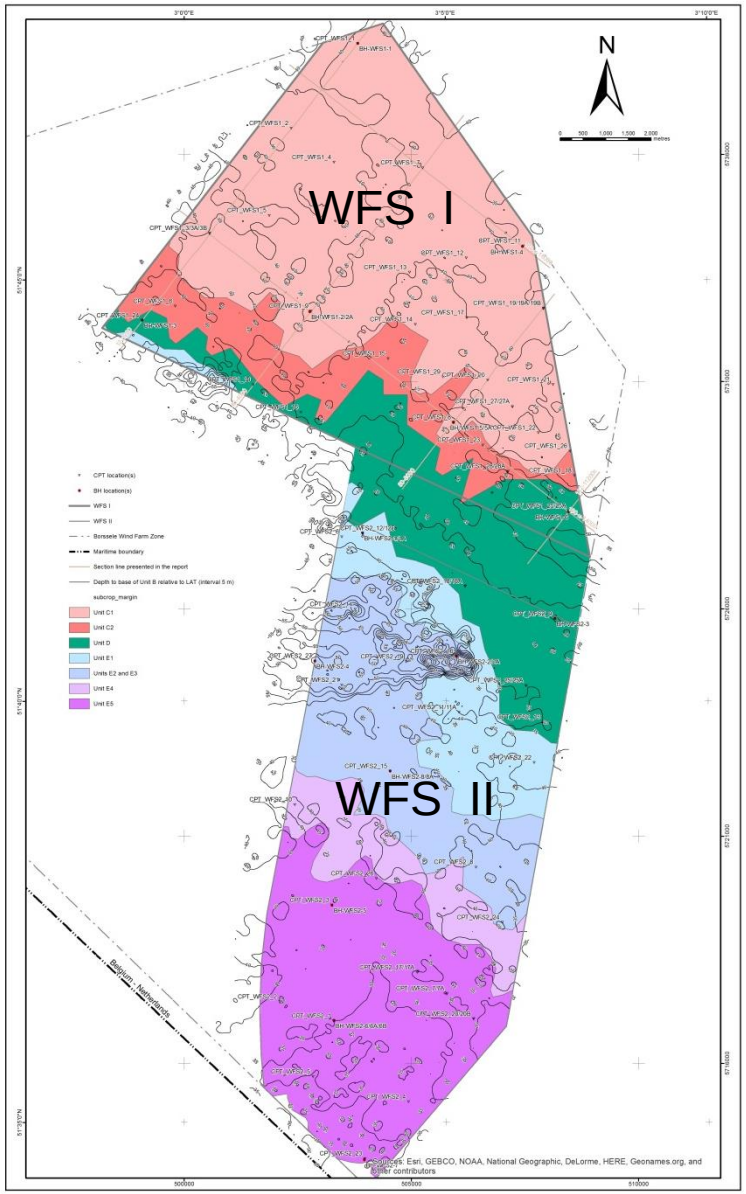
WFS II



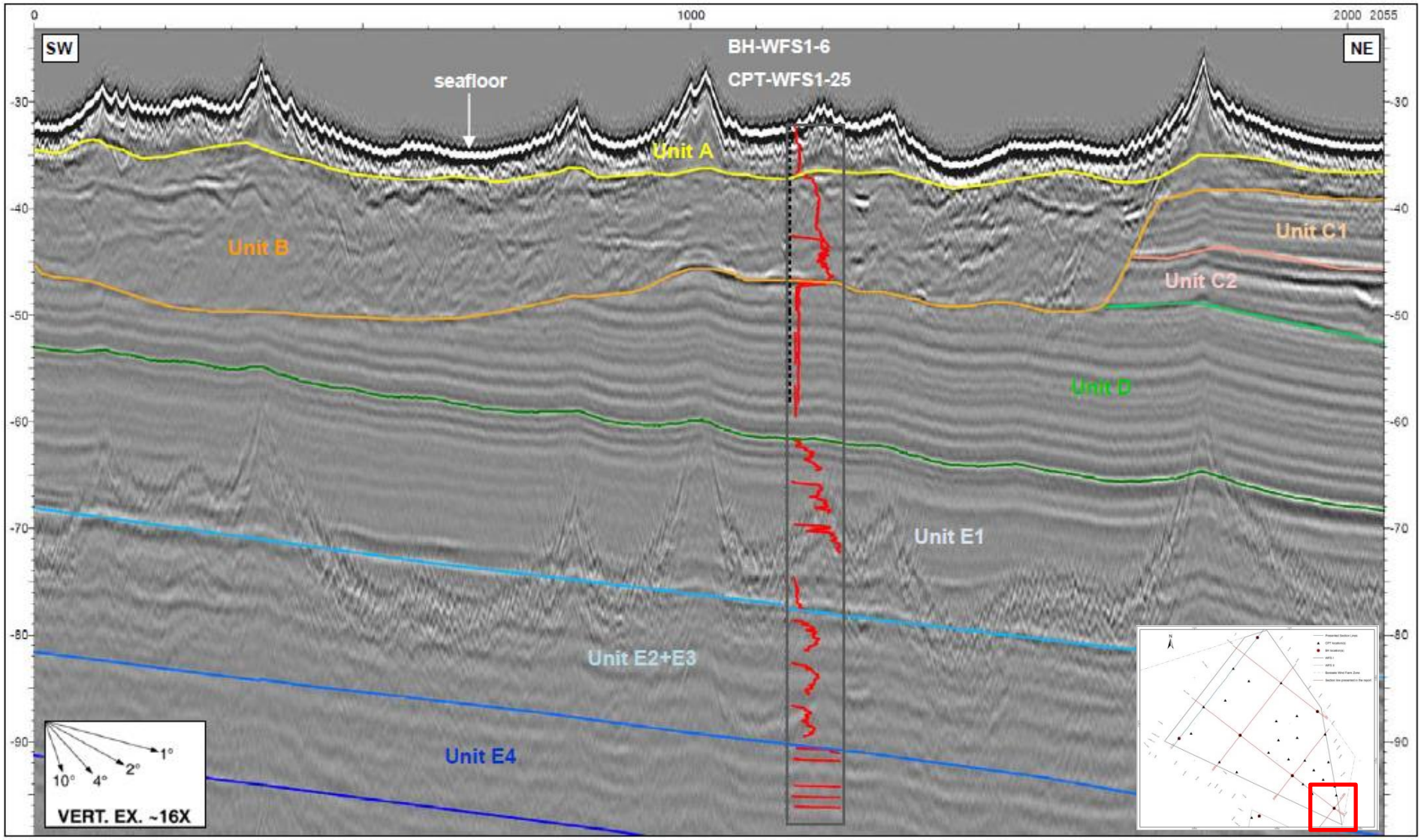
Geological Ground Model – Spatial Stratigraphy

