Netherlands Enterprise Agency

Webinar Geophysical and Geotechnical Survey results

Hollandse Kust (west) Wind Farm Zone

5 November 2020

Frank van Erp

Welcome

- Introduction of the webinar
- Presentation of geophysical and geotechnical survey results by Bogusia Klosowska and Erik Schoute (Fugro)
- Expert panel: John Carey (Windsupport), Ana Branco Fernandes (RIL), Sven Plasman, Dirk-Jan Karssen, Peter-Paul de Graaf, Heike Neumann (Fugro), Ben de Sonneville, Jeroen Godtschalk (BLIX) and Matté Brijder (RVO)
- Alias assigned for private chat
- Slides disclosed at https://offshorewind.rvo.nl

RVO philosophy

- 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 - Geophysical and Geotechnical Site Investigations

Webinar - 5 November 2020

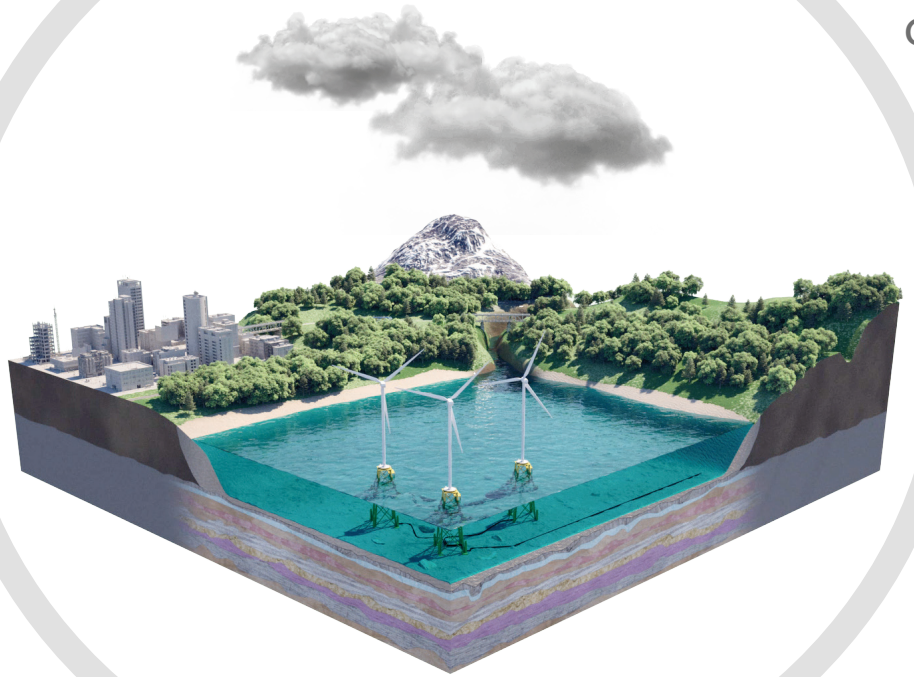
Fugro is the world's leading Geo-data specialist

Geophysical

Global Positioning

Metocean

Geospatial



Geohazard

Geochemical

Geodynamic

Geotechnical

Contents

Presenters

- Bogusia Klosowska – Principal Geologist:
  - Geophysical Site Investigations
  - Geological Ground Model

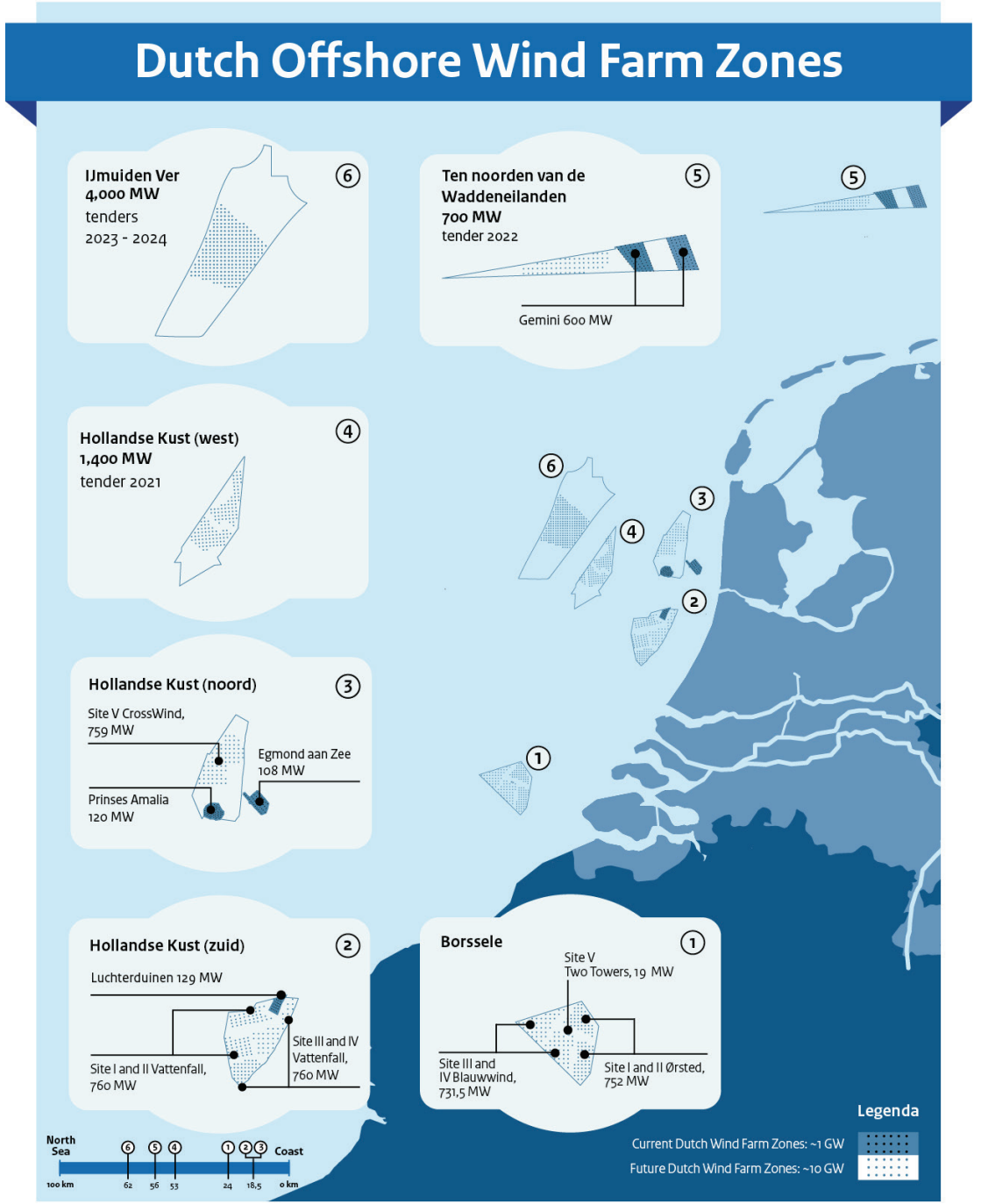
- Erik Schoute – Senior Geotechnical Engineer:
  - Geotechnical Site Investigations
  - Laboratory Test Programmes

01

Introduction

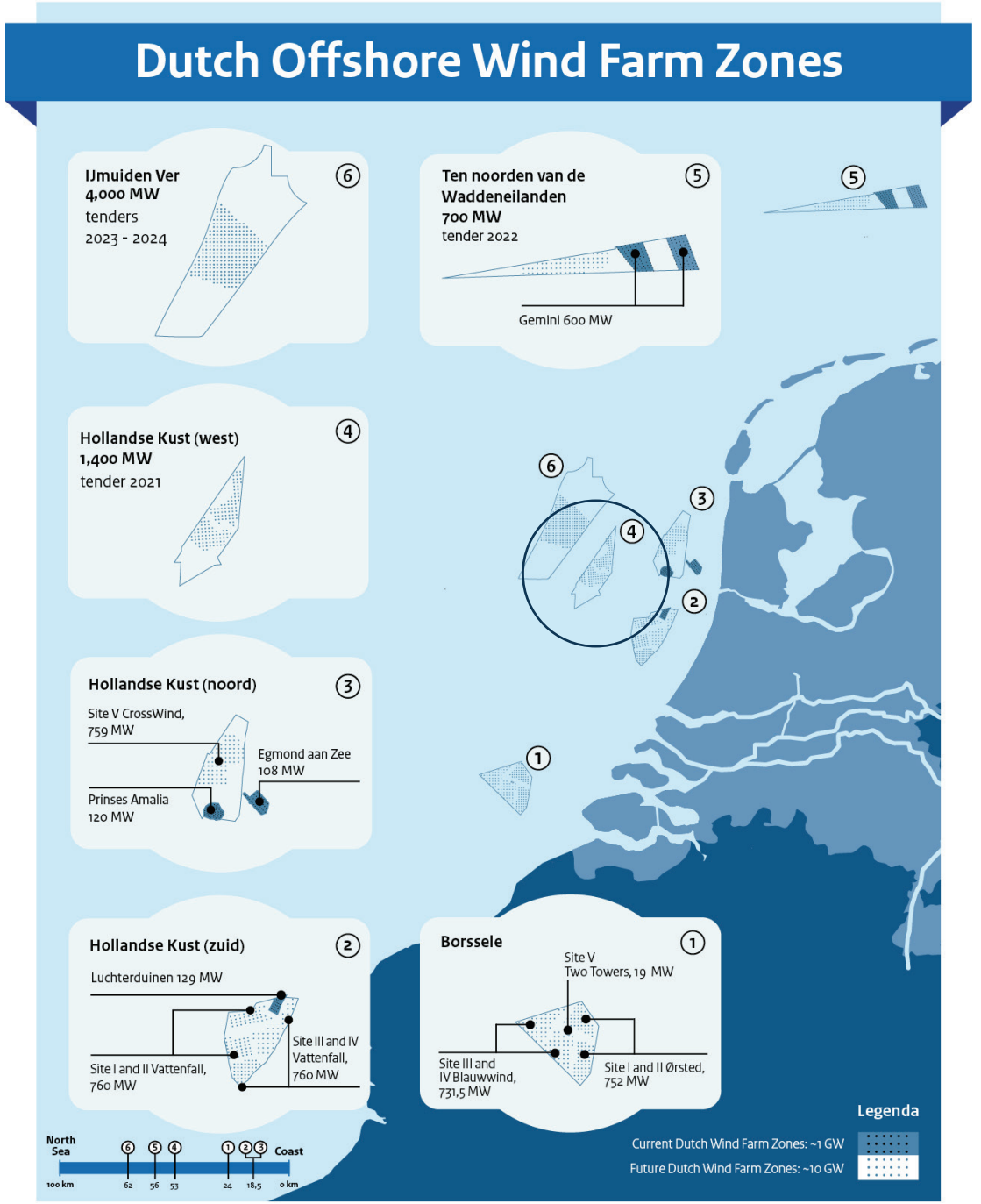
Hollandse Kust (west) Wind Farm Zone

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



Hollandse Kust (west) Wind Farm Zone

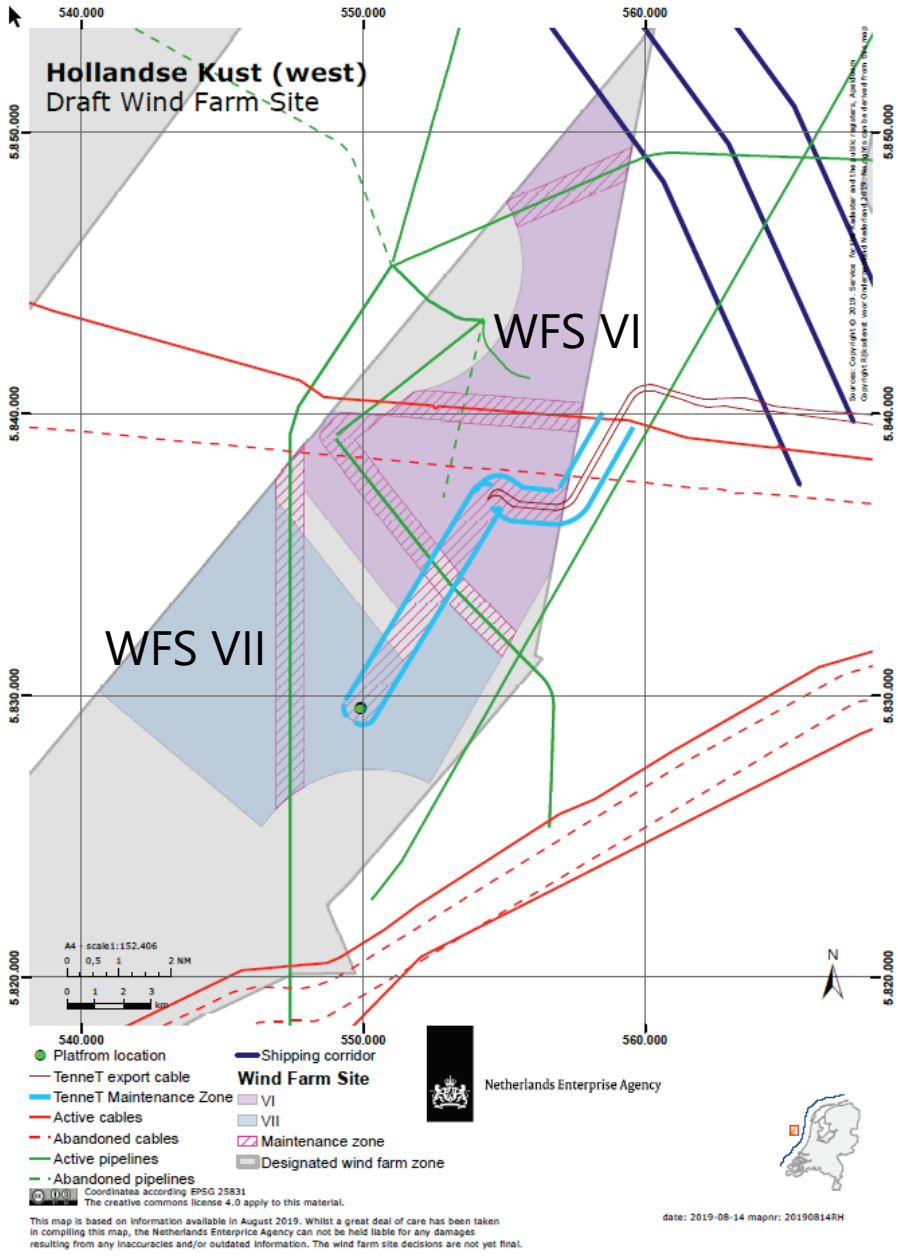
Source:
english.rvo.nl/topics/sustainability/offshore-wind-energy/hollandse-kust-west-wind-farm-zone



Hollandse Kust (west) Wind Farm Zone

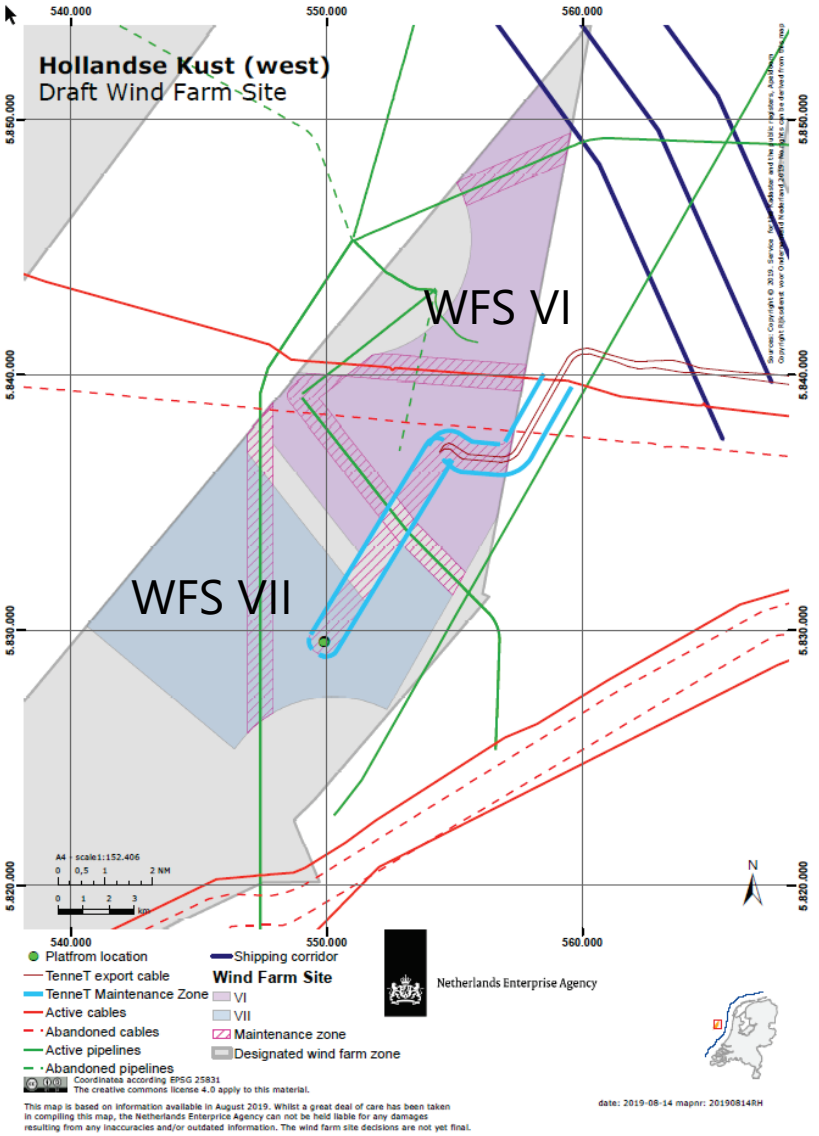
Status: August 2019

Source:
offshorewind.rvo.nl/generalw



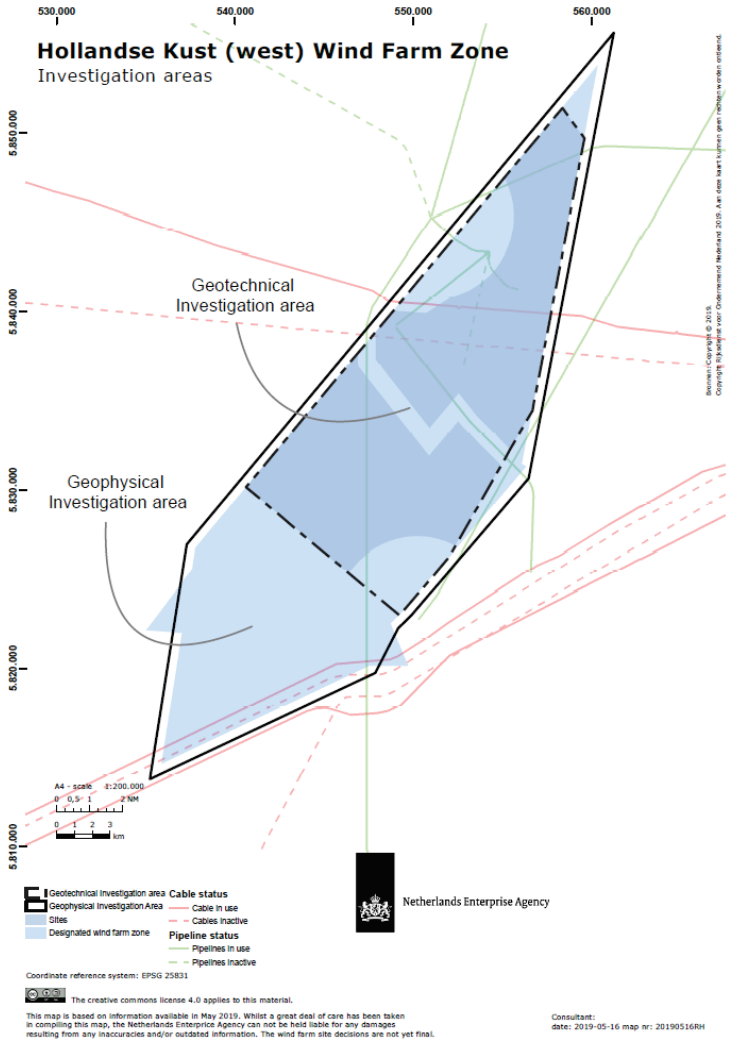
Hollandse Kust (west) Wind Farm Zone

- Hollandse Kust (west) Wind Farm Zone (HKW WFZ) is located ~ 28.6 nautical miles (~53 km) off the west coast of the Netherlands
- HKW WFZ surface area: ~415 km^2
- Water depths WFS: ~21 to 33 m LAT
- Pipelines, cables, platforms
- Total surface area WFS VI and VII: ~176 km^2
- 2 x 700 MW
- Two TenneT platforms for grid connections



Source: offshorewind.rvo.nl/generalw (status: August 2019)

Hollandse Kust (west) Wind Farm Zone



- Two different investigation areas:
  - Geophysical investigation area (solid line): ~395 km^2
  - Encompasses most of WFZ
  - Geotechnical investigation area (broken line): ~224 km^2
  - Encompasses planned WFS (WFS VI and WFS VII)

Road Map

- Desk studies provided by RVO
- Geophysical site investigations
- Geophysical reporting
- Geotechnical site investigations
- Laboratory testing programmes
- Geotechnical reporting
- Geological reporting

Hollandse Kust (west) Wind Farm Zone

- RVO approach to site studies:
  - High quality site investigations resulting in lower costs of offshore wind energy
  - Allowing developers to submit a competitive proposal during tenders

- Desk studies:
  - UXO desk study
  - Geological desk study
  - Archaeological assessments
  - Morphodynamics
  - Scour and scour mitigation
  - Metocean desk study

All reports available at:
offshorewind.rvo.nl/generalw

Hollandse Kust (west) Wind Farm Zone

- Site investigations:
  - Geophysical surveys
  - Geotechnical site investigations
  - Metocean campaign

All reports available at:
offshorewind.rvo.nl/generalw

02

Geophysical Site Investigations

Geophysical Site Investigations - Objectives

- Provide bathymetry and information on the presence of seafloor features, including boulders, wrecks, and debris (both known and previously unmapped)
- Provide exact positions of existing (in service and out of service) cables and pipelines
- Provide a comprehensive interpretation of the survey results resulting in a geological model of the site, including:
  - Elevation and depth below seafloor charts for the main seismostratigraphic units
  - Locations of any structural complexities or geohazards within the shallow geological succession such as faulting, accumulations of shallow gas, peat, and buried channels
  - Detailed geological interpretation to show facies variations and structural feature changes via appropriate maps and sections
- Provide input into specifications and scope for geotechnical site investigations

Geophysical Site Investigations - Equipment

MV Fugro Frontier

- 22 October 2018 to 17 February 2019
- Shallow geophysical operations consisting of single pass survey with:
  - Sidescan sonar (SSS)
  - Magnetometer (MAG)
  - Multibeam echo sounder (MBES)
  - Sub-bottom profiler (SBP)
  - Ultra high resolution single channel seismic (SCS-UHR)

Geophysical Site Investigations - Equipment

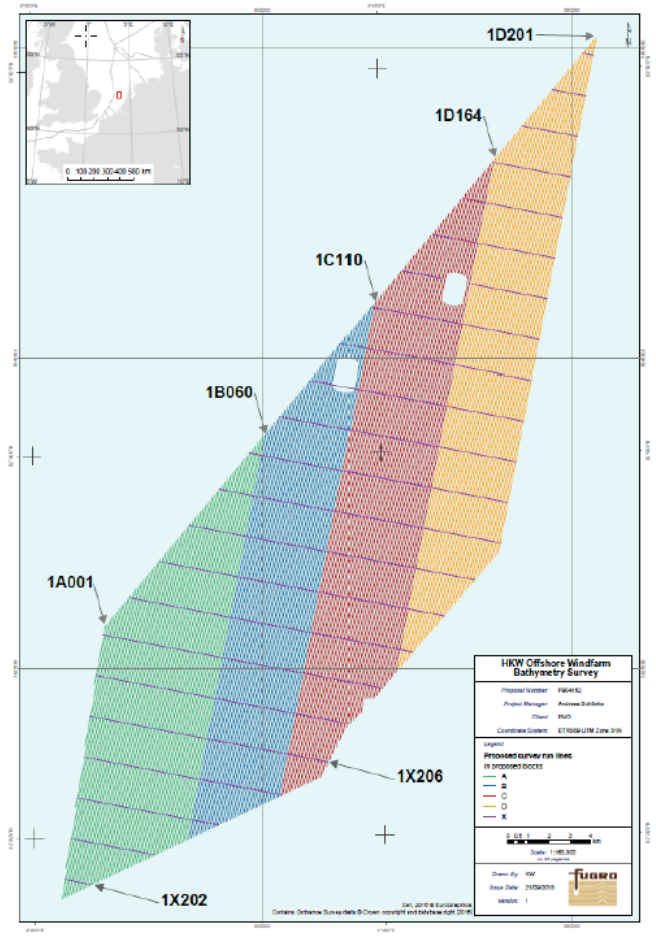
MV Fugro Pioneer

- 11 October 2018 to 25 January 2019:
  - Ultra high resolution multichannel seismic (MCS-UHR)
- 25 January 2019 to 16 February 2019:
  - Shallow geophysical operations, the same spread as Fugro Frontier

Geophysical Site Investigations - Equipment

Sensor Type	Equipment	Line Spacing [main / cross]	Resolution
Multibeam Echo Sounder	Hull-mounted dual head Kongsberg EM2040	100 m / 2000 m	The survey was conducted in accordance with International Hydrographic Organization (IHO). The requirement was to achieve the requirements of the Order 1a standard.
Sidescan Sonar	EdgeTech 4200-FS (LF: 100 kHz HF: 600 kHz)	100 m / 2000 m	Heights of seafloor obstructions estimated from the SSS data are considered to have an across track accuracy of ± 0.1 m
Magnetometer	Geometrics G-882 marine magnetometer	100 m / 2000 m	-
Sub-bottom Profiler	Hull-mounted pinger (4 x 4 Massa TR-1075, 16 transducers)	100 m / 2000 m	Useful acoustic penetration up to 10 ms (approximately 8 m below seafloor) The vertical resolution estimated is better than ± 0.2 m with penetration > 3 m
UHR Single Channel Seismic	Fugro Single Level Sparker 200J	100 m / 2000 m	The vertical resolution is estimated at ± 0.3 m in the shallower part [-40 m LAT] (average Vp of ~1650 m/s)
UHR Multi Channel Seismic	Fugro Multi Level Sparker 800J 48 channels	400 m / 400 m	The vertical resolution estimated at ± 0.5 m in the shallower part [-40 m LAT] (average Vp of ~1700 m/s) to ± 1.6 m in the deeper part [-100 m LAT] (Vp of ~1800 m/s)

Geophysical Site Investigations - Survey Programme



MBES/SSS/MAG/SBP/SCS-UHR

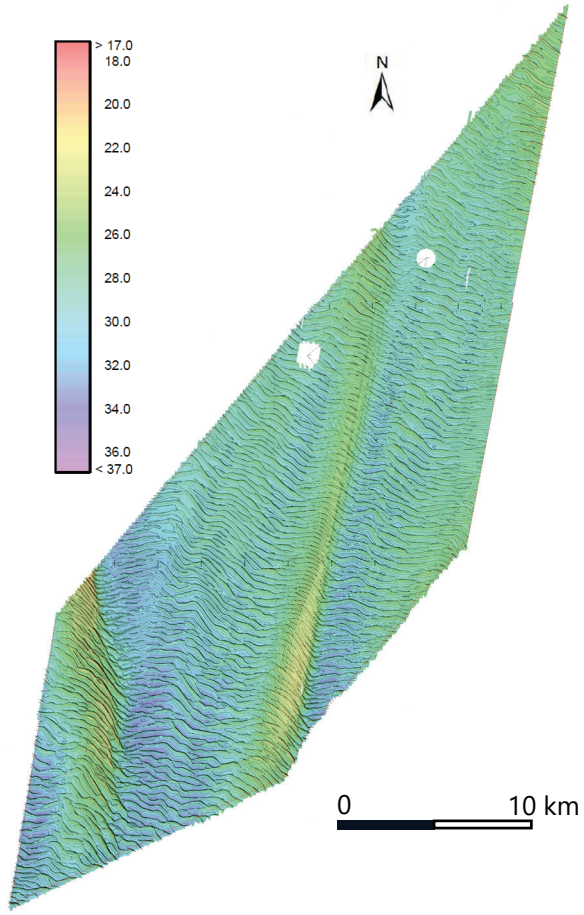
- Main lines:
  - No. lines: 201
  - Total length: 3 898 km
  - Spacing: 100 m
- Cross lines:
  - No. lines: 24
  - Total length: 195 km
  - Spacing: 2 000 m

MCS-UHR

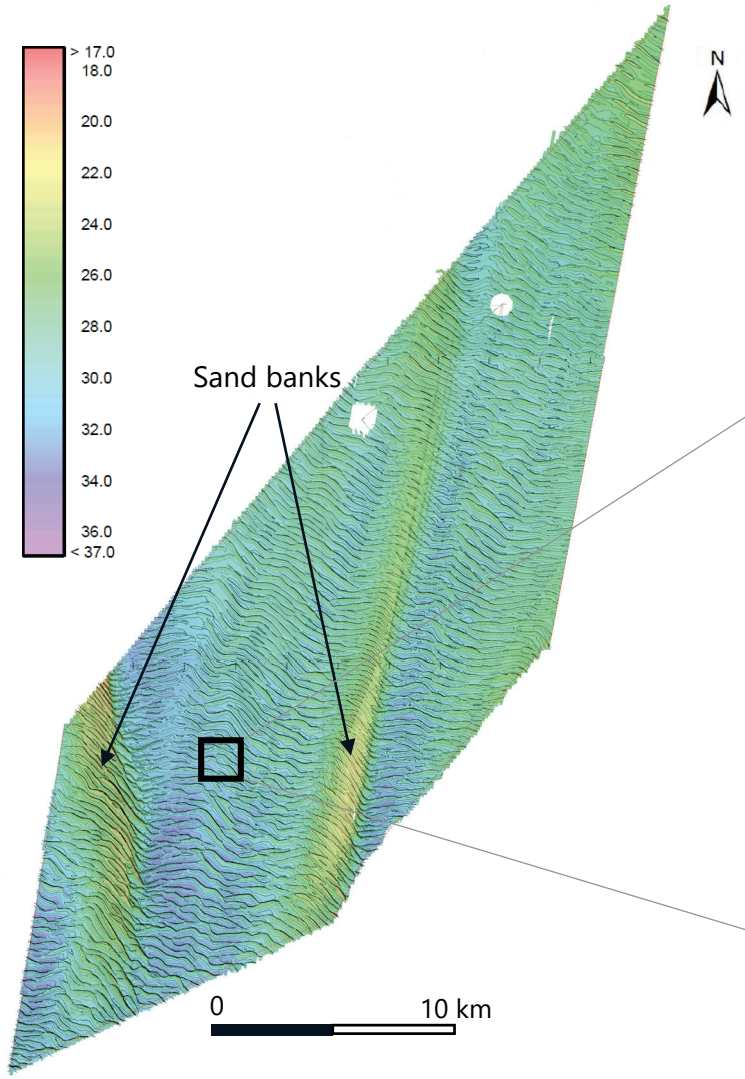
- Main lines:
  - No. lines: 52
  - Total length: 983 km
  - Spacing: 400 m
- Cross lines:
  - No. lines: 120
  - Total length: 975 km
  - Spacing: 400 m

Geophysical Site Investigations - Bathymetry and Bedforms

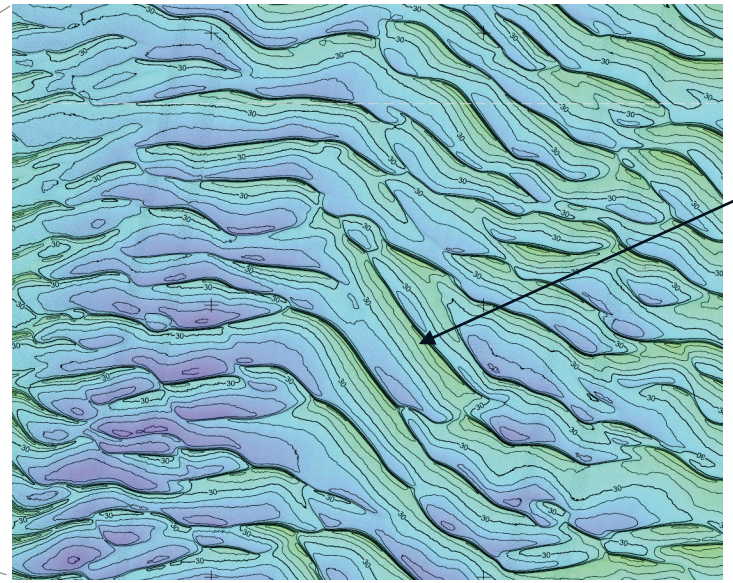
- Measured water depths range from 18.6 m to 35.5 m LAT. The shallowest areas are on top of the sand bank crests and the deepest areas are adjacent to the sand banks in the southwest.
- The water depth increases from the northeast corner of the survey area with average depth values approximately 25 m LAT, to the southwest corner with average depth values of around 32 m LAT
- Most of the survey area has gentle slopes of less than 6°. Highest seafloor gradients observed within HKW WFZ are associated with wrecks and man-made objects present on the seafloor.
- The highest seafloor gradient is around 40° associated with seafloor bedforms in the western part of the HKW WFZ and is related to the lee side of the sand waves



Geophysical Site Investigations - Bathymetry and Bedforms



Bedform	Wave Length [m]	Wave Height [m]	Mobility
Megaripples	10-20	0.5-1.5	Mobile and transient
Sand waves	120-700	1.5-5.0	Mobile and persistent
Sand banks	10 000	6.0	Stationary



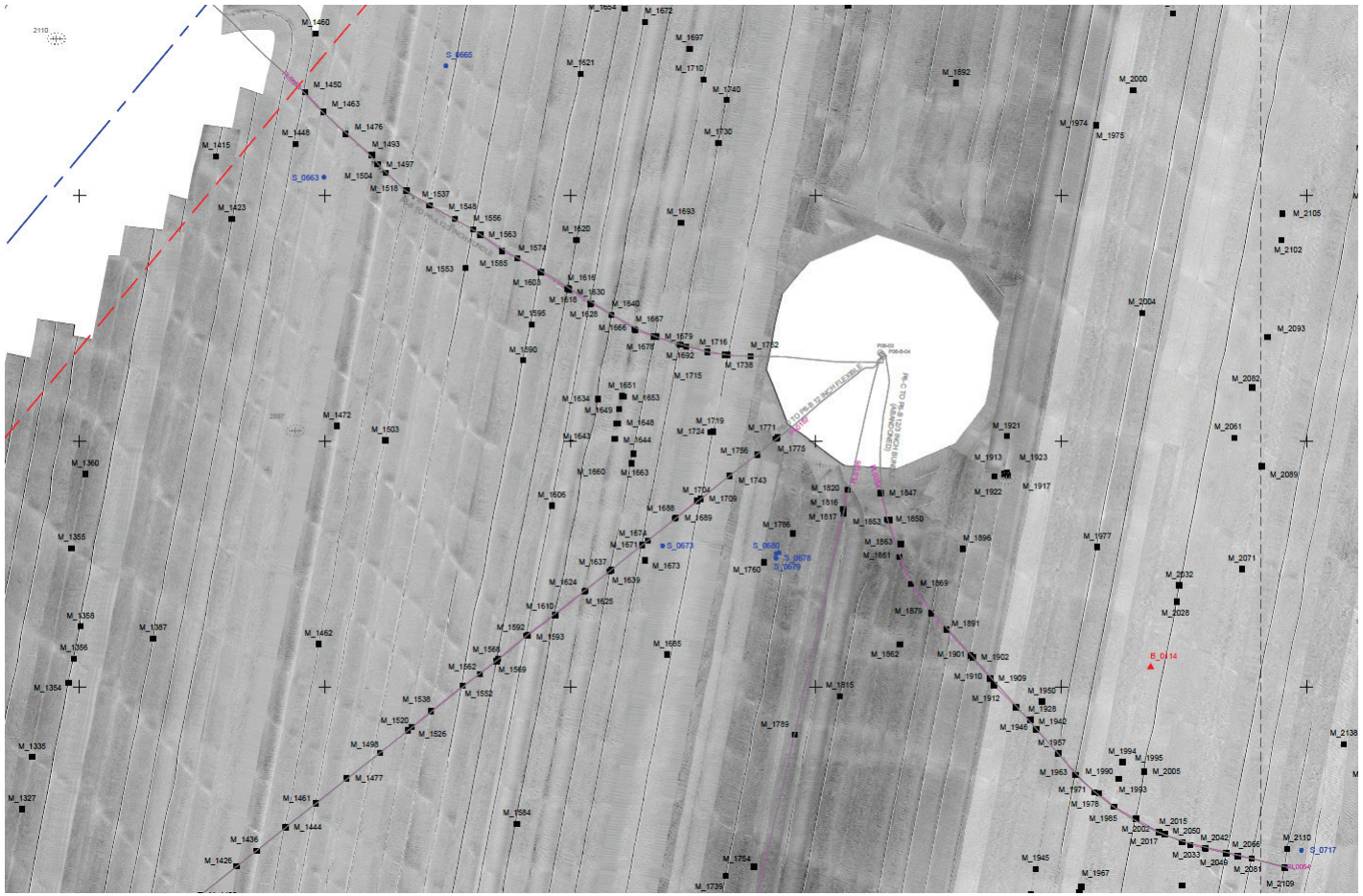
Detailed information in morphodynamics study report at:
offshorewind.rvo.nl/soilw

Geophysical Site Investigations - Seafloor Features

- Seafloor features were picked on sidescan sonar (SSS), magnetometer (MAG) and multibeam echo sounder (MBES) datasets
- Twelve wrecks, five cables and eight pipelines from the database were identified from the geophysical data. Within a detection size limit of 0.3 m, 405 objects were detected on the seafloor of which 61 ‘significant’.
- Other detected seafloor features comprise rock dumps, debris, boulders, depressions, trawl scars, wellheads, and several linear features of unknown origin
- In addition, three platforms are present: P6-B in the northeast, P6-D near the northwestern survey boundary, and P09-Horizon on the southeastern boundary. P06-S in the eastern part of the site was removed. Spudcan depressions and MAG anomalies were observed here.

