Netherlands Enterprise Agency

wind & water works

Webinar 5 July 2018

Geotechnical & Geophysical Assessment Hollandse Kust (zuid) Sites III and IV

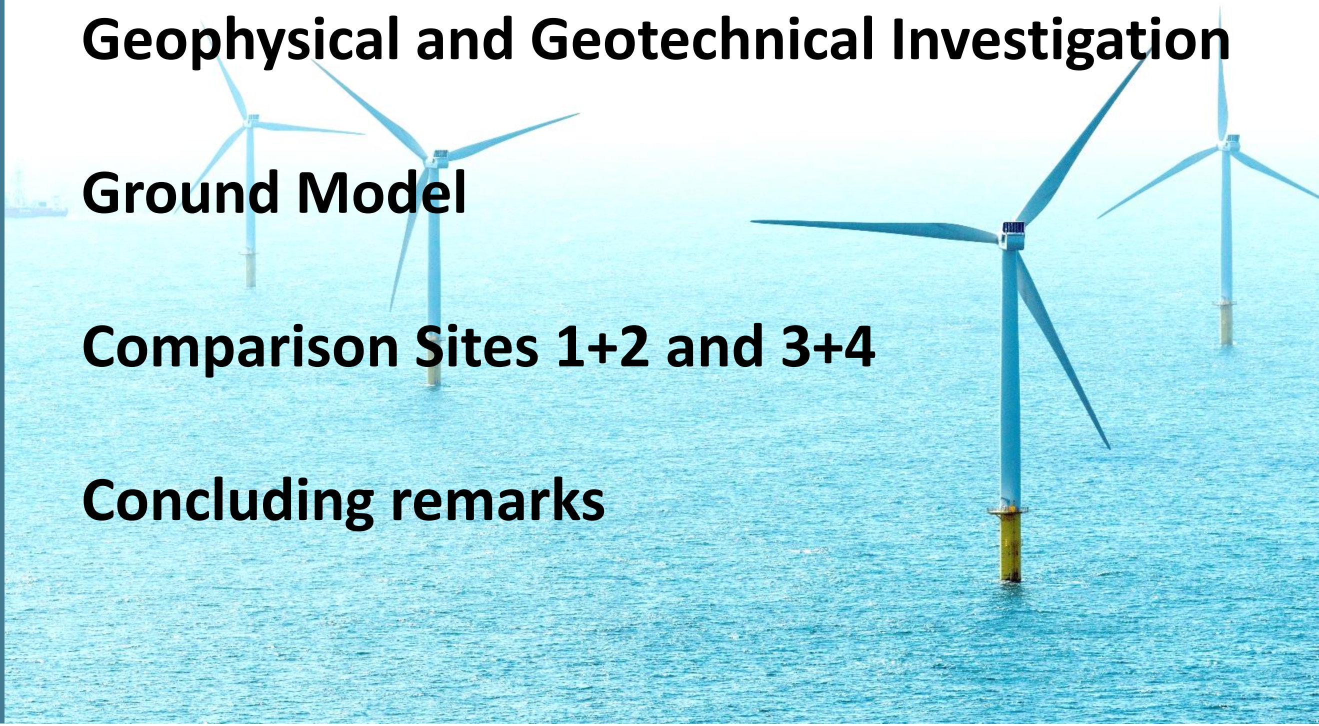
Welcome

- Introduction by Ruud de Bruijne, the Netherlands Enterprise Agency
- Goal of this webinar
- Introduction of the speaker and the panel

Hollandse Kust (zuid) WFS III & IV – Geophysical and Geotechnical Site Investigation

Webinar, 05 July 2018, Martijn Klein (Fugro)

Presentation Outline



Introduction and Objectives

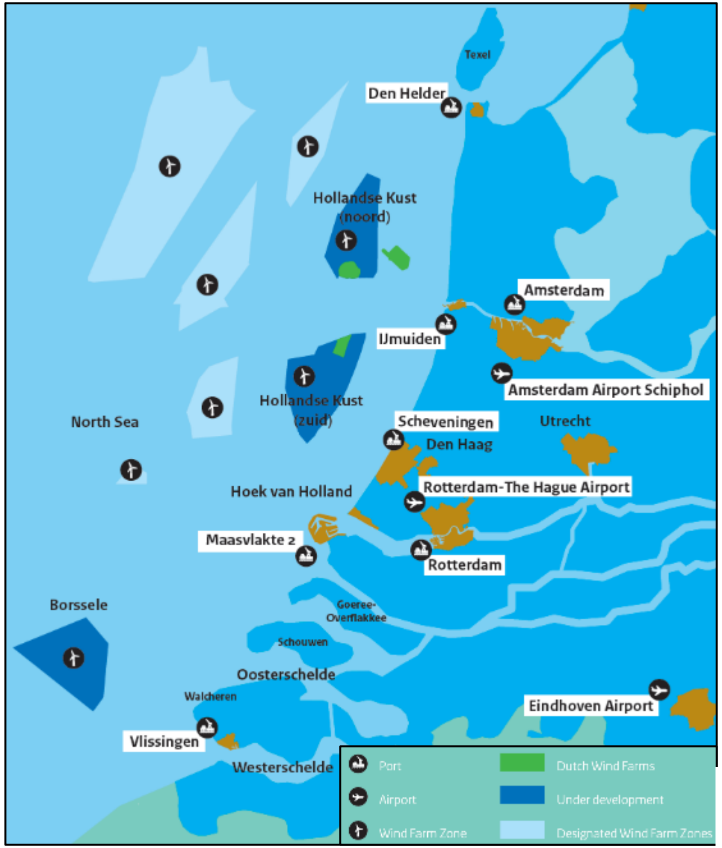
Geophysical and Geotechnical Investigation

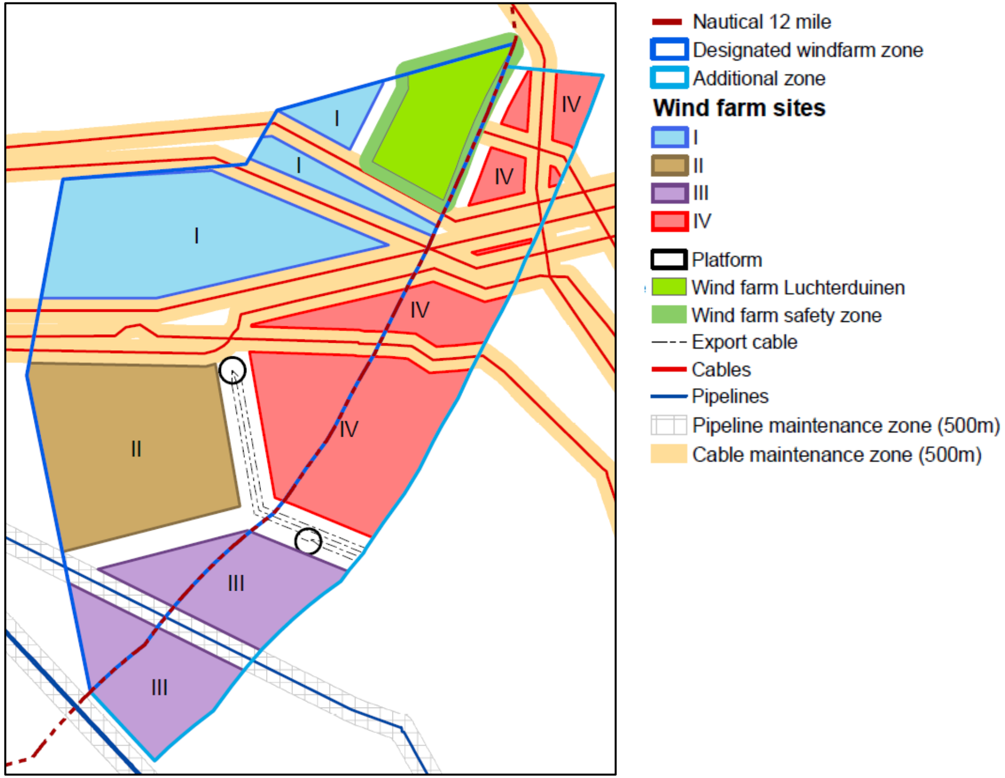
Ground Model

Comparison Sites 1+2 and 3+4

Concluding remarks

Wind Farm Zone – Hollandse Kust (zuid)





Sources: "Existing port and manufacturing infrastructure base in the Netherlands" and "RVO_basiskaart", www.offshorewind.rvo.nl Note verification recommended, presented figure may have been updated.

Concluding Remarks

- The available geotechnical and geophysical data align well. They provide a robust basis for the geological ground model.

- The investigation area is characterized by limited lateral correlation of soil properties. Variations in soil conditions are evident from presented geotechnical parameters.

- Soil conditions at individual geotechnical locations as well as within soil units between geotechnical locations show sequences of sand, clays and intermediate soils.

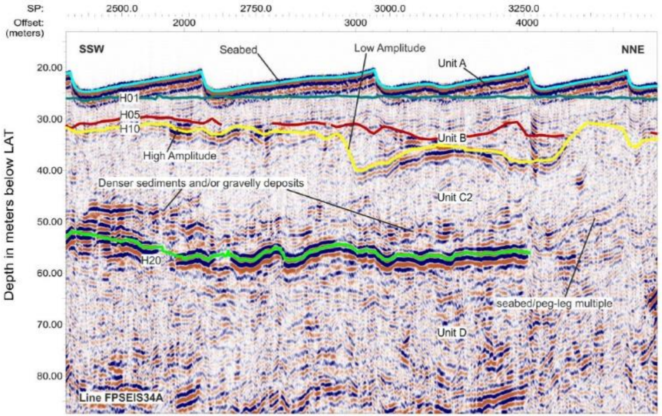
- Geotechnical assessment of suitability of possible foundation elements indicates that the more commonly used types are feasible, particularly multiple pile and monopile foundations.

Site Investigations

Geophysical & Geotechnical

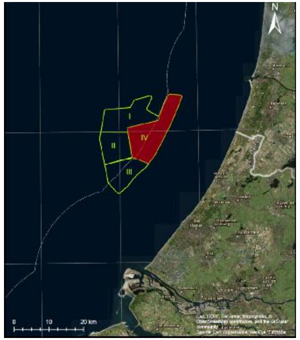
RVO Objectives for Geophysical Investigation

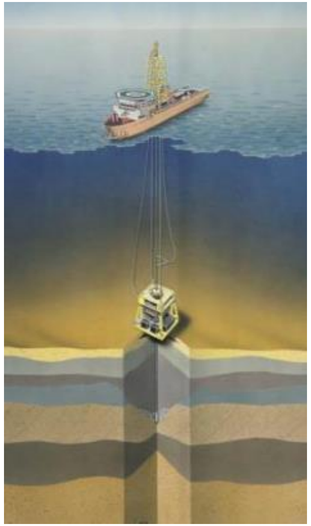
- To gather data to assist in the design of offshore foundations/ structures and cable burial for the wind farm development
- To obtain accurate bathymetry of the development areas
- To provide information on the presence of all seabed features including natural features and any man-made objects such as existing cables, pipelines, wrecks, debris and/or UXO items
- To provide detailed geological interpretation showing facies variations and structural feature changes
- To locate any structural complexities or geohazards within the shallow geological succession such as faulting, accumulations of shallow gas, buried channels, etc.
- To provide input into the specification and scope for a geotechnical sampling and testing programme

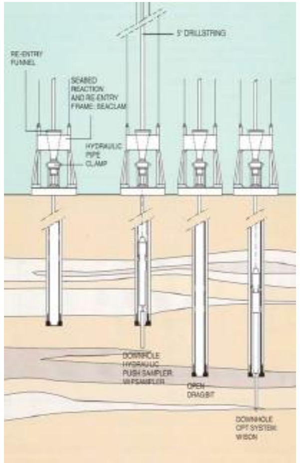


RVO Objectives for Geotechnical Investigation

- Further develop geological/geophysical model for HKZ
- Determine vertical and lateral variation in seafloor and seabed conditions
- Provide relevant geotechnical data for design, including but not limited, to foundations and cables
- Update geological desk study and provide geological ground model to a depth of 100m bLAT
- No need for further (sampling) boreholes in future site investigations





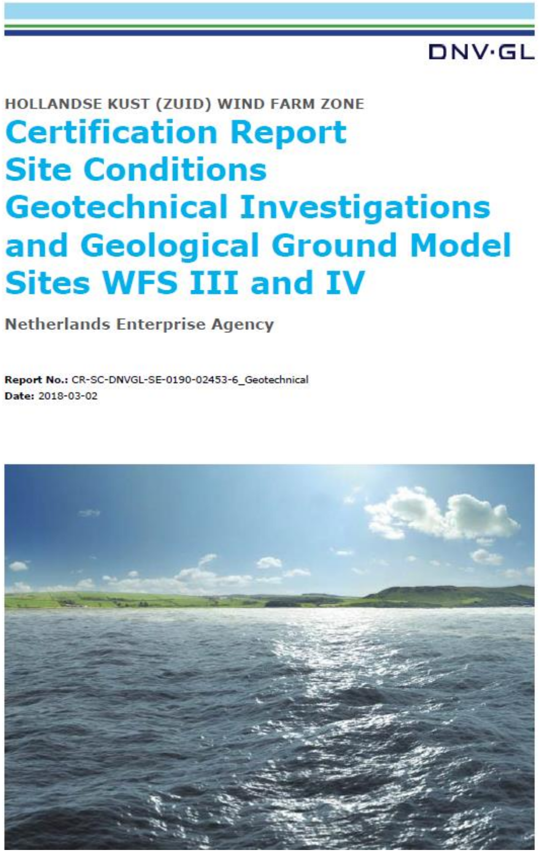


RVO Objectives – DNV GL Certification

Conclusion DNV GL on the site investigation and deliverables for HKZ (WFS III and IV):

“The comprehensive geotechnical campaign and the advanced laboratory test program were defined as a joint effort between multiple parties and reviewed by DNV GL with the objective to reduce the need for boreholes and additional laboratory tests in later stages of development. With a proper CPT calibration and additional CPTs at each planned turbine location it is likely that additional boreholes may be omitted.”

Report No.: CR-SC-DNVGL-SE-0190-02453-6_Geotechnical (dated 2 March 2018)


DNV·GL

HOLLANDSE KUST (ZUID) WIND FARM ZONE

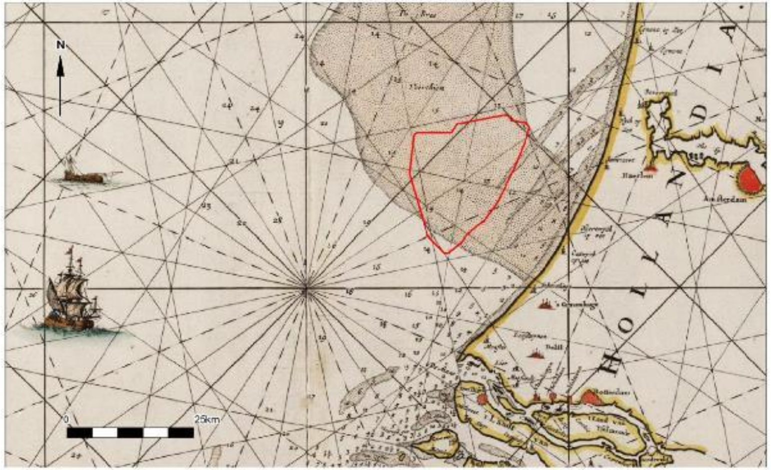
Certification Report
Site Conditions
Geotechnical Investigations
and Geological Ground Model
Sites WFS III and IV

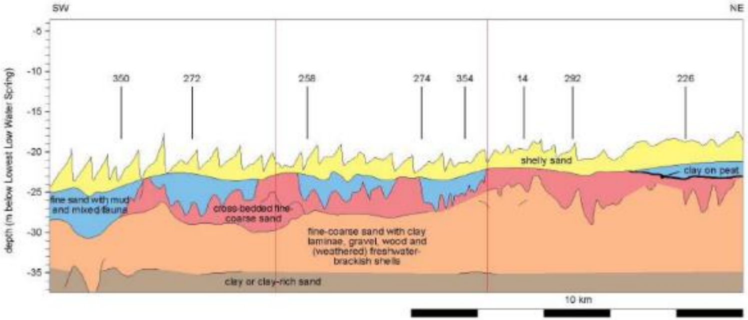
Netherlands Enterprise Agency

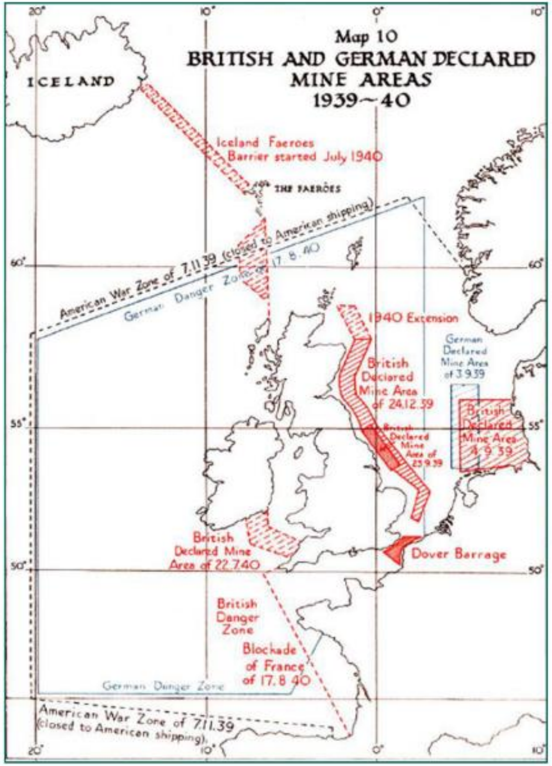
Report No.: CR-SC-DNVGL-SE-0190-02453-6_Geotechnical
Date: 2018-03-02

Starting Points for Investigation Plan

- RVO desk studies
- Geophysical SI
- First Ground Model
- Seafloor Testing SI
- Borehole Drilling SI
- Laboratory Test Prog.
- Final Ground Model







Geophysical Investigation - Overview

RVO desk studies

Geophysical SI

First Ground Model

Seafloor Testing SI

Borehole Drilling SI

Laboratory Test Prog.

Final Ground Model

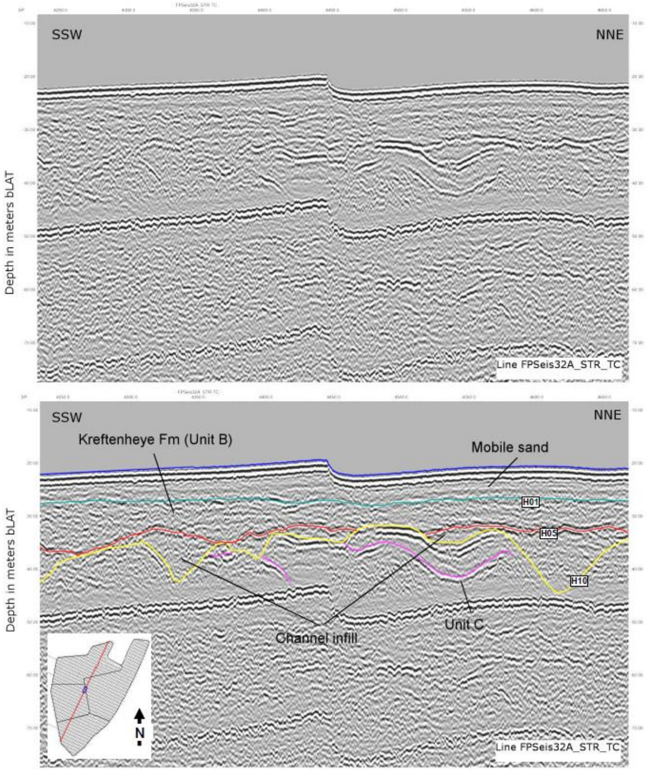
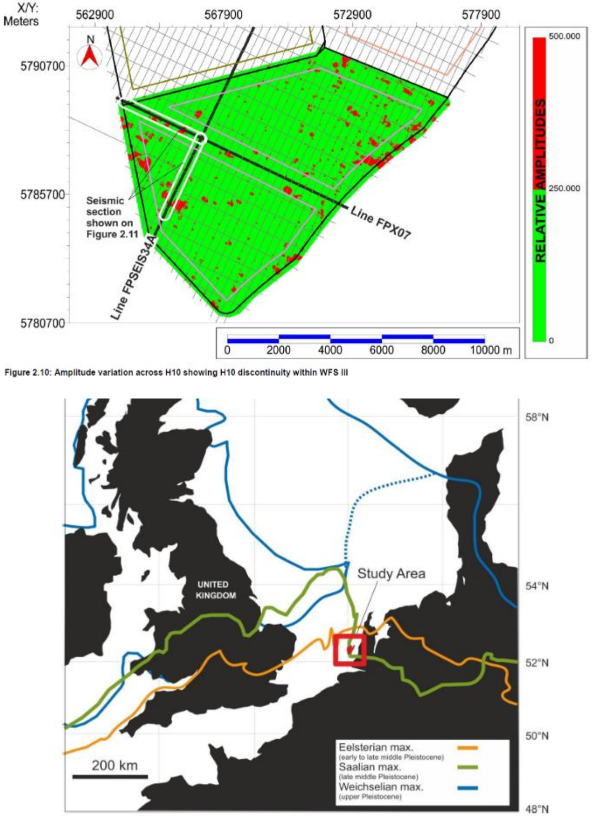


Figure 2.14: SCS line showing buried channels representing lateral soil variability within Unit B, with (top) the un-interpreted data and (bottom) the data overlain with the interpretation



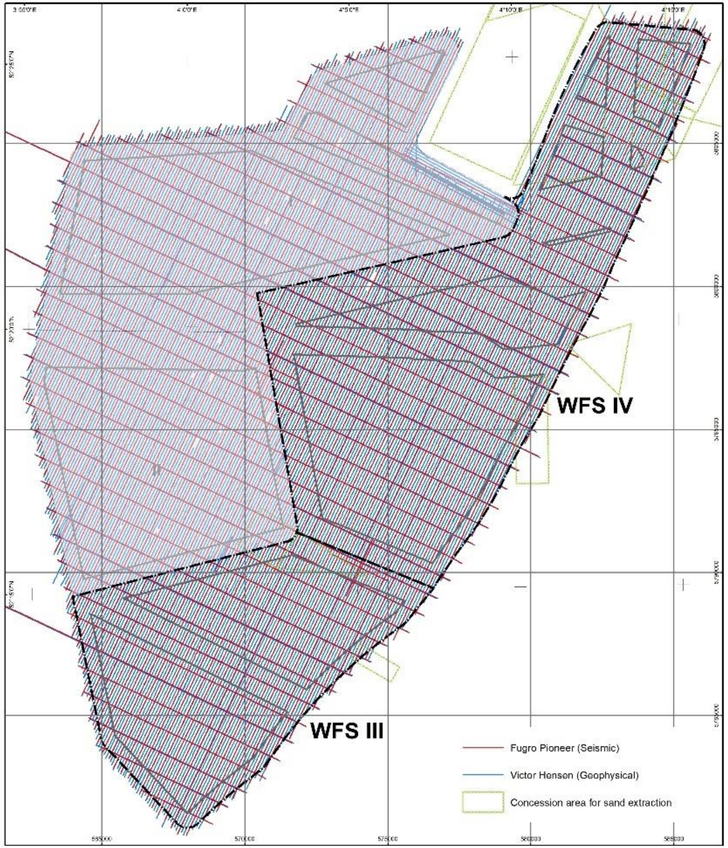
Geophysical Investigation - Equipment and Line Plan

MV Victor Hensen: **Geophysical scope**

- Main lines: 100-m spacing
- Cross lines 750-m spacing
- **MBES**: Kongsberg EM2040 dual-head
- **SSS**: EdgeTech 4200-FS (100/600 kHz)
- **MAG**: G-882 Marine magnetometer
- **SBP**: Massa TR-1075 pinger 4x4+2 array (hull-mounted)

MV Fugro Pioneer: **Seismic scope** (UHR)

- Main lines: 300-m spacing
- Cross lines 750-m spacing
- **SCS:** GSO 100-tip parker with Geo-Resources Geo-Sense mini-streamer
- **MCS**: GSO 540-tip dual-frequency sparker with Geometrics GeoEel 48 channel streamer (half-fold recording)



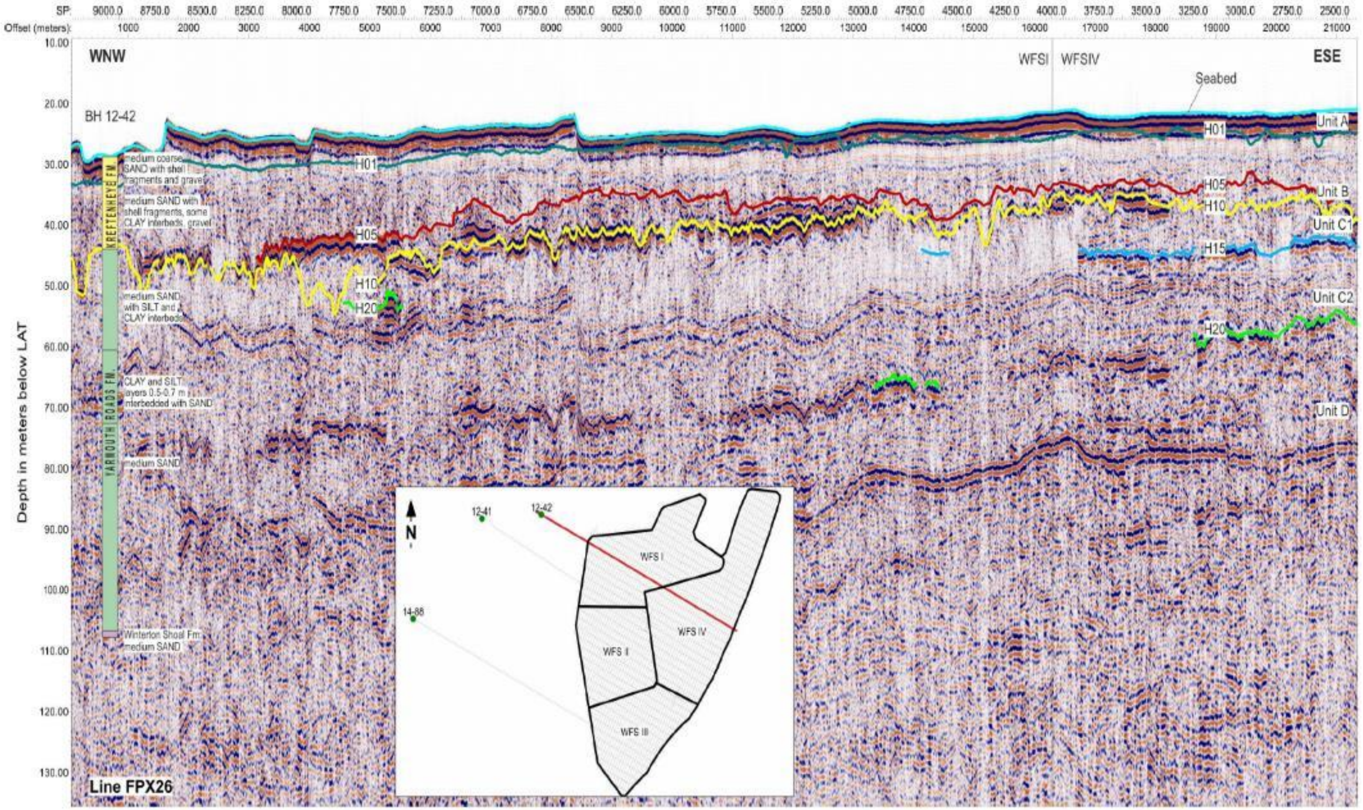
Geophysical Investigation - Equipment and Resolution

Sensor Type	Equipment	Resolution
Multibeam Echo Sounder	Kongsberg EM2040 dual-head	▪ The theoretical footprint ranges from 0.1 m to 0.5 m. A bin cell size of 0.5 m was used for the creation of the final DTM. Targets smaller than 0.5 m may not be identified in the final DTM ▪ The Danish Technical University (DTU13) model was used for vertical (tide) reduction. The vertical accuracy was generally observed to be within 0.15 m
Sidescan Sonar	EdgeTech 4200-FS (100/600 kHz)	Lateral resolution of approximately 0.2 m
Magnetometer	G-882 Marine magnetometer	-
Sub-bottom Profiler	Massa TR-1075 pinger 4x4+2 array (hull-mounted)	The useful acoustic penetration was generally limited due to local geological constraints to about 10 ms (approximately 8 m) below seabed. The vertical resolution is estimated as 0.1 m
Single Channel Seismic	GSO 100-tip parker with Geo-Resources Geo-Sense mini-streamer	The vertical resolution is estimated at 0.5 m
Multi Channel Seismic	GSO 540-tip dual-frequency sparker with Geometrics GeoEel 48 channel streamer (half-fold recording)	The vertical resolution is estimated at 0.5 m in the shallower part (average Vp of ~1600 m/s) to 0.9 m in the deeper part (Vp of ~1800 m/s).