Unit	Lithostratigraphy Netherlands (Rijsdijk, 2005) (TNO, 2003)		Seismostratigraphy	Period	
A	Southern Bight Fm.		Southern Bight Fm.	Quaternary	
B	Kreftenheye Fm./ Eem Fm.		Kreftenheye Fm./ Eem Fm.		
C1	Westkapelle Ground Fm.		Westkapelle Ground Fm.	Neogene	Tertiary
C2					
D	Rupel Clay Mb.		Rupel Fm.	Palaeogene	
E1	Ruisbroek Sand	Zelzate Fm.	Tongeren Fm.		
E2	Watervliet Clay				
E3	Basseveld e Sand				
E4					
E5a					
E5b					
F1a	Asse Mb.		Dongen Fm.		
F1b					
F2					
F3					

Notes:
- Fm. = Formation
- Mb. = Member

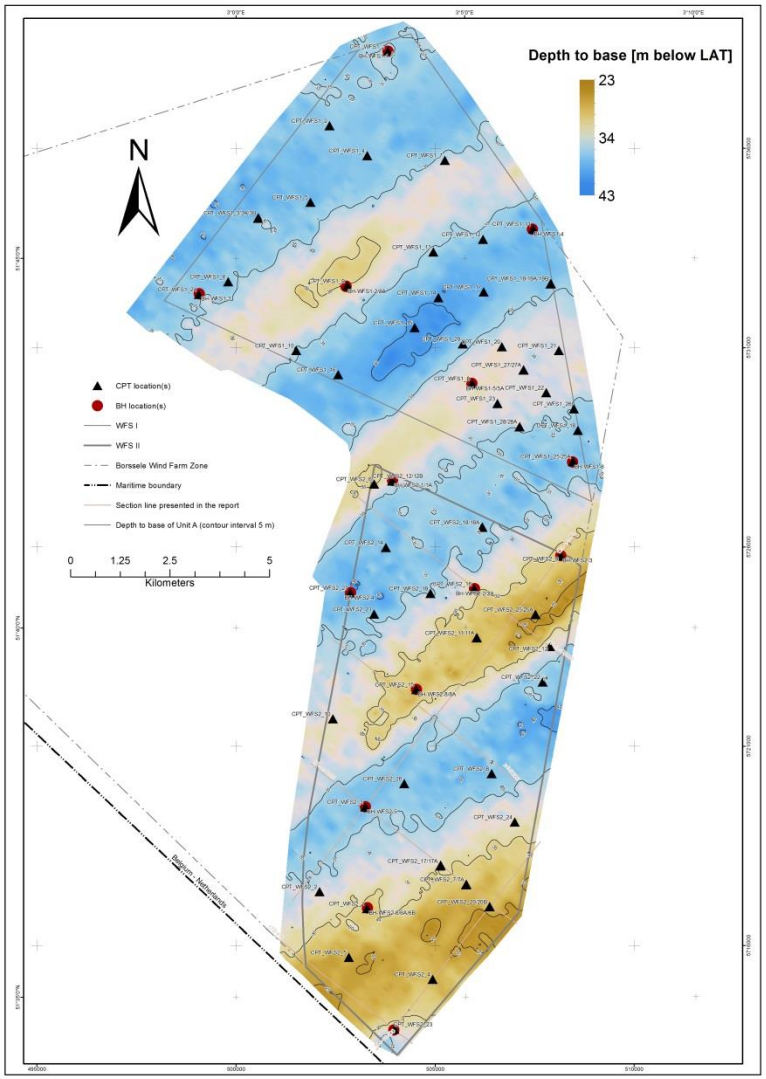