Geophysical Site Investigations - Seafloor Features

Contacts identified on SSS, MAG, and MBES were cross-correlated



LEGEND:

GENERAL

- GEOGRAPHICAL GRID
- UTM GRID
- SURVEY AREA
- INVESTIGATION AREA
- CABLE AND PIPELINE DATABASE (Client Supplied / Fugro database)
- WELL HEAD (Client Supplied)
- 16720 OBSTRUCTION (NCN NUMBER) (Client Supplied)
- Anchor 14263 ANCHOR (Client Supplied)
- P06-10 PLATFORM (Fugro database)
- 1723 WRECK (Client Supplied)

CONTACTS

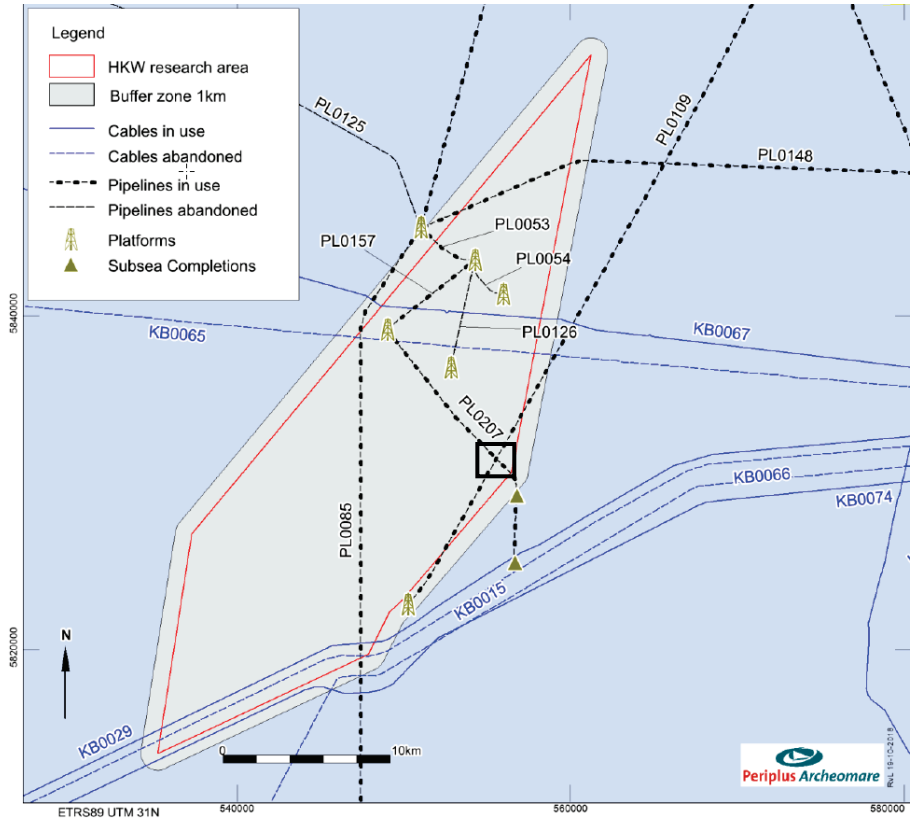
- PIPELINE AS-FOUND (POSITION INTERPRETED BY MAGNETOMETER CONTACT)
- CABLES AS-FOUND (POSITION INTERPRETED BY MAGNETOMETER CONTACT)
- M_0576 MAGNETOMETER CONTACT
- S_0516 SIDESCAN SONAR CONTACT
- B_0516 MULTIBEAM CONTACT
- LINEAR CONTACT (POSITION INTERPRETED BY MAGNETOMETER CONTACT)

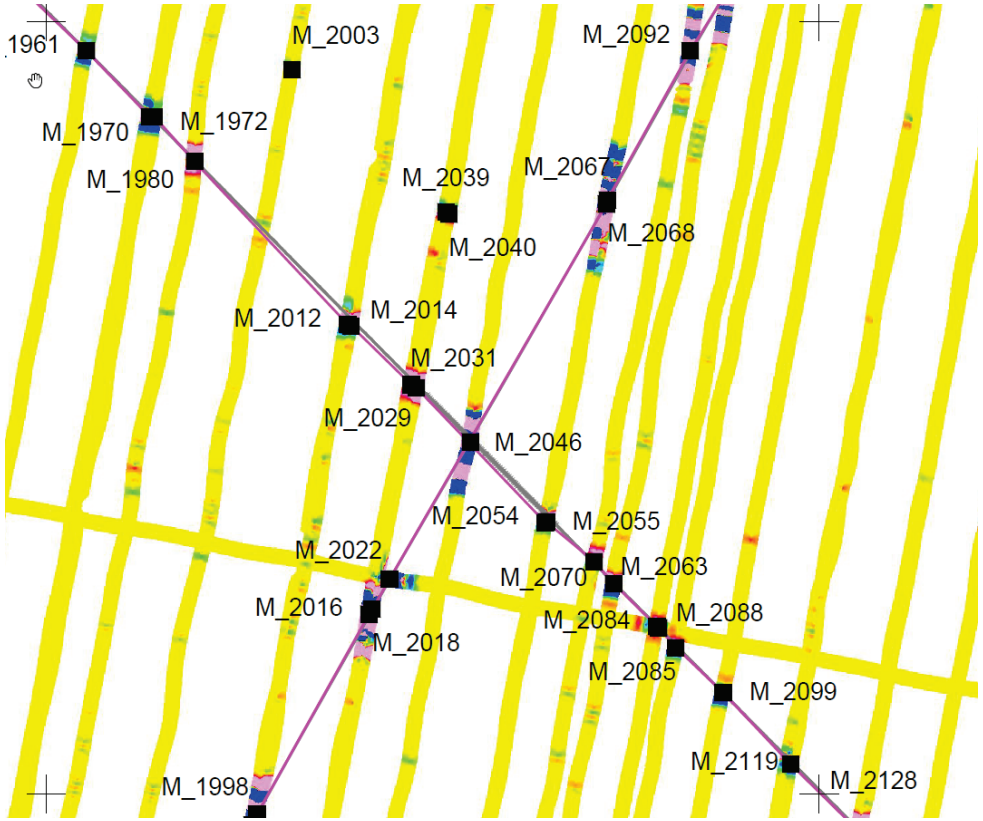
SSS MOSAIC

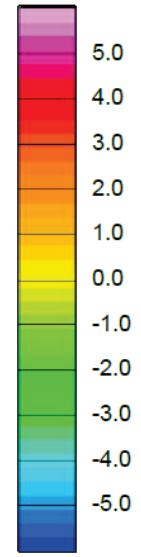
- SIDESCAN SONAR MOSAIC

Geophysical Site Investigations - Seafloor Features

Crossing of pipelines PL0207 and PL0109 as found by magnetometer



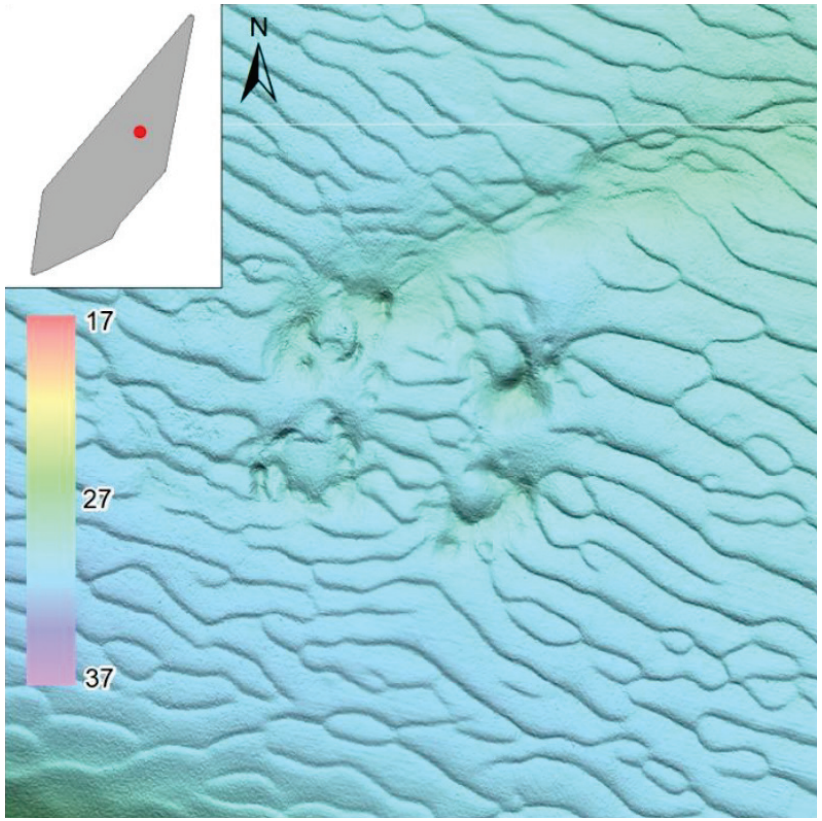




Magnetic Residual Scale Bar (in *nT*)

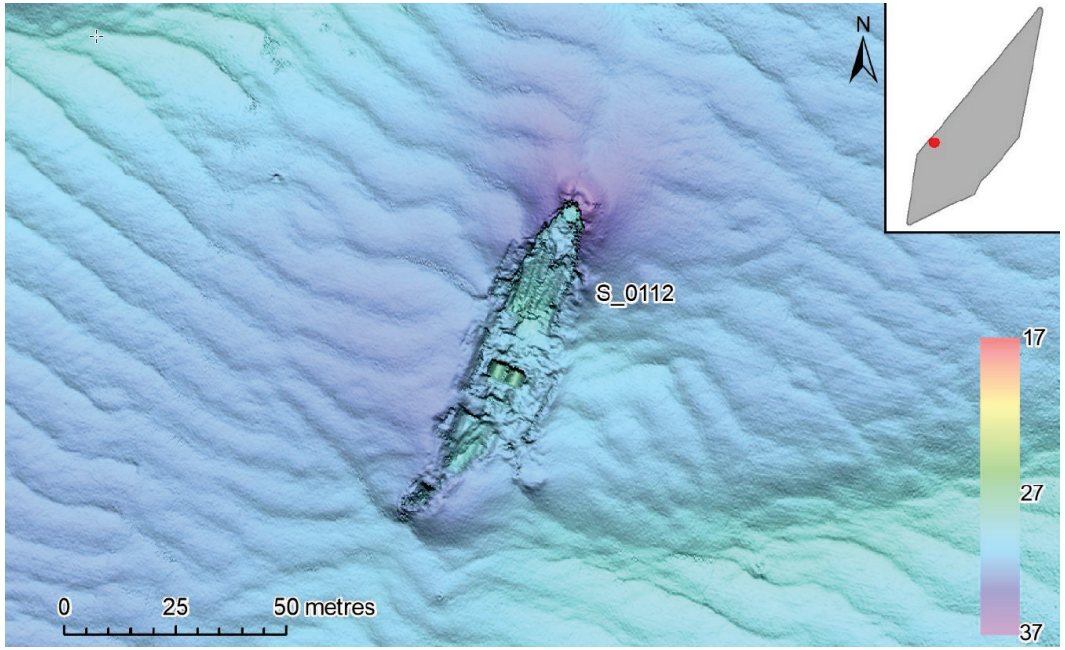
Geophysical Site Investigations - Seafloor Features

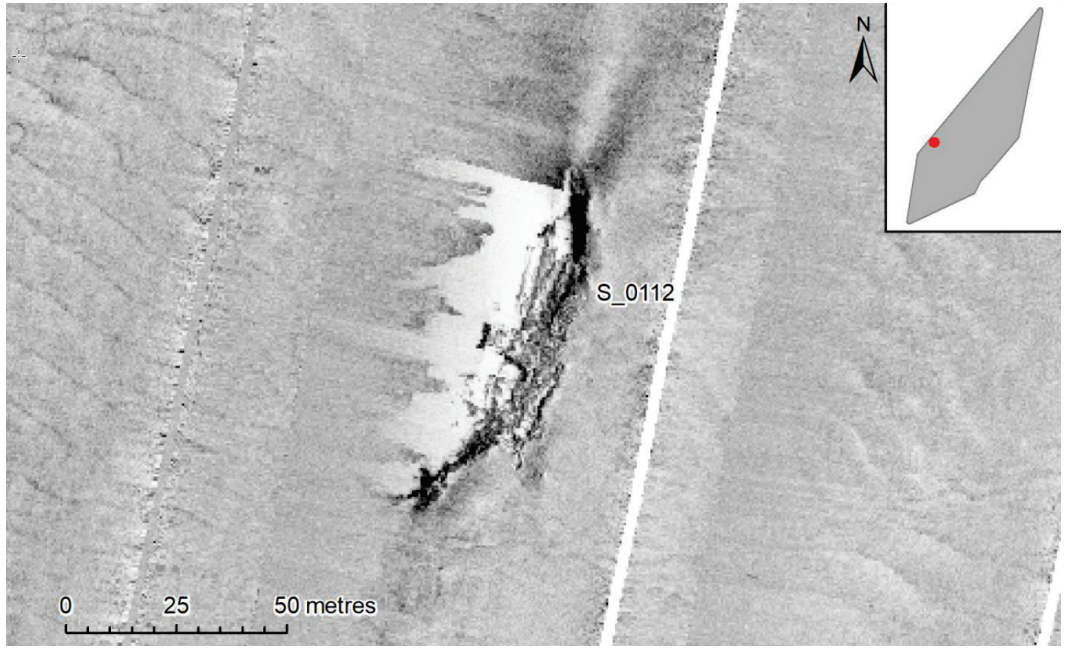
Bathymetry and SSS image of spudcan depressions near wellhead P06-10



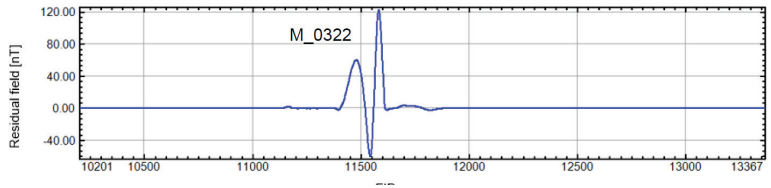
Geophysical Site Investigations - Seafloor Features

DS Biarritz (Norwegian merchant vessel, torpedoed and sunk 25 January 1940)



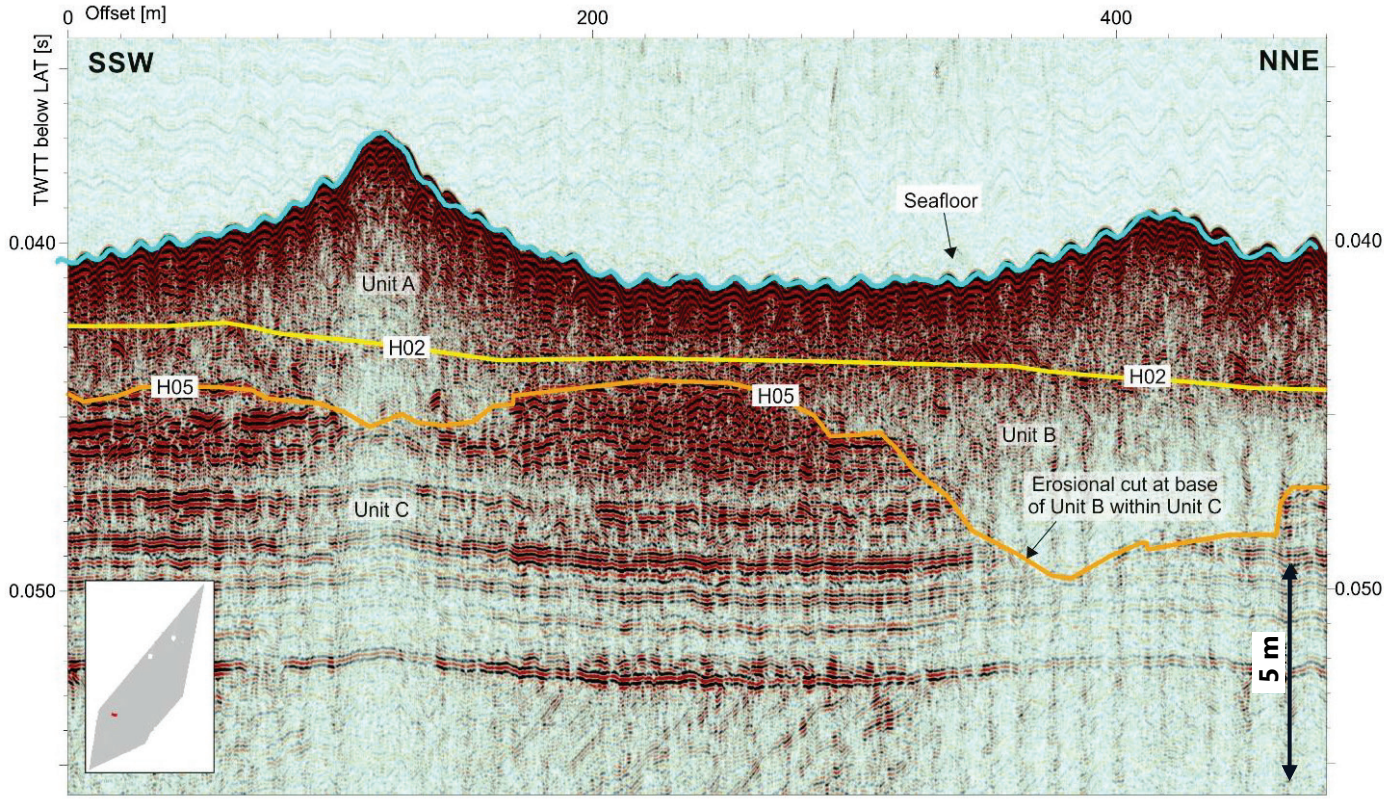


Bathymetry, SSS, and magnetic anomaly



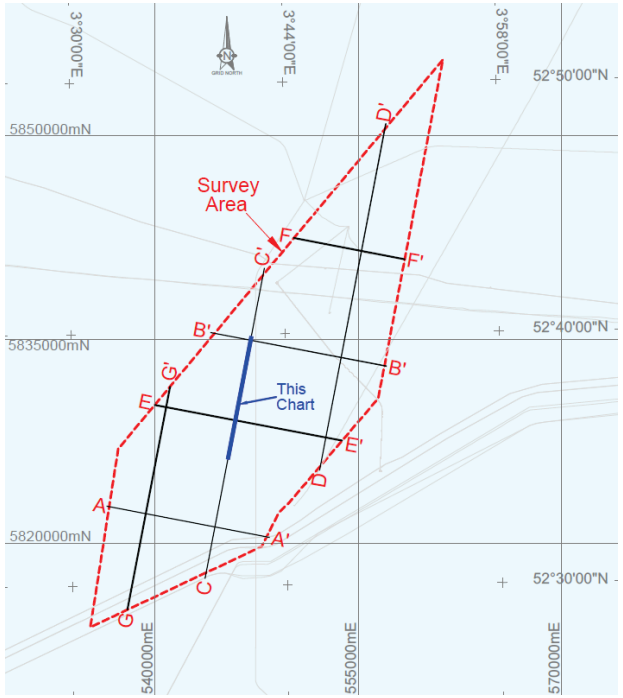
Geophysical Site Investigations - SBP Results

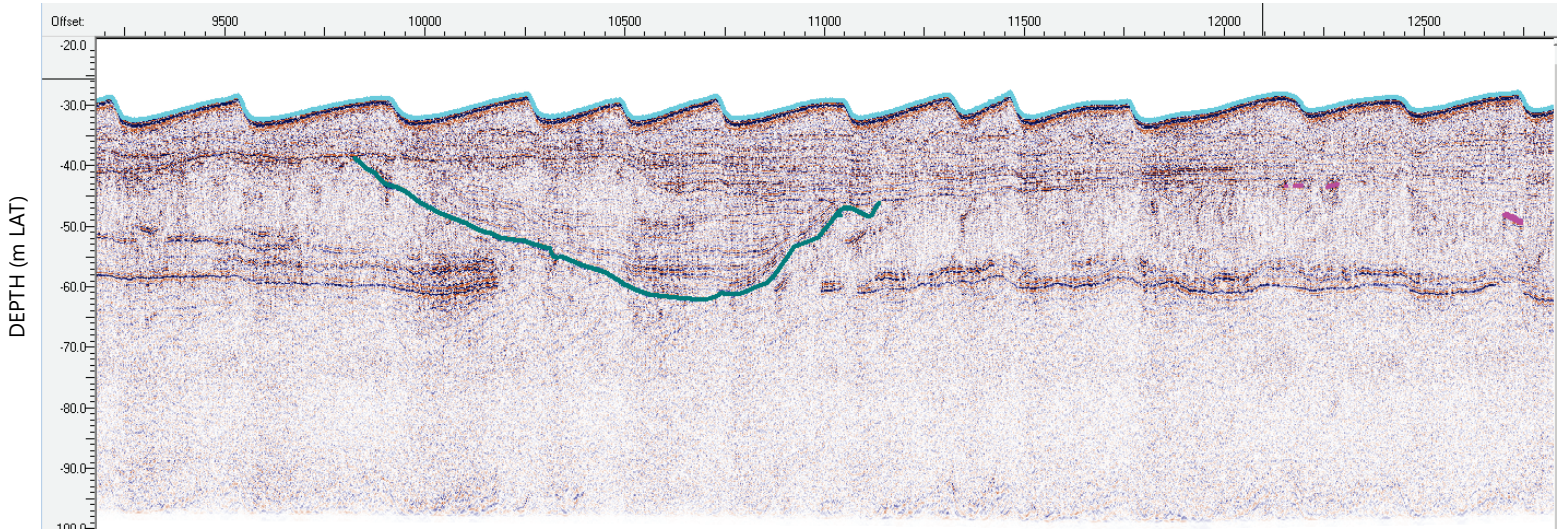
Data example (seismic line1A038)



Geophysical Site Investigations - SCS-UHR Results

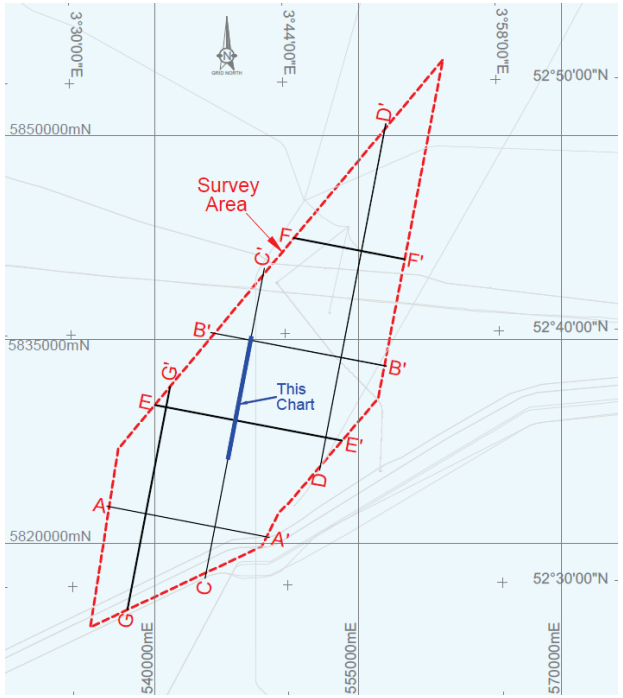
Profile C-C’ (seismic line Seq036_1B081)

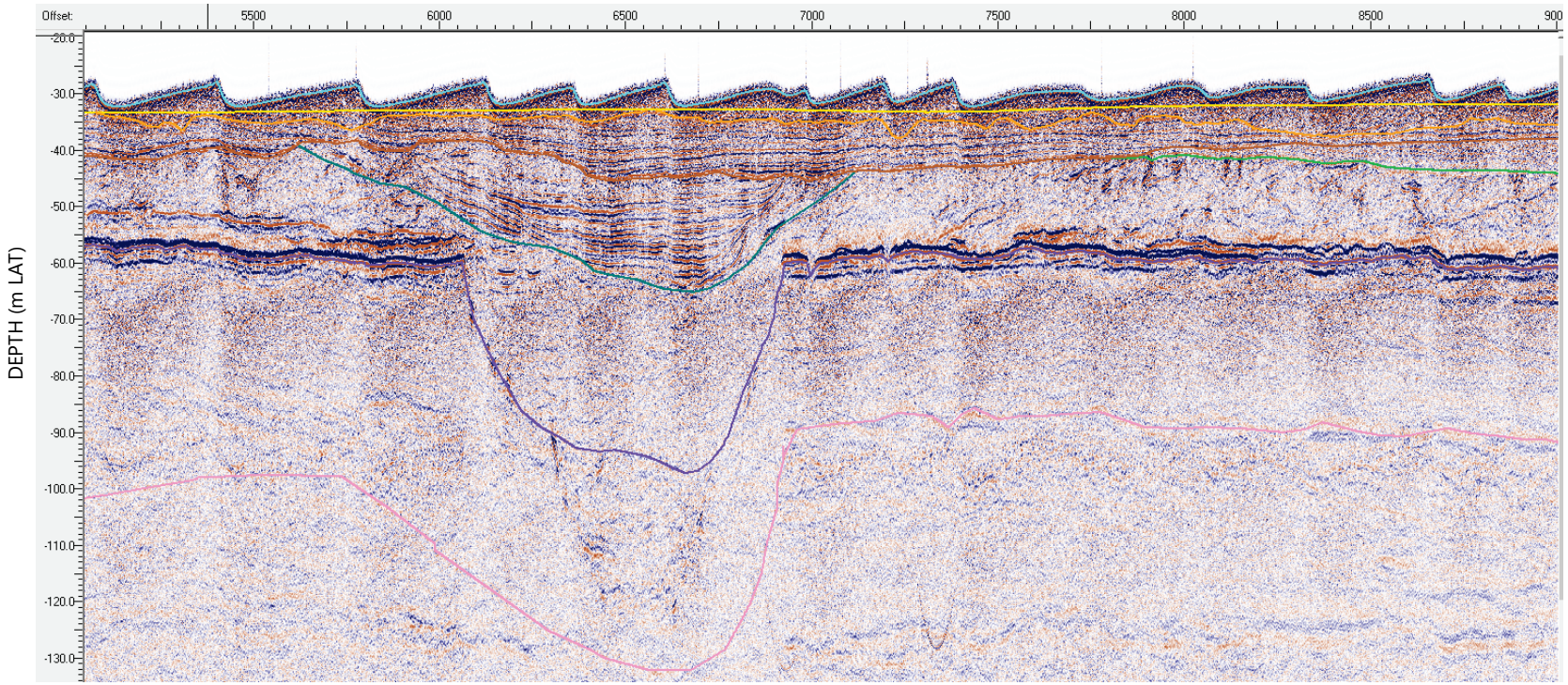




Geophysical Site Investigations - MCS-UHR Results

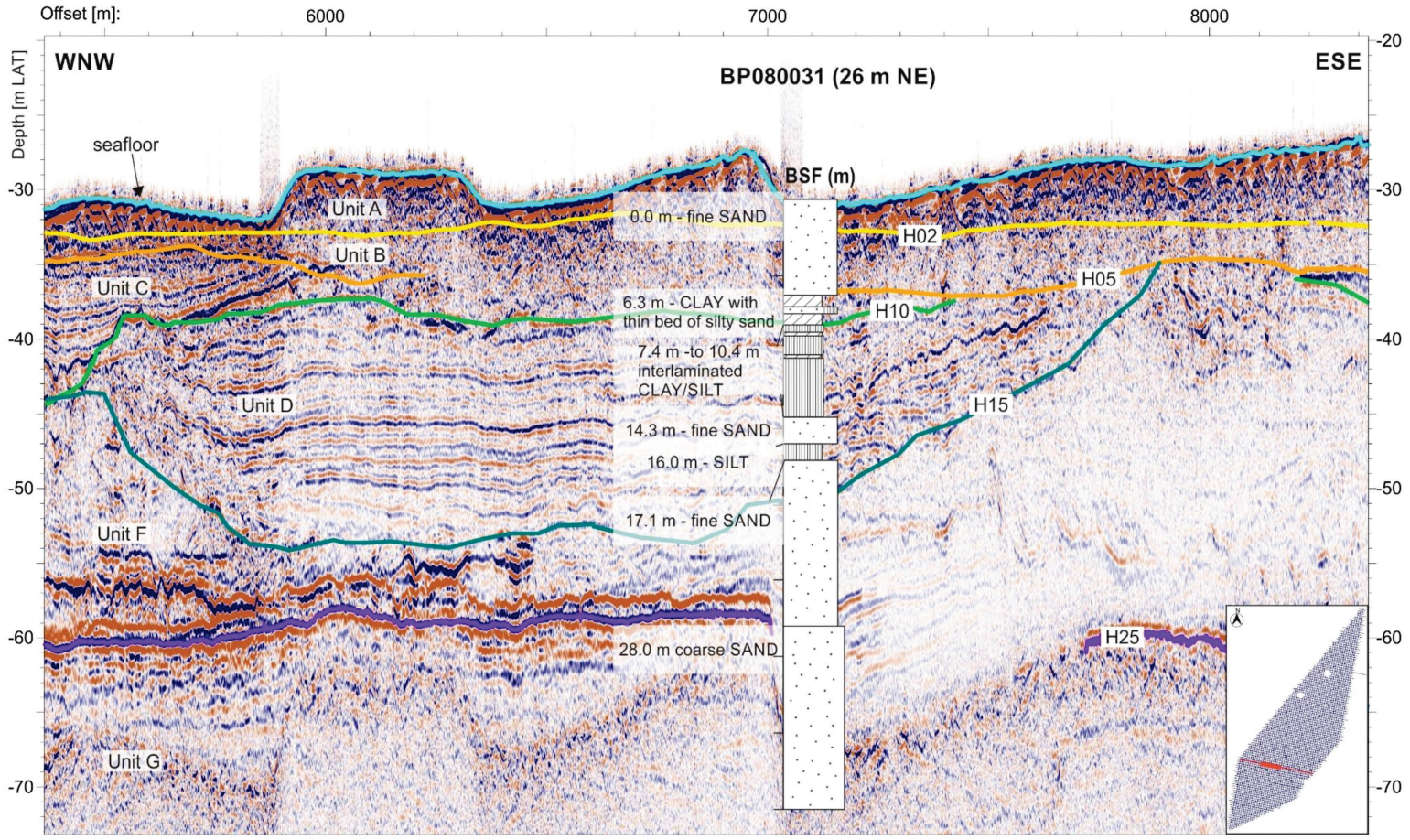
Profile C-C’ (seismic line Seq100_2B521)





Geophysical Site Investigations - Ground Model

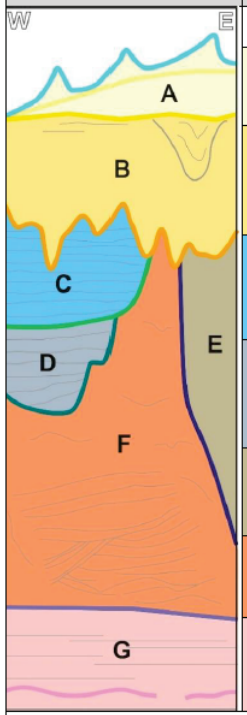
System	Reflector	Description
SBP	H01	Internal interface in Unit A
SBP	H02	Base of Unit A
SBP, MCS	H05	Base of Unit B
MCS	H10	Base of Unit C
SCS, MCS	H15	Base of Unit D
SCS, MCS	H20	Base of Unit E
MCS	H25	Base of Unit F
MCS	H30	Internal interface in Unit G



Geophysical Site Investigations - Ground Model

- Geological interpretation is based on SBP, SCS-UHR, MCS-UHR and public domain data to a depth of 100 m below seafloor
- Main interfaces and seismostratigraphic units (7) were interpreted and mapped:
  - Two top units (A and B), interpreted to be of Holocene age
  - Underlying units (C to G) of Pleistocene age
  - Units A, B and F are interpreted to be present across the majority of the HKW WFZ
  - Unit C is present in the south and in the western part
  - Units D and E are present only locally

Geophysical Site Investigations - Ground Model

Schematic Log	Seismic Unit	Reflector		Depth to Base [m LAT]	Depth to Base [m BSF]	Geometry of Base	Seismic Signature	Amplitude Distribution	Continuity of Internal Reflectors	Internal Structure	Depositional Environment	Formation (Member)	Age
		Top	Base										
	A	Seafloor	H02	24 to 35	<1 to 14	Flat to slightly undulating	Transparent to semi-transparent, locally some weak reflectors	Generally low	Low	Controlled at the top by sand wave morphology	Shallow marine	Southern Bight (Bligh Bank)	Holocene
	B	H02	H05	27 to 45	1 to 18	Erosion surface	Discontinuous internal reflectors	Variable from low to high	Low to medium	Variable from sheet-like to channelised	Intertidal to coastal	Naaldwijk	Holocene
	C	H05	H10	31 to 50	2 to 23	Horizontal to sub-horizontal	Stratified (sub-)horizontal internal reflectors	Variable from low to high	High	Sheet-like, horizontally layered	Brackish marine	Eem (Brown Bank)	Late Pleistocene
	D	H05 or H10	H15	35 to 66	5 to 36	Erosion surface	Stratified (sub-)horizontal, divergent internal reflectors	Variable from low to medium	Medium to high	Inclined, sub-horizontal layers	Shallow marine	Eem / Egmond Ground	Late Pleistocene
	E	H02 or H05	H20	31 to >60	3 to >35	Erosion surface	Transparent	Low	Low	Uniform / transparent	Glacio-fluvial to marine	Valley infill	Post-Saalian
	F	H05 or H10 or H15 or H20	H25	39 to 79	7 to 51	Undulating erosion surface	Chaotic, locally structureless, locally imbricated	Variable from low to high	Low to medium	Complex configuration locally channelised	Fluvial	Yarmouth Roads	Early to Middle Pleistocene
	G	H25	N/A	N/A	N/A	Not visible	Discontinuous to transparent, some continuous reflectors	Variable from low to medium	Medium	Channelised to Sheet-like	Fluvial to Fluvio-deltaic		

Notes:
N/A = Not Applicable

Geophysical Site Investigations - Geological Features

- Buried channels were interpreted and mapped. They are present at various levels.
- Possible boulders or cobbles in the subsurface were interpreted based on SCS-UHR data
- Small diffraction hyperbola indicating possible gravel were observed occasionally on SBP data within Unit A
- Several levels of possible peat /organic clay, and seismic anomalies that may indicate possible gas/fluid-charged sediments were interpreted and mapped
- No direct indication for glacial deformations were observed
- No faults were identified; however, their presence cannot be excluded

FUGRO

03

Geotechnical Site Investigations

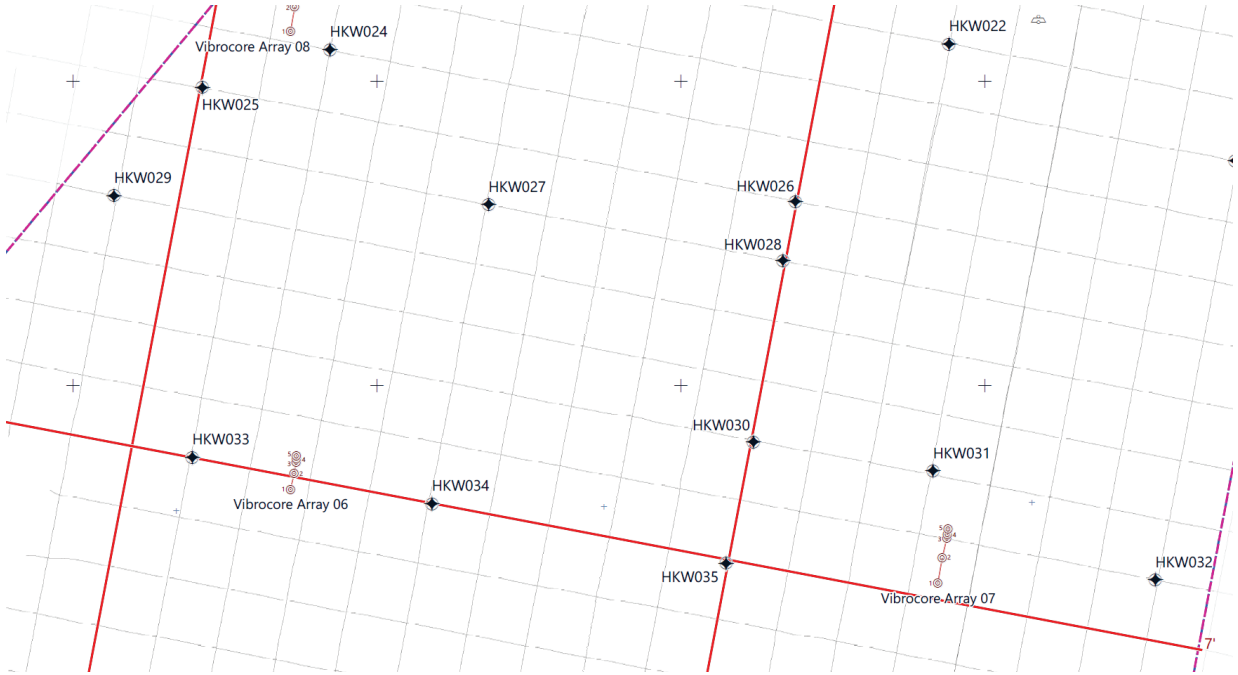
Geotechnical Site Investigations - Objectives

Client objectives of the geotechnical site investigations and associated laboratory testing programmes were to:

- Further develop and update the geological/geophysical model for the Hollandse Kust (west) WFZ
- Determine the vertical and lateral variation in subsurface conditions
- Provide relevant geotechnical data for the design of the Hollandse Kust (west) WFZ including, but not limited to, foundations and cables
- Provide a robust data set, including spare samples for immediate further testing upon award to increase development speed

Geotechnical Site Investigations - Strategy

- Geotechnical target locations selected together with RVO, based on geophysical site investigation results and to confirm and enhance current understanding
- Capture predominant soil conditions to reduce future need for additional site investigations
- Target location can exist of combinations of multiple investigation types (in situ test points and boreholes)
- Phased approach: seafloor in situ testing -> borehole drilling -> laboratory testing



Geotechnical Site Investigations - Location Density

WFZ	Investigation Area [km²]	CPT			Borehole		
		No.	[...] CPT per 1 km²	1 CPT per [...] km²	No.	[...] BH per 1 km²	1 BH per [...] km²
HKN	304	75	0.25	4.05	28	0.09	10.86
HKW	224	118	0.53	1.90	46	0.21	4.87

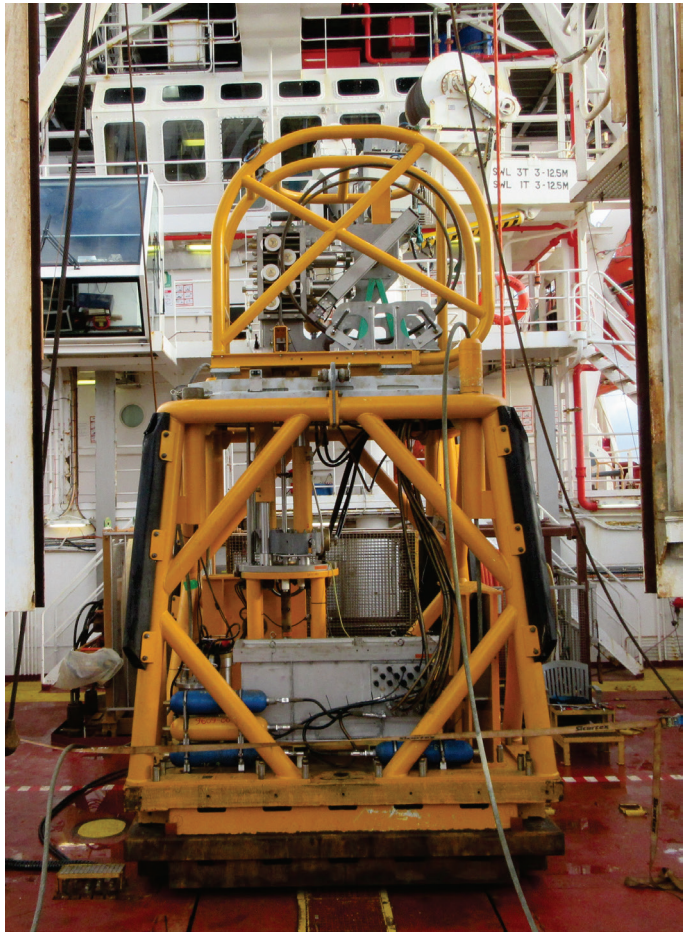
Seafloor Phase - Equipment

Source photo: www.geoff.no

MV Despina

- 15 May to 17 June 2019
- Seafloor in situ testing (cone penetration tests)
- Sampling from seafloor (vibrocores)
- Onsite laboratory testing