Note: Geophysical (SSS, SBP, MBES and MAG) and reflection seismic (UHR) scopes/surveys were combined in a single pass acquisition campaign

Geophysical Investigation – Ground Model Development

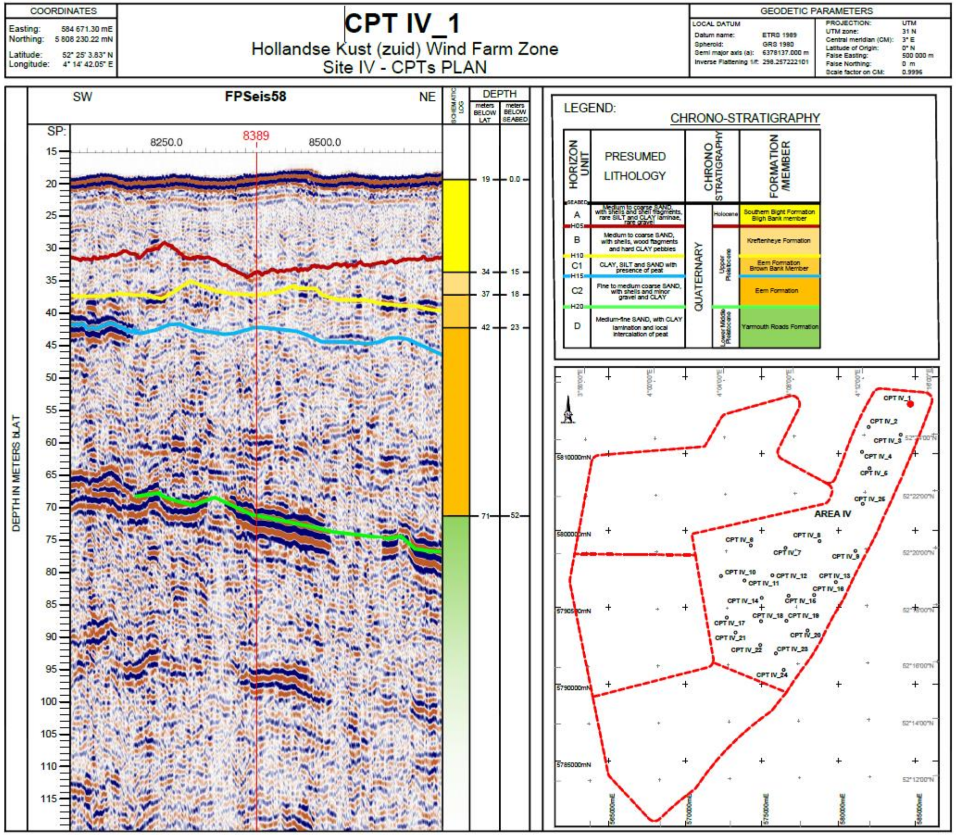
- RVO desk studies
- Geophysical SI
- First Ground Model
- Seafloor Testing SI
- Borehole Drilling SI
- Laboratory Test Prog.
- Final Ground Model



Geophysical Investigation – Geotechnical Investigation Plan

Key considerations for location selection:

- Characterisation of (main) geological features / identified layers
- Adequate coverage of main units for refinement of geophysical ground model
- Preferably located on seismic reflection lines to limit uncertainty resulting from lateral offset
- Avoiding seafloor objects and magnetic anomalies



Geotechnical Investigation – Seafloor In Situ Test Phase

- RVO desk studies
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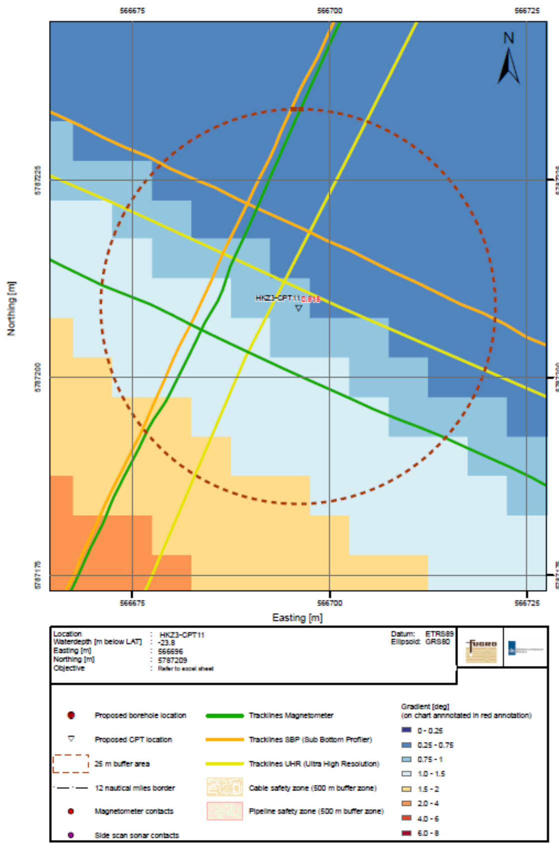
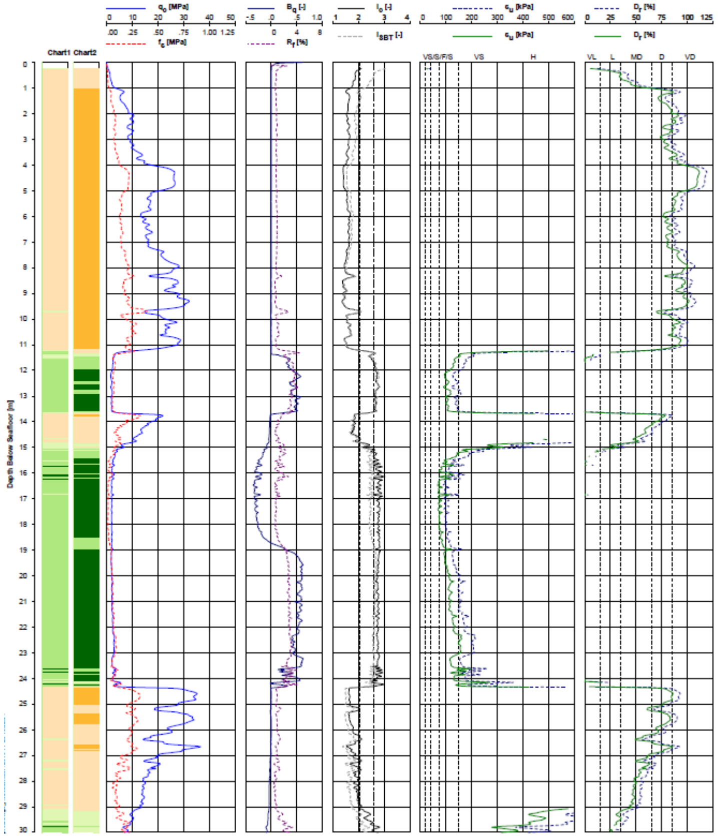
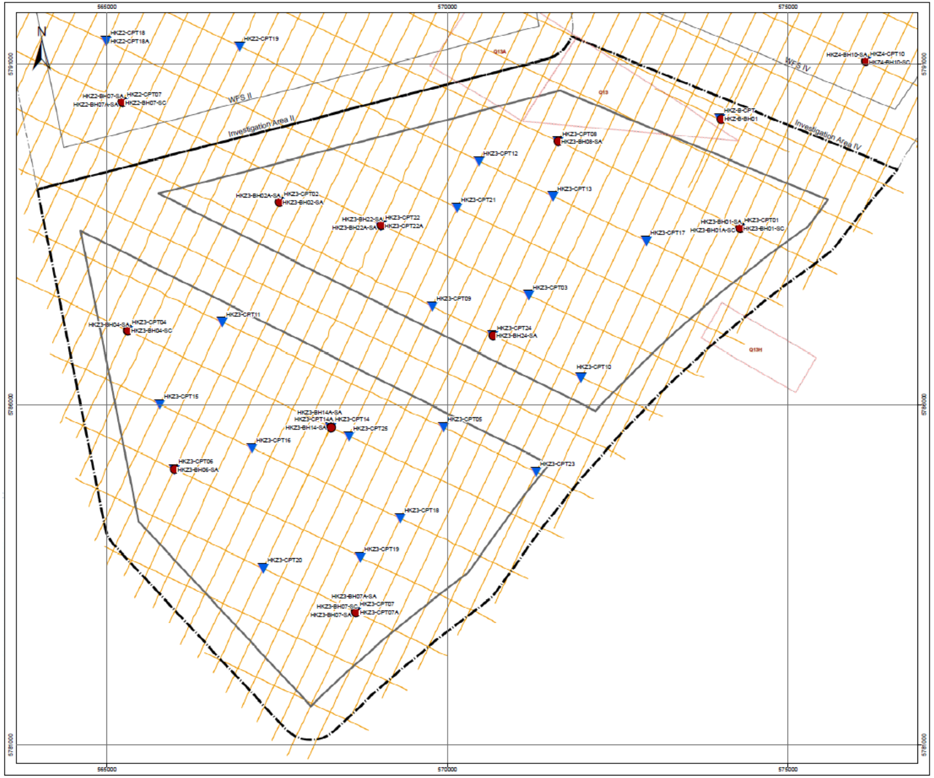
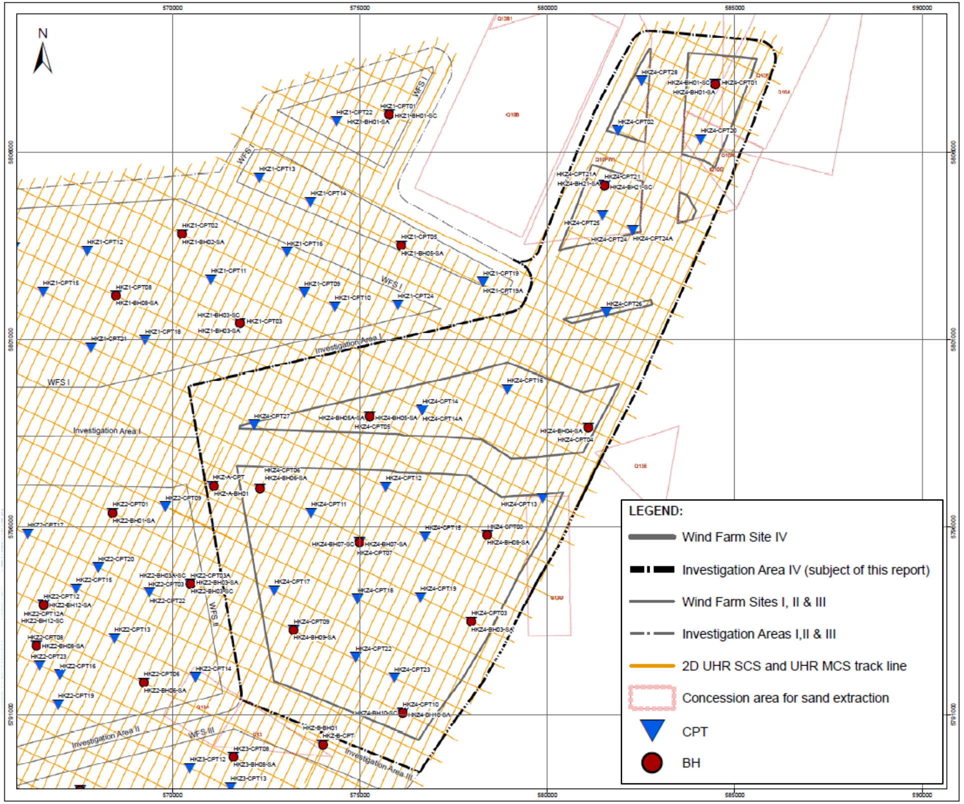
- Final Ground Model





Geotechnical Investigation – Seafloor In Situ Test Phase



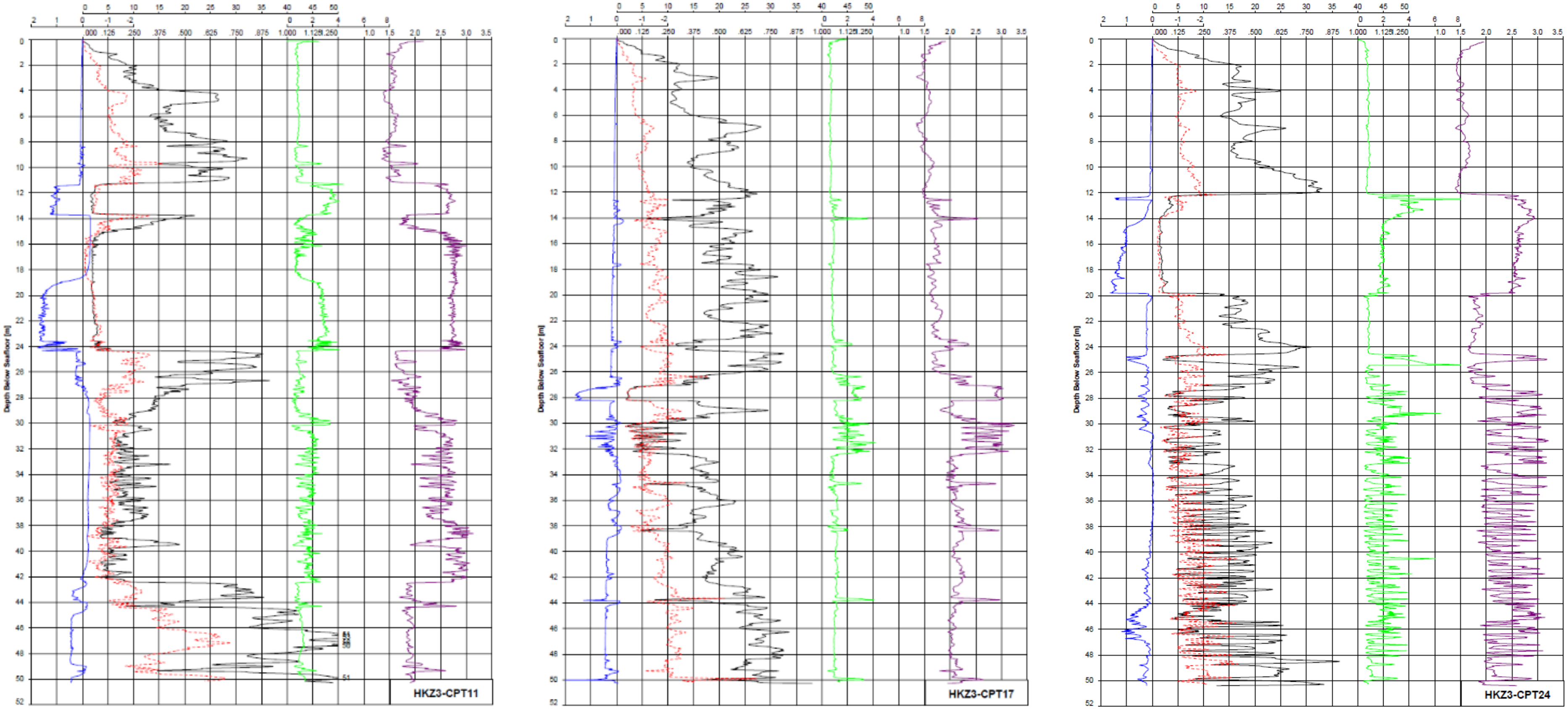


Geotechnical Investigation – Seafloor In Situ Test Phase

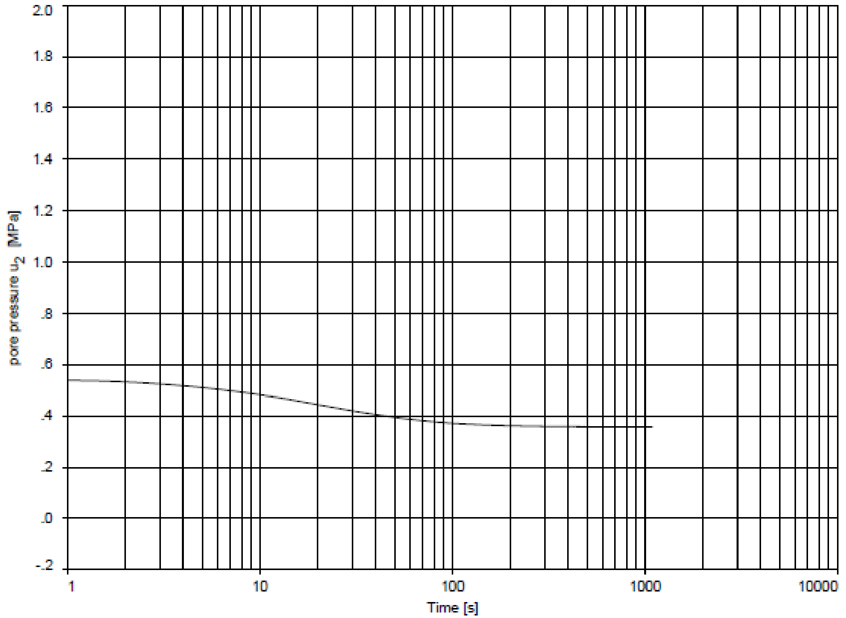
- SEACALF® 20 tons double block-drive unit with 1500 mm^2 piezo-cone penetrometers
- WFS III: 28 seafloor PCPT (at 25 distinct locations) to depths of 26.1m to 51.1m BSF, including 19 PPDT
- WFS IV: 31 seafloor PCPT (at 28 distinct locations) to depths of 28.9 m to 50.8 m BSF, including 44 PPDT

Hollandse Kust (zuid) - Overview Penetration Performance seafloor in-situ testing										
Penetration Depth [m]	WFS3		WFS4		WFS1+2		WFS3+4		Totals	
	[No.]	[%]	[No.]	[%]	[No.]	[%]	[No.]	[%]	[No.]	[%]
0m to 45m	4	14%	9	29%	3	6%	13	22%	16	15%
45m to 50m	2	7%	7	23%	10	20%	9	15%	19	17%
>50m	22	79%	15	48%	38	75%	37	63%	75	68%
Total	28		31		51		59		110	

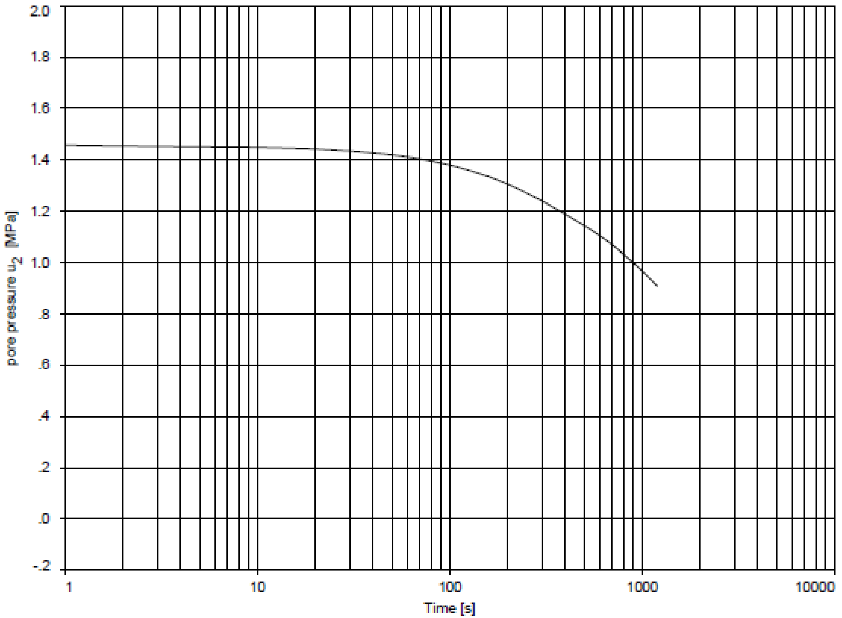
Geotechnical Investigation – Seafloor In Situ Test Phase



Geotechnical Investigation – Seafloor In Situ Test Phase



location	:	HKZ4-CPT08	pore pressure at start	:	0.536	MPa
date of testing	:	22-Jul-2016	pore pressure at end	:	0.356	MPa
dissipation test depth	:	14.3 m below seafloor				
water depth reduced to LAT	:	21 m				
measured water depth	:	21.2 m				
note	:	pressures relative to atmospheric				



location	:	HKZ4-CPT02	pore pressure at start	:	1.472	MPa
date of testing	:	23-Jul-2016	pore pressure at end	:	0.907	MPa
dissipation test depth	:	25.1 m below seafloor				
water depth reduced to LAT	:	19.1 m				
measured water depth	:	19.2 m				
note	:	pressures relative to atmospheric				

Geotechnical Investigation – Borehole Drilling Phase

- RVO desk studies
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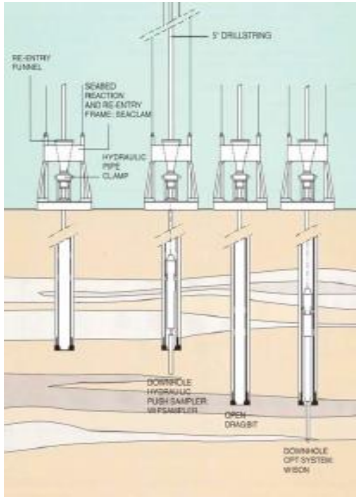
- Final Ground Model

Location	Order	Borehole	Target Co-ordinates Easting [m]	Target Co-ordinates Northing [m]	Water Depth [m LAT]	Distance following [m]	Depth from [m]	Depth To [m]	Testing / Sampling
WFS4-06	01	HKZ4-BH06-SA	572342	5797025	21.1	-	0	50	Sample
WFS4-08	02	HKZ4-BH08-SA	578401	5795785	21.2	-	0	50	Sample
WFS4-03	03	HKZ4-BH03-SA	577976	5793476	19.9	2380	0	50	Sample
WFS4-10	04	HKZ4-BH10-SA	576146	5791038	20.5	3050	0	50	Sample
							50	65	CPT/Sample
	05	HKZ4-BH10-SC					0	50	SCPT
WFS3-01	06	HKZ3-BH01-SA	574302	5788589	20.0	3050	0	50	Sample
							50	65	CPT/Sample
	07	HKZ3-BH01-SC					0	50	SCPT



Geotechnical Investigation – Borehole Drilling Phase

WFS III - 17 boreholes (at 9 distinct locations) to depths of ~20 m to ~66 m BSF

- 4 x boreholes with sampling (*TD = 50 m BSF*)
- 5 x boreholes with sampling to ~25 m to ~45 m BSF, followed by sampling & CPT (*TD = 50 m BSF*)
- 4 x boreholes with sampling to ~50 m BSF followed by sampling and CPT (*TD = 65 m BSF*)
- 4 x boreholes with seismic CPT with seismic shear wave testing (*TD = 50 m BSF*)

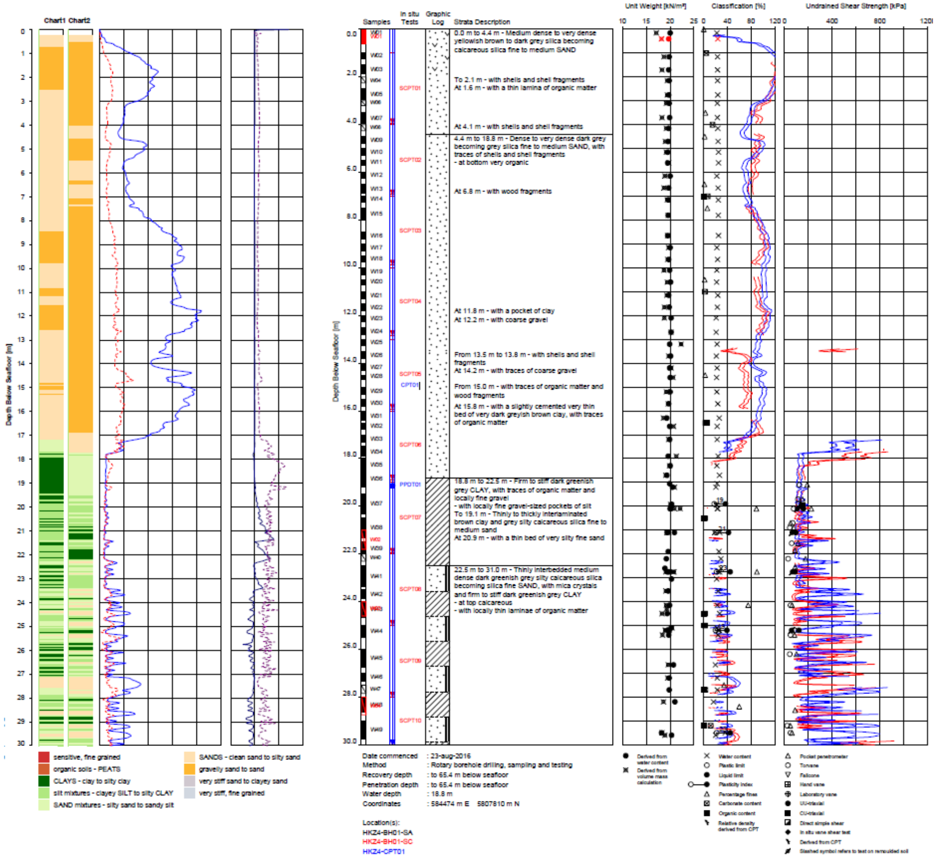
WFS IV - 15 boreholes (at 10 distinct locations) to depths of ~3 m to ~65 m BSF

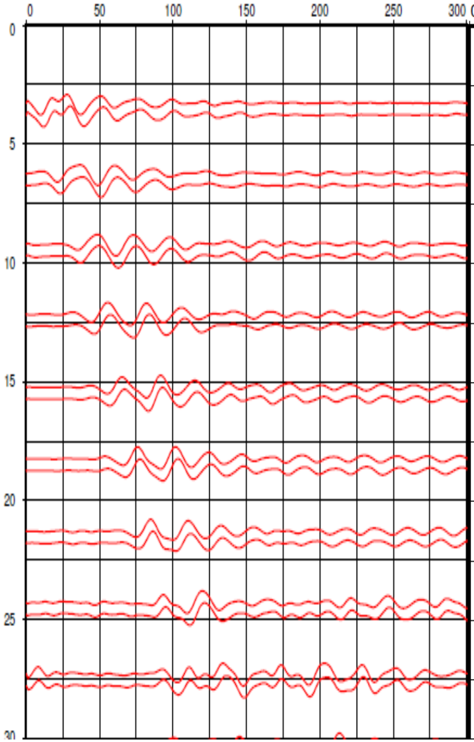
- 4 x boreholes sampling (*TD = 50 m BSF*)
- 2 x boreholes sampling to ~36 m BSF followed by sampling & CPT (*TD = 50 m BSF*)
- 5 x boreholes sampling to ~47 m and ~50 m followed by sampling & CPT (*TD = 65 m BSF*)
- 4 x boreholes with seismic CPT with shear wave testing (*TD = 50 m BSF*)

Geotechnical Investigation – Borehole Drilling Phase

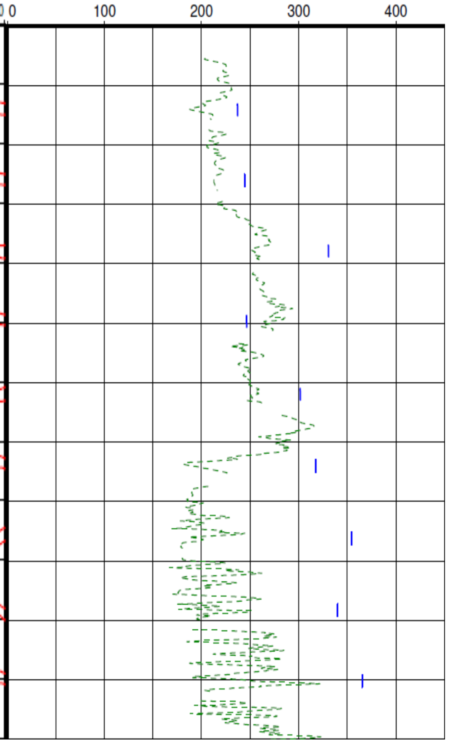
- Locations (seafloor CPT and boreholes) within approximately 5m radius from target location
- Open-hole rotary drilling (API-type drill string, 7”-drag bit) with SEACLAM for drill support
- WISON® downhole tools with 500 mm^2 and 1000 mm^2 cone-penetrometers
- Seismic CPTs with double seismic array (x, y, z), hydraulic underwater shear hammer on SBF
- WIP sampler with selection of Shelby tubes (2- and 3-inch / thin & thick walled / core catcher/ inner liner)

Geotechnical Investigation – Borehole Drilling Phase





Stacked seismic trace (Y-component)
Time [ms] vs depth [m BSF]



Shear Wave Velocity
[m/s] vs depth [m BSF]

Geotechnical Investigation – Laboratory Testing

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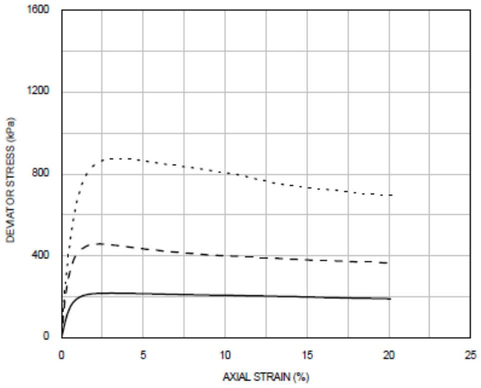
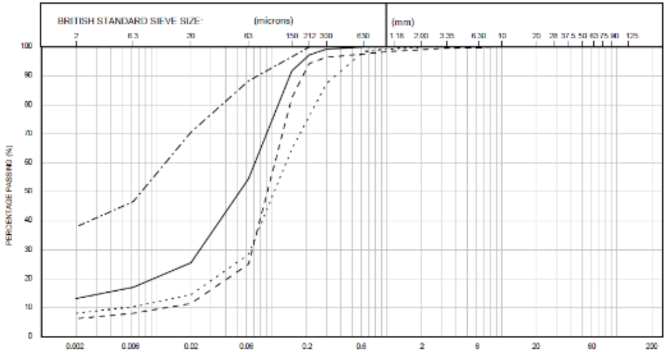
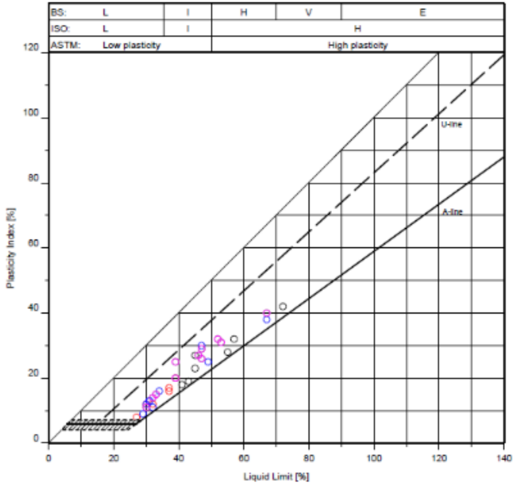
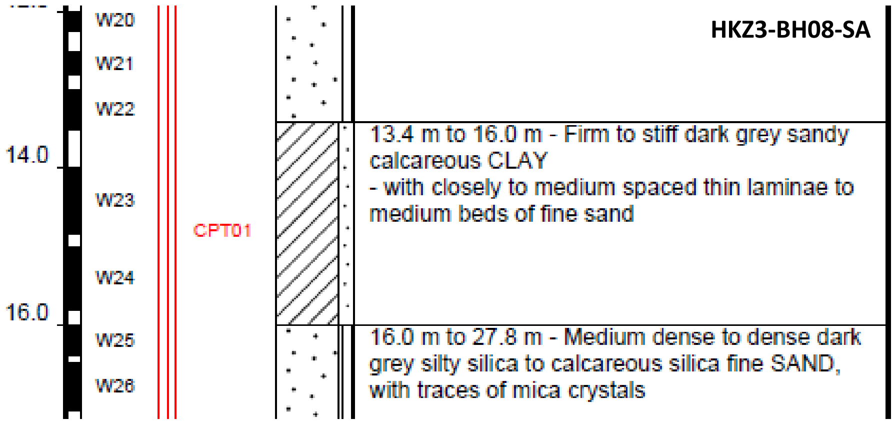






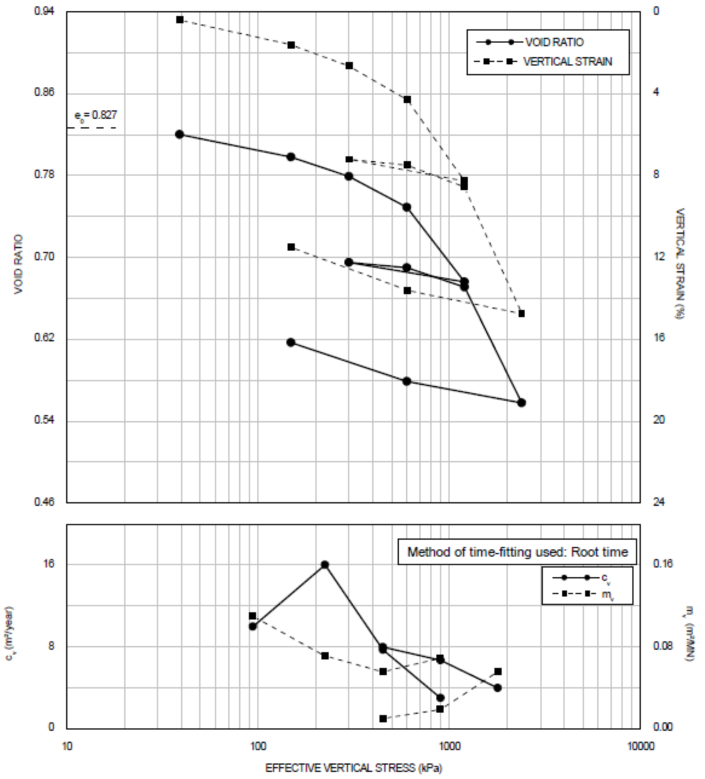
Laboratory Testing – Site Programme

- Sample description *(according BS 5930, BSI,1999)*
- Sample photography *(intact and split)*
- Geotechnical index (*water content, unit weight)*
- Index strength *(TV, PP and UU triaxial)*



Laboratory Testing – Standard Programme

- Confirm and extend site findings (classification / characteristics)
- Test (in principle) all major (>2m thickness) layers identified
- Allow for sufficient data points to confirm heterogeneity or homogeneity of individual layers across the sites
- Test (where relevant) anomalies and/or unusual soil bodies
- Test execution in general accordance with ISO 19901- part 8, supplemented with (inter)national standards such as BS or ASTM



Laboratory Testing – Standard Programme

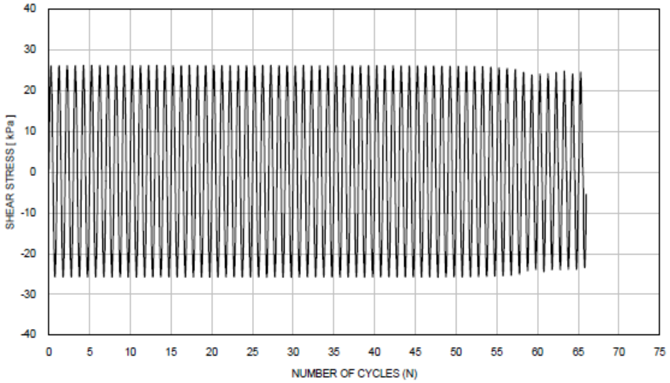
Test Type	WFS III	WFS IV
Geotechnical Index		
Density of Solid Particles (Small Pycnometer)	64	72
Particle Size Analysis (Sieving and Pipette)	142	194
Minimum and Maximum Index Dry Unit Weight	48	59
Atterberg Limits	53	69
Geochemical		
Carbonate Content	108	116
Organic Content (dichromate oxidation / mass loss on ignition)	61 / 7	80 / 11
Strength (Index)		
Unconsolidated Undrained Triaxial compression (UU) – undisturbed / remoulded	37 / 39	36 / 40
Isotropically Consolidated Undrained Triaxial (CIUc) / with bender element testing	5 / 6	10 / 11
Isotropically Consolidated Drained Triaxial (CIDc) / with bender element testing	21 / 20	21 / 24

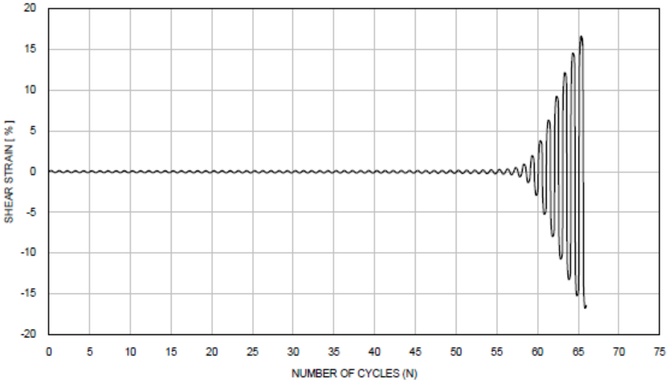
Laboratory Testing – Standard Programme

Test Type	WFS III	WFS IV
Interface Angle		
Ring Shear (Soil-Soil Interface / Soil-Steel Interface)	10 / 21	9 / 29
Compressibility		
Incremental Loading (IL) Oedometer	8	13
Constant Rate of Strain (CRS) Oedometer	9	17
Other		
Permeability Tests	8	12
Thermal Conductivity	9	12
Microscopic Inspection and Photography	27	27

Laboratory Testing – Advanced Programme

- Advanced test programme prepared in consultation with client
- Build upon and extend information from sites WFSI&II
- Provide a broad use of test results of (1) soils predominantly present across the sites, and (2) soils relevant future design
- Variety of test types, specimens conditions and loading conditions
- Test execution in general accordance with ISO 19901- part 8





Laboratory Testing – Advanced Programme

Test Type	Total	A	B1	B2	C1	C2	D
Geotechnical Index							
Particle size analysis (sieving and pipette) (PSD)	**5**	1	1	-	-	1	2
Sample micro photography	49	23	10	-	-	6	10
Shear (Static)							
Direct Simple Shear (DSS)	**10**	1	2	1	1	3	2
Shear (Cyclic)							
Stress-controlled Cyclic Simple Shear (CSS)	**44**	7	10	4	4	11	8
Strain-controlled Cyclic Simple Shear (CSS)	**12**	-	4	-	4	4	-
Triaxial (Static)							
(An)Isotropically Consolidated Undrained Triaxial compression/extension (CIUc/CAUc/CAUe)	**4 / 3 / 1**	1 / - / -	1 / - / -	1 / - / -	1 / - / -	- / 2 / 1	- / 1 / -
Isotropically Consolidated Drained Triaxial compression (CIDc)	**2**	1	1	-	-	-	-

Laboratory Testing – Advanced Programme

Test Type	Total	A	B1	B2	C1	C2	D
Triaxial (Cyclic)							
Stress-controlled Isotropically Consolidated Undrained Cyclic Triaxial (CTX)	**8**	2	2	1	3	-	-
Stress-controlled Anisotropically Consolidated Undrained Cyclic Triaxial (CTX)	**10**	-	-	-	-	6	4
Stress-controlled Isotropically Consolidated Drained Cyclic Triaxial (CTX)	**8**	4	4	-	-	-	-
Triaxial (Dynamic)							
Bender Element (BE)	**10**	1	2	1	1	3	2
Resonant Column (RC)	**7**	1	1	1	1	2	1

Site Characterization – Ground Model

RVO desk studies

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Geophysical SI

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First Ground Model

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Seafloor Testing SI

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Borehole Drilling SI

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Laboratory Test Prog.