Geotechnical Data Example - Soil Units B and E2 / E3

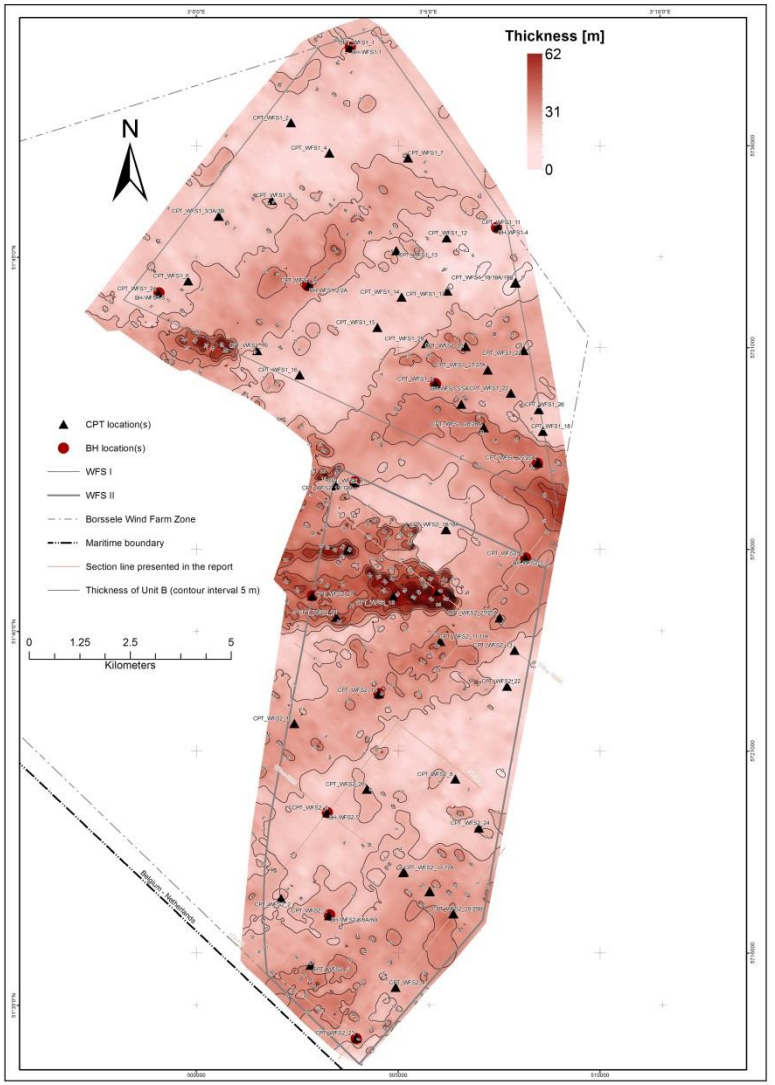


Geotechnical Data Example – Spatial Distribution Soil Unit B

Depth to Top of Unit B

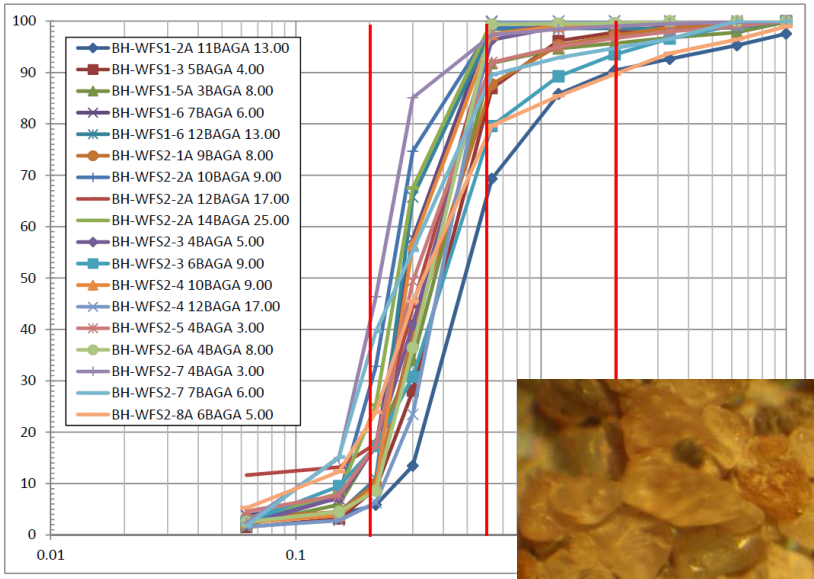


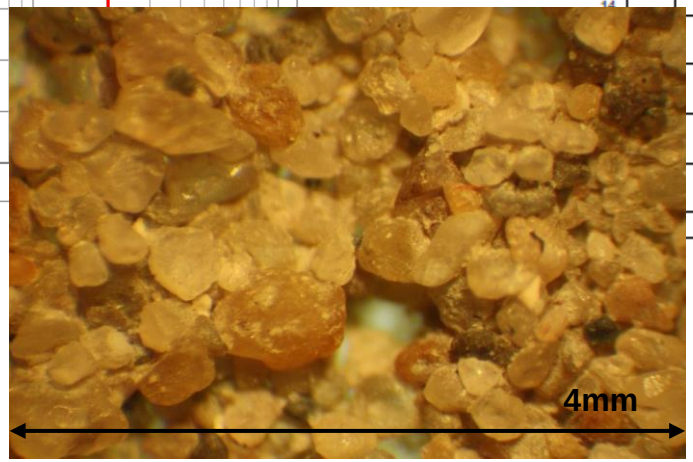
Thickness Distribution of Unit B

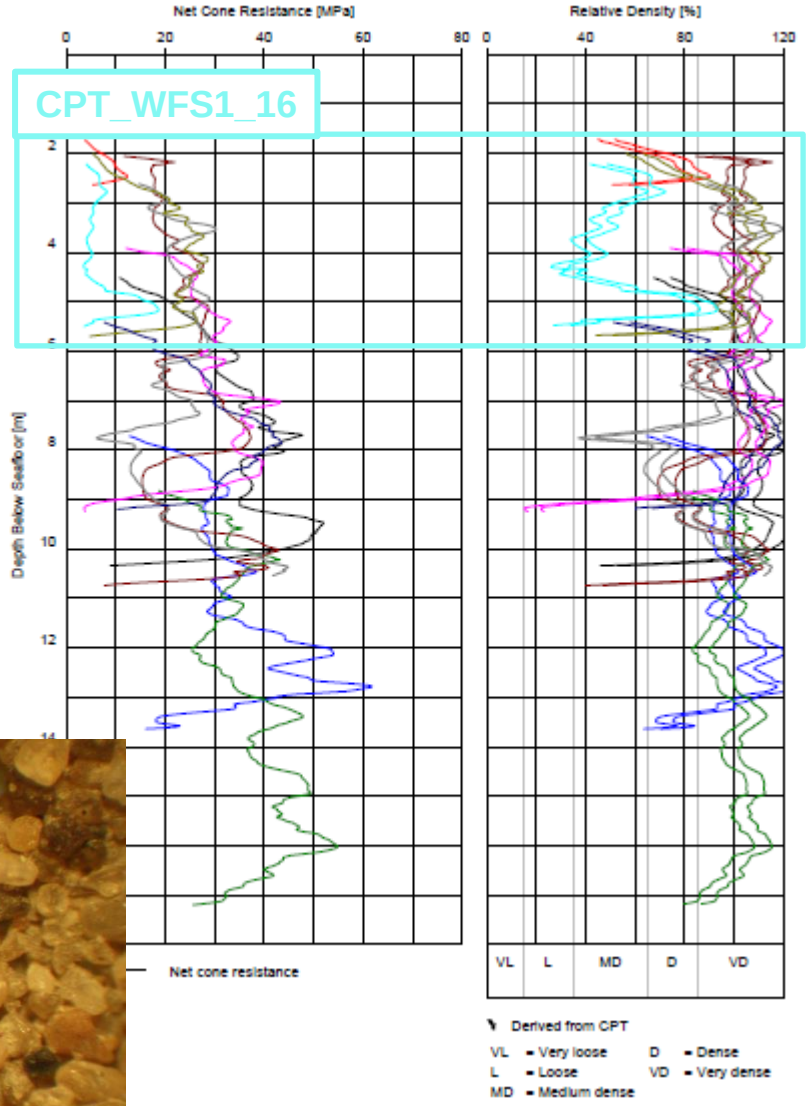


Geotechnical Data Example - Soil Unit B

- Present across both WFSI&II
- Thickness from approximately 1m up to 16m
- Typically dense to very dense medium sand
- Limited variation across the sites
- Locally clayey and loose to medium dense sand