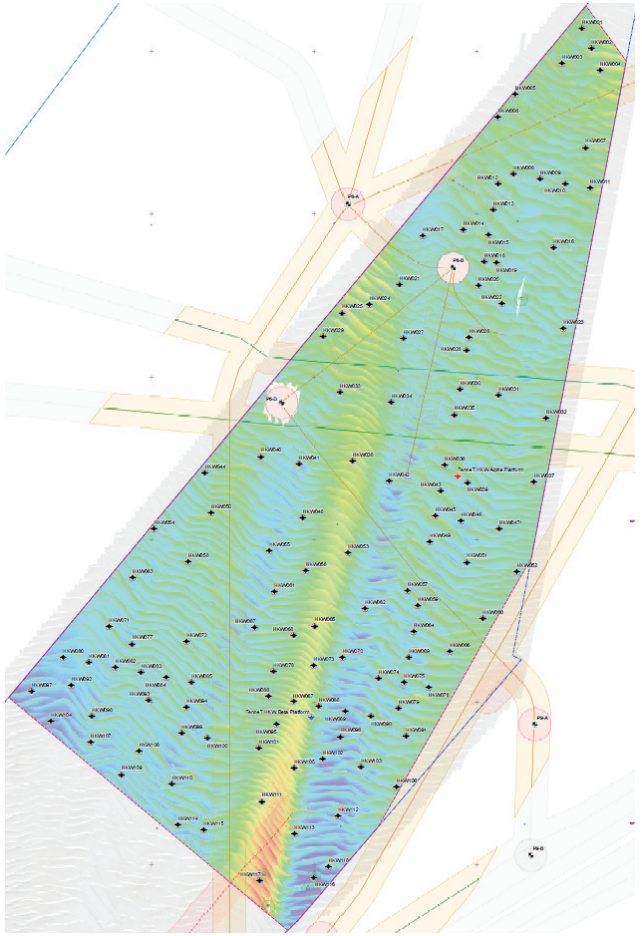
Seafloor In situ Testing - Equipment



- SEACALF® MkIV Continuous Drive System
- Hydraulic underwater shear wave hammer (HUSH) on seabed frame for SCPT
- Various cone penetrometers (1000 mm^2 and 1500 mm^2):
  - Type CP10-CF50TA30SN2 thermal cone penetrometers (TCPT)
  - Type CP15-CF75PB7SN2 piezocone penetrometers + seismic add-on (SCPT)
  - Type CP15-CF75PB20SN2 piezocone penetrometers (PCPT) (+ seismic add-on for SCPT)
  - Type CP15-CF120PB20SN2 piezocone penetrometers (PCPT)

Seafloor In situ Testing - Programme

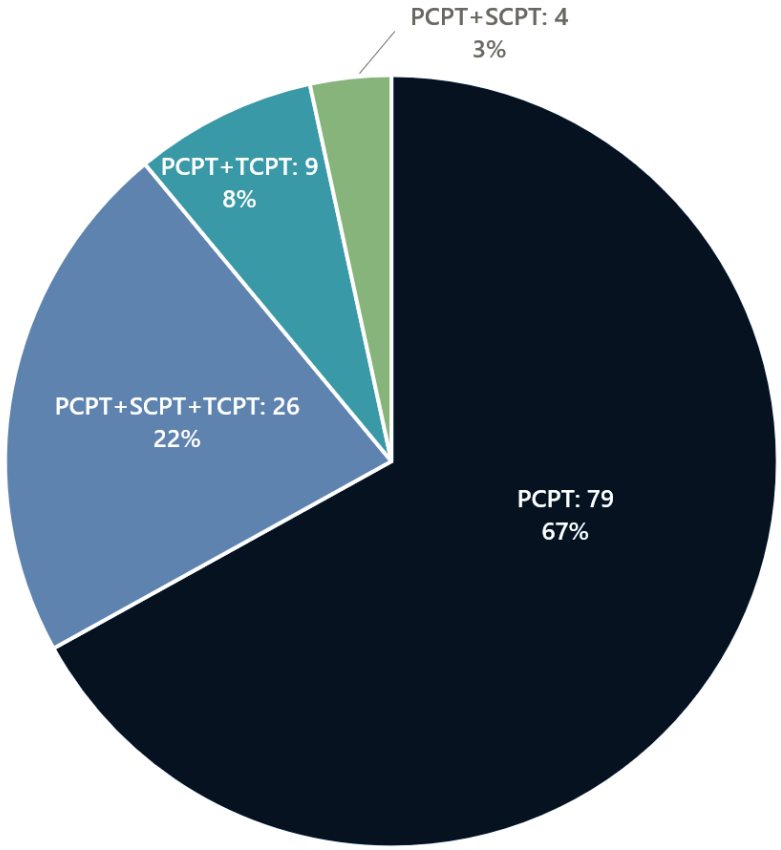
- One hundred twenty-two (122) seafloor piezocone penetration tests (PCPTs) at 118 locations to depths ranging between 13.1 m and 56.6 m below seafloor (BSF)
- Thirty (30) seafloor seismic cone penetration tests (SCPTs) including seismic velocity tests at 30 locations to depths ranging between 36.4 m and 56.0 m BSF
- Thirty-six (36) seafloor temperature cone penetration tests (TCPTs) including temperature equilibrium tests at 35 locations to depths ranging between 2.1 m and 7.5 m BSF
- Eighty (80) pore pressure dissipation tests at selected depths in PCPTs and SCPTs at 29 locations



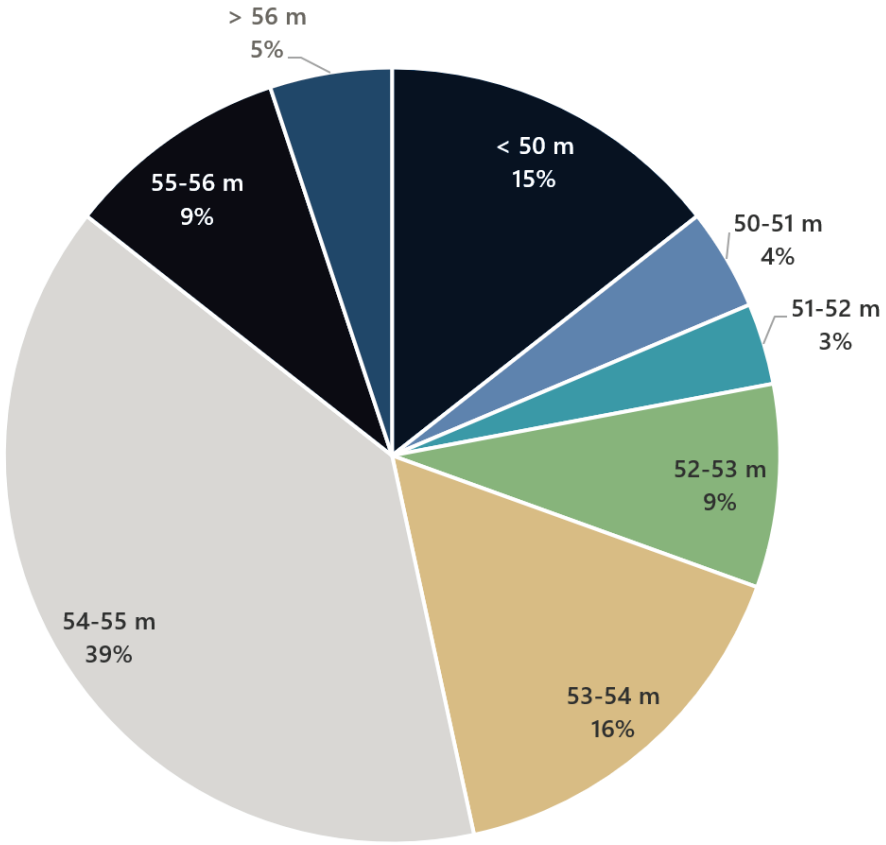
Seafloor In situ Testing - Programme

- Various combinations of in situ test types:
  - Total 118 locations
  - PCPT only: 79 locations
  - PCPT + SCPT + TCPT: 26 locations
  - PCPT + TCPT: 9 locations
  - PCPT + SCPT: 4 locations

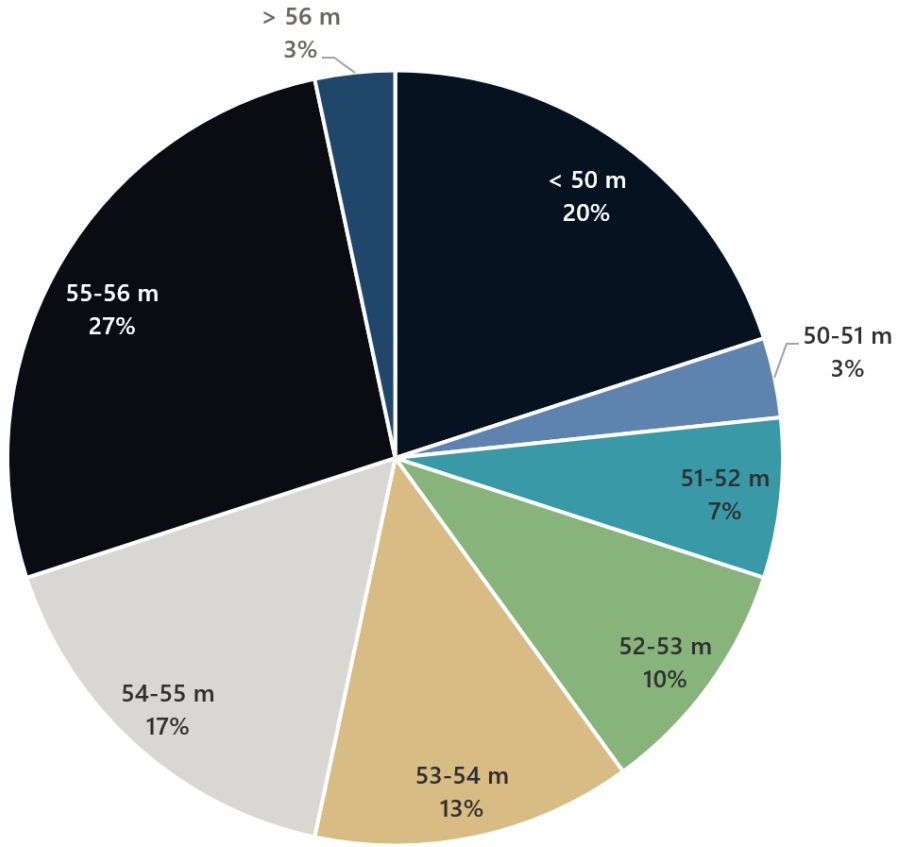
- Test points within 5 m radius around target location



Seafloor In situ Testing - Results



PCPT (118 test points)

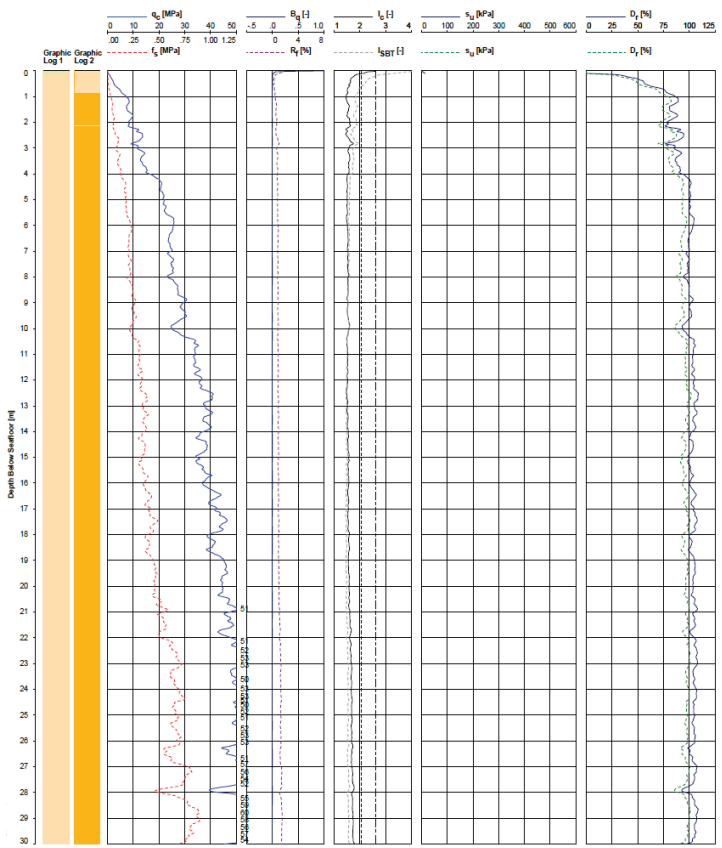


SCPT (30 test points)

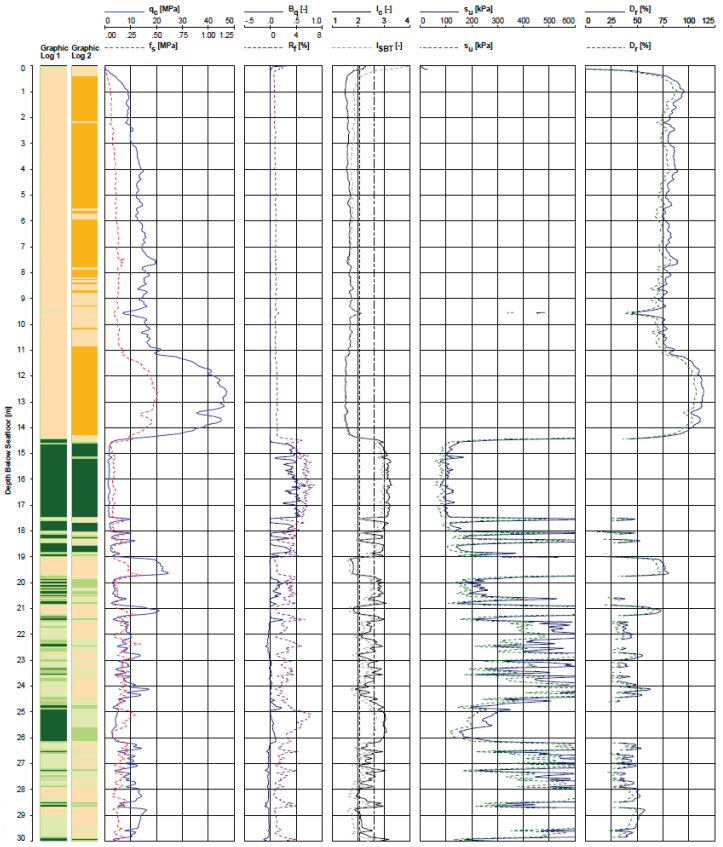
Seafloor In situ Testing - Results

- Main output:
  - Standard CPT plots (q_c, f_s, u_2, q_n, q_t, B_q, R_f,etc.)
  - Automated geotechnical logs incl. Robertson (2009) classification

HKW007-PCPT



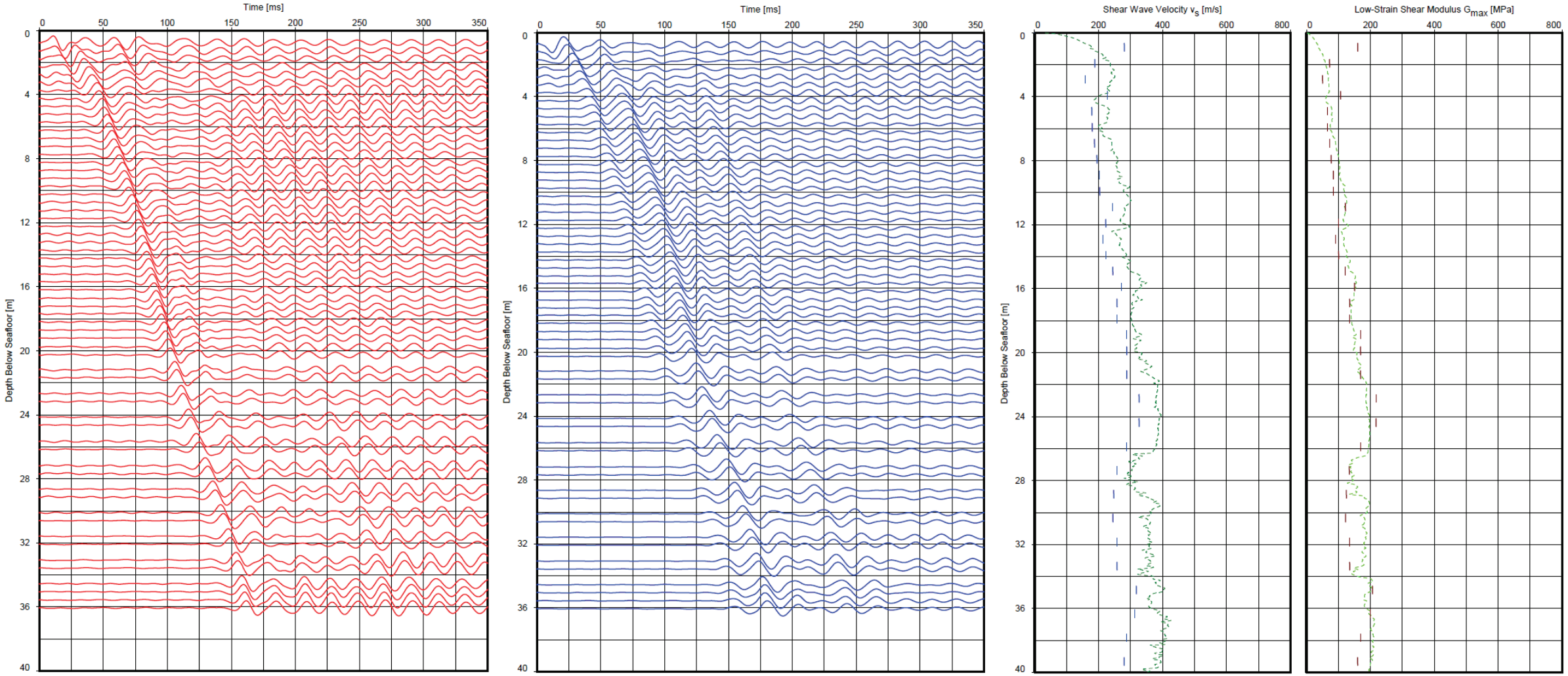
HKW071-PCPT



Seafloor In situ Testing - Results

- Seismic velocity tests at regular intervals in SCPTs
- Seismic cones with array of two geophones with each three receivers (x-y-z)
- Fixed distance of 0.5 m between geophones, lower geophone ~0.27 m above cone base
- Data acquisition for shear wave velocity at selected depths to CPT termination depth:
  - 1.5 m to 20.5 m penetration length: seismic velocity test every 1.0 m
  - 20.5 m penetration length to end of test: seismic velocity test every 1.5 m
- Result plates:
  - Stacked seismic trace (X-component) with 10 to 100 Hz band-pass filter applied
  - Stacked seismic trace (Y-component) with 10 to 100 Hz band-pass filter applied
  - Shear wave velocity (v_s) and low-strain shear modulus (G_{max}) as measured and using correlations with CPT data according to Robertson and Cabal (2010) for v_s and according to Mayne and Rix (1993) and Rix and Stokoe (1991) for G_{max}

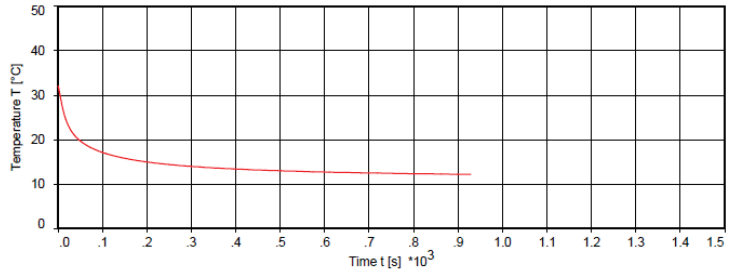
Seafloor In situ Testing - Results

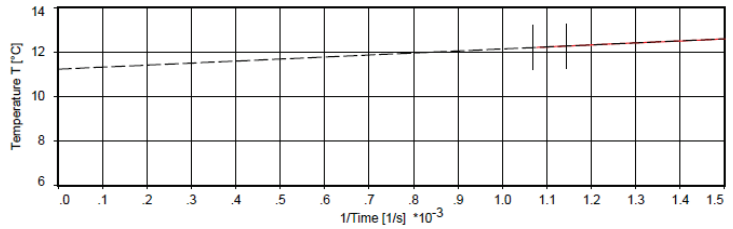


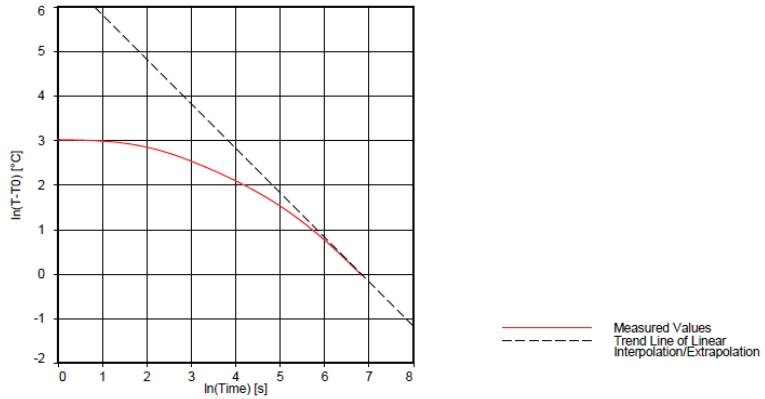
Seafloor In situ Testing - Results

- Temperature equilibrium tests (TETs) at selected depths in TCPTs
- TET nominally every 1.0 m penetration length from seafloor to approximately 6.0 m BSF, inclusive
- Heating of the cone is a result of the soil-steel friction during penetration (~1 °C per 1 MPa cone resistance)
- Interpretation of thermal conductivity from thermal equilibrium tests requires as a minimum 3 °C of temperature difference between background soil temperature and steel temperature. As a result, at some locations no TET could be performed at every planned test depth.

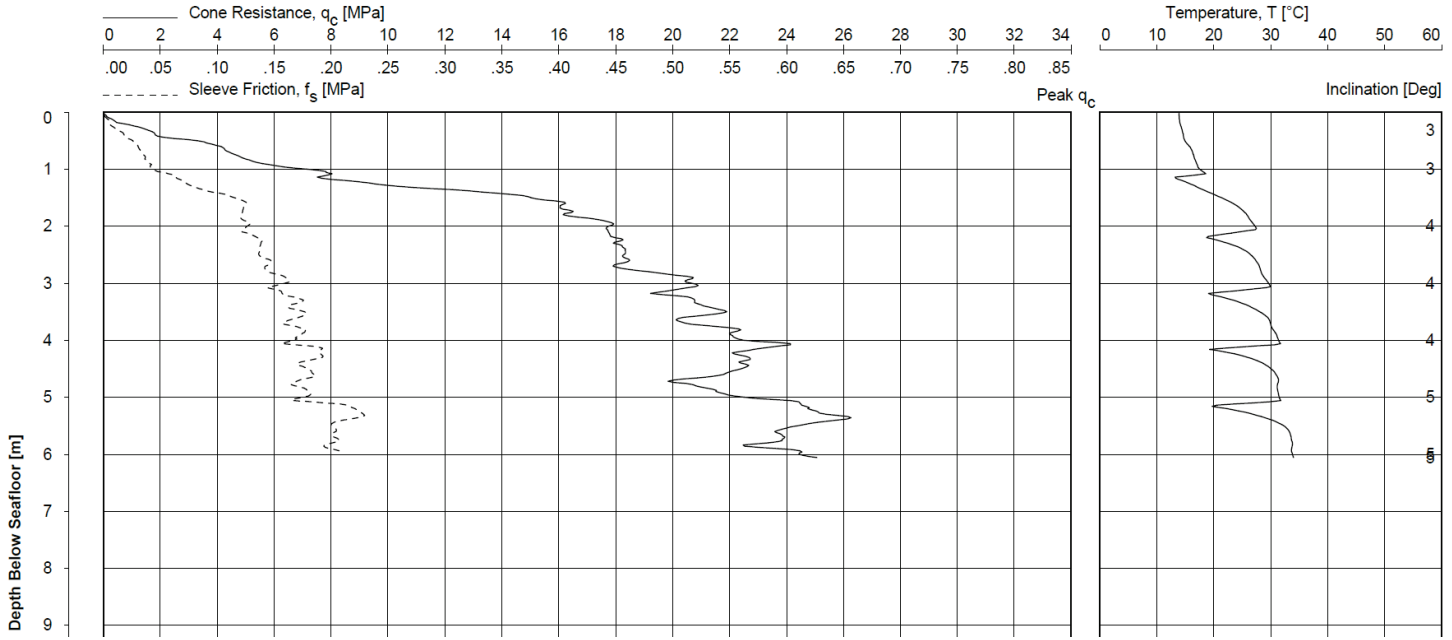
Seafloor In situ Testing - Results



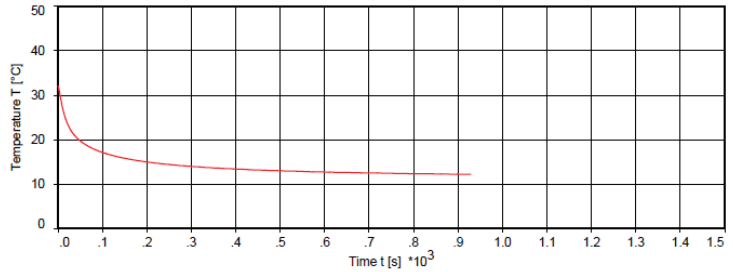


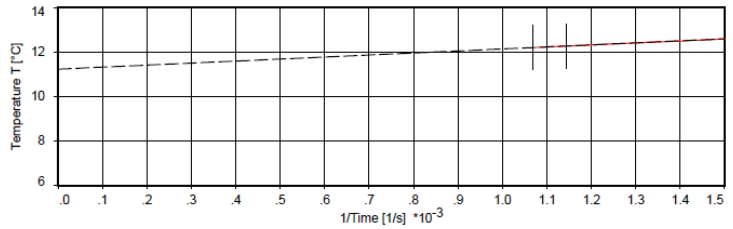


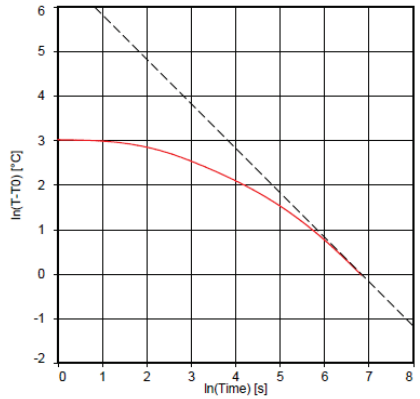
Location	: HKW016-TCPT		Limit Temp	: 11.2	[°C] (Value at t = infinite)
TET Number	: 5		yIntercept	: 6.8	
Tool and Probe ID	: CP10-CF50TA30SN2		k	: 2.4	[W/mK]
Date of Testing	: 14-Jun-2019				
Water Depth	: 28.8	m			
Sensor Depth below Seafloor	: 5.1	m			



Seafloor In situ Testing - Results







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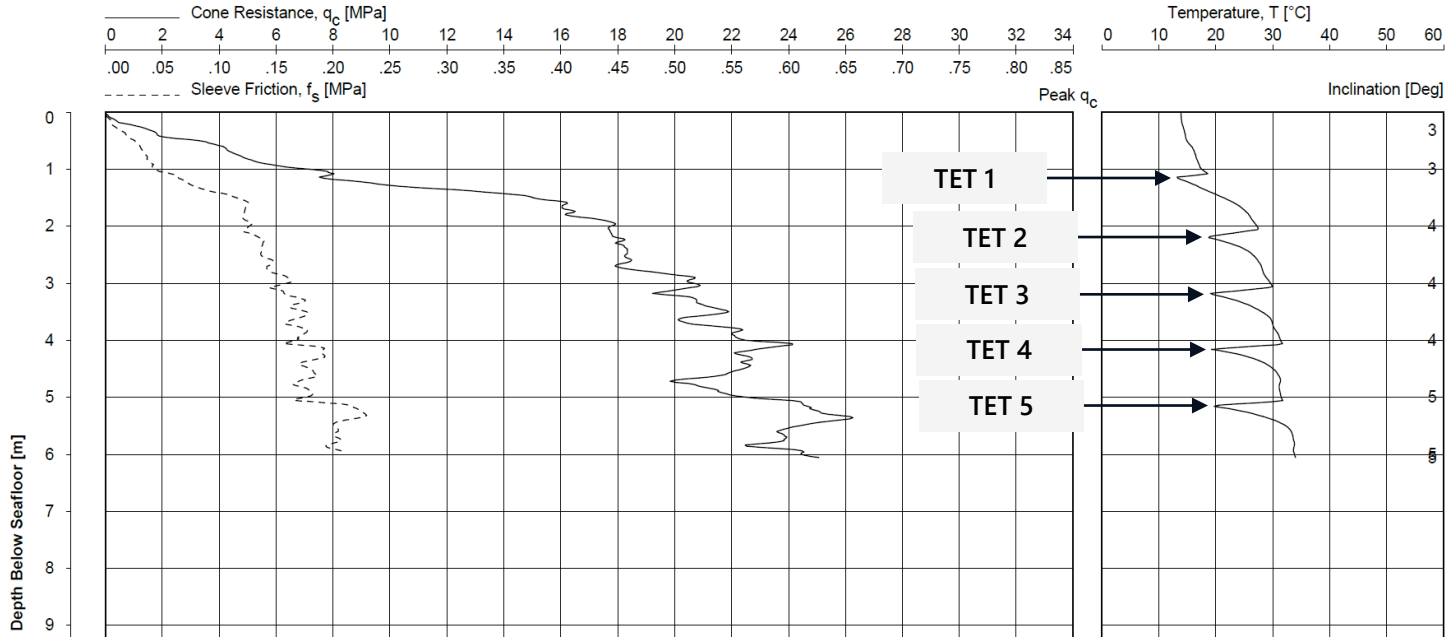
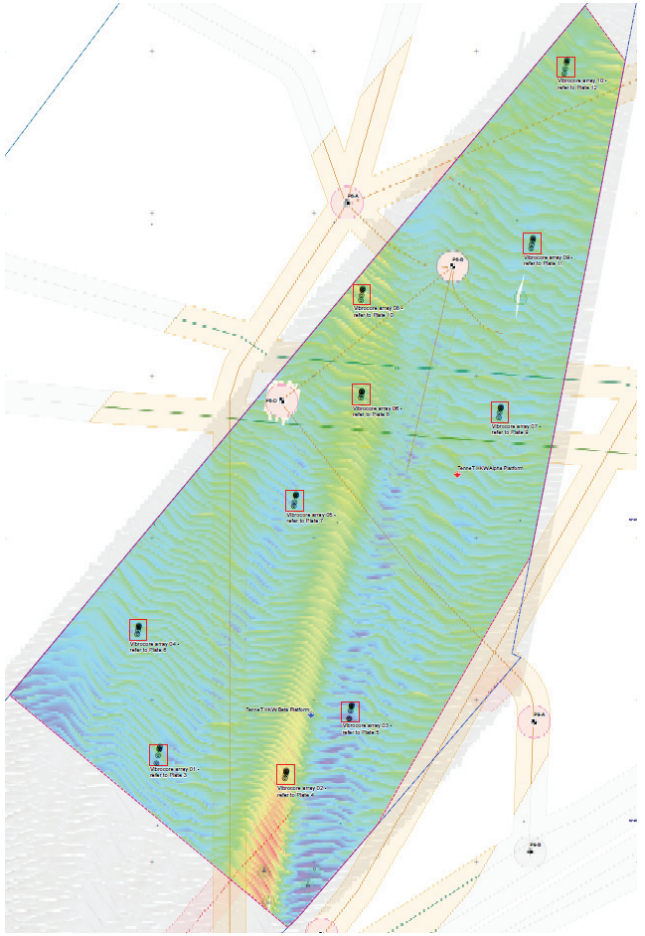


Sampling from Seafloor - Equipment

- Fugro High Performance Corer (HPC™)
  - Vibro-unit supplying vibratory motion, supplemented by self-weight penetration
  - Thick-walled open tube, 6.4 m long, 84 mm ID, with PVC inner liner

Sampling from Seafloor - Programme

- Fifty-one (51) vibrocores at 50 locations to depths ranging from 2.4 m to 6.4 m BSF
- Main purpose was to investigate sand wave properties in predefined morphodynamics zones (Deltares morphological desk study)
- The sample points were aligned along magnetometer track lines and are together referred to as a ‘vibrocore array’
- No direct connection with target locations for in seafloor situ tests and downhole boreholes



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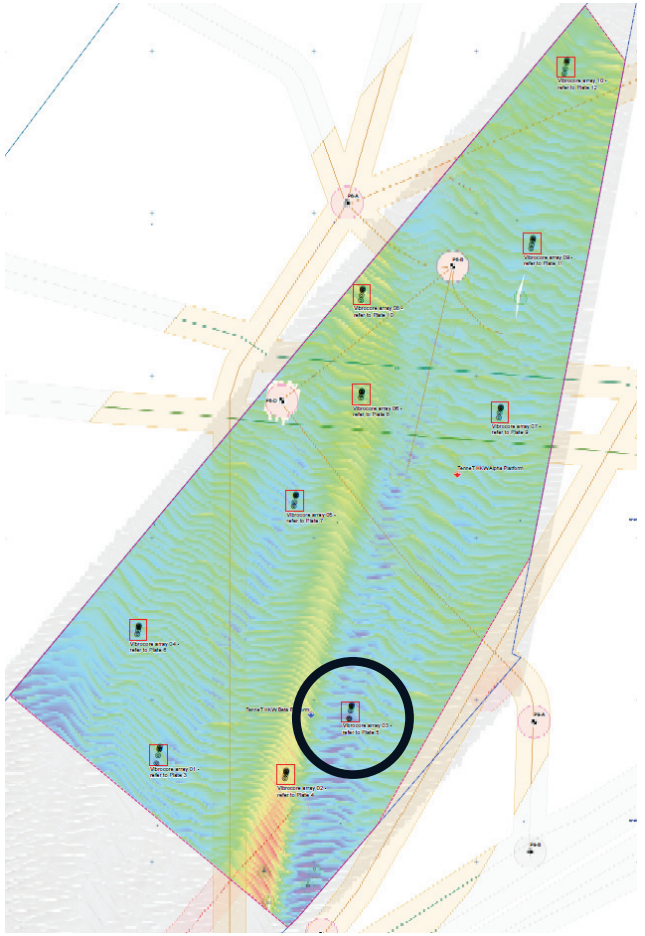
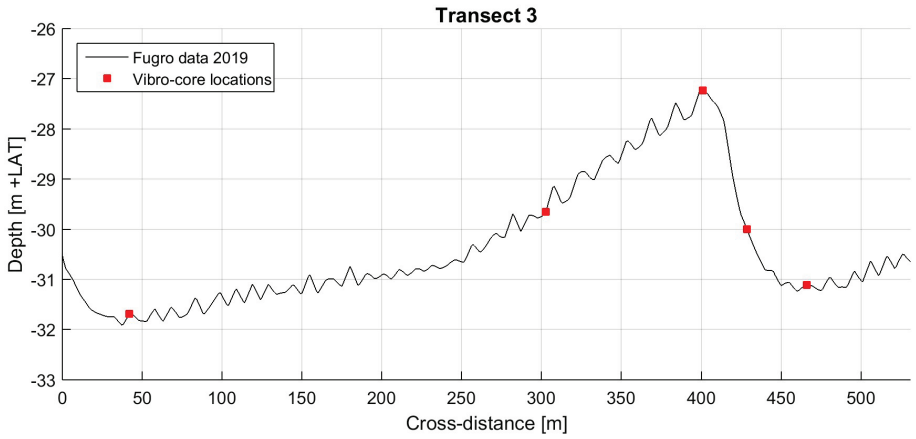
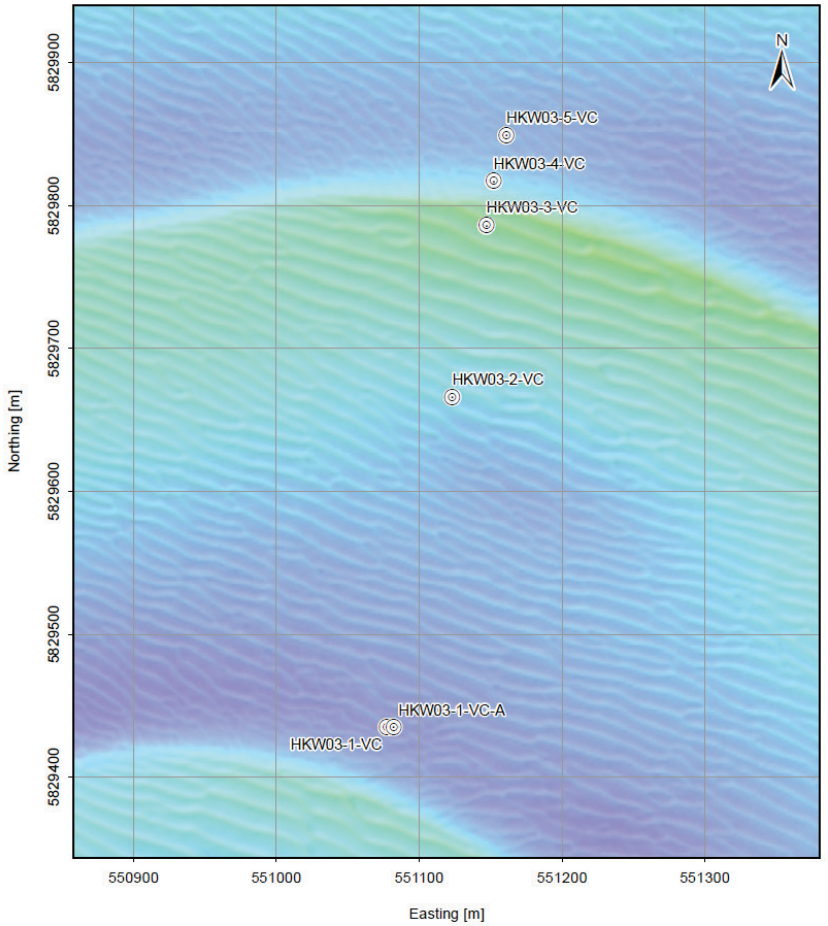