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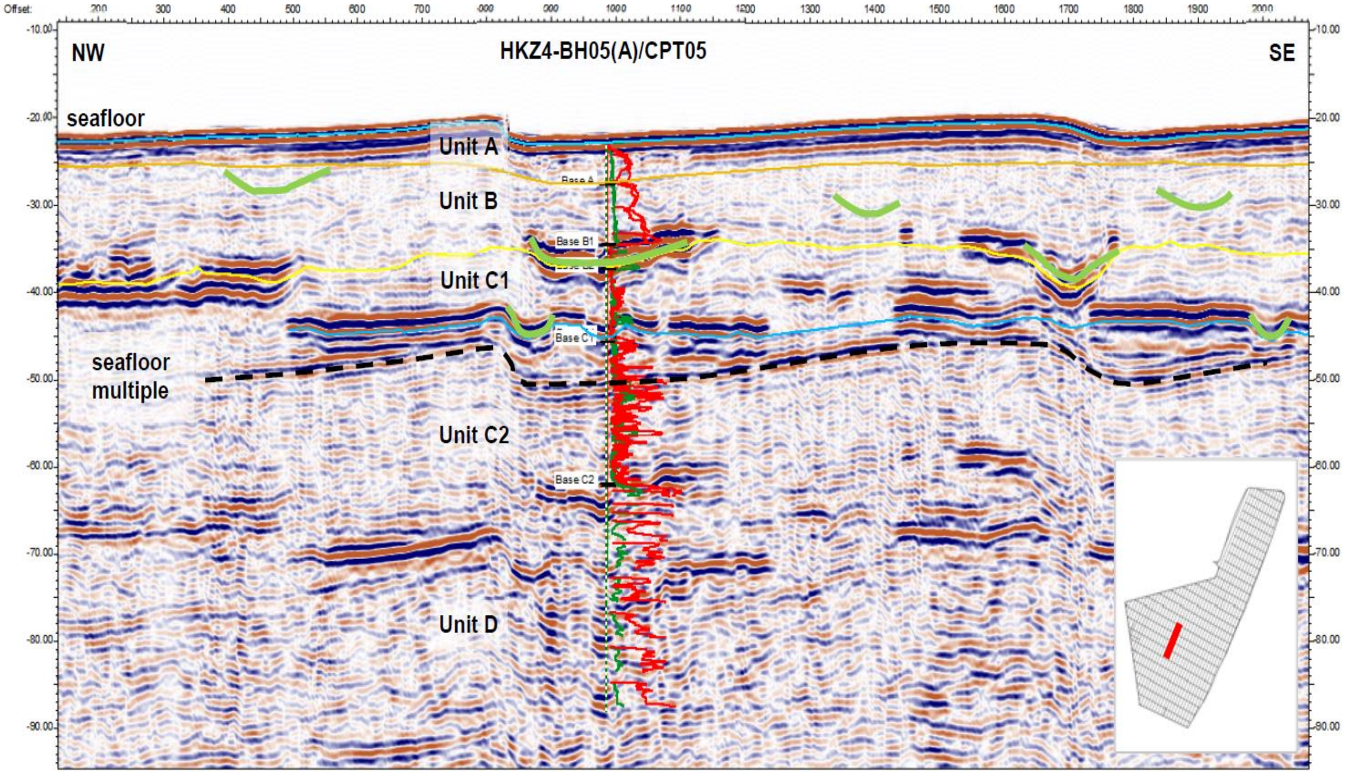
Final Ground Model



Deliverables

Geophysical and Geotechnical Deliverables – Reports

Report Number	Title	Contents
GH176-R3	Geophysical Site Investigation Survey - Wind Farm Site III	Geophysical site survey data with accompanying charts (track plots, bathymetry, seafloor sediment classification, contacts, geohazards, geological charts and profiles).
GH176-R4	Geophysical Site Investigation Survey - Wind Farm Site IV	
N6196/05	Investigation Data - Geotechnical Borehole Locations - Wind Farm Site III	Geotechnical data including geotechnical logs, results from downhole (seismic) cone penetration tests and results from geotechnical laboratory tests.
N6196/07	Investigation Data - Geotechnical Borehole Locations - Wind Farm Site IV	
N6196/06	Investigation Data - Seafloor In Situ Test Locations Wind Farm Site III	Geotechnical data including geotechnical logs, results from seafloor cone penetration tests and pore pressure dissipation tests.
N6196/08	Investigation Data - Seafloor In Situ Test Locations Wind Farm Site IV	
N6196/11	Geological Ground Model – Wind Farm Site III	Geological ground model including stratigraphy, lateral soil variability, geohazards, geological analyses, biostratigraphic analyses, basic geotechnical parameter values and assessment of geotechnical suitability of selected types of structures.
N6196/12	Geological Ground Model – Wind Farm Site IV	
N6196/14	Laboratory Test Data – Wind Farm Sites III & IV	Results of advanced static and cyclic laboratory tests.

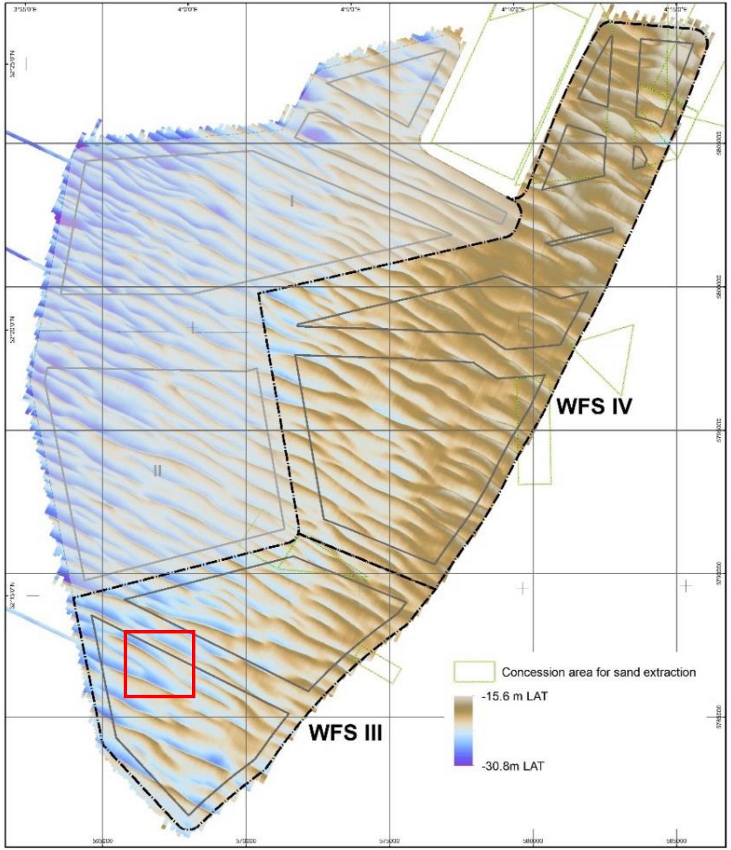
Geophysical and Geotechnical Deliverables – Digital

<table>
<tr><th>Project Phase</th><th colspan="2">Data (Format)</th></tr>
<tr><td rowspan="2">Geophysical</td><td>Raw data</td><td>▪ Multibeam echo sounder (.all, .xyz , .svp)
▪ Sidescan Sonar (.xtf)
▪ Magnetometer (.csf)
▪ Sub-bottom Profiler (.segY)
▪ 2D UHR seismic (.segD)
▪ Tidal data (.csv)</td></tr>
<tr><td>Processed Data</td><td>▪ Multibeam echo sounder (.xyz, .xyb, GeoTiff)
▪ Sidescan Sonar (.GeoTiff)
▪ Magnetometer (Oasis Montaj project)
▪ Sub-bottom Profiler (Kingdom project)
▪ 2D UHR Seismic (Kingdom project, .segY - migrated sections time and depth, near trace)
▪ ArcGIS geodatabase</td></tr>
<tr><td>Geotechnical</td><td colspan="2">▪ (S)CPT- data (.ags, .asc) / raw seismic shots (.asc) & stacked seismic traces (.xls)
▪ sampling/borehole/standard laboratory – data (.ags)</td></tr>
<tr><td>Ground Model</td><td colspan="2">▪ Kingdom project
▪ ArcGIS geodatabase</td></tr>
</table>

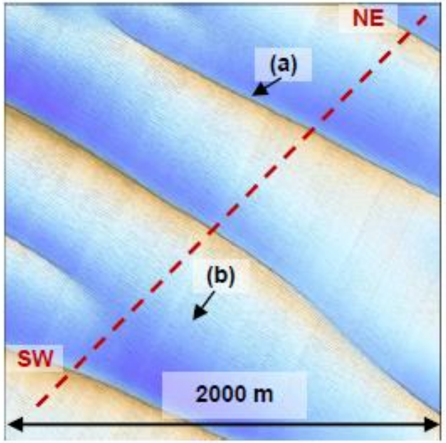
Geological Ground Model

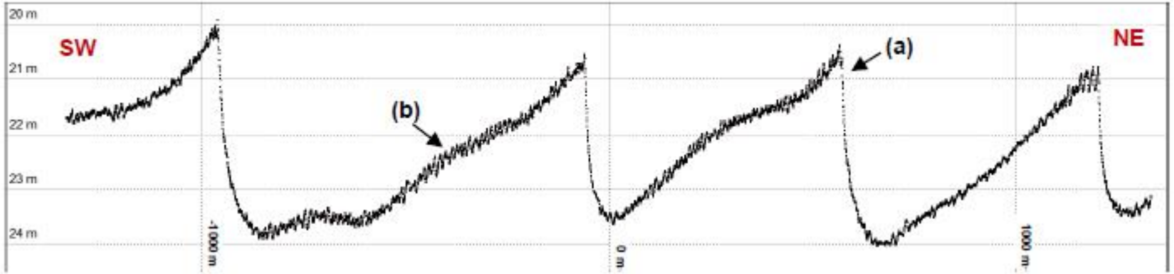
Geological Ground Model - Bathymetry

- The bathymetry shows a dynamic morphology characterised by a complex pattern of bedforms (very large dunes), with superimposed medium dunes
- Very large dunes have NW to SE trending crests with heights ranging from 2 to 6 m
- Maximum gradients of up to 10° on the lee sides of the very large dunes
- WFS III: 18.6 m bLAT to 25.3 m bLAT
- WFS IV: 15.6 m bLAT to 24.5 m bLAT



Geological Ground Model – Seafloor bedforms (WFSIII)

Class	Wavelength	Height	Bedform description	Data example
1	300-1000 m 4-20 m	2-6 m 0.2-0.4 m	Very large 2D and 3D dunes with superimposed medium 2D dunes	



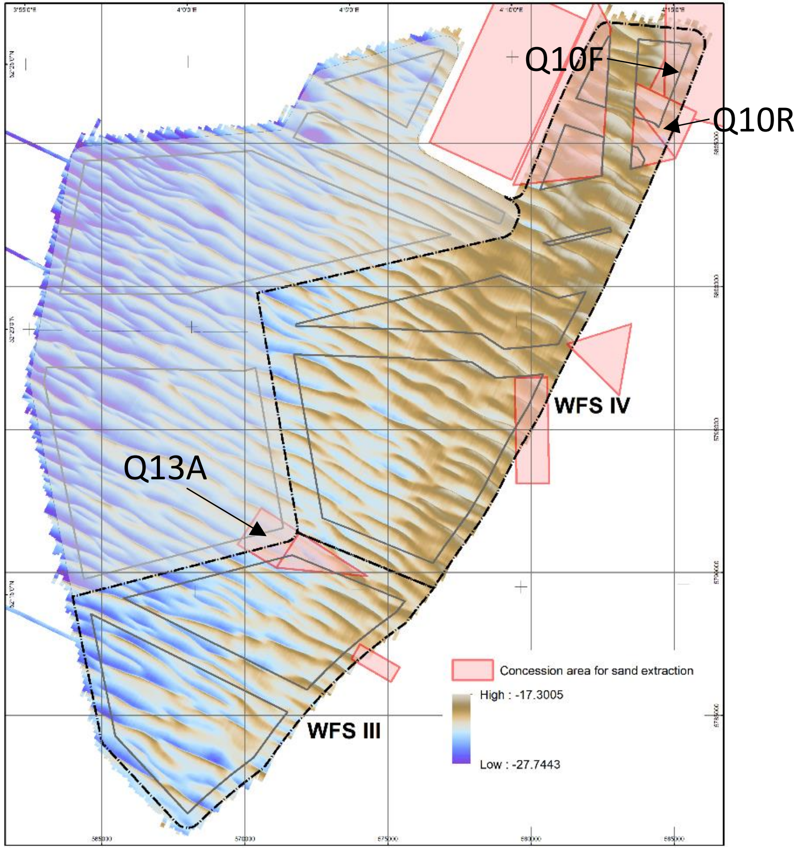
Bathymetry – Concession Areas for Sand Extraction

WFSIII:

- 3 concession areas
- Sand extraction area Q13A has not been used since 2002 (no current permit applies)
- No information on historic dredging in the area

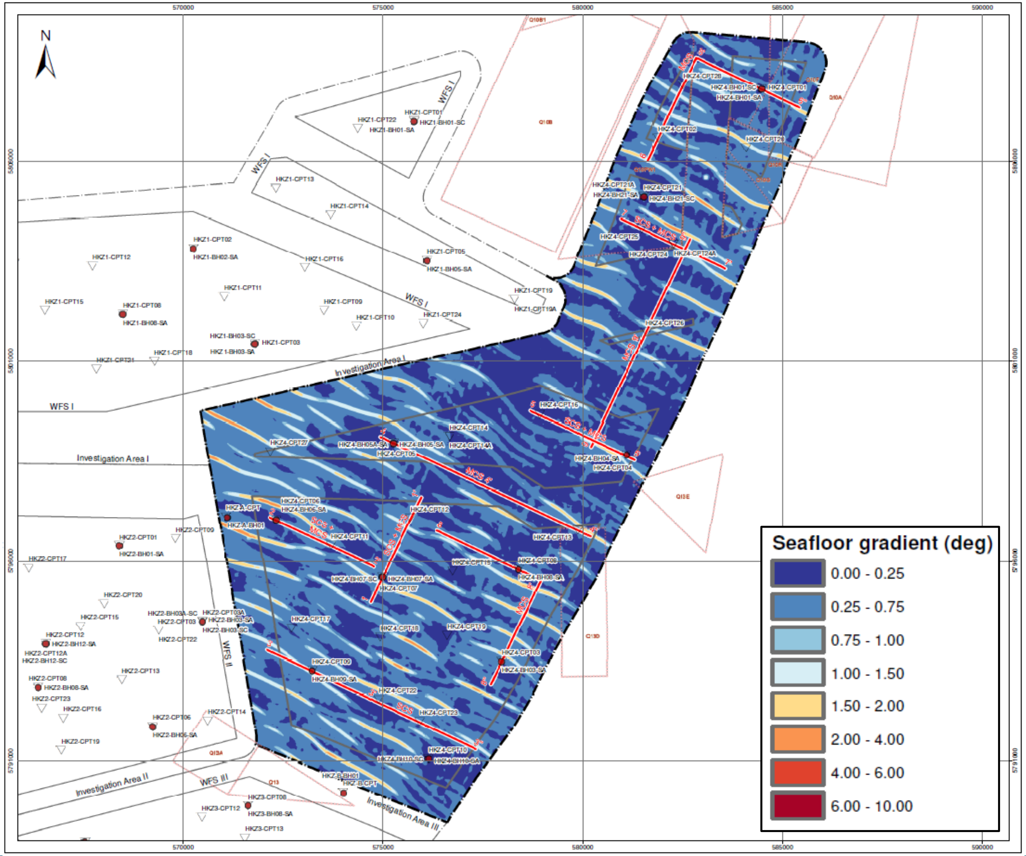
WFSIV

- Multiple concession areas within or partially overlapping WFS IV
- Q10F and Q10R reportedly active with maximum dredging depth of 2 m BSF until 31 December 2018.
- MBES bathymetric data shows local evidence of past dredging in these areas (increased water depth – up to 2 metres)



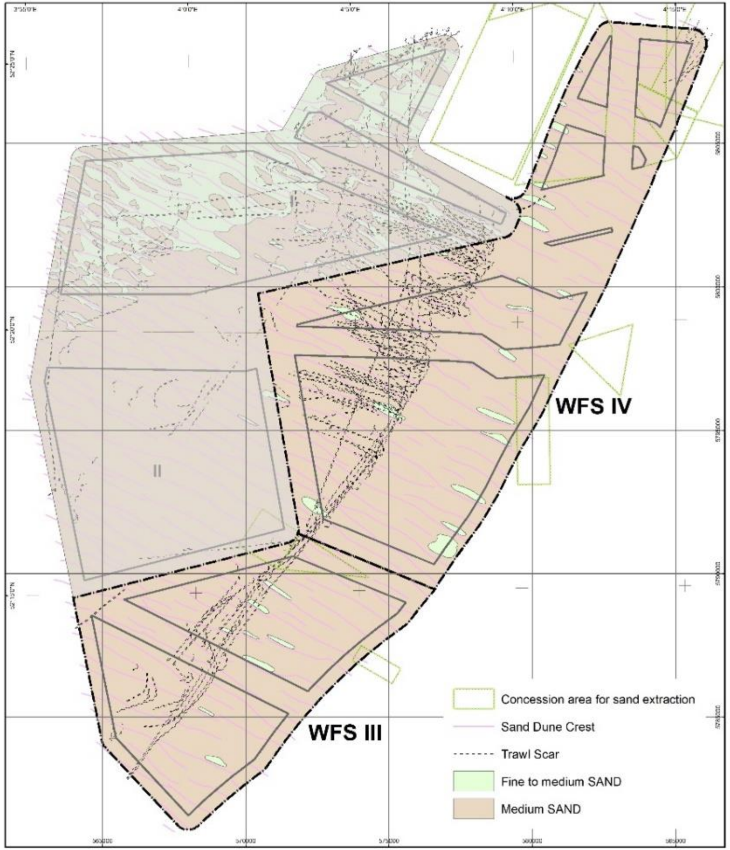
Geological Ground Model – Seafloor Gradient

- Seafloor gradient determined by presence of very large dunes and mega ripples
- General gradients < 1.5°
- Steep gradients > 10° occur on the lee sides of the seafloor dunes and mega ripples



Seafloor Sediments - Overview

- Sediments are classified as fine to medium SAND and medium SAND
- Only few patches of fine to medium SAND in WFS III and WFS IV
- Seafloor trawl scars occur within WFS III and WFS IV (outside 12 nautical mile zone)
- Very large dunes with NW to SE trending crests



Seafloor Conditions - Infrastructure

WFSIII:

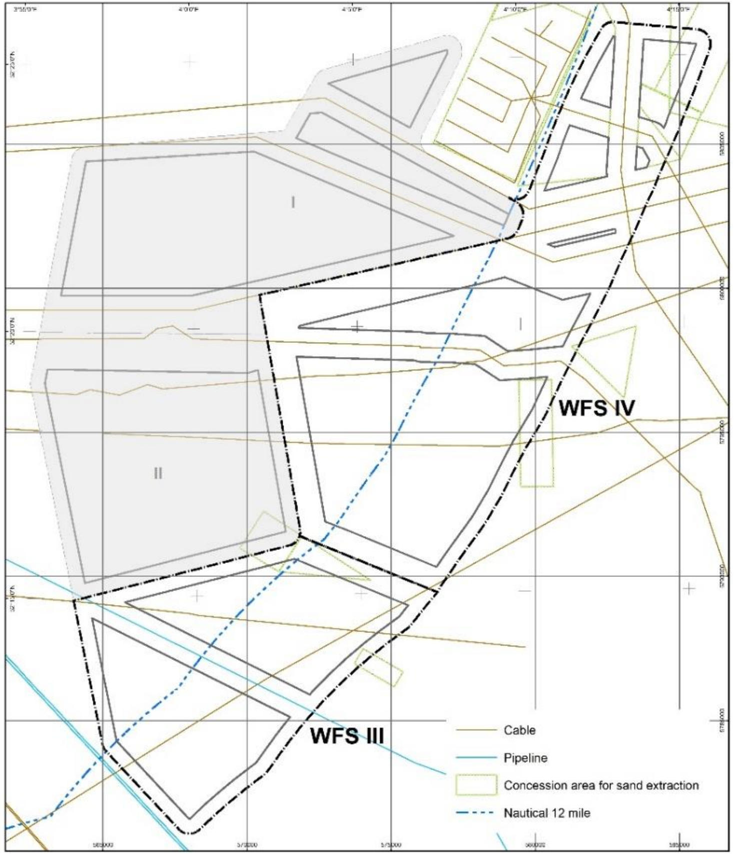
- 1 pipeline
- 3 cables

	MAG	SSS	MBES	As-found position
Cables				
Concerto 1E (abandoned)	YES	NO	NO	Observed by magnetometer data to be up to 30 m offset with respect to the provided database position
UK – NL 7 (abandoned)	YES	NO	NO	Observed by magnetometer data to be up to 80 m offset with respect to the provided database position
Pipelines				
ENGIE Q13a-A to P15-C 8 inch pipeline	YES	NO	NO	Observed by magnetometer at the provided database position at 0 m offset.
Notes: Please note that the magnetometer data have a horizontal accuracy of approximately 1-3 m.				

WFSIV:

- no pipelines
- 9 cables

	MAG	SSS	MBES	As-found position
Cables				
Tat 14 Seg J	YES	NO	NO	Observed by magnetometer at the provided database position at 0 m offset.
Eneco_WP_Q10_Power-Cable	YES	NO	NO	Observed by magnetometer data to be up to 35 m offset with respect to the provided database position
Concerto 1N	YES	NO	NO	Observed by magnetometer data to be up to 35 m offset with respect to the provided database position
Ulysses 2	YES	NO	NO	Observed by magnetometer at the provided database position at 0 m offset.
Circe 1 North	YES	NO	NO	Observed by magnetometer at the provided database position at 0 m offset.
Hermes 1	NO	NO	NO	Not observed
Tat 14 Seg I	YES	NO	NO	Observed by magnetometer at the provided database position at 0 m offset.
UK – NL 6 (abandoned)	YES	NO	NO	Observed by magnetometer at the provided database position at 0 m offset.
Concerto 1E (abandoned)	YES	NO	NO	Observed by magnetometer data to be up to 250 m offset with respect to the provided database position
Unknown	YES	NO	NO	Potential unknown cable (or pipeline)
Notes: Please note that the magnetometer data have a horizontal accuracy of approximately 1-3 m				



Seafloor Conditions - Contacts and Wrecks

WFS III

- 96 SSS contacts
- 585 MAG contacts

Sensor	Contact classification	No. contacts
SSS	Suspected debris	52
	High backscatter	38
	Boulders	4
	Linear debris	1
	Cable	0
	Pipeline	0
	Wrecks	1

Sensor	Contact classification		No. contacts
Magneto-meter	Unknown		415
	Cables	UK – NL 7 (abandoned)	23
		Concerto 1E (abandoned)	55
	Pipelines	Q13a-A to P15-C 8 inch oil pipeline	91
		P15-C to Hoek van Holland 10 inch oil trunkline	1
	Wrecks		0

- 1 wreck was identified from SSS and MBES data, 3 known wrecks could not be identified from the acquired data.

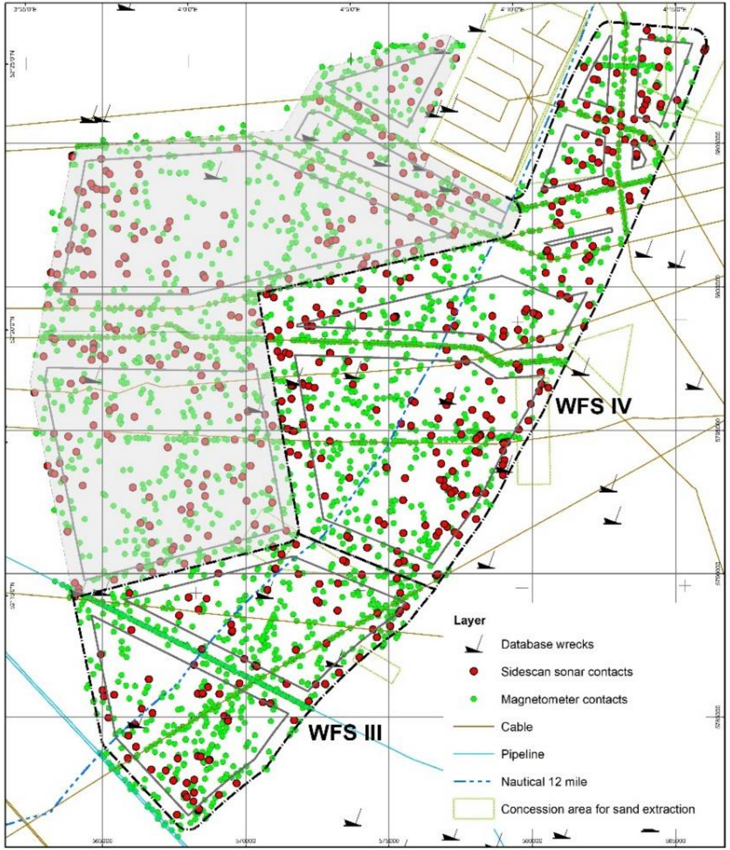
WFS IV

- 234 SSS contacts
- 860 MAG contacts

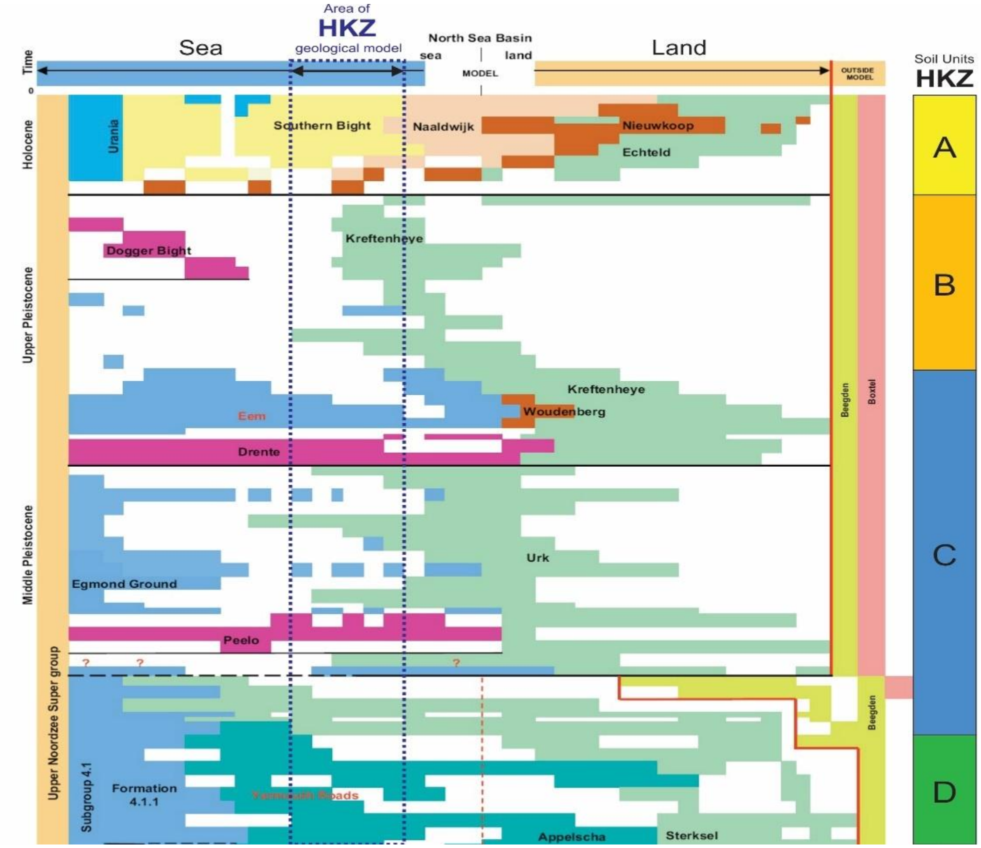
Sensor	Contact Classification	No. Contacts
SSS	Suspected debris	92
	High backscatter	111
	Boulders	19
	Linear debris	8
	Cable	0
	Pipeline	0
	Wrecks	4

Sensor	Contact Classification		No. Contacts
Magneto-meter	Unknown		589
	Cables	Tat 14 Seg I	76
		UK – NL 6 (abandoned)	43
		Tat 14 Seg J	39
		Concerto 1N	38
		Eneco_WP_Q10_Power Cable	25
		Circe 1 North	20
		Ulysses 2	7
		Concerto 1E (abandoned)	1
		Hermes 1	0
	Unknown linear feature		21
	Pipelines		0
	Wrecks		1

- 4 wrecks were identified from SSS, MBES and MAG data, 3 known wrecks could not be identified from the acquired data.



Geological Ground Model – Lithostratigraphic Framework



Marine deposits
- Undivided
- open marine, low energy
- open marine, high energy
- coastal and lagoonal deposits

Fluvial deposits
- Fluvial, Rhine / Meuse
- Fluvial, Eridanos (Baltic)
- Fluvial, Middle Germany / Bohemian
- Fluvial, Proto Rhine / Meuse

Glacial deposits
- Undivided

Peat
- Peat

Local terrestrial deposits
- Undivided

Meuse system
- Fluvial deposits of the Meuse (terraces)

Source: Rijsdijk et al., 2005

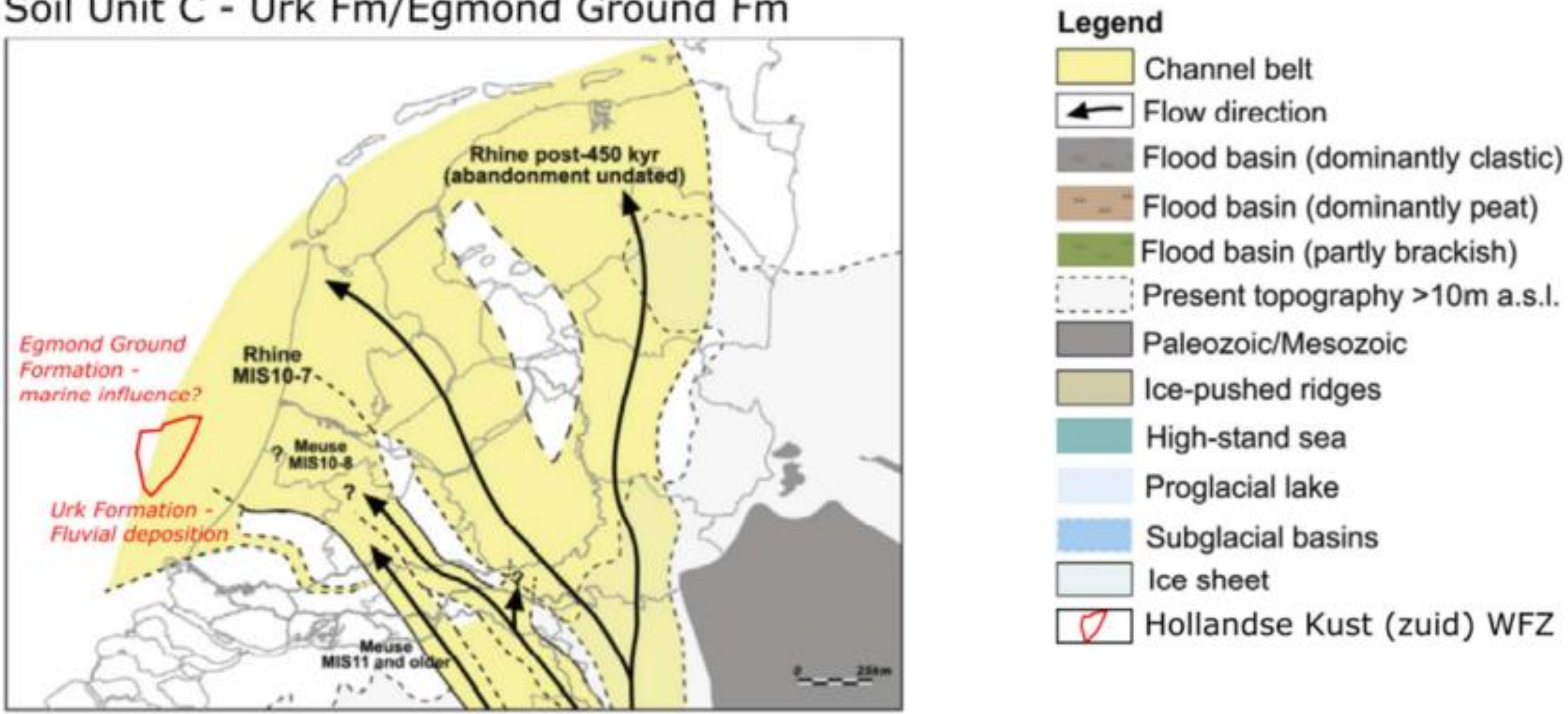
Geological Ground Model – Lithostratigraphic Framework

Soil Unit		Rijsdijk et al. 2005				Geological Dating Analysis	
Unit	Sub-unit	Formation	Member	Age	Epoch	Depositional Environment	Age
A		Southern Bight	Bligh Bank	Holocene	Holocene	marine	Holocene
B	B1	Kreftenheye		Weichselian Eemian (Saalian)	Upper Pleistocene Holocene	fluvial to coastal plain	Weichselian
	B2					lacustrine	Weichselian (prior to LGM)
C	C1	Eem Drente Egmond Ground Urk	Brown Bank	Eemian Saalian Holsteinian	Middle to Upper Pleistocene	marine	Eemian (Early Late Pleistocene)
	C2					fluvio-deltaic to estuarine to coastal plain with marine influences	Cromerian to Saalian (Middle Pleistocene)
D		Yarmouth Roads (possibly Winterton Shoal, Ijmuiden Ground)		Elsterian Waalian	Lower Pleistocene	fluvio-lacustrine	Tiglian(?) to Waalian (Early to Middle Pleistocene)

Source: Rijsdijk, K.F., Passchier, S., Weerts, H.J.T., Laban, C., Van Leeuwen, R.J.W., and Ebbing, J.H.J., 2005. Revised Upper Cenozoic Stratigraphy of the Dutch Sector of the North Sea Basin: towards an Integrated Lithostratigraphic, Seismostratigraphic and Allostratigraphic Approach. Netherlands Journal of Geosciences – Geologie en Mijnbouw, Vol. 84, No. 2, p. 129-146.