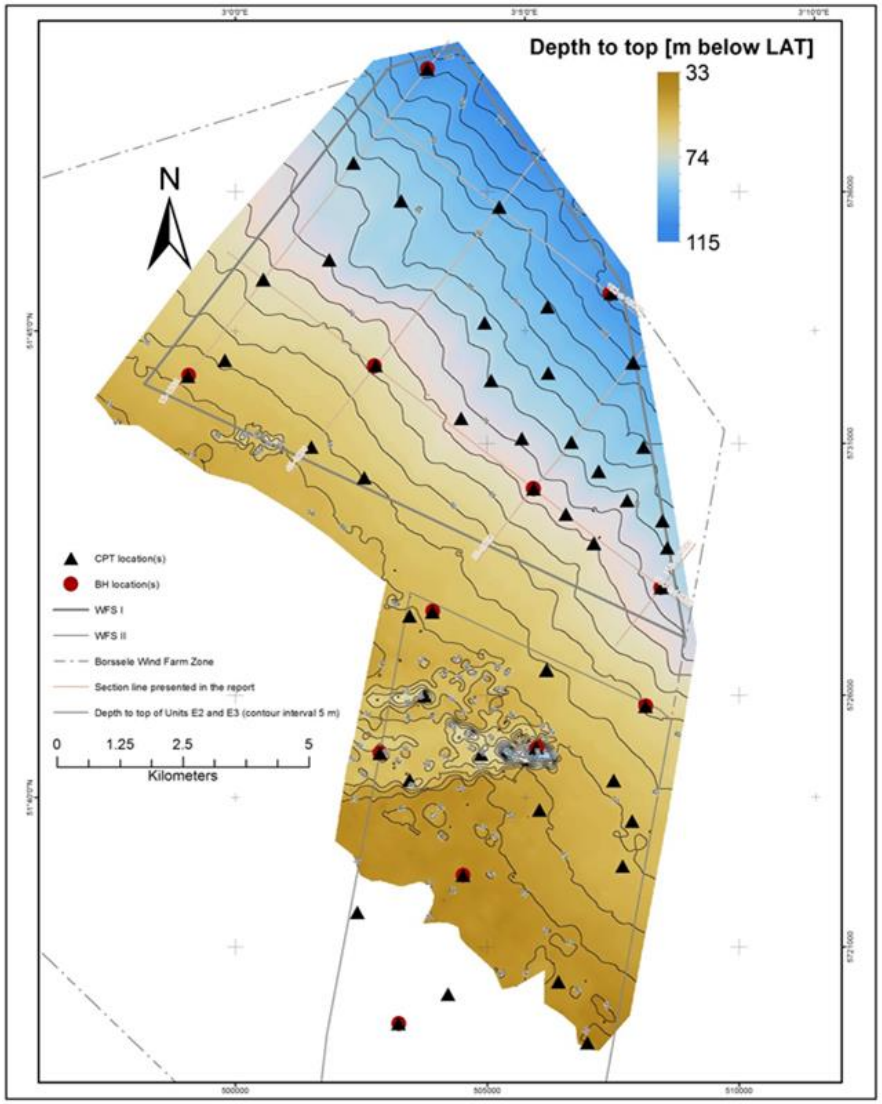




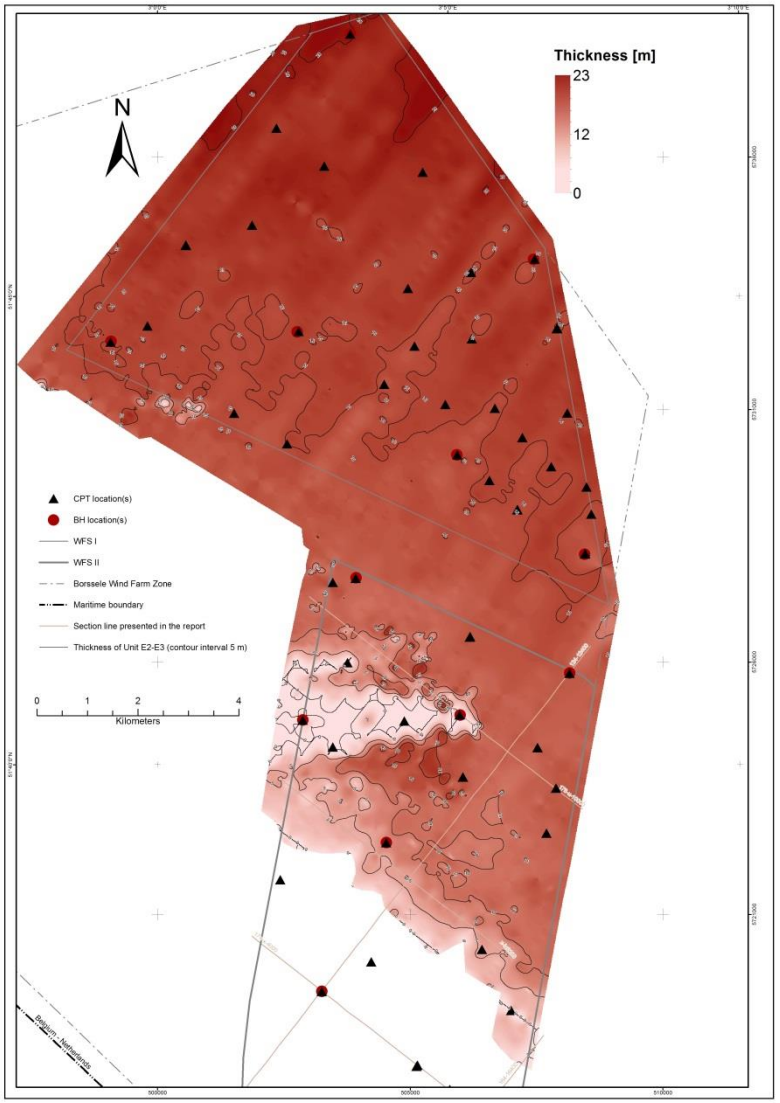


Geotechnical Data Example – Spatial Distribution Soil Units E2 / E3

Depth to Top of Units E2 / E3