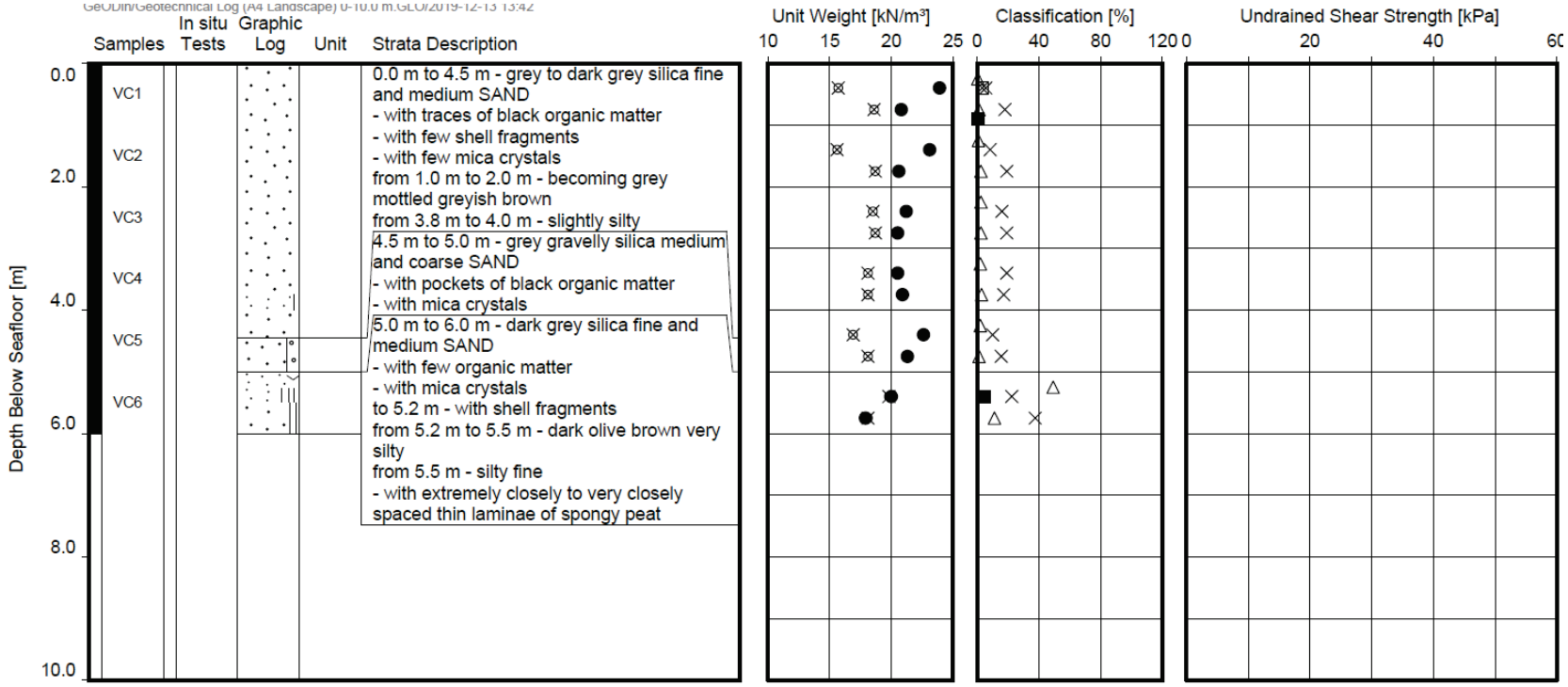
Sampling from Seafloor - Programme

- At selected sand waves a group of five locations were sampled at different sides of a sand wave:
  - Two locations at the (lower angle) stoss side
  - One location on or close to the crest
  - Two locations at the (higher angle) lee side





Sampling from Seafloor - Results



Date commenced : 25-May-2019
Method : Vibrocore sampling and testing
Recovery : to 6.0 m below seafloor
Penetration : to 6.4 m below seafloor
Water depth : 28.5 m
Coordinates : 544571 m E 5832151 m N

Location(s):
HKW04-2-VC

- Derived from water content
- Derived from volume mass calculation
- Water content
- Plastic limit
- Liquid limit
- Plasticity index
- Percentage fines
- Carbonate content
- Organic content
- Relative density derived from CPT
- Pocket penetrometer
- Torvane
- Fallcone
- Laboratory vane
- UU-triaxial
- CU-triaxial (q_{max})
- CU-triaxial (q/p'_{max})
- Direct simple shear
- In situ vane shear
- Undrained shear strength derived from CPT
- Slashed symbol refers to test on remoulded soil

RVO HKW WFZ
P904711
HKW04-Z-VC
5.00-6.00
04.07.19
Colour Chart #14
TOP
10 20 30 40 50 60 70 80 90 cm
TOP
10 20 30 40 50 60 70 80 90 cm
TOP
10 20 30 40 50 60 70 80 90 cm
TOP
10 20 30 40 50 60 70 80 90 cm
TOP
10 20 30 40 50 60 70 80 90 cm

Video ‘Fugro Offshore Wind Farm Development Solutions’ can be found at:

www.youtube.com/watch?v=iygxa1SepbI

Downhole Phase - Equipment

MV Normand Flower

- 16 July to 17 September 2019
- Geotechnical borehole drilling
- Downhole sampling
- Downhole in situ testing
- Borehole geophysical logging
- Onsite laboratory testing

Source photo: www.tugspotters.com

Downhole Phase - Equipment

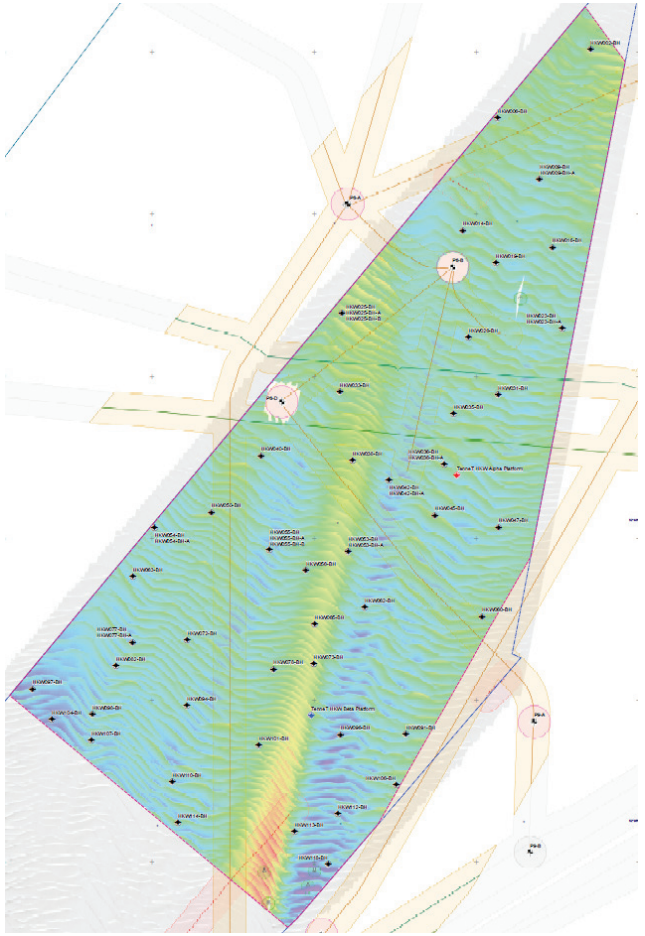
- R100 Marine Drill
- Open-hole rotary drilling (API)
- SEACLAM seafloor template for lateral support at seafloor during drilling and for clamping of drill pipe during logging, testing and sampling
- WISON® and WIPSAMPLER® downhole tools for push sampling and in situ testing
- Various cone penetrometers (500 mm^2 and 1000 mm^2):
  - Type CP5-CF50 friction cone penetrometers
  - Type CP10-CF80PB10 piezocone penetrometers
  - Type CP10-CF80PB20 piezocone penetrometers

Downhole Phase - Equipment

- Various Shelby tubes:
  - Thick-walled 3”, 80 mm OD, 72 mm ID
  - Thin-walled 3”, 76 mm OD, 72 mm ID
  - Thin-walled 3”, 76 mm OD, 72 mm ID, with internal PVC liner and cutting shoe
  - Thick-walled 2”, 60 mm OD, 53 mm ID
- Borehole geophysical logging tools:
  - Caliper tool: Antares sonde 1005
  - Natural gamma radiation tool: Antares sonde 921
  - Spectral gamma radiation tool: Antares sonde 1489
  - P- and S-suspension logger: Geovista P and S micro-seismic sonde

Downhole Phase - Programme

- Fifty-five (55) boreholes (including 9 re-drills) at 46 locations to depths ranging between 1.0 m and 90.6 m BSF
  - Target depth in principle 60 m BSF; selection of locations 70 m BSF (7), 80 m BSF (4), and 90 m BSF (1)
  - Including downhole sampling to depths approximately equal to the deepest penetration depth of the performed seafloor in situ test(s) at that location
  - Followed by cone penetration testing with (over-)sampling
  - Of these 55 boreholes, four boreholes at four target locations also included borehole geophysical logging
- Two (2) boreholes at two locations with borehole geophysical logging only, to depths of 64.9 m and 74.6 m BSF



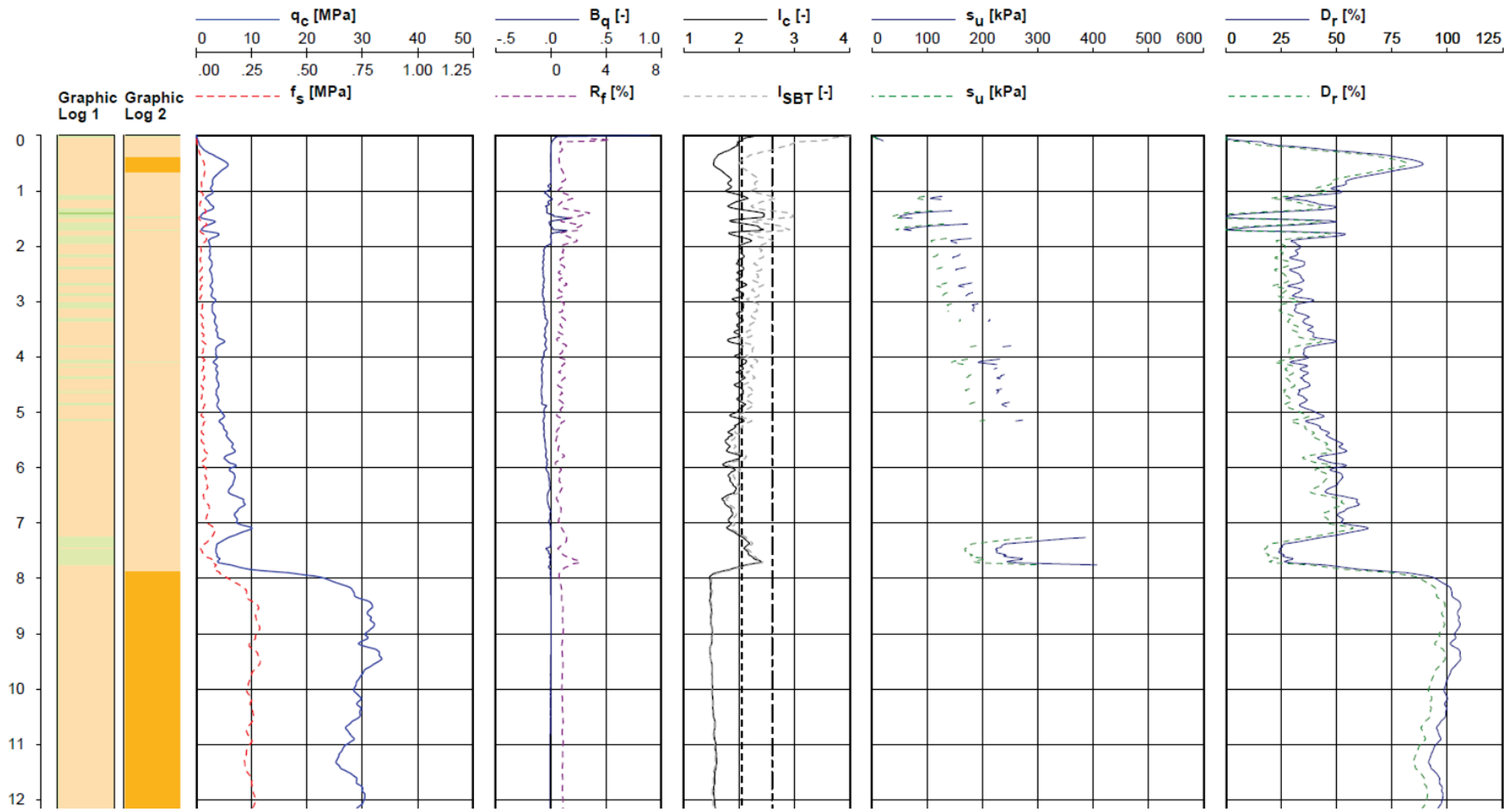
Downhole Phase - Programme

- Downhole site investigation programme included borehole drilling at the location of future TenneT Beta Platform:
  - One (1) borehole with downhole sampling at the centre of the proposed platform, to a depth of 80.5 m BSF
  - Five (5) boreholes (including 1 re-drill) at 4 locations with downhole cone penetration testing at the corners of the proposed platform, to depths ranging between 3.0 and 80.9 m BSF
- TenneT Alpha Platform geotechnical site investigation performed separately in February 2019
- Results reported in standalone reports which are included as appendices to the downhole report

Downhole Phase - Programme

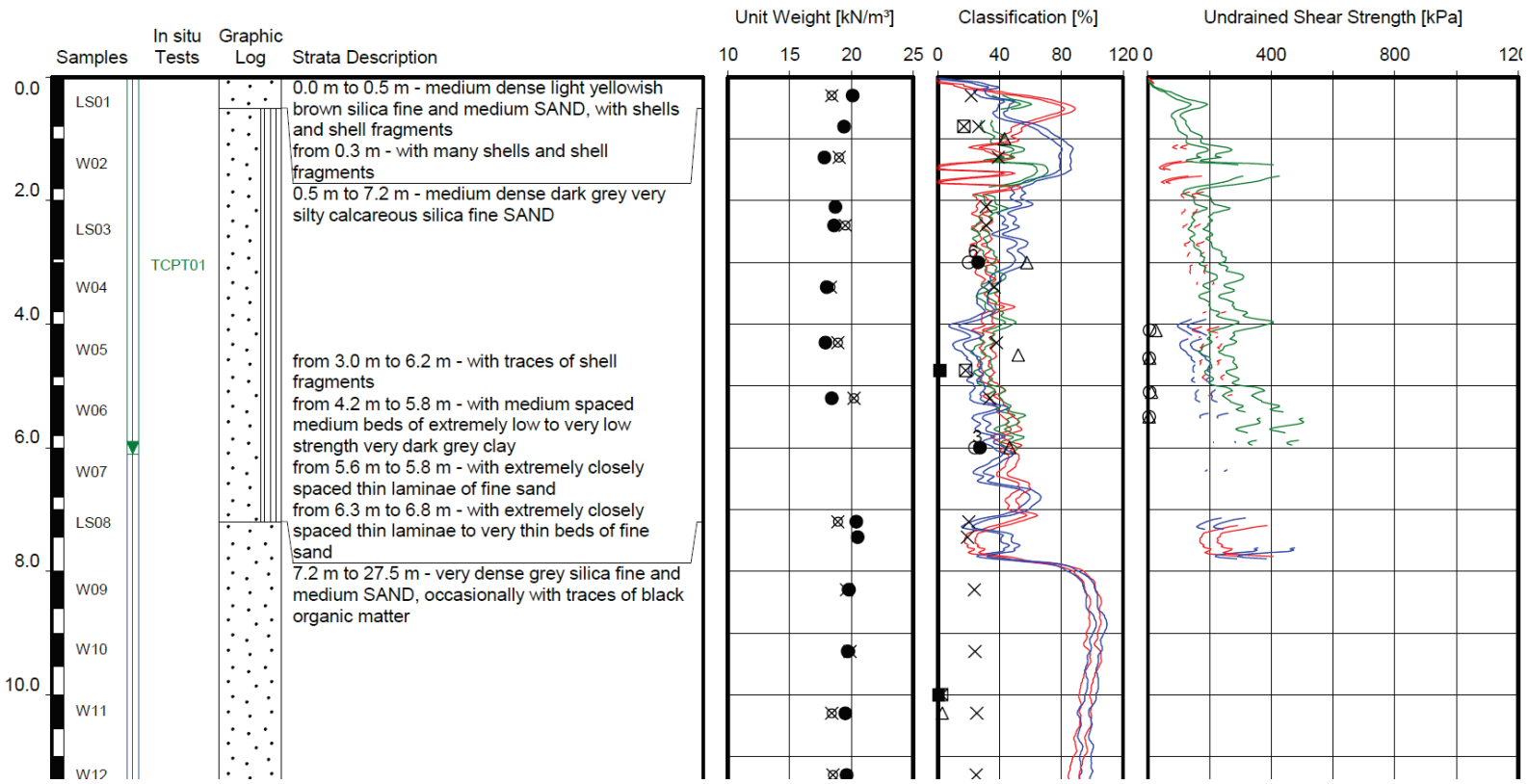
- Sample extrusion, sample photography, and soil description and classification
- Fifty-five (55) liner samples for biogeochemical analyses (in support of microbiologically influenced corrosion (MIC) risk analyses) taken from selected depths in 13 boreholes
- Samples for geological dating analyses taken from selected depths in 12 boreholes
- Onsite geotechnical laboratory testing:
  - Soil description and classification in accordance with ISO 14688-1:2017, ISO 14688-2:2017, BS 5930:2015, and Clark and Walker (1977)
  - Geotechnical index (MC, UW, CC)
  - Strength index (UU, PP, TV)

Downhole Phase - Results



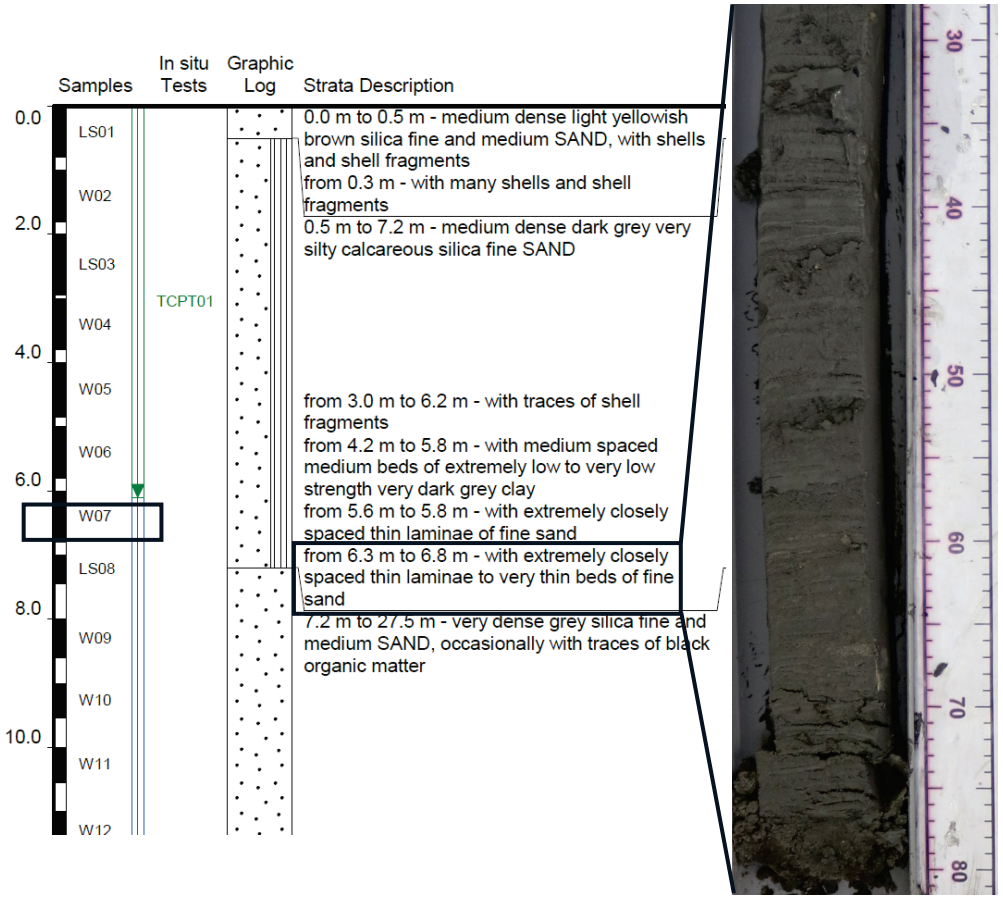
- HKW002-PCPT
- Clear layer change visible at ~7.8 m BSF
- Boundary between Unit A and B
- Evident from changes in q_c, PWP response, I_c

Downhole Phase - Results



- HKW002-BH
- Layer change identified at ~7.2 m BSF
- UW, MC, PSD, sample photographs

Downhole Phase - Results



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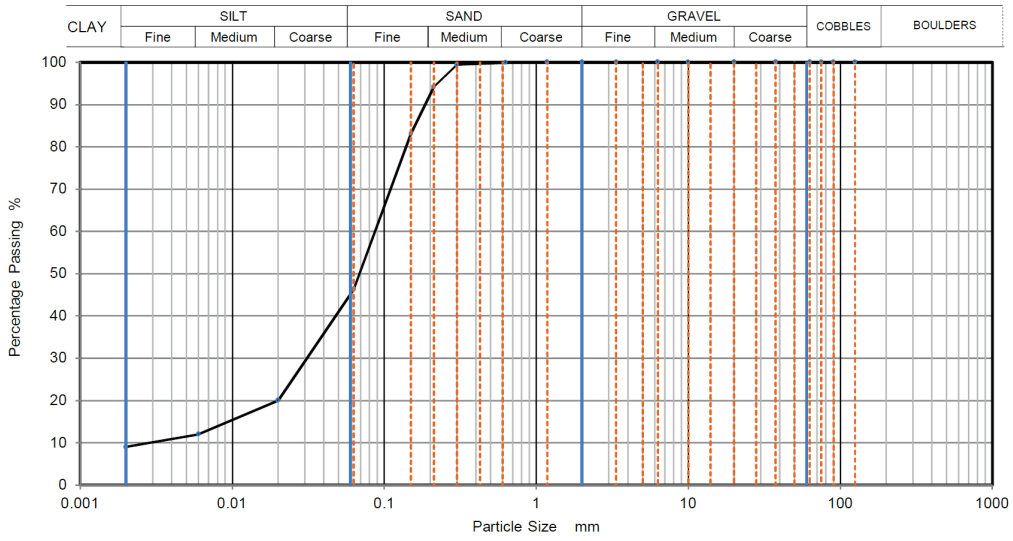
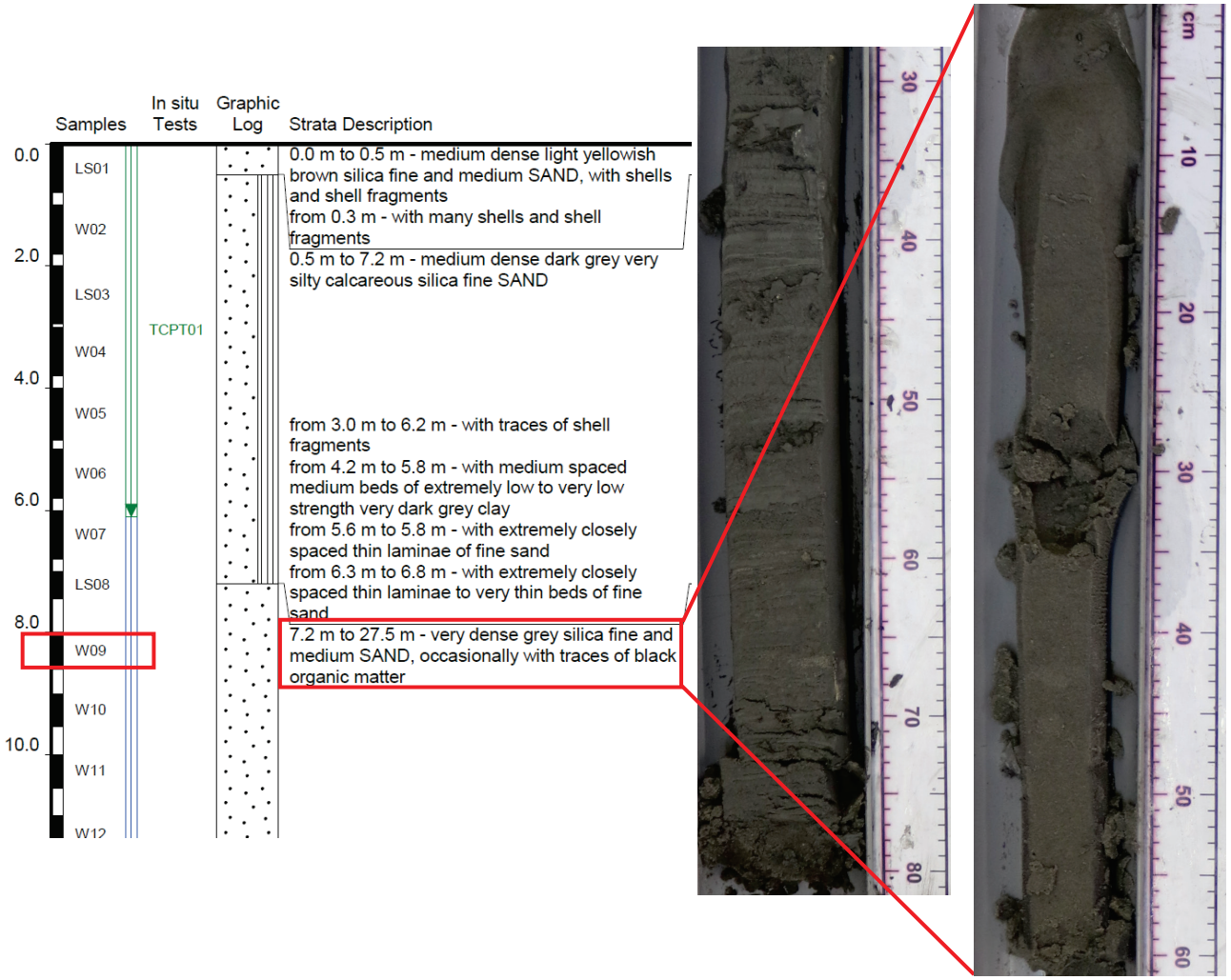


Downhole Phase - Results



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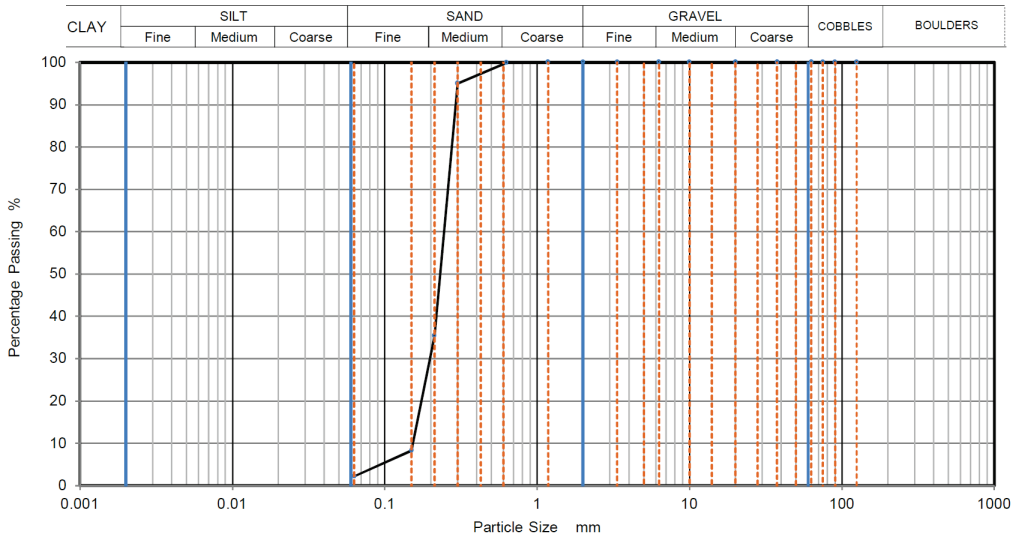
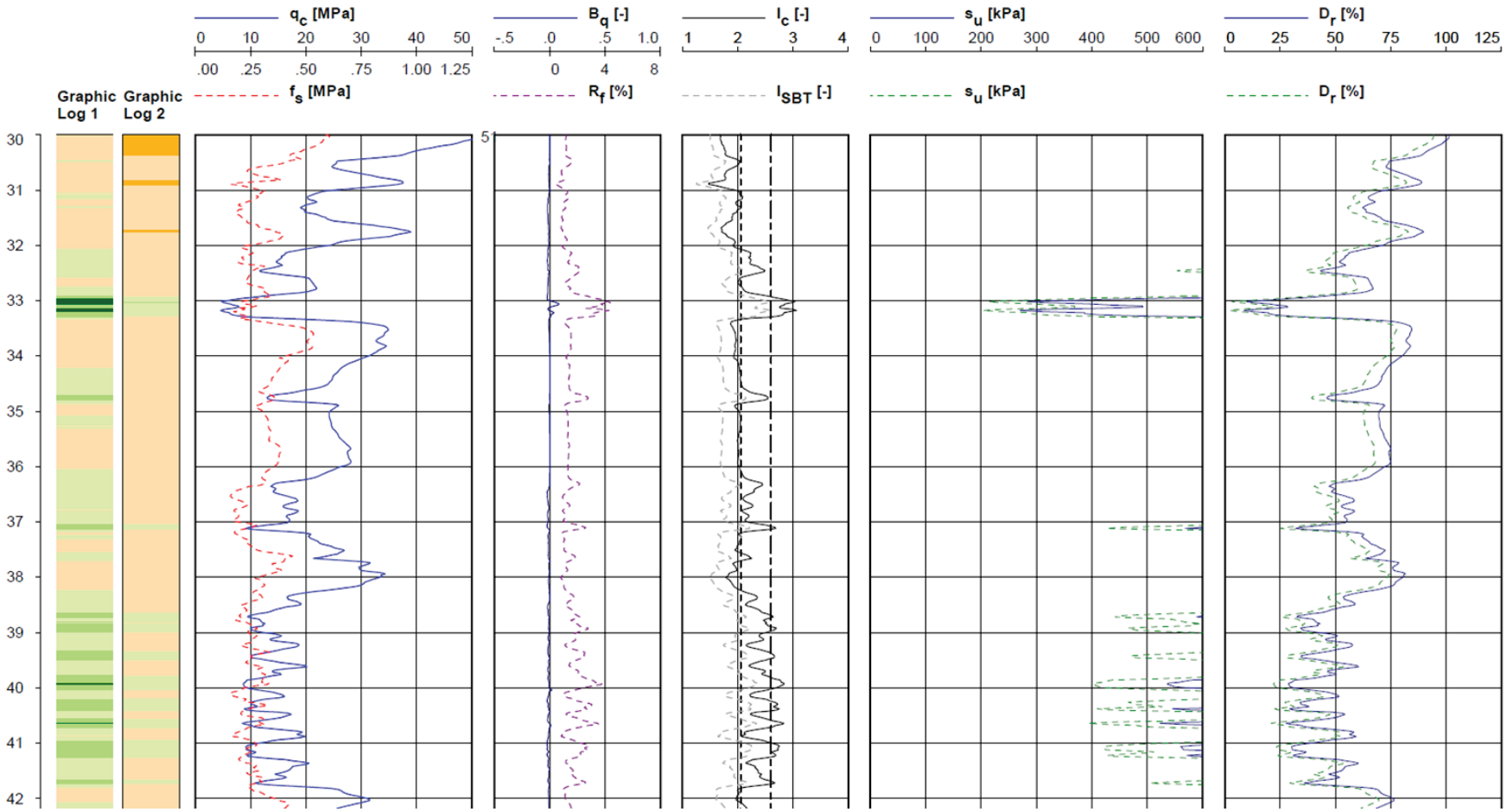
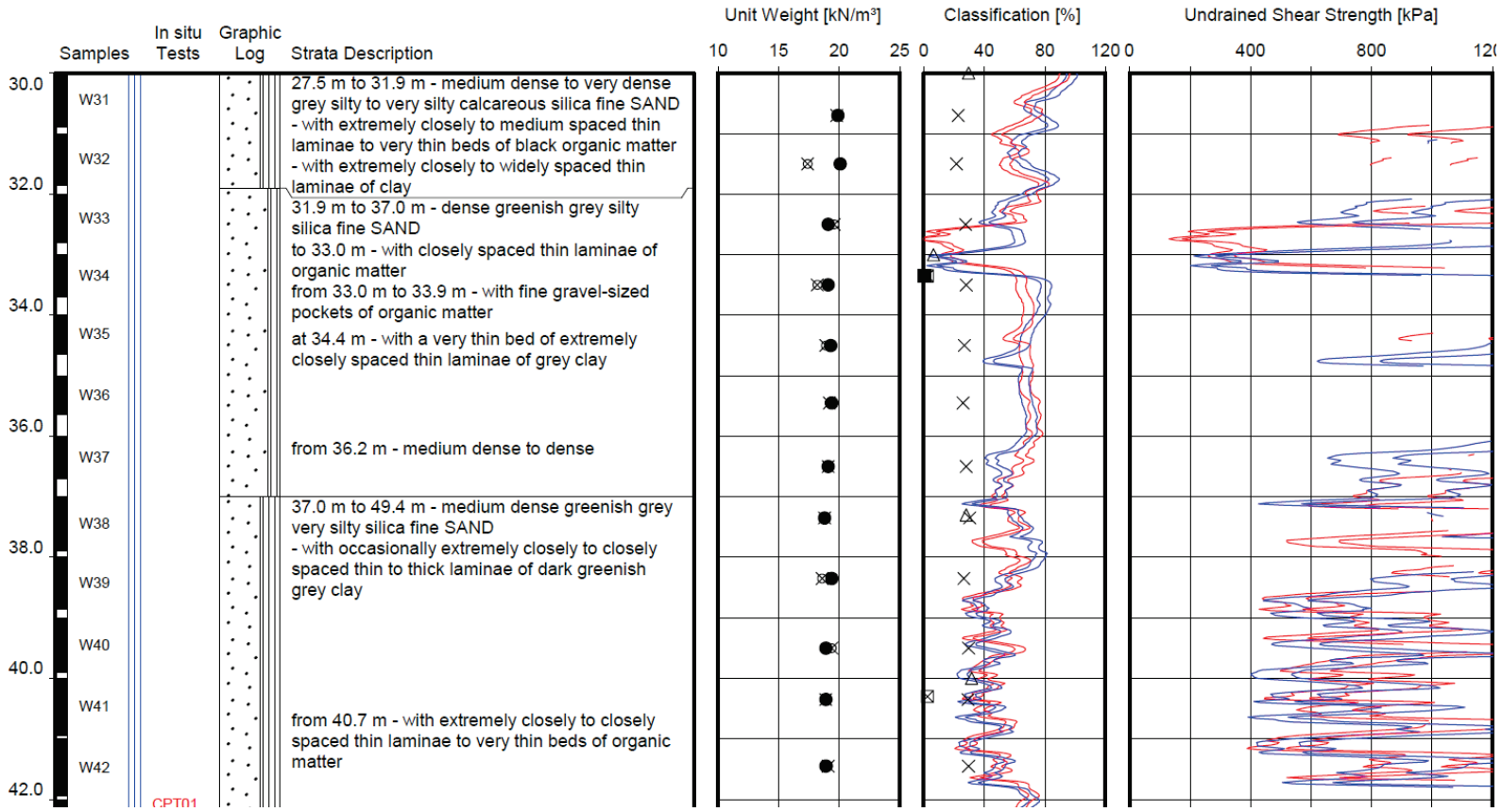


Downhole Phase - Results



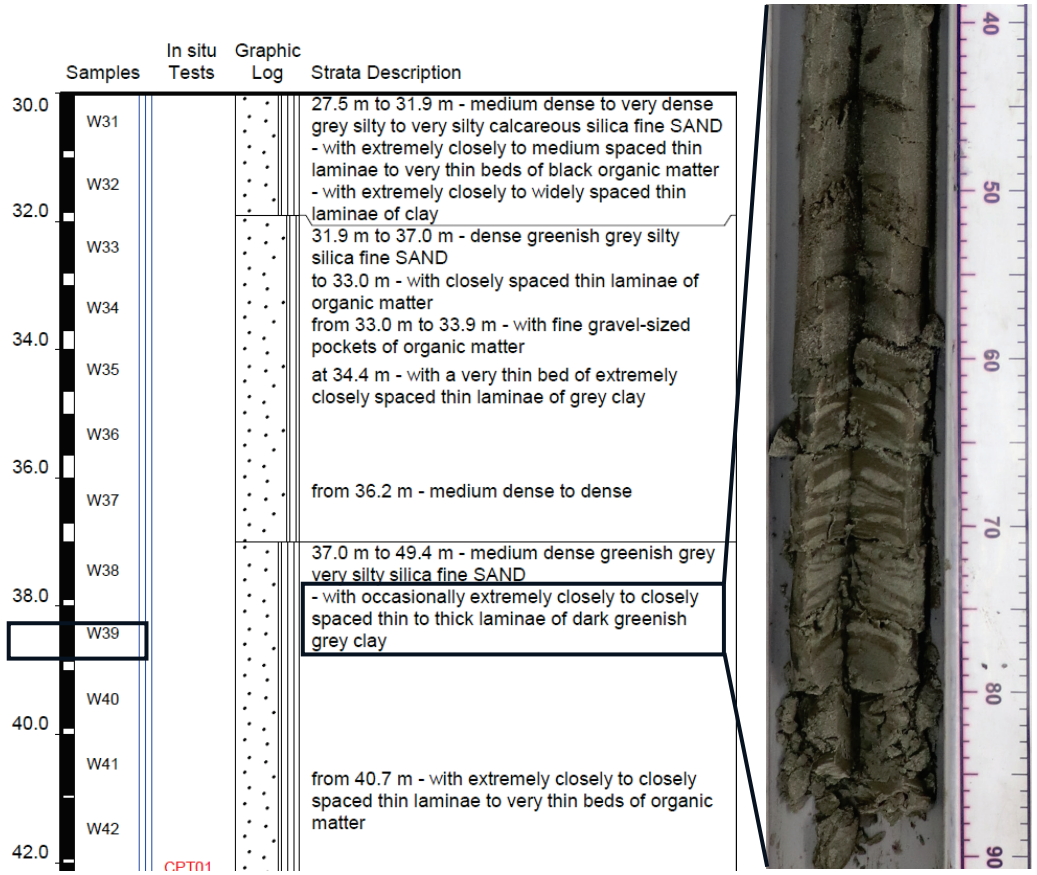
- HKW050-SCPT
- Bedded/laminated strata from ~38.5 m BSF
- Boundary between Unit C2 and F

Downhole Phase - Results



- HKW050-BH
- Bedded/laminated strata from ~37.0 m BSF
- Boundary between Unit C2 and F