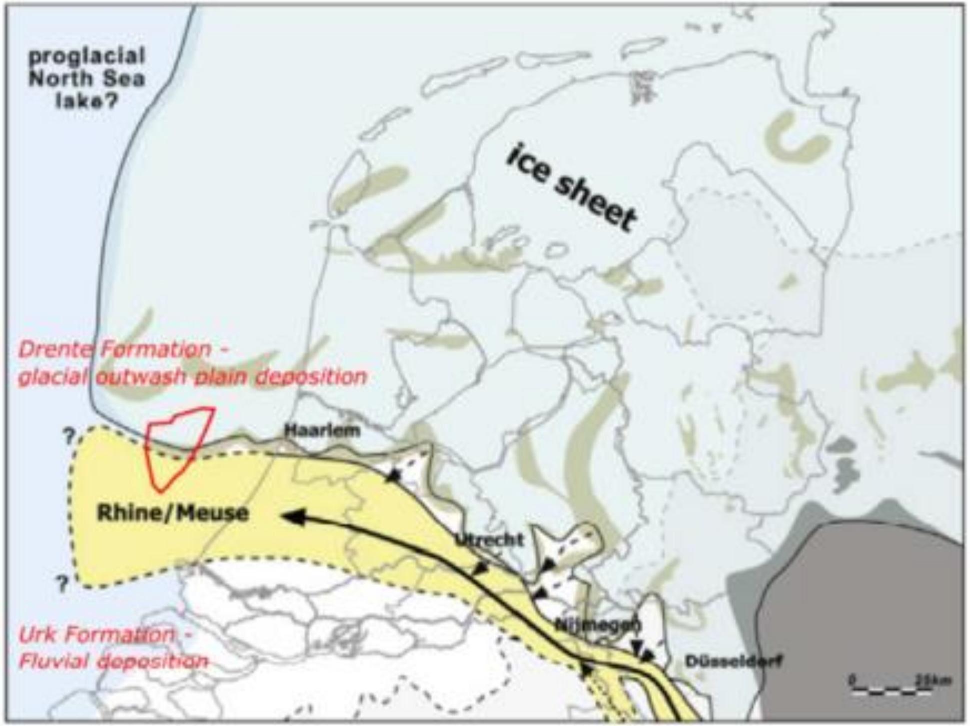
Geological Ground Model – Site Setting

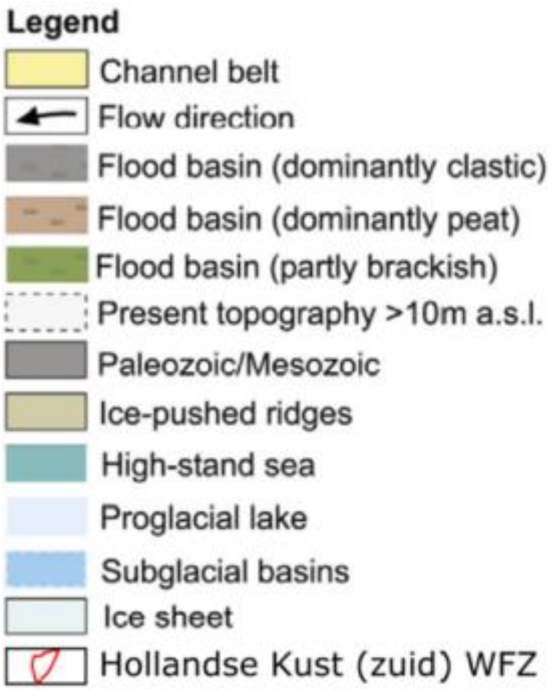
Prior to Saalian glaciation:
Soil Unit C - Urk Fm/Egmond Ground Fm



Geological Ground Model – Site Setting

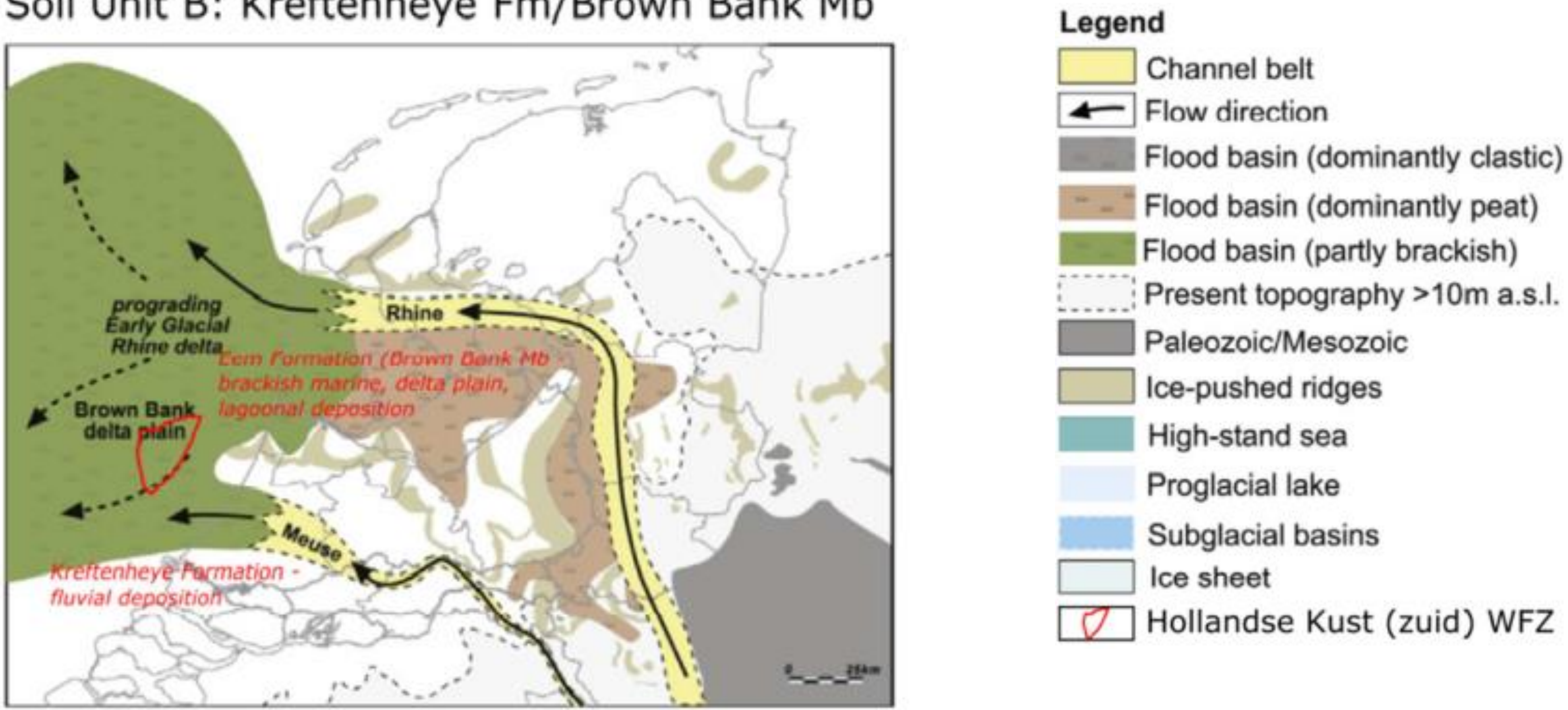
Saalian maximum ice extent:
Soil Unit C - Urk Fm/Drente Fm





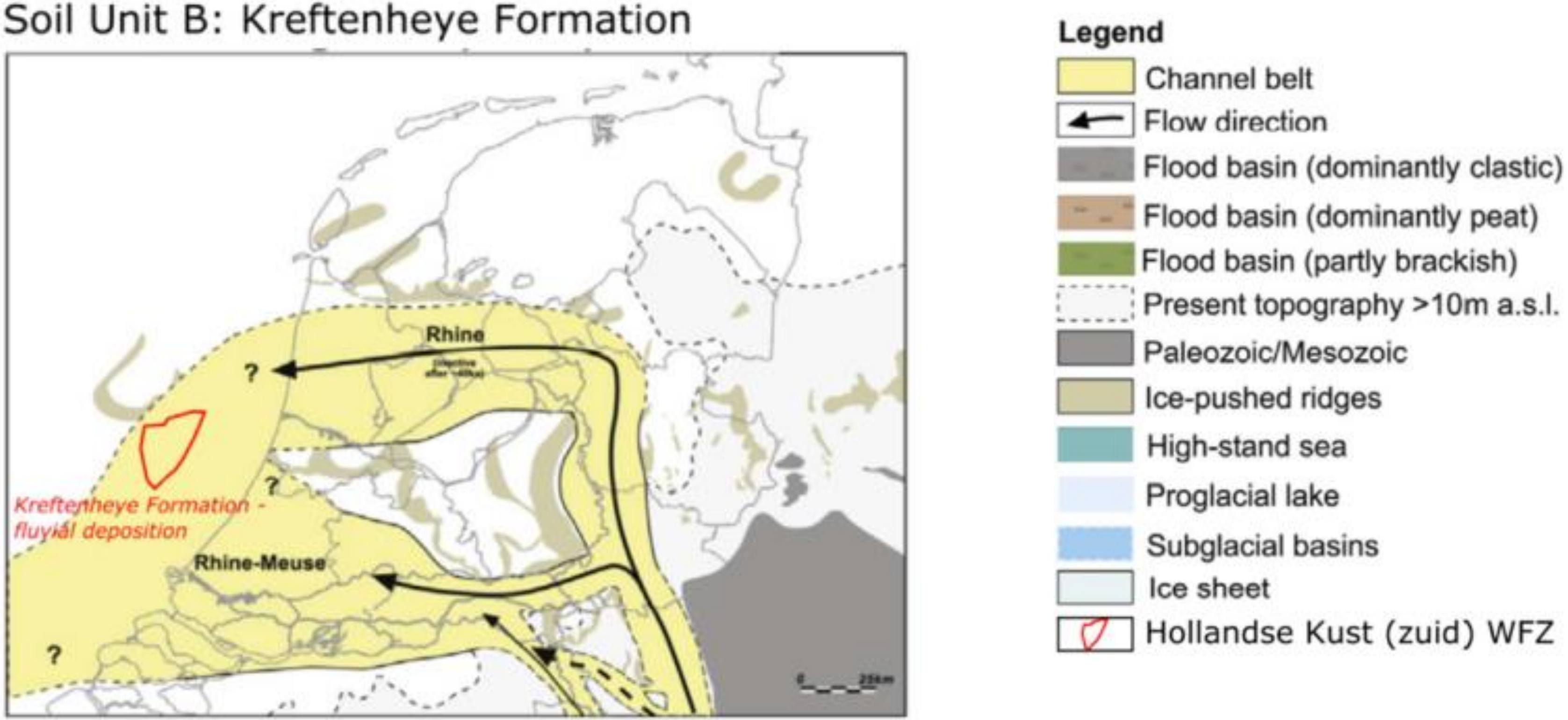
Geological Ground Model – Site Setting

Late Eemian Marine Regression/Early Weichselian:
Soil Unit B: Kreftenheye Fm/Brown Bank Mb



Geological Ground Model – Site Setting

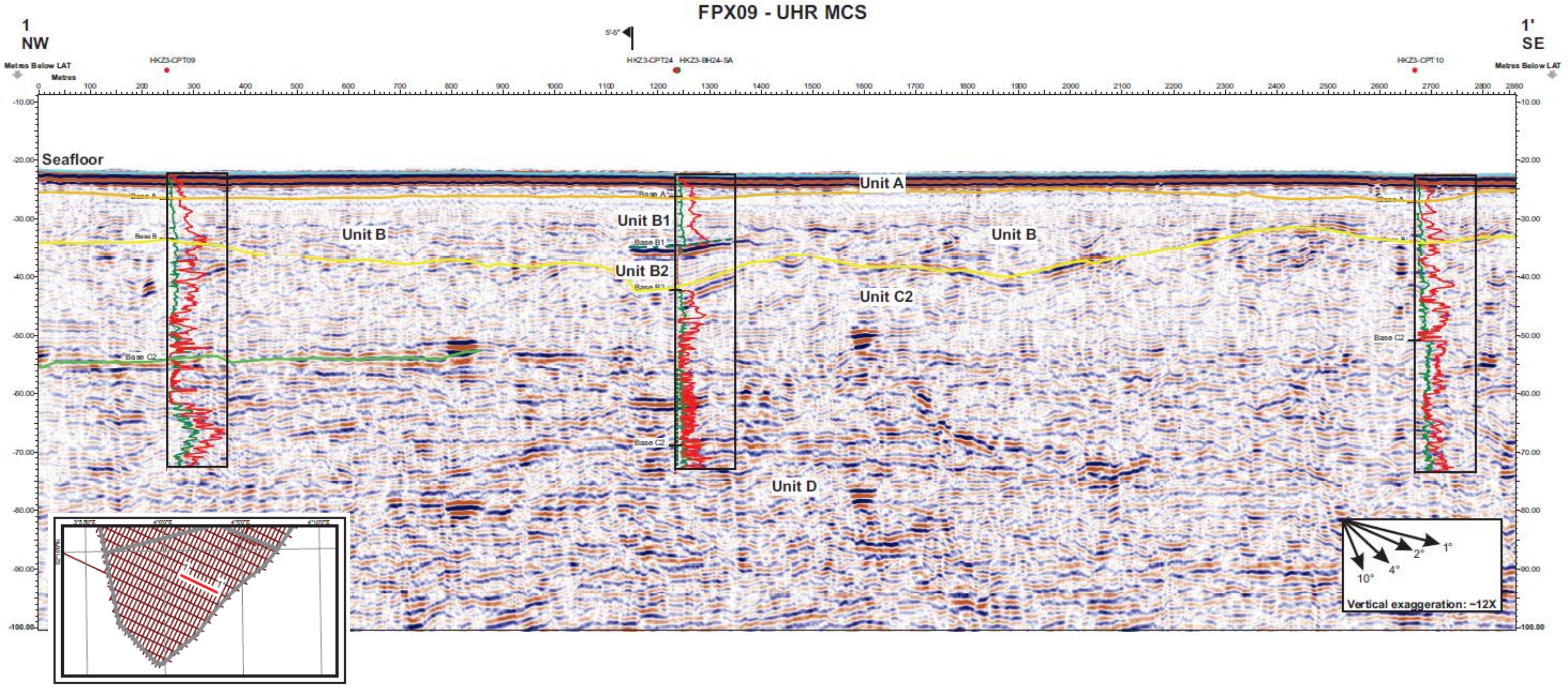
Middle Weichselian:
Soil Unit B: Kreftenheye Formation



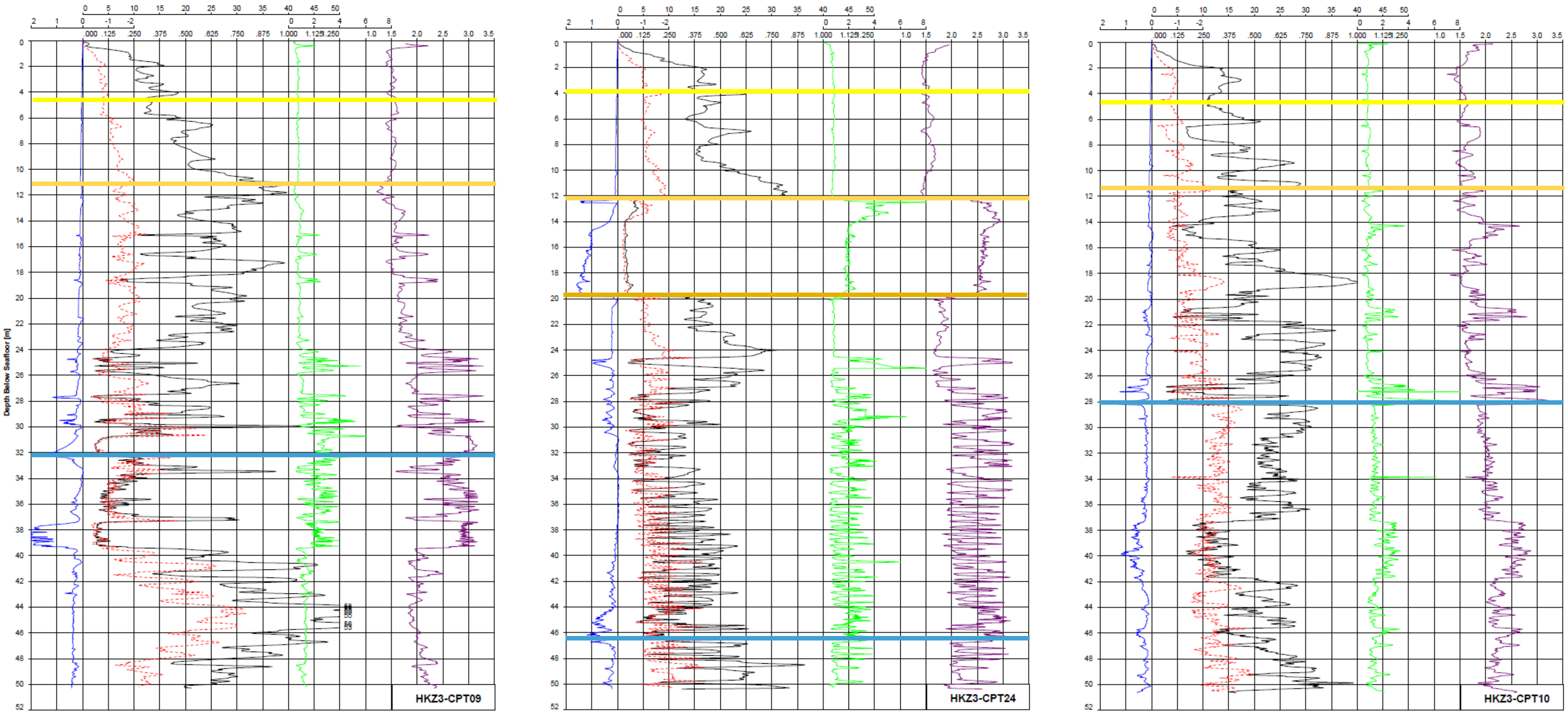
Geological Ground Model – Site Setting

Soil Unit	Soil Sub Unit	WFS III	WFS IV	WFS III	WFS IV	Soil Description
		Depth to Base of Unit [m LAT]		Thickness Range [m]		
DS	-	not known	not known	not known	not known	Disturbed SAND and/or CLAY (locally present in sand extraction areas)
A	-	23 to 29	22 to 28	1 to 7	1 to 8	Dense to very dense silica fine to coarse SAND with shell fragments
B	B1	29 to 46	30 to 45	4 to 19	5 to 21	Dense to very dense silica fine to medium SAND
	B2					Firm to hard clay to calcareous CLAY, with laminae of sand and silt
C	C1	-	38 to 55	-	0 to 22	Interbedded medium dense to very dense silica SAND and firm to hard calcareous CLAY
	C2	50 to 62	52 to 77	9 to 28	9 to 42	Medium dense to dense silica fine to medium SAND, with laminae and beds of clay/silt
D	-	>90	>90	> 40	>38	Medium dense to dense silica fine to coarse (silty/clayey) SAND with laminae of clay; and very stiff to hard (sandy) CLAY with laminae of sand

Geological Ground Model – Site Setting



Geological Ground Model – Site Setting



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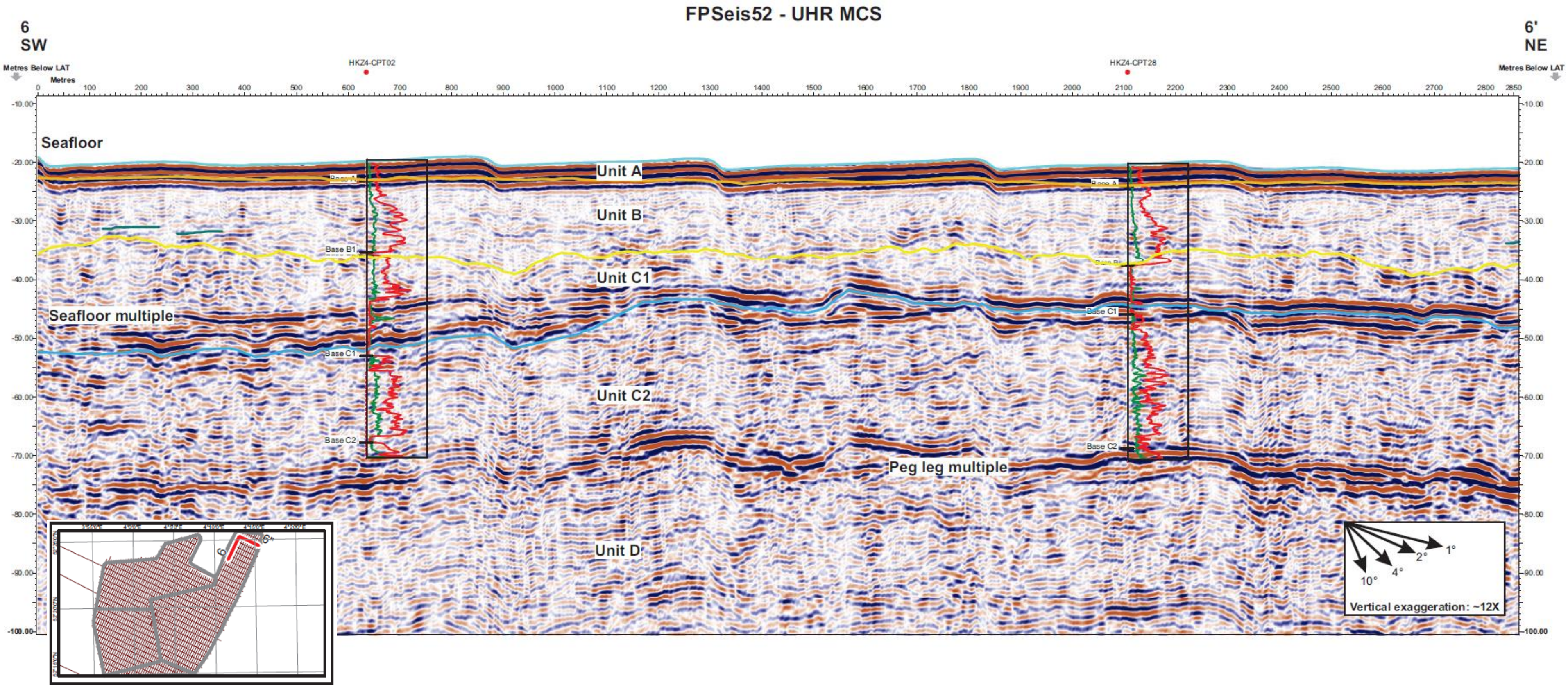

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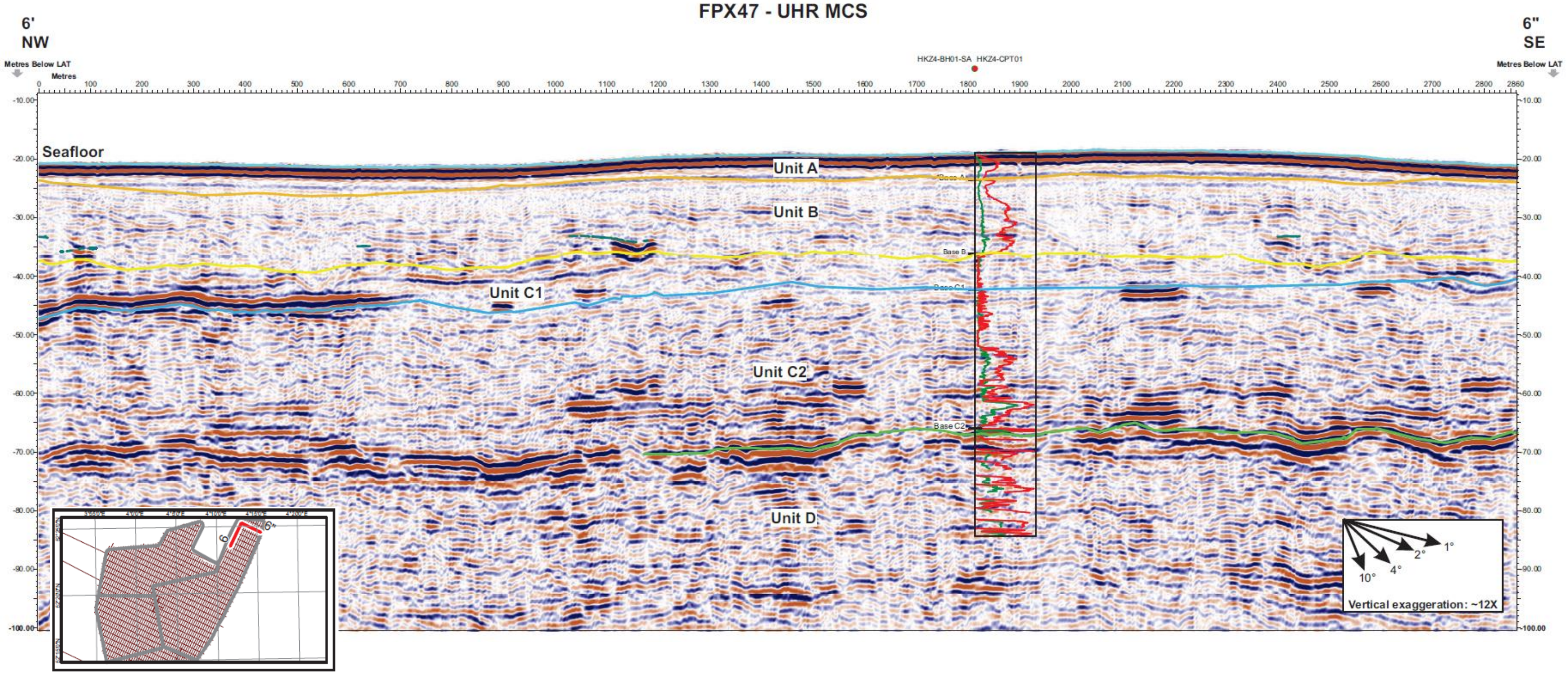
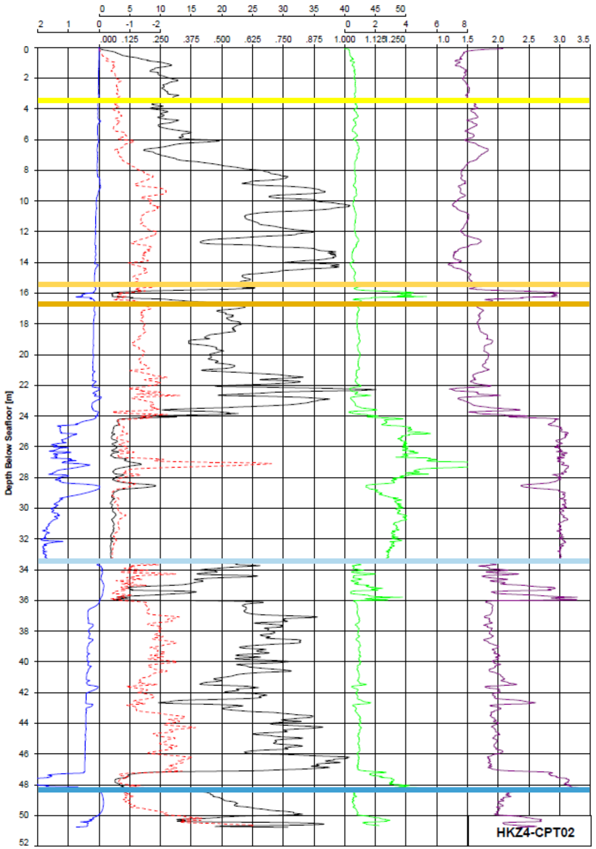
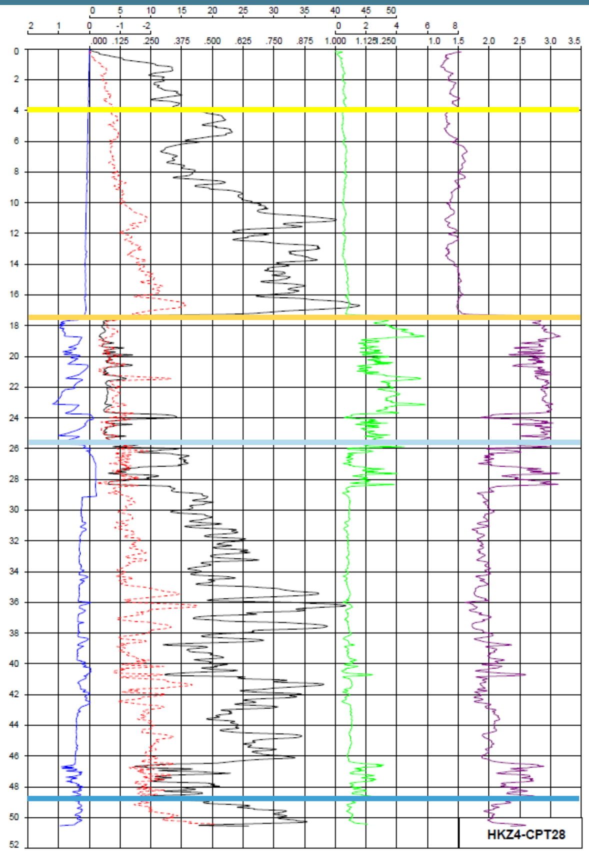
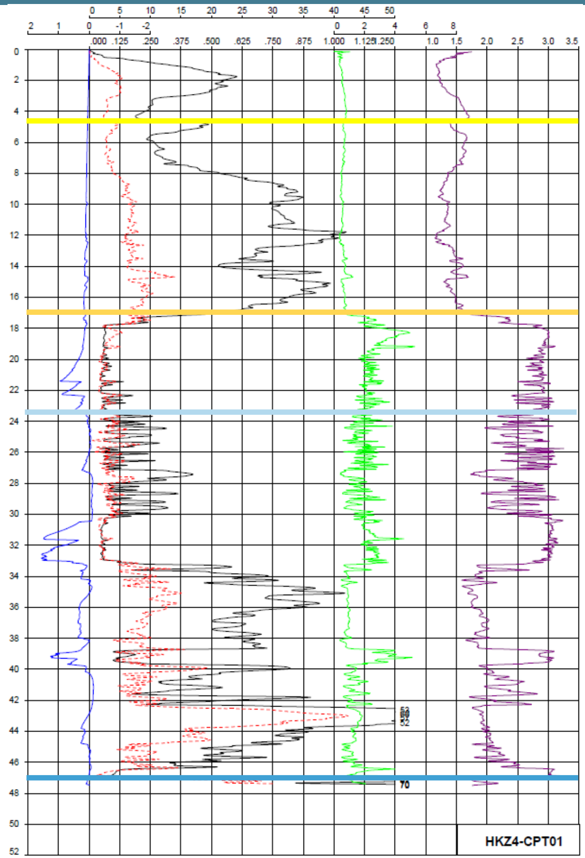