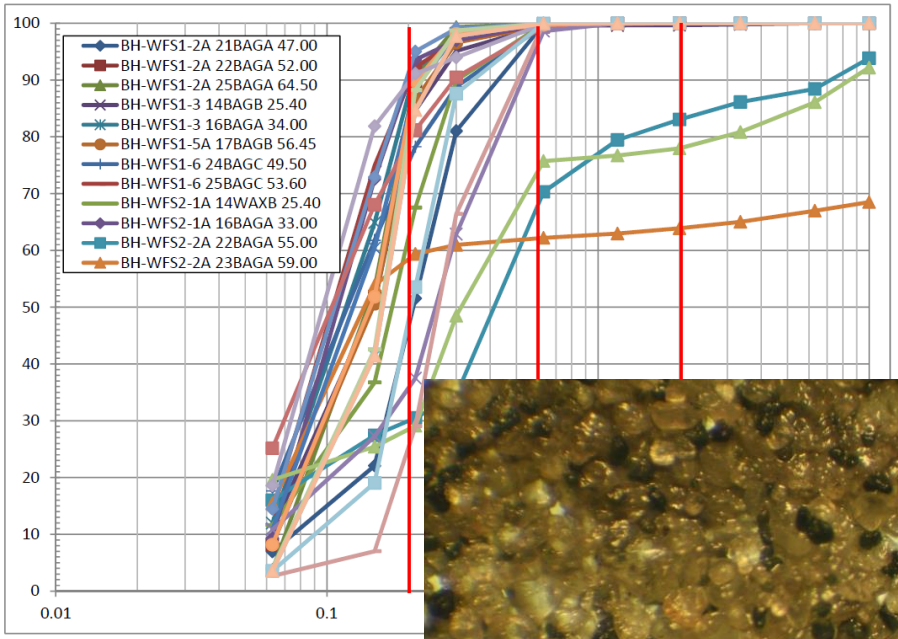
Thickness Distribution of Unit E2 / E3

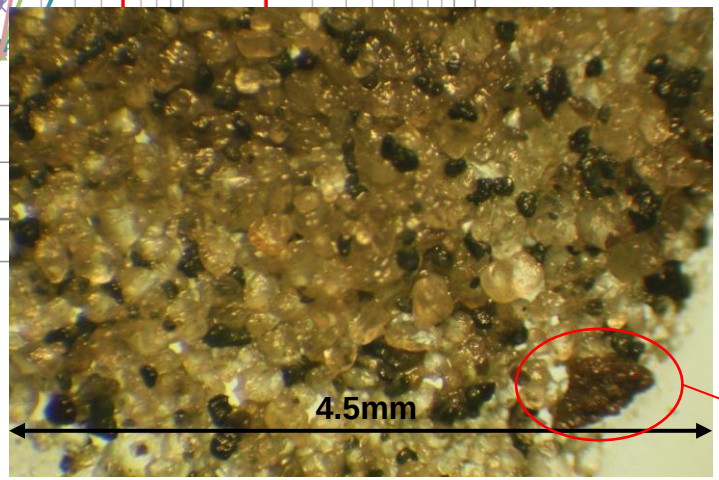


Geotechnical Data Example – Soil Unit E2 / E3

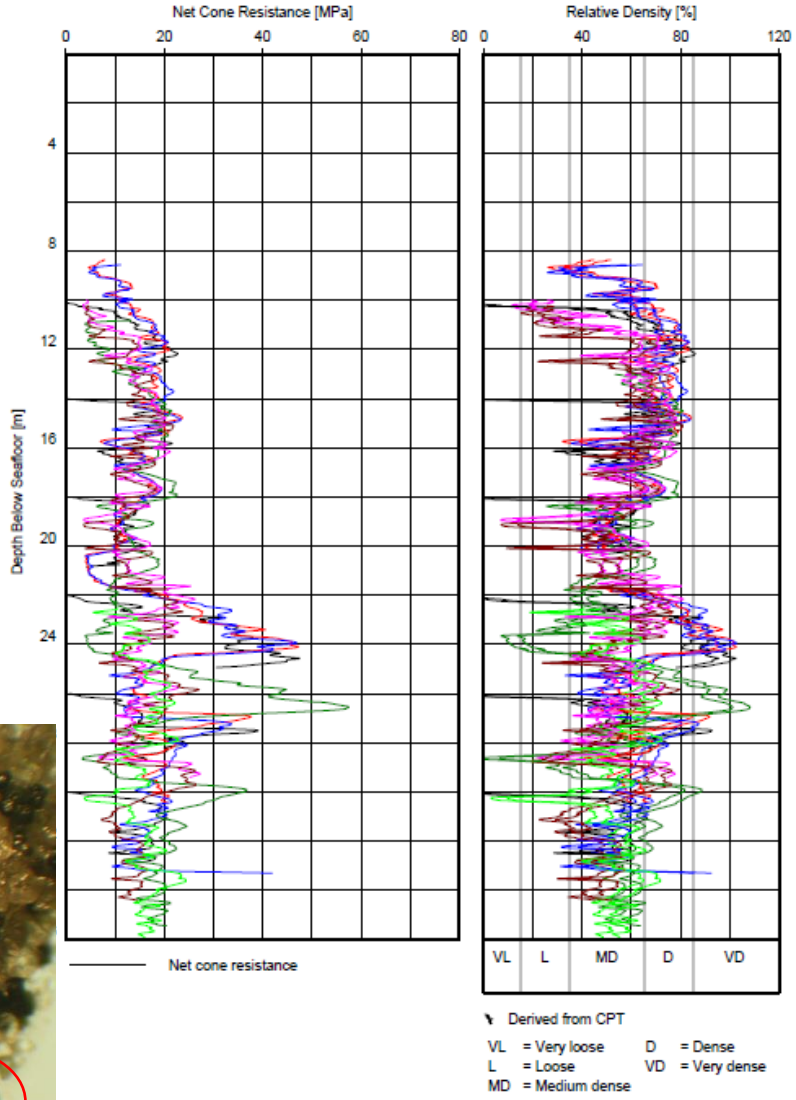
Soil Unit E2 / E3

- Present across bot WFSI and part of WFSII
- Thickness from approximately 0m up to 35m
- Typically medium dense (very clayey sand with locally thin to thick beds of clay
- Variation across the site evident