Downhole Phase - Results



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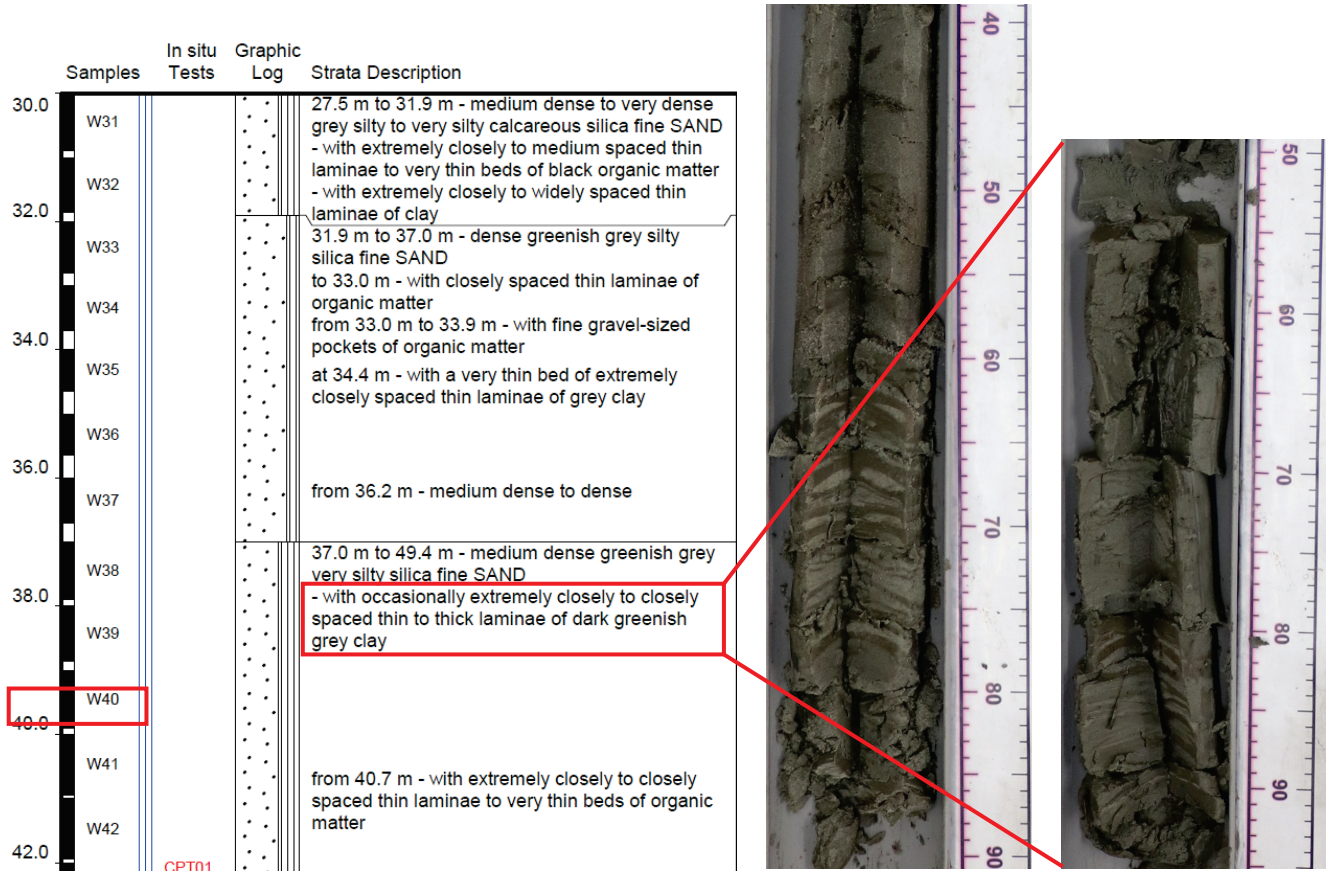
Downhole Phase - Results



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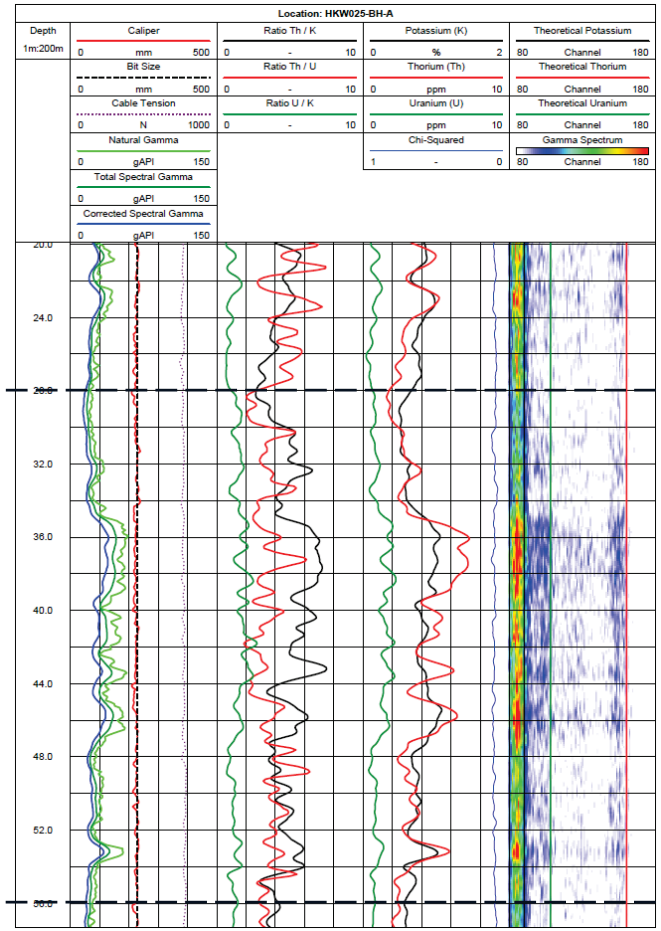
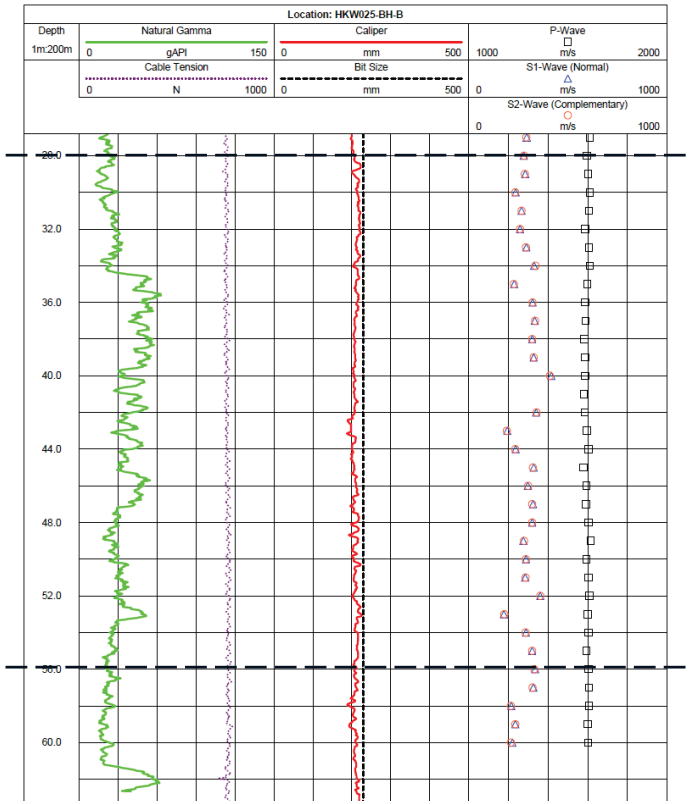
Downhole Phase - Results



HKW025-BH-A (CAL, NGR, SGR)

HKW025-BH-B (CAL, NGR, P&S)



04

Laboratory Test Programmes

Geotechnical Site Investigations - Laboratory Test Programmes

- Standard laboratory testing programme
  - 4 330 individual tests, excl. water content, unit weight, torvane, pocket penetrometer, age dating, and biogeochemical analyses, and TenneT scope
  - In accordance with BS, ISO, ASTM, or documented in-house standards and test methods
- Cyclic and dynamic laboratory testing programme
  - 359 individual tests, incl. index and static/monotonic tests
  - In accordance with BS, ISO, ASTM, or documented in-house standards and test methods
- 'Specials':
  - Biogeochemical analyses (microbiologically influenced corrosion, MIC)
  - Age dating analyses
  - Archaeological age dating analyses

Standard Laboratory Test Programme - Overview

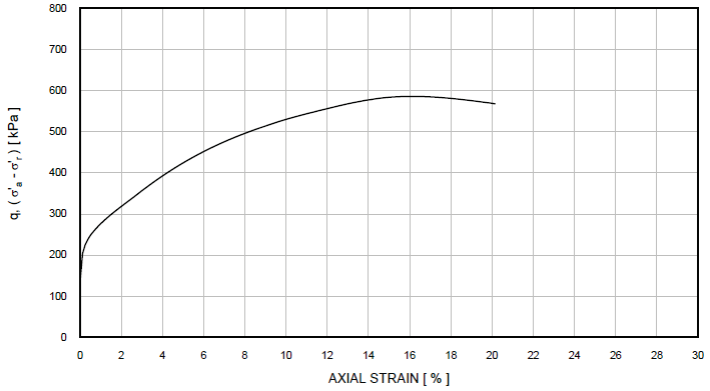
- Particle density: **472**
- Particle size distribution: **1 047**
- Minimum and maximum index dry density: **227**
- Atterberg limits: **291**
- Carbonate content: **424**
- Organic content: **374**
- Mass loss on ignition: **46**
- Pore water salinity: **54**
- Thermal conductivity: **53**
- Electrical resistivity: **53**
- Transient plane source: **51**
- Microscopic sample photography (simple): **189**
- Microscopic sample photography (detailed): **59**
- UU triaxial compression (undisturbed): **6**
- UU triaxial compression (remoulded): **5**
- CAU/CIU triaxial in compression: **35**
- CAU/CIU triaxial in compression + BE: **33**
- CID triaxial in compression: **266**
- CID triaxial in compression + BE: **84**
- Ring shear (soil-soil interface): **55**
- Ring shear (soil-steel interface): **145**
- Direct shear: **145**
- Incremental loading oedometer: **22**
- Constant rate of strain: **66**
- Permeability: **128**

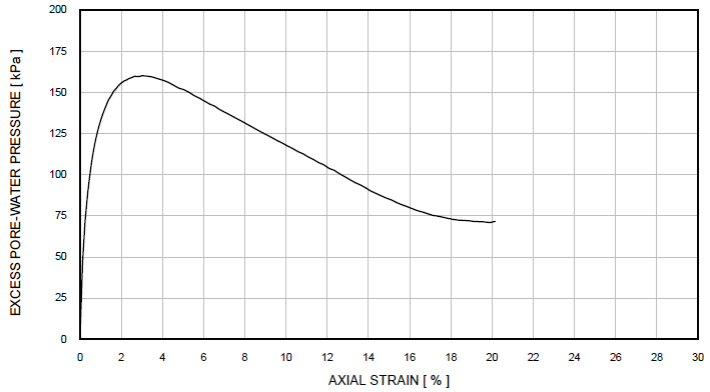
Standard Laboratory Test Programme - Results

SPECIMEN PHOTOGRAPHS

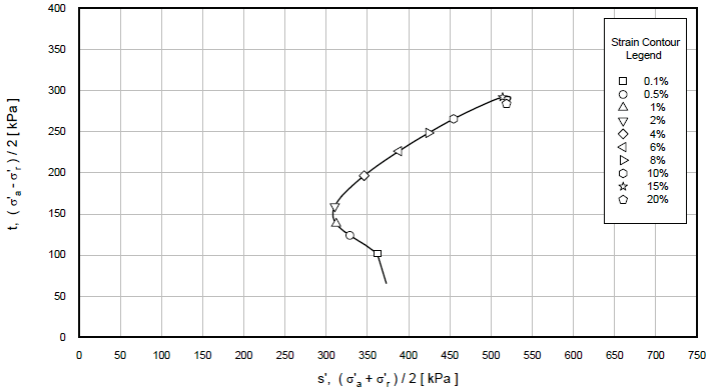
FINAL CONDITIONS		
Water content	[%]	24.6
Bulk density	[Mg/m³]	2.06
Dry density	[Mg/m³]	1.65

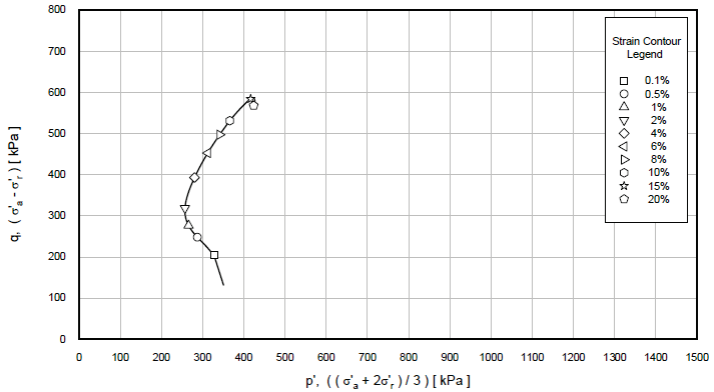
TEST IDENTIFICATION	
Borehole	HKW033-BH
Sample	46WAXB
Depth [m]	44.14
Test number	CAUc30





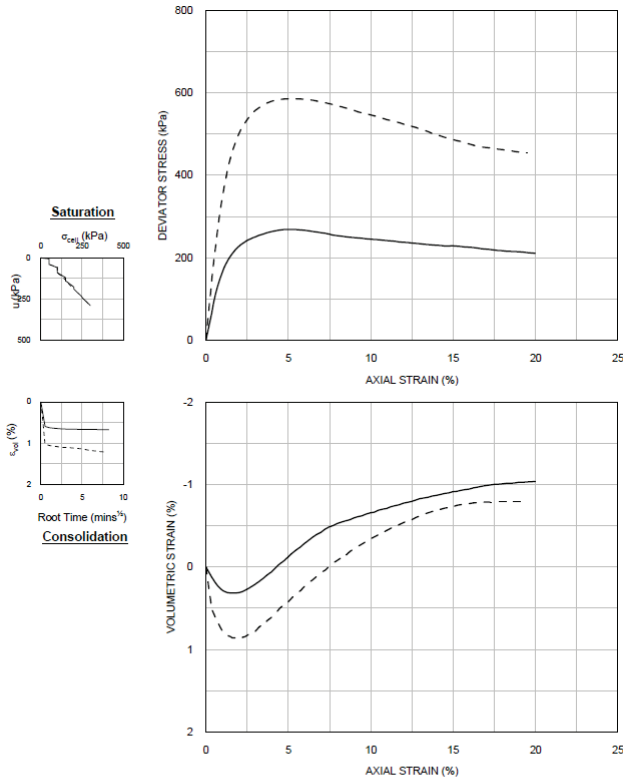
Initial σ'r	: 307 kPa	Borehole	: HKW033-BH
Initial σ'a	: 439 kPa	Sample	: 46WAXB
q_{peak}	: 586 kPa	Depth [m]	: 44.14
Ext. ε at q_{peak}	: 16.12 %	Test No.	: CAUc30
Rate of strain	: 0.41 %/hour		



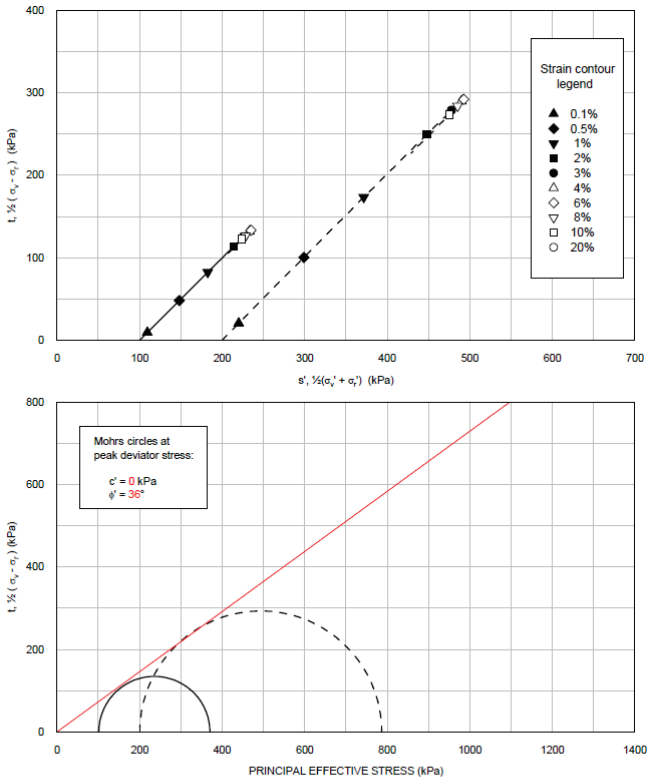


Initial σ'r	: 307 kPa	Borehole	: HKW033-BH
Initial σ'a	: 439 kPa	Sample	: 46WAXB
q_{peak}	: 586 kPa	Depth [m]	: 44.14
Ext. ε at q_{peak}	: 16.12 %	Test No.	: CAUc30
Rate of strain	: 0.41 %/hour		

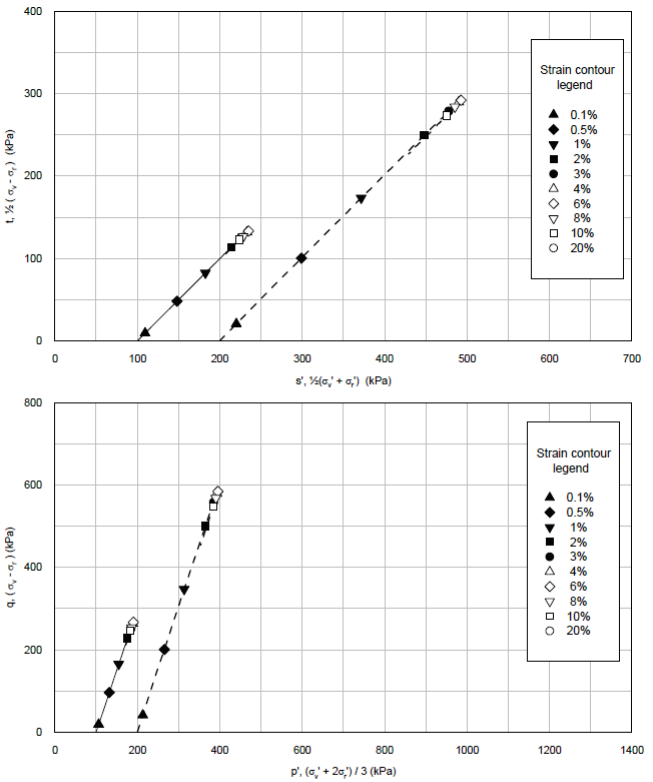
Standard Laboratory Test Programme - Results



Curve	Specimen	σ_{rc}' (kPa)	σ_{vc}' (kPa)	Borehole	Sample	Depth (m)
——	1	100	100	HKW014-BH	09BAGA	8.00
– –	2	200	200			

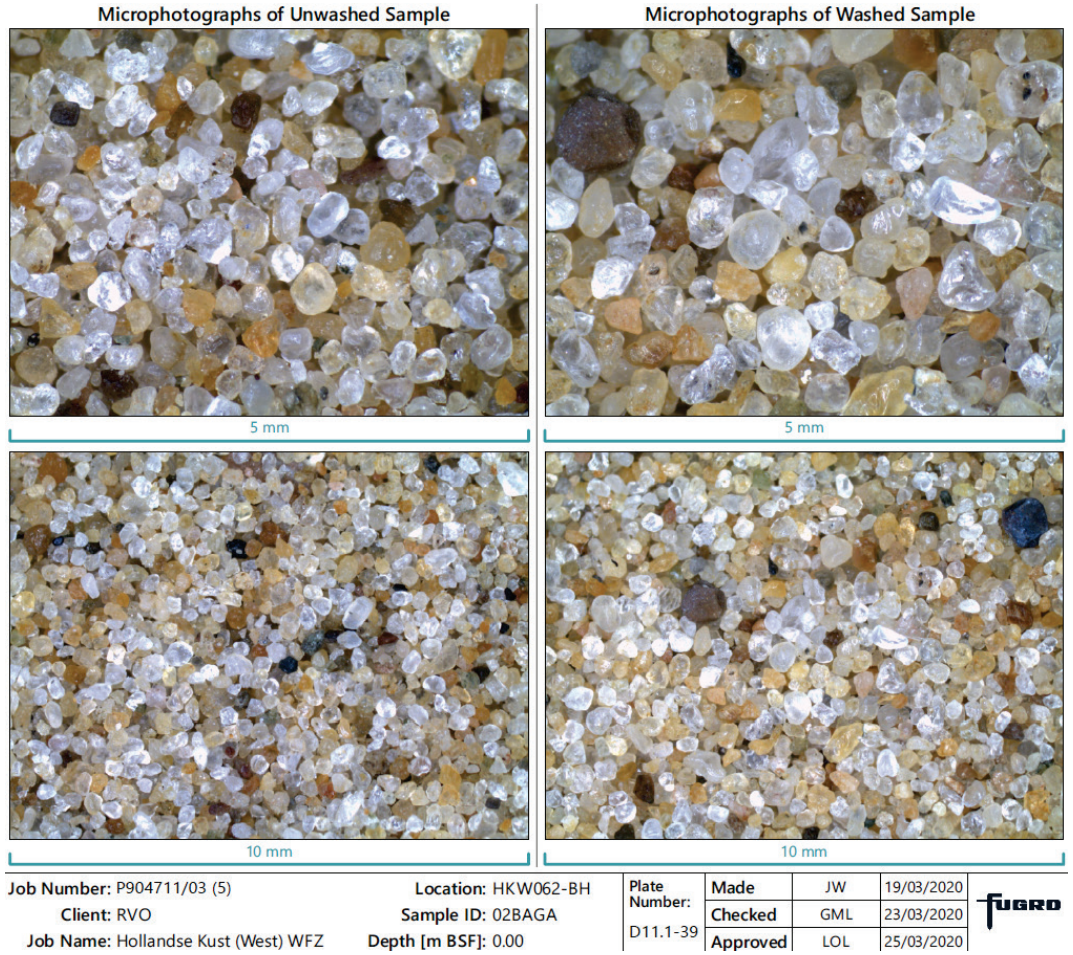


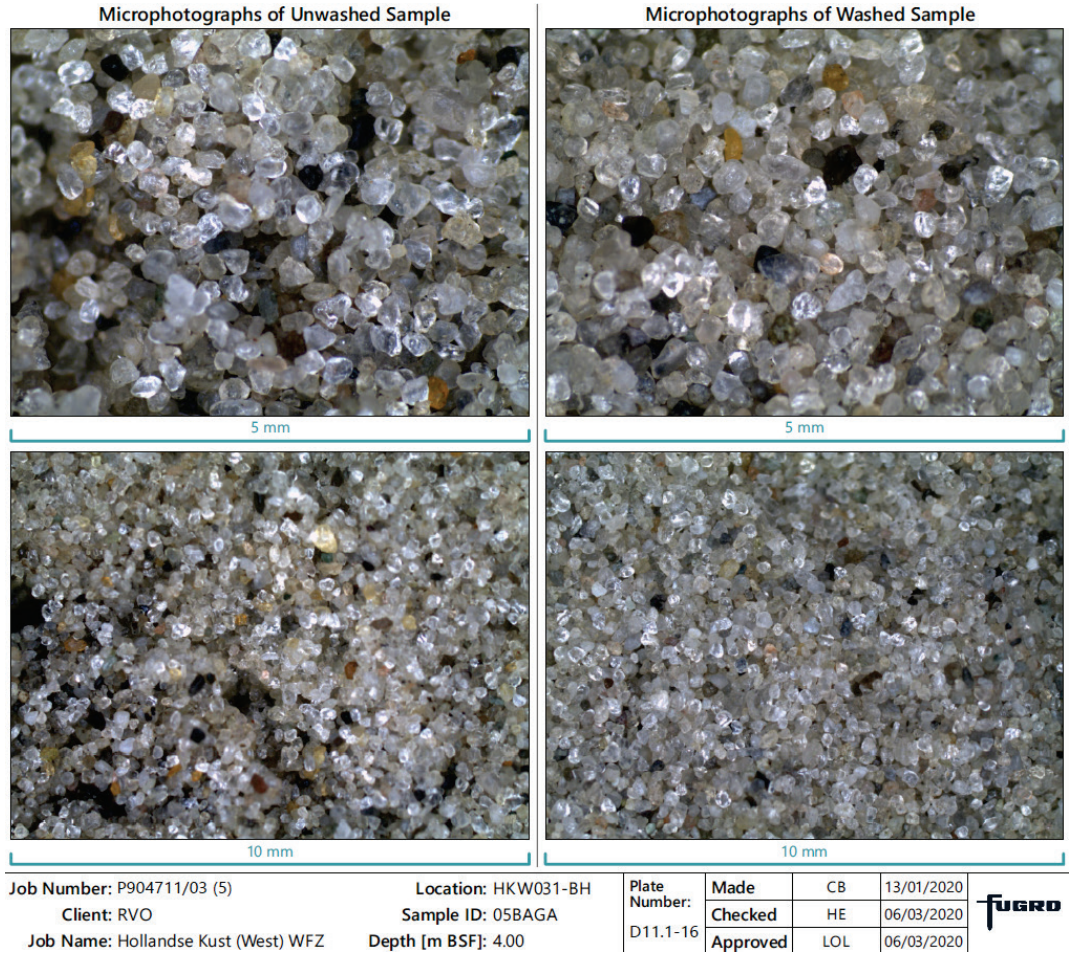
Curve	Specimen	σ_{rc}' (kPa)	σ_{vc}' (kPa)	Borehole	Sample	Depth (m)
——	1	100	100	HKW014-BH	09BAGA	8.00
– –	2	200	200			



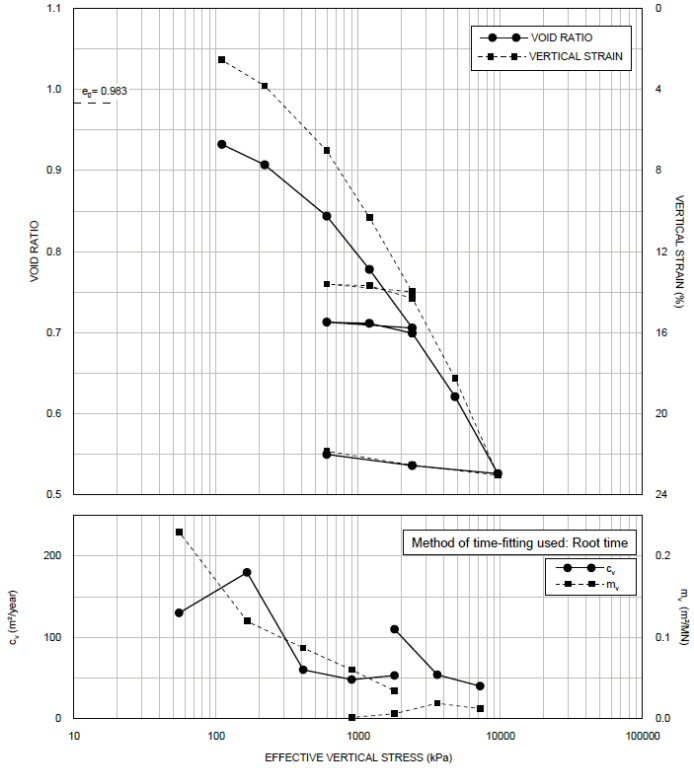
Curve	Specimen	σ_{rc}' (kPa)	σ_{vc}' (kPa)	Borehole	Sample	Depth (m)
——	1	100	100	HKW014-BH	09BAGA	8.00
– –	2	200	200			

Standard Laboratory Test Programme - Results



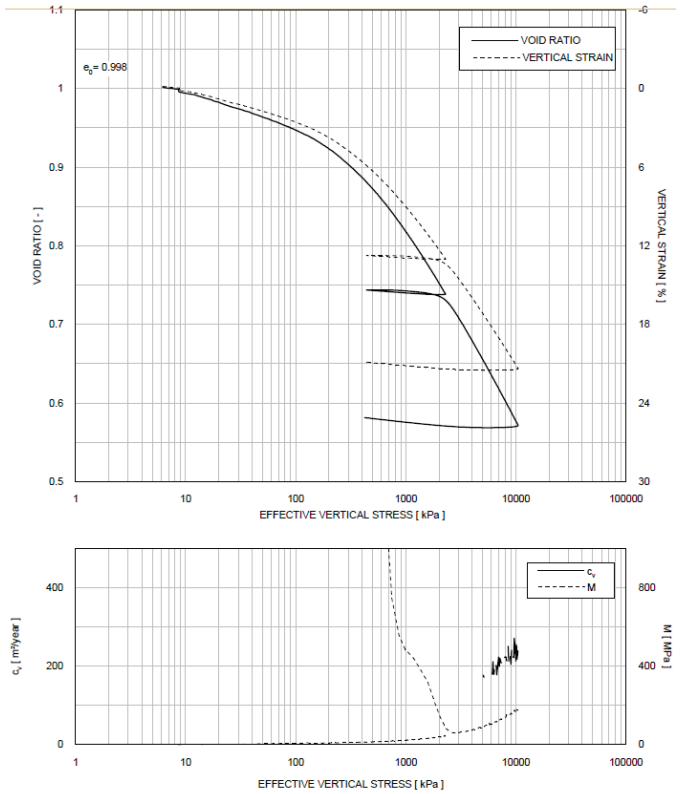


Standard Laboratory Test Programme - Results



Initial Conditions			
Specimen height	: 19.0 mm	Bulk density	: 1.81 Mg/m³
Specimen diameter	: 50.5 mm	Dry density	: 1.36 Mg/m³
Degree of saturation	: 90 %	Water content	: 32.8 %
Particle density	: 2.70 Mg/m³ (Assumed)	Lab. temperature	: 20 °C
Specimen condition	: Undisturbed	Swelling pressure	: NA kPa
Method of time fitting	: Root Time Method		

Borehole : HKW104-BH
Sample : 23WAXD
Depth [m] : 21.64



Borehole	Sample	Depth [m]
HKW104-BH	23WAXD	21.7

Initial void ratio : 0.998
Particle Density : 2.70 Mg/m³
Strain rate (constant) : 0.70 %/hour

Cyclic and Dynamic Laboratory Test Programme - Overview

- Particle size distribution: **10**
- Microscopic sample photography (detailed): **10**

- CAU/CIU triaxial in compression + BE: **29**
- CAU triaxial in extension + BE: **1**
- CAD/CID triaxial in compression + BE: **6**

- Direct simple shear (constant volume): **12**
- Direct simple shear (constant stress): **9**

- Stress-controlled undrained CTX: **43**
- Stress-controlled CTX with drainage: **18**

- Stress-controlled CSS (constant volume): **115**
- Stress-controlled CSS (constant stress): **57**

- Strain-controlled CSS (constant volume): **37**

- Resonant column: **12**

We acknowledge the large number of advanced tests performed and reported. With additional interpretation this can support the design with a high degree of accuracy for cyclic degradation and initial stiffness. The geotechnical testing program can be considered as the 'cutting edge' with respect to the amount of detailed factual data that is available by the time of the initiation of the tender phase for an offshore wind farm.

DNV GL Certification Report on Laboratory Test Data Report

Cyclic and Dynamic Laboratory Test Programme - Overview

- Cyclic/dynamic laboratory test programme has been prepared in consultation with client, client consultants, and Fugro experts
- Progressively planned and executed as results became available
- Laboratory test programme focused on:
  - Predominant soil units present across the geotechnical investigation area (GIA) which are relevant for engineering purposes
  - Soil units present locally but considered to be of importance for engineering purposes, e.g. local weaker layers such as channel infills
- Laboratory test programme aimed for typical, high, and low cyclic resistance curves for the geological units of interest

Cyclic and Dynamic Laboratory Test Programme - Overview

Test Series*	Batch / Location(s)	Sample Depth [m BSF]	Target Relative Density [%]	Target Dry Density [Mg/m³]	Vertical Consolidation Stress† [kPa]	Selection Criteria
A-CG-T	**Batch 1** (HKW053-BH, HKW056-BH)	0.00 to 4.15	90	1.62	20	- Cone resistance ~15 MPa - Relative density: dense to very dense - Soil behaviour type index I_c ~ 1.5
B-CG-T	**Batch 2** (HKW053-BH, HKW053-BH-A, HKW056-BH)	1.70 to 7.60	80	1.60	45	- Cone resistance ~15 MPa - Relative density: dense to very dense - Soil behaviour type index I_c ~ 1.5
C-CG-T	**Batch 3** (HKW107-BH)	13.35 to 17.30	50	1.54	145	- Cone resistance ~10 MPa - Relative density: medium dense - Soil behaviour type index I_c ~ 2.0
C-FG-T	HKW055-BH HKW062-BH HKW077-BH	4.05 to 8.85	-	-	40 - 80	- Cone resistance ~2 MPa - High undrained shear strength - Soil behaviour type index I_c ~ 2.5 - Similar soil characteristics between selected locations
D-CG-T	**Batch 4** (HKW065-BH)	11.60 to 17.85	60	1.59	145	- Cone resistance ~15 MPa - Relative density: medium dense to dense
E-CG-T	**Batch 5** (HKW016-BH)	4.00 to 11.50	90	1.64	80	- Cone resistance ~30 MPa - Relative density: very dense - Soil behaviour type index I_c ~ 1.5
E-CG-H	**Batch 6** (HKW016-BH)	15.00 to 22.20	100	1.68	190	- Cone resistance ~45 MPa - Relative density: very dense - Soil behaviour type index I_c ~ 1.5
F-CG-L	**Batch 7** (HKW112-BH)	19.50 to 28.80	60	1.60	250	- Cone resistance ~20 MPa - Relative density: dense to very dense - Soil behaviour type index I_c ~ 2.0
F-CG-T1	**Batch 8** (HKW062-BH, HKW113-BH)	6.85 to 20.05	90	1.68	150	- Cone resistance ~25 MPa - Relative density: dense to very dense - Soil behaviour type index I_c ~ 1.5
F-CG-T2	**Batch 9** (HKW062-BH, HKW113-BH)	24.50 to 34.30	50	1.64	150	- Cone resistance ~15 MPa - Relative density: medium dense - Soil behaviour type index I_c ~ 2.0
F-CG-H	**Batch 10** (HKW038-BH, HKW045-BH)	14.25 to 26.65	110	1.70	250	- Cone resistance ~50 MPa - Relative density: very dense - Soil behaviour type index I_c ~ 1.5
F-FG-T	HKW114-BH	33.40 to 35.45	-	-	335 - 360	- Cone resistance ~5 MPa - High undrained shear strength - Soil behaviour type index I_c ~ 3.0

Notes:
* = A to F: soil unit; CG = Coarse-grained, FG = Fine-grained, L = low cyclic resistance, T = typical cyclic resistance, H = high cyclic resistance
† = Vertical consolidation stress for FG-T series is assessed for individual samples

- Coarse-grained cohesionless soils:
  - Unit A: 1 test series (typical; Batch 1)
  - Unit B: 1 test series (typical; Batch 2)
  - Unit C: 1 test series (typical; Batch 3)
  - Unit D: 1 test series (typical; Batch 4)
  - Unit E: 2 test series (typical, high; Batches 5 and 6)
  - Unit F: 4 test series (low, typical 1, typical 2, high; Batches 7 to 10)
- Fine-grained cohesive soils:
  - Unit C: 1 test series (typical)
  - Unit F: 1 test series (typical)

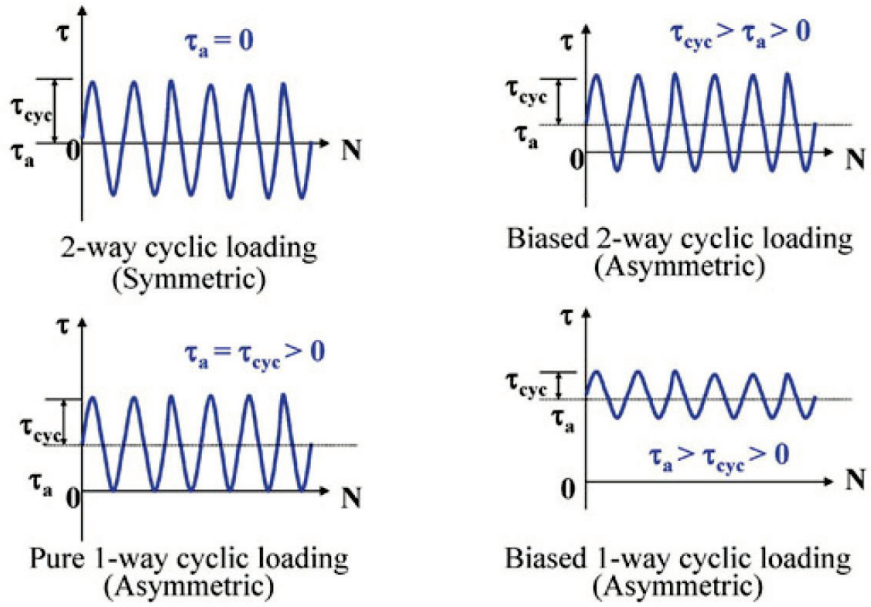
Cyclic and Dynamic Laboratory Test Programme - Test Strategy

- Cyclic direct simple shear (CSS)
  - With/without pre-shear (400 cycles)
  - One cyclic stage (1500 cycles)
  - Symmetric/asymmetric two-way loading or pure/biased (asymmetric) one-way loading
  - Target is failure between ~5 and 400 cycles
  - Post-cyclic monotonic shearing in case of no failure
- Cyclic triaxial (CTX)
  - No cyclic pre-shear
  - Two cyclic stages (1500 cycles followed by 400 cycles)
  - Symmetric two-way loading
  - Target is no failure
  - Post-cyclic static shearing in case of no failure

Cyclic and Dynamic Laboratory Test Programme - Test Strategy

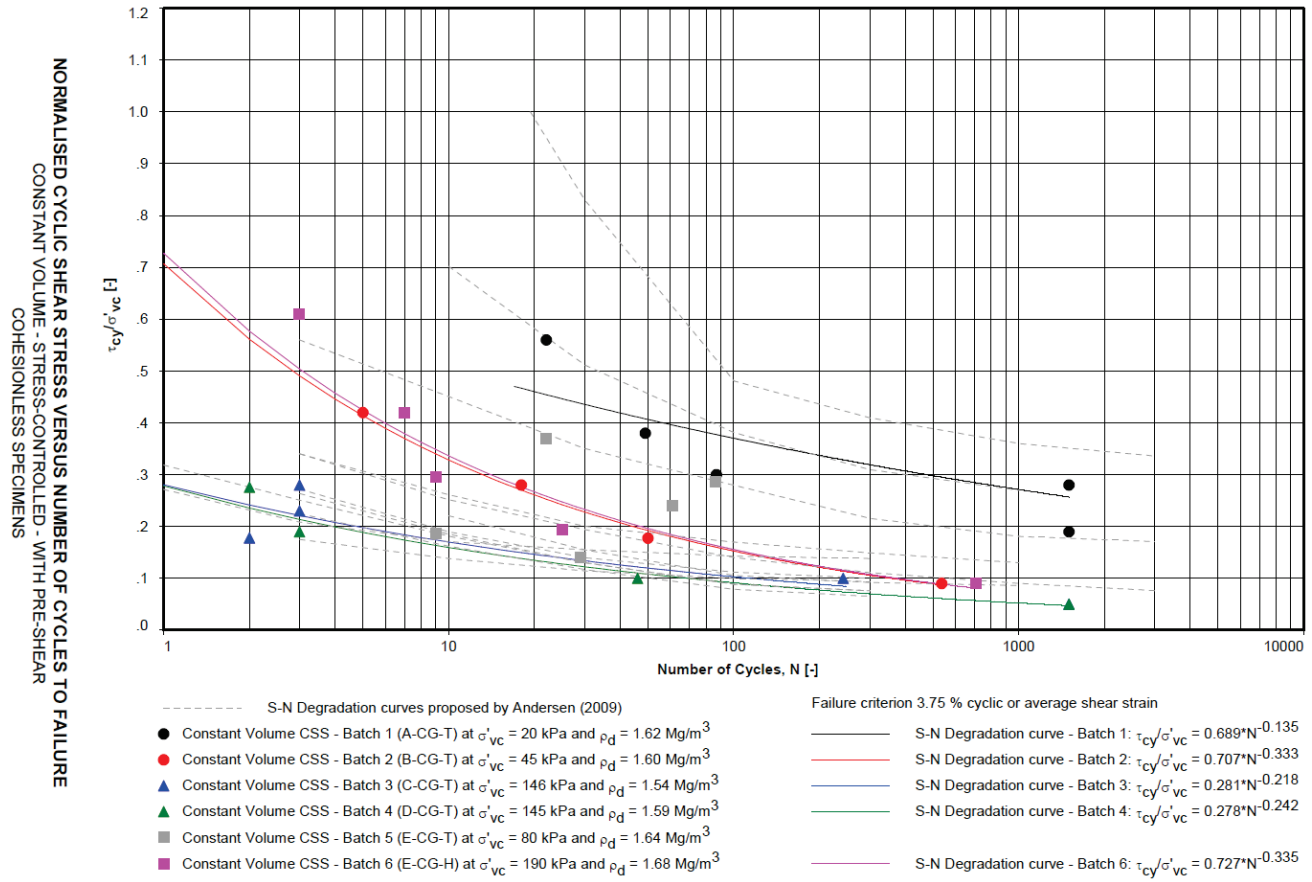
Test variables:

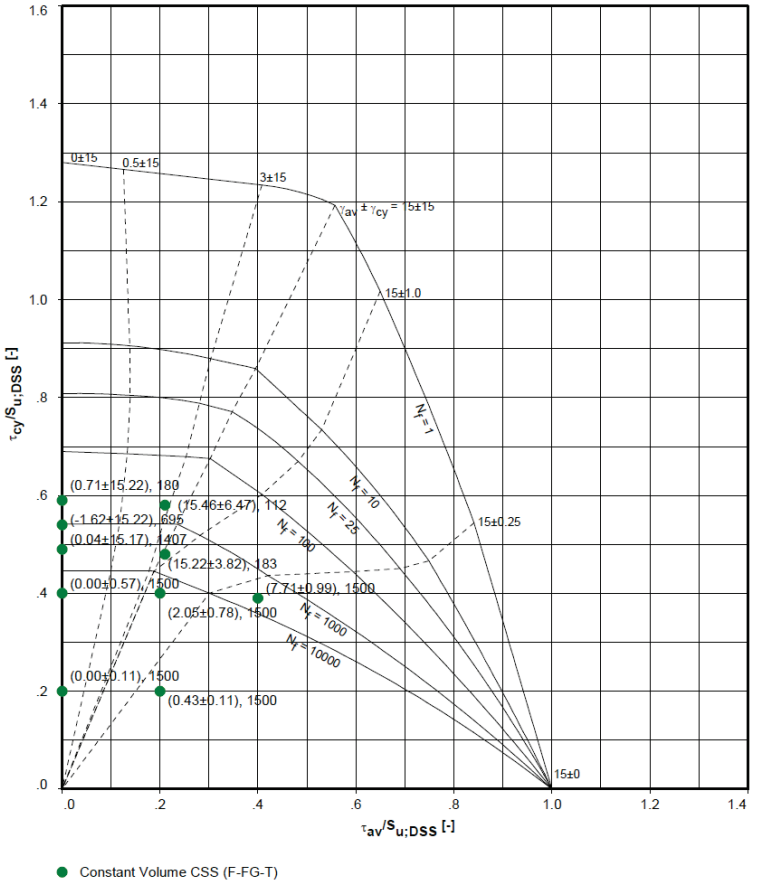
- Dry density
- Consolidation stress
- With/without cyclic pre-shear
- Undrained/with drainage
- Constant volume/constant stress
- Average and cyclic stress ratio
- Pure/biased (asymmetric) one-way loading
- Symmetric/asymmetric two-way loading



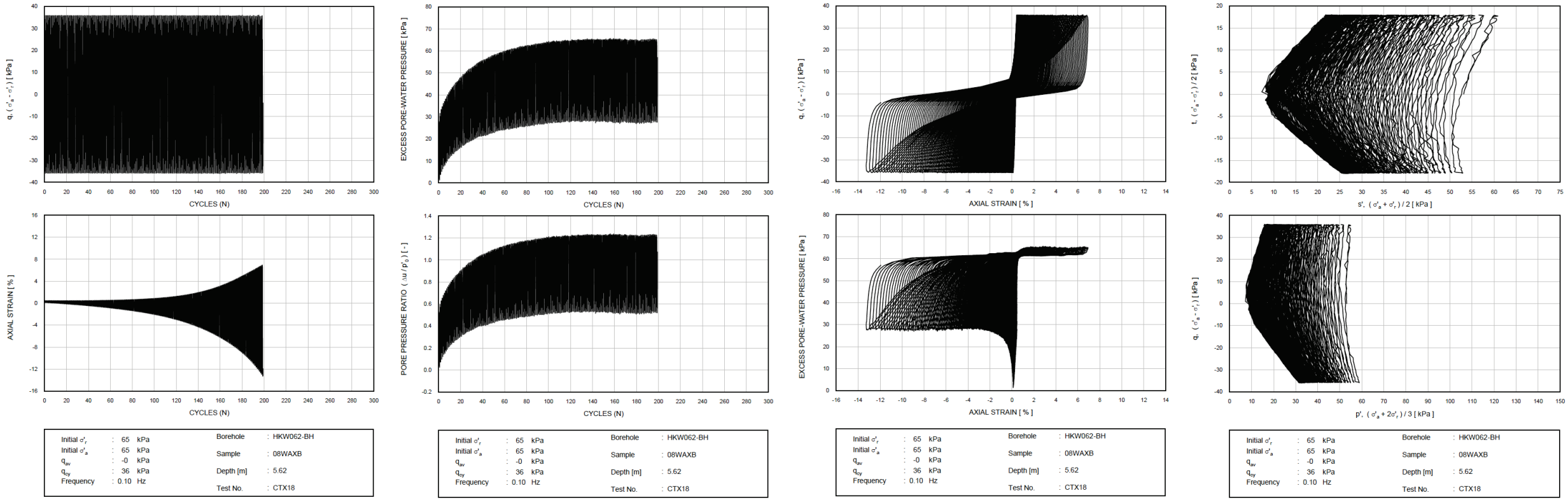
Source graph: Randolph, M.F. (2012). Offshore Design Approaches and Model Tests for Sub-Failure Cyclic Loading of Foundations. In: C. di Prisco et al. (eds.), *Mechanical Behaviour of Soils under Environmentally Induced Cyclic Loads.* CISM, Udine.

Cyclic and Dynamic Laboratory Test Programme - Results



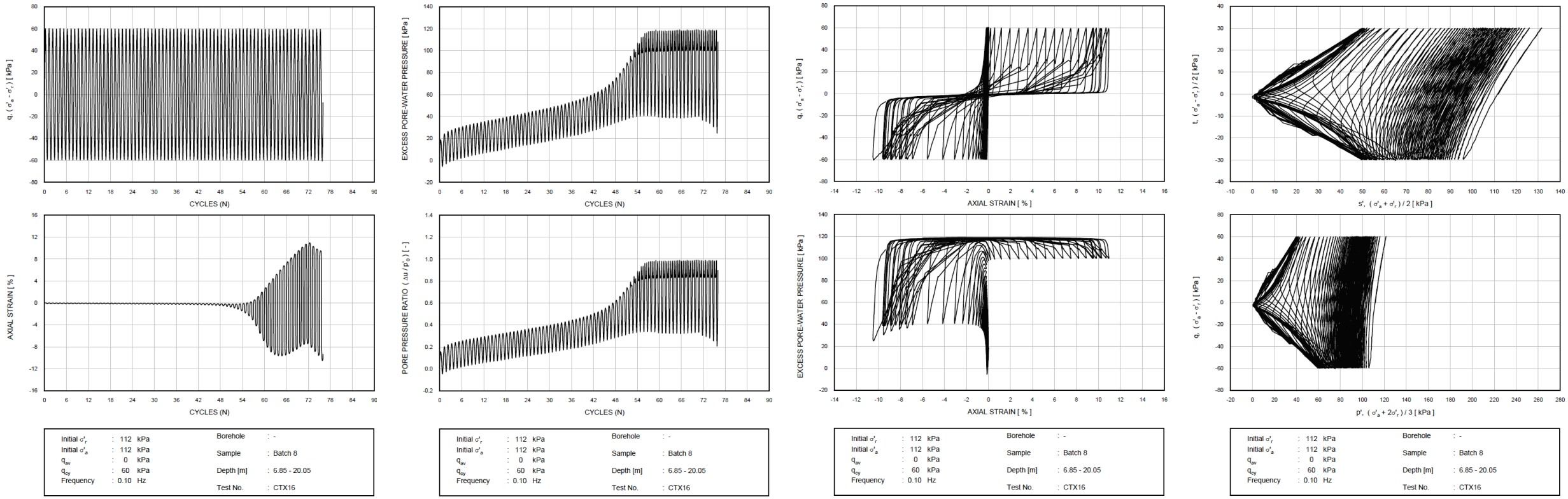


Cyclic and Dynamic Laboratory Test Programme - Results CTX



Undrained cyclic triaxial test on clay

Cyclic and Dynamic Laboratory Test Programme - Results CTX



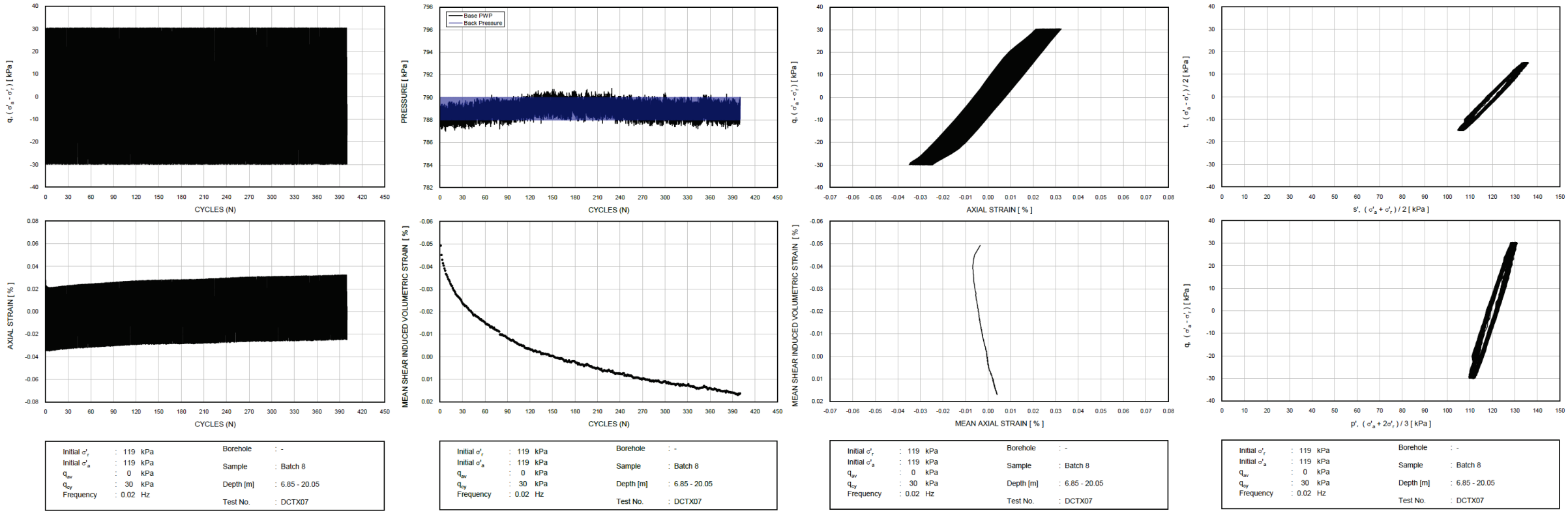
Initial σ'_r	: 112 kPa	Borehole	: -
Initial σ'_a	: 112 kPa	Sample	: Batch 8
q_{av}	: 0 kPa	Depth [m]	: 6.85 - 20.05
q_{cy}	: 60 kPa	Test No.	: CTX16
Frequency	: 0.10 Hz		

Undrained cyclic triaxial test on sand

Cyclic and Dynamic Laboratory Test Programme - ‘Drained’ CTX

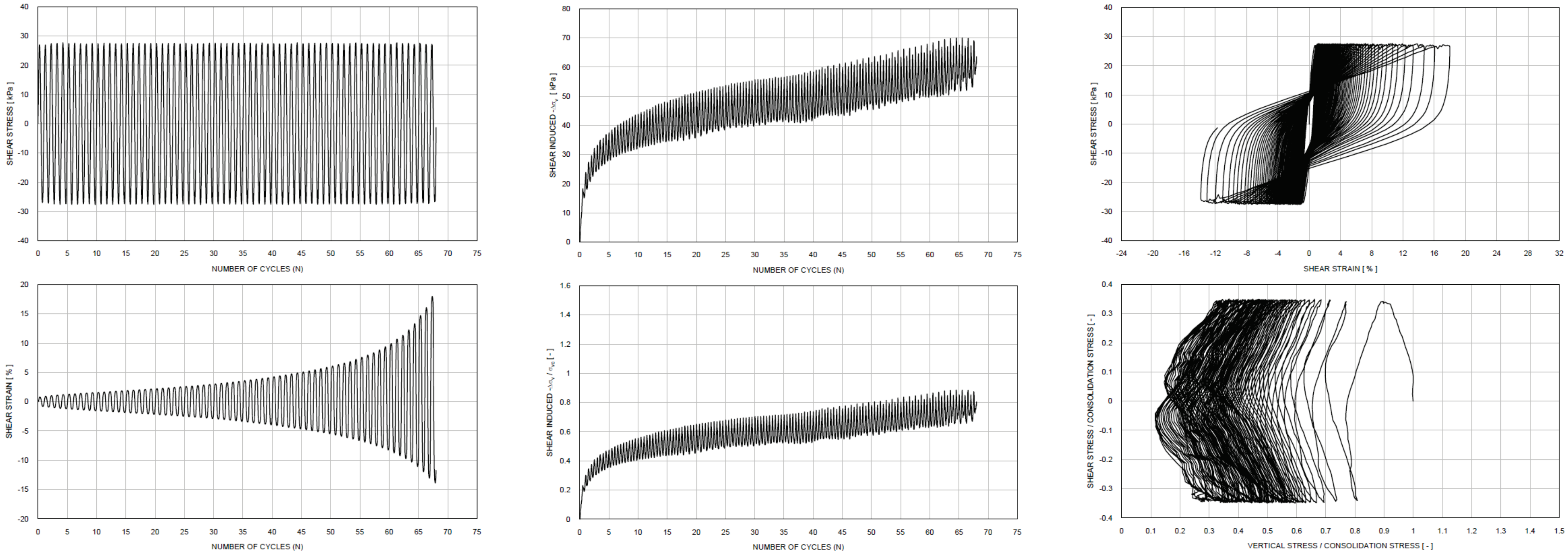
- Test programme set up after two trial rounds, to test influence of frequency and loading conditions
- Cyclic loading frequency: 0.02 Hz (50 s); relatively low cyclic stress amplitudes
- Drainage through top cap, pore water pressure measured at the base of the specimen
- Fully drained conditions not obtained within specimens, but degree of pressure dissipation assumed to be high
- Some pore pressure cycling was measured due to the back pressure control system not being able to handle the rate of flow of water in and out of the specimen during cyclic loading
- Effective stress variations following from this kept to a minimum
- Low to moderate uncertainty is present in the derived parameters (e.g. volumetric strain and stiffness)

Cyclic and Dynamic Laboratory Test Programme - Results CTX



Cyclic triaxial test with drainage, on sand

Cyclic and Dynamic Laboratory Test Programme - Results CSS



σ_{vc}	: 79	kPa	Borehole	: HKW077-BH
Mean τ_{av}	: 0	kPa	Sample	: 09WAXC
Mean τ_{cy}	: 27	kPa	Depth [m]	: 8.4
Frequency	: 0.10	Hz	Test No.	: CSS205

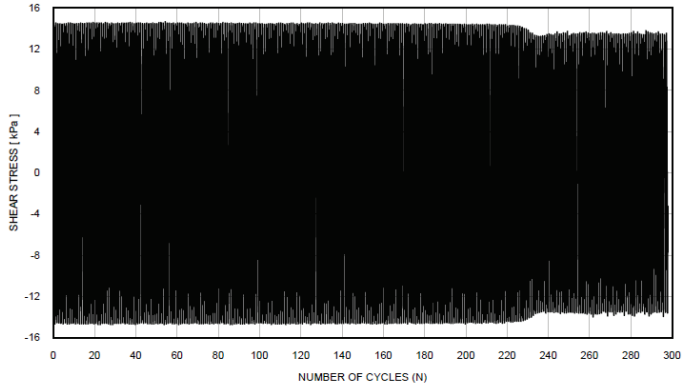
σ_{vc}	: 79	kPa	Borehole	: HKW077-BH
Mean τ_{av}	: 0	kPa	Sample	: 09WAXC
Mean τ_{cy}	: 27	kPa	Depth [m]	: 8.4
Frequency	: 0.10	Hz	Test No.	: CSS205

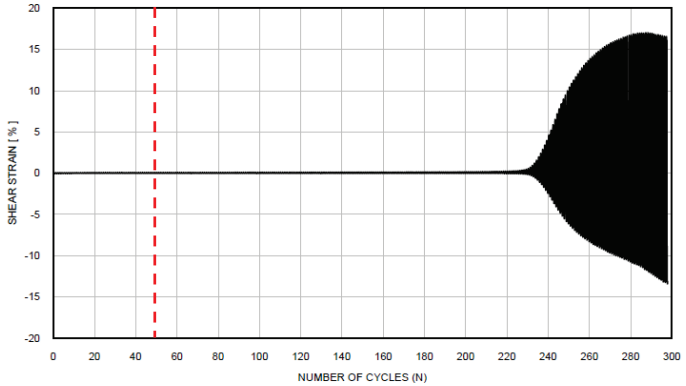
σ_{vc}	: 79	kPa	Borehole	: HKW077-BH
Mean τ_{av}	: 0	kPa	Sample	: 09WAXC
Mean τ_{cy}	: 27	kPa	Depth [m]	: 8.4
Frequency	: 0.10	Hz	Test No.	: CSS205

Constant volume cyclic direct simple shear test on clay

Cyclic and Dynamic Laboratory Test Programme - Results CSS

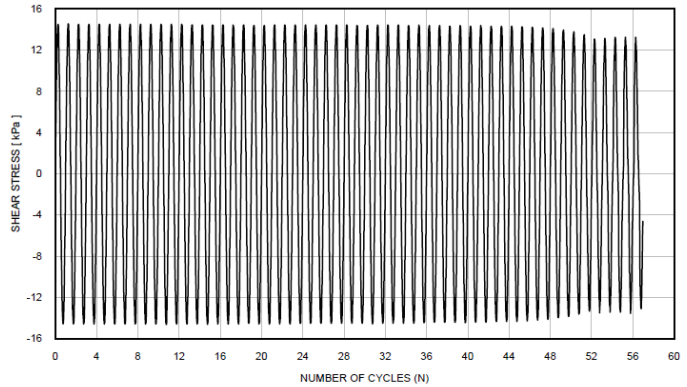
With cyclic pre-shear

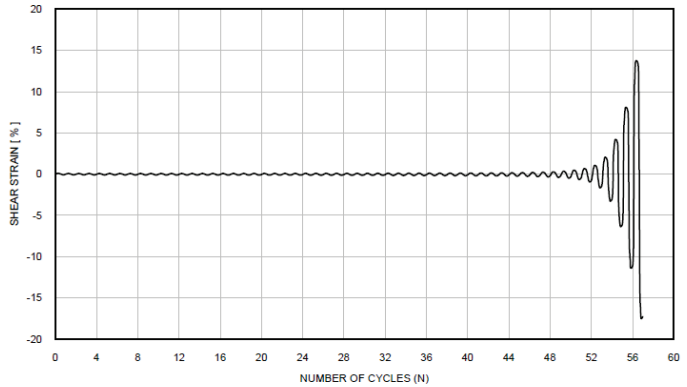




σ_{vc}	: 146 kPa	Borehole	: -
Mean τ_{av}	: -0 kPa	Sample	: Batch 3
Mean τ_{cy}	: 14 kPa	Depth [m]	: 13.35 - 17.30
Frequency	: 0.10 Hz	Test No.	: CSS108B

Without cyclic pre-shear

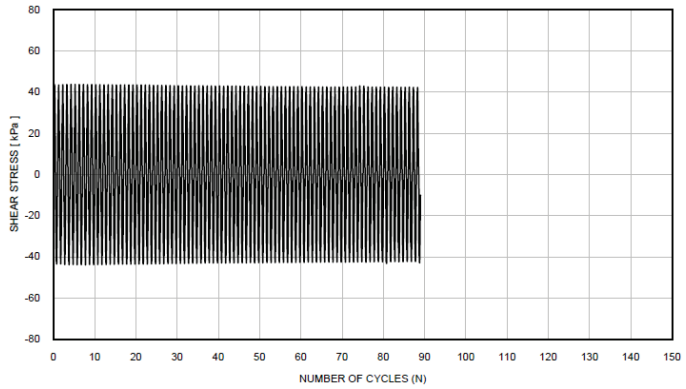


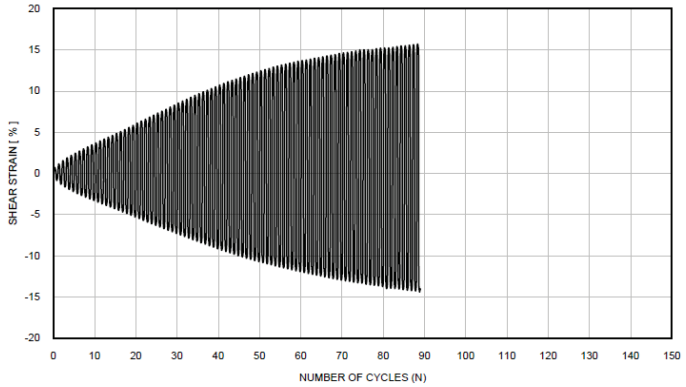


σ_{vc}	: 146 kPa	Borehole	: -
Mean τ_{av}	: -0 kPa	Sample	: Batch 3
Mean τ_{cy}	: 14 kPa	Depth [m]	: 13.35 - 17.30
Frequency	: 0.10 Hz	Test No.	: CSS88

Cyclic and Dynamic Laboratory Test Programme - Results CSS

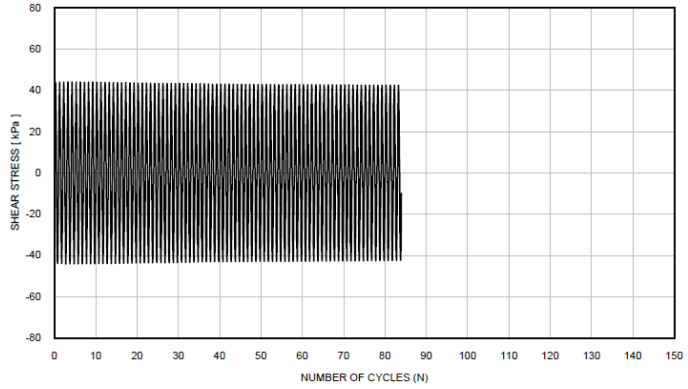
With cyclic pre-shear

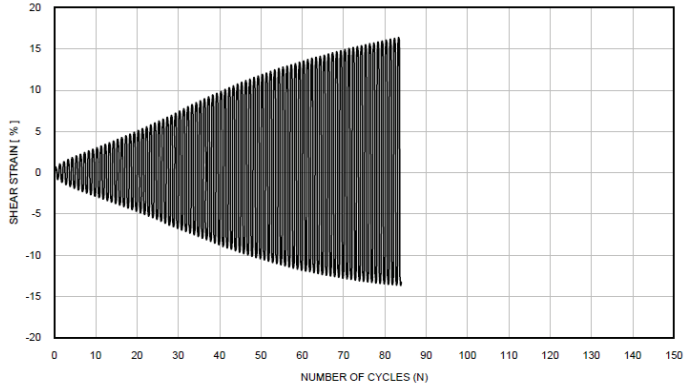




σ_{vc}	: 150 kPa	Borehole	: -
Mean τ_{av}	: -0 kPa	Sample	: Batch 9
Mean τ_{cy}	: 43 kPa	Depth [m]	: 24.50 - 34.30
Frequency	: 0.10 Hz	Test No.	: CSS58

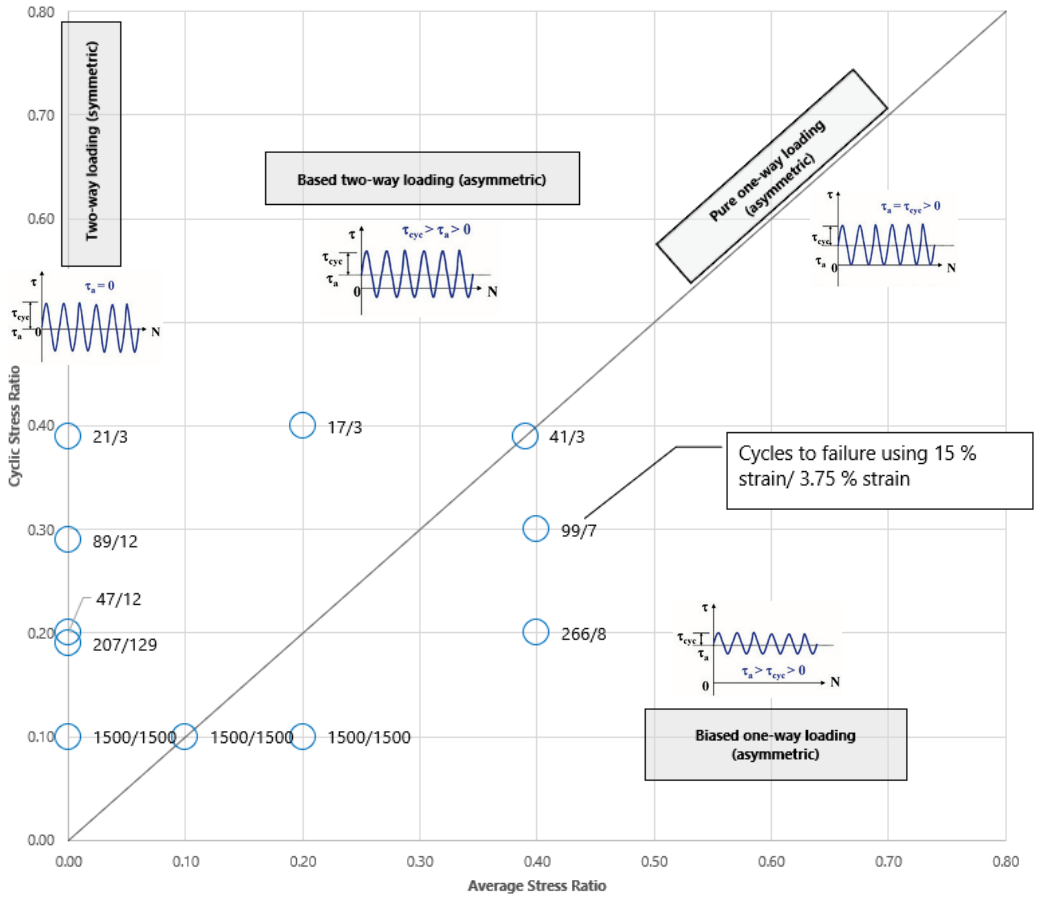
Without cyclic pre-shear





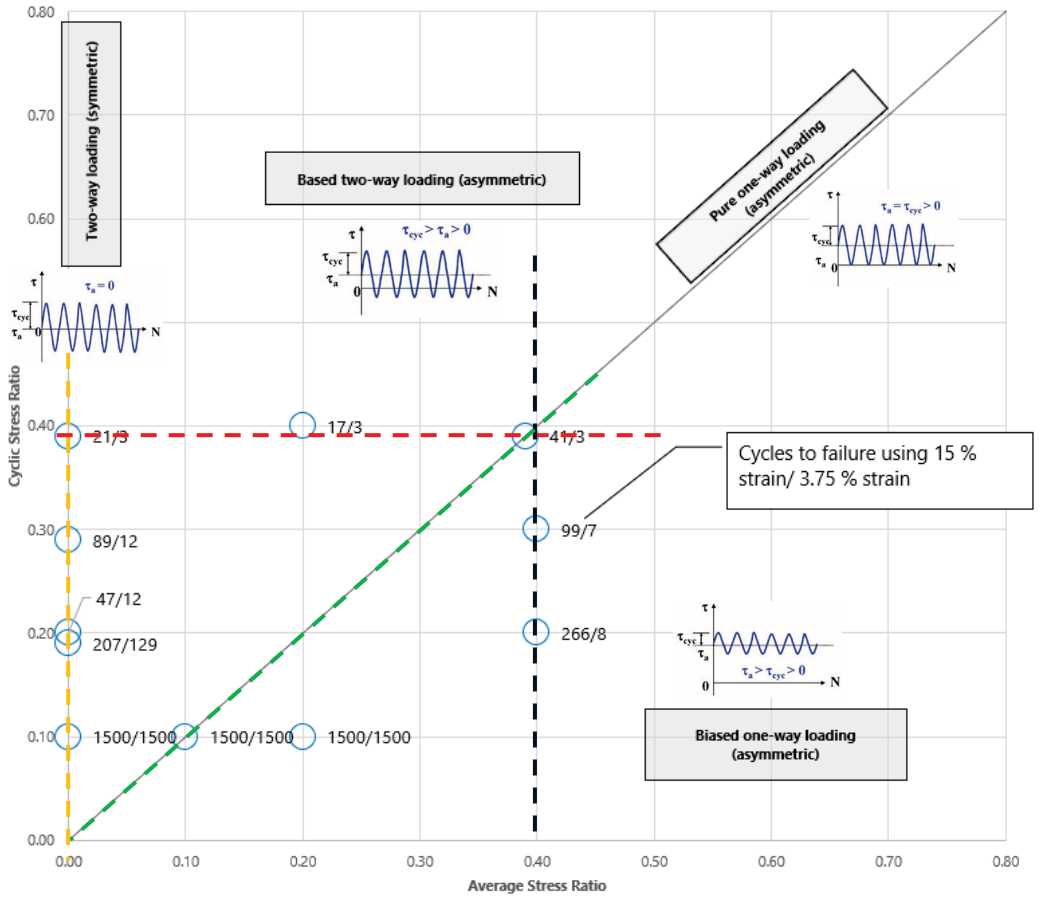
σ_{vc}	: 150 kPa	Borehole	: -
Mean τ_{av}	: -0 kPa	Sample	: Batch 9
Mean τ_{cy}	: 43 kPa	Depth [m]	: 24.50 - 34.30
Frequency	: 0.10 Hz	Test No.	: CSS90

Cyclic and Dynamic Laboratory Test Programme - Results CSS



- Constant volume cyclic direct simple shear tests on sand
- Example:
  - Batch 9
  - Combination of all four ‘scenarios’
  - Equal average stress and/or cyclic stress
  - All with cyclic pre-shear

Cyclic and Dynamic Laboratory Test Programme - Results CSS

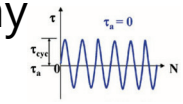


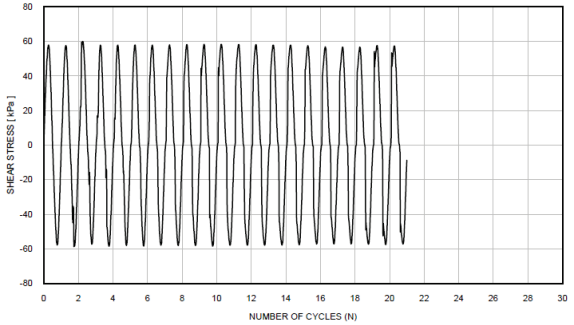
- Constant volume cyclic direct simple shear tests on sand

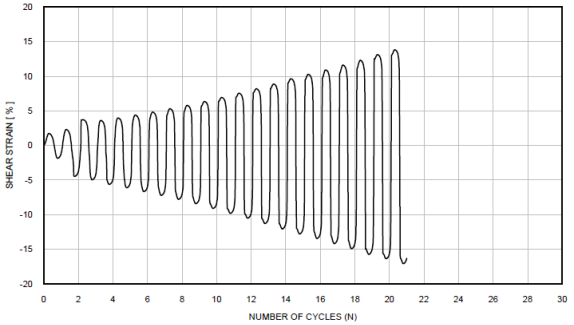
- Example:
  - Batch 9
  - Combination of all four ‘scenarios’
  - Equal average stress and/or cyclic stress
  - All with cyclic pre-shear
  - Number of cycles to failure using 15 % and 3.75 % strain

Cyclic and Dynamic Laboratory Test Programme - Results CSS

Symmetric two-way loading



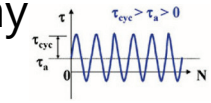


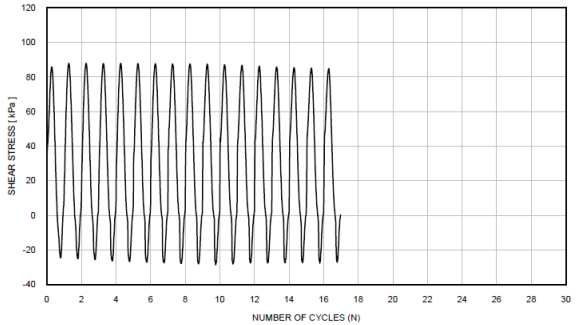


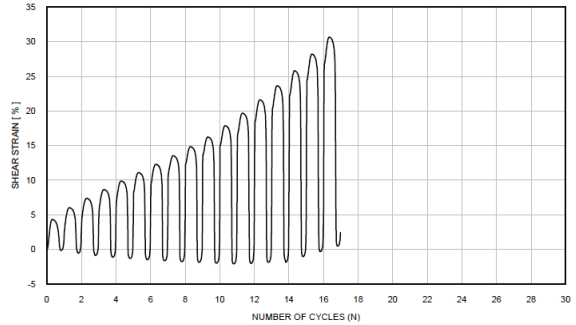
σ_{vc}	: 150 kPa	Borehole	: -
Mean τ_{av}	: -0 kPa	Sample	: Batch 9
Mean τ_{cy}	: 58 kPa	Depth [m]	: 24.50 - 34.30
Frequency	: 0.10 Hz	Test No.	: CSS99Rb

$\tau_{av} = 0$; τ_{cy} = variable

Biased two-way loading



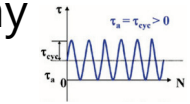


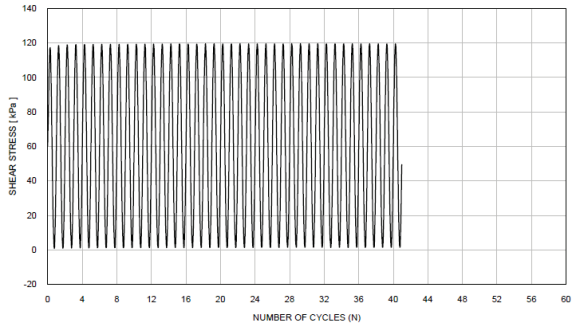


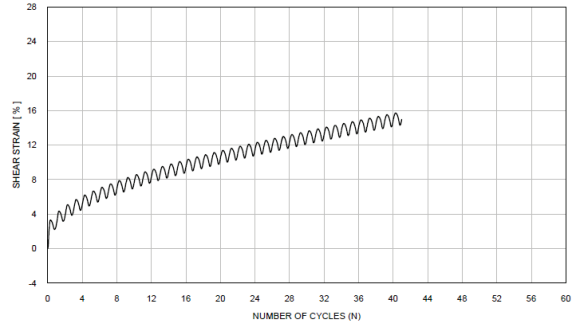
σ_{vc}	: 150 kPa	Borehole	: -
Mean τ_{av}	: 30 kPa	Sample	: Batch 9
Mean τ_{cy}	: 57 kPa	Depth [m]	: 24.50 - 34.30
Frequency	: 0.10 Hz	Test No.	: CSS197

$\tau_{cy} > \tau_{av} > 0$

Pure one-way loading



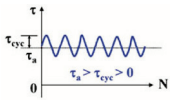


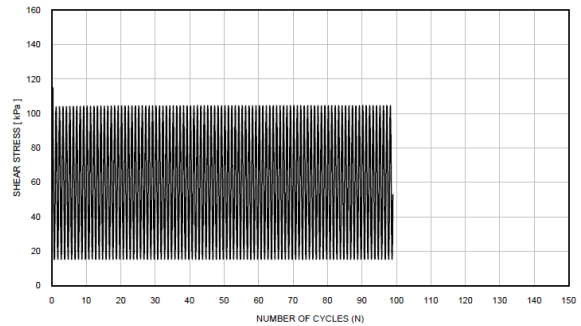


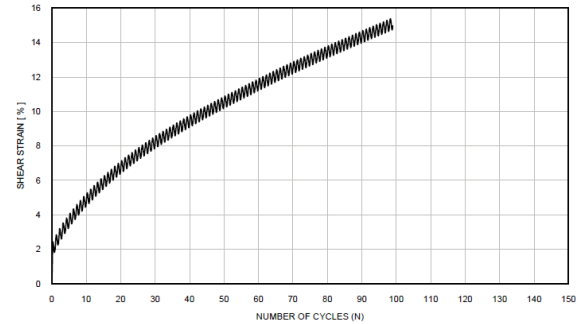
σ_{vc}	: 150 kPa	Borehole	: -
Mean τ_{av}	: 60 kPa	Sample	: Batch 9
Mean τ_{cy}	: 59 kPa	Depth [m]	: 24.50 - 34.30
Frequency	: 0.10 Hz	Test No.	: CSS105RR

$\tau_{av} = \tau_{cy} > 0$

Biased one-way loading







σ_{vc}	: 150 kPa	Borehole	: -
Mean τ_{av}	: 60 kPa	Sample	: Batch 9
Mean τ_{cy}	: 45 kPa	Depth [m]	: 24.50 - 34.30
Frequency	: 0.10 Hz	Test No.	: CSS188