Geological Ground Model – Site Setting



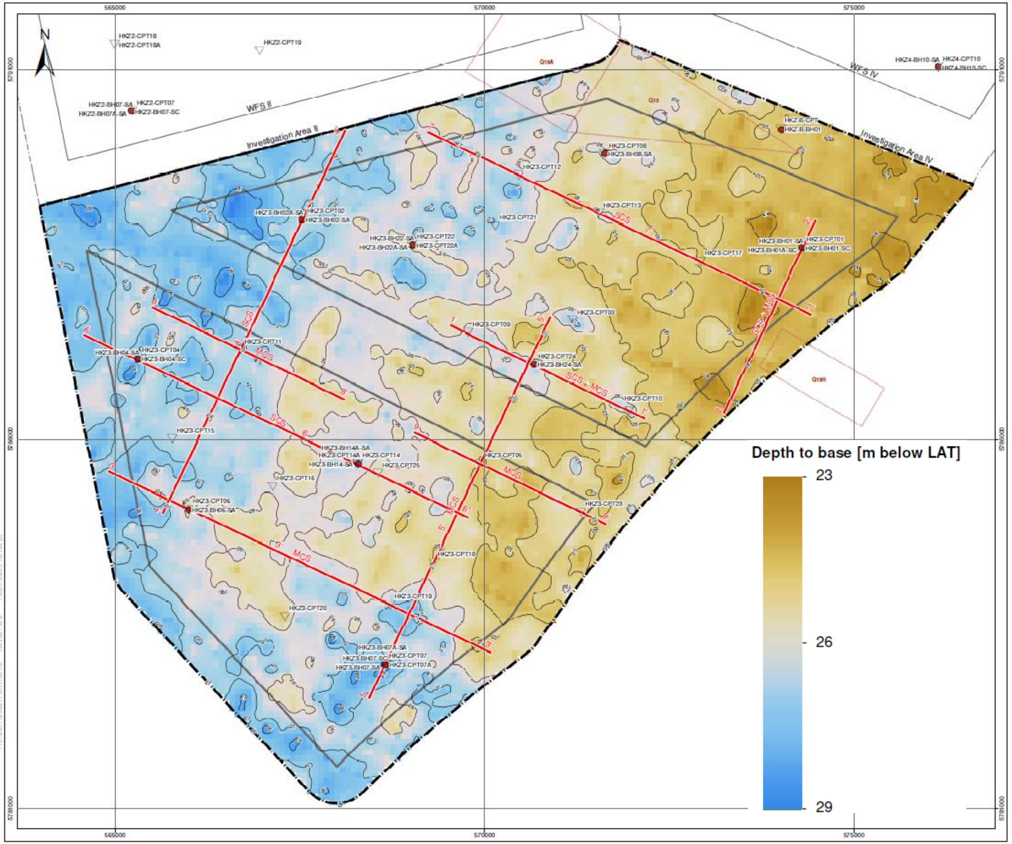




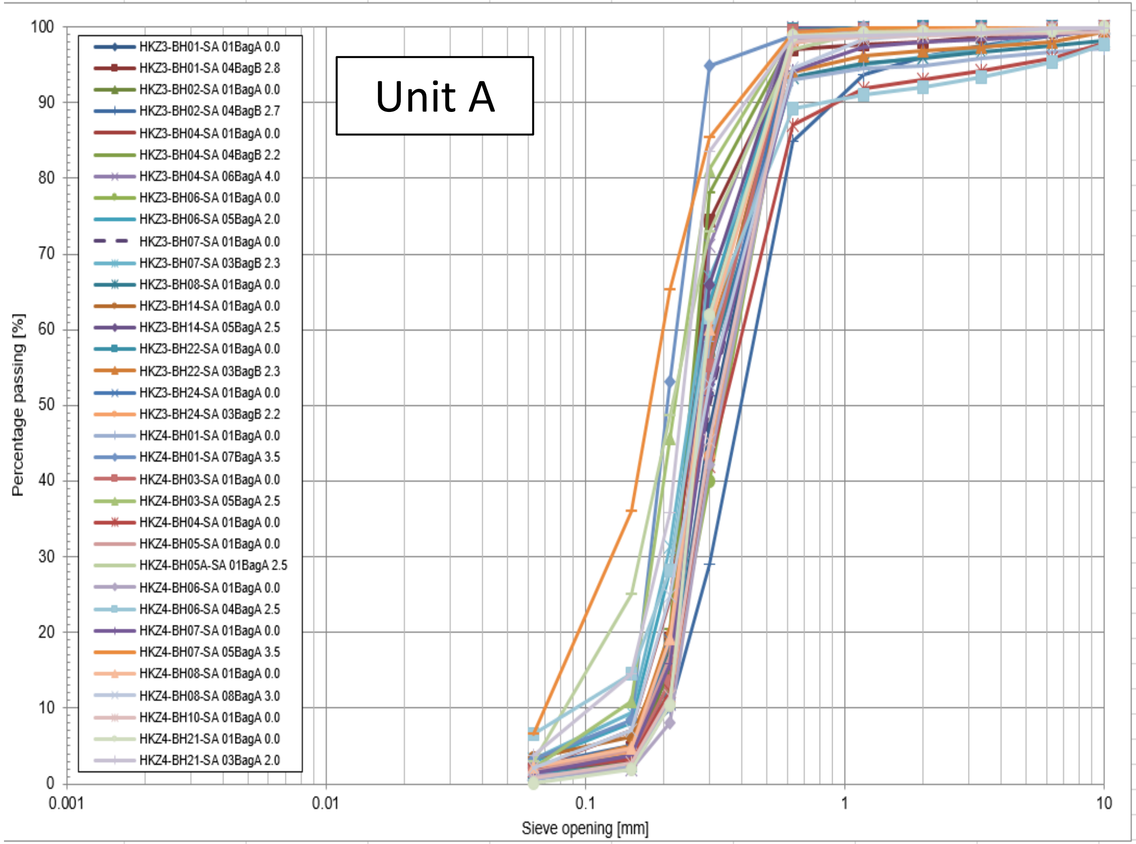
Geological Ground Model – Site Setting

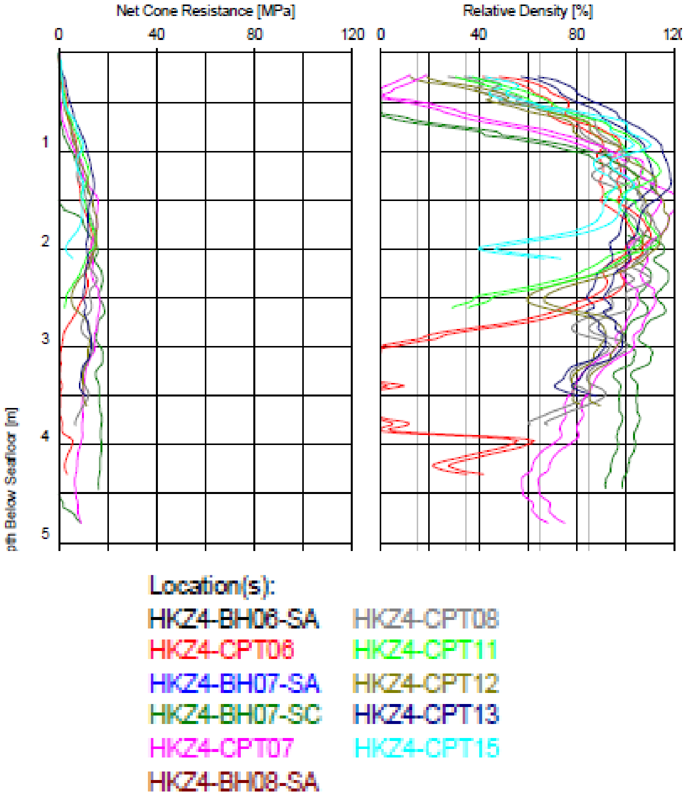
Unit A (Southern Bight Formation)

- Surficial SAND layer
- Generally thin but has larger thickness at the crests of sand dunes
- Comprises sediments reworked from underlying units (Unit B)
- Boundary between Unit A and underlying Unit B based on colour and particle size changes of sand
- Boundary cannot always be differentiated from seismic data as underlying soil unit is of similar lithology



Geological Ground Model – Site Setting

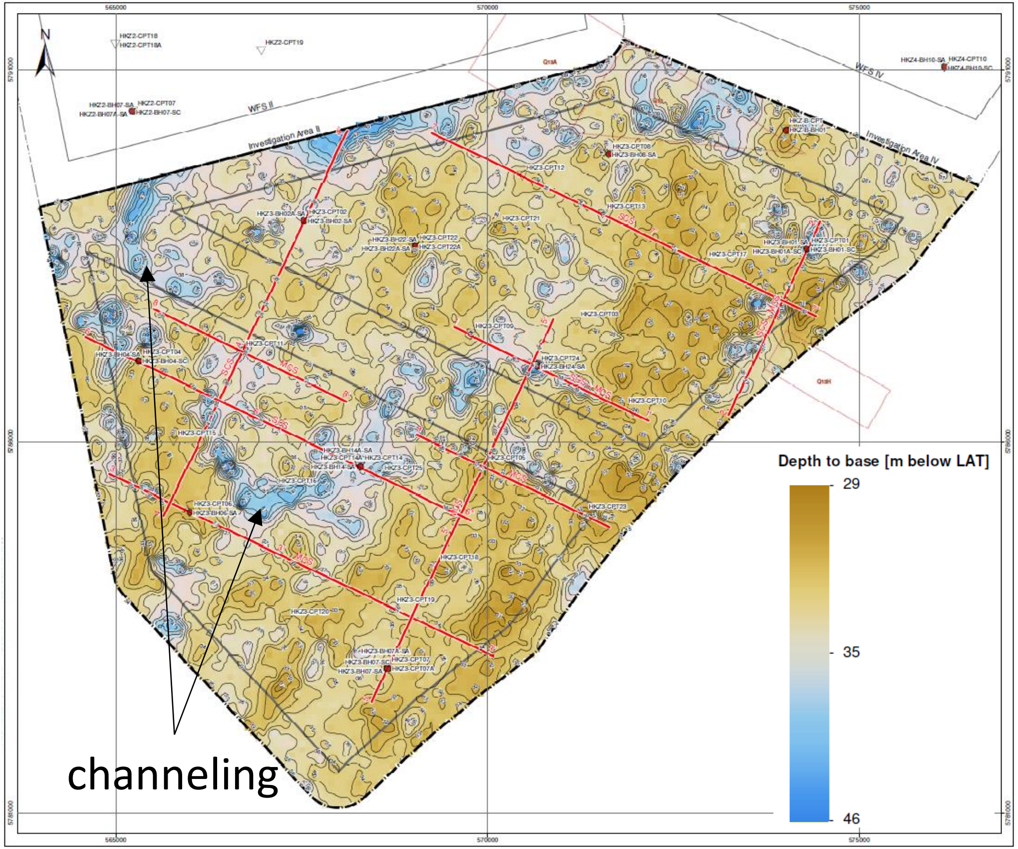




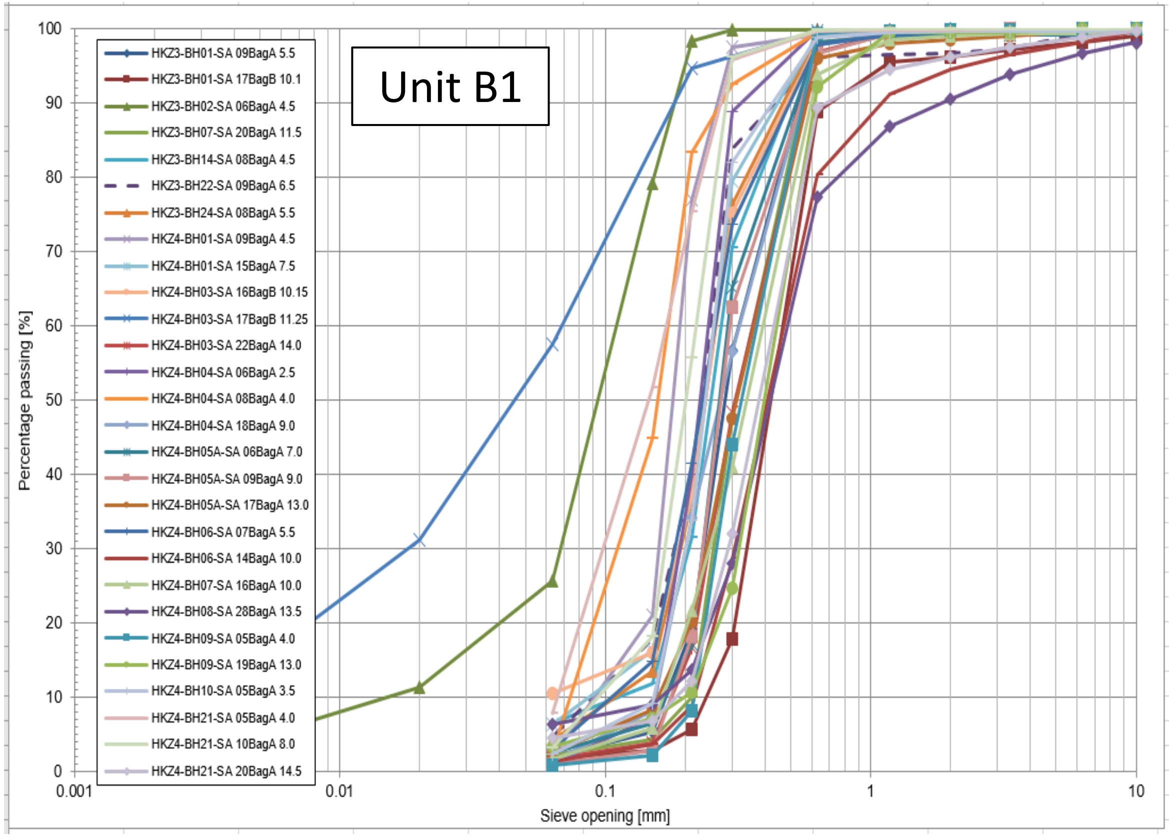
Geological Ground Model – Site Setting

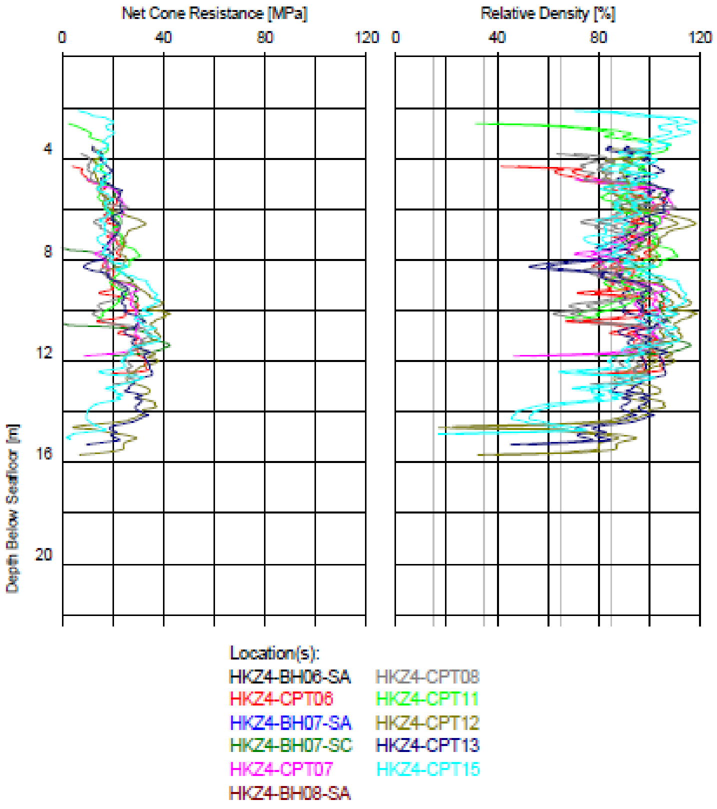
Soil Unit B (Kreftenheye Formation)

- Two sub-units: B1 and B2, mainly differentiated by different geotechnical properties:
  - Soil Unit B1: dense to very dense fine to medium SAND
  - Soil Unit B2: calcareous CLAY with laminea of sand, (fibrous) organic matter and peat
- Base of Soil Unit B1 represents an erosional boundary (channels)
- Soil Unit B2 is only locally present below Soil Unit B1 and is also considered represent channel-infill deposits
- Irregular base of Soil Unit B attributed to channeling

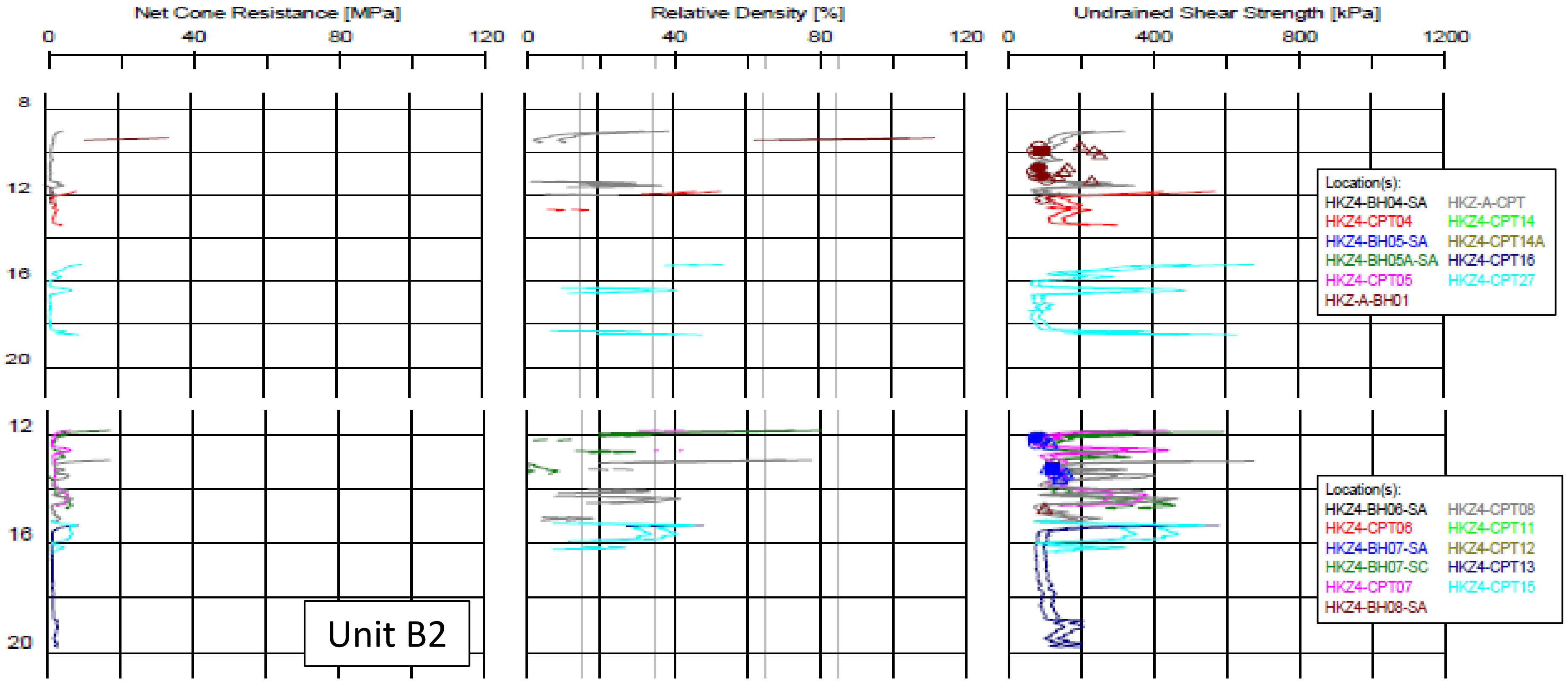


Geological Ground Model – Site Setting



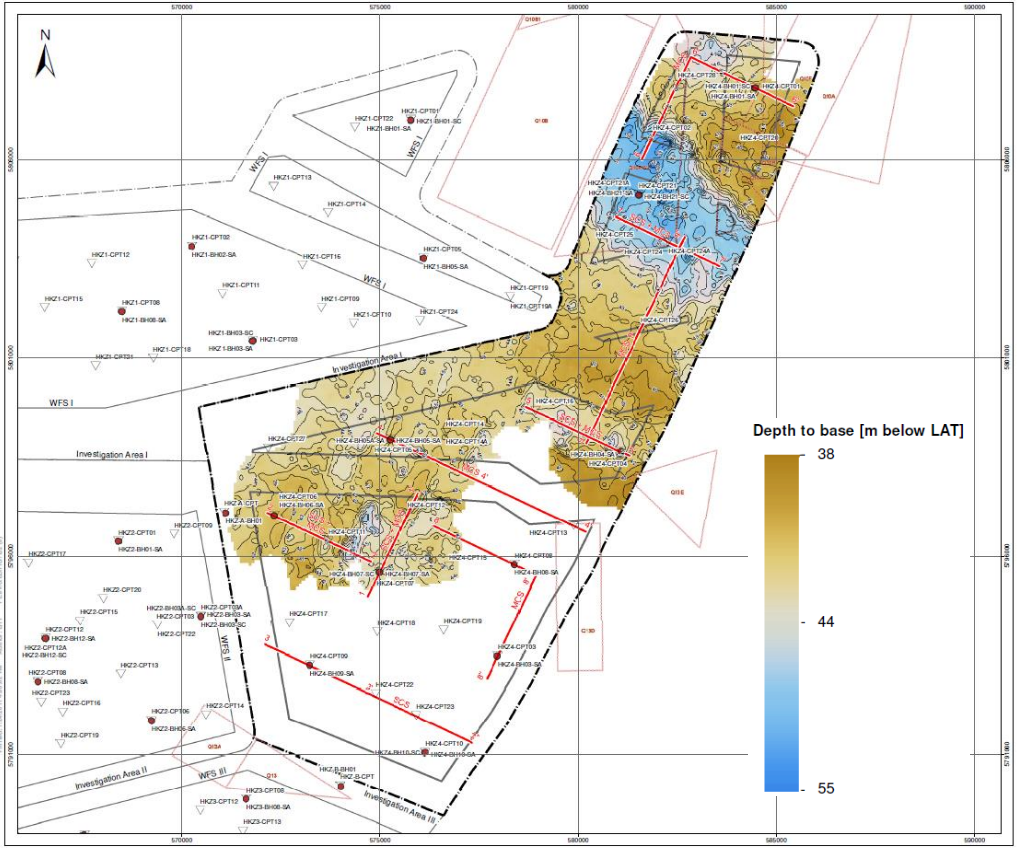


Geological Ground Model – Site Setting



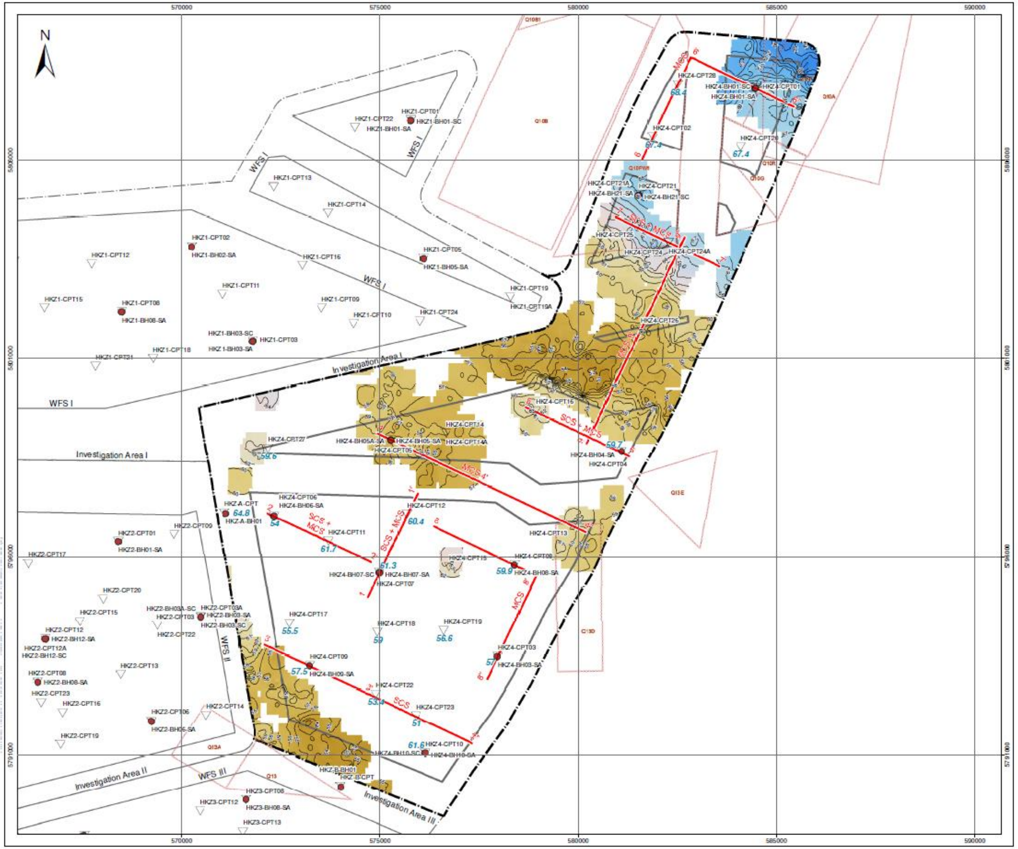
Soil Unit C (Eem, Drente Egmond Ground, Urk Formation)

- Two sub-units: C1 and C2, mainly differentiated by different geotechnical properties:
  - Soil Unit C1: SAND and CLAY (locally interbedded)
  - Soil Unit C2: uniform SAND, with laminae and beds of clay/silt
  - High spatial soil variability
- Soil Unit C1 is present in the north and centre of WFSIV
- Within WFSII Soil Unit C1 is absent probably due to erosion/non-deposition
- Unit C1 could not be identified from seismic data in WFSIII and in parts of WFSIV

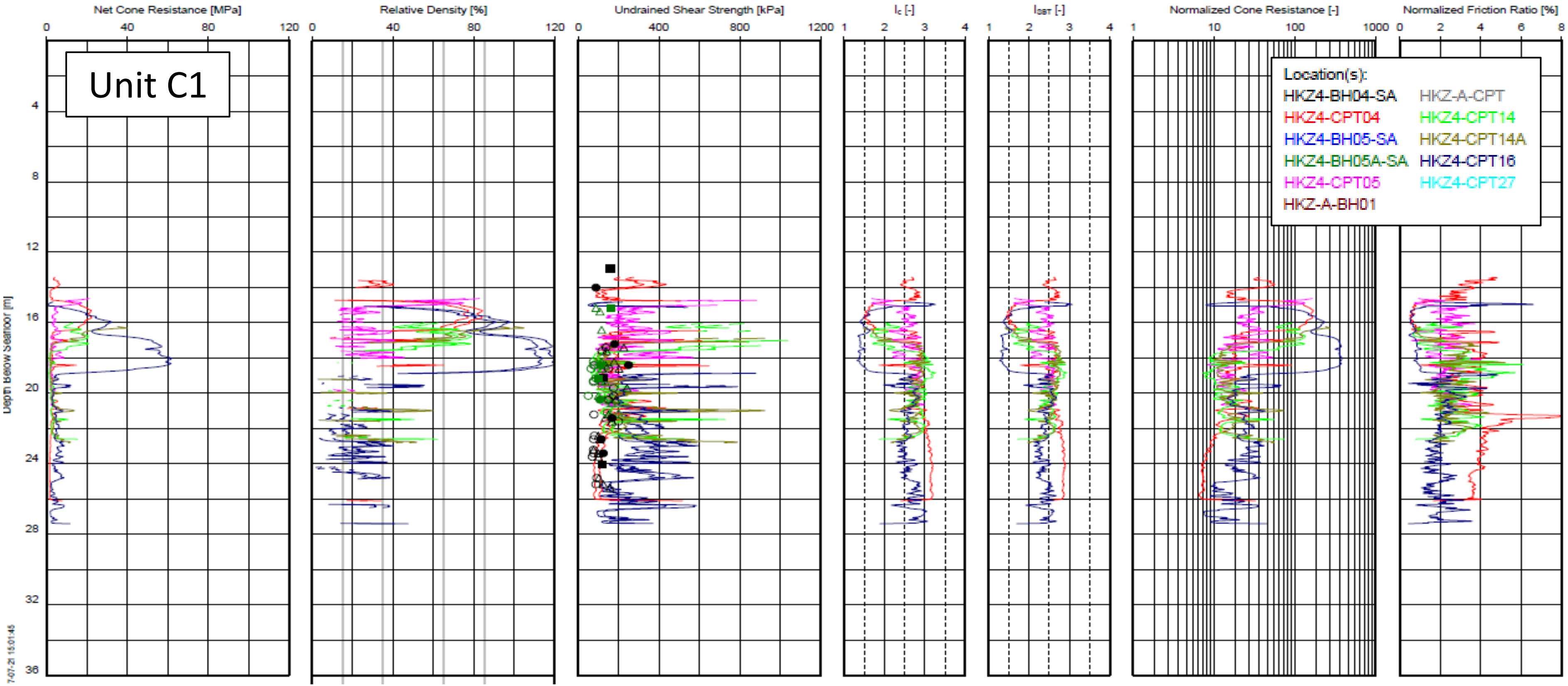


Geological Ground Model – Site Setting

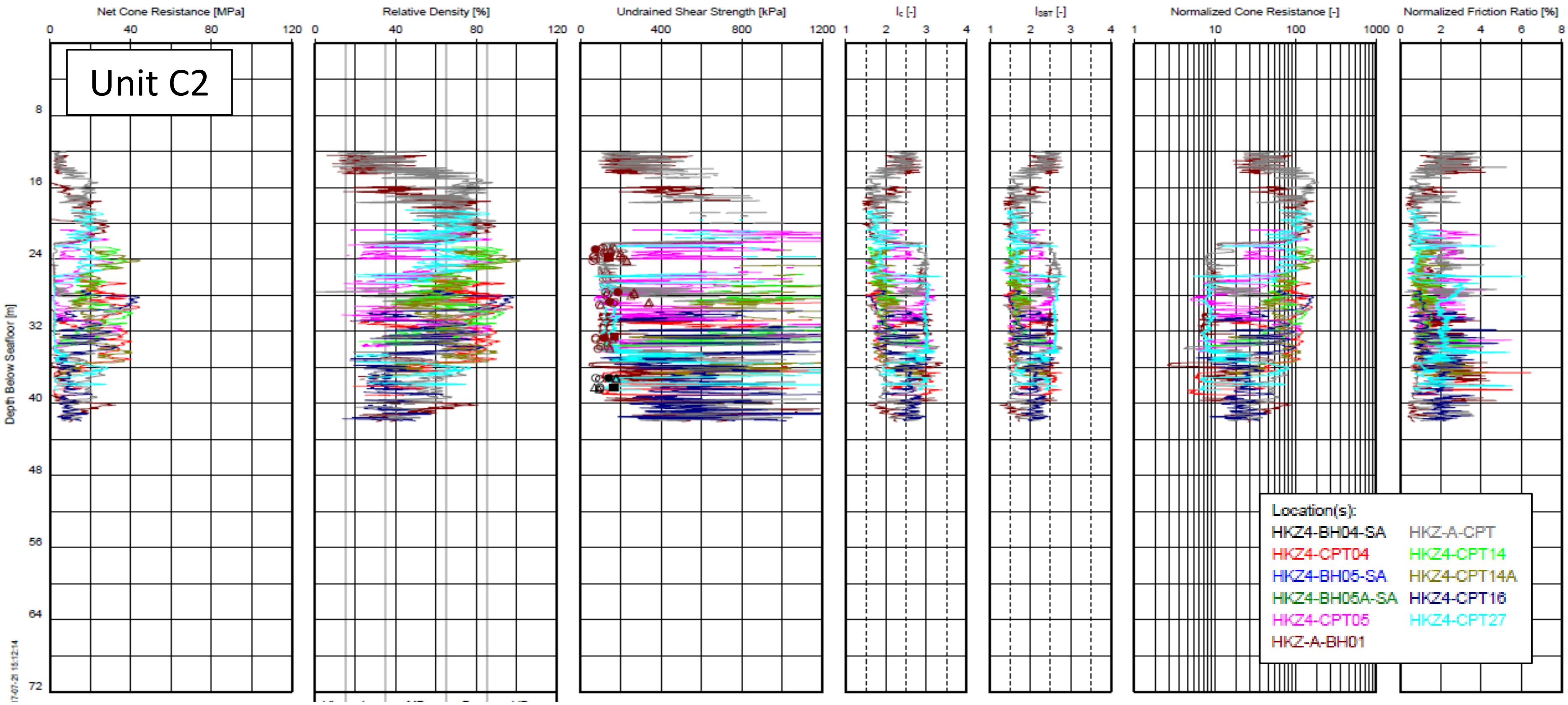
- Soil Unit C2 is present across entire WFSIII and IV (based on geotechnical data)
- Base of Soil Unit C2 could not be identified from seismic data in WFSIII and in parts of WFSIV
- The seismic character of Soil Unit C2 is variable, predominanty chaotic. Locally the seismic data is masked by both seafloor multiples and peg-leg multiples
- Evidence for channel sequences and local glacial deformation
- High amplitude reflectors within Soil Unit C2 correspond to beds of peat/organic clay
- Lower boundary is taken at the base of a clay layer in the geotechnical locations (not associated with a distinct and continuous seismic reflector)