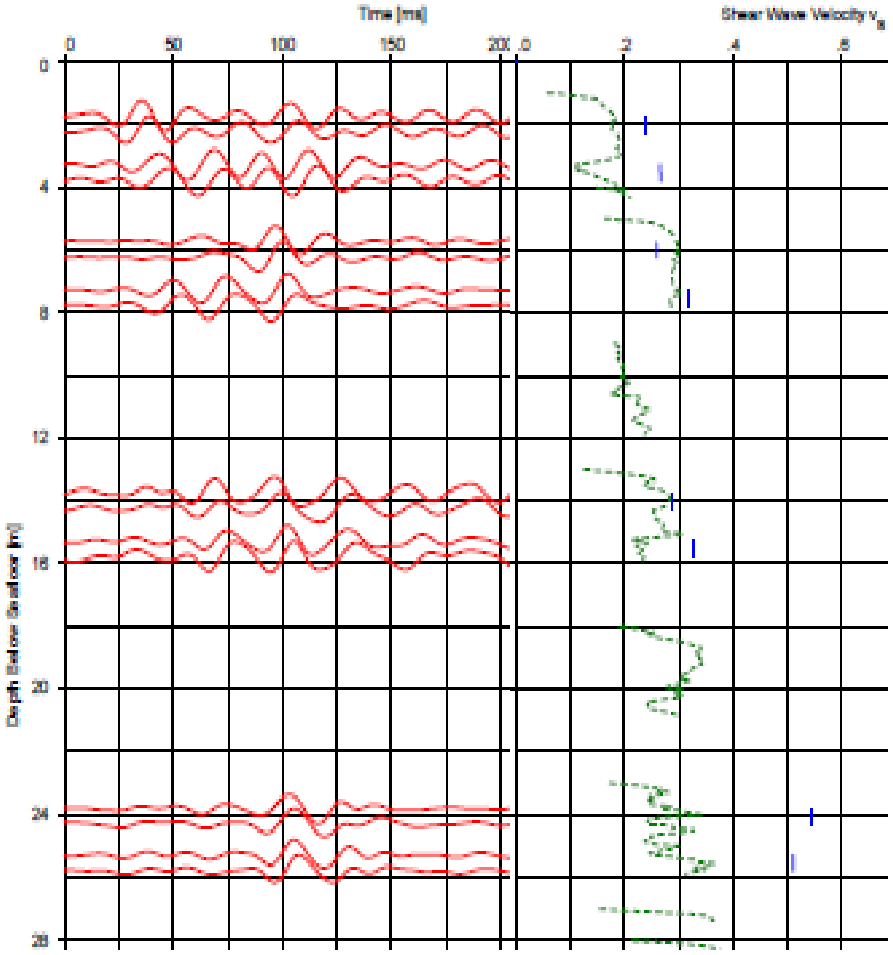


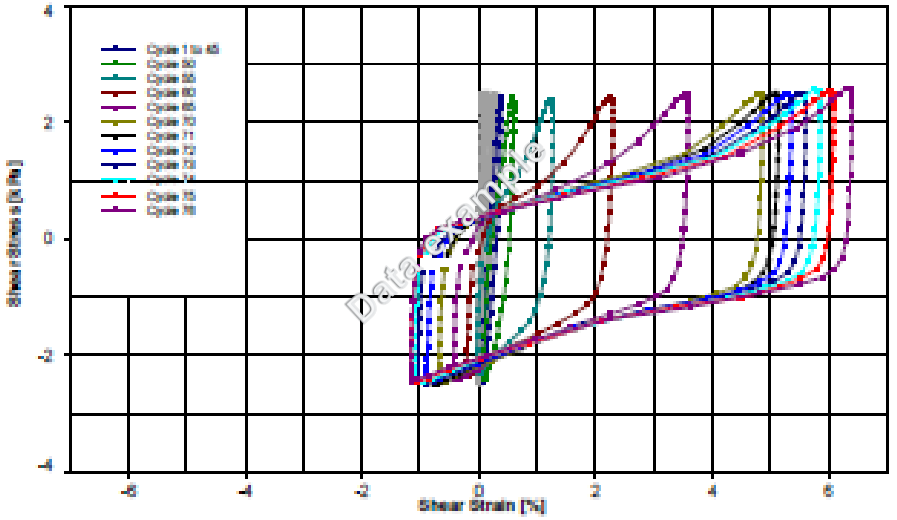


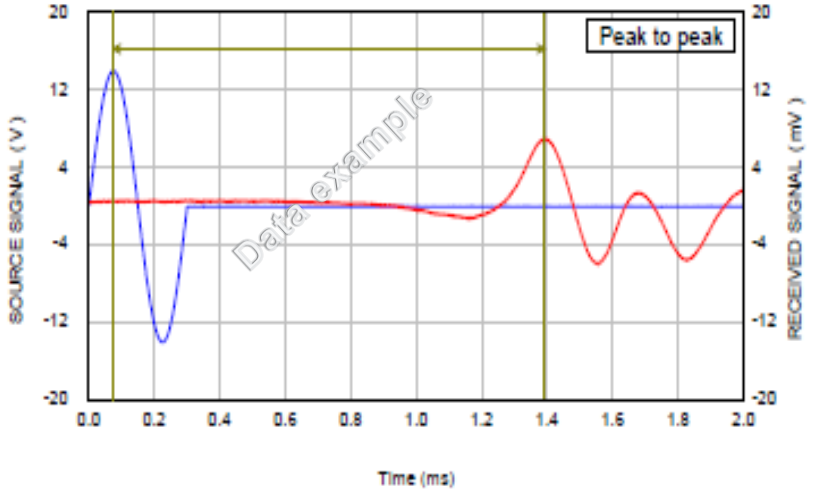
Glauconite particles



Geotechnical Data Example – Seismic and Cyclic Testing







Potential Site-Specific Hazards Assessment

Geological Feature & Hazard Type	Occurrence Area	Constraints on Structure	PL	JU	GB	SC	CB
Migrating bedforms / mobile seabed sediments	Entire WFS I & II	▪ All: exposure or burial of structure due to local, general and regional scour or sedimentation affecting structure stability, structure stiffness ▪ CB: exposure or burial of cable affecting thermal characteristics	H (L)	L (N)	H (N)	H (L)	L (N)
Loose to medium dense sand	Locally in Unit A	▪ All: cyclic loading of seabed and structure can affect structure stability and structure stiffness ▪ CB: liquefaction of sand can affect cable flotation and thermal characteristics	H (N)	L (N)	H (N)	L (N)	L (N)
Very dense sand/ hard clay	▪ Unit C – very dense sands ▪ Unit D – stiff to very stiff clay ▪ Unit E – very dense sands	▪ PL: early refusal of pile installed by impact driving ▪ SC: limited penetration ▪ CB: trenching difficulties	L (N)	N (N)	N (N)	L (L)	L (N)

Key:
PL=Pile Foundation / JU=Jack-up Platform / GB=Gravity Base Foundations / SC=Suction Caisson Foundation / CB=Cables
- Letter indicated hazard probability rating; **H = high / L = low / N = Negligible**
- Hazard probability rating in bracket considers application of relevant mitigation measures

Concluding Remarks

- The available geotechnical and geophysical data align well. They provide a robust basis for the geological ground model. The geological ground model fits published regional frameworks. The geotechnical data set further enhances and refines the understanding of the identified soil units.

- The geotechnical parameters indicate that spatial soil variability is limited for a majority of the soil units. Notable exceptions are soil Units C1, E1 and E3.

- Geotechnical assessment of suitability of possible foundation elements indicates that the more commonly used types are feasible, particularly multiple pile and monopile foundations

THANK YOU