$\tau_{av} > \tau_{cy} > 0$

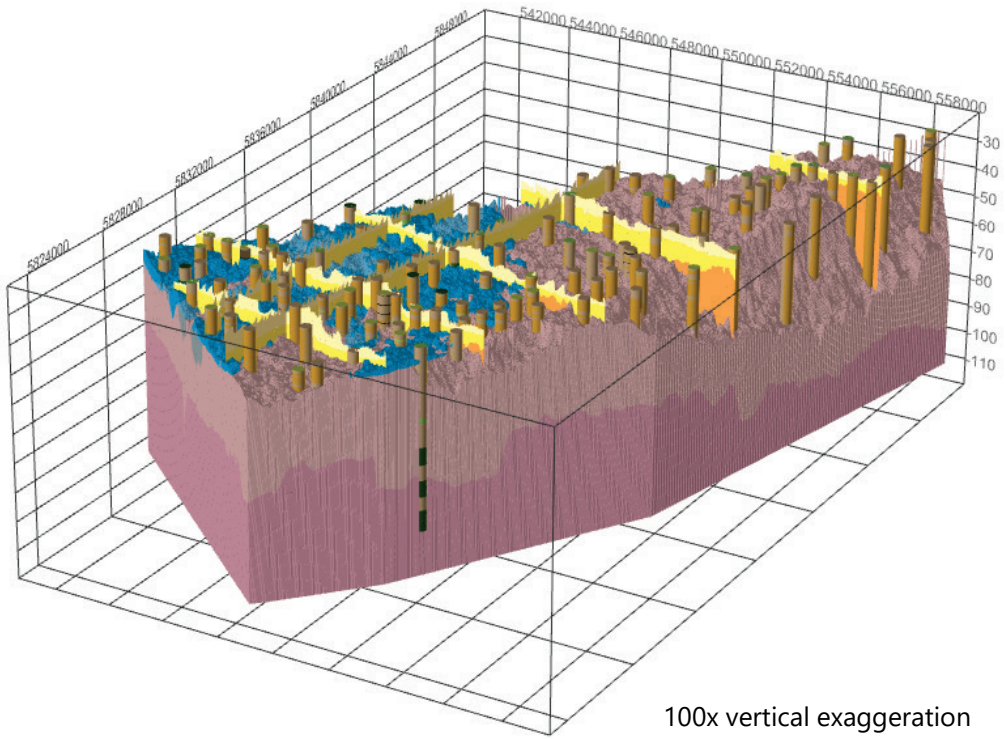
05

Geological Ground Model

Geological Ground Model

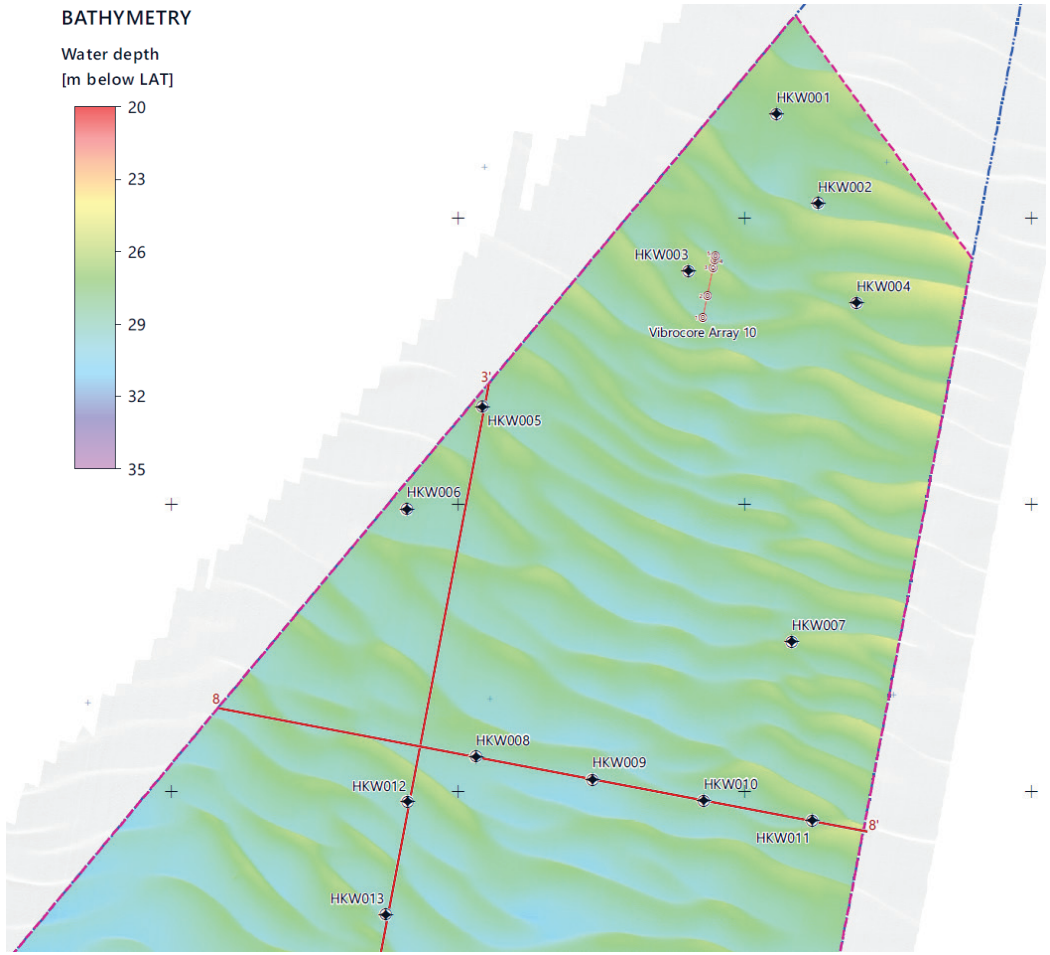
- Interpretation in geophysical survey report limited to ~100 m BSF
- Depth coverage of GGM ~100 m LAT

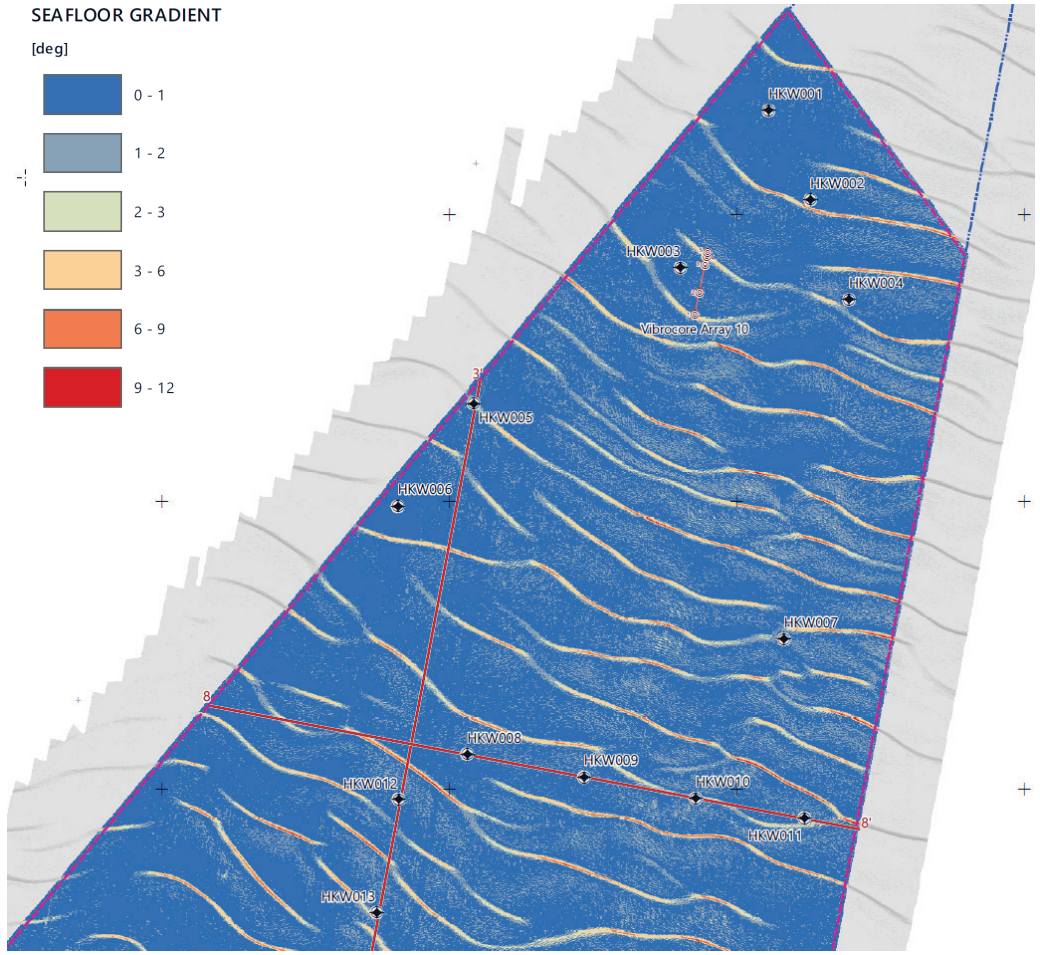
- Deliverables:
  - Report incl. detailed cross sections, depth to base and thickness charts
  - ArcGIS database
  - IHS Kingdom project with geological interpretation and geotechnical data
  - 3D geological ground model allowing visualisation by open-access application (SubsurfaceViewer Reader)



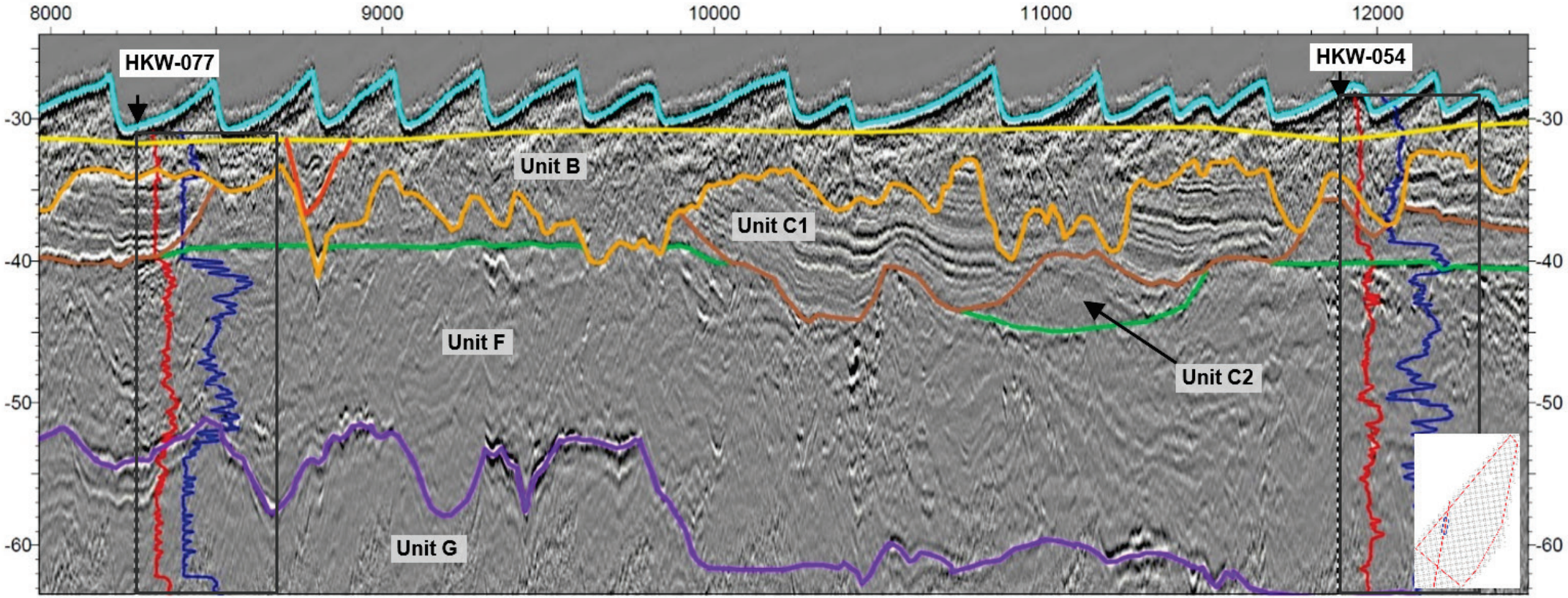
100x vertical exaggeration

Geological Ground Model - Seafloor Gradient and Bathymetry

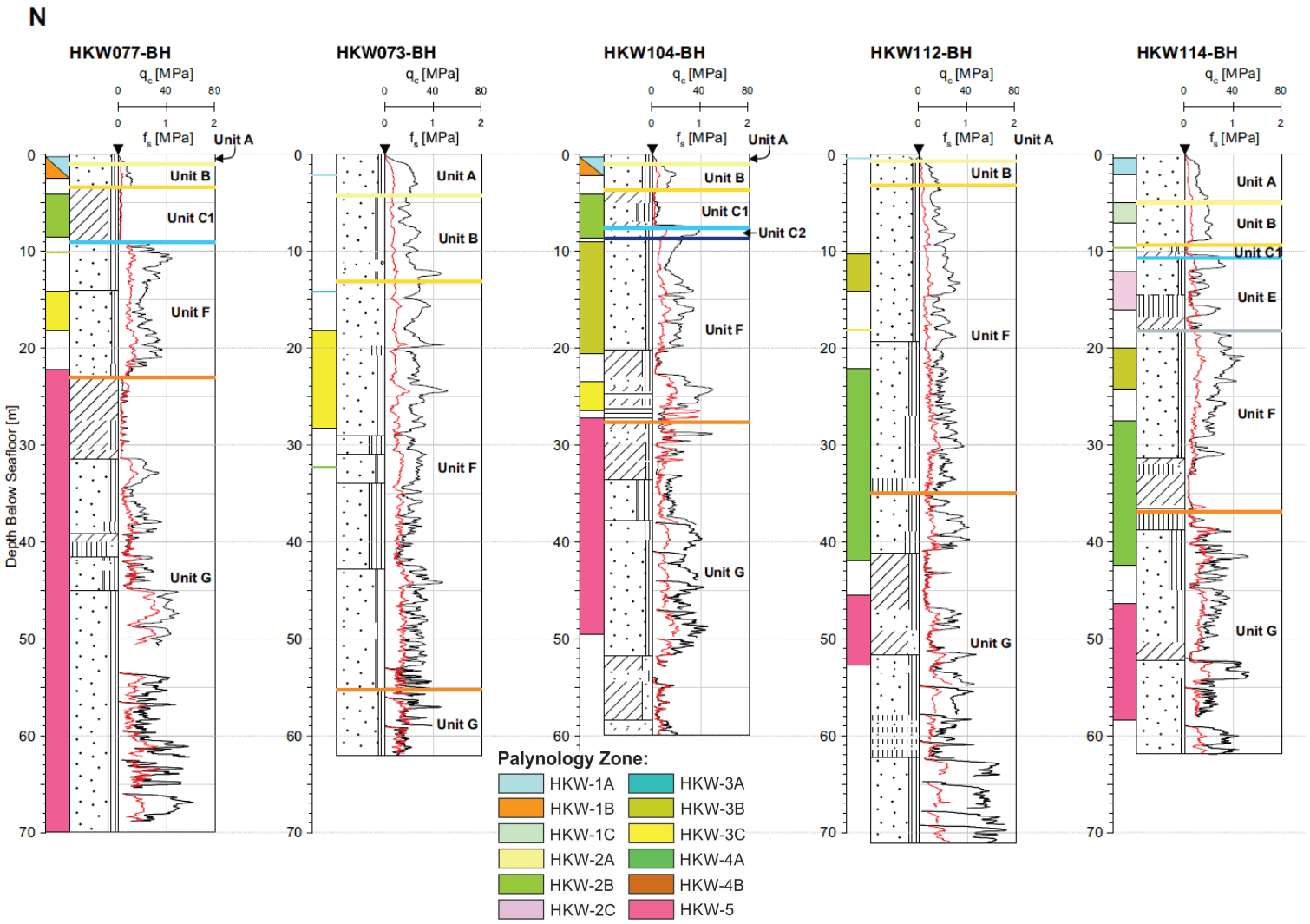




Geological Ground Model - Data Integration



Geological Ground Model - Geological Dating

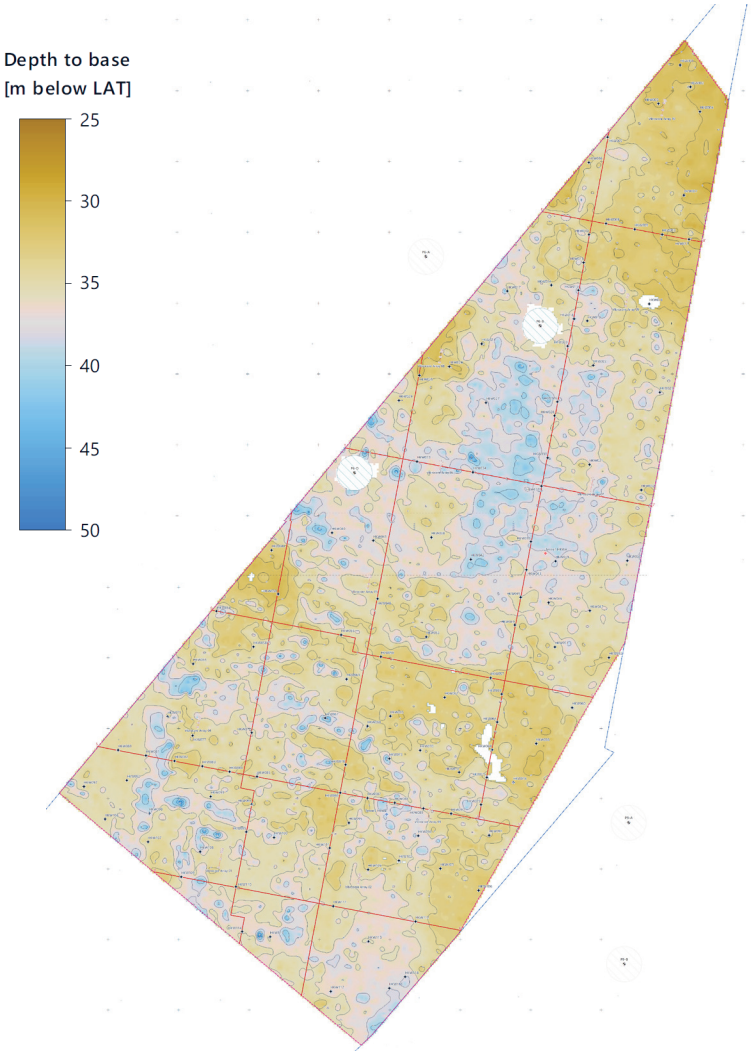


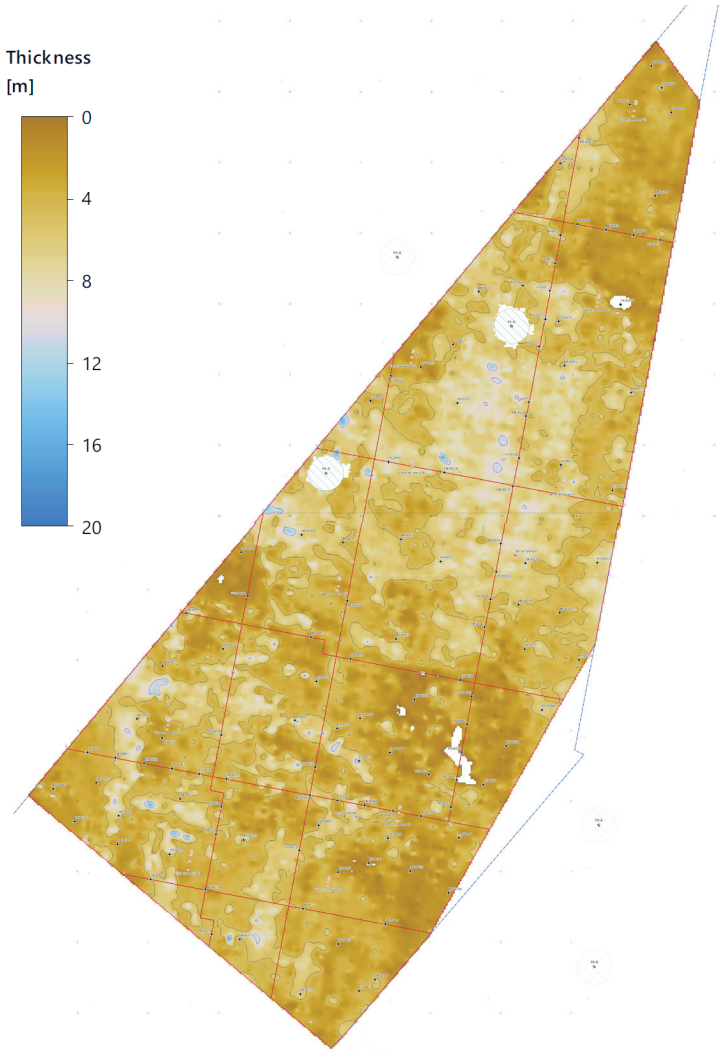
Unit	Rijsdijk et al. 2005		This study		
	Formation [Member]	Age	Seismic Reflector	Depositional Environment	Palynology Zone
A	Southern Bight [Bligh Bank]	Middle to Late Holocene	H02 (base)	marine	HKW-1A
B	Naaldwijk / Kreftenheye / Dogger Bight	Late Pleistocene to Middle Holocene	H05 (base)	coastal to tidal flat and lagoonal glacio-fluvial	HKW-1B HKW-1C HKW-2A
C1	Eem [Brown Bank]	Late Pleistocene	H09 (base)	shallow marine to lagoonal	HKW-2B
C2	Eem	Late Pleistocene	H10 (base)	shallow to open marine	HKW-2B
D	Eem	Late Pleistocene	H15 (base)	shallow to open marine	HKW-2C
E	Eem	Late Pleistocene	H20 (base)	glacio-fluvial to marine	HKW-2B HKW-2C
F	Yarmouth Roads	Early to Middle Pleistocene	H25 (base)	fluvio-deltaic to marine	HKW-3A HKW-3B HKW-3C HKW-4A HKW-4B
G	Yarmouth Roads (possibly partly Winterton Shoal)	Early Pleistocene	H30 (internal)	fluvio-deltaic to marine	HKW-4B HKW-5

Geological Ground Model

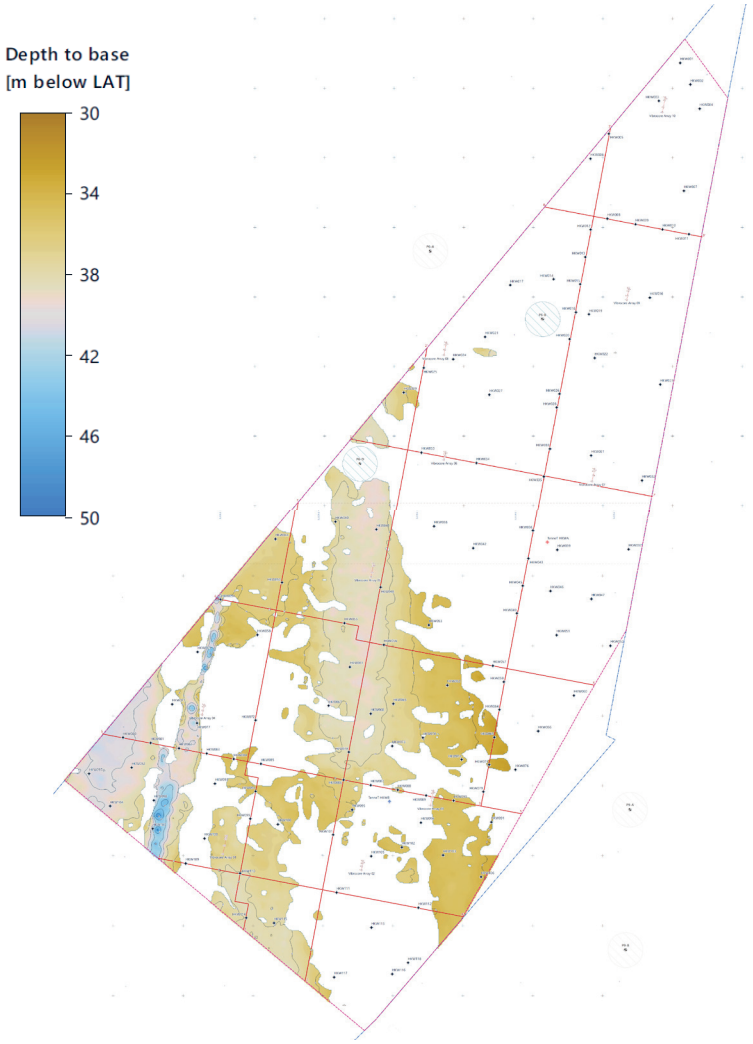
- Seismostratigraphic framework of geophysical report largely retained, modifications as follows:
  - Addition of interpretation of base Unit B (horizon H05) on MCS-UHR dataset
  - Addition of interpretation of base Unit C1 (horizon H09), interpreted as clay-rich interval
  - Adjustments of base of Units D, E and F particularly at and close to geotechnical locations
  - Adjustments to extents of buried channels and extents of peat/organic clay

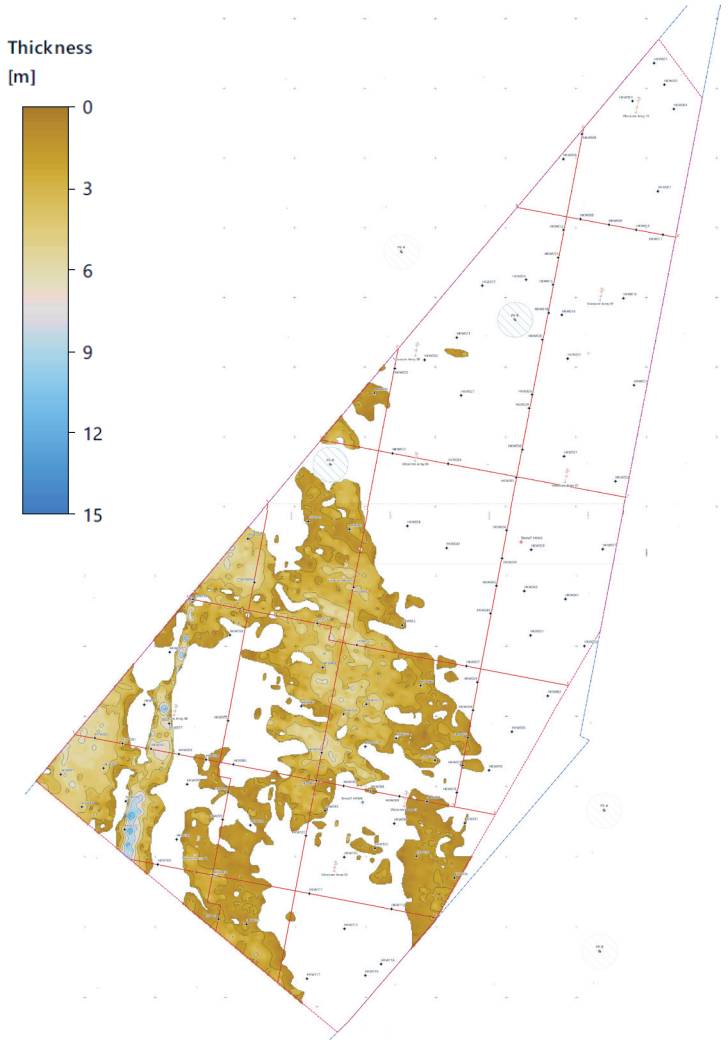
Geological Ground Model - Depth to Base and Thickness Unit B



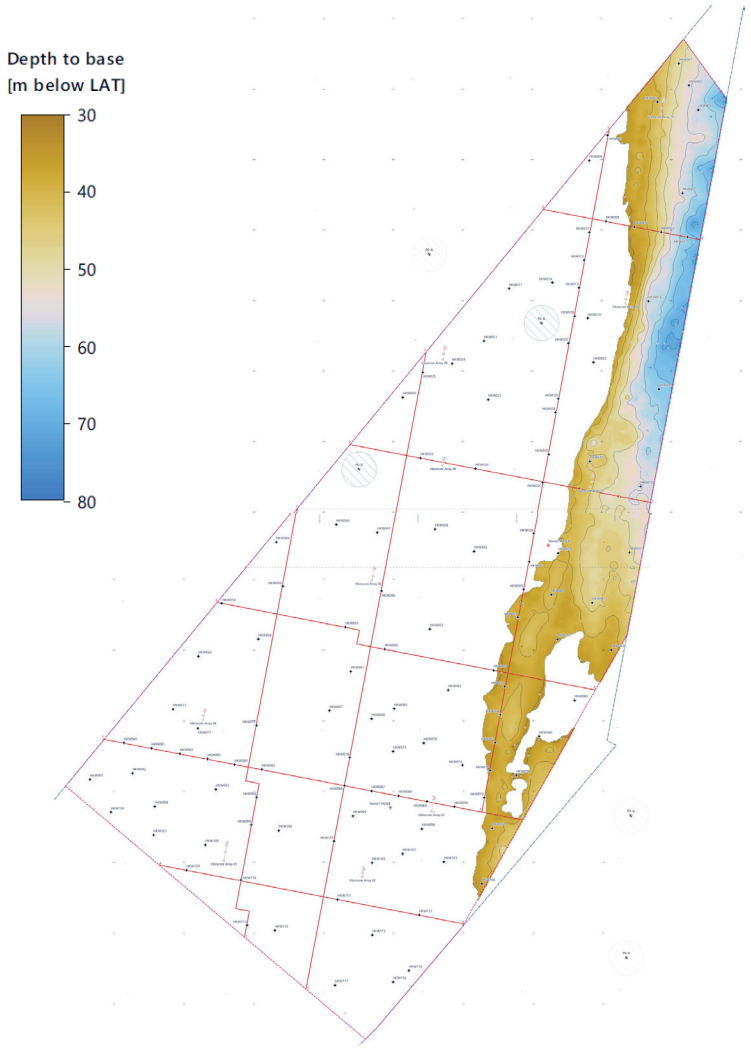


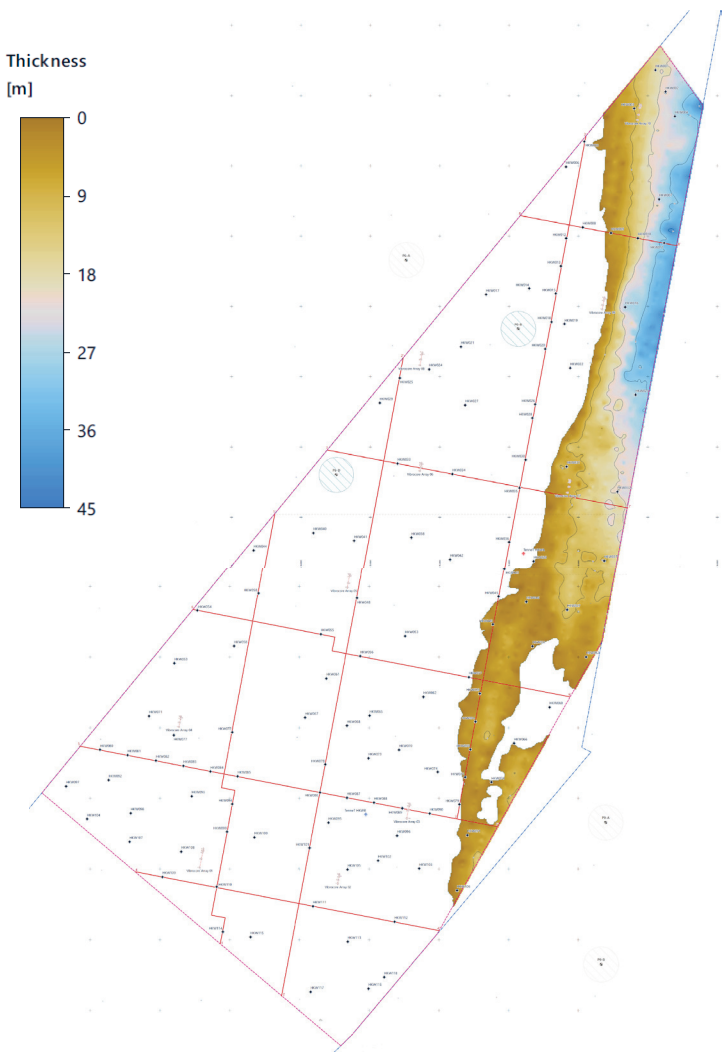
Geological Ground Model - Depth to Base and Thickness Unit C1



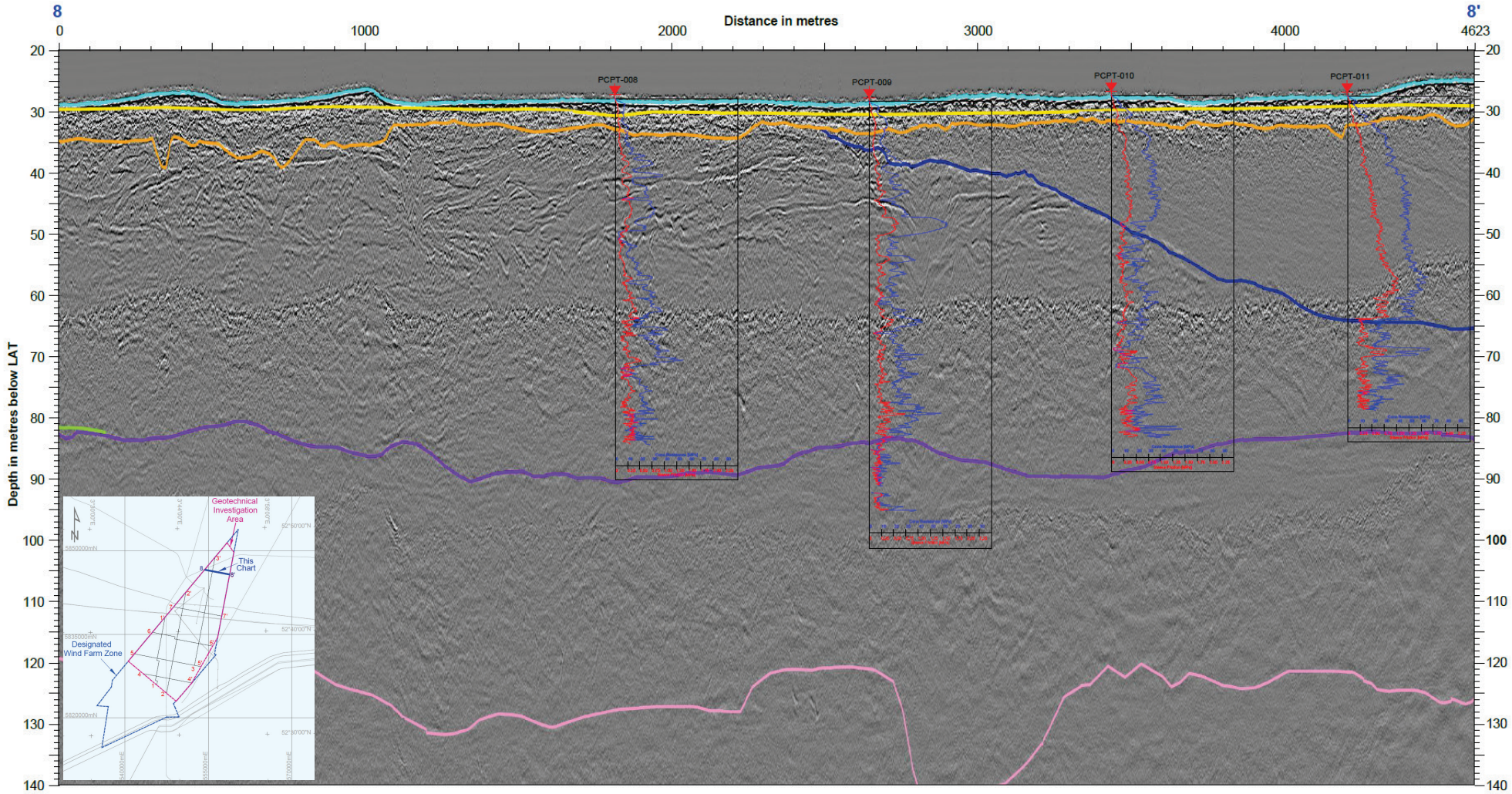


Geological Ground Model - Depth to Base and Thickness Unit E

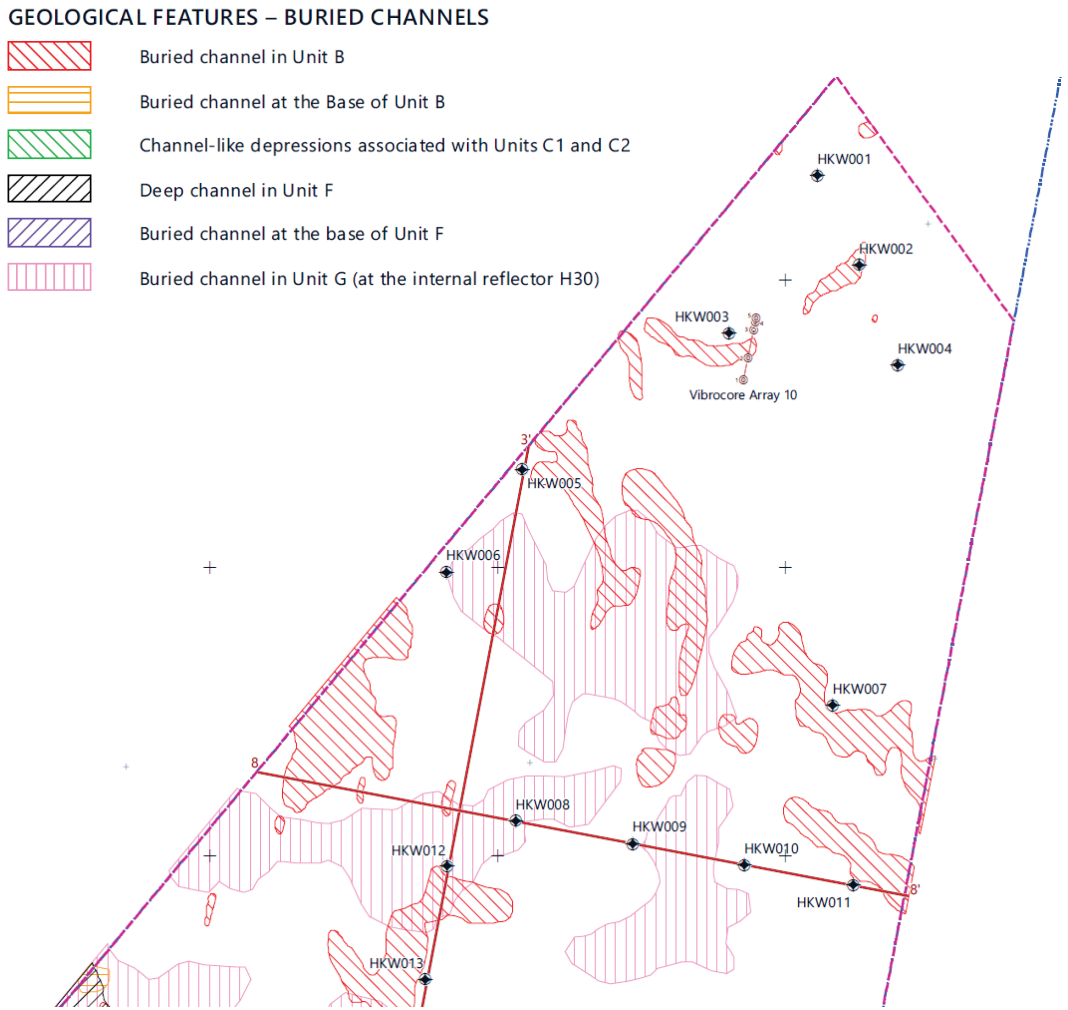




Geological Ground Model - Cross Sections



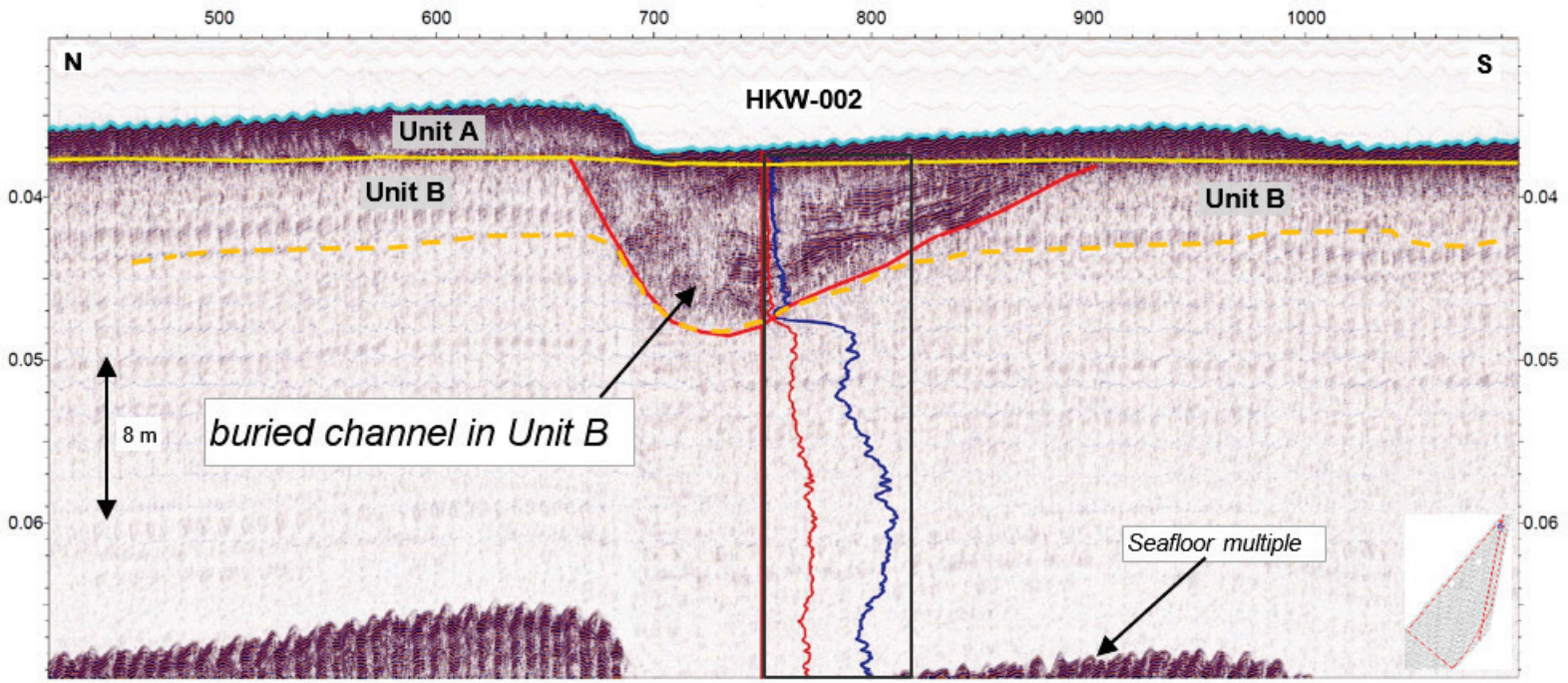
Geological Ground Model - Geological Features