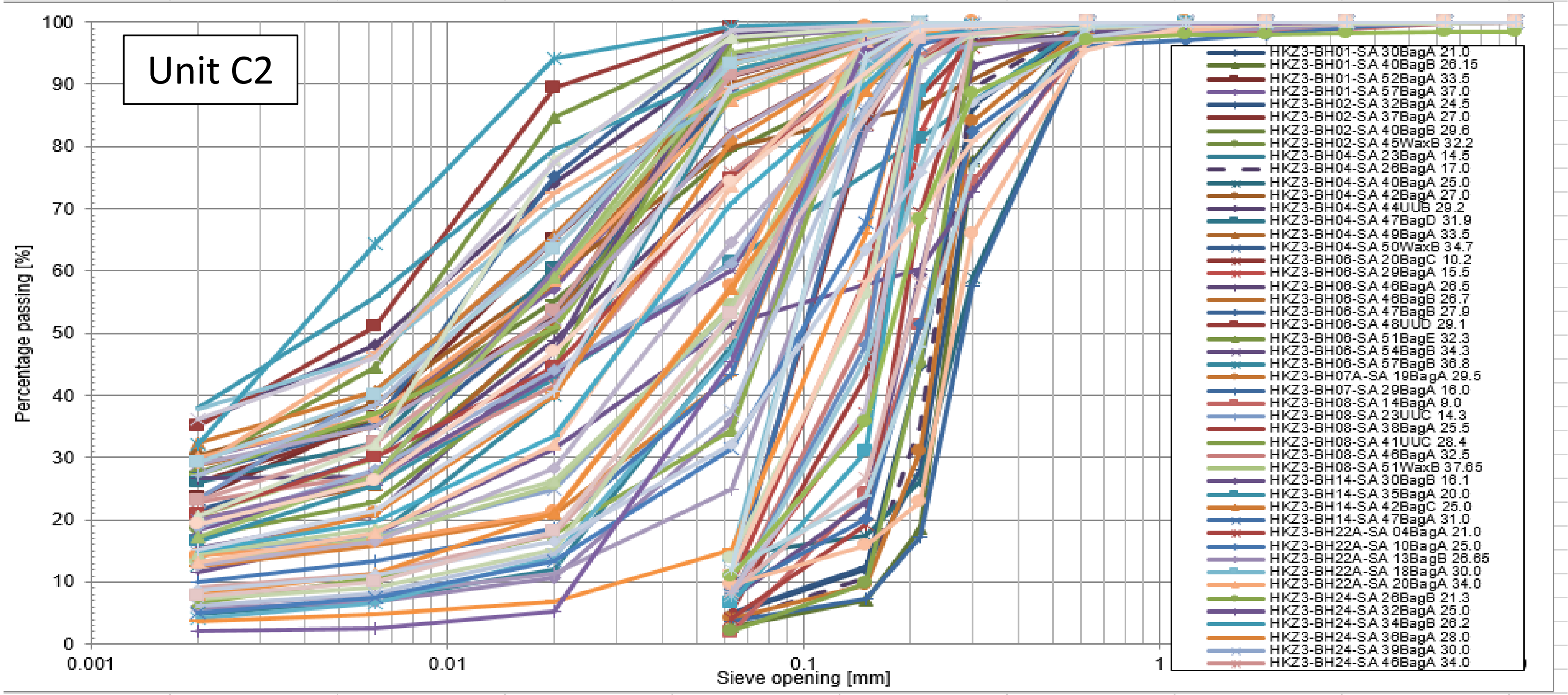
Geological Ground Model – Site Setting



Geological Ground Model – Site Setting



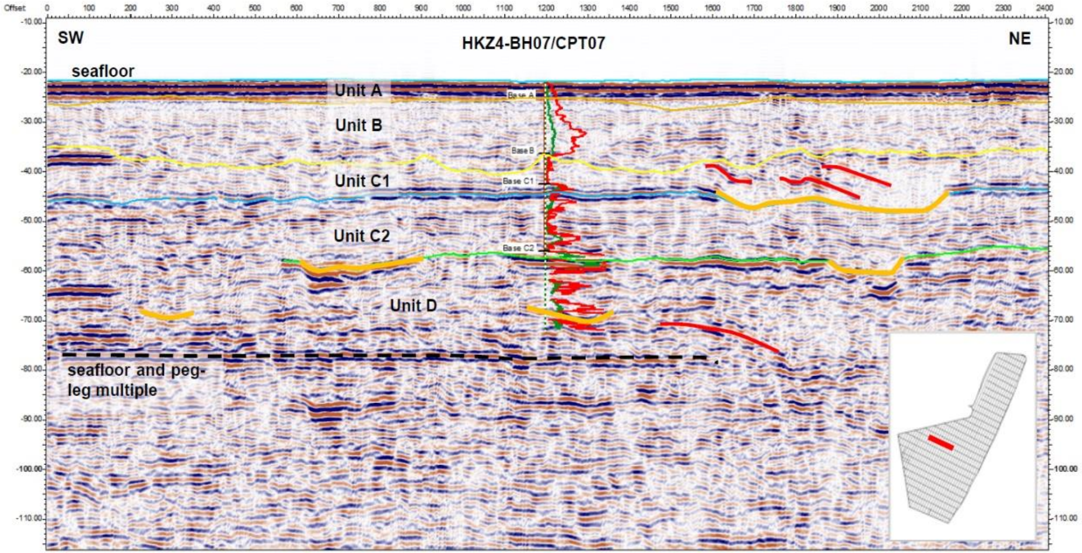
Geological Ground Model – Site Setting



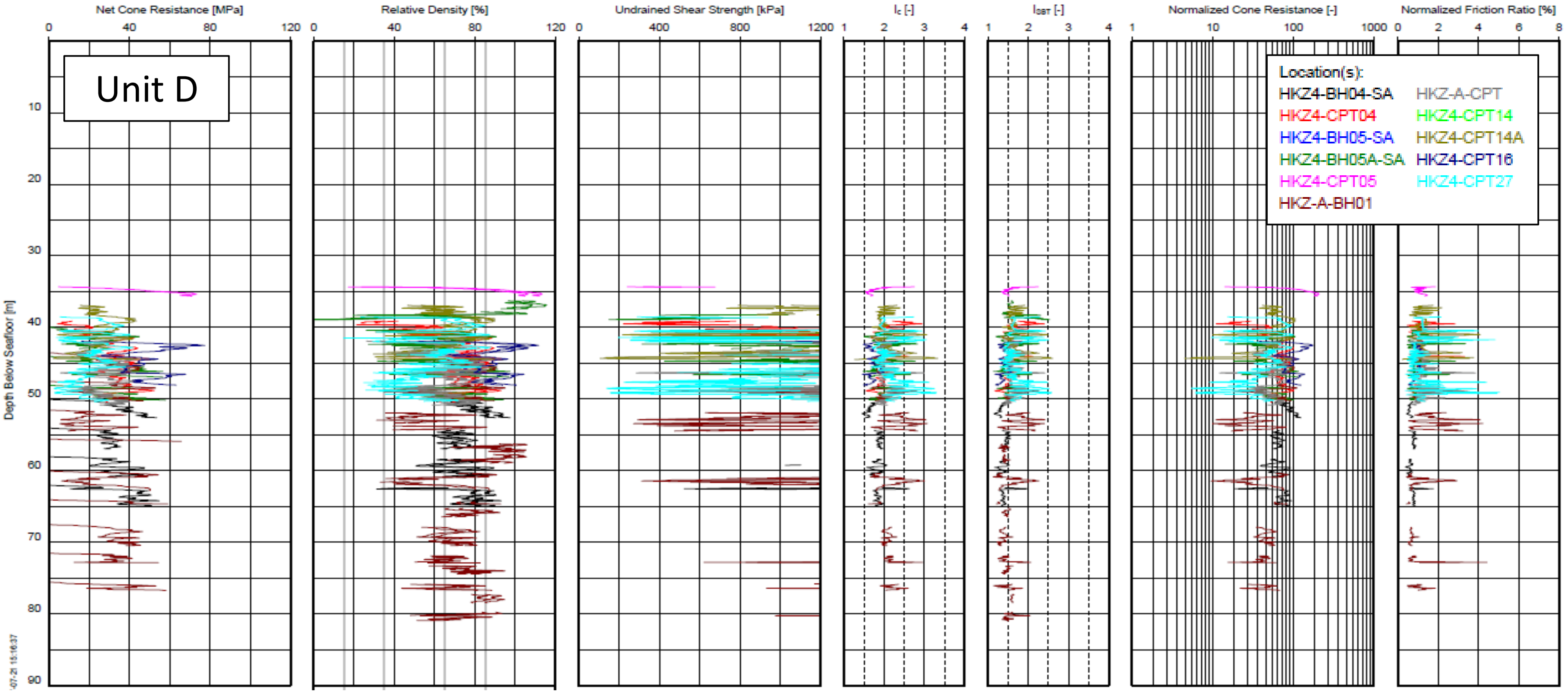
Geological Ground Model – Site Setting

Soil Unit D (Yarmouth Roads Fm)

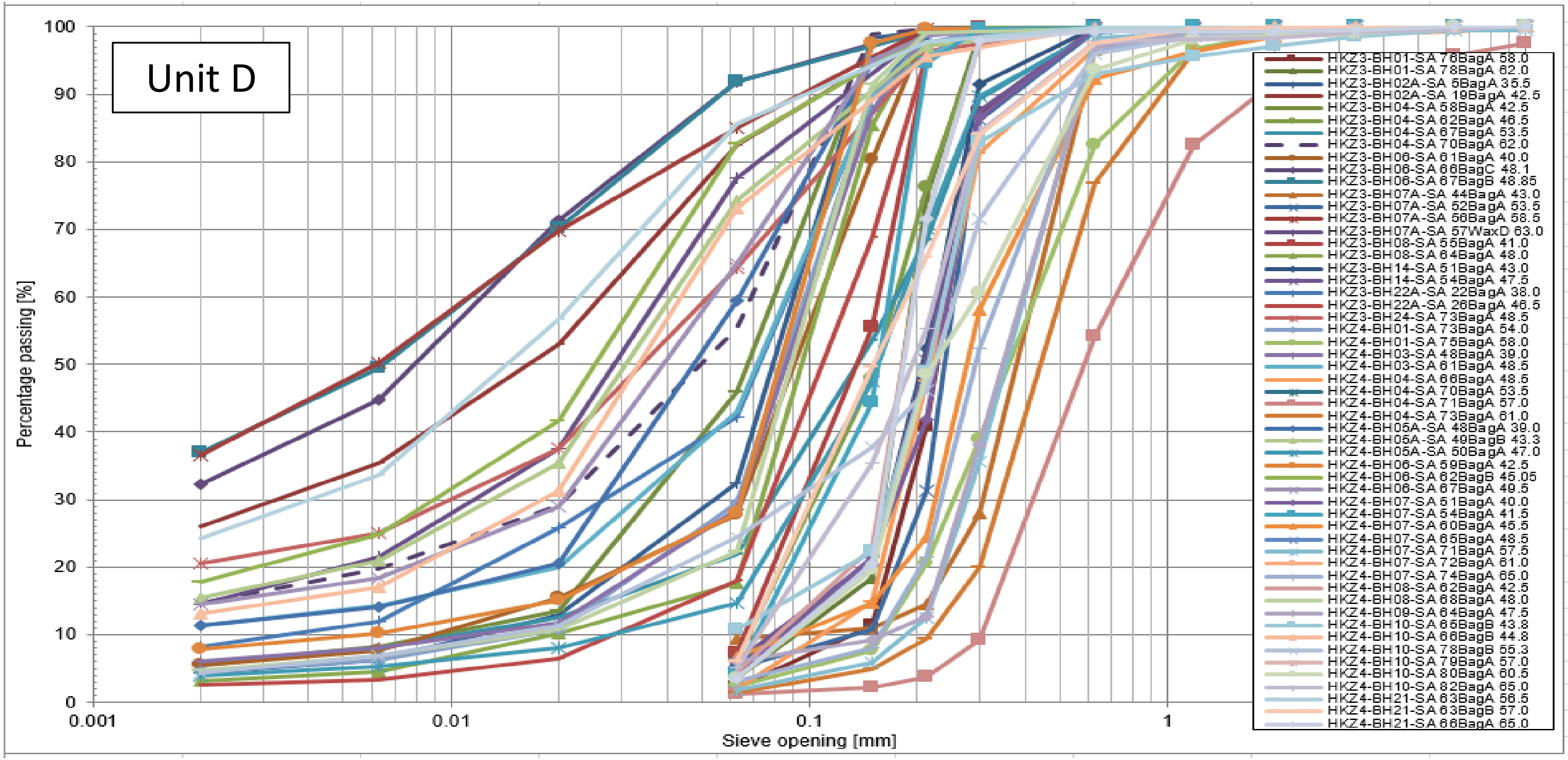
- Medium dense to dense SAND with laminae of clay and very stiff to hard CLAY with laminae of sand
- The seismic character of Soil Unit D is similar to that of Soil Unit C2, making it difficult to distinguish these two units in the absence of a clear seismic response at the base of Soil Unit C2
- The base Soil Unit D is below the depth coverage of the geological ground model



Geological Ground Model – Site Setting



Geological Ground Model – Site Setting



Geological Ground Model – Geological Features

Peat / organic clay accumulation

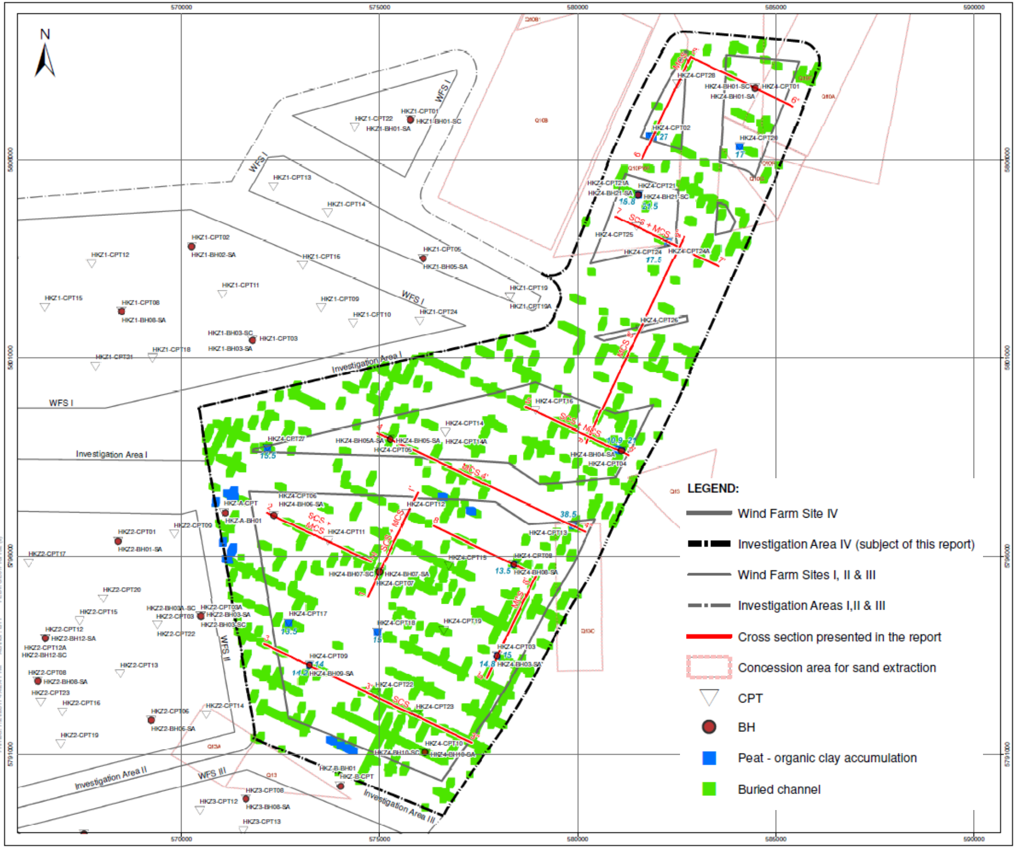
- High amplitude, reverse polarity reflections
- At various levels below Soil Unit A

Buried channels

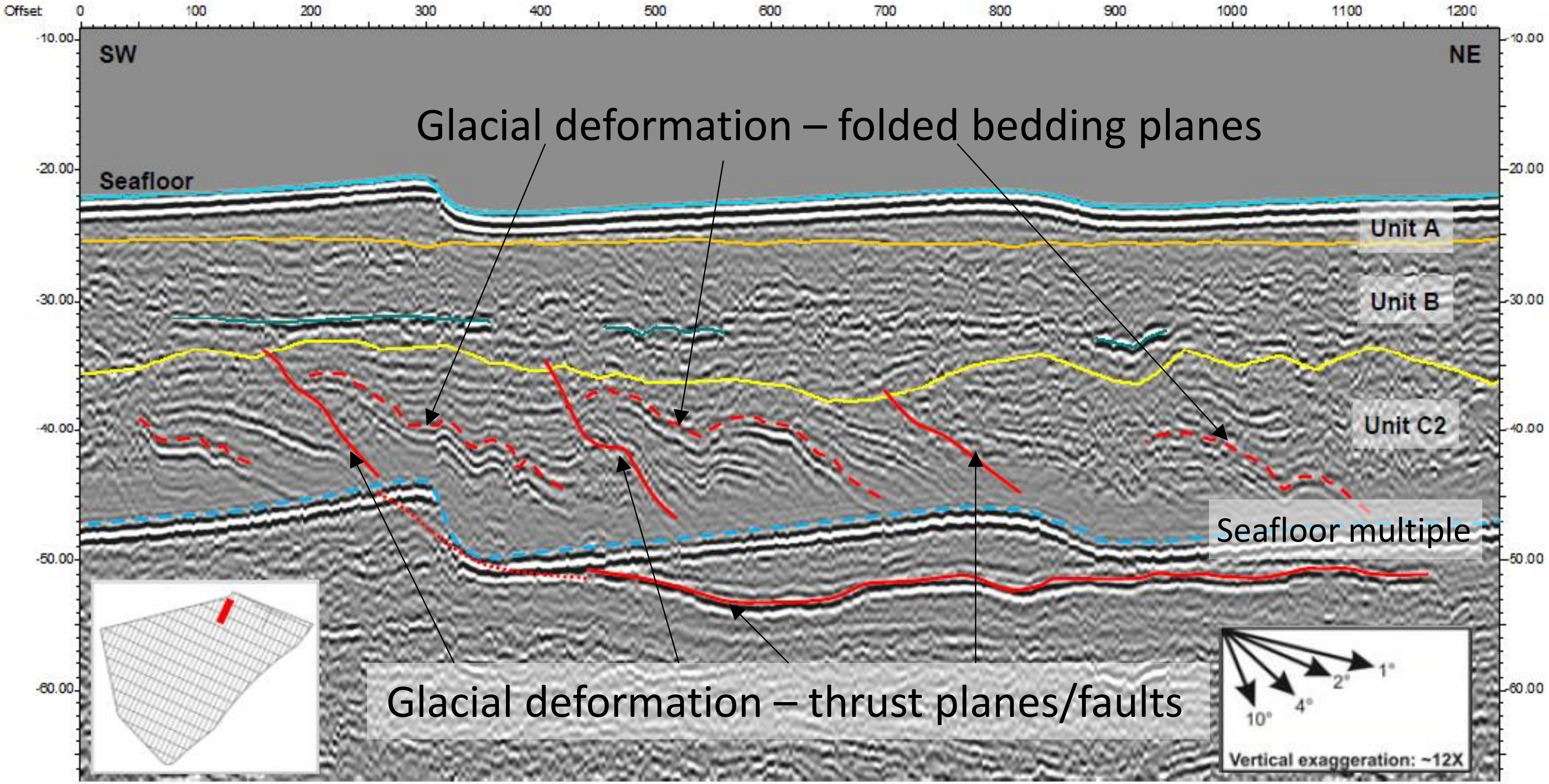
- Extensive channeling at the base of Soil Unit B and within Soil Unit C

Glacial deformation

- Folding and thrusting of soil layers (Soil Unit C2)
- Observed in WFSIII



Geological Ground Model – Glacial Deformation in Unit C2



Potential Site-Specific Hazard Assessment

Geological Feature & Hazard Type	Occurrence Area	Constraints on Structure	PL	JU	GB	SC	CB
Migrating bedforms / mobile seabed sediments	Entire WFS III & IV	▪ 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	- Very dense sand in Soil Units A, B1, C2 and D - Hard clay in Soil Units C2 and D	▪ 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

Potential Site-Specific Hazard Assessment

Pile Foundation:

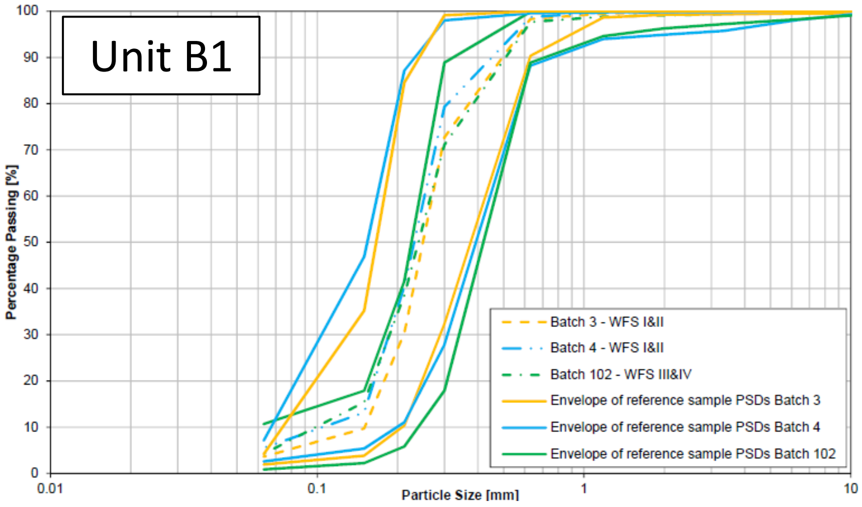
- Pile foundation are assessed feasible
- The assessment considers monopiles, jacket piles and piles for tripod support structures installed by impact driving
- Where applicable, driven pile installation should be sufficiently robust for penetration of very dense sand layers and/or concentrations of gravels and cobbles in the subsurface

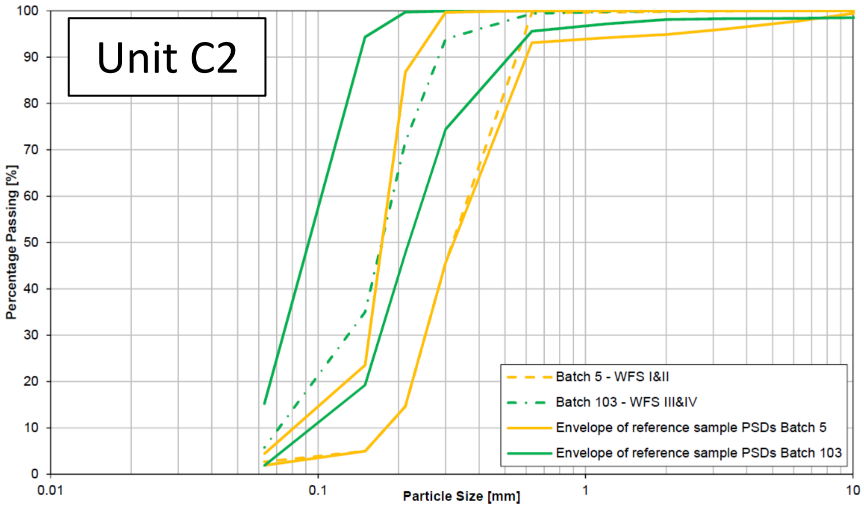
Jack-up Platforms:

- Use of jack-up platforms for temporary works is assessed feasible
- Particularly, scour and soil deposition around spudcans should be allowed for
- Considerations for jack-up leg punch-through will primarily apply to jack-ups equipped with spud-pile type foundations with relatively high bearing pressure at the spud-pile tip. Jack-ups equipped with spudcans can probably benefit from high bearing resistance available from Soil Units A and B1.

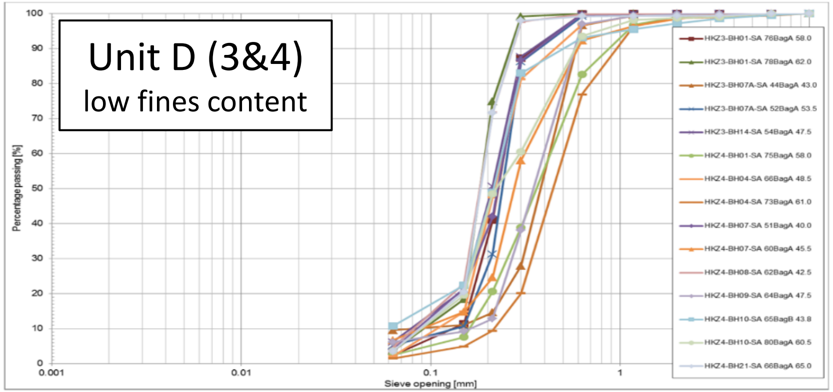
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

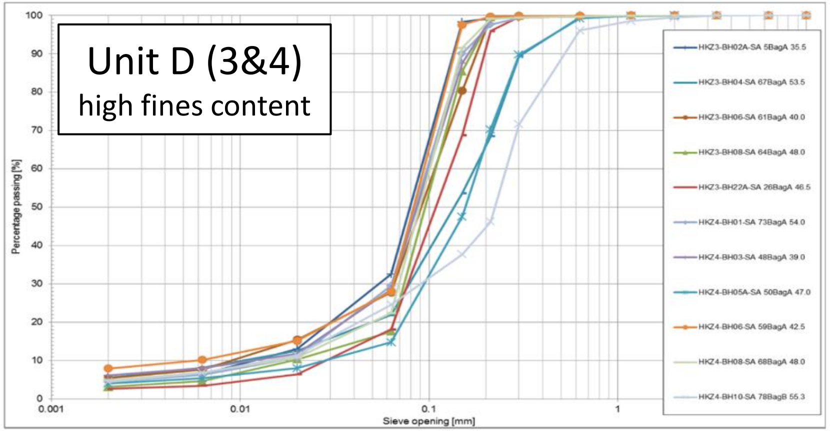
- Soil conditions are similar across the different sites for Soil Units A and B1
- Variation in Soil Units C and D is more evident, between the individual four sites
- Soil Unit C1 present at sites 1 and 4 only

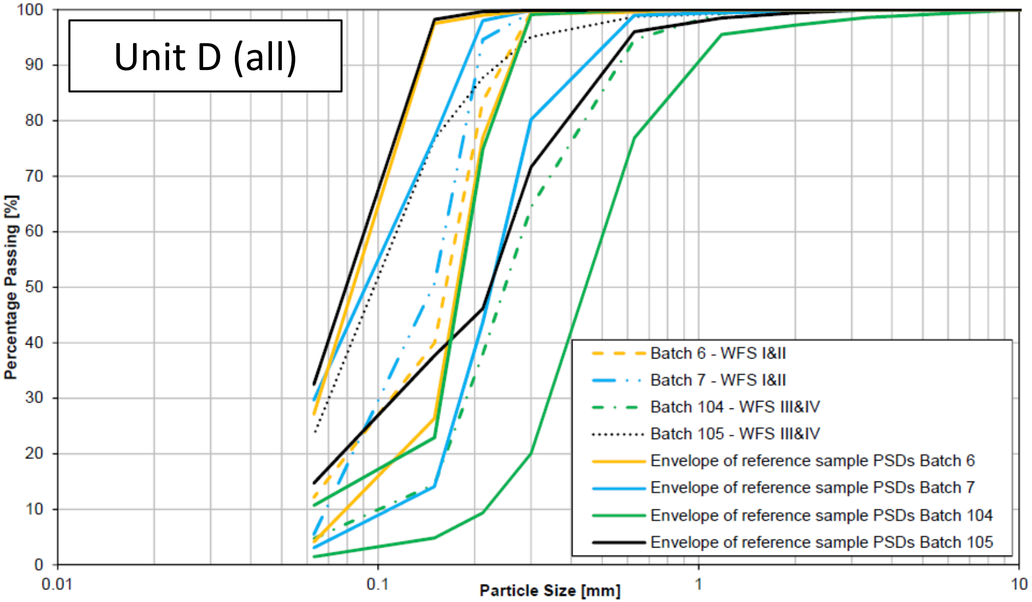




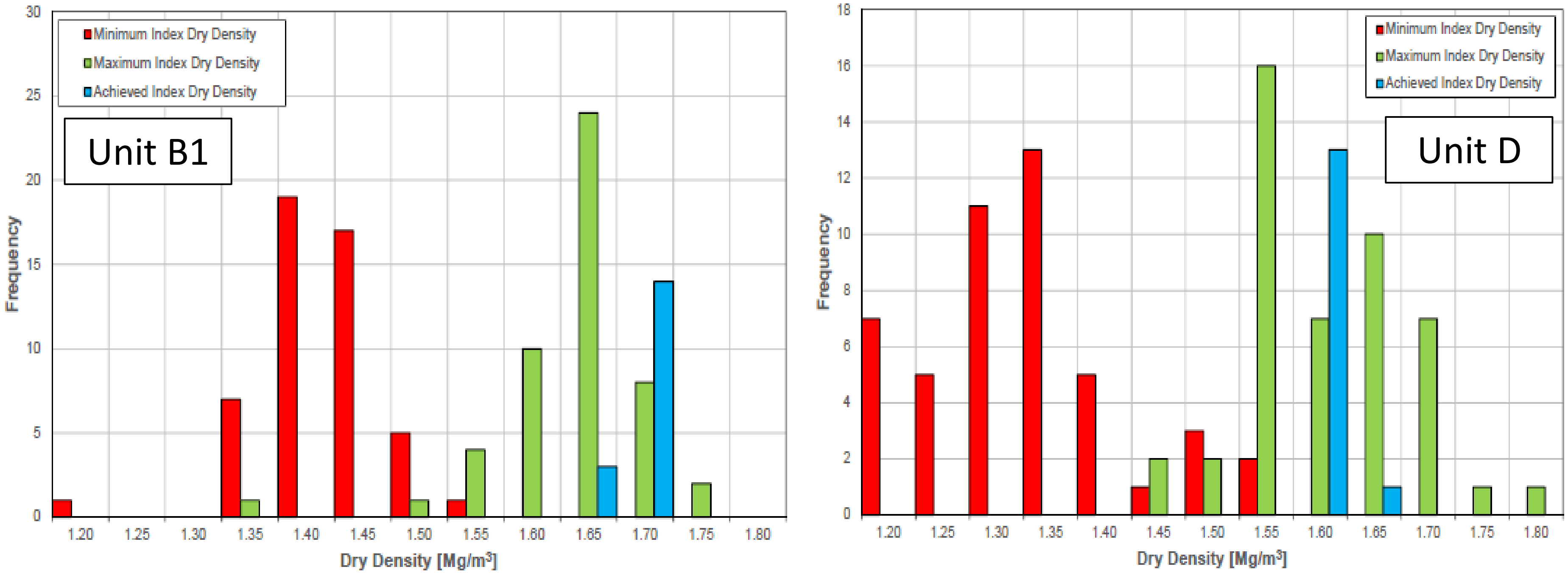
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results