- Buried channels observed at different stratigraphic levels
- Internal channels in Unit B: infill characterised by high-amplitude reflections, different from the otherwise acoustically semi-transparent character
- Occasionally, complex cross-stratification and sub-parallel bedding were observed inside the channels
- Low to high strength clay or silt, locally laminated or interbedded with fine sand

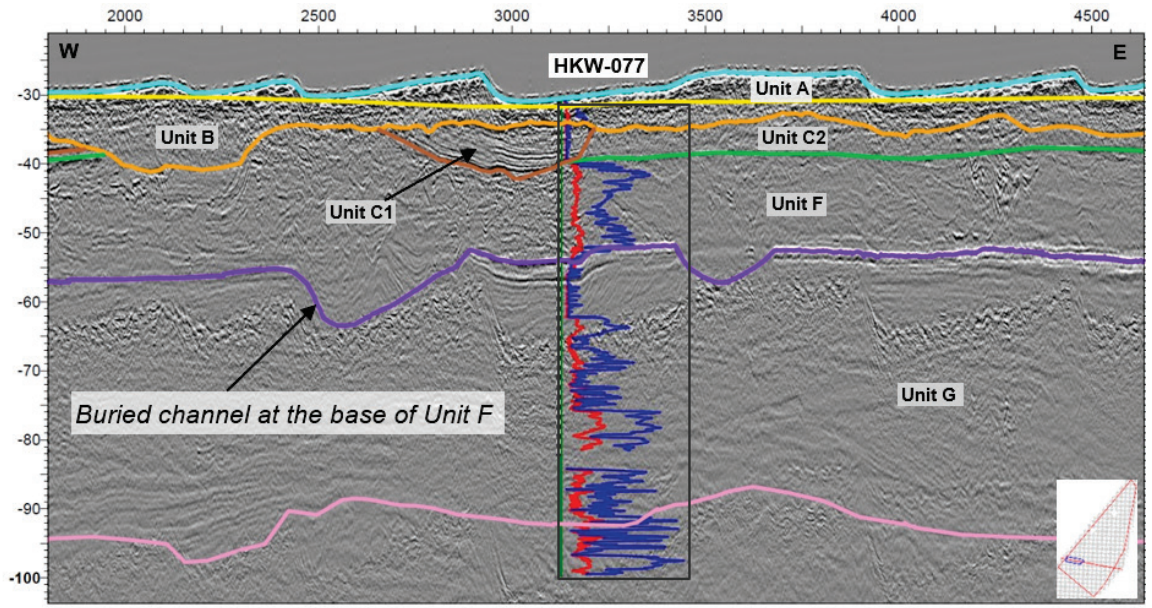
Geological Ground Model - Geological Features

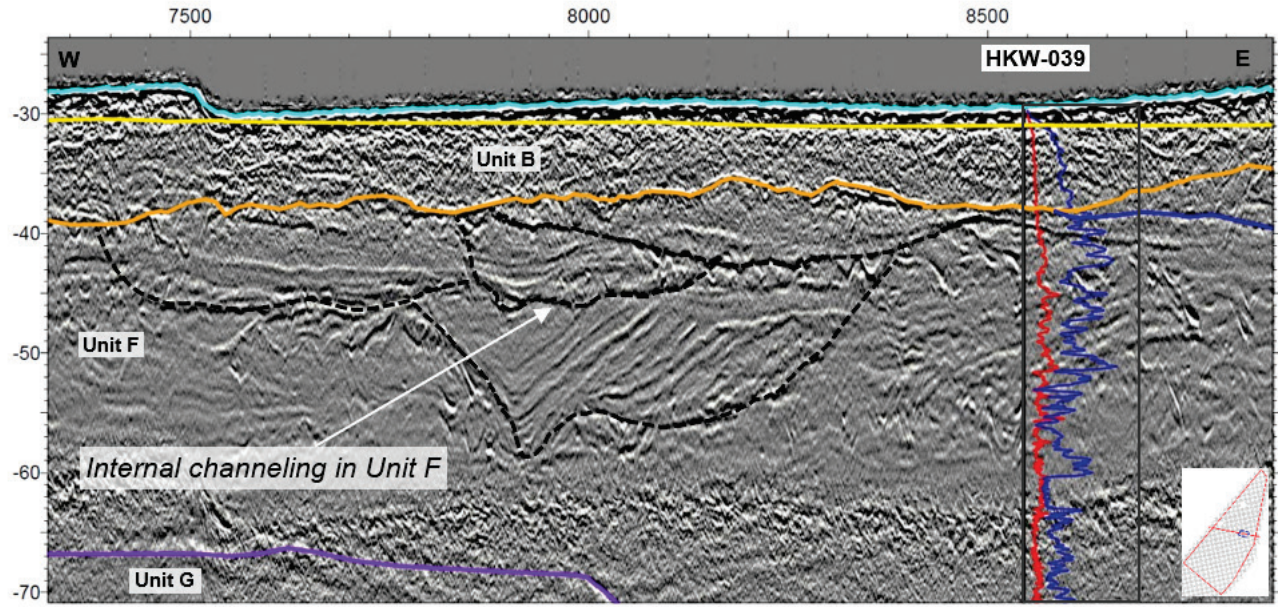
Data example of buried channel in Unit B



Geological Ground Model - Geological Features

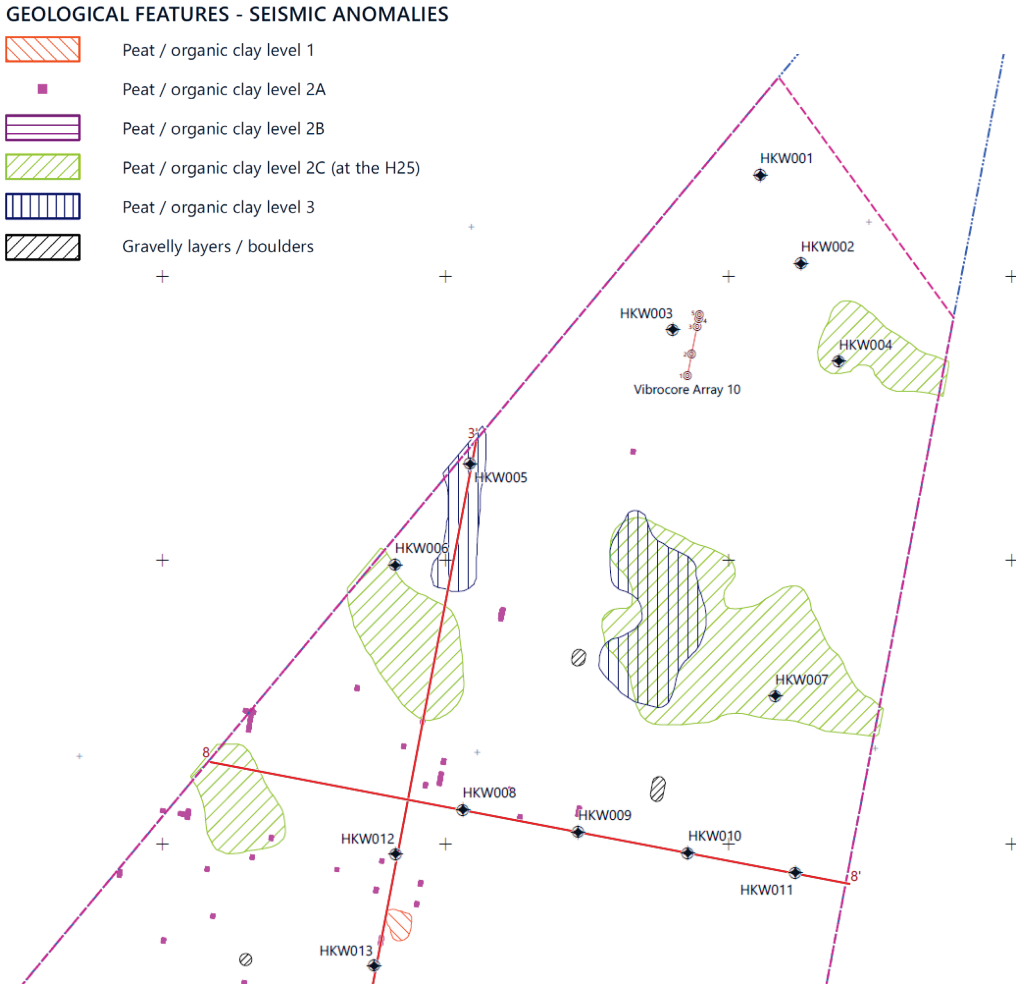
Data examples of buried channels



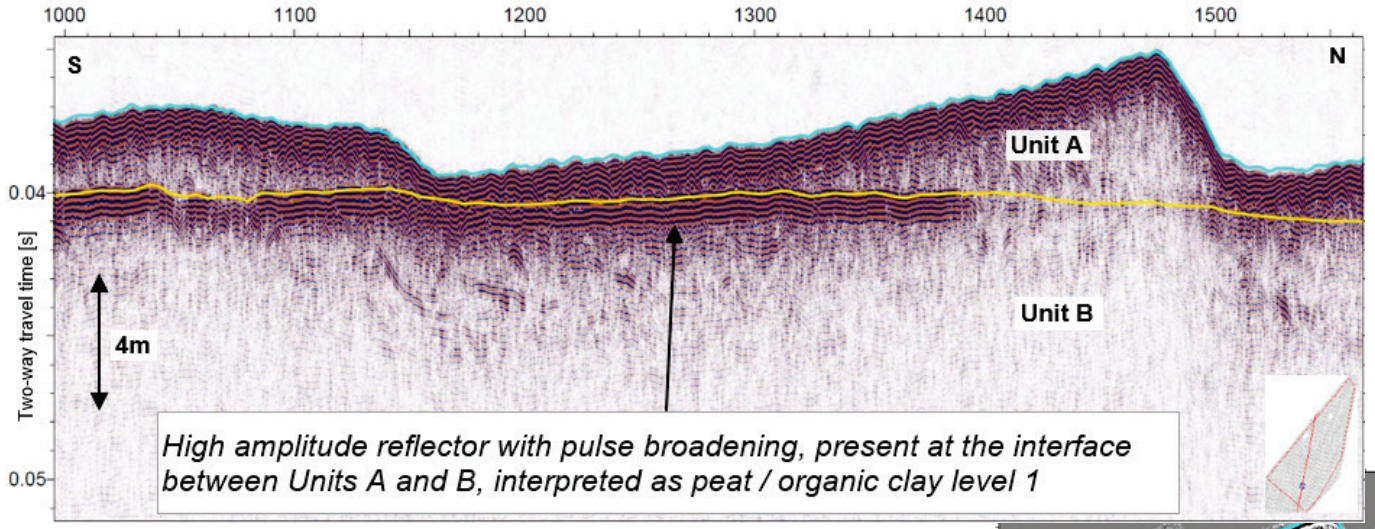


Geological Ground Model - Geological Features

- Seismic anomalies observed at different stratigraphic levels
- Seismic anomalies are in the form of high-amplitude reflections typically associated with reverse polarity and/or pulse broadening
- Identified seismic anomalies usually related to laminae or beds of peat/organic clay
- Various levels differentiated:
  - Peat/organic clay level 1: interface Unit A and B
  - Peat/organic clay levels 2A, 2B and 2C: in Unit F
  - Peat/organic clay level 3: in Unit G



Geological Ground Model - Geological Features



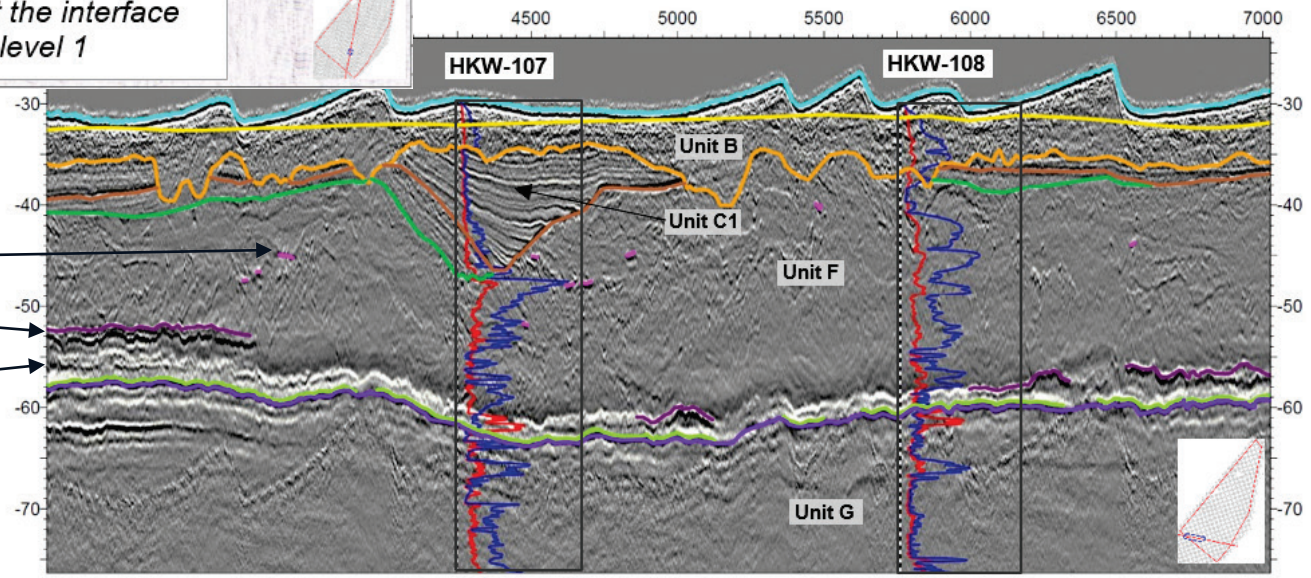
Data examples of seismic anomalies

Peat/organic clay within Unit F:

Level 2A

Level 2B

Level 2C



Geological Ground Model - Site-Specific (Geo)Hazard Assessment

Geological Feature / Hazard Type	Occurrence Area	Constraints on Structure	PL	JU	GB	SC	CB
Migrating bedforms / mobile seabed sediments	Entire HKW WFZ	▪ 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; spanning of cable leading to snagging from trawling or anchoring	H (L)	L (N)	H (N)	H (L)	H (N)
Loose to medium dense sand or silt	Sand: locally in Unit A Silt: locally in Unit B	▪ All: cyclic loading of seabed and structure can affect structure stability and structure stiffness ▪ CB: liquefaction of sand / silt can affect cable flotation and thermal characteristics	H (N)	L (N)	H (N)	L (N)	L (N)
Gravel, cobbles and/or boulders	Locally possible in all units except Unit A	▪ PL: possibly early refusal or damage and pile verticality issues during pile 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 Foundation / SC=Suction Caisson Foundation / CB=Cables
- Letter indicates hazard probability rating; H = High / L = Low / N = Negligible
- Hazard probability rating between brackets considers application of relevant mitigation measures

06

Concluding Remarks

Concluding Remarks

- The available geotechnical and geophysical data align reasonable 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.
- Soil conditions at individual geotechnical locations as well as within soil units between geotechnical locations show predominantly sand. Locally, beds and laminae of clay and sandy clay are present.
- The investigation area is characterized by limited lateral correlation of soil properties, except Units C1, C2, and E
- 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

Reports and digital deliverables provide the following for end users:

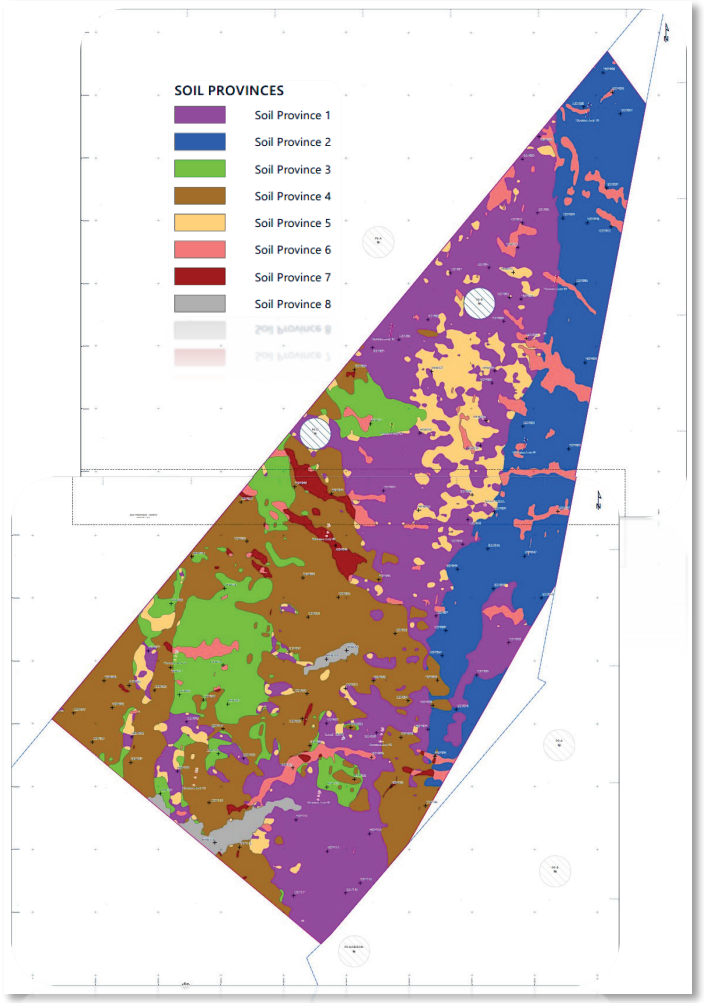
- A robust and reliable data set which covers the full site, and which can be used for optimizing the preliminary OWF design and assist in fine-tuning final development costing
- Additional sample material which can directly be used for any additional tests, if required
- Possible minimization of additional site investigation requirements, in most cases limited to additional seafloor cone penetration testing for verification purposes
- Overall de-risking of ground risks before the bidding stage
- A reliable data set for input into the geotechnical ground model (to be covered in Webinar 2 on 19 November 2020)

07

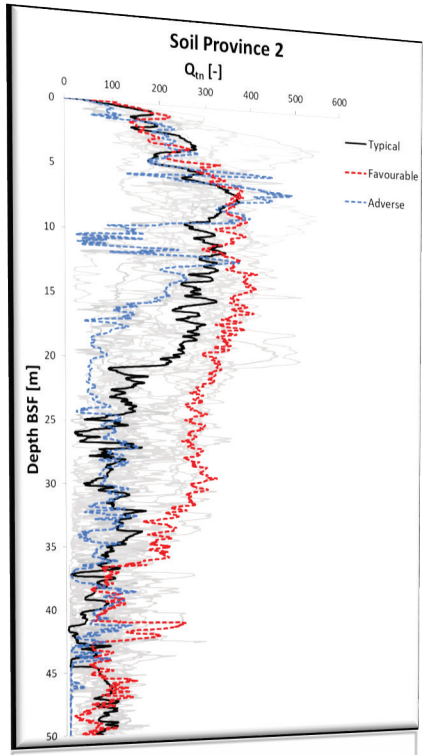
Preview Webinar 2 (19 November 2020)

Preview Webinar 2

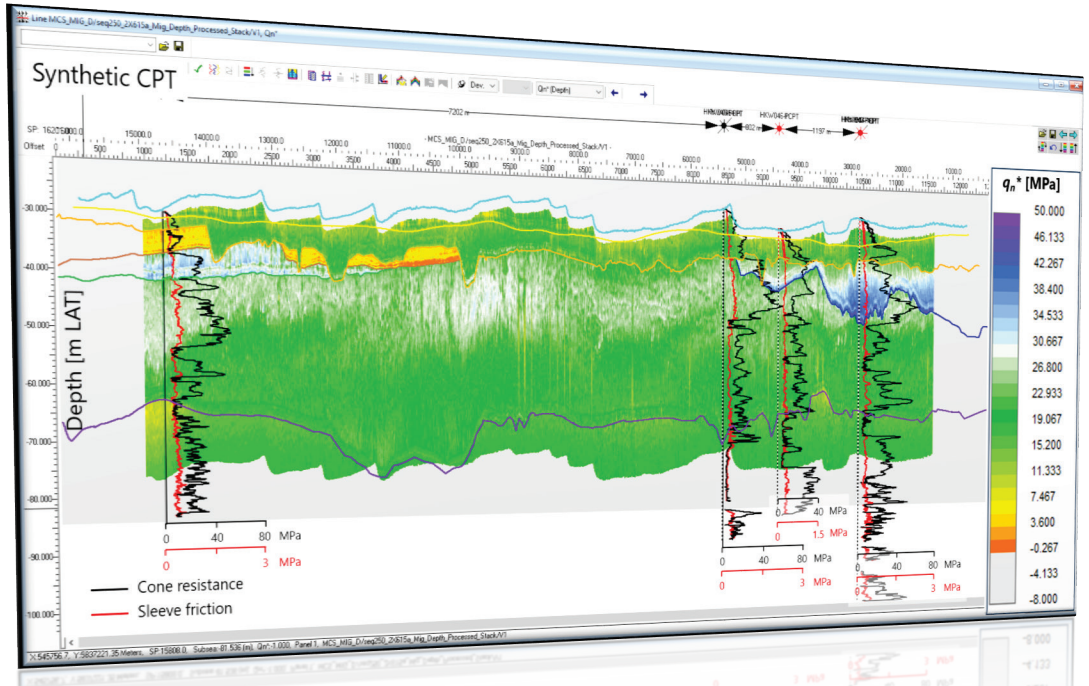
Geotechnical Ground Model



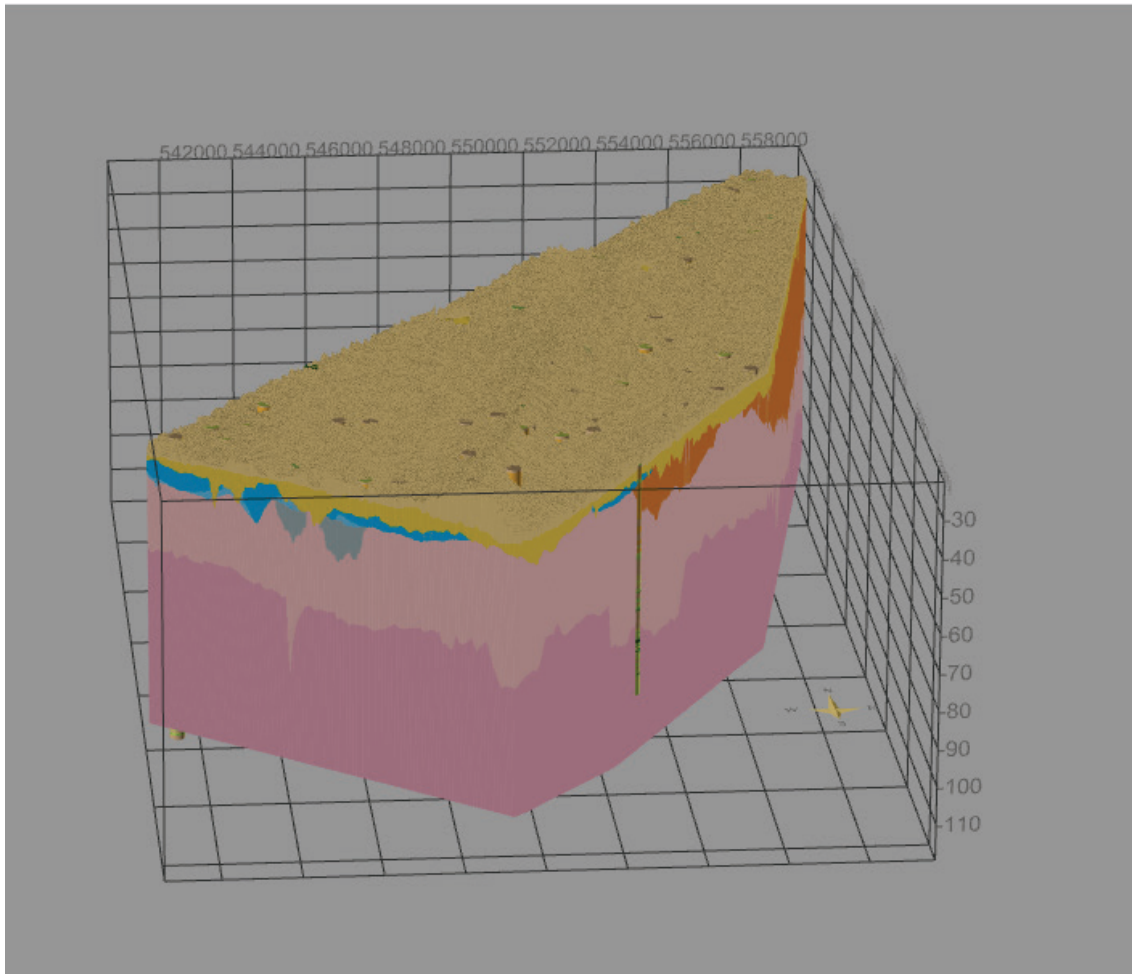
Geotechnical Parameters



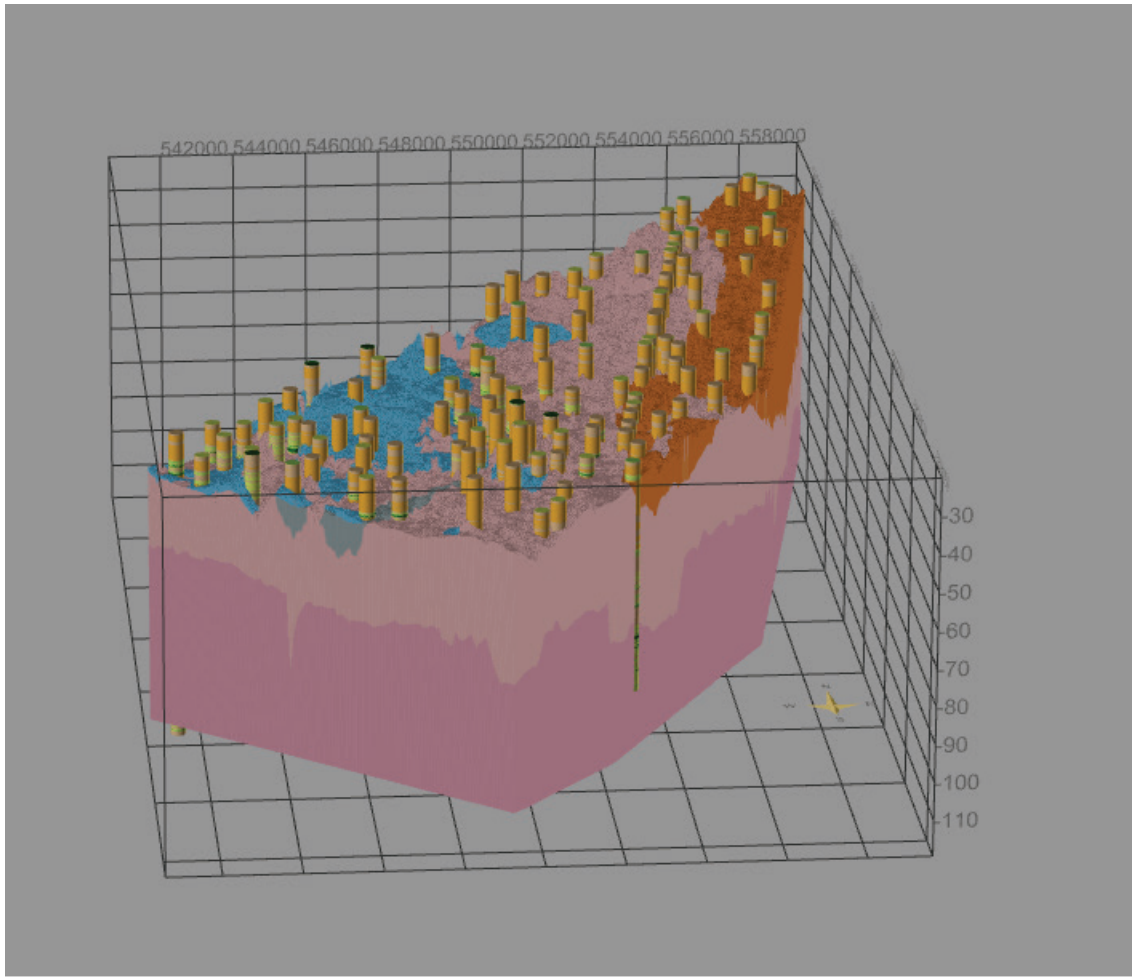
Innovative Developments: Synthetic CPTs



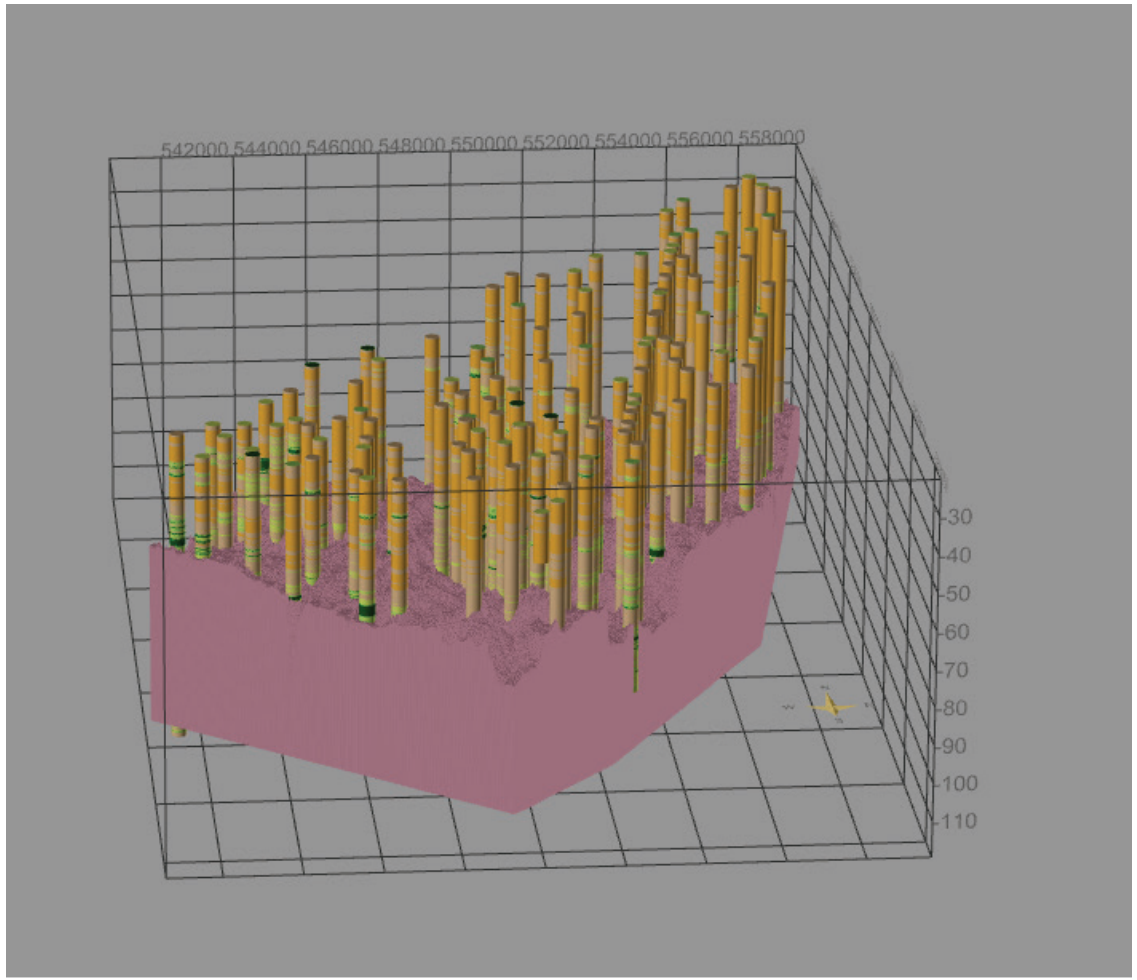
Preview Webinar 2



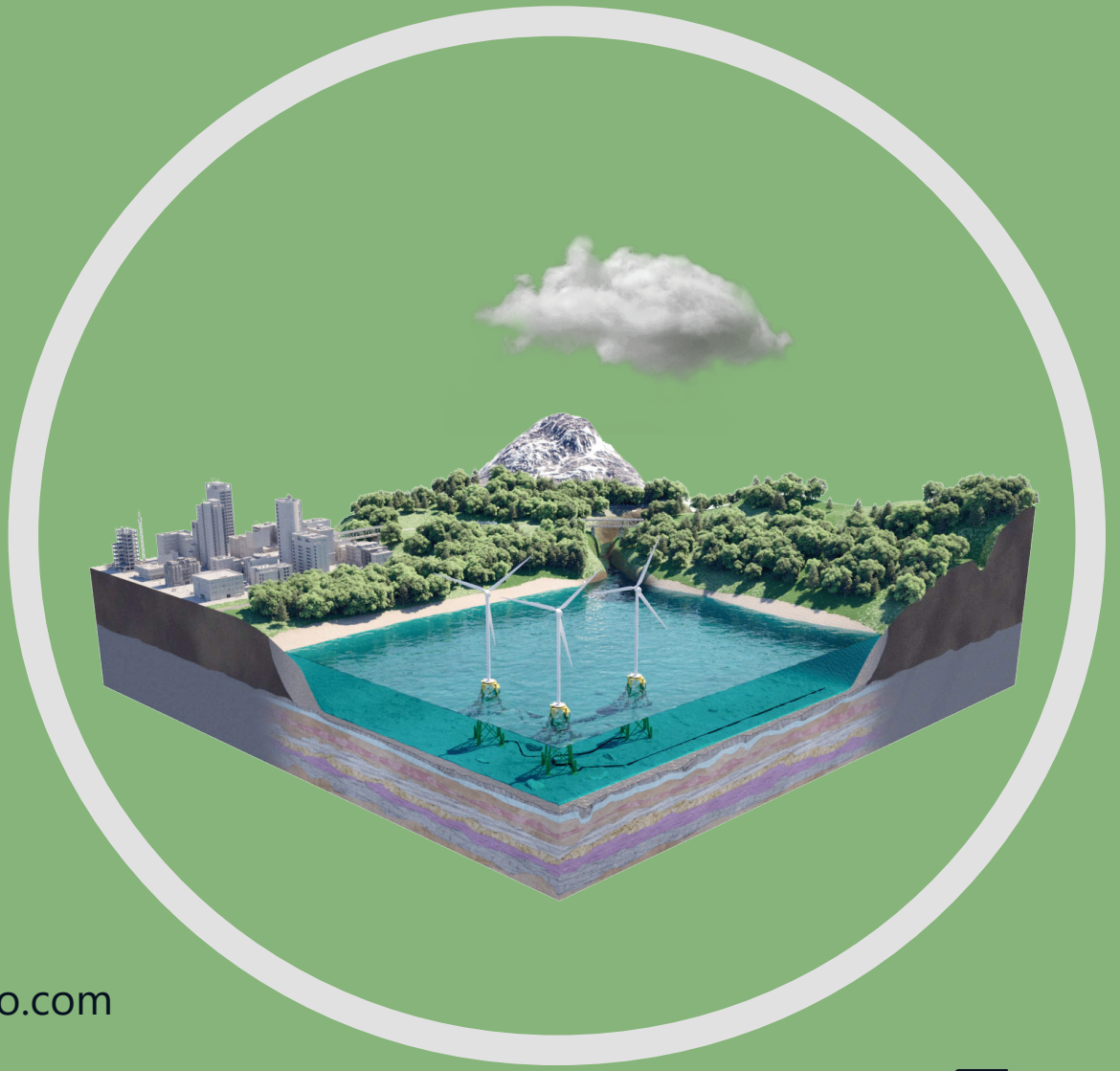
Preview Webinar 2



Preview Webinar 2



Together we create a safe and liveable world



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Netherlands Enterprise Agency

Closing the webinar

Please fill in the questionnaire

https://offshorewind.rvo.nl

- Geophysical and geotechnical deliverables
- Watch this webinar
- Download presentation
- List with questions and answers

Thank you for participating in this webinar!

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