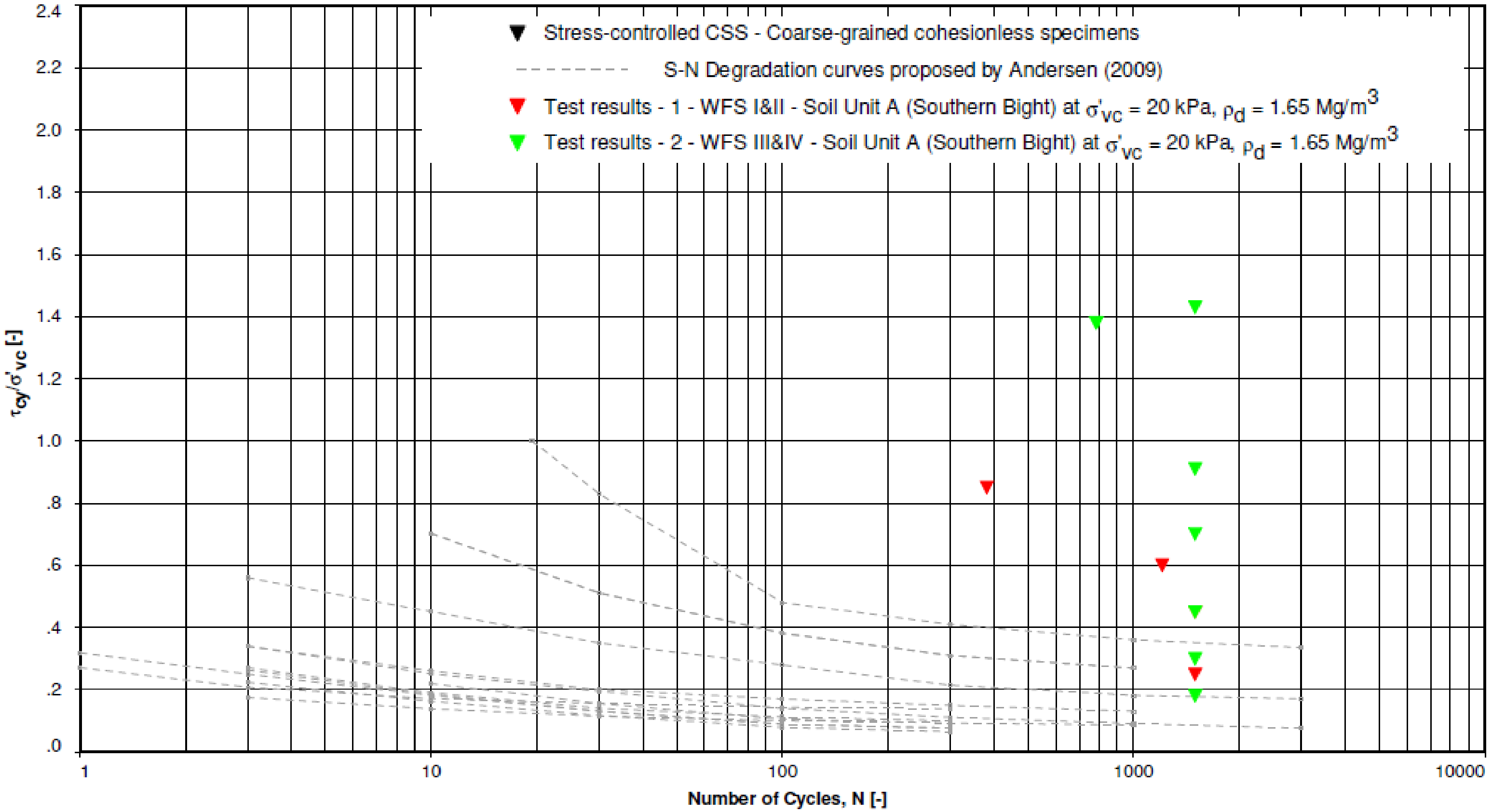


Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

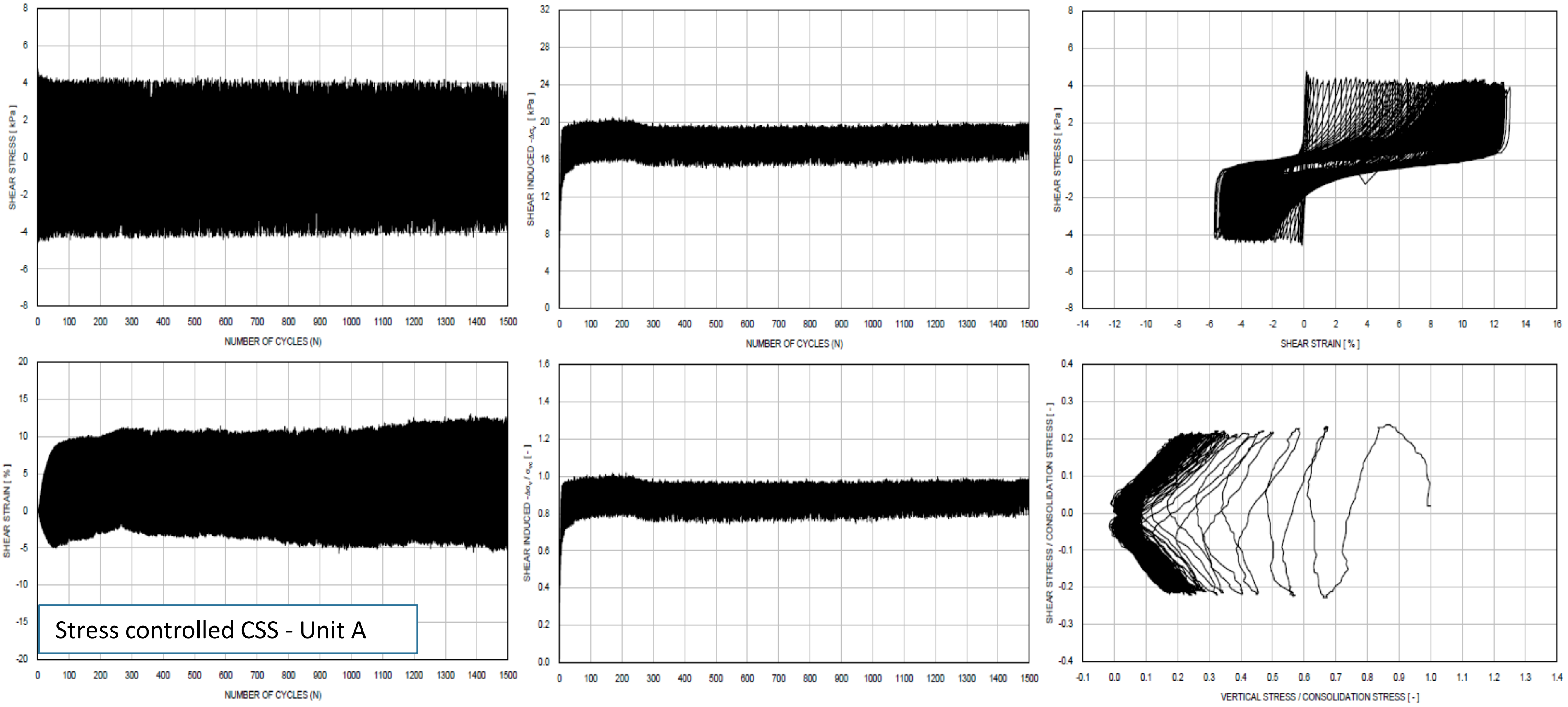


Examples achieved build-in dry densities for triaxial tests WFS I to WFS IV (advanced test programme)

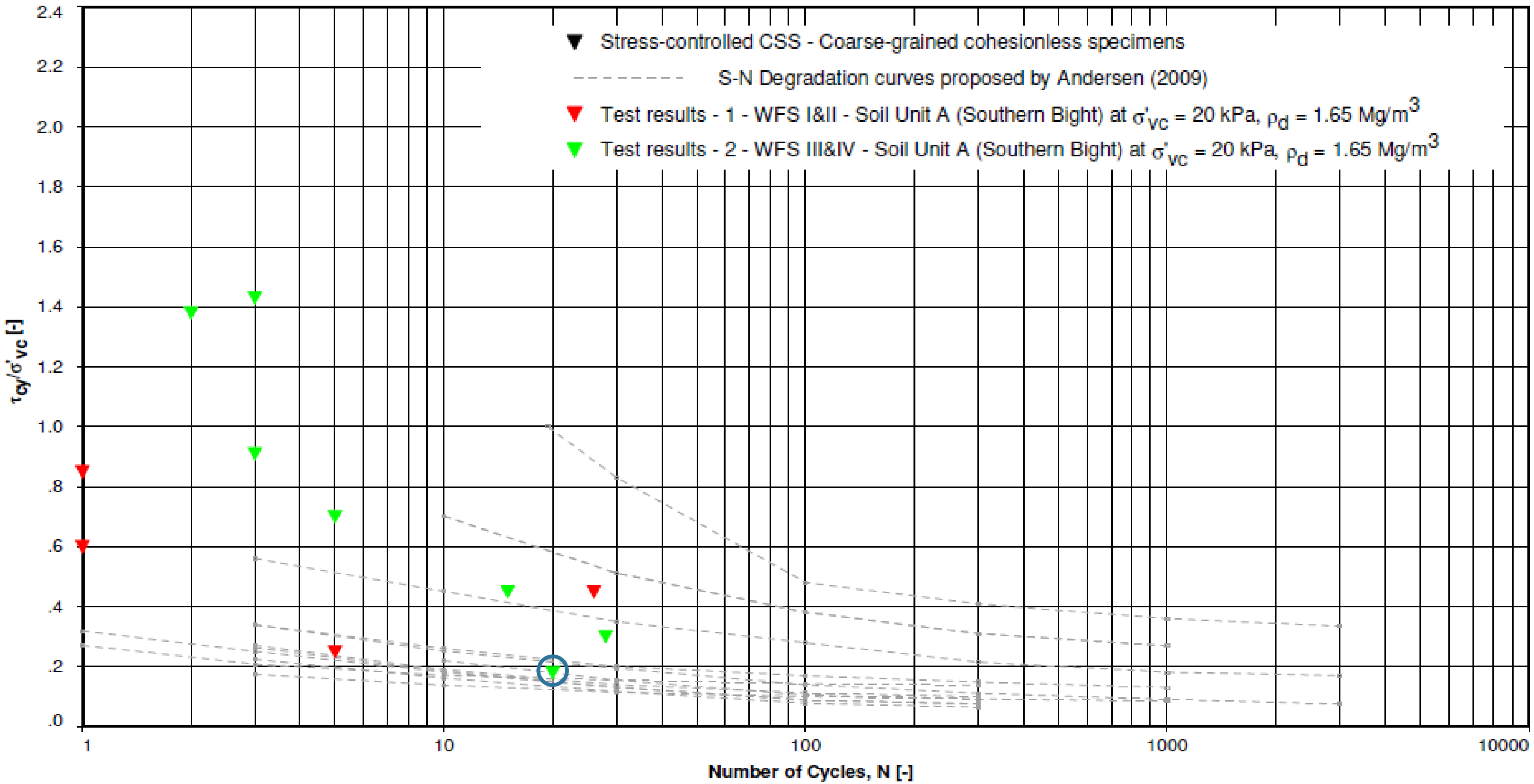
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



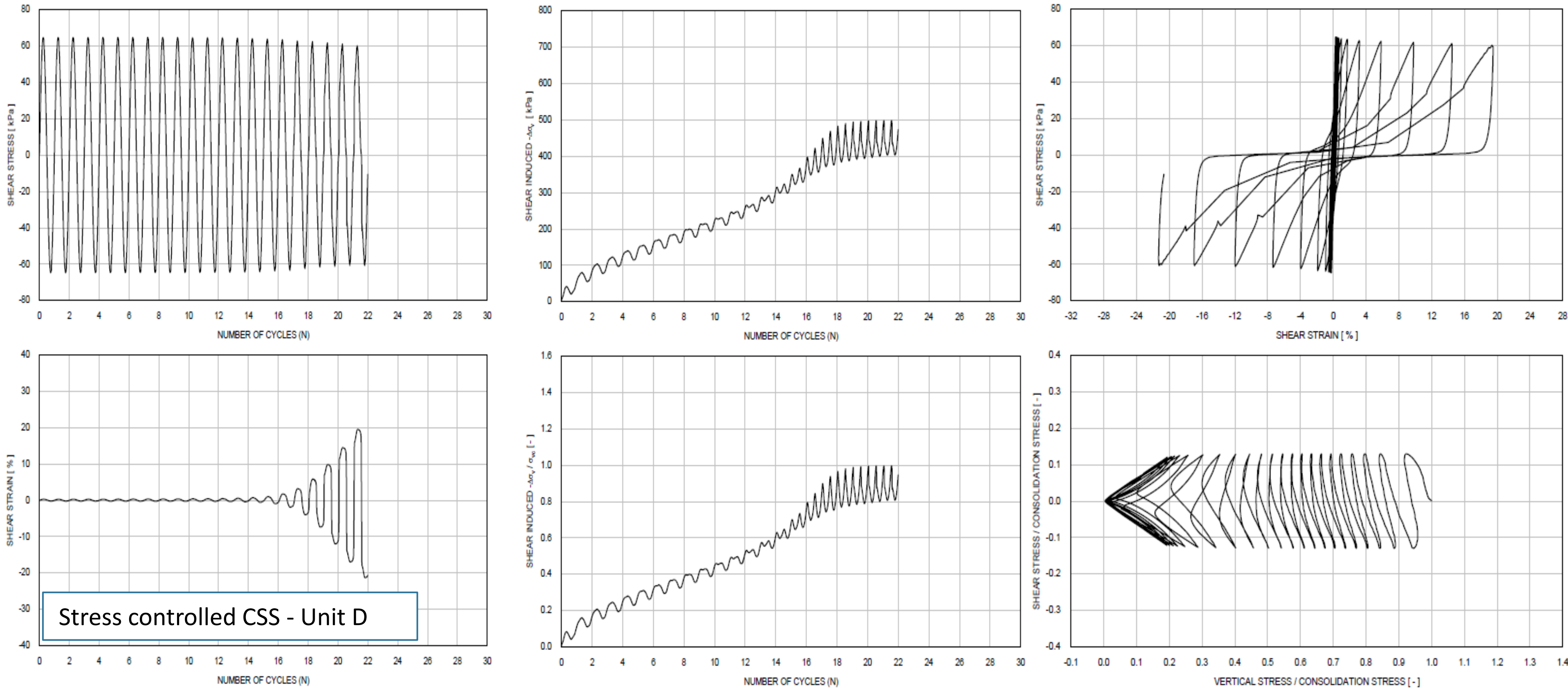
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



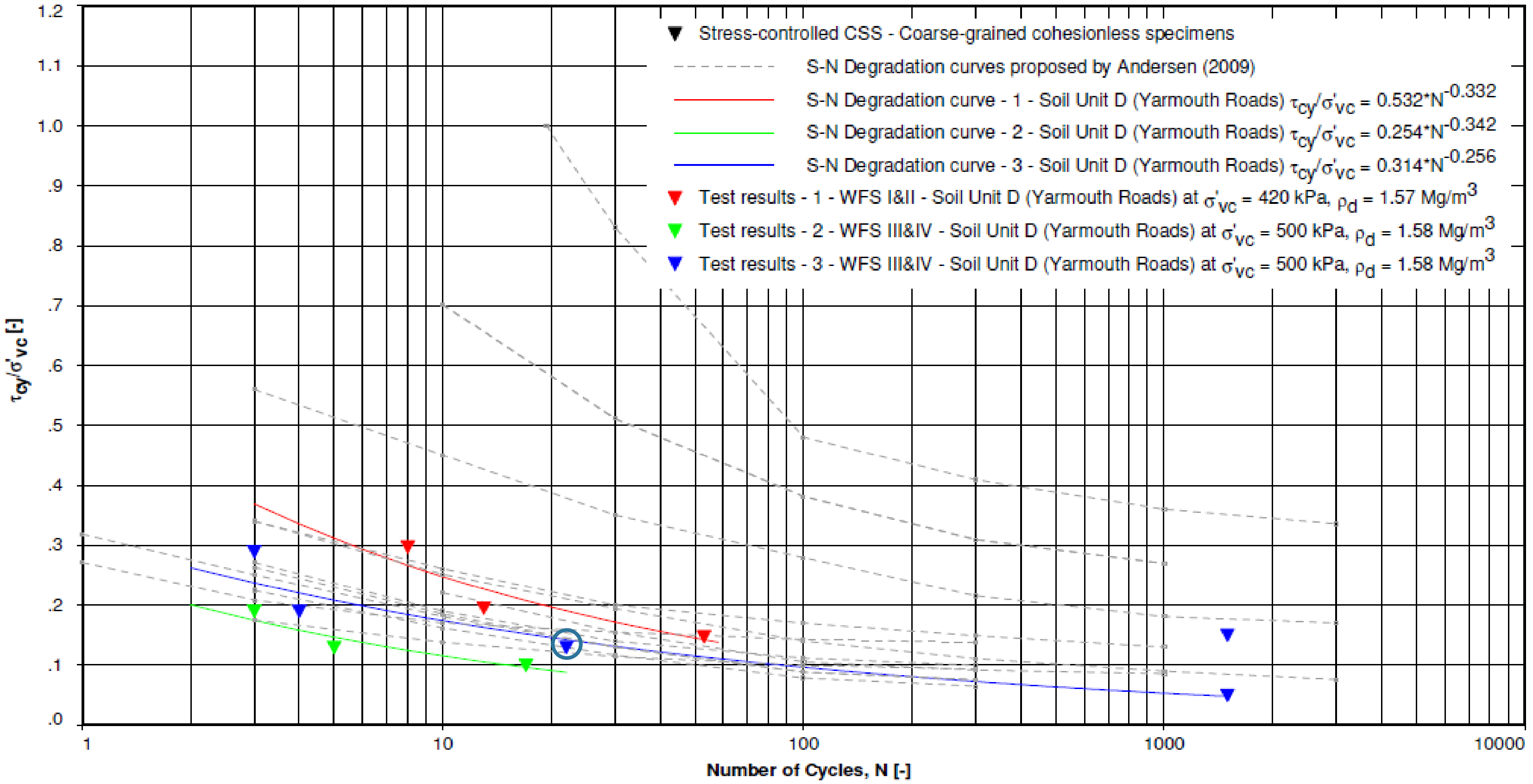
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



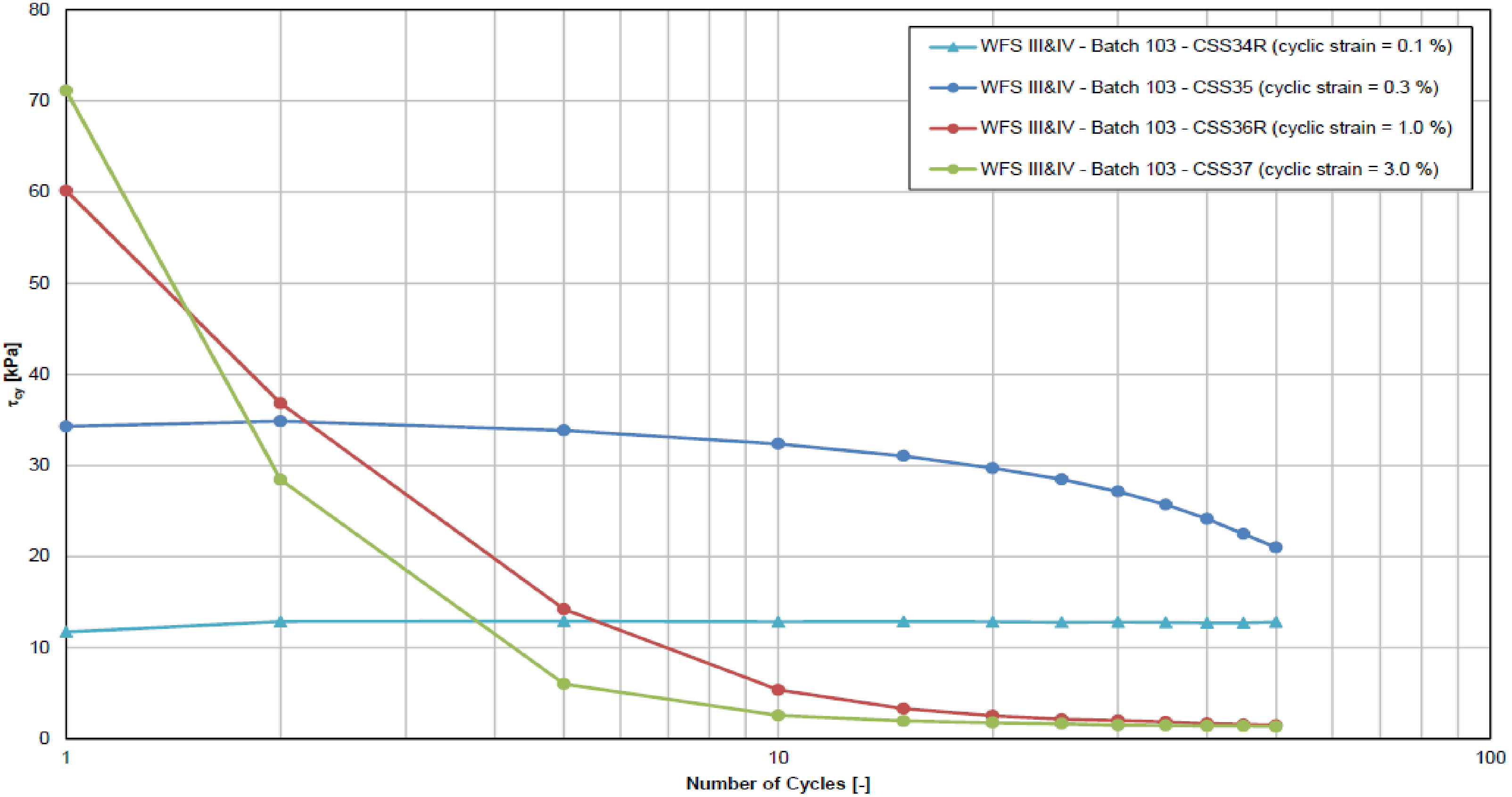
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



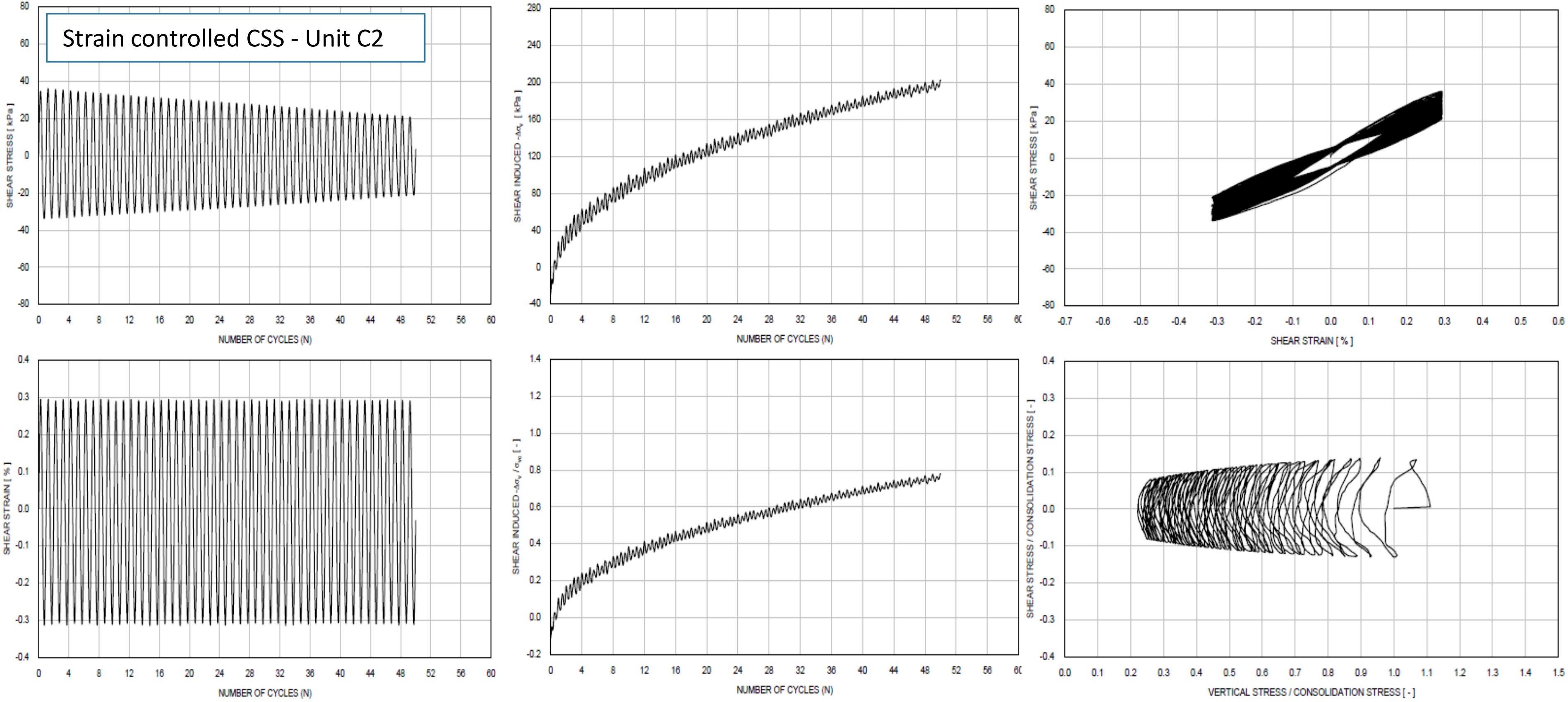
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



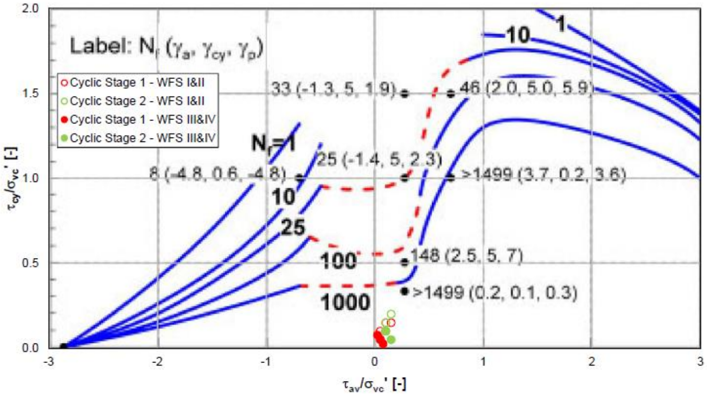
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

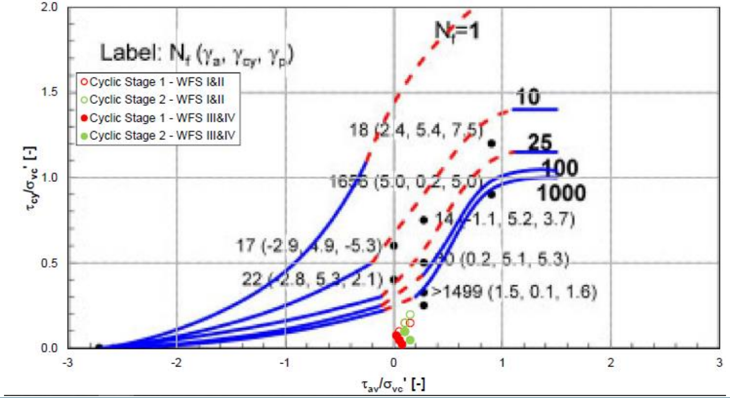


Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

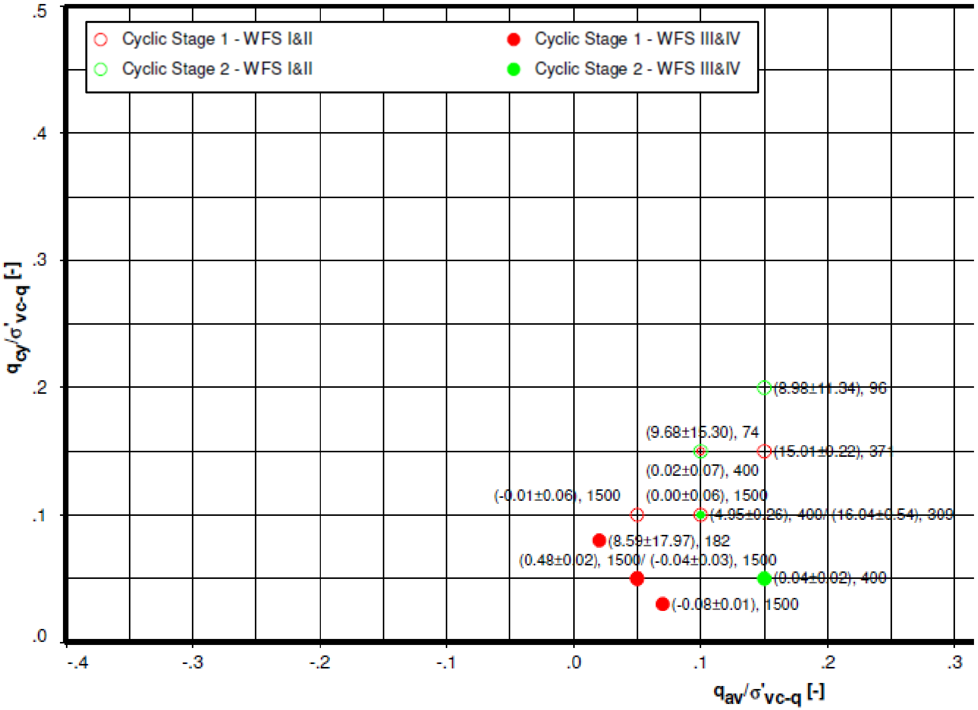


Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



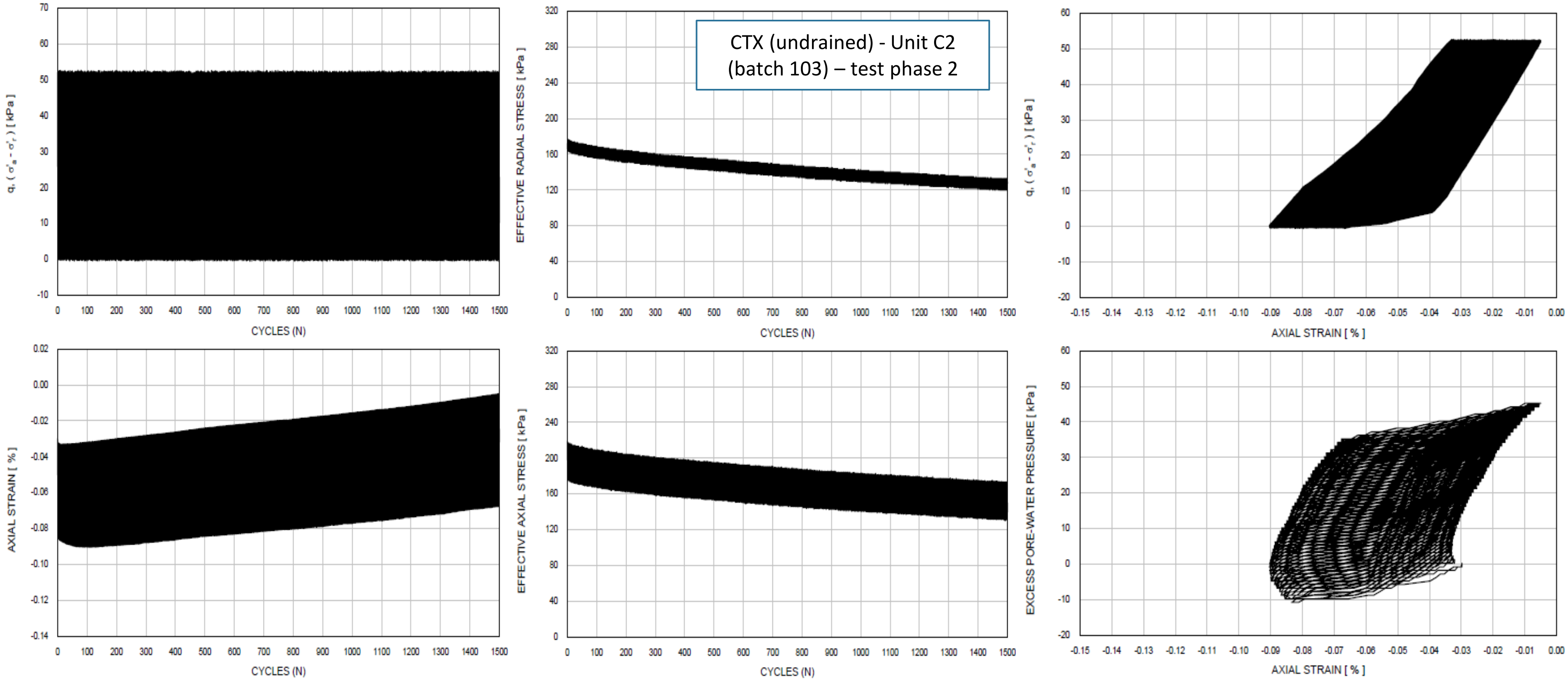


Overview Stress controlled CTX (undrained) - Unit C2

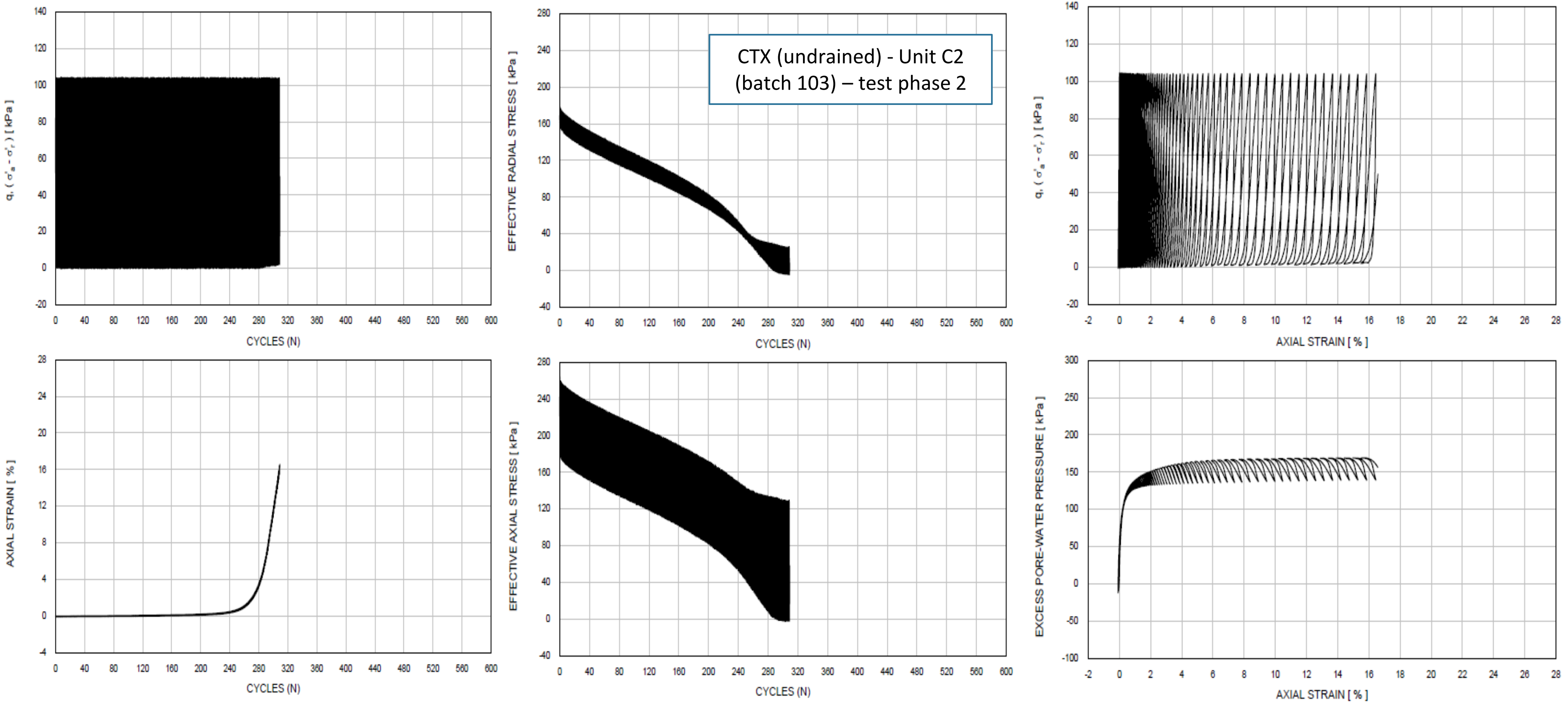


Background curves based Andersen (2015)

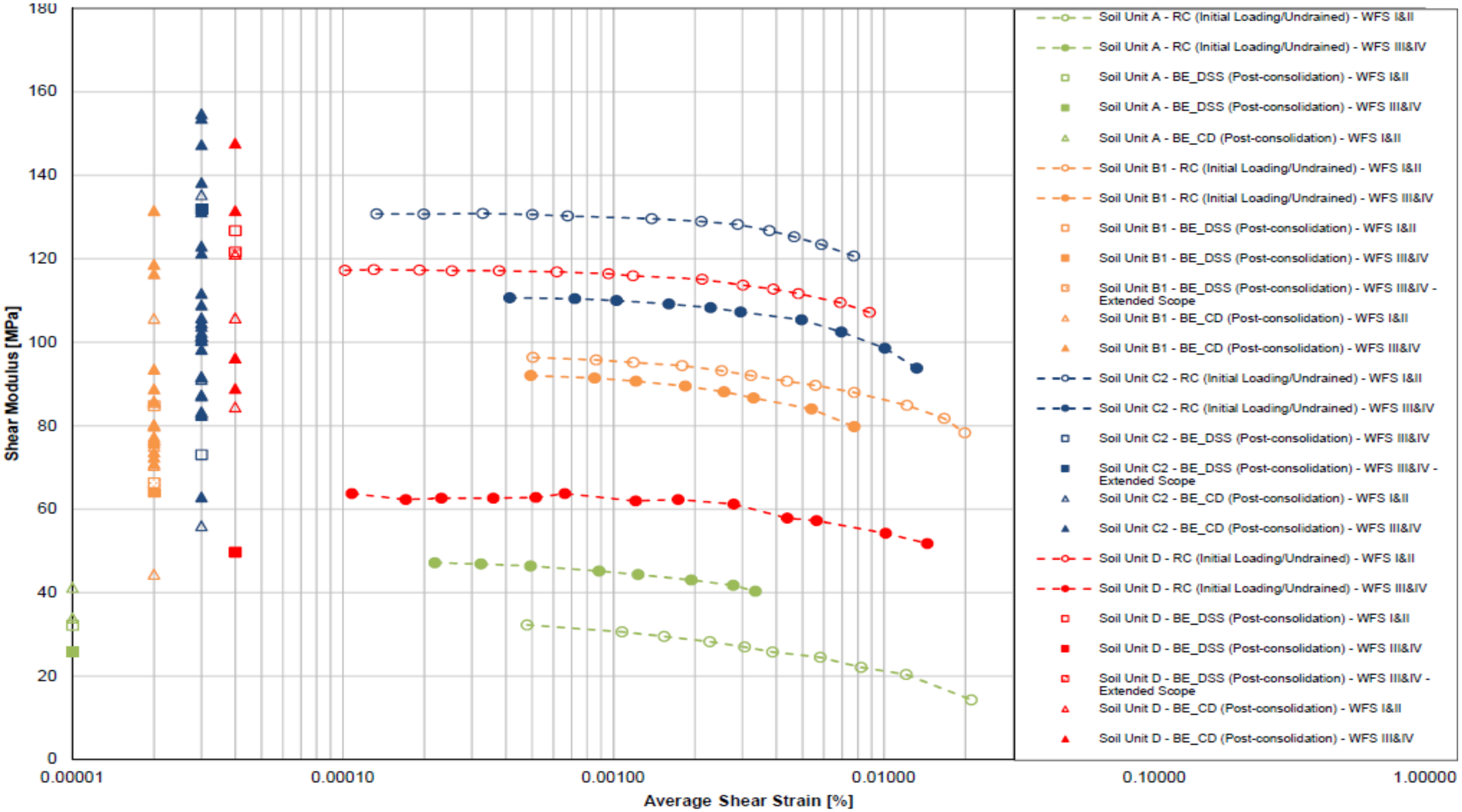
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



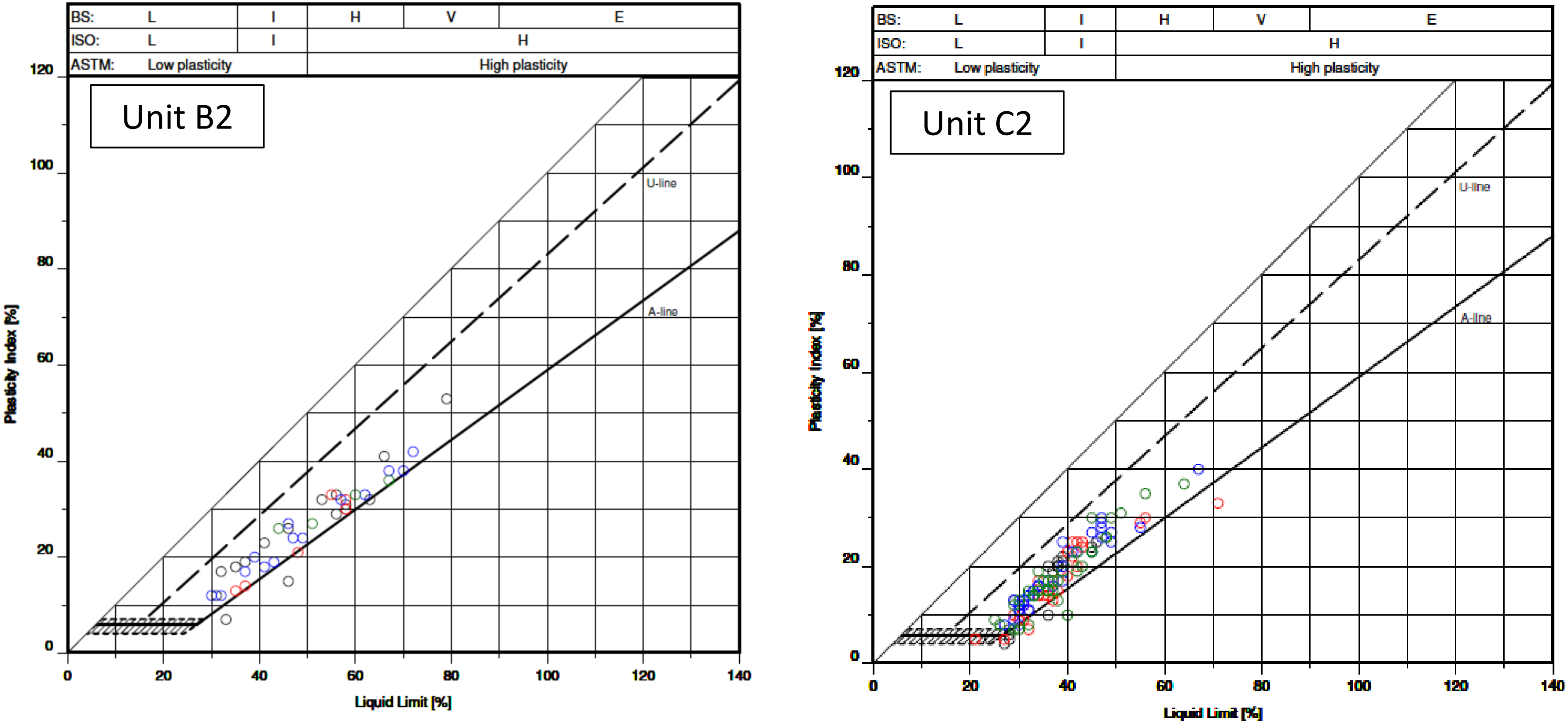
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



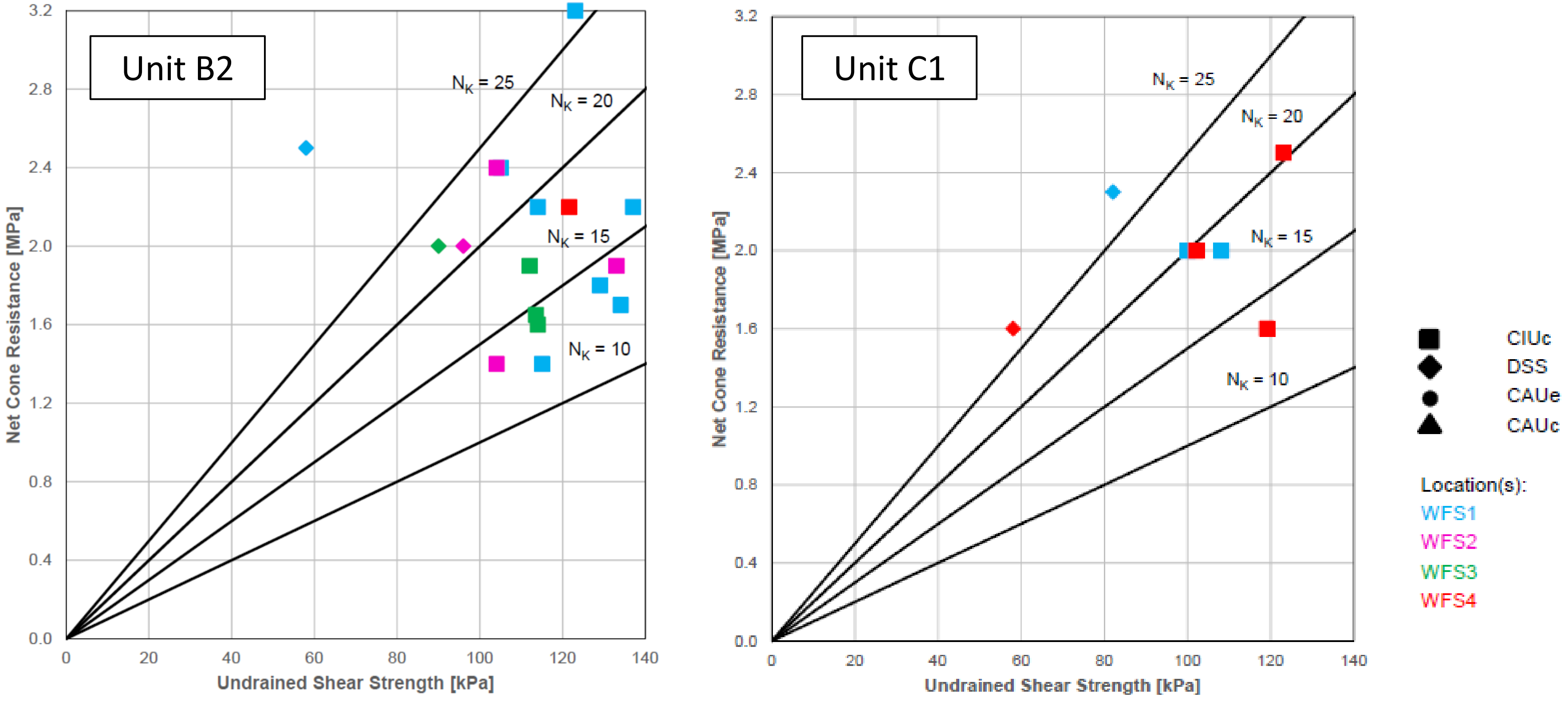
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



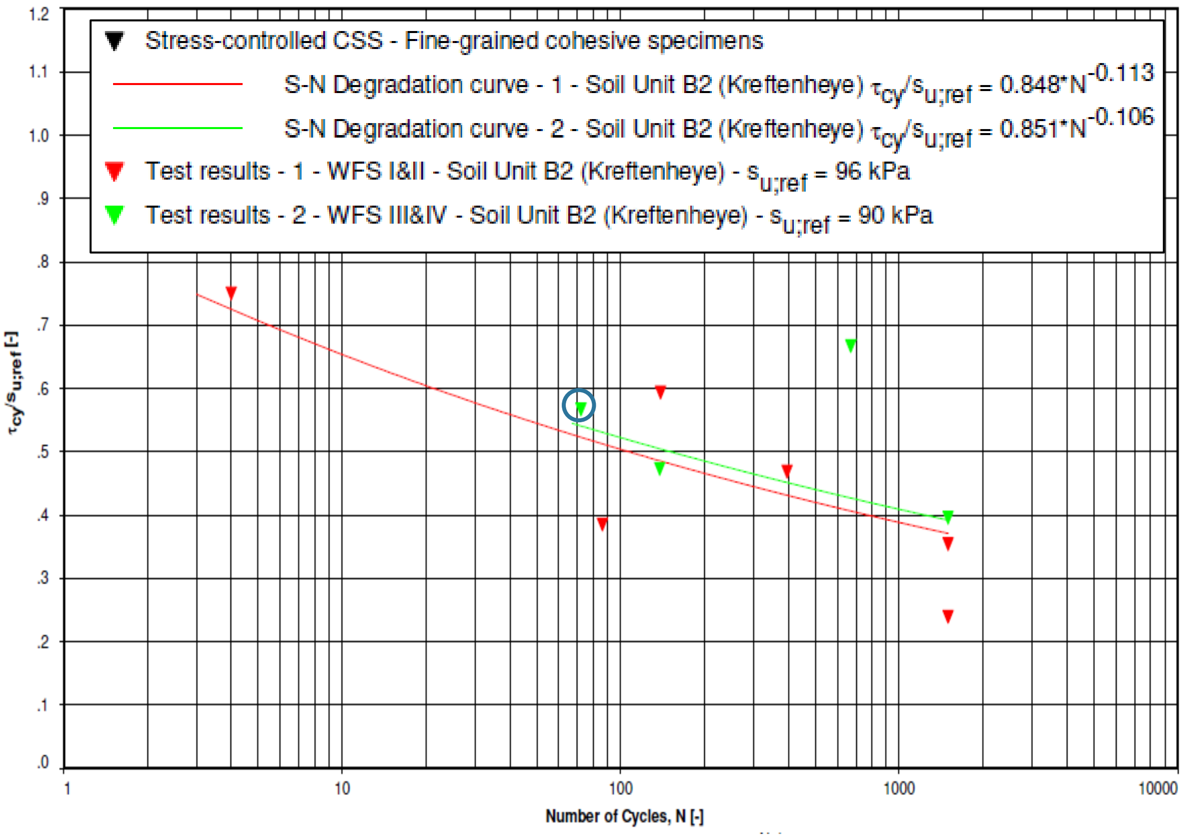
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

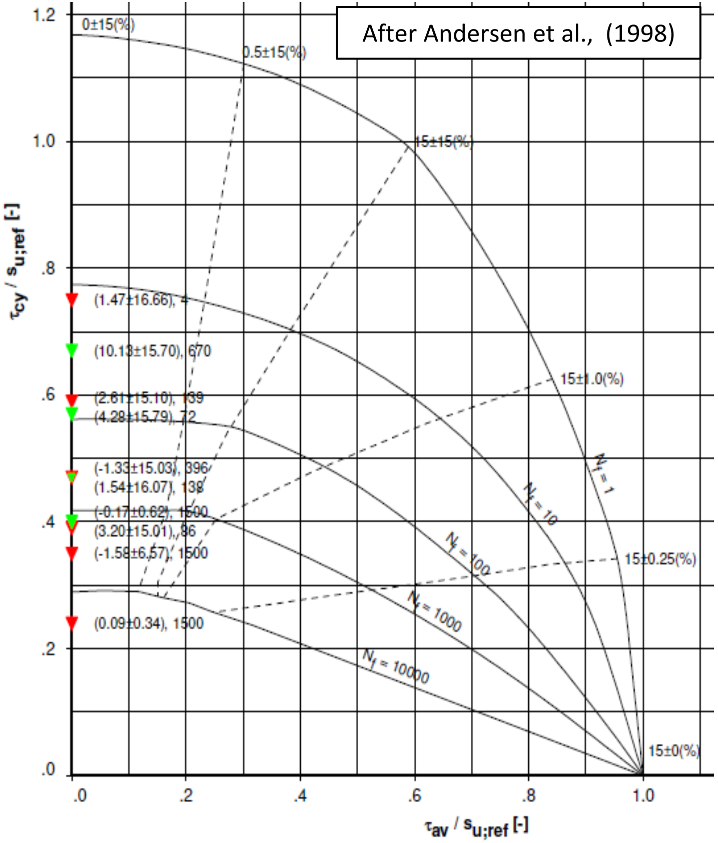


Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

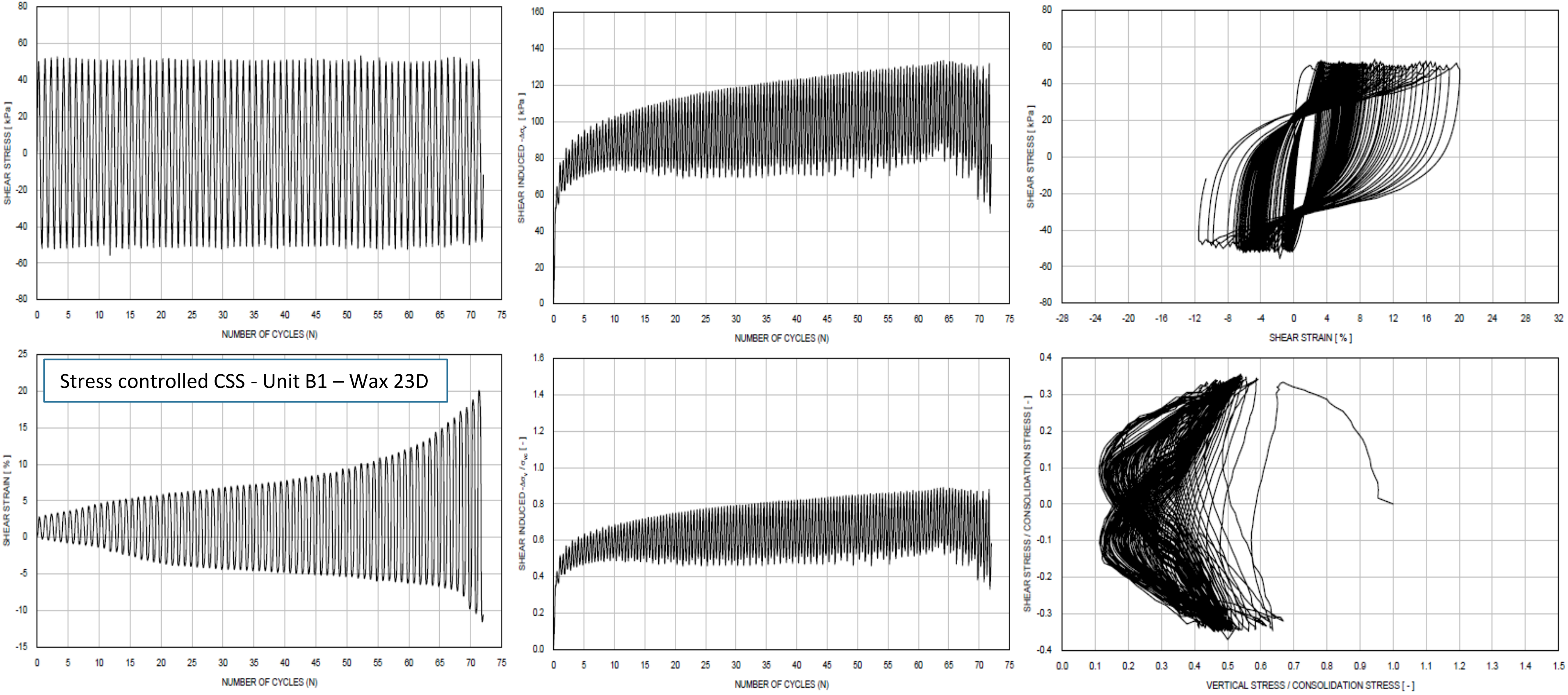


Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

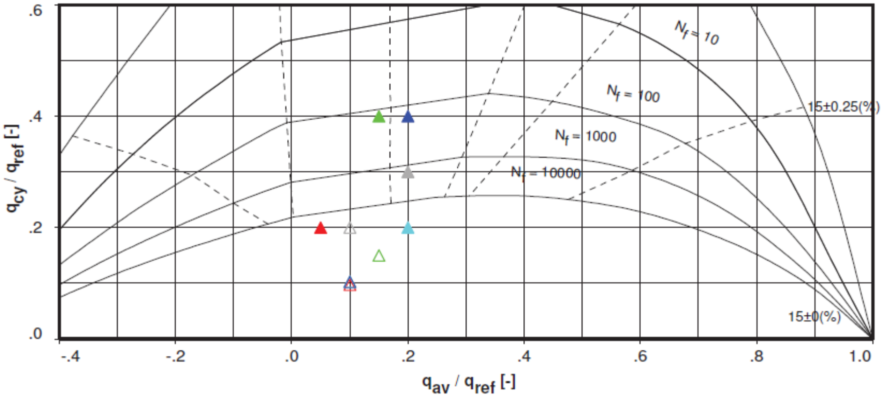




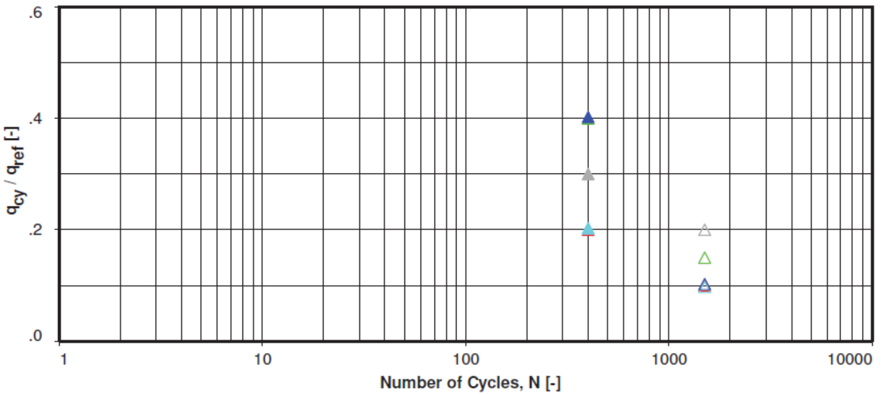
Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

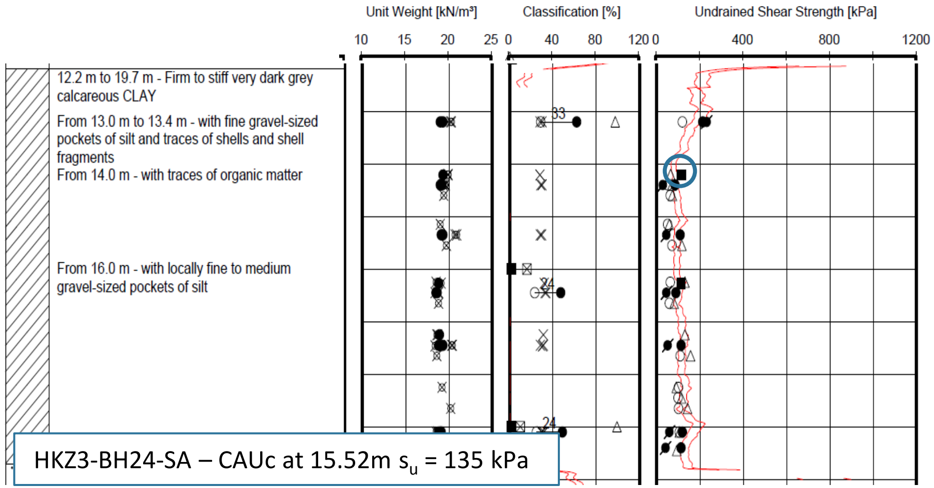


Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



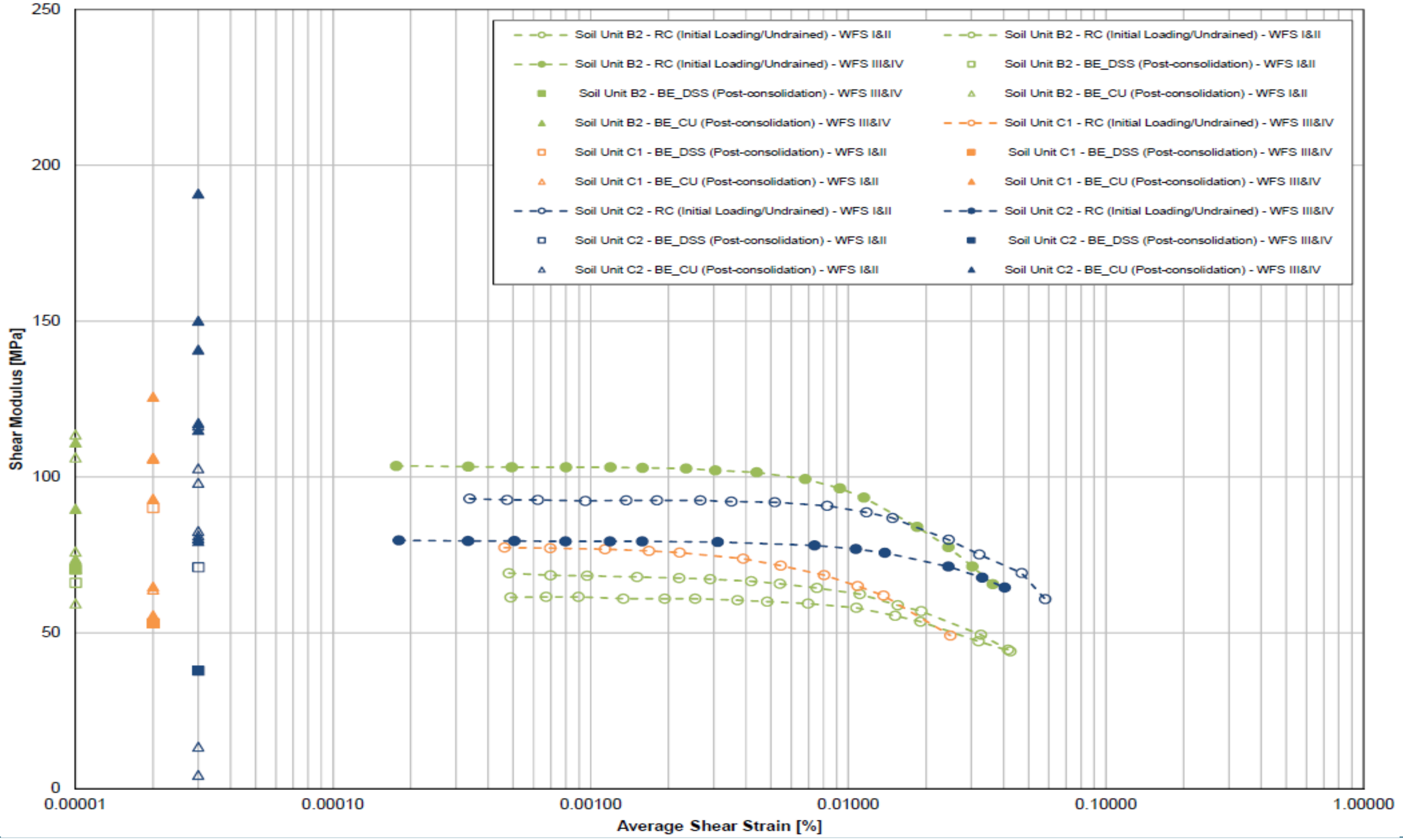
Symbol	Location	Sample No.	Depth	Test ID	$s_{u;ref}$	Cyclic Loading Stage 1			Cyclic Loading Stage 2		
			[m]		[kPa]	ε_{av} [%]	ε_{cy} [%]	Nf [-]	ε_{av} [%]	ε_{cy} [%]	Nf [-]
▲ (red)	HKZ1-BH01-SA	17WaxC	14.86	CTX12	117	0.03	0.02	1500	0.04	0.07	400
▲ (light blue)	HKZ1-BH01-SA	17WaxD	15.08	CTX13	117	0.03	0.04	1500	0.33	0.09	400
▲ (green)	HKZ1-BH01-SA	21WaxC	18.92	CTX14	104	0.04	0.03	1500	0.16	0.18	400
▲ (dark blue)	HKZ1-BH01-SA	21WaxD	19.10	CTX15	104	0.02	0.02	1500	0.33	0.20	400
▲ (grey)	HKZ3-BH24-SA	20WaxD	15.52	CTX13	135	1.10	0.45	1500	0.96	0.46	400





HKZ3-BH24-SA – CAUc at 15.52m s_u = 135 kPa

Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results



Comparison WFS 1+2 & 3+4 - Advanced Laboratory Test Results

It is assessed that the laboratory test results applicable to WFS I&II and WFS III&IV can be judiciously combined within the context of reliability of geotechnical structures according to Annex D of ISO (2015) or equivalent.

The combined use of the data can:

- improve the understanding of spatial soil variability applicable to the soil units present across the HKZ WFZ;
- optimise the range of parameter values required for design and reduce uncertainties in design.

Particularly, it is assessed that the HKZ WFZ shows no evidence of significant differences in geological setting and associated geotechnical characteristics between WFS I&II and WFS III&IV.

Note that the deliverables considered for the geophysical and geotechnical campaigns for HKZ WFZ provide no guidance on the selection of characteristic values. The selection of characteristic values of geotechnical parameters takes place within the context of a calculation model and thus includes consideration of limit states, actions, geometry, limiting values and partial factors or safety factors.

Concluding Remarks

- The available geotechnical and geophysical data align well. They provide a robust basis for the geological ground model.

- The investigation area is characterized by limited lateral correlation of soil properties. Variations in soil conditions are evident from presented geotechnical parameters

- Soil conditions at individual geotechnical locations as well as within soil units between geotechnical locations show sequences of sand, clays and intermediate soils.

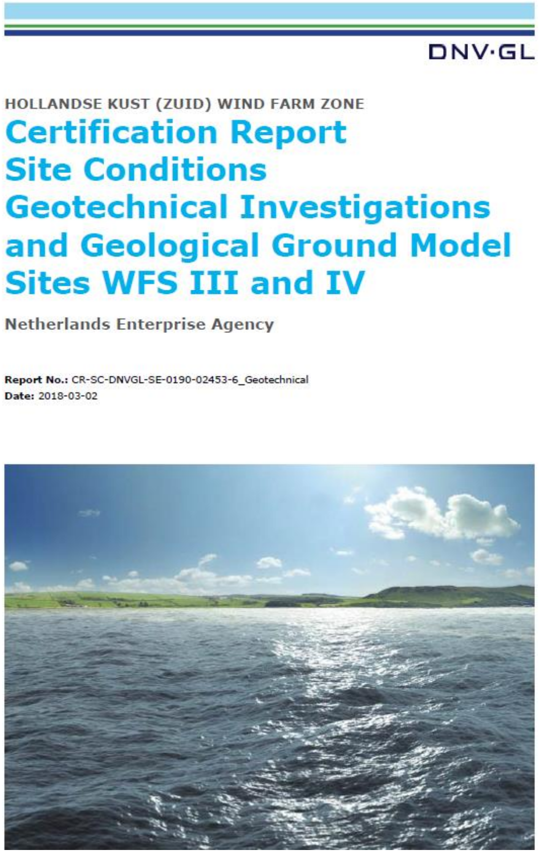
- Geotechnical assessment of suitability of possible foundation elements indicates that the more commonly used types are feasible, particularly multiple pile and monopile foundations

Concluding Remarks

Conclusion DNV GL on the site investigation and deliverables for HKZ (WFS III and IV):

"The comprehensive geotechnical campaign and the advanced laboratory test program were defined as a joint effort between multiple parties and reviewed by DNV GL with the objective to reduce the need for boreholes and additional laboratory tests in later stages of development. With a proper CPT calibration and additional CPTs at each planned turbine location it is likely that additional boreholes may be omitted."

Report No.: CR-SC-DNVGL-SE-0190-02453-6_Geotechnical (dated 2 March 2018)


DNV·GL

HOLLANDSE KUST (ZUID) WIND FARM ZONE

Certification Report
Site Conditions
Geotechnical Investigations
and Geological Ground Model
Sites WFS III and IV

Netherlands Enterprise Agency

Report No.: CR-SC-DNVGL-SE-0190-02453-6_Geotechnical
Date: 2018-03-02

Thank you for your interest and attention

For further questions or feedback you may contact me at m.klein@fugro.com

Or visit Fugro’s website at www.fugro.com

Closing the webinar

- Questionnaire
- Lessons learned
- Availability panel
- Communications
  - https://offshorewind.rvo.nl
  - woz@rvo.